Integrating V2V Functionality at 5.9GHz Into an Existing Quad-Band Antenna for Automotive Applications

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Abstract

A DSRC antenna integrated in an existing automotive roof-mount quad-band antenna (Cell, GPS & XM) is presented. VSWR, isolation and gain measurements are shown for this antenna. On-vehicle measurements show that a DSRC antenna with better than 2:1 VSWR and -5dBi vertical average gain at azimuth can be achieved with minimal effect on existing multi-band antenna.

Keywords: V2V DSRC Gain Isolation Radiation Pattern Automotive Antennas

1. Introduction

Testing of a wireless-based vehicle safety system is underway between the United States Department of Transportation (USDOT) and the Crash Avoidance Partnership-Vehicle Safety Communications 2 (CAMP-VSC2) Consortium, which include General Motors, Ford, Honda, Mercedes-Benz and Toyota [1][2]. The consortium was founded in 2006 [1] to determine if Dedicated Short Range Communications (DSRC) at 5.9 GHz can be used for such safety applications. The FCC (Federal Communications Commission) has dedicated a frequency band between 5.85 and 5.925GHz [3] with a 75MHz bandwidth for this service.

Recently, Laird Technologies' Telematics & Wireless M2M business unit along with General Motors (GM) Global Research & Development Centre have initiated a combined effort to design and develop a production-feasible antenna technology for DSRC. Furthermore, the DSRC antenna must function in conjunction with other existing available wireless services on GM's vehicles such as OnStar (cell phone & GPS) and XM satellite radio reception. The Laird antenna will be used by GM to participate in a road test in the summer of 2011 along with the USDOT and other CAMP-VSC2 consortium members. In addition, the DSRC receiver fitted in the vehicle will also require an additional GPS antenna input. Both systems (DSRC & GPS) are used to exchange safety information such as time, location and other vehicle data to nearby vehicles [4].

The purpose of this paper is to show that DSRC functionality can be integrated with other antennas serving existing wireless services. Results of the antenna radiation patterns (gain patterns), VSWR plots and coupling issues will be presented.

2. Design & Integration of the DSRC Antenna Element

2.1 **Strategy**

Laird Technologies was tasked with integrating the DSRC antenna into an existing roof-mount quad-band antenna on the Cadillac DTS. The objective of the project was to make sure that existing antenna functionality, styling, footprint or attachment scheme is not affected by adding the DSRC functionality. This insures, at a very early stage in antenna development, that if the DSRC project is successful and the USDOT decides to adopt such system in future vehicle designs, OEM vehicle manufacturers such as GM will be able to implement DSRC with minimum tear-up to their existing wireless systems architecture.

The current roof-mount quad-band antenna covers the XM satellite Radio band (2332.5 – 2345 MHz), the GPS band (1574 – 1576 MHz), the DAMPS/GSM850 band (824 – 894 MHz) and the PCS/GSM1900 band (1850 – 1990 MHz). The design of the current antenna allows for simultaneous operation of all these wireless services.

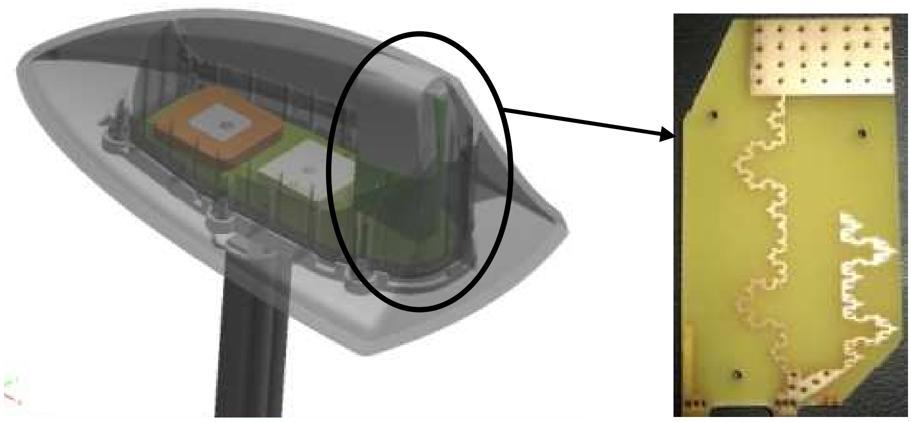
2.2 **The DSRC Antenna**

The DSRC antenna was simulated and optimized using HFSS as a stand-alone structure. The design parameters for the antenna are given in Table 1.

Table 1: Design parameter goals for the DSRC antenna

Design Parameter	**Targeted Value**	**Units**
Operating Frequency	5.850 – 5.925	GHz
VSWR	2:1 or better	
Gain @ 0°Elevation on Ground Plane	-0.5	dBi
Polarization	Vertical	
Gain min/max @ 0°Elevation on Ground Plane	< 10	dB

The simulated DSRC element was then placed along with a dual-band cell phone antenna on the same substrate. The cell phone antenna was designed for North America’s DAMPS/GSM850 and PCS/GSM1900 bands. Both antennas were optimized for gain, VSWR & isolation. The resultant multi-band antenna (dual band cell + DSRC) etched on a substrate material is shown in Figure 1b. The complete antenna along with GPS and XM satellite radio is shown in Figure 1a. The plastic cover (radome) and attachment scheme were exactly the same as the existing antenna without the DSRC functionality.



(a) (b)

Figure 1: Multi-Band Antenna configuration with XM, GPS, dual-band cell phone & DSRC.

3. Measurements

3.1 **VSWR**

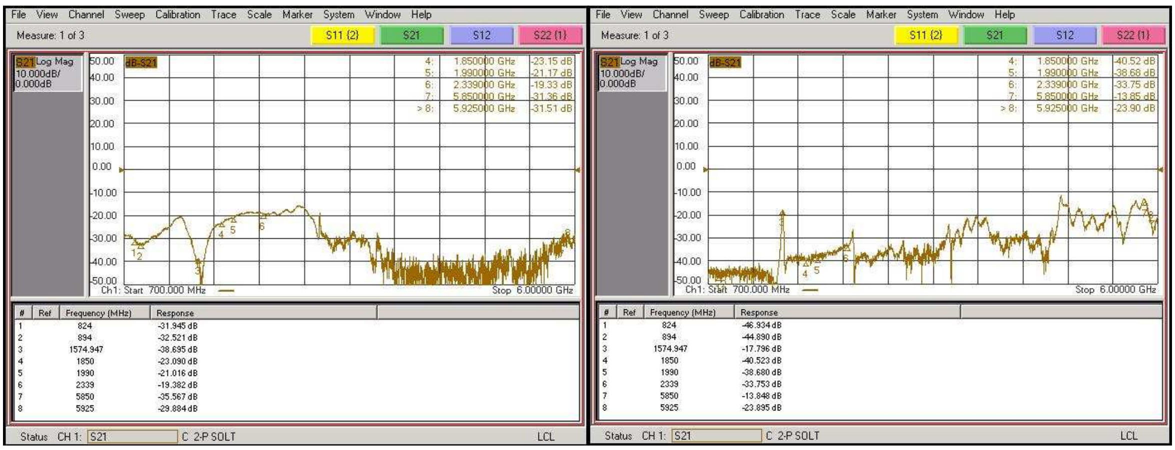
The VSWR of the antenna was measured using a 6GHz Agilent 5072 vector network analyzer. The cell and DSRC antenna VSWR measurements are shown in Figure2a and b, respectively. Across the whole DSRC bandwidth, the VSWR was measured to be < 1.66:1. For both, the DAMPS/GSM850 and the PCS/GSM1900 bands, a VSWR of 2:1 or better was achieved. The measurements were performed using a 4" coaxial 50Ω semi-rigid cable that was terminated with an SMA connector. In the vehicle, however, the DSRC antenna was connected to the receiver using a 65" LMR200 coaxial cable, while the cell antenna was connected to the OnStar receiver using the vehicle production coaxial cable (RG58LL).

(a) (b)

Figure 2. VSWR measurements for a) cell and b) DSRC antennas.

3.2 **Cell and GPS to DSRC Antenna Isolation**

Isolation or S_{21} measurements between the different antenna feeds were conducted at multiple bands of operation. The purpose of these measurements is to make sure that there is minimal coupling between the antennas resonating at different bands, which would optimize the radiation patterns and guarantee simultaneous operation with minimal interference. Figure 3a shows the isolation measurement between the DSRC antenna and the dual-band cell antenna. The isolation measurements shows > 32dB at DAMPS/GSM850 band, >21dB at PCS/GSM1900 band and >30dB at the DSRC band. In Figure 3b, the passive isolation between the DSRC and the GPS antennas is presented. The measurement shows > 17.8 dB isolation at GPS and >14 dB at DSRC. The measured isolation is enough to guarantee that these systems can operate simultaneously with minimal interference from each other taking into consideration that the DSRC receiver's maximum transmit power is +20dBm, while the cell modem transmits a maximum power of +24dBm at both cell bands.



(a) (b)

Figure 3. Passive isolation between the DSRC and a) dual-band cell antenna and b) GPS.

3.3 **XM to DSRC Antenna Isolation**

During the initial measurement of the XM to DSRC antenna isolation, an issue was discovered causing the DSRC antenna to have a degraded radiation (gain) pattern. After some investigation and initial calculation, it was attributed to a higher order mode excitation on the XM ceramic Microstrip antenna. Per equation (1), the frequency of resonance for a Microstrip antenna with a thin substrate is given by [5]:

$$f_{res,nm} = \frac{c_o}{2\pi\sqrt{\epsilon_{eff}}}\sqrt{\left(\frac{n\pi}{a}\right)^2 + \left(\frac{m\pi}{b}\right)^2}$$

where $f_{res,nm}$ is resonant frequency at excitation mode nm, c_o is the speed of light universal constant, ϵ_{eff} is the effective relative dielectric constant of the substrate material, and a & b are the physical dimensions of the Microstrip antenna in the x and y directions. For ϵ_{eff} of 19.17, a & b of 13.06mm, the TM_{21}/TM_{12} resonance modes are calculated to be at 5.874 GHz, which is a resonance in the middle of the DSRC band. The XM antenna was modified to suppress or shift the TM_{21}/TM_{12} resonance frequency. Figure 4a shows the non-modified XM antenna resonance modes where the return loss at 5.963 GHz is measured to be better than 14dB. Figure4b shows the same antenna after the TM_{21}/TM_{12} resonance modes were suppressed. The return loss at the same frequency mentioned earlier is measured to be 2.6dB.

(a) (b)

Figure 4. XM antenna TM_{21}/TM_{12} resonance modes a) before suppression b) after suppression.

After suppressing the TM_{21}/TM_{12} resonance modes, the isolation between XM and DSRC antennas was measured. Figure 5 shows the resulting isolation to be >37.7dB and >21.8dB at the XM and DSRC bands, respectively.

Figure 5. Passive isolation between DSRC and XM antennas.

The DSRC antenna gain patterns before and after suppressing the TM_{21}/TM_{12} resonance modes on the XM antenna are presented in Figure 6a and 6b. As can be seen, the distinct nulls in the DSRC gain pattern before suppressing the TM_{21}/TM_{12} on the XM antenna were dramatically improved. In addition, the average gain of the DSRC antenna before the XM higher resonance modes were suppressed was about -6 dBi across the entire band, while it was about -0.67dBi after suppression, getting the average gain measurement much closer to the design objective. The min/max ratio before suppression was 12.5 dB, while it was 9.9 dB after suppression.

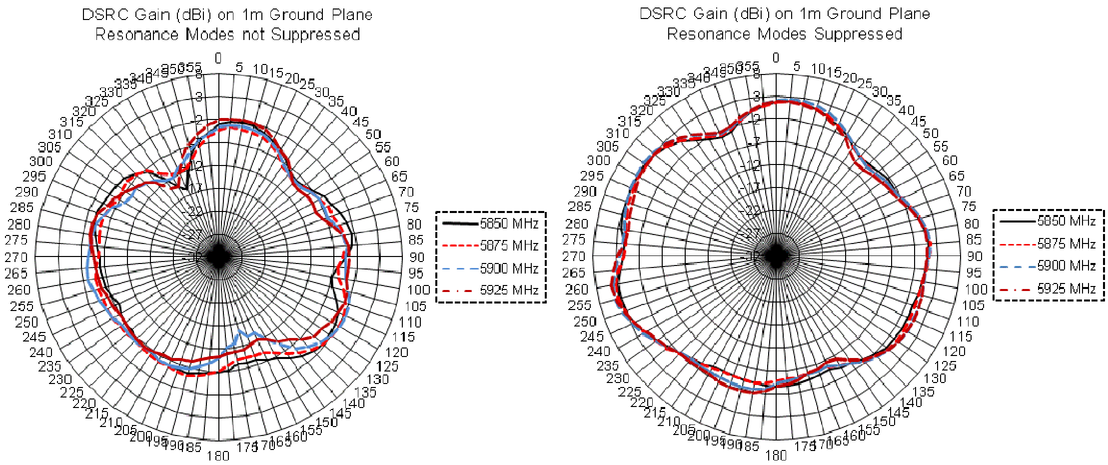
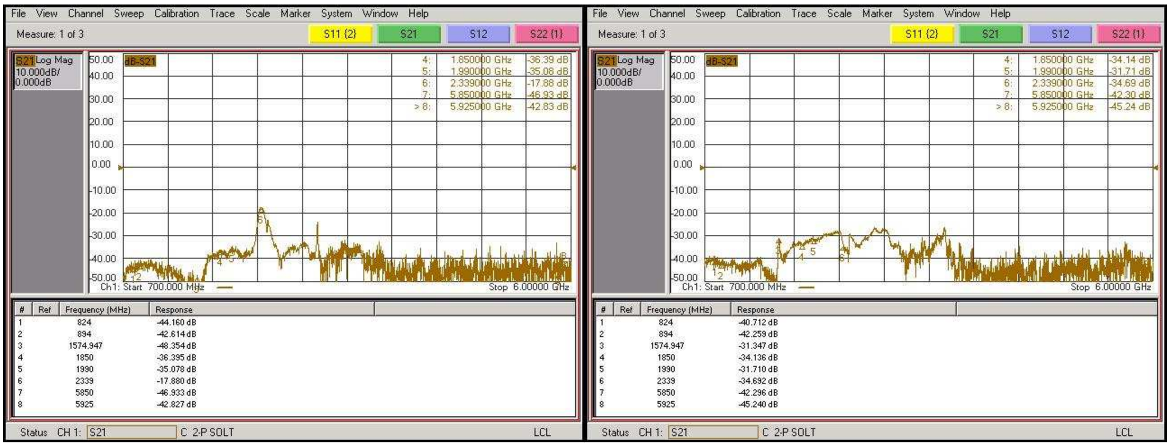


Figure 6. DSRC gain patterns on 1m circular Aluminum ground plane a) before suppressing the XM TM_{21}/TM_{12} modes b) after suppression of these modes.

The isolation measurement was repeated between the cell antenna and both the XM and GPS antennas. These measurements are shown in Figure 7a and 7b, respectively. At DAMPS/ GSM850 band, the isolation with respect to XM was >42.6 dB, while at PCS/GSM1900, the isolation was >35 dB. At the XM band, >24.5dB isolation was achieved. Between the cell phone and GPS antennas, the isolation was >40.7 dB at DAMPS/GSM850, >31.7 dB at PCS/GSM1900 and >31.3 dB at the GPS bands.



(a) (b)

Figure 7. Passive isolation between cell phone and a) XM and b) GPS bands.

3.4 **On-Vehicle Gain and Radiation Pattern**

The antenna radiation patterns (gain patterns) were measured on-vehicle in a production location using Laird's vehicle-level antenna testing range. The cable used to connect the DSCR antenna to the receiver was a 65" LMR200 coaxial cable terminated in a SMA-type RF connector. A commercially available standalone DSRC antenna was used as a reference antenna during these measurements. The gain pattern on the Cadillac DTS is shown in Figure 8. The gain was measured at four different frequencies; namely, 5850, 5875, 5900 and 5925 MHz. All measurements were performed at an elevation angle of 0º (Azimuth cut), where the DSRC system will be required to operate. The average gain measured was about -5 dBi at the end of the vehicle coaxial cable across the DSRC frequency bands, minimum and maximum gains measured were -12 dBi and +0.1 dBi, respectively. The same measurements were conducted using the reference antenna with the same cable attachment. The average gain at azimuth for the reference antenna was about -7 dBi across all frequencies; minimum gain was -16 dBi while maximum gain was -3.0 dBi. The Laird integrated cell antenna measured about -2dBi at azimuth for the DAMPS/GSM850 band and -1dBi at the PCS/GSM1900 band. Both XM and GPS antennas measured within specifications with little to no degradation seen in these measurements.

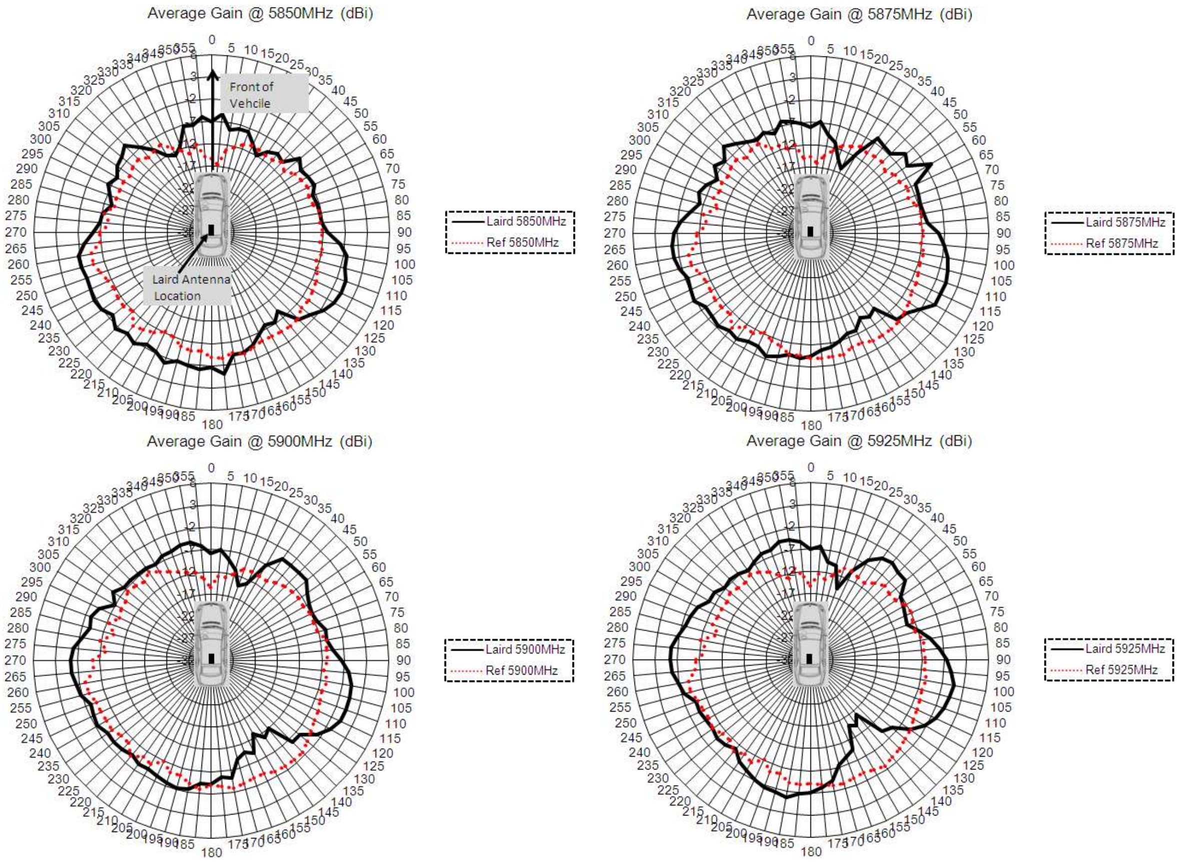


Figure 8. Measured DSRC on-vehicle gain for both Laird and the reference antennas.

Conclusion

A DSRC antenna was successfully integrated in an existing automotive-grade roof-mount quad-band antenna that serviced XM satellite radio, GPS and North American cell phone bands. No change in the multi-band antenna functionality, styling, footprint or attachment scheme was necessary when DSRC functionality was added to it. VSWR of the DSRC antenna was better than 1.7:1 across the entire band and the average vertical gain at azimuth measured on 1m Aluminum ground plane was better than -0.7 dBi. On-vehicle, however, the average gain was better than -5dBi with the use of a 65" LMR200 coaxial cable to connect the roof-mount antenna to the DSRC receiver. Isolation measurements between the DSRC element and XM, GPS and cell phone antennas were also presented and optimized to insure simultaneous operation of all antennas at various bands.

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Acknowledgments

The authors would like to thank Dr. Hriharan Krishnan (GM R&D), Mr. Randy Andreen (Laird Tech.), Dr. Tim Talty (GM R&D) and Mr. Mike Tarasi (Laird Tech.) for making this development project feasible.