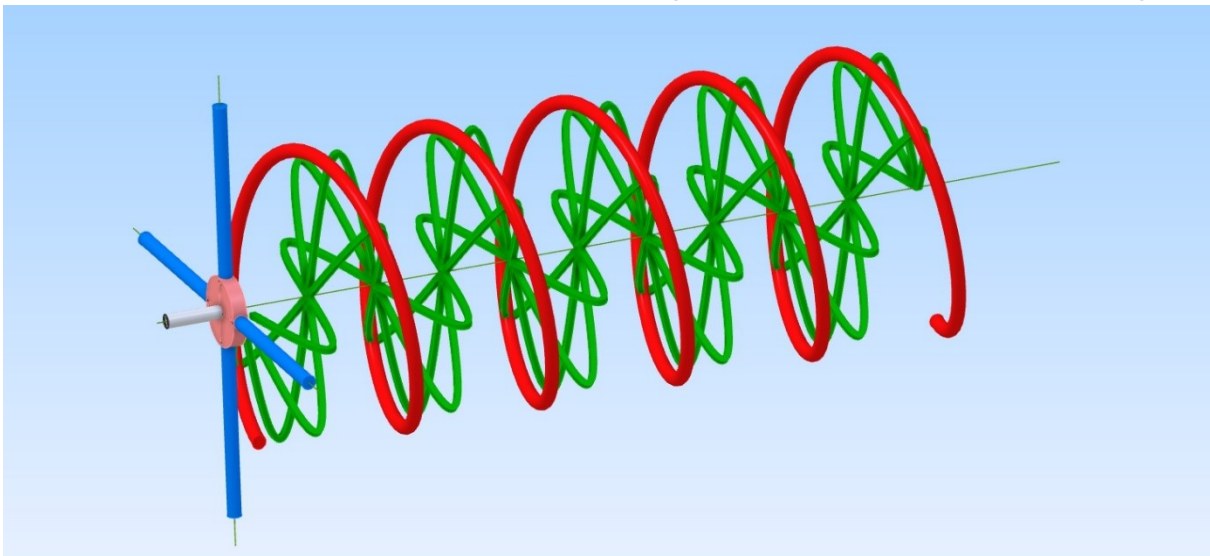


## Circular Polarization – How is your Axial Ratio today?



Beside Horizontal and Vertical polarizations there is a technique called Circular Polarization. This article explains what that is, how it behaves and [how it can be measured](#).

This article was published in [Microwave & RF magazine](#).

When using antennas for communication it is important to get the polarization right between the transmitter and receiver.

Most people are familiar with Horizontal or Vertical Polarization, and the fact that it is best if the transmitter and receiver have the same polarization. In fact, if the transmitter is using a Vertical antenna and the receiver is using a Horizontal antenna, chances are minimal that a communication link can be established.

### The Electro-Magnetic field

These polarizations are only half of the story: EM waves are Electro-Magnetic waves and consist of an Electric part and a Magnetic part that has a perpendicular polarization to the Electric wave.

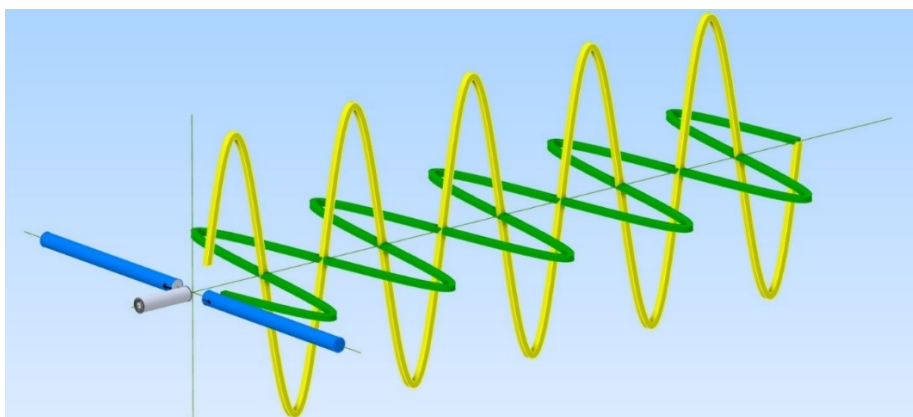


Figure 1. Electric (green) and Magnetic (yellow) fields generated by a dipole antenna

Figure 1 shows a dipole antenna that is fed by a coax at an RF frequency. The dipole produces both an electric field along its length and a magnetic field perpendicular to the electric field.

This is a simplified picture: near the antenna the field distribution can be quite different, depending on the type of antenna. This is called the Near-Field zone.

But EM waves tend to organize themselves when travelling away from the antenna and form a perfect match and alignment between E and M field further on at a few wavelengths distance, the Far-Field zone.

Also, a dipole radiates in all directions perpendicular to its length, but we show only one of the travelling directions.

As is customary, in the rest of this article we will consider only the Electric waves and their polarizations.

## Linear Polarization

Using a horizontal and vertical dipole makes it possible to create a composite polarization.

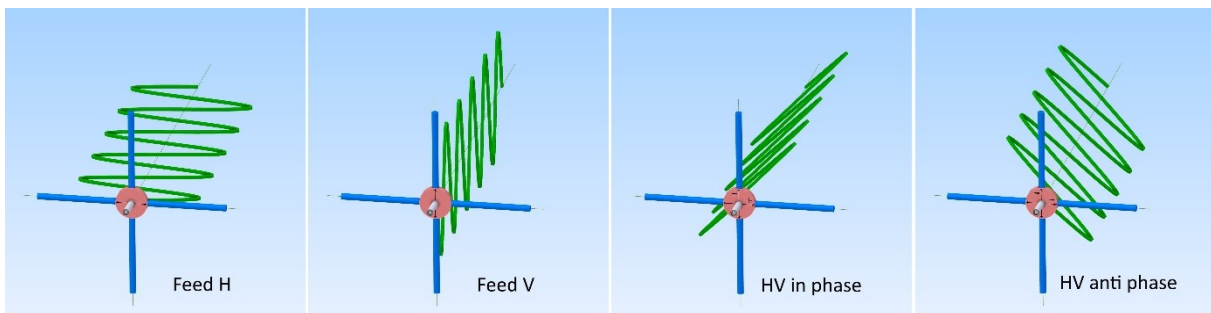


Figure 2. A Horizontal and Vertical dipole and their polarizations

Figure 2 shows how the feed of this combination can change the resulting polarization. In the left two pictures only one dipole gets a signal. In right two pictures the dipoles are fed in phase and in anti-phase. These result in a slanted polarization.

It is not possible to create a kind of dual polarization at the same time: the fields of the two dipoles will add up together to a single EM wave.

These are all Linear polarizations: the EM wave uses only one spatial axis to vibrate. This axis can be horizontal, vertical, or anything in between depending how the antenna is oriented.

## Circular Polarization

As was shown above, connecting the two dipoles in parallel creates a slanted, linear polarization. But, using a phase shifting network to feed the second dipole, the straight, slanted line becomes an ellipse. At 90 degrees phase shift the polarization becomes circular, hence the name Circular Polarization.

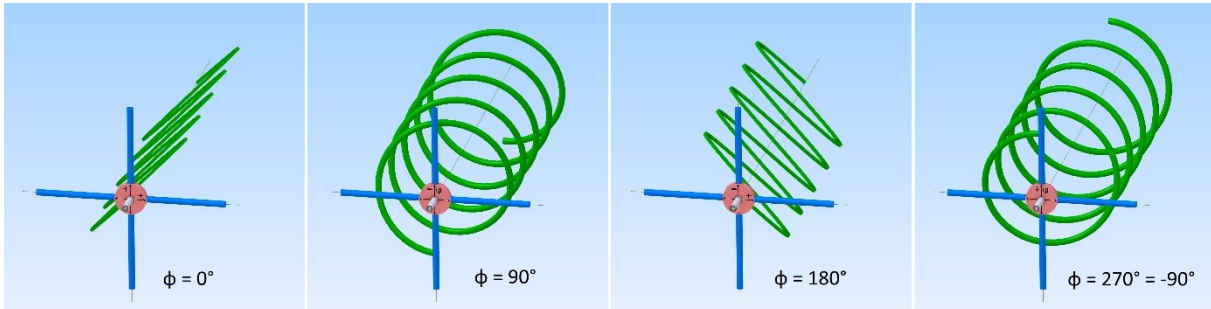


Figure 3. Using a phase shift network to create circular polarization

Figure 3 shows the two dipoles with different phase shifts from the feed. At zero degrees the dipoles produce the slanted polarization. But with a shift of 90 degrees the EM field becomes circular. Moving on to 180 degrees produces the other slanted orientation and at 270 degrees (-90 degrees) the EM field becomes circular again, but with an opposite spin.

These two circular polarizations are considered opposite to each other. They are called Left-Hand Circular Polarization (LHCP) and Right-Hand Circular Polarization (RHCP).

There is some confusion about these designations however. depending on whether you look out of the antenna (towards the receiver) or you look at the antenna from the receiver, Left becomes Right and vice versa.

With antennas and RF EM waves the convention is to look out from the transmitting antenna and determine whether it is Right- or Left-handed. In Optics, that has the same polarization phenomena with light waves, the definition is the opposite. Fortunately, the RF world and the Optics world are not (yet) crossing paths because of the large frequency difference.

### Axial Ratio

A circular polarized signal can have several deviations from a perfect circular signal. It can have an imbalance between the horizontal and vertical components, or it can have a deviation from +90 or -90 degrees phase shift, or both.

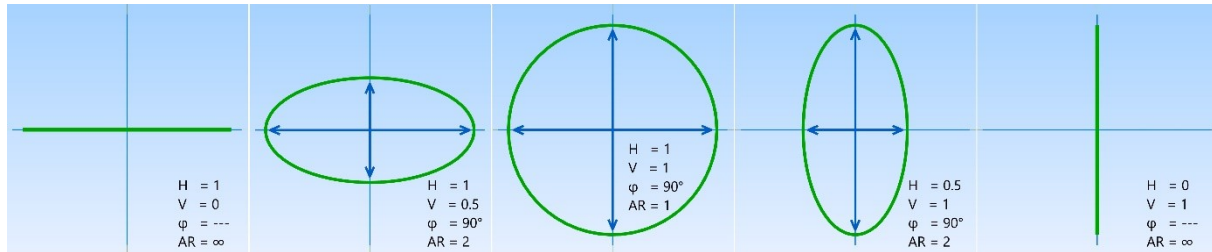


Figure 4. Imbalances between the horizontal and vertical components

Figure 4 shows what the polarization looks like with unbalanced horizontal and vertical components. It is assumed that the components have a 90 degrees phase shift.

The first figure only has a horizontal component, so it is actually linear and horizontal. Next is the polarization where the vertical component is half the vertical component. It is an elliptical signal. In the center is a proper circular signal. The right figures have half or zero horizontal components.

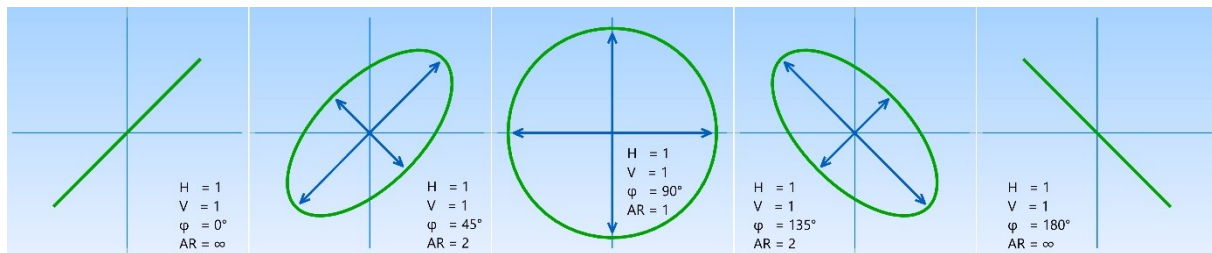


Figure 5. Deviation of the 90 degrees phase between horizontal and vertical components

Figure 5 depicts what the signals look like when the phase shift goes from 0 to 180 degrees. At 0 and 180 degrees we have a linear polarization. At +/- 45 degrees the signal is a slanted ellipse and at 90 degrees it is a proper circular signal again.

These deviations can be expressed as a number called the Axial Ratio (AR). It is the ratio between the two axes of the ellipse. The AR of a perfect circular signal is 1 (1:1), or 0 dB. For imperfect signals the AR is higher and for a linear polarization it goes to infinite.

The effects of these deviations result in a reduced reception and a limited suppression of the opposite polarization.

Although the AR does not describe how exactly the polarization is un-circular, it correlates directly to the attenuation of cross-polarized signals.

## Co- and Cross-polarization

When both transmitting and receiving antennas have the same polarization, they have co-polarization. The receiver has optimal reception of the transmitted signal.

When an antenna is subject to a polarization opposite of its own polarization, it should not receive anything.

However, in the real-world antennas are not perfect and an antenna may still be sensitive to some of the opposite polarization. This is called cross-polarization (XP).

This applies to both linear and circular polarization. A vertical antenna receives little or none of a horizontal signal. Similarly, an RHCP antenna receives little or none of an LHCP signal.

The suppression of cross-polarized signal can be used to attenuate unwanted interfering signals or reflections. For some applications it is an important characteristic.

## Cross Polarization from Axial Ratio

For circular antennas the cross-polarization XP can be calculated when the Axial Ratio is known:

$$XP_{dB} = 20 * \log\left(\frac{AR_{lin} + 1}{AR_{lin} - 1}\right)$$

Where  $AR_{lin}$  is a linear number. To convert AR from dB to linear:

$$AR_{lin} = 10^{\left(\frac{AR_{dB}}{20}\right)}$$

## Mixing linear and circular polarizations

While cross-polarized antennas do not receive each other, one may wonder how a linear antenna responds to a circular signal and vice versa.

As we have seen before, a circular signal is composed of a horizontal and vertical component. Consequently, a linear antenna will always receive a circular signal. No matter how the linear antenna is positioned, it will 'see' the circle of the polarization.

Likewise, a circular antenna can receive any type of linear polarization because it is 'looking' with its circle.

In these situations, the receiving antenna will only receive half of the signal so the effective antenna gain is reduced by 3dB.

## Signal propagation of different polarizations

Both kinds of polarization have different behavior in environments with (multiple) reflections, such as domestic and urban settings.

## Penetration

Most buildings are constructed from concrete containing steel rebar. The concrete itself does have some attenuation but not dramatic.

The rebar can be a large EM obstacle, depending on its spacing and the wavelength involved.

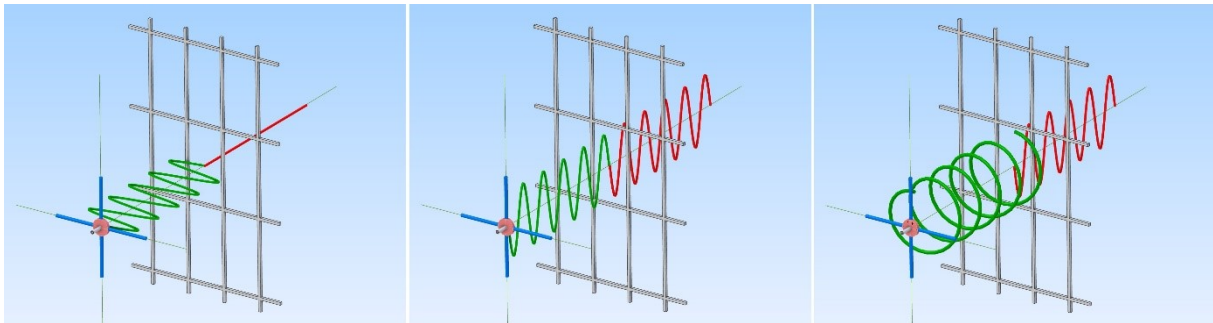


Figure 6. Penetration through a rebar wall of horizontal, vertical and circular signals

In figure 6 the signals are trying to travel through the rebar of a concrete wall. Here the rebar is horizontally spaced at a distance smaller than half wavelength, while the vertical spacing is larger than that.

The rebar forms a kind of filter: horizontal waves do not pass through while vertical waves fit through the holes.

For circular waves the effect is that the horizontal component is stripped off and the resulting wave has a linear, vertical polarization.

### Reflection

When a signal is reflected on a surface the polarization components can change, depending on the angle and orientation of the surface.

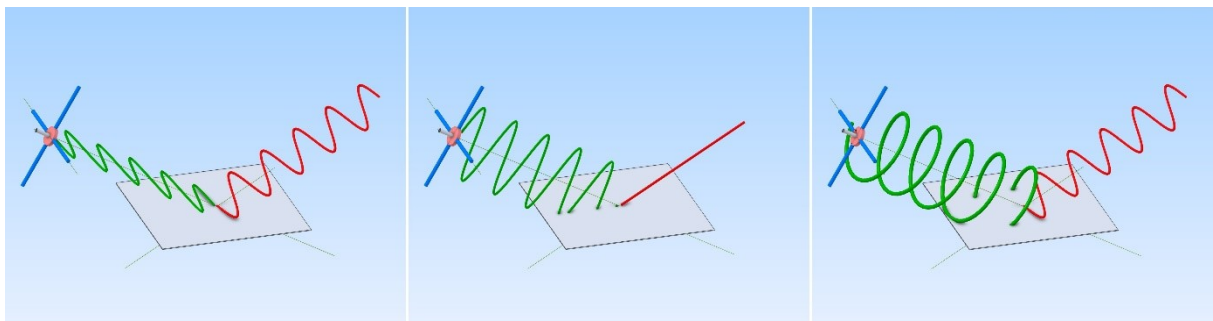


Figure 7. Reflections of horizontal, vertical and circular signals

Figure 7 shows that the component in-line with the surface is reflected well while a perpendicular component gets mostly attenuated. In case of a circular signal, only the in-line component survives and the signal becomes (more) linear.

These images are exaggerated: the amount of surviving components depends on the surface and the incidence angle.

So, in an urban or domestic environment, circular polarization has a better chance than linear that some of its components will survive the various obstacles.

The polarizing effect of reflection is actually exploited by Polaroid sunglasses. Since most of the light reflected on the ground or a water surface has mostly horizontal components, it can easily be filtered out by a vertically polarized filter.

## Comparison of Linear vs. Circular applications

Linear and Circular polarization have their own application areas because of their propagation difference and antenna designs.

Aspect	Linear Polarization	Circular Polarization
<b>Antenna Alignment</b>	Must be aligned	Works at any orientation
<b>Misalignment loss</b>	High loss if not aligned	Minimal loss due to misalignment
<b>Multipath Interference</b>	More susceptible	Less susceptible
<b>Mobile/Rotating Apps</b>	Not ideal due to alignment	Ideal for mobile or rotating devices
<b>Penetration through Obstacles</b>	Can be less effective	Sometimes better penetration
<b>Applications</b>	TV, broadcast, point-to-point	Satellite, RFID, aviation, mobile, GNSS
<b>Design Complexity</b>	Simpler design	More complex design
<b>Cost</b>	Generally lower	Sometimes higher

In general, circular polarization is good for mobile communication while linear polarization is good for fixed communication links.

However, linear antennas are usually easier and cheaper to manufacture and can be made more compact than circular antennas. It is also more difficult to make a more or less omnidirectional circular antenna. Domestic applications often require omnidirectional radiation patterns because the wireless clients are moving around.

For these reasons, many of the small and tiny wireless devices in the market have linear antennas, but GNSS (GPS) antennas are often circular to match the satellite signals.

## Analyzing circular polarization

As we can use two linear antennas to produce circular polarization, it is also possible to receive a signal with two linear antennas and analyze the polarization properties.

By measuring the amplitude of the two signals we can determine if it is a horizontal or vertical signal, or something in between. But the amplitude alone doesn't tell us if it is a slanted linear or circular polarization.

We also need to measure the phase between the two signals to determine if it is linear (0 or 180 degrees) or circular (plus or minus 90 degrees). Or it can be anything in between.

Many antenna measurement setups are not suited for this because they measure one polarity at the time, which makes it impossible to measure the phase between them.

## Measuring Linear and Circular polarizations

A device that can do these measurements and analyze them is the [Radiation Measurement System \(RMS\)](#) from MegiQ. This is a standalone system with a turn table, dual polarization antenna and a dual channel phase coherent receiver.

The RMS can measure radiation patterns of standalone wireless devices that transmit a constant carrier or constant test pattern.

With its built-in tracking generator, it can also perform rotation and sweep measurements of bare antennas.

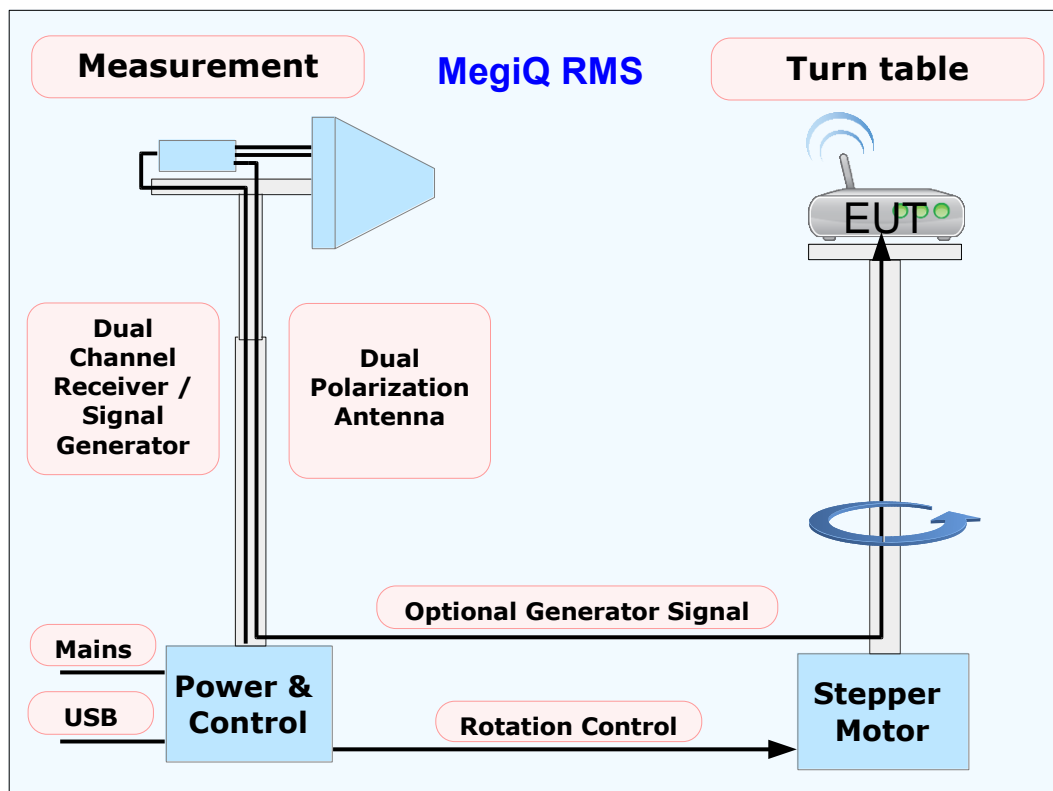


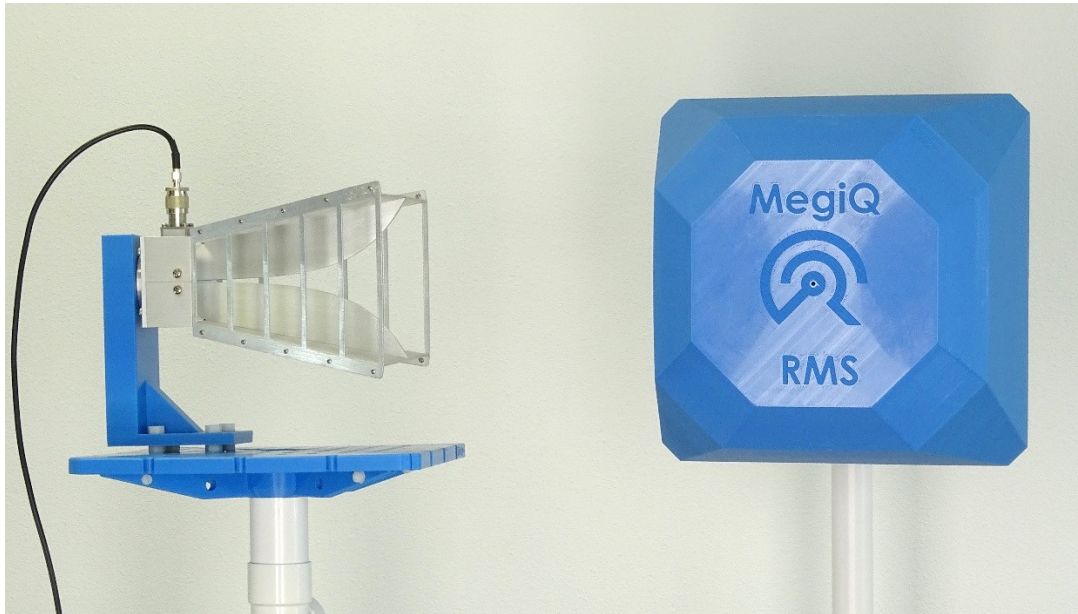
Figure 8. The MegiQ [RMS system](#)

The phase coherent receiver makes it possible to measure the phase between the horizontal and vertical signals and thus calculate circular properties of an antenna.

The system is designed so that only minimal anechoic measures are required to get accurate and meaningful measurements.

Figure 9 shows the RMS antenna and turn table. The receiver is mounted behind the antenna.

The RMS systems can measure between 370MHz and 6GHz, depending on the model.



*Figure 9. The RMS measuring a horn antenna*

The RMS system is very useful when there are limited resources such as budget and space, or as a way to get quick antenna measurements and not have to wait and pay for measuring time at a test lab.

The accuracy of the RMS is in the same order as certified test labs.

### Measurements of a circular satellite communication antenna.

The RMS system measures the horizontal and vertical polarization and their phase relation and the user can open a graph for Linear polarizations or Circular polarizations. These graphs use the same measurement but differ in the kind of post-processing of the data.

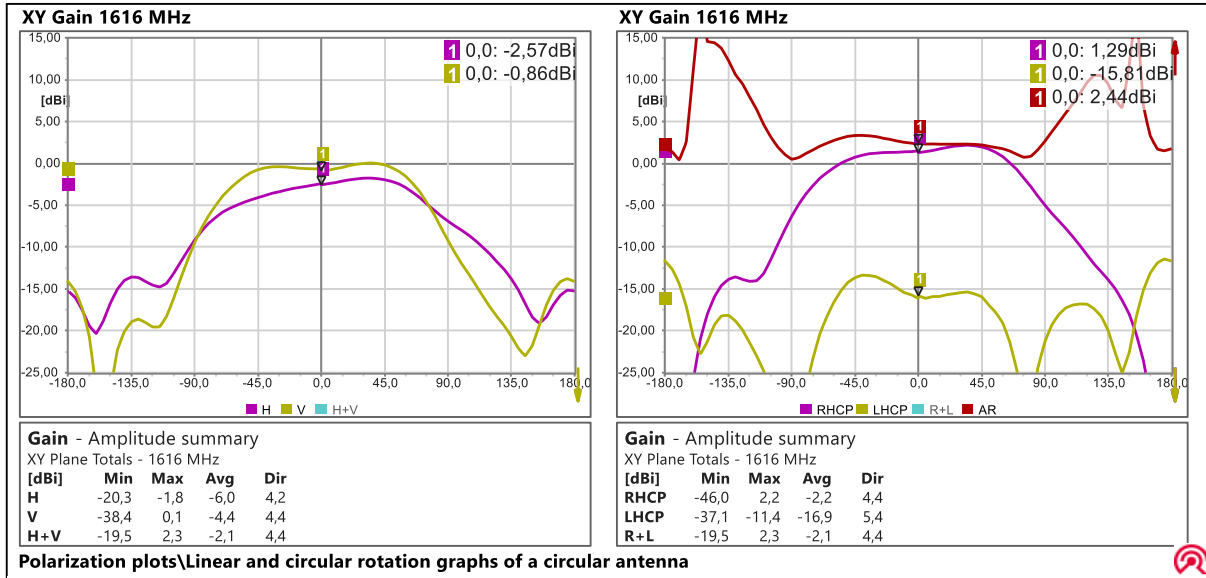


Figure 10. Linear and circular graphs of a satellite antenna rotation

In figure 10, the left graph shows the linear result. The antenna has more or less equal horizontal (purple) and vertical (brown) components. In the statistics at the bottom line, the maximum of the combined gain is 2.3 dB.

The same maximum of the total gain of 2.3 dB can be found in the right graph, where the gain is converted to a RHCP component (purple) and a LHCP component (brown). Now, there is a large difference of 17.1 dB between RHCP and LHCP.

The Axial Ratio (red) is 2.44 dB at the center, which converts to 17.1 dB cross polarization.

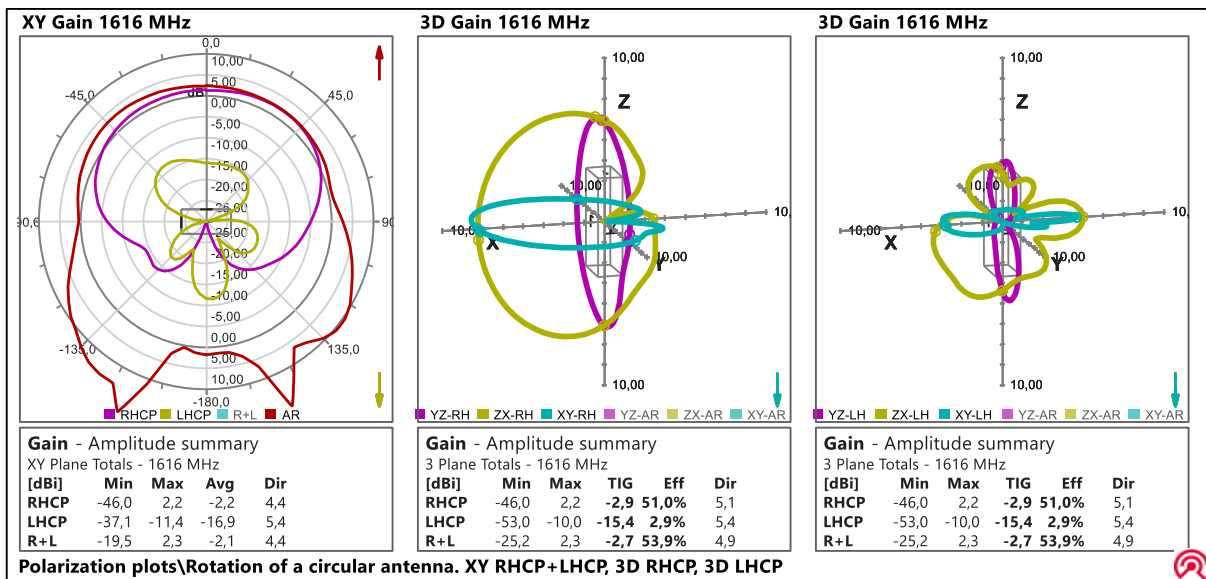


Figure 11. Radiation patterns of the same satellite antenna

The rotation radiation patterns in Figure 11 are measured with the same antenna. The left graph shows how the Axial Ratio is only good in the main lobe of the antenna and deteriorates to higher values in the other direction.

The center and right graphs show the RHCP radiation pattern and the LHCP radiation pattern. Again, there is a large difference between the RHCP and LHCP gains.

Also, the Total Isotropic Gain (TIG), which translates to antenna efficiency of the two components are very different at -2.9 dB / 51 % for RHCP versus -15.4 dB / 2.9 % for LHCP.

### Measurement of a circular GNSS patch antenna

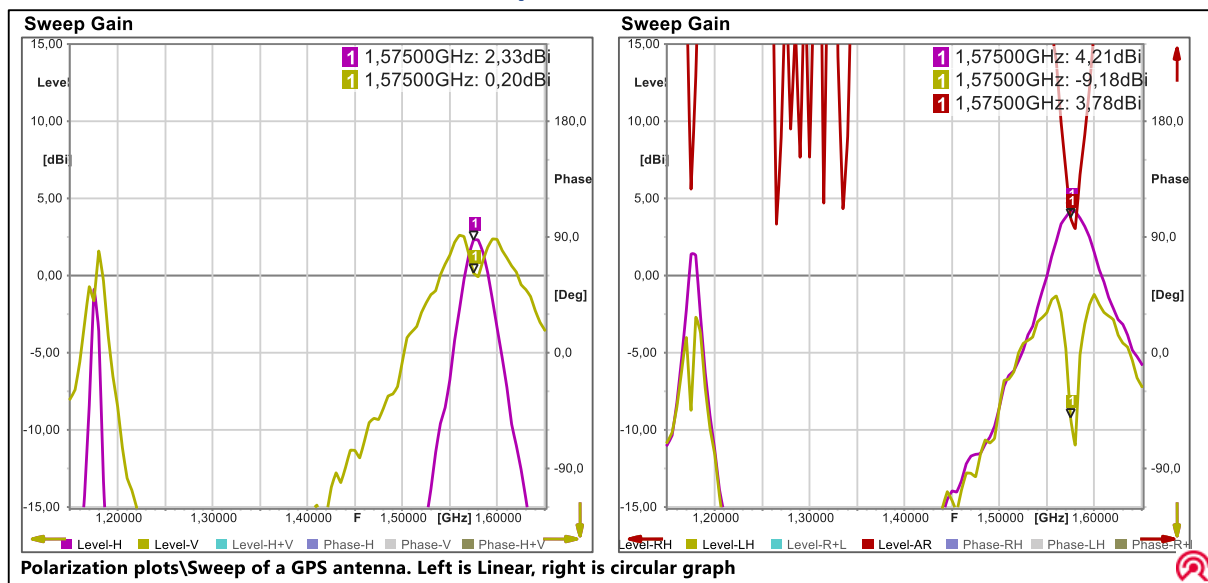


Figure 12. Linear and circular plots of a dual band GPS antenna frequency sweep

The frequency sweep in Figure 12 shows the linear and circular of a GNSS (GPS) patch antenna. In the operational bands the Horizontal and Vertical gains are again similar to each other.

The RHCP and LHCP graphs on the right shows the circular operation of the antenna. The cross-polarization in the main band is around -13 dB. The Axial Ratio also drops to reasonable levels in the two bands.

### Conclusions

Linear and Circular polarization have their own areas of application, but since it is more difficult or expensive to create very compact circular antennas, they are not used in some areas that would benefit from it.

Measuring and analyzing circular signals require a measurement system that can measure the horizontal and vertical components and the phase between them. The MegiQ RMS system is one of the few systems that can do this with good accuracy.