AN X-BAND PLANAR TRANSMIT-ARRAY

Mariano Barba, Eduardo Carrasco, Jose A. Encinar
Universidad Politécnica de Madrid
ETSI Telecomunicación
Ciudad Universitaria, s/n, 28040-Madrid (Spain)
Email: mbarba@etc.upm.es, carrasco@etc.upm.es, encinar@etc.upm.es

INTRODUCTION

Planar arrays are a very interesting option to substitute reflector antennas because of their well-known characteristics of low profile, potential low cost, reliability and flexibility in achieving contoured beams and multiple beams with a simple planar geometry. Suitable solutions using planar antennas for space applications have been proposed using reflect-arrays with countered beams and multibeam.

Another proposed solution consists of transmit arrays. In this case, the antenna acts as a lens [1]. This consists of a periodic planar array having two patch antennas connected by a line. One element receives the signal from –z direction and the other transmits the signal in the +z direction. By a proper selection of the phase delay in the connection line, the phase distribution in the transmitting array can be adjusted. In an equal output phase configuration the transmitting array behaviour would be similar to the obtained with a parabolic reflector, having the advantage of removing the feed blockage.

Moreover, lenses are less sensitivity to thermo-elastic distortions than reflectors because the phase-shift introduced in each element is not affected by distortions of the surface. In addition, transmit array entails less volume and mass than conventional lenses. However the design of the proper and suitable radiating elements to obtain a transmit array is not trivial because many difficulties appear due to the fact of the radiating configuration in the positive and negative directions. In the literature several configurations have been proposed. One of them is based in two slot coupled-patches [2], however, when the authors try to design a transmit-array using this configuration in the X-band, no suitable solutions were found because the generation of modes in the parallel plate waveguide that results due to the presence of the two ground planes of the patches. This problem was overcome by designing suitable transmit array configurations having just one ground plane, as proposed in [3].

This paper briefly recalls the transmit-array configuration proposed in [3] and presents the design, manufactured and test of a transmit-array in the band from 9.5 GHz to 9.8 GHz for a typical X-Band SAR application. The measured radiation patterns are in close agreement with the expected patterns.

ANTENNA ELEMENTS

As it has been stated in the introduction, a detailed description of the elements can be found in [3], however some of their main features are discussed here, since their geometry is essential to define the antenna architecture.

Two elements are necessary, one acts as receiving element of one cell and the other acts as transmitting element of the same cell, being both of them connected by a microstrip line. To avoid the parallel plane effect in the transmit array, the target was to develop a structure with just one ground plane, therefore a directly fed patch is necessary, where the input microstrip line is connected to the radiating patch, having both line and patch the same ground plane. Directly fed patches are very narrow-band structures, therefore to obtain the desired bandwidth with a high matching level and to keep low the undesired radiation of the microstrip, a two-stacked patch structure is required. Due to manufacturing considerations, this second patch is printed on a substrate and this substrate is placed over the lower patch using spacers, having an air layer in between them. This air layer makes that the input line, which is connected to the lower patch, behaves as a microstrip from impedance and propagation features. Figure 1 shows the resulting geometry for this patch, where the radiation direction of element is +z.

A second radiating element was developed. This is a patch antenna aperture-coupled to the line that directly feeds the patch previously described. This element consists also in two stacked patches in order to have at the same time high bandwidth and low back radiation. Fig. 2 shows the geometry of this patch. In this figure, the radiation direction is –z.

These elements were simulated and verified by prototypes, some of these measurement are also presented in [3]. Their main features, especially those needed for the array design, are listed in table 1.

To obtain the proper delay in the transmit array, delay lines are required to connect the radiating and transmitting elements. Microstrip bends were designed for this geometry. Also a microstrip via was been designed, which would produce an alternate antenna configuration, which is not included here. These designs are not included here because the space constraints.

By using the direct fed patch, let us say, as transmitting element and the slot coupled patch as receiving element, the transmit-array cell configuration is obtained. The output line of one element is used as the input line of the other element, having the required length to obtain the desired phase shift. This cell is shown in figure 3 and is similar to the one presented in [4].

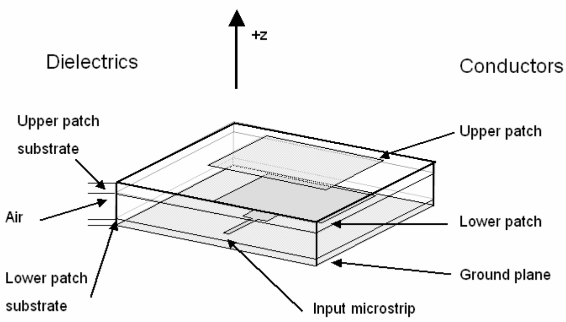

Figure 1. Directly fed patch

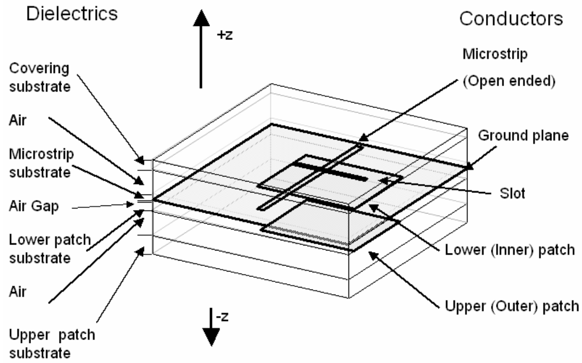

Figure 2. Slot coupled patch.

Table 1. Main features of the elements

	Direct patch	Slot coupled
Return losses	< -22 dB In band	< -24 dB In band
Directivity	8.35 dBi	7.43 dBi
3 dB Bandwidth	74 º (φi=0º); 82º (φ=90º)	78 º(φ=0º); 106º (φ=90)
Gain	7.83 dBi	6.69 dBi
All losses (including surface wave)	0.52 dB	0.74 dB

TRANSMIT ARRAY DESIGN ANTENNA DESIGN

Feed system.

In order to have a fast antenna development and because the proper horns were not available, a 4-element circular-patch array was designed. The pattern of this antenna was suitable for the current development, with a very symmetric pattern, 13.8 dBi of directivity and 10 dB beamwidth of 60º and 58º for the main beam in E-plane and H-plane. However it has very high levels of radiation out of 10 dB beamwidth region, which as it will be seen, produces high "spill-over", meaning by spillover the energy not received in the transmit-array. The losses are 1.5 dB. A photo of the fed antenna located in the whole transmit array structure can be seen in figure 4.

Arrays.

As first approach, a circular transmit array was designed. Figure 5 shows the drawings of this antenna, it has 16 elements in the diameter, resulting in a total of 208 elements in both arrays, receiving and transmitting, with a cell size of 25 mm, 0.8 λ. It was designed for a centred fed in the receiving array and for a radiating pencil beam pattern. Therefore the design objective is to focus the beam. The phase shift of the phase-correction lines was set to 10º steps, and the phase shift was kept in one turn (360º), having the maximum shifting in the elements of the centre of the arrays. The fed antenna was located at distance of 330 mm from the receiving array, giving an apparent F/D=0.875 (where the D considered is the outer of the cell of the outer elements, D=403 mm, however the complete antenna is greater to allow the antenna fixing as it will be seen later. Considering the fed antenna and the radiation pattern of the receiving elements, the power received by the antenna (and, therefore, reradiated as desired in the design is 0.466 times (46.6%) of the transmitted power by the feed. Because the transmit array concept, the energy that is not “captured” is radiated randomly by the antenna, produces a “noise” in the pattern, and results in an increase of the isotropic level (reduction of directivity), compared to the one that it would be obtained by an array having the same amplitude and phase distribution that the presented in the transmitting array. Considering this and the transmitting element features, the expected radiation pattern has a beam width 5.2º with a directivity of 28 dBi. It has to be note that a 32% of the power is radiated out of the surface (spillover) of the receiving antenna by the feed system, so improving it, the received power could be increased, as well as the directivity, in about 2 or 3 dB according to computations.

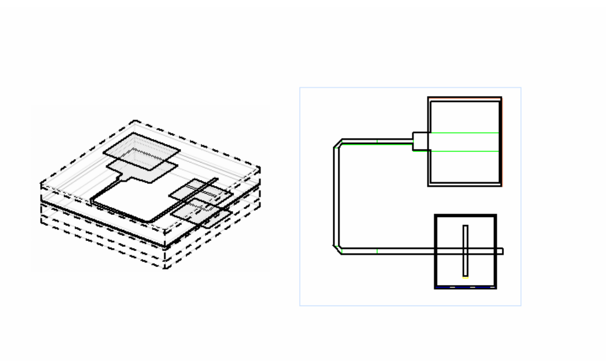

Figure 3. Transmit array cell using a directly fed patch and a slot coupled patch.

Figure 4. Fed antenna details

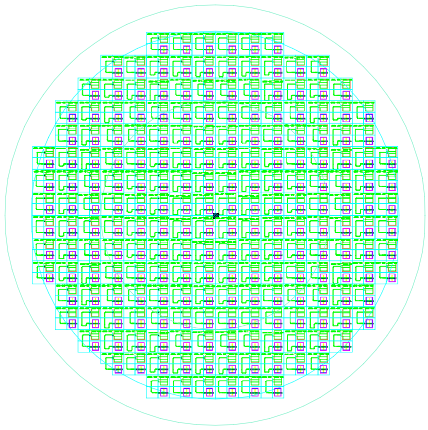

Figure 5. Transmit array drawings.

RESULTS

The X band transmit array was manufactured and measured. Figures 6 and 7 show the back side (receiving array) and front side (transmitting array), respectively. Figure 8 shows the measured radiation pattern (gain) for E and H planes. This figure also shows the simulated pattern of the transmitting array. The computed isotropic level and maximum value of the expected ripple are depicted as well. It can be seen that the radiation pattern is as expected, with a beam width of 5.2º and a ripple of typically 22 dB below the maximum of radiation. Figure 9 shows and expanded view of these cuts and the crosspolar measurements of the E and H planes. It can be seen that the crosspolar level is at least 25 dB below the maximum.

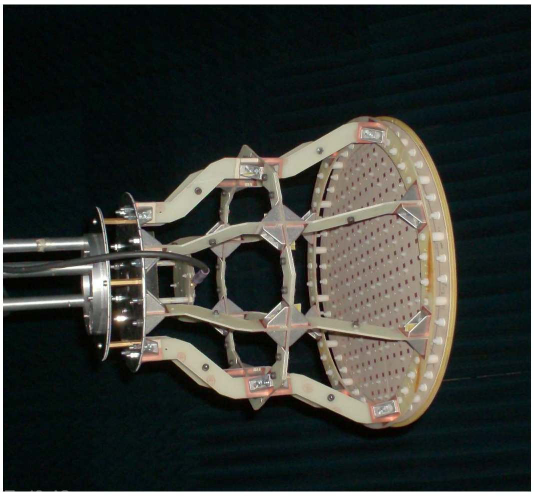

Figure 8. Manufactured transmit array. Back view.

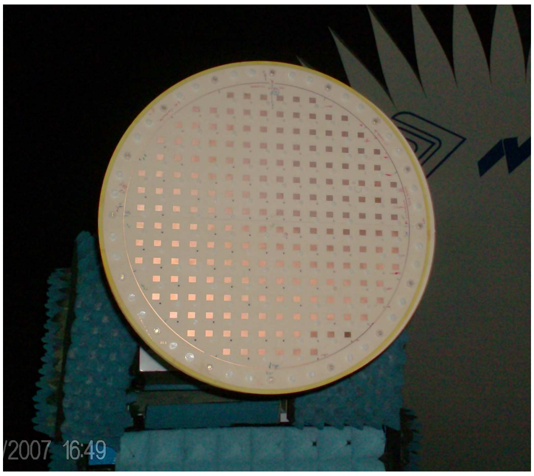

Figure 7. Manufactured transmit array. Front view.

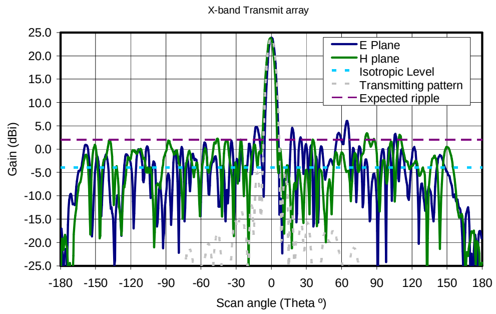

Figure 8. Measured radiation pattern. (Copolar, E and H planes) and expected figures.

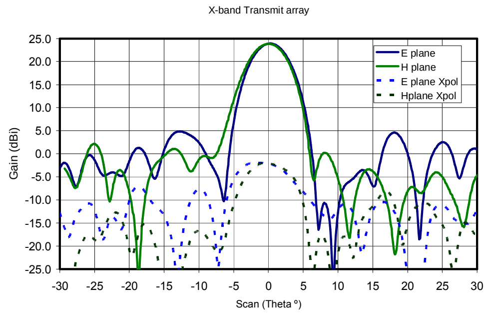

Figure 9. Measured radiation pattern. (Copolar and Crosspolar, E and H planes) and expected figures.

Considering the computed directivity, the antenna has overall losses of 4 dB, where 1.5 dB comes from the feed, 1.5 dB from the elements and their connection lines. However 1 dB is still to be identified, it can be originated by gain measurement uncertainty and by the fact that the phase centre of the fed antenna is not well defined. The phase centre of the E plane is 25 mm separated from the position of the phase centre in the H plane, according to measurements. The origin of this small discrepancy will be investigated by using a new feed antenna to improve the antenna directivity by reducing the "noise" level by and a three-dimensional measurement of the radiation pattern to have an accurate evaluation of the directivity. Nevertheless, the results obtained are considered fairly good and demonstrates the viability of the proposed transmit-array configuration.

CONCLUSIONS

A limited size demonstrator of an X-band transmit array for SAR applications (9.6 GHz) has been designed, manufactured and measured. The obtained results are in close agreement with the expected patterns, and demonstrate the viability of this type of antennas, having the advantages of both planar antennas and lenses antennas, with better mechanical performances for space applications than classical lenses or reflector antennas.

Moreover the fact of having transmission lines connecting the transmitting and receiving elements offers the possibility of adding circuitry in order to electronically reconfigure the beam, as is being considering by authors for reflectarray antennas.

ACKNOWLEDGEMENT

This work was supported in part by the European Space Agency (ESA) under the project ESTEC/16919/02/NL/JA, by the Spanish Ministry of Science and Technology under the project MEC TEC 2004-02155 and by the Mexican National Council of Science and Technology (CONACYT).

REFERENCES

1. C.J. Sletten (Editor), "*Reflector and Lens Antennas*", Inc. Chap. 6. D. MacGrath, "Constrained Lenses", Artech House, Inc., Norwood, M.A., 1988.

2. D.M. Pozar, "Flat lens antenna concept using coupled microstrip patches", *Electronics Letters*, 7th November, 1996. Vol. 32, No. 23, pp. 2109-2110.

3. M. Barba, E. Carrasco, J.A. Encinar, "Suitable planar transmit-arrays in X-band", European Conference on Antennas and Propagation (EuCAP 2006), 6Th-10th November, 2006, Niza, France

4. M.E. Bialkowski, H.J. Song, "A KU-Band Active Transmit-Array Module with a Horn or Patch Array as Signal Launching/Receiving Device", IEEE. Trans. on Antennas and Propagation, Vol. 49, No. 4, April 2001, pp.535-541.