A Circularly Polarized Antenna Element for Highly Integrated Array Antennas

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Abstract

In many areas of wireless communications and radar, there is a fast growing demand for antennas to be highly integrated with microwave sub-systems. To achieve this task, there is a considerable interest in reduced-size antennas. However, reducing the antenna size works against operational bandwidth. In particular, a significant challenge is faced when circular polarization has to be accomplished. In this paper, a small size three-strip coupler is proposed as an external polarizer for a dual feed aperture coupled patch to achieve high purity circular polarization over an increased operational bandwidth. Design, development and experimental results for such an antenna element and a linear array are presented.

1 Introduction

The task of achieving high scale integration of array antennas with microwave sub-systems in applications such as wireless communications and radar is challenging when these systems have to operate over an increased frequency band. In particular, a considerable difficulty is faced when an array of circular polarization (CP) with broad frequency band has to be achieved. This challenge is due to difficulty of obtaining wideband and well balanced feeding network, which could meet the constraint of dense packed antenna elements. One approach to obtain CP for densely packed arrays is to use broadband linearly polarized (LP) elements and sequential feeding network. In this approach, the LP elements are rotated in the array and the feeding network adds an extra phase shift to achieve CP. Using this method, the array meets the requirement of limited space for a feeding network. However, our experience in generating CP using this method has not always been favorable. This is because such arrays have shown high level of cross polarization - in some of the cut-planes, exceeding the co-polar radiation. This shortcoming can be eliminated using CP elements forming the array. For individual elements, such as microstrip patches, CP can be achieved using a single slot feed (see Fig. 1 [1]) and perturbation techniques or dual orthogonal feeds. Both methods rely on launching two orthogonal field modes in space and phase quadrature [2]. The dual-feed method offers much better axial ratio values and larger axial ratio bandwidth than the single feed method. However, it requires an external polarizer, for example, in the form of quadrature coupler. An extra condition is that the antenna element two feeding ports have to be well isolated. The main challenge in realizing such a CP antenna element comes from devising a suitable external polarizer, which has to be sufficiently compact to fit the available space under the patch.

Fig. 1. Layout of the CP patch fed with a cross-slot featuring low space demands.

2 Antenna Element

The first task is to design a miniaturized antenna element featuring large CP bandwidth. We choose the configuration of a dual linear polarized aperture coupled microstrip patch, as shown in Fig. 2. When the element's orthogonal ports are highly isolated, connecting a 3 dB quadrature hybrid that provides two signals of equal magnitude and 90° phase difference, automatically produces high quality CP. The polarization bandwidth of this antenna element including polarizer is mostly governed by the bandwidth of the polarizer (coupler), provided that the element’s ports feature good isolation and return loss. In the present case, we choose the design frequency of 1.6 GHz (Inmarsat) and 2.4 GHz. Due to the choice of low microwave frequencies, integration with other sub-systems requires antenna elements which favor lightweight materials (see Fig. 3). Here, we choose cured honeycomb composites, which incorporate thin
bonding films placed on the bottom and upper sides of the panel filler [3], [4]. The chosen materials feature highly stable electrical properties over a large temperature range [5]. This is of importance in applications such as antennas for airborne platforms.

Fig. 2. Layout of the patch with two orthogonal feeding slots.

In the antenna design we used both theoretical (infinite ground) and experimental (finite ground) approaches. It was found that in order to obtain a favorable coupling between the patch and the feeding line, as well as to increase isolation, displacements of the slots off the patch principal symmetry axes were hard to avoid. Improvements were obtained when the coupling slot in the ground was arranged partially out off the patch outline (ref. Fig. 2). An obvious drawback of this solution is the extension of the area that must be reserved for each element. However, the benefit is that enough space is available for mounting a wideband directional coupler under the patch.

The effect of slot displacement along the x and y axes on the center frequency and bandwidth shows when the slot is hidden entirely under the element, the impedance match deteriorates (see Fig. 4). Pushing the slot part out the patch results in corrupting symmetry in the radiation pattern. Regardless of the x and y directions, for a greater offset of the slot a higher resonant frequency is obtained. From the point of view of achieving a compact size element, a suboptimum bandwidth is obtained for a small SY displacement (SY=0.46⋅D and the slot is slightly out of the patch area). Similarly, the broadest bandwidth is obtained when the slot is shifted by about SX=0.72⋅0.74⋅D towards the edge of the patch. The achieved isolation between the ports varied between 14 and 22 dB. Impedance and bandwidth tuning are sensitive to stub length and the largest bandwidths are obtained for a narrow range of the LZ values (see Fig. 5).

The 3dB coupler was designed using customized software (Spectral Domain Technique [6]). This coupler was initially developed as an individual element and thoroughly tested. Its tests have shown 3dB (±0.5) dB over 1210 MHz frequency band (50%). The phase characteristic has shown 90 ± 1° phase balance between the output ports over 460 MHz, symmetrically around f0. These results clearly indicate that this device features an extremely large bandwidth performance. Its size is only 23 x 19 mm (at 2400 MHz) which represents a 27% of the 40x40 mm area taken by the patch. Therefore this hybrid very well meets miniaturization requirement of tightly spaced arrays.

Fig. 3. Generic view of a lightweight antenna element.

Fig. 4. Calculated bandwidth and centre frequency for different offsets of the feeding slot. SX and SY values are normalized with respect to D and RL is return loss at a given frequency.
3 CP Array

The present choice of the three-strip coupler as a power divider/combiner in the feeding network of a large size array is attractive from the point of view of its electrical characteristics and compact size. However, its use requires some efforts to handle the $90^\circ$ phase shift between the output ports. To compensate for this phase shift and to ensure wide bandwidth a sequential rotation of the antenna element is applied (see Fig. 6). The element rotation has a mitigating effect on the asymmetry of the element radiation patterns which is unavoidable when the feeding slots are extended outside the patch. Our comparison studies into various array geometries (CP elements) have shown that the sequential rotation improves quality of the CP in the main beam (the axial ratio within the main beam is lower than $1.3 \, \text{dB}$). Furthermore, the level of cross polarization (LHCP in our case) is significantly reduced from $-16$ to almost $-32 \, \text{dB}$ at the main beam axis (see Fig. 7). When comparing to an array with identically oriented CP elements, the quality of the CP in array with rotated elements is better in the major lobe radiation and becomes slightly poorer at the farther sidelobes (at least $14 \, \text{dB}$ below the peak of the main beam). The same characteristic is observed at the diagonal planes, which usually feature a high cross-polar level. The proposed element design may be considered in dual band arrays utilizing perforated patches [7].

4 Conclusions

Wideband operation of highly integrated array antennas is difficult to achieve when CP is required. In order to achieve high purity CP over an increased operational bandwidth the use of dual polarized antenna elements with an external polarizer in the form of 3dB quadrature coupler has been proposed. In order to meet tight spacing of array elements, the coupler has to be arranged within the available antenna element area. As a result, only small size hybrids can be used. In the presented work, the design of a small size three-strip coupler has been demonstrated as an external polarizing element to achieve a CP aperture coupled antenna element with increased operational bandwidth. The presented solution uses low weight and temperature resistant dielectric materials to achieve suitable integration of the array antenna with microwave sub-systems. The use of the proposed CP antenna has been demonstrated in an example of a small linear array.

5 References


Fig. 6. Generic configuration of a four-element linear array with a feeding network using compact broadband directional couplers.

Fig. 7. Radiation pattern in the $\phi=0^\circ$ plane of the four-element RHCP polarized linear subarray when (a) a sequential rotation (for compact broadband directional couplers) is applied and when (b) the CP elements are arranged without any rotation.