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Circular Polarized — 435 MHz Corner Reflector Antenna

A classic 90-degree corner reflector is reimagined for 435 MHz by simply tilting the dipole to achieve low-axial-ratio circular polarization, with effortless RHCP/LHCP switching via a single-feed mechanical rotation and a compact, easy-to-build structure.

The Basics

The reflector antenna corner is well-known and widely used since its invention in 1939 **[1]**. Its multiple uses are exclusively in horizontal or vertical linear polarization.

By tilting only the dipole, the antenna transitions from elliptical polarization to circular polarization. This surprising and almost unknown property is explained and detailed in the *Principles of Antenna Theory* **[2]**. The theory is only valid for reflectors with infinite dimensions. Following the author, it is not possible to reach circular polarization with a 60-degree corner reflector angle.

Despite my research, I was unable to find any commercial antennas or references in amateur radio literature like this design. This is the reason I decided to model, design, build, measure, and experiment with this novel antenna.

Circular Polarization (Figure 1)

Different methods are used for obtaining circular polarization, such as a phase shift 90-degree cable (delay line), mechanical phase offset, tilting radiating elements, the use of a 90-degree hybrid coupler, LC phasing circuits, etc.

Changing the rotation sense of the polarization (RHCP/LHCP) is generally done with coaxial switches with delay lines. Antennas, like helicals, have the direction of rotation defined by the design and it is not possible to change the polarization rotation sense.

My antenna has the property that tilting only the dipole in the opposite direction (with the same angle) will change the polarization from RHCP to LHCP, using only a simple rotary movement (**Figure 3B**) with only one feeder. This is the amazing property of this antenna.

Axial Ratio (Figure 2)

The axial ratio (AR) is the ratio of orthogonal H and V components of an E-field. A circularly polarized field is made up of two orthogonal H and V components of equal amplitude (and 90 degrees out of phase). Because the components are equal magnitude, the axial ratio is 1 (or 0 dB).

The axial ratio for an ellipse is larger than 1 (> 0 dB). The axial ratio for pure linear polarization is infinite because the orthogonal components of the field are zero.

Axial ratios are often quoted for antennas in which the desired polarization is circular. The ideal value of the axial ratio for circularly polarized fields is 0 dB. Also, the axial ratio tends to degrade away from the main beam of an antenna, so the axial ratio may be indicated in a specification sheet (datasheet) for an antenna as follows: "Axial Ratio: <3 dB for +/-30 degrees from the main beam." This shows that the deviation from circular polarization is less than 3 dB over the specified angular range.

Unfortunately, most "circularly polarized" antennas are elliptically polarized. The axial ratio shows you how close your antenna is to the ideal situation (AR = 1), or 0 dB. The axial ratio is a determinant parameter that defines the figure of merit of any circularly polarized antenna.

Design

I used the *4nec2* **[3]** software for design and simulation (**Figures 3A–B**). The design was verified using *MATLAB* software **[4]** (**Figures 4A–B**).

I started with the reflector dimension given by the *ARRL Antenna Handbook* (21st edition). Like most reflector antennas, the bigger the reflector is, the better characteristics like axial ratio, cross polarization, gain, F/B, and F/R are obtained.

Here the situation is even more decisive. Computer simulation clearly shows that the axial ratio of the 90-degree corner

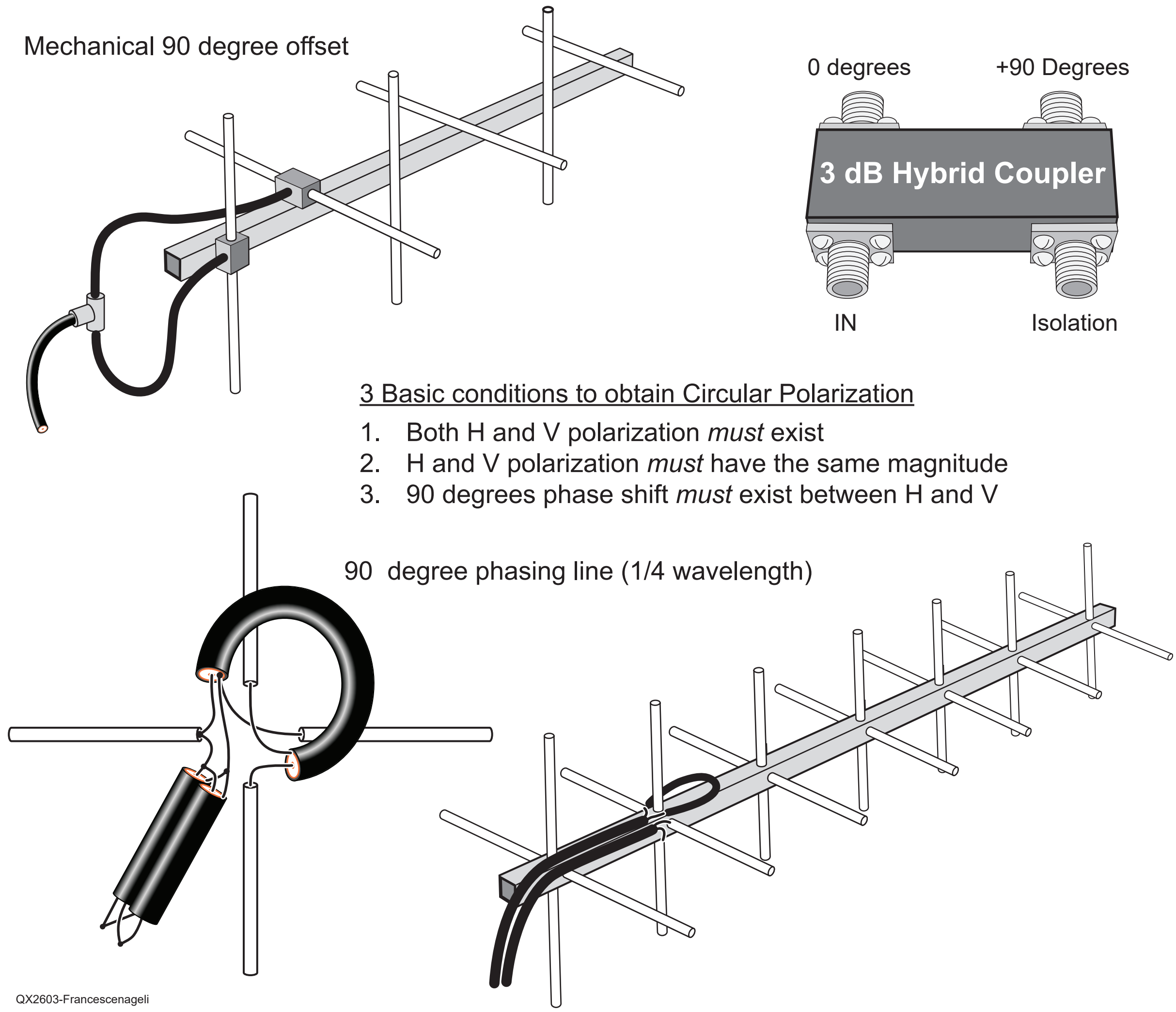

Figure 1 – The conditions for circular polarization.

reflector antenna is better when the reflector is larger than the classical dimensions used in the ham radio literature.

Wind exposure significantly limits the use of corner reflector antennas. In the design, I sought the best balance between compact size and excellent circular polarization (AR <1.3 dB theoretical value).

I used a 52 cm × 52 cm (0.7 λ × 0.7 λ) for each sheet reflector dimension (**Figure 5**), but we can reach an exceptionally low axial ratio with a 1 λ × 1 λ reflector dimension, particularly useful if you plan to work at higher frequencies.

My main goal was to make this antenna simple, cheap, and easy to build, with the best specifications possible.

The dipole tilt angle (θ) used to obtain circular polarization is only valid for a specific reflector dimension and dipole-to-vertex spacing distance. There are multiple possibilities with a large variation of antenna impedance. The rule is simple: the larger the dipole-to-vertex distance, the bigger the tilting angle (θ). The variation is quite linear.

In my design, I reached the best measured results with s = 19.5 cm and θ = 28 degrees, giving an AR <1.83 dB at 435 MHz, close to *MATLAB* simulation (**Figure 6**).

Construction

All materials are easily found in hardware stores. The antenna frame structure is made with 1-inch PVC tubes assembled with homemade 3/4-inch PVC inner couplers, glued together and fixed with self-tapping screws (**Figure 7A**). For the reflector, I have used a 26-gauge galvanized steel sheet (**Figure 7C**) to obtain a surface closer to the ideal flat reflector glued and fixed on a corrugated plastic (**Figure 7B**). The overall measured flatness irregularities are less than 3 mm. This reflector is suitable up to several GHz. A cold galvanizing final protective coating (zinc > 95%) was applied (**Figure 7D**).

The narrowband dipole is made with 1/4-inch threaded rod fixed with hex coupling on the boom. Turning each dipole arm allows easy tuning of the antenna (**Figure 8**).

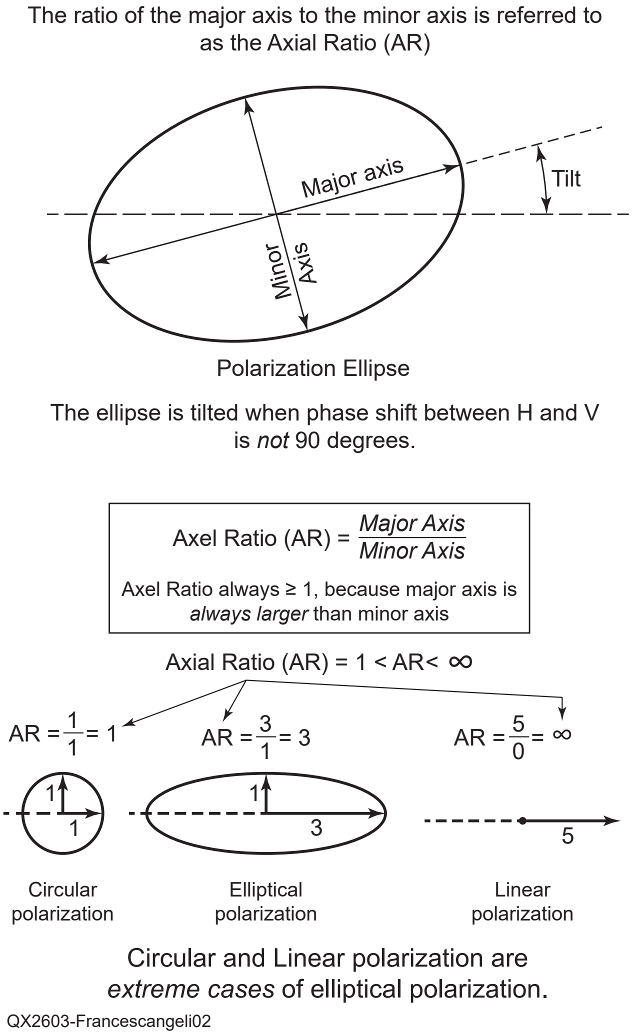

Figure 2 – Formula for determining axial ratio.

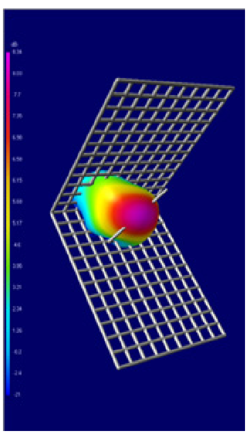

Figure 3A – Gain simulation from *4nec2* modeling.

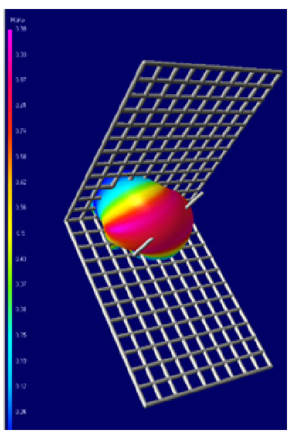

Figure 3B – Axial ratio figure of merit simulation from *4nec2* modelling.

I have expressly chosen galvanized steel material based on my professional experience with VHF – UHF broadcasting antennas. Partially for the low price, but also for its good electrical conductivity and excellent resistance to weather.

Copper and aluminum are excellent conductors, but copper oxide is not. Aluminum needs chemical treatment (Alodine or SureTec 650, for example) to avoid corrosion.

The feeder is a simple coaxial RG8X cable. Impedance matching was achieved by adjusting the dipole length, changing vertex distance and dipole tilt, without degrading the axial ratio. I have not used a UHF balun because the measurements of the radiation diagram showed me that there are no clear pattern distortions. However, to avoid common-mode current radiation from disturbing the balance between the H and V polarization, I have installed an air-wound RF choke made with 1.9 turns of coaxial cable (**Figure 9**).

$$Z_{choke} = \left[10^{\frac{CMRR\ choke}{20}}(Z_{in} + Z_{out})\right] - (Z_{in} + Z_{out})\Omega$$

$$Z_{choke} = \left[10^{\frac{26.8\ \mathrm{dB}}{20}}(50 + 50)\right] - (50 + 50)\Omega$$

$$Z_{choke} = 2087\,\Omega\ \text{(equivalent)}$$

The result gave a measured CMRR of -26.8 dB at 435 MHz, a 2,087 Ω impedance equivalent, as the calculations above show.

Servo-Controlled Polarization Control

To get the maximum potential out of the antenna, I have installed a remote mechanical rotation system for the dipole consisting of a radio control servo motor used as an actuator with a controller.

This is a pulse width modulation (PWM) antenna polarization control. The pulse width changes the rotation angle and controls the linearity of the axial ratio of my antenna (**Figures 10A–D**).

We can switch from RHCP to LHCP easily without any loss, and no power limitations. The switching time is around 0.3 seconds. Tilting the dipole in any position allows you to reach all types of polarization (linear, elliptical, circular) in left or right rotation sense.

Tilting the dipole allows you to change the linearity of the antenna axial ratio from infinite to a value close to 1.8 dB. It is a nice result due to the simplicity of the system employed. The RC servo motor with the manual controller costs less than $20.

Measurements

The main parameters of the far field antenna were measured (**Table 1**) in an open, flat desert area in front of my home. Ground and other unwanted reflections were canceled by applying advanced Vector Network Analyzer (VNA) techniques. Measuring full circular polarization characteristics is a little more complicated **[5]** and time-consuming because of the need to repeat each measurement in vertical and horizontal polarization with a calibrated dipole for magnitude and phase measurements. Today, exceptionally low-cost, high-performance VNAs on the market can easily do the job. The axial ratio, rotation sense, ellipse tilt, gain, and cross polarization were calculated using a homemade spreadsheet from the measured data collected. The post-processing results are not far from expected (**Figure 11**).

On the Air

I was able to easily receive LEO satellite signals on an SDRplay receiver without LNA. Tilting the dipole gives a nice advantage gaining signal dB over classical ham radio satellite antennas.

This antenna clearly shows that it is often better to use a lower-gain antenna with accurate polarization control than a higher-gain antenna without a polarization system.

This antenna opens the way to future azimuth-elevation-polarization control for optimized communication.

Polarization Filter

After measuring and evaluating the antenna, I was able to rediscover a wonderful antenna property. Tilting the dipole acts like a continuously variable polarization filter, which means the antenna is more sensitive in some polarizations than others. Rotating the dipole a few degrees, we begin to clearly hear very low signals, without moving the corner reflector.

Retrofit of the Older Corner Reflector Antenna

It can be done by covering the antenna with flat conductive material or a squared screen mesh above the reflector structure and creating a method of rotating the dipole. Tilting the dipole changes the antenna impedance.

Conclusions

This 90-degree corner reflector antenna can produce any kind of polarization by tilting the dipole to obtain any axial ratio value. Innovative servo-controlled polarization control is also presented. This system is lossless and uses a single feeder.

The measured axial ratio is 1.83 dB in the beam direction and less than -3 dB in the half-power beamwidth (HPBW) of the main beam. The mea-

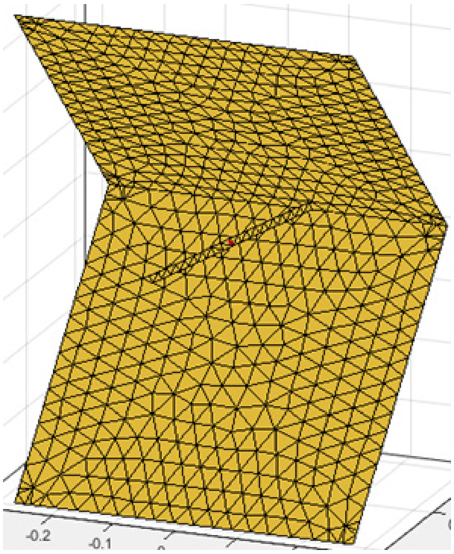

Figure 4A – *MATLAB* modeling meshing graphic.

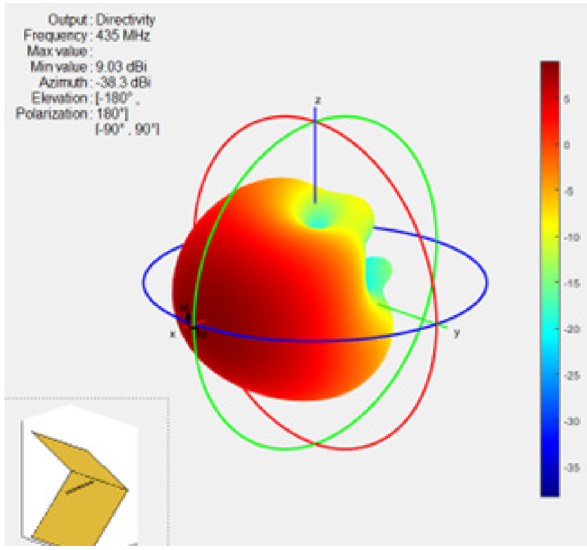

Figure 4B – *MATLAB* modeling – 3D pattern.

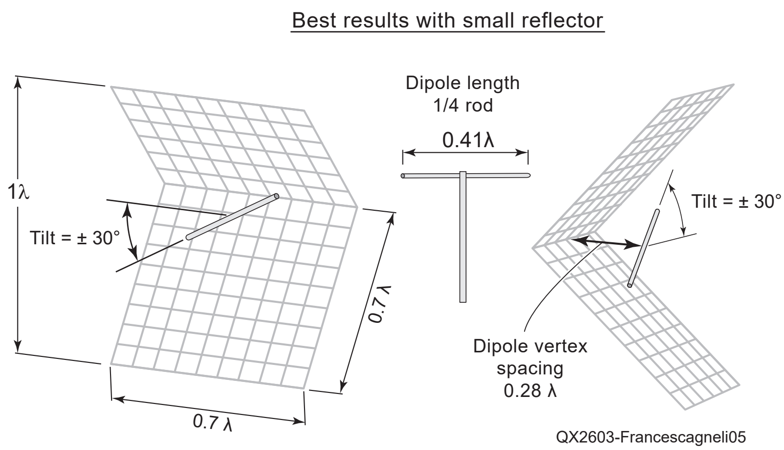

Figure 5 – The antenna design dimensions.

Table 1 — Measurement Results

		4NEC2	Matlab	Measurement	Measurement
	Unit				*Tolerance*
Gain	dBic	8.6	9.03	**8.38**	± 0.31
Axial Ratio	dB	1.29	1.25	**1.81**	± 0.27
Cross Polarization	dB	22.61	22.91	**19.7**	± 2.62
F/B	dB	13	14	**14.87**	± 1
VSWR RHCP		1.07	1.032	**1.06**	± 0.018
VSWR LHCP		1.07	1.032	**1.073**	±0.017
VSWR LINEAR		1.42	1.6	**1.56**	± 0.08
Dipole Tilt	degree	33	30	**28**	± 2
Dipole to Vertex	cm	22	19	**19.5**	± 0.5
Dipole Length	cm	28.635	30.19	**28.4**	± 0.5
Reflector Dimension	cm	48.5 × 48.5	50 × 50	**51.5 × 51.5**	± 0.5

sured RHCP/LHCP gain reached 8.3 dBic value. The total antenna weight is around 11 pounds.

The antenna VSWR is 1.07:1 value at 435 MHz in RHCP and or LHCP position.

We can use this antenna at any frequency from 400 MHz up to several GHz cutting only the 1/4-inch threaded rod dipole arms, reducing the dipole-vertex distance and tilting the dipole again. Final fine tuning would be made turning each dipole arm to reach the best axial ratio.

The final estimated cost is $130. The assembly time took me around 9 hours with basic tools.

This directional, moderate-gain antenna has endless uses. A nice tool for any UHF radio operator but also for antenna experimenters looking for greater performance.

I hope that this novel antenna will take a little place in the extensive ham radio antenna collection.

I could not finish this article without paying tribute to Dr. John Kraus, W8JK (SK), inventor of the corner reflector antenna. His book, *Antennas*, has been a faithful companion throughout my life and gave me the pleasure of discovering and loving antennas.

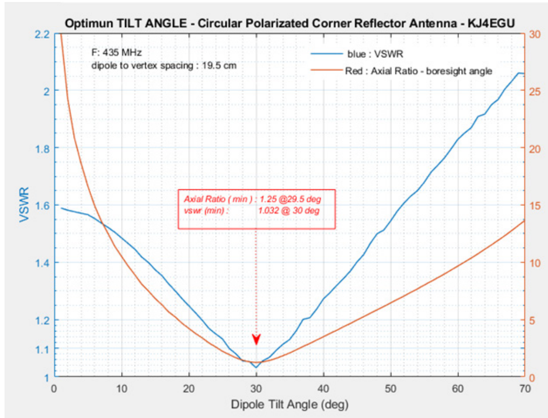

Figure 6 – The optimum axial ratio and VSWR from *MATLAB* simulation.

Figure 7A – The antenna PVC frame assembly.

Figure 7C – The metallic reflector glued and screwed to the Plaskolite.

Figure 7B – The antenna PVC frame with the Plaskolite corrugated plastic applied.

Figure 7D – The final metallic coating protection has been applied.

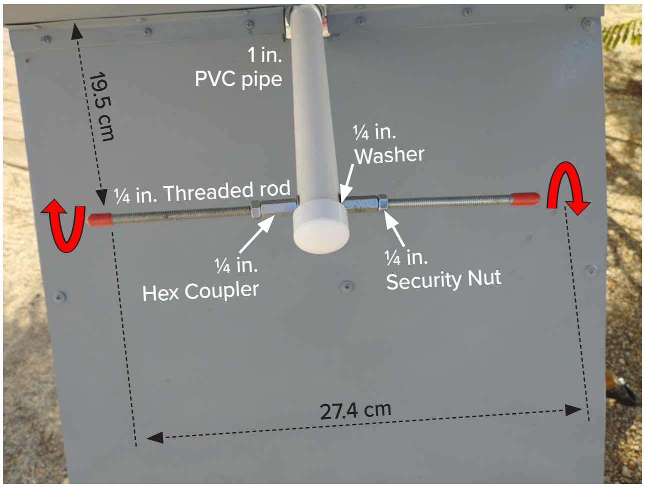

Figure 8 – The 435 MHz dipole dimensions, with an LHCP axial ratio of 1.83, VSWR of 1.061 at 435 MHz, a tilt of 30 degrees, and the spacing vertex at 19.5 cm.

Figure 9 – This air-wound, common mode choke is made of 1.9 turns of RG8X coax with a diameter of 40 mm. The RF choke must be tuned. See text.

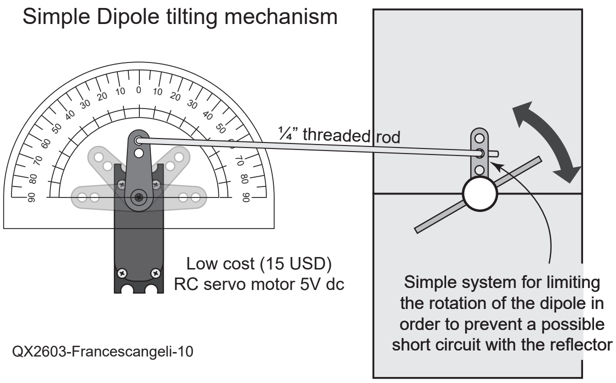

Figure 10A – The dipole tilting mechanism.

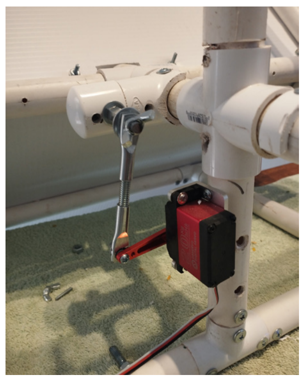

Figure 10C – The RC servo motor (5V DC High torque 20 Kg) attached to the rotating PVC tube support and tilting dipole mechanism.

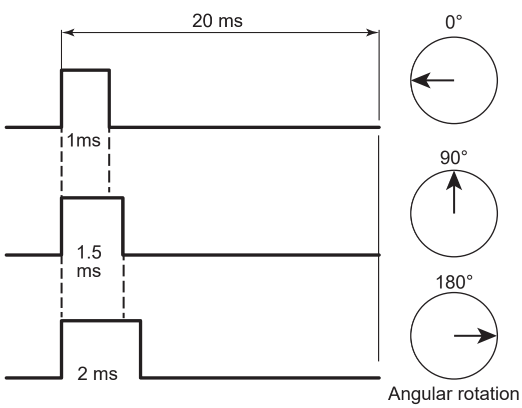

Figure 10B – The pulse width modulation rotation control for the tilting mechanism.

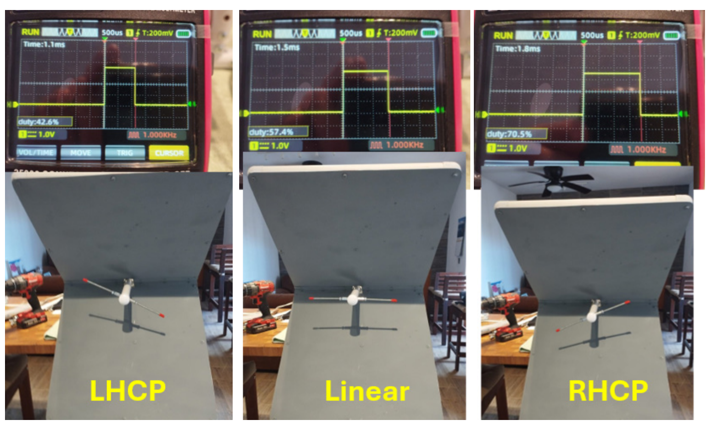

Figure 10D – Oscilloscope displays polarization pulse width modulation control.

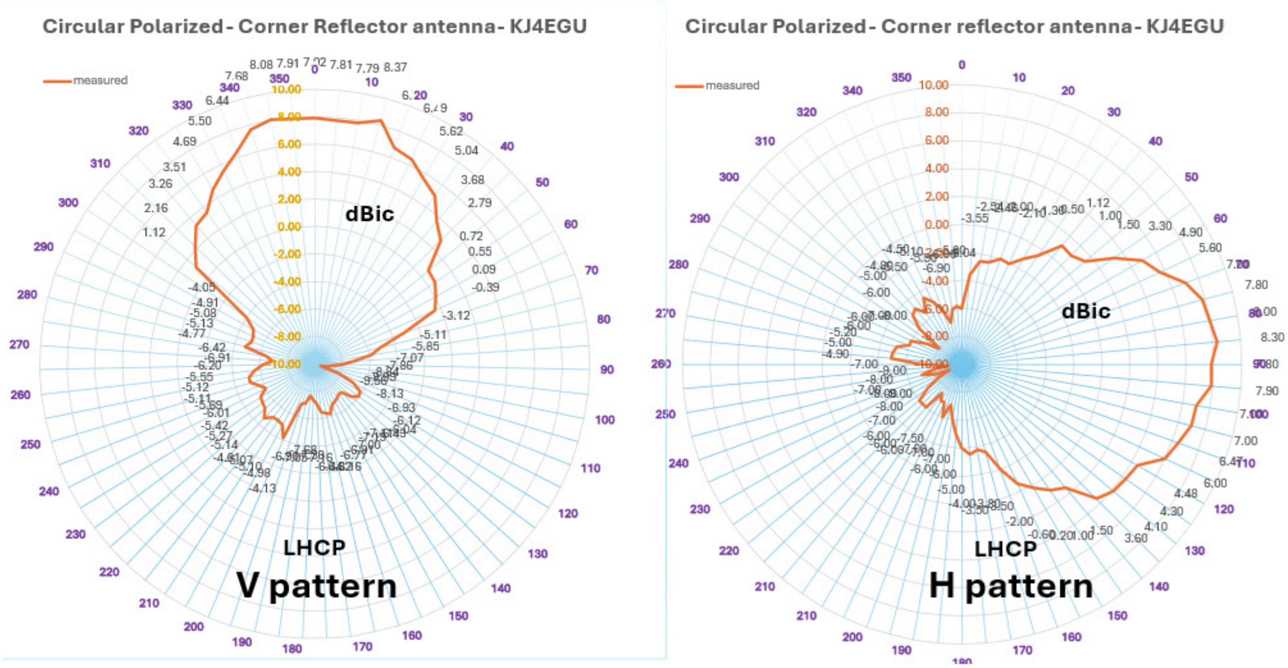

Figure 11 – The far field measured patterns.

Carlo Francescangeli is an RF broadcast engineer. He was born in Liege, Belgium. After completing his electrical engineering studies in 1981, he worked in more than 120 countries installing high-power broadcast transmitters, antennas, TX lines, and passive combiners. Between 1996 and 2015 he was also an RF Senior Consultant for Radio France Internationale.
He was first licensed in South America in 1982, and has held the call sign KJ4EGU since 2008. He shares his life now between California and Baja, Mexico, and is still active as an RF consultant for the TV and radio broadcast industry. He now enjoys RTTY, antenna work, sailing, friendship, humanitarian activities, and family life.

Notes

[1] J. D. Kraus, W8JK-SK, "The Square-Corner Reflector Beam Antenna for Ultra-High Frequencies," *QST,* Nov. 1940, pp. 18-23

[2] Kai Fong Lee, *Principles of Antenna Theory*. John Wiley & Sons, New York, 1984

[3] *4nec2* software – Arie Voors

[4] *MATLAB* R2019b - **www.mathworks.com**

[5] IEEE Standard Test Procedures for Antennas, Std 149-1979