

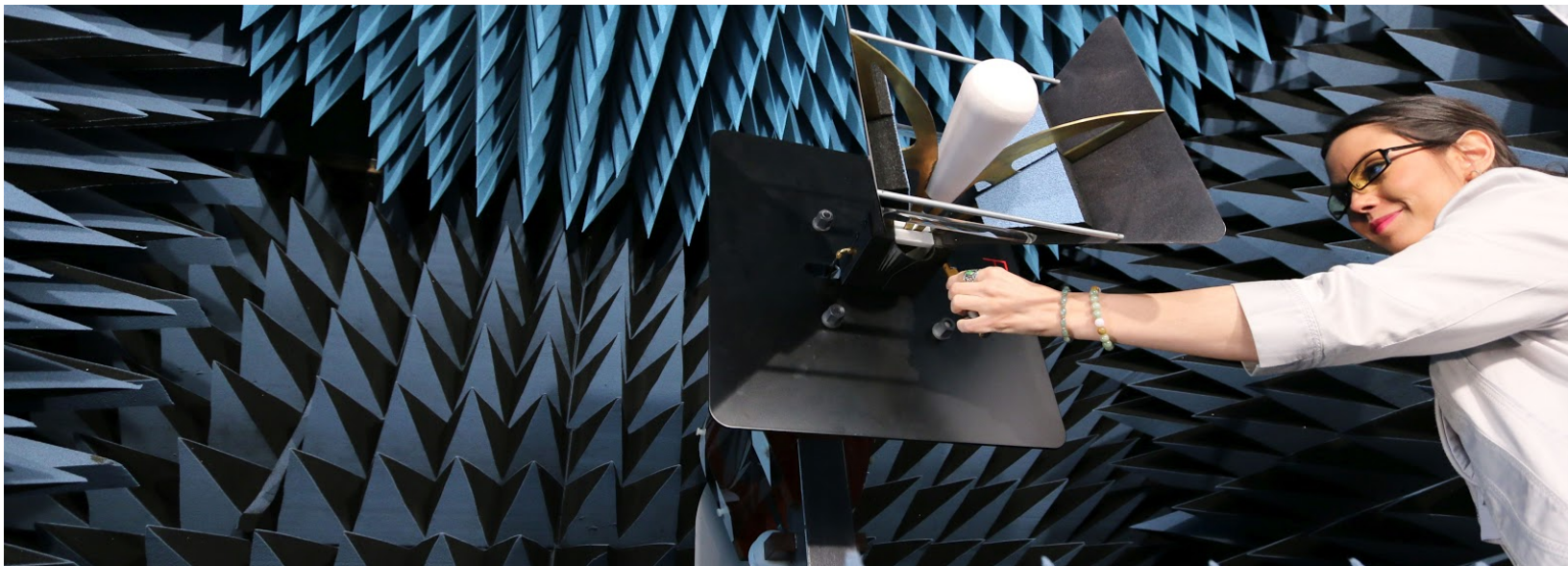
Circularly Polarized Antennas Explained, Without The Math

Details and examples of circularly polarized (CP) antenna test results are discussed along with laboratory test methods. A no-math tutorial on CP measurement procedures is also presented.

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Forward

Our goal in this whitepaper is to explain the concepts of circularly polarized (**CP**) antennas, and the details of their test lab evaluations, without resorting to “math”. It is true that antenna engineering and vector antenna testing is indeed “math heavy”. However, initial concepts are best introduced with examples and diagrams, while the math is best saved for detailed analysis.

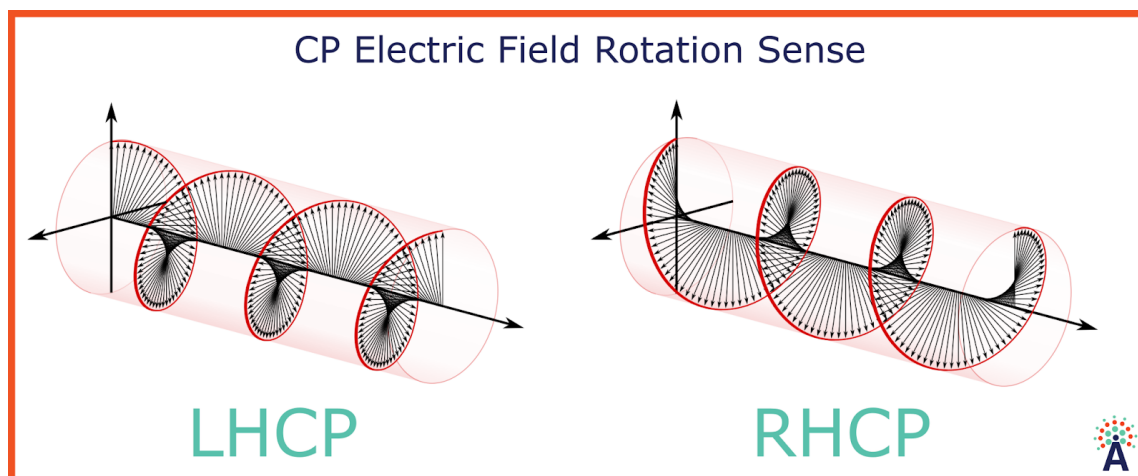
We will start with some background about the historic and present uses of CP antennas. CP rotating field concepts will be made clear later in this paper, when the detailed procedures for laboratory evaluation are explained. Finally, we will close with a set of example test results for a CP antenna, and walk the reader through its various measurements and performance metrics.

Background

Satellites

Up until the 1990's, circularly polarized antennas used to be an exotic microwave technology used only for satellite communications. It allowed satellites and ground station antennas to “talk” without worrying about the vertical/horizontal alignment of standard linearly polarized antennas (waveguide horns, rods, or dipoles). This antenna challenge came from possible satellite rotation, and its ever-changing angles of view as it arcs across the sky from horizon to horizon. Even atmospheric disturbances could rotate microwaves. Keeping “**linear**” antennas (vertical / horizontal) in alignment would require constant rotation.

However, the field of a CP antenna is always rotating (unlike a linear antenna). It can rotate in two possible directions, and this “**sense**” of rotation is referred to as Left or Right Hand Circular Polarization. Using both “senses”, allows a 2X multiplexing frequency reuse to the same satellite, since a **LHCP** and **RHCP** antenna reject each other's signals. So for a single frequency allocation, two simultaneous RF links may be used with two different rotational sense antennas.



Modern Mobile “Wireless” Applications

While there are many benefits in satellite applications for CP to CP antenna radio links, a CP to linear antenna link is also quite useful. In fact, when just one end of a radio link uses a CP antenna, all of the rotation-independent benefits of CP antennas are realized. This can be a huge benefit to mobile devices, where the vertical / horizontal orientation of their simple linear antennas is always changing with movement and reflections. Whether or not the CP antenna has a left hand or right hand rotational sense, it does not matter to the linear antenna! If the mobile antenna is rotated from vertical to horizontal, the CP antenna still works !

This is why CP antennas are becoming popular in many common wireless applications, and even have a future in 5G. Typically, mobile devices are smaller and still tend to have linearly polarized antennas. However, the fixed “base” or “gateway” ends of the RF links can benefit from CP antennas. At Antenna Test Lab Co we are seeing more and more CP antennas, and not just for GPS reception (which is RHCP at 1575 MHz).

GPS Applications

The GPS and other navigation satellites use RHCP downlink signals. This allows simple linear antennas to be used in GPS receivers, with only minimal loss in signal. This small 3 dB loss comes about from the linearly polarized antenna's ability to receive only one component (like the vertical or horizontal) of the GPS signal. More sophisticated GPS receivers use a RHCP antenna for two performance boosting reasons.

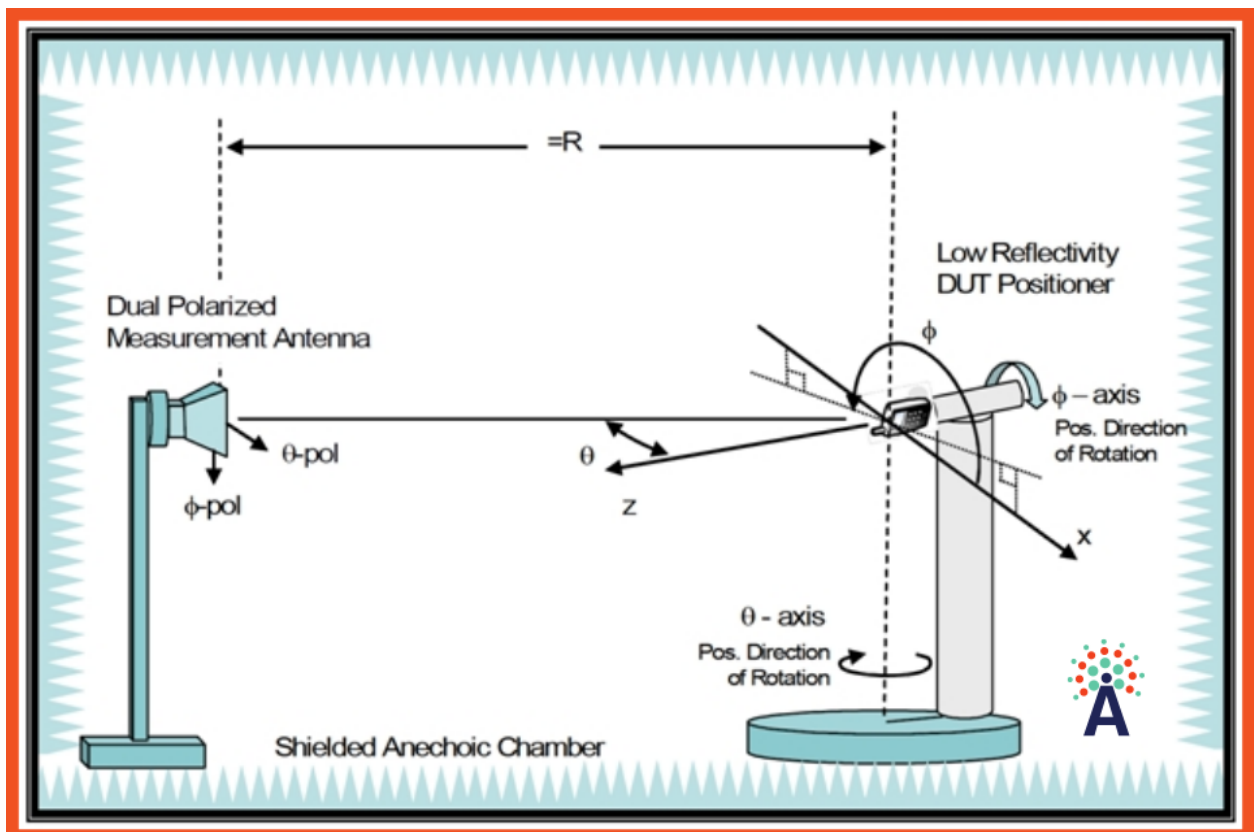
- Using a RHCP antenna improves sensitivity (and lock time), since it receives 3 dB more signal than would a linear GPS receive antenna.

- A RHCP will reject LHCP reflections. Think about optical reflections in a mirror and what happens to text ... reflections are “backwards”. CP signals also reverse their rotation sense when reflected. So a RHCP antenna can reject reflections, often from large buildings in urban environments, which arrive as LHCP.

Measuring “Vector Gain”

The Chamber Configuration

We use the substitution method to test antenna gain by exciting your antenna (**AUT**, or Antenna Under Test) with a swept RF signal in our anechoic chamber. The substitution method involves setting up our known calibrated laboratory reference antenna over a radiated path in the chamber, then **normalizing** (or “zeroing”) that path loss to 0 dB. We also normalize the received phase to zero degrees. In other words, the signal level (magnitude) and relative delay time are normalized (“zeroed”) as a sort of starting point for comparison measurements.




The Quad Ridge Chamber Antenna

The “measurement antenna” in the previous diagram is an open boundary quad-ridge Vivaldi horn antenna. It is actually two antennas that occupy the same space. The gain/phase normalization described above is actually done twice. Once for the vertical ridges, and again for the horizontal ridges, since they are different antennas with slightly different gain and phase.



The Substitution

Then we exchange our reference antenna for your Antenna Under Test (AUT), and re-measure the path gain/loss and phase changes relative to the previously normalized



reference path. In other words, your AUT will have gain higher, the same, or lower than our reference antenna (a relative measurement).

By simply adding our reference antenna's calibrated gain (in dBi) to these path change measurements, we determine the AUT's gain in dBi. Our inventory of reference antennas are chosen to span wide frequency ranges. For example, using our calibrated 300 MHz to 30 GHz reference horn allows us to measure your antenna's gain over its entire operating range, in hundreds of physical directions, in one test run. Tests DO NOT have to be repeated at each individual frequency, as with tuned dipole substitution.

Understanding Phase Data

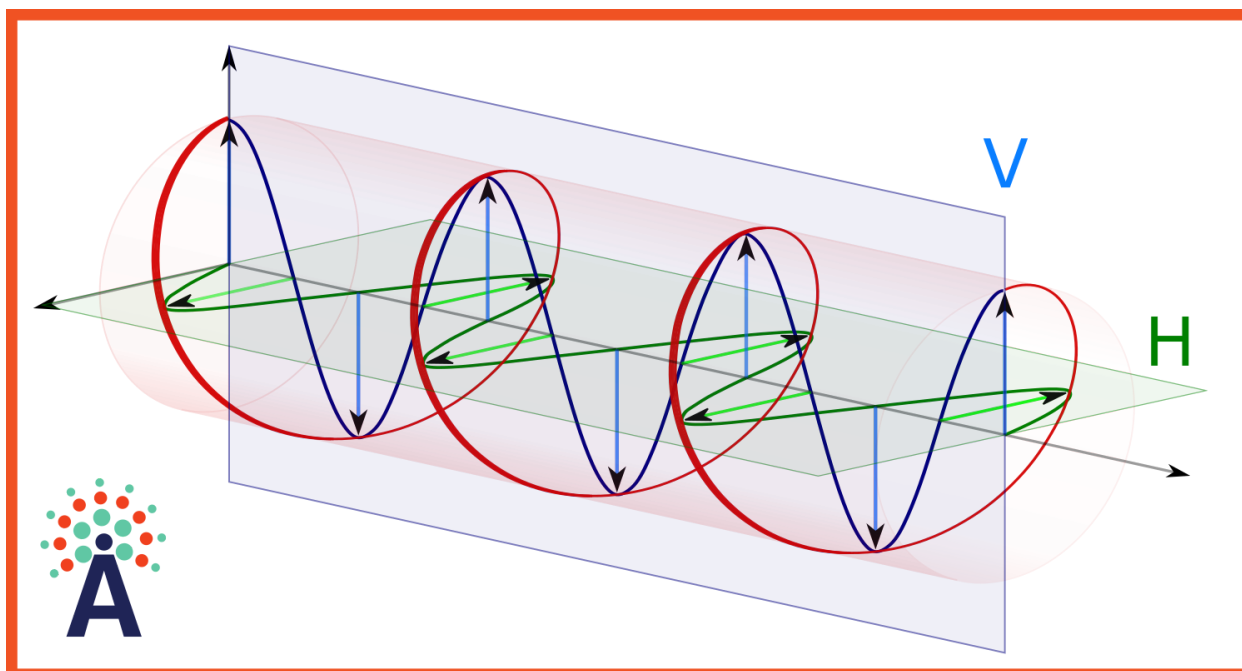
The substitution method math above is relatively straightforward to understand for gain magnitude, but we also use phase data to calculate CP gains. There are many explanations of using orthogonal (vertical/horizontal) gain-phase data on the web. However, those explanations all utilize vector math to describe the detailed calculations. "Heavy" math is not always helpful for understanding new concepts. In our lab, we start by describing the CP calculations without referencing vector geometry.

Example: Transverse Waves On Rope

The fields coming from an antenna propagate outwards as waves. We find it useful to make a rope comparison. If you have a long rope with one end tied to a tree, you can wiggle or wave the free end. If you wave the rope upwards and downwards, your waves will travel towards the tree. You have created a vertical wave, technically called a vertically polarized **transverse wave**. Similarly, you can easily create a horizontal transverse wave by waving the rope from side to side. These transverse waves are like linearly polarized radio waves. Relative to the ground, they can be labeled as vertical or horizontal. You can even wave your rope on a random angle, neither vertical or horizontal. Such a wave is still transverse, it just has a "slant" polarization.

Example: Circular Waves On Rope

CP waves may sound complicated, but even a child can make circular waves on the rope. Just circle your hand, like you are "skipping rope". The corkscrew shaped waves can be RHCP if you rotate your hand clockwise, or LHCP if you rotate your hand counter-clockwise. The waves have both up/down and left/right components, just like CP radio waves.



Using The Phase Data

We use our quad-ridge measurement antenna to separate the vertical and horizontal components of received energy. In the diagram above, the blue plane, arrows, and wave show the vertical components from the red CP wave. Horizontal components are in green. Please notice in the diagram above, that the vertical and horizontal components of the CP waves are offset by $\frac{1}{4}$ turn. This is measurable as a 90 degree phase shift in our laboratory. Whether there is an advance or delay by 90 degrees between the vertical and horizontal components, tells us if the wave is RHCP or LHCP.

The phase data from the vertical/horizontal measurements also tells us about the ratio of rotating gain to non-rotating gain. Often the phase shift is less than 90 degrees, because real antennas are not perfectly CP ... they have some linear component as well. We calculate the ratio of these two types of gain for you to yield a performance merit called axial ratio.

Your CP Antenna Testing Options

Legacy

Your options for CP antenna evaluations used to be limited. The old satellite/military legacy of CP antennas often dictated that larger chambers and big organizations were supported by expensive contracts for such antennas. Whereas commercial and wireless labs concentrated more on linear antennas. Sometimes labs would give you raw vector gain/phase data, and expect you to calculate circular polarization parameters yourself.

Today's Options

Antenna Test Lab Co's evaluation service includes fully circular polarization antenna evaluations, at no extra charge. Practical antenna evaluations with 2D or 3D patterns in hundreds of test directions (and frequencies) are available for \$525. This means that in all of the physical test directions of your patterns, and at all swept test frequencies, you have full CP results and analysis, without having to do any math! Easy to use spreadsheet results include:

- LHCP and RHCP Gains in dBi
- Total Gain Magnitude in dBi
- Axial Ratio in dB
- Graphs of LHCP, RHCP, and Axial Ratio vs frequency for the preferred antenna direction (and data is available for *all* test directions)
- Raw orthogonal vector gain and phase data for specialized post processing
- Accommodating "active" antennas, such as GPS antennas with built-in LNAs

Example Results

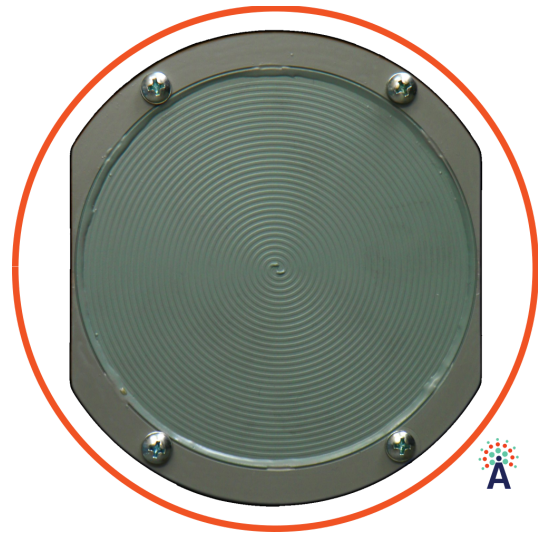
CP Gains Pre-Calculated

Here is a screenshot of our basic CP data reporting. In this screenshot, only 20 directions (rows) and two test frequencies (out of hundreds) are shown.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
	Theta	Phi	1000 MHz Vert Gain (dBi)	1000 MHz Vert Phase (deg)	1000 MHz Horiz Gain (dBi)	1000 MHz Horiz Phase (deg)	1000 MHz LHCP Gain (dBi)	1000 MHz RHCP Gain (dBi)	1000 MHz Axial Ratio (dB)		1025 MHz Vert Gain (dBi)	1025 MHz Vert Phase (deg)	1025 MHz Horiz Gain (dBi)	1025 MHz Horiz Phase (deg)	1025 MHz LHCP Gain (dBi)	1025 MHz RHCP Gain (dBi)	1025 MHz Axial Ratio (dB)
1	0	0	-4.89	359.48	-9.48	258.05	-15.08	-3.91	4.94		-7.83	333.26	-6.14	231.97	-21.14	-3.98	2.42
2	2	0	-4.89	359.64	-9.44	258.4	-15.13	-3.9	4.9		-7.84	333.44	-6.12	232.54	-21.2	-3.96	2.4
3	4	0	-4.89	359.54	-9.4	258.47	-15.19	-3.88	4.85		-7.86	333.31	-6.09	232.85	-21.25	-3.96	2.39
4	6	0	-4.89	359.42	-9.37	258.42	-15.24	-3.87	4.81		-7.87	333.13	-6.07	232.98	-21.27	-3.95	2.38
5	8	0	-4.9	359.35	-9.36	258.36	-15.27	-3.87	4.79		-7.89	332.9	-6.06	232.98	-21.28	-3.95	2.38
6	10	0	-4.91	359.33	-9.34	258.21	-15.31	-3.87	4.77		-7.9	332.57	-6.06	232.84	-21.3		2.37
7	12	0	-4.93	359.26	-9.32	257.98	-15.37	-3.88	4.74		-7.92	332.13	-6.07	232.53	-21.3		2.37
8	14	0	-4.96	359.11	-9.31	257.6	-15.43	-3.89	4.72		-7.95	331.47	-6.08	232.02	-21.3		2.37
9	16	0	-4.98	359.02	-9.29	257.26	-15.48	-3.91	4.69		-7.98	330.85	-6.08	231.58	-21.3		2.37
10	18	0	-5.02	359.03	-9.28	257.09	-15.55	-3.92	4.67		-8	330.29	-6.07	231.28	-21.33		2.38
11	20	0	-5.06	358.86	-9.29	256.82	-15.62	-3.95	4.64		-8.03	329.52	-6.05	230.93	-21.3	-4	2.38

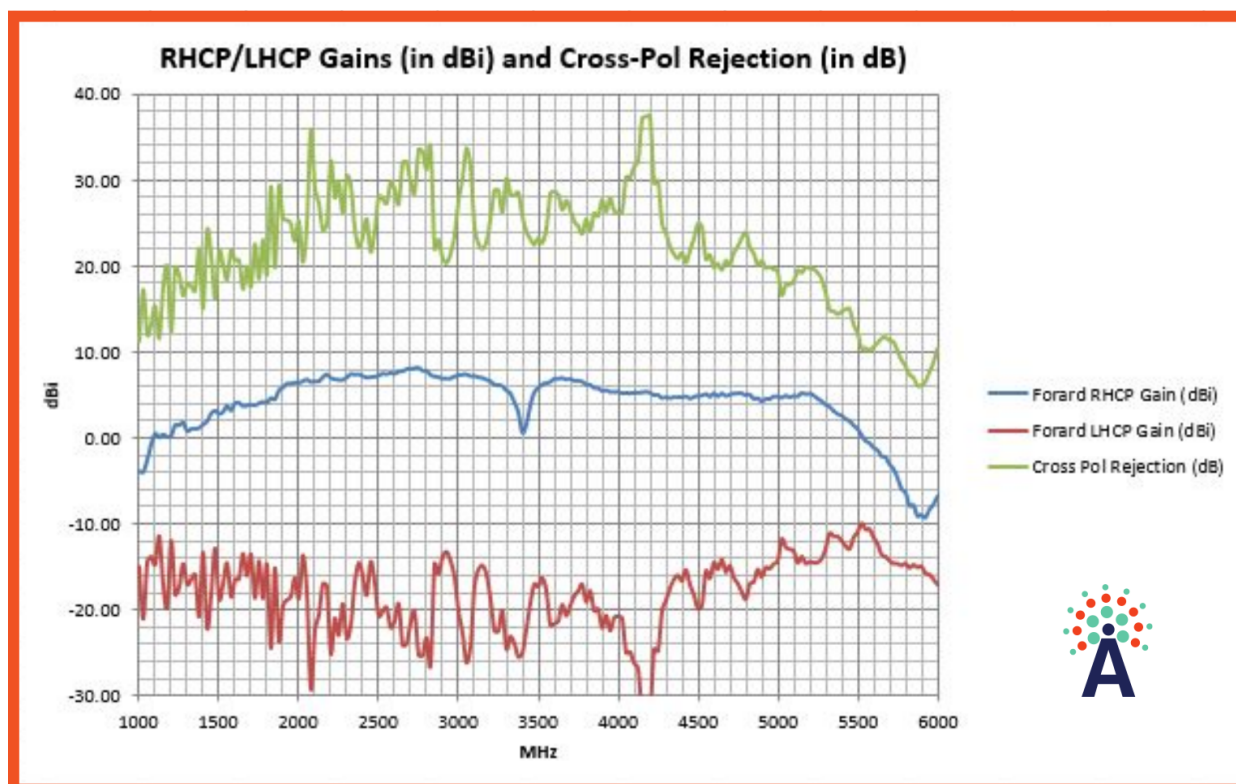
For each test pattern's direction and frequency, you have the raw "vector gain" data (V/H gain and phase) as well as calculations of LHCP & RHCP gain and axial ratio. With this example antenna (pictured to the right), you can see in the spreadsheet data that it is RHCP, since its RHCP gain is much higher than its LHCP gain.

The advantage to Excel spreadsheets (as opposed to proprietary patterns and results files) is that any specialized or custom post processing or graphing is made easy. Virtually any plot can be created, including overlaying co-polarization and cross-polarization parameters on the same graph.



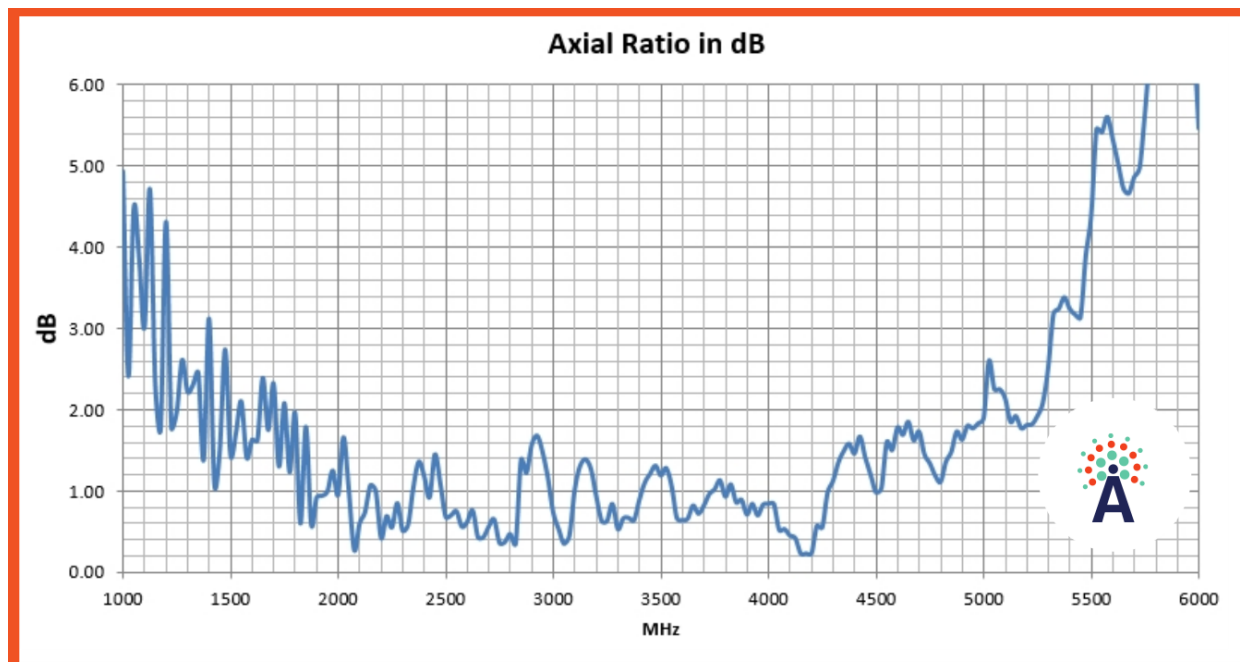
Graphing CP Gains

For example, with this example RHCP antenna, the desired “**co-polarization gain**” is the RHCP gain, and the undesired “**cross-polarization gain**” is the LHCP gain. The CPRR “**cross polarization rejection ratio**” is simply the difference between the RHCP and LHCP gains. The plot illustrates RHCP, LHCP, and CPRR all on the same graph, vs frequency for the prime (boresight) direction of the antenna. (Keep in mind, this data is available in all tested directions.)



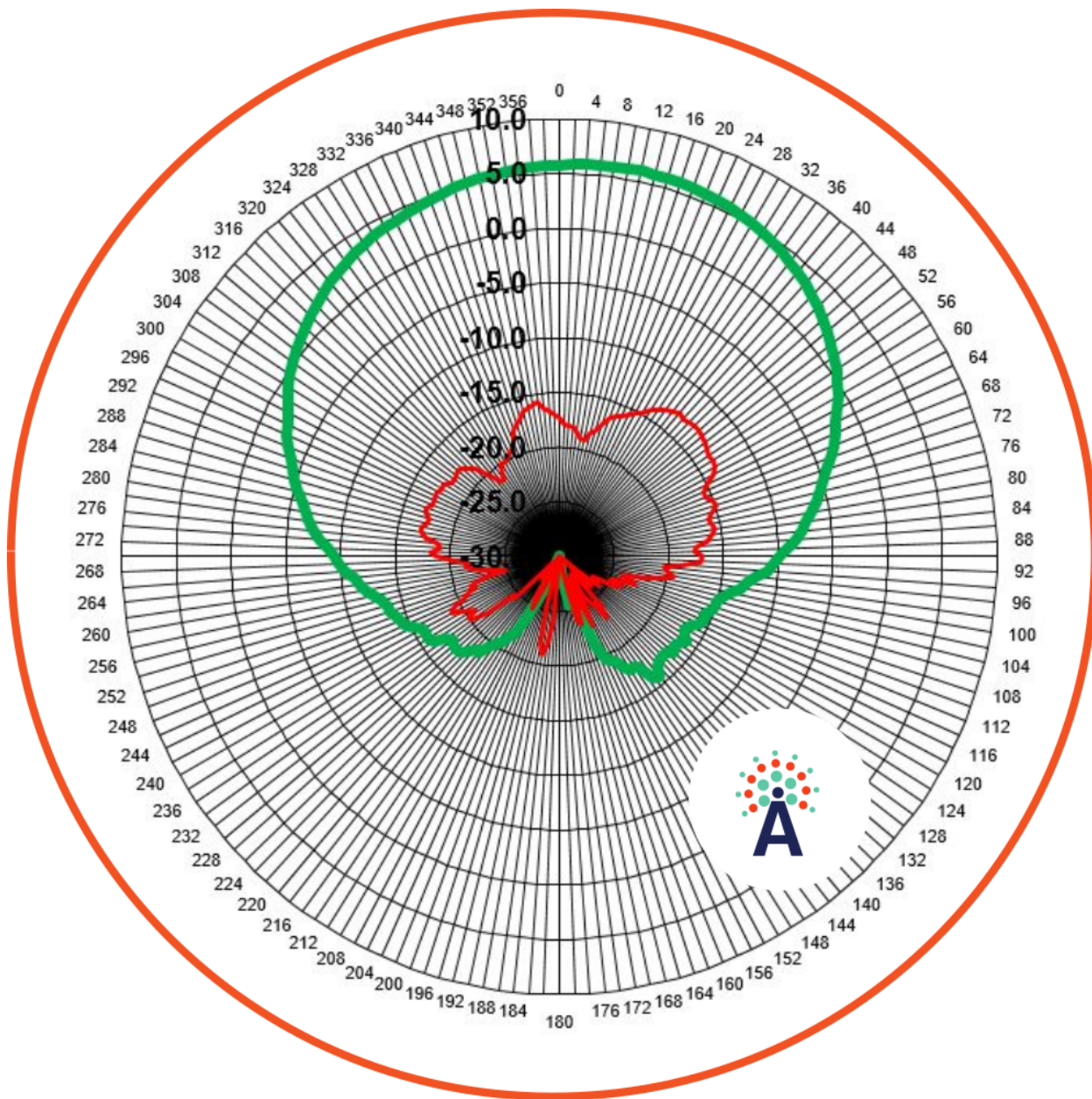
Graphing Axial Ratio

The graph below is the main-axis (“boresight”) axial ratio vs frequency plot for our example antenna. The same graph (or overlaid curves) can be made with results data from any other test direction, and are great for illustrating the deterioration in axial ratio for off angle directions.



Graphing Patterns With Mixed Data

The graph below is a standard polar plot, with separate RHCP (in green) and LHCP (in red) gains overlaid on the same graph. In this antenna, you can see that RHCP gain is always higher than LHCP, except in the non-functioning part of the antenna's pattern (behind the antenna).



Further Reading

Antenna Test Lab Co strives to deliver antenna insights and comprehension to our customers. Understanding antennas, terminology, pattern types, and test options is often the best place to start your design and evaluation project. We have created an educational section on our website to help you get up to speed ...

<http://antennatestlab.com/antenna-education-tutorials>

Contact Us

We hope that you have enjoyed this white-paper, and that our no-math explanation of CP waves and measurements has helped you understand this advanced topic.

We would love to hear from you, and hope that you will contact us with your comments. Please feel free to ask us for an antenna testing quotation or to discuss your testing needs. Standard antennas are normally \$525 for the first antenna (and \$350 per additional antenna), and include full CP results data.

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About the Author

Glenn Robb is a Founder and Principal Engineer at Antenna Test Lab Co, www.AntennaTestLab.com

Glenn is an EE who has been working professionally with antennas for 30 years. He has a passion for testing antennas and providing customer insights. Day to day, he runs the anechoic chamber at Antenna Test Lab Co and is responsible for hundreds of customer antenna evaluations. Glenn also designed all of the lab's custom software and test hardware configurations for accuracy, speed, and cost-effectiveness.

