Some comments on GMTI false alarm rate

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ABSTRACT

A typical Ground Moving Target Indicator (GMTI) radar specification includes the parameters Probability of Detection (P_D) – typically on the order of 0.85, and False Alarm Rate (FAR) – typically on the order of 0.1 Hz. The PD is normally associated with a particular target 'size', such as Radar Cross Section (RCS) with perhaps some statistical description (e.g. Swerling number). However, the concept of FAR is embodied at a fundamental level in the detection process, which traditionally employs a Constant-FAR (CFAR) detector to set thresholds for initial decisions on whether a target is present or not. While useful, such a metric for radar specification and system comparison is not without some serious shortcomings. In particular, when comparing FAR across various radar systems, some degree of normalization needs to occur to account for perhaps swath width and scan rates. This in turn suggests some useful testing strategies.

Keywords: GMTI, false alarm, detection, CFAR

1 INTRODUCTION

A typical Ground Moving Target Indicator (GMTI) radar specification may include the following parameters

Probability of Detection (P_D) – typically on the order of 0.85

False Alarm Rate (FAR) – typically on the order of 0.1 Hz

There are others, such as False Alarm Time, but for the discussion below we focus on the False Alarm Rate. The P_D is normally associated with a particular target 'size', such as Radar Cross Section (RCS) with perhaps some statistical description (e.g. Swerling number[1]).

Indeed, the concept of FAR is typically embodied at a fundamental level in the detection process, embedded in the very name of the traditionally employed Constant-FAR (CFAR) detector, used to set thresholds for initial decisions on whether a target is present or not. We refer the reader to any of a number of texts for more information on target detection algorithms and performance.[2,3,4]

However, while useful, a FAR metric for radar specification and system comparison is not without some serious shortcomings. We address some of these below.

2 FALSE ALARM RATE AND PROBABILITY OF FALSE ALARM

A fundamental measure of 'goodness' is the likelihood that a single detection calculation makes a mistake to indicate a target is present when in fact it is not, that is, indicates a False Alarm (FA). This is embodied in a measure called the Probability of False Alarm (P_{FA}) for that single detection calculation.

As a probability, the P_{FA} can be expressed as the number of independent occurrences of a FA for an independent opportunity. That is,

$$P_{FA} = \frac{\#\,False\ Alarms}{Independent\ Opportunity} \tag{1}$$

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An independent opportunity is often a range-Doppler resolution cell in a non-overlapping Coherent Processing Interval (CPI).

The P_{FA} depends on the relative noise level of the processed data at the stage on which detection occurs. Consequently, it depends on processing gains in Signal to Noise Ratio (SNR). It may also depend on 'spatial noise', that is clutter, or clutter residue.

However, P_{FA} is too far removed from the experience base of most radar operators, and the people that buy radars. They are interested in False Alarms, to be sure, but in a framework to which they can relate. Convention has caused the GMTI community to converge on the metric "False Alarm Rate" (FAR).

The FAR is thus calculated as

$$FAR = \frac{\#\, False\ Alarms}{\sec} = P_{FA} \times \frac{Independent\ Opportunities}{\sec} . \tag{2}$$

Of course, a low FAR is good, and a high FAR is bad.

What becomes immediately obvious is that for a given P_{FA}, we can influence the FAR by adjusting the rate of Independent Opportunities. Consequently, we can influence the FAR just by adjusting the number of independent range-Doppler resolution cells (their size remaining equal). The number of independent range-Doppler resolution cells is directly proportional to the range swath being interrogated.

One formulation for FAR is as follows.

$$FAR = P_{FA} \times \frac{Independent\ Opportunities}{\sec} = P_{FA} \times \left(\frac{D_r}{\rho_r} \right) \times PRF , \tag{3}$$

where

$$\begin{aligned} D_r &= \text{range swath,} \\ \rho_r &= \text{range resolution in the same plane as the range swath,} \\ PRF &= \text{Pulse Repetition Frequency.} \end{aligned} \tag{4}$$

This assumes that all pulses are used from a constant PRF, and that the entire Doppler spectrum is used for detection. If only the exo-clutter region is used, then the endo-clutter spectrum represents discarded opportunities. Consequently the FAR becomes

$$FAR = P_{FA} \times \left(\frac{D_r}{\rho_r} \right) \times \left(PRF - B_{clutter} \right), \tag{5}$$

where

$$B_{clutter} = clutter\ bandwidth . \tag{6}$$

For exo-clutter operation, we often desire the PRF to be large compared to the clutter bandwidth.

In any case, other things being equal, two radars with different range swaths will indicate different FAR metrics. The radar with the larger range swath will be penalized.

Example:

Radar A scans a 1 km swath with a FAR of 0.1 per second. Radar B scans a 10 km swath with a FAR of 0.4 per second. (See Figure 1.) Other things equal, which is better performance?

Since radar B can always reduce its swath to 1 km by throwing away data, if false alarms are uniformly distributed across the swath, then by throwing away 9 km of swath it will reduce its FAR to 0.04 per second, making it the clear 'winner'.

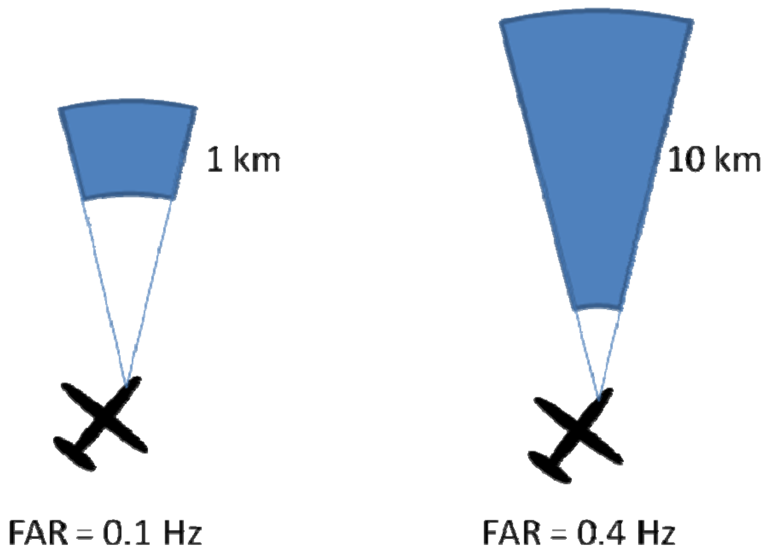

Figure 1. A lower FAR at the expense of a smaller scanned swath may not always be preferable.

The question becomes "Would a radar operator eagerly trade the swath to enhance FAR?" It seems doubtful.

This suggests that when comparing FAR statistics, the swath must be considered. This also suggests that a better metric than FAR is a 'swath normalized' FAR, with perhaps units "false alarms per second per km swath".

We note that other parameters can also be 'adjusted' to influence FAR, although these also have important secondary effects. For example coarsening resolution may reduce FAR but makes clutter brighter. Reducing PRF reduces FAR but also adversely affects velocity ambiguity, and may reduce observable velocity ranges. Reducing PRF may also reduce SNR for targets, reducing P_D as well.

3 FALSE ALARM RATE AND AREA

In the previous discussion we associated FAR with P_{FA}, and noted that FAR depends on the swath of interest. We extend this concept now from the other direction.

We now pose the question "What would we expect for a FAR in a limited subregion of the overall scan?"

We construct the relationship

$$FAR = \frac{\#\,False\ Alarms}{\text{sec}} = \frac{\#\,False\ Alarms\ in\ total\ scan\ area}{total\ scan\ area} \times \frac{total\ scan\ area}{total\ scan\ time} . \tag{7}$$

We note that for a single scan or sweep

$$\frac{total\ scan\ area}{total\ scan\ time} = area\ scan\ rate \approx \dot{\theta}\, R\, D_r , \tag{8}$$

where

$$\dot{\theta} = \text{angular scan rate,}$$
$$R = \text{nominal range to center of range swath.} \tag{9}$$

However, if we believe that false alarms are uniformly distributed in the scanned area, then we can equate

$$\frac{\#\,False\ Alarms\ in\ total\ scan\ area}{total\ scan\ area} = \frac{\#\,False\ Alarms\ in\ subregion}{subregion\ area} = FAAR , \tag{10}$$

where we define

$FAAR$ = False Alarm Area Rate, with units of False Alarms per reference area. (11)

We identify a subregion as having some area within the scanned region of the GMTI radar. A subregion might be, for example, a particular 1 km^2 area. Putting these observations together yields

$$FAR = FAAR \times \dot{\theta} R D_r \ . \quad (12)$$

4 FALSE ALARM RATE TESTING

The foregoing analysis suggests a reasonable testing strategy as follows. (See Figure 2.)

1. Define a 'test region' where movers are controlled. It need not be the entire scanned area. Ascertain the area of the test region. This becomes the subregion area in the equation.

2. Scan over the test region, counting all detections that are not controlled movers, but limited to those detections assigned to the subregion. The False Alarm count for the subregion is another element of the equation.

3. Calculate FAAR using the above equation.

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This also suggests that perhaps FAAR might be an important metric all by itself, perhaps with units False Alarms per square km. We note that this figure of merit would generally depend on range and scan rate.

Recall also that this is for a single scan.

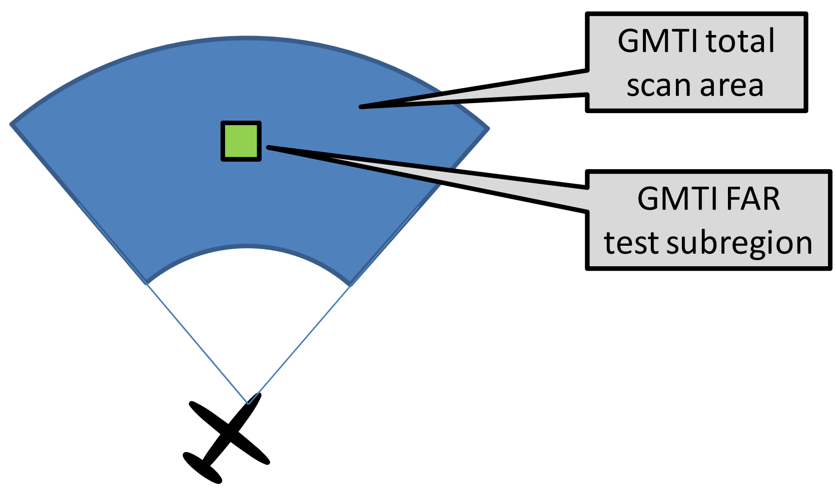

Figure 2. FAR testing can occur over a limited test subregion, and then calculated for the entire scan.

5 WHICH PROBABILITY OF DETECTION?

GMTI processing functionality can be roughly divided into the following major blocks.

1. Single CPI processing

2. Inter-CPI processing (across multiple CPIs) within a single scan

3. Inter-scan processing (across multiple scans)

Although we use the nomenclature CPI, we allow that this might also be some degree of noncoherent processing.

We note that depending on the processing architecture, that is the degree to which inter-CPI and inter-scan processing is used, different P_D and FAR performance is achieved. A reasonable question is "To which output do we want to measure and specify P_D and FAR performance?"

Recall that the previous development measured FAR after a single scan, therefore allowing measurement of inter-CPI processing. To incorporate inter-scan processing, we need to account for the fact that the same area is scanned multiple times. The FAR equation then becomes

$$FAR = FAAR \times \frac{\dot{\theta} R D_r}{N_{scan}}, \tag{13}$$

where

$$N_{scan} = \text{the number of scans over which data was collected.} \tag{14}$$

In addition, FAAR now is a count of the cumulative false alarm detections over all scans for the test region. To be fair, any 'start-up' scans for which GMTI reports were not valid need to be omitted from the count.

6 A SECOND LOOK AT WHAT IS A FALSE ALARM

A typical presumption is that a false alarm is just the occasion of system thermal noise breaching the threshold for declaration of a legitimate signal. In fact, to a radar operator, a false alarm is the apparent detection of 'anything' that he isn't specifically looking for, which for a GMTI radar, is anything that isn't a target of interest to him.

The list of possible sources of false alarms might include any of the following

Thermal Noise
Multiplicative Noise from clutter or targets
Artifacts from spurs, EMI, etc.
Strong targets in the antenna sidelobes
Animals such as flocks of birds, other wildlife, etc.
Foliage in the wind
Rotating structures such as turbines, windmills, fans, propellers, etc.
Other radar antennas
Vibrating objects such as vent pipes, engine cowlings, etc.
Weather effects
Chaff

In maritime environments, the water itself will move, and move anything in it or on it, including any of the following

Buoys, Mooring balls
Floating trash, debris, flotsam, jetsam
Icebergs, Ice flows
Breaking waves
Marine Life

False alarms due to unknown or non-apparent sources are often referred to as 'artifacts', 'ghosts', or 'angels'.

Note that some of these are due simply to uncertainty in the echo energy, some are due to non-ideal radar performance, and some are legitimate targets – but simply not the kind of target of interest to the radar operator.

Ad hoc and heuristic techniques are often employed to reduce false alarms due to many of these sources.

7 CONCLUSIONS

We reiterate the following points.

- False Alarm Rate comparison between different GMTI systems can be misleading. An improved measure normalizes FAR for swath width.
- FAR can be calculated from False Alarms counted just over a test area. This allows controlling movers over only the test area, and not the entire swath or scanned area.

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