Document Title: Multi-Band Antenna System for AGILE

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The 150 MHz antenna has an impedance matching network attached to its base with a female Mini-UHF connector on the radio side of the housing, as shown in Figures 6A and 6B. The 150 MHz antenna's matching network is in turn connected to the radio equipment via a seventeen feet of coax cable with a male Mini-UHF connector on the antenna side and the appropriate coax connector for the radio side.

The spoiler housing was designed by Reactive Resin Product of Perrysburg, Ohio to fit the current body style Ford Crown Victoria vehicle. This vehicle was chosen because of it's wide spread use throughout the Law Enforcement community. Their design includes a U. S. Department of Transportation approved rear facing brake light for safety purposes. Additionally, the antenna can be delivered to a Law Enforcement agency either in primer or color matched paint format. Figures 2 and 3 illustrate a molded and painted spoiler antenna system from the driver and rear views.

The spoiler antenna is securely fastened to the vehicle's trunk lid of the vehicle through two ¼ inch bolts located on the each of the outside stanchions, as shown in Figure 4. The three antenna rods and their associated hardware provide additional mounting security.

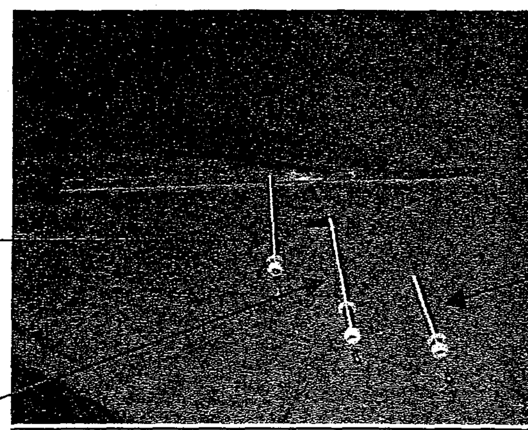

Figure 1 – Spoiler Antenna System Rod Details

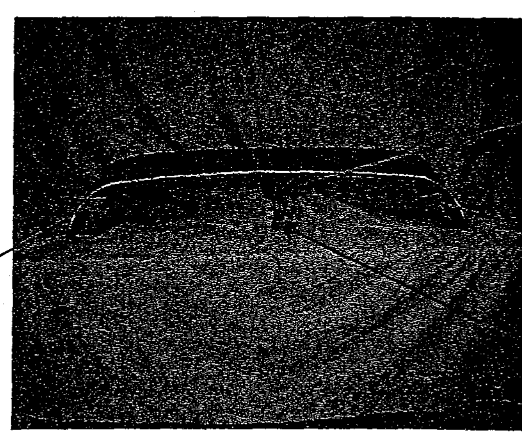

Figure 2 – Spoiler Antenna System Driver Side View

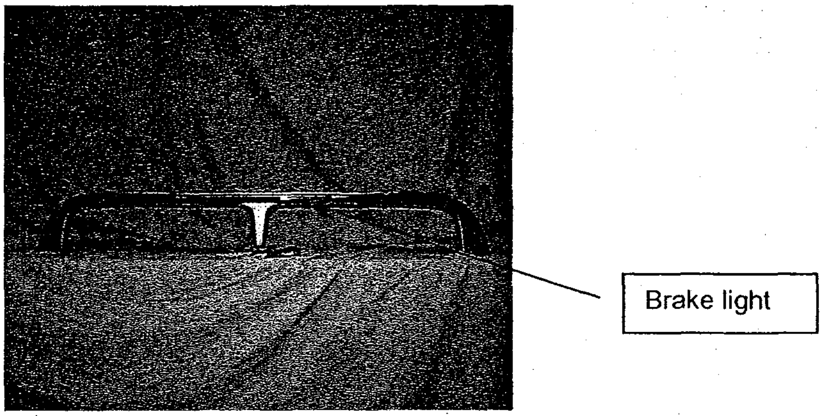

Figure 3 – Spoiler Antenna System Rear Side View

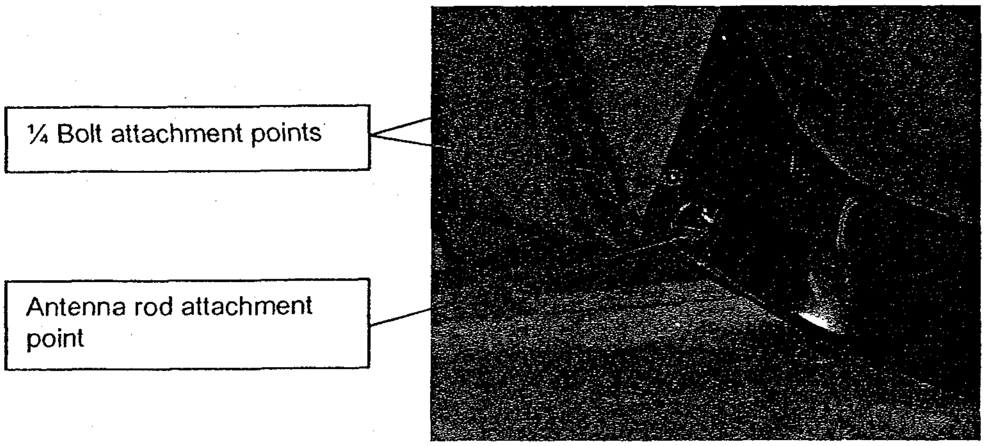

Figure 4 – Spoiler Antenna System Stanchion Mounting Detail

Area 1

The first article spoiler antenna system was inspected for antenna element stability during the injection molding process. Metallurgical Services, Inc. 2681 East River Road Dayton, Ohio 45439 performed the X-RAY photography and supplied Mission Research Corporation (MRC) with the film. Inspection of the X-RAY film by Russ Bertke (MRC) and Wes Soper (MRC) revealed the molding process did not cause deformation of the antenna elements.

Area 2

The VHF antenna rod was lengthened to accommodate the decreased center rise of the late model Ford Crown Victoria's trunk lid. Lengthening the rod resulted in a corresponding antenna feed point impedance change. Feed point impedance measurements were made with an Agilent 8510 network analyzer. Analysis of the impedance data at the 150, 155 and 160 MHz points indicated a network comprising of two capacitors was needed to transform impedance close to 50 Ohms. More specifically, WINSMITH Computer Aided Design (CAD) software was used to design a matching network consisting of a 39 pF series capacitor (C_2) between the coax connector and antenna rod, and a 22 pF shunt capacitor (C_1) from the coax connector center pin to ground. The results for WINSMITH CAD design are shown in Figure 5 Smith Chart plot. The three transformed impedance points lie within the 2:1 constant VSWR circle on the plot, meeting the design goal for a VSWR of less than 2:1.

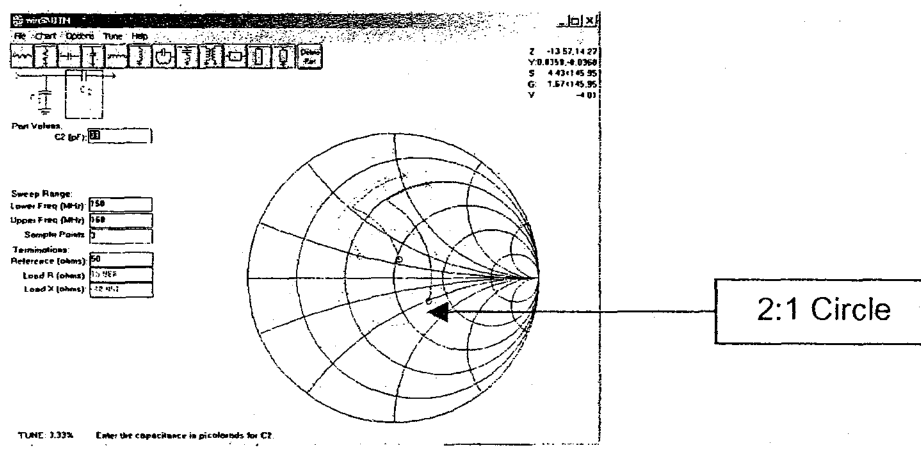

Figure 5 – WINSMITH Smith Chart Plot for VHF Matching Network

The assembled prototype matching network, shown in Figure 6A and 6B, was attached to the VHF antenna for verification of its VSWR with the AGILENT 8510 Network Analyzer. The results of this VSWR test are discussed in detail within Area 3 text.

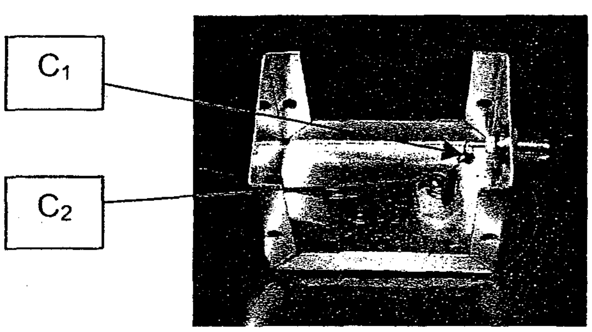

Figure 6A – VHF Matching Network Interior View   Figure 6B – Ready for Test

Area 3

VSWR measurements for the first article spoiler antenna system 's three frequency bands of are shown in Figures 7, 9 and 11. These figures depict graphs of Frequency versus VSWR for the respective bands as plotted by the AGILENT 8510 Network Analyzer.

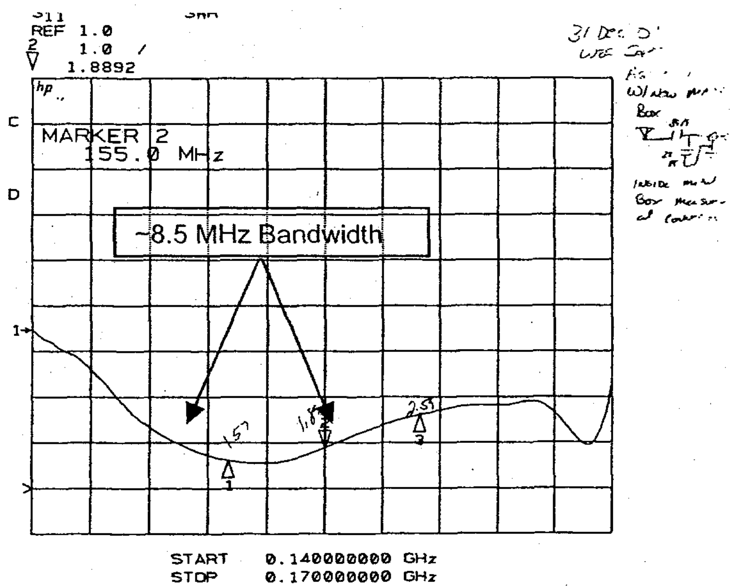

Figure 7 – VSWR Plot for VHF 155 MHZ Antenna

The VHF antenna VSWR Plot shown in Figure 7, exhibited a bandwidth of approximately 8.5 MHz for a VSWR of less than 2:1. H. A. Wheeler has described this narrow bandwidth situation in his paper "Fundamental Limitations of Small Antenna" [1]. Our design requirements for minimal rear window view blockage called for antenna rod length of 6 inches. This length is approximately .08λ of the center operating frequency that falls within the definition set forth by H. A. Wheeler for a small antenna. However, the antenna impedance matching was greatly improved by the inclusion of the power lead to the brake light, which acts like a parasitic element of an Open-Sleeve Antenna as described by Roger A. Cox in [2]. However, Increasing the bandwidth using Cox's method requires additional elements and wider spacing for which this vehicular application does not have the physical space allotment required. To date this 8.5 MHz bandwidth has been the greatest amount of achieved for this frequency band.

A near term solution for this narrow bandwidth situation is to make this matching network tunable so as to move bandwidth window throughout the frequency range from 150 to 160 MHz by use of a trimmer capacitor in place of a fixed value for C_2. A simulation using WINSMITH CAD software to produced a similar VSWR response as that of Figure 7 by adding a 9 nH series inductive element. (This inductor represents the capacitor's wire lead lengths.) Then varying the value of C_2 to 28.89 pF compensated for this added inductance allowed realignment of the window, as can be seen in Figure 8. In turn, the low frequency end moved toward the constant 2:1 VSWR circle limit. In the future, when this antenna system is teamed with the software defined radio an automatic antenna tuner-matching network would need to be designed for frequency changes across the whole bandwidth.

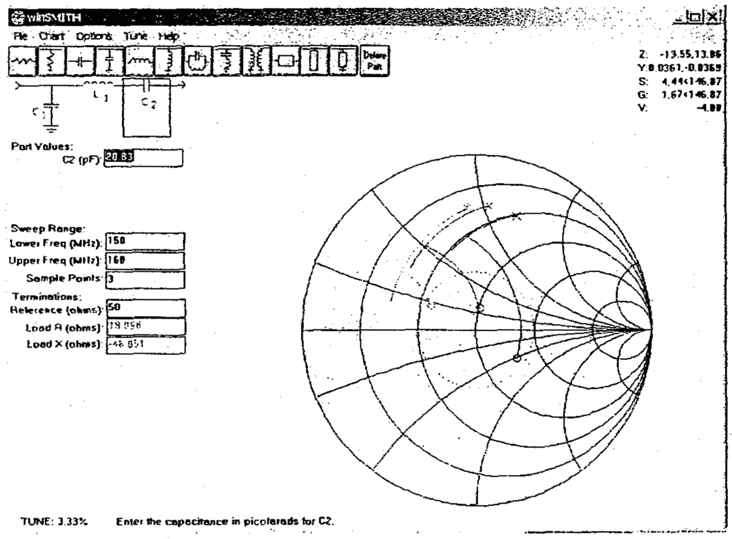

Figure 8 – WINSMITH Plot of VHF Matching Network Modifications

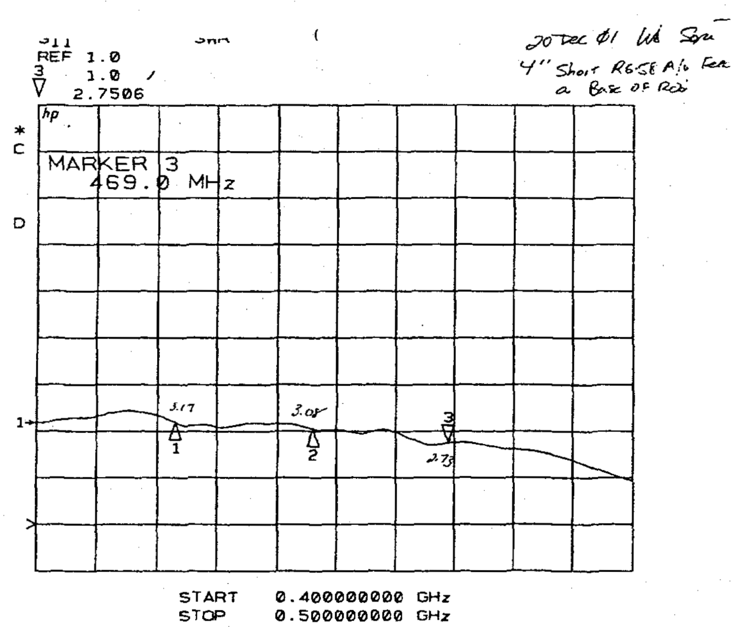

Figure 9 – VSWR Plot for UHF 446 MHZ Antenna

The 446 MHz UHF antenna's feed point VSWR Plot shown in Figure 9, exhibited a nearly flat bandwidth for a VSWR of less than 3.5:1. The design goal was to meet a VSWR of less than 2:1 over the bandwidth from 423 MHz to 469 MHz; this VSWR is achievable by increasing antenna's the top load element length. This design change was verified with NEC4WIN95VM CAD program as shown in Figure 10 for a top load element length of 1.25 inches.

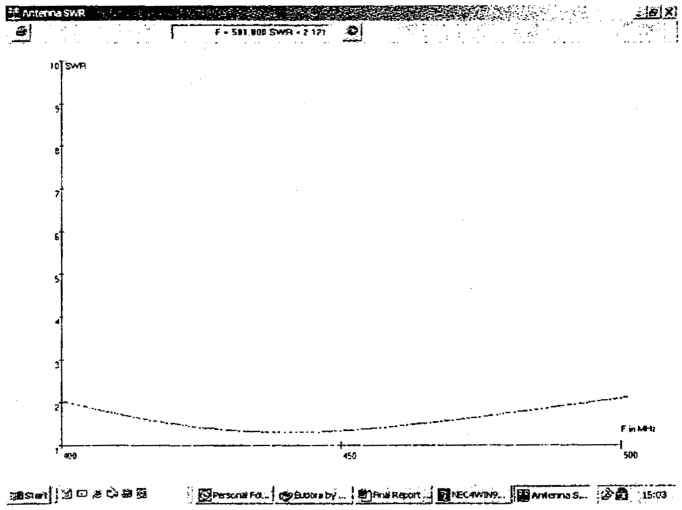

Figure 10 – NEC4WIN95VM VSWR Plot of 446 MHz Top Load Length Change

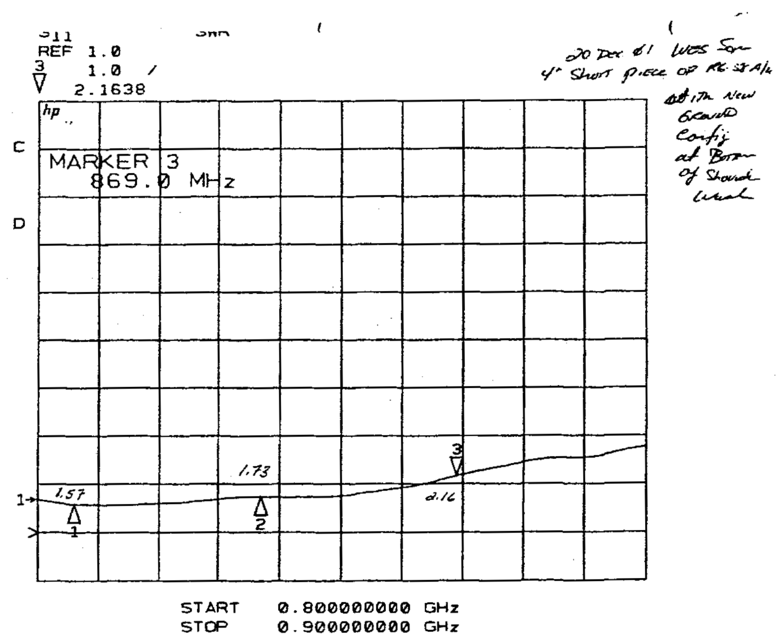

Figure 11 – VSWR Plot for UHF 836 MHZ Antenna

The 836 MHz UHF antenna's feed point VSWR Plot shown in Figure 11, exhibited a nearly flat 2:1 VSWR across the desired frequency spread. In future, versions of the 800 MHz antenna the rod will be slightly shorten to bring the VSWR even further below the 2:1.

Area 4

The first article spoiler antenna system pattern tests were conducted on the aircraft ramp of the 178th Fighter Wing Ohio Air National Guard base in Springfield, Ohio. Present were Jim Stall (Beavercreek Police Department), Patrolman Scott Spangler (Beavercreek Police Department), Pat Wile (MRC) and Wes Soper (MRC).

Prior to the commencement of the antenna pattern tests, Mr. Stall and Patrolman Spangler were given the opportunity to review the antenna system for suggestions or concerns. Both observed the VHF matching network housing was too large. This was due to lighting equipment mounted underneath the BCPD vehicle's trunk lid. This size concern was included in the redesigning of the matching network as described in Area 2 of this document. Overall, they were impressed with the styling and features of the antenna system.

The test equipment and software configuration was modified to provide greater data collection accuracy than during previous tests. The original MATLAB computer code was written to gather only signal level data was modified to collect antenna aspect reference data via Global Positioning System (GPS).

Preliminary testing of the modified code indicated the signal level and GPS data appeared to be reliable. However, post-test analysis revealed antenna pattern data gaps, of which could not be recovered, coinciding with the GPS data acquisition time periods. Plots of the available data were made illustrate the pattern of the Motorola monopole (red line) antenna versus the first article spoiler antenna system (black line), as shown in Figures 12, 13 and 14. (Note: the pattern scale is the relative signal strength in dB to show pattern shape, not dBi for antenna gain.) These plots illustrate a tendency of the spoiler antenna system to possess the same pattern as the Motorola monopole antennas.

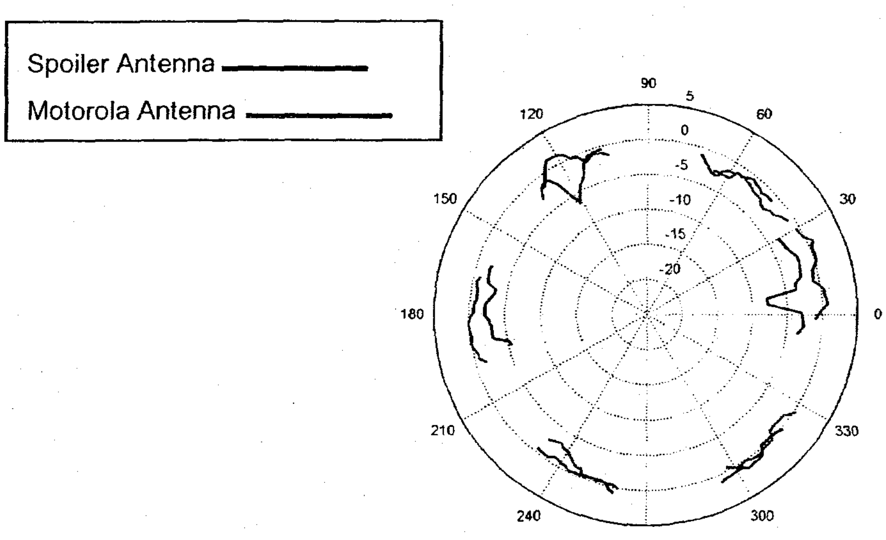

Figure 12 – VHF 155 MHz Antenna Pattern Plots

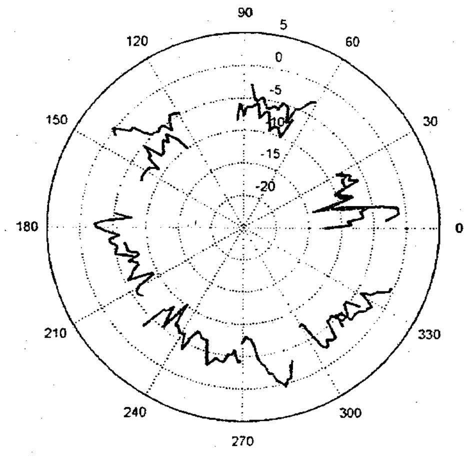

Figure 13 – UHF 446 MHz Antenna Pattern Plots

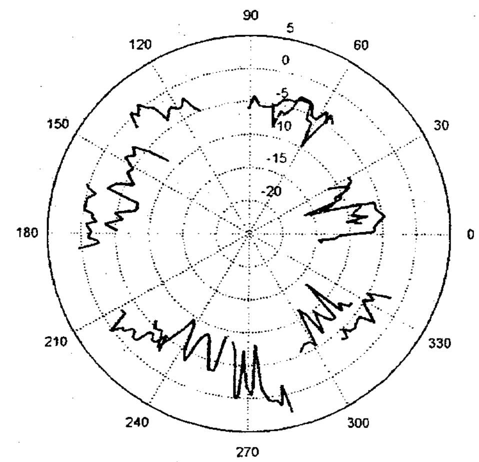

Figure 14 – UHF 837 MHz Antenna Pattern Plots

Area 5

The three deliverable antennas as part of this grant are currently in the manufacturing phase. The expected delivery date will be near the end of January 2002, as discussed with the NIJ Project Manager.

Area 6

Mission Research Corporation recommends further post development field tests of the spoiler antenna system. These tests include working with OLETC partnered Law Enforcement Agencies including MRC's partner agency, the Beavercreek Police Department to identify improvements or problems with this design.

Another area of future design development is to expand the VHF coverage by 20 MHz. This would allow the spoiler antenna system to cover the 130 to 138 MHz Public Safety band after the Federal Communication Commission's spectrum restructuring.

Conclusions

The solicitation for this project called for an antenna that would be compatible with a Software Defined Radio (SDR) and to consider the system's size and weight. The Mission Research Corporation spoiler antenna system is compatible with a single port SDR, if all three antennas are combined into one port with a device such as a Tri-Plexer. Additionally, this antenna is compatible with existing and legacy radio equipment in its current configuration.

The only problem foreseen when used with a SDR is during the VHF frequency-changing mode; either more antenna bandwidth or retuning of the matching network would be required. This concern can be resolved by utilizing an automatic antenna tuner or similar technology to maintain the antenna at minimum VSWR.

Considering the size, only minor differences exist between aftermarket air spoilers currently in use by law enforcement agencies and the Mission Research Corporation spoiler antenna system. Our spoiler antenna system weighs approximately 5 pounds more than RRP's stock aftermarket spoilers, due to the inclusion of the brass antenna elements and the associated mounting hardware. When compared to a spoiler manufactured from metal, our spoiler is of similar or less weight.

References:

[1] H. A. Wheeler, "Fundamental Limitations of Small Antennas", Proc. IRE, vol. 35, pp. 1479-1484
[2] Roger A. Cox, "The Open-Sleeve Antenna" in R. Dean Straw, Ed., The ARRL Antenna Book, American Radio Relay League, 1997