1.0 RAdio Detection And Ranging… RADAR

“A system for detecting the presence of objects at a distance, or ascertaining their position or motion, by transmitting short radio waves and detecting, or measuring their return after being reflected” - Oxford English Dictionary

If you were to ask a number of recreational boaters which electronic device they would be most likely to buy first, you would probably find the most common answer would be GPS. Professional seamen and seawomen would probably disagree. They prefer to use radar in poor sailing conditions because radar has the advantage of being entirely self-contained on the boat. It is not dependent upon orbiting satellites or shore bound radio towers. This course will try to explain why the professional just might be right!

RADAR has become such a well-known and broadly used device that today the acronym RADAR is now accepted as the word “radar” in common English usage. We will use radar in this course.

At the start of the 21st Century radar was already over 65 years old, born out of the necessity of impending war. It was further refined and polished by the dual incentives of commercial expedience and the lingering threat of world conflict. While the threat of all-out violence may seem to have lessened, at least on a “superpower” scale, the technological advances resulting from the Cold War have allowed the commercial viability of small, power-miserly and quite effective recreational marine radar sets.

In the following pages we will look at how radar works; how to set it up and use it; how to monitor its performance; and finally; how to extract from it the maximum value for safety.

1.1 Simple echolocation

If we face a cliff, a short distance away, and shout, we will probably hear an echo of that shout a short time later. The further away we are from the cliff, the longer the echo will take to get back to our ears, and the fainter the echo will be. If we turn our head a bit to the side and shout, we will probably find our head automatically turning back in the direction from which the echo reverberates from the cliff. If we turn our back to the cliff face and shout, we will probably not hear an echo at all. However, if the shout is longer, or louder, an echo may be heard from an even more distant cliff face.

Radar uses all of the same principles used in the experiment above. Our lungs supply the power and the length of the shout, our mouth forms the shout and determines the direction in which the shout will travel. That is the transmitter function. Our ears hear the echo, recognize it from among all of the other background noises, and determine the direction from which the echo has arrived. The delay between the shout and the echo’s return gives an indication of the distance that the cliff face is from our head. That is the receiver function.

1.2 What is radar?

Radar and SONAR (SOund Navigation And Ranging) are both echolocation devices. Sonar and depth sounders use high frequency sound waves travelling through the water. Radar uses the much shorter wavelength radio waves in the Radio Frequency (RF) portion of the frequency spectrum. RF waves travel efficiently through the ether in space. However, the earth's atmosphere can interact with them causing distortion and interference.

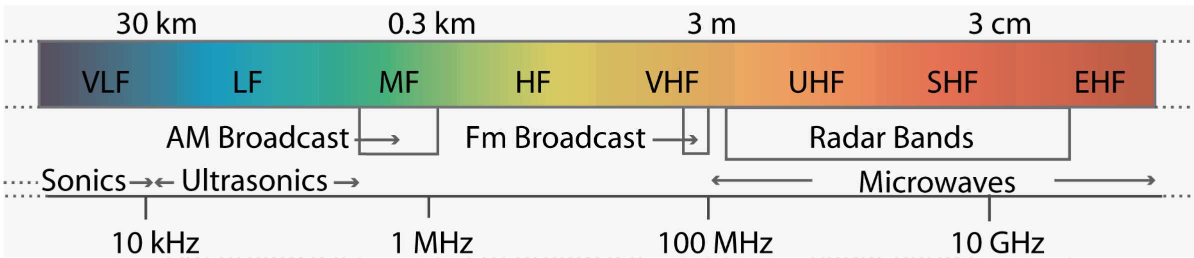


Figure 1.1 - The frequency spectrum

The illustration in Figure 1.1 shows the most familiar portion of the frequency spectrum. This is a graphic way of illustrating the relative groupings of various technologies according to the frequencies and wavelengths in which they operate. The wavelength of a signal is shown across the top of the diagram with its corresponding frequency across the bottom. Sonars and depth sounders operate in the Ultrasonic band to the left (low) end of the range, whereas most marine radars operate in the SHF (Super High Frequency) 3 cm band towards the right (high) end.

The wavelength of a signal is the physical distance between the crests of a single wave (see Figure 1.2). If you look at the top line of Figure 1.1 you see that a single sound wave can be as much as 30 km long between crests while, at the other end of the diagram, a single marine radar wave is only 3 cm, long crest to crest. This is a significant difference as we will see later. The frequency of a signal is the number of times a complete wave (cycle) is generated in one second. One hertz (Hz) = one cycle per second.

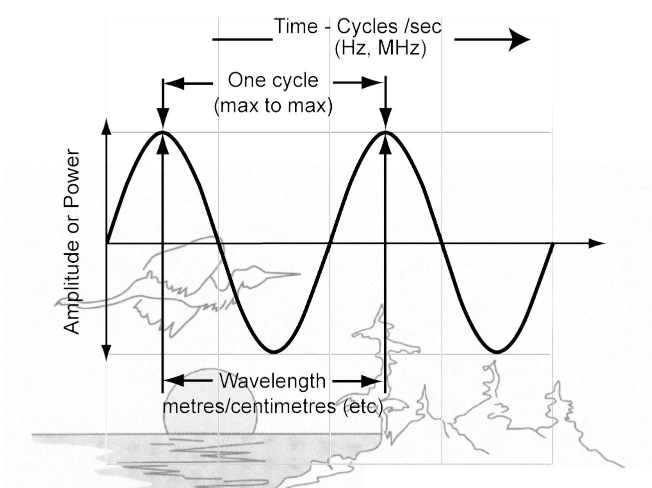


Figure 1.2 - Length and frequency of a waveform.

Both marine sonar and radar systems transmit a focused "burst", or pulse, of energy, and then listen for any echoes reflecting back from objects in their path. We already know the speed at which both sound waves and radio waves travel, so the distance to an object can be calculated with great precision by accurately measuring the elapsed time between the pulse's transmission and the echo received from it. The radar antenna points in the direction towards the reflected signal.

1.3 The functions within radar.

There are eight different functions inside a radar set (see Figure 1.3). These enable us to use this physical phenomenon to generate and display a rough image of the traffic and geographic features around us.

These functions are:

1. a common power supply;
2. master timer circuitry;
3. the modulator and pulse forming network;
4. the transmitter;
5. an antenna switching system;
6. an antenna;
7. the receiver; and,
8. the display.

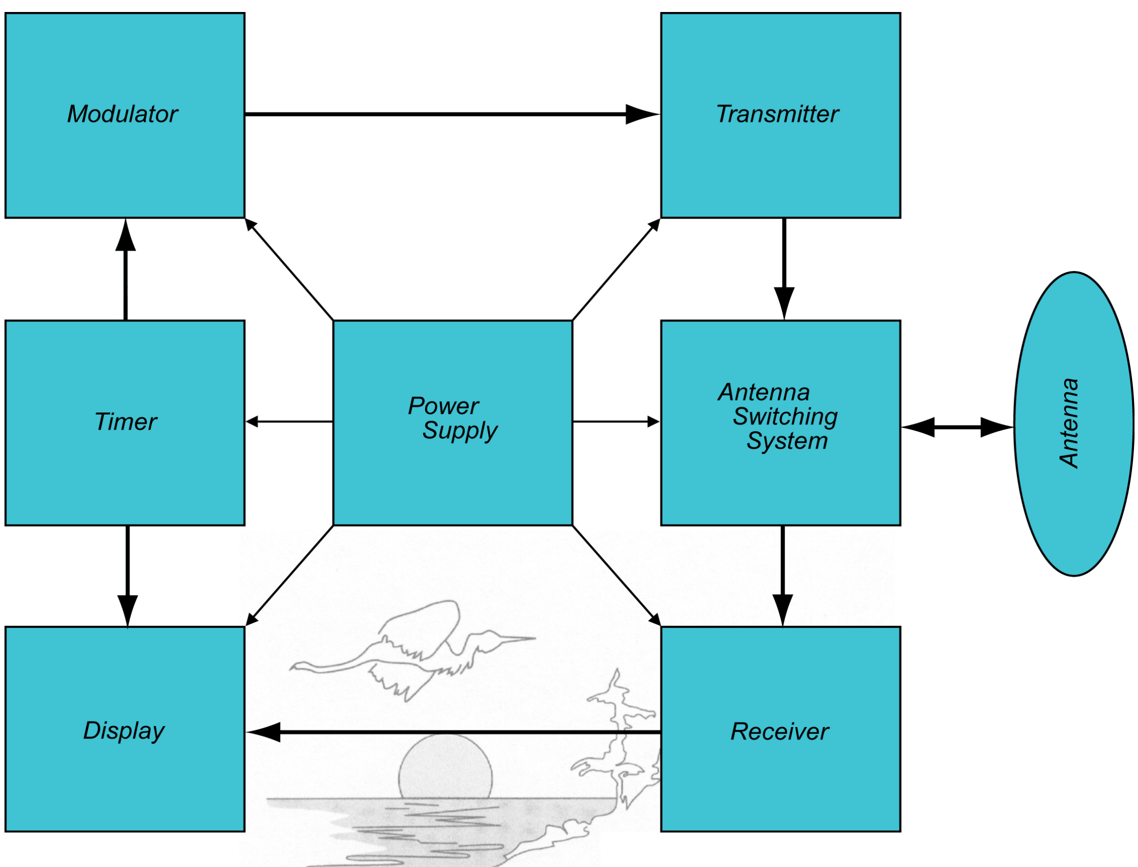


Figure 1.3 - Radar functional diagram.

The power supply provides all of the other functions with clean stable power. The timer is the single most important part of the set. It provides the "master trigger pulses" which keep all of the other functions in locked step. The modulator accepts the steady flow of power from the power supply and systematically stores it in the pulse-forming network to the required voltage and shape needed to "excite" the transmitter. The transmitter's magnetron tube changes the precisely shaped and timed pulse of direct current (DC) into a high-powered burst of RF energy. This is passed directly to the antenna through the antenna switching system. The antenna switching system is a clever device that enables the single antenna to serve the needs of both the outgoing high power energy burst from the transmitter, yet allowing the receiver to listen for the tiny returning echoes without it being "fried" by the transmitted energy surges. The radar receiver is extremely sensitive and capable of detecting very weak returns. It must amplify them many times to useful values for the display. The modern display is also a clever device that can present the detected paints in various formats to ease the task of interpretation for the operator.

With the tremendous advance in solid-state electronics and micro-miniaturization over the last number of decades, the typical small marine radar can now be packaged into two units, a display unit and an antenna unit. The display unit encloses the display itself, the master timer, the power supply and, occasionally, the receiver. The antenna unit houses the modulator, the transmitter, the antenna switching system, and the receiver and its pre-amplifier. A representative 46 cm (18 in) domed antenna unit will weigh about 6.5 kg (14 lb). This allows it to be mounted well up a sailboat mast or on top of a powerboat's superstructure, with minimal instability effects.

1.4 How radar works - frequency and wavelength

Radar works at the speed of light! Radar does not need the atmosphere to work. A RF energy pulse travels through space even better than it can pass through the earth's atmosphere.

The speed of light is generally accepted as travelling at:

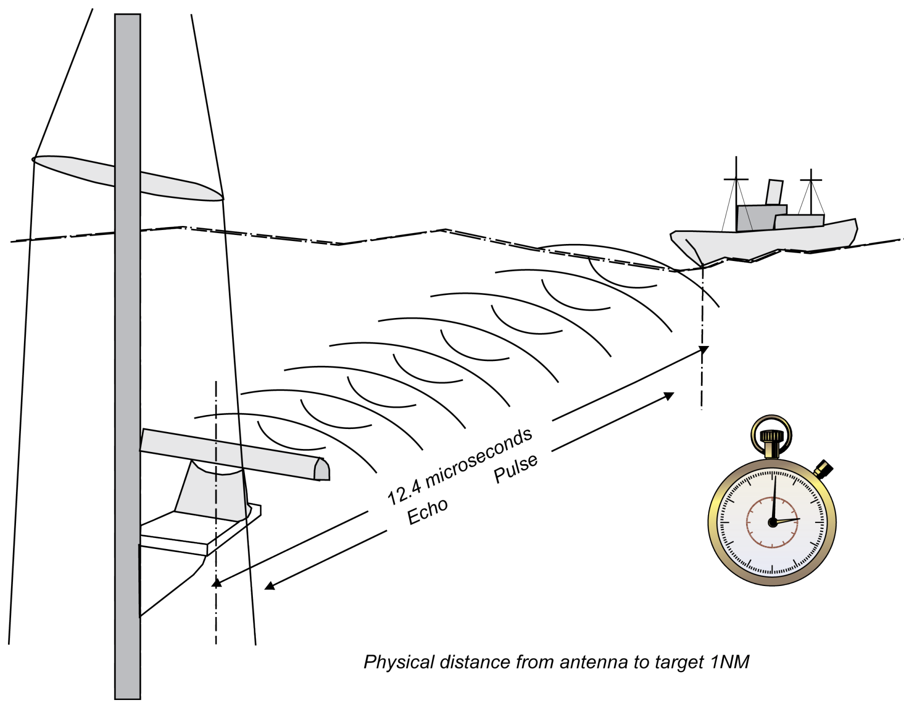
300 000 000 metres per second or, 162 000 nautical miles per second.

These numbers are just too large for easy understanding or ready manipulation. The accepted way to cut them down to size is to reduce them to the distance light travels in one millionth of a second, or one microsecond (μsec), which then gives us:

300 m/μsec or, 0.162 NM/μsec

Like all echolocating systems, the key to radar's accuracy is its ability to measure precisely, the time which elapses from the start of a pulse being transmitted to the start of the echo being received. As we know the speed at which the energy is travelling out, and back, we can calculate the distance, with precision, to the object of our interest.

When we use out-and-back timing, we find that the elapsed time for a radar signal to reach and an echo to return from an object that is one nautical mile away from our antenna, is 12.4 µsec. This has become known as a radar mile, although the unit is time and not a distance (see Figure 1.4).



One radar mile = 12.4 µsec

Figure 1.4 – Radar mile

Radar is classified by its wavelength, rather than by the more familiar "radio" frequency band. This may be because of the relationship between frequency and wavelength. When any radio frequency and its wavelength are multiplied together, the result must equal 300 000 000, the speed of light [in metres] over one second. Therefore as a frequency rises, its corresponding wavelength must shrink;

frequency (hertz) x wavelength (metres) = speed of light (300 000 000)

or,

frequency (Megahertz) x wavelength (metres) = 300

To be efficient, the size of any RF antenna has to be directly related to the wavelength of the signal it is going to transmit or receive. The longer the wavelength the bigger the antenna must be. Early radar worked in the low Very High Frequency (VHF) band [20MHz] and required immense antennas slung between 350 foot (107 metre) high steel towers. These were metric wavelength sets. Today, sophisticated equipment is almost exclusively centimetric and operates in the Super High Frequency (SHF) band. (see Figure 1.1)

1.5 Antenna considerations

The four most common radar "sizes" have wavelengths of about 10 cm, 5 cm, 3 cm and 1 cm. Land-based air surveillance radar is mainly 10 cm and uses the large antennas you can see rotating near airports. Large ships can support the substantial antennas required for 10 cm and 5 cm operation. The smaller antennas used by 3 cm sets, adorn ships both large and small. One centimetre band radar is usually found on aircraft, in space, or in other specialized applications.

The small marine radar wavelength is in the 3 cm group. That puts it in the 10 Gigahertz frequency band (billion cycles per second = GHz) and the usual frequencies used are 9.41 GHz and 9.445 GHz, each ±30 MHz (Megahertz = million cycles per second).

This means that 3 cm radar sets can effectively use antenna designs small enough, and light enough, to be used on recreational vessels. However, the smaller an antenna is, for its design wavelength, the less concentrated the power will be in the transmitted beam of energy. This limits both the effective range of the equipment and its azimuth discrimination. These subjects will be discussed later.

A typical 46 cm (18 in) domed radar antenna can manage no more than a 5.2° horizontal beam-width. A 61 cm (24 in) dome can produce a beam-width of 3.9° while a 122 cm (48") open antenna can produce a beam-width as narrow as 1.85°. All of these antennas have similar vertical beam widths of about 25°. Narrower vertical beam widths can be obtained by enlarging the antenna size in height. However, this would result in an increase in weight and cost.

Note: Each manufacturer has its own way of presenting specifications, and claimed attainable beam-widths vary from model to model. The values above tend towards the best available performance.

1.6 Summary

- Radar has been around a long time and is now a mature echolocation technology which, when properly operated, can display a reliable picture of the surrounding traffic, navigating aids and land.

- A boat equipped with operating radar has a self-contained navigation system which does not rely upon external signals to present positioning information to the navigator.

- Modern recreational marine radar works at a very short wavelength and high frequency. This allows it to be small, compact and quite frugal in its demand for electrical power.

- Radar works at the speed of light which allows it to display the distances to a "target" with great accuracy.

- The short wavelength of 3 cm allows the radar antenna to be sufficiently small to be mounted high enough on the mast or superstructure of a recreational boat to provide a useful range.

***Next* – The "shout"**

We will take a look at the transmitter and the pulse of energy it puts out through the antenna, how it is changed in length and why, and the common sense behind different pulse widths.

Warning: Radar is a "microwave" device, and as such, is potentially just as dangerous as the microwave oven in your kitchen. However, kitchen microwaves are carefully shielded to prevent the escape of microwave energy, which can harm a bystander, but radar is not! The radar antenna is designed to project its microwave energy outward in high-powered bursts. When it is operating, there is an area around a radar antenna that is constantly filled with RF microwave energy. It is not advisable to remain, work or sit in the immediate vicinity of a transmitting radar antenna. The radar should by put into "stand by" mode or turned off, if it is necessary for a crew member to be close to, or in line with the antenna, for any extended time.