PASSIVE PLANAR TRANSMIT-ARRAY MICROSTRIP LENS FOR MICROWAVE PURPOSE

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ABSTRACT: *A complete transmit-array lens device at 12 GHz, for microwave purpose, is offered in this manuscript. In this document, an overview of the functioning of this kind of devices is given and the proposed transmit-array lens is thoroughly studied, with architecture discussion and selection, as well as the design, manufacturing, and validation of all the constituting elements of the lens (radiating elements, transmission circuits, and transitions). Eventually, a complete prototype of transmit-array lens is assembled and radiation pattern measurements in anechoic chamber, as well as gain and directivity values, are offered.*

Key words: *constrained lens; transmit array; Ku band; microstrip circuit; patch antenna; antenna array; microstrip technology*

1. INTRODUCTION

In technical world, in the area of antennas and radiating systems, there is a growing interest for lens-type or reflector-type structures called transmit arrays and reflect arrays, respectively [1–14]. These structures replace and, in cases, improve the outcomes of traditional structures, such as reflectors or lenses, depending on the structure considered.

In this article, transmit-array lens structures are focused and a particular transmit array is defined, designed, prototyped, and measured.

The document is organized as follows: Section 2 describes slightly transmit-array theory. Section 3 offers the complete transmit-array lens device characterization and design. In Section 4, all the constituting elements are characterized, designed, and prototyped. Section 5 describes the assembly and measurements of the manufactured transmit-array prototype. Finally, in Section 6, conclusions are drawn.

2. TRANSMIT-ARRAY THEORY

The basics of this sort of structures are easy to be understood: an electromagnetic wave with specific wave front properties is received, processed in a particular way (change in the radiation pattern, amplification, etc.), and finally signal is retransmitted, and a new wave front is generated, as sketched in Figure 1.

Attending to literature, there are different transmit-array models. Quite relevant are the models proposed in [1, 2]. Some of these models are used in a multibeam working scheme: depending on the position of the feeder related to the lens, the main beam direction is going to be different. Regarding circuitry applied to deal with received signal, lenses are classified into active lenses (if external control signal is used for the inner circuitry configuration) [2, 3] or passive lenses on the contrary [4, 6]. In this document, the attention is focused in the design and manufacture of a complete passive microwave lens.

The main value in this device, despite the multibeam functionality, consists of placing it in front of a particular antenna to obtain two main advantages:

- Phase error correction due to spherical wave front coming from the feeding antenna.
- New radiation pattern configuration, modifying the phase response of each forming transmit-array cell.

Figure 2 highlights these two effects.

3. COMPLETE TRANSMIT-ARRAY LENS CHARACTERIZATION AND DESIGN

The transmit-array structure is divided into two principal devices: the radiating interface for reception and transmission and the processing interface, for array phase configuration in each transmit-array cell.

3.1. Transmit-Array Lens Specifications

The transmit-array design and prototype satisfy the next requirements, set as basic ones:

- Working frequency: 12 GHz.
- Band width: >1 GHz (8%).
- Matching levels: For all the constituting elements, a minimum matching level of −20 dB is applied.

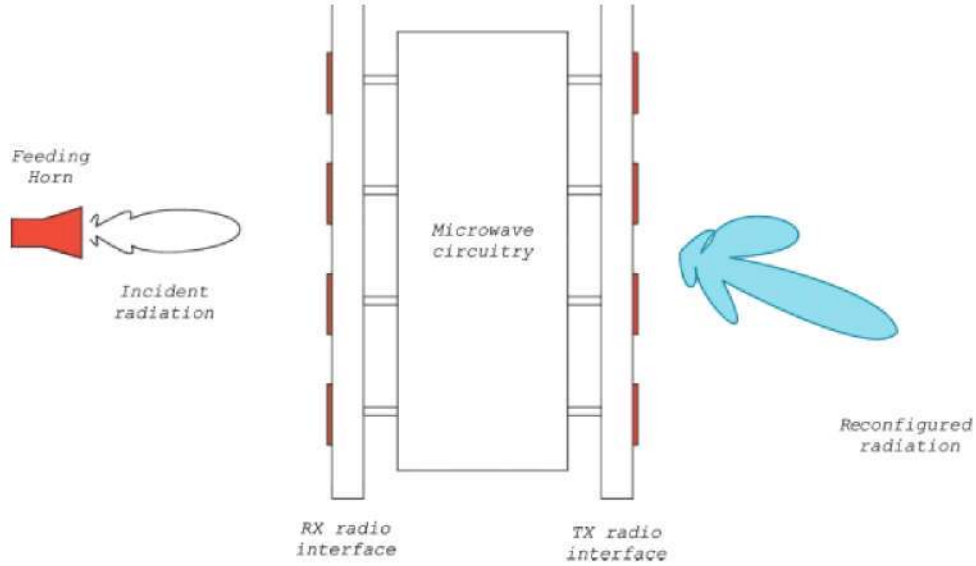


Figure 1 Scheme of transmit-array lens general functioning. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

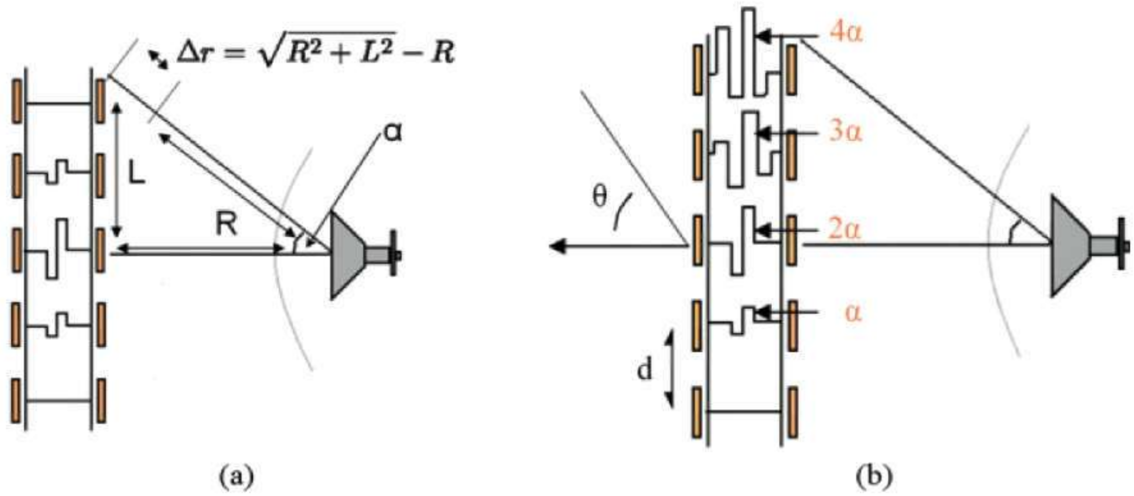


Figure 2 Transmit array main advantages. (a) Phase error correction and (b) radiation pattern reconfiguration. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

- Linear polarization.
- Stacked patches as radiating elements.
- Radiation pattern with $\theta = 10^\circ$ steering direction tilt, for one of the main axis, maintaining the steering direction for the other.
- Feeding antenna: corrugated horn at 12 GHz, linearly polarized.
- Number of transmit-array elements: 10×10 element array.
- Separation between neighbor elements (in terms of vacuum wavelength λ_0): 0.6 λ_0.
- Feeding horn position regarding the lens: 120 mm. This yields 75% of the radiation pattern, in terms of available power arising in the lens device.
- Ground plane to reflect not captured power.

3.2. Transmit-Array Geometry

Considering transmitarray structure with planar technology, the most troublesome task is to place the processing interface inside the structure, between both radiating interfaces, being feasible to locate and solder transmission circuits, because of the space available. Both interfaces (processing and radiating ones), which form the transmit array, are designed in planar architecture over

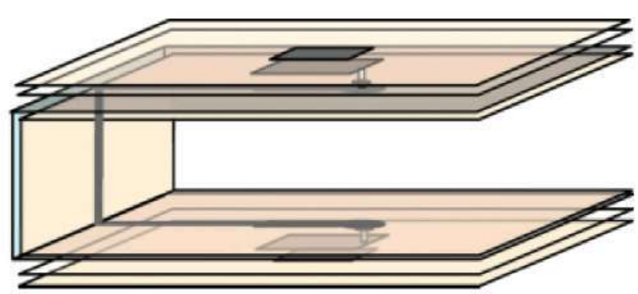


Figure 3 Scheme of the connection between processing interface and radiating one, with 90° change.in reference plane. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

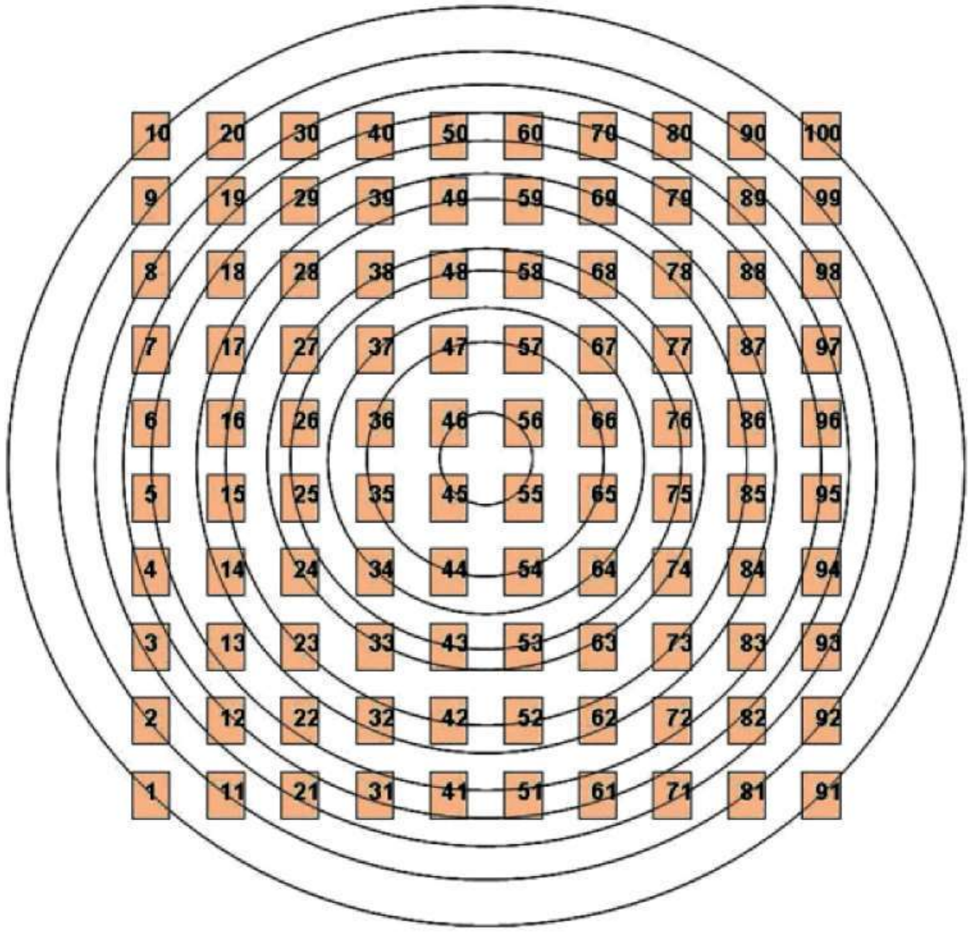


Figure 4 Ring distribution of the patch array for the definition of the transmit-array configuration. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

ground plane. However, if the connection point between them is discharged of this restriction (planar connection), being possible to introduce 90° change in the reference plane for each interface by means of perpendicular connection, the space constraint in one of the dimensions is widely reduced, being possible to apply microstrip lines for the processing interface. Figure 3 exhibits this fact, with the perpendicular connection election between planar interfaces.

In the defined architecture for the complete structure, all the complexity of connecting the stacked patch array structures for transmission and for reception by means of microstrip lines is condensed in the connection point. Figure 3 reveals the necessity of designing a transition between coaxial-type patch connection and microstrip transmission lines, as well as the necessity of designing a 90° transition with reference plane change in the microstrip line.

4. DESIGN, SIMULATION, AND PROTOTYPING OF FORMING TRANSMIT-ARRAY ELEMENTS

4.1. Complete Transmit-Array Phase Configuration

To satisfy the radiation pattern requirements, the patch structure is classified depending on the distance of each patch to the feeding horn (concentric rings), as depicted in Figure 4. Therefore, phase error correction together with new phase configuration for pattern modification can be introduced, in terms of lengths in transmission lines in the processing interface.

4.2. Radiating Element

For the radiating elements, there are no particular constraints as patches are selected, due to their planar structure, specially suitable for transmit-array lens devices, in regard to the selected geometry. To increase certain features, multilayer stacked patch elements over ground plane are applied rather than simple patch ones because of their wider working frequency band. Concerning the design stage, CST Microwave Studio is applied. Figure 5 depicts the layer distribution and materials used.

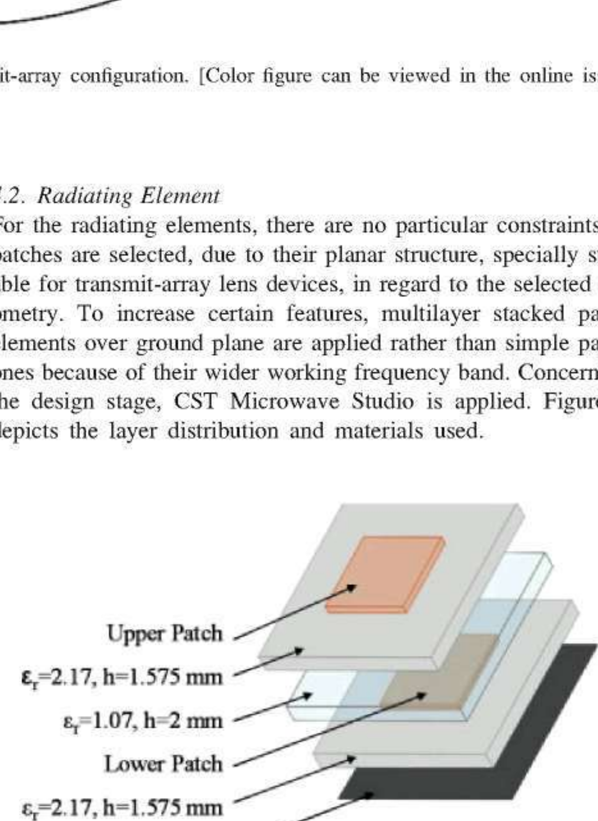


Figure 5 Model for patch design, in layer scheme. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

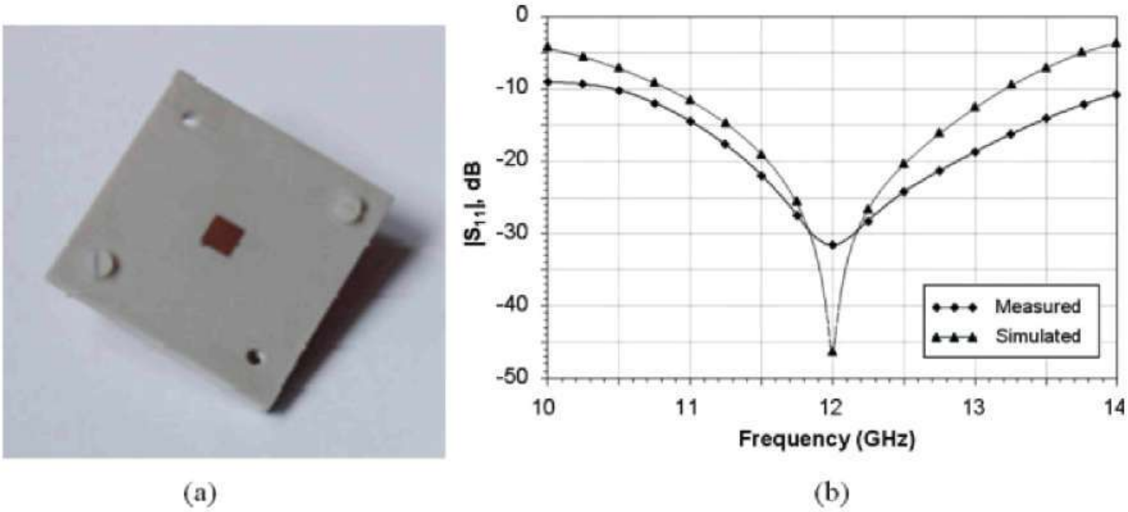


Figure 6 Stacked patch cell. (a) Prototype and (b) simulated and measured results. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

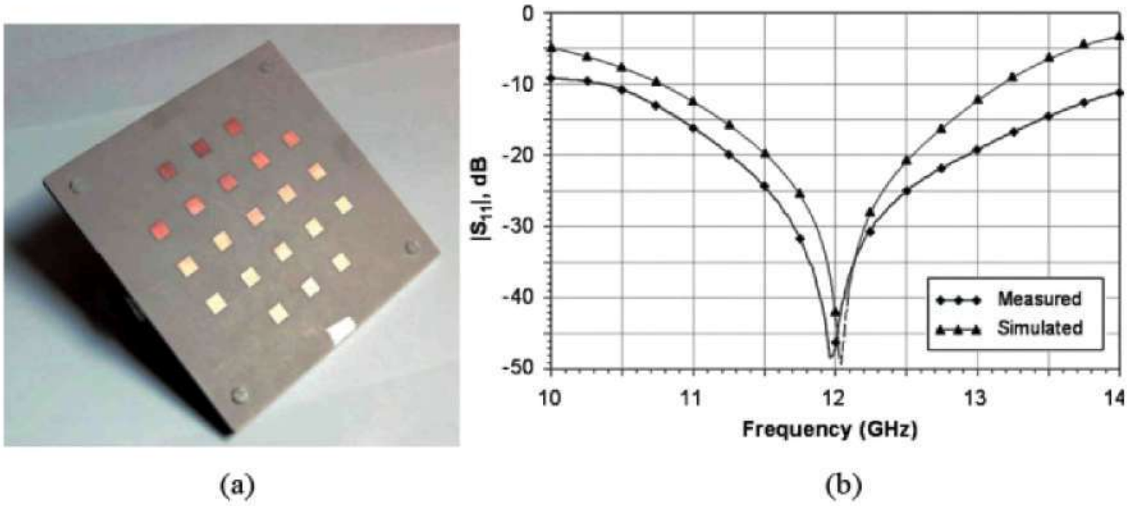


Figure 7 Stacked patch cell embedded in array. (a) Prototype and (b) simulated and measured results. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

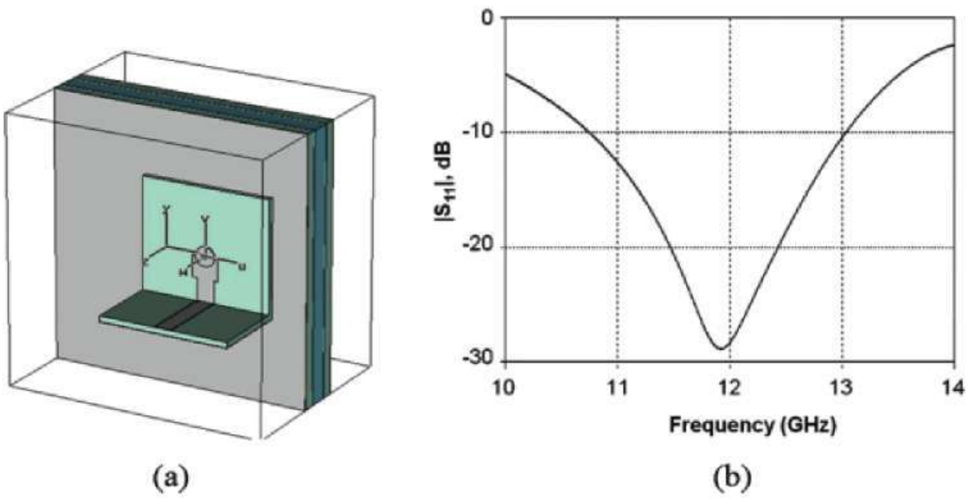


Figure 8 Coaxial to microstrip and 90° transition for simulation. (a) Simulation model and (b) |S11|. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

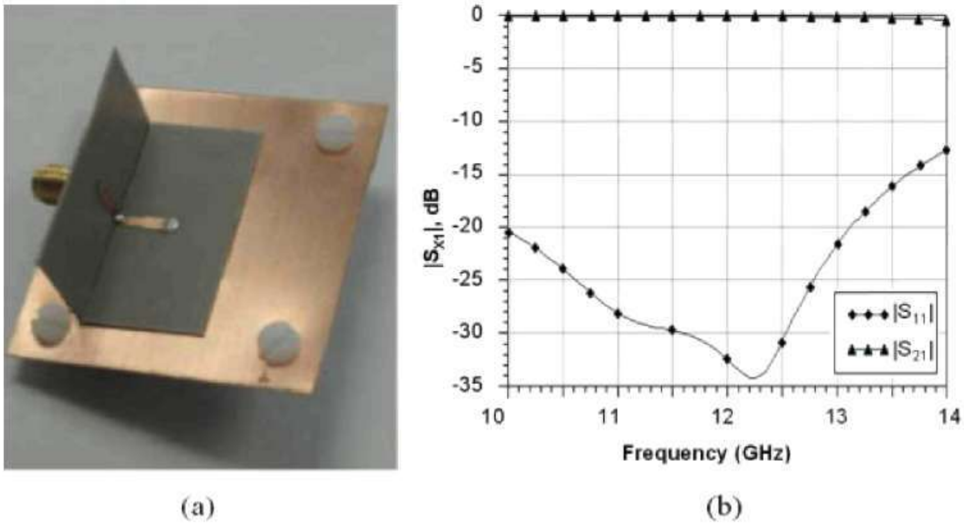


Figure 9 90° transition prototype. (a) Prototype and (b) |SX1|. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

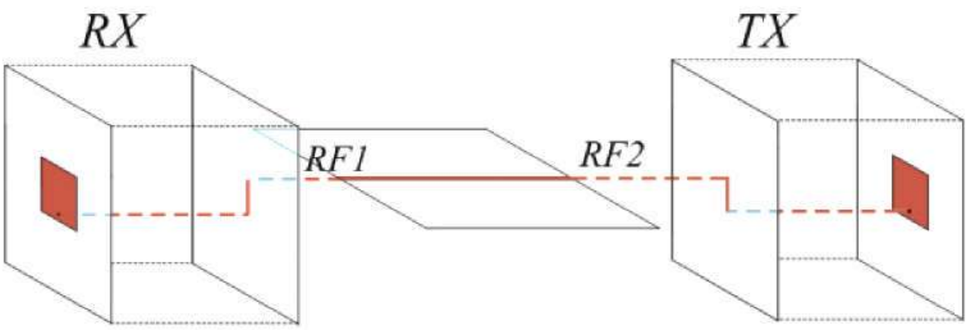


Figure 10 Assembly model for transmit-array cell. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

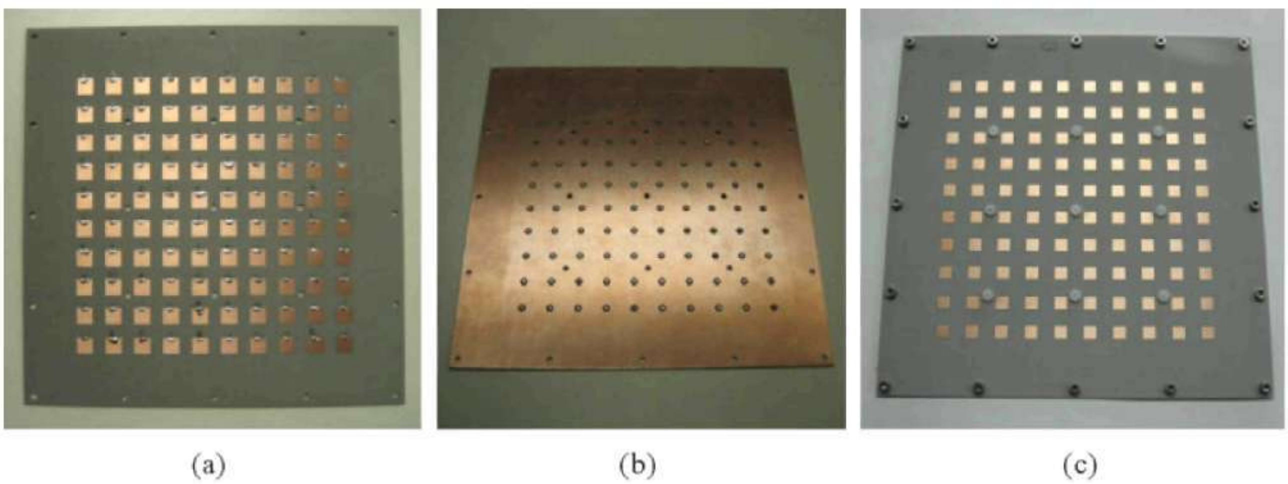
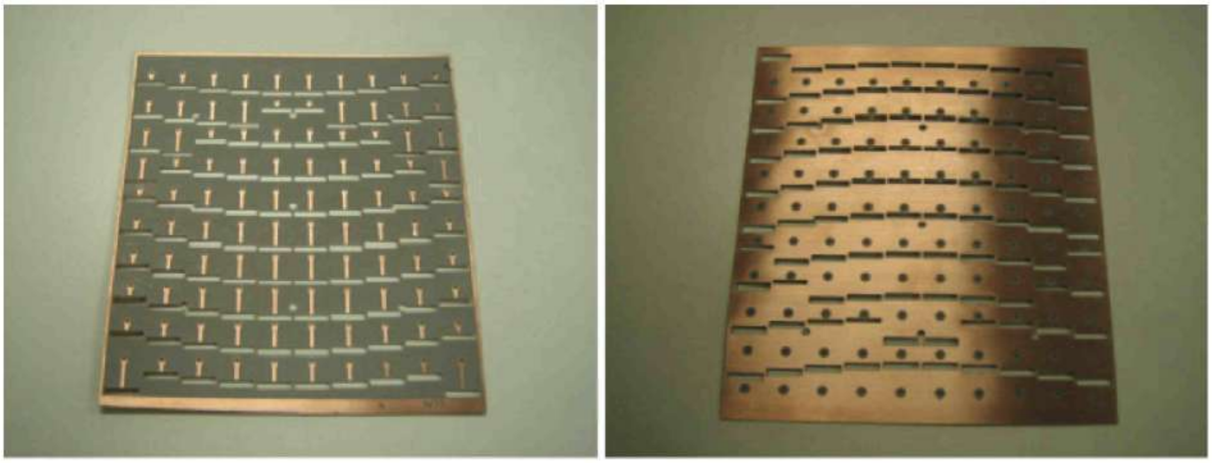


Figure 11 Transmit array radiating interface. (a) Lower array layer, (b) lower layer connection detail, and (c) upper layer. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

In the designing process either one unique stacked patch or stacked patch embedded in array is considered, the last one to include mutual coupling effects with surrounding patches. Figures 6 and 7 show prototypes, design results, and prototype results for a single stacked patch cell and for stacked patch cell embedded in array, respectively.

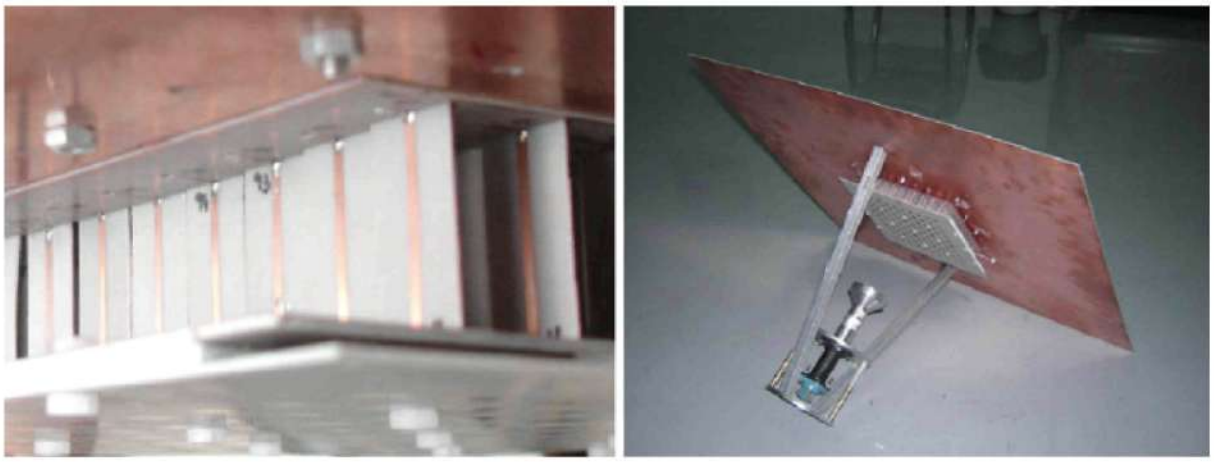
4.3. Coaxial to Microstrip Transition and 90° Transition

The transition with reference plane change and the one for microstrip to coaxial lines are characterized and designed. Figure 8 shows design results for these transitions. Figure 9 shows the prototype and results for the transitions.



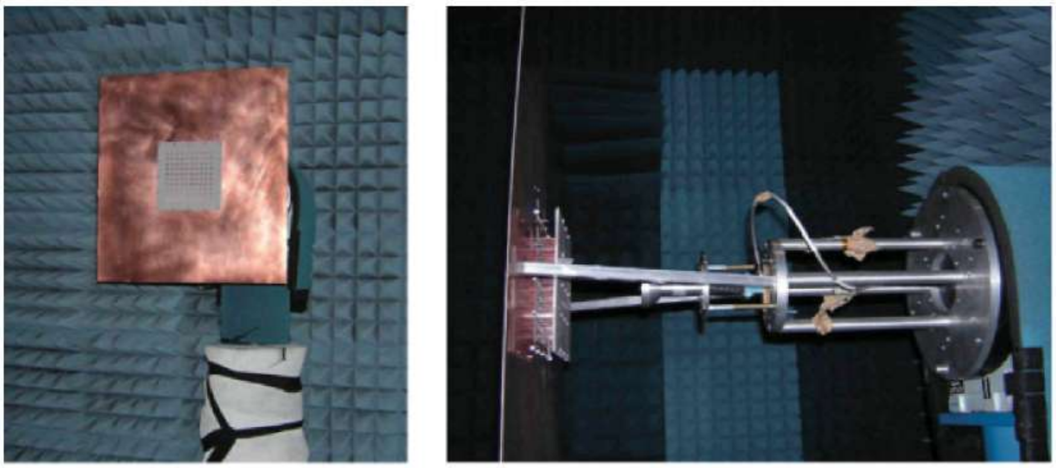
(a) (b)

Figure 12 Transmit array processing interface. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]



(a) (b)

Figure 13 Complete assembly (a) Detail and (b) complete transmit array. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]



(a) (b)

Figure 14 Transmit array in anechoic chamber, different views. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

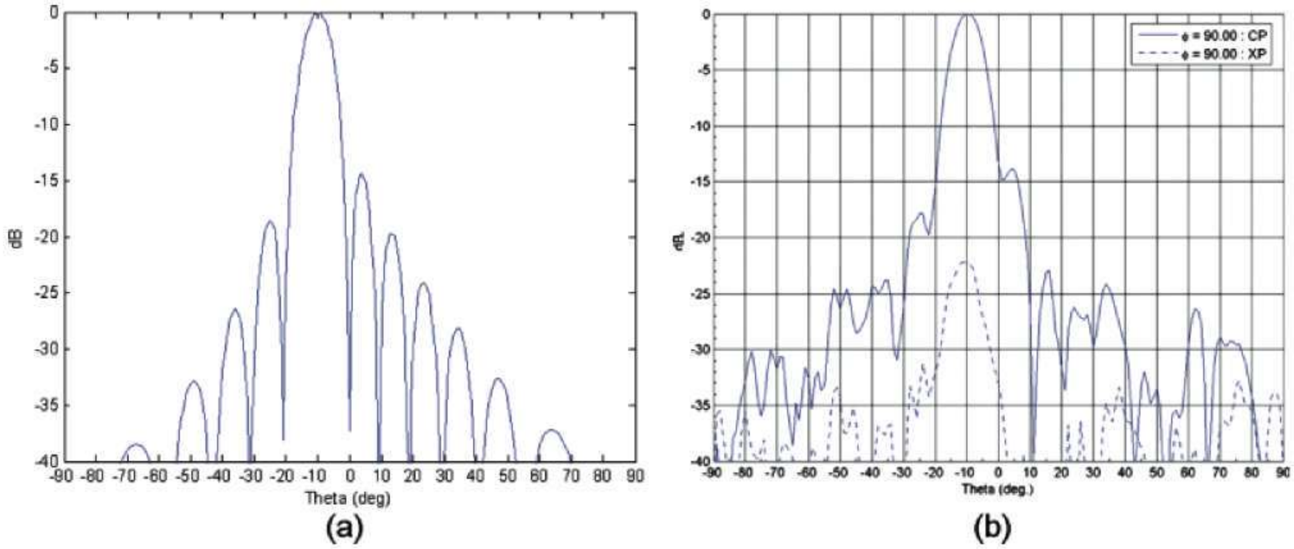


Figure 15 Transmit array measurements. (a) Theoretical radiation pattern and (b) measurement results for the axis with modified tilt. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

5. COMPLETE TRANSMIT-ARRAY LENS ASSEMBLY AND MEASUREMENT RESULTS

Globally, the assembly to be performed, for each transmit-array cell, includes the transition device between the coaxial-type feeding at each patch and the microstrip lines, and the transition device with 90° change in reference plane, as it is offered in Figure 10.

Details of the assembly process are depicted in Figures 11–13. Figure 14 shows the transmit array mounted in anechoic chamber for measurement acquisition.

For validation, the prototype is measured in anechoic chamber. Measurement results for the prototype are offered in Figures 15 and 16, together with theoretical results.

With these results, it is convenient to analyze measured gain results and expected directivity values. Measurements yield 23.8 dBi in directivity and provide 22.5 dBi mean value in gain, for the working frequency. The reduction is due to the accepted horn power (considered that not all the power available in the lens is accepted), and processing interface insertion losses, as expected.

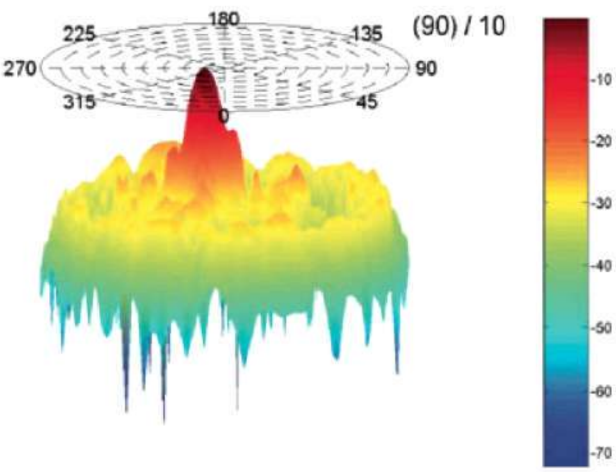


Figure 16 Transmit-array 3D lens radiation pattern. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

6. CONCLUSIONS

In this work, a complete transmit-array device has been presented. Some theoretical background and architecture considerations are offered and adequate architecture is chosen, adapted to admit the integration of the processing interface inside the complete lens design. A complete transmit array is designed, manufactured, assembled, and measured in anechoic chamber. Deep design and manufacture considerations have been mentioned, and a hundred element array device is manufactured. Once the first prototype is assembled, measurements in anechoic chamber are obtained to achieve the proper behavior of the transmit-array lens prototype. Main antenna features (gain and directivity) are extracted.

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