HF Radar Cross Section Primer

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What Is a Radar Cross Section? When an electromagnetic/radar wave strikes an object (ship, sphere, etc.), the target acts like an antenna. It captures some of the incident energy and reradiates it. The amount of energy it captures and scatters depends on its size with respect to a wavelength; we will discuss this below. The directional preference for the scatter depends on its shape and orientation. ***The term that describes its echo-generating effectiveness is called its radar cross section (RCS).*** It has dimensions of area because as mentioned above, this is meant to describe roughly how much of the incident energy density it intercepts. At a given frequency, it also depends on the angle of incidence and the desired angle of scatter. It also depends on relevant incident/scatter polarizations. The common symbol for it is $\sigma(\Omega,\mathrm{P})$, where Ω denotes all relevant incidence/scatter angles and P denotes the relevant incidence/scatter polarization states of interest.

Start with Resonant Monopole Model for Ship. For HF coastal surface-wave radars, only vertical polarization for incidence and scatter is relevant (horizontal polarization is suppressed by the highly conducting sea surface). Like an antenna, a target has a "first resonance" -- the lowest frequency relative to its size at which it is a highly effective radiator. This is a critical "benchmark reference" with respect to higher or lower frequencies vs. target size, as we will discuss below. ***Because vertical polarization is used, it is a vessel's height that matters -- from waterline to mast-top.*** A quarter-wave monopole antenna is a very good model for any vessel at its first resonance. The quarter-wave monopole is merely a resonant half-wave dipole cut in half and shorted into the conducting water plane, i.e., assume we see its mirror image below the surface.

The RCS in this case is simple: $\sigma = 0.2\lambda^2$ in square meters, where λ is the radar wavelength in meters. Often RCS is expressed in decibels above a square meter, termed dBsm, which is obtained by taking 10 times log-based-ten of σ. For example suppose the radar is operating at 5 MHz where wavelength is 60 meters, then the RCS is about 28.6 dBsm at resonance for this 15-meter high monopole/target model.

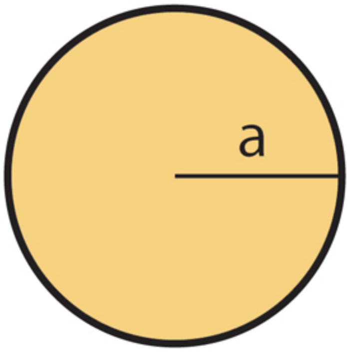
What Happens below Resonance? Something surprising happens below resonance. That is, when the vertical height is smaller than a quarter wavelength. The RCS decreases extremely rapidly. If h is vertical height, then its RCS decreases from its value at resonance as h^6. Is this rate of decrease rapid? Let's take a look. Suppose I cut the height in half at 5 MHz, from 15 m to 7.5 m: the RCS drops 18 dB (a factor of 64), from 28.6 to 10.6 dBsm. Suppose I cut it in half again, to 3.75 m: RCS is now -7.4 dBsm (negative means it is less than a square meter). One more time, cut it in half to 1.875 m, and the RCS has dropped to -25.4 dBsm. The total by cutting it to 1/8 of its resonant size has been to drop it by 54 dB, i.e., a factor of a quarter of a million!

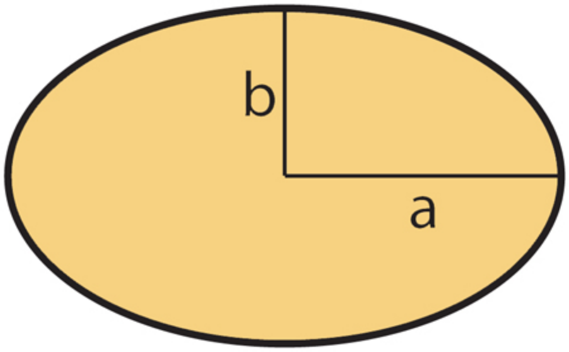
Let's put this in perspective and relate to a question we are often asked. " Gee, we like the long-range SeaSonde because it can see out to 200 km (for currents), well beyond the horizon. We'd like to use it to detect hostile low-profile "go-fast" boats only 6 feet high out of the water (very close to our 1.875 meter example above). Can you do it?" Suppose we can see the quarter-wave resonant vessel at 5 MHz to a distance of 100 km. What would it take to see the go-fast boat at this range? Well, we'd need to increase our radiated power from 40 watts to 10.5 megawatts! Sound practical? Hardly!

Short monopoles aren't the only targets that obey this size-to-the-sixth power below resonance. All of them do. In RCS parlance, this is called the "Rayleigh" or low-frequency region (compared to target size). A standard reference target is a conducting sphere, and its Rayleigh RCS is well known to be $\sigma = 9\pi\left(\frac{2\pi f}{c}\right)^4 a^6$, where f is the frequency; c is the speed of light (3e08 m/s), and a is the radius of the sphere.

What Happens above Resonance? So above resonance (in size or frequency), does the target RCS increase in a very rapid fashion, the opposite of what happens below resonance? No. Two things stand out. (i) The RCS begins to fluctuate ever more rapidly as frequency or target size increase, with fluctuations depending on the incidence/scattering angles and frequency/size. (ii) Its mean RCS, averaging out these fluctuations, is proportional to the cross sectional area of the target. The source of the fluctuations is higher target resonances as well as complex electromagnetic interactions among various features of the target: e.g., masts and other superstructure objects.

It makes sense that the energy removed from the incident wave is proportional to the area of the target. This intercepted energy is reradiated in all directions, some being preferred over others depending on target shape and aspect with respect to the viewing radar(s). Like the energy radiated by an antenna, the reradiated echo field diverges as inverse distance from the scatterer, and the RCS vs. angles, like antenna gain, dictates where it goes. Consider two simple examples: a sphere and an ellipsoid as shown below. Above resonance when the radii of curvature of these objects is large with respect to a wavelength, the RCS for each becomes, respectively: $\sigma = \pi a^2$ and πab. These are identically their cross sectional areas viewed by the radar. The sphere radiates omni-directionally.





So we argue that for any target, like a ship, a good approximation for the mean RCS above resonance is $\sigma = LH$, where L is vessel length and H is its height, waterline to mast top. Like the sphere or ellipsoid, its RCS does not increase further as frequency increases.

Consider an example: a midsize cargo vessel with length 150 m and height above the waterline of 20 m. The RCS will be 3000 square meters, or about 35 dBsm. We caution that this is the RCS ***average***. The actual value could be as much as 15 dB above this number (e.g., looking broadside) or 10 dB below it (viewed end on).

Disclaimer -- There are tens of thousands of scientific papers written on RCS, how to calculate it, and a multitude of measurements. My 1970 books (*Radar Cross Section Handbook*, Plenum Press) is one set of several on the subject. Complex computer codes are written that will calculate RCS; it gets much more difficult for large targets, well above first resonance. However, one often needs a quick, ***average*** number. For example perhaps one doesn't know the target aspect (i.e., a ship is out there, I don't know its orientation). But give me a quick number within "order-of-magnitude" precision. That's the gap my simple document here is meant to fill.