60 GHz Patch Antenna in LTCC with an Integrated EBG Structure for Antenna Pattern Improvements

William E. McKinzie III
WEMTEC, Inc.
Fulton, MD, USA
will@wemtecinc.com

Deepukumar M. Nair
Bradley A. Thrasher
Michael A. Smith
Elizabeth D. Hughes
James M. Parisi
DuPont Microcircuit Materials
Research Triangle Park, NC, USA
Deepukumar.Nair@usa.dupont.com

***Abstract*—We present a 60 GHz LTCC aperture-coupled patch antenna with an integrated Sievenpiper EBG structure used for suppression of TM mode surface waves. This is believed to be the first demonstration of a Sievenpiper EBG structure used inside a millimeterwave LTCC antenna. The merit of this EBG structure is to yield a predicted 6 dB improvement in broadside directivity. Without the EBG structure, edge diffraction of surface waves degrades the pattern into two main beams. The combination of a new LTCC material system (DuPont 9K7 Greentape^{TM}) along with laser ablation processing for fine line and fine slot definition allowed the integration of a successful EBG structure with an aperture coupled patch antenna.**

I. Introduction

Low temperature co-fired ceramic (LTCC) is a desired packaging technology for the integration of millimeterwave antennas with chip scale packages. However, an issue with LTCC, and other medium permittivity substrates ($4< \varepsilon_r <10$), is that transverse magnetic (TM) mode surface waves are readily excited by antenna elements, vertical transitions, and unshielded feed networks. These parasitic surface waves diffract at edges of ground planes which cause antenna pattern distortion. A known solution for suppression of surface waves is the use of a Sievenpiper (mushroom-type) electromagnetic bandgap (EBG) structure [1], [2]. This EBG structure may be integrated into an LTCC substrate as a perimeter treatment around the antenna element(s), as proposed by [3] for organic substrates. The Sievenpiper EBG structure was selected because its unit cell is considerably smaller than other options such as the UC_PBG structure [4] and the planar circularly symmetric (PCS) EBG structure [5]. This allows the antenna system to be small enough to fit on a chip scale package.

II. Antenna Design

Fig. 1 is a cutaway view of the proposed antenna along its plane of symmetry. Fig. 1 shows the salient features while Fig. 2 shows orthogonal views and overall dimensions. The LTCC material used is DuPont Greentape 9K7 in a 5 mil nominal thickness. The LTCC part has 6 tape layers and 5 Au metal layers. Salient features include a broadband 50 ohm wafer probe transition (a CPW-to-stripline transition) [6] fabricated into the shelf of the LTCC part. Also included are a shielded stripline feed network, an H-shaped coupling slot, and a 3-row perimeter Sievenpiper EBG structure designed to suppress TM modes in the E-plane (xz plane).

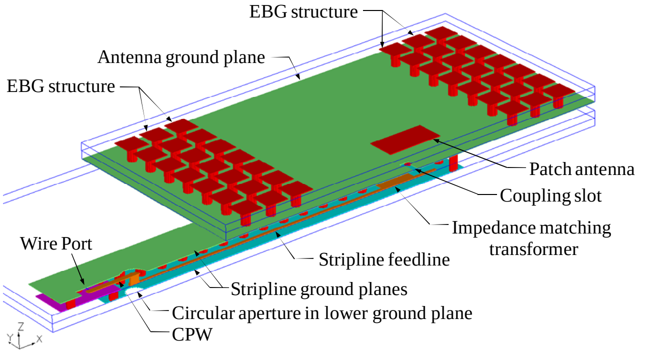

Fig. 1. Features of the 60 GHz LTCC patch antenna.

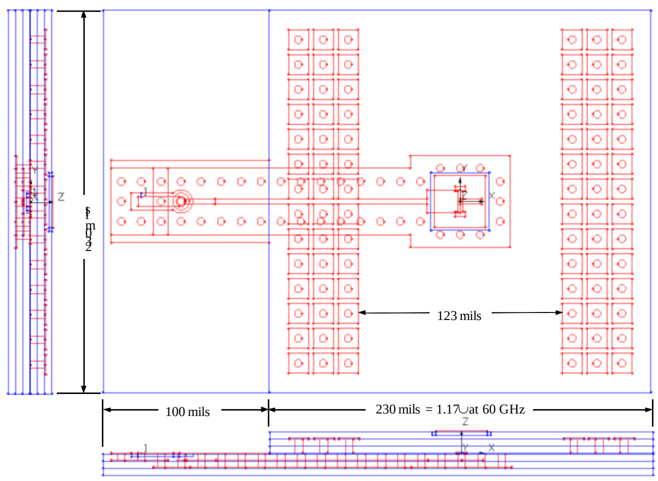

Fig. 2. Orthogonal views of the 60 GHz LTCC patch antenna.

III. EBG STRUCTURE

The EBG structure consists of the top three LTCC tape layers ($\varepsilon_r \sim 7.0$), the Au ground plane below these layers, three rows of patches as shown in Fig. 2, and Au vias that span two of the interior tape layers above the ground plane. The unit cell period is 15 mils (381 um), and the nominal 5 mil vias have a post-fired diameter of about 116 um. Au patches are fabricated using ultraviolet laser ablation of a metalized green sheet. As shown in Fig. 3, this manufacturing process yields clean and uniform 55 um wide slots. Post-fired slot with is about 50 um. As a large array, this LTCC EBG structure has a measured TM mode cutoff frequency of about 53 GHz [7] which is ideal to center its surface wave stopband near 60 GHz.

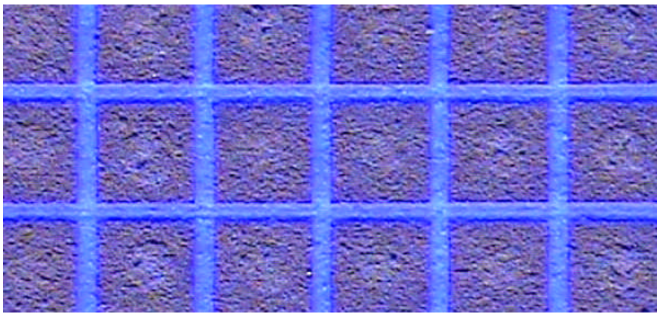

Fig. 3. Photo of the EBG patch layer as a green sheet (pre-fired).

IV. ANTENNA PERFORMANCE

The simulated 3D directivity patterns are compared with the integrated EBG structure in Fig. 4, versus without any EBG structure as shown in Fig. 5. Without an integrated EBG structure, the well-formed main beam divides into two lobes in the E-plane (xz-plane), and the z axis directivity falls from 8.6 dBi to 2.6 dBi. These two directivity plots graphically illustrate the value of an integrated EBG structure.

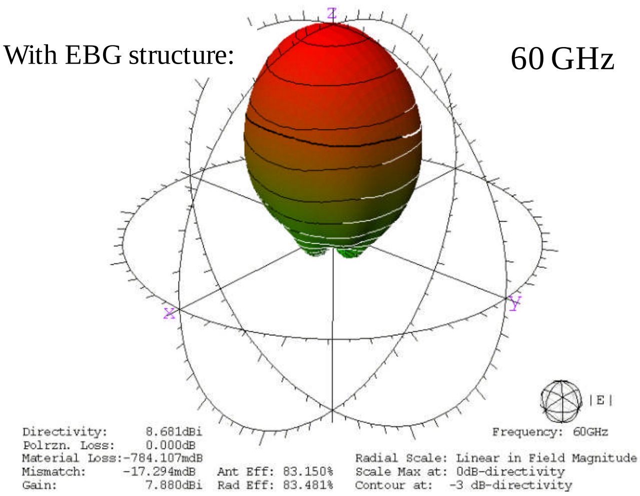

Fig. 4. 3D directivity at 60 GHz with the EBG structure.

With the EBG structure, the main beam is well formed over at least 56 GHz to 64 GHz with the peak directivity predicted to be between 8.15 dBi and 8.75 dBi. Antenna efficiency is predicted to peak at 83%, and exceed 70% over 58-62 GHz.

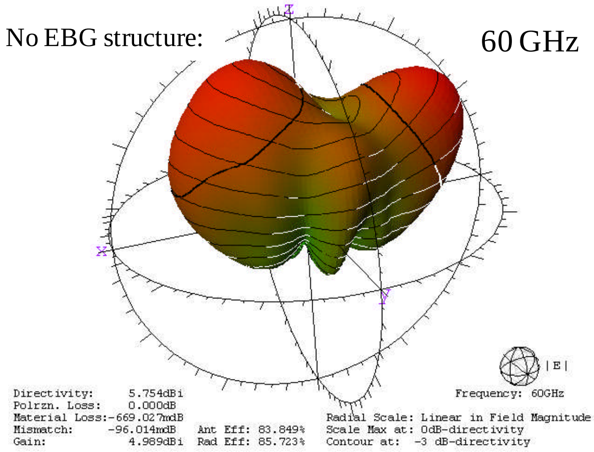

Fig. 5. 3D directivity at 60 GHz without the EBG structure.

V. CONCLUSIONS

Presented here is 60 GHz LTCC patch antenna with an integrated Sievenpiper EBG structure for surface wave suppression resulting is much improved antenna patterns. The EBG structure allows the broadside directivity to be as high as 8.0 dBi over 56-64 GHz despite the fact that the substrate relative permittivity is as high as 7. This is believed to be the first demonstration of Sievenpiper EBG structure used at a frequency as high as 60 GHz in an LTCC antenna. Fabrication of this antenna is possible using ultra-violet laser ablation of the green sheets. More details including measurements will be shown at the conference.

REFERENCES

[1] Daniel F. Sievenpiper, "High-impedance electromagnetic surfaces", Ph.D. Diss., Dept. of Electrical Engineering, University of California, Los Angeles, 1999.

[2] Dan Sievenpiper, Lijun Zhang, Romulo F. Jimenez Broas, Nicholas G. Alexopoulos, and Eli Yablonovitch, "High-impedance electromagnetic surfaces with a forbidden frequency band," *IEEE Trans. Microwave Theory and Techniques*, Vol. 47, No. 11, November 1999.

[3] F. Yang and Y. Rahmat-Samii, *Electromagnetic Bandgap Structures in Antenna Engineering*, United Kingdom: Cambridge University Press, 2009. Section 5.2.1, pp. 130-133.

[4] Antti E. I. Lamminen, Antti R. Vimpari, and Jussi Saily, "UC-EBG on LTCC for 60 GHz Frequency Band Antenna Applications," *IEEE Trans. on Antennas and Propagation*, Vol. 57, No. 10, October 2009, pp. 2904-2912.

[5] Nuria Llombart, Andrea Neto, Giampiero Gerini, and Peter de Maagt, "Planar Circularly Symmetric EBG Structures for Reducing Surface Waves in Printed Antennas," *IEEE Trans. on Antennas and Propagation*, Vol. 53, No. 10, October 2005, pp. 3210-3218.

[6] D. M. Nair, W. E. McKinzie III, B. A. Thrasher, M. A. Smith, E. D. Hughes, and J. M. Parisi, "A 10 MHz to 100 GHz LTCC CPW-to-Stripline Vertical Transition," *2013 IEEE Intl. Microwave Symp.*, Seattle, WA, June 2-7, 2013, pp 1-4.

[7] W. E. McKinzie III, D. M. Nair, B. A. Thrasher, M. A. Smith, E. D. Hughes, and J. M. Parisi, "Millimeter Wave Measurement of the TM Mode Cutoff for EBG Structures Fabricated in LTCC for Antenna Applications," *2013 IEEE Antennas and Propagation Intl. Symp.*, Lake Buena Vista, FL, July 5-12, 2013, pp. 83-84.