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UWB with Gain Enhancement Archimedean Spiral Microstrip serial Array Antennas for On-board Satellite Communications

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ABSTRACT
Microstrip Archimedean spiral antennas are suitable for wideband satellite communications when CubeSat is used because of its light weight and small size. The wide band frequency response of the spiral antennas can be achieved by properly choosing their outer and inner radius .In this paper a spiral microstrip antennas are designed on **FR-4,** giving an ultra-wide band from 6-to-22GHz which covers all working satellite bands. High gain directive beam with suitable radiations in multiple frequencies for on-board satellite communications is obtained.

Keywords
UWB, Serial Array, DASMA, RT 5880, Gain enhancement

1. INTRODUCTION
Spiral antenna is widely used in satellite communications due to its wide band frequency response, the circular polarization, and the directive beam [1]-[5]. The continuous change in the diameter along the spiral radiating elements provides the smooth variation of the operating frequency response [3]. For this type of spiral configuration, the smaller and bigger diameter determines the high frequency and the low frequency of the operating band respectively. Traditionally to make the spiral radiating only in a one half-space, it is imperative to fill cavities by absorbing materials. In spite of cavities absorb the back radiation from the spiral and keeping the bandwidth features of the antenna, it suffers from certain limitations, including the 3 dB gain reduction, reducing the available radiation power by 50% and the extended volume occupied of the metallic cavity filled by a properly absorbing material. For these reasons, the hot area of research on spiral antennas is the possibility of having spirals on a substrate directly stacked over a metallic ground plane, without absorbers and cavities. This design may lead to overcome the previous disadvantages. In fact, the ground plane produces unwanted reflections, which may effect on the radiation pattern shape and limiting the bandwidth of operation. Choosing the substrate of suitable dielectric constant to the space environment FR-4 is chosen [6]-[10]. Six antenna designs are presented in this paper. The first antenna design is a dipole Archimedean spiral microstrip antenna DASMA on FR-4 substrate and ground plane forms UWB circular polarization which is suitable for on-board satellite communications with the earth station. The second antenna design is a dipole Archimedean spiral microstrip antenna DASMA on FR-4 substrate stacked on RT 5880 substrate with ground plane which is giving more gain and circular polarization with directive beam which increases the visibility duration with the earth station [11]. The third antenna design is a 2x2 dipole Archimedean spiral microstrip array antenna DASMA on FR-4 substrate and ground plane. The fourth antenna design is a 2x2 dipole Archimedean spiral microstrip array antenna on FR-4 stacked on RT 5880 substrate with ground plane. The fifth antenna design is a 3x2 Archimedean spiral microstrip serial array antenna on FR-4 substrate and ground plane. The sixth antenna design is a 3x2 Archimedean spiral microstrip serial array antenna on FR-4 stacked on RT 5880 substrate with ground plane. All antenna designs presented in this paper demonstrated without using cavities or absorbing materials since these may reduce the bandwidth and distort the radiation pattern, [12]-[14]. The simulation processes are performed using the CST microwave studio simulator. The measurements of the S-parameters are recorded using ROHDE & SCHWAEZ ZVA 67 vector network analyzer. The manufacturing is performed at ERI.

2. DIPOLE ARCHIMEDEAN SPIRAL MICROSTRIP ANTENNA DASMA DESIGN WITH GAIN ENHANCEMENT

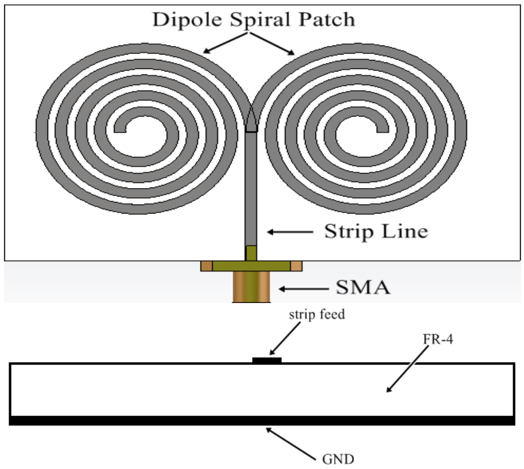


Fig 1: The configuration Cross sections for a dipole Archimedean spiral microstrip antenna DASMA without RT 5880 layer

The dipole Archimedean spiral patches designed with four spiral turns as a dipole which is represented in Fig. (1, and printed on a FR-4 substrate with (ε_r=4.7) with a height h=0.75mm stacked on the infinite metallic ground plane .The dimension of spiral patch center diameter D_c is 2mm,the thickness of spiral arm width T_w is 1.47mm the separation between the arms T_s is 1mm with strip line feed on the substrate surface with same dimension of spiral arm width After doing optimization and parameterization on the geometrical dimensions and taking into account the available material and fabrication techniques, the antenna with this design operate in the band between 7.5-to-24GHz as shown in Fig. (2) [15]. Circular polarization achieved with this antenna as shown in figure (3) having an axial ratio below 3dB. The gain is too low, as shown in figure (4) which need to increase to be suitable for on-board communications so stacked substrates gain enhancement technique can be used to raise the gain and radiation direction [16]-[20].

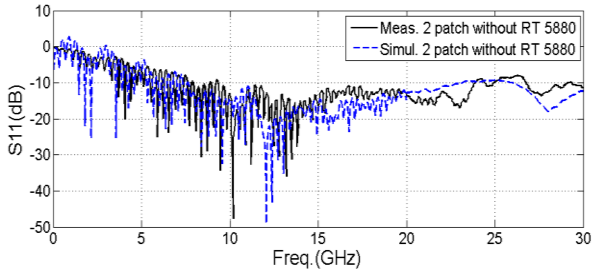


Fig 2: The return loss for a dipole Archimedean spiral microstrip antenna DASMA without RT 5880 layer.

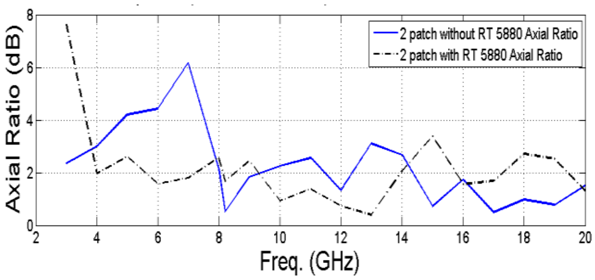


Fig 3: The axial ratio in broadband form for a dipole Archimedean spiral microstrip antenna DASMA with and without RT 5880 layer

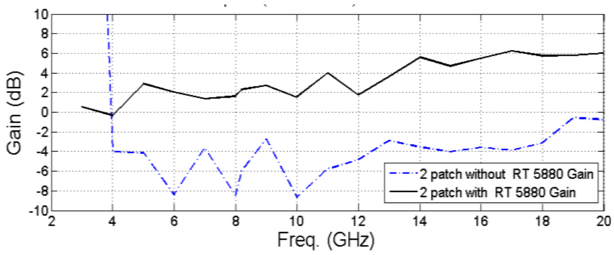


Fig 4: Gain in broadband form for a dipole Archimedean spiral microstrip antenna DASMA with and without RT 5880 layer

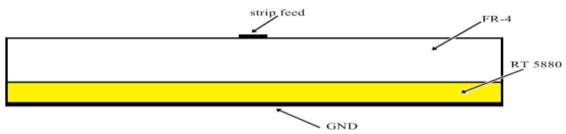


Fig 5: The configuration of the cross section for a dipole Archimedean spiral microstrip antenna DASMA with RT 5880 layer

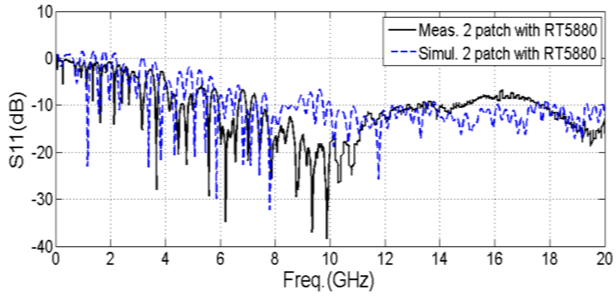
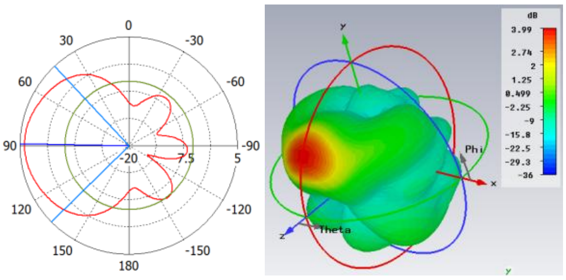
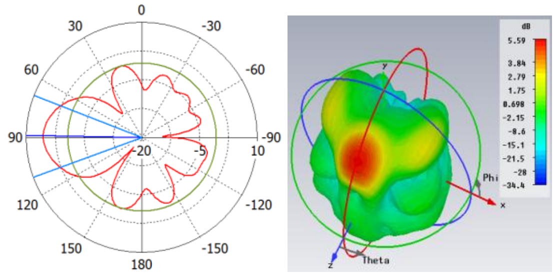


Fig 6: The return loss for a dipole Archimedean spiral microstrip antenna DASMA with RT 5880 layer

Performing the enhancement technique on the dipole configuration shown in Fig. (5). The frequency band of operation is decreased between 7.5-15 GHz with approximately 7 GHz working band as shown in Fig. (6). The polarization of the new design is circular as shown in Fig. (3) with an axial ratio below 3dB. This design has narrower band than the previous design, because of the mutual induction phenomena. Radiation patterns at multiple frequencies presented in polar and 3D forms are shown in figure (7), which forms an isoflux radiation shapes. On the other hand the antennas gain shown in Fig. (4) Increases by +10dB relative to the normal DASMA where no stacked RT 5880 layer is employed. The fabrication shown in Fig. (8).



(a)



(b)

Fig 7: The gain in polar and 3D form in multiple frequencies for a dipole Archimedean spiral microstrip antenna DASMA with RT 5880 layer. (a) At frequency 11GHz with gain 4dB. (b) At frequency 14GHz with gain 6dB

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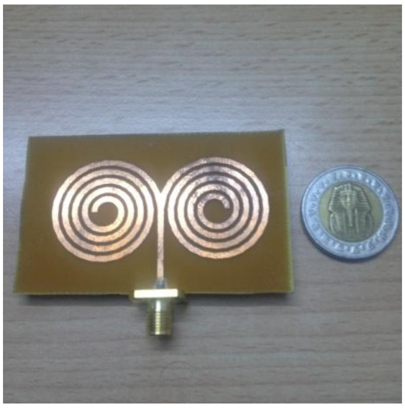


Fig 8: The fabricated DASMA photo

3. SERIAL ARRAY DIPOLE ARCHIMEDEAN SPIRAL MICROSTRIP ANTENNA 2x2 DASMA DESIGN AND GAIN ENHANCEMENT

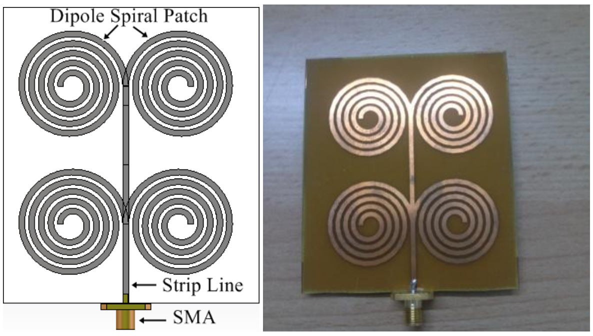


Fig 9: The cross section for 2x2 DASMA without RT 5880 layer and its fabricated photo

The modified design of the dipole Archimedean spiral microstrip antenna DASMA is represented by adding another dipole in series forming an array. The four patches are printed on FR-4 stacked directly to the ground plane as shown in Fig. (9).This new antenna array design operates in the band between 7.5-to-25 GHz as shown in Fig. (10). Circular polarization is achieved having an axial ratio below 3dB as shown in Fig. (11), and a gain over 0 dB; depicted in figure (12).More enhancement is employed by adding stacked substrate that improves the gain [16]-[20].

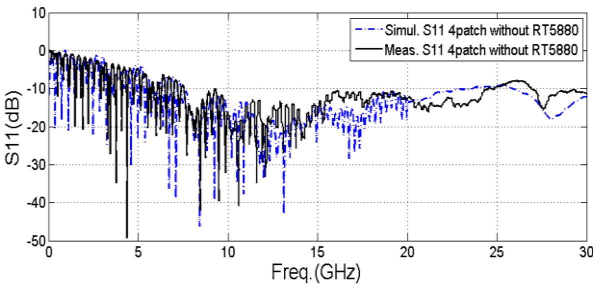


Fig 10: The return loss for 2x2 DASMA without RT 5880 layer

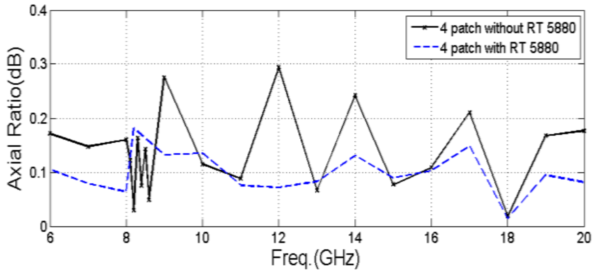


Fig 11: The axial ratio in broadband form for 2x2 DASMA with VS without RT 5880 layer

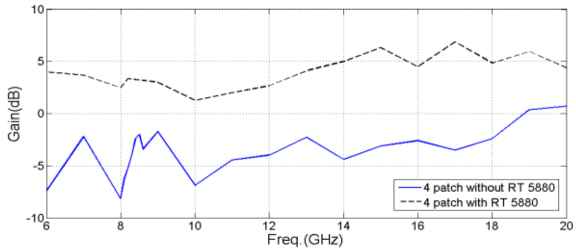


Fig 12: The gain in broadband form for 2x2 dipole Archimedean spiral microstrip antenna DASMA with and without RT 5880 layer

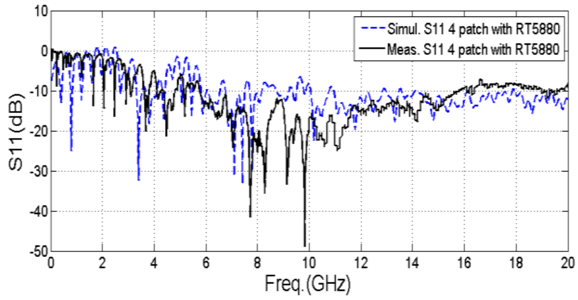
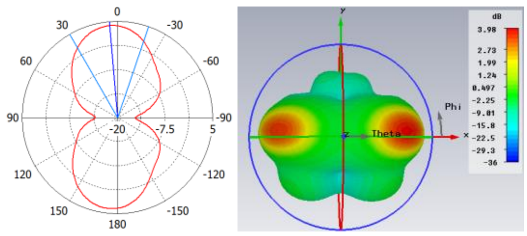


Fig 13: The return loss for 2x2 dipole Archimedean spiral microstrip antenna DASMA with RT 5880 layer

The new array design with the stacked substrates technique is shown in Fig. (5).This new geometry increases the thickness of FR-4 substrate to 1.5mm; adding RT 5880 layer (ε_r=2.2) giving a new height of (0.508mm). Thus the total substrate height becomes 2.008mm.The new antenna design will operate between 5.8-to-16 GHz forming a width of 10.2GHz with circular polarization as shown in Fig. (13) and Fig. (11) respectively



(a)

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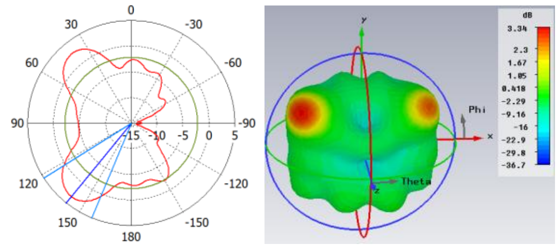

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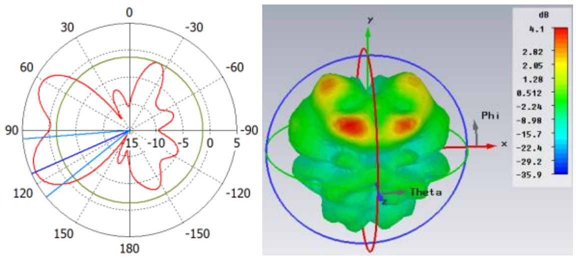

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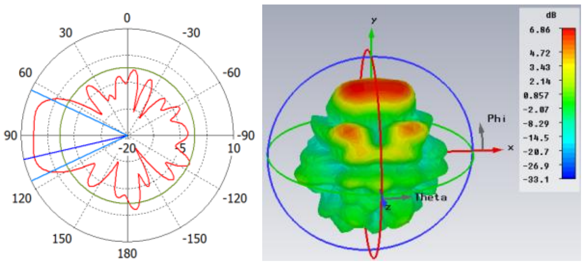

(d)

Fig 14: The gain in polar and 3D at different frequencies for 2x2 DASMA array with RT 5880 layer. (a) Frequency at 6GHz-gain 4dB. (b) Frequency at 8.2GHz-gain 3.4dB. (c) Frequency at 13GHz-gain 4dB. d) Frequency at 17GHz-gain 7dB

This new design has narrower band than the previous design; without stacked substrate; because of the mutual induction phenomena. For satellite bands operation this antenna can operate in C-band, X-band, Ku-band and K-band. To utilize most of these antenna bands, additional microwave devices should be used e.g. circulators, isolators, couplers and filters. Radiation patterns at multiple frequencies are presented in the polar and 3D forms shown in figure (14), giving an isoflux radiation shapes. In addition the antennas gain is increased by +12dB compared to DASMA where no stacked RT 5880 layer is employed as shown in Fig. (12).

4. SERIAL ARRAY DIPOLE ARCHIMEDEAN SPIRAL MICROSTRIP ANTENNA 3x2 DASMA DESIGN AND GAIN ENHANCEMENT

The modified design on the 2x2 dipole Archimedean spiral microstrip serial array antenna 2x2 DASMA is by adding another dipole in front of the original array in serial form forming 3x2 serial array, this design saves the same geometry of the patches. The first design prints the six patches on FR-4 stacked directly to the ground plane as shown in Fig. (15).

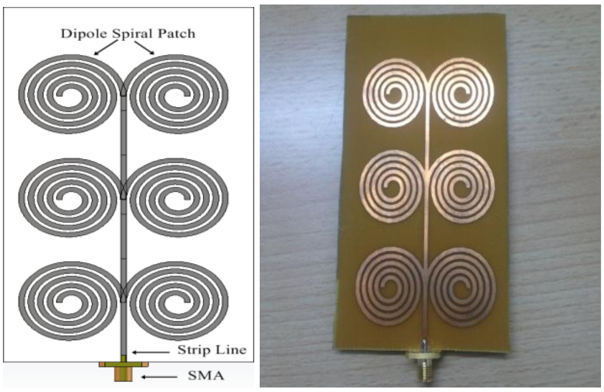

Fig 15: The cross section for 3x2 DASMA and its fabricated photo

After doing optimization and parameterization on the geometrical dimensions and taking into account the available material and fabrication techniques, the antenna with this design operate in the band between 7.5GHz to more than 40 GHz as shown in Fig. (16) [15]. Circular polarization achieved with this antenna as shown in figure (17) having an axial ratio below 3dB. The gain tread over the 0dB, as shown in figure (18) which need to increase to be suitable for on-board communications so stacked substrates gain enhancement technique can be used to raise the gain and radiation direction [16]-[20].

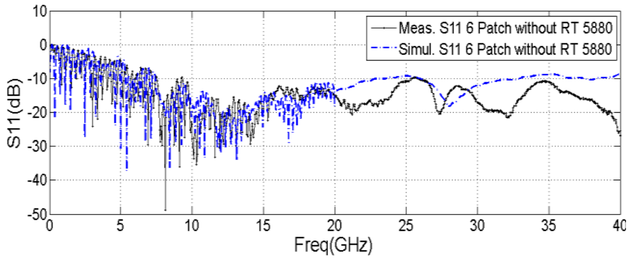

Fig 16: The return loss for 3x2 DASMA without RT 5880 layer

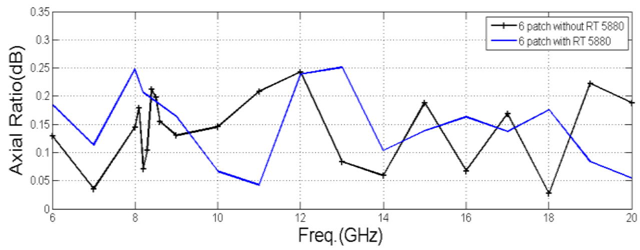

Fig 17: The axial ratio in broadband form for 3x2 DASMA with VS without RT 5880 layer

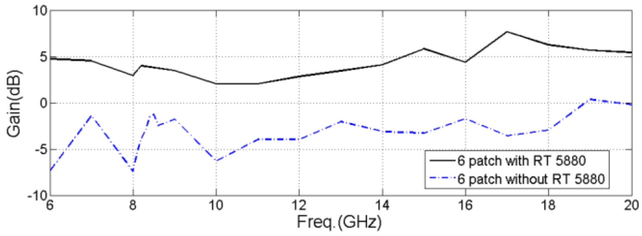

Fig 18: The gain in broadband form for 3x2 DASMA with VS without RT 5880 layer

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The modified design on 3x2 dipole Archimedean spiral microstrip serial array antenna DASMA saves the same geometry of the patches, stacked substrates technique employed in Fig. (5), which increases the thickness of FR-4 to 1.5mm and adding RT 5880 (ε_r=2.2) with height (0.508mm) as a new stacked material, thence the total substrate height between patches and ground plane reaches 2.008mm.This new modifications added to the previous antenna which can be operated in the band between 6-to-22GHz forming 16GHz of working band with circular polarization as shown in Fig. (19) and Fig. (17) respectively.

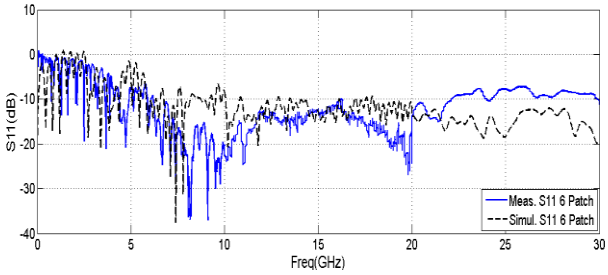
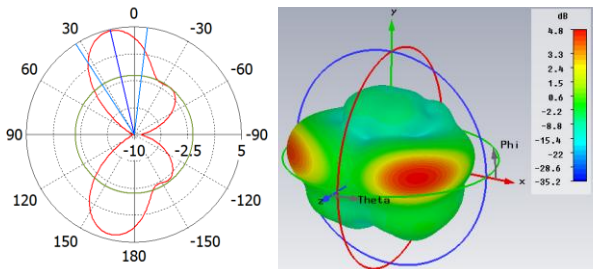


Fig 19: The RL for 3x2 DASMA with RT 5880 layer

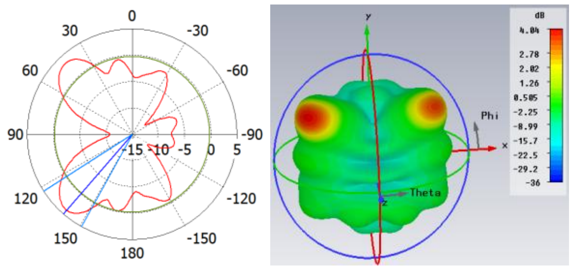
This design had become narrower band than the previous design of 3x2 DASMA [15], because mutual induction phenomena takes place. For satellite bands operation this antenna can operate in C-band, X-band, Ku-band and K-band. To utilize the most utilization of these antenna bands, some of microwave devices can be used as circulators, isolators, couplers and filters. Circular polarization achieved with this antenna as shown in figure (17) having an axial ratio below 3dB. Radiation patterns in multiple frequencies presented in the polar and 3D forms as shown in figure (20), which is forming isoflux radiation shapes in some frequencies. In addition the operation of the antenna gain increases to be 7.8dBi as shown in Fig. (18).

5. RESULTS DISCUSSION

Starting with the normal Dipole Archimedean spiral microstrip antenna DASMA and it's modified by gain enhancement technique, the normal DASMA bandwidth extended from 7.5-to-24GHz and the achieved gain below 0dB which considered as low gain as shown in Fig. (21) and Fig. (22) respectively.



(a)



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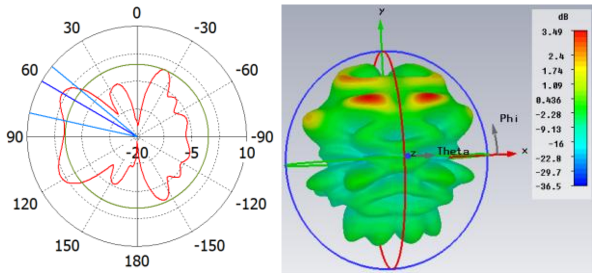

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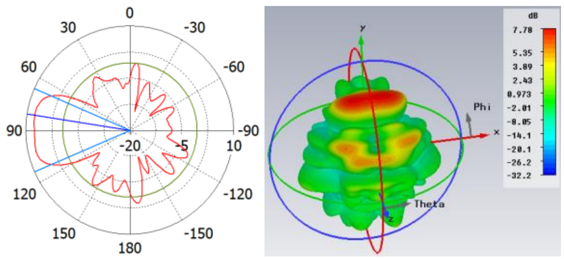

(d)

Fig 20: The gain in polar and 3D form in multiple frequencies as an examples for 3x2 DASMA serial array with RT 5880 layer, (a) at 6GHz-gain 4.8dB, (b) at 8.2GHz-gain 4dB, (c) at 13GHz-gain 3.5dB, (d) at 17GHz-gain 7.8dB

When gain enhancement technique is used by adding stacked RT 5880 layer the gain increase but the bandwidth decreased that extended from 7.5-to-15GHz as a continues bandwidth with gain enhancement by +8dB more than the normal DASMA. For further improvement in antenna bandwidth and for further enhancement in the antenna gain, another two patch added to the normal DASMA forming 2x2 Archimedean spiral serial array antenna, bandwidth extended from 7.5-to-25 GHz and the achieved gain increased by +5dB which achieved gain above 0dB to be 1dBi as shown in Fig. (21) and Fig. (22) respectively which is good gain but onboard satellite communications need more gain. The key solution, stacked RT 5880 layer added to the normal array which increased the gain by +10dB more than the normal DASMA to be 7dBi, but the bandwidth decreased that extended from 5.8-to-16 GHz, This bandwidth shrinkage also is caused by the mutual induction. Finally, 3x2 Archimedean spiral serial array antenna bandwidth extended from 7.5GHz to more than 40 GHz and the achieved gain increased by +6dB relative to the normal DASMA which achieved gain above 0dB to be 1dBi as shown in Fig. (21) and Fig. (22) respectively. Stacked RT 5880 layer added to the normal array which increased the gain by +12dB more than the normal

DASMA to be 7.8dBi, but the bandwidth decreased that extended from 6-to-22GHz, which still more than the 2x2 DASMA, This bandwidth shrinkage also is caused by the mutual induction. For all the previous antennas are radiating in circular polarization as shown in Fig. (23), which is the advantage of spiral shapes.

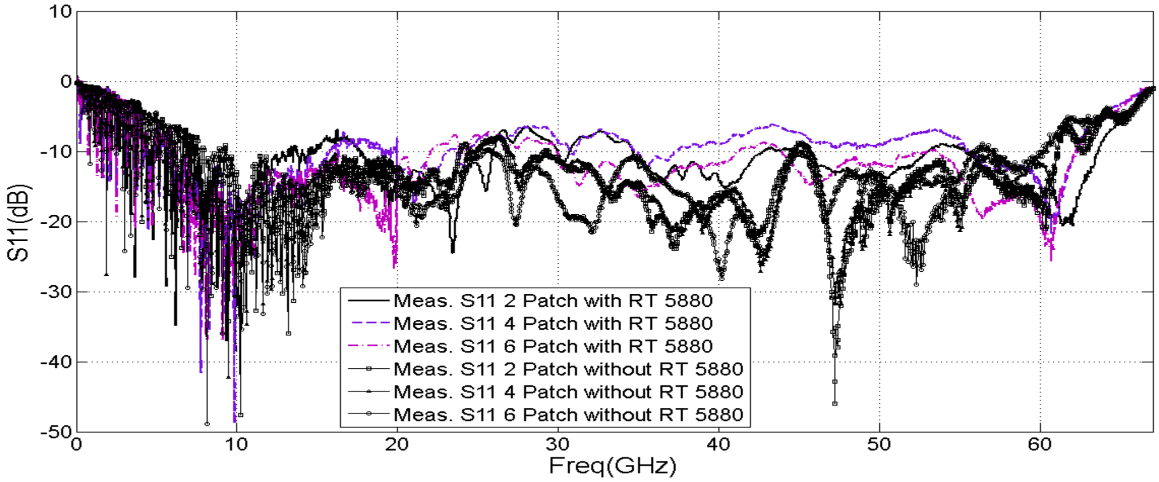

Fig 21: The return loss for all measured antennas with and without RT 5880

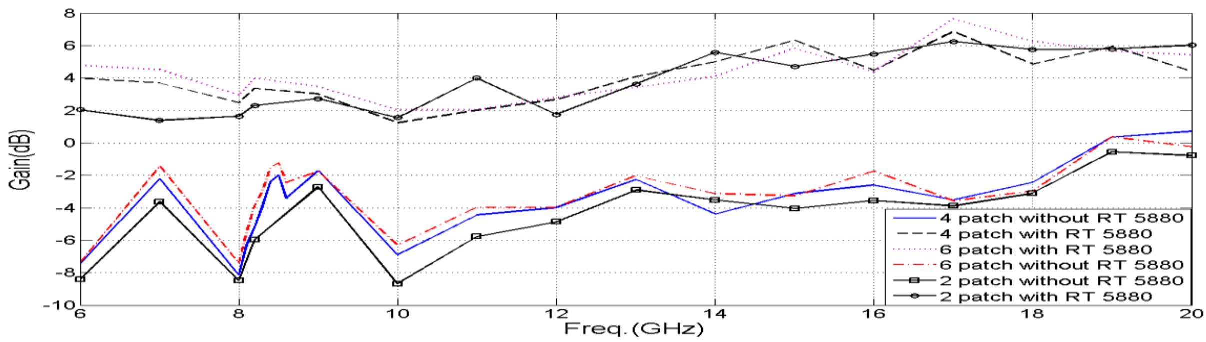

Fig 22: The gain in broadband form for all antennas with and without RT 5880 layer

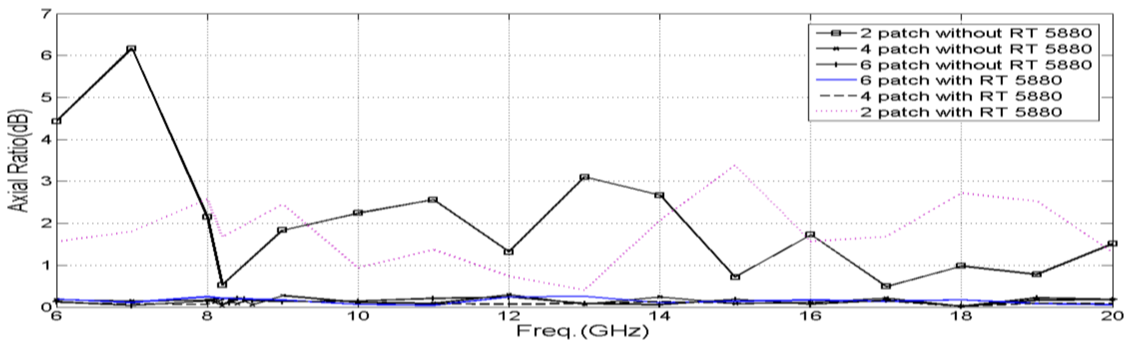

Fig 23: The axial Ratio in broadband form for all antennas with and without RT 5880 layer

6. CONCLUSION AND FUTURE WORK

An ultra-wide band UWB antenna design is presented using spiral shapes on FR-4 substrate without using cavities or absorbing materials. 3x2 Dipole Archimedean spiral microstrip serial array antenna DASMA achieve 6-to-22GHz of working band and gain increases to 7.8dBi. This antenna can be considered as UWB antenna in addition the use of RT 5880 increases gain, bandwidth and radiate in circular polarization. The gain enhancement technique by using stacked substrates as RT 5880 layer is outperforming the array technique or multiple patch when using FR-4 as a basic substrate. But when we added the two techniques with each other the result be in the best case. All of these features increase the visibility duration of the satellite and the ground station in multiple satellite bands. The future works will be focused on using other techniques to enhance the gain and overcome the mutual induction.

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