Ultra-Wideband Dual-Circularly Polarized Array with Simple Cost-Effective Feeding Network

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Abstract — A dual-circularly polarized hexagonal array operating over multi-octave bandwidth with cost-effective feeding network is presented. A four-arm spiral antenna with two planar Klopfenstein microstrip feeds is used as a unit cell. The 7-element array is fed by two 7-way power dividers and a single 90° hybrid. The used feeding network in conjunction with fundamental properties of a four-arm spiral supports left and right hand circularly polarized operation over more than 3:1 bandwidth. The performance of the feeding network, frequency and time-domain characteristics of the proposed array are demonstrated through simulation and comprehensive measurements.

Index Terms — Corporate feed, circular polarization, spiral antenna, ultra-wideband.

I. Introduction

Ultra-wideband (UWB) circularly-polarized (CP) arrays are receiving growing interest for wide range of applications including pulsed through-wall imaging, ground penetrating radar, and communication systems [1]. The design thereof is however quite challenging and it is commonly done in a single (frequency or time) domain. While the recent resurgence of wideband arrays based on closely coupled elements is of interest, typically joint time/frequency operation is desired over pulse/RF bandwidth of up to 4:1. Additionally, the individual functionality of a single element is lost which can be a limiting factor when smartness or multi-functionality is desired. Thus, the classical approach based on a single wideband element and control of element-to-element spacing for the level and appearance of side and grating lobes, respectively, should be revisited.

In this paper, a hexagonal 7-element four-arm spiral antenna array able to perform equally well in frequency and time domain over at least 3:1 bandwidth is demonstrated for the first time. New feeding scheme is proposed to alleviate the cost/complexity issues associated with four-arm spirals while at the same time enabling a crucial design/performance tradeoff: a very high growth rate so important for achieving low-dispersion performance while maintaining superior far-field performance of multi-arm spirals.

II. Design Description

A conventional beamformer for a mode 1 four-arm spiral has two 180° and one 90° hybrids as shown in Fig. 1(a). Complexity, high cost, and overall bandwidth of this network are main reasons for the lack of wide spread use of electrically much superior (to two-arm counterparts) four-arm spirals. To reduce the complexity of the feed network, a microstrip feed of the four-arm spiral antenna is developed as shown in Fig. 1(b). In this design, two planar microstrip impedance transformers having Klopfenstein taper are used to feed the two opposite arms of the antenna. The metallic spiral arms are the ground plane for the microstrip having 50 Ω impedance at one side and 140 Ω at the other side (antenna input). This way the need for 180° hybrids is eliminated.

The proposed array (shown in Fig. 2) is hexagonal and composed of 7 four-arm slot spirals with discussed microstrip feeds. To achieve good time-domain response, impedance match and small feed loss, the single-turn Archimedean four-arm spiral with 70/30 metal to slot ratio is designed. The array is fabricated on 20 mils thick Rogers RO3003 substrate ($\varepsilon_r = 3, \tan\delta = 0.0013$).

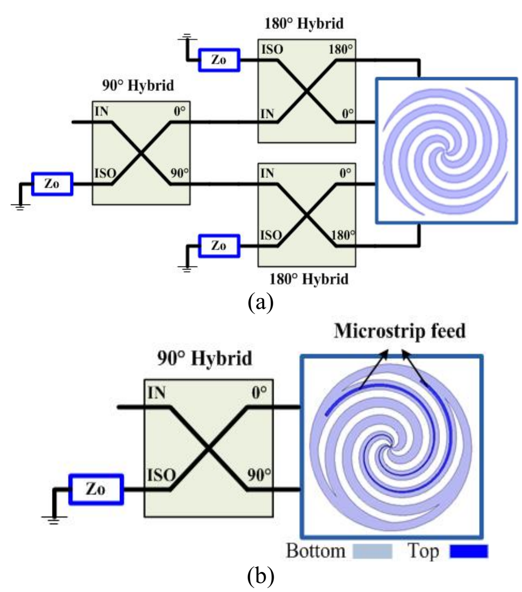

Fig.1. (a) Conventional way to excite mode 1 operation of a four-arm spiral antenna (b) Proposed microstrip feeding technique to reduce the mode-former complexity.

The block diagram of the array feeding network is shown in Fig. 2. The designed corporate feeding network consists of two 7-way power dividers and a single 90° hybrid. This

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configuration enables both left hand (LHCP) and right hand (RHCP) circularly polarized operation by exciting a proper port of the 90° hybrid.

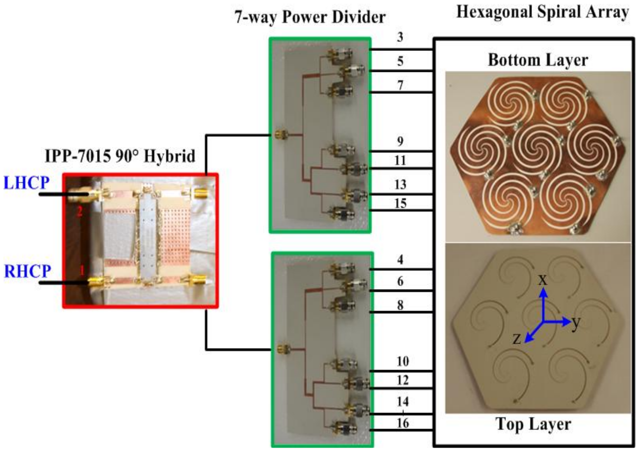

Fig.2. Array's schematic with photographs of individual array building blocks.

The 7-way equally-split microstrip power divider is based on the design in [2] and is also realized on a 20 mils thick Rogers RO3003 substrate. Microstrip impedances in all phase-matched branches are shown in Fig. 3. For ease of integration and desired power/bandwidth the chosen 90° hybrid is surface mountable IPP-7015 operating over 1 GHz-4.2 GHz range with VSWR< 1.3 and isolation >18 dB. It has amplitude and phase balance of $\pm$ 0.6 dB and $\pm$ 5°, respectively.

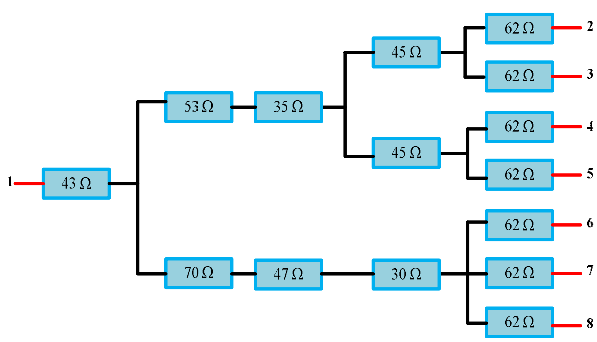

Fig.3. Impedances of the realized 7-way equal-split power divider.

III. Results and Discussion

Measured magnitudes of S-parameters and output phase differences of the feeding network are shown in Fig. 4. As seen, the reflection coefficient ≤ -16 dB and isolation > 13 dB are measured over the desired bandwidth of operation. Amplitude and phase imbalances of 1.2 dB and 10°, respectively, are also obtained.

The measured reflection coefficient and coupling between the RHCP and LHCP ports when the feeding network is connected to the array are shown in Fig. 5. At both ports, VSWR < 1.5 is seen over the most operating bandwidth. However, the coupling between the two polarization channels is quite high at frequencies < 1.8 GHz. This is due to the higher active VSWR at the element ports at the low-frequency end ($2 \leq \mathrm{VSWR_{active}} \leq 3.2$). The approaches considered to overcome this issue include increasing the size of the spiral antenna (i.e. unit cell) which can improve the impedance match; however, the array's bandwidth will be reduced since the spacing between the elements will increase. The second approach is based on terminating the spiral arms with resistors; at the expense of completely eliminating the array operation in other circularly polarized mode. Enhancing the isolation between the two polarization channels is currently under investigation.

The proposed array is absorber-backed, and is thus aimed for low-power applications. The array's far-field performance is measured for both polarizations and normalized radiation patterns at 2 GHz and 3 GHz are shown in Fig. 6. Broadside axial ratio below 1 dB is measured over 4:1 and 3:1 bandwidth in the case of RHCP and LHCP, respectively. The highest side lobe level (SLL) of -10 dB is obtained at 4 GHz.

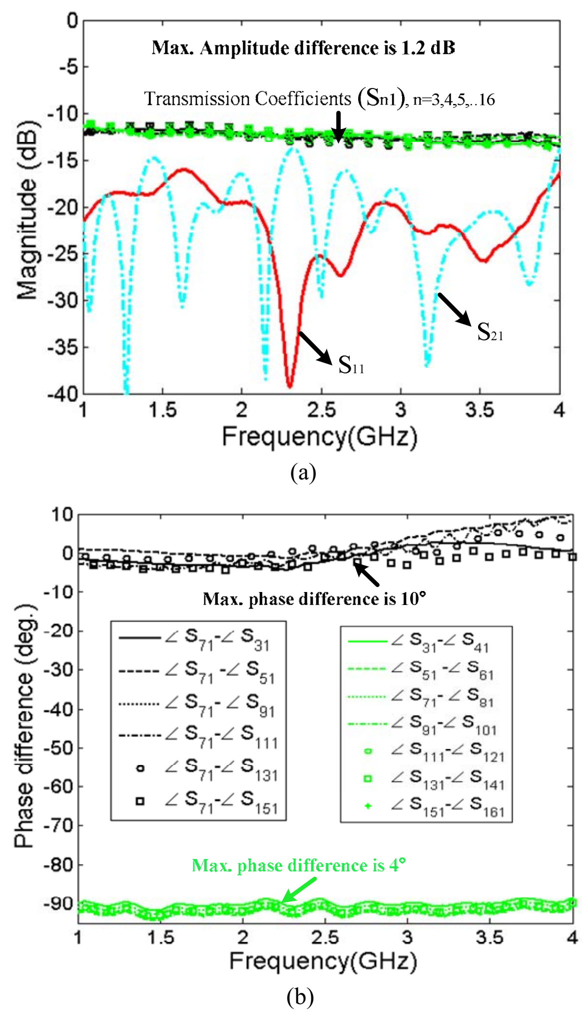

Fig.4. (a) Magnitude of S-parameters of the feeding network shown in Fig.2 (Dark-color curves: Odd-number ports; Light-color curves: Even-number ports).(b) Phase difference.

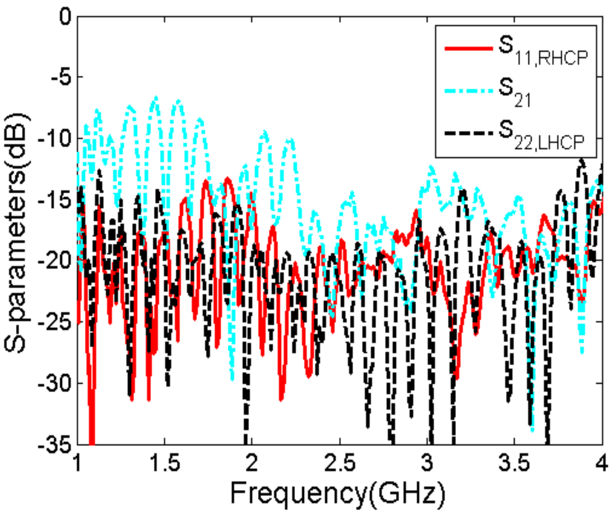

Fig.5. Measured reflection coefficients and the isolation when feeding network is connected to the array.

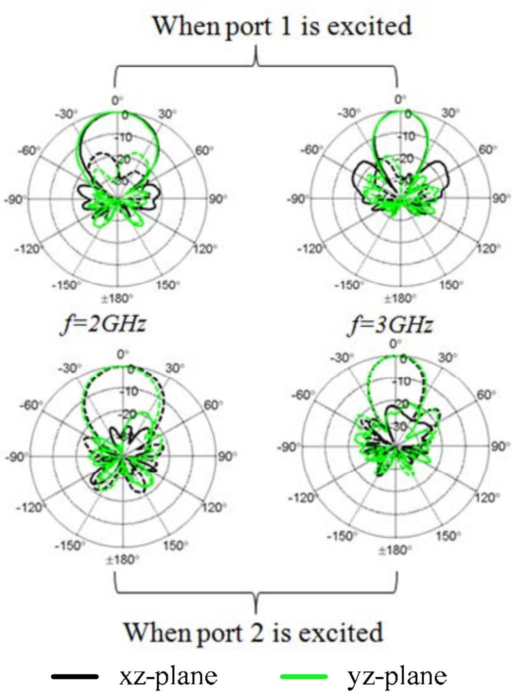

Fig.6. Measured radiation patterns of the array at two frequencies for both polarizations (Solid lines: RHCP, Dashed lines: LHCP).

To characterize the array's time-domain performance, the fidelity factor (FF) is used. FF is defined as the normalized maximum cross-correlation between the input and the radiated pulses [3]. First, the transmitting transfer function of the array is synthesized from the measured radiated electric fields and realized gain [3]. Then, the excitation in lieu of the second derivative Gaussian pulse having 10 dB power spectral density bandwidth from 0.90 GHz to 4.6 GHz is applied. Finally, the inverse Fourier transform is computed to obtain the radiated pulses at any direction over the full field of view. The measured and simulated fidelity factors (averaged over 61 azimuthal cuts from 0° to 180°) are shown in Fig. 7. As seen, high values are achieved over wide field of view indicating array's very good time-domain performance. As expected, due to its wider bandwidth, higher fidelity factor is achieved with RHCP mode of operation. The time-domain simulations are carried on in the CST-MWS environment.

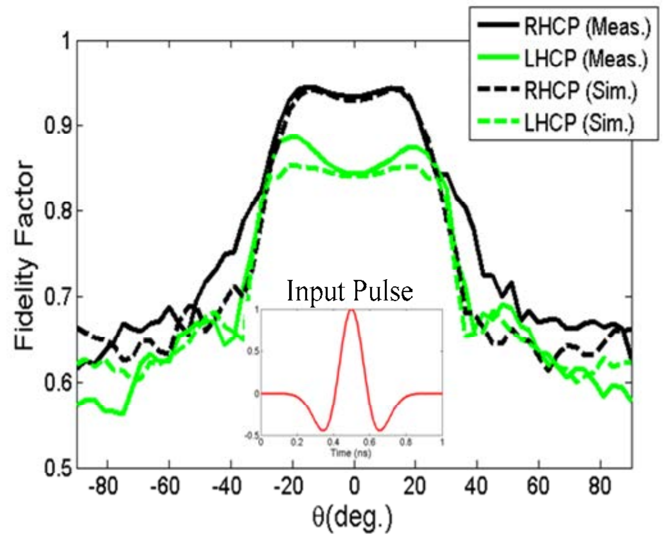

Fig.7. Measured and simulated average fidelity factors over 61 azimuthal cuts for the input second derivative Gaussian pulse (shown in the inset) for the two polarizations.

IV. Conclusion

A dual polarized ultra-wideband four-arm spiral antenna array with simple feed is demonstrated. The developed planar microstrip feed of antenna element leads to the reduced complexity of the feeding network making the array of this kind for the first time economically feasible to consider. The performance of the complete array system is assessed experimentally and numerically. Simultaneously good time- and frequency-domain performances are demonstrated for both polarizations. Enhanced isolation between the two polarization channels and the phased array realization are currently being researched.

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