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The Design of a 0.35THz Microstrip Patch Antenna on LTCC Substrate

M. El-Nawawy*, A. M. M. A. Allam, D. Korzec

Faculty of Information Engineering and Technology, German University in Cairo

Abstract A microstrip patch antenna on Low Temperature Co-fired Ceramic (LTCC) substrate operating at 350GHz for THz communication has been designed. CST MWS package has been used for simulation and S_{11} reached a minimum of -25.6dB at 349GHz with 8.6% bandwidth. The maximum gain achieved is 5dBi. Furthermore, a prototype for a downscaled antenna designed at 10GHz with available FR4 substrate has been fabricated and measured.

Keywords Patch, Low Temperature Co-fired Ceramic (LTCC), THz Communication

1. Introduction

In future indoor wireless communication systems data rates around 10 Gb/s will be needed[1] for applications such as wireless extension of 10 gigabit Ethernet and wireless transmission of uncompressed high-quality video signals, e.g., high-definition television (HDTV) or future ultra-HDTV[2,3]. Professional applications cover, e.g., fast file exchange on conferences, telemedicine, and the provision of interference-free wireless high speed networks in trade fair halls by dividing the huge available bandwidth into multiple subbands[4]. However, in the case of current wireless communication systems the available bandwidths are limited with maximum data transfer speeds of around 3 Gb/s. Hence there is no alternative but to turn toward higher carrier frequencies in order to support ultra-broadband information carrying signals. In order to provide terabit systems, frequencies of and beyond 120GHz must be tapped[5], leading to the initiation of the IEEE 802.15THz interest group (IG THz)[4]. The frequencies around 350 GHz are especially interesting as they lie in a low absorption atmospheric window with 47GHz of available bandwidth[6]. Moreover, as technological advance keeps up with the ever increasing demand for wireless data transmission capacity, electrical components for the generation of THz frequencies are already commercially available.

LTCC offers good microwave performance combined with low production costs[7], provides processes that yield circuits with low loss interconnects and fine-line definition beside the practical advantages of compact size and potentia-l mass production[8].

In this paper a microstrip patch antenna operating at 350GHz designed on LTCC substrate is proposed. Section 2 describes LTCC technology, section 3 the antenna geometry and section 4 discusses the simulation results of the proposed antenna. Section 5 compares the simulated results for a LTCC antenna downscaled to 10GHz with the simulated and measured results of the same antenna with FR4 substrate.

2. LTCC Technology

Low-temperature co-fired ceramics (LTCC) multilayer technology has been actively studied for millimeter-wave antenna and package solutions[9,10,11]. The high material reliability, electrical characteristics, and compatibility with a wide range of assembly techniques is advantageous for mass-market consumer electronics.

With the evergrowing need for compact, highly integrated and small size transceiver systems in the wireless industry, low temperature co-fired ceramic (LTCC) technology offers many attractive features and possibilities to achieve these goals. The size of an LTCC substrate can be reduced considerably because of its 3-D capabilities and because passive components, such as capacitors, resistors, inductors and antennas, can be embedded within it. This makes LTCC an ideal medium for system-on-package (SoP) applications[12]. Efficient passive elements can be designed in LTCC because of its low losses. Furthermore, some researches such as[13,14] show the method in detail for integrating the antenna and transceiver electronics into compact modules with the LTCC technology.

Considering the easy integration, flexible via holes distribution, and mechanically strong, hermetically sealed, dimensionally stable process properties, the LTCC has been regarded as the promising technology of light weight,

* Corresponding author:
mohamed.elnawawy@guc.edu.eg (M. El-Nawawy)
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compactness and excellent high frequency performance which is suitable for single integrated circuit solutions of modern microwave and millimeter-wave communication systems[15].

Figure 1 shows the technology steps for fabricating a LTCC circuit. The metallization pastes are screen printed layer by layer upon the un-fired or “green” ceramic foil, followed by stacking and lamination under pressure. The multilayer ceramic stack then is fired (sintered) in the final manufacturing step. The temperature of sintering is below 900°C for the LTCC glass-ceramic. This relative low temperature enables the co-firing of gold and silver conductors[16].

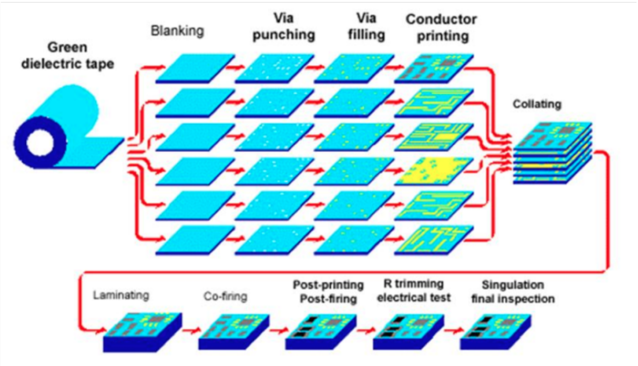


Figure 1. Technology steps for fabricating a LTCC circuit.

3. Antenna Design

Figure 2 shows the geometry of the proposed antenna. The substrate used is Ferro A6M with ε_r=5.99, tanδ=0.002, and thickness h=75 µm. The optimized patch dimensions are L_p=0.14 mm and W_p=0.115 mm. The 50Ω microstrip feed line has a width W_f = 0.114 mm. It should be noted here that a quarter wavelength matching microstrip line has been used to match the 50Ω impedance of the feed line to the input impedance of the patch. The substrate dimensions are L_{sub}=W_{sub}= 0.6mm.

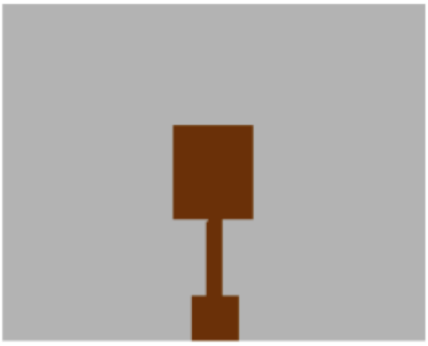


Figure 2. Antenna Geometry.

4. Simulation Results

Figure 3 shows the simulated S_{11} for the proposed design using CST MWS simulation package. S_{11} reaches -25.6dB at 349GHz. The impedance bandwidth is 8.6% calculated at -10dB. The patch width has been varied with all other parameters kept constant to study its influence on the reflection coefficient. Figure 4 shows the S_{11} plot for patch width values W_p=0.1, 0.11, 0.12, and 0.14 mm. It is seen that as the patch width increases the resonant frequency increases and better matching is obtained. On the other hand, the bandwidth increases as the patch width decreases. The optimum value of Wp has been chosen to be 0.115 mm.

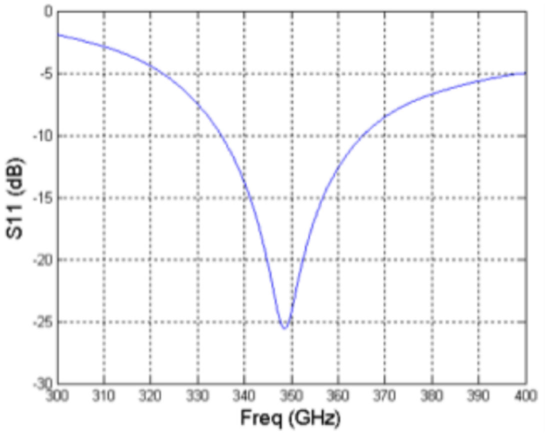


Figure 3. Simulated S_{11} for proposed design.

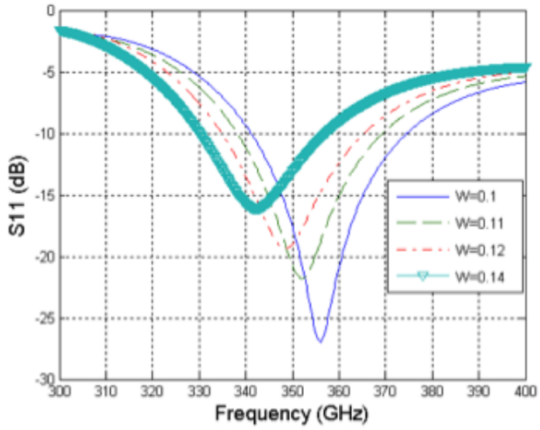


Figure 4. Simulated S_{11} for different patch width.

Furthermore, the ground plane has been truncated with values ranging from 0.05mm to 0.2mm. Figure 5 shows S_{11} for different truncation values. It is seen that the highest bandwidth is achieved for a truncation value of 0.05mm while the lowest is for a truncation value of 0.15mm. The truncation value of 0.15mm results in best matching at resonance frequency 350GHz.

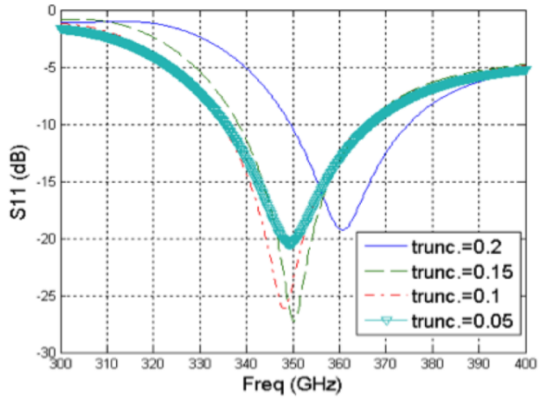


Figure 5. Simulated S_{11} for different ground truncation.

Figure 6a shows the simulated directivity pattern for x-z plane. The figure is symmetric with respect to z-axis as expected from structure symmetry. The main lobe magnitude is 6.3dBi at direction 0° with 3dB beamwidth of 89.6°. Figure 6b shows the directivity pattern in y-z plane. The maximum directivity in this plane is 6.5dBi at 10° direction. There is a sidelobe at direction 130° with magnitude -8dBi. Figure 6c shows the directivity pattern at 45° elevation from x-y plane. The pattern is seen to be unidirectional in this plane with magnitude of 3.7dBi.

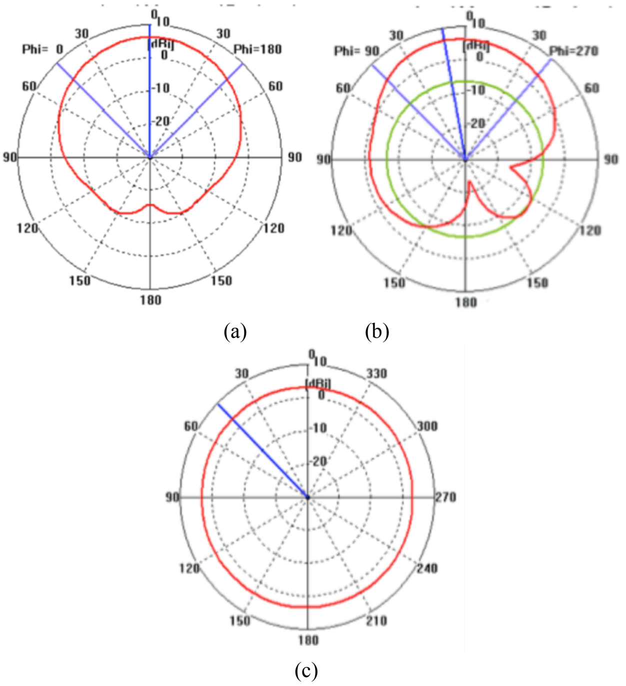


Figure 6. Simulated Directivity patterns for proposed antenna (a) x-z plane (b) y-z plane (c) 45° elevation from x-y plane.

Figure 7 shows the radiation efficiency versus frequency for the whole operating band of the proposed antenna. It is seen that the radiation efficiency increases as frequency increases with an increase of about 3% between maximum and minimum.

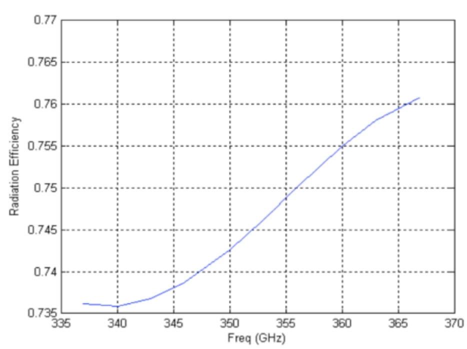


Figure 7. Radiation Efficiency versus frequency for proposed antenna.

5. Fabrication and Measurement

In order to experimentally verify the proposed design, scaling down was done for the antenna to 10GHz with LTCC as a substrate. Moreover, the same 10GHz design was simulated and measured using FR4 substrate which is available in the lab with ε_r=4.4 and substrate height h=1.6mm. Figure 8 shows a photo of the fabricated FR4 antenna scaled down to 10GHz.

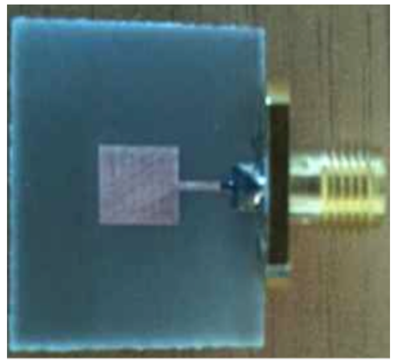


Figure 8. Photo of FR4 scaled antenna prototype.

Figure 9 shows the simulated S_{11} for the antenna with LTCC substrate with magnitude of -14.5dB at 9.7GHz and the simulated and measured S_{11} for the antenna with FR4 substrate with magnitude of -16dB at 10GHz. The bandwidth for the LTCC antenna is 4% and for the FR4 antenna is 6%.

Figure 10 shows the radiation efficiency versus frequency for both the LTCC and FR4 antennas. It seen from the figure that the radiation efficiency for LTCC substrate is about 55% better than that of FR4 which is expected since the loss tangent for LTCC is much less than that of FR4.

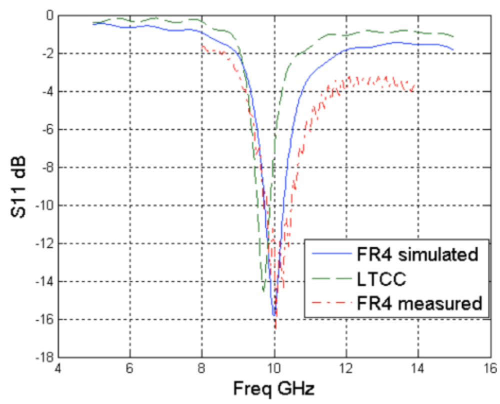


Figure 9. S_{11} for scaled antenna, LTCC and FR4.

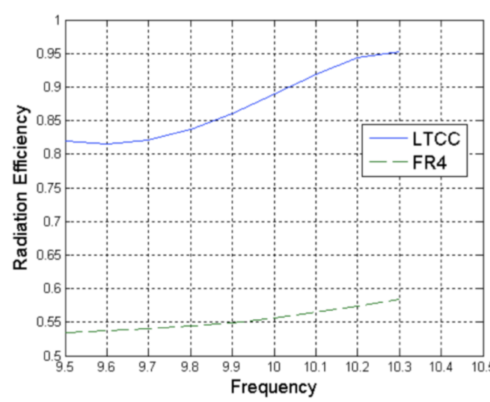
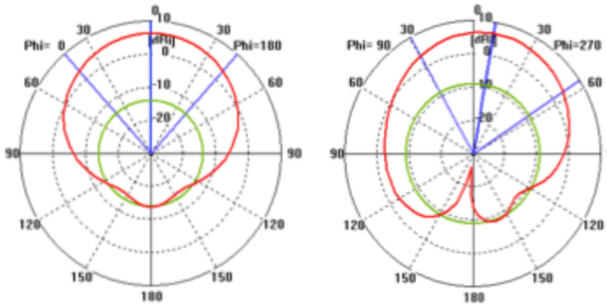


Figure 10. Radiation efficiency versus frequency for scaled antenna, LTCC and FR4.

Figure 11 shows the directivity patterns for the FR4 antenna in both the x-z and y-z planes. The maximum gain is 3.8dBi.



(a) (b)

Figure 11. Simulated directivity patterns for FR4 scaled antenna (a) x-z plane (b) y-z plane.

6. Conclusions

A microstrip patch antenna operating at THz frequency range suitable for future high data rate wireless communications has been designed on LTCC substrate. The radiation efficiency relation with frequency has been studied. Simulated S_{11} was -25.6 dB at 349GHz with 8.6% bandwidth and the radiation patterns show a maximum gain of 5 dBi. Good agreement has been shown between simulated and measured results for the antenna downscaled to 10GHz using FR4 substrate.

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