Microstrip Patch Antenna Design: Issues at Terahertz Frequencies

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Abstract—In recent years a new trend of research has been observed in literature dealing with the design of microstrip antennas at the terahertz band of frequencies. The present work addresses some of the issues associated with such implementation. Although simulation provides various effective designs and desired performance characteristics, practical realization of such printed antennas beyond 0.9THz remains questionable without the availability of proper and low cost technologies. Rigorous research into this aspect of practical realizability of printed antennas at terahertz frequencies holds tremendous potential for future wireless communication networks.

Keywords—Terahertz frequency band; terahertz antenna; microstrip patch antenna; rectangular microstrip patch antenna; polytetrafluoroethylene; Ansoft HFSS.

I. INTRODUCTION

Terahertz (THz) frequency band (0.3THz-30THz, ITU) has witnessed a global increase in research interest in recent years owing to several potential applications in the fields of medicine, security and communications. The main characteristics of THz that has enabled this band to carve a significant niche in the electromagnetic spectrum is the property of THz waves to penetrate matter without ionization. THz frequency band also holds huge potential for short distance wireless communications.

Microstrip antenna (MSA) related research work in the THz band is presently carried out in the simulation domain as appropriate THz signal sources have yet to be made readily available for study and analysis. Recent work [1] shows the simulation results of a Rectangular Microstrip Antenna (RMSA) over a frequency range of 0.7-0.85THz. The substrate used for the simulation is Rogers RT/Duroid 6006 substrate with a dielectric constant of 6.15 and a loss tangent of 0.0019. The present work explores in detail, the feasibility of the realization of RMSA in the THz band.

II. ANTENNA DESIGN ISSUES AT THz

An antenna, being a passive transducer, requires an appropriate source signal for radiation. Although the design and characterization of MSA, in the THz band, have been simulated and reported in literature, such designs are of no practical significance until appropriate THz signal sources, detectors and connectors are designed in order to carry out experimental verifications of the performance of such antennas.
III. RMSA DESIGN ISSUES AT THz BAND

3.1 Availability of Substrates

For a given height \( h \) and dielectric constant \( \varepsilon_r \) of a substrate material, the maximum resonant frequency at which the substrate is expected to produce reliable results, can be estimated by:

\[
fr_{0;\text{max}} = \frac{1}{2h}\sqrt{\mu_0\varepsilon_0} \sqrt{\frac{2}{\varepsilon_r+1}}
\]

where \( \mu_0 \) and \( \varepsilon_0 \) are the permeability and permittivity of free space respectively. Literature [2, 3] shows that Polytetrafluoroethylene (PTFE) and its composites exhibit almost constant dielectric constant and loss tangent values up to frequencies of about 3 THz. Commercially available, low \( \varepsilon_r \) materials which are PTFE based composites, such as Rogers RT/DUROID 5880LZ (\( \varepsilon_r = 1.96 \)), Arlon AD250C (\( \varepsilon_r = 2.50 \)) are of thickness 254 \( \mu \)m and 508 \( \mu \)m respectively. Using (1), the calculated \( fr_{0;\text{max}} \) of RT/DUROID 5880LZ and Arlon AD250C are 0.48 THz and 0.223 THz respectively. Using these substrates with the given specifications for microstrip antenna design at frequencies higher than \( fr_{0;\text{max}} \) may lead to unreliable results.

![Figure 1: Real and imaginary parts of the complex conductivity of Gold, Silver, Copper and Aluminium.](image)

3.2 Conductor Modelling

The dispersion behavior of normal metals at room temperature is modelled using the Classical Relaxation Effect Model. The intrinsic bulk conductivity of a normal metal at room temperature is expressed as [4]:

\[
\sigma(\omega) = \frac{\sigma(\omega=0)}{1 + j\omega\tau}
\]

where \( \sigma(\omega = 0) \) is the DC conductivity of the metal, \( \omega \) is the angular frequency and \( \tau \) is the characteristic carriers scattering life time of the free carriers in the metal. In case of metals, \( \tau \) is of the order of femtoseconds. Due to this extremely small value, the effect of finite conductivity of metals in antenna modelling is sometimes ignored by commercial EM solvers.

Fig. 1 shows that at low frequencies the imaginary part of the intrinsic conductivity in equation (2) is insignificant. However, as frequency increases into the THz band, the imaginary part starts being
significant as well as the real part of the conductivity decreases, these effects have to be taken into account for proper antenna design and characterization at THz.

3.3 Dimensions of Antenna Feed

At high frequencies, it is difficult to achieve impedance matching at lower values of characteristic impedances on commercially available substrates due to the fact that the width of the microstrip feed line approaches and even exceeds the width of the microstrip patch antenna. Therefore at THz band impedance matching has to be done at higher characteristic impedances. This facilitates the edge feeding in antennas because at the edges of the patch, the impedance is usually high.

3.4 Thickness of Metallic Patch and Ground Plane

Thickness of commercially available copper cladding on dielectric substrate material, ranges from 9μm-70μm on a dielectric laminate of 127μm thickness. One such example is the RT/Duroid 5870 laminate which has been characterized for a frequency range of 8-40 GHz, as per data sheets. In metals, since at a depth of 5 skin depth the fields attenuates to less than 1% of the value at the surface, we are considering 5 skin depth as a reference thickness. At 40GHz, t is well above 5 skin depths of copper at the same frequency. At 1 THz, 5 skin depths(5δs) of copper is approximately 1.7μm and to maintain the same t/h ratio, the corresponding height of substrate has to be about 24μm. However, commercial substrates have not yet been available at such low values of thickness to be used as printed antenna substrates.

Further, as the frequency increases, the thickness of the cladding becomes comparable to the wavelength of operation thereby bringing other effects into the performance. To maintain the same t/δs ratio at 1 THz, the corresponding cladding thickness has to be about 0.14μm. Clearly this value is less than 5δs of Copper at 1 THz thereby leading to unreliable quality of performance. Moreover, reducing thickness of rolled copper to 3-4μm is tremendously costly as well as it renders copper hard to handle and it may begin to have pinholes. An alternative process for producing a thin copper layer on a dielectric substrate used in a patch antenna is with electroless plating of copper onto the dielectric material surface. However, proper and good bonding of such thin copper layers with thin dielectric materials, in practice, needs to be ascertained for reliable quality of performance.

Therefore, although simulations could produce a variety of proposed designs and desired performances of printed antennas at THz band frequencies, practical realization of such designs would not be feasible without the availability of proper and low cost fabrication technology. As per available printed antenna substrates from various commercial manufacturers such as Rogers Co., Arlon EMD etc., the maximum resonant frequency that can be realized is around 0.9THz calculated using equation (1).

IV. ANTENNA SIMULATIONS

Incorporating the above design issues, a simple rectangular microstrip patch antenna has been designed to resonate at 0.9THz and simulated using Ansoft HFSS Version 15. Fig. 2 shows the return loss and input impedance parameters of the designed antenna. The antenna has been simulated on PTFE based substrate: RT Duroid 3003 and the metallic cladding is chosen to be of copper since it has a better conductivity at high frequency relative to the other metals as seen from fig. 1. The dimensions of the patch and the substrate have been estimated using standard design formulae for rectangular MSA [5]. The thickness of the metallic claddings for the patch and the ground planes have been estimated appropriately for meeting the above reliability criteria. From the plot of the
impedance of the MSA, it can clearly be seen that the antenna shows a resonance at ~0.9THz. To testify the radiating capability of the antenna, the realized gain of the antenna in the $\phi = 0^\circ$ and $90^\circ$ planes have been plotted in fig. 3.

![Figure 2: Return Loss and input impedance parameter plots of the designed patch antenna.](image1)

![Figure 3: Plot of the realized gain of the antenna in the $\phi = 0^\circ$ and $90^\circ$ planes.](image2)

**V. CONCLUSION**

In this work, issues regarding implementation of microstrip antenna technology at terahertz band has been highlighted. Although simulations could provide antenna designs for different applications at THz frequency band, practical implementation of resonant printed antennas at frequencies above 0.9THz still offers an open area for investigations. Also, incorporating the discussed issues, a rectangular MSA has been simulated to resonate at 0.9THz. Further research into this aspect of printed antenna technologies holds potential for future high speed wireless communication networks.

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