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Wide bandwidth Metamaterial Microstrip Patch Antenna Array using 12.9 Relative Permittivity at 60 GHz

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***Abstract*—in this paper bandwidth and gain of 1x2 antenna array has been enhanced by using defected ground structure (DGS). A Microstrip Patch antenna has been designed on Gallium Arsenide substrate with relative permittivity of 12.9 at 60 GHz for short range communication systems. Due to high relative permittivity, the size of the antenna is very small due to which the gain of the antenna is also very small. Then 1x2 array is designed with spacing between the elements less than half a wavelength. Array has gain and bandwidth of -1.6 dB and 9 GHz while the dip at 60 GHz is -47 dB By using inverted T-shaped DGS, gain and bandwidth is improved up to 2.1 dB and 7.1 GHz. Gain, S11, and VSWR of the array with and without DGS are shown and compared in this paper. HFSS 15 is the simulation software used for designing all these antennas.**

Keywords: Relative Permittivity ε_r, Gain enhancement, Bandwidth enhancement, Directivity, Gain, return loss, Gallium Arsenide, VSWR, HFSS15, 60 GHz.

I. INTRODUCTION

Nowadays the world is progressing very fast, and communication has been very essential part of this progress and development. Modern days need short-range, high speed wire- less communication with less interference. The U.S Federal communications commission (FCC) has allocated 57 GHz to 64 GHz spectrum unlicensed for the applications of scientific, industrial and medical applications. Due to multiple communication systems developed at lower Giga Hertz frequencies, unlicensed 60 GHz frequency has found significant attention in the field of short communication due to its ability to support gigabit-per-second data rates [1]. The communication at 60 GHz provide high capacity for the channel and the size of antenna has become very compact due to high frequency, however communication at 60 GHz causes high propagation losses due to oxygen molecules present in the atmosphere which absorption of mm-waves [2].

As the size of the antenna depends on the frequency of operation and the relative permittivity of the substrate used for the design. At higher frequencies the wavelength is very small called millimeter waves. The size is further shrinked by using substrate with high value of relative permittivity. As the size is reduced, the gain of antenna is also decreased. For short range communication high gain and directive antennas are required for good communication. For this purpose, array are very useful and plays an important role in high gain and directive communications for millimeter waves. For this Purpose 1x2 array is designed for 60 GHz applications. Also there are some techniques used to improve the gain and bandwidth of the antenna. One of the method is to make some defective changes in the ground of the antenna called Defective ground structure.

A Microstrip patch antenna with inset feed is designed in

[3] at 2.4 GHz for WLAN applications. The bandwidth of the antenna is improved using DGS technique. U-shaped, E- shaped, Double E-shaped and Psi shaped DGS are introduced in the ground of the patch and bandwidth is improved from 67 MHz to 302 MHz a modified inset-feed Microstrip patch antenna is proposed in [4] to increase bandwidth and return loss of the antenna. A dumbbell shape DGS is introduced in the ground of the antenna below the patch center. Bandwidth is improved to 57 MHz from 34.5 MHz while return loss is improved to -41 dB from -12 dB a double U-shaped DGS structures are used to widen the bandwidth of the trapezoid monopole [5]. -10 dB bandwidth is enhanced from 790 MHz to 2060 MHz A Microstrip patch antenna with I-shaped slot in the ground is proposed in [6] for bandwidth improvement for C-band applications. Bandwidth is improved up to 126 MHz with center frequency at 6 GHz and S11 up to -47 dB 5% of the size is reduced due to I-shape slot in the ground. A circular Microstrip patch antenna is proposed in [7] for 2.4 GHz resonant frequency. The conventional design has low gain

and narrow bandwidth while it is improved by using DGS. Gain is improved by 1.7 dB while 421 MHz of bandwidth is also enhanced which is further enhanced by creating a gap through the center of the circular patch. A narrow band rectangular patch antenna is presented in [8] for wearable devices in biomedical applications at 2.45 GHz. Gain and bandwidth of the antenna is increased up to 17% using DGS. Using DGS, gain of the antenna is increased from 2.96 dB to

3.45 dB while S11 is improved from -12 dB to -22 dB [9]. The effect of recessed ground on the performance of patch antenna is studied in [10] for 60 GHz applications. Gain is improved up to 2.6 dB and 10% bandwidth is improved while the overall efficiency is improved up to 25%.

In this paper, DGS is used to increase the bandwidth and gain of the antenna. Inverted T-shaped DGS is used for this purpose. There are different types of defected ground structures used for this purpose. It may be rectangular shaped, Circular shaped, dumbbell shaped, U-shaped, E-shaped and many other types as well. These defective ground structures when introduced in the ground of the patch, create fringing field between the patch and the DGS due to which parasitic capacitance is created. Mutual coupling is enhanced by the parasitic capacitance which results in the bandwidth improvement [4].

II. DESIGNING MICROSTRIP PATCH ANTENNA

Microstrip Patch antenna consists of three layers called ground, substrate and patch. Ground is the metallic structure above which substrate lies. Substrate is the dielectric material which has some losses denoted by loss tangent and has some relative permittivity denoted by ε_r as well. The thickness and relative permittivity of the dielectric material plays an important role in the design and characteristic properties of the antenna. The bandwidth of the antenna increases with the thickness of the substrate and vice versa. For antennas we use high thickness to increase the bandwidth as well as to increase the radiation from the patch [11]. The fields generated by the antenna are loosely attached and can easily detached from the antenna and travel long distances. In other words the efficiency of the antenna is increased. If the thickness is decreased then field lines will be closely attracted and radiations will not be effective. This type of substrate with smaller thickness is more preferred in RF circuits and power dividers where radiations is not the primary requirement. Dielectric constant of the substrate has also an important impact on the performance of Microstrip patch antenna. By increasing the relative

permittivity of the substrate, the dimensions of the antennas are reduced and the resonant frequency will be a higher one with high gain and narrow bandwidth [12].

III. FEEDING MECHANISM

There are different types of feeding mechanism for Microstrip patch antenna such as Microstrip line feeding, probe feeding, coaxial feeding, edge feeding, and parasitic feeding. Microstrip line feeding technique is used to feed the antenna. In this method a line with some characteristic impedance is used to feed the patch from the edge in the center of the width. There is a big difference in the edge impedance of the patch and the line impedance, so there will always be some mismatching. To transfer maximum power there should be some impedance matching between the line and the patch. Inset feed and quarter-wave transformer is used for impedance matching in Patch antennas. In this work inset feeding method is used for impedance matching at 60 GHz. For 1x2 array, T- junction is used for feeding the array. Instead of using multi- stage impedance matching, simple T-junction is used to feed the arrays. T-junction is used to split the single input power into two equal halves output power which is fed to the arrays.

IV. DIMENSIONS CALCULATION FOR PATCH ANTENNA

As the dimensions of the patch antenna are very important and it requires some calculation for the design if the desired Frequency, thickness and relative permittivity of the substrate is known. Then we can calculate the length of the patch L_p, width of the patch W_p, the length of the ground L_g, width of the ground W_g and length of the inset cut y_0 as shown in 1. The width of the patch can be calculated by

$$W = h \; \underline{C_0} \; \mathbf{iq} \; \underline{\quad 2}$$

Where C_0 is the speed of light while f_0 is the frequency of operation and ε_r is the dielectric constant of the substrate material.

As we know that radiation occurs through fringing effect. Some of the fields passes through substrate while some of the fringing fields passes through the air as well. As the medium is different so both the fields will have different phase velocities and have different impact due to its lower permittivity than the substrate. For this purpose to include the effect of both air and substrate we define another parameter called effective relative permittivity which can be calculate as

$$\varepsilon_{reff} = \underline{\varepsilon_r+1} + \underline{\varepsilon_r-1}[1 + 12\underline{h}]^{-1/2}$$

Where H is the height while W is the width of the substrate used for antenna designing.

Fig. 1. VSWR of 1x2 Array with DGS

TABLE I
DIMENSIONS OF THE ARRAYS.

Parameters (mm)	Gallium Arsenide
Patch Length	0.5
Patch Width	0.5
Ground Length	1.3
Ground Width	1.2
Inset Length	0.05
Inset width	0.01
Feedline Length	0.35
Feedline width	0.1
Spacing d	0.7

The length of the patch plays an important role in designing an antenna. The resonant frequency of the antenna depends on the length of the antenna, therefore it should be calculated carefully. Instead of using the practical length of the antenna effective length is considered for the antenna where the fringing effect is also taken into the account. As the width sides are considered as slots where fringing occurs along the length of the patch. Due to this the length of the patch is increased a little bit and is taken in the effective length calculated for the patch.

$$L_{eff} = \frac{C_o}{2f_o\sqrt{\epsilon_{ref}}} - 2\delta L$$

Where δL is the change in length that occurs due to the two slots at the width along the length of the patch. This change in length can also be calculated using

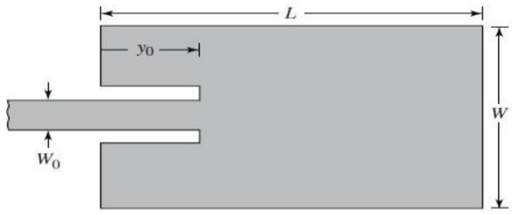
$$\delta L = 0.412\frac{(\epsilon_{ref}+0.3)\left(\frac{w}{h}+0.264\right)}{(\epsilon_{ref}-0.258)\left(\frac{w}{h}+0.8\right)}$$

For feeding the patch two impedance matching techniques can be used, either quarter-wave transformer or inset feeding. At the edge of the patch the impedance is very high while near the center of the patch the impedance decreases and is zero at the center of the patch. So the feedline moves inside the patch with some patch removed from the sides of the line. The impedance matching depends on the inset length y_0. For inset feeding the length of the cut section y_0 can be calculated from the following expression

$$R_{in}(y = y_0) = (R_{in} = 0)\cos\theta^2\left(\frac{\pi}{L} y_0\right)$$

V. ANTENNA ARRAY

A single element cannot provide enough gain for some applications where high gain is required. For this purpose multiple antennas are arranged to form an array of antennas which provide better gain as compared to single antenna. In arrays, the fields radiated from the antennas reinforce each other in the far field and constructively interfere to increase the gain and directivity in the direction of maximum



radiation. The spacing between the elements also play an important role in the design of arrays. The spacing d should be less than one wavelength. At spacing equal to or greater than one wavelength, the radiations are in phase in more than one direction and multiple lobes with high gain are formed called grating lobes. Grating lobes are undesired lobes and occurs when spacing is greater than one wavelength. The gain and directivity of the array is greater than the single antenna. For antenna array we define a factor called array factor which is a function of the spacing and excitation phase of the elements. Array factor is independent of the directive properties of the antenna. The total field radiated by the two elements array is given by

$$E_t = E_1 + E_2$$

$$(AF)_n = \cos\vartheta \ \frac{1}{\;} (kd\cos\vartheta + \beta)$$

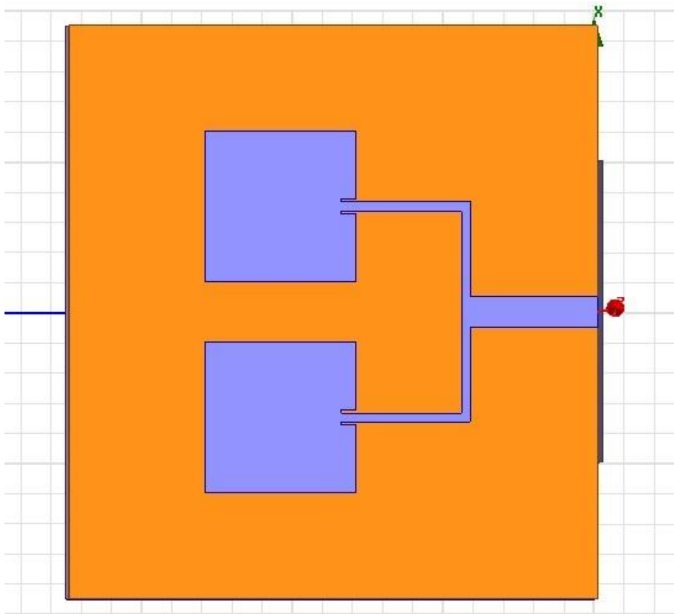


Fig. 2. 1x2 Microstrip Patch Array

Where β is the phase excitation difference between the two elements, K is the Boltzmann's constant. If the array factor of an array is known and the electric field pattern is known then the total electric field radiated by the array can be calculated using a method called Pattern multiplication.

VI. T-JUNCTION POWER DIVIDER

T-junction is the basic device for splitting the power. It is a T-shaped transmission line with two different types of impedances [13]. Input is applied at one end with some input impedance while split power is available at the two output ports which has different impedance from the input port as shown in figure 2 [14]

VII. DEFECTED GROUND STRUCTURE

In defected ground structure the ground of the antenna is modified by removing some part of the ground to change the radiation properties of the antenna. By removing some part of the ground, fringing effect is enhanced which causes parasitic capacitance between the ground plane and the patch. Patch and ground plane is coupled which improve the radiation properties of the antenna. There are different types of structures that are introduced in the ground. It may be circular, rectangular, dumbbell, E- shaped, H-shaped, T-shaped etc. In this work an inverted T-shaped DGS is introduced below the feedline which improves gain and -10 dB impedance bandwidth of the array. Its effect on the antenna depends in the size, shape and position where it is introduced as shown in 3. DGS helps in impedance matching which improve bandwidth and also maximum power is transferred to the antenna which can increase the gain. DGS also control the phase and amplitude of the electromagnetic waves.

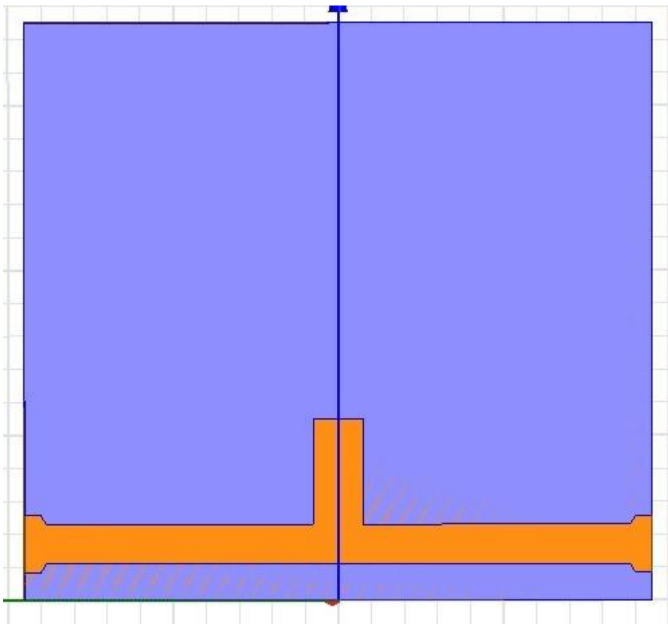


Fig. 3. 1x2 Array with DGS

VIII. SIMULATION AND RESULTS

All the dimensions of the arrays are given in Table I. Antennas are designed and simulated in HFSS. Then arrays are designed and the results are given in the Table II for array antennas with and without GDS.

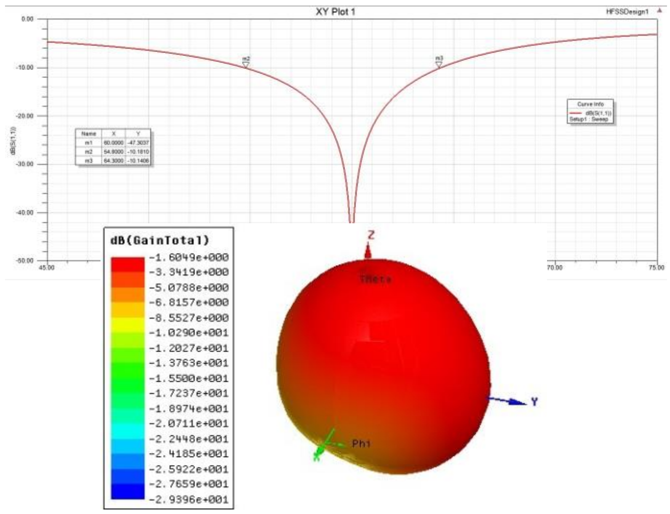


Fig. 4. S11 of 1x2 Array without DGS

TABLE II
RESULTS OF THE ARRAYS WITH AND WITHOUT DGS.

Parameters (mm)	Without DGS	WithDGS
S11	$-47dB$	$-48.6dB$
BandWidth	$9GHz$	$16.1GHz$
Gain	$-1.6dB$	$0.56dB$
$VSWR < 2$	$54.2 - 64.65GHz$	$49.7 - 66.1GHz$

Fig. 5. Gain of 1x2 Array without DGS

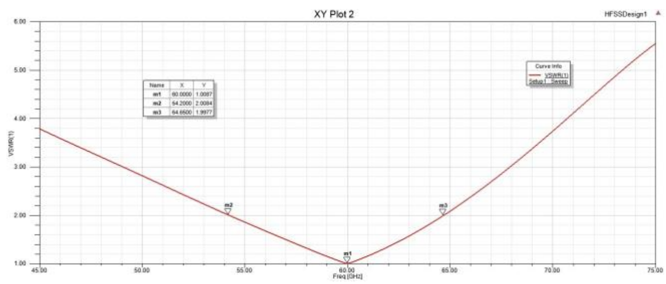


Fig. 6. VSWR of 1x2 Array without DGS

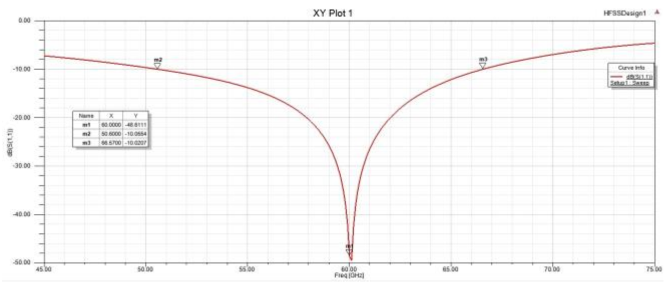


Fig. 7. S11 of 1x2 Array with DGS

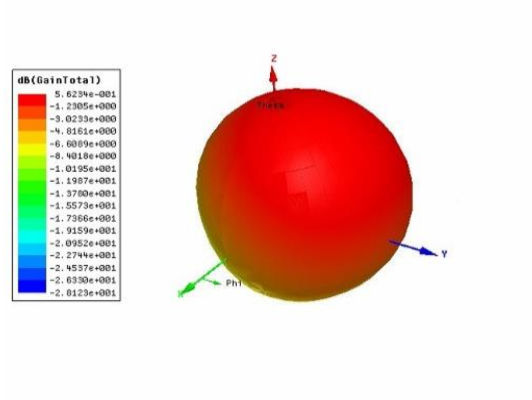


Fig. 8. Gain of 1x2 Array with DGS

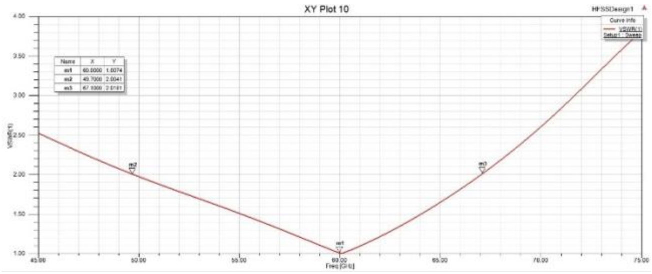


Fig. 9. VSWR of 1x2 Array with DGS

IX. CONCLUSION

A Microstrip patch antenna 1x2 array with defected ground structure has been presented in this work. At higher frequencies the size of the antennas are very small and it is further shrinked by the use of high relative permittivity substrate materials. The gain of the array is very small while the bandwidth is also narrow. For high data rate high bandwidth is required. DGS method is used to enhance the gain and bandwidth of the array. DGS produce parasitic capacitance which create coupling between the ground and patch and thus enhance the bandwidth of the array. Gain is improved from

-1.6 dB to 0.56 dB while bandwidth is enhanced form 9 GHz to 16.1 GHz.

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