Study of mm-Wave Scattering of Roadside Targets for Vehicular Road Departure Detection Applications

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Abstract. The main objectives of this study were characterizing the radar scattering properties of common highway roadside objects in 24 GHz and 77 GHz bands. So far, we have developed measurement methodology and studied scattering properties of concrete curb and concrete. This paper focused on collecting initial scattering data of roadside objects under stationary. The measurements were conducted at 24 GHz with 1 GHz bandwidth using a commercial software-defined radar (SDR) manufactured by Ancortek. These measurements were mainly conducted for understanding the general scattering strength and measurement setup requirements, and were not for detail characterization of the radar cross section (RCS) properties. We also measured the reflection coefficient of concrete for spraying water. In preparation for fabricating roadside surrogates, we also began to measure the reflectivity of several conductive fabric in our possession to determine if any of them could be suitable for dressing the roadside surrogates for producing similar reflectivity as the surface of selected representative roadside objects.

Keywords: radar cross section (RCS), reflection coefficient, curb, concrete, fabric, polarization.

1. Introduction

In recent years the number of fatal vehicle crashes related to road departure has risen significantly. A vehicle road-departure crash is defined as when the vehicle moves from the road to the roadside and consequently leads to a crash [1]. In order to solve this problem and reduce road-departure related crashes, roadway departure mitigation system (RDMS) and lane keeping assistance system (LKAS) [2-4] have been developed and introduced to new vehicles by many auto companies. RDMS can detect not only lane markings but also road edges based on roadside objects, such as grass, metal guardrail, curb, concrete barrier, etc. [5]. The road departure detection can be based on the recognition of road edge markings. However, there is a need for an accurate and safe way to test the effectiveness of different RDMS developed by different manufacturers. Therefore, realistic roadside surrogates are being developed for this purpose. The most important thing is to determine the proper shape and materials used for making these surrogates for producing similar sensor (radar and camera) signatures as real roadside objects. This paper presents the preliminary findings on mm-wave radar scattering characteristics which can be used as the characteristics requirements for designing and fabricating the roadside object surrogates.
2. RCS of Canonical Targets

The linear system of equations related to radar target scattering problem can be expressed in matrix form, which is called the polarimetric scattering matrix [6]:

$$\begin{bmatrix} E_v \\ E_h \end{bmatrix} = \begin{bmatrix} S_{vv} & S_{vh} \\ S_{hv} & S_{hh} \end{bmatrix} \begin{bmatrix} E_v \\ E_h \end{bmatrix}$$

Or

$$\vec{E}_s = \vec{S} \cdot \vec{E}_i$$

Assuming a complex scattered electric field, a polarimetric RCS scattering matrix is defined as [7]:

$$\sqrt{\sigma} = \begin{bmatrix} \sqrt{\sigma_{vv}} \\ \sqrt{\sigma_{hh}} \end{bmatrix}$$

The RCS scattering matrix presents representation for all polarizations in terms of complex incident and scattered fields.

The peak RCS of some common conical electrically conducting targets are shown in Figure 1. These RCS values are only a function of wavelength and target geometry alone if the target distance is in the far-field zone. Canonical targets, or simple targets which have a known solution for their RCS are very useful for calibration of a radar measurement and also for error analysis. RCS of a target in general, varies with field polarization and incident angle respective to the target’s orientation[8].

3. Stationary 24 GHz Radar Measurement Setup

The stationary 24 GHz radar measurements were conducted using the Ancortek SDR module (SDR-KIT 2500B) mounted on a tripod at a height of approximately 55cm as shown in Fig.1 For stationary measurements, we selected FMCW waveform with 2 GHz bandwidth (23-25 GHz) and 256 samples/sweep.

4. 24 GHz Concrete Barrier Reflection Measurements

For large (in terms of wavelengths) flat medium such as the surface of a concrete barrier, pavement, etc., it is more meaningful to measure the surface reflection coefficient, rather than RCS. This would allow for determining proper material property that can produce similar reflectivity as the real object. The measurement calibration was done by comparing measured reflection data to that obtained from a flat copper plate that is 60 cm by 60 cm in size, placed directly over the side wall of concrete barrier to be measured as shown Figure3. Before the measurement, the aiming of the radar was adjusted carefully so that the radar beam is normal to the surface of copper plate, which was indicated by maximum reflection. The distance of between radar and the surface under measurement was 57cm.
The antenna height was 60 cm. In order to remove the undesired coupling between transmitting and receiving antennas, we also conducted a background measurement by pointing the antenna to sky as shown in Figure 2.

Figure 3 shows the geometry of concrete barrier used for the measurement. The measured reflection coefficient of dry concrete surface was approximately -7.3 dB. To study the effect of wet concrete surface on the reflection, we subsequently spayed water onto the concrete surface and then collected reflection data at 5 minutes intervals while it was drying. Figure 4 plots the measured reflection coefficient as a function of drying time. This results shows that a wet concrete surface produces a stringer reflection coefficient of approximately -3.5 dB due to higher dielectric constant. As surface dries, the reflection coefficient gradually decreases, and eventually approaches the reflection coefficient of dry concrete, which is approximately -7.3 dB. If we assume that the reflection of the concrete is mainly due to dielectric contrast between air and concrete, then the dielectric constant of wet and dry concrete can be derived from the measured reflection. As shown in Figure 4.

![Figure 2](image1.png)  
*Figure 2. Calibration measurement setup for reflection coefficient measurement and measurement situation*

![Figure 3](image2.png)  
*Figure 3. The information of concrete divider measured and right after spaying a water on the side wall of concrete divider.*
Figure 4. The measured reflection coefficients of concrete block surface as a function of time after water was sprayed onto it (Left) and the relationship of reflection coefficient and dielectric coefficient (Right).

5. Conductive Fabric Reflection Measurement Setup

For the roadside object surrogates (except for vegetation), we plan to cover shaped foam or plastic material with proper conductive/resistive fabric which produce similar surface reflection coefficient as the real object. Fabrics that produce reflection coefficient of approximately -7.3 dB can be used on surrogate for concrete objects such as curbs or concrete blocks. This section discusses about the 24 GHz and 77 GHz measurement setups and results of reflection measurements for some of fabrics in our possession. More type of fabrics have been order and will be measured later.

A flat copper plate was used a reference and was placed at the same surface as the fabric to be measured as shown in Figure 5. Before the data collection, the radar aiming was carefully adjusted to maximize the magnitude of the reflection data. In order to correctly measure the reflection coefficient of a fabric sheet, it was held open and flat without wrinkles as demonstrated in Figure 6. The distance between the measurement surface (glass window) and radar is 30 cm and the height of radar is 68cm. Several different fabric material were measured (Figure 5 and Figure 6). The resultant reflection coefficient data are shown in the right of Figure 6 and Figure 6. The “silver” color sample, CobalTex and Marktex fabric samples all have high reflection coefficient as metal and have similar color as aluminum. Therefore they are good candidates as W-beam and I-beam surrogate covers.

| Material     | 24GHz radar |
|--------------|-------------|
| Golden color | 0.21 dBsm   |
| Silver color | -0.59 dBsm  |
| CobalTex     | 0.19 dBsm   |
| Marktex Inc. | 0.13 dBsm   |

Figure 5. 24 GHz reflection measurement setup and reflection coefficient measurement results for the reference copper plate.
6. N-Field 77 GHz Curb RCS Measurements

6.1. 77 GHz Measurement Setup
The near-field curb RCS pattern measurement setup as shown the top of Figure 7. We measured both horizontal polarization and vertical polarization at different depression angle from 5 degree to 35 degree in 5 degree increments. The new 77 GHz up/down converter specifically designed and fabricated for this paper was used so that it can be used with the 24 GHS SDR without the cumbersome vector network analyzer and DC power supply equipment. This configuration in FMCW mode also has a much faster data collection speed. The radar was mounted on a tripod whose height and distance were carefully adjusted to obtain maximum reflection response for each depression angle and polarization. This can be easily achieved from the real-time time-domain response output of the SDR. The distance between the radar and curb is approximately 3 meters. The RCS value was derived from calibration the curb reflection data against the reflection data of a reference trihedral corner reflector which was carefully placed on the curb so that it faced the antenna to produce the maximum radar response. The corner reflector was place on curb to ensure the same range and beam angle. This is possible since the reflection of reflector is much stronger than the curb. After the corner reflector measurement, the curb reflection data was measured immediately after removing the corner reflection. This procedure was repeated for each different polarization and depression angle.

Figure 7. Measurement setup for 77 GHz radar (Right) horizontal polarization (Left) vertical polarization.

7. Near-Field 24 GHz Curb RCS Pattern Measurements

7.1. 24GHz Measurement Setup
The measurement setup for 24 GHz is similar to the 77 GHz discussed except that 77 GHz up/down converter was not used and 24 GHz horn antennas are used. The measurement and calibration procedure are also the same as the 77 GHz measurements. Figure 8 shows the calibrated RCS of the
curb at 24 GHz as a function of depression angle for both vertical and horizontal polarizations. This RCS level is lower than that observed at 77 GHz as expected. However, the vertical polarization has higher RCS value than horizontal polarization in most angle region, which is opposite to what observed in 77 GHz data. This needs further investigation.

Figure 8. Measurement setup for 24 GHz radar (Right) horizontal polarization (Left) vertical polarization.

Figure 9 shows the calibrated RCS of the curb for horizontal and vertical polarizations as a function of depression angle. In general, the horizontal polarization has a stronger RCS, as expected from the geometry of the curb. Also, lower depression angle has stronger RCS as expect from the vertical face of the curb. It should be noted that although these results may be different from the RCS obtained from a greater distance, it is sufficient to use this method for designing and validating the RCS of surrogate.

Figure 9. 77 GHz RCS pattern measurement result (left) and 24 GHz RCS pattern measurement result (right).

8. Conclusions
This paper summarized the radar scattering properties of common highway roadside objects in 24 GHz and 77 GHz bands. Concrete wall reflection coefficient was measured by 24 GHz with 1 GHz bandwidth software-defined radar (SDR). To study the effect of wet concrete surface on the reflection coefficient, we subsequently spray water on the concrete wall and then collected reflection data at 5 minutes intervals while it was drying. In preparation for fabricating roadside surrogates, we also measured the reflectivity of several conductive fabric in our possession to determine if any of them could be suitable for dressing the roadside surrogates for producing similar reflectivity as the surface
of selected representative roadside objects. We measured both horizontal polarization and vertical polarization at different depression angle from 5 degree to 35 degree in 5 degree increments in 24GHz and 77GHz.

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