JOURNAL OF NANO- AND ELECTRONIC PHYSICS *ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ*
Vol. **15** No 2, 02010(5pp) (2023) Том **15** № 2, 02010(5cc) (2023)

High-Co and Low-Cross Polarization Measurements in a Miniaturized Ultra-Wideband Compact Array Antenna for Multi-Mission Radars

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(Received 24 February 2023; revised manuscript received 16 April 2023; published online 27 April 2023)

This paper describes a simple methodology to obtain an Ultra-Wide Band characteristic with dual polarization and high radiation performance of a miniaturized compact array antenna for Multi-Mission C band Radars applications. The proposed array antenna is composed of a principal T-junction power divider and 32 circular radiating elements. It is manufactured on 1.58 mm thick FR 4 epoxy with miniaturized dimensions (110 mm × 214 mm × 1.58 mm). Design objective adopted in this work is to explore the Ultra-Wide Band characteristic and high radiation pattern performance consisting of high co-polarization at resonance frequencies and low cross-polarization for a miniaturized antenna structure that covers the entire C band. The intended design of the optimal proposed structure has been obtained after processing through many steps, starting from the basic antenna and its optimization to the final proposed array antenna structure. All the simulation investigations have been carried out using numerical methods and verified with measurement. The suggested array antenna is well miniaturized and it has good characteristics in terms of bandwidth (122 %), gain (15-24 dB), side lobes level and co-cross polarizations which are required in the majority of radars processing area.

Keywords: Array antenna, Ultra-Wideband Communication, Polarization, Radar, Side lobes.

DOI: 10.21272/jnep.15(2).02010 PACS number: 84.40.Ba

1. INTRODUCTION

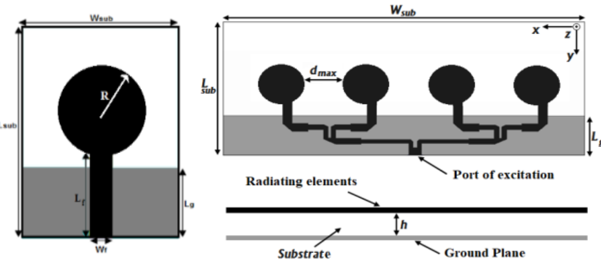
Radars systems are used since their appearance in a lot of area like military fields and civil applications. In terms of frequency ranges, radars systems have many bands, like S, C, X, K and others. The type of transmitted signals by several radars is focalized on two popular methods: narrowband or Ultra-Wideband (UWB) radio pulse technologies [1-3]. UWB is a radio transmission technology through which a wide bandwidth of 500 MHz can be utilized for signal transmission as fixed by FCC (Federal Communications Commission). The frequency range fixed in this work ranges from 4 to 8 GHz that covers the whole spectrum of C band. Generally, radars are composed of a lot of different components, the most important parts are: diplexers for switching input output signal, filters for filtering unwanted signals, antenna for receiving and transmitting radio signals, transmitters for generating signals to antennas, receivers for signal processing and screens [4-5]. In recent year, many researchers have designed and reported various UWB antenna structures [6-13]. The principal goal in this article is to improve the antenna performance in terms of size and radiation patterns as compared to antenna structures reported in [14-17] with UWB characteristics. The proposed article is presented with the following sections highlighting the major contributions, design, and studies conducted. In section 2, we presented theoretical development methods for the design of single element antenna, planar array antenna, and proposed UWB PGB array antenna structures with simulation results, while in section 3, a comparison analysis between the experimental and simulated results for the proposed array antenna is discussed including a comparison with other recent works is included. Finally, section 4 concludes the proposed work.

2. ANTENNA DESIGNS AND RESULTS

All deign steps are executed with a depth study and optimization in order to find the desired results [9-10].

2.1 The Basic Antenna

In Fig. 1(a), the proposed basic single antenna is presented, the gray color is the partial ground plane.



(a) (b)

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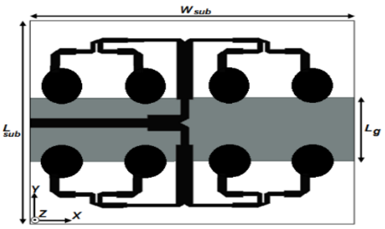
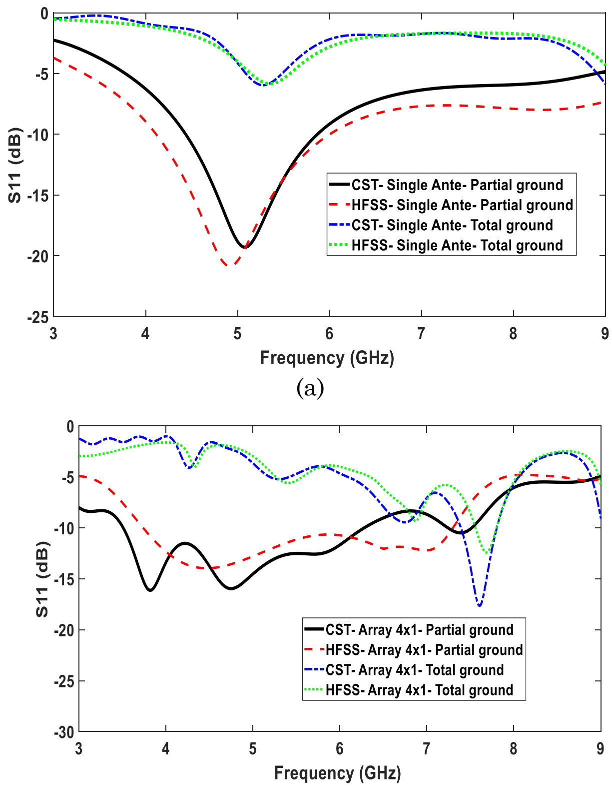


(c)

Fig. 1 – (a) basic antenna, (b) linear 4 × 1 array antenna (c) planar array antenna

Its principal dimensions are (Unit: mm): $L_{sub} = 30$, $W_{sub} = 20$, $L_f = 12$, $W_f = 2$, $L_g = 8.5$, $R = 8.5$.

To ameliorate the bandwidth and to achieve high gain, it is required to increase the number of radiating elements. In order to achieve it, the design has been transformed from single antenna to the linear array antenna [see Fig. 1(b)] and then to the planar array antenna of eight circular radiating elements [see Fig. 1(c)]. Fig. 2(a) shows the simulated reflection coefficient (S_{11}) results taken from two numerical methods (CST and HFSS) for both cases of ground plane (total (TGP) and partial (PGP)). Clearly, it can be observed that, for the PGP case, an UWB property is verified and from 4.2 GHz to 5.8 GHz, we have – 10 dB of S_{11} which is approximately about 1600 MHz in terms of bandwidth. On the other hand, for TGP case, it indicates poor matching of antenna. In general, the design goal is to reach UWB to cover whole C band with high gain, which is not attained by single element antenna. The S_{11} parameters for 4 × 1 linear array with different ground planes are shown in Fig. 2(b). For this linear array antenna, UWB band requirements



(b)

Fig. 2 – S_{11} comparisons for (a) single element antenna (b) 4 × 1 linear array antenna

covering entire C band is not achieved.

Fig. 3 presents the structure of T-junction power divider required to design the proposed planar array antenna. The basic goal of this power divider development is to supply a power into input port, the power transmission to ports 1 and 2 should be maintained equally. The principal dimensions after optimization are (Unit: mm): $L_{sub} = 64$, $W_{sub} = 78$, $L_g = 20.3$, $W_1 = 3.5$, $W_2 = 28.7$, $W_3 = 5.2$, $W_4 = \lambda_g/4$, $W_5 = 2$, $W_6 = 4$, $W_7 = 4$, $Z_1 = 44\Omega$, $Z_2 = 33.9\Omega$, $Z_4 = Z_1 = 40.4\Omega$, and $Z_3 = \sqrt{Z_1 \cdot Z_4 / 2} = 54\Omega$. Fig. 4 shows the T-junction power divider input impedance. It is shown that our input impedance has a resistive part of 50 Ohm while the reactive part is zero at the operating band frequency. Hence, the power divider is well matched to the source. It can be observed from Fig. 5 that the planar array with total ground plane has no matching in all band of interest, hence UWB characteristic is not reached. For the partial ground plane, we can conclude that the array antenna reaches our objective in terms of bandwidth, it has a S_{11} inferior to – 10 dB from the frequency of 3.5 GHz to 8.8 GHz, so this array antenna is Ultra wideband and covers all C-band.

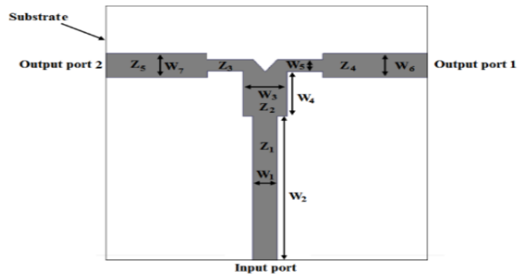


Fig. 3 – Proposed power divider

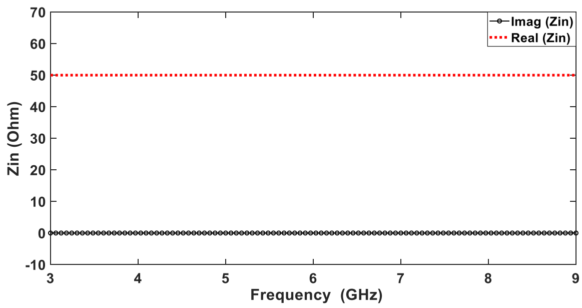


Fig. 4 – Simulated T power divider Input impedance

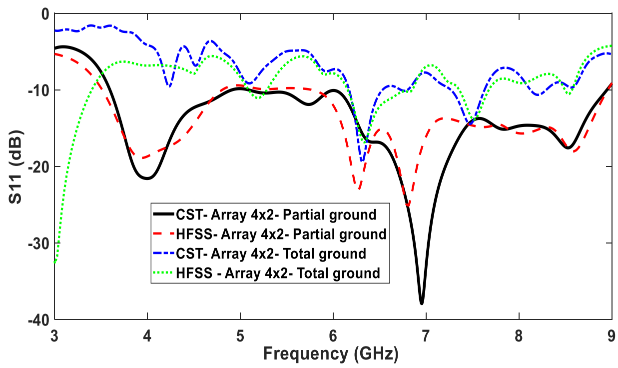


Fig. 5 – S_{11} for planar array with different ground planes

2.2 Proposed Array Antenna Structure

Fig. 6 presents the proposed compact planar array antenna geometry with partial ground (PG) plane. The principal dimensions after optimization are (Unit: mm): $L_{sub} = 110$, $W_{sub} = 214$, $L_g = 80$, $W_g = 21.2$, $Y_1 = 93.8$, $Y_2 = 11.7$, and $R = 6$. As per observations demonstrated in Fig. 7(a) in terms of S_{11}, it can be noticed that the array antenna with a total ground plane (TGP) is not well matched over the whole band of interest (4-8 GHz). It also has many resonance peaks with a lot of distortions. So, therefore, the total ground plane is not suitable for UWB communication. As per the simulation results of partial ground plane, we can observe that it provides a bandwidth greater than 5.5 GHz ($S_{11} < -10$ dB), over the frequency spectrum 3 to 9 GHz, which covers the required band for our radar applications in the *C*-band. The gain versus frequency for different proposed antenna structures are shown in Fig. 7(b). It can be clearly seen that the gain increases from the single antenna (with a maximum of 4 dB) to the final proposed array antenna (which increases from 15 dB to 24 dB for total *C*-band). It justifies the proposed array structure be used in several radars which need high radiation performance.

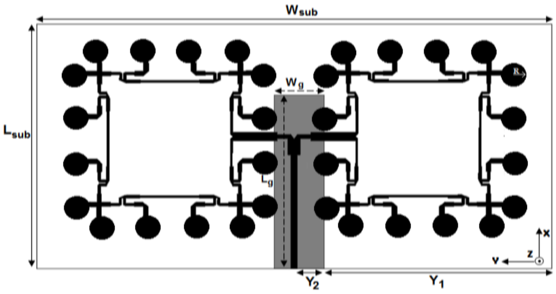


Fig. 6 – Final proposed UWB PGP array antenna

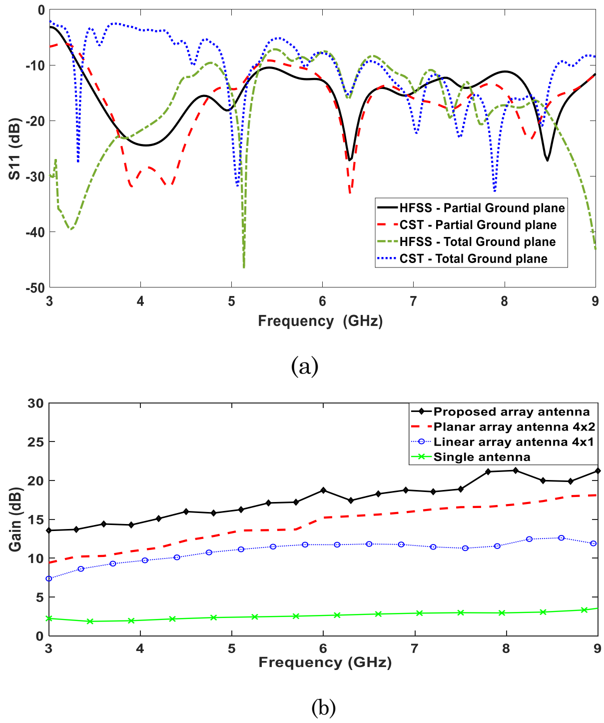


Fig. 7 – Proposed array antenna (a) S_{11} (b) gain comparisons

3. MEASUREMENT RESULTS

Fig. 8 represents the fabricated structure with its dimensions. It is examined by a VNA Network Analyzer through its SMA Female connector.

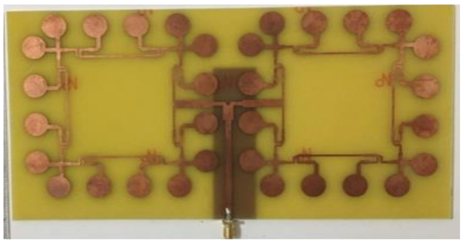


Fig. 8 – Fabricated structure of UWB array antenna

3.1 S_{11} comparison

As indicated in Fig. 9, the simulated results obtained using both simulators (CST and HFSS) are experimentally verified through measurements using vector network analyzer. The measured operating band ranges from 3 GHz to 9 GHz with several resonance frequencies [3.61 GHz, 4.11 GHz, 5.01 GHz, 7.01 GHz, and 8.39 GHz].

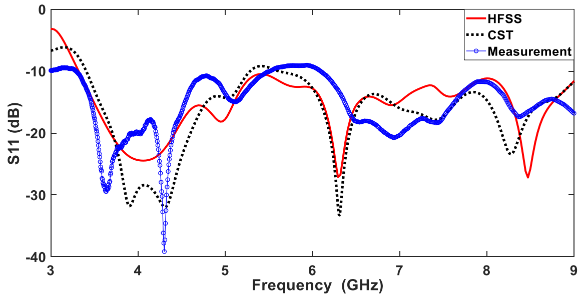
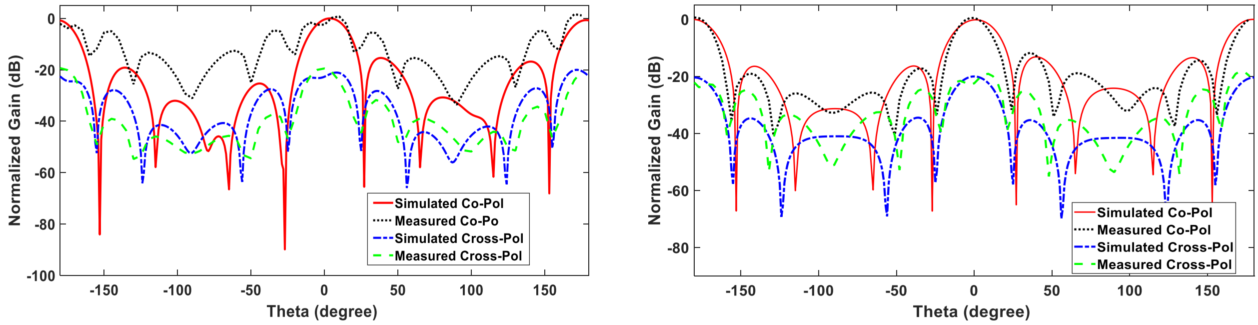


Fig. 9 – Simulation and measurement results

3.2 Gain and Radiation Pattern Study

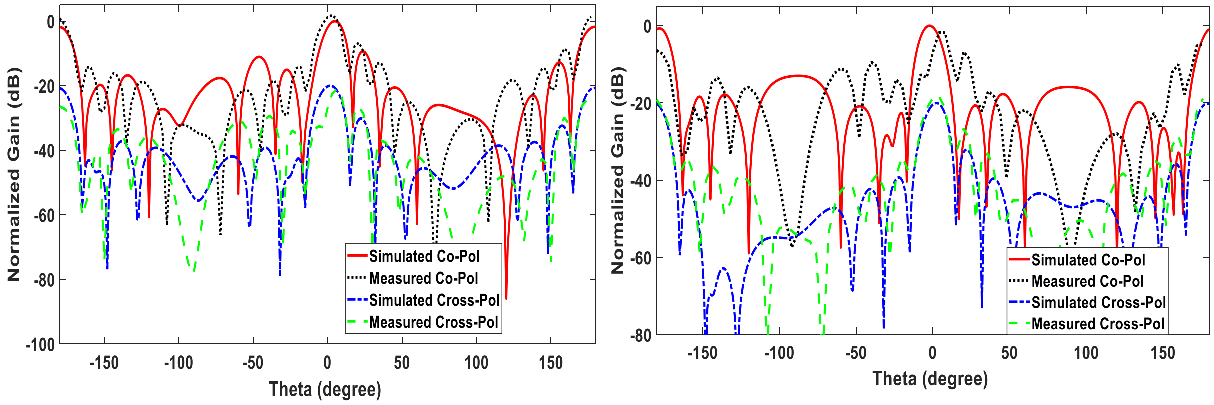
To better understand the array antenna behavior, a comparison between simulation and measurements radiation performance in terms of normalized gain are given in Figs. 10 and 11. The comparison is made in the two radiation planes (*E* and *H*). During the measurement, the transmitter antenna is positioned at 10 meters from the receiver array antenna. The array antenna alignment is very important to get the desired results in all measured polarization cases. Fig. 10(a-b) represent the comparison between CO-POL and CROSS-POL for *E* and *H* planes respectively, at 4 GHz. Simulation and measurement results are in well agreements. The measured half power beam width (HPBW) at 3 dB is about 15 degree and 18 degree, the side lobes levels are lower than – 13.5 dB and – 12.5 dB for *E* and *H*-polarization, respectively.

The comparison between CO-POL and CROSS-POL for both cases of E and H planes at 6.3 GHz are shown in Figs. 11(a-b). The CROSS-POL are higher than 20 dB, the HPBW is about 8 degree and 10 degree, the side lobes levels are lower than – 10.5 dB and – 18.9 dB for the *E* and *H*-polarization, respectively. The slight discrepancy between simulation and measurements are due to measurement tolerances.



(a) (b)

Fig. 10 – CO-POL and CROSS-POL radiation patterns at 4 GHz for (a) *E*-Plane (b) *H*-Plane



(a) (b)

Fig. 11 – CO-POL and CROSS-POL radiation patterns at 6.3 GHz for (a) *E*-Plane (b) *H*-Plane

The elements distribution decreases the side lobes level in comparison with the principal lobe in the main direction, which gives rise to very high co-polarization and low cross polarization. The proposed work has been compared with other reported designs used for radars applications [14-17] as presented in Table 1. The comparison is made in terms of dimensions, radiation performance and UWB characteristics. It can be concluded that proposed structure is well miniaturized, with high radiation and good bandwidth performance which respects the UWB norms compared to other recent works.

Table 1 – Comparison between our work and other recent works

Ref.	Antenna Size ($W \times L$) m^2	Maximum gain (dB)	UWB Charac-teristic	Full C band Coverage
[14]	> 0.151 × 0.347	17.26	No	No
[15]	> 0.114 × 0.114	10.7	No	No
[16]	0.50 × 0.400	13.2	Yes	No
[17]	0.197 × 0.197	21	Yes	No
This Work	0.11 × 0.214	23.5	Yes	Yes

4. CONCLUSION

A miniaturized UWB compact array antenna is designed and fabricated in this paper. The design is carried out through several steps to obtain the desired results. In this work, we have focused on the improvement of radiation performance along with maintaining miniaturized antenna size and bandwidth requirements for UWB communication systems. To achieve a lower cross-polarization characteristic with minimum sides lobes, a vertical distribution between linear arrays antenna is utilized in the final structure. The proposed array antenna is optimized, fabricated and tested, showing an impedance bandwidth greater than 5.5 GHz at – 10 dB level in terms of S_{11} which satisfies the UWB characteristic and covers the total *C* band frequency spectrum. The designed array antenna also exhibits good radiation performance better than 15 dB in terms of gain, with a cross-polarization better than – 20 dB, a small HPBW and lower side lobes level of – 10 dB for the operating band.

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Вимірювання високої та низької перехресної поляризації в мініатюрній надширокосмуговій компактній антенній решітці для багатоцільових РЛС

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У цій статті описано просту методику отримання надширокосмугової характеристики з подвійною поляризацією і підвищеними характеристиками випромінювання мініатюрної компактної антенної решітки для застосування в багатоцільових РЛС C-діапазону. Запропонована антена складається з головного Т-перехідного дільника потужності і 32 круглих випромінюючих елементів. Вона виготовлена на епоксидній смолі FR 4 товщиною 1,58 мм з мініатюрними розмірами (110 мм × 214 мм × 1,58 мм). Метою роботи є дослідження надширокосмугової характеристики та підвищеної ефективності діаграми спрямованості, що складається з високої поляризації на резонансних частотах і низької перехресної поляризації для мініатюрної структури антени, яка покриває весь C-діапазон. Запланована конструкція оптимальної структури була отримана після опрацювання багатьох етапів, починаючи від базової антени та її оптимізації до остаточної запропонованої структури антенної решітки. Всі імітаційні дослідження були проведені з використанням чисельних методів і підтверджені розрахунками. Запропонована решітчаста антена добре мініатюризована і має гарні характеристики з точки зору смуги пропускання (122 %), коефіцієнта підсилення (15-24 дБ), рівня бічних пелюсток і перехресних поляризацій, які є необхідними в більшості областей обробки радіолокаційних сигналів.

Ключові слова: Антенна решітка, Надширокосмуговий зв'язок, Поляризація, Радар, Бічні пелюстки.