3.0 The antenna and radar receiver

3.1 The radar antenna

Most of the effectiveness of any radar set rests on the ability of its antenna to not only shape the outgoing energy into a narrow beam but to focus the tiny returning echo into a useful signal for the receiver to process. This critical area has fuelled the intense research and development of radar antennas that has been, and continues to be undertaken, over the seventy-five or so years of radar's evolution. The main difficulty in designing a superior radar antenna is controlling the interaction between two signal waves at the same wavelength, as they meet in space. As complicated as this sounds it can be illustrated in simple terms.

3.1.1 Harnessing interference patterns

Any boater who has experienced rough seas can relate to the effects of one swell (wave) interacting with another. Two seemingly innocuous waves meeting from different angles will suddenly seem to rear up into a threatening monster or, conversely, two threatening whitecaps might meet in a fizzle of flat water. It is these effects that antenna designers try to harness as they seek the perfectly designed antenna. Figure 3.1 overleaf illustrates how this works.

A representative sine wave signal is shown across the top row of the graphic. The signal's power starts off at 0 units, rises to its maximum value in the positive (plus) direction, then falls through the 0 unit mark to its maximum value in the negative (minus) direction, only to rise back through 0, and so on. Should it meet with any of the three other identical sample signals shown in the segment representations immediately below, the combined result of each of these mergers would be as drawn on the bottom area. Compare the size of the original signal with the composite one on the bottom and you will see that the original signal can be doubled, made just a bit bigger, or simply cancelled out completely.

In radar, if we transmit the basic RF signal from a single antenna dipole element, the signal's power, or energy, will radiate equally in all directions like a huge doughnut, with no beam being formed. If we place a reflector behind the first transmitting element, at half of the wavelength distance of the signal to be reflected from it, the reflected signal cycle will arrive back at the transmitting element exactly "in phase" with the emerging second signal. Thus, through signal augmentation, the power of the transmitted signal will have been effectively doubled in the outward direction, away from the reflector side of the radiating element. This is illustrated as the first case in the "Resultant Wave" line of Figure 3.1 below.

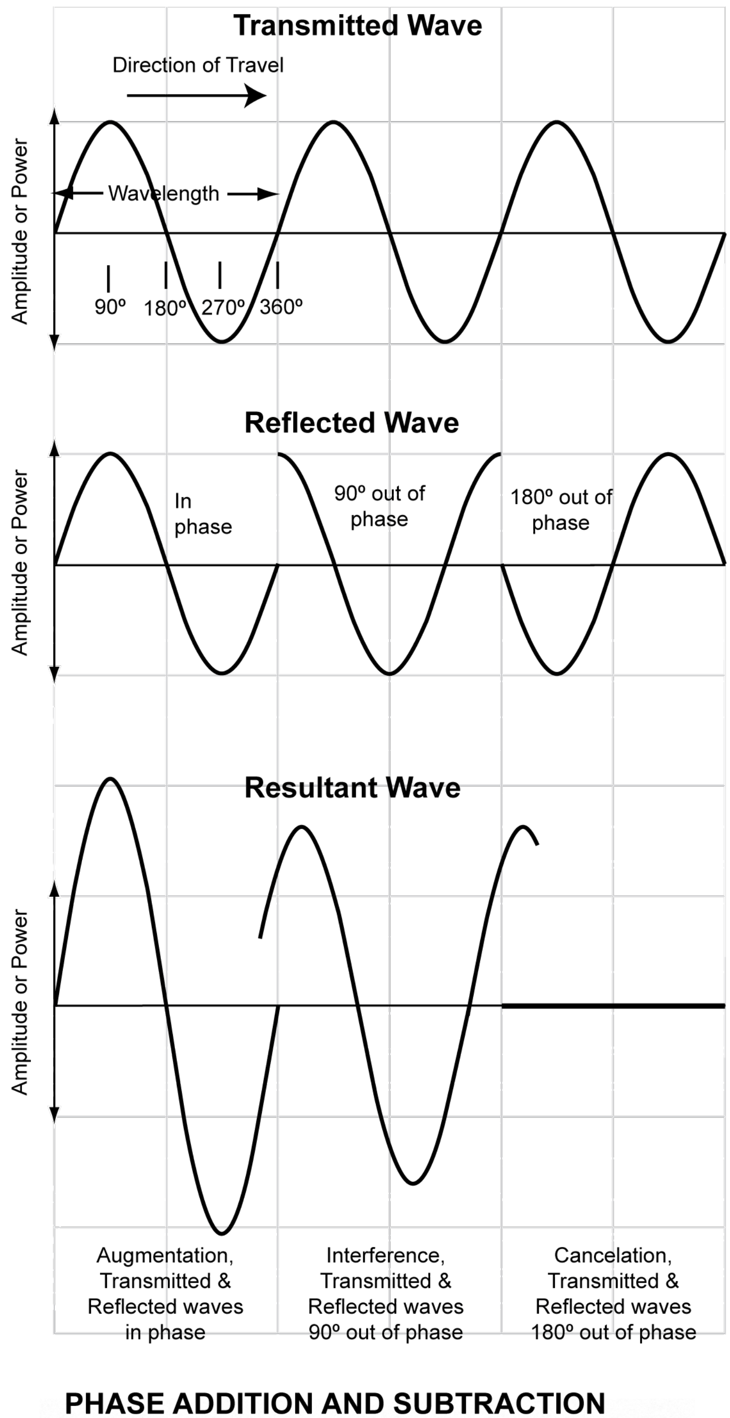


Figure 3.1 Signal augmentation and cancellation

The accumulative results are shown in Figure 3.2 next and you can see that we have now formed a rudimentary "beam" which is able to very crudely indicate the side (direction) on which an echo might lie.

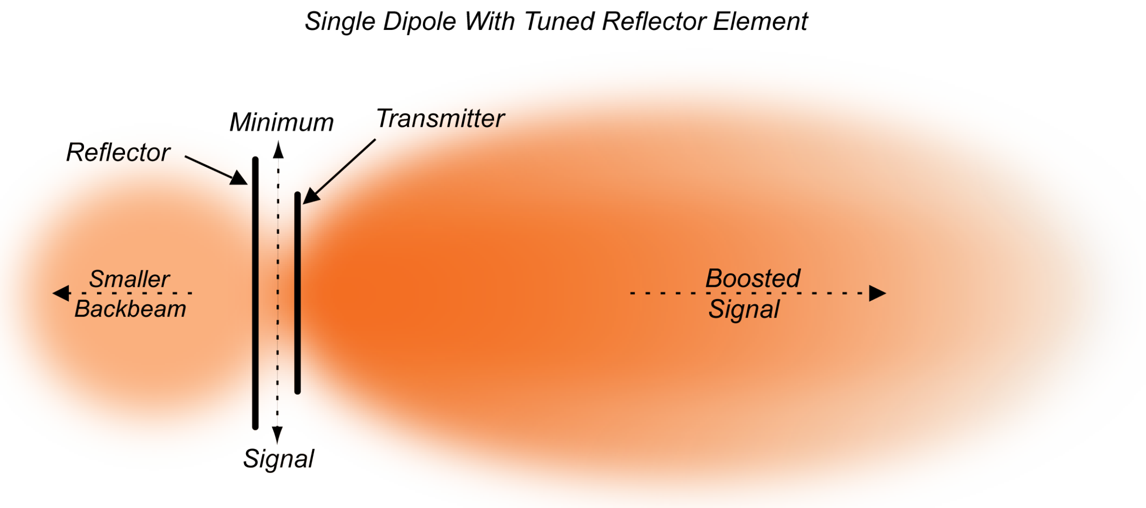


Figure 3.2 Single dipole with tuned reflector element

3.1.2 Shaping the beam

The width of a radar beam can be further narrowed by adding a series of these transmitting elements side by side. Because of this interaction between the signal pulse transmitted simultaneously from each element, the more elements that are added the narrower the beam will become. Of course it is not quite as straightforward as that. To be "tuned" to each other and achieve the optimum results, these elements themselves must be extremely accurately sized to the transmitter frequency and positioned at precise distances apart. If this precision is not achieved, the transmitting signals will interfere with one another in the wrong way preventing the formation of the desired tight pattern. Similarly, adding elements one above the other will reduce the angle of the resultant beam in the vertical plane. In the radar "business" the elements are said to be in horizontal *rows* and vertical *stacks*.

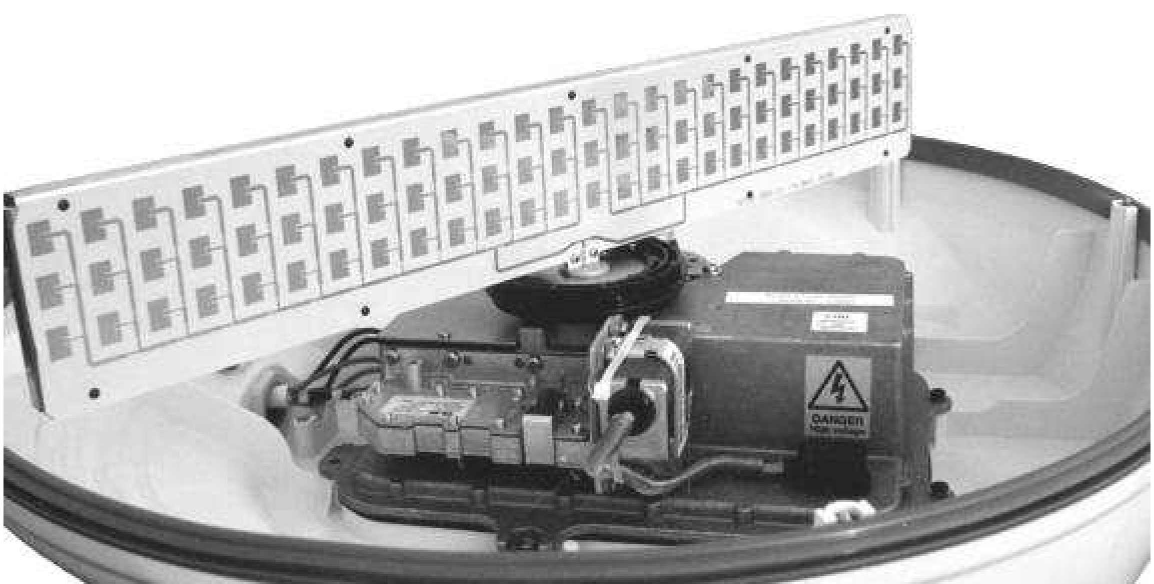


Figure 3.3 Picture of the JRC1500 antenna
(Courtesy Practical Sailor)

Figure 3.3 is an excellent example of the 26 row by 3 stack antenna design used in one of JRC's small marine radar radomes. It is particularly interesting that the radiating elements of this modern antenna design are etched onto a printed circuit board (PCB) with potential weight savings and improved manufacturing precision over older generations of individually machined slotted-waveguide units.

The following four figures, Figures 3.4a, b, c, and d attempt to illustrate how the expanding energy waves interact as they are radiated from one (Fig 3.4a), two (b), three (c) and four (d) adjacent transmitting elements. The lines depict the points of maximum (+) energy only. Therefore where they cross each other there will be double the value of the transmitted power. The farther away from the centreline of the beam, the less often the waves meet “in-phase” with one another, therefore the augmentation boost rapidly disappears and the cancellation effect increases. It is this effect that creates the side lobe pattern. The tighter the lobe pattern, or beam, an antenna can produce, the better for both the transmitted pulse, and the antenna’s greater ability to concentrate the small returning echoes for processing by the receiver. The sequence of drawings is a graphic illustration of the narrowing of the beam as elements are added to the antenna design.

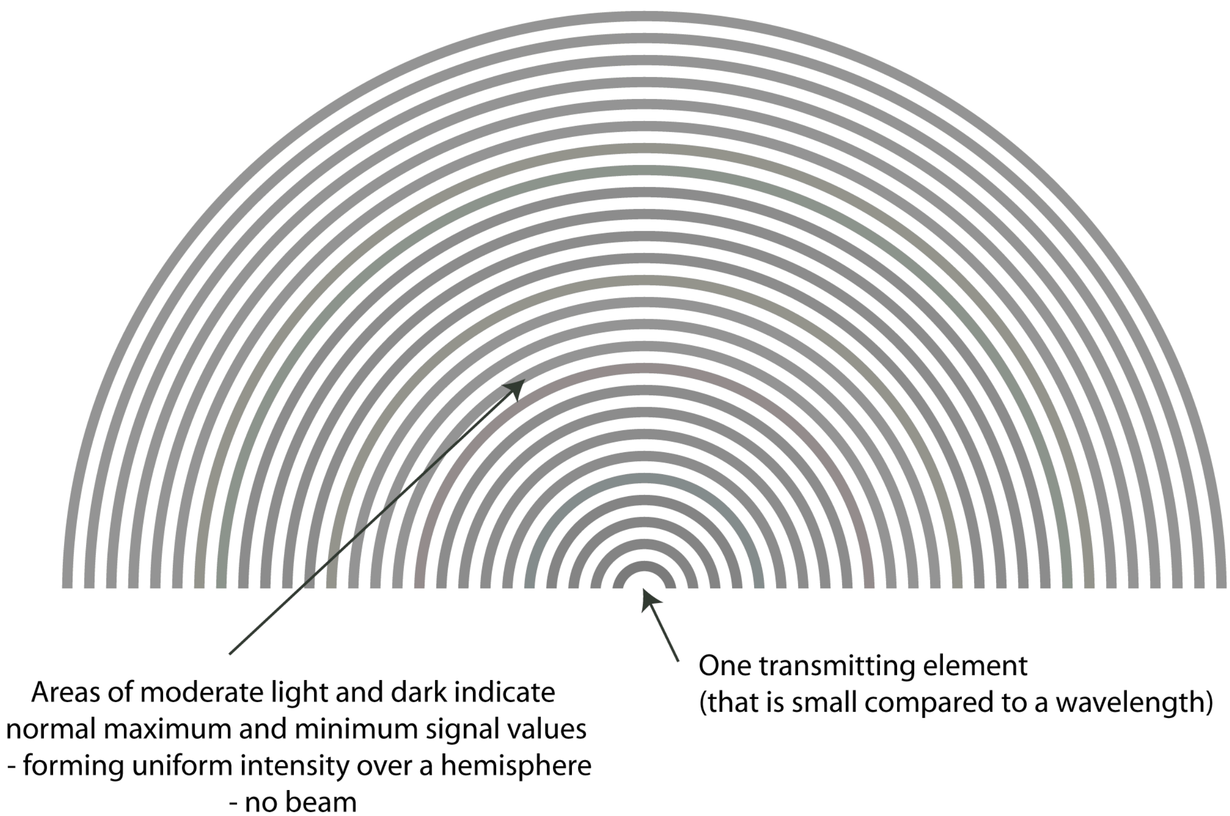
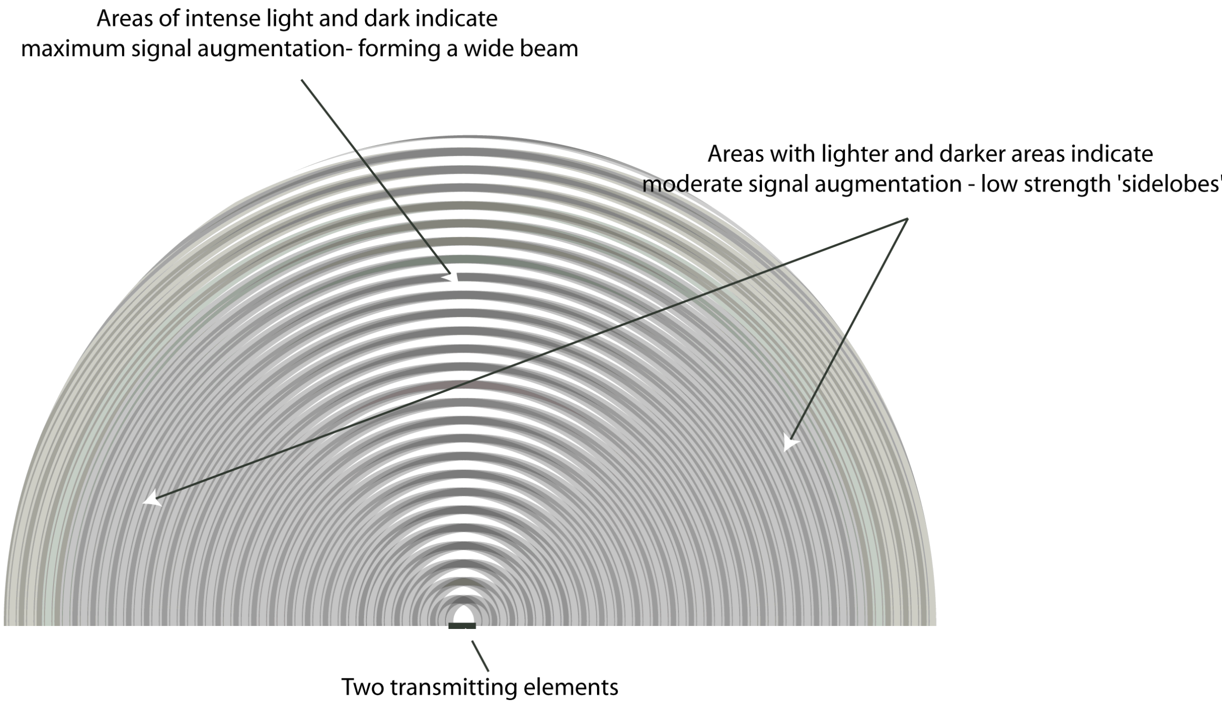
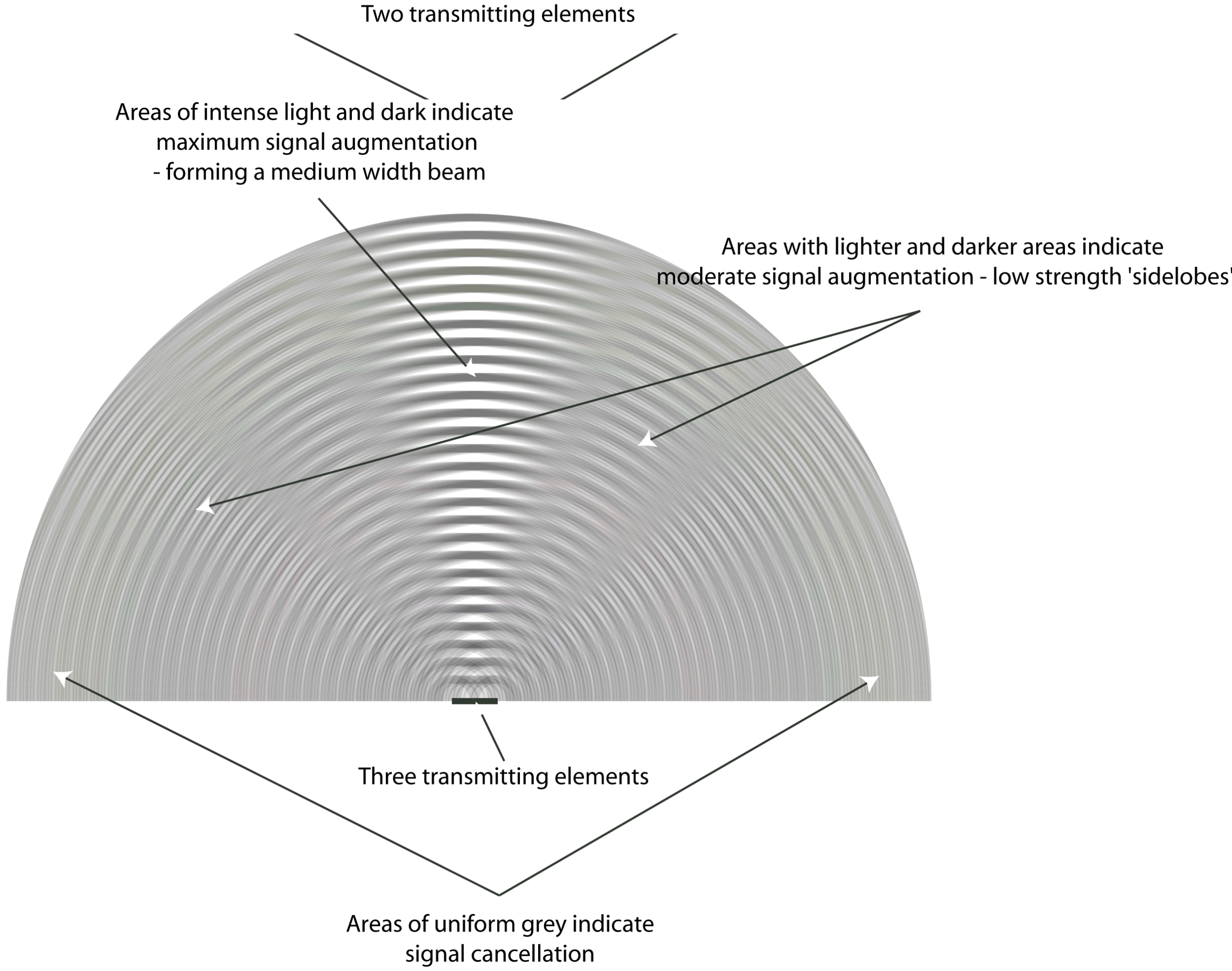


Figure 3.4a The radiated pattern from one transmitting element

When the number of transmitting elements is doubled to two you start to notice a rudimentary beam being formed as illustrated in Figure 3.4b next. It is still very wide, perhaps as much as 50° but the effect is significant.

The concentration of power into a beam becomes even more pronounced as more elements are added as shown below in Figure 3.4b, two elements, and Figure 3.4c three elements.





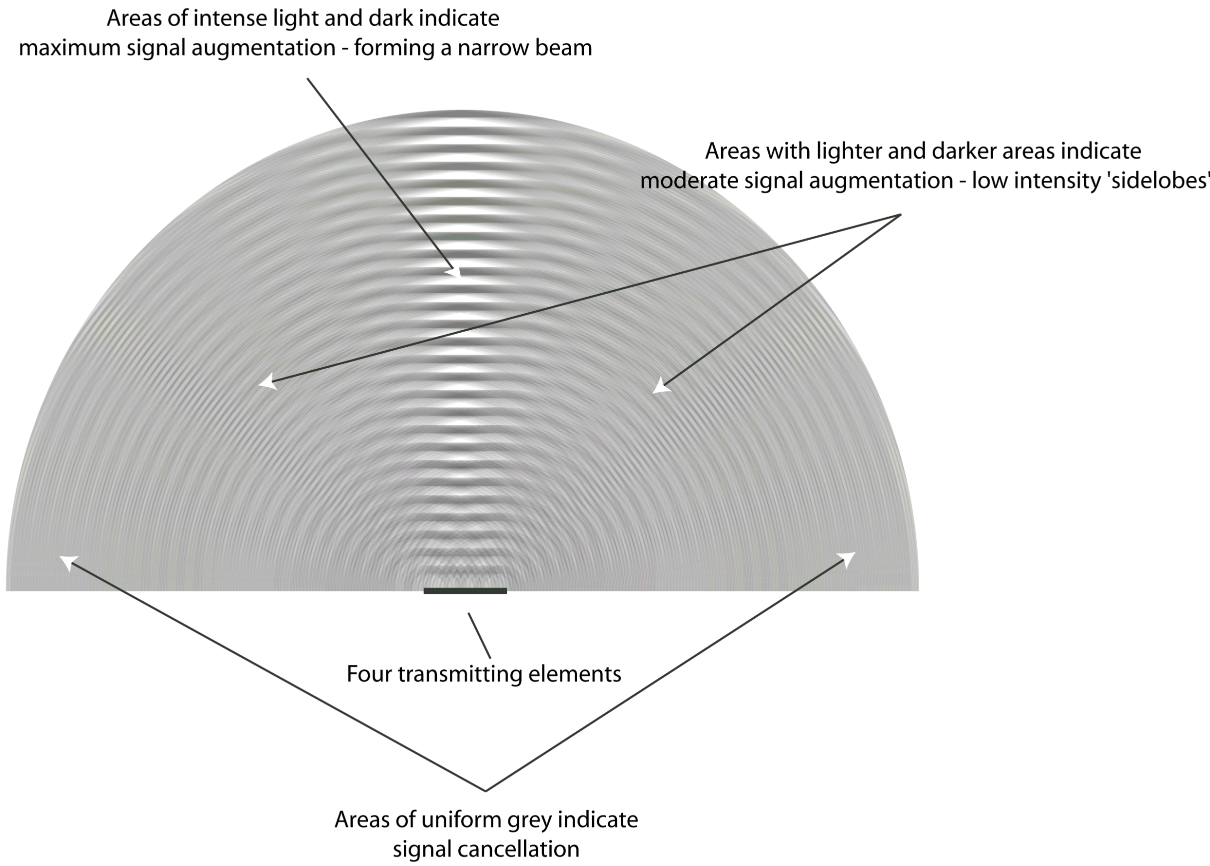


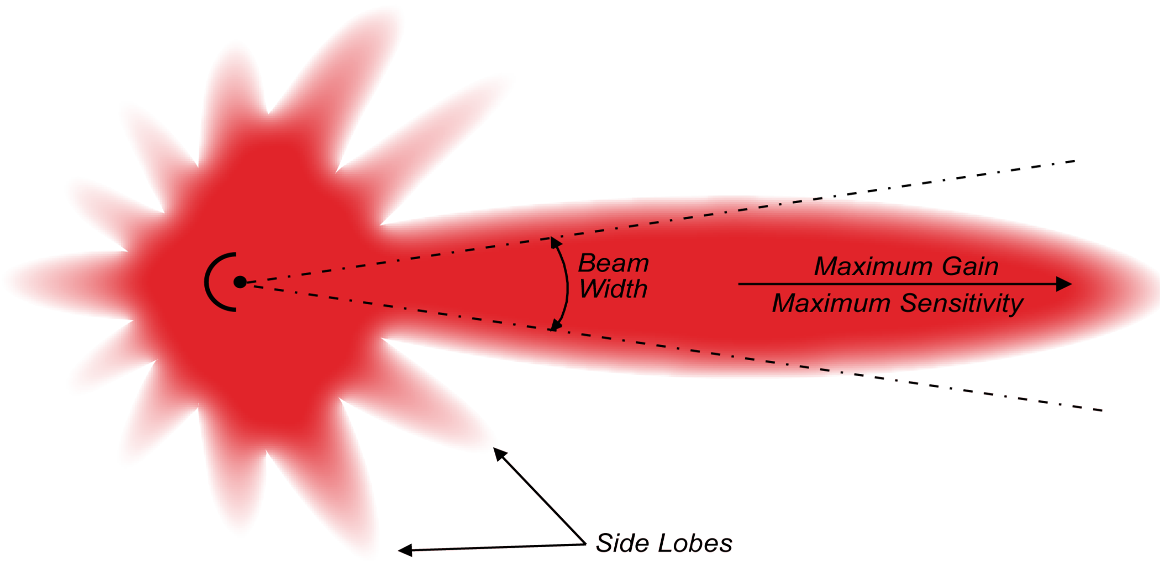
Figure 3.4d A four element radiation pattern

In Figure 3.4d a much more distinct "beam" can now be seen as are the much weaker and rather "shadowy" side lobes shown above. By adding many more elements to our antenna, like the ones shown in the picture in Figure 3.3, the beam can be increasingly refined into a much more usable narrow beam which will give us longer range, better target discrimination and more sensitivity to weaker radar echoes.

Because the size of these transmitting elements are determined by the radar's operating frequency, the physical width of the antenna must increase if we wish to have a narrower beam. Thus a 48" wide open antenna gives a beam less than 2° wide and a 24" domed antenna can only manage a little bit more than a 5° wide effective beam.

3.1.3 Side lobes

The pattern of the radiated energy from a typical radar antenna will be similar to the diagram shown in Figure 3.5 on page 25. This is known as the Horizontal Polar Diagram (HPD) of the antenna. The radiating energy forms lobe patterns around the antenna with the main lobe forming the search beam and the others "side lobes".



This diagram is *not* drawn to scale

Figure 3.5 Radar horizontal polar diagram

3.1.4 Cross-section of the main beam

The width of a radar beam is determined somewhat arbitrarily by measuring the angles at which the energy detected is 71% (actually 0.707) of the maximum in the centre of the beam as it passes over a point in front of the rotating antenna. This is shown by the dotted lines in the diagram below.

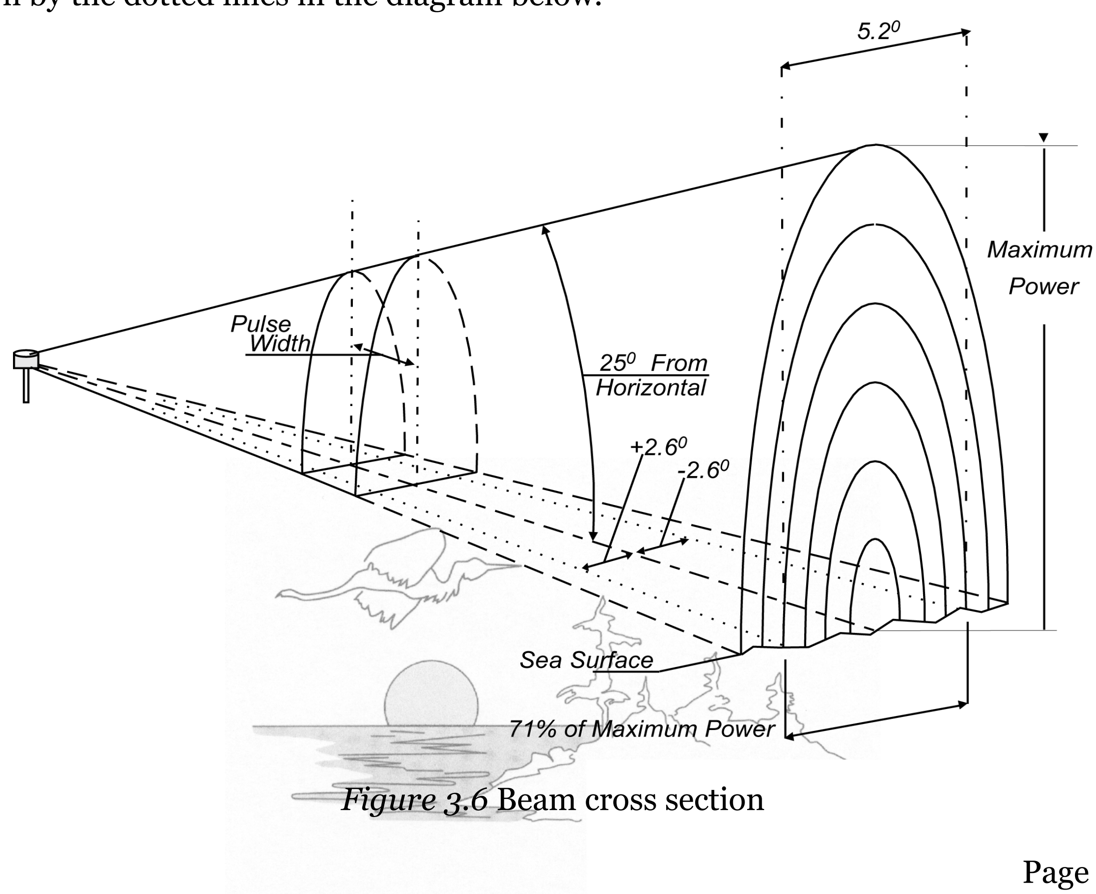


Figure 3.6 Beam cross section

Figure 3.6 illustrates this looking from a different perspective. A slice through the main beam shows how its make-up is not consistent in energy strength across its effective width. The core has the greatest power that falls off on either side of the centre azimuth. The implications of this physical characteristic on the interpretation of displayed radar echoes are discussed later.

The final factor, which greatly affects a radar antenna's coverage of the area around the vessel, is its height above the water. The effects of positioning the antenna on the ability of the radar to "see" are discussed in some detail in a later chapter.

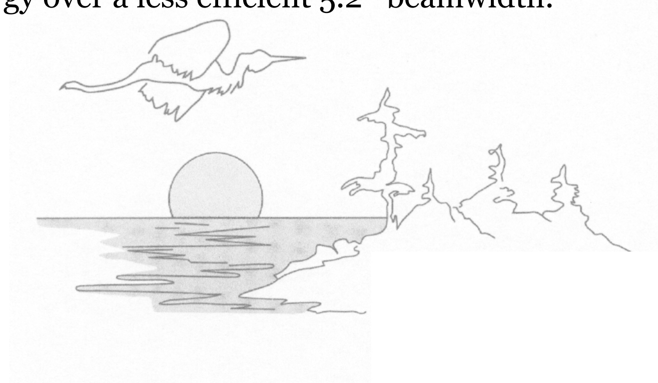
3.2 The Radar Receiver

When you switch your radio to the Amplitude Modulation (AM) broadcast band and it is not tuned to a transmitting radio station, you can hear the "hissing" noise called static. Sometimes there are "crackles and pops" interspersed with the background noise, all of which may be loud enough to drown out a distant station you want to hear. This is the environment in which a radar receiver operates all of the time. It is not merely trying to detect a transmitted signal, but the reflected echo of that signal in among the ever present "snap, crackle and pop" of the static, and the noises from other electronic systems that always exist in the atmosphere.

3.2.1 Signal attenuation

A signal transmitted from a single point will spread evenly out from that point in all directions. You can see that the signal strength in watts per square metre (W/m2) will diminish very rapidly indeed over the entire inner surface of the expanding bubble. Even when a reasonably efficient antenna is used to concentrate the energy in to a beam the drop in power received at a point is significant.

Figure 3.7 on page 27 attempts to show you approximately how the power contained in one radar transmitted pulse would be "distributed" at 5 NM from the antenna and the real advantage of a narrow 1.85° beamwidth antenna's ability to concentrate the energy over a less efficient 5.2° beamwidth.



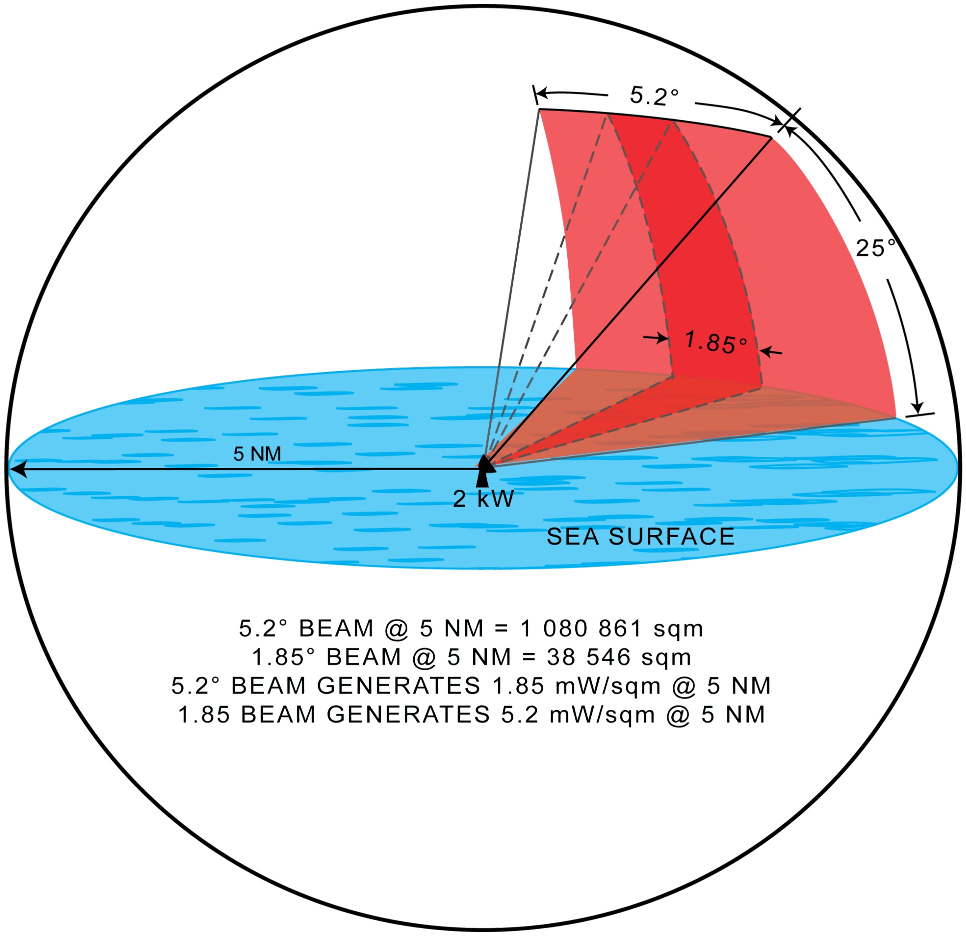


Figure 3.7 Beam areas at 5 NM

For instance, using the antenna specifications we have used in earlier examples, and assuming that the transmitted 2 kW power transmitted will be dispersed evenly, which it is not, (see Figure 3.6) at 5NM distance the area of the beam is some 1,080,861 m^2. The resulting signal strength will have fallen to 1.85 mW/m^2, a remarkable drop in RF energy (see Figure 3.7). This explains why a larger reflecting surface gives a better echo. When this logic is applied to the 122 cm (48") antenna with its 1.85° beam-width, the power density at 5 NM rises to 5.2 mW/m^2 which supports the main argument for using the widest antenna possible. These are theoretical numbers and do not allow for the fact that the power distribution within the beam is higher in the centre and fades towards the edges; however, they do illustrate the rapid drop in the energy available for generating a usable reflected signal.

3.2.2 Reflecting surfaces

There are three main factors that will influence the formation of a usable echo:

a) the relative size of the target (cross sectional area);
b) the reflectivity of the material from which it is made (steel, fibreglass etc.); and,
c) its shape (flat, square to the signal, sloped, round, etc.).

Any of these variables can, and will, decrease the strength (power) of the reflected echo. Therefore a radar receiver must be designed to detect echoes in the microWatt (µW) range.

3.2.3 Radar cross section (RCS)

The radar cross section (RCS) of an object is the area of an equivalent perfectly reflecting surface that a radar would see, once all of the variables listed above are taken into consideration. For instance the Queen Mary II, beam on, would present the almost perfect RCS, i.e the real cross section would be the about the same as the RCS. Contrast that example with a fiberglass hull and you can see that even if the physical dimensions were the same a steel hull will reflect energy more efficiently than a similar fiberglass one will. This is the material effect. Lastly, if the fiberglass hull is rounded, as most are, then the energy reflected will tend to be scattered over a larger area.

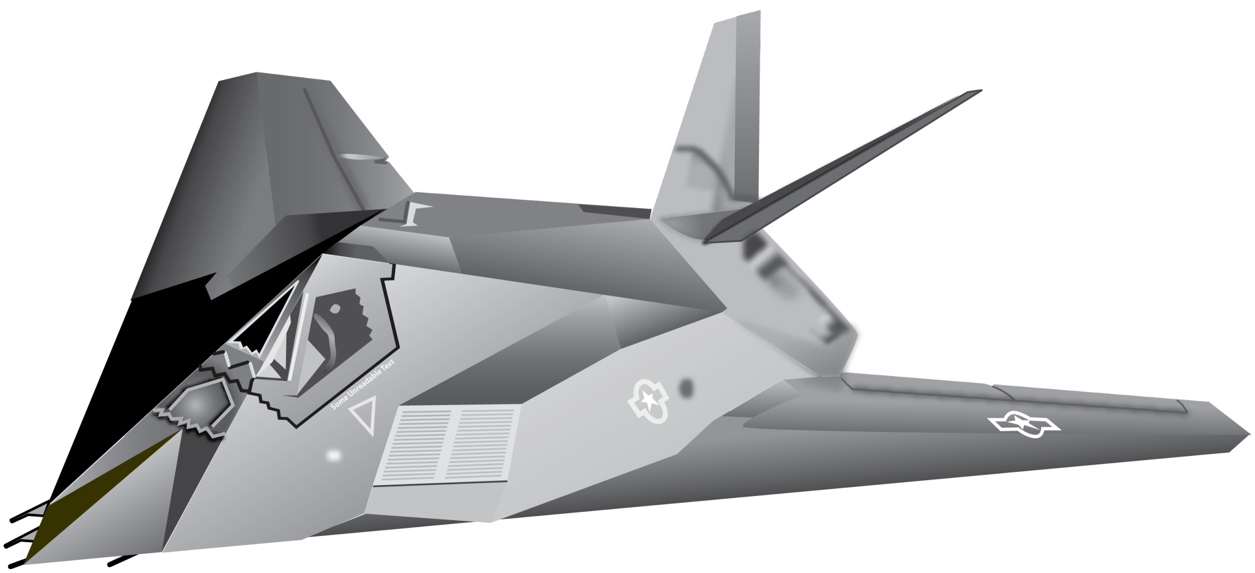


Figure 3.8 F117A "Stealth Fighter"

Here is where the RCS can come into play. A modern example of the effect of RCS on a radar return is the USAF F117A "Stealth Fighter"(Figure 3.8). The aircraft was designed to reflect the smallest amount possible of any radar energy striking its surface. As you can see the aircraft is designed to show the minimum amount of flat surfaces to radar pulses approaching it from the side. Most of the energy striking it will be reflected or bounced in a direction other than back towards the source of the signal. A further deterrent to a good radar echo is the aircraft's special rubber-like coating "tuned" to absorb as much energy as possible. This aircraft is reputed to have an RCS in the square millimetre range, much less than the radar reflector discussed in Section 9 (Figure 9.5) and about that of a sparrow!

The reverse is also true. Some vessel structures might reflect a large amount of the received radar energy directly back to the transmitting antenna, if its orientation happens to be optimal, but a small change in that alignment could drop the energy reflected dramatically, like the Stealth Fighter.

These factors are among the reasons why some small objects appear to paint like a billboard while other apparently substantial ones do not paint at all. The lesson here is don't assume a clear radar display has no hazards.

3.2.4 The "black box"

The efficiency of the antenna's transmitting ability is equally important in it's receiving function. The larger the receiving surface the better the collection of the weak echo will be. A pre-amplifier immediately boosts all of the tiny signals arriving at the antenna, before they are changed into a more usable frequency for the receiver-proper to get to work. The receiver itself is truly the black box of modern radar where most of the electronic magic takes place. The receiver consists of a sequential series of clever circuits. In addition to a number of signal amplifying circuits, some reduce the effects of strong signals overriding weaker ones. Others try to compensate for the distance an echo has travelled, and so on. Later we discuss the conditions that can hide valuable signal information from us. We will see how the various controls on the display unit of the receiver can be used to adjust these circuits and how they might reduce lost echoes.

We will leave a description of these receiver circuits and discussion on the remaining function, the display, until a little later.

3.3 Summary - antenna

- Because the wavelength of a radar signal is much, much longer than that of visible light, a small radar antenna is not able to form transmitted energy into the tight-knit beam of light we expect from a good flashlight.

- A well designed antenna can concentrate the transmitted pulse into a very usable horizontal beam-width, depending upon how many transmitting elements wide the antenna is made (rows). The vertical beam-width can be also be reduced by increasing the number of transmitting element's height (stacks).

- The signal power in a radar beam is strong in the middle of the beam but it becomes weaker quite quickly as you move away from the centre core.

- There are also weaker side and back-beam lobes around an antenna that can occasionally give very misleading information to a radar operator.

3.4 Summary - receiver

- The receiver has to be able to work in the "dirty" environment of static noise plus any spurious radiations from other radars and electronic equipment around it.

- It has to be sensitive enough to identify an echo of less than one hundred thousandth of the transmitter power it works beside.

- It must have controllable circuitry to compensate for the wide range of distortions produced by the environment in which it operates.

- Above all, the receiver must pass clean, usable signals to the display unit if it is to generate as unambiguous a radar picture as possible.

Next - Target discrimination

We will look at the effects of, and interactions between, the physical variables we have learned about so far, and how they can affect our ability to interpret the radar picture on our display.