Enhancing Patch Antennas Performance Using Micromachining and EBG Technologies

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Abstract

This paper presents the performance enhancements in a microstrip line fed patch antenna by the use of selective etching based on micromachining (MEMS technology), and triangular lattice 2-D electromagnetic band gap (EBG) substrate. This paper addresses the issues related to the fabrication of patch antenna on a high permittivity substrate such as Gallium Arsenide (GaAs), silicon with the increased surface wave losses. Three different patch antennas have been considered. The first is a conventional rectangular patch fabricated over a silicon substrate, in the second selective lateral etching has been carried in the substrate below the patch. The third structure that is being proposed in this paper uses an EBG substrate constructed by drilling cylindrical air holes in triangular lattice pattern in addition to the micro machined element. The use of both these methods have shown an increased bandwidth and reduction in surface wave losses.

Index Terms ---- **Patch antenna, Electronic bandgap, Micromachining.**

I. INTRODUCTION

Microstrip antennas are preferred for various applications due to their small size, low weight, and low manufacturing cost. Also substantial research efforts have been carried out worldwide [1] making it a very well established field. The requirements of an antenna are quite different from that of a closed circuit. Antenna has to be an efficient radiator hence the existence of loosely bound fringing fields at the edges of the patch is detrimental to its performance. Thus while substrates with high dielectric constants are small in patch size suffers from losses inherent in the substrates due to the increased surface waves, substrates with low permittivity are good radiators. Ideally a microstrip antenna should thus have a substrate with low permittivity for good performance. On the other hand using high permittivity substrates like silicon and gallium arsenide are in demand due to the rapid growth of IC technology and requirement of small size antennas for wireless communications. With such substrates it would be possible to integrate the antenna on a single chip with other circuit elements. As circuit design moves towards higher levels of system integration fabrication of microstrip antennas on high permittivity substrates is desired. Such a design i.e. on high permittivity substrates leads to increased surface wave losses and reduced bandwidth. Surface waves, which propagate along the substrate, will also lead to increased coupling between adjacent elements. In highly compact circuits with large packing density surface waves will degrade the system performance [2]. One of the methods used [3] has been to use selective lateral etching whereby a part of the silicon substrate below the patch is removed leading to the reduction in surface waves. Another method for the reduction of surface waves is the use of electromagnetic bandgap substrates [4].

EBG materials are a class of periodic metallic, dielectric or composite structures that exhibit transmission and reflection bands in their frequency response. The EBG substrate is constructed by means of periodic cylindrical air columns drilled in the silicon substrate. These substrates show a complete bandgap for TE and TM modes with triangular type of lattice [5]. Thus if the periodicity is chosen such that the resonance of the patch falls in the stop band of the EBG substrate then no surface wave will exist in the substrate.

Both of these methods have already been investigated but no microstrip antenna design has been reported that have utilized both of the techniques on the same substrate. In this paper, we elaborate on a design with EBG and micro machined element on the same substrate. The return losses of these three antenna configurations have been comparatively studied to establish the superiority of unifying both these methods.

II. PATCH ANTENNA IN 3 CONFIGURATIONS

Three patch antennas are designed based on the different technologies. The simulated results are generated using the accurate commercially available High Frequency Structure Simulator (HFSS) version 9 [6]. The antenna design has been carried out in the K-band with silicon substrate of relative permittivity 11.8. The first one is the conventional rectangular patch with the microstrip line feeding network. In the second design a part of the silicon substrate has been removed below the patch by micromachining. For the third antenna design triangular lattice Electromagnetic Band Gap (EBG) structures of cylindrical air holes have been incorporated in the substrate surrounding the antenna in addition to the micromachined element below the patch.

A. K-Band Patch Antenna

The substrate thickness of 0.6mm has been taken and the dimensions of the patch calculated for a resonance frequency of 28.8GHz.

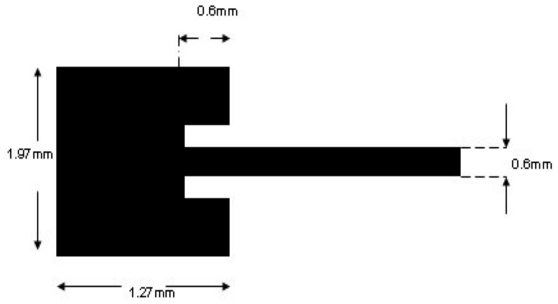

Fig 1. Geometry of simple patch

Figure 1 shows the top view of the patch. The inset has been used for impedance matching. Position of the inset has been calculated using [7]. The width of the microstrip line has been chosen such that the microstripline is matched to the antenna element.

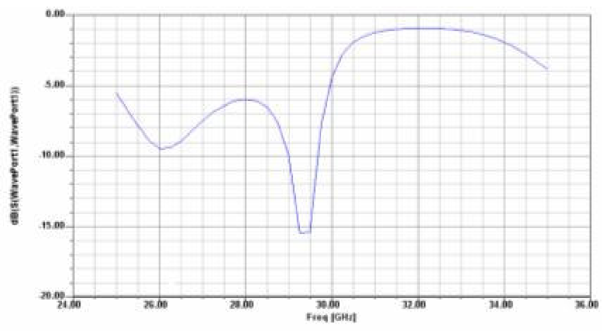

Fig 2. Return loss of the simple patch

Figure 2 shows the plot of return loss for the patch designed in dB versus frequency in GHz. The resonance frequency is at 28.8 GHz and the bandwidth below -10dB is 0.7 GHz.

B. K-Band Micromachined Patch

The substrate beneath the patch is removed to create two separate dielectric regions of air and silicon. The height of the air region is half that of the substrate region and the lateral dimensions are same that of the patch. In micromachining the lateral etching takes place at an angle of 55 degrees. The simulation however has been carried out with perpendicular walls. Figure 3 shows the micromachined patch

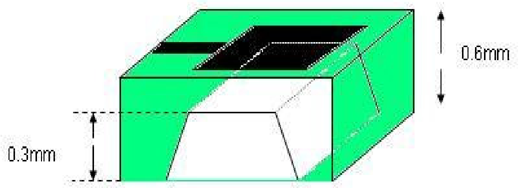

Fig 3. Geometry of micromachined antenna

The return loss obtained for the micromachined patch antenna is shown in Figure 4.

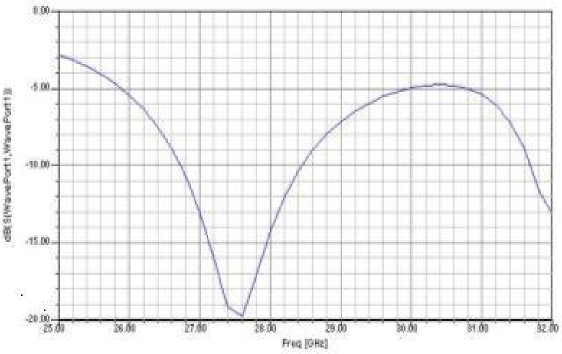

Fig 4. Return loss for micromachined patch

The -10dB bandwidth is 1.5GHz while the resonance frequency has shifted to 27.6GHz. There is a slight downward shift in the resonant frequency, which is inevitable due to the reduced relative permittivity since a portion of the silicon substrate below the patch is removed. The introduction of the air gap below the patch, which is usually called as micromachining has lead to the increased bandwidth

C. Patch with EBG substrate and micromachining

The antenna design proposed by us is one in which both the micromachining element and the EBG substrate is incorporated. Figure 5 shows such a microstrip antenna.

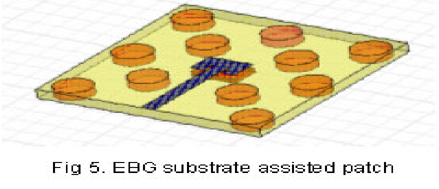

Fig 5. EBG substrate assisted patch

The lattice used is triangular triangular lattice of cylindrical air holes in the substrate, with the ratio of radius (r) to lattice constant (a) being 0.2. The dimensions are calculated so that EBG substrate has a complete band gap for TE and TM modes at 30 GHz.

At this frequency wavelength in free space (λ) is 1cm. r/λ = 0.4 [5]. The calculated values are radius = 0.8mm and lattice constant = 4mm. the antenna return loss is plotted in Figure 6.

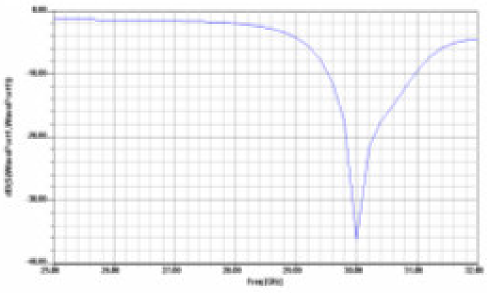

Fig 6. return loss in patch with micromachining and EBG substrate

The -10dB bandwidth is 1.5GHz and resonance is at 30GHz. At resonance the return loss is -35dB. Here we see that the return loss for the antenna at the resonance has been reduced to a great value, which is due to the EBG structure surrounding the patch makes the substrate with no propagation at that frequency thereby there is more propagation of electromagnetic (EM) waves in the broadside direction of the antenna which is more desirable.

III. COMPARISON OF OTHER ANTENNA FUNDAMENTAL PARAMETERS

Apparently there seems to be no improvement on introduction of the EBG substrate in the bandwidth of the patch antenna in comparison to the micromachined patch antenna. But to be conclusive on the surface wave losses few other parameters like gain, efficiency of these two structures are compared in Table 1.

	S11 bandwidth -10 db	**Directivity**	**Efficiency**	**Gain**
Plain patch	0.7 GHz	2 db	70 %	1.45 db
Micromachined patch	1.7 GHz	4.4 db	81 %	3db
Micromachined patch with EBG substrate	1.7 GHz	6.7 db	95 %	7 db

Table 1.

The micromachining element has been designed in such a way that it just covers the underneath of the patch. For better efficiency and directivity the etching has to be carried out even further. Such a design ensures that the fringing fields are also covered by the element. Nevertheless the introduction of EBG substrate has increased the efficiency, directivity as well as the gain. Efficiency with the EBG substrate is 95 percent as compared to 81 percent for simple micromachined patch. These results indicate that there has been reduction in surface wave losses with the introduction of EBG substrate.

IV. CONCLUSION

Three different configurations of the microstrip patch antennas on a silicon substrate have been investigated at the K-band. First one is the conventional patch antenna on a silicon substrate. Second one is a patch antenna on a micromachined silicon substrate. And the third one is the patch antenna surrounded by triangular EBG lattice of cylindrical air holes printed on micromachined silicon substrate. It has been observed that micromachining technology improves the patch antenna bandwidth considerably whereas the substrate with both the micromachined elements as well as the triangular lattice EBG exhibits an increased bandwidth and deeper return loss in the passband of the antenna depicting that there is considerable reduction in the surface wave losses thereby more radiation in the broadside direction of the patch antenna which is a desirable feature. A rectangular patch antenna fabricated over a silicon substrate has certain limitations like small bandwidth, surface wave losses. Micromachining methods enhance the performance of such an antenna. In this paper we have used a micromachined patch with an EBG substrate and demonstrated an enhanced efficiency and gain. The micromachining element design however has not been optimised. Our motive is to propose that using an EBG substrate in tandem with the micromachining element drastically improves the antenna performance.

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