Antenna design activities in the Grupo de Radiación

Manuel Sierra Pérez, José Luis Besada, Belén Galocha, José Luis Fernández Jambrina, Leandro de Haro, Manuel Sierra Castañer, José Luis Masa, José Manuel Fernández, Pedro Rodriguez, Pablo Padilla
Grupo de Radiación. Dpt. Señales, Sistemas y Radiocomunicaciones. Universidad Politécnica de Madrid
ETSI de Telecomunicación. Ciudad Universitaria s/n
28040 Madrid, Spain
e-mail: {manuel.sierra.perez, masa,belen}@gr.ssr.upm.es

***Abstract*—. Grupo de Radiación has been developing a remarkable design activity in antennas sector. Antennas for base-station in mobile systems, satellite space applications, radar, radioastronomy or radio-links are some of the examples of the research activity of the Group. In this paper, some remarkable projects and research methods are presented. Important contributions to state of art have been done by the published papers related with these designs.**

Keywords*—. Planar array, conformal array, radial line, dicroic surface, splash sub-reflector, parallel plate waveguide.

I. INTRODUCTION

Grupo de Radiación (GR-UPM) is a registered Research Group in the Polytechnic University of Madrid. During last 10 years Grupo de Radiación members have been developing an active research process in antenna design. The three main research lines of the Group are:

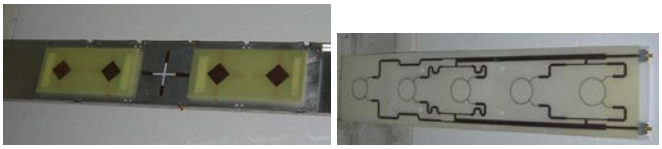
- Design of **Linear Arrays**: Single and dual polarization antennas for base station of mobile system applications: GSM 900 and 1800 MHz, UMTS, DECT (3,5 GHz). In this aspect, several collaborations with professional antenna companies have emerged: RYMSA, Sistemas Radiantes Moyano, Siemmes.
- Design of **Planar and Conformal Arrays**: Bidimensional and conformal arrays with linear and circular polarization for several applications as: Digital Broadcasting Satellite reception in Ku band, civil and military radar systems applications in L band and Signal Identification Systems in L and millimetric band. In this area the collaboration with INDRA and Televés is remarkable.
- Design of **Reflector and Horn Antennas**: Design of horn antennas in S and X band for Radioastronomy applications in Observatorio Astronómico de Yebes (Guadalajara, Spain). Likewise, Grupo de Radiación has developed several projects based on reflector antennas in Ku band. They take part of radio links of terrestrial or on-board systems.

Two Full Professors, Manuel Sierra Pérez and José Luis Besada, lead this research Group, in which four Associate and one PhD Assistant Professor, as well as, three PhD students work in the design of all this kind of antennas.

II. LINEAR ARRAY DESIGNS

Mobile systems have noteworthy grown up in last decade. Grupo de Radiación has contributed to this aspect by incorporating the design of base station antennas. Commonly, these antennas are composed of a linear array of planar radiating elements, with a sectorial azimuthal coverage. Linear vertical polarization is used for rural areas or road covertures, while dual +/- 45º polarization antennas are more adequate in urban environments.

In Grupo de Radiación all the designs have been developed with microstrip patch as single element. The most usual feeding configuration of the patch is through a slotted ground plane (Fig. 1a). A microstrip or stripline feeding network is used to couple the field from the slots to the radiating patches, according to the parameters of the desired radiation pattern (Fig. 1b). Teflon lowlosses substrates are used. They are more adequate to optimize antenna efficiency. Patches have been used in 65º, 90º (Fig. 2a), 120º and omnidirectional azimuthal beamwidth antenna. In this last case, parasite patches are used in a two 180º array. Both arrays are placed pointing to opposite directions, and fed by a common network. The sum pattern is omnidirectional with a maximum ripple of 3 dB (Fig. 2b).



(a) Coupled slotted patches (b) Stripline feeding network

Fig. 1: 65º & dual (+/-) 45º polarization UMTS antenna.

(a) DCS - 65º&90º (b) DECT - Omnidirectional

Fig. 2: Vertical polarization base station antennas

In order to get a more uniform coverage in the sector, a cosecant radiation pattern in elevation plane of the antenna is desirable.

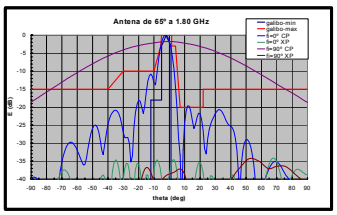


Fig. 3: Cosecant radiation pattern – DCS

In this case, coupling mechanism in the array is very important to be considered in the design process. In Grupo de Radiación, a coupling characterization model has been developed. Feeding network and radiating elements coupling are included and compensated in the antenna design. Scattering parameters and active radiation pattern measurements are necessary to configure the equivalent multipole model in Fig. 4. After these measurements, the designer is able to include matching networks to makes the antenna radiate according to the desired radiation pattern (b_e coefficients). In this case a new equivalent single elements network is defined by considering the adaptive circuits.

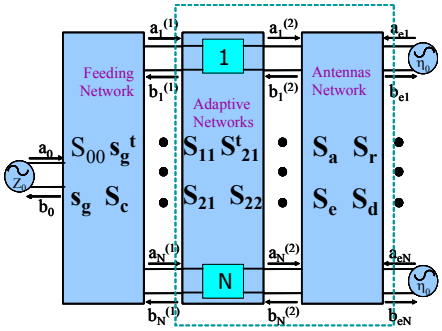


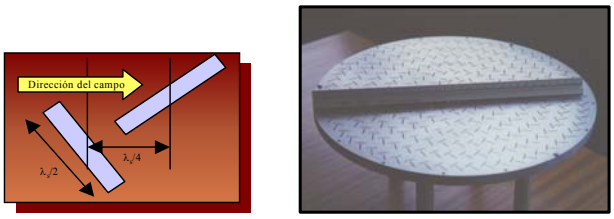
Fig. 4: Characterization and compensation model in array antennas.

III. PLANAR AND CONFORMAL ARRAY DESIGNS

Another important research line in Grupo de Radiación is planar array designs. In this aspect, high efficiency and gain antennas have been developed. In this kind of antennas, microstrip feeding networks are not suitable due to losses. In high frequency applications, this factor is even more important. Likewise, in some applications a planar shape of the antenna is required, due to the receiver or transmitter connection to the antenna. Parallel plates waveguides used as feeding network of bidimensional arrays is a reasonable solution to all these aspects. A waveguide network is lowlosses structure. A big size array fed by a parallel plate waveguide can obtain high values of gain and efficiency. Grupo Radiacion has been working with two kind of radiating elements in these planar arrays: slots and patches.

Design parameters are directly connected with slots position. Furthermore, these antennas are more rigid from a design point of view than patches option. Nevertheless, they are very easy to manufacture. Appreciable results have been achieved in both cases. As feeding waveguide, also two possibilities have been studied: radial waveguide, and parallel plate waveguide with side feed. In the first case, a coaxial centre input is used in one of the two metallic plates. A radial wave as a TEM mode is propagated in the waveguide. Furthermore, the radial waveguide can be considered as a transmission line (Radial Line). The other option is composed of two metallic plates fed in one side. For this possibility, a TEM or TE_{N0} mode can be excited and propagated in the waveguide.

Radial slotted waveguides are very useful in circular polarization designs. Two orthogonal slots, separated by a radial distance of a quarter of the wavelength, are used as single element (Fig. 5a). The array is configured with rings of single pairs of slots as Fig. 5b shows.



(a) Slot pair as single element (b) Slot array in radial line

Fig. 5: Radial slot line antenna.

These antennas have been analyzed by considering an equivalent multipole model with admittance and hybrid matrix parameters. The voltage and currents relations based on the slots coupling mechanism inside the waveguide and in free space, provide the necessary information to implement the antenna.

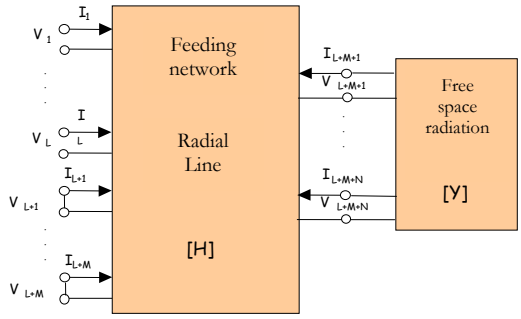


Fig. 6: Equivalent multipole for a radial slot line.

The Digital Broadcasting Satellite system requires receiver antennas with high gain and efficiency properties. Radial slot lines can provide these characteristics, as well as a planar configuration. Some circular polarization applications have been developed. Good radiation pattern results have been measured (Fig. 7). The antenna presents a peak gain of 27 dBi, and 60% of aperture efficiency. The antenna radius is 170 mm.

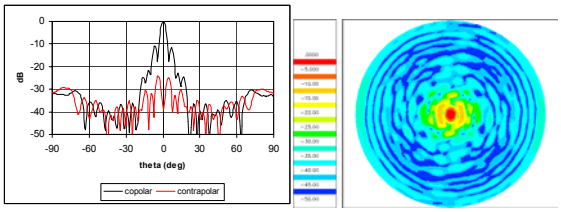


Fig. 7: Radial line slot radiation pattern- 12.1 GHz

Monopulse radiation pattern antennas have also been designed, by using a hybrid network in a microstrip circuit to feed the radial waveguide.

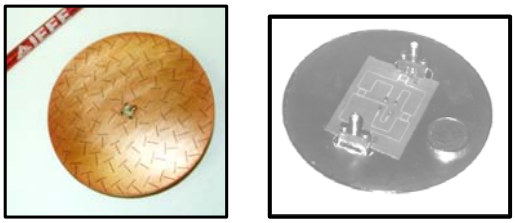
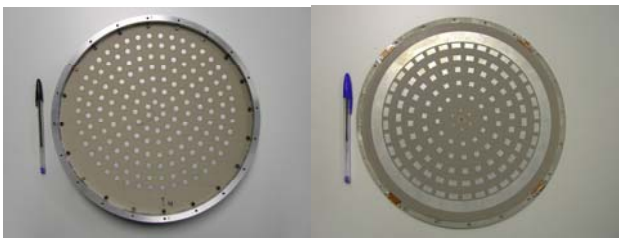


Fig. 8: Monopulse radial line slot

Patch designs have been focused in linear polarization antennas, in order to solve the reflection and feeding difficulties indicated in state of art. Patch designs are based in the use of a new coupling structure to feed the radiating patches placed out of the radial waveguide. Microstrip lines inside the waveguide are used. The different length and width of the lines, fix the amount of power coupled from the waveguide to the patch. Metallic holes are used to connect the microstrip coupling lines inside the waveguide to the patches. All the structure is manufactured in a multilayer Teflon circuit, which is placed on the top of a metallic cylindrical piece of aluminum (radial waveguide) (Fig. 9)



(a) Patch array (b) Microstrip coupling lines

Fig. 9: Radial patch line antenna.

The main advantage of this new coupling structure is the independency between the physical configuration of the patch array, and the feeding network design. A free patch disposition is available according to the design requirements. Satisfactory results have been tested in measurements of the manufactured antennas, with low level of crosspolar component (Fig. 10). The measured maximum gain value in DBS band is 28dBi, with 88% of aperture efficiency. The antenna radius is 130 mm.

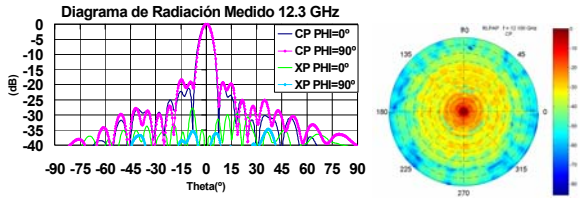
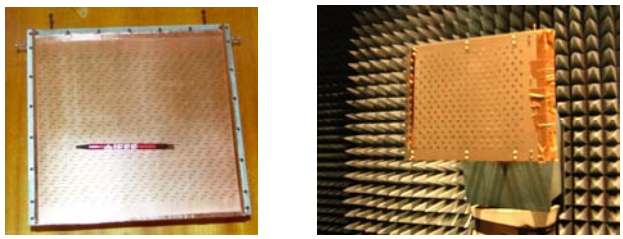


Fig. 10: Radial patch line radiation pattern- 12.1 GHz

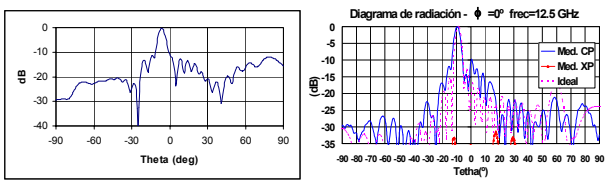
Both concepts of design have been implemented in parallel plate waveguide antennas with side feed. In slot antennas a TEM mode is excited by the use of a feeding network places in one side of the waveguide (Fig. 11a). Field falls next to the metallic walls of the antenna affect to the antenna efficiency. Likewise, reflections inside the waveguide force to the use of slots of reflection cancellation. In patch designs (Fig. 11b), Grupo Radiación has studied the excitation of a TE_{N0} mode in the waveguide. By placing the microstrip coupling lines at the peak points of the field inside, feeding amplitude is not affected by field falls.



(a) Slot antenna (b) Patch antenna

Fig. 11: Parallel plate waveguide antennas with side feed

Beam tilted antennas have been manufactured in slot (Fig. 12a) and (Fig. 12b) patch cases, with a good performance in DBS band.



(a) Slot antenna (b) Patch antenna

Fig. 12: Elevation radiation pattern. Parallel plate with side feed antenna

Grupo de Radiación has also developed antennas for Radar systems. LANZA P & N are two terrestrial and naval radars developed for INDRA (Fig. 13). The antenna part consists of an array of 42 horizontal rows. Each row is composed of 56 dipoles with horizontal polarization, and fed by a stripline network. An artificial ground plane is established among dipole rows to avoid the back radiation. An active network is used to vary the main beam direction of the radiation pattern in elevation plane. The total size of the antenna is 10.5 x 7.2 m (Fig. 13) in terrestrial system, and 5.5 x 3 m in naval application. In this last case, the antenna also presents a monopulse radiation pattern in the azimuth plane.

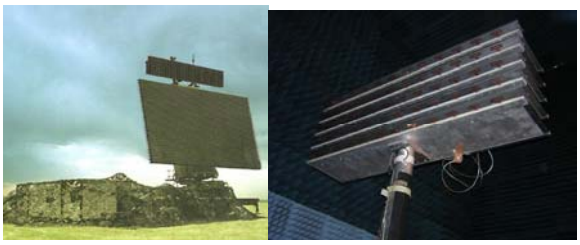


Fig. 13: LANZA N radar. Final antenna& partial prototype.

In millimetric band Grupo de Radiación has developed a slot conformal array (Fig. 14). Circular polarization is required, as well as a -10º/ +30º elevation coverage and omnidirectional azimuth radiation pattern. The antenna is based on the excitation of a TM_{11} mode in a circular waveguide. The vertical currents in the waveguide excite an array of 8 pairs of cross slots (Fig. 5a), which are placed on the walls of the waveguide. The same kind of radiation pattern has been achieved with a monopole antenna over a conical ground plane (Fig. 15). A two layer polarizer of 45º inclined strips, changes the vertical monopole polarization to the desired circular one.

Fig. 14: Omnidirectional conformal slot array

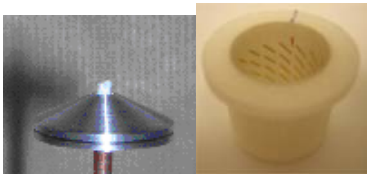


Fig. 15: Monopole and strips polarizer in 37 GHz band

The measured results of both antennas are presented in Fig. 16.

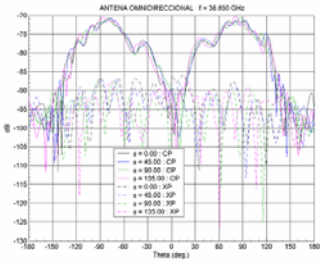
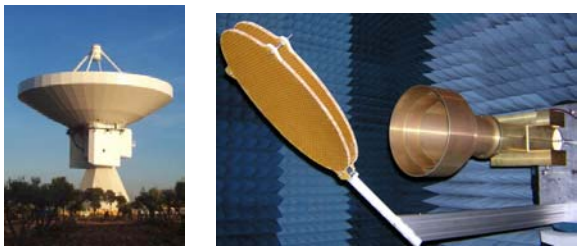


Fig. 16: Elevation pattern. (-10º / +30 º) coverage

IV. HORN AND REFLECTOR ANTENNAS

Grupo de Radiación actively collaborates in Radioastronomy applications. An important Project has been developed with Observatorio Astronómico de Yebes (Guadalajara). In this case Grupo de Radiación has designed horn feeders for the sub-reflector of a 40 metre Radio-telescope. This antenna takes part from a Very Long Base-line Interferometer (VLBI, Fig. 17a). The feeder is a corrugated horn antenna with circular polarization. A septum polarizer in rectangular waveguide is used to obtain circular polarization. A rectangular to circular waveguide transition before the cylindrical corrugate horn is required. The feeder must be able to work in a multi-beam system. The aim is to point to a pair of sub-reflectors of 1.8 and 4 metres, in different operation frequency bands. Furthermore, a dicroic surface is placed in front of the horn antenna (Fig. 17b). The dicroic surface allows transmission of S band signals and reflects X band field. The horn antenna operates in both bands.



(a) 40m. Radio-telescope (b) Horn feeder & dicroic surface

Fig. 17: 40 m. Radio-telescope for VLBI Interferometer

Likewise, Grupo de Radiación has designed reflector antennas for several civil and military systems. The Spanish High-Speed Rail (AVE) is developing a communication service. Grupo de Radiación has designed a reflector terrestrial or on-board reflector antenna for that system in Ku band. A horn antenna with splash sub-reflector has been used to point a shaped parabolic reflector (Fig. 18).

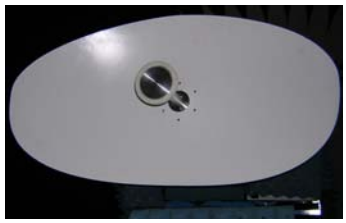


Fig. 18: AVE reflector antenna.

The splash sub-reflector avoids a high block effect due to the mechanical structure used to fix the feeder. Likewise, a more easy connection to the input waveguide of the system is achieved. Very satisfactory results have been obtained with this idea (Fig. 19).

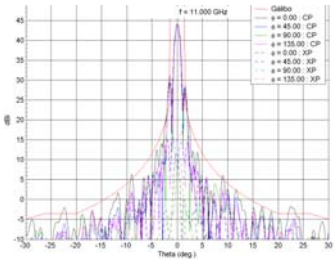


Fig. 19: Measured radiation patter of AVE antenna.