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EXTINCTION CROSS SECTION MEASUREMENTS

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ABSTRACT

An experimental method to determine the extinction cross section over a large bandwidth in the microwave region is described. The method is based on a measurement of the complex-valued radar cross section (RCS) amplitude in the forward direction using the optical theorem. It is shown that the extinction cross section can be determined with good accuracy over a large frequency interval down to levels of -30 dBsm using coherent background subtraction and time domain gating.

1. INTRODUCTION

The motivation for this study is to develop an experimental method that can be used to verify a general sum rule for the extinction cross section (*i.e.*, the sum of the scattering cross section and the absorption cross section) introduced in Ref. 1. For an arbitrarily shaped object the sum rule bounds the total amount of electromagnetic scattering and absorption available in the entire frequency domain.

A previous paper describes an experimental method to determine the extinction cross section for thin and planar samples using a monostatic RCS measurement [2], while the method described in this paper is applicable to objects with arbitrary geometry. The experiments described here are performed on spheres with different radii and forward RCS in order to determine the accuracy of the measurement technique by comparing the results with the Mie theory [3].

The direct measurement of the forward RCS is experimentally difficult since the largest part of the field at the receiving antenna consists of a direct illumination by the transmitting antenna. This direct contribution to the total field has to be subtracted in order to obtain the forward RCS.

Measurements of bistatic and forward RCS are less common compared to monostatic measurements since a large majority of radar applications are monostatic *i.e.*, the transmitting and receiving antennas are co-located. Bistatic systems are used for some applications but are more complicated than monostatic systems due to the requirement in those systems to synchronize the received signal with the transmitted signal [4]. This becomes especially difficult if either one or both of the transmitter and the receiver are in

motion. There are some applications where improved functionality due to the bistatic setup provides an offset to the increased system complexity, *e.g.*, counter stealth. Systems that utilize the scattering in the forward direction (scattering at 180° bistatic angle) have some special applications such as radar fences [4] or ground target identification [5].

Most free space indoor or outdoor measurement ranges therefore have a monostatic setup. As a consequence, there are relatively few published studies that treat the free space measurement of forward scattering at microwave frequencies.

A bistatic system where forward scattering can be measured in a laboratory area is described in Ref. 6. It operates in the 2–12.4 GHz range with a measurement accuracy of ± 1 dB at a level of -18 dBsm for the forward RCS. This should be compared to the corresponding results for monostatic RCS where it is possible to measure down to -50 dBsm with the same accuracy.

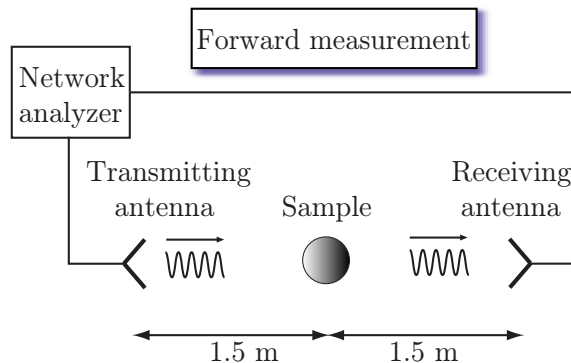


Fig. 1. The experimental setup for the forward RCS measurements.

2. THEORY

Consider the direct scattering problem of a plane electromagnetic wave $\mathbf{E}_0 e^{i2\pi\hat{\mathbf{k}}\cdot\mathbf{r}f/c_0}$ with time dependence $e^{-i2\pi ft}$ impinging in the $\hat{\mathbf{k}}$ -direction on a bounded scatterer surrounded by free space (c_0 is the phase velocity of light in free space). The scattering properties in the $\hat{\mathbf{r}}$ -direction are described for the polarization of the incident wave $\hat{\mathbf{e}}_i = \mathbf{E}_0/|\mathbf{E}_0|$, polarization of the

scattered wave $\hat{\mathbf{e}}_s = \mathbf{E}_s(\mathbf{r})/|\mathbf{E}_s(\mathbf{r})|$, and polarization of the received wave $\hat{\mathbf{e}}_r$. The bistatic RCS amplitude that is recorded in a measurement is then defined as,

$$A(f, \hat{\mathbf{r}}) = \frac{2\sqrt{\pi}}{|\mathbf{E}_0|} \lim_{r \rightarrow \infty} e^{-i2\pi fr/c_0} r \mathbf{E}_s(\mathbf{r}) \cdot \hat{\mathbf{e}}_r, \quad (1)$$

where the complex-valued quantity $A(f, \hat{\mathbf{r}})$ preserves the phase information in the measurement, and $r = |\mathbf{r}|$ denotes the magnitude of the position vector \mathbf{r} . The bistatic RCS is then defined as,

$$\sigma(f, \hat{\mathbf{r}}) = |A(f, \hat{\mathbf{r}})|^2. \quad (2)$$

The scattering cross section σ_s is defined as the total scattered power in all directions divided by the incident power flux. It is obtained by averaging $\sigma(f, \hat{\mathbf{r}})$ over the unit sphere with respect to $\hat{\mathbf{r}}$ [3],

$$\sigma_s(f) = \frac{1}{4\pi} \iint \sigma(f, \hat{\mathbf{r}}) dS. \quad (3)$$

The extinction cross section is defined as the sum of the scattering and absorption cross sections [7],

$$\sigma_{\text{ext}}(f) = \sigma_s(f) + \sigma_a(f), \quad (4)$$

where $\sigma_a(f)$ is a measure of the absorbed power in the scatterer. The extinction cross section can also be determined from the forward RCS via the optical theorem [8],

$$\sigma_{\text{ext}}(f) = \frac{c_0}{\sqrt{\pi}f} \text{Im} A(f, \hat{\mathbf{k}}), \quad (5)$$

where c_0 denotes the phase velocity of light in free space. In this study the optical theorem (5) is used to determine the extinction cross section from a measurement of the complex-valued RCS amplitude in the forward direction.

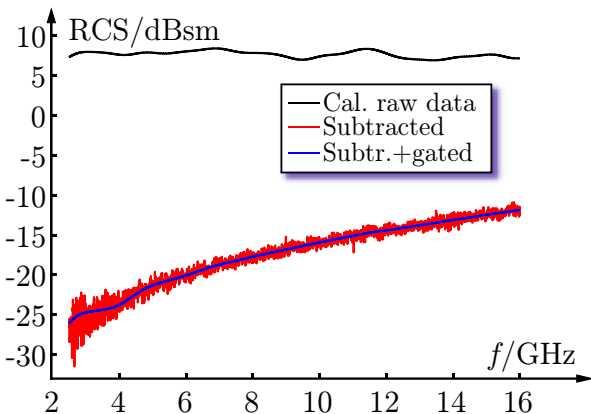


Fig. 2. This figure shows calibrated raw data from a measurement on a 2.00 cm radius sphere. Also shown are the corresponding curves for the data after background subtraction and after background subtraction and time domain gating.

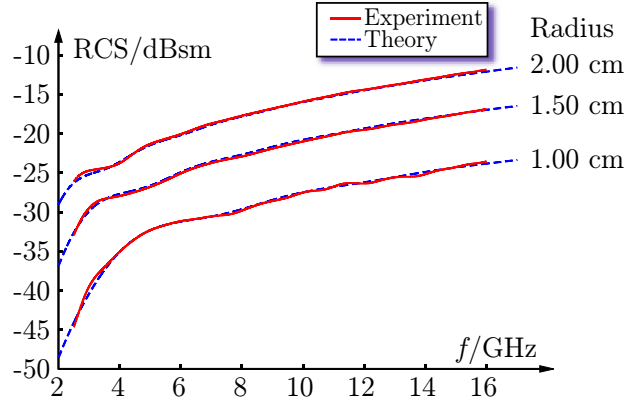


Fig. 3. The experimental and theoretical forward RCS for the 1.00 cm, 1.50 cm, and 2.00 cm radii spheres.

3. EXPERIMENTAL SETUP

Forward RCS measurements are performed in a non-anechoic laboratory area. The sample is mounted on an expanded polystyrene (EPS) sample holder. A pair of ridged horn antennas are positioned facing each other at a distance of 3.0 m with the sample at the midpoint, see Fig. 1. Four frequency sweeps from a HP 8720C Network Analyzer are interlaced to obtain 6404 frequency points in the interval [1, 18] GHz corresponding to an unambiguous time range of 378 ns, sufficient to avoid influence of room reverberations.

The calibration with a 2.50 cm radius metallic sphere is followed by a measurement of the background that is coherently subtracted. The Mie series result for a perfectly electric conducting sphere [3] is divided by the background subtracted calibration to obtain a calibration vector. A sphere is an ideal calibration object for forward scattering since there are no alignment problems for spheres that would arise with other objects [6]. The sample is then measured followed by a background measurement that is coherently subtracted from the sample measurement. We perform the background measurement within less than 2 minutes after each measurement (calibration). The repeated background measurements are performed in order to increase the efficiency of the background subtraction. The background subtracted data is then calibrated with the calibration vector. The calibrated data is finally gated with a 1.7 ns window in the time domain, chosen to minimize the influence of the background. This signal processing reduces the useful frequency interval to [2.5, 16] GHz. The signal processing suppresses the background by approximately 60 dB giving an estimated background level of less than -50 dBsm for the forward RCS.

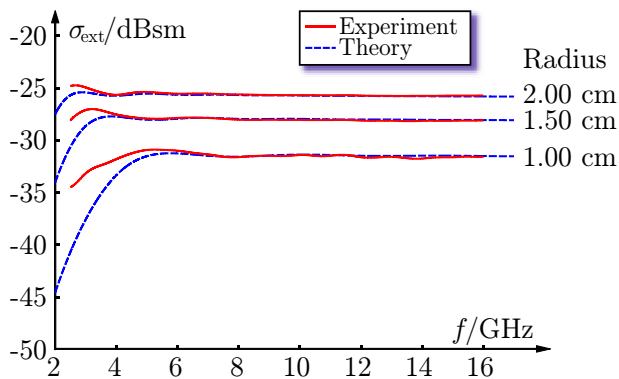


Fig. 4. The experimental and theoretical extinction cross sections calculated from (5).

4. RESULTS AND DISCUSSION

The experiments are performed on high precision steel ball bearing spheres with 1.00 cm, 1.50 cm, and 2.00 cm radii. Small high conductivity spheres are ideal objects for the forward RCS for two reasons. They are, as pointed out above, easy to align and the RCS and the extinction cross section are straightforward to calculate using the Mie series [3].

Fig. 2 shows data for the forward RCS with different steps in the signal processing for the 2.00 cm radius sphere. The figure shows that subtraction is necessary in order to obtain useful data for the forward RCS. The remaining noise in the subtracted data is most severe for the low frequencies. This is probably due to the large beam width of the horn antennas at these frequencies. The large beam width causes a large area of illumination. The figure also shows that time domain gating is effective to further reduce the noise caused by the remaining background.

In Fig. 3 the measured forward RCS from the spheres are compared with the Mie theory. The measured results differ less than 1 dB from the theory over the entire frequency range. This is consistent with a background level, after coherent subtraction and time domain gating, of less than -50 dBsm. An error in the calibration vector caused by the remaining background would explain the high measured RCS values in the low frequency region.

The extinction cross section calculated from the forward RCS amplitude using (5) is also more sensitive to the background in the low frequency part of the range due to the additional division by f . The difference between experiment and theory is less than 1 dB for the 2.00 cm radius sphere at an extinction cross section level of -25 dBsm. The extinction cross section is only -41 dBsm for the 1.00 cm radius sphere for 2.5 GHz and here the largest difference, 7 dB, between experiment and theory is observed.

Note that the extinction cross sections for the spheres have the expected high frequency behavior

for highly conducting spheres. This corresponds to levels of two times the geometrical cross section areas [7]. This means extinction cross section levels of -32.0 dBsm, -28.5 dBsm, and -26.0 dBsm for the 1.00 cm, 1.50 cm, and 2.00 cm spheres, respectively.

5. CONCLUSIONS

The results in this paper show that the extinction cross section can be determined with good accuracy down to levels of -30 dBsm from forward RCS measurements using coherent background subtraction and time domain gating. The method of using forward scattering to determine the extinction cross section is currently being used to verify new theoretical results that bound the total scattering and absorption from general objects. This work will be reported in forthcoming papers.

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