Characterizing RADAR Interference Immunity

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Introduction:

Due to increased domestic air travel and threats to National security it is important that our Aviation RADAR systems function properly. The current airwaves are filled with many natural and artificial sources of interference. The natural background noise in RADAR bands is fairly constant, but there has been an increase in wireless communications traffic causing unintentional interference that may overflow into these bands besides the risk from intentional interference. These factors make it important to characterize your RADAR system and clearly understand all of the limitations. This article will demonstrate a simple test strategy to characterize Aviation RADAR system performance.

Radar Signal Discussion:

The Primary Surveillance RADAR used for aviation is a pulse-modulated sinusoidal carrier signal. The output of this type of RADAR has short pulse bursts with fast rise time power envelopes to resolve distant targets with adequate resolution (see Fig.1)

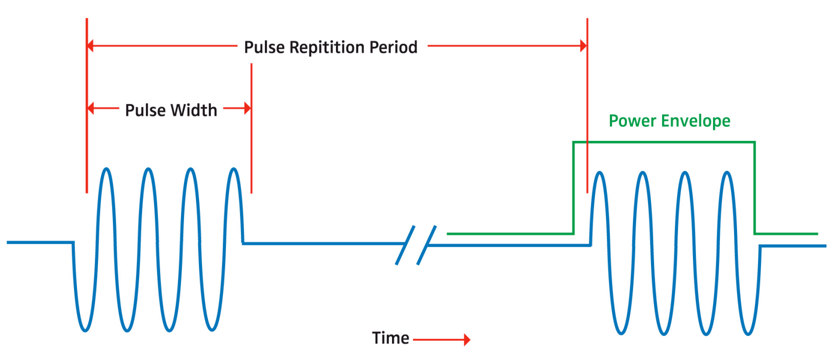


Fig.1

The short duration pulses allow detailed “target” resolution, while long pauses between each pulse provide enough time for distant signals to return without interfering with the next pulse. These high power pulsed signals may have rise times under 10 ns with pulse widths in the microsecond and sub-microsecond ranges.

These low duty cycle signals, often << 1% create a large peak-to-average ratio, or crest factor. This makes accurate power measurements with traditional, thermal detectors difficult, and requires a wide dynamic range peak power sensor to measure the power of the transmitted pulse. (see Fig.2).

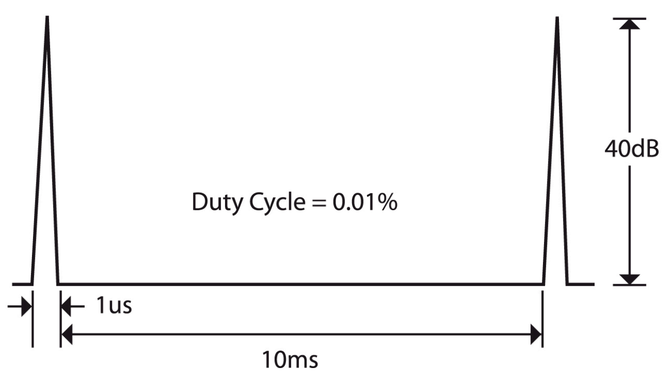


Fig.2

These types of RADAR signals require a large system signal-to-noise ratio (SNR) to locate and define the target properly.

For this reason the receiver portion of a RADAR system must be resistant to natural background RF radiation, un-intentional wireless communication signal interference and intentional signal interference, or “jamming” signals. This article will illustrate the value of using an advanced peak power meter in conjunction with a computer controlled noise generator to test RADAR receiver and transmitter system performance by varying SNR.

The importance of calculating SNR:

Figure 3 is a typical return signal from a pulsed radar system that includes the target signature, random noise, and deterministic false alarms. A specific threshold must be determined to discriminate between the real target and the noise. The minimum power value that can be sensed or Smin is equivalent to the minimum detectable signal, or MDS of the RADAR receiver. The MDS must be calculated in order to determine the maximum detection range, or MDR of the system. Point 1 is a false positive, where the noise is above the test threshold and point 2 is an undetected target return below the threshold. Some of the issues below can be resolved with the latest DSP circuitry by averaging out the common mode noise and correlating deterministic events that rise above the MDS. This capability must be tested to prove the system is functioning properly.

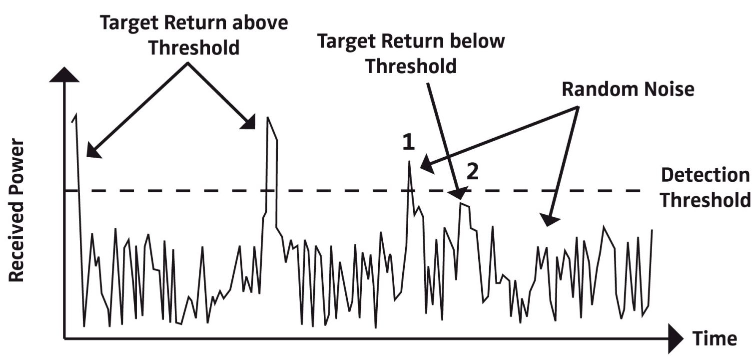


Fig.3

$$P_r = S_{min} = \frac{P_t G_t G_r \sigma \lambda^2}{(4\pi)^3 R^4} \Rightarrow R_{max} = \left(\frac{P_t G_t G_r \sigma \lambda^2}{(4\pi)^3 S_{min}} \right)^{1/4}$$

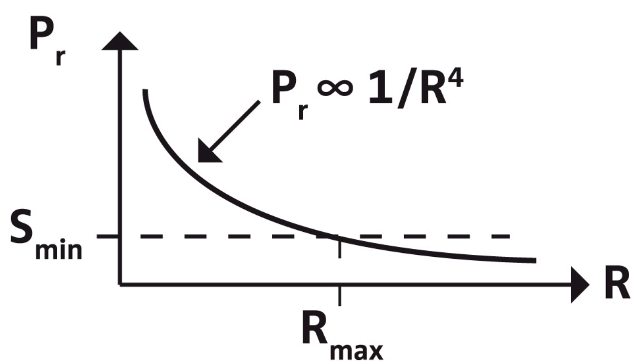
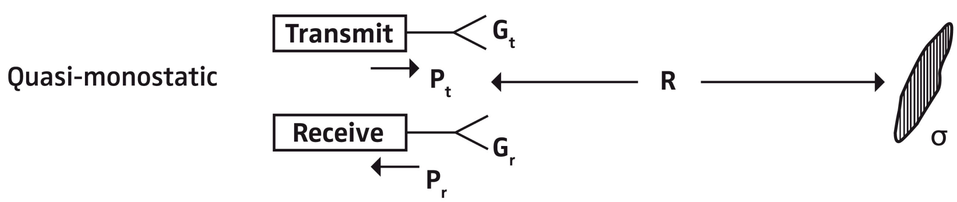


Fig.4

SNR Calculation:

MDS, MDR, and the receiver noise floor are all dependent upon one another. When calculating the received power, Pr, the maximum transmit power Pt, antenna gains, minimum radar cross section, and effective aperture of the antenna must be known in order to solve the equation. Each parameter value will be a function of available investment capital, current technology, and FAA regulatory guidelines for each RADAR system project.

The received power (Pr) calculation is illustrated in figure 5, but an accurate transmit power must be known to solve for the variable. The value for Pt can be calculated by subtracting the antenna return loss from the transmitter output power in dB. The return loss can be measured using a peak power meter shown in the test diagram in Fig. 6 and explained in the test procedure section.



P_t = transmit power (W)
P_r = received power (W)
G_t = transmit antenna gain
G_r = receive antenna gain
σ = radar cross section (RCS, m^2)
A_{ER} = effective aperature area of receive antenna

$$P_r = \frac{P_t G_t \sigma A_{ER}}{(4\pi R^2)^2} = \frac{P_t G_t G_r \sigma \lambda^2}{(4\pi)^3 R^4}$$

This example Pr calculation is for a Quasi-monostatic system, but our monostatic example has the same transmit and receive antenna gain value.

Fig.5

We need to find a reasonable value for the noise density, No in order to calculate the system SNR. The total system noise will be a combination of natural background RF and electronic system noise. The formula to calculate thermal noise power is (Np = kTB), where the noise power Np is equal to (Boltzmann’s constant, k) x (temperature in Kelvin) x (bandwidth B). The standard temperature for an external antenna is 62° F, or 290°K. The noise power in a 1Hz BW is equal to 4.004e -21 W/Hz. This value normalized to 1mW in a 50Ω system displayed in a logarithmic scale is the familiar -174 dBm/Hz. In the case or RADAR, the noise density is commonly normalized to Bn, or 1/ τ (envelope pulse width). This noise density value, No, must be added to the electronic noise of the RADAR test system and includes the receiver Noise Figure and all RF path components in terms of temperature °K. The calculation for amplifier noise figure can be found in most microwave text books, but is omitted for this article.

The formula below to calculate system SNR uses the values of received power (Pr) and noise density (No) previously calculated.

$$SNR = \frac{P_r}{N_o} = \frac{P_t G_t G_r \sigma \lambda^2 G_P L}{(4\pi)^3 R^4 k_B T_S B_n}$$

Factors have been added for processing gain Gp and loss L

Most radars are designed so that Bn ≈ 1/τ (envelope pulse width)

No = Ts= thermal noise + electronic noise density normalized to Bn

Test procedure:

Initial testing with simulation software or a proto-type will determine the type of DUT's used for testing. Below is a simplified block diagram of a typical RADAR system including transmitter, receiver, and antenna structures. This example is a full scale system using real aircraft. The monostatic system used for this example is only one of many possible RADAR systems. In a monostatic system the transmit and receive antennas are co-located (ie.the same antenna is used for both transmit and receive), but either bistatic, or quasi-monostatic sytems can be tested in a similar manner.

Example System Block Diagram:

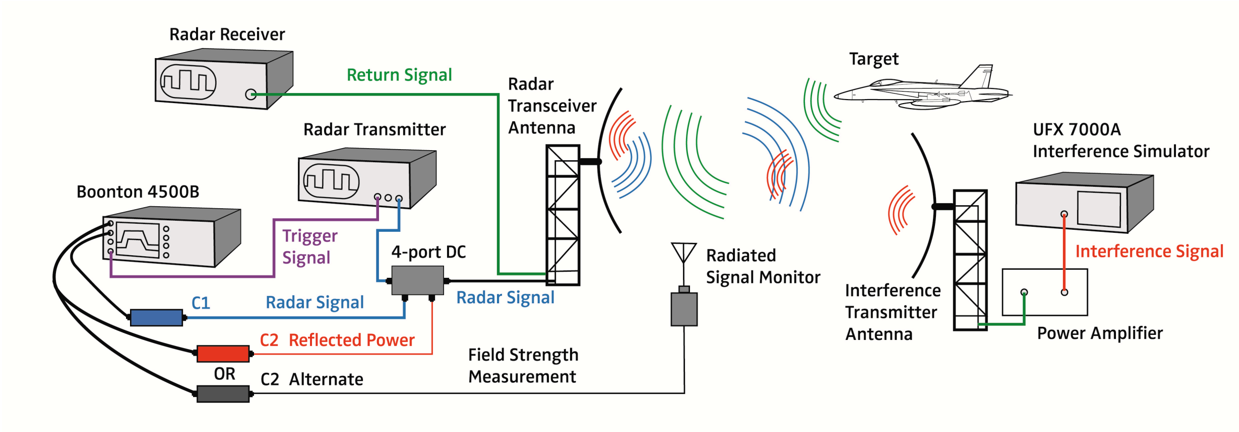


Fig.6

The Radar output signal (blue) is transmitted towards the target aircraft, and the return signal (green) is switched through to the radar receiver under normal working conditions. The peak power meter can monitor the effective radiated power of the antenna system via the field strength measurement, or the system mismatch using the ratio of forward to reflected power. The C2 alternate path is used to measure the signal field strength via a calibrated antenna or the forward power (C1 blue) is compared to the reflected power (C2 pink) to measure the actual power delivered to the antenna. The ratio of forward to reflected power, or return loss in dB is an important figure of merit for the system because actual transmit power (Pt) has a major influence on the maximum distance of the RADAR system. The Radar transmitter has an output trigger pulse (purple) that can be used as an external trigger input for the power meter to synchronize system measurements in addition to using the main power measurement channels. The receiver can be used in a similar manner as an external trigger input via the second trigger channel. The power meter can trigger on a single pulse, or a complex sequence of events using the transmitter, or the receiver external inputs similar to a digital oscilloscope.

The receiver system is disturbed by the interference simulator signal (red) to emulate either un-intentional wireless interference, or intended interference, “jamming”. This interference simulator provides versatile, repeatable interference for complex system testing. The Noisecom UFX7000A noise generator can be configured as an interference simulator with multiple AWGN sources, CW sources, and filtered signal paths to emulate real world interference and jamming. A 0.1 dB minimum attenuation step size over a total of 80 dB of attenuation allows accurate, repeatable disturbance control for precise SNR system testing.

Conclusion:

A Boonton Peak Power Meter and a Noisecom UFX7000A series RADAR interference generator pair is one example of an advanced solution for testing these RADAR systems. The combined transmitter and receiver pair can test system performance by providing complex random and deterministic repeatable interference in addition to accurate peak & average power measurements.