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Design and Implementation of Compact Planar Array Antenna for Ultra-wide band Applications

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Abstract - *Ultra-wideband (UWB) antennas have recently gained prominence in communication, radar technology, and electronic warfare domains. The quick development of these antennas is due to the wide bandwidth requirements of pulse radar, ground penetrating radar, electromagnetic compatibility, spaceborne communication systems, stealth target detection, and more. Aiming to address the defects of existing UWB antennas, which often have narrow bandwidth and low gain, a planar ultra-wideband microstrip array antenna can be designed to achieve good ultra-wideband characteristics and effectively improve the gain of the antenna by loading multiple steps on monopole patch, defected ground structure and implementing array with different feedings. The initial bandwidth of the rectangular monopole antenna was 10GHz–20GHz. After loading multiple steps on the monopole patch, the bandwidth was increased to between 10 and 45GHz. Using the new ultra-wideband array method that combines series feed and angle feed and the defective ground structure (DGS), the array maintains the ultrawide bandwidth span of 10–45GHz of the array element, and the maximum gain of the antenna in the bandwidth was increased from 4.72dBi to 9.34dBi. The challenge of impedance matching of antenna units in ultra-wideband is resolved by the novel array technique, which also increases the antenna's gain within the bandwidth. The antenna simulation is consistent with the measurement results. With its extensive operating frequency band, high gain, compactness, and favorable radiation attributes, this newly designed antenna holds significant promise for application in UWB radar systems.*

Key Words: **Ultra-wideband antennas, defective ground structure (DGS), Array Antenna,**

1.INTRODUCTION:

Ultra-wideband antennas play a crucial role in UWB radar systems and are indispensable microwave components in UWB wireless technology. The rapid progress in ultra-wideband antenna technology is primarily motivated by the increasing need for wide bandwidth in applications like pulse radar, ground penetrating radar, electromagnetic compatibility, spaceborne communication systems, stealth target detection, and more. With the advancement of electronics and information technology, there is a noticeable shift towards enhancing ultra-wideband antennas in terms of both size reduction and wider bandwidth. This field has emerged as a key area of focus for research in recent times. Planar antennas are extensively utilized in the realm of ultra-wideband due to their cost-effectiveness, compact design, low profile, and broad impedance bandwidth. However, during the antenna design phase, factors such as stability of antenna pattern, radiation efficiency, and antenna volume must also be taken into account, posing challenges in the development of ultra-wideband antennas.

Researchers have extensively studied ways to enhance the bandwidth of microstrip antennas, valued for their small size and flat profile. Techniques include altering patch shapes, adding slots or grounding structures, and using defective structures. In the studies [1-4], various designs like U-shaped slots, E-shaped patches, and stacked patches have been explored. For example, Majidzadeh et al. [5] introduced a quasi-square patch with steps and a rectangular slot, achieving a bandwidth from 2.78 GHz to 19.38 GHz. Another study [6], featured a broadband printed monopole antenna with a peak gain of 4.1 dBi across the entire UWB spectrum. Other designs, like [7], a rectangular microstrip patch with truncated corners, achieved bandwidths from 3.1 GHz to 10.6 GHz with gains up to 3.3 dBi. Nevertheless, monopole microstrip antennas often demonstrate limited gain across the entire bandwidth. In order to enhance the gain of the UWB antenna, it is essential to employ an array configuration of microstrip antenna elements. However, the overall bandwidth of the microstrip antenna array, formed by connecting each unit with the microstrip line, is affected due to the constrained bandwidth of the microstrip line itself. Consequently, it is valuable to investigate methods of utilizing a microstrip antenna array to augment gain without significantly compromising antenna bandwidth.

Current research on planar UWB arrays focuses on series feed[8], parallel feed[9-18], fractional and Fibonacci arrays[19,20], and MIMO arrays[21]. The series feed structure has limited bandwidth, requiring adjustments like extending the feed point into the patch and optimizing feeder-patch distance. In [8], a three-series log-periodic antenna achieved a bandwidth of 12.2 GHz to 21.71 GHz with increased gain. Another study[12] utilized a UC-EBG structure and parallel feeding for a wearable antenna array with high gain. An 8x8 microstrip array achieved an impedance bandwidth of 22 GHz to 46.3 GHz and maximum gain of 23.4 dBi. In [21], Fractal and Fibonacci techniques expanded the bandwidth of a microstrip unit. A triple band-stop MIMO/diversity UWB antenna operated in three frequency bands, enhanced by zigzag patch design, decoupling strips, and ground slot structure for isolation.

The paper outlines an innovative design for an ultra-wideband array antenna, combining horizontal corner feed and vertical series feed for construction. Each array element has multiple current excitation points to cover various frequency bands simultaneously, ensuring performance across different frequency bands without interference. The feed network is compact, enhancing efficiency. Compared to previous designs, this antenna offers a broader bandwidth range and satisfactory gain levels. Additionally, the design features a stepped ultra-wideband microstrip antenna unit and a novel microstrip array approach, achieving an impedance bandwidth from 10 GHz to 45 GHz with a maximum gain of 9.25 dBi.

1.1 ULTRA-WIDEBAND ANTENNA UNIT

The ultra-wideband antenna described in this study functions within the frequency range of 10 GHz to 45 GHz. Achieving an ultra-wideband design for the microstrip antenna unit involves incorporating multiple steps on the rectangular unit. The multilevel stepped structure at the edge of the microstrip patch proves to be an effective method for expanding bandwidth, reducing size, and achieving ultra-wideband capabilities. As the strong current of the patch is mainly concentrated at the edge, modifications made at the edge significantly impact the current distribution of the antenna, thereby broadening its operational bandwidth.

Processing the edge of the patch has a notable impact on the antenna's current distribution, leading to increased bandwidth. To enhance the antenna's bandwidth, this study introduces the loading of 4 steps onto the patch's edge. Figure 1(b) displays the simulation structure of the radiation unit loaded with 4 steps. The width of the antenna steps is optimized, resulting in the following dimensions: width of the rectangular patch part = 7 mm, length = 6.5 mm, feed line length = 5 mm, feed line width = 0.5 mm, ground plate width = 4.7 mm, all steps having the same dimensions with a side length of 0.5 mm. The antenna unit has overall dimensions of 6.5 mm × 14 mm. The simulation results in Figure 2 demonstrate the S-parameters when loading a 4-level stepped antenna. This antenna has 4 resonance points at frequencies of 11.3 GHz, 23 GHz, 30.8 GHz, and 40 GHz. The antenna's bandwidth range is from 10 GHz to 45 GHz. Each resonance point corresponds to a step size of the antenna. Figure 3 displays the current

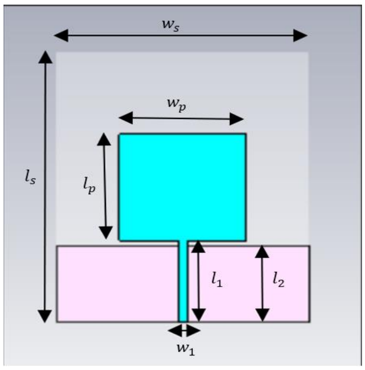


Fig -1(a): Rectangular radiation patch antenna

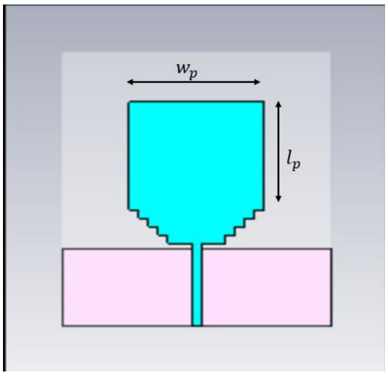


Fig -1(b): 4-level ladder radiation patch antenna

distribution of the 4-level stepped antenna at each frequency point. It is evident that the current is evenly spread along the patch's edge and the feeder. However, as the frequency changes, the current distribution and working model significantly alter, resulting in variations in the antenna's pattern and impedance. This poses challenges for impedance matching in ultra-wideband antenna elements.

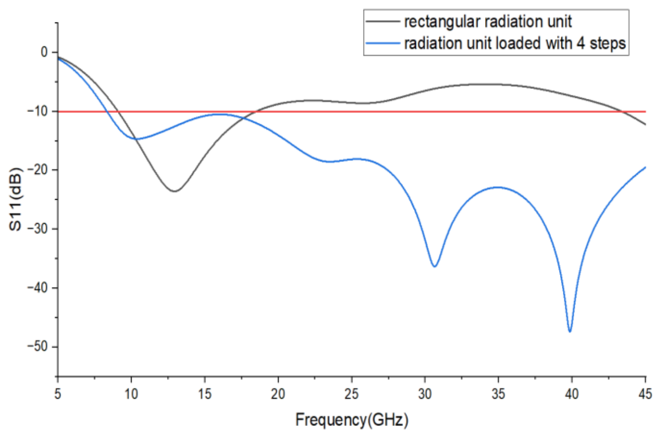
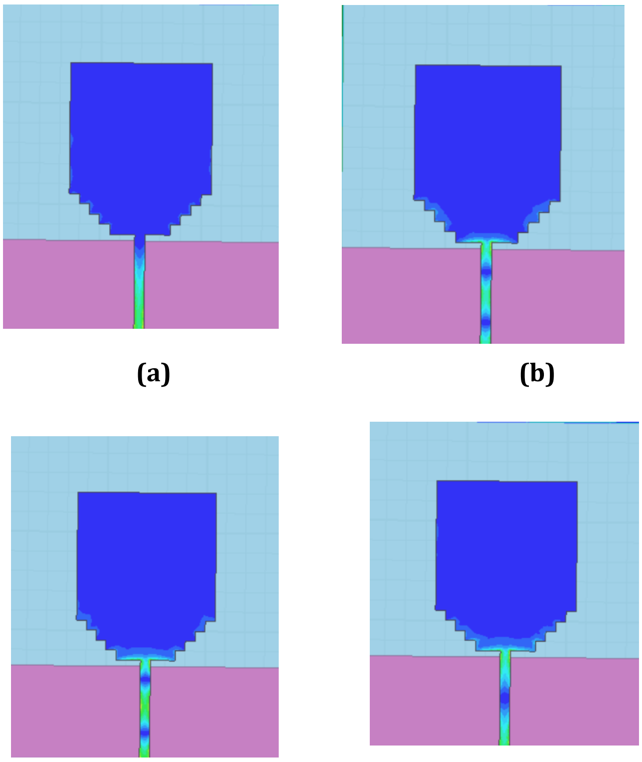


Fig -2: S-parameters of rectangular radiation unit and 4-level ladder element antenna.

1.2 ULTRA-WIDEBAND ANTENNA ARRAY

The average gain of a monopole antenna is typically only 3-5 dBi, which falls short of the requirements for a radio system despite providing basic transmission and reception capabilities. To overcome this limitation and improve the antenna's gain and directivity, it is often necessary to form an array. However, designing ultra-wideband arrays poses challenges due to the significant changes in internal field distribution and working model with frequency, as well as fluctuations in port impedance.

The proposed composition method for UWB arrays involves a combination of series feed and corner feed, enabling multiple feed points on the array element to enhance bandwidth. Variations in feeder length, width, and impedance across multiple frequency bands ensure impedance matching and bandwidth. Implementing this design improves antenna gain, addressing low gain in existing wideband antennas. Figure 4, illustrates the antenna simulation model. The radiation unit uses a radiation patch loaded with four steps, adopting series feeding in the longitudinal direction and corner feeding in the transverse direction for optimal performance.



(a) **(b)**

(c) **(d)**

Fig -3: Current distribution of 4-level stepped antenna:

(a)11.3 GHz , (b) 23 GHz , (c) 30.8 GHz and (d) 40 GHz

PARAMETERS	DIMENSION (in mm)
Width of the substrate	14
Height of substrate	0.254
Length of substrate	16.5
Length of the patch	6.5
Width of the patch	7
Length of ground	4.7
Width of the ground	14
Length of the feedline	5
Width of the feedline	0.5
Height of port feed	0.254
Width of port feed	0.5
Length of the step size	0.5
Width of the step size	0.5

Table -1: Dimensions of simple patch antenna

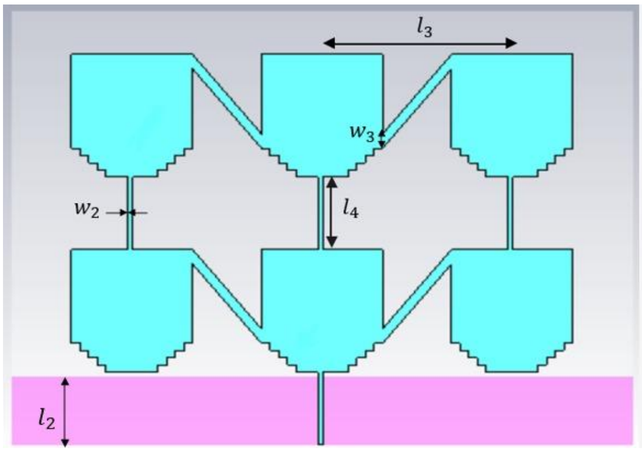


Fig -4: Simulation model of 2 × 3 UWB array antenna

Model and simulate the antenna as shown in Figure 4. The simulation analysis of the patch transverse spacing l3 is carried out. To study the impact of corner-fed microstrip line on the antenna resonant frequency and pattern, change the transverse spacing l3 from 9 to 13 mm in steps of 1 mm.

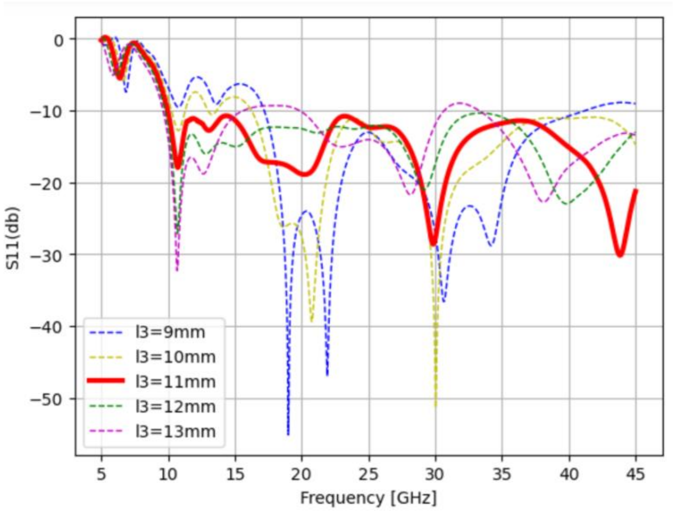


Figure 5: Variation of resonant frequency and S-parameters with the transverse spacing l3

Figure 5 shows the change of resonant frequency and S-parameters of the antenna with the transverse spacing of the patch l3. With the increase of the spacing l3, each resonant point gradually shifts to the low frequency direction. Among which, the first and second resonant points tend to fuse. The S-parameter value of the third resonant point gradually decreases. The return loss of the fourth resonant point is between −20 dB and −30 dB. After extensive analysis, it was determined that the transverse spacing l3 should be 11 mm because, when l3 is small, the antenna does not resonate in the frequency range of 10 GHz–20 GHz and the impedance is not matched, and when l3 is large, the pattern is poor. The width of the corner-fed microstrip line was determined to be 1 mm, the length of the series-fed microstrip line to be 5 mm, and the width of the feed line to be 0.3 mm using the same method that was used to simulate the transverse spacing.

2. The Effect of DGS on Antenna Performance

The gap distance between the patch and the floor is crucial for impedance matching. However, as the number of radiating parts increases, simply changing the ground plate's size to alter the distance between the patch and the ground will not be sufficient to modify the impedance matching of the entire antenna. Therefore, this paper improves the grounding plate.

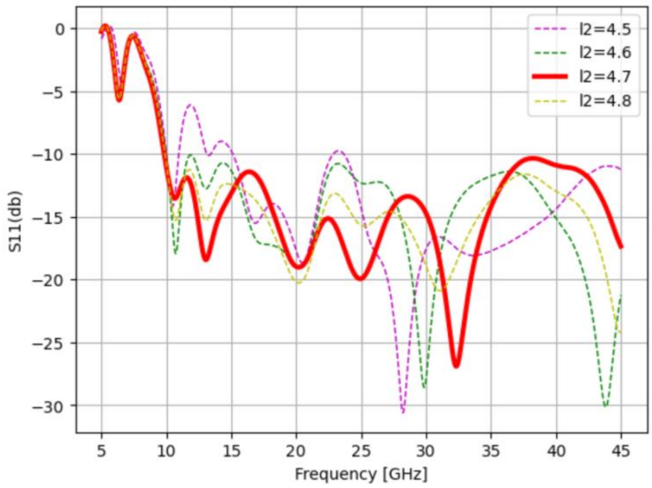


Figure 6: Effects of ground plate width l2 on antenna impedance matching.

Figure 6 shows that the effect of changing the ground plane width l2 on the impedance matching in the frequency range of 17GHz–23GHz is relatively minimal when no slot is created. After carving a tiny rectangular groove on the ground plate, the distributed capacitance and distributed inductance are modified to provide the band-pass characteristic in the aforementioned frequency range.

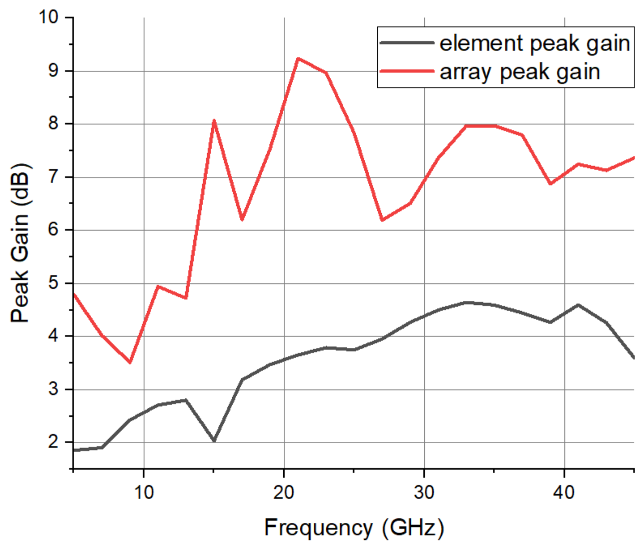


Figure 7: Simulation results of UWB unit and array peak gain.

The size of the optimized array antenna is 36mm×30mm. The comparison of the maximum gain of the UWB antenna unit and array at each frequency is shown in Figure 7.

Frequency (GHz)	Peak Gain of Array Antenna
8	3.5
13	4.8
17	6.2
27	6.2
38	6.8

Table -2: Maximum Gain of UWB array antenna

As shown in Table 2, the maximum gain of the UWB array antenna at 11.3GHz, 23GHz, 30.8GHz, and 40GHz is significantly higher than that of the radiation unit. The antenna achieves the effects of increasing gain and enhancing directivity. Meanwhile, in the design of the array, there are two ways to feed the array elements. The radiating elements are directly connected by the series feeder and the corner feeder, which reduces the antenna size and realizes the antenna's miniaturization design.

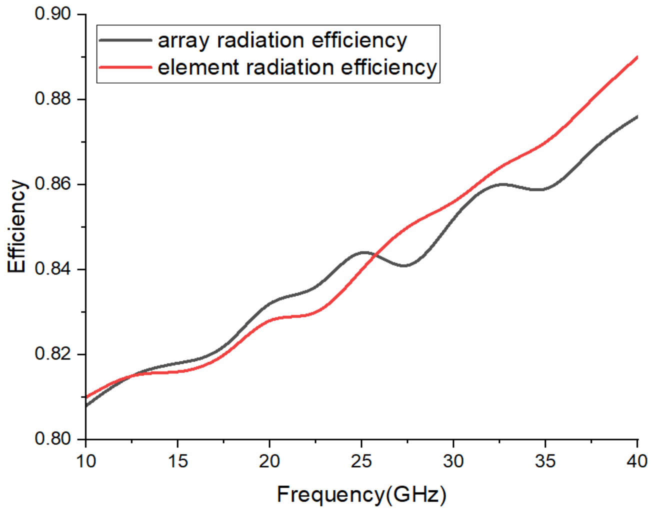


Figure 8: Radiation efficiency of antenna unit and array.

Figure 8 shows the radiation efficiency of the antenna unit and the array, both of which are in the range of 0.8-0.9.

3. Conclusions

This paper describes the design process of planar UWB antenna arrays. The UWB antenna unit is designed first. The antenna unit's bandwidth is increased from 10–20GHz to 10–45GHz by loading multilevel steps on a conventional rectangular microstrip patch and altering the current distribution at the patch's edge. The UWB elements are then assembled into arrays. The array uses a series feed mode longitudinally and the corner feed method transversely. The longitudinal and transverse array element spacing and feeder width are adapted, and the defective ground structure is used to adjust and optimize the performance of the array. As a result, the maximum gain of the ultra-wideband antenna array at 10GHz, 17GHz, 24GHz, 31GHz, and 38GHz reaches 4.45dBi, 7.30dBi, 9.55dBi, 8.07dBi, and 6.26dBi respectively, which is a significant improvement compared to ultra-wideband units exhibiting good performance.

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