Magis Air5™ Antenna Array Development Work

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28 May 2003

Advance Information

This product is in a formative or design state. The document contains design target specifications for product development.

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1. Introduction

Antennas play a very key role in the productization of any wireless product. This is particularly true for 5 GHz systems like Air5, because large link margins are desired for link reliability, and casual usage of antennas at these high frequencies can easily lead to many dB of performance loss.

The first Magis Core Modules (CM) provided to customers were primarily intended to provide a demonstration platform for the Air5 technology, rather than be a fully optimized reference design. Because of this objective, a number of different antennas were provided with the CMs so customers could quickly get on the air with the hardware.

This brief memorandum presents the results of several lengthy antenna measurement efforts conducted recently at Magis.

2. Early Third-Party Antennas

Several individual antenna elements have been considered and characterized at Magis over the past year. A wide range of in-house antenna types were used in Air5 testing, but Skycross antennas of one type or another have generally been shipped with the Magis Air5 CMs. The most common antennas shipped with CMs have been the array shown in Figure 1 or the individual antenna elements shown in Figure 2.

In general, the testing efforts have shown that third-party antennas often perform as advertised when used one at a time, but their performance can degrade substantially as they are assembled into an array where each element has some proximity to other similar antenna elements. Some coupling between the individual elements was anticipated, but not to the degree that has been observed in our testing.

A linear array of the Skycross patch antennas (#222-0189) was used for the Remote Terminal (RT) end of the communication link in a lengthy field testing effort carried out by Magis staff in December 2002. The array elements were spaced approximately 1.5 to 2.0 inches apart, as shown in Figure 4. This linear array was characterized for gain and directivity about one month later. The findings showed that, although the peak-gain remained reasonably unchanged, the 3 dB beamwidths of the different receive antenna elements became smaller than desired.

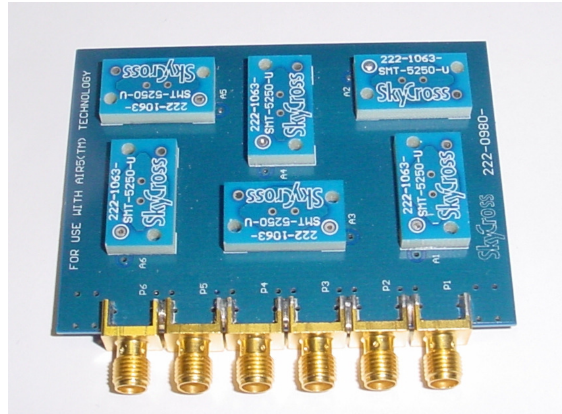


Figure 1: Skycross Antenna Array Originally Shipped With Some Magis Air5 CMs

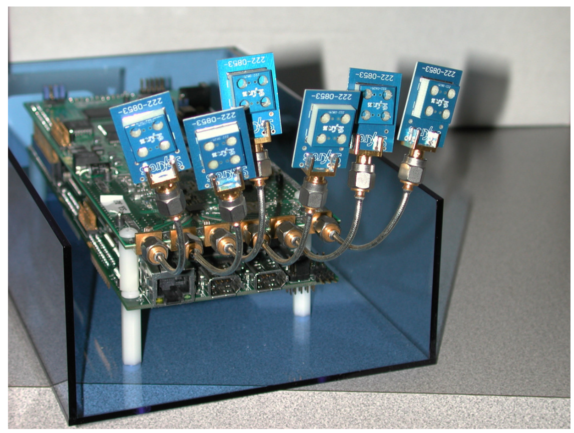


Figure 2: CM Configured With Individual Skycross Antenna Elements

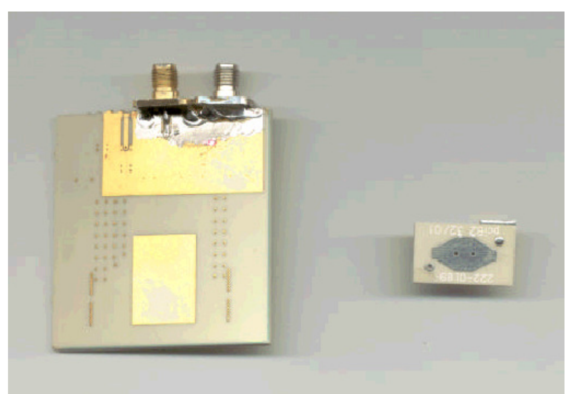


Figure 3: Quarter-Wavelength Patch Antenna (Left). Skycross #222-0189 (Right)

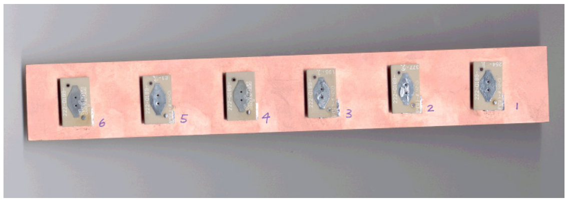


Figure 4: Linear Array of Skycross #222-0189 Patch Antennas Used for Remote Terminal (RT) in December 2002 Field Testing

At the Access Point (AP) side of the communication link, the same individual Skycross patch antennas were used. They were arranged in a pentagonal shape, again with 1.5- to 2.0-inch spacing, with the main lobe of each patch directed vertically.

With the AP and RT antenna combinations used during the field testing, testing on the same floor in a home meant that the RT antenna gain would be reasonably good (i.e., the main lobe), whereas most of the AP energy was directed toward the ceiling with increasingly less energy directed as the horizontal elevation was reached.

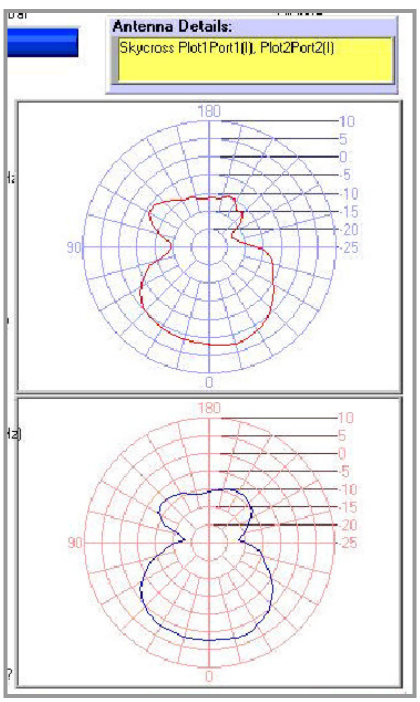


Figure 5: Linear Antenna Array of Figure 4 With Different Gain Directivity Cuts[1]. Antennas 1 and 2 With "I" Orientation.

As a result, the link margin suffered. When the AP was left on the first-floor and the RT was put on the second-floor of the home, the AP and RT antennas were both operating off of their side lobes when the units were at their maximum separation in the home. Since the antenna side lobe gain falls off fairly rapidly above look-angles exceeding about ±50 degrees in the antenna gain measurements presented in Figure 5, the impact to the link margin for first-floor to second-floor links was substantial in many cases.

In order to exhibit the Air5 technology in its best configuration, rather than introduce antenna-related impairments, two different antenna types were designed at Magis for shipment with future CMs. These are briefly described in the following sections.

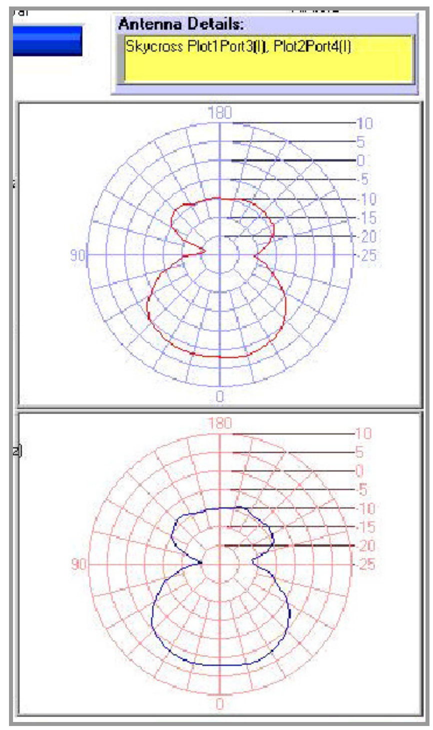


Figure 6: Linear Antenna Array of Figure 4 With Different Gain directivity Cuts. Antennas 3 and 4 With "I" Orientation.

[1] See the Appendix for a definition of gain directivity cuts.

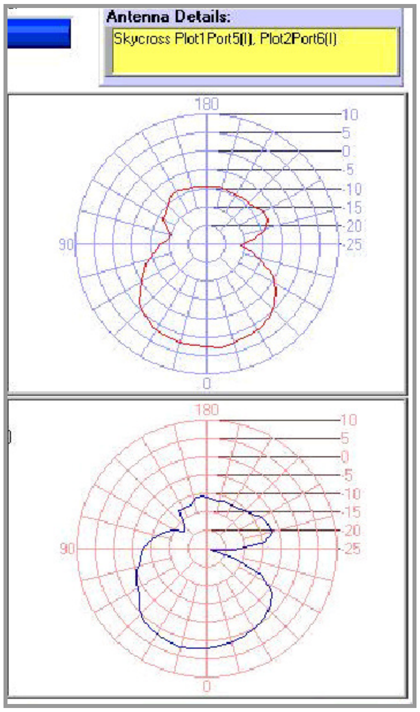


Figure 7: Linear Antenna array of Figure 4 With Different Gain Directivity Cuts. Antennas 5 and 6 With "I" Orientation.

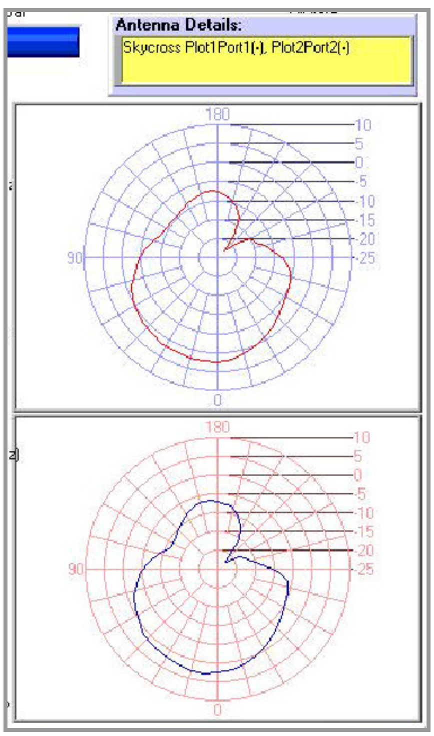


Figure 8: Linear Antenna Array of Figure 4 With Different Gain Directivity Cuts. Antennas 1 and 2 With "-" Orientation.

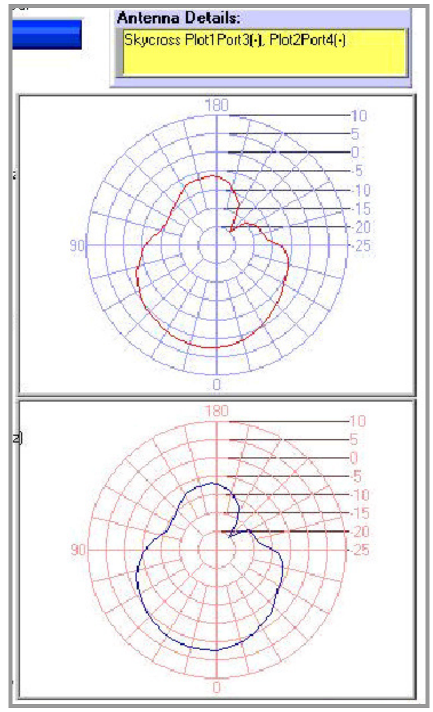


Figure 9: Linear Antenna Array of Figure 4 With Different Gain Directivity Cuts. Antennas 3 and 4 With "-" Orientation.

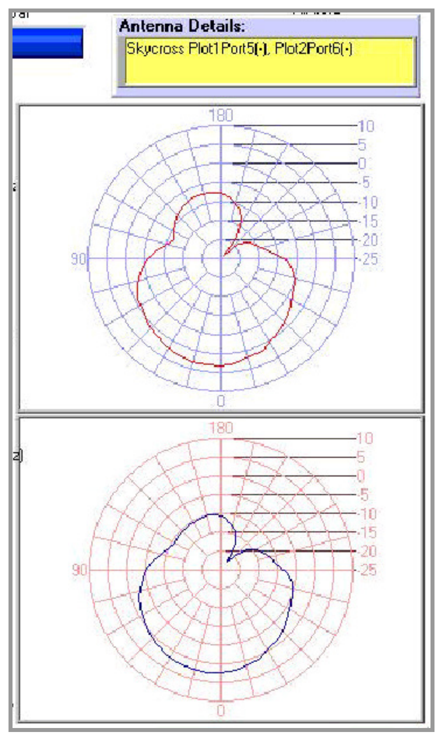


Figure 10: Linear Antenna Array of Figure 4 With Different Gain Directivity Cuts. Antennas 5 and 6 With "-" Orientation.

3. New Access Point Antenna Array

An omni-directional antenna gain pattern is desired at the AP location because the location of the RT(s) in the home is generally unknown. Ideally, the array would be circular (thereby showing no directional preference in azimuth) but this arrangement would normally present product-related form-factor issues. The gain pattern of a quarter-wave monopole is a good design choice because it delivers excellent broadside gain in azimuth, and although the gain falls off with increasing elevation, the straight-line distance between the AP and a RT also decreases with increasing elevation, reaching a minimum when the RT is directly above the AP in a home. The quarter-wavelength monopole antenna that was designed is called a "bow-tie" antenna due to its physical appearance when it is constructed as a dipole rather than a monopole.

A picture of a Magis bow-tie antenna array is shown here in Figure 11. A pair of bow-tie antennas were constructed and separated by 1.5 inches and the gain directivity patterns measured in order to assess the gain impairment caused by the coupling between the antennas. These measurements are shown in Figure 12 and Figure 13. As clearly shown in Figure 12, the azimuth gain is extremely uniform as desired. As shown in Figure 13 and Figure 14, the expected gain null (corresponding to directly above or directly above the AP) shows up, but the broadside gain remains fairly good over a larger extent than the patch antennas.

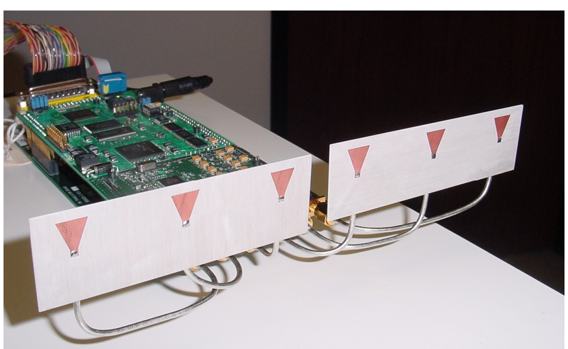


Figure 11: Three-Element Bow-Tie Antenna Arrays Developed at Magis for the AP

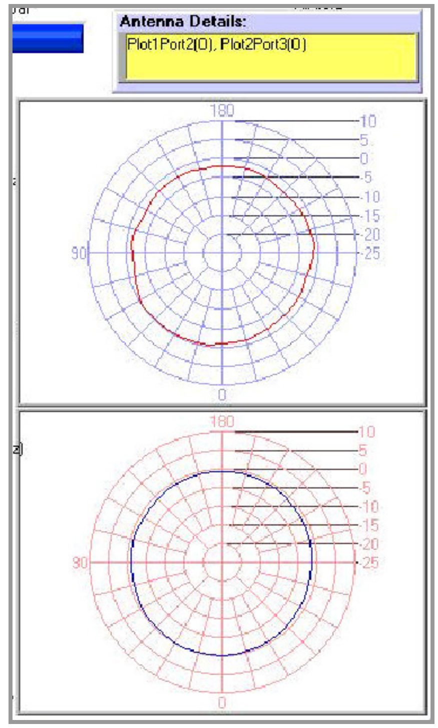


Figure 12: Bow-Tie Antenna Pair With Different Directivity Cuts. "O" Orientation (Expected Omni-Directional Pattern in Horizontal Plane With Antenna Arrangement in Figure 11)

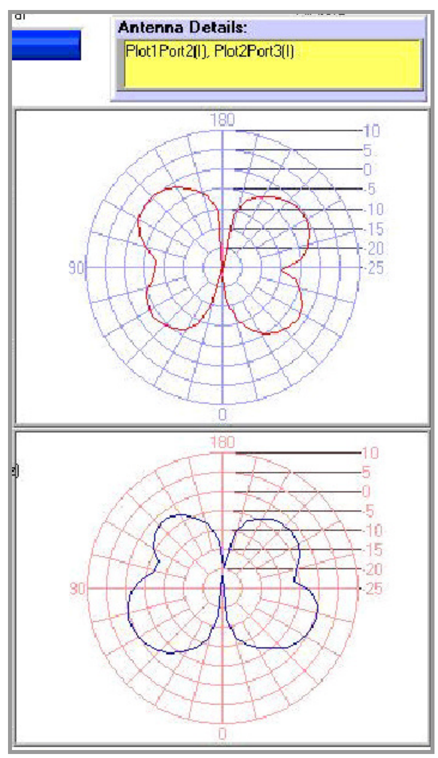


Figure 13: Bow-Tie Antenna Pair With Different Directivity Cuts. "I" Orientation.

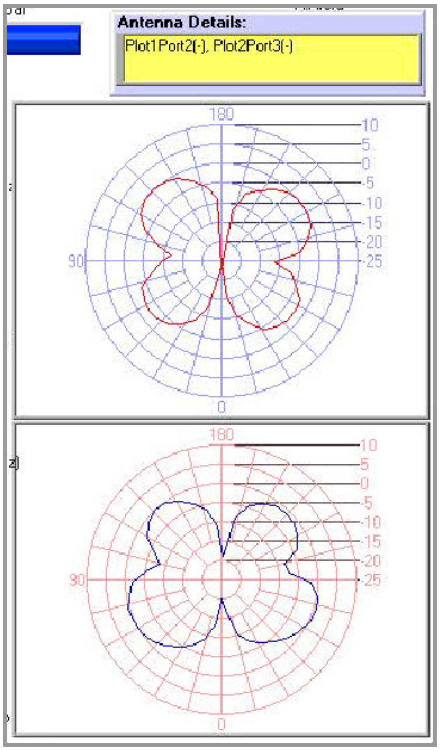


Figure 14: Bow-Tie Antenna Pair With Different Directivity Cuts. "-" Orientation.

4. New RT Antenna Array

The omni-directional bow-tie antenna arrays can in principle be used at both the AP and RT ends of a communication link. At the RT end in the case of a large flat-panel display or semi-fixed terminal application, some antenna directivity can normally be used which leads to improved link margins. Wishing to exploit this flexibility to a degree with the CM demonstration platforms, a yagi antenna array was developed at Magis. A three-element yagi antenna array is shown here in Figure 15. Two such arrays are normally used with a CM, as shown in Figure 16.

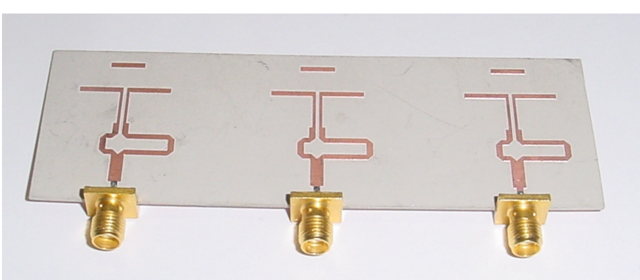


Figure 15: Three-Element Yagi Antenna Array

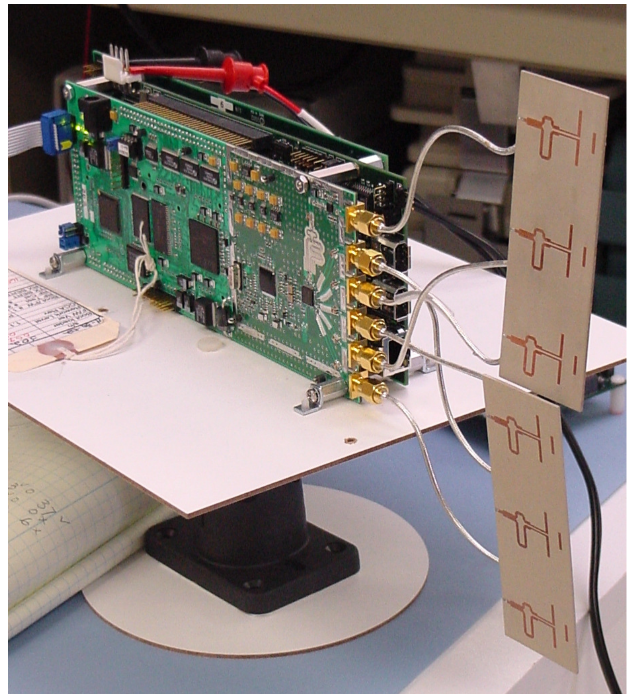


Figure 16: Example Usage of the Yagi Antenna Arrays With a Magis CM

An individual yagi antenna was fully characterized and the results were outstanding (Figure 17 and Figure 18). The yagi exhibited a very wide, almost full hemispherical high-gain pattern. Characterization of the individual yagi elements within the antenna array followed.

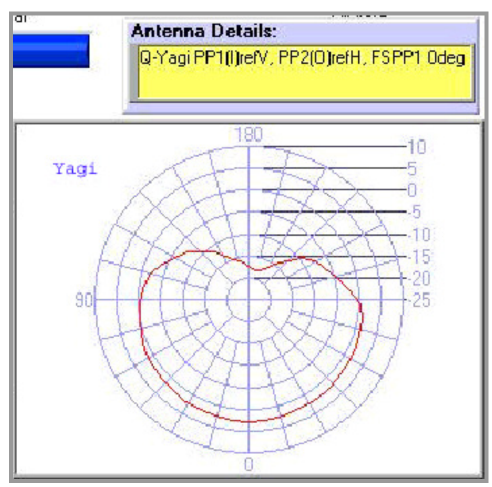


Figure 17: Single Yagi Antenna Element, "I" Cut

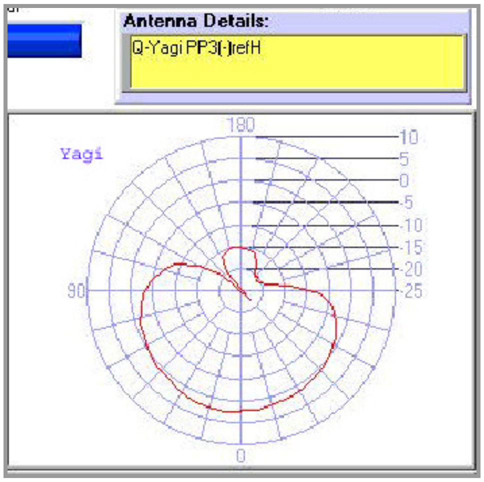


Figure 18: Single Yagi Antenna Element, "-" Cut

Some beamwidth narrowing occurred with the multi-element yagi array as compared to the individual yagi element, but the peak gain was not compromised and the increase in directivity does not pose a problem. The 0 dBi beamwidth for the “-“ cut is impressively ±60 degrees approximately and the +3 dBi beamwidth is approximately ±45 degrees.

For the “I” cut, the +4 dBi beamwidth is clearly reduced in the array configuration as compared to a single yagi element in free-space, but the 0 dBi beamwidth still remains almost unchanged at ±60 degrees.

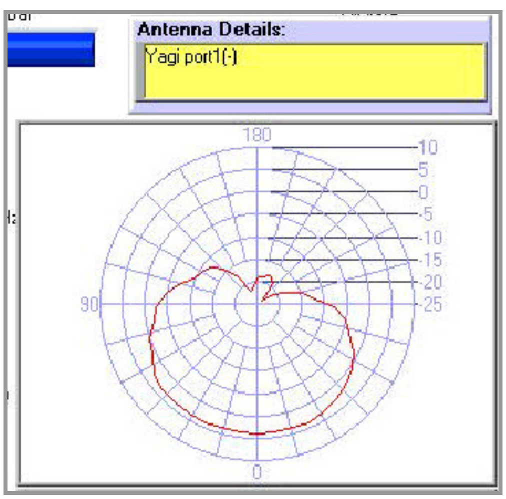


Figure 19: Yagi Array, Antenna #1, "-" Cut

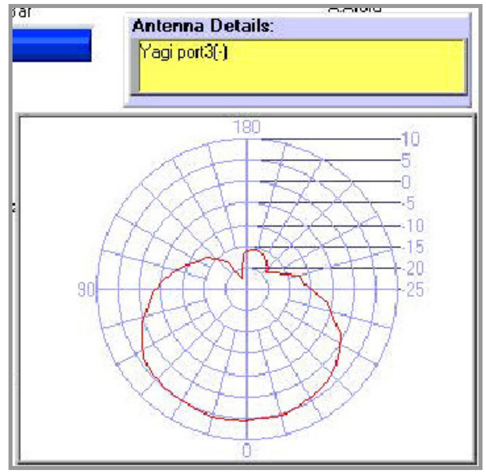


Figure 20: Yagi Array, Antenna #3, "-" Cut

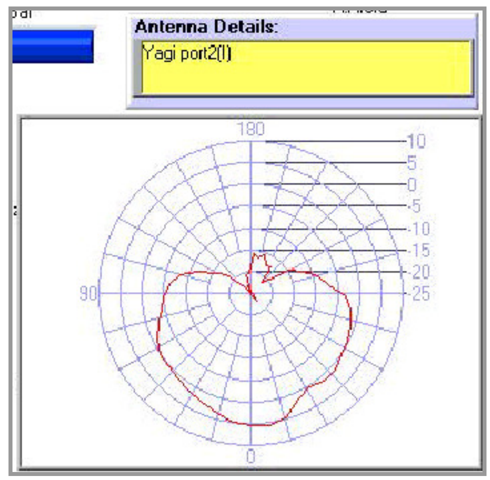


Figure 21: Yagi Array, Antenna #2, "I" Cut

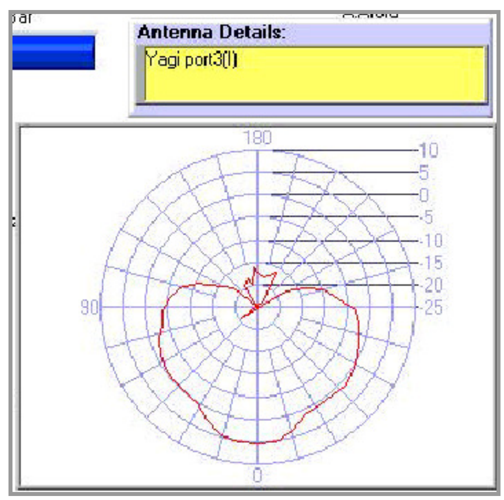


Figure 22: Yagi Array, Antenna #3, "I" Cut

5. Summary

Whether equipped with bow-tie arrays at both the AP and RT ends of a communication link, or the AP and RT ends using bow-tie and yagi arrays respectively, the field test performance with the new antennas has been substantially better, particularly in the two-story home scenario. The new antenna arrays also do a better job at matching polarization between the AP and RT arrays and this is beneficial for links that are more line-of-sight in nature. Magis plans to provide these antennas or similar antennas with CMs from now on, and as inventory becomes available, provide the improved arrays to customers who originally received the earlier Skycross arrays.

6. Recent Work on Product-Oriented Antenna Arrays

The antenna discussions provided thus far have focused on array configurations where form-factors have not been an issue and the primary intention was to simply show the Air5 technology in its best light. Incorporation of the Air5 technology into real-world products is rarely so accommodating. Several antenna concepts that have received attention at Magis recently for inclusion in consumer electronic products are reported on in this section.

6.1 External Antennas

An external “whip”-style antenna is very well

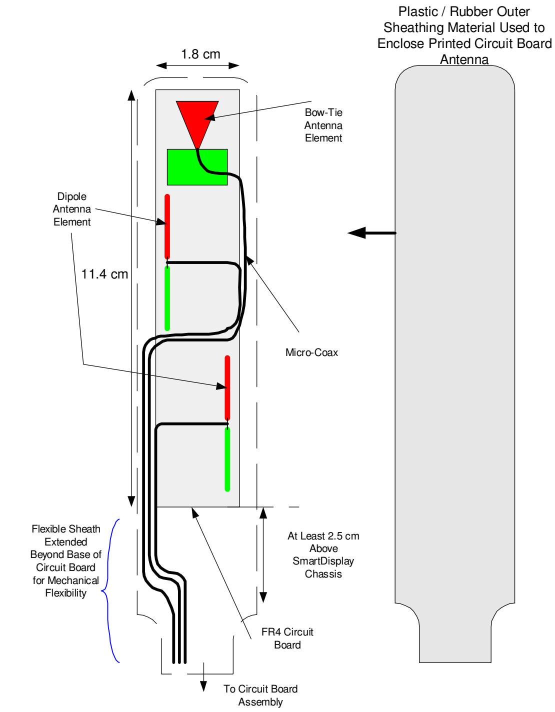


Figure 23 Assembled Vertical Whip Antenna Array With (a) Micro-Coax to Each Antenna Element and (b) External Sheathing (Dimensions not *to scale, in cm)*

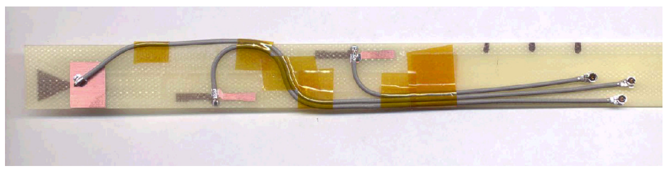


Figure 24 "Whip" Antenna Array Prototype Shown with Micro-Coax Connecting Each Antenna Element (Less Any Plastic/Rubber Sheathing). (Bow-Tie Element is at the Far Left.)

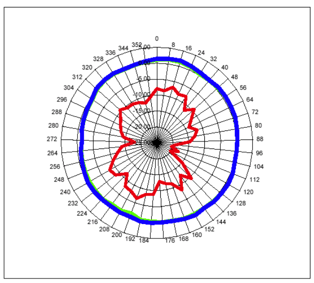
suited for the Air5 application because electronic packaging effects on the antenna performance can be substantially minimized. At 5 GHz, it is important to realize the best antenna gain possible in order to extend range performance. A multi-element vertical “whip”-style antenna is shown in Figure 23 and Figure 24. The top “bow-tie” element is intended for transmit use owing to its excellent omni-directional gain pattern and good power gain. Two vertical dipole antennas accompany the transmit antenna element and they are used for 2 of the 5 Air5 receive antennas. The excellent gain characteristics of all three antenna elements are shown in Figure 25 through Figure 27.

Item Description	Detail	Comments
Circuit Board Material	FR4	31 mil thickness
Micro-Coax	1) RF-MF5010 manufactured by Nissei Electric Co. 2) A12B1054 manufactured by Junkosha Co.	Either coax type can be used.

Table 1 Antenna Materials Summary for “Whip” Vertical Antenna

NOTE: The bottom of the circuit board assembly should be placed a minimum of 2.54 cm above any metallic packaging associated with the product..

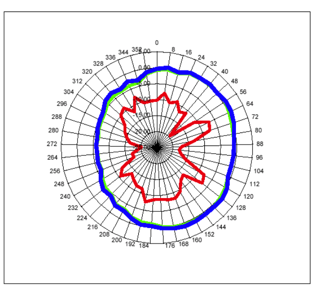
1-Bow + 2-Dipole FR4 offset array, (D sweep)



"Port 1"			
	V, dB	**H, dB**	**V+H, dB**
Min	-1.67	-20.33	**-1.57**
Max	1.17	-6.50	**1.81**
Max-Min	2.84	13.83	**3.38**
Std dev	0.77	3.46	**0.74**
Avg 0/180	0.03	-9.35	**0.50**
Avg tot	-0.10	-10.56	**0.27**

"Port 2"			
	V, dB	**H, dB**	**V+H, dB**
Min	-6.50	-20.17	**-6.26**
Max	0.67	-6.83	**1.05**
Max-Min	7.17	13.34	**7.32**
Std dev	2.49	3.70	**2.44**
Avg 0/180	-1.28	-9.80	**-0.71**
Avg tot	-1.64	-10.78	**-1.14**

"Port 3"			
	V, dB	**H, dB**	**V+H, dB**
Min	-3.67	-24.00	**-2.86**
Max	2.83	-4.50	**3.12**
Max-Min	6.50	19.50	**5.98**
Std dev	2.09	4.69	**1.88**
Avg 90/270	0.42	-10.77	**0.73**
Avg tot	0.68	-9.05	**1.12**



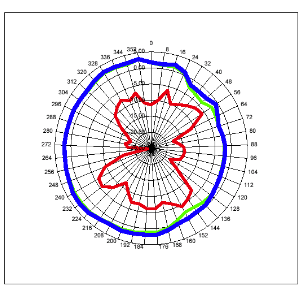
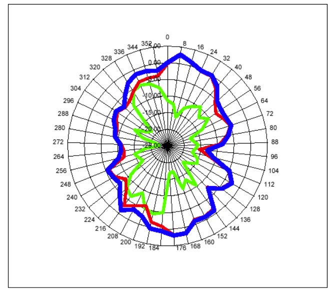


Figure 25 Antenna Gain Patterns for Individual Antenna Elements in Figure 24, D-Sweep (See Figure 28)

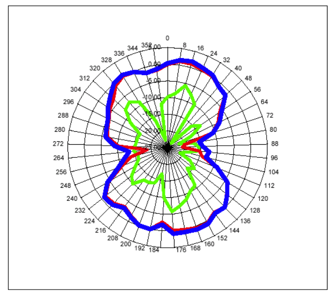
1-Bow + 2-Dipole FR4 offset array, (U sweep)



"Port 1"			
	V, dB	**H, dB**	**V+H, dB**
Min	-22.67	-15.33	**-12.94**
Max	-4.17	2.50	**2.64**
Max-Min	18.50	17.83	**15.58**
Std dev	4.82	4.10	**3.91**
Avg 0/180	-8.35	-1.54	**-0.72**
Avg tot	-10.48	-3.46	**-2.68**

"Port 2"			
	V, dB	**H, dB**	**V+H, dB**
Min	-23.33	-20.50	**-15.29**
Max	-5.67	1.00	**1.85**
Max-Min	17.66	21.50	**17.14**
Std dev	4.42	5.93	**4.94**
Avg 0/180	-9.64	-0.56	**-0.05**
Avg tot	-11.54	-2.41	**-1.91**

"Port 3"			
	V, dB	**H, dB**	**V+H, dB**
Min	-22.67	-20.00	**-11.26**
Max	-7.33	1.00	**1.20**
Max-Min	15.34	21.00	**12.47**
Std dev	3.45	5.23	**3.61**
Avg 0/180	-11.31	-1.77	**-1.31**
Avg tot	-11.13	-3.87	**-3.12**



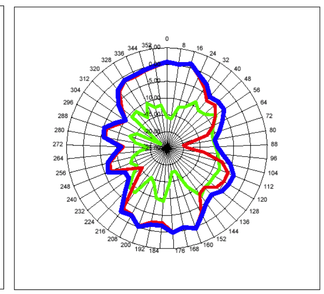
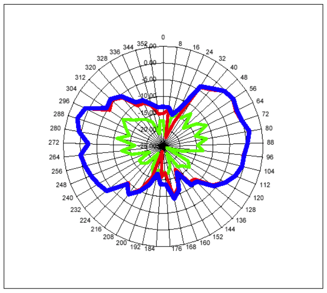


Figure 26 Antenna Gain Patterns for Individual Antenna Elements in Figure 24, U-Sweep (See Figure 28)

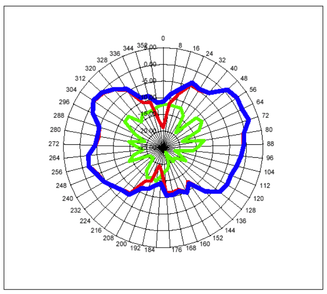
1-Bow + 2-Dipole FR4 offset array, (T sweep)



"Port 1"	V, dB	H, dB	V+H, dB
Min	-23.83	-23.50	**-16.66**
Max	-10.50	2.00	**2.10**
Max-Min	13.33	25.50	**18.76**
Std dev	3.20	6.90	**5.71**
Avg 0/180	-14.19	-1.34	**-1.12**
Avg tot	-15.19	-3.58	**-3.29**

"Port 2"	V, dB	H, dB	V+H, dB
Min	-23.50	-19.50	**-14.27**
Max	-11.00	2.00	**2.03**
Max-Min	12.50	21.50	**16.31**
Std dev	3.38	5.73	**4.47**
Avg 0/180	-15.09	-1.82	**-1.62**
Avg tot	-14.86	-3.77	**-3.45**

"Port 3"	V, dB	H, dB	V+H, dB
Min	-23.00	-21.83	**-15.85**
Max	-9.50	3.00	**3.23**
Max-Min	13.50	24.83	**19.07**
Std dev	3.03	6.76	**5.72**
Avg 0/180	-14.29	-1.51	**-1.29**
Avg tot	-14.35	-3.44	**-3.10**



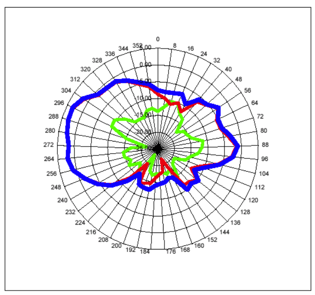


Figure 27 Antenna Gain Patterns for Individual Antenna Elements in Figure 24, T-Sweep (See Figure 28)

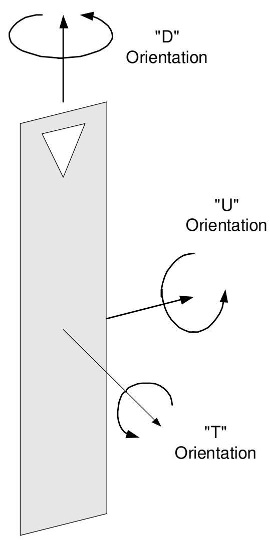


Figure 28 Antenna Gain Measurement Cuts (for "Whip" Antenna Array)

6.2 Built-In Antennas

In some situations where form-factor issues are more important than getting the last portion of antenna performance, or where additional receive antenna elements are needed in addition to the vertical antenna array just described in Section 6.1, built-in antenna elements are very attractive for use.

6.2.1 Inverted-F Type Antennas

A linear array of inverted-F antenna elements using standard FR4 circuit board material is shown in Figure 29. Each antenna element can be connected to the modem electronics using micro-coax in order to alleviate the signal losses at 5 GHz had microstrip been used for the long signal runs.

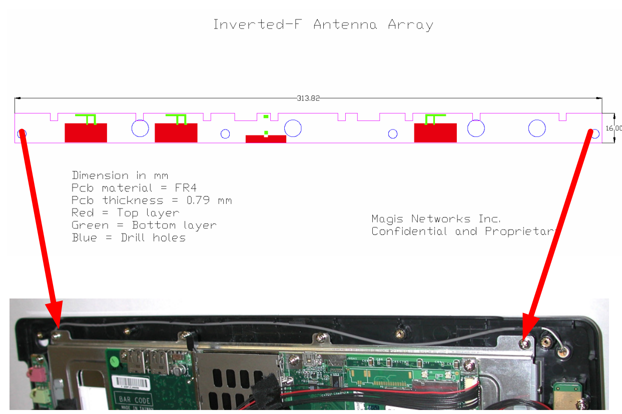


Figure 29 "Ruler"-Style Array of Inverted-F Antenna Elements Suitable for Embedding Within Consumer Electronic Product Pre-Existing Packaging

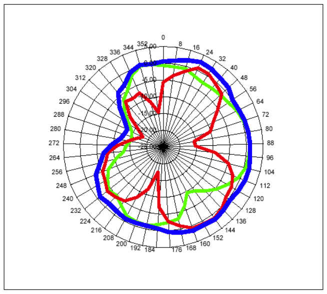
The inverted-F antennas display antenna gain patterns that are not as omni-directional as those possible with the external "whip"-antenna elements, primarily due to the proximity of the metal chassis shown in Figure 29. Even so, with good over-all system design, these low-cost antenna elements can deliver excellent performance in an Air5 system.

The antenna gain patterns for the individual inverted-F antenna elements are provided in Figure 30 through Figure 32. The orientation key for the measurements is provided in Figure 33.

6.2.2 Dipole Antennas

Some product form-factors will experience better performance if the integrated dipole antenna elements like those used in Figure 23 are used rather than the inverted-F style. This determination can only be made on a case-by-case basis.

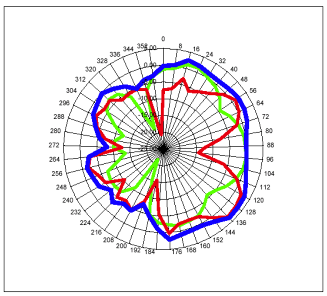
Inverted-F 3-Ant array (D sweep)



"Port 1"	V, dB	H, dB	V+H, dB
Min	-15.03	-18.20	**-12.98**
Max	0.97	1.13	**2.68**
Max-Min	16.00	19.33	**15.66**
Std dev	4.78	5.67	**4.22**
Avg 0/180	-2.56	-3.02	**0.22**
Avg tot	-2.73	-4.00	**-0.31**

"Port 2"	V, dB	H, dB	V+H, dB
Min	-21.53	-20.70	**-8.09**
Max	1.30	2.97	**3.48**
Max-Min	22.83	23.67	**11.58**
Std dev	5.16	4.80	**2.95**
Avg 0/180	-2.86	-4.25	**-0.49**
Avg tot	-3.29	-2.96	**-0.11**

"Port 3"	V, dB	H, dB	V+H, dB
Min	-14.03	-14.70	**-9.57**
Max	1.97	3.97	**4.88**
Max-Min	16.00	18.67	**14.44**
Std dev	4.76	4.90	**3.83**
Avg 0/180	-2.69	-3.26	**0.04**
Avg tot	-2.51	-2.31	**0.60**



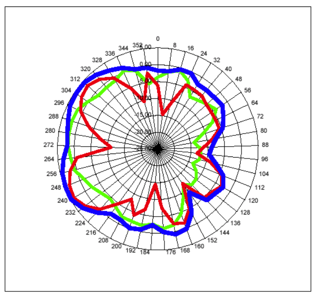
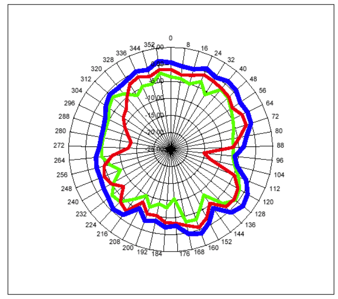


Figure 30 Antenna Gain Patterns for Individual Antenna Elements in Figure 29, D-Sweep, (See Figure 33)

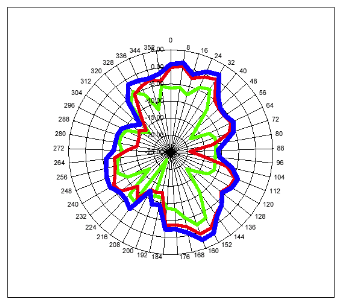
Inverted-F 3-Ant array (U sweep)



"Port 1"	V, dB	H, dB	V+H, dB
Min	-10.53	-15.20	**-6.13**
Max	-0.87	-0.70	**1.90**
Max-Min	9.66	14.50	**8.02**
Std dev	2.22	3.73	**2.00**
Avg 0/180	-4.78	-2.83	**-0.69**
Avg tot	-4.53	-3.68	**-1.08**

"Port 2"	V, dB	H, dB	V+H, dB
Min	-22.53	-19.37	**-12.90**
Max	-2.37	0.47	**2.29**
Max-Min	20.16	19.84	**15.19**
Std dev	4.38	5.17	**3.92**
Avg 0/180	-6.56	-3.20	**-1.55**
Avg tot	-8.33	-4.85	**-3.24**

"Port 3"	V, dB	H, dB	V+H, dB
Min	-24.53	-20.20	**-9.43**
Max	-2.70	-0.20	**0.44**
Max-Min	21.83	20.00	**9.87**
Std dev	4.45	4.21	**2.45**
Avg 0/180	-7.37	-3.22	**-1.81**
Avg tot	-8.21	-4.11	**-2.68**



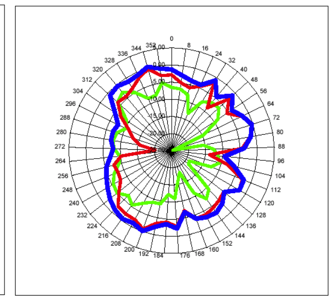
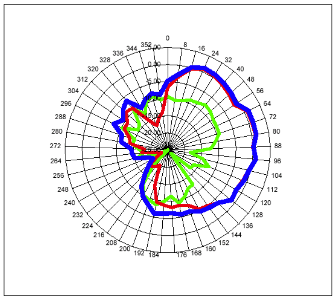


Figure 31 Antenna Gain Patterns for Individual Antenna Elements in Figure 29, U-Sweep, (See Figure 33)

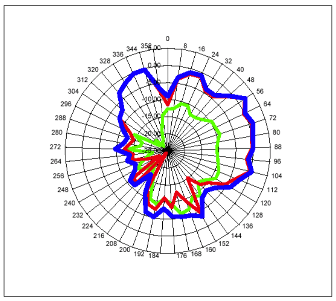
Inverted-F 3-Ant array (T sweep)



"Port 1"			
	V, dB	H, dB	V+H, dB
Min	-25.03	-23.03	**-20.04**
Max	-7.87	0.97	**1.25**
Max-Min	17.16	24.00	**21.29**
Std dev	4.55	7.67	**6.00**
Avg 0/180	-13.20	-3.33	**-2.91**
Avg tot	-11.37	-4.08	**-3.34**

"Port 2"			
	V, dB	H, dB	V+H, dB
Min	-23.20	-24.20	**-16.55**
Max	-6.20	2.13	**2.42**
Max-Min	17.00	26.33	**18.97**
Std dev	4.61	6.38	**4.98**
Avg 0/180	-12.22	-3.98	**-3.37**
Avg tot	-11.70	-4.34	**-3.60**

"Port 3"			
	V, dB	H, dB	V+H, dB
Min	-22.03	-20.87	**-13.70**
Max	-6.70	3.30	**3.53**
Max-Min	15.33	24.17	**17.23**
Std dev	3.51	6.93	**5.05**
Avg 0/180	-11.30	-2.68	**-2.13**
Avg tot	-11.00	-3.78	**-3.03**



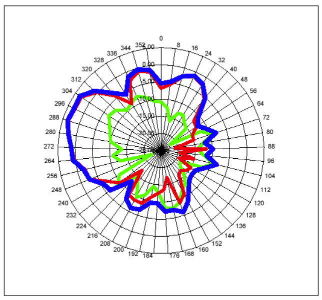


Figure 32 Antenna Gain Patterns for Individual Antenna Elements in Figure 29, T-Sweep (See Figure 33)

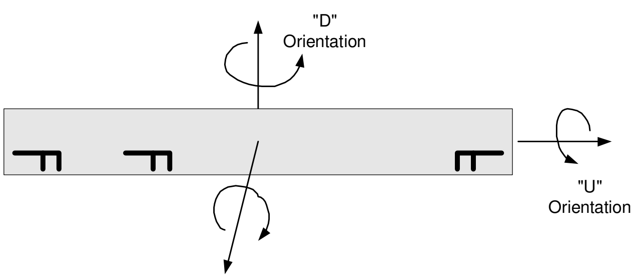


Figure 33 Antenna Gain Measurement Cuts (for Inverted-F Antenna Array)

CAUTION: In general, it is very important that the antenna design be considered very early in the product development cycle because product form-factor choices can ultimately dictate very difficult antenna-related trade-offs if not thoroughly planned and evaluated in advance.

7. Appendix: Antenna Directivity Cut Orientations

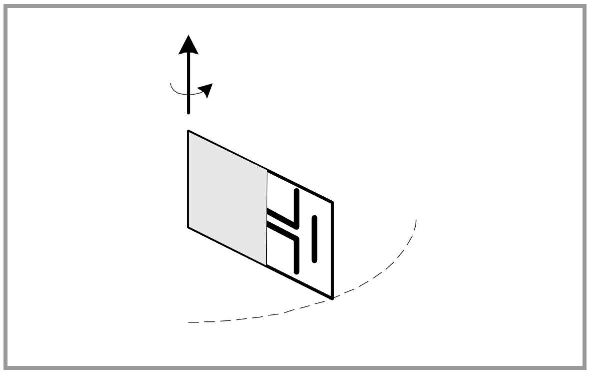


Figure 34: Yagi Antenna, "I" Measurement Orientation

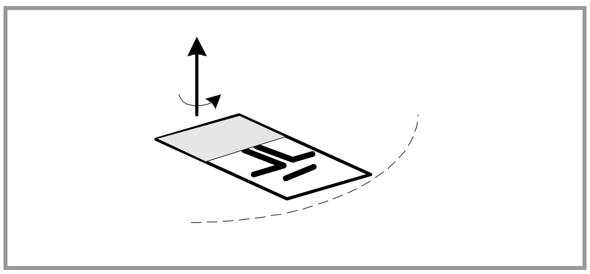


Figure 35: Yagi Antenna, "-" Measurement Orientation

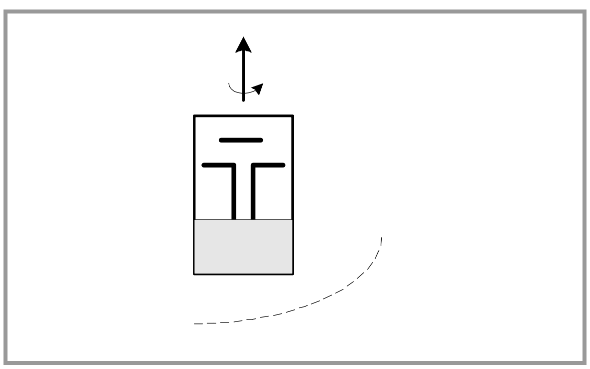


Figure 36: Yagi Antenna, "O" Measurement Orientation

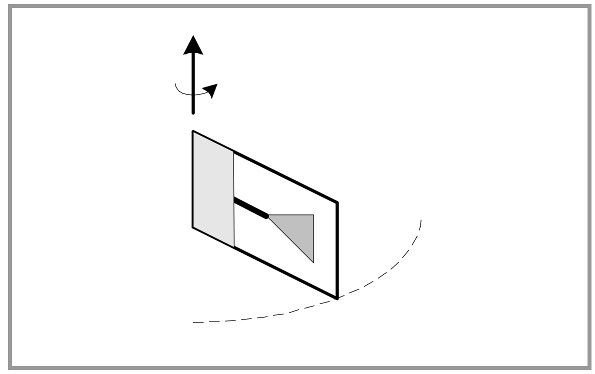


Figure 37: Bow-Tie Antenna, "I" Measurement Orientation

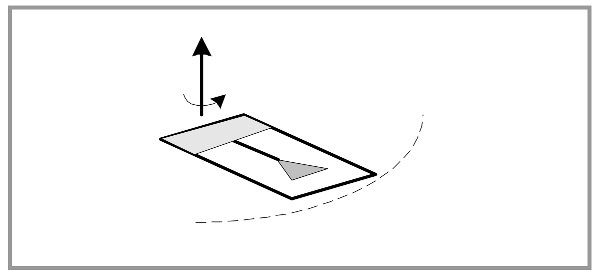


Figure 38: Bow-Tie Antenna, "-" Measurement Orientation

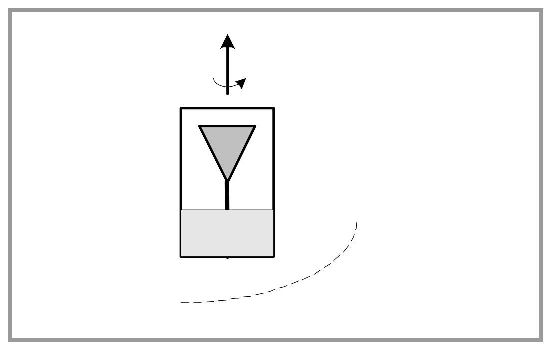


Figure 39: Bow-Tie Antenna, “O” Measurement Orientation