Measurement Method for the TE Mode Cutoff Frequency in EBG Structures Fabricated in LTCC for Antenna Applications

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***Abstract*—This paper presents characterization of low temperature co-fired ceramic (LTCC) based electromagnetic bandgap (EBG) structures. We show a new test method to measure the TE mode cutoff frequency of an EBG structure. This test method is implemented at millimeter wave frequencies. Exponentially-shaped TE mode surface wave launchers are fabricated in the same LTCC substrate as the EBG structure under test to realize a compact and repeatable test vehicle. A pair of two port coupling measurements experimentally yields the TE mode cutoff frequency, below which a bound TE mode surface wave is suppressed. The TE mode cutoff frequency is important where EBG structures are integrated into millimeterwave LTCC antennas because this cutoff frequency must be greater than the antenna's operational frequency range. This proposed test method differs from previous experimental techniques because it employs a calibration test vehicle, and this test method provides a clear indication of the TE mode cutoff frequency.**

I. INTRODUCTION

Low temperature co-fired ceramic (LTCC) is an attractive multilayer substrate technology for millimeterwave antennas. However, one of the major issues is the excitation of parasitic surface waves by the antenna elements, transitions, and other discontinuities. TE mode surface waves can distort the H-plane antenna pattern, and therefore surface wave suppression is a critical design goal. One means of suppression is to fabricate an electromagnetic bandgap (EBG) structure into the LTCC substrate. A prominent example is the Sievenpiper high-impedance surface [1], [2] which will be used here as an example.

The TE mode cutoff frequency has been difficult to clearly identify in experiments because it is defined on a dispersion diagram by a very subtle transition from a leaky mode to a bound mode where the slope of the dispersion curve is continuous and almost constant where it crosses the light line.

In this test method, a candidate open EBG test structure is fabricated in a multilayer LTCC substrate. The substrate contains two integrated surface wave launchers; one to launch power and another to receive power. The surface wave launchers have a microstrip feedline excited by a GSG wafer probe. This test vehicle may be wafer probed as a two port network. Another test vehicle, identical to the first except without the vias and patches of the EBG structure, is measured as a calibration case. The two sets of coupling data are subtracted (in dB), and the normalized coupling curve reveals a sharp peak which is the TE mode cutoff frequency. To our knowledge, an experimental procedure to extract the TE mode cutoff has not previously been demonstrated with EBG structures fabricated in LTCC, nor has it been demonstrated using a calibration test vehicle.

Our test method is described using an example of a full wave simulation from CST Microstripes 2012. During the conference we will show experimental results of LTCC test vehicles fabricated with DuPont 9K7 LTCC Greentape^{TM}.

II. TE MODE SURFACE WAVE LAUNCHER

Two TE mode surface wave launchers are fabricated with the EBG structure under test. Features of the launcher design are shown below in the wire-frame view of Fig. 1. TE modes with a transverse (horizontal) electric field are excited by a pair of coplanar strips whose inside and outside edges have exponential shapes. Length and width of the coplanar strips is 1.3 mm and 2.7 mm respectively. It was designed to excite millimeterwave EBG structures in the 60 GHz to 100 GHz frequency range. A buried microstripline with a tapered ground plane is used to feed the coplanar strips. This LTCC test vehicle has 5 tape layers where each tape layer is nominally 5 mils thick.

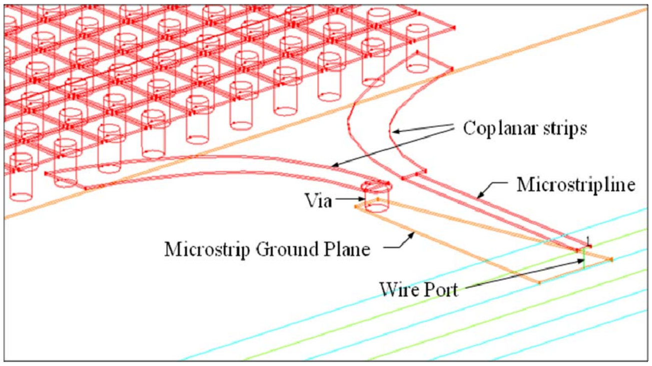

Fig. 1. Features of the TE mode surface wave launcher.

III. EXAMPLE OF THE EXPERIMENTAL METHOD

A Sievenpiper EBG structure was designed for 60 GHz operation using effective media models [3] and transverse resonance equations to analytically predict the surface wave bandgap. This EBG structure employs 3 layers of 108 um thick DuPont 9K7 LTCC tape (ε_r=7; loss tangent 0.0012 at 70 GHz) above its ground plane, and it has one layer of 275 um square patches spaced two tape layers away from the ground plane. The square lattice has a 305 um period, and vias of diameter 116 um. These are all post-fired dimensions. The predicted TE mode cutoff is about 76 GHz, but this a little too high since the analytic model does not account for metal thickness.

Fig. 2 shows orthogonal wire-frame views of the simulated TE mode test vehicle where the workspace has a footprint of 12 mm x 9 mm. Note that the ground plane for the EBG structure extends across the entire 9 mm transverse width of the workspace, and this ground plane is isolated from the ground planes of the microstrip feedlines for the surface wave launchers. The calibration test vehicle is identical to what is shown in Fig. 2 except for the lack of vias and patches. Therefore, the calibration test vehicle contains the wide central ground plane and surface wave launchers. The test procedure involves making two scalar two port measurement of insertion loss; one for the test vehicle with the EBG structure, and then repeating that measurement for the calibration test vehicle. The difference (in dB) between these two measurements yields a normalized coupling plot for TE mode surface waves.

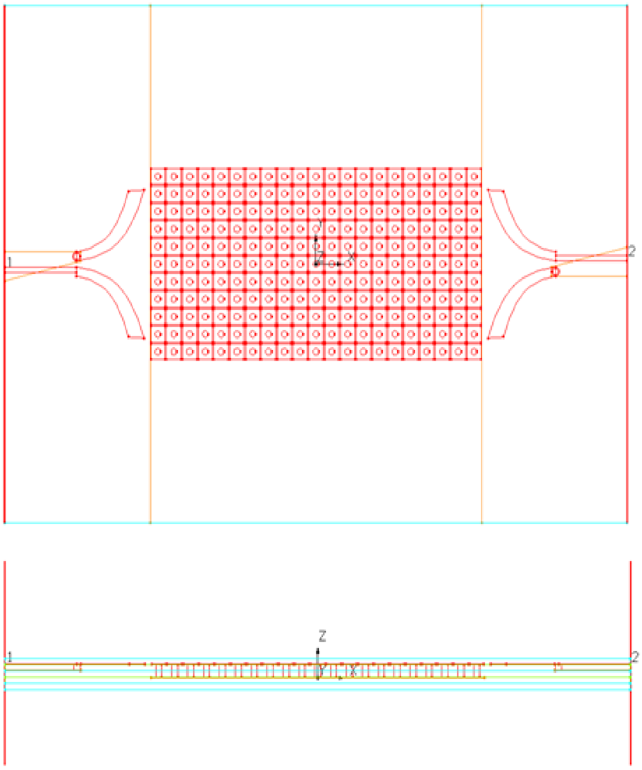

Fig. 2. Plan and elevation views of a two-port TE mode surface wave test vehicle.

The simulated normalized coupling plot is shown in Fig. 3 where the peak value of this curve is associated with the TE mode cutoff frequency. It is about 69 GHz. The rapid rise in coupling level with frequency from about 60 GHz to 69 GHz is explained by the TE mode transitioning from being very leaky near 60 GHz to becoming only marginally leaky as frequency approaches 69 GHz. Ripple in this plot is caused in part by surface wave reflections from edges of the EBG structure and its finite length. Above 69 GHz the TE mode transitions into a bound mode where the level of coupling decreases rapidly with frequency because of two factors. One factor is that the TE mode wave impedance changes making it more difficult for the launcher to excite the TE mode. Another factor is that the metal losses become exacerbated with increasing frequency as the bound TE mode exhibits patch currents which increase in magnitude as the surface wave slows down.

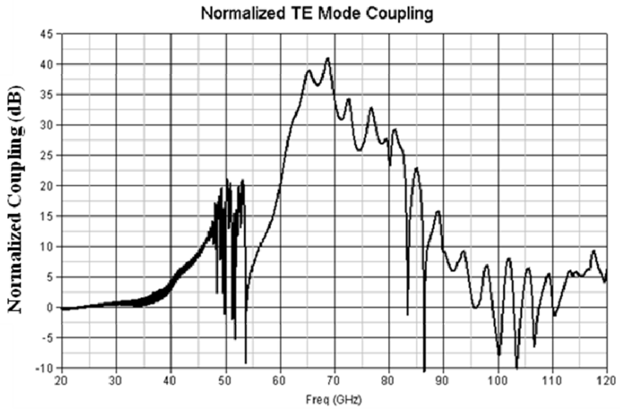

Fig. 3. Simulated normalized coupling plot for the TE mode surface wave for the test vehicle shown in Fig. 2.

IV. CONCLUSIONS

We have presented a new test method to measure the TE mode cutoff frequency of a Sievenpiper EBG structure at millimeter wave frequencies where the EBG structure is fabricated in low temperature co-fired ceramic (LTCC). Exponentially-tapered surface wave mode launchers are integrated into the LTCC test vehicle. Two port broadband millimeterwave measurements reveal the TE mode cutoff as the peak value in a normalized plot. A numerical example is shown for a 60 GHz EBG structure to demonstrate the test method. Measured data on 60 GHz and 77 GHz EBG structures in LTCC will be presented at the conference.

REFERENCES

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