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Investigation on Using CPSS Elements in Dual Circular Polarization Reflectarray Antennas

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Abstract—In this paper, properties of three types of Circular Polarization Selective Surface (CPSS) cells including Pierrot, Morin, and Tilston, for using in dual circular polarization reflectarray antenna design are investigated. First they are designed for a center frequency about 10 GHz, and circular polarization properties including Reflection Loss, Transmission Loss, Reflected Axial Ratio, and Transmitted Axial Ratio are calculated and presented. Finally, reflection phase curves are presented, and the comparison between simulated properties is accomplished. Simulations show that Tilston cell is more optimum in dual circular polarization reflectarray antennas.

1. INTRODUCTION

The rapid growth of satellite communication has stimulated intensive research concerning medium and high gain planar antennas. Microstrip antennas are considered as an obvious choice for such an application due to their low cost, low weight and low profile [1]. Many of the applications in space-based systems and personal electronic devices have strict restraints on the size and weight of the antenna element, favoring a low-profile, lightweight device [2]. In such cases, circular polarization (CP) is usually preferred to prevent from losses due to polarization rotation, as there is no need to align the transmitter and receiver [3]. The receiving antenna must instead be specifically designed to receive (or transmit) Left Hand Circular Polarization (LHCP) or Right Hand Circular Polarization (RHCP), and the antennas must simply be pointed at each other. Several circularly-polarized unit-cells have been proposed in the literature using either a linearly-polarized [4] or circularly-polarized [5] incident wave.

As the handedness of CP wave is reversed when it is reflected off a mirror, which cannot be received by the transmitting antenna according to the antenna theory [6], it has the advantages of restraining interference from rain and fog, suppressing multipath effect, etc. In some satellite communication systems, different circular polarizations are required, i.e., left-hand circularly polarized (LCP) wave for the up-link and right-hand circularly polarized (RCP) wave for the down-link at Ku band. The usual method for the above requirement is to design two antennas with different circular polarizations as transmitter and receiver, respectively.

A simple configuration to receive two different polarizations on a satellite can be seen on the left in Figure 1. In this arrangement, a plane wave containing both polarizations is focused using two solid parabolic dish reflectors onto two different receiving antennas, and one of which will pick up the LHCP signal and one the RHCP signal. This is however a large and heavy arrangement using two reflectors, so instead, a system, as can be seen on the right, would be preferred.

In this arrangement a two-layered reflector would be used [7]. The first layer would reflect one polarization onto a suitable antenna, while at the same time it is invisible to the other polarization. The other layer would then focus the remaining polarization onto the other antenna. For linear polarization, this could be achieved using a Dual-Gridded Reflector (DGR). A DGR, however, does not work for

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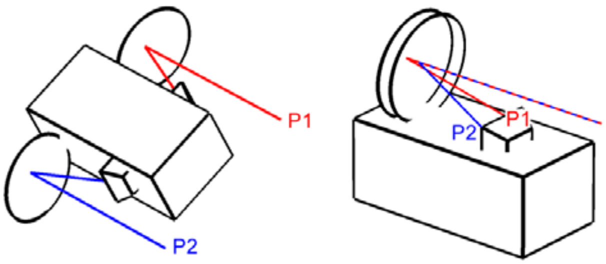

(a) (b)

Figure 1. (a) An antenna arrangement using two solid reflectors and (b) an arrangement using a single CPSS reflector to separate the polarizations. Figure based on concepts from [7].

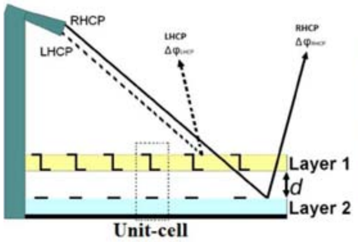

Figure 2. Schematic representation of the reflectarray with Independent control of both incident circular polarizations.

circular polarization, so creating a DGR equivalent would be desirable [8]. One way to do this would be to make the reflector out of a Circular Polarization Selective Surface (CPSS) which would ideally function exactly as desired: one polarization would be completely reflected by the surface and one would be completely transmitted. Such surfaces can be constructed [9]; however, whether their performance is good enough to construct a proper reflector out of them is unclear.

The arrangement can be more suitable for satellite communication in weight and cost. This can be done using reflectarray antenna instead of solid parabolic reflectors. reflectarray antennas are very attractive for a number of applications. Cost and fabrication process are reduced using printed technology.

Many passive unit cells have already been proposed for circularly polarized reflectarrays. They use either a linearly polarized incident wave [10–13] or a circularly polarized one [14–17]. Excellent performance has been reported for single circular polarization in X-band by using multiple-resonance broadband elements (bandwidth of 14% in [18] and even up to 18% in [19]). However, dual circular polarization has only been demonstrated by using a different frequency band for left-hand CP (LHCP) and right-hand CP (RHCP) [20–23]. One idea consists in designing a unit cell with two different layers, each of them operating in one frequency band. Obviously, in such configurations, the upper layer should be transparent in the other frequency band. On the other hand, a few reconfigurable configurations in CP have also been reported by using a CP incident wave [23–26].

Proposed configuration in this paper is shown in Figure 2. The top layer of this reflectarray antenna is made of CPSS cells that reflect LHCP signal and pass the RHCP signal. The bottom layer consists of RHCP reflectarray cells that reflect the RHCP signal transmitted through top layer. There are three basic types of CPSS unit cells ever presented, Pierrot, Tilston and Morin. All others are derivations of these cells. So we have an investigation on properties of these cells conformal to reflectarray requirements.

All simulation is done using frequency domain solver of CST software package with numerical accuracy of 1e-4 and boundary condition of unit cell.

2. PIERROT CELL

The oldest known design was first introduced by Pierrot in a French patent in 1966 [27]. It is the simplest of the designs and is essentially a bent wire as can be seen in Figure 3.

Pierrot cell is simulated using commercial software CST studio suit and optimized for center frequency of 10 GHz with parameters shown in Figure 3. The best parameters were found as: $l_{xy} = 13.590\,\text{mm}$ ($\approx 0.45\lambda$), $l_z = 7.508\,\text{mm}$ ($\approx 0.25\lambda$), $p_x = 13.328\,\text{mm}$ ($\approx 0.44\lambda$), $p_y = 11.929\,\text{mm}$ ($\approx 0.40\lambda$) and $a = 0.362\,\text{mm}$ that is wire diameter. Results such as Insertion Loss (IL), Reflection Loss (RL), Axial Ratio Transmission and Axial Ratio Reflection are obtained against frequency for various incident angles up to 30° and shown in Figure 4.

The Pierrot cell performs differently for positive and negative angles of incidence (although only for the AR). This demonstrates a lack of symmetry with respect to positive and negative angles of incidence in this plane, and means that one needs to think about which side the incoming waves are hitting in

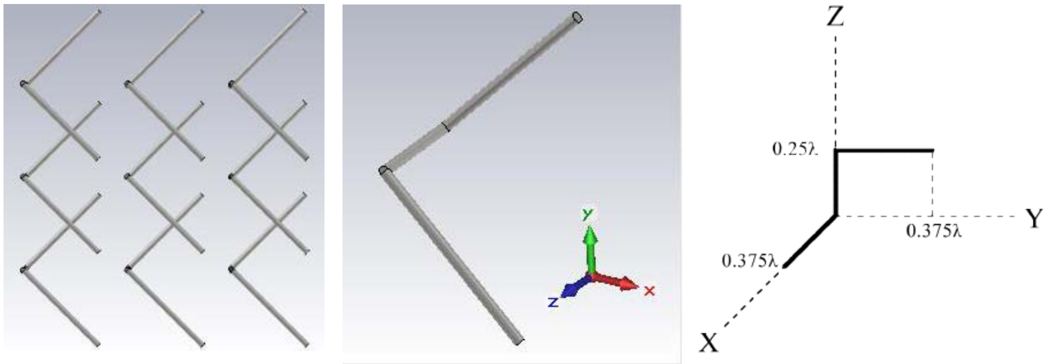

Figure 3. Geometry of a Pierrot cell and simulation in CST software. The figure depicts an LHCPSS (assuming the wave is travelling in the positive z-direction).

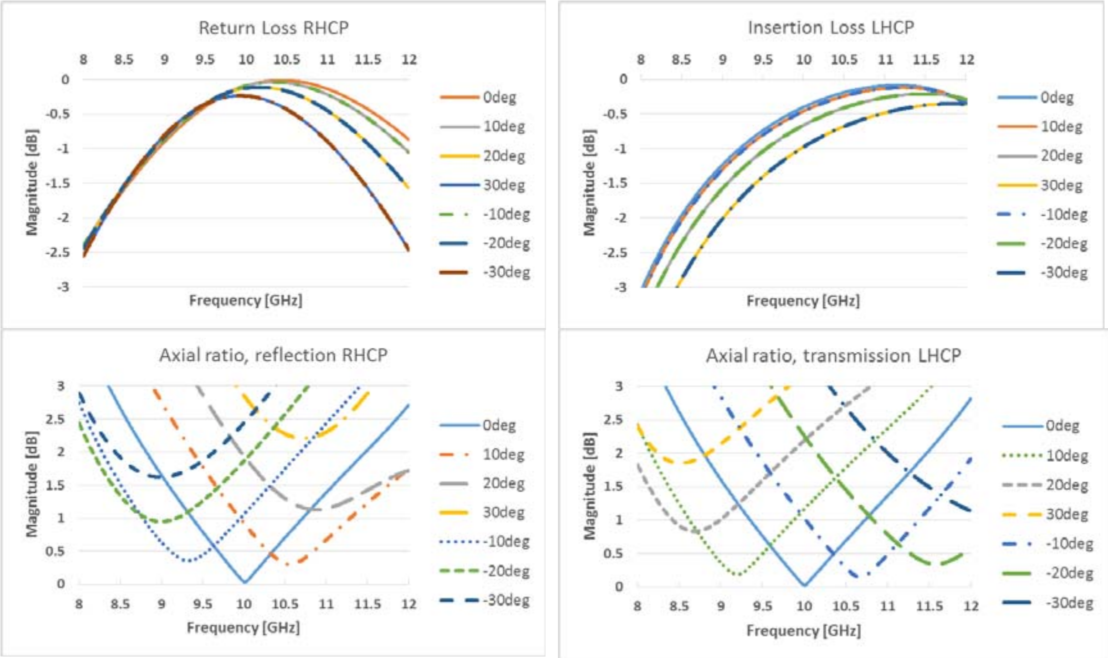

Figure 4. Insertion Loss (IL), Reflection Loss (RL), Axial Ratio Transmission and Axial Ratio Reflection of Pierrot cell.

Figure 5. Reflection Phase of Pierrot cell against rotation about z-axis.

order to get the expected performance. The impact on the IL and RL performance is minimal at up to 10° and could probably be manageable even at 20°. The AR, however, experiences a strong frequency shift which means that even at 10° the impact is notable. A 0° to ±10° could probably be manageable in spite of reduced AR bandwidth.

Another parameter that should be obtained is reflection phase curve for using in reflectarray antenna design. The elements are individually phased to achieve a desired radiation beam. The methods to obtain a proper phase control include the delay line technique [28], variable element size technique [29] and element rotation technique [30]. Various parameters are changed and reflection phases obtained. If we change l_{xy} parameter, 360° phase shift is obtained, but IL and RL are strongly increased. L_z also has impact on center frequency and cannot be used for this purpose. However, the element rotation technique introduces element phase compensation independent of the frequency, which provides a possibility to build reflectarrays.

So reflection phase of Pierrot cell has been calculated using rotation cell about z-axis. The results can be seen in Figure 5. It shows that one cycle about 360° with rotation of Pierrot cell can be obtained.

3. TILSTON CELL

The second design was introduced by Tilston [27]. Like the Pierrot cell, it relies on the linear components of the circularly polarized wave and a quarter wavelength. The Tilston cell consists of two dipoles, connected together by a transmission line as can be seen in Figure 6. Which end of the dipoles (upper or lower) connected together by the transmission line determines whether it is an LHCPSS or RHCPSS.

Tilston cell is simulated and optimized for center frequency of 10 GHz with parameters shown in Figure 6. The best parameters were found as: $l_{xy} = 16.399\,\text{mm}$ ($\approx 0.55\lambda$), $l_z = 7.121\,\text{mm}$ ($\approx 0.24\lambda$), $p_x = 12.47\,\text{mm}$ ($\approx 0.42\lambda$), $p_y = 12.53\,\text{mm}$ ($\approx 0.42\lambda$), $D = 3.934\,\text{mm}$ that is dielectric cylinder diameter,

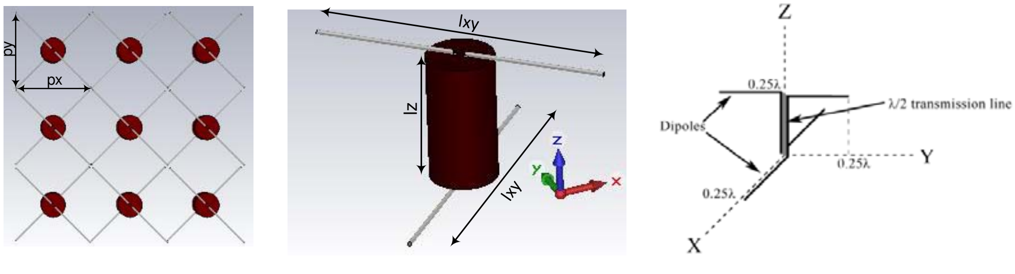

Figure 6. Geometry of a Tilston cell and simulation in CST software. The figure depicts an LHCPSS (assuming the wave is travelling in the positive z-direction).

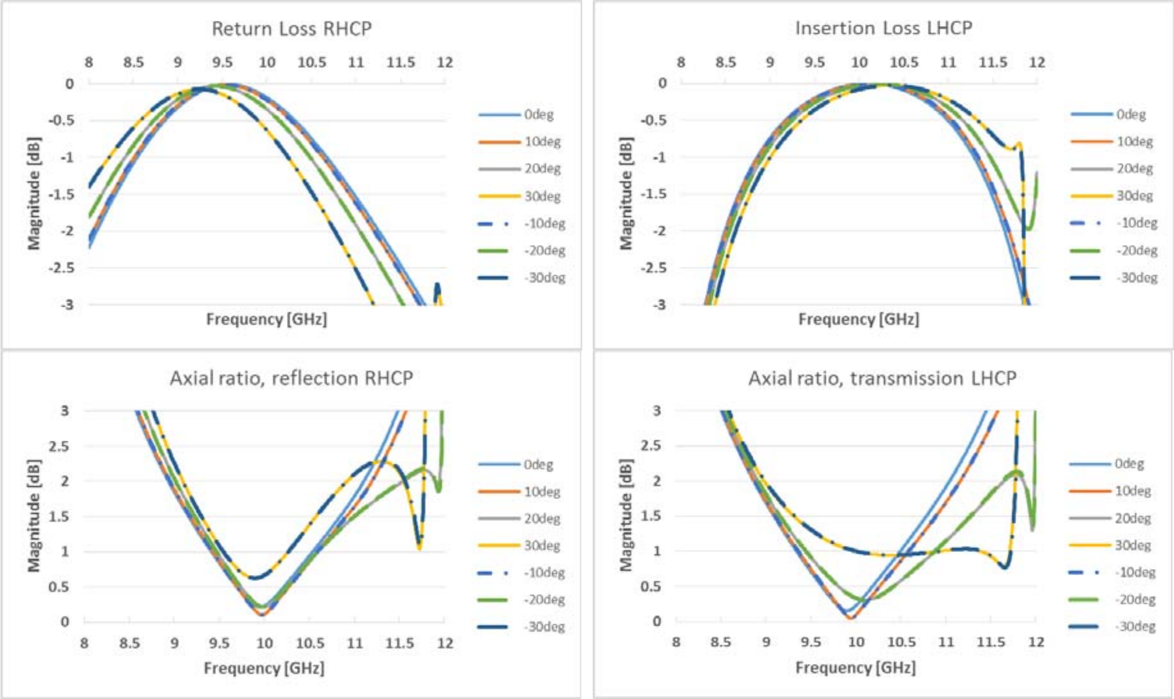

Figure 7. Insertion Loss (IL), Reflection Loss (RL), Axial Ratio Transmission and Axial Ratio Reflection of Tilston cell.

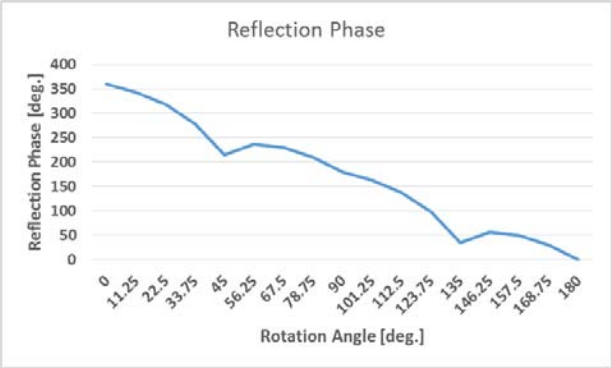

Figure 8. Reflection Phase of Tilston cell against rotation about z-axis.

$a = 0.257\,\text{mm}$ and $\varepsilon = 4.267$ that is dielectric relative permittivity. Again results such as Insertion Loss (IL), Reflection Loss (RL), Axial Ratio Transmission and Axial Ratio Reflection are obtained against frequency for various incident angles up to 30° and shown in Figure 7.

The Tilston cell performs identically for positive and negative angles of incidence. This demonstrates symmetry with respect to positive and negative angles of incidence in this plane. As such, if the permittivity cannot be freely chosen to any desired value, it is possible to design the rest of the structure around the available material. The IL is quite good, as is the RL. The AR has a slightly lower bandwidth than the Pierrot cell which means that overall the performance is slightly worse.

As before reflection phase curve for using in reflectarray antenna design should be obtained. Again the element rotation technique is used. So reflection phase of Tilston cell has been calculated using rotation cell about z-axis. The results can be seen in Figure 8.

Figure 8 shows that one cycle of 360° with rotation of Tiston cell can be obtained. The curve is not as smooth as Pierrot cell.

4. MORIN CELL

The final design was introduced by Morin [31] and is different from the other two previous cells. In the Morin cell, each of the cells is interconnected to nearby cells and forms a long helix-like structure as can be seen in Figure 9.

Morin cell is simulated again using CST and optimized for center frequency of 10 GHz with parameters shown in Figure 9. The best parameters were found as: $l_{xy} = 14.36\,\text{mm}$ ($\approx 0.48\lambda$), $l_z = 7.5\,\text{mm}$ ($\approx 0.25\lambda$), $p_x = 20.31\,\text{mm}$ ($\sqrt{2}\cdot l_{xy}$), $p_y = 4.062\,\text{mm}$ ($0.2\cdot\sqrt{2}\cdot l_{xy}$) and $a = 0.245\,\text{mm}$. Results

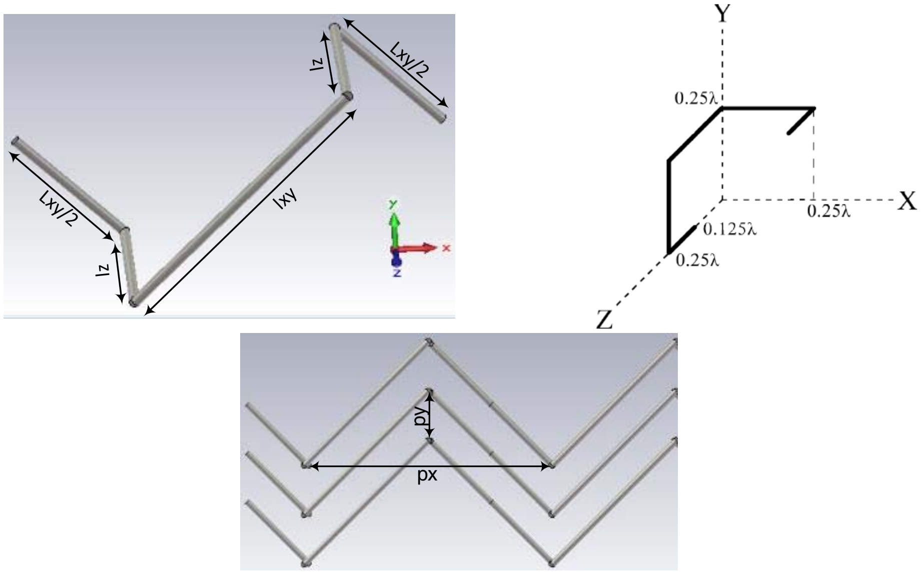

Figure 9. Geometry of a Morin cell and simulation in CST software. The figure depicts an LHCPSS (assuming the wave is travelling in the positive z-direction).

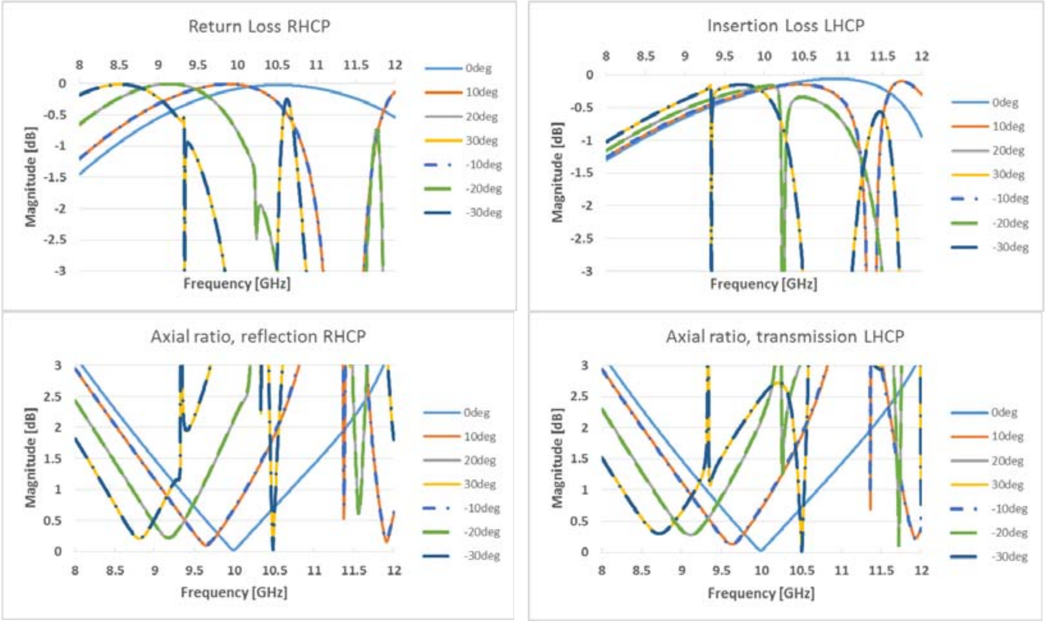

Figure 10. Insertion Loss (IL), Reflection Loss (RL), Axial Ratio Transmission and Axial Ratio Reflection of Morin cell.

such as Insertion Loss (IL), Reflection Loss (RL), Axial Ratio Transmission and Axial Ratio Reflection are obtained against frequency for various incident angles up to 30° and are shown in Figure 10.

The Morin cell performs identically for positive and negative angles of incidence. This demonstrates symmetry with respect to positive and negative angles of incidence in this plane. In order to increase the RL bandwidth, the helices are placed very close together, which is also the cause of the odd shape of the IL.

As before the elements should individually phased to achieve a desired radiation beam. Because of introducing high losses and array type of this cell, there is no technique for obtaining reflection phase curve. So this cell is not suitable for reflectarray design.

5. CONCLUSION AND REMARKS

An investigation on using CPSS cell on dual polarized reflectarray antenna is presented. Required curves and properties of three basic types of CPSS cells, including Pierrot, Tilston and Morin, are obtained. Since Morin cell cannot rotate, there is no optimum way to use this cell in reflectarray antenna because of introducing high loss.

Comparing between Pierrot and Tilston cells, it is obvious that Tilston cell has a better performance and can be a good candidate for reflectarray antenna because of better symmetry in curves. But in view of the fact that it has a more complicated structure and requires dielectric, reflectarray of this type may not be cost effective. But for reflectarray antennas by small F/D ratio, it is necessary to use a cell with wider incident angel properties. For simplifying reflectarray antennas of large F/D ratio, one can use Pierrot cell in a low dielectric constant material.

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