Technical E-Paper

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Professional Circularly Polarized Antennas

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Whether it concerns a sophisticated installation in the military or aerospace sector, or a more common application such as GPS or IoT systems, circularly polarized antennas are essential for many specific applications.

What are the different types of circularly polarized antennas and their specific characteristics?

In this brief article, we provide an overview of this category of products in order to identify the strengths and limitations of certain antenna types, which may be optimal for specific applications while proving unsuitable for others.

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1. Circular polarization: what it is and why it is used.

If we consider a transmitting antenna, it generates an electromagnetic field $(\vec{E},\vec{H})$ with a specific characteristic polarization, which by convention is defined by the spatial orientation of the electric component $\vec{E}$ of the field $(\vec{E},\vec{H})$. At a sufficiently large distance from the antenna, the electromagnetic field exhibits the characteristics of a plane wave, with the electric component $\vec{E}$ and the magnetic component $\vec{H}$ orthogonal to each other and to the direction of propagation.

In the case of linear polarization, such as that generated by a simple dipole, the $\vec{E}$ vector lies in a plane defined by the electric field itself and the direction of propagation (**Figure 1.1**).

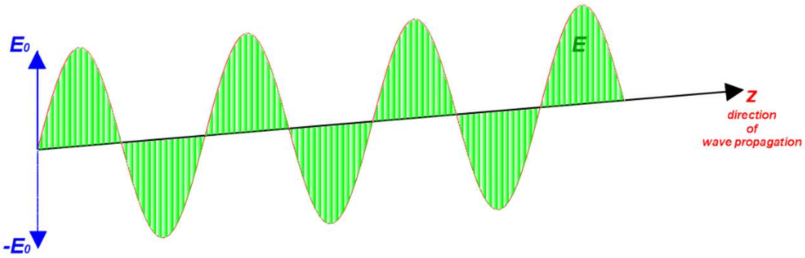

Figure 1.1

Representation of a linearly polarized wave.

In the case of circular polarization, the electric field vector rotates clockwise (right-hand circular polarization, **Figure 1.2**) or counterclockwise (left-hand circular polarization) as it propagates away from the source, describing a helical path with a pitch equal to the wavelength λ. With reference to **Figure 1.2**, the projection of $\vec{E}$ onto the (x,y) plane traces a circle of constant radius E_0.

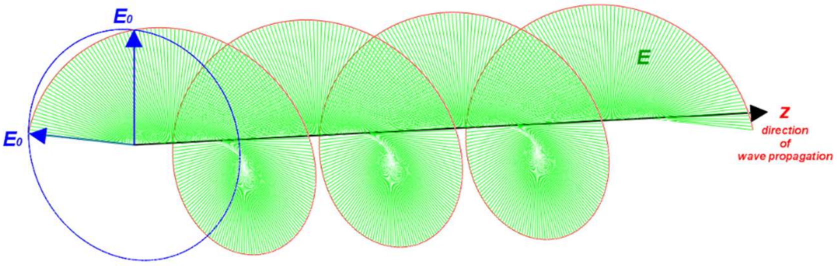

Figure 1.2

Representation of a Right-Hand Circularly Polarized wave.

A perfect circular polarization, as shown in **Figure 1.2**, obviously represents an ideal case. In practice, one generally deals with elliptical polarization, as illustrated in **Figure 1.3** (also right-hand in this example). As can be seen from the figure, the projection of the electric field vector onto a plane normal to the direction of propagation forms an ellipse whose axial ratio is determined by the maximum and minimum values, E_M and E_m.

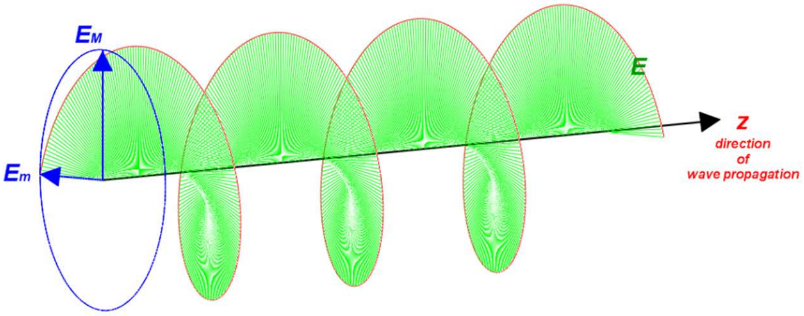

Figure 1.3

Representation of a Right-Hand Elliptically Polarized wave.

The characteristic polarization depends on the antenna design. When used as a receiving antenna, it is sensitive only to the same polarization as that of the incident wave. It follows that, in order to maximize the link margin of a given radio link, polarization mismatch — that is, the loss caused by a difference in polarization — must be minimized.

In most line-of-sight radio links, polarization mismatch is minimized by using two antennas with the same characteristic polarization.

However, there are many cases in which this is not possible, for two main reasons:

a) propagation conditions randomly alter the polarization of the electromagnetic wave arriving at the receiving antenna;
b) the relative orientation of one or both antennas in the radio link may also vary randomly.

In case (a), it is possible to consider a satellite link, where the electromagnetic wave undergoes rotation as it passes through the atmosphere (*Faraday rotation*); or a radio link in which the received signal has experienced reflections due either to the presence of obstacles (natural or artificial) or to specific physical characteristics of the troposphere (multipath propagation).

In case (b), reference can be made to a radio link between a base station and a Client device, such as an IoT device or even a smartphone, whose spatial orientation may vary significantly over time in a manner that cannot be determined in advance.

As will be discussed later, in a radio link the use of circular polarization makes it possible to minimize attenuation effects caused by the aforementioned propagation mechanisms.

2. Electrical parameters of circular polarization.

Any real antenna, even if designed to achieve circular polarization, will in practice exhibit elliptical polarization. The extent to which this elliptical polarization approaches ideal circular polarization is defined by the axial ratio (see **Figure 2.1**):

$$AR = \frac{E_M}{E_m}$$

generally expressed in dB rather than in linear units.

This parameter depends on both frequency and direction. In the first case, it is calculated at the centre frequency, or alternatively a maximum value not to be exceeded across the entire operating bandwidth is specified. In the second case, an angular sector is defined — usually symmetrical about the direction of maximum radiation — within which the axial ratio remains below a given threshold, typically set at 3 dB (**Figure 2.1**).

For example, in the case of directive antennas, axial ratio (*AR*) values even below 1 dB can be achieved in the direction of maximum radiation. In contrast, for antennas with a hemispherical radiation pattern, the objective is to maintain a relatively low axial ratio throughout the entire main lobe.

It should be noted that the gain of a circularly polarized antenna must be expressed in *dBic*, that is, in dB referenced to an isotropic radiator with circular polarization — a detail that is often overlooked in datasheets.

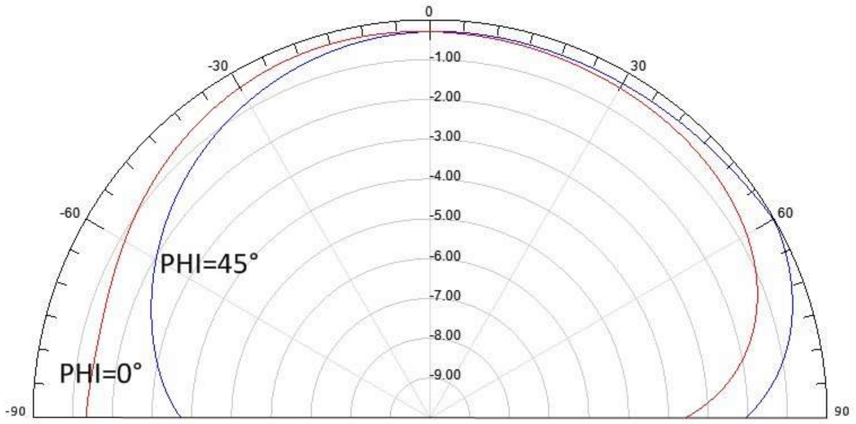

Figure 2.1

Axial ratio [dB] at centre frequency of a patch antenna for satellite applications, as a function of the angle relative to the direction of maximum radiation (*Θ=0°*). The two curves represent the respective planes *φ=0°* and *φ=45°*.

3. Polarization mismatch.

Polarization mismatch is a phenomenon that introduces an additional loss between the transmitting and receiving antennas in a radio link. This loss adds to the free-space attenuation when the antennas do not share the same characteristic polarization in the pointing direction.

This physical mechanism can cause significant signal attenuation (*fading*), up to the limiting case in which the polarization of the wave incident on the receiving antenna is orthogonal to the antenna's characteristic polarization. In such a case, the attenuation is theoretically infinite, since two orthogonal polarizations are completely decoupled from each other.

In the previously mentioned case of an Earth–satellite link, where the electromagnetic wave passing through the ionosphere is affected by a propagation phenomenon known as *Faraday rotation*, the use of circular polarization for both antennas (on board the satellite and at the ground station) eliminates this issue, since circular polarization is insensitive to this effect.

In the case of a stage wireless microphone operating with a linearly polarized antenna that assumes a random orientation during use, employing a circularly polarized receiving antenna significantly reduces fading phenomena, while introducing a constant theoretical loss of 3 dB in the link margin. This is because circular polarization can always be regarded as the combination of two orthogonal linear polarizations in quadrature, that is, mutually phase-shifted by 90°.

In the case of two linearly polarized antennas, or of one circularly polarized antenna and one linearly polarized antenna, the calculation of polarization mismatch is straightforward. The situation differs when dealing with two elliptically polarized antennas characterized by specific *axial ratio values*. In this case, it is more convenient to refer to a nomograph such as the one shown in **Figure 3.1**, from which the minimum and maximum loss can be derived. These correspond to the conditions in which the polarization ellipses of the transmitting and receiving antennas have their principal axes either mutually aligned or orthogonal.

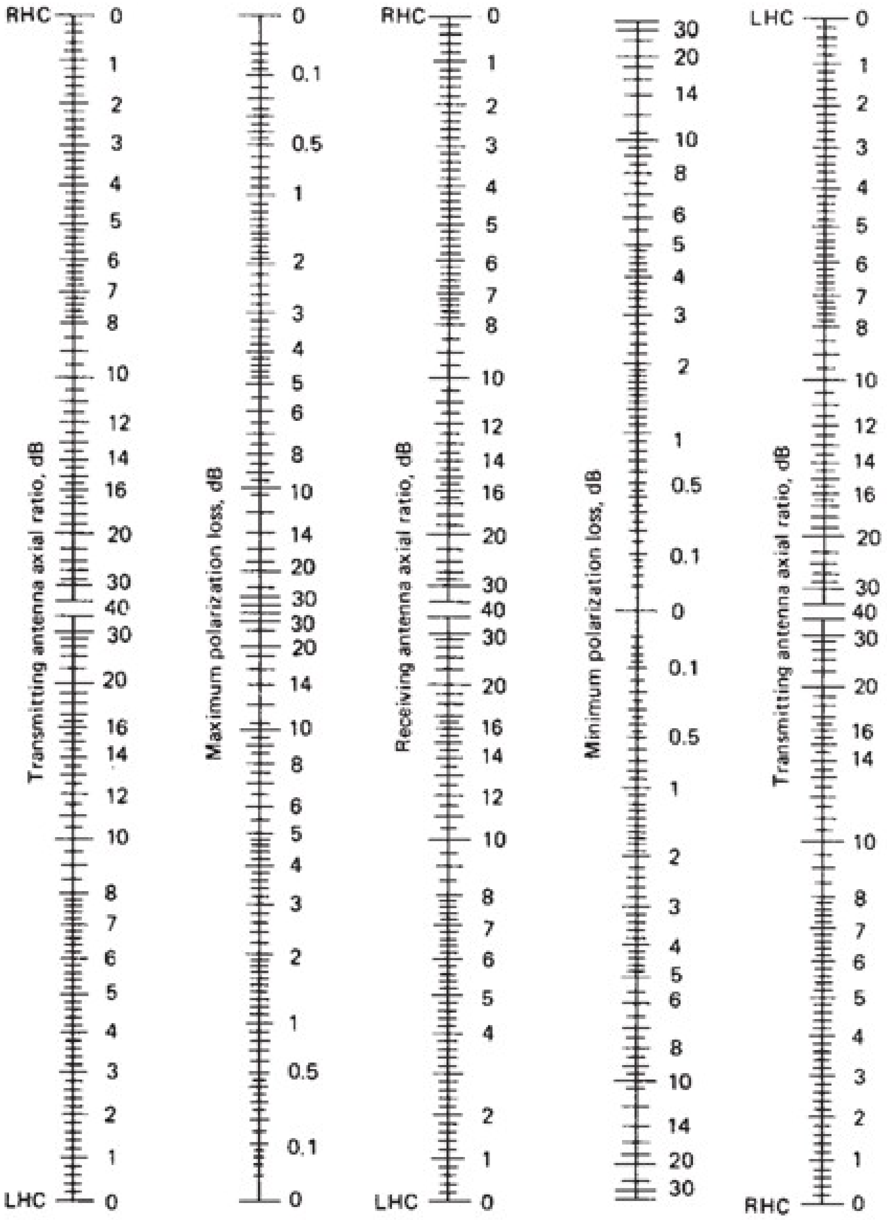

Figure 3.1

Nomograph for calculating the maximum and minimum losses due to polarization mismatch (source: John Wiley & Sons, Ltd).

When using this nomograph, it should be borne in mind that an axial ratio of 0 dB corresponds to ideal circular polarization, whereas an axial ratio of 30 or 40 dB practically corresponds to linear polarization. By drawing a line between the point RHC (right-hand circular polarization) at 0 dB (first column on the left) and the point RHC (central column) at 40 dB (linear polarization), a point corresponding to a polarization loss of 3 dB is intersected on the second column. The same procedure can be applied using the third and the fifth columns from the left.

4. Types of circularly polarized antennas.

A circularly polarized antenna can be implemented in various ways, depending on the electrical characteristics to be achieved.

In addition to the usual specifications regarding impedance matching, radiation pattern, and gain, circular polarization requires consideration of the *polarization sense* (right-hand or left-hand) and the *axial ratio*. The latter may be specified either in the direction of maximum radiation or over a given solid angle, typically corresponding to the main lobe.

Circularly polarized antennas can be classified as follows.

A. *With a radiating element that is intrinsically circularly polarized.*

B. *With one or more pairs of orthogonal linearly polarized radiating elements fed in quadrature by means of an appropriate power division and phase-shifting network.*

C. *With a single radiating element supporting two orthogonal linear polarizations, whose geometry enables a 90° phase quadrature between them, while using a single feed point.*

We now provide some examples of these types of antennas.

4.1. Intrinsically circularly polarized antennas.

There are radiating elements whose geometry inherently enables the achievement of characteristic circular polarization, without the need to resort to more complex configurations.

A notable example is the *axial-mode helical antenna*, shown both in the cover image and in **Figure 4.1**.

This antenna consists of a wire conductor wound into a helical shape and fed in an unbalanced configuration with respect to a metallic reflector having dimensions on the order of λ. If the circumference of the helix is approximately equal to the wavelength λ, the antenna radiates in the endfire direction with circular polarization, whose axial ratio improves as the number of turns increases. The winding direction of the helix determines the sense of the circular polarization.

In practice, the conductor operates as a travelling-wave radiating element: the entire helix can therefore be regarded as a sequence of many small contiguous current elements, whose phase depends on the distance of each individual element from the antenna feed point. Without going into a rigorous explanation of the radiation mechanism, it is the shape and dimensions of the helix that enable this structure to generate circular polarization.

Naturally, as the number of turns increases, the antenna directivity also increases, and gain values exceeding 10–12 dBic can easily be achieved. As with travelling-wave antennas, an indefinite increase in conductor length does not, beyond a certain limit, result in a corresponding gain improvement, since the current flowing along the element gradually decreases due to radiation as the distance from the antenna feed point increases.

Figure 4.1
Axial mode helical antenna for the 1400÷1650 MHz band.

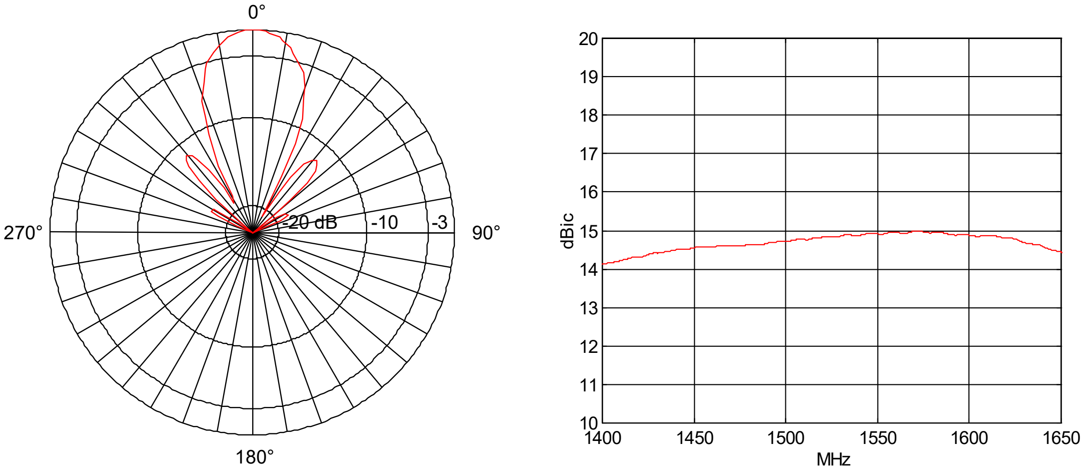

Figure 4.2
Radiation pattern and gain curve
of the antenna shown in Figure 4.1.

There are other types of antennas that achieve circular polarization by means of a single radiating element, properly dimensioned and shaped, essentially based on spiral configurations.

4.2. Antennas comprising orthogonal linearly polarized radiating elements fed in quadrature by a dedicated power division and phase-shifting network.

This category certainly includes a large number of circularly polarized antennas, such as crossed Yagi antennas (see cover image) or the *turnstile* antenna, which consists of a pair of orthogonal dipoles fed in quadrature by means of a power divider and a delay line, mounted above a metallic ground plane.

An example of a turnstile antenna is shown in **Figure 4.3**, where the two pairs of orthogonal dipoles actually consist of four distinct radiating elements arranged in a *half-sloper* configuration.

These elements are fed separately by a four-way power divider with –6 dB outputs, with relative phases of 0°, –90°, –180°, and –270°, respectively.

Figure 4.3
Example of a *turnstile* antenna mounted on a circular reflector (top) and the corresponding power division and phase-shifting network (bottom).

Figure 4.4 instead shows a panel antenna operating in the 2.0÷2.3 GHz band, consisting of a two-dimensional 3×3 array of composite circularly polarized radiating elements. Each radiating element comprises two pairs of orthogonal linearly polarized dipoles, fed through a power divider and delay lines implementing a 90° phase shift between the +45° and –45° directions.

Each of these composite radiating elements is then fed in phase by a central power divider located near the antenna input connector.

Figure 4.4
LP13C circularly polarized panel antenna.

When a wideband antenna and/or stringent axial ratio requirements are involved, it is necessary to design a dedicated power division and phase-shifting network capable of providing the inputs of the individual linearly polarized radiating elements with precise amplitude and phase values, remaining substantially constant across the entire operating bandwidth.

An example is shown in **Figure 4.5**, where two custom-designed feeding networks for *UHF Satcom* antennas can be seen. This design employs a –3 dB, 90° hybrid coupler, allowing quadrature to be maintained within ±1° across the entire antenna operating band, from 240 to 320 MHz, with an output amplitude imbalance of 0.5 dB.

Such a design choice is clearly adopted only for specific applications where a low and stable axial ratio across the entire operating bandwidth is required.

In many cases, the antenna implementation can be simplified by adopting design solutions that eliminate the need for a dedicated power division and phase-shifting network, as will be discussed in the next paragraph.

Figure 4.5
Power division and phase-shifting network employing two power dividers and a –3 dB hybrid coupler for the UHF Satcom band.

4.3. Antennas with a single radiating element supporting two orthogonal linear polarizations, whose geometry enables phase quadrature using a single feed point.

There are applications for which stringent *axial ratio* requirements are not necessary, and where an elliptical — or in any case circular — polarization over a relatively narrow bandwidth is sufficient.

In such cases, the antenna construction can be significantly simplified by eliminating the power division and phase-shifting network, through design techniques that enable both orthogonal polarizations to be excited in quadrature within a single radiating element.

Figure 4.6
Ceramic substrate patch antenna for GPS applications

An example is the square patch element on a ceramic substrate, shown in **Figure 4.6** — a very common antenna for GPS applications.

A second example is shown in **Figure 4.7**, which depicts an air-suspended patch element for RFID applications operating at approximately 900 MHz.

Instead of adopting two independent feed points positioned along the orthogonal symmetry axes of the antenna to excite the two respective resonant modes of the patch, these designs employ a single, asymmetrical feed point. Chamfers, truncations, or slots are introduced in the radiating element in order to generate two orthogonal current distributions that are approximately in phase quadrature.

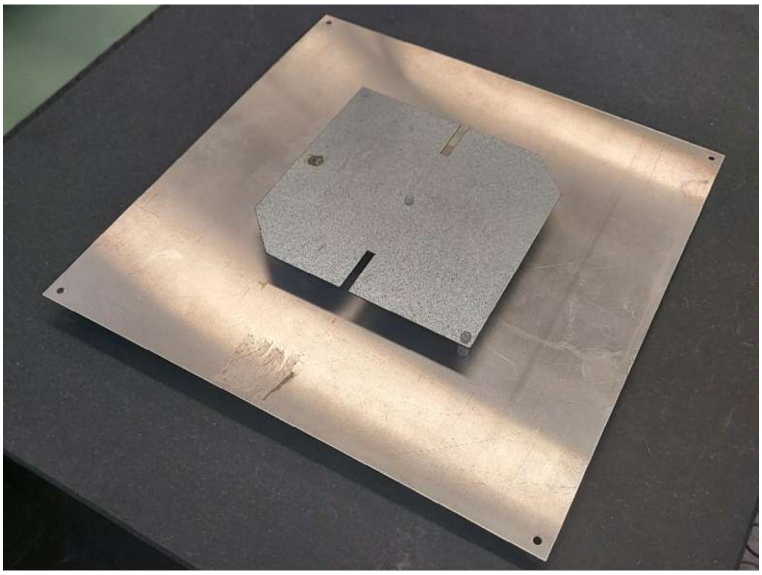

Figure 4.7
Circularly polarized patch antenna for RFID applications

This construction simplification can also be applied to other types of radiating elements, such as the GPS turnstile antenna shown in **Figure 4.8**. In this case, the pair of orthogonal dipoles (here in an inverted-V configuration) is fed in parallel through a single balun, which also serves as a mechanical support for the elements themselves.

In this case, the 90° phase shift is introduced by adjusting the lengths of the X and Y dipoles (oriented according to a Cartesian coordinate system X, Y, Z) relative to their resonant length, thereby modifying their respective input impedances as follows:

$Z_X = R - jX$, by making one dipole shorter than its resonant length;
$Z_Y = R + jX$, by making the dipole longer than its resonant length;

and dimensioning the entire radiating element so as to obtain $R = X \cong 50\ \Omega$.

With this approach, the parallel combination of Z_X and Z_Y results in an input impedance equal to *R,* and a 90° phase shift between the X and Y dipoles which, according to these conventions, produces right-hand circular polarization (Y lagging X by 90°).

Figure 4.8
GPS antenna implemented with a pair of orthogonal dipoles arranged in an inverted-V configuration to widen the beam, fed in parallel through a single balun and coaxial cable.

5. Conclusions.

As we have always done in our articles on the world of professional custom antennas, our aim once again has been to provide an overview of this specific topic for all those who, directly or indirectly, may need to use a circularly polarized antenna.

Naturally, in discussing the different types of antennas, the approach adopted here has been intentionally as general as possible, keeping the examples at a conventional level and deliberately omitting more specialized solutions, such as low-profile antennas. This topic may be addressed in greater detail in a future, more focused publication.

In any case, it is important to emphasize that there are numerous specific applications for which a careful assessment of the Customer’s requirements may lead to the proposal of a custom circularly polarized antenna, thereby significantly improving the radio link margin and minimizing service downtime.

For the design of this type of antenna as well, it is essential to select the most appropriate configuration, both in terms of the radiating element type and the structure of any feeding network involved, in order to develop a technically tailored product while keeping costs under control.

When commissioning a custom antenna for one’s products or installations, the key factor always remains the ability to select professionals with proven expertise and experience in this specific field. It is therefore essential to gather the right tools and information in order to choose the appropriate partner for any future collaboration, without unexpected outcomes.

All the information and experiences presented in this article are the result of the design, development, and production of custom professional antennas carried out by ***ElettroMagnetic Services Srl*** *using the* ***AntennaCustomizer*** *method.*

For questions, clarifications, or further information on this or other topics related to professional antennas, please contact ***bollini@elettromagneticservices.com****.*

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