

Modeling the effect of bend radius on the performance of a conformal dual-band mm-wave patch antenna array

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Abstract

There is growing interest in the use of additive manufacturing for the fabrication of RF devices due to fast prototyping capabilities and the use of less material as opposed to traditional fabrication techniques. In addition to the previously mentioned advantages, the aerosol jet printing method in particular allows for the conformal printing of RF components. This work models the effect of the bend radius on the return loss and radiation pattern of a dual-band (28 GHz and 39 GHz) mm wave patch antenna array design that will be aerosol jet printed. The antenna is modeled on a 5-mil thick flexible substrate (PET) and the simulation is run from 27 GHz to 40 GHz using HFSS. The return loss and radiation pattern results of the antenna are compared for various bend radii (0.25 in to 2 in) of the conformal surface the antenna is to be printed upon. Simulation results show a maximum frequency deviation of about 400 MHz on the return loss for the low (28 GHz) frequency band of the antenna when it is bent from a bend radius of 0 in to 2 in.

Keywords

dual-band, mmwave, array, patch antenna, additive manufacturing, HFSS

I. INTRODUCTION

The Internet of Things (IoT) is a collection of devices that are connected using standard based communication protocols for the purpose of sharing data [1]. There is a growing demand to connect more devices to the IoT networks thereby increasing the total amount of data that needs to be transmitted. As a result, there has been growing interest in 5G mm-wave technology because it allows for high data rate and low latency communication [2]. Printed flexible electronics are among the components that have seen an increased demand to include in the IoT application space [3]. These devices require antennas for communication and hence the study and design of antennas is important to achieve IoT connectivity. Some factors considered in choosing antennas for flexible electronics IoT applications include conformability, flexibility, and durability[3]. These antennas can be fabricated using conventional techniques such as electroplating or additive manufacturing such as Aerosol Jet Printing (AJP) or screen printing. Additive manufacturing offers the advantage of fast prototyping and low-cost fabrication however their performance is not as good as those of conventionally manufactured antennas especially at high frequencies due to issues such as surface roughness, uneven trace profiles and non-uniform edges which lead to decreased antenna gain and impedance mismatches [3]. Planar antenna arrays can be used to improve on this decreased gain and directionality and allow for beam forming and beam steering. They also have the advantage of a low profile as compared to reflector or horn antennas [4]. Patch antennas are planar antennas that are low

cost, compact in size and easy to design and hence are good candidates for mm-wave applications [5].

In this paper, we design a two-element dual-band mm-wave planar patch antenna array and investigate the effect of the bend radius on the return loss and gain of the antenna at the two design frequencies of 28 GHz and 39 GHz.

II. SINGLE ANTENNA DESIGN

The antenna is designed on a 127 μm thick PET substrate with a dielectric constant, D_k of 2.9 and loss tangent of 0.008. The conductor is silver nanoparticle ink with conductivity of 7812500 S/m. Thickness of the conductor used is 10 μm to minimize losses associated with the skin effect. Design frequencies are 28 GHz and 39 GHz. The antenna comprises of a square patch with L-shaped slots near the edges to allow for the excitation of distinct frequencies [6]. An approximate equation for calculating the length of the patch for 28 GHz operations is

$$f_r = \frac{c_0}{2L_{eff}\sqrt{\epsilon_{eff}}} \quad (1)$$

Where f_r is the resonant frequency of the patch and L_{eff} and ϵ_{eff} are the effective length of the patch and the effective permittivity of the substrate respectively. Fig. 1. show a top and front view (cross section) of the antenna.

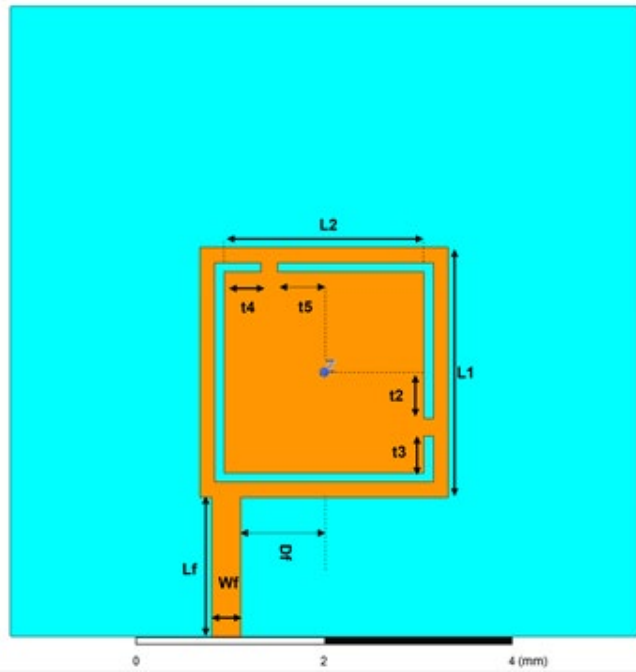
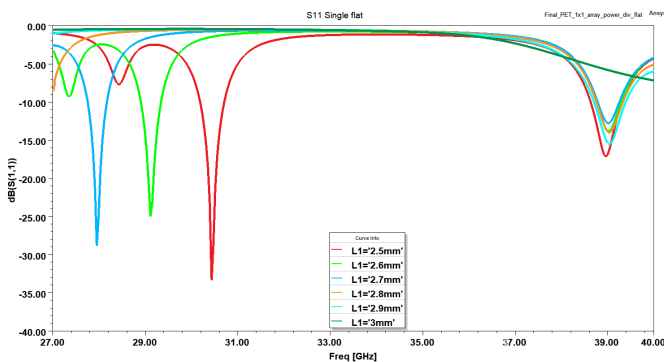
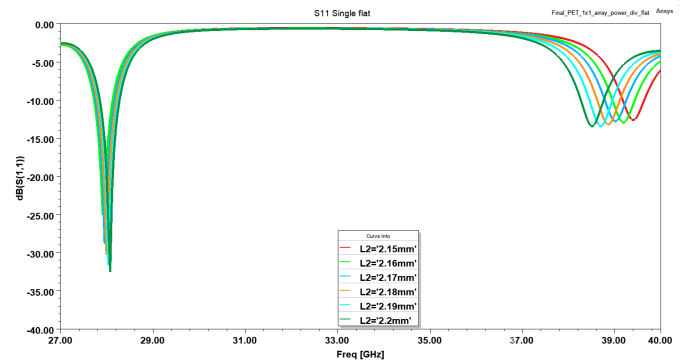


Fig. 1. Top and front, cross section, view of antenna

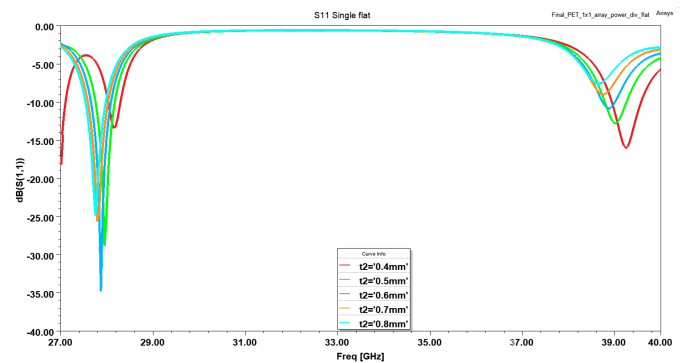
The simulated reflection coefficient of the antenna is shown in Fig.2 below. It is observed that increasing the length $L1$ has minimal effect on the upper frequency band of 39 GHz while there's a more pronounced shift in the lower band of 28 GHz.

Fig. 2. Antenna reflection coefficient vs length, $L1$.

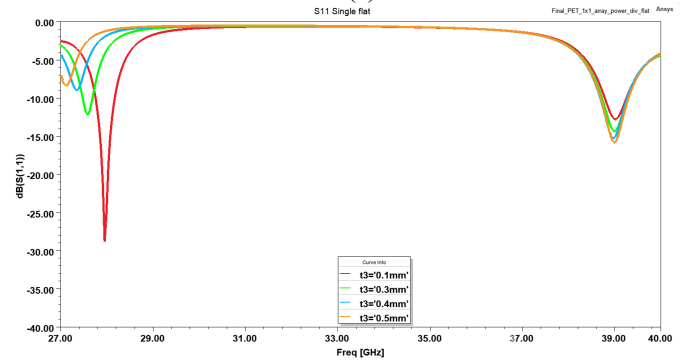
On the other hand, Fig. 3. shows the effect of changing length, $L2$ on the resonant frequencies. This time, the upper frequency of 39 GHz has a more pronounced shift while the 28 GHz frequency is virtually unaffected.

Fig. 3. Antenna reflection coefficient vs length, $L2$.

Varying the length $t2$ results in a slight increase in the upper frequency as well as improving the impedance match while the low frequency remains relatively unchanged. A change in $t3$ results in a higher shift for the low frequency and a negligible change in the higher frequency. This behavior can be seen in Fig. 4(a) and (b) respectively.



(a)



(b)

Fig. 4. Antenna reflection coefficient vs lengths, $t2$ and $t3$.

A change in $t4$ and $t5$ improve the impedance matching of both frequencies even though this is accompanied by a frequency

shift as t_5 is varied. This observation can be seen in Fig. 5(a) and (b) respectively.

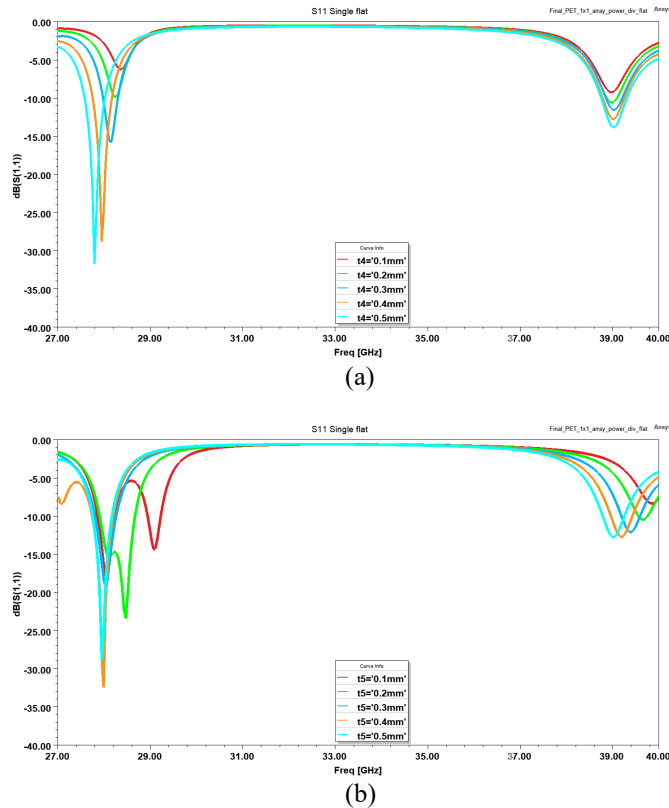


Fig. 5. Antenna reflection coefficient vs lengths, t_4 and t_5 .

With equation (1) together with the parametric study of the variables above, we arrive at an optimized antenna design with parameters shown in Table 1.

Table 1. Design parameters of antenna with units in mm

L1	L2	T1	T2	T3
2.7	2.17	0.1	0.5	0.1
T4	T5	Lf	Wf	Df
0.4	0.5	1.5	0.315	0.9

The return loss and radiation pattern of the optimized antenna using the variables in Table 1 is as shown in Fig. 6. The return loss is less than -10 dB for both frequencies.

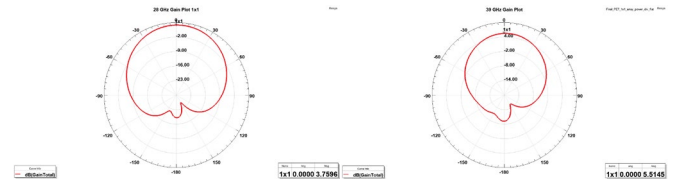
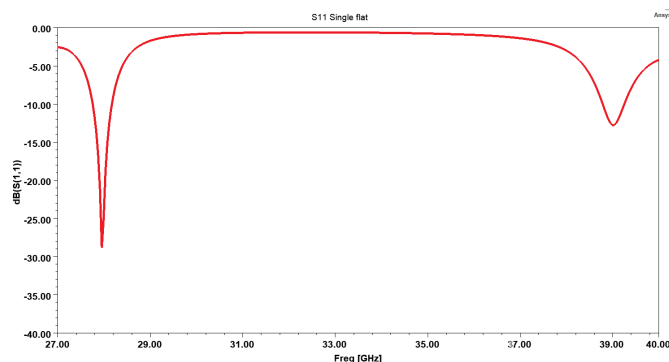


Fig. 6. Reflection coefficient and radiation patterns for single antenna.

III. POWER DIVIDER

For proper antenna array design, two components are of utmost importance. The feeding network and the spacing between the antenna elements. A well-designed feed network allows for maximum power to be transferred to the antenna while minimizing reflections while a properly chosen interelement spacing allows for the radiation pattern from the individual elements of the antenna array to add up constructively thereby increasing the directionality and gain of the antenna array. The power divider for the two-element array consists of a $50\ \Omega$ transmission line which branches out to two $70.7\ \Omega$ arms. The power divider and its geometric parameters are shown in Fig. 7. In Fig 8., we see the s- parameters of the power divider. At both frequencies of interest, we see that the power is almost equally divided and there is minimum reflection (less than -10 dB for both frequencies).

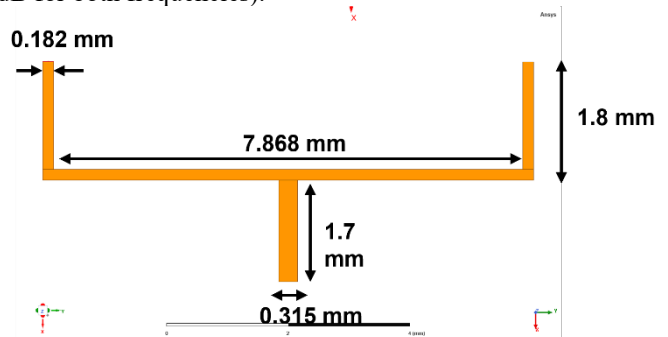


Fig. 7. Power divider

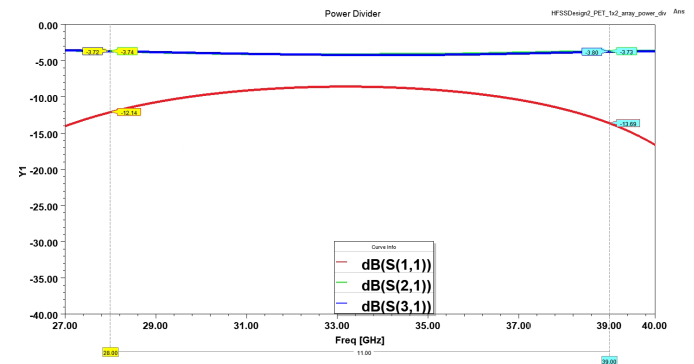


Fig. 8. S-parameters of power divider

IV. ANTENNA ARRAY

Having completed the single patch antenna as well as power divider design, we now connect the two together to have the two-element planar antenna array as shown in Fig 9. The reflection coefficient and radiation pattern for the array are shown in Fig 10. For both design frequencies we see that the return loss is less than -10 dB and the antenna gains are larger for the array as expected. Furthermore, the radiation pattern for the array is more focused than that of the single antenna.

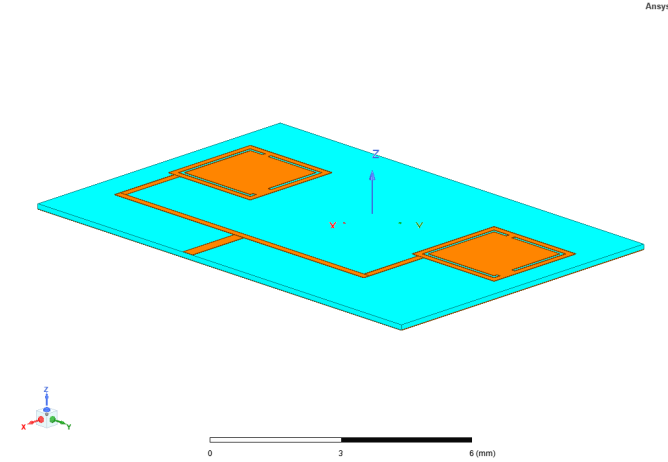


Fig. 9. Two-element dual-band planar antenna array

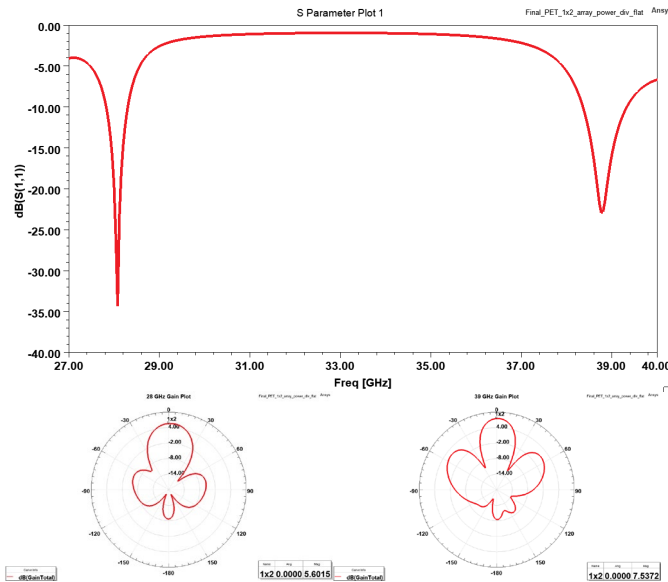


Fig. 10. Return loss and radiation patterns of two-element dual-band planar antenna array

In Fig. 11., we study the effect of the distance between the elements of the antenna array D12 on the radiation pattern. We see that when the two antenna elements are placed side by side with no spacing between them, the radiation pattern is distorted and the gain is minimum. For other values of D12, there is an improvement of the pattern and gain of the antenna.

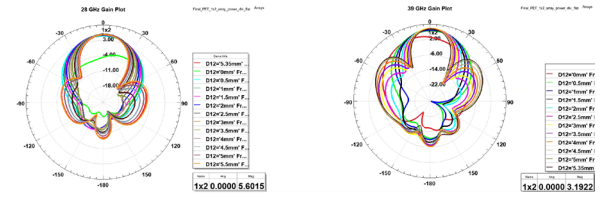


Fig. 11. Radiation pattern of array with changing interelement spacing.

V. BENDING RESULTS

In this section, we study the effect of wrapping the antenna array on a cylindrical object in both the x and y axes on the radiation pattern. Fig. 12 illustrates how the antenna is wrapped around the cylinder. In both cases, the radius of the cylinder is varied from 0.25 in to 5 in.

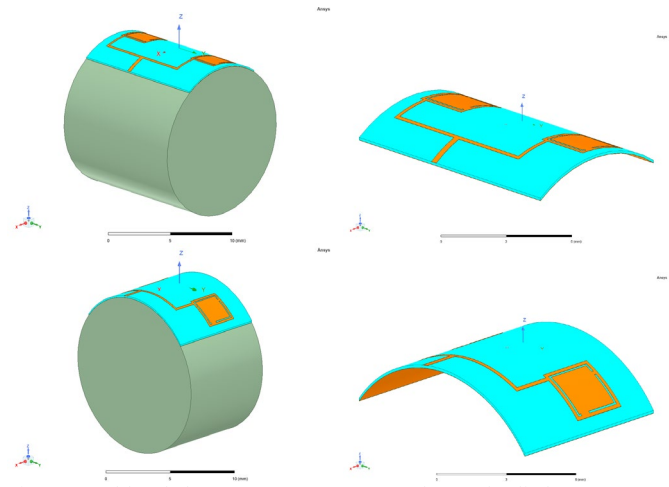
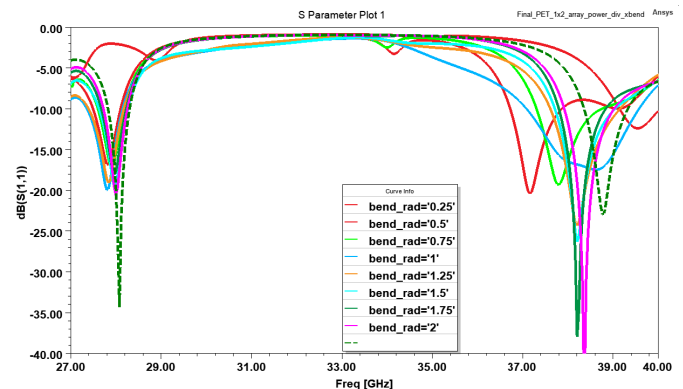


Fig. 12. Dual-band planar antenna array wrapped around cylinder.

In Fig. 13 we have the return loss as well as radiation patterns for the antenna bent around the x-axis. For the lower frequency of 28 GHz, there is minimal shift in the resonance frequency compared to the upper frequency of 39 GHz. For a bend radius of 0.25 in at 28 GHz, we have minimum gain. Similarly, for a bend radius of 0.25 in at 39 GHz, we have relatively low gain. This could be happening because at this bend radius the antenna array elements are farthest from each other.



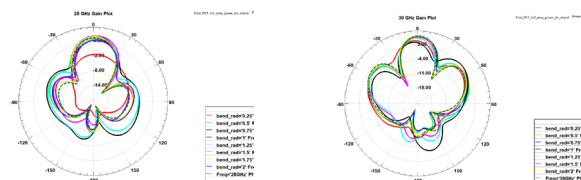


Fig. 13. Return loss and radiation patterns of two-element dual-band planar antenna array bent around the x-axis.

The results for bending the antenna around the y-axis are shown in Fig. 14. Unlike the bending around the x-axis, the return loss at the upper frequency of 39 GHz shows minimal shift. The lower frequency of 28 GHz shows more frequency variation in this case. For the radiation patterns, bending in the y direction shows less variation for both frequencies. This could be because the two antenna elements move in the same direction when the antenna is bent as opposed to bending around the x-axis where the antenna elements move in opposite directions.

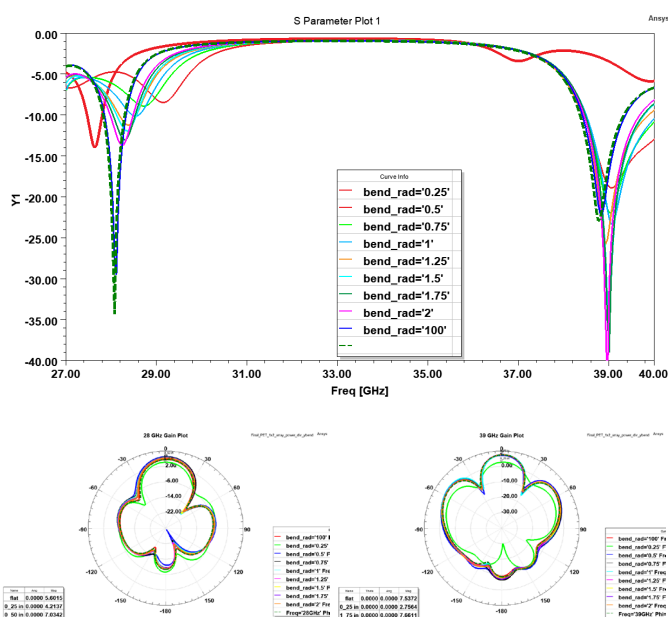


Fig. 14. Return loss and radiation patterns of two-element dual-band planar antenna array bent around the y-axis.

VI. CONCLUSION

In this paper, we designed and simulated a dual-band mm-wave planar patch antenna array and studied the effect of the bend radius on the return loss and radiation pattern of the antenna at the design frequencies of 28 GHz and 39 GHz. The simulation results show that there is a minimal change in the radiation characteristics of the array for bend radius of 0.5 in to 5 in. Future work will be to fabricate the antenna using additive techniques such as aerosol jet printing and perform the bend tests.

Acknowledgment

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