Professional radar, poor visibility

by Philip G. Gallman

Recreational sailors generally feel safe knowing that professional mariners with professional equipment are watching out for sailboats.
When collisions between ships and sailboats do occur, the ship's lookouts often are blamed for neglecting their duties.
While sadly true sometimes, I believe that collisions between big ships and recreational sailboats are usually due to the confluence of several technical factors and our overly optimistic reliance on the big ship's ability to detect sailboats.
I recently reviewed the radar screen images from a **large ship** involved in a collision with a **46-foot sailboat**.
What I saw profoundly changed my understanding of why big ships have difficulty detecting small sailboats.
I reviewed a sequence of radar screen images covering roughly **14 minutes prior** to the **collision**, tracking the sailboat blip from image to image. The sailboat's blip was consistently much smaller than I expected. The **blip** became **smaller** and **dimmer** as the **range** between the two vessels became **shorter**, to the point of near **invisibility** at less than **one mile**.
In addition, the **blip disappeared** entirely for one long period of **several minutes** and two shorter periods.
In many years sailing on Chesapeake Bay and watching sailboats on radar, I have always seen rather large blips for sailboats, they generally get brighter at shorter range, and they do not disappear except at extreme long range or in severe clutter.
Detailed engineering analysis shows that what I saw in the radar images is in complete agreement with technical characteristics of professional marine radar no matter how contrary to conventional wisdom.
Recreational sailors are generally not aware of these issues because what they see with low-end radar systems is different from what ship lookouts see with professional radar systems.

Point or extended targets

Radar targets are **either point targets or extended targets.**

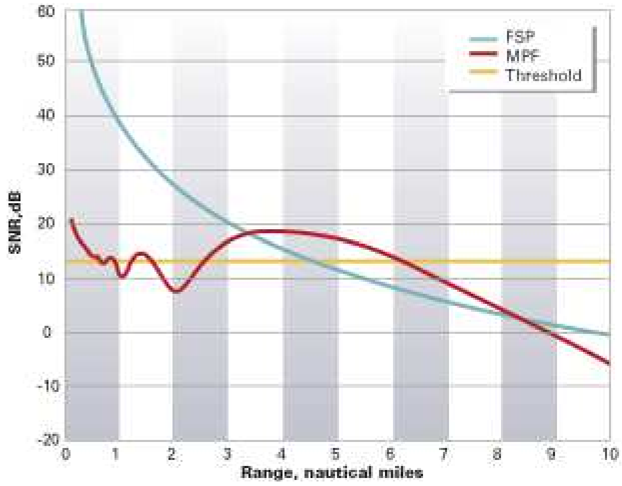
Point targets are so small that they are either outside the radar beam or entirely inside it as the beam sweeps past the target. A point target looks like a single point of reflection with a single radar cross section (RCS) as long as it is within the beam.
Conversely, extended targets are so large that they are never completely within the beam. The RCS of an extended target changes dynamically as the beam sweeps across it. Small pleasure boats are point targets; large ships are extended targets. What radar sees when scanning a point target is very different from what it sees when scanning an extended target.

You also have to know that **radar waves reflect off water**. Interference with the water plays a major role in detecting marine targets.
Interference depends on geometry, and **antenna height** is critically **important**. What radar on a ship with the antenna high above the water can see is very different from what radar on a small craft with the antenna within a dozen feet above the water can see.

Finally, detecting marine targets is a two-stage process. The first stage is the radar system detecting the target and displaying a blip on the display screen.
The second stage is the radar operator or lookout seeing the blip and recognizing it as representing a target. Both stages are necessary; it does not do any good for the targets to provide strong echoes if the

lookout cannot see the blips on the display.

These elements interact to make detecting sailboats difficult for large ships.
First, **echo strength** determines **whether** the **system detects** the **target**, and also the **brightness** of the resulting blip.
A **common belief** is that **echo strength**, and hence blip brightness, **increases** steadily as **range shortens**. This is not necessarily true at sea. Indeed, while a reasonable approximation to reality when the antenna is low to the water, as on a small craft, it is definitely **not true** when the **antenna** is **high above** the **water**, as on a big ship.
The graphs show my calculations of how echo strength would vary with range during the ship-sailboat encounter I reviewed for this article.



FSP Free space propagation: Propagation in vacuum with no physical objects that disrupt or distort the radiated beam

Echo strength fluctuates between strong and very weak, with a generally weakening trend, as the sailboat approaches the ship. Moreover, the echo is so weak that the sailboat is **undetectable** in **several blind zones**, one of which was nearly a mile wide.

Second, because a **sailboat** is a **point** relative to the radar beam, the **size** of the **blip** displayed on the radar screen depends on the radar antenna and the range. The physical size of the sailboat is irrelevant. I will explain with a specific example. **Pulse width** determines the **depth** of the blip in the **along-range** direction. The typical pulse width is **0.3 microseconds** for **three-mile** range setting, and the blip depth is **45 meters. Antenna beamwidth** determines blip width in the **cross-range** direction. The typical beamwidth on professional radar is **one degree**, so the width of the beam is **97 meters** at **three miles.** That is, the **area covered** by the sailboat radar target on the water is **97 by 45 meters**. Next, assume that the **display** is **770 by 770 pixels** (the dimensions of the screen dumps I reviewed) and the radar range setting is three miles. The 770-pixel-wide screen display covers six miles of ocean; **each pixel** on the screen represents **14.4 meters** on the water. The 97 by 45 meter spot on the water displays on the screen as a blip **seven pixels wide by three pixels high**.

Scaling with range

On one hand, blip width scales linearly with range. That is, the **seven-pixel-wide blip at three miles** becomes a **three-pixel-wide blip at one mile**.
On the other hand, blip size scales inversely with range scale. The seven-pixel-wide blip on a display set to the three-mile scale is a four-pixel-wide blip on the six-mile scale. The blip displaying a sailboat at one mile, with the display set to the six-mile range scale, is approximately one pixel wide. These pixel

dimensions might be slightly different on other radar systems with higher resolution displays, but the crucial point is that **the blip is vanishingly small at ranges of a couple miles or shorter**. Such small blips are exceedingly difficult to see, and are **easily lost on a cluttered display**.

Display usage adds another complexity. I normally operate my radar with the scan center at the center of the display. In this mode, the display covers the same distance forward, aft, and to each side, and I can see vessels approaching from all directions. Many fast vessels, concerned more about where they are going than with the unlikely occurrence of a faster vessel coming up from aft and overtaking them, operate with an offset center — the display covers almost twice the range setting forward of the vessel and little distance aft. The display does not show distant targets unless they are well forward of the beam. This means that **the ship might not be aware of a sailboat to the side** that a large course change would endanger.

Display clutter is an additional issue. The display shows many vessels and navigation aids, sea clutter, overlays from automatic radar plotting aids (ARPA), overlays from automatic identification systems (AIS), overlays from electronic charts, course and heading lines, variable range marker (VRM) circles, and electronic bearing lines (EBL). Detecting small, dim sailboat blips on the cluttered display is difficult.

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