URSI GASS 2021, Rome, Italy, 28 August - 4 September 2021

A ten element sequentially fed sub-array for circular polarization links in C-band

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Abstract

This paper presents a pentagonal array composed of ten elements for operation at 5.8 GHz. The proposed device operates in circular polarization exploiting the sequential rotation architecture applied to five pair of disc-based patch elements.

A pentagonal sub-array is well-suited to be packed in icosahedral arrangement, which in turn is the ideal shape for smart antennas with wide angle spatial coverage. A single layer via-less prototype is simulated on a FR408 substrate. A realized gain up to 11.6dBi with a polarization purity exceeding 30 dB at 5.8 GHz is observed.

1 Introduction

Sequential rotation arrangement (SRA) is a well-known technique for the design of Circularly Polarized (CP) Array. The SRA rationale consists in the arrangement of N progressively rotated antennas with suitable progression of phase and relative geometric position at the same time [1, 2].

The typical SRA array found in literature is based on 4 elements or possibly other powers of 4, since they are easier to design and implement [3, 4, 6]. In [7] a five element sequential array shaped as a pentagon was implemented. Later, in [8], a six element sequential array shaped as a hexagon was implemented. These shapes are suitable for the arrangement of more complex structure, such as the dodecahedron and the truncated icosahedron.

Here, the design proposed in [7] is enhanced increasing the number of element to 10. The elements are arranged to fit on a single-layer pentagonal substrate, for the maximum compatibility with the cited polyhedral structures.

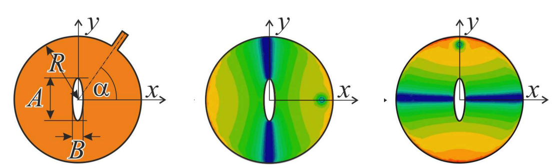
Considering the importance of C-band for many applications (802.11xy WiFi from 4.9 to 5.7 GHz, WAVE protocol at 5.9 GHz, Dedicated Short Range Communications at 5.8 GHz, Mid-Band 5G), this frequency band will be considered. In particular, the proposed sub-array is optimized for the frequency of 5.8 GHz. A maximum gain of 11.6 dB is estimated, with a polarization purity exceeding 30 dB.

2 Antenna Element

The antenna element involved in the present sub-array structure has already been proposed for C-band communications [5] and has been exploited in configurations exhibiting 4, 5 or 6 elements, [6, 7, 8]. Hence, it is hereinafter only briefly summarized. A disc patch operating with the fundamental TM_{11} mode is the source of a broadside directional beam. Normally, it is characterized by linear polarization [9, pp. 318–324].

The introduction of a perturbation, such as a slight asymmetry, creates the condition for the degeneration of the TM_{11} fundamental mode into two orthogonal ones. When the two degenerate modes, labeled TM_{1e} and TM_{1o}, are appropriately excited in phase quadrature with the same intensity a Circular Polarization (CP) is achieved.

With reference to Fig. 1a, the degeneration driver is the elliptically shaped central cut, which have axes A and B, while the disc radius is indicated by R.



(a) geometry **(b)** TM_{1e} mode **(c)** TM_{1o} mode

Figure 1. Pictorial representation of the modes of a disc centrally slitted with an elliptical cut operating in modal degeneration.

3 Sequential Rotation Architecture

With reference to Fig. 2, the core of SRA implementation is the sequential phase network (SPN), a six port network which provides the needed geometrical and electrical phase progression, as well as equal power at each output port.

The SPN comprises a cascade of four transmission lines in series with characteristic impedance Z_i and electrical length θ_i, $i = 1\ldots,4$. Five shunt output lines are characterized by impedances Z_i^o and electrical lengths θ_i^o, with $i = 1\ldots,5$. Furthermore, five stubs are placed in correspondence of the five junctions, to reduce series line lengths (impedances Z_i^s, electrical length θ_i^s).

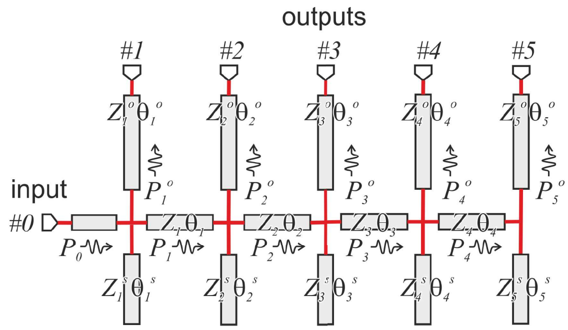


Figure 2. The sequential phase network.

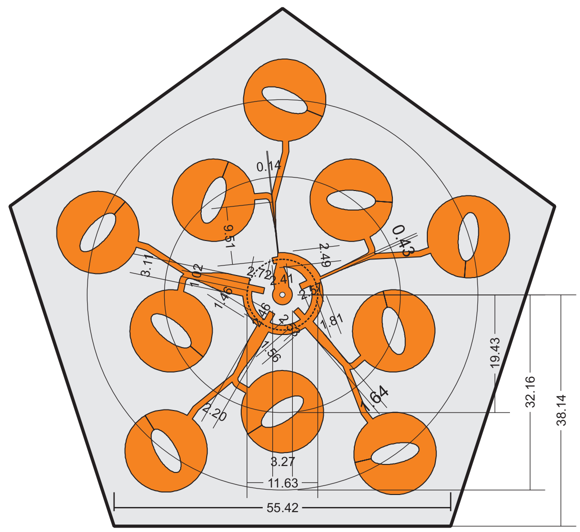


Figure 3. Quoted layout of the ten element sequential sub-array. All dimension in mm.

Following the approach in [7, 8], the synthesis of the feeding network is here addressed via numeric optimization on a custom cost-function. In the ideal case, the six output transmission parameters S_n exhibit identical module $\widehat{S_n} = \frac{1}{\sqrt{5}}$ as well as identical phase sequential increment equal to $\angle S_{n+1} - \angle S_n = 2\pi/5$. Therefore, it is assumed a relative error metric which measures the distance between such an ideal value and the numerically computed one, S_n, at each step. For every single output the error is:

$$E_n = \frac{|\widehat{S_n} - S_n|}{|S_n|} \tag{1}$$

And their sum provides the error metric for the whole network.

This approach, driven by an opportune optimization algorithm, [10] allows for the balance of both the magnitude and the phase at the same time at each port.

4 Assembly and Simulation

With reference to Fig. 3, to successfully assemble the set of ten discs elements, the patches are evenly distributed within the pentagon, roughly in correspondence of intersection points for a five-point star. Each output line is hence connected to a pair of antenna elements. The input line of the SPN is located at the center of the pentagonal substrate. The series TLs arranged as circular arcs. Dimensions are given on the figure in millimeters.

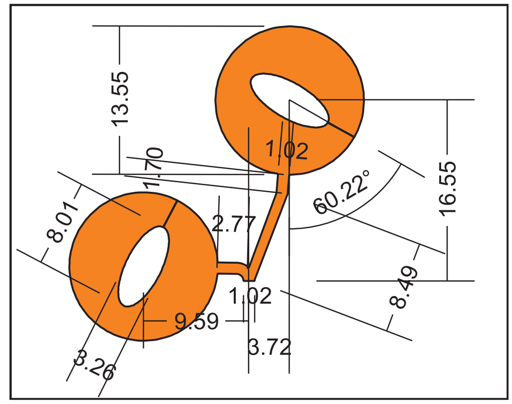


Figure 4. Quoted layout of the pair of elements (detail). All dimension in mm.

With reference to Fig. 4, the part of sub-array comprising two element sharing the feed is shown with higher detail, again with dimensions given in millimeters. It is worth noticing that the five two-element structures used are all identical.

Simulations were carried out considering commercial FR408 substrate for the sub-array (thickness = 1.6 mm, ε_R = 3.65, $\tan\delta$ = 0.01). The final design, optimized for best gain at 5.8 GHz, is arranged inside a pentagon of side 55 mm.

Figure 5 shows the reflection coefficient of the proposed array. Return loss exceeding 16 dB is observed at 5.8 GHz and it is above 15 dB in the 5.75–6.21 GHz range, that is a 7.6% band.

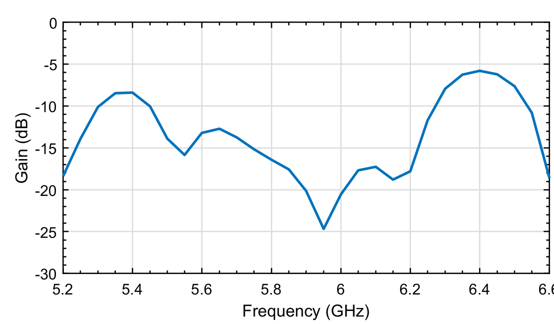


Figure 5. Reflection coefficient in the band of interest.

Figure 6 depicts the gain pattern at 5.8 GHz, measured over the x-cut and y-cut. Adequate symmetry of the main lobe is observed, as well as an high gain exceeding 11.6 dB.

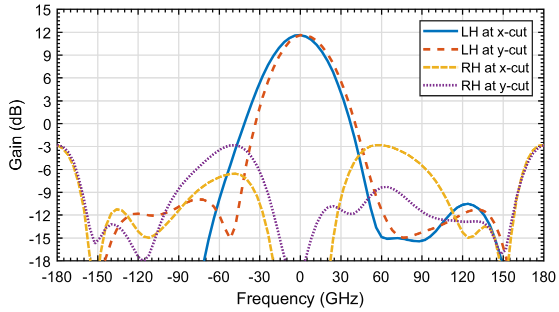


Figure 6. Realized gain pattern at 5.8 GHz.

Figure 7 shows the realized gain in boresight position for a wide span of frequency. The left-hand, right-hand and total component are considered. An extreme flatness of the gain response between 5.75 GHz and 6.21 GHz is observed.

In addition, the Right Hand component, which is the cross-polar is very modest over the same bandwidth. The RH component minimum is at -20 dB at the design frequency of 5.8 GHz. The cross polarization ratio hence exceeds 30 dB at the frequency of 5.8 GHz and is anywhere better than 15 dB in the 5.75–6.21 GHz band.

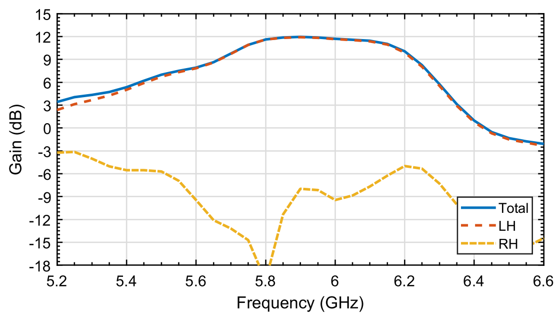


Figure 7. Realized gain versus frequency in the band of interest.

5 Conclusions

A design for a broadband CP antenna array for mid-band 5G applications has been proposed and simulated. The array is based on the concept of sequential rotation architecture combined with splitters and pairs of elements for each output port of the SRN.

The size of the device is $43.83\,\mathrm{cm}^3$, and it is compatible with the use of cheap commercial substrate. The antenna is implementable in mobile nodes either for 5G operation or vehicular communication.

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