ANTENNA MEASUREMENT TECHNIQUES FOR SDARS ANTENNAS

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ABSTRACT

The purpose of this paper is to present antenna measurement techniques of antenna modules for Satellite Digital Audio Radio System (SDARS). SDARS employs dual-transmitter broadcasting formats which include simultaneous transmission of signals from both satellites and terrestrial transmitters. An SDARS antenna efficiently receives both satellite and terrestrial signals: it has relatively good circularly polarized gain at high elevation angles and acceptable linearly-polarized gain at the horizon. Popular SDARS antennas are small ground-depended patch antennas etched on ceramics and ground-independent mast antennas such as quadrifilars. Ceramic patch antennas have a relatively narrow bandwidth of operation. Thus, tuning such antennas to the right frequency is critical. The measurement techniques presented help engineers and technicians evaluate SDARS antennas and determine whether they are correctly designed. We shall describe hardware platforms for evaluating impedance, radiation characteristics, and real-world performance. Parameters such as VSWR, antenna gain, axial ratio, as well as receiver satellite C/N and terrestrial BER will be discussed.

Keywords: SDARS, Satellite Radio, patch antennas

1.0 Introduction

Automotive vehicles are increasingly being equipped with special electronic modules such as global positioning system (GPS), telematics, and infotainment devices that require wireless data communication. Each wireless device typically employs an antenna to communicate with remote transmitting and/or receiving modules. One such popular system is SDARS. This system employs dual-transmitter broadcasting formats which include simultaneous transmission of signals from both satellites and terrestrial transmitters. The satellite transmissions cover the vast majority of the geographic broadcast area. The terrestrial transmissions complement the satellite coverage primarily in urban areas where the satellite signals may be blocked by tall buildings and structures. XM Satellite Radio [1] and SIRIUS Satellite Radio [2] are two competing service providers in the contiguous United States. They provide paying subscribers with over 100 channels of "MP3-quality" digital radio wherever they are, in their vehicle or at home.

Parameters	Value
Frequency Band, MHz	2326 - 2345
Antenna Polarization	Left-Hand Circular
Antenna Gain, dBic*	+2 to +5 (20^0-90^0)
Antenna Gain, dBi*	-3 to -4 (at horizon)
Current Drain, mA	50 - 60
Voltage, volts	4 - 8
LNA Gain, dB (typical)	32
LNA NF, dB	0.7-1.0
Filter Attenuation at +/-250 MHz	35

*antenna placed on center of a 1-m diameter ground plane

Figure 1-SDARS antenna module performance

An SDARS antenna consists of a passive element and an LNA configured such that good reception of both TER and SAT signals is achievable. Such modules exhibit vertical polarization properties along the horizon and circular polarization properties at higher elevation angles (20-90 deg.). A good candidate for a roof-mount SDARS antenna is a microstrip patch antenna etched on a low-loss ceramic or substrate. The right choice of ceramic or substrate can produce acceptable TER performance (gain over the horizon) and satisfactory SAT performance (gain from 20 to 90 deg. elevation angles).

2.0 Antenna Performance

A typical antenna module for SDARS is comprised of a sophisticated Low Noise Amplifier (LNA) and a passive antenna element that receives low-power satellite signals as well as terrestrial signals. Due to low-noise figure requirement, the LNA is located directly below the passive antenna. The LNA output is connected to a long RF cable which is typically 15 to 20 feet in length. An SMB connector is attached to the other end of the cable.

Fig. 1 summarizes some of the basic electrical parameters of SDARS antenna modules [3]. The polarization of the SAT antenna at high elevation angles is left-hand circular, while the polarization of the antenna along the horizon is vertical. Type approval antenna testing requires that the mobile antenna is mounted at the center of a 1.0 m-diameter circular ground plane with rolled edge as shown in Fig. 2.

Figure 2-Ground plane used in SDARS type approval testing

3.0 Antenna Measurements

3.1 Laboratory

Fig.3 shows the S11 response of a typical XM antenna. In this case the antenna is optimized for the XM radio band (2333-2345 MHz). This is the desired response of the antenna inside the housing. The housing shifts the antenna response by 10 to 20 MHz depending on proximity of antenna to top surface of housing, material type, and housing thickness. The small loop formed (at marker 2338 MHz) indicates good axial ratio for the XM frequency band.

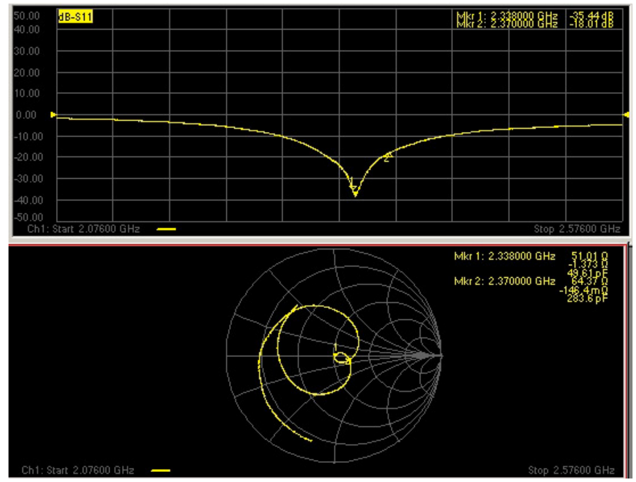


Figure 3-SDARS antenna S11 response

3.2 Anechoic Chamber/Antenna Range

Once the desired antenna/housing response is obtained, the next step is to take radiation pattern measurements at different elevation angles. Fig. 4 shows a typical TER radiation pattern of an XM antenna placed at the center of a 1-meter round ground plane. Fig. 5 shows a summary of gain of the antenna along the horizon. The lowest ripple is at frequency 2338 MHz. This is the frequency at which the value of the axial ratio is minimum, indicating that the antenna is correctly tuned.

Fig. 6 shows the XM antenna gain at 45-deg. elevation angle. The antenna is placed at the center of the 1-meter ground plane. The same antenna is placed on a vehicle roof and spaced 15 cm from the back roof edge. The radiation pattern at 45-deg. elevation in this case is shown in Fig. 7. As seen, the pattern curves are not as smooth as the ground plane curves of Fig. 6 due to the vehicle asymmetries. While on a vehicle, the antenna must be positioned in a substantially unobstructed view of the satellites. The ideal location of an SDARS mobile antenna module is the vehicle roof. SDARS roof-mount antennas require a minimum of six inches from sheet metal edge in order to provide satisfactory antenna performance [4].

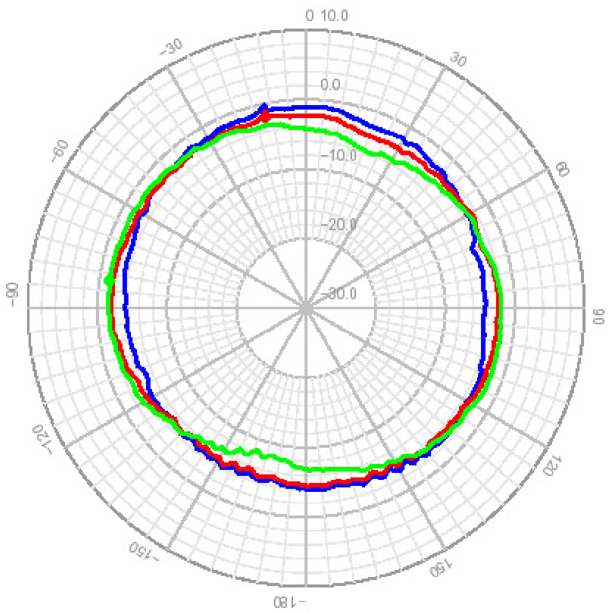
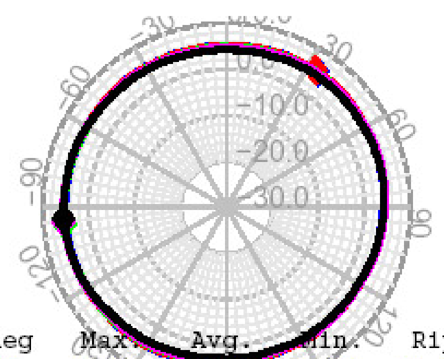


Figure 4-XM antenna radiation pattern along the horizon (TER performance)

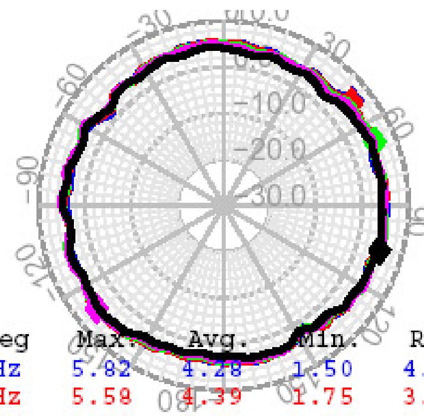
dB,deg	Max.	Avg.	Min.	Ripple
2332 MHz	-0.93	-3.22	-5.20	4.27
2338 MHz	-1.89	-3.22	-5.64	3.75
2345 MHz	-1.47	-3.53	-8.43	6.96

Figure 5-XM antenna gain along the horizon (TER performance)



dB,deg	Max.	Avg.	Min.	Ripple
2320 MHz	5.50	4.65	3.27	2.23
2326 MHz	5.56	4.70	3.26	2.30
2332 MHz	5.41	4.53	3.03	2.38
2338 MHz	5.60	4.53	3.03	2.57
2345 MHz	5.52	4.19	2.71	2.81

Figure 6-XM antenna gain at 45-deg elevation angle (ground plane)



dB,deg	Max.	Avg.	Min.	Ripple
2320 MHz	5.82	4.28	1.50	4.32
2326 MHz	5.58	4.39	1.75	3.83
2332 MHz	5.54	4.29	1.68	3.86
2338 MHz	5.46	4.17	1.77	3.69
2345 MHz	5.14	3.75	1.70	3.44

Figure 7-XM antenna gain at 45-deg elevation angle (vehicle roof)

3.3 Hidden Antennas

One of the problems with SDARS adoption is that larger antenna structures can be aesthetically displeasing when mounted on vehicle roofs or glass. For this reason, manufacturers are currently investigating the use of multiple hidden antennas located in the vehicle interior. The goal is to match the performance of a single roof or mast antenna by using a minimum of two hidden antennas. This is a challenging task, since antennas located inside the vehicle would yield poor performance due to signal blockage from the roof, pillars, and other vehicle structures.

Fig.8 shows two radiation patterns corresponding to an SDARS SAT antenna located inside a sedan (front dash and rear deck lid) for the elevation angle of 25^0. As seen, each radiation pattern by itself is not acceptable. However, when the two are combined through a receiver diversity algorithm, the resulting radiation pattern can be significantly improved. A potential antenna choice for this application is a patch antenna. A pair of patch antennas can be used, one placed in the front and the other in the rear of the vehicle. A perceived disadvantage of implementing hidden antennas is the cost increase associated with each additional antenna module: antenna element, LNA, cable, and connector.

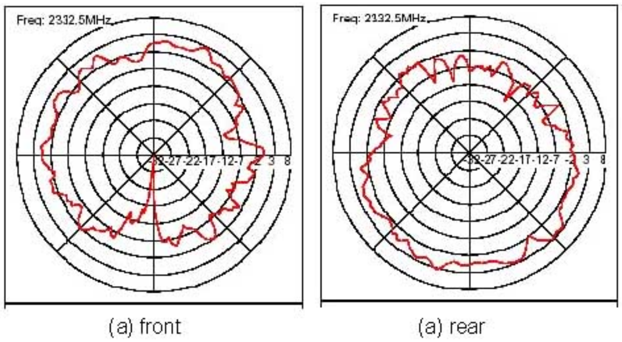


Figure 8-SDARS antenna gain inside vehicle (25-deg elevation angle)

3.4 Y-Factor, Noise Temperature, and G/T

During this measurement, the complete antenna module is tested: antenna, LNA, and cable. For roof-mount antennas, two separate noise temperature measurements on ground plane are required. The setups are shown in Figs 9a and 9b. Both measurements are done outdoors and away from large buildings or other structures and RF sources. The measurement in Fig. 9a yields P_{hot} (dBm), where an absorber box at ambient temperature serves as a hot noise source. The measurement in Fig. 9b yields P_{cold} (dBm), where the sky serves as cold noise source. In the case of mast SDARS antennas, the setups in Fig. 9a and b can be used without the ground plane.

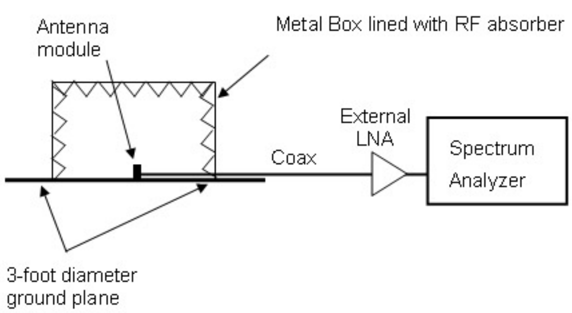


Figure 9a-Y-Factor measurement setup (P_{hot})

The spectrum Analyzer settings are as follows:

Parameter	Value
Center Frequency	2.338 GHz
Span	40 MHz
RES BW	1.0 MHz
Video BW	1 kHz
Scale	2 dB/div
NF of external LNA	1 dB (typical)

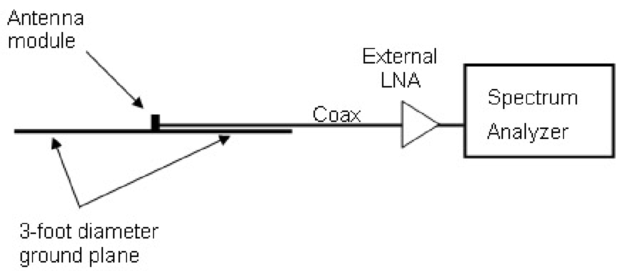


Figure 9b-Y-Factor measurement setup (P_{cold})

The y-factor is:

$$Y = P_{hot} - P_{cold} \text{ (dB)}, \quad (1)$$

and

$$y = 10^{(Y/10)}. \quad (2)$$

The Y-factor for SDARS antennas is between 4 and 5 dB. The active antenna module noise temperature, T_s, or system noise temperature is given by:

$$T_s = [(T_0 - yT_{cold})/(y-1)] + T_{cold} \quad (3)$$

where, T_0 is the ambient temperature, in degrees K, at the measurement site and $T_{cold} = 35$ K (mean sky noise temperature). The system noise temperature is also given by:

$$T_s = T_{ant} + (F-1)^* T_0 \quad (4)$$

where, F is the noise figure of the receiver measured at the LNA input, in linear units, or, the noise figure of the antenna module, including cable.

The system G/T is:

$$G/T = G_a/T_s \quad (5)$$

where G_a is the antenna gain corresponding to a particular elevation angle.

It should be noted that in the USA, the difference in noise floors should be measured at frequencies outside the SDARS spectrum (2320-2345 MHz) and inside the filter response of the LNA, i.e., 2350 to 2355 MHz.

3.5 Driving Test

Driving tests are very important as they show how the antenna performs in "real-world" conditions. One important test is driving under heavy foliage and no terrestrial signal present. The Carrier-to-Noise (C/N) signal level corresponding is recorded during the drive.

Typical driving test duration is 3 to 5 minutes. At the end of each test the average C/N is calculated for each antenna tested. Fig. 10 shows a typical street used for such testing. The results of a typical drive tests are provided in Fig. 11, where C/N is shown corresponding to each of the XM satellite signals.
In areas in the vicinity of terrestrial repeaters, the terrestrial performance can be evaluated by recording the BER corresponding to each antenna.

Figure 10- Street with heavy foliage (SAT testing)

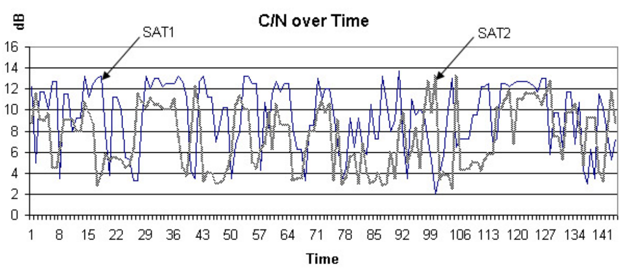


Figure 11- Driving test results corresponding to XM SAT1 and XM SAT 2

4.0 SUMMARY

In this paper we presented several measurement techniques for SDARS antenna modules. We have provided descriptions for each technique along with measurement results. These measurements are very important as they help engineers and technicians to correctly design and evaluate SDARS antennas.

5. REFERENCES

[1] Xm radio web page: www.xmradio.com

[2] Sirius web page: www.sirius.com

[3]A. Petros, I. Zafar, S. Licul “Reviewing SDARS Antenna Requirements," *Microwaves and RF*, pp. 51-62, September 2003.

[4] M. Daginnus, R. Kronberger, A. Stephan, G. H. Hassmann, H. Lindenmeier, J. Hopf, and L. Reiter, "SDARS – Antennas: Environmental Influences, Measurement, Vehicle Application Investigations and Field Experiences," SAE Technical Paper Series, 2002-01-0120, SAE World Congress, Detroit, Michigan, March 4-7, 2002.