International Journal of Management, IT & Engineering
Vol. 9 Issue 4, April 2019,
ISSN: 2249-0558 Impact Factor: 7.119
Journal Homepage: http://www.ijmra.us, Email: editorijmie@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

FREQUENCY RECONFIGURABLE MILLIMETER-WAVE ANTENNA DESIGN FOR 5G APPLICATION

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Abstract

This paper addresses frequency reconfigurable U-shaped patch antenna that can operate at Ka-band of 26.5 GHz to 40 GHz for the 5th Generation (5G) application. The effective length of antenna current is controlled using the MEMS switch mounted in between two L-shape strips forming the U structure with square shape wing patch. Inductive and capacitive coupling between the two L-patches helps in achieving two-frequency band reconfiguration. When the switch opens for the OFF condition both the asymmetrical L-shaped patch get capacitive coupled along with the square shaped wing as before. Geometrical shape and size of the substrate is exactly the same as the black coloured patch. Dielectric constant has been appreciably reduced by using RT Rogers-air combination as substrate. Antenna gain of 9dB is obtained for the two frequency band at par with other standard works. Total efficiency falls in the range of 70-75%, VSWR in between 1-2. Key radiation patterns are also described in the paper.

Keywords: Patch antenna ,Reconfigurable antenna,Frequency ,reconfigurable antennaMillimeter wave,5th generation,Ka-band, MEMS.

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1. Introduction

Antennas are an essential part of a communication system. Millimeter-wave wireless communication has the capability of large broadband with a demerit that propagation losses increase as a function of operation frequency because millimeter waves are sensitive to the high degree of atmospheric and oxygen absorption losses [1-2]. This demands an antenna with high gain and beam-steering capability. This will no doubt be at increased complexity and high expense. There has been much interest within the antenna research community to develop efficient antenna design for the future 5G specifically design to operate in two 5G frequency bands 28 GHz band and 38 GHz band [3-4]. Microstrip planar antenna structures are apt for these communication systems.

Reconfigurable antennas have been seriously investigated in the past decade for a variety of applications requiring use of some kind of switching mechanism. Recently, many kinds of reconfigurable antennas have been reported [5–8]. Reconfigurable antennas can address complex system requirements by adapting to changes in environmental conditions and or system requirement[15-16]. Be it changes in operating frequency, enhanced band-width, polarization or radiation pattern. Reconfiguring of an antenna is achieved by willingly changing its polarization, frequency or radiation characteristics by techniques that redistribute the antenna currents and alter the electromagnetic fields due to it. Use of MEMS is one of such techniques. Antenna with MEMS technology shrinks the volume of the communication system very much. It improves reliability, increases life-span, enhances efficiency and reduces power loss.

In this paper, frequency reconfigurability of the antenna has been achieved by connecting two L shaped patch by a RF MEMS switch. When the switch closes for the ON state both the L-shaped patch gets inductively coupled and when the switch opens for the OFF condition both the L-shaped patch get capacitive coupled. Inductive coupling increases the effective length of antenna whereas capacitive coupling reduces it and hence the change in operating frequency. This leads to achieve change in operating frequency of antenna from 28 GHz to 38 GHz in Ka-Band. Use of air as dielectric material as considerably reduced dielectric constant and hence the antenna gain and efficiency has increased. This is different from some works reported on DRA and other antennas. Due to use of air as dielectric for substrate, another advantage is that the metallic and surface wave loss in the proposed antenna does not stand in way of gain and efficiency of antenna. Further, with decrease in dielectric constant the bandwidth has also increased.

2. Millimeter Wave Communication

Current wireless systems operate at HF (3MHz to 30MHz), VHF (30MHz to 300MHz) and UHF (300MHz to 3GHz) bands, the electromagnetic spectrum at these bands is crowded [9]. Also the relative bandwidth of communication channels at these bands is in the range of few megahertz. According to Shannon–Hartley theorem (equation 1), channel capacity (C) is related to signal to noise ratio (S/N) and the bandwidth (BW) of the communication channel [10] through the relation:

$$C = BW \log_2 (1+S/N) \qquad (1)$$

Therefore, applications requiring higher data speed cannot operate satisfactorily at these low bandwidth channels. The most appropriate solution of this problem is the shifting of wireless applications towards higher frequencies. Typically, the electromagnetic spectrum in the range of 30 GHz to 300 GHz (i.e. wavelength of 10 mm to 1 mm) is referred to as the millimeter wave (MMW) frequency band. It can be also defined as Extremely High Frequency (EHF) band [11].
Millimeter wave characteristics have many advantages from the communication system point-of-view. Smaller wavelengths allow for a compact system. For same physical size, as the operating wavelength is smaller, narrow beamwidth can be obtained. Wide bandwidth channels can be allocated in MMW frequencies as the bandwidth available in this case is extremely large. Wide band spread spectrum capability for reduced multipath and clutter. Availability of certain high attenuation bands having potential for highly secure short distance communication is another important feature with the use of MMW.

But, at the same time shortcomings cannot be ruled out. One of the biggest challenges of MMW communications is to reduce the cost of the system. In the MMW range as the component size gets smaller, processing techniques of this precision are expensive. This results in high cost of complete systems. Also, due to small wavelength MMW components are sensitive to edge diffraction as compared to microwave range components [11]. Furthermore, the standard datasheet values of materials available are given for microwave frequencies. Their properties differ reasonable when it comes to use at the millimeter wavelength range. This poses a challenge in designing the MMW components. Various technologies proposed at MMW have not yet reached the industry and research laboratories. Above all, the biggest challenge at MMW communication is ever increasing atmospheric attenuation. It is still a challenge to design high gain antennas with a potential to nullify the effects of the atmospheric attenuation [12].

3. RF MEMS Switch Design Configuration

RF microelectromechanical systems (MEMS) switch is a component developed by Dr. Larry Larson at Hughes Research Labs in Malibu, California, with the support of DARPA (Defence Advanced Research Projects Agency) in 1990-1991 [13].

The RF MEMS switch is modeled the same way as in [14] using Ansoft HFSS (Figure. 1). The switch lies between two copper patches printed on a dielectric material. Copper pads help to keep the switch connected to the patch and allow for the dc bias voltage. There is no thin dielectric slab separating the bridge from the patch. When the switch is in the down position it is in contact with both copper patches. This produces inductive coupling between the two copper patches. There is no connection between the switch and the patches when the switch is in the up position and this provides capacitive coupling. The RF MEMS switches are fabricated using gold with a width of 50 um and a thickness of 2 um.

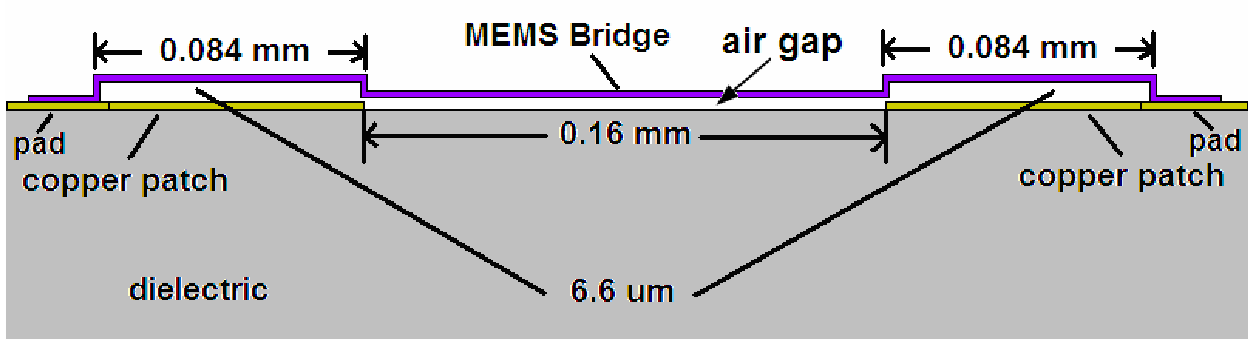


Figure. 1. RF MEMS switch modeled in HFSS

4. Antenna Design

In this paper, proposed antenna, based on microstrip technology, has been designed to perform at Ka band. The chosen substrate is 0.9mm thick, RT5880 Rogers Corporation with dielectric constant 2.2 and relative permittivity of 0.009 loss tangent. Although there are various substrates available but RT5880 Rogers Corporation has been chosen because of their suitability for high frequency broad band application which demands minimal dispersion and losses. Further their low water absorption ability makes them more suitable candidate for antenna application in high moisture environment, particularly in India during the monsoon and the sea coastal low land areas. First through MATLAB antenna design and antenna parameters were worked out so that it performs at the said frequency with optimum features. Then its behavior simulated in HFSS 13 to establish the desired features. Substrate size is taken exactly same as that of size of the upper metallic surface of the antenna shown by blue color in fig. 1. The left out space is due to air dielectric. By this we have reduced the cost and material input of the substrate which in turn will cut down the cost of antenna fabrication. Probably, this has happened for the first time to the knowledge of authors. The antenna is designed with a central frequency of 28 GHz and 38 GHz. The feed line starts as a 50 Ω port, where the antenna is fed from. The antenna has a dimension of $11 \times 13\ mm^2$ which is smaller than most of the previous designs. The antenna can integrate more wireless applications simultaneously within a more compact size. This design has been analyzed for two antenna configurations. The case in which the switches are open resonates at 38 GHz and the case in which they are closed resonates at 28 GHz.

A major limitation for the performance of the patch antenna is the dielectric substrate. The idea of using air as dielectric was therefore considered to overcome that limitation exploiting the fact that air has the lowest permittivity and no loss. The goal of this work is to build an air-spaced patch antenna. This work is novel because the air-spaced patch antenna has not been extensively studied.

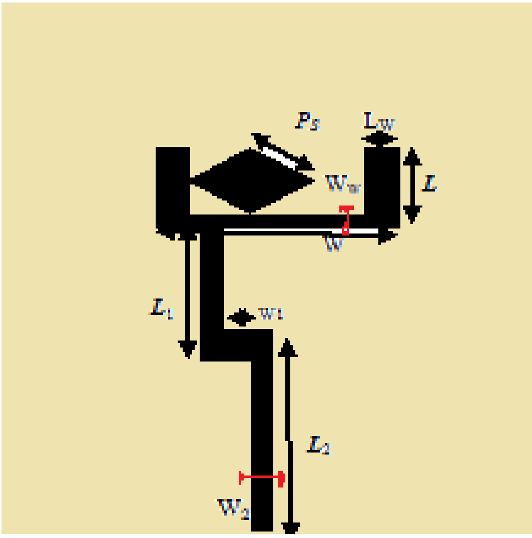


Figure 2

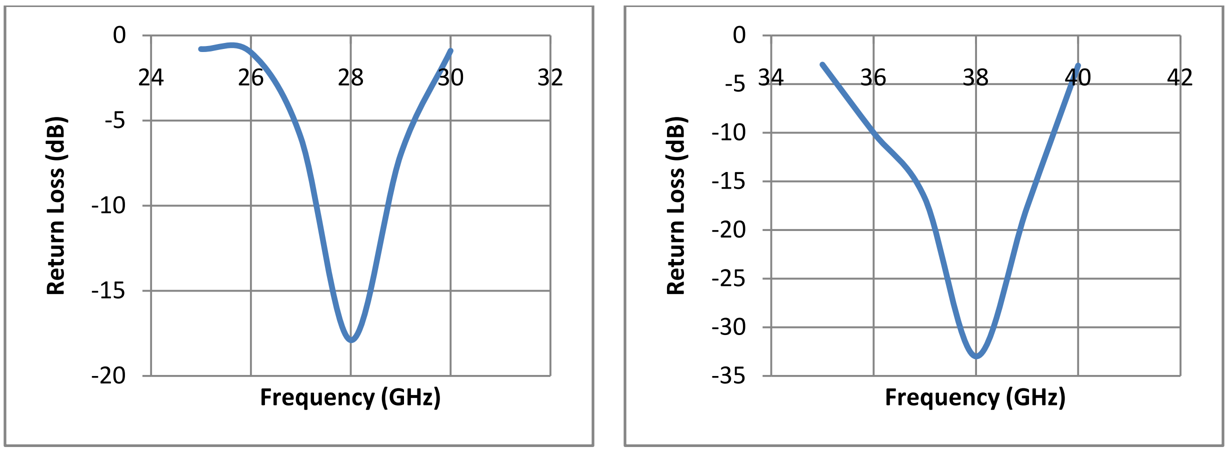
The antenna design is shown in figure 2. Antenna is excited by a single feed microstrip line. Antenna ground is rectangular patch that comprises L-shaped patch. This arrangement adds capacitive and inductive effects, which result in desirable two distinct resonant mm-wave frequencies. The antenna was fabricated on RT/Duroid 5880 with a thickness of 0.9mm, dielectric constant of 2.2 and loss tangent 0.0009. The parameters for the proposed antenna are shown in table 1.

Table 1

Parameters	Value(mm)
L	2
W	4.8
L_w	0.4
W_w	0.2
P_s	1.4
L_1	3.7
L_2	4
W_1	0.5
W_2	0.3

5. Result and Discussion

The simulation was carried out using the Ansoft high frequency structure simulator (HFSS) software which is based on a finite element method, its accuracy and powerful features makes it a good and common tool for antenna designers. The entire designed structure feed by a microstrip line was simulated.

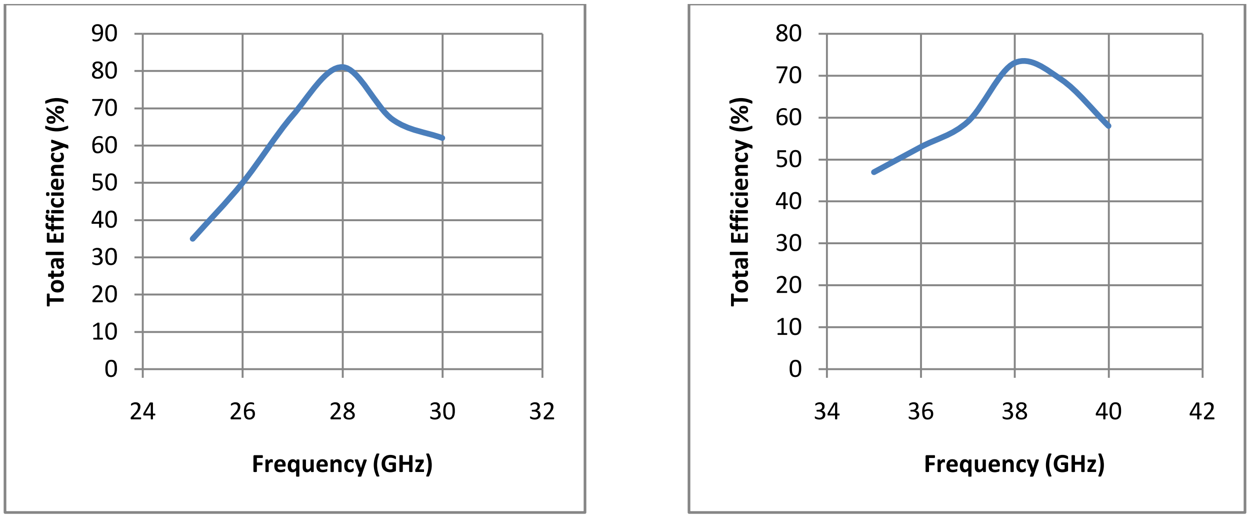


(a) (b)

Figure 3: Return loss at (a) 28 GHz and (b) 38 GHz.

The return loss of the antenna is depicted in Fig. 3 for the two operating frequencies of 28 GHz and 38 GHz. The simulated result shows the resonant frequency at 28.25 GHz. The return loss of the antenna at this point is 18 dB. The bandwidth of the antenna is 1GHz. Return loss (S11) was obtained at < -20dB, implying that 80% of the available power is delivered to the antenna. Also the bandwidth obtained is 2GHz with a centre frequency of 38.34 GHz which satisfied the condition for wideband application.

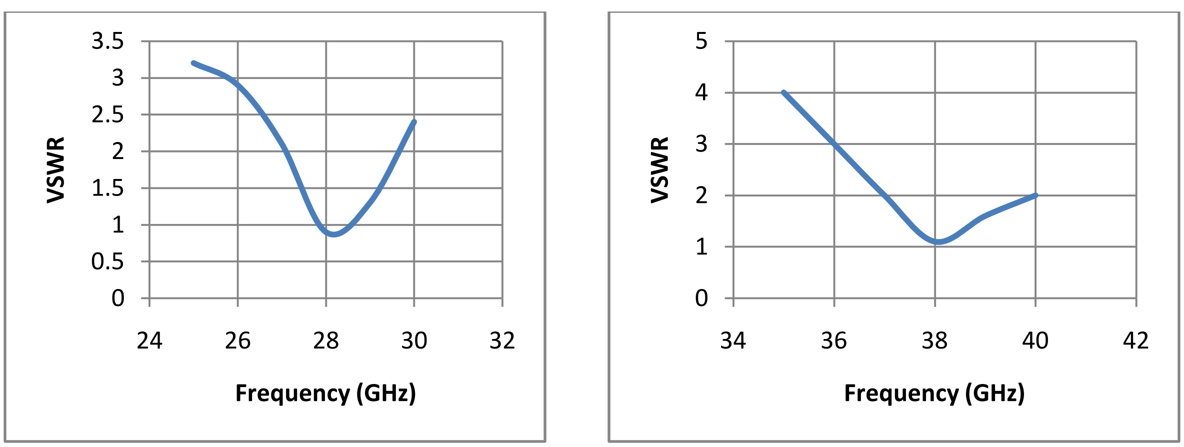
Figure 4 shows total efficiency above 75-80% at operation frequency 28 GHz and above 70-74% at operation frequency 38 GHz. The two graphs however, have slightly different trend on either side of the resonant frequency.



(a) (b)

Figure 4: Total efficiency at (a) operating frequency 28 GHz and (b) operating frequency 38 GHz.

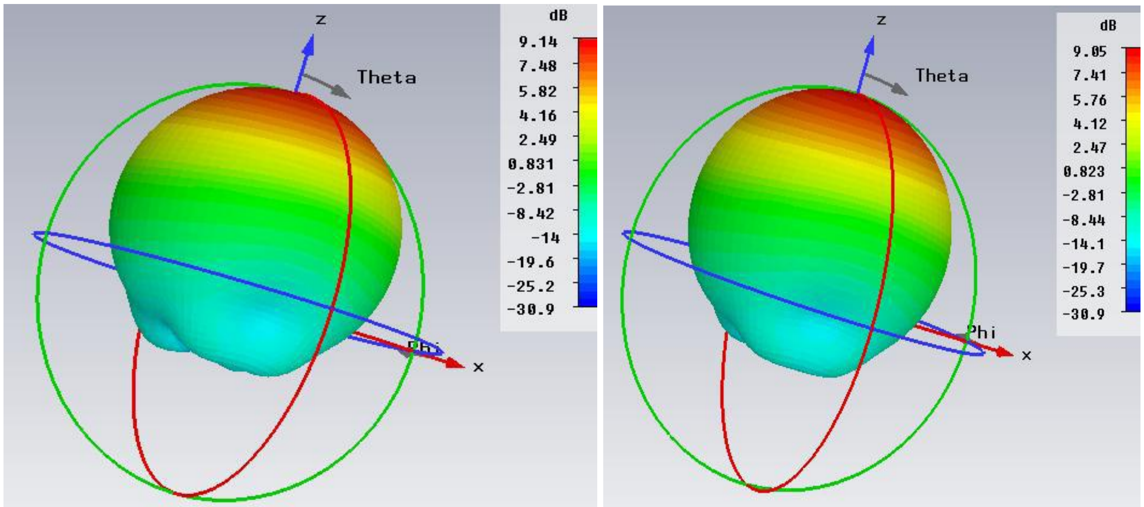
Variation of VSWR against frequency is shown in figure 5. The observations are in line with the expected results. Resonant feature is well defined at the operational frequency 28 GHz. The voltage standing wave ratio (VSWR) lies within 1 and 2 as expected.



(a) (b)

Figure 5: VSWR-frequency relation at (a) 28 GHz and (b) 38 GHz.

The simulated radiation patterns obtained at the resonant frequency of 28 GHz and 38 GHz are shown in Figure 6. At these frequencies, maximum radiation is emitted at the top of the antenna. The gain of antenna at frequency 28 GHz is about 9.14 dB and 9.05 dB at frequency 38GHz.



(a) (b)

Figure 6: Gain and Radiation fields of antenna at (a) 28 GHz and (b) 38 GHz

6. Experimental Validation

For validation the dual frequency microstrip patch antenna has been realized through transmission lines replacing RF MEMS switches. The experimental results are shown in Figure 7 where the 28 GHz antenna resonates at 27.85 GHz and the 38 GHz antenna resonates at 37.99 GHz.

Figure 7. measured loss

7. Conclusions

The design of frequency reconfigurable dual frequency microstrip patch antenna using RF MEMS switches has been established. Antenna ground is rectangular patch that comprises L-shaped patch. This arrangement adds capacitive and inductive effects turn by turn when the switch is in OFF state or ON state. This results in desirable two distinct resonant mm-wave frequencies, 28 GHz and 38 GHz. For ease of computational time and for construction, the switches have been replaced by transmission lines to represent the closed state. The performance has been validated through simulation, construction and measurement. The return loss of the antenna at the resonant frequencies is 18 dB. The bandwidth of the antenna is 1GHz. Return loss (S11) was obtained at < -20dB, implying that 80% of the available power is delivered to the antenna. Also the bandwidth obtained is 2GHz with a centre frequency of 38.34 GHz which satisfied the condition for wideband application.

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