MINIATURISATION OF CONVENTIONAL RADIO-LINK REFLECTOR ANTENNAS BY USING OF ACTIVE ARRAYS

J. Segador-Álvarez(1), L. Fernández-Martínez(1), L. de Inclán(1), V. González Posadas(2), D. Segovia-Vargas(1)

(1)Universidad Carlos III de Madrid, Avda. Universidad 30, 28911 Leganés, Madrid
juan.segador@alumnos.uc3m.es; dani@tsc.uc3m.es;
(2)Universidad Politécnica de Madrid, vgonzalz@diac.upm.es;

ABSTRACT

Using of active array antennas has been shown as a suitable technique to improve the figure of merit (G/T) of a radio-link, increase the effective gain or make a better distribution of the power what can reduce the number of amplifiers used in the feeding network [1]-[2]. As one of the characteristics of active antennas is that it can improve the effective gain, a trade-off between the increase of effective gain and the reduction of antenna size can be done. The effect of including active elements to increase the effective gain while maintaining the radio-link gain implies a reduction in the antenna size. The paper presents the reduction that can be achieved in the antenna size by using of an active array. A study of the level of active element integration (patch level or subarray level) has been done to obtain the optimum situation between the size reduction factor and the power associated to any of the amplifiers in the active array.

1. INTRODUCTION

The objective of this paper is to reduce the size of a conventional radio-link antenna while maintaining its radio electrical performances. The proposed line of sight reflector is a circular polarised antenna working at a frequency of 3.5 GHz in a receiving way, with a gain of 23 dBi, a size of 24.5 λ^2 and a radiation efficiency of 0.65.

The replacement of the parabolic reflector has been done by an active array. Using of active systems has allowed us to achieve very interesting properties: improve the figure of merit (G/T), increase the effective gain and optimal distribution of the power inside the feeding network [1]-[2].

With these characteristics it is possible to achieve other improvements if we analyze the service where the antenna is used. The total gain of the active array can be approached by the sum of the passive array gain plus the amplifier gain (active device inside the feeding network). If we impose that the active array gain is the same as the parabolic, it can be deduced that the necessary gain for the passive array in the active array system is less than the reflector gain. Then, a reduction in the necessary system gain directly implies a reduction in the size of the active array. This method of work implies an increasing in the antenna beamwidth. However, by taking into account the ITUR recommendation [3], this is not critical.

The active array will consist of a modular design of several square subarrays. Each subarray is composed of 2x2 patches. Therefore, the design process can be summarised as follows: the first step must be the subarray design, and then estimating the number of modules (subarrays) to achieve the proposed objectives. The steps concerning the subarray design are: choice of the elementary radiator, design of the radiating face and active feeding network design (integration of passive feeding network and amplifier). Finally, the optimal position of the amplifiers inside the feeding network will be chosen according to the value of its figure of merit; three possible situations have been studied: subarray level integration (only one amplifier for the four radiators), intermediate level integration (one amplifier for two radiators) and radiator level integration (one amplifier for each radiator).

2. CHOICE OF THE RADIATOR

Our first task is to design a primary radiator that works in circular polarisation at 3.5 GHz. The radiator chosen is a circular patch, because of its simple and well-known geometry. Using this structure is easy to obtain circular polarisation and a symmetric radiation pattern [5].

To obtain circular polarization using patches we have to excite two independent orthogonal modes. This situation can be achieved in two different ways: excite the principal orthogonal modes and apply the necessary delay between the inputs or introducing perturbations in the patch geometry to excite and delay the orthogonal principal modes with only one input to the radiator. For the first method (two inputs) it is necessary to have an external circuit (usually branch-line) that provides the adequate power distribution.

The other technique consists of exciting simultaneously the two orthogonal degenerated modes into the patch cavity. In a patch without perturbations, the degenerated mode is not delayed, so this delay has to be generated by introducing a perturbation in the patch geometry that adds asymmetry in the radiator. The advantages of this kind of antennas are obvious: reduction of cost and complexity since external circuits are removed. Besides, as there is only one input, it is suitable for its integration in active antennas. However, an antenna working on circular polarization with only one input is sensible to manufacturing errors and has a smaller bandwidth.

Proc. 'EuCAP 2006', Nice, France
6–10 November 2006 (ESA SP-626, October 2006)

The proposed patch with perturbations can have any of the shapes shown in figure 1. The thickness of the patch varies from 2mm to 5 mm and its permittivity is 2.3. The feeding method is the coaxial because has good properties and is a well-known technology. With the 5 mm substrate asymmetries in the radiation pattern starts to appear. However, the degradation seen is not critical and the thickness increasing allows improving the radiation efficiency and bandwidth. The dimensions of the patch are modified when we increase the substrate thickness (the patch radius decrease and the perturbation size increase). Besides, the increase in the thickness of the patch provides an improvement in the bandwidth of the axial ratio. For all these reasons, the choice in the substrate thickness is 5 mm. The results obtained for the two methods are good, so we finally decide to build and measure two antennas: one based on the two inputs method and one based on the perturbation method (antenna with slot).

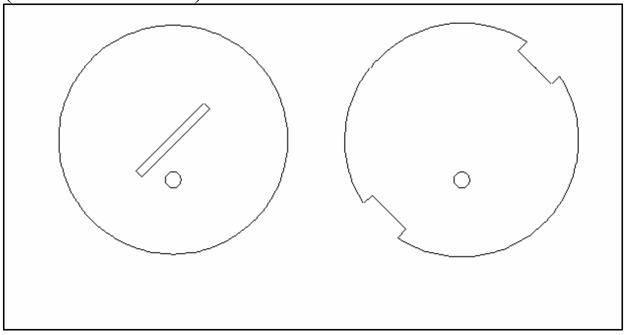

Figure 1: Perturbation based radiators

Table I shows the measurements of the manufactured radiators.

Antenna	Matching	Gain	Axial Ratio
Two Inputs	28 dB	3.5 dB	2 dB
Slot	10 dB	4 dB	1 dB

Table 1. Primary radiators measurements.

Since one of the critical parameters is the obtained axial ratio, a graph of the variation of this parameter vs. the frequency for the slot antenna is shown in figure 2.

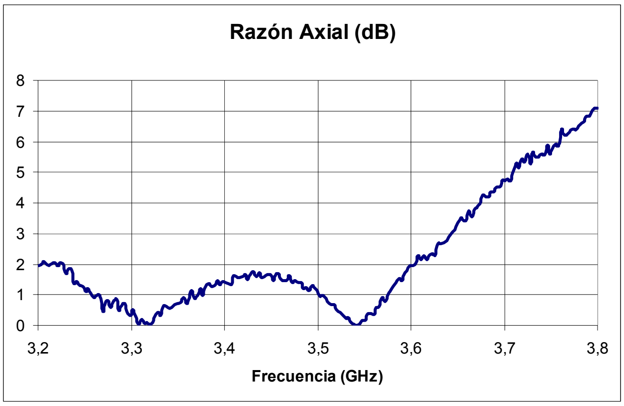

Figure 2: Axial ratio of the slot antenna

The slot antenna has not a very good matching in a broad bandwidth but as this is a narrow bandwidth application this is not a critical problem. However, the gain and axial ratio performances are better than for the two inputs antenna. Besides, we have to keep in mind the reduction in the fabrication allowed by the use of a perturbation based radiator. The two inputs antenna has a good matching, but the gain and axial ratio are worse than the slot antenna one. Finally we decide to assign the slot antenna as the primary radiator.

3. SUBARRAY RADIATING FACE

The array surface is equivalent to an aperture antenna with a discrete illumination law. Now it is necessary to introduce the concept of the optimal sample of the array surface, which has relation with the surface efficiency. The array surface efficiency is a concept that implies if the entire array surface with the effective surface can be covered without holes and overlapping. Three situations are studied: optimal sample (the entire surface is covered), subsample (the array surface presents holes) and oversample (the effective surfaces of radiators are in contact). Obviously, the design objective must be optimal sample because with this situation the superficial efficiency is maximized.

To obtain the design objective it is necessary to calculate the effective surface of the primary radiator and set the patches in the adequate way. We know the patch gain and its efficiency, so it is possible to obtain the radiator surface. The obtained value is $0.24\lambda^2$. We have a circular patch working on circular polarisation, so the radiation pattern has azimuthally symmetry. This property implies that the beamwidth of the E and H planes are the same, so the effective surface of the radiator has square geometry. With the area and the geometry we can obtain its dimensions that are detailed in figure 3.

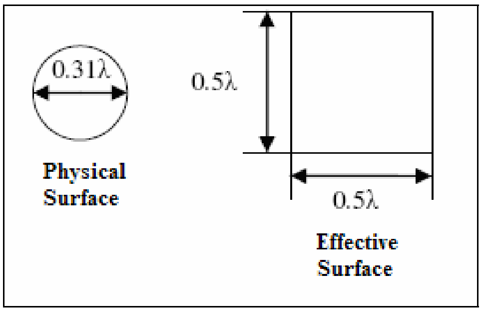

Figure 3: Physical and effective surface of the radiator.

The obvious solution for achieve optimal sample is to set the radiator at a vertical and horizontal distance of 0.5λ. With this setting the estimated gain of the subarray is 10 dB. To complete this section figure 4 shows the layout of the radiating face.

4. ACTIVE FEEDING NETWORK

The next step is the design of the active feeding network. For the design three steps have been followed: low noise amplifier design, passive feeding network and study of the different possibilities for active element integration.

Firstly, we realize the design of the amplifier. It can initially be assumed that the input and output impedances are 50 Ω and that matching networks are used at the input and output ports. The proposed amplifier is a general purpose FET transistor from Avagotech (ATF-34143) The performance of the amplifier in the simulation process can be summarised as follows: gain 12 dB, noise factor 0.58 dB and matching 20 dB at input and output. Maybe we have to modify this design because the impedance depends on the antenna feeding point. However, this design will be a good reference for the rest of the study.

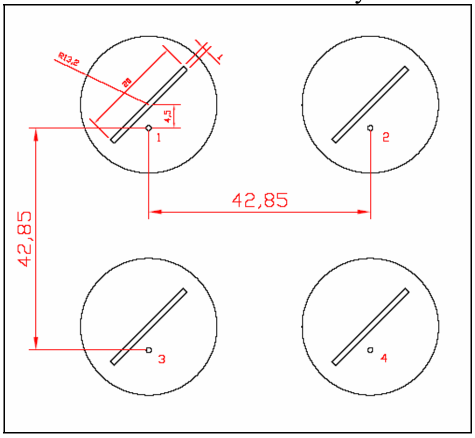

Figure 4. Subarray radiating face

For the feeding network care must be taken with the following fact: the distance between the feeding points and the network must be matched from all inputs and from the output. The layout of the designed network is shown in Fig. 5.

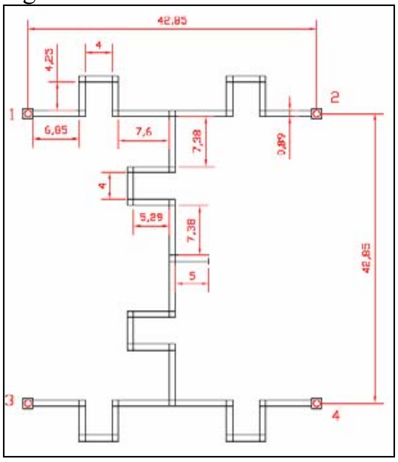

Figure 5: Subarray feeding network

The proposed feeding network is well matched from all inputs and output. The simulated (AWR@) network looses are shown in figure 6. As the division factor is 6 dB it can be concluded that the simulated losses are 0.2 dB at the working frequency.

With the design of the amplifier and feeding network, a study on the different integration levels can be done. There are three options: subarray level integration, intermediate level integration and radiator level integration. Theoretically, when the integration level is displaced from the subarray level to the amplifier level, the noise introduced by the feeding lines is less and an an improvement in the G/T can be achieved. For the first case, the amplifier is placed at the output of the feeding network, so the preliminary design is suitable for this setting. For the second one, the amplifier is placed in a point with impedance of 25 Ω so a modification in the input and output matching networks have to be done.

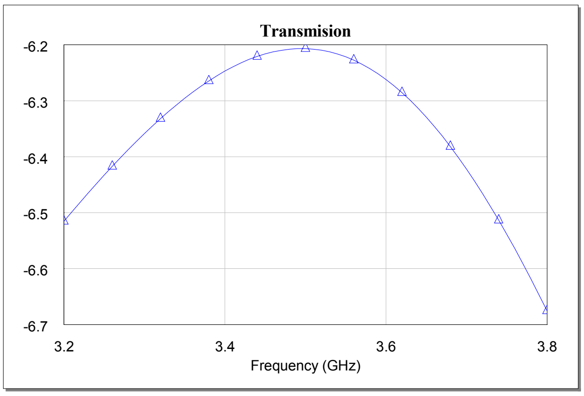

Figure 5: Feeding network looses

In the third case, the input matching network must be removed and the transistor is directly loaded with the radiator impedance. This impedance is far from the FET optimal noise impedance, so the noise figure increases. With lineal polarisation the radiator feeding point can be changed to search the optimal noise situation, but the circular polarisation fix a feeding point to keep a good axial ratio. Then a trade-off between the minimum impedance noise and the impedance to achieve a good axial ratio must be kept. For that reason a line has been inserted between the patch and the amplifier what moves the radiator impedance from the original point to other that offers an acceptable value of the noise factor. This situation limits the G/T improvement to the losses that are avoided by setting the transistor as near as possible to the radiating element. This implies a net improvement of 0.2 dB by setting the amplifier at any of the corresponding levels: array, subarray or radiating elements. However, the measured improvement is low due to two reasons:

- The network looses obtained in the simulation are very low.
- The circular polarisation imposes a feeding point and we can't optimize the noise factor.

Due to the circular polarisation that fix an impedance at the FET input it can be concluded that for circular polarisation the best integration level is the subarray level.

5. ARRAY DESIGN

From the criteria established at the first section, the number of subarray modules to substitute the reflector is

4, so the array will be composed of a 2x2 subarrays. This size implies a size reduction factor of 6 in comparison with the reflector size. All the estimated parameters are showed in Tab. 2

	Size	Beamwidth (º)	G/T (dB/K)
Reflector	24.5 λ^2	11.6	-18.30
Array	4 λ^2	28.7	-10.05

Table 2. Array and reflector performances

With the same equivalent gain, a size reduction factor of 6 factor has been obtained and an improvement in the figure of merit (G/T) of 8 dB. However, the beamwidth increases in a 2.5 factor. The ITU recommendations [3] do not make any assumptions on the beamwidth what allow us to maintain the proposed solution at a price of increasing in a no critically way the beamwidth. In fact, the array has been designed for have an effective gain larger that that of the reflector. Then, the link budget specifications are satisfied.

6. SUBARRAY MEASUREMENT

The subarray module has been measured and its result has been extended to the whole array. The input and output reflection coefficients, the radiation pattern, axial ratio, increase of effective gain have been measured for the active subarray. Figure 6 shows the subarray radiation pattern for the E and H planes.

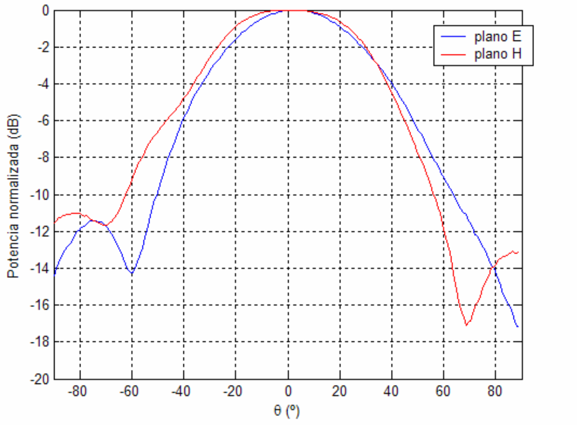

Figure 6: Subarray radiation pattern

This result agrees with the simulated ones. In fact the directivity obtained from this radiation pattern is 10.2 dB (similar to the simulated one 11 dB) and the E and H planes patterns are similar. Figure 7 shows the reflection coefficient at the output of the active array. A good matching level at 3.5 GHz has been achieved. The increase in the effective gain in the active vs. the passive antenna is shown in figure 8. The subarray axial ratio shows good agreement with the corresponding one of the passive array.

7. CONCLUSION

In this paper it is shown that is possible to reduce the size of a conventional reflector antenna by using of active arrays. The reduction factor depends on the integration level and if there are some constraints that can be modified. In the proposed application a size reduction factor of 6 factor has been achieved keeping the effective gain (net effect of the array and amplifier) of the initial reflector but at a price of increasing the antenna beamwidth.

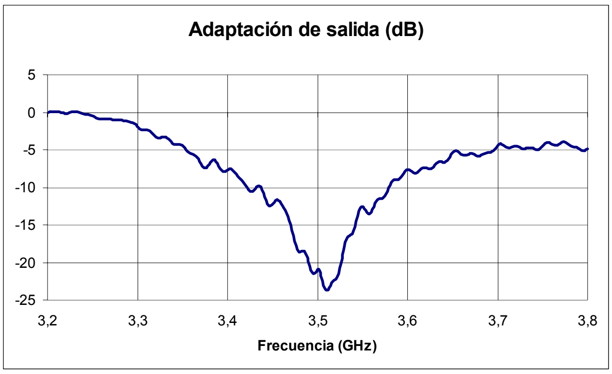

Figure 7: Output reflection coefficient of the active subarray.

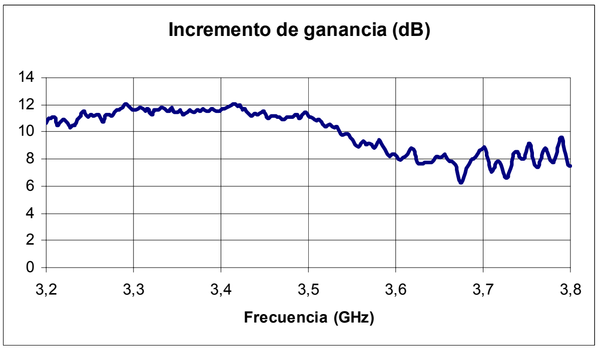

Figure 8: Increase of equivalent gain in the active subarray

REFERENCES

[1] D. Segovia Vargas, V. González Posadas: “Progress in Active Antennas: Broadbanding, Mixing and Diplexing”, Invited Seminar IEEE Croatian Chapter, ICECOM 2005, Zagreb October 2005.

[2] Y. Qian, T. Itoh, “Progress in Active Integrated Antennas and Their Applications”, IEEE Transactions on Microwave Theory and Techniques. Invited Paper; vol. MTT 46-11, Nov. 1998, pp. 1891-1900.

[3] Recommendation ITU-R F-1245*

[4] D. Segovia-Vargas, V. González Posadas, J.L. Vázquez Roy, L. Inclán and C. Martín: “An active broadband transmitting patch antenna for GSM-1800 and UMTS”, Microwave and Optical Technology Letters, June 2004, pp. 350-354.

[5] Carlos Martín Pascual, Vicente González Posadas and Eva Rajo Iglesias: “Patches: the most versatile radiator”. AIC 2001, Rhodes, Greece.