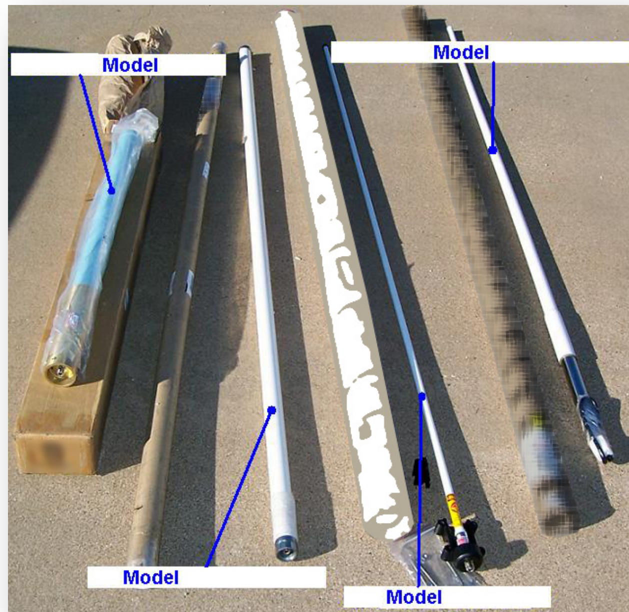
**2011**

## INTRODUCTION

360°RF has been retained to perform comparative characterization of four omnidirectional antennas intended for the 220 – 225 MHz band. The provided antennas are listed below and shown to the right (along with their shipping tubes):

- **Brand #1** Model #1
- **Brand #2** Model #2
- **Brand #3** Model #3
- **Brand #4** Model #4

360°RF's performance evaluation included calculated analysis of the wind loading of each antenna and subjecting each antenna to a simulated wind load to test survival.




### Antenna Construction and Inspection Notes

The Brand #1 antenna is a tapered fiberglass tube, 102" long, 1.5" thick at the base and 0.8" at the tip. It appeared to be mistuned somewhat, its resonant frequency being at about 228.9 MHz.

As can be seen from the above photo, the Brand #2 antenna at the left is the shortest and thickest, at only 43" long and 2.7" thick. It also has the least gain, but is clearly designed to withstand very high wind speeds. Base clamp assemblies are shown on the next page.

The Brand #3 antenna is the longest and thinnest at 106" and only 0.7" thick. It also showed the highest gain, but was the weakest in terms of ability to withstand high wind speeds.

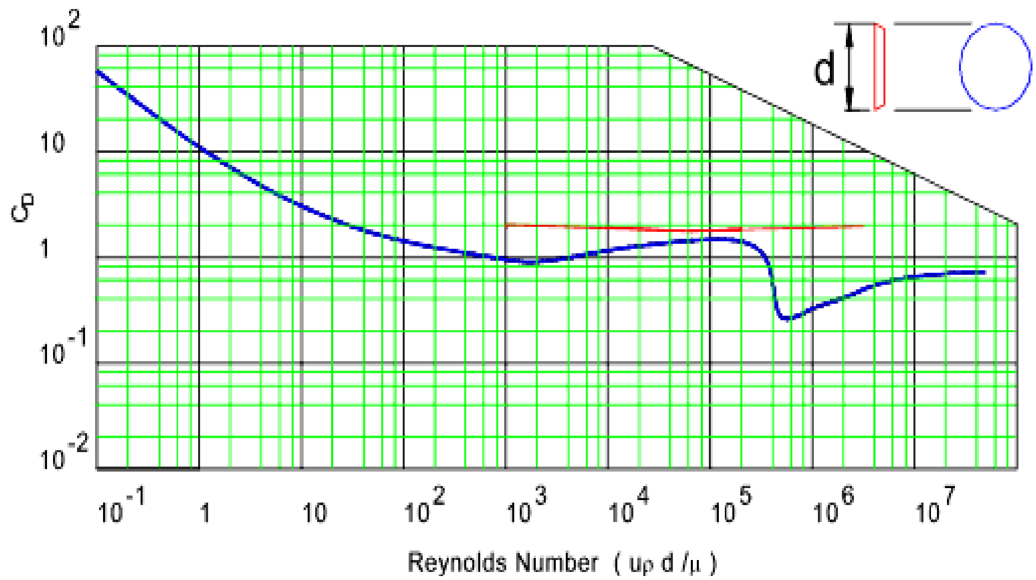
The Brand #3 antenna is designed to screw into a mounting base which was not initially provided. During RF testing, 360°RF used the Brand #1 clamp assembly to hold this antenna as it would not affect tested electrical performance. The Brand #3 antenna is 99" long and 1-3/4" diameter. It displayed good gain and VSWR.

**Above Left: Base and Mounting Clamps of Brand #2 antenna. Right: Base of the Brand #3 antenna. As no clamping assembly was provided, we used the clamps from the Brand #1 antenna during our RF testing.**

**Above Left: Base of Brand #3 antenna. Right: Brand #1 antenna base clamps. Note the VSWR directional bridge connected to the Brand #3 antenna.**

**Wind Load Calculations Objective**
The wind loading force for an anticipated storm of 150 miles per hour was applied to each of the unique antennas. For each antenna's geometry, the size was used to calculate the force that would be applied to the object from the postulated storm winds.

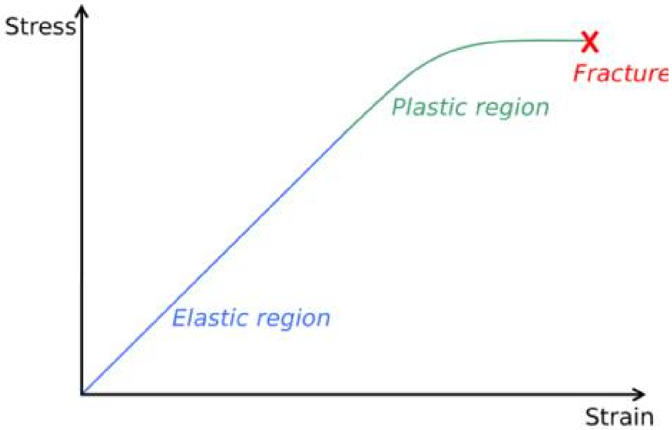
**Overview of wind loading calculation:**
The air temperature is assumed as 40°F. The cooler average air temperature gives slightly higher air density and viscosity values that provide for conservatively higher wind forces. The antenna diameter and length are used to calculate the projected area that is exposed to the incoming wind stream. The diameter and viscosity are used to calculate the Reynolds numbers, which is a measure of the turbulence. This dimensionless number is needed to identify the drag coefficient from the reference graph. Finally, all of the values are combined to calculate the resulting drag force on the object.




The mounting of each antenna is to tighten the bolted connections until the provided split washers are flat. This criteria insures that the bolts are in full tension to provide the best attachment. The torque value for each attachment is recorded for each antenna.

**Brand #1 Model #1**

The Brand #1 antenna was mounted using provided hardware. Each of the four 3/4” bolts were tightened to approximately 20 ft-lbs to flatten the split washers. Weights were added to simulate up to 65 pounds of wind loading to the antenna. There was creaking and obvious strain at this weight loading. Upon removing the weights, there was permanent deformation of the antenna.




The tip of the antenna is not perfectly straight from the base after the simulated 150 miles per hour storm winds were applied. However, the antenna did not crack and break. By viewing the graph on the left, as the weight is applied to the antenna, first the elastic region is where the antenna is fully undamaged and will restore to the original position. As the weight increases, then the plastic region of permanent deformation occurs immediately prior to ultimate failure. Although this antenna barely passed the static simulated 150 mile per hour winds, the dynamic winds of a real storm may damage this antenna.

**Verdict: Barely passed 150 miles per hour storm winds.**

**Brand #2 Model #2**

The Brand #2 antenna was mounted using provided hardware. Each of the four 9/16” bolts were tightened to approximately 15 ft-lbs to flatten the split washers. Weights were added to simulate 58 pounds of wind loading to the antenna. There were no signs of damage or weakness. The weight was increased by approximately 50% to 82 pounds with no signs of damage or weakness.

**Verdict: This antenna easily withstood the force loading that is equivalent to 175 miles per hour storm winds.**

**Brand #3 Model #3**

The Brand #3 antenna was mounted using the provided hardware. Each of the four 1/2” (13mm) bolts were tightened to approximately 1.5 ft-lbs against the plastic mounting base. As the weights were added, the antenna tip deflected 48 inches to the deflection limit of the testing setup at 12 pounds. There were visual signs of creaking and strain at 12 pounds.

This antenna is highly flexible and has a very low area subject to wind forces. Further analysis was performed to estimate the angular deflection and applied force of this antenna. As a force is applied to this antenna, the antenna deflects and reduces the wind surface area. The decrease in surface area also decreases the force due to the applied wind. This iteration solution is also presented for this unique case.

Using the measured data of 48 inches of deflection with 12 pounds, the projected deflection at full 150 miles per hour winds is calculated. (The calculated iteration solution becomes numerically unstable above 147 mph wind speed due to high deflection of the antenna.)

| Wind Speed (mph) | Wind Force (lbs) | Deflection (inches) | Angle (Degrees) |
|---|---|---|---|
| **91 mph** | 12 lbs | 48” | 26° |
| **100 mph** | 14 lbs | 56” | 30° |
| **135 mph** | 21 lbs | 83” | 45° |
| **147 mph** | 23 lbs | 91” | 50° |

**Verdict: The extreme deflection of the antenna tip in high wind situations will lead to possible fatigue failure and decreased RF effectiveness at extreme angles. This antenna FAILS to withstand 150 mile per hour storm winds. However, this antenna can withstand 100 mile per hour storm winds.**

**Brand #3 Model #3**

The Brand #3 antenna was mounted using the provided hardware. Each of the four (4) 9/16” bolts were tightened to approximately 15 ft-lbs to flatten the washers. The four (4) 5/32” hex Allen screws were tightened to approximately 1.7 ft-lbs. Weights were added to simulate 86 pounds of wind loading to the antenna. There were no signs of damage or weakness. The weight was increased by approximately 75% to 150 pounds with no signs of damage or weakness. There was very minor permanent deflection (approximately 3/4” deflection at the tip) when the extreme loading was removed.

**Verdict: This antenna easily withstood the force loading that is equivalent to 200 miles per hour storm winds.**

**Antenna Mechanical Summary**

| Brand | Model | 150 MPH Force | Pass / Fail | Comments |
|---|---|---|---|---|
| Brand #1 | Model #1 | 64.36 lbs | Pass | Permanent deformation |
| Brand #2 | Model #2 | 57.80 lbs | Pass | Very strong |
| Brand #3 | Model #3 | 16.13 lbs | Fail | See discussion |
| Brand #3 | Model #3 | 85.38 lbs | Pass | Very strong [1] |

[1] Tested at a later date, 05/11, due to delay in receipt of IPT proprietary mount

## Wind Loading on a Cylindrical Antenna

Brand #1  Model #1

**INPUTS**

| | | |
|---|---|---|
| Antenna Diameter (Average) | 1.31 | inches |
| Antenna Length | 98.5 | inches |
| Assumed Wind Speed | 150 | Miles / Hour |

**LOOKUPS**

| | | |
|---|---|---|
| Drag Coefficient (lookup from table) | 1.2 | |
| Absolute Viscosity @ 40°F (mu) | 3.62E-07 | lbf-sec/ft² |
| Assume 40°F air | 40 | °F |

**CALCULATIONS**

| | | |
|---|---|---|
| Density of air (ideal gas law)(rho) | 0.07943 | lbm/ft^3 |
| Kinematic viscosity (nu=mu*Gc/rho) | 1.47E-04 | ft² / sec |
| Air Speed in Feet/Second | 220 | ft / sec |
| Reynolds Number (D*vel/nu) | 1.64E+05 | dimless |
| Projected Area of Antenna | 0.90 | ft² |

**RESULTS**

| | | |
|---|---|---|
| Drag Force (Cd*A*rho*vel²/2Gc) | **64.36** | **lbs-force** |
| | 7.84 | lbs / ft |

REFERENCES

1) Mechanical Engineering Reference Manual, Section 17-55

## Wind Loading on a Cylindrical Antenna

Brand #2 Model #2

| | | |
|---|---|---|
| **INPUTS** | | |
| Antenna Diameter | 2.7 | inches |
| Antenna Length | 43 | inches |
| Assumed Wind Speed | 150 | Miles / Hour |
| | | |
| **LOOKUPS** | | |
| Drag Coefficient (lookup from table) | 1.2 | |
| Absolute Viscosity @ 40°F (mu) | 3.62E-07 | lbf-sec/ft² |
| Assume 40°F air | 40 | °F |
| | | |
| **CALCULATIONS** | | |
| Density of air (ideal gas law)(rho) | 0.07943 | lbm/ft^3 |
| Kinematic viscosity (nu=mu*Gc/rho) | 1.47E-04 | ft² / sec |
| Air Speed in Feet/Second | 220 | ft / sec |
| Reynolds Number (D*vel/nu) | 3.38E+05 | dimless |
| Projected Area of Antenna | 0.81 | ft² |
| | | |
| **RESULTS** | | |
| Drag Force (Cd*A*rho*vel²/2Gc) | **57.80** | **lbs-force** |
| | 16.13 | lbs / ft |

REFERENCES

1) Mechanical Engineering Reference Manual, Section 17-55

## Wind Loading on a Cylindrical Antenna

Brand #3  Model #3

**INPUTS**

| | | |
|---|---|---|
| Antenna Diameter | 0.69 | inches |
| Antenna Length | 106 | inches |
| Assumed Wind Speed | 91 | Miles / Hour |

**LOOKUPS**

| | | |
|---|---|---|
| Drag Coefficient (lookup from table) | 1.2 | |
| Absolute Viscosity @ 40°F (mu) | 3.62E-07 | lbf-sec/ft² |
| Assume 40°F air | 40 | °F |

**CALCULATIONS**

| | | |
|---|---|---|
| Density of air (ideal gas law)(rho) | 0.07943 | lbm/ft^3 |
| Kinematic viscosity (nu=mu*Gc/rho) | 1.47E-04 | ft² / sec |
| Air Speed in Feet/Second | 133.4667 | ft / sec |
| Reynolds Number (D*vel/nu) | 5.21E+04 | dimless |
| Projected Area of Antenna | 0.51 | ft² |

**RESULTS**

| | | |
|---|---|---|
| Drag Force (Cd*A*rho*vel²/2Gc) | **13.35** | **lbs-force** |
| | 1.51 | lbs / ft |

**REFERENCES**

1) Mechanical Engineering Reference Manual, Section 17-55

**FURTHER INVESTIGATION**

As the antenna significantly deflects the projected area to the wind decreases.

As the projected area exposed to the impacting wind speed decreases, then the applied force decreases.

This calculation finds the angle of total deflection and the updated force.

| | | |
|---|---|---|
| Deflected distance [delta = force*(length/2)^2 * (3*Length-Length/2) / 6EI] | | |
| | 48.02 | inches |
| Deflected Angle | 25.96 | degrees |
| Reduced projected length [Length*cos(delta/Length)] | | |
| | 95.31 | inches |
| Reduced Projected Area | 0.46 | ft² |
| Drag Force (Cd*A*rho*vel²/2Gc) | **12.01** | **lbs-force** |

## Wind Loading on a Cylindrical Antenna

Brand #4 Model #4

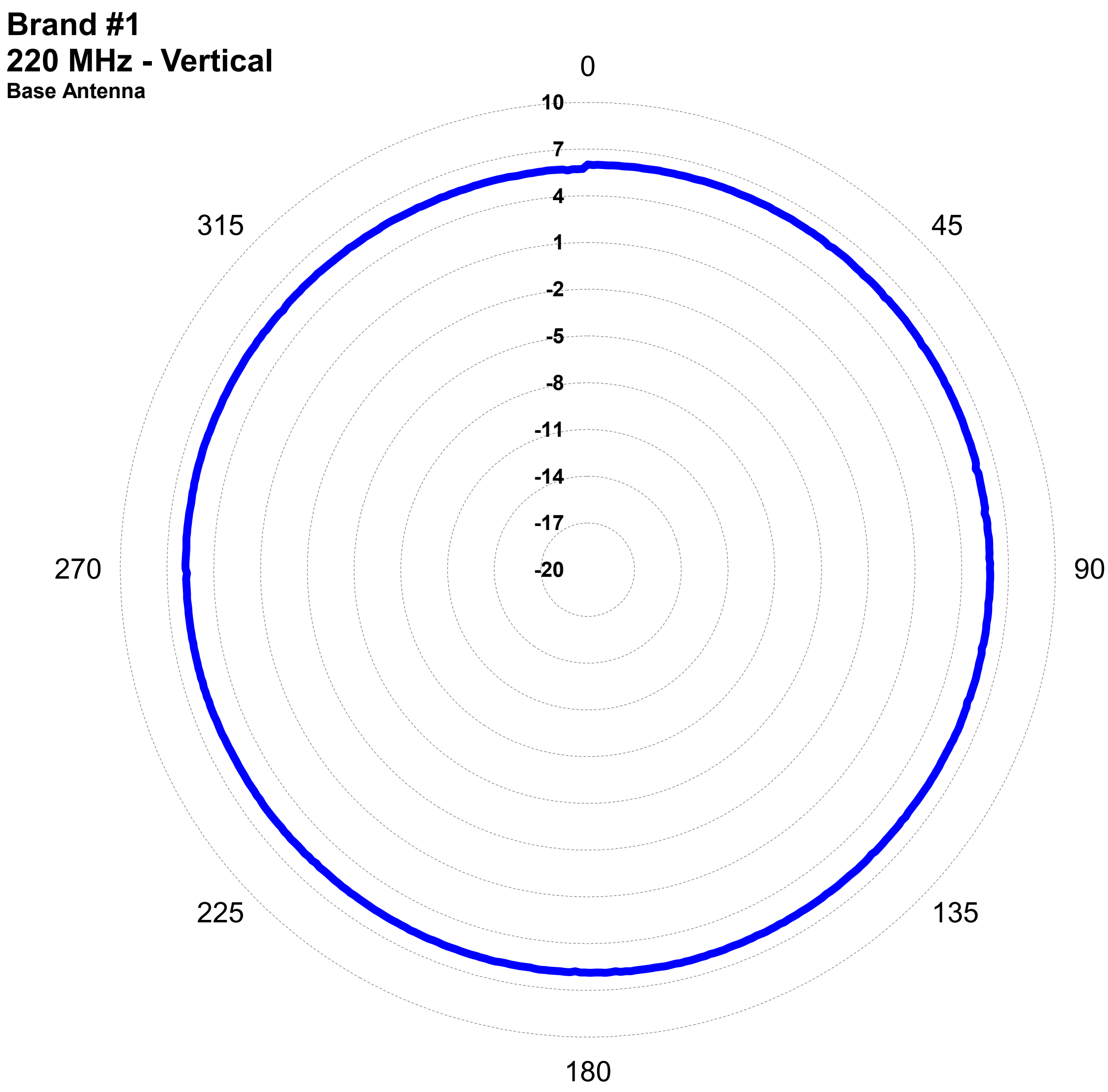
| | | |
|---|---|---|
| **INPUTS** | | |
| Antenna Diameter | 1.75 | inches |
| Antenna Length | 98 | inches |
| Assumed Wind Speed | 150 | Miles / Hour |
| | | |
| **LOOKUPS** | | |
| Drag Coefficient (lookup from table) | 1.2 | |
| Absolute Viscosity @ 40°F (mu) | 3.62E-07 | lbf-sec/ft² |
| Assume 40°F air | 40 | °F |
| | | |
| **CALCULATIONS** | | |
| Density of air (ideal gas law)(rho) | 0.07943 | lbm/ft^3 |
| Kinematic viscosity (nu=mu*Gc/rho) | 1.47E-04 | ft² / sec |
| Air Speed in Feet/Second | 220 | ft / sec |
| Reynolds Number (D*vel/nu) | 2.19E+05 | dimless |
| Projected Area of Antenna | 1.19 | ft² |
| | | |
| **RESULTS** | | |
| Drag Force (Cd*A*rho*vel²/2Gc) | **85.38** | **lbs-force** |
| | 10.46 | lbs / ft |

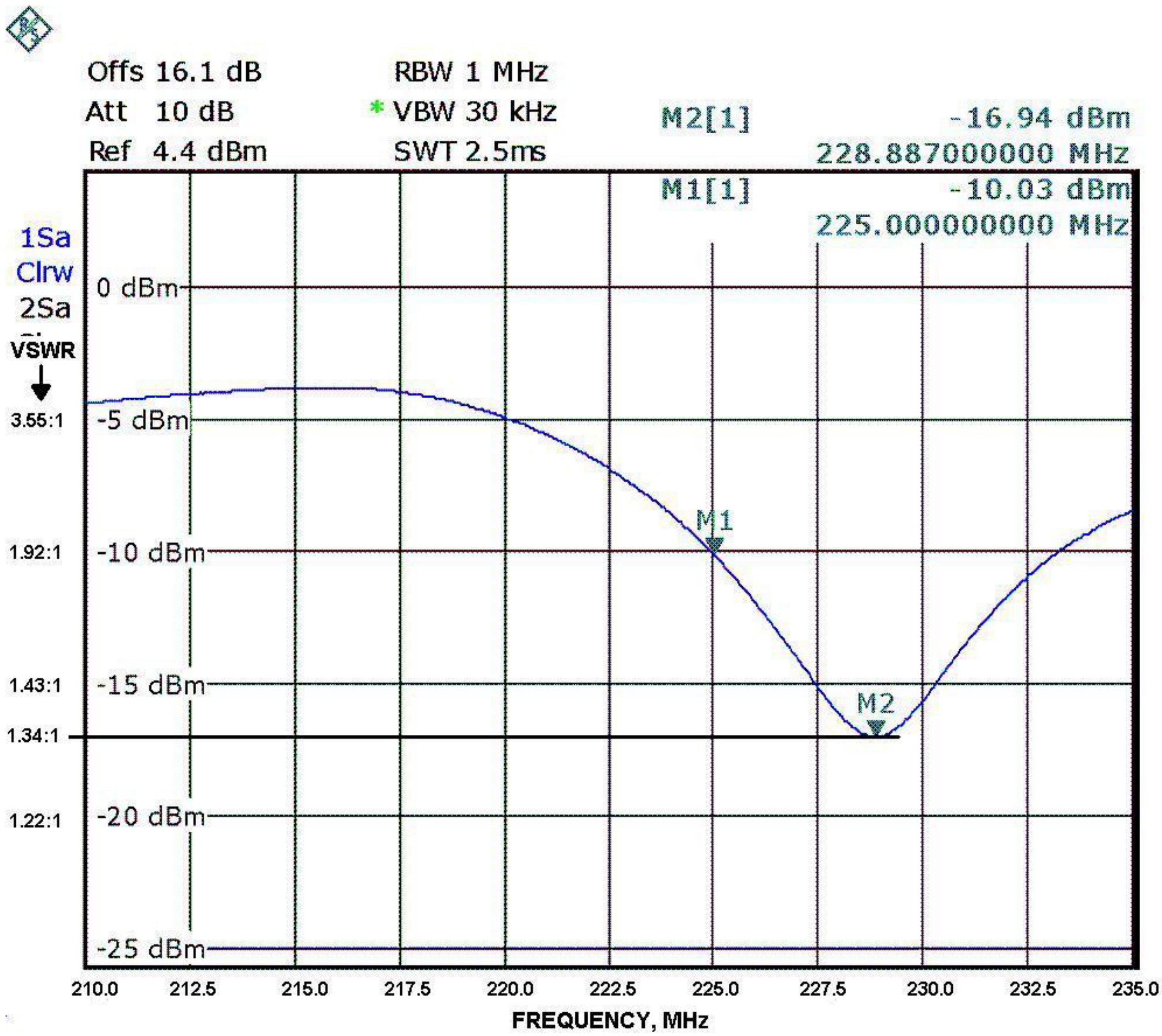
REFERENCES

1) Mechanical Engineering Reference Manual, Section 17-55

**Antenna Measurement**
**(**See linked Excel plots, “220MHz-Omni-Antenna-Patterns_2011.xlsx”**)**

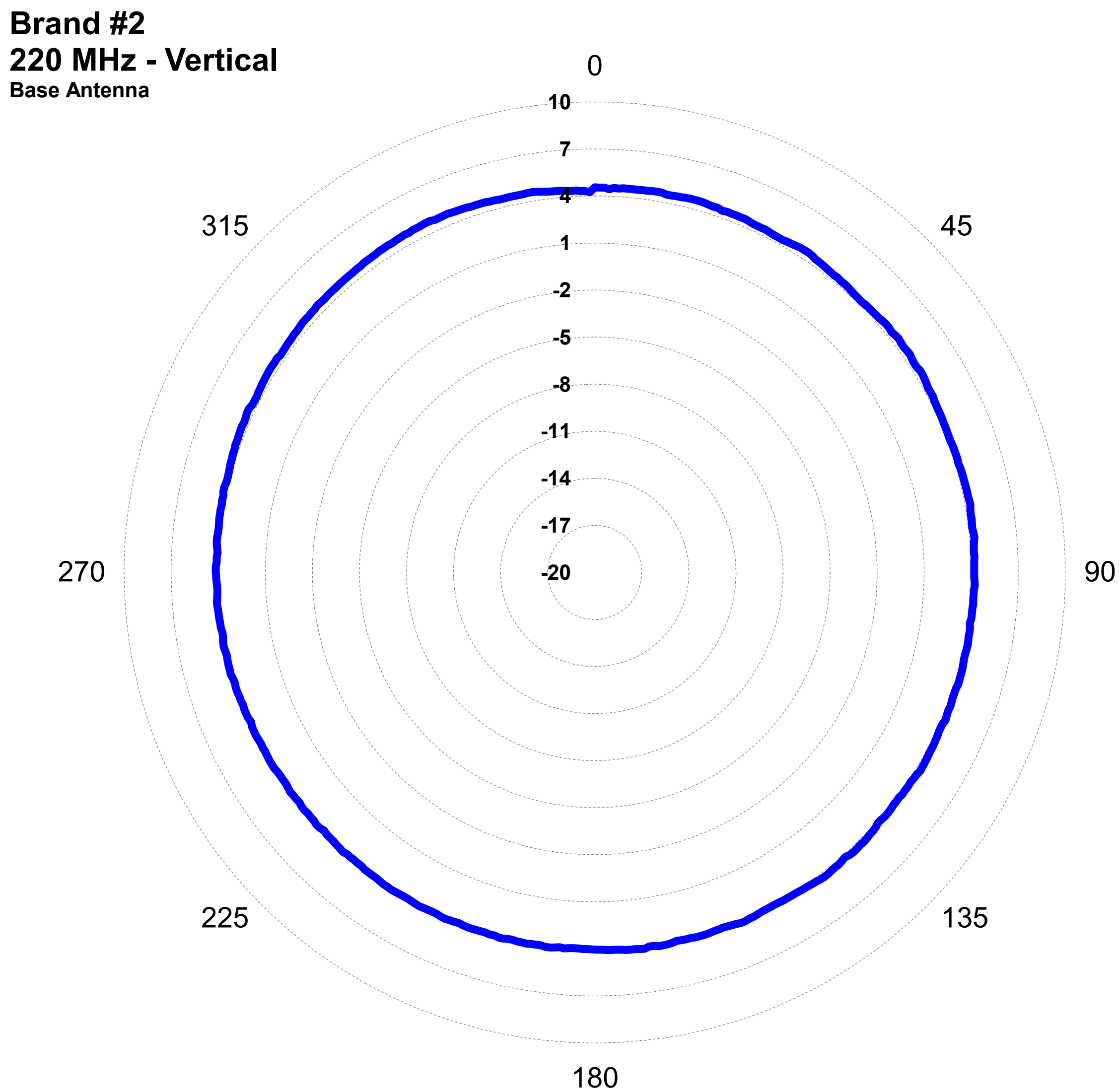
The Brand #1 Model #1 has the 3rd highest gain overall at about 6.2 dBi. Its resonant frequency was a bit high, but we were unable to ascertain what is causing it (VSWR was about 3.6:1 at 220 MHz and about 2:1 at 225 MHz. Its base clamp is an interesting and rugged clamp design. Although the clamp complexity makes assembly somewhat more difficult, it will clamp to most anything. If it were tuned to 222.5 MHz, the gain might rise slightly by 1/2 dB. The pattern is shown below with the VSWR on the next page.

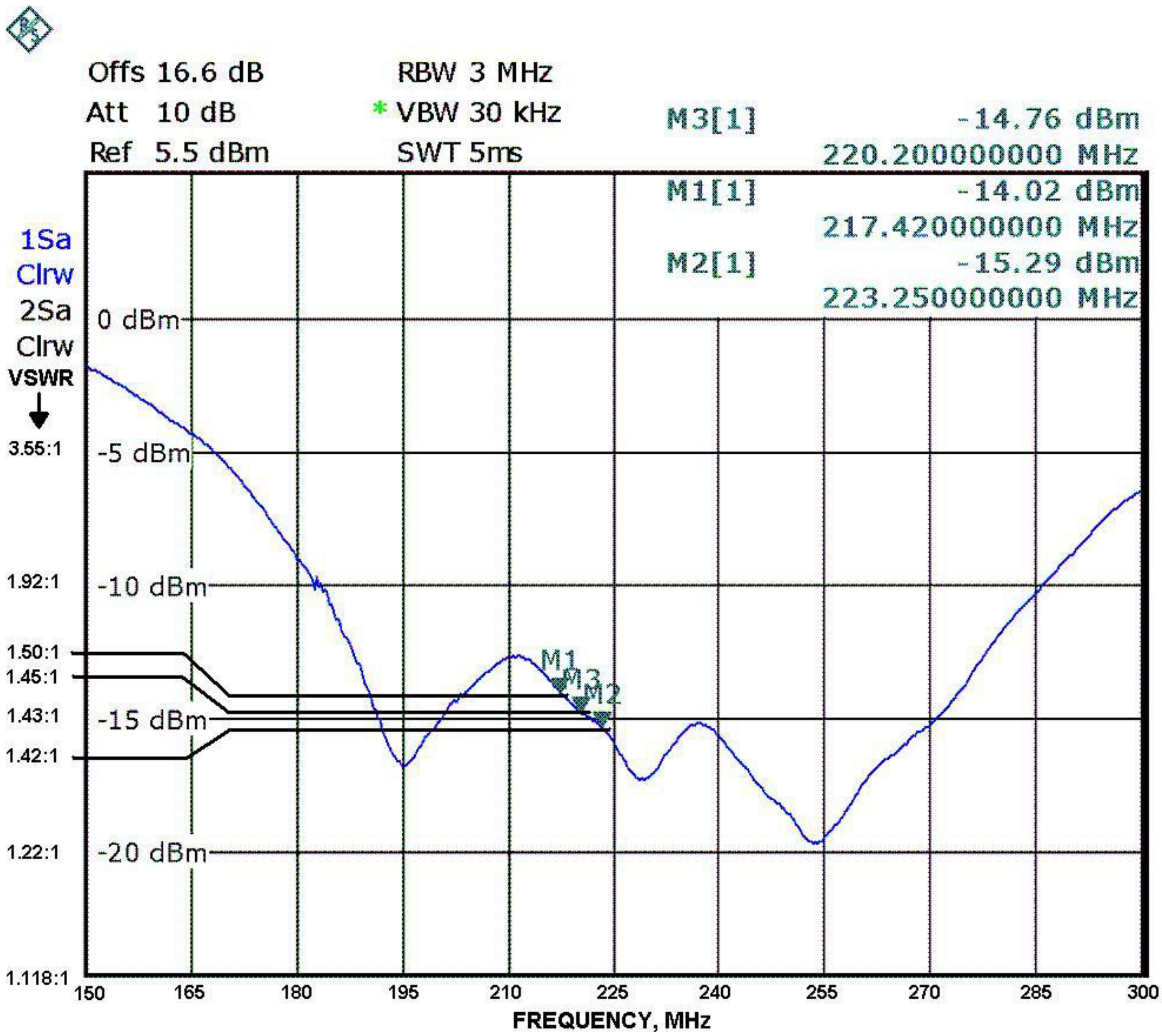




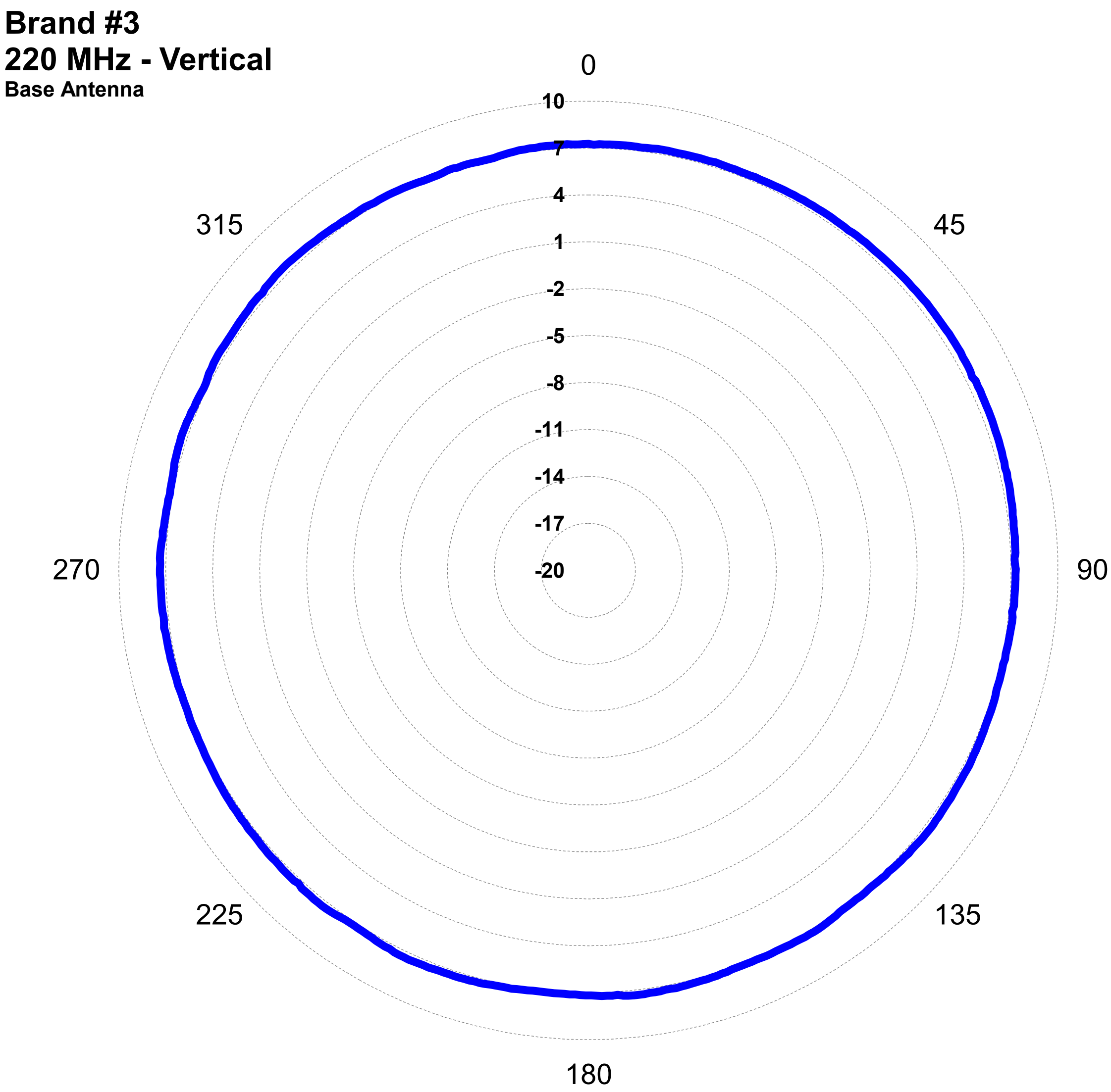
Offs 16.1 dB
Att 10 dB
Ref 4.4 dBm
RBW 1 MHz
* VBW 30 kHz
SWT 2.5ms
M2[1]
-16.94 dBm
228.887000000 MHz
M1[1]
-10.03 dBm
225.000000000 MHz
1Sa
Clrw
2Sa
VSWR
3.55:1
1.92:1
1.43:1
1.34:1
1.22:1
0 dBm
-5 dBm
-10 dBm
-15 dBm
-20 dBm
-25 dBm
M1
M2
210.0
212.5
215.0
217.5
220.0
222.5
225.0
227.5
230.0
232.5
235.0
FREQUENCY, MHz

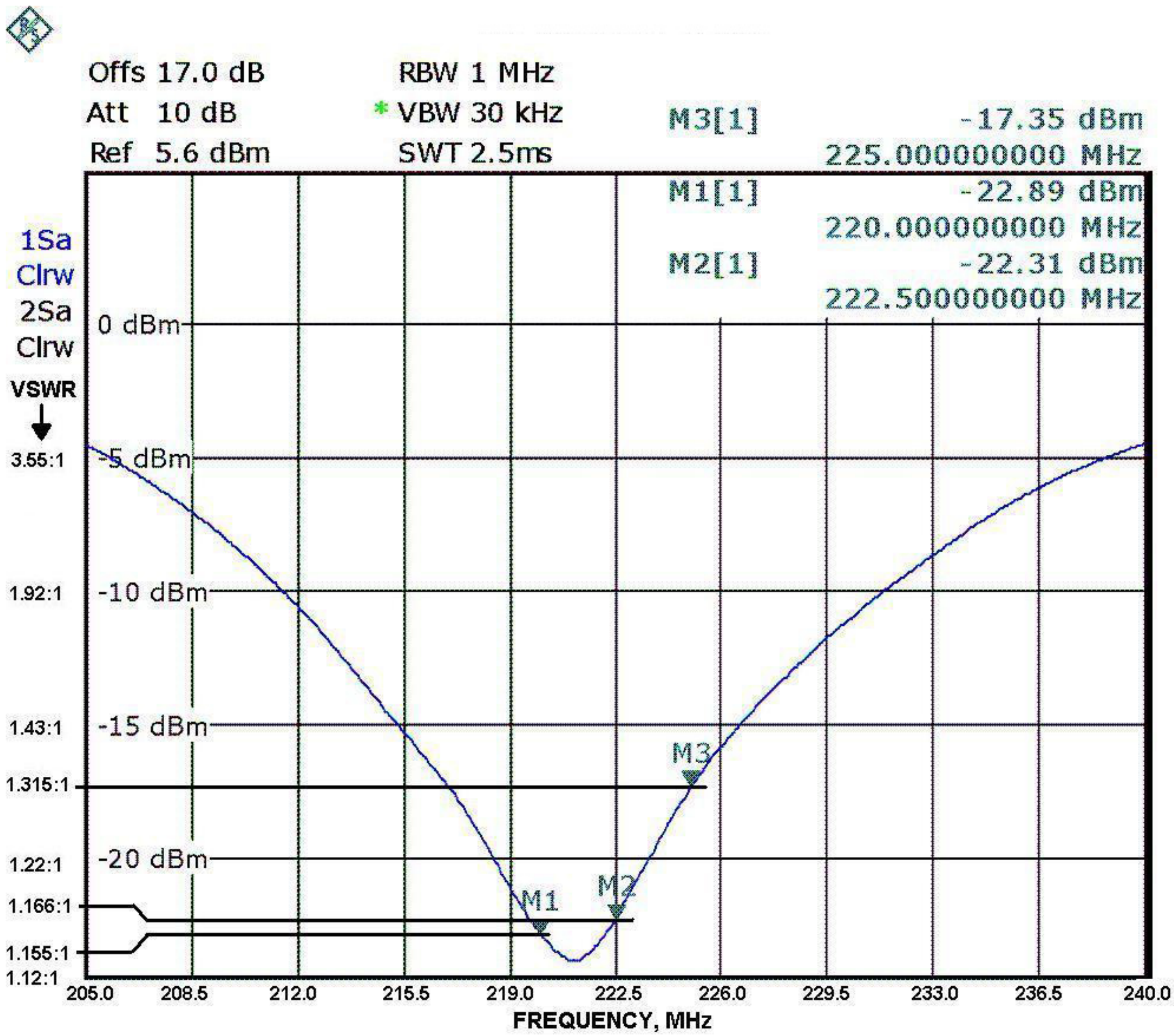
The Brand #2 Model #2 showed the lowest gain at about 4.76 to 3.85 dBi, but the second greatest likelihood to survive 150+ mile per hour winds. This antenna is also extremely wideband, having a VSWR d 2:1 response of over 100 MHz. Rain, ice or snow would have very little effect upon the VSWR. Its radiation pattern is shown below followed by its VSWR curve.



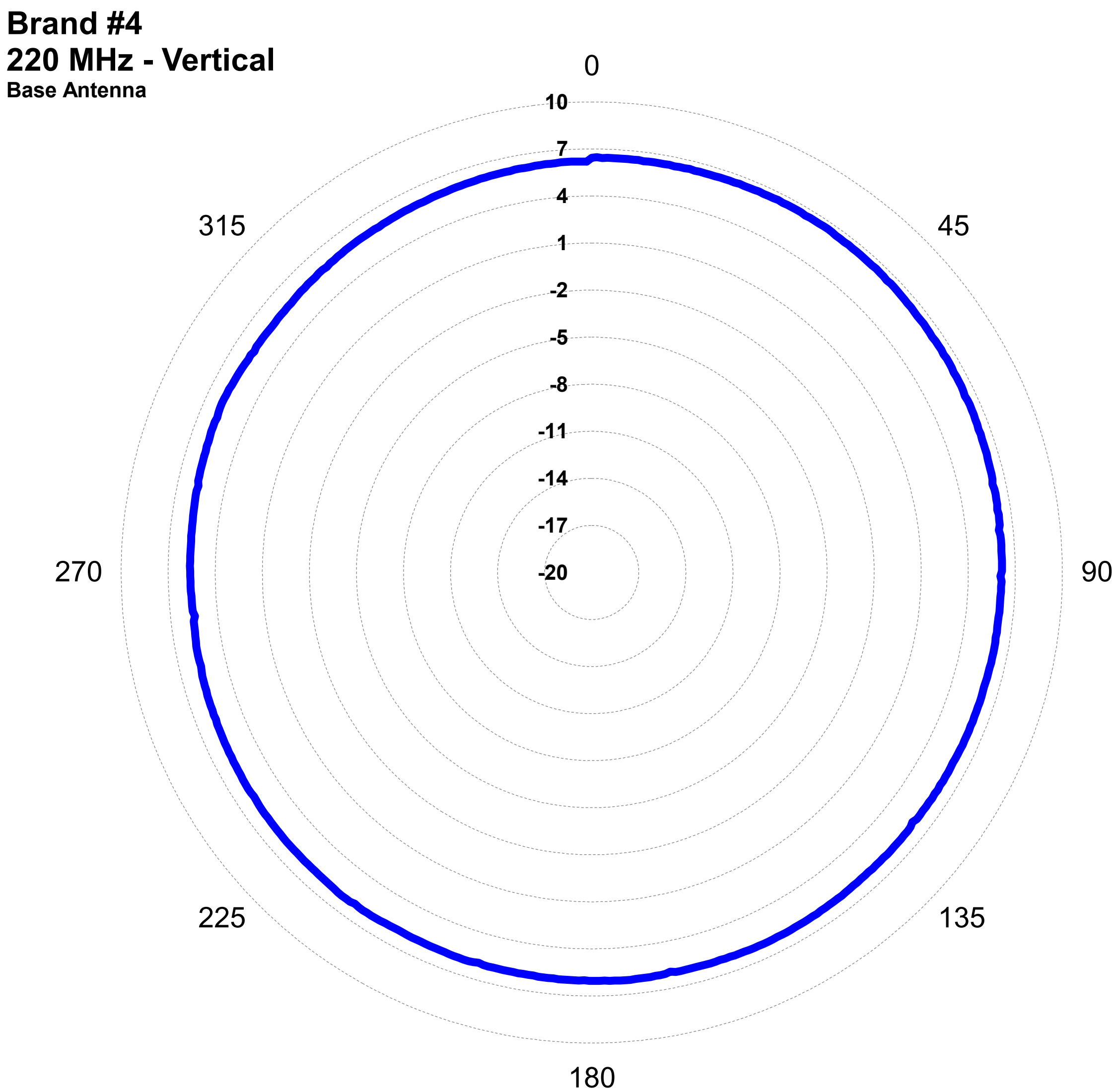

Offs 16.6 dB
Att 10 dB
Ref 5.5 dBm
RBW 3 MHz
* VBW 30 kHz
SWT 5ms
M3[1] -14.76 dBm
220.200000000 MHz
M1[1] -14.02 dBm
217.420000000 MHz
M2[1] -15.29 dBm
223.250000000 MHz
1Sa
Clrw
2Sa
Clrw
VSWR
3.55:1
1.92:1
1.50:1
1.45:1
1.43:1
1.42:1
1.22:1
1.118:1
0 dBm
-5 dBm
-10 dBm
-15 dBm
-20 dBm
M1
M3
M2
150
165
180
195
210
225
240
255
270
285
300
FREQUENCY, MHz

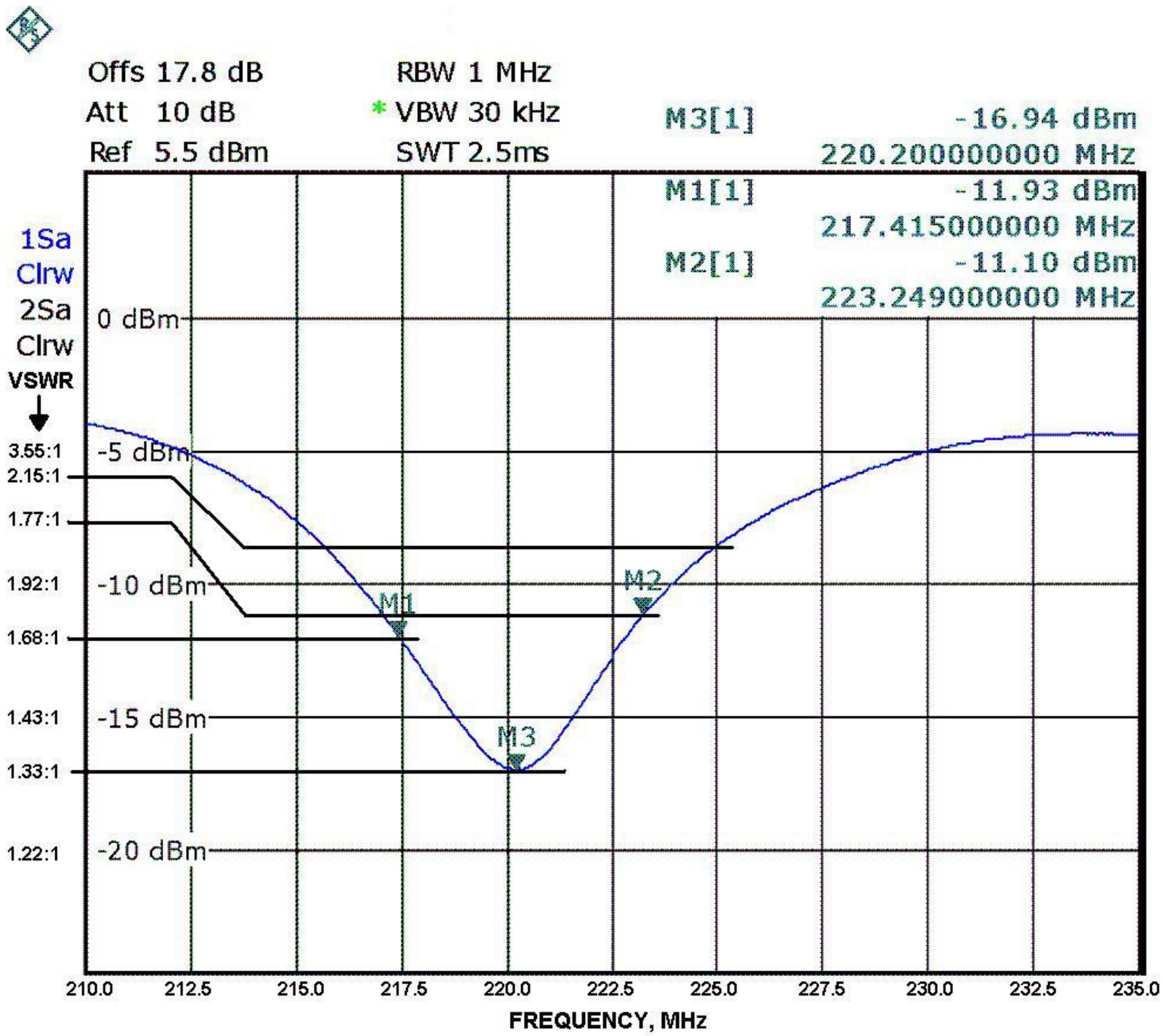
The Brand #3 Model #3 showed the highest gain at 7.57 dBi; its lowest gain was about 7.03 dBi. The radiation pattern is shown below, followed by the VSWR plot.




Offs 17.0 dB
Att 10 dB
Ref 5.6 dBm
RBW 1 MHz
* VBW 30 kHz
SWT 2.5ms
M3[1] -17.35 dBm 225.000000000 MHz
M1[1] -22.89 dBm 220.000000000 MHz
M2[1] -22.31 dBm 222.500000000 MHz
1Sa
Clrw
2Sa
Clrw
VSWR
3.55:1
1.92:1
1.43:1
1.315:1
1.22:1
1.166:1
1.155:1
1.12:1
0 dBm
-5 dBm
-10 dBm
-15 dBm
-20 dBm
M1
M2
M3
205.0
208.5
212.0
215.5
219.0
222.5
226.0
229.5
233.0
236.5
240.0
FREQUENCY, MHz

The Brand #4 Model #4 antenna tested to have the greatest likelihood to survive 150+ mile per hour winds of the four antennas.  The Brand #3 antenna has nearly as much gain, 6.85 dBi, as the Brand #3 antenna, and displayed a good VSWR curve over the intended bandwidth of 220 – 225 MHz, although it does appear to be trimmed slightly low. For RF measurements, we used the Brand #1 clamps. The pattern plot is shown below with the VSWR curve shown on the next page.






## Conclusion

The Brand #2 antenna showed the lowest gain, broadest bandwidth, and second strongest construction at 175+ mile wind survivability. The Brand #3 antenna showed excellent bandwidth and the most gain, but is also the weakest of the four antennas. While it may survive 100 mph winds, it does not appear capable of much more. The Brand #3 antenna, strongest wind survivability, and Brand #1 antenna, apparently tuned high, were found to be in-between the two gain extremes of the Brand #2 and Brand #3 antennas.