A 77GHz on-chip Microstrip patch antenna with suppressed surface wave using EBG substrate

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***Abstract*— This paper presents the design of a patch antenna with suppressed surface waves by means of applying an electromagnetic band-gap structure. Establishing the antenna on high dielectric substrate such as Silicon makes it possible to integrate the antenna with RFIC active component and circuitry. However, the performance (gain and radiation pattern) of antenna will be degraded due to the presence of surface waves on a thick dielectric substrate. It is possible to design an engineered substrate that filters out the surface wave around the frequency of interest. Moreover, having high dielectric substrate will localize EM wave to substrate and hence reduce antenna gain. For this problem, available silicon etching technology is used to remove the substrate right under the patch and have a locally low dielectric constant substrate underneath the antenna. Proposed microstrip antenna resonates at 77GHz with 7dB realized gain which can be used in array for Automotive Radar purposes. Simulation results show great improvement in radiation pattern and 3dB increase in antenna's broadside gain in comparison with antenna on normal substrate.**

I. INTRODUCTION

Microstrip patch antennas are widely used in wireless communications due to the advantages of low profile, light weight, and low cost. Recent applications have pushed the frequency into the mm-wave region for application such as automotive radars at the 77 GHz band [1]. Fabricating microstrip-based planar antennas on Silicon (ε_r=11.9) are strongly preferred for easy integration with the MMIC/RFIC and RF circuitry. However, patch antennas on high dielectric constant substrates are highly inefficient radiators due to surface wave losses and have very low gains because of localized EM waves. This results in a patch antenna with low gain, efficiency and distorted pattern as well as high level of cross-polarization and mutual coupling within an array environment.

In order to tackle the problems caused by surface wave in patch antenna, two approaches have been pursued to have a patch antenna with optimum performance on high-dielectric constant substrate. First method uses micromachining technology, while the second makes use of the concept of electromagnetic bandgap (EBG) structures [2]. In the first approach, part of the substrate right under the radiating element is removed to establish a low effective dielectric-constant environment for the antenna. Doing so, power loss due to surface-wave excitation is reduced and efficiency of energy coupling to space waves improves. The second approach take advantages of EBG structures: the high-permittivity substrate is engineered by putting periodic structure to change the propagation characteristic of a surface wave around antenna operative frequency. Various types of periodic loading of substrate have been studied [3]. One approach is to drill a periodic pattern of holes in the substrate or ground plane. Another method is to embed a periodic pattern of metallic pads inside the substrate; pads are shorted to the ground plane with vias. In the last one, a type of planar or 2-D loading (no vias are required) were proposed which is compatible with standard monolithic microwave integrated circuit fabrication technology (uni-planar compact photonic bandgap (Uni-EBG)).

This paper studies a 2-D Uni-EBG structure that is designed specifically to enhance the performance of microstrip patch antennas at 77GHz. First, the design procedure of 2-D surface to forbid the propagation of transverse magnetic (TM) surface waves in a grounded dielectric substrate around antenna's operative frequency elaborated. It is then demonstrated that a substantial improvement in antenna performance can be achieved simply by surrounding a microstrip patch antenna with this 2-D Uni-EBG surface, resulting in a significant increase in both antenna gain and radiation pattern.

II. CHARACTERIZATION OF THE EBG STRUCTURE:

An EBG substrate is characterized by a dispersion or ω-β diagram. For a periodic structure such as the EBG, the field distribution of a surface wave is periodic with a proper phase delay determined by the wave number k and periodicity p. Moreover, the dispersion curve for both $k_x(\omega)$ and $k_y(\omega)$ is periodic along the k axis with a periodicity of $2\pi/p_x$ and $2\pi/p_y$: $0 \le k_{xn} \le 2\pi/p_x$, $0 \le k_{yn} \le 2\pi/p_y$, which is known as Brillouin zone [4]. Figure 1 shows the geometry of our 2-D uni-planar EBG surface together with HFSS model for unit cell of EBG.

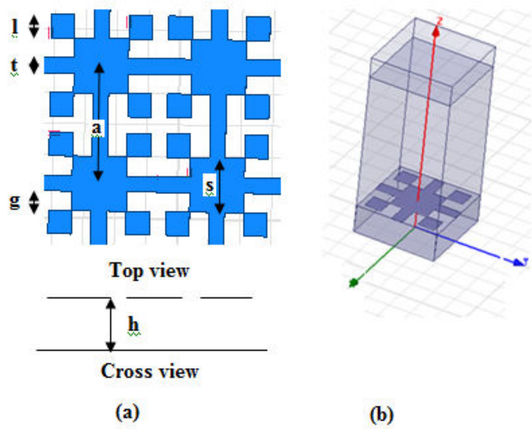

Fig.1 a) Uni-planar EBG surface b) HFSS Model for unit cell of Uni-Planar EBG surface

Full wave numerical method (FEM of HFSS) has been used to analyze characterestics of EBG structures. Both PML and periodic boundary conditions were used. With the utilization of periodic boundary conditions (PBCs), only a single cell of the EBG structure needs to be modeled in full wave simulation [5]. At low frequencies, the impedance is inductive and structure supports TM surface waves, while in upper bands it supports TE surface waves due to capacitive nature of structure. In between there would be a stop-band in which no wave propagates. Surface waves with TM nature are responsible for distortion in pattern since they have same polarization with patch modes and easily harvest energy from patch mode and block the energy coupling to the space wave. So, our primary goal is to keep Surface waves with TM nature away from our frequency of interest (77GHz). On the other hand, surface wave with TE nature have orthogonal polarity with patch mode, so, for the most part, their impact can be ignored. However, their presence will degrade cross-polarization. Based on the concepts discussed above, we start to characterize the dispersion diagram of the Uni-planar EBG structure using the Ansoft HFSS. The dimensions of the analyzed EBG structure are:

a= 600um, l=120um, s=278um, t=80um, g=98um, h=250um

Fig.2 shows the dispersion diagram of the surface wave's different modes in designed EBG structure.

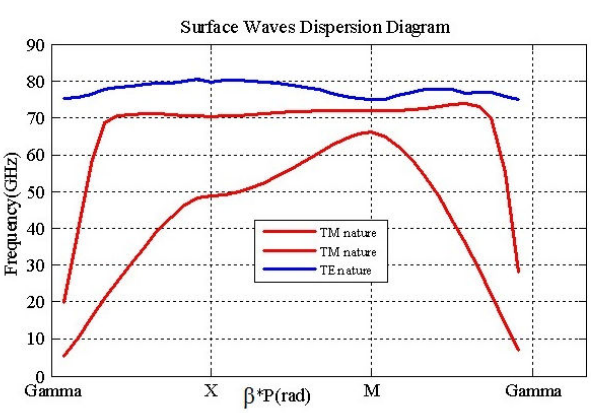

Fig.2 Surface wave dispersion diagram for EBG structure

III. EBG-Patch Antenna design:

Once the proper EBG surface has been designed for surface wave suppression, the design of an EBG antenna is straightforward. This is done simply by surrounding the antenna with EBG surface (Fig.3). The EBG surface does not interfere with the near field of the antenna, and it just suppresses the surface waves [3]. However, the presence of the EBG near the patch drops the resonance frequency which can be removed easily by tuning the length of the patch.

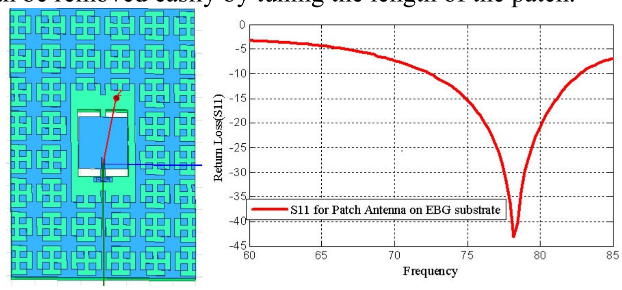

Fig.3 Designed Antenna with its S11

For comparison purposes, another patch antenna designed on a same substrate without EBG surface. Figure 4 compares the radiation pattern and gain of these antennas, both in the E and H plane.

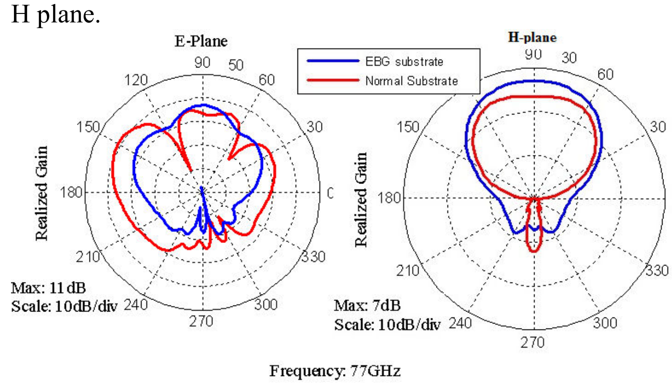

Fig.4 Radiation pattern for two type of antenna

IV. Conclusion:

A 77 GHz on-chip patch antenna with suppressed surface waves by applying an electromagnetic band-gap structure is simulated with 7 dB gain with undistorted radiation patterns. A sample of antenna is delivered to IHP for fabrication and measurement result would be presented at the conference.

ACKNOWLEDGEMENT

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