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Antena Compacta de Microstrip con Arreglo en Fase y Orientación Electrónica para Sistemas de Comunicación de Alta Frecuencia

Compact Phased Array Microstrip Antenna with Electronic Beam Steering for High-Frequency Communication Systems

Antena Microstrip Compacta com Phased Array e Direção Eletrônica para Sistemas de Comunicação de Alta Frequência

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Artículo de Investigación

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Resumen

Las antenas con orientación de haz representan la mejor solución para aplicaciones como la gestión del tráfico, radares de prevención de colisiones o antenas inteligentes de estaciones base para sistemas WLAN y de comunicaciones celulares. Normalmente, esto se logra mediante arreglos en fase, los cuales utilizan desfases para controlar la dirección del haz principal. Esta investigación tiene como objetivo analizar e implementar un desfase para arreglos de antenas utilizados en el escaneo angular. Se eligió un arreglo de antenas de microstrip debido a su facilidad de diseño y fabricación. El cambio de fase se logra variando las longitudes de las líneas de transmisión se utilizó el software Advanced Design System (Ansoft Designer) para simular tanto el diseño como el rendimiento de la antena. La antena propuesta será impresa sobre un sustrato Epoxy FR4 con una permitividad de 4.3, dimensiones compactas de 80 × 27 mm y está diseñada para lograr un desfase de 30 grados con buenas características de radiación. Los resultados obtenidos muestran un coeficiente de reflexión S_{11} de –30 dB a una frecuencia de 12.2 GHz, demostrando un gran desempeño en esa banda, adecuado para trabajar en aplicaciones de comunicación de alta frecuencia, como sistemas de radar avanzados y redes inalámbricas de nueva generación.

Palabras Claves: Antena; desfase; coeficiente de reflexión; radiación.

Abstract

Beam-steering antennas represent the best solution for applications such as traffic management, collision avoidance radars, or smart base station antennas for WLAN and cellular communications systems. Typically, this is achieved through phased arrays, which use phase shifters to control the direction of the main beam. This research aims to analyze and implement phase shifting for antenna arrays used in angle scanning. A microstrip antenna array was chosen due to its ease of design and fabrication. Phase shifting is achieved by varying the transmission line lengths. Advanced Design System (Ansoft Designer) software was used to simulate both the antenna design and performance. The proposed antenna will be printed on an Epoxy FR4 substrate with a permittivity of 4.3, compact dimensions of 80 × 27 mm, and is designed to achieve a 30-degree phase shift with good radiation characteristics. The results obtained show an S11 reflection coefficient of –30 dB at a frequency of 12.2 GHz, demonstrating excellent performance in this band, suitable for work in high-frequency communication applications, such as advanced radar systems and next-generation wireless networks.

Keywords: Antenna; phase shift; reflection coefficient; radiation.

Resumo

Antenas com direcionamento de feixe representam a melhor solução para aplicações como gerenciamento de tráfego, radares anticolisão ou antenas de estação base inteligentes para sistemas de comunicação WLAN e celular. Normalmente, isso é obtido por meio de matrizes em fase, que usam deslocadores de fase para controlar a direção do feixe principal. Esta pesquisa visa analisar e implementar o deslocamento de fase para matrizes de antenas usadas em varredura angular. Uma matriz de antenas microstrip foi escolhida devido à sua facilidade de projeto e fabricação. O deslocamento de fase é obtido pela variação dos comprimentos da linha de transmissão. O software Advanced Design System (Ansoft Designer) foi usado para simular o projeto e o desempenho da antena. A antena proposta será impressa em um substrato Epoxy FR4 com permissividade de 4,3, dimensões compactas de 80 × 27 mm e foi projetada para atingir um deslocamento de fase de 30 graus com boas características de radiação. Os resultados obtidos mostram um coeficiente de reflexão S11 de –30 dB na frequência de 12,2 GHz, demonstrando excelente desempenho nesta faixa, adequado para trabalho em aplicações de comunicação de alta frequência, como sistemas de radar avançados e redes sem fio de última geração.

Palavras-chave: Antena; deslocamento de fase; coeficiente de reflexão; radiação.

Introduction

In a single antenna element, the radiation pattern is usually very wide in coverage, but the directivity is relatively low. This problem can be solved by increasing the element size, which increases the gain value, however this can indirectly modify the desired bandwidth. Another way to improve the directivity of the antenna without modifying the dimension is to assemble several of these radiating elements in a geometric configuration known as an “array”(Kim et al. 2022; Yu et al. 2025).

Therefore, in many communications system applications, antennas require that the direction of the transition/receive beam lobe be modified over time or scanned. This is usually accomplished by manually mechanically rotating an individual antenna or an array with a fixed angle or phase on each element. This means that mechanical scanning requires a costly and time-consuming positioning system. This is why electronically scanning antennas, better known as phased array antennas, are used. These allow the beam direction to be swept by electronically varying the phase of each radiating element in the array, thus obtaining a moving radiation pattern without the need for mechanical parts. Figure 1 schematically illustrates a phased array antenna, which is composed of a power distribution network, phase shifters and radiating elements (Li, Qu y Yang 2022; Yusuf y Gong 2008).

Phased array antennas are known for their ability to electronically steer the beam pattern with high efficiency, achieving minimal sidelobe levels resulting in intermittency and reduced beamwidths. Implementations began in the 1950s, however, given the basic technology these relied heavily on microwave circuit components such as phase shifters and variable amplifiers. To meet performance specifications such as a narrow beam or a considerable scanning range with high angular resolution, many antennas were required to build the array. Typically, phase shifters are the devices that allow beam steering in a phased array (Yang et al. 2018).

As mentioned above, an array antenna allows directing the radiated beam in a certain direction. Depending on the method of manufacture, offsets can be classified into the following categories: ferrite offsets, mechanical offsets, transmission line offsets and semiconductor device offsets. For each of these, various types of antennas are used, including microstrip patch antennas, wire, waveguides and horn antennas. In addition, power splitters are used to split the microwave signals and feed the radiating elements, using connection methods such as coaxial probe feed, aperture coupling, microstrip line and proximity coupling (Wang, Zhu y Gao 2016; Yin et al. 2024; Gautier et al. 2008).

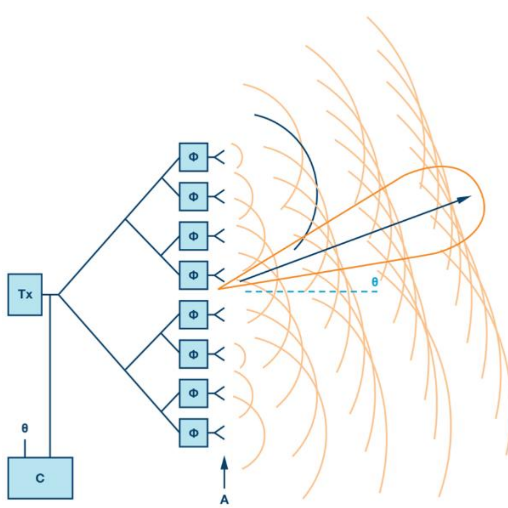

Figure. 1 Corporate fed phase shifter

Methods or methodology

Parameters for antenna design

The proposed antenna is designed to operate at high frequency, specifically centered at 12.2 GHz with a bandwidth of 800 MHz. To ensure a compact structure, microstrip patches were used due to their flat configuration and compatibility with printed circuit board fabrication techniques. The initial design of each individual element consists of a rectangular patch with dimensions of approximately 16 × 19 mm, optimized to resonate at the desired frequency. The antenna array will be fabricated on an FR4 substrate, a dielectric material widely used in antenna implementation, with a relative permittivity (εr) of 4.3, a height of 1.6 mm and an impedance of 50 Ω (Li et al. 2013; Jihao 2020).

To achieve the desirable electronic beam steering, phasing is implemented by varying the lengths of the transmission lines feeding each patch. These variations introduce phase delays that allow directing the main lobe of the radiation pattern to the desired angle (for this research, 30 degrees).

Antenna geometry

The antenna array proposed for this research consists of four rectangular microstrip-type patches arranged linearly along the horizontal axis. The array allows the main radiation lobe to be steered at a 30-degree angle by introducing a progressive phase shift between the elements. To avoid using active components for phase shifting, this array achieves passive beam steering by varying the lengths of the feed lines connecting each radiating element. To achieve a 30-degree orientation, the feed lengths used in the design are L1 = 9.01 mm, 2L1 = 18.02 mm and 3L1 = 27.03 mm, which corresponds to a linear progression of phase between the elements. This feedline-based phasing technique offers a compact, low-cost solution while maintaining the radiation characteristics of the traditional antenna. Figure 2 the array designed in Ansoft software forming each phase shift starting from the second radiating element.

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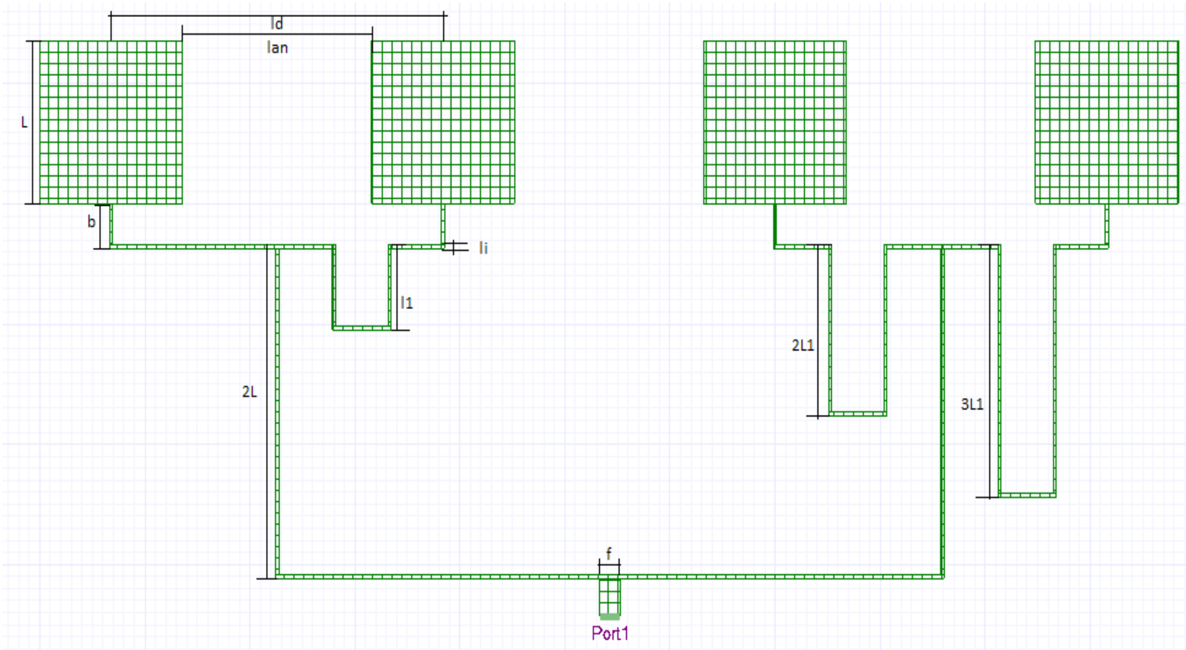

Figure 2. The geometry and parameters of proposed antenna

However, after the first simulation and subsequent analysis of multiple configurations, it could be identified that the best radiation characteristics and desired half power beamwidth (HPBW) were obtained with adjusted line lengths: L1 = 3.257 mm, 2L1 = 6.514 mm and 3L1 = 9.771 mm. With these modified values, the antenna array achieves an offset at 30 degrees while maintaining optimized directivity and a stable radiation pattern. Figure 3 shows the final design with the adjusted measurements.

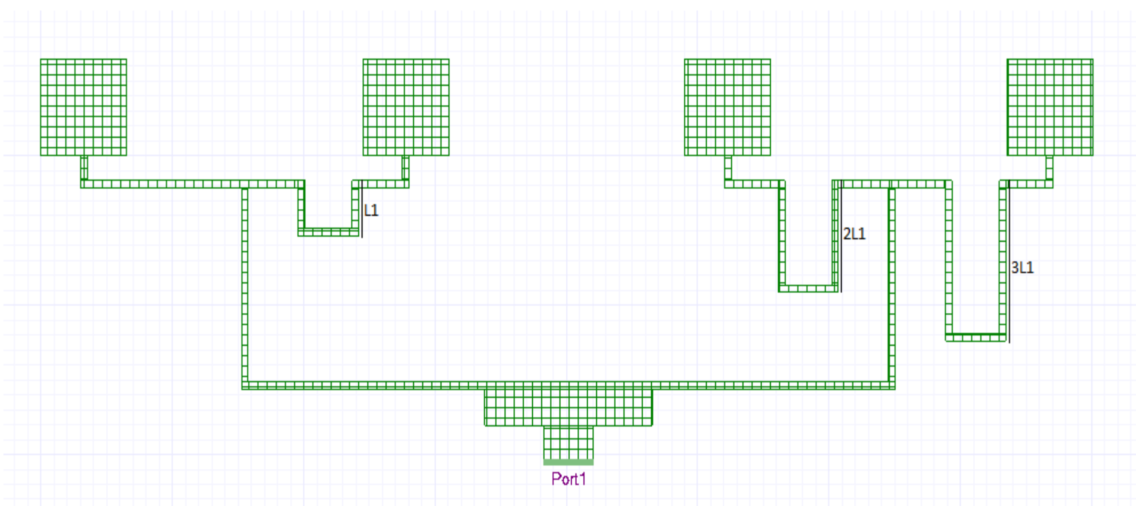

Figure 3. The final design of proposed antenna

Finally, based on the dimensions and the simulation, we proceeded with the manufacturing of the antenna array. Figure 4 shows the implemented antenna with a total dimension of 94 mm x 36 mm.

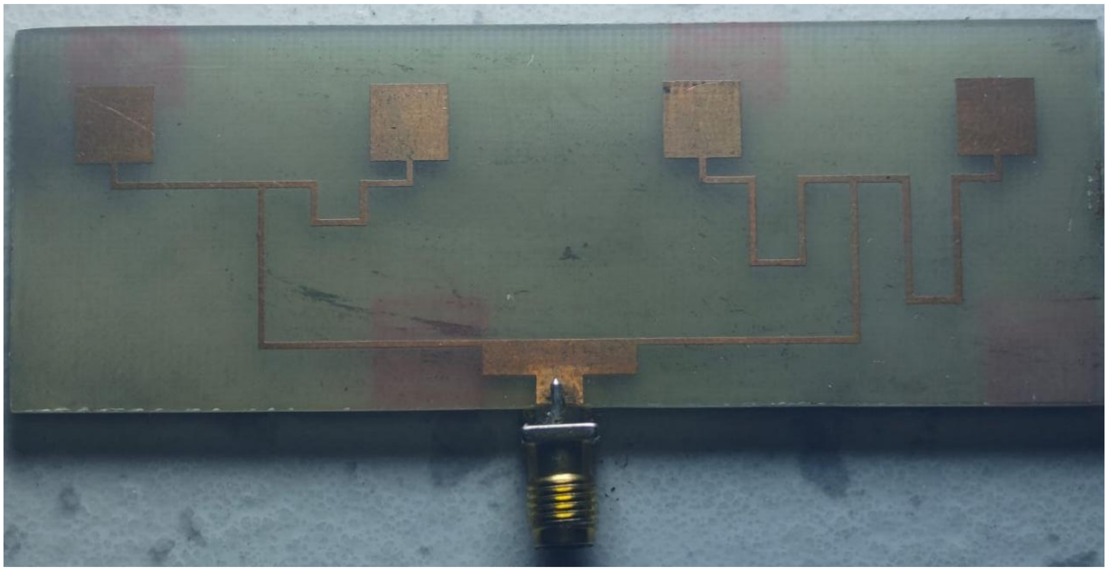

Figure 4. Phase Array Antenna

Results and discussion

Simulation results

a. Radiation Pattern

Using Designer software, the radiation pattern at 10.17 GHz of the designed antenna without scan is shown in Figure. 5. The half power beam width is 30º. In the figure we can appreciate the radiation pattern when the length of feeders (L1) is 6.257mm, with this length the phased array antenna doesn’t radiate in 30 grades.

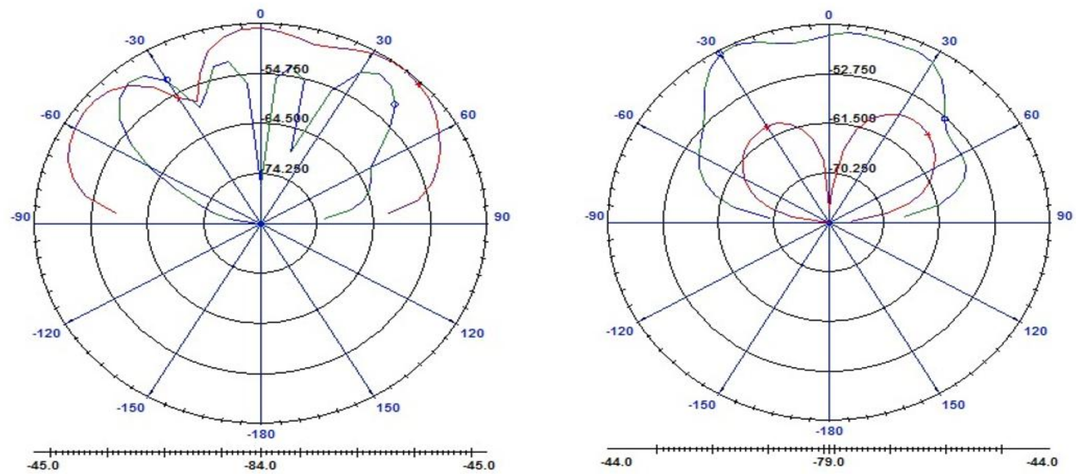

Figure 5. Polar radiation pattern of array antenna without scan in E-theta and E-phi

In the Figure. 6 and 7 we can appreciate the radiation pattern when the length of feeders (L1) is 4.257mm at 10.17 and 12.34 GHz, with this length the phased array antenna doesn't radiate in 30 grades.

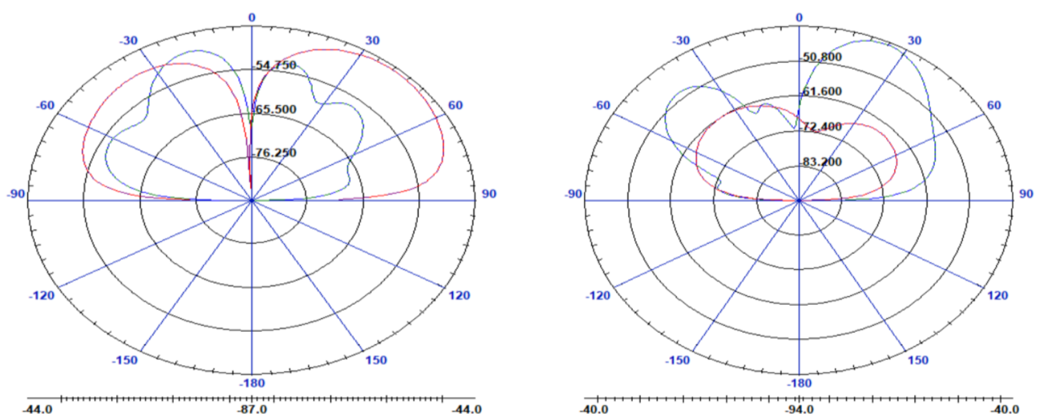

Figure 6. Polar radiation pattern of array antenna with scan in E-theta and E-phi at 10.17 GHz

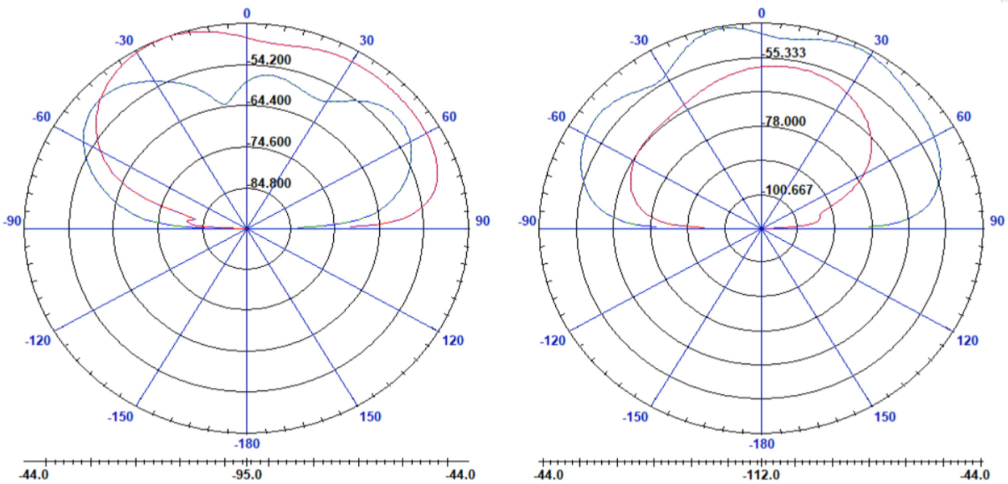

Figure 7. Polar radiation pattern of array antenna with scan in E-theta and E-phi at 12.34 GHz

In figures 6 and 7, the blue line shows the radiation pattern in 0 grades, the red line shows the radiation pattern in 90 grades.

b. *Return Loss*

The return loss of the antenna is shown in Figure. 8. From the figure the resonance frequency of the antenna is at 10.17 GHz S_{11} = - 26.17 dB and 12.24 GHz S_{11} = - 30 dB. As can be seen, the phased array antennas have allowed working with 2 frequencies, each with a bandwidth of 500 MHz, complying with the established requirements.

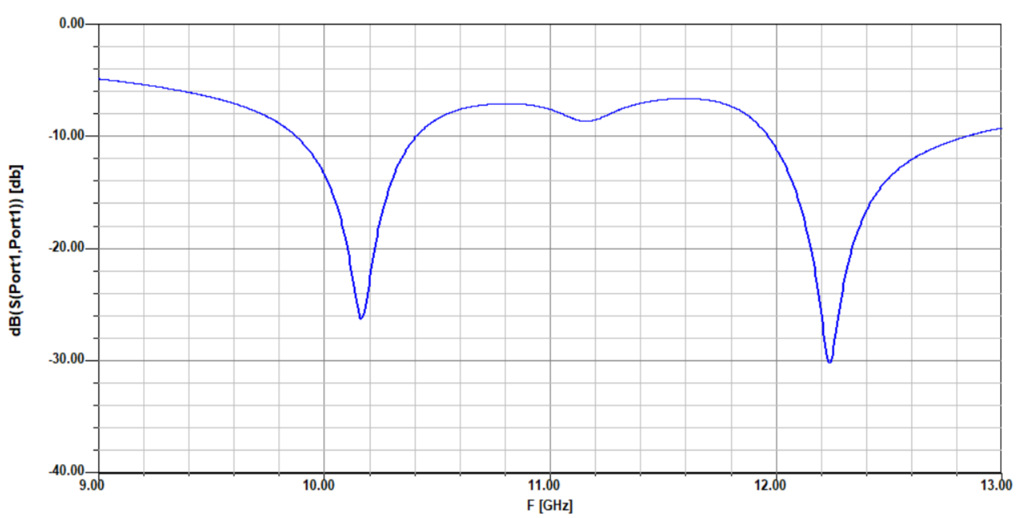

Figure 9. Return loss of phase array antenna with scan

Antenna performance results

Return loss

Using the Anritsu spectrum analyzer, it was determined that the implemented antenna is working in the 2 bands initially established, despite having lost some power in return, both frequencies are operating without complications. Figure 10 shows the result of the developed antenna.

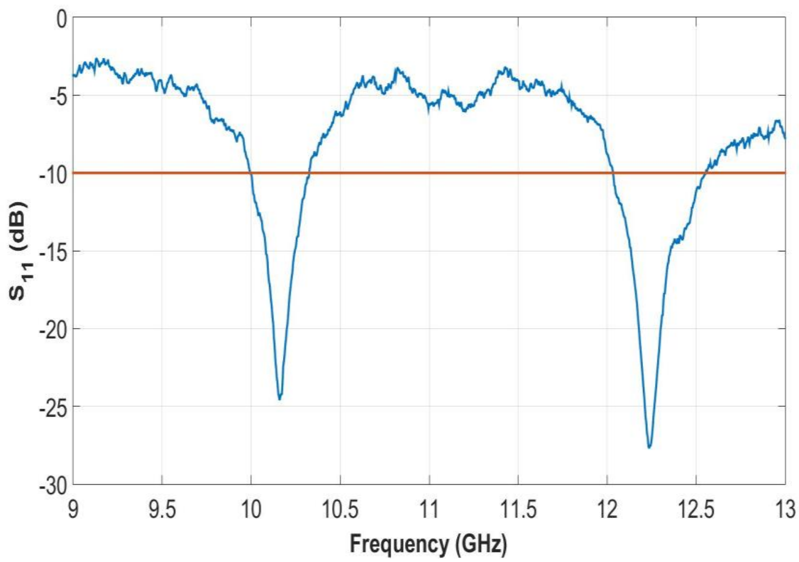

Figure 10. Return loss of phase array antenna with scan implemented

Conclusion

In this research, a four-element microstrip-type phased array of antennas was designed, simulated and implemented to achieve passive beam steering. This was achieved by varying the lengths of the transmission lines between the radiating elements, this design allowed electronically steer the main lobe at 30 degrees, without the need for active components or mechanical or manual movement. This study proved to be an efficient, low-cost solution, especially suitable for high-frequency communication systems.

Simulations showed that the best phase shift performance was obtained with a feed line length L1 of 3.257 mm, which provided an adequate radiation pattern and excellent impedance matching at 50 ohms, so that, at a frequency of 12.2 GHz, the array achieved a reflection coefficient of -30 dB, indicating minimal signal loss, while upon implementation this parameter varied insignificantly.

These results confirm the effectiveness of the phasing method using transmission lines in compact microstrip arrays.

It should be emphasized that during the design process important considerations arose, one of the challenges to overcome was beam distortion, known as scanning loss, so it was necessary to increase the steering angle due to the larger inter-element mismatches. In addition, the spacing between radiating patches was shown to be a critical factor since larger spacing generates unwanted secondary lobes. Although coaxial delay lines offer better manufacturing accuracy, they are not ideal for compact systems due to their short size. Overall, the proposed design achieved the stated goals and represents a solid foundation for future development and application studies.

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