Design and Analysis of Ku/Ka Multiband Frequency Reconfigurable Antenna using Varactors

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***Abstract**: In this paper, initially a multiband microstrip patch antenna covering 20.2GHz (Ka-Band) satellite applications is designed and fabricated, that utilizes the concept of frequency reconfigurability and can dynamically change its frequency and thereby occupies Ku band as well. Multiple frequency bands with different bandwidths are achieved and can be used effectively by incorporating the varactor diodes on/off principle. In particular, the performance of the antenna in terms of bandwidth at higher frequencies especially at Ka Band due to the impact of varactors diodes with different diode configurations is analyzed. The designed antenna resonated at two Ka band frequencies 20.2GHz and 25.5GHz. 66% of bandwidth improvement at 20.2GHz and 63% at 25.5GHz were observed compared to a traditional antenna. The proposed antenna is simulated using Ansoft HFSS software and the simulated results are compared with the measured ones.*

Index: Ansoft HFSS; Frequency reconfigurability; Microstrip Patch antennas; Varactor diodes.

I. INTRODUCTION

Reconfigurability has become a desired feature in present day antenna systems. Most of the applications which include radar, mobile communication, satellite communications etc. demand the concept of reconfigurability to effectively meet the user needs [1]. Reconfigurable antennas by modifying their geometrical as well as electrical behavior can address complex system requirements [2-3]. Recon-figuration is achieved in terms of frequency, radiation pattern and polarization, which can therefore reduce the usage of number of hardware components and thereby reduces design complexity of the system [4-6]. Thus, antenna designers use various RF components such as varactors, PIN diodes, MEMS switches etc. to vary the characteristics of the antenna by redistributing the current direction and altering the radiated field. The proposed antenna is capable enough to reconfigure at six different frequencies covering Ku/Ka bands by incorporating two RF varactor diodes in between the slots. Various research works using PIN diodes, voltage variation across the varactors or MEMS switches and investigated the reconfigurability of the antenna are presented in [7-11].

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Implementation of passive components is extensively useful at higher frequencies i.e. at Ka band and above. It is because as frequency of operation increases size of the antenna decreases therefore achieving of reconfigurability through the implementation of passive components in between the slots on small size antenna becomes complex. Improvement in bandwidth is observed dominantly at higher frequencies due to the impact of diodes. Simulated as well as measured results are compared and tabulated the key aspects. This paper is organized as follows: Antenna design and characteristics of varactor diode are discussed in detail in Section II. Results and Discussions of the frequency reconfigurable antenna in terms of return loss and radiation pattern are highlighted in Section III, followed by Conclusions and References in Section IV.

II. ANTENNA DESIGN

The design parameters of the proposed antenna are summarized in Table 1. Initially an edge fed rectangular microstrip patch is de-signed and is placed on a dielectric substrate of 40mm X 40mm X 31mil whose permittivity is $\epsilon r = 3.66$ with a loss tangent of 0.004 as shown in figure 1. The proposed antenna structure comprises of a rectangular patch containing slots of 0.52mm on either side of the line to enhance the current flow on the patch. In addition to, an in-verse U slot is loaded on the patch with a thickness of 0.25mm and the other side of the substrate is entirely filled with copper ground [12-14]. This is because, slot loaded antennas function effectively in terms resonant frequency, bandwidth and return loss compared to traditional rectangular patch antenna [15]. In this work, the horizon-tally placed diode on the left is considered as D1 and the vertically placed diode on the top is considered as D2. Silicon hyper abrupt junction varactor diodes especially manufactured to operate at higher frequencies in the order of GHz, efficiently for fine tuning and for considerable shift. Variation of biasing voltage can result in varying the capacitance of a corresponding varactor as shown in figure 2. In comparison to RF-MEMS, varactors are more fast and compact, their switching speed is in the range of 1-100nsec [1]. The reason behind its choice includes attractive features like high Q-factor, low capacitance range, low phase noise and availability.

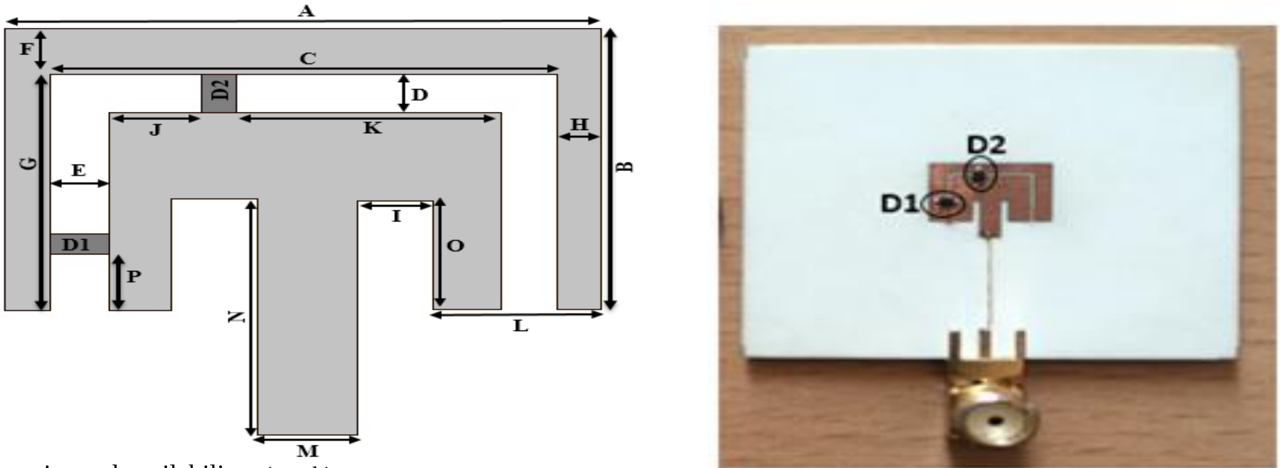

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Fig. 1: Layout of a) proposed design b) fabricated antenna structure.

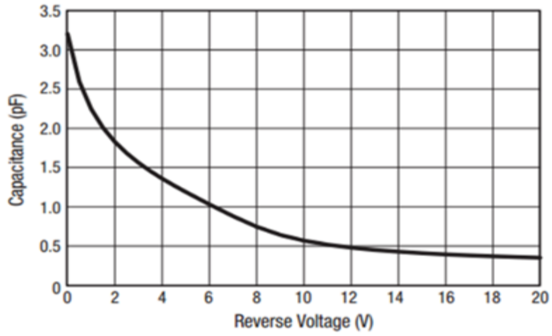


Fig. 2: Variation in Capacitance with respect to Voltage.

Table 1: Design parameters of the proposed antenna

Parameter	Dimension(mm)	Parameter	Dimension(mm)
A	10	I	0.52
B	7.5	J	1.75
C	7	K	4.5
D	0.25	L	3.6
E	0.25	M	1.9
F	1.25	N	4.6
G	6.25	O	2.6
H	1.5	P	2.7

III. RESULTS AND DISCUSSION

Figures 3 and 4 shows the performance of the antenna when D1 in ON, D2 in OFF condition and D2 in ON, D1 in OFF condition respectively. From the figures, it is clear that, there is a reconfiguration in frequency for different voltages across the diodes as considerable variation in capacitance is attained. When D2 is ON, the antenna resulted multiple frequency bands compared to D1 ON for 20V across the diodes. The antenna resonated at 15.1GHz and 20.2GHz frequencies when D1 is ON and at 10.5GHz, 18.2GHz, 19.8GHz and 25.5GHz when D2 is ON. The return loss curve is more dominant in simulation rather than the measurement. The variation in measured and simulated results is and performed the following switching configurations: D1 ON, D2 ON. The performance is summarized in Table 2. Similarly, the performance metrics, by maintaining 10V and 1V across the diodes are summarized in Tables 3 and 4 respectively.

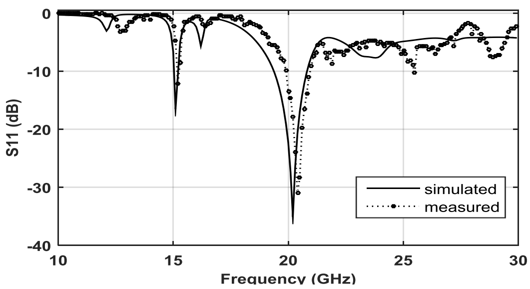


Fig. 3: S11 Vs Frequency when Diode D1 is ON at 20V.

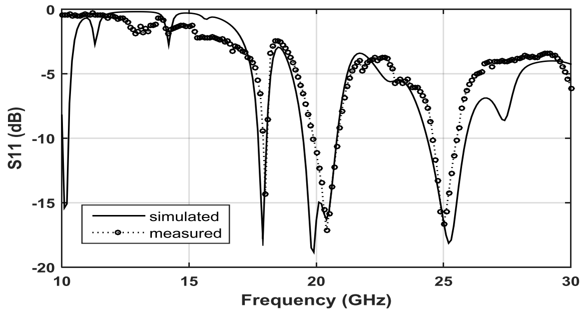


Fig. 4: S11 Vs Frequency when Diode D2 is ON at 20V.

Table 2: Performance metrics of the proposed antenna when voltage across the diodes is 20V under different configurations.

Parameter	**D1 ON**		**D2 ON**			
Resonant Frequency (GHz)	15.1	20.2	10.5	18.2	19.8	25.5
S_{11} (dB)	-16.1	-35.08	-23.26	-22.89	-18.42	-16.13
Frequency Band (GHz)	15.0-15.2	19.3-20.8	10.4-10.6	17.9-18.3	19.5-20.8	25.4-27.3
Bandwidth (GHz)	0.2	1.5	0.2	0.4	1.3	1.9

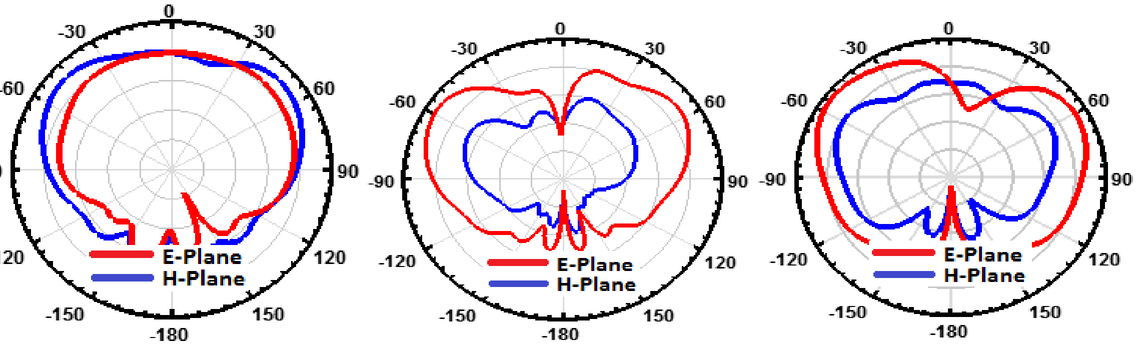
Table 3: Performance metrics of the proposed antenna when voltage across the diodes is 10V under different configurations.

Parameter	**D1 ON**		**D2 ON**		
Resonant Frequency (GHz)	14.4	20.4	17.8	20.8	25.5
S_{11} (dB)	-13.44	-26.8	-18.96	-17.83	-17.33
Frequency band (GHz)	14.33-14.44	19.4-21	17.6-17.9	19.7-21.2	24.6-26.1
Bandwidth (GHz)	0.11	1.6	0.3	1.5	1.5

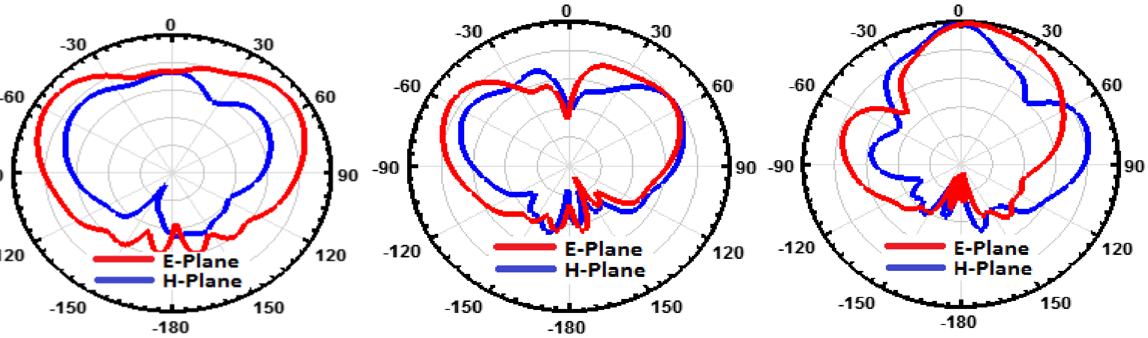
Table 4: Performance metrics of the proposed antenna when voltage across the diodes is 1V under different configurations.

Parameter	**D1 ON**		**D2 ON**		
Resonant Frequency (GHz)	13.3	20.4	17.5	20.8	25.5
S_{11} (dB)	-12.07	-23.14	-11.77	-22.19	-17.34
Frequency band (GHz)	13.20-13.35	19.4-21	17.40-17.54	19.7-21.2	25.0-26.2
Bandwidth (GHz)	0.15	1.6	0.14	1.5	1.2

From Tables 2, 3 and 4 it is clear, that for every configuration either D1 ON, D2 ON a considerable variation in resonant frequency is observed. It is the fact that, at these frequencies the antenna parameters that include S11 and bandwidth vary due to the impact of the diodes configuration. This also varies with respect to placement of the diodes. The proposed antenna incorporated with diodes pro-vides an additional degree of freedom in the view of bandwidth [16]. Resemblance of different bandwidths at same frequency of operation is observed as in case of [17]. As the antenna is designed at 20.2GHz Ka band satellite frequency, the bandwidth of the pro-posed antenna incorporated with varactors resulted 66% greater compared to traditional rectangular patch antenna. Improvement in bandwidth of the proposed antenna is significant from frequencies greater than 19GHz, the frequency bands of the antenna for different configurations covering 20.2GHz resulted 1.5GHz bandwidth, whereas regulation in voltages in 10-20V range across the varactor diodes improves the antenna's bandwidth almost from 1.2 to 1.9GHz at 25.5GHz, in other words 63% of bandwidth improvement is observed. Therefore, impact of the diodes is dominant at Ka band frequencies rather than Ku. Deterioration in bandwidth at higher frequencies is observed by maintaining low voltages across the diodes. Conversely, improvement in bandwidth is observed at higher voltages across the diodes which maintain low capacitance. Thus, we can control the states of the diodes by varying the voltages across the diodes for required tuning of the desired frequency band. Under different configurations of the diodes the choice of bandwidth at particular frequency helps to accommodate larger number of service users and at times of interference with adjacent bands, reduction in bandwidth can reduce interference from adjacent band.

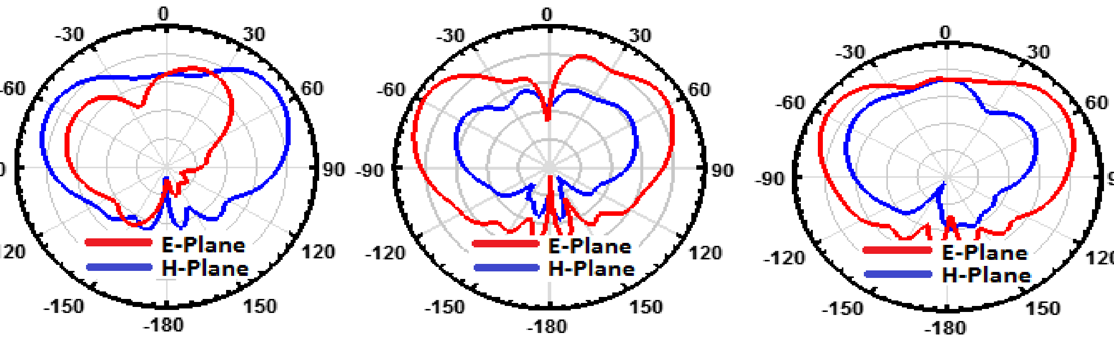


15.1GHz (D1 ON) *20.2GHz (D1 ON)* *10.5GHz (D2 ON)*

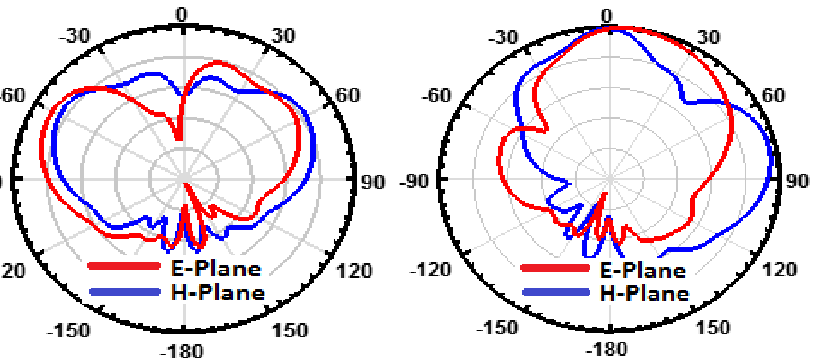


18.2GHz (D2 ON) *19.8GHz (D2 ON)* *25.5GHz (D2 ON)*

Fig. 5: Schematic of E and H planes at different resonant frequencies at 20V across the diodes.

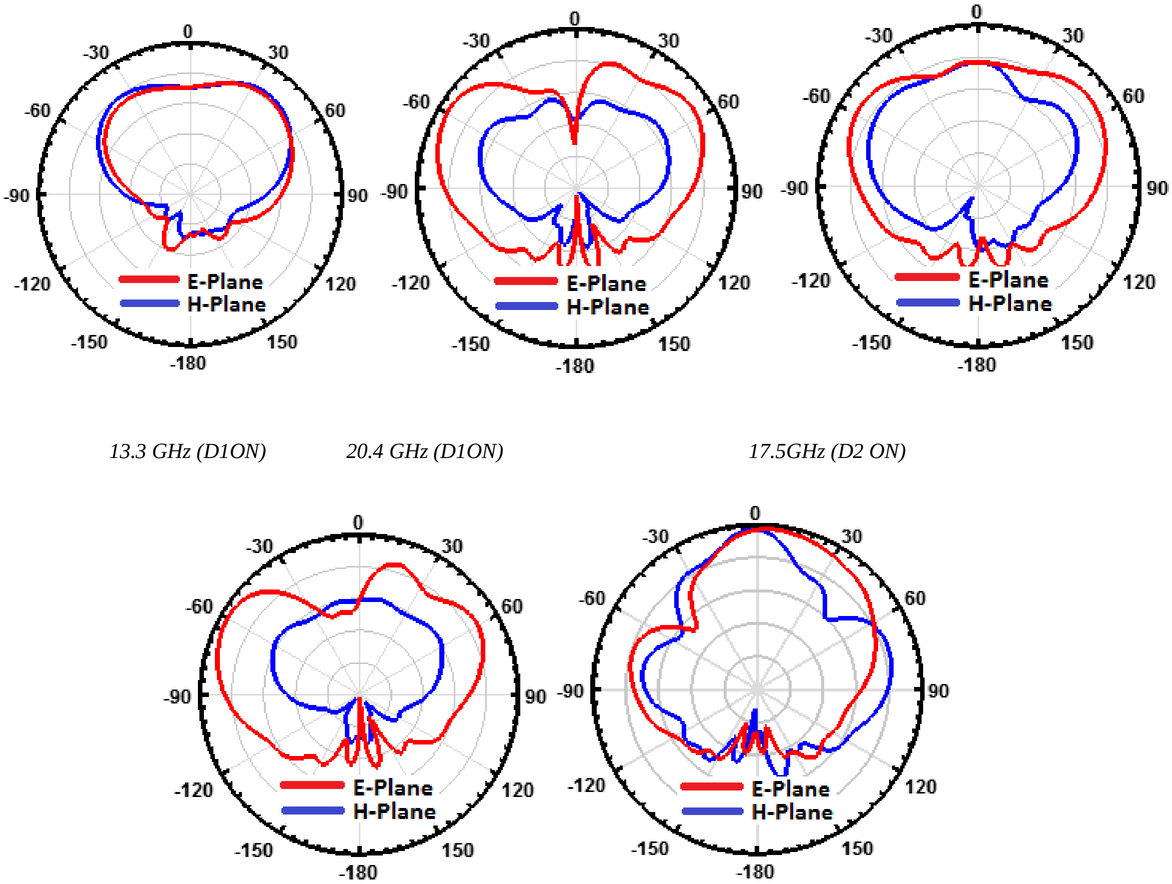


14.4GHz (D1 ON) *20.4GHz (D1 ON)* *17.8GHz (D2 ON)*



20.8GHz (D2 ON) *25.5GHz (D2 ON)*

Fig. 6: Schematic of E and H planes at different resonant frequencies at 10V across the diodes.



13.3 GHz (D1ON) *20.4 GHz (D1ON)* *17.5GHz (D2 ON)*

20.8GHz (D2 ON) *25.5GHz (D2 ON)*

Fig. 7: Schematic of E and H planes at different resonant frequencies at 1V across the diodes.

The E plane and H plane patterns of the proposed reconfigurable antenna at all resonating frequencies for different configurations of the diodes are shown in figures 5, 6 and 7. As shown in figure 5 at 20V across the diode D1, the radiation pattern at 15.1GHz is observed to be omnidirectional in both E and H planes whereas bidirectional

at 20.2GHz. When diode D2 is in ON, the radiation pat-tern seems to be directional and bidirectional at 10.5GHz and 19.8GHz respectively and omnidirectional and nearly directional at 18.2GHz and 25.5GHz respectively. When a voltage of 10V is maintained across the diode D1, the patterns at the resonances seems to be nearly omnidirectional at 14.4GHz and bidirectional at 20.4GHz in both E and H

planes, whereas in case of D2 in ON, pattern seems to be bidirectional at 17.8GHz and 20.8GHz and nearly directional at 25.5GHz as shown in figure 6. When a voltage of 1V is maintained across the diodes at the first resonance 13.3GHz, the radiation patterns of E and H planes are nearly equal and bidirectional at the second resonance 20.4GHz when D1 is ON, whereas the pattern is omnidirectional and nearly omnidirectional and nearly directional at 17.5GHz, 20.8GHz and 25.5 GHz respectively at D2 ON as shown in figure 7.

Table 5: Similar resonant frequencies under different configurations.

Parameter	D1 ON		D2 ON	
Frequency (GHz)	20.2		25.5	
Voltage	10V	1V	20V	10V
Gain (dB)	8.2	8.17	9.47	8.79

Considering similar resonant frequencies of different configuration of diodes, the radiation patters are seeming merely equal. Table 5 summarizes the performance of gain parameter in dB at similar resonant frequencies. The radiation pattern of the antenna for diode D1 ON condition resulted similar pattern with minute variation in gain. Unlike at 20.2 GHz, there is an improvement in gain pattern at 25.5GHz for D2 ON condition for different voltages across the diodes.

IV. CONCLUSION

The work presented the design and analysis of multiband frequency reconfigurable antenna for satellite applications especially at Ku and Ka band frequencies. It is observed that the impact of the diodes is dominant at Ka band frequencies rather than Ku.

The designed antenna resonated at two Ka band frequencies 20.2GHz and 25.5GHz. At 20.2GHz, 66% of bandwidth improvement is observed com-pared to a traditional antenna and at 25.5GHz, 63% of bandwidth improvement is observed for different configurations. It is noticed that the implementation of passive components like varactors has influence on the bandwidth at different resonant frequencies over the spectrum and obviously helpful for the designers to regulate the trade-off between the parameters of the antenna particularly at high frequencies. Implementing the concept of frequency reconfigurability greatly reduces the usage of multiple antennas and saves cost.

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