



SURFACE VEHICLE RECOMMENDED PRACTICE

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Test Target Correlation - Radar Characteristics

RATIONALE

Surrogate targets are used throughout the automotive industry to safely and repeatably test active safety systems as well as other vehicle systems. For the test results to be representative of real-world scenarios, the surrogate targets must be representative of the real-world objects that they represent. Existing methods for comparing radar characteristics of objects typically require substantial equipment, time, and facilities. At this point, there is no widely accepted method to verify that a surrogate target has the same characteristics as a real-world object that allows for the use of automotive-grade equipment. Additionally, there is no widely accepted method to verify that the characteristics of a target, which has been in use, are unchanged. This document will provide these procedures.

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1. SCOPE

This document will provide methodologies and procedures to validate active safety test targets and correlate them to the objects they are intended to represent. This process will be separated into three procedures. The correlation procedure will document a means of measuring representative object characteristics and how to calculate a correlation score for a test target using that objective characteristic measurement. The validation procedure will be utilized to determine the correlation score for the test target. A confirmation procedure will identify unacceptable characteristic deviations of the targets during use in the field. Test targets may include cars, pedestrians, motorcycles, bicycles, or any other object that may be encountered by a vehicle. This document relates only to the radar characteristics of these test targets.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of the document to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J3088 Active Safety System Sensors

2.1.2 Other Publications

1. Knott, E.F., "Radar Cross Section Measurements." SciTech Publishing Inc. 2006.
2. Electronic Warfare and Radar Systems Engineering Handbook, NAWCWPNS TP 8347, Rev 2, NAVAL AIR SYSTEMS COMMAND, Washington, D.C. 20361 and NAVAL AIR WARFARE CENTER, Point Mugu, CA 93042, April 1999.
3. Balanis, C.A., "Antenna Theory: Analysis and Design." Third edition. Chapter 2, page 34. 2005.
4. Swerling, "Probability of Detection for Fluctuating Targets." Rand Research Memorandum RM-1217, March 17, 1954.
5. Massey, F.J., "The Kolmogorov-Smirnov Test for Goodness of Fit." Journal of the American Statistical Association. Vol. 46, No. 253, 1951, pp. 68-78.

3. DEFINITIONS

Definition terms are presented in order of appearance in the document.

3.1 TEST TARGET OR SURROGATE TARGET

A device intended to represent a set of radar characteristics of a population of representative objects that may be encountered by a vehicle during its operation and designed to be repeatably used in a controlled environment for determining the performance of vehicle active safety systems.

NOTE: Types of objects that may be encountered by a vehicle include, but are not limited to, cars, pedestrians, motorcycles, bicycles, and animals.

3.2 REPRESENTATIVE OBJECT (RO)

Specific example of a type of object that may be encountered by a vehicle during its operation.

Examples: A specific make and model of a car is one of several representative objects that will be used to represent cars in general. A moose is one of several representative objects that will be used to represent large animals in general.

3.3 RADAR CROSS-SECTION (RCS)

“The radar cross section of an object exposed to a radar is a fictitious area that describes the intensity of the wave reflected back to the radar.” (Ref. 1)

3.4 FIXED-AZIMUTH MEASUREMENT

A measurement of an object, such as a target or RO, using a constant radar height, where the azimuth angle of the target stays the same throughout the measurement, but the distance between the radar and the center of the object changes over some span of distances.

3.5 FIXED-RANGE MEASUREMENT

A measurement of an object, such as a test target or RO, using a constant radar height, where the distance between the radar and the center of the object stays the same throughout the measurement, but the azimuth angle changes over some span of angles.

3.6 CALIBRATION OBJECT (CO)

An object fabricated from a radar-reflective material whose theoretical RCS can be calculated based on the physical properties of the object (e.g., size, shape) and which is used as a means to confirm the accuracy of a radar.

4. PROCEDURE OVERVIEW

This document provides a framework for validating the radar characteristics of a test target for use in automotive testing. The framework can be used by a target developer to validate the target and by the target user to check the target. This approach uses a correlation score as an objective measure of how well a target matches the population which it is designed to represent. All of the procedures require the use of a calibrated radar (described in [5.2](#)) and a set of radar measures (described in [5.3](#)).

The correlation procedure (Section [6](#)) describes the process whereby the target validity regions are defined and the population of ROs are selected. It also describes the correlation score calculation.

The validation procedure (Section [7](#)) describes the procedure to validate a candidate target against the measurements of the ROs. The procedure applies an objective statistical comparison of the target radar data to the radar data from the ROs.

The confirmation procedure (Section [8](#)) describes the process for checking a new or in-use target to ensure it is valid for testing.

The details of each procedure are provided in this document and the general process is depicted in the following flow charts.

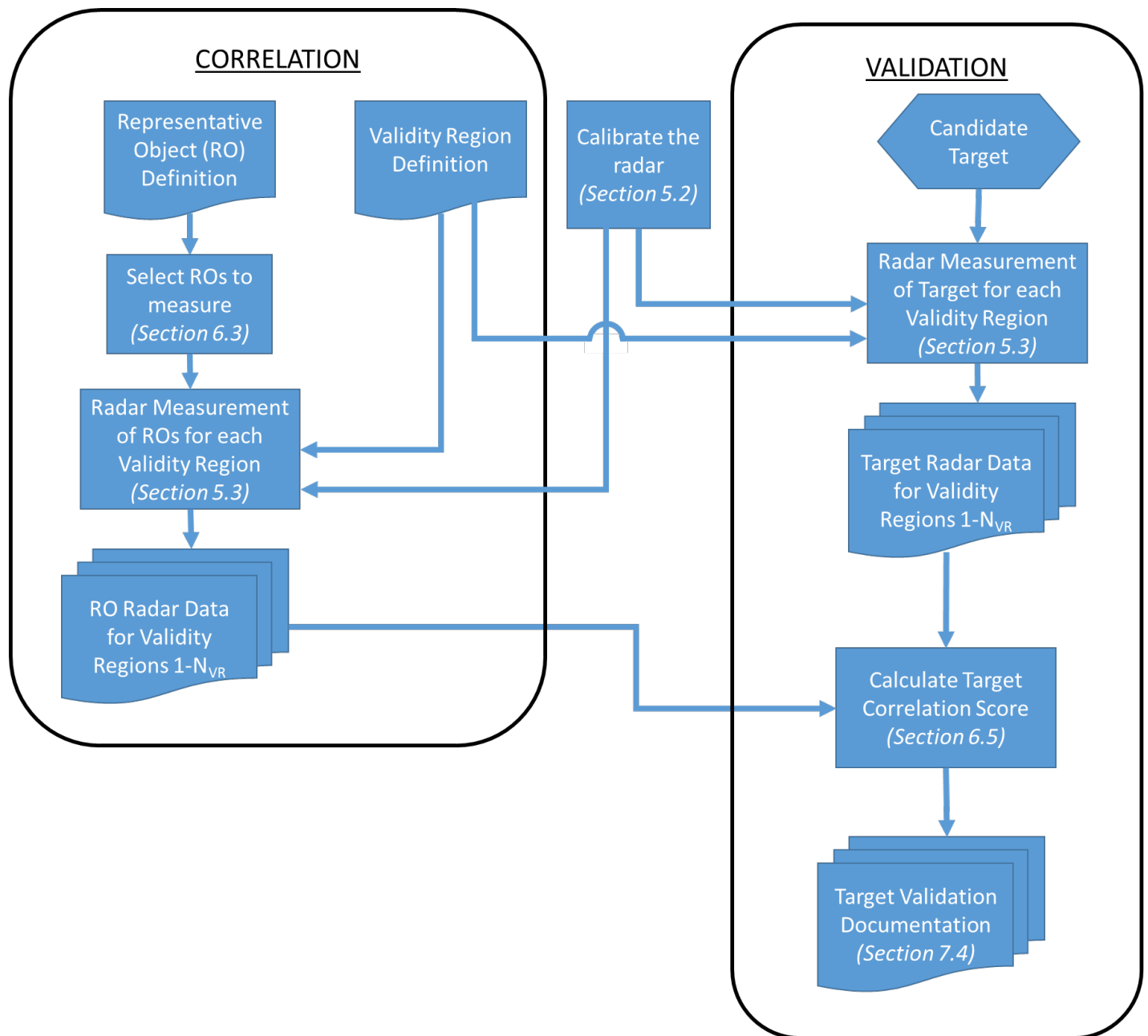


Figure 1 - Correlation and validation procedure flow chart

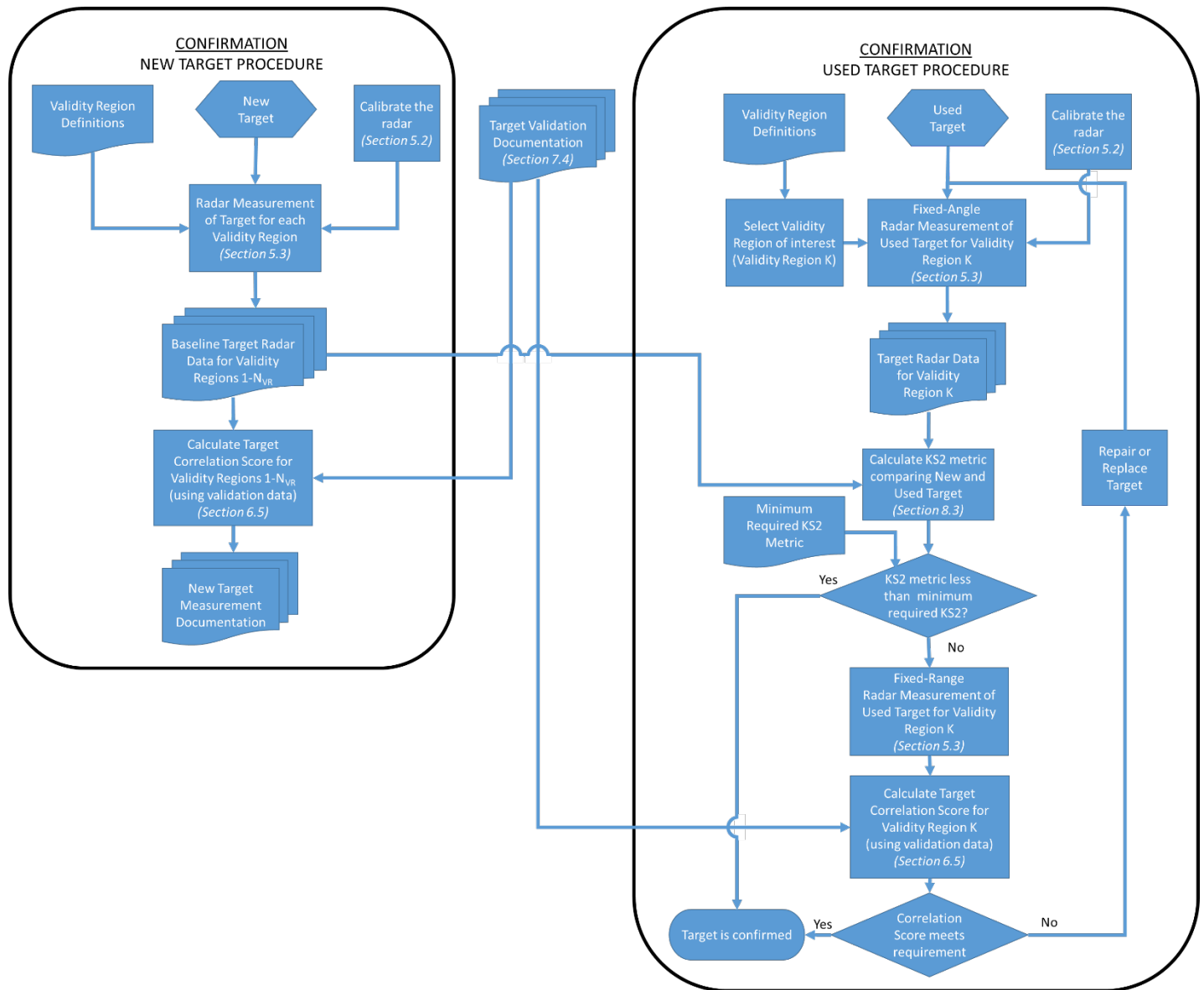


Figure 2 - Confirmation procedure flow chart

5. RADAR CALIBRATION AND TARGET MEASUREMENTS

When the term “radar” is used in this document, it is referring to a device that both transmits and receives radar signal transmissions.

The principal feature of an object to which a radar system responds is its effective radar cross section (note: the term “effective RCS” is used to consider measurements that do not meet all the criteria to measure the far-field RCS of a target). The measurement is dependent on:

- Intrinsic radar parameters: wavelength and polarization.
- Extrinsic radar parameters: aspect angle, distance from target, and beamwidth.
- Ground effects and/or other environmental effects.

If these factors are held reasonably constant, then the measured effective RCS of many targets may be compared. The RCS of an extended object may vary widely with small changes in aspect, so a meaningful comparison needs to consider a window that admits a statistical sampling and mitigates small errors in target positioning or radar alignment. The angular beamwidth of the specular reflection from the broadside represents the largest statistical variation of a vehicle's RCS and is seen to be on the order of a degree. Therefore, reasonable target preparation procedures should allow for accuracy near 1 degree. Thus, a window of 10 degrees in aspect angle should serve to achieve a sufficient statistical sample and mitigate variation in target preparation.

5.1 Applicable Radar and Data Output

The measurement equipment includes a radar and other equipment necessary for position measurements. The sensors applicable for target measurement include any instrument suitable for measuring the RCS of an object in the frequency bands used in automotive radar applications as indicated in SAE J3088. The output data of the measurement equipment should include:

- a. The orientation of the object relative to the radar in the horizontal plane (i.e., the azimuth angle).
- b. The distance between the radar and the object.
- c. The reflected wave energy as a function of time or frequency.
- d. The relative position (longitudinal and lateral) of the scattering centers with respect to the radar.

The radar should be calibrated by the radar manufacturer such that the radar response should be stable over the measurement time and be (nearly) linear over the dynamic range of outputs induced during RCS measurements. The radar boresight should be known to allow for proper alignment.

5.1.1 Radar Parameters

The radar parameters that should be documented are those that will impact measurements of the RCS of an object. Specifically, it includes:

- Antenna vertical and horizontal half-power beamwidth.
- Antenna polarization.
- Radar frequency.

5.1.2 Radar Output Definition

The output of a radar receiver is the signal amplitude reflected from the object being measured. This data is typically output either in terms of power or RCS with units of m² or dB-sm. RCS outputs in dB-sm should be converted to m² for mathematical computations using the equation:

$$\text{RCS(m}^2\text{)} = 10^{(\text{RCS(dB-sm)}/10)}$$

For visualization and discussion purposes, the RCS power in m² can be converted back to dB-sm using the equation:

$$\text{RCS(dB-sm)} = 10 \times \log_{10}(\text{RCS(m}^2\text{)})$$

5.2 RCS Calibration

There are two types of calibration required for RCS measurements.

- Internal calibration, which is accomplished by the radar manufacturer prior to shipment, requires the radar response should be stable over the measurement time and be (nearly) linear over the dynamic range of the voltages induced during RCS measurements.
- External calibration, which is described in Section 5, converts the output signal amplitude into RCS and requires that the environment of the measurement must be characterized. Typically, this is performed using a calibration object (CO) with known RCS (substitution method).

The external calibration procedure specified in this document will provide a means to account for variability in the equipment and environment, as well as the effect of ground reflections. This will be accomplished by performing a measurement of an object with a known RCS over a range of distances. Known formulas for radar power as a function of distance are then used to calculate a calibration factor that provides a best fit of the ideal response to the real-world measured data.

A radar transmits electromagnetic waves into the direction of a target and then records received electromagnetic waves reflected back to the radar by the target. This received electromagnetic power can be predicted via the well-known radar equation:

$$P_r = \frac{P_t G_t}{4\pi r^2} \sigma \frac{1}{4\pi r^2} A_{\text{eff}} \quad (\text{Ref. 1}) \quad (\text{Eq. 1})$$

where:

P_t = power transmitted by the radar (watts)

G_t = gain of the radar transmit antenna (dimensionless)

r = distance from the radar to the target (meters)

σ = radar cross-section of the target (meters squared)

A_{eff} = effective area of the radar receiving antenna (meters squared)

P_r = power received back from the target by the radar (watts)

The equation can be simplified to:

$$P_r = \frac{K}{r^4} \sigma \quad (\text{Eq. 2})$$

where K a combined term that includes P_t , G_t , A_{eff} , and the numeric constants. The equation can be represented in terms of decibel power as below, where the unknown combined term, K , and the σ term have been further combined into the constant, c .

$$P_r(\text{dB}) = -40 \log_{10}(r) + 10 \log_{10}(K\sigma) = -40 \log_{10}(r) + c \quad (\text{Eq. 3})$$

5.2.1 Calibration Object with Known RCS

Example calibration objects include metallic spheres, cylinders, top-hat (cylinder on metal-plate), dihedrals, and trihedral reflectors. The most commonly used calibration objects are spheres and trihedrals due to their insensitivity to orientation. The user should select a calibration object with an RCS value within the range of the expected RCS for the object. It is optional but recommended that a second calibration object be used, one whose RCS is also within the range of the expected object RCS, but is not similar to the RCS of the first calibration object. For field collections, low-scattering mounts or mounts masked by radar absorbers should support calibration targets from the rear (relative to the radar) or from below. The descriptions in [Table 1](#) can help identify a suitable mixture of calibration targets for a radar.

Table 1 - Some common radar calibration target shapes, along with descriptions of utility and set-up requirements

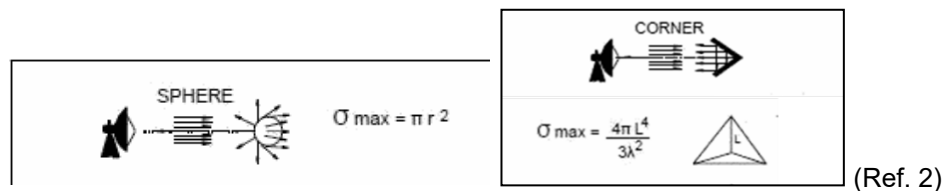
Shape	RCS (m ²)	Polarization	Ease of Orientation	Notes
Sphere	πr^2	Co-pol	Always oriented correctly	Good lower RCS reference
Trihedral	$\frac{4\pi L^4}{3\lambda^2}$	Co-pol	Not sensitive to small pointing errors	Good upper RCS reference

where:

r = radius

L = trihedral baseline

λ = radar wavelength



5.2.2 RCS Calibration Procedure

This section discusses the RCS calibration procedure for determining the RCS values of an object. Note that the calibrated RCS value is a property of the object alone, independent of the radar types (pulsed, continuous wave (CW), pulsed CW, frequency-modulated continuous wave (FMCW), etc.), antenna response, and waveforms.

During radar measurements, the absolute transmitted power, antenna gain, and target distance are not usually known. Therefore, the RCS of a target is usually determined via the substitution method where the measured reflected power from the target, $P_{r,target}$, is compared to the measured reflected power from the CO, $P_{r,CO}$, under the same measurement conditions (distance, height, and radar parameters).

Note that if the object-to-radar distance is greater than the Fraunhofer distance (Ref. 3) and the target is fully illuminated by the radar beam, the RCS value should be independent of distance. If the object-to-radar distance is much less than the Fraunhofer distance, if the target is not fully illuminated by the radar beam, or if there are environmental effects, the RCS value may vary substantially with distance, radar height, and the target's position and orientation. This latter situation is typical of automotive applications.

Step 1: Measure the radar response of a primary calibration object (CO#1) whose theoretical RCS is known, with a maximum cross dimension D by moving the radar towards the object from a distance ranging from R_1 to R_0 . The effect of supporting structure should be minimized or removed. The distance R_0 should satisfy $R_0 > 2D^2/\lambda$. The distance R_1 should be similar to the maximum distance where an automotive radar would be able to detect the object. The radar output should be converted to return power in decibel, P_r (dB).

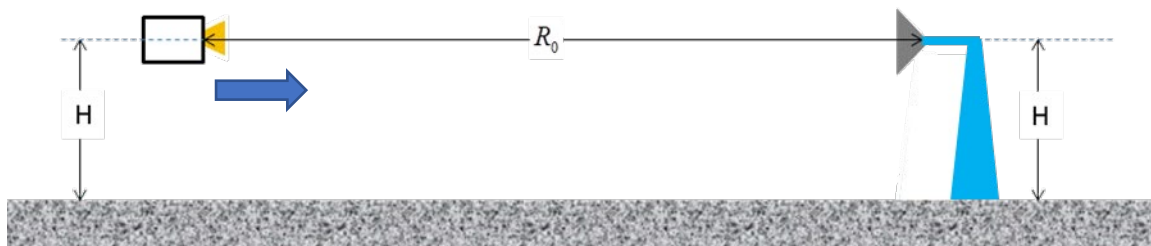


Figure 3 - Measure the radar response of the primary calibration target (CO#1)

Step 2: Apply a moving-average to the return power as a function of range to reduce the effect of multi-path reflections.