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A Shared Aperture Dual-Frequency Circularly-Polarized Microstrip Array Antenna

A.B. Smolders, *Senior member IEEE*, R.M.C. Mestrom, A.C.F. Reniers and M. Geurts

Abstract— A novel 2x2 array of microstrip antennas was developed that generates orthogonal circularly-polarized waves at two frequencies simultaneously. This true shared aperture can be used as a building block in full-duplex wireless communication applications such as focal-plane arrays for satellite internet (VSAT) and wireless connectors. An alternative implementation of the sequential rotation technique was applied to create dual-frequency operation using only a single aperture. The concept was verified with experimental results from a prototype consisting of a 2x2 array of Aperture Coupled Microstrip Antennas (ACMA) with corresponding feed network operating at 4 GHz and 6 GHz. Measurements show that the Axial Ratio (AR) is below 1.2 dB for both the low-band as well as the high-band mode of operation. The isolation between both modes is larger than 26 dB, eliminating the need of high-performance duplexers.

Index Terms—Circular polarization, full duplex, aperture coupled microstrip antennas, dual frequency, shared aperture.

I. INTRODUCTION

Several full-duplex applications would benefit from a compact shared-aperture dual-frequency array with specific polarization features and a high isolation between both channels. An interesting example is a focal-plane array with a single reflector operating at 20 GHz and 30 GHz in terminals for two-way satellite communication for TV and internet access (VSAT) [1]. Other potential applications include wireless connectors for industrial applications, radio astronomy and remote sensing. A shared aperture reduces size, weight and cost. It also improves the performance in focal-plane arrays, since the phase-centers for both frequencies are at the same location. In the VSAT application we would like to re-use the antenna aperture for transmitting (30 GHz) and receiving (20 GHz) data. In addition, electronic beam scanning over a limited scan range is required for simultaneous communication with various satellite positions and for automatic installation purposes. The antenna is required to generate circular polarization with excellent Receive (RX) versus Transmit (TX) isolation. Some recent papers have reported on shared apertures for dual-polarization and dual-frequency [2-5]. In these studies separate antennas for the low-band and high-band operation are used and are integrated into each-other, for example by using perforations in the low-frequency patch antennas.

The applications which are targeted in these studies require a relative large scanning range. In order to avoid grating lobes, the element spacing for the low-frequency operation is chosen different from the element spacing for the high-frequency band. As a consequence, these concepts typically lack ease of manufacturing and have limitations with respect to aperture efficiency and cross-polarization levels [2]. In this paper we explore a concept in which the antennas physically “share” the same aperture for the low-band and high-band mode of operation. This is possible due to the specific scanning requirements of the intended applications. An elegant way to create circular polarization (CP) with linearly polarized (LP) elements in an array environment is by using the sequential rotation technique as introduced by John Huang in 1986 [6]. We will present a novel extension of this technique in order to create a shared aperture array antenna for dual frequency operation with circular polarization. The specifications of our demonstrator are derived from the system requirements for terminals in future TV/internet satellite communications:

- *Circular polarization with frequency separation between low- (RX) and high-band (TX) of 2:3.*
- *Limited electronic beam scanning.* For example, the orbital positions for ASTRA are 5° , 19.2° , 23.5° , 28.2° and 31.5° East, resulting in a scan range requirement of $\pm 15^\circ$ in a single plane, including some margin. This allows for an element spacing at the highest frequency up to $0.8\lambda_0$ (λ_0 is the free-space wavelength).
- *Fractional bandwidth ranging from 2-16%.* Aperture-coupled microstrip antennas can achieve this bandwidth [10-13].
- *System isolation between lower and higher frequency bands.* Additional isolation that is obtained at the antenna level will eliminate the need of using a duplexer or filters in the receiver/transmitter modules.
- *Compact aperture.* Focal plane arrays using a single reflector for both frequencies benefit from a compact shared aperture. The phase centers for both frequency bands will be at (approximately) the same location.

II. DUAL-FREQUENCY CIRCULARLY-POLARIZED SHARED APERTURE USING THE SEQUENTIAL ROTATION TECHNIQUE

It is well-known that CP radiation can be achieved by applying proper phase shifts to sequentially rotated LP antenna elements [6-8]. We have extended this concept to the novel configuration as shown in Fig. 1. This figure shows a

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A.B. Smolders, R.M.C. Mestrom and A.C.F. Reniers are with the Eindhoven University of Technology, The Netherlands; e-mail: a.b.smolders@tue.nl). M. Geurts is with NXP Semiconductors.

2x2 sub-array, which can be seen as the unit cell of a larger array. The configuration of Fig. 1 generates Right-Hand-Circular (RHC) polarization at low-band operation and Left-Hand-Circular (LHC) polarization at high-band operation. The radiating element is a rectangular microstrip patch antenna of which the length L_p is approximately $\lambda/2$ at the lower frequency band and the width W_p is approximately $\lambda/2$ at the higher frequency band, where λ is the effective wavelength of the substrate on which the patch is printed. Each patch is fed by two microstrip lines which are coupled to the patch via slot-apertures in the ground plane. In this way, each of the elements can operate in two frequency bands. This particular choice increases the isolation between lower and upper band, eliminating the need of a duplexer. Note that the proposed concept also allows for other combinations of RHC and LHC polarization. The overall RF system including shared-aperture antenna and beamformers is shown in Fig. 2. The low-band and high-band signals are each connected to a feed network consisting of delay lines and three 2:1 Wilkinson power combiners. Optionally, additional electronic phase-shifters can be used to enable beam scanning and calibration. The main advantages of the configuration of Fig. 1 as compared to conventional solutions are its simplicity, compactness and the fact that mutual coupling between the elements is reduced. Moreover, its symmetry results in a low Axial Ratio (AR). Remaining systematic phase and amplitude errors could be further reduced by using the concept as proposed in [9]. Of course, there are also disadvantages of which the relevance depends on the final application. One of the main draw-backs of sequential rotation with LP antenna elements is that relative high sidelobes of cross polarization may appear in the diagonal plane ($\phi=45^\circ$) [6-8]. This effect strongly depends on the element spacing d , and is therefore a design parameter. Another option is to create a non-regular array of the 2x2 sub-arrays, possibly with additional sequential rotation of the sub-arrays. However, in our focus applications the main concern is the performance in the E-plane ($\phi=0^\circ$).

III. PROTOTYPE DESIGN AND EVALUATION

Our shared-aperture antenna prototype uses 4 GHz for low-

Fig.1. Shared-aperture array of slot-coupled microstrip patch antennas that generates CP radiation at two frequencies simultaneously using sequentially rotated LP dual-frequency antenna elements (top-view). At low-band frequencies, RHC polarization is obtained and at high-band frequencies LHC polarization.

band and 6 GHz for high-band operation. These relatively low frequencies allow for proving the concept, without running into technology issues which might occur at higher frequencies. Of course, our design can be scaled up to the 20/30 GHz band. A photograph of the 4/6 GHz prototype including the 2x2 array of ACMA radiators and both low- and high-band beamforming networks is shown in Fig. 3. The beamformer consists of Wilkinson power combiners and delay lines to create the required phasing for each array element according to Fig. 1. Note that our prototype demonstrates the concept only for broadside scan. All antenna related design parameters are summarized in Table I. The element spacing of $d = 35$ mm equals to $0.7\lambda_0$ at 6 GHz. In this way, grating lobes are avoided in both frequency bands over the required scanning range of $\pm 15^\circ$ in the $\phi=0^\circ$ plane. The input matching bandwidth ($S_{11} < -10$ dB) of the individual ACMA antennas is approximately 4.5% around f_l and 10% near f_h .

Fig. 2. Functional diagram of the shared-aperture 2x2 sub-array and the corresponding low-band and high-band RF beamforming networks. The phase-shifters in the beamforming networks generate the required phases for creating RHC polarization for low-band operation and LHC polarization for high-band operation. Optionally, additional electronic phase-shifters and variable gain amplifiers can be added to each branch of the beamforming networks to enable beam scanning and electronic calibration.

Fig.3. Photograph of the prototype including the 2x2 array. The low-band (f_l) and high-band (f_h) feed network is located on the backside of the ground plane. Ground plane size is 150x150 mm².

Fig. 4. Top- and side-view of the Aperture Coupled Microstrip Antenna (ACMA).

TABLE I
Optimized parameters of the ACMA sub-array.

Parameter	Description	Value [mm]
L_p	Length of patch	17.5
W_p	Width of patch	10.2
S_{sl}	Width of slot (low-band)	1.5
S_{vl}	Length of slot (low-band)	10.5
S_{sh}	Length of slot (high-band)	9.3
S_{vh}	Width of slot (high-band)	1.5
L_{sl}, W_{sl}	Center position of slot (low-band)	(11.55, 5.75)
L_{sh}, W_{sh}	Center position of slot (high-band)	(4.2, 6.7)
W_m	Width of microstrip lines	1.8
$L_{sub,l}$	Length of microstrip stub (low-band)	11.9
$L_{sub,h}$	Length of microstrip stub (high-band)	4.6
d	Element spacing in sub-array	35
h_1	Height of layer 1	0.813
h_2	Height of layer 2	3.048
ϵ_r	Dielectric constant of layer 1 and layer 2	3.55

As a first step in the evaluation of the prototype, the return loss of the 2x2 array with 4 GHz and 6 GHz feed network was measured and compared with simulations. Fig. 9 shows the results for the low- and high-band mode of operation. In both cases there is a quite good agreement between measurement and simulation (with ADS Momentum [14]). We believe that further optimization of the high-band mode of operation is possible, for example by using a different stack of substrate

layers. However, for our functional demonstrator the return loss performance as shown in Fig. 5 is sufficient.

Fig.5. Measured and predicted S_{11} at low-band and high-band.

Next, the radiation properties of the 2x2 array were measured in an anechoic antenna facility. The measured and predicted co- and cross-polar patterns are shown in Fig. 6 for both modes of operation. The gain of each individual antenna element is about 5.1 dBi at 4 GHz and 5.4 dBi at 6 GHz, excluding the losses in the beamformer networks. The axial ratio is shown in Fig. 7. The agreement between measurements and simulations is excellent in the low-band mode. The measured AR is below 1.2dB over a θ range of 41.5^o around broadside. In the high-band mode the cross-polar level is somewhat larger than expected, with clear peaks around $\theta = \pm 20^o$. The AR around broadside is, however, quite low (AR < 1dB). The cross-polar peaks around $\theta = \pm 20^o$ and the slightly reduced co-polar beam width are due to surface wave diffraction at the edges of the grounded dielectric slab. Diffraction from the edges of the ground plane will also occur in the low-band mode, but is less severe since the relative thickness of the substrate is smaller. When our 2x2 sub-array is used as a building block in a larger array on a large ground plane, the effect of diffraction will be reduced. In addition, electromagnetic bandgap (EBG) structures could be used to reduce this effect [15]. Next to this, a calibration technique with active electronics [9] could be applied on element or sub-array level to improve the axial ratio and to enable beam scanning. The measured isolation between the low- and high-band ports of the individual antenna elements is larger than 26 dB.

Fig.6. Measured and predicted co- and cross-polar patterns for low-band (4 GHz) and high-band (6 GHz) operation.

Fig.7. Measured and predicted Axial Ratio (AR) for low-band (4 GHz) and high-band (6 GHz) operation.

IV. CONCLUSION

In this paper we have shown that a compact shared-aperture array can be constructed that operates at two frequency bands simultaneously and generates orthogonal circular polarization. A novel implementation of the sequential rotation technique provides excellent circular polarization properties of a 2x2 array of dual-frequency aperture-coupled microstrip antennas (ACMA). The concept was demonstrated with a prototype consisting of a 2x2 sub-array of ACMA radiators and the low- and high-band feed networks. The measured AR was well below 1.2 dB for both the low-band (4 GHz) and the high-band (6 GHz) mode of operation at broadside. The isolation between both bands is larger than 26 dB, eliminating the need of high-performance duplexers in the overall system. The high-band mode of operation is limited by edge-diffraction due to surface-waves. The performance can be further improved by applying EBG structures to reduce the edge diffraction and/or by applying calibration using active phase shifters and variable gain amplifiers. The addition of active phase shifters will also enable beam scanning.

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