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TECH BRIEFS

Application Briefs

Measuring Radar Cross Section with Handheld VNAs

Radar cross section (RCS) is the measure of an object's ability to reflect radar signals in the direction of the radar receiver, i.e. it is the measure of the ratio of backscatter per steradian (unit solid angle) in the direction of the target radar to the power density intercepted by the target. RCS measurements help ensure the design of commercial and military aircraft and radar systems, as well as to maintain their performance once they are deployed.

Accuracy in measuring RCS can have a direct result on safety and successful aviation operations. In military, stealth technology is used to reduce RCS and make it difficult to detect aircraft. For commercial planes, a large RCS is necessary, so air traffic radar systems can easily locate aircraft and help guide them during take-offs and landings. For reference, tactical jets typically have RCS ranging from 5 to 100 m^2, whereas bomber jets usually have an RCS from 10 to 1000 m^2. By contrast, stealth aircraft exhibit RCS under 0.1 m^2, with some advanced designs under 0.0002 m^2.

Vector Network Analyzers (VNAs) have become the instrument of choice when measuring RCS because of their speed and accuracy in making S-parameter measurements. Advances in handheld VNAs have allowed them to deliver the necessary performance, as well as features such as time domain gating, to simplify RCS testing on the flight line or in the field.

Radar Range Equation

The radar system in Figure 1 transmits a pulse of energy through the transmit antenna of gain (Gt). Signal

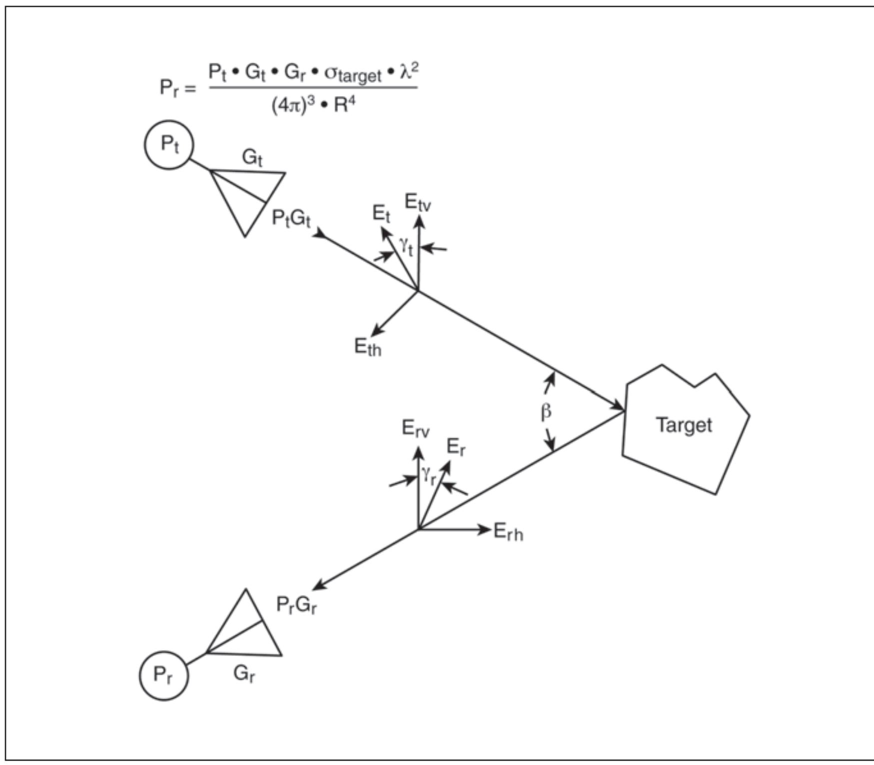

Figure 1. Radar range equation diagram.

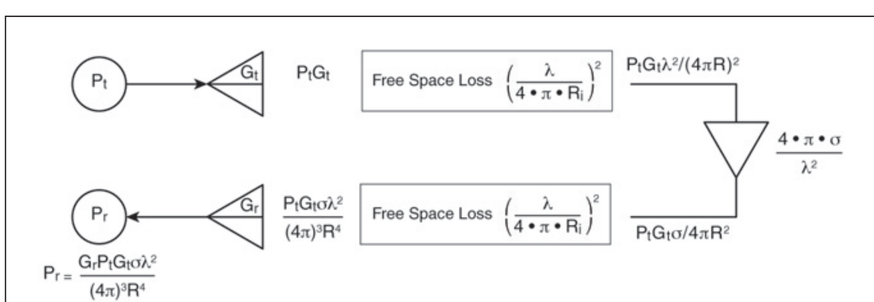

Figure 2. Simple block diagram describing the physical representation of a radar.

amplitude at the output of the transmit antenna is reduced by the free space propagation loss. At the target, some of the power (backscatter) is reflected back towards the radar. The ratio of the backscatter power to the incident power is the RCS (σtgt) of the target. Amplitude is further reduced by the free-space propagation loss. Then, the signal is received by the receive antenna with gain (Gr) and detected in the receiver.

A block diagram describing the physical representation of a radar is shown in Figure 2. The equivalent circuit description of the radar is shown in Figure 3. The transmit and receive antenna gains are represented by amplifiers, as is the RCS of the target.

Resistors are used to represent propagation losses. A VNA system, when used to measure S_{21}, has the same equivalent circuit description as the radar. It measures the frequency domain response S_{21} of the system when Port 1 of the VNA is connected to the transmit antenna and Port 2 is connected to the receive antenna.

Although VNAs are most commonly used to provide measurements vs. frequency, the addition of Time Domain Analysis and Time Gating help simulate pulsed radar functionality by removing reflection distances not associated with the target. The 12-term error correction of the VNA will minimize the systematic errors due to mismatch and leakage, and accurately establish a reference plane.

Polarization

The polarization of the electric field vector of the reflected signal can be different than that of the transmitted radar signal. The shape of the target is responsible for the depolarizing characteristics.

To correct for depolarization, full polarization matrix imaging is utilized by measuring both the vertical and horizontal components of the electric field independently. This will require two transmit and two receive polarizations. From the measurements, a polarization matrix is generated

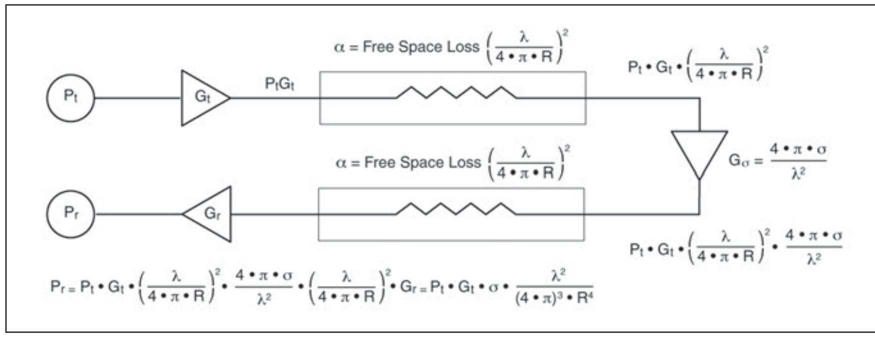

Figure 3. Circuit diagram of the radar depicted in Figure 2.

to describe the effect of the polarization to correct for the depolarization.

VNA Measurements

The VNA shown in Figure 4 measures the S-parameters in the frequency domain. The frequency range for the measurements corresponds to the radar frequency band (8.2-12.4 GHz for WR-90 X-band waveguide). The time domain function of the VNA will transform the S-parameter frequency domain measurement to the time domain.

A property of the transform process is the Alias Free Range (AFR). The transform is a circular function and repeats itself periodically outside of its inherent time range, that is t = 1/(Frequency Step Size). The frequency step size is proportional to the frequency span and inversely proportional to the number of data points.

For example, at X-band using a 4.0 GHz frequency span and 4,001 data points, the AFR is 4000/4.0 GHz = 1000 nanoseconds corresponding to a 300 meter alias free range. The 300 meter range is the round trip time, thus the target should not be placed more than 150 meters from the VNA.

A typical aircraft RCS measurement configuration using a VNA is shown in Figure 5. The transmit antenna (connected to Port 1 of the VNA) and receive antenna (connected to Port 2 of the VNA) are positioned in the same plane. The measurement target consists of the aircraft, either mounted on a low-reflection pedestal or situated on a flight line.

The operation of a $S_{21(f)}$ measurement for the VNA is shown to be the equivalent to radar when configured as shown. The coaxial cable output of Port 1 is connected to the coax to rectangular waveguide transition. The output of Port 2 is connected to the output of the receive waveguide antenna.

Both antennas are located as close as possible, in either the vertical or horizontal plane. To develop the polarization matrix, both transmit and receive antenna should be capable of 90° rotation. The target should be located at a distance less than AFR/2 but far enough from the antenna to insure that the entire target is within the beam of the antennas.

RCS Measurement

A full 12-term calibration is performed at the output

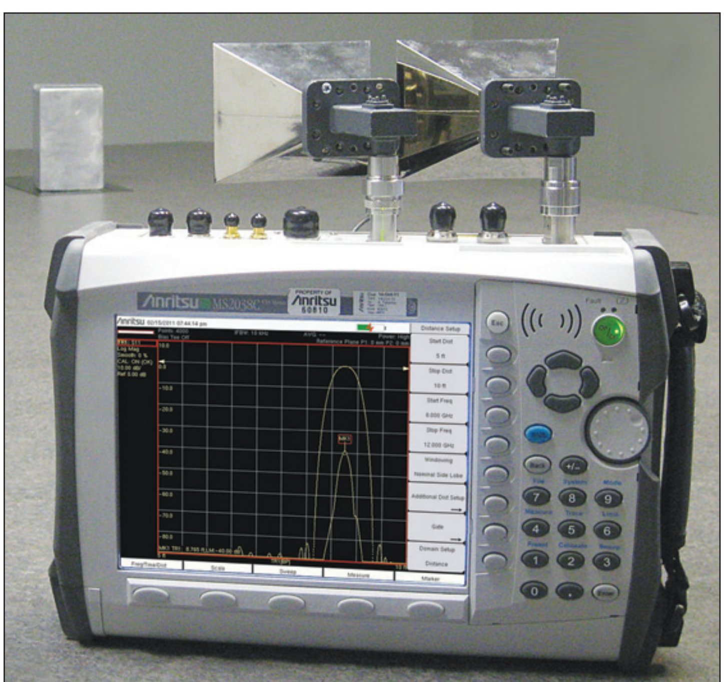

Figure 4. Vector Network Analyzer

of the coaxial cables to establish the reference plane for the RCS measurements. The $S_{21(f)}$ frequency domain measurement is performed on the target area. The S-parameter data $S_{21(f)}$ is transformed to the distance domain mode $S_{21(d)}$ using band-pass processing. The system can be calibrated in RCS by measuring a target of known RCS and referencing all other targets to the known target.

An $S_{21(f)}$ frequency domain measurement is performed on the standard to be measured. The S-parameter data is transformed to the time domain mode and an appropriate time gate is placed at the standard's location. The magnitude of the $S_{21(std)}$ amplitude of the standard reflection is measured.

This measured value is the reference for the RCS measurement. If the standard were a sphere having a RCS of 1 m^2, then the RCS of the target is given by:

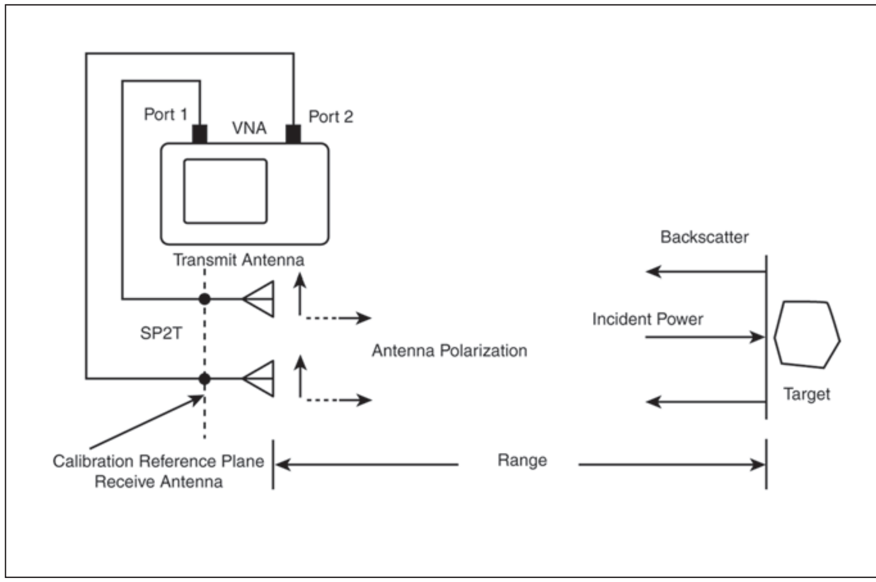

Figure 5. A typical aircraft RCS measurement configuration using a VNA.

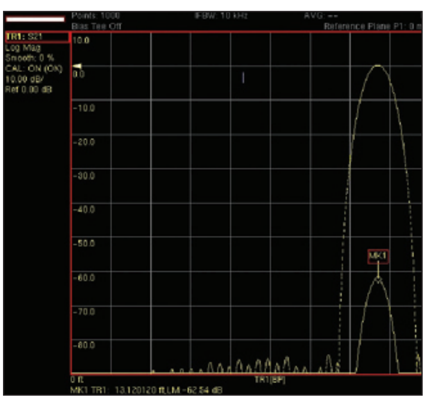

Figure 6. VNA calibration.

$$RCS_{tgt}\ (dBsm) = RCS_{std}\ (dB) - RCS_{tgt}\ (dB)$$

The data is expressed in dBsm. RCS in square meters can be converted to dBsm by:

$$dBsm = 10Log(RCSm^2)\ (dB)$$

The target in this case is a known calibration standard which is positioned in the target area. The calibration standard reflection is identified and a range gate is placed on the calibration standard to remove all other reflections, as shown in Figure 6. The amplitude $S_{21(tstd)}$ of the calibration standard reflection is measured. The S_{21} measurement in dB corresponds to the known RCS (in meters^2).

Conclusion

RCS measurements are an important part of detecting commercial and military aircraft. Handheld VNAs now have the performance and necessary test features to simplify conducting RCS measurements on the flight line and in the field.

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