Multilayer K-band microstrip patch antenna array for aerospace applications

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Abstract **– Fast data rate transmission and broadband Satcom networks for multimedia application services at Ku/K/Ka band (12-40 GHz) call for brand new antenna array technologies. Light, low profile and easily integrated antennas are in particular strongly desired for these applications. In this paper, we present results of our studies on a dual circularly polarized antenna featuring a high degree of antenna circuit integration.**

Index Terms **— Antennas, antenna arrays, microstrip antenna, stripline, coupler, feed network.**

I. Introduction

Civilian aviation is showing a strong increase in cargo and people volume every year. It is expected that more than 20,000 large commercial planes will be needed in the next decade. The current advancement in RF-electronics is fostering new developments and establishing the basis for new wireless systems implementations.

On the other hand, next Inmarsat-5s and Iridium satellite constellations will be launched soon, creating a much higher demand for Ku/K terminal aviation antennas than nowadays. Finally, it must be pointed out that these antennas have plenty of potential alternative applications, such as unmanned aircrafts, broadband telecommunication services to high-speed trains or telecommunication in the Earth's Polar Regions.

Microstrip patch antenna is lightweight, low profile and easily integrated with the frontend components. However, typical microstrip patch antennas are narrowband and have low gain. Therefore, it is desired to develop wideband antenna array to set the link budget. Double polarized antenna requires a multilayered feed network. Usually, the feed network is made in stripline technology but it could partially use substrate integrated waveguides or classic waveguides in order to decrease the losses.

II. Antenna element

The antenna proposed here is constructed considering the specific context of an airborne application. This particular environment involves the specific requirements of both aircrafts and satellites [1,2]. In addition, the manufacturing restrictions that apply in the case of high frequency antenna design have also been considered here.

Fig. 1 depicts the proposed K-band antenna element, which consists of four main layers, including the antenna elements and their beamforming network. The patch is a circular element placed on the rectangular grid (A layer) fed by two H-shaped slots in the element's ground plane (B layer). The patch is printed on 5 mils thick substrate and is suspended 1.2 mm above the ground plane. The whole feed network is made in stripline technology. Several metallic pins have been placed around the striplines and below the slots, in order to avoid radiation from surface waves (C layer). The line which feeds the slots is designed based on an asymmetric stripline technology (0.254 mm and 0.787 mm thick – RT5870), in order to decrease the capacitive susceptance and therefore, increase the energy coupling to the slot in a wider band (C layer). The two H-shaped slots are feed out of phase (90° phase shift) to produce circular polarization. A miniaturized two-stage branch-line coupler is designed to divide the input power and to produce the previous 90° phase shift (D&E layers). Symmetric stripline technology is here employed (2 x 0.506 mm RT5870). The miniaturization of the coupler is achieved by substituting the quarter wavelength line by an undersized line loaded with an open-ended stub [3]. The transition between layers is made through holes in the ground plane and a central wire of 0.4 mm diameter that is surrounded by seven shielding wires of 0.6 mm diameters.

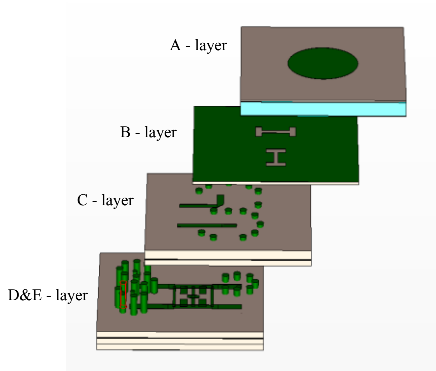

Fig. 1. Structure of the patch antenna element with two H-slots and coupler printed on a dielectric substrate. The layers of the antenna elements were shifted in order to visualize the layout of each layer.

The simulated return losses and the isolation characteristics between the two antenna ports are plotted in Fig 2. This figure clearly shows the broadband nature of the antenna element. In particular, it provides 4 GHz (21%) bandwidth, adopting the -20 dB return loss criteria. The isolation between ports (including the coupler) is better than -20 dB from 17.5 GHz to 20 GHz, whereas the isolation between slots is below -29 dB in this range (considering the antenna element without coupler).

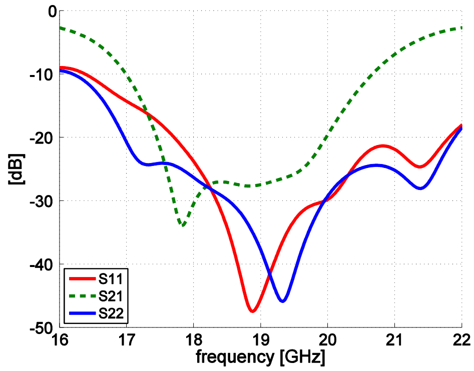

Fig. 2. Calculated S-parameters of the patch antenna elements (simulation results with CST).

Other relevant parameters of the antenna element, such as efficiency, beamwidth, axial ratio, side lobe level and realized gain, are included in Table 1.

TABLE I
PARAMETERS OF ANTENNA ELEMENTS AND ANTENNA ARRAY

	Antenna element	Antenna array
Return loss bandwidth for 20 dB	4 GHz	2.1 GHz
Isolation between RHCP and LHCP ports in 17.7-19.7 GHz	-20dB	-14 dB
Efficiency 17.7 GHz to 19.7 GHz	>95 %	>80%
Antenna gain for 18.7 GHz	8.1 dBi	20.6 dBi
Beamwidth in both principal cut planes	±35 degrees	±7 degrees
Axial ratio for 3 dB for 18.7 GHz	±50 degrees	±15 degrees
Side lobe level	-	7.7 dB
Number of feed circuit layers	2	4

III. ANTENNA ELEMENT IN ARRAY ENVIRONMENT

Figure 3 presents the layout of a 4x4 antenna array integrated with its feed network. Spacing between array elements is 14 mm (~0.9 λ) to mitigate the occurrence of grating lobes and to maximize the gain, while making more room for highly isolated circuits.

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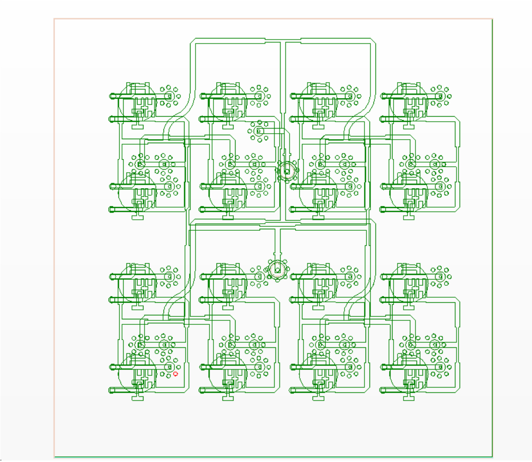

Fig. 3. Structure of the microstrip antenna array made on nine substrates- all layers wireframe view.

Four feed layers are used to obtain high isolation between the two polarizations generated. One of the feed layers is to excite the electromagnetically slot-coupled patches, while a second one supports the couplers. The remaining two feed layers contain the circuits distributing the power between antenna ports and antenna elements.

T-junction dividers are used in order to distribute the power between antenna elements. In spite of its compactness, these dividers show low isolation between output ports. Indeed, the S21 parameter (shown in Fig. 4) is roughly higher than -15 dB in the operating band. However, the calculated isolation between slots and between antenna elements is better than -24 dB. The bandwidth of the array is 2.1 GHz, for the -20 dB return loss criterion. Other parameters of the antenna array are also summarized in Table 1.

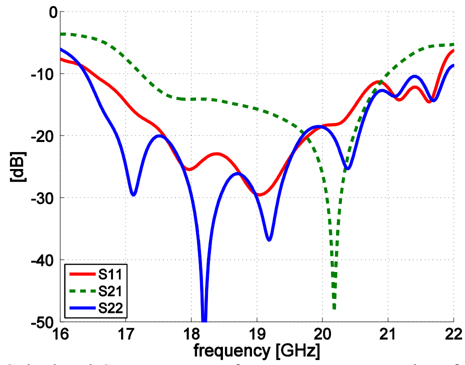

Fig. 4. Calculated S-parameters of antenna array consist of 16 antenna elements (simulation results with CST).

IV. CONCLUSIONS

In this contribution, we propose an original and compact K-band antenna element that provides dual circular polarization and allows easy array integration. The antenna performances have been simulated and optimized both for the single element and for a 4x4 array configuration. The main challenges encountered in the present design have been the suppression of surface waves and the reduction of the capacitive susceptance associated to the stripline feeding the elements through slots. The matching of the feed network to the coax connectors was also highly challenging, and solved by placing additional stubs close to the transition. A prototype is being built and further results, including measurements, will be shown in course of presentation.

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