Ka band active array antenna for mobile satellite communications

Manuel Sierra Castañer, Jose Manuel Fernández González, Manuel Sierra Pérez, Adrián Tamayo Domínguez, Alfonso Muriel Barrado.
E-mail: manuel.sierra@upm.es
Dpto. de Señales, Sistemas y Radiocomunicaciones.
Universidad Politécnica de Madrid. E.T.S.I. de Telecomunicación. Av. Complutense 30. 28040 Madrid

***Abstract* - This paper describes a modular active antenna for satellite communications in the K/Ka band. The application is thought for mobile satellite communications and internet links, mainly for commercial airplanes. The impossibility to build full active antennas, including amplifiers in all the elements, leads to a modular semi active antenna. Here the module is a small subarray with complete phase control in the elements. The phase control is made with ad-hoc phase shifters giving the minimum losses. Only two-bit control has been selected to perform phase shifters associated to a circular polarization radiating element. The feeding network has been selected to minimise the losses and the gap waveguide has been designed to perform the network. The radiating element is a circular double patch fed into two points to obtain circular polarization. The entire prototype has been designed in LTCC substrate to minimise the losses and stabilise the structure.**

***Index Terms* — Phased Array Antennas, Ka Band, Satellite Communications.**

1. Introduction

The specifications for Ka band satellite communication antenna systems lead to large antenna gain in the ground terminal [1], [2], [3]. As presented in a previous communication [4], there exists an important restriction in the antenna design for mobile terminals. The main beam direction electronic control must be large and is required to include phase shifters and amplifiers associated to each element in the array. On the other hand, a high gain is required in the antenna force to perform a large antenna size and, most importantly, a large number of radiating elements, reaching values of several thousands. The large number of active circuits to be included in the antenna makes the active antenna implementation physically and economically impossible.

The option presented here is dividing the antenna into passive subarrays, with the minimum possible losses, in order to drastically reduce the number of active integrated circuits like amplifiers or phase shifters. Some phase control is needed at the radiating element level and one of the problems is how to obtain information about the losses added in these situations. Here we study the option of several passive subarrays with some control in the main beam direction. Also the circular polarization switch must be implanted at this level.

Although many papers have been published about the design and fabrication of Ku and Ka band antennas for mobile-satellite communications; few commercial antennas have been done with full phase control in the radiating elements [5], [6], [7]. Some of the commercial antennas seen in the web pages of several companies ensure their success in the construction but do not offer information about the way or the electronics used to do it [8], [9], [10].

2. Passive subarrays

The proposal is a passive subarray with a variable number of elements from 2x2 to 8x8 as a maximum. This range has been selected as a function of the antenna size to obtain the required antenna gain. To satisfy the gain over noise temperature conditions of G/T=12dB/k for the receiving antenna at 20 GHz, a minimum antenna gain, around 35dBi, has been estimated for a typical 2dB noise figure amplification associated to each element. To cover the pointing capacity of 60º from the broadside, the minimum size of the antenna is around 0.5x0.5 m^2. Any additional losses due to phase sifters or passive feeding network increase the size and the number of elements in the antenna. Table I compares the size of the antenna for several passive subarray configurations.

TABLE I
Subarray size comparison

Subarray size	Added Network losses [dB]	Array size [m^2]	Total number of elements	Number of subarrays
None	0	0.5x0.5	4096	-
2x2	1	0.6x0.6	5476	1369
4x4	1.6	0.68x0.68	7056	441
8x8	2.4	0.84x0.84	10816	169

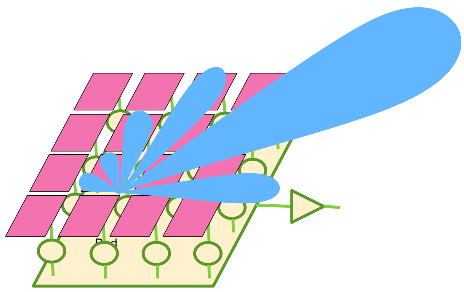

Fig. 1. Subarray schematic circuit.

As the subarray number of elements grows the loss factor due to the distribution network takes higher values and the total size of the antenna must be larger to compensate these losses. On the other hand, the number of subarrays and the number of active integrated circuits needed to build the antenna is lower and cheaper.

3. Radiating element

The circular polarization specified for the antenna includes the option to switch the polarization sense from RHCP to LHCP. To perform this specification a circular printed patch, fed by a metalized via, has been selected as a radiating element. The bandwidth is broadened with a parasitic patch and the coupling to the neighbour elements is minimized with a metallic cavity. Both patches are implemented in a printed circuit over dielectric substrates keeping an air layer in between. The cavity in that air layer is achieved by using a mechanized metallic sheet.
Figure 2 shows the layers in the antenna element. The feeding is performed through a metalized via to connect the printed strip line to the patch through the ground plane.

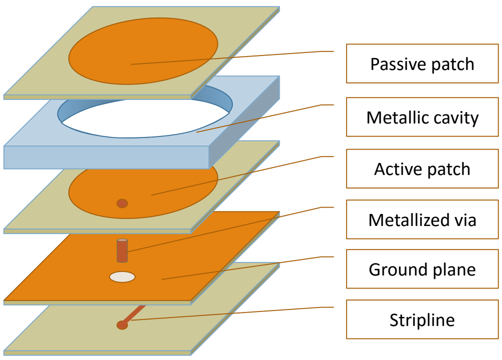

Fig. 2 Printed patch fed with strip line.

Figure 3 and figure 4 show the antenna patch main response.

4. Phase shift circuit

To get the appropriate phase at each array element in the main beam pointing process, we need a phase sifter attached at each radiating element. These phase sifters must support minimum losses to avoid gain reduction. To reach this goal a two bit phase sifter has been designed. It is based on several switches (PIN diodes, MEMS …) to select the feeding point in the printed patch.
Mainly in directions far from the main beam, two bit phase control is not enough to get a low side-lobe level pattern. To avoid grating lobes and prevent strong jumps in the main beam direction in the pointing process, a random phase has been added in the phase discretization process. This process allows working with a random phase term in the array aperture, lowering the antenna directivity a few tenths of a dB [11].
It can be seen that the high phase error discretization produces high grating lobes associated to the subarray structure. The lobes are farther from the main lobe in small subarrays but their level is lower for large subarrays.

5. Feeding network

The subarray feeding structure is especially important to reduce losses as much as possible. Several transmission lines have been studied to perform this structure. Simulations have been done with two dielectric materials: A dielectric substrate like Rogers RO 4003 and a ceramic LTCC substrate like Dupont 9K7V.

6. Conclusion

High gain phased array antennas at high microwave frequencies or millimeter waves require a large number of elements and a high cost when each element is driven with a low noise amplifier and a phase sifter. The connection of these circuits and the associated control circuits in a very small size radiating element is also very difficult. To make the antenna viable, passive subarray modules have been designed. The phase control has been limited to two bit phase shifters and the transmission line has been selected to reduce, as much as possible, the distribution losses. Simulations of all these circuits have enabled a design that we expect to show in the conference.

Acknowledgment

This study has been made under the project Jetstream, supported by the call "Retos Colaboración" from the Spain "Ministerio de Economía" (RTC-2015-3495-7) and with the collaboration of the company Telnet. We also acknowledge the contribution from the project Enabling 5G supported by the Spanish "Plan Nacional de Investigación" (TEC2014-55735-C3-1-R) and the project Spacer Debris Radar (Project number S2013/ICE-3000 SPADERADAR-CM) that supported most of the simulation software.

References

[1] ITU-R SA.364-5 *Preferred Frequencies and Bandwidths for manned and unmanned near-earth research satellites*.

[2] UIT-R S.580-6 *Radiation diagrams for use as design objectives for antennas of earth stations operating with geostationary satellites*.

[3] ITU-R S.524-9 *Maximum permissible levels of off-axis e.i.r.p. density from earth stations in geostationary-satellite orbit networks operating in the fixed-satellite service transmitting in the 6 GHz, 13 GHz, 14 GHz and 30 GHz frequency bands*.

[4] Manuel Sierra Pérez "*Antenas en array activas para comunicaciones y sistemas de localización*" XXX Symposium Nacional de URSI. Pamplona 2-4 de septiembre de 2015. España.

[5] R. Baggen, S. Holzwarth, M. Böttcher, B. Sanadgol *Phased Array Technology for Mobile User Terminals*. Eucap 2011.

[6] S. Vaccaro, D. Llorens del Río, M. C. Viganó *Phased arrays with reduced number of phase shifter bits for polarization and pointing control*. IEEE APS 2013

[7] Nathan Kundtz, Redmond, Wash. "*Next Generation Communications for Next Generation Satellites*" Microwave Journal. Augost 2014.

[8] Mikala C. Johnson, Steven L. Brunton, Nathan B. Kundtz, and J. Nathan Kutz "*Sidelobe Canceling for Reconfigurable Holographic Metamaterial Antenna*" IEEE TAP VOL. 63, NO. 4, APRIL 2015.

[9] *Introduction to Reconfigurable Holographic Metamaterial Antenna (RHMA)*. In Q-Tel Article. 2014

[10] Bahram Sanadgol, Sybille Holzwarth, Alberto Milano, Rafi Popovich "*60 GHz Substrate Integrated Waveguide Fed Steerable LTCC Antenna Array*" EuCAP 2010.

[11] M. C. Viganó, D. Llorens del Río, F. Bongard and S.Vaccaro *Sparse Array Antenna for Ku-Band Mobile Terminals Using 1 Bit Phase Controls*. IEEE TAP, Vol. 62, No. 4, April 2014A.