Search Mode Operations

Developing a realistic radar model

Over the past several months, we have been developing a realistic radar-model of search mode operations. This paper describes the features and how they are accounted for in our model. The focus of the paper is the target detection process, its probability-based nature, and the reasons for that randomness. We will also briefly discuss detection performance of our AN/APG-73 and AN/APG-68(V)5 radar models and related features.

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1. Fluctuation of Target Radar Cross Section (RCS).

Real targets have complex shapes, and their linear sizes are often larger than radar wavelength. This means that radar returns from different parts of the airframe may add or cancel each other depending on their relative phase. This can cause the RCS to fluctuate. In our approach, RCS is approximately constant during dwell (the time that antenna spends on a target), but randomly changes from dwell to dwell according to exponential distribution (this approach is known as a Swerling Case I model). This results in non-constant detection ranges and target detection probability.

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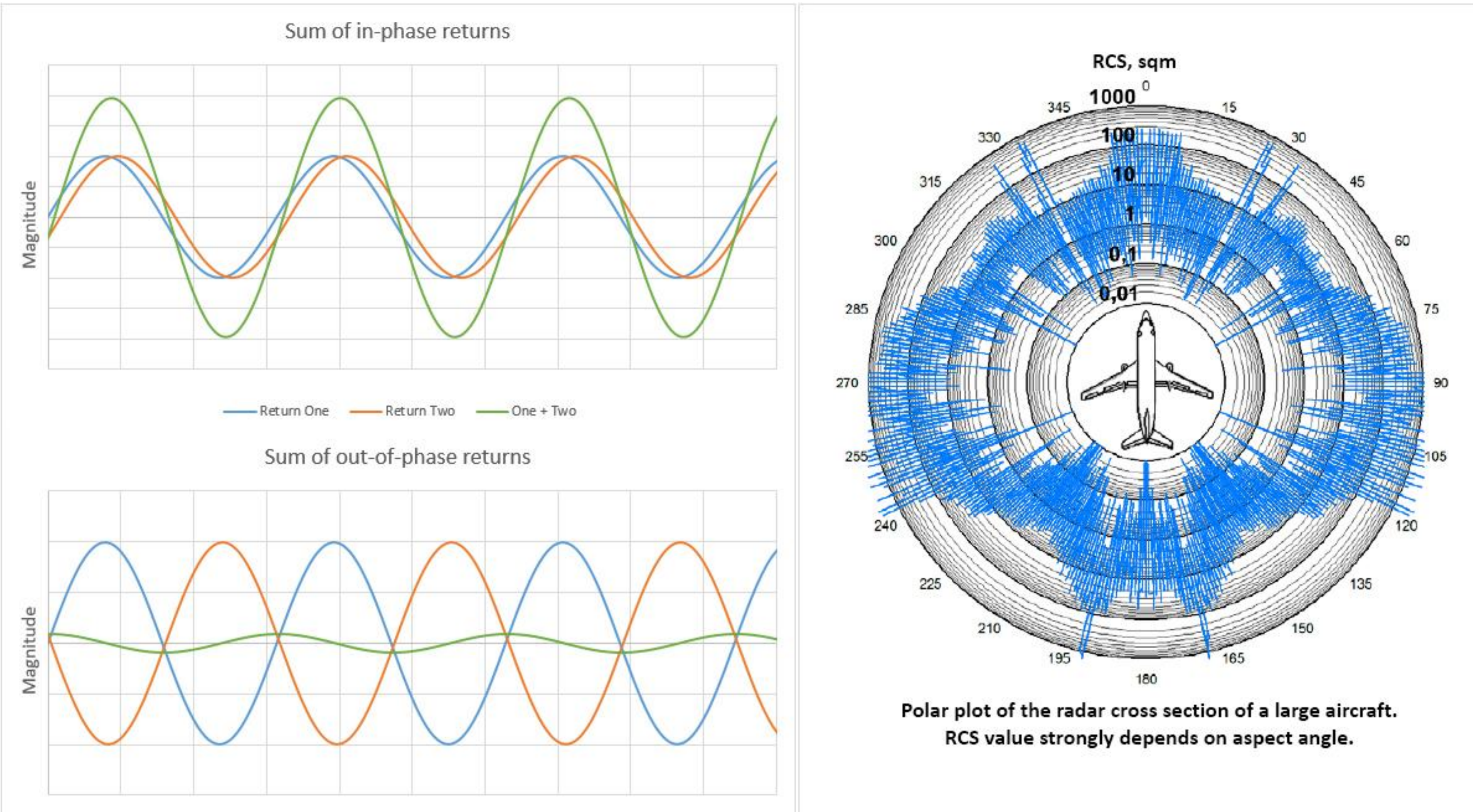

Polar plot of the radar cross section of a large aircraft.
RCS value strongly depends on aspect angle.

Effect of Radar Return Interaction and Results

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2. Background Noise.

There is another factor that can determine detection probabilities – background noise. Recall that an old radio hisses when it's not properly tuned, or the signal is weak because it's from a distant station. That hissing sound is a background noise. Target returns compete with similar noise in the radar receiver. Sources of this noise vary and include internal parts of the radar like the antenna, waveguides, and receiver input circuitry, and external inputs like the ground surface, atmosphere, and sun. However, the nature of noise itself (despite it produced by different sources) is essentially the same – thermal agitation. That is why receiver noise is often called thermal noise. Because the receiver output noise level is random and continuously changes, it can also result in detection randomness. While the average noise level may mask a weak target return, strong noise spikes may result in generating false targets.

To determine if a target is detected, threshold detectors are used, and the threshold level is critical. To best understand this, some statistical properties of noise and target signal should be considered. For clarity, we will represent these properties by a probability density chart. This chart shows the probability at which a certain magnitude of signal-plus-noise or noise alone will appear as receiver output. The total area under each curve is equal to one because it encompasses all possible magnitudes (if we sum the probability of an event over all possible events it will be equal to one). In other words, if we define a certain range of magnitudes, the area under the curve that is enclosed in this interval will be equal to the probability at which a signal with magnitude from that range will appear at receiver output. For example, the blue area to the right of threshold equals the probability of a false target, and orange area (including shaded) to the right of threshold equals probability of true target detection. The width of bell-shaped curves is proportional to noise variability, and the position of the signal-plus-noise curve is defined by mean signal power.

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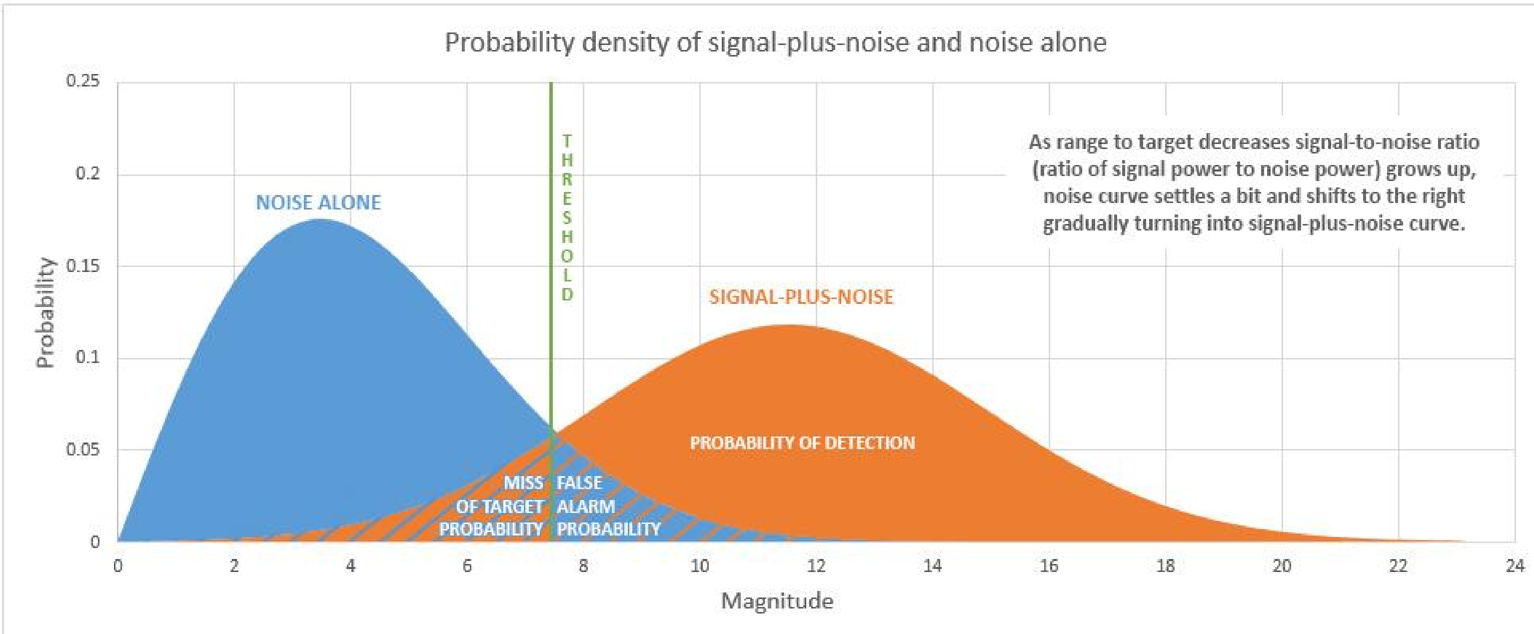

As can be seen in the chart, lowering the threshold leads to increased probability of crossing threshold by noise alone and thus increases the probability of a false target. Conversely, an excessive rise of the detection threshold will decrease the probability of target detection and increase probability of missing weak signals from distant or small RCS targets. Thus, the choice of detection threshold is a tradeoff between reduction in detection range and quantity of false targets. For practical purposes, the threshold is usually set to guarantee noise crossings with some approximately constant rate in order of one crossing (false target) per several minutes. In our radar model, we use a statistical model which is an equivalent of a real target detection process.

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3. Coherent Processing Intervals (CPI).

Pulse doppler radars transmit and receive trains of pulses. The portion of train that is processed jointly forms a bank of doppler filters called a Coherent Processing Interval (CPI). Dwell time is divided into several mode-dependent CPIs, which may have different pulse repetition frequencies or carrier wave frequencies. This division serves several purposes like blind zone elimination, range and velocity ambiguity resolution, and frequency modulation ranging / frequency agility implementation (e.g., to reduce glint noise in gun/dogfight mode). Because the noise level continuously changes, the target may or may not be detected in a particular CPI. This means that the detection probability will also depend on the number of CPIs per dwell. For example: There are three CPIs per dwell in HPRF RWS mode, and for successful ranging, the target should be detected in all three CPIs. Obviously, the probability of detection in all three CPIs is lower than, say, the probability of detection in one of three CPIs or in three of eight CPIs (like in MPRF mode). In HPRF VS mode, post-detection integration (PDI) replaces frequency modulation ranging (FMR). In that mode, signals from three CPIs are summed up in a special way to make noise fluctuations smaller and thus minimize the probability of false alarm (shapes on probability density chart become narrower, overlapping area reduces). That allows to lower threshold sensitivity and increase detection range without increasing the false alarm probability. These effects are also accounted for in our model.

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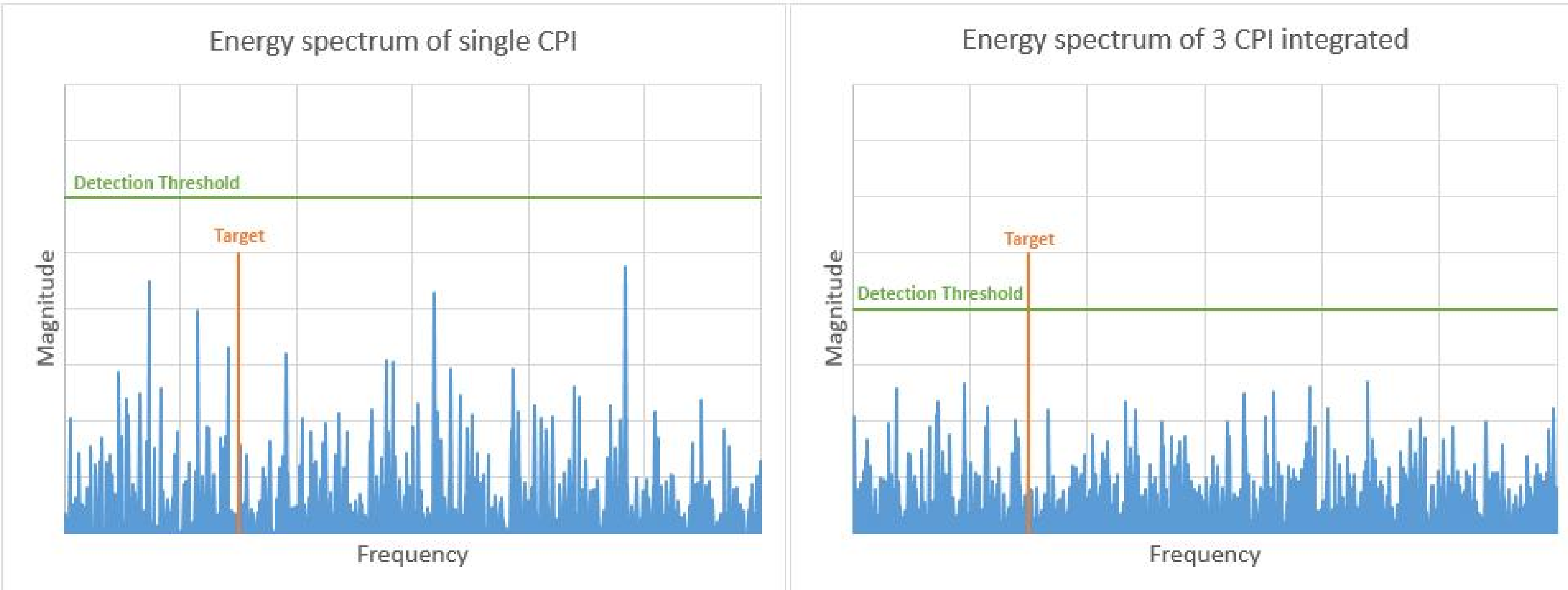

Effect of Post Detection Integration on noise variability

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4. Current Radar Detection Performance.

We are now ready to discuss the detection performance that our model provides. The table on the right shows detection range data for a co-altitude MiG-29A (5sqm RCS) target with probability of 50 percent for the AN/APG-73 and AN/APG-68(V)5 radars. Since the atmosphere absorbs radio waves proportionally to its density and that affects detection range, data provided for several altitudes.

DCS APG-73 Pd50 range data			
Altitude	Mode		
	RWS MED	RWS HI	VS
1500ft	28nm	55nm	65nm
15Kft	30nm	61nm	74nm
40Kft	31nm	65nm	80nm

DCS APG-68v5 Pd50 range data		
Altitude	Mode	
	RWS	VSR
1500ft	32nm	35nm
15Kft	34nm	38nm
40Kft	35nm	40nm

The charts below show how an AN/APG-73 single scan probability of detection of the high aspect MiG-29A changes with range. As can be seen in the chart, due to differences in signal processing between MPRF and HPRF, RWS modes vary not by detection range only, but also by the rate at which probability of detection increases as range to target decreases (MPRF curve slope is steeper in its middle part).

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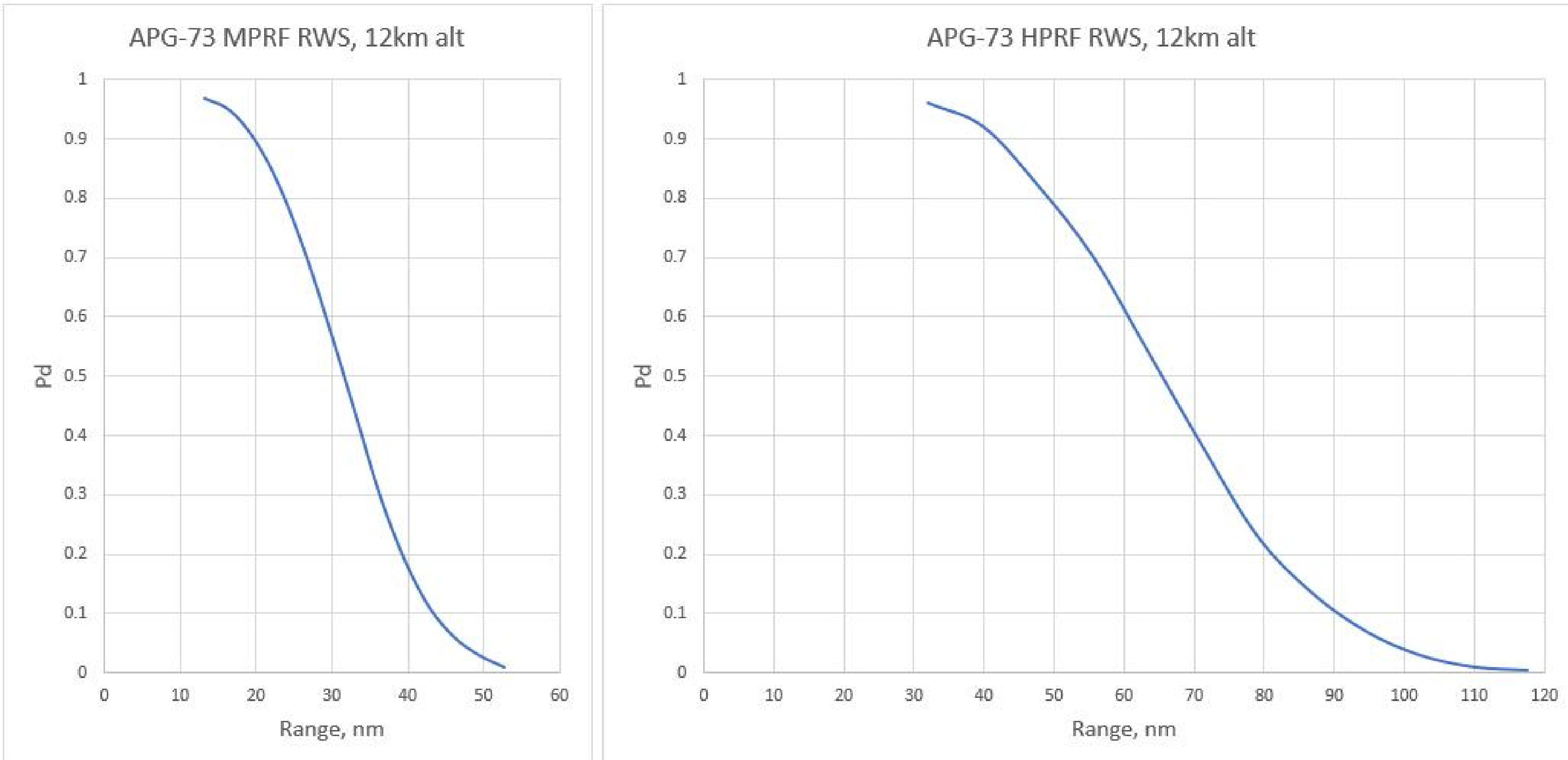

DCS APG-73 single scan probability of detection depending on range to target

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5. Mode-Specific Range and Doppler Resolution.

This is another new feature in our updated radar model that also affects detection probabilities. Closely spaced targets may not be resolved individually, and they may be displayed as a single target. Return energy off such targets may fall into a single doppler/range bin and result in detection at longer ranges. Velocity resolution depends on CPI duration – the longer CPI duration the better velocity resolution (narrower doppler bins). So, in HPRF with three CPIs per dwell resolution is better than that in MPRF mode with eight CPIs per dwell (dwell duration is constant, so CPIs are shorter). In RAID mode, up to four CPIs may be merged into one, thus increasing velocity resolution four times. RWS HPRF mode uses linear frequency modulation for ranging, and it has poor range resolution (in order of 2 nm, which improves four times in RAID mode). In MPRF mode, range resolution is defined by range bin size and it is always equal to 150 meters.

In summary, the Phase 2 radar changes provide a more realistic simulation of radar detection probabilities that has more variable detection ranges, low-quality/spurious detections, more accurate RCS effects, and modeling of finite velocity and range resolution.

In Phase 3 we will focus on false targets, look-down performance, and improved modeling of Single Target Track (STT) mode.

Thank you for your passion and support,

Yours sincerely,

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