High Performance 94GHz Holes-backed Integrated Antennas Fed by Inset Tapered Microstrip Line

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Abstract – **This paper present design of microtrip integrated antennas printed on Gallium arsenide materials wafer and fed by inset tapered microstrip line to minimizing the reflection at the interface between the feed line and antenna patch. The antenna is designed for MMICs application at 94GHz band. Different shapes of back holes underneath and around patch have been used to reduce surface wave and improve the antennas performance. The back holes patch antennas have demonstrated a significantly improved radiation performance and bandwidth than the conventional patch antenna directly printed on top of the same type of substrate. The maximum predicted gain for the back holes antennas is 4.2dB with the front-to-back ratio of 13.3dB and lower side lobe regardless, showing high radiation efficiency of the antenna structure. A conventional patch on the same substrate gives a maximum predicted gain of 2.2dB with a bad front-to-back ratio of 0.2dB, but no longer at the broadside direction as a consequence of surface wave triggered in this electrically thick dielectric substrate.**

Keywords – **surface wave, integrated microstrip antenna, tapered microstrip lines, surface wave, back holes patch antenna.**

I. INTRODUCTION

The growing demands of wireless communication systems have called for the development of small, low profile antennas that are low cost and have high performance over a large range of frequencies.and they must also be suited to integration with integrated circuits and MMICs. The needs for larger bandwidths and thus higher data transmission rates have pushed the wireless communications systems to higher frequency bands in the millimeter wave regions. Considering these requirements, microstrip millimeter wave antennas appear to be a suitable choice of antenna technology for wireless communication systems [1-4].

Microstrip millimeter wave antennas are continuing to attract attention and find applications in emerging wireless systems. The increasing popularity of this class of antennas can be attributed to a number of factors. Firstly, they can be manufactured at a minimal cost using a simple lithographic process. Secondly, they are low profile and lightweight making them more suitable for the mobile environment than traditional millimeter wave antennas. Thirdly, they are suitable for integrating with microwave and millimeter wave circuit components. Fourthly, the narrow beam width of millimeter waves provide better resolution and can penetrate through environments of smoke, dust, and fog where optical waves arenot applicable and suffer from high attenuation. Finally, the planar nature of printed antennas makes them ideal for applications that require low profile structures and offer convenience in the design of large arrays [3, 5]

The integration of antennas with Integrated Circuits (ICs) or packages provide the benefit of improved performance and space efficiency in many millimeter wave designs. However, the utilization of high dielectric constant materials has its drawbacks, such as narrow bandwidth and pronounced surface waves, which lead to limited radiation efficiency, low gain, and undesired coupling between the various elements in array configurations. These factors limit their application in broadband modules and they cannot be applied well at millimeter wave frequencies. Several techniques have been discussed to improve the antenna performance. In order to reduce the substrate effect, several techniques have been reported such as making a cavity or holes around and underneath the patch antenna, electromagnetic bandgap (EBG), stacking substrates and coupling through aperture and suspending the patch antenna over an air cavity using a membrane or by using posts to lift the patch into air [4-10].

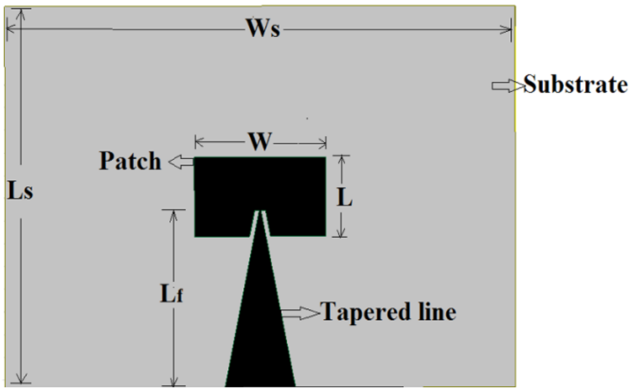
Making holes around and underneath the patch antenna approach can be considered as an alternative to a conventional microstrip antenna approach, with concomitant advantages of broad bandwidth, low loss, and reduced dependence on substrate. However, feed network loss has prevented them from being efficiently implemented in integrated fashion. Therefore, using tapered microstrip line to feed patch has excellent advantage concerning the loss characteristic in high frequency than the conventional transmission line structures [8, 10].

The design of microstrip millimeter wave antennas on high-permittivity substrate working at mm-wave band frequencies and possessing high performance and fully combatable with MMICs still remain a challenging task. The main goal of this paper is to enhance the antenna performance by reducing the surface wave emphasis on antenna integration with other MMICs at W-band frequencies.

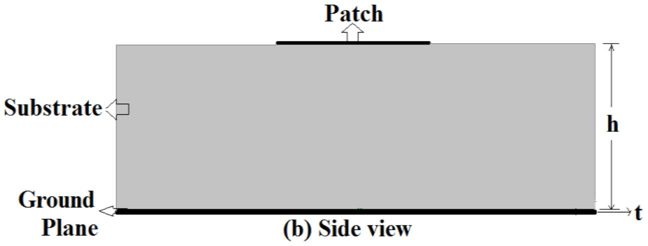
II. CONVENTIONAL PATCH ANTENNA DESIGN

The microstrip patch antenna is designed to operate at 94GHz frequency band. It Consist of rectangular patch fed by 50ohm microstrip line. The ground plane and patch have 0.002mm thickness of gold and separated by 0.4mm gallium arsenide dielectric substrate. The geometry of the proposed antenna is shown in Fig.1. First design of this antenna was the patch fed by typical microstrip line. The simulation result shows that it is difficult to get matching between feed line and patch because the width microstrip line is large compare with the patch width, this is cause mismatch between microstrip feed line and patch due to reflection at interface. In order to overcome this problem inset tapered microstrip line has been used to minimizing the reflection at the interface and to match microstrip feed line with radiator. Microstrip taper line in this design is used as matching sections between two different characteristic impedances.

The dimension of tapered line and patch were calculated using [8] and optimized with HFSS simulation software as describe in Table I.



(a)Top view



(b) Side view

Fig1. structure design micro-strip patch antenna

TABLE I
DIMENSIONS OF PATCH ANTENNA.

Parameter Description	Dimensions
the width of the patch (W)	0.3mm
the length of the patch (L)	0.166mm
The width of the Tapered feed line W_1 , W_2	W_1=0.004mm, W_2=0.291mm
Length Tapered feed line	0.703mm
length of the ground plane	1.445mm
width of the ground plane	2mm

The acceptable return loss for a microstrip antenna is *-10dB* or below. It is better if the antenna having the return loss of lower than *-20dB*. The simulation results of antenna return loss is shown in Fig.2. The 10dB bandwidth is about 1.2GHz at 94GHz resonant frequency with return loss about 43dB. It can be clearly observed that the insertion loss is very high and suffer from narrow bandwidth. Also the antenna has poor radiation efficiency and high back and side lobes over its bandwidth, Fig.3 shows 3D radiation pattern for antenna gain. The maximum antenna gain is 2.2dB at resonant frequency.

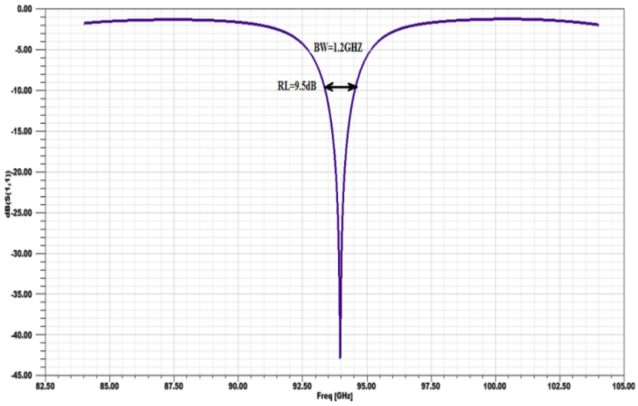


Fig. 2 Return loss of the patch antenna

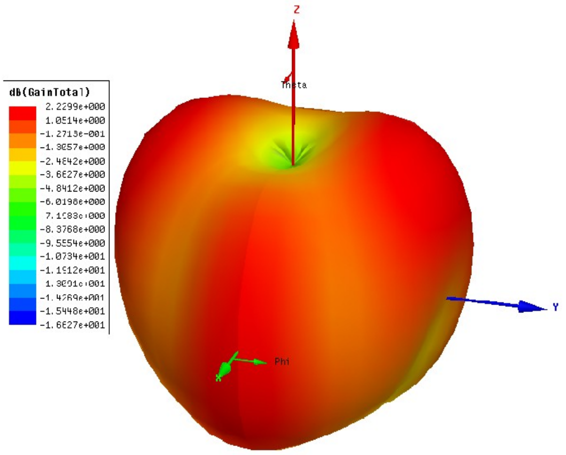


Fig. 3 3-D radiation pattern of the patch antenna.

III. REDUCTION OF SURFACE WAVE EFFECT USING BACK HOLES

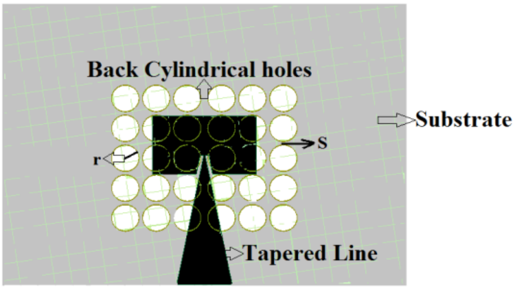
The degradation of microstrip antenna performance on GaAs substrate is due to the excitation of surface wave modes, since it difficult to control and are not radiated in the main beam direction. This distorts the main beam radiation pattern and increases the level of the side and back lobes. For GaAs substrate with 400µm thickness and dielectric constant of 12.9 which is used in this design, the surface waves will propagate slightly downwards from the antenna patch into the substrate, having an elevation angle θ between $90^o \le \theta \le 163.83^o$. Then these wave hits the ground plane, where it is reflected, it hits the dielectric-to-air boundary and is again reflected, and so on. The excitation of surface waves becomes significant when the substrate is electrically thick and has a large permittivity. For 94GHz band frequencies, the first surface wave mode TM_0 has zero cut-off frequency and there are possibility of exciting other mode which is TE1, since its cut-off frequency (54.3GHz) less than 94GHz band.

Holes backed microstrip antennas have improved performance in terms of bandwidth and radiation efficiency compared to conventional microstrip patch antennas. In this paper the surface wave effect reduced by using different shapes of back holes by etch portion of the substrate material underneath and around the radiating element.

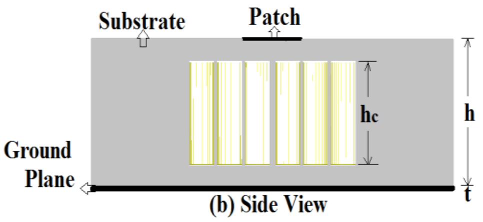
The antenna structures combines the advantages of inset taper microstrip feed line with the advantages of backed holes patch antenna and it simplifies the structure of the antenna to make the patch antenna easier to integrate with MMICs. This approach is based on using bulk micromachining to etch or drill serial as matrix of very closely spaced holes underneath and around the antenna patch. The effective dielectric constant can be controlled by choosing a diameter and spacing of the holes. Also, the spacing period of the holes must be small compared to wavelength of operating frequency. In this paper three shapes of back holes have been used which are square back holes, cylindrical back holes and rectangular back holes.

A. Cylindrical Back Holes Patch Antenna:

In this design has thirty holes, all hole has height h_c=0.278mm, radius r=0.04mm and spacing between holes s=0.02mm. As Fig.7 shows this structure.



(a)Top View



(b) Side View

Fig.4. microstrip patch antenna with Back cylindrical holes

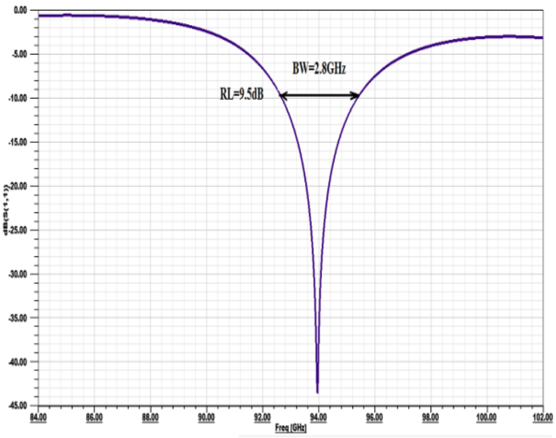


Fig. 5 Return loss of the patch antenna with cylindrical back holes

The 10dB bandwidth is about 2.8GHz at 94GHz resonant frequency with low insertion loss as shown in Fig. 5. The proposed antenna also demonstrates broadside radiation pattern with low side lobes over its bandwidth. The maximum antenna gain is 3.3dB at resonant frequency. The pattern is found to be stable across the whole bandwidth of the antenna with front-to-back ratio of 12dB (worst case). Fig.6 shows the simulated 3-D radiation pattern of antenna gain at resonance frequency.

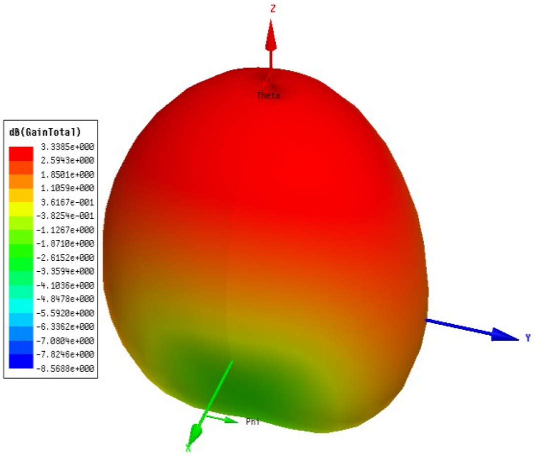
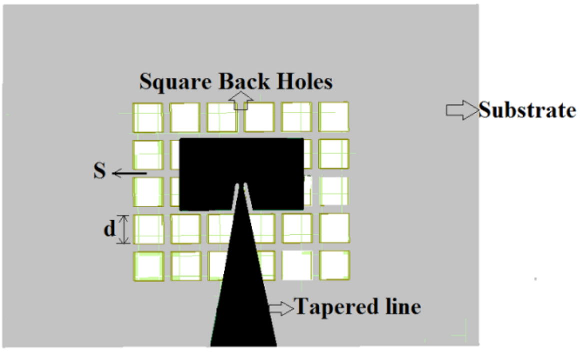


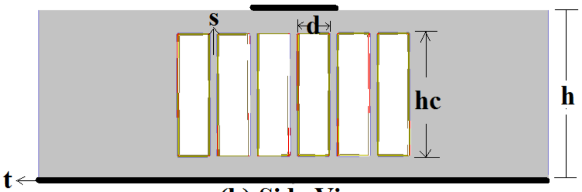
Fig. 6 3-D radiation pattern of the patch antenna with cylindrical back holes

B. *Square Back Holes Patch Antenna:*

In this design has thirty holes and all holes have square cross section holes with height hc=0.278mm, length d=0.071, width d=0.071 and spacing between holes s=0.02mm. All these dimensions have been optimized by using HFSS simulation software. Fig. 7 shows the top view and side view of this antenna structure.



(a) Top View



(b) Side View

Fig.7 microstrip patch antenna with back square holes.

The bandwidth is about 2.8GHz at 94GHz resonant frequency wich is the same result of previous design as shown in Fig. 8. The maximum antenna gain is 3.4dB at resonant frequency. The pattern is found to be stable across the whole bandwidth of the antenna. Fig.9 shows the simulated 3-D radiation pattern of antenna gain at resonance frequency.

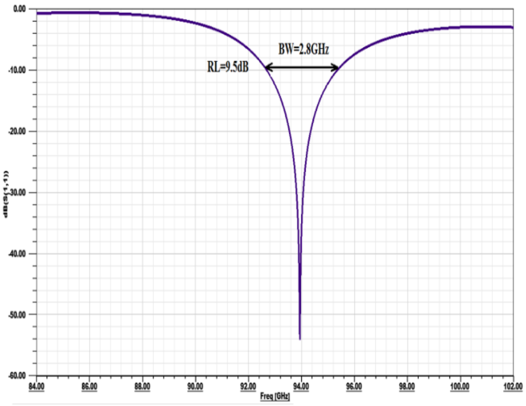


Fig. 8 Return loss of the patch antenna with square back holes

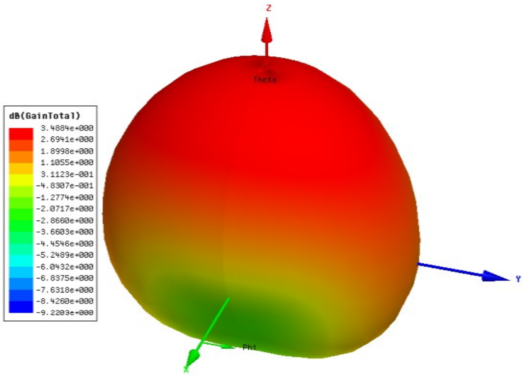


Fig. 9 3-D radiation pattern of the patch antenna with square back holes

C. *Rectangular Back Holes Patch Antenna:*

In this design has ten rectangular holes and all holes have height hc=0.32mm, length Lc=0.76mm, width d=0.024mm and spacing between holes s=0.034mm. The antenna topology is shown in Fig.10.

The Fig.11 shows a radiation resonance at about 94GHz with a return loss of *56 dB* with wide bandwidth of *3GHz* has been achieved (for *10dB* return loss). Also, simulation demonstrates a symmetrical radiation pattern about the broadside direction across antenna bandwidth with high gain of *4.22dB* as shown in Fig. 11. The gain diminishes slowly towards the edges of the antenna bandwidth, and falls sharply for frequencies out of the antenna bandwidth. It is postulated that this is due to significant surface wave generation outside the impedance bandwidth of the antenna as the energy is no longer strongly coupled to the patch element. The pattern is found to be stable across the whole bandwidth of the antenna with low back-lobe and excellent front-to-back ratio of 13.3*dB* (worst case), indicating a reduction of surface wave.

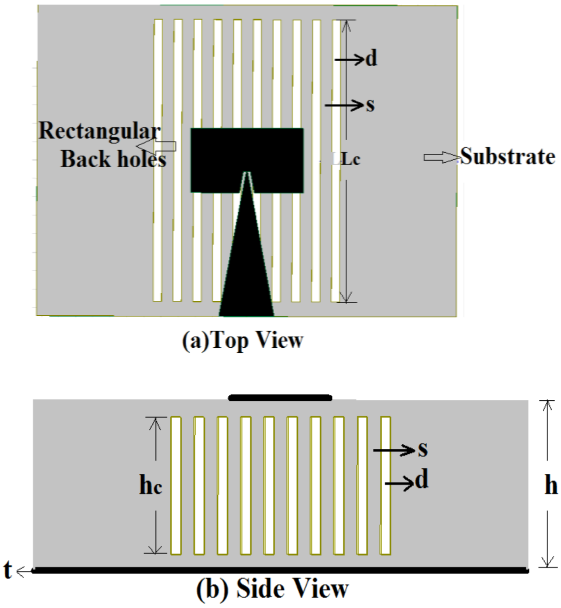


Fig. 10 microstrip patch antenna with back rectangular holes.

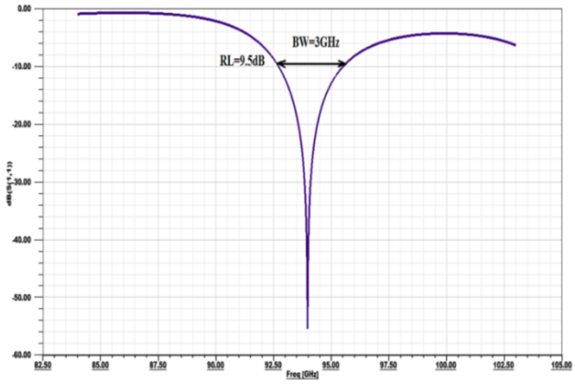
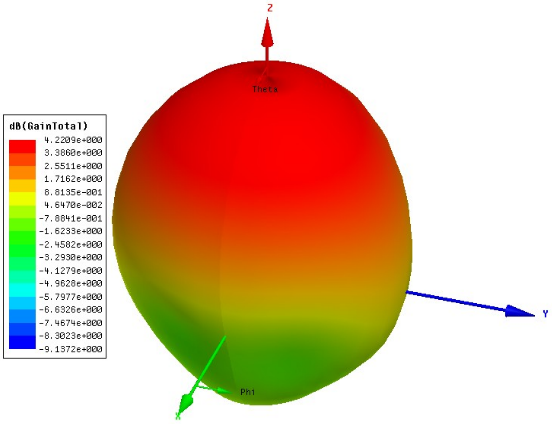


Fig. 11 Return loss of the patch antenna with rectangular back holes



Fi g. 12 3-D radiation pattern of the patch antenna with rectangular back holes

IV. COMPARING BACK HOLES WITH CONVENTIONAL PATCH ANTENNA

A conventional microstrip patch antenna directly printed on top GaAs substrate compared with back holes antenna with different shapes at the same resonance frequency as shown in Table II. The back holes patch antennas have demonstrated a significantly improved radiation performance and bandwidth than the conventional patch antenna directly printed on top of the same type of substrate. The maximum predicted gain for the back holes antennas is 4.2dB with the front-to-back ratio of 13.3dB and lower side lobe regardless, showing high radiation efficiency of the antenna structure. A conventional patch on the same substrate gives a maximum predicted gain of 2.2dB with a bad front-to-back ratio of 0.2dB, but no longer at the broadside direction as a consequence of surface wave triggered in this electrically thick dielectric substrate. It can be clearly observed that there is a deep drop in the antenna radiation performance without back holes due to the diffraction of surface waves at the edge of the substrate.

TABLE IIIII
COMPARING BACK HOLES WITH CONVENTIONAL PATCH ANTENNAS.

Antenna	**Return loss dB**	**Bandwidth GHz**	**Gain dB**
conventional	-43	1.23	2.2299
cylindrical back holes	-43.5	2.8	3.3385
Square back holes	-54.06	2.8	3.4884
Rectangular back holes	-56.24	3	4.2209

V. CONCLUSION

It can be seen that the proposed antenna configurations, which is designed in this paper, offer significant improvements in performance compared with conventional antenna. A new feeding mechanisms of microstrip antenna offer more degrees of freedom for antenna design, and they are provide low radiation loss and less dispersion The proposed antenna configurations have several advantages on high dielectric substrate such as: antennas scheme maximize the antenna performance on high dielectric substrates and allowing integration of 3-D antennas with RF circuitry on a single chip

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