

# RADAR AND ELECTRONIC NAVIGATION AIDS

*(Contains extracts courtesy of A.N.T.A. and Col Tritton)*

## Introduction

### 1. Radar equipment

Power Supply  
Transmitter  
Waveguide  
Scanner  
Time Base Unit  
Receiver  
Display unit or PPI  
Colour Displays  
LCD Display  
Interfacing and interlacing

### 2. Basic radar controls

Power/standby/transmit  
Brilliance  
Gain  
Heading marker  
Range  
Tuning  
Anti-sea & rain clutter  
Interference rejection  
Echo enhancement  
Heading marker and range rings  
Pulse length control  
Off centring

### 3. Tuning the radar

Turning on, tuning in, switching off  
Incorrect adjustment

### 4. Radar presentations

SHU - Relative motion unstabilised display  
CU - Relative motion course-up stabilised display  
NU - Relative motion north-up display  
TM - True motion display

### 5. Radio propagation and radar performance

The radio wave  
Marine radar types  
Radar transmissions  
Target acquisition  
Navigational aids  
Performance monitoring

## **6. False radar information**

False echoes

Beamwidth distortion

Range and bearing discrimination

## **7. Navigating with radar**

Bearings

Ranges

Position fixing

Pilotage

## **8. Collision avoidance**

Early warning of risk of collision

Relative Motion

Plotting

## **9. Automatic Identification Systems (AIS)**

External link

## **10. Electronic chart display information systems (ECDIS)**

External link

## Introduction

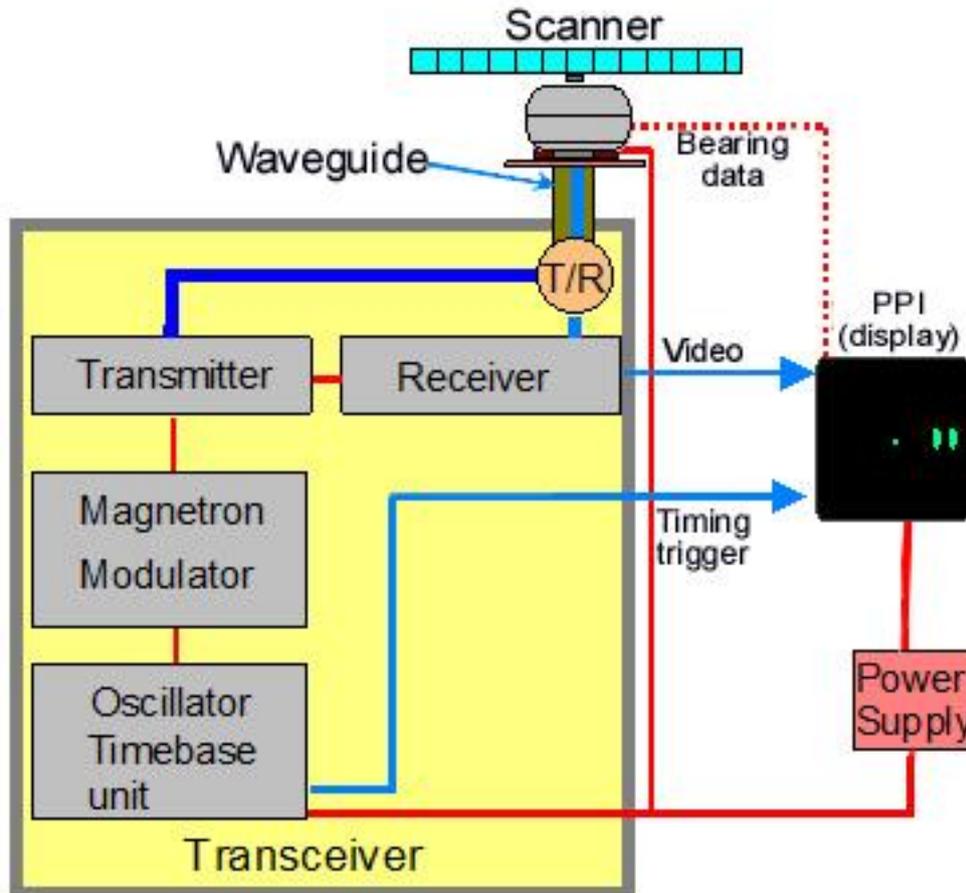
The first time I shipped with radar was a revelation to me. Where previously night navigation and out of sight of land required careful plan and anxious hope, now the ship appeared as if on a map, and better still the many approaching dangers beyond sight were highlighted. Radar can pierce darkness, rain, fog, and weather. It can, when within range, show ships, aircraft, storms, islands, headlands and prominent landmarks. But here lies its great advantage and disadvantage, as with reliance on any radio aid – if tuned and interpreted properly you find a signal, but if not, you get nothing. You can falsely assume that nothing displayed indicates that nothing is there. The purpose of this text is to explain how to tune a radar set, maintain the display for optimum performance and to interpret the information displayed.

The name radar comes from “**radio detecting and ranging**”, a system that Scotsman Robert Watson-Watt patented in 1935. During World War II, from a shed facing the North Sea so bristling with electromagnetism that his hair stood on end, my father in law operated the prototypes that successfully warned of enemy aircraft attack. Squeezing the 360° radio wave propagation into a narrow beam remains only partially achieved requiring dangerously high microwave energy. However trials have improved radar so much that it is now standard equipment on vessels.

Radar now enables range and bearings for position fixing, navigational aids, collision avoidance and search and rescue devices. However, in order to safely operate the master is responsible to correctly use all electronic instrumentation and understand its limitations, including radar.

# 1. Radar equipment

Radars transmit directional microwave radio pulses with a rotating ariel (the scanner) in a 360° circle around the machine. It detects the bearing and range of echoing pulse returns from significant surrounding targets to produce a map like display.



## Power Supply

Considerable power is required by a radar for transmit mode, of up to 400 watts even in the smaller sets. The supply is usually a small solid state power pack or motor alternator or a generator with larger sets.

## Transmitter

Super high frequencies of electromagnetic energy waves (3000 to 10000 MHz, these are wavelengths of 10 and 3 cm, respectively) are produced in the oscillator. The operating cycle of the oscillator is initiated by the trigger, which determines the pulse repetition frequency (PRF). The pulses are shaped in the modulator, which determines the pulse length, then passed to the magnetron, which converts the energy into radio waves and determines the radar frequency. They are then passed to the transmitter, which in modern radars is usually combined with the receiver (the transceiver). The transceiver is usually located within the scanner unit.

## Waveguide

The pulses are transmitted to the scanner unit by the waveguide. A waveguide is hollow copper tubing, usually rectangular in cross section, having dimensions according to the wavelength of the carrier frequency. An electronic switch in the waveguide, called the transmit/receive cell (T/R) isolates the receiver during transmission to protect it from the high power of the transmission. In modern radars the waveguide and the T/R switch are usually located within the scanner unit.

## Scanner

The most common type of radar aerial, the open array scanner is shown below.

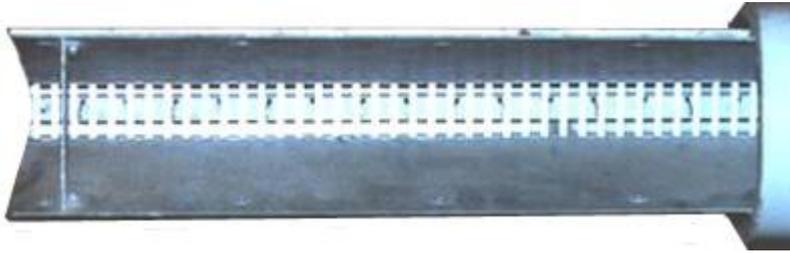


Scanner can be housed within a radome as below. This particularly suits yachts as the rotating scanner can turn without fouling sails and rigging.



The scanner unit radiates the radar pulses and passes returning target echoes to the receiver. The scanner also focuses the outgoing microwaves into a tight beam in much the same way as a torch reflector focuses the light from a bulb. This is done in most marine radars by feeding the microwaves into a hollow tube inside the rotating scanner, which is also called a waveguide. The waveguide is sealed at both ends but has a series of small slots in one side. Each slot acts like a small aerial but their combined effect is to focus the microwaves into a narrow beam. This type of scanner is called a horizontal slotted waveguide.

The length of the scanner will determine the radar's horizontal beamwidth (HBW). A wider scanner will result in a narrower beamwidth which will produce better bearing discrimination. The inside of a horizontal slotted radar scanner is shown below.



In every revolution of the scanner, radar pulses hit the target not once but many times during the time it is aimed at the target. The effect on the screen is cumulative, the more hits the brighter the target appears on the screen. Should insufficient pulses hit the target only a weak echo will be displayed and it will disappear quickly. The number of scanner revolutions should be between 20 and 30 revolutions per minute in order to both display the target brightly and prevent the disappearance of the picture between scanner revolutions. Most scanners operate at 24 rpm.

A more recent innovation is the patch aerial. This aerial uses a printed circuit consisting of an array of copper pads, to focus the beam.

### **Time Base Unit**

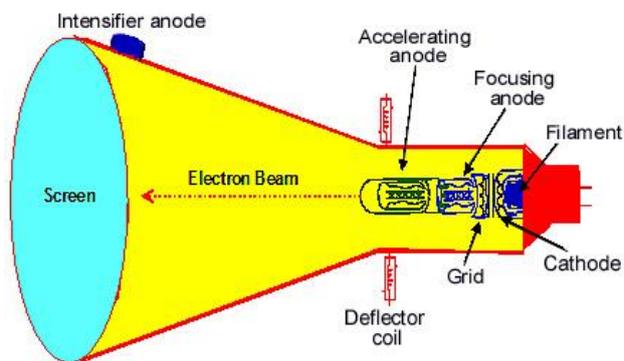
With an analogue radar, a motor rotates the scanner at approximately 24 rpm and a signal from the time base unit to the display unit causes the trace to rotate in synchronisation with the scanner. As the scanner passes the fore-and-aft line, a heading marker will appear on the display. Digital radars use microprocessors to add heading and timebase information to the display.

### **Receiver**

The receiver unit detects incoming echoes which are at more or less the same frequency as the outgoing frequency and mixes them with a signal from the local oscillator to reduce them to an intermediate frequency, usually about 60MHz. The signal is then amplified by the IF amplifier, weaker distant targets are amplified more than stronger/closer targets and is passed to the video amplifier, which converts the signal to a suitable form for video display. The signals are then passed on to the display unit, with the addition of range and bearing marker signals. The receiver in modern radars is combined with the transmitter and called the transceiver. It is usually located within the scanner unit.

## Display unit or PPI

Analogue type (older) radars consist of a cathode ray tube (CRT), the face or screen of which is commonly referred to as the scope, and various timing circuits and controls. In the scope a stream of electrons is directed towards a fluorescent screen. The phosphorus glows when illuminated by the electrons, while internal circuitry forms the trace or sweep. A beam begins at the centre and sweeps out again and again, each sweep corresponding to the progress of a microwave pulse going out and back, and each successive sweep moving a little further around the screen in time with the rotating scanner. A returning echo is added to the sweep signal so that the screen is more brightly illuminated (painted) at a point corresponding to the bearing and range of the targets echo. This produces a very clear but very dim picture and the scope is fitted with a cowl to allow daylight viewing. This presentation is called a Plan Position Indicator (PPI).



The diagram above shows a cathode ray tube (CRT) using magnetic deflection obtained from coils placed around the neck of the CRT-other CRT's use electrostatic deflection, by use of deflection plates.

Modern displays units, called rasterscan radars (colour radar) use microprocessors to analyse echo range and bearing and present like a TV. The rasterscan picture (paint) is rectangular rather than a circular. In rasterscans there is no rotating trace, instead the echo is digitalised and painted line by line across the screen (called interlacing). As the sweep moves across the screen the pixels (picture cells) are illuminated and can be further electronically enhanced in colour or duration of illumination. A small rasterscan radar is shown below.



To obtain a sharp image a high resolution is required. Resolution is measured by the density of the pixels, the more pixels per square inch the higher the resolution. A common radar display resolution of 640x480 means that the screen consists of 640 columns by 480 rows of dots, that is,  $640 \times 480 = 307,200$  pixels.

Pixels are electronically refreshed or updated so they will remain bright, at a rate of about 30 or more times each second. Displays may be interlaced or non-interlaced. Interlaced displays do not draw the entire picture in one pass. On the first pass, it draws every other line and draws the remaining lines on the second pass. Non-interlaced displays will therefore be more stable.

On early model raster scan radars piccolos were either on or off, which meant that there was no visible difference between a weak echo and a strong one. This could result in weak echoes like rain clouds completely blocking out the display and masking targets within the blocked out display. Later models have multi-level quantisation displays, in which each pixel can operate at several levels of monochrome, which allows the operator to distinguish between a weak and a strong echo. On modern raster scan radars remote displays or full dual displays units are available.

Most radars produced for small craft today have a green and black monochrome quantised display. However, some of the larger more expensive radars feature full colour displays.

### **Colour Displays**

Colour radars offer several different formats, with up to four different colours. Multi-level monochrome displays can display 16 levels of quantisation in yellow or green. Or multicoloured displays can identify the echo's relative strength and display the echoes as different colours (green, yellow and red) on the display. A drawback with this type of display is that the operator's attention is drawn to the red echoes while weaker less intense echoes, but possibly more significant echoes, are ignored. Colour technology provides valuable information such as filtering out fog, rain, etc, and is preferred by many operators.



Other colour displays use colour to differentiate between genuine targets and display information, EBLs and VRMs, etc. Still others apply colour to targets to increase their contrast, usually a yellow-orange colour for targets and a different colour for display information.

Probably the best feature of colour radars is their ability to select the background colour. In daylight a blue background would usually be selected as the display is easy to read in bright sunlight. While at night most operators would select a black background as it reduces glare, preserving night vision.

Below is shown a Furuno 72 mile analogue radar. The scope radars are characterised by their circular display and daylight viewing hood.



### **LCD Display**

Another type of modern presentation is the LCD (liquid crystal display). LCD displays use rasterscan technology to create the picture. But, instead of using a CRT, LCD radars use an array of liquid crystal diodes, sandwiched between panel of glass to produce the picture. LCD displays are lightweight and require little power. However, they produce less contrast, produce more glare and have poorer screen resolution than CRT's. To overcome the contrast problem most are back lit, allowing daylight viewing. On the other hand, CRT's are bulky, fragile, and consume a lot of power.



### **Interfacing and interlacing**

Most radars today are capable of interfacing with other navigational equipment, such as GPS, electronic compasses, logs, sounders, weather instruments, engine instruments and autopilots. For example, when interfaced with a GPS navigator, electronic compass and log, the position and vector of any radar target on the screen

that has been acquired by the ARPA (Automatic Radar Plotting Aids) can be digitally displayed on the chart. In order to interface the instruments must be able to communicate with each other in the same software language. To allow this most manufacturers have adopted a standard code defined by the National Marine Electronics Association (of America). A later version of this standard is NMEA-0183.



The above figure shows a north-up radar display interfaced with the GPS and other instruments to give own ship's position, position of target acquired by the ARPA, SMG, CMG, waypoint information, air temperature, sea temperature and barometer reading.

Interlacing on the other hand refers to the line by line process by which pixels are activated in digital displays. Pixels are electronically refreshed or updated so they will remain bright, at a rate of about 30 or more times each second. Displays may be interlaced or non-interlaced. Interlaced displays do not draw the entire picture in one pass. On the first pass, it draws every other line and draws the remaining lines on the second pass. Non-interlaced displays will therefore be more stable.

## 2. Basic radar controls

Shown below, the main control panel of a simple radar.



There is no standard radar control panel and even names vary with differing brands. However, the IMO (International Maritime Organisation) has a set of standard symbols for the most important controls, but they may not be used on all radars.

### IMO SYMBOLS FOR RADAR CONTROLS

anti-clutter rain minimum	anti-clutter rain maximum	anti-clutter sea minimum	anti-clutter sea maximum	radar on	radar stand-by	aerial rotating	north-up presentation
scale illumination	display brilliance	range rings brilliance	Variable range marker	ship's head up presentation	heading marker alignment	range selector	short pulse
bearing marker	transmitted power monitor	transmit receive monitor	off	long pulse	tuning	gain	

The basic controls used to tune the performance of a radar are:

- power/standby/transmit
- brilliance
- gain
- heading marker
- range
- tuning
- anti sea clutter control (STC)
- anti rain clutter control (FTC)

### Power/standby/transmit

The power/standby/transmit switch usually has three positions. Pressing the power switch will activate the radar to standby, however it doesn't come on immediately as the magnetron needs a few minutes to warm up before it can transmit. The radar will have some form of visual signal to count down this wait period, the approved best standard being within 120 seconds. The radar can then be switched to 'transmit' and on some sets a short or long pulse can be selected at this time, normally long pulse would be selected. A long pulse will be more likely to show an echo from a weak target or a target at a longer range. A short pulse will achieve better definition on short ranges.



radar on



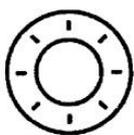
radar  
stand-by



aerial  
rotating

As well as its main function of giving the magnetron time to warm up, in 'standby' mode the scanner is not rotating (on most sets) and is a way of conserving power and prolonging the life of the magnetron while keeping the set ready for immediate use. It is a good practice at sea to leave the radar on 'standby' at all times as this will prevent condensation forming inside the radar set.

### Brilliance



display  
brilliance

The brilliance control on an analogue radar (old style) controls the brightness of the rotating trace and will also affect the brightness of the displayed echo so it needs to be adjusted so that the trace itself is just visible, to give a good contrast between echo and background.

On a raster scan display (new style) the brilliance control regulates the brightness of the picture (scale illumination), making it bright enough for daylight viewing or dim enough so as not to impair the operators night vision.

## Gain



gain

The gain control may appear to function like the brilliance control in that it makes the picture brighter or darker, but it is completely different so it is vital not to confuse the two. Gain affects the receiver and not the display as the brilliance does. Turning up the gain increases the amplification of the incoming signal, making weak echoes look stronger, but confusing the display with background speckle or noise, similar to the background crackling of an ordinary radio. Turning down the gain will reduce the sensitivity of the receiver and reduce the noise, but care must be taken not to overdo as weak or distant echoes can be lost.

## Heading marker

The heading marker and the range rings can obscure small targets. So it's a good idea to have the range rings turned off when they are not in use and to delete the heading marker every few minutes to see if it is masking a small target, dead ahead. The heading marker delete control is usually self cancelling; that is the heading marker will reappear as soon as the button is released.

## Range



range  
selector

The range control regulates the range at which the set operates by changing the size or scale of the area on the display. Changing range also affects the radar's pulse length, PRF (pulse repetition frequency), and video presentation. You change the range just as you change charts for passage making or close-in piloting. For coastal navigation you might select a range of 12 miles so that appropriate coastal features are displayed, for collision avoidance a range 24 miles may be appropriate, for pilotage into a confined anchorage a range of  $\frac{1}{2}$  a mile may be needed.

Radars can superimpose range rings to scale the distance of targets displayed on the PPI. A more precise feature is the variable range marker (VRM) that enables a target to be highlighted so its range information is displayed in print format.

*Note: It is considered good watch keeping practice to vary the range monitored, so as to get best use of radar's detection capability.*

## Tuning



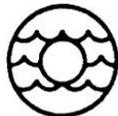
tuning

The tuning control can be compared to the tuning control of an ordinary radio, in that it tunes the receiver to the frequency of the transmitter. Poor tuning adjustment may not be easily recognised on the screen. Tuning slightly out will eliminate some very weak echoes, but still produce a clear picture of the stronger ones, hence the importance of frequent fine tuning of the set. Not all sets have a tuning control.

## Sea Clutter Control (STC)



anti-clutter  
sea  
minimum



anti-clutter  
sea  
maximum

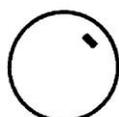
The radar beam will bounce echoes off the sea around the ship, particularly if the weather is a little rough. This result will be a bright sunburst pattern in the middle of the screen which will be more pronounced in the upwind direction. You could reduce this by turning down the gain, the down side to that solution however, is that the echoes of more distant targets will be lost as well.

The solution is the sea clutter control. It works by reducing the receiver gain for a few microseconds after each pulse is transmitted, then gradually restores it to its former level. It works very well, but its use requires care. Too much sea clutter control will result in the loss of close range targets. At sea the sea clutter control must be continually monitored and adjusted.

## Rain Clutter Control (FTC)



anti-clutter  
rain  
minimum

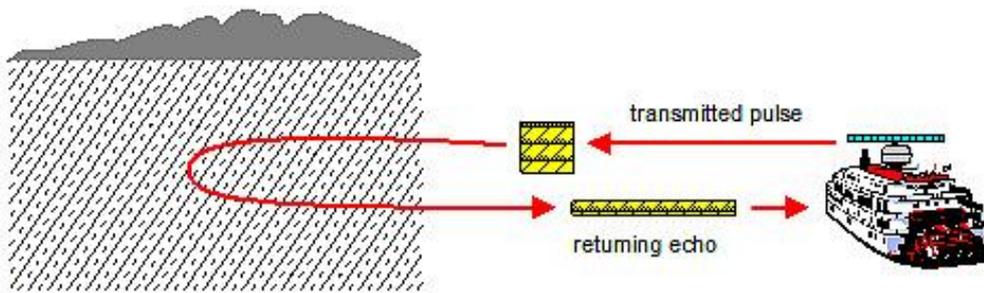


anti-clutter  
rain  
maximum

The rain clutter control will reduce the interference on the screen due to the rain and increase the chance of seeing targets within rain showers. The effect on returning

echoes from rain on the screen is usually no more than a transparent smear, looking a little like cotton wool, but it can be dense enough to conceal other echoes within the shower. In a tropical downpour however, the rain can completely block out all echoes, at times requiring the operator to stop the vessel.

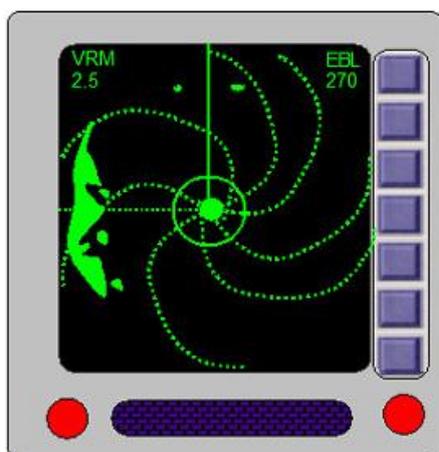
The rain clutter control works by making use of the fact that the returning echo from rain is different from the returning echo of a solid object. The returning echo from rain is much longer and very much less dense than the echo from a solid object. The rain clutter circuitry works by passing on to the receiver only the leading edge of a returning echo. This does not affect the returning echo from a solid object like a ship, but drawn out, weak returning echoes from the rain however, will be weakened considerably.



In practice however all returning echoes will be affected, resulting in a reduction in strength from all returning echoes and a reduction in picture quality. Sometimes the sea clutter control may be used to better effect, to see through the rain. However, if you adopt this approach remember that close-in targets will also be lost, which may defeat the purpose.

### Interference Rejection (IR)

Mutual Radar Interference is caused by other radars in the locality operating on a similar frequency to your ship's radar. The interference shows up as bright spots



scattered over the screen, or as a distinctive pattern of dotted lines curving outwards from the centre of the screen. It is more common on longer range scales as on shorter range scales only a few of the interfering pulses will be displayed.

If only one other radar is involved this is not too serious, but in busy traffic areas the clutter can be dense enough to cause confusion. An interference rejection circuit can minimise this problem. It works by rejecting any echo which does not return from any two successive pulses. While large targets will not be effected by IR, some small echoes may be lost. There is no IMO symbol for IR.

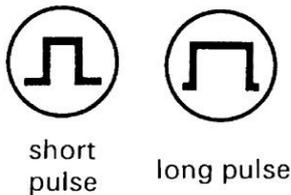
### Echo enhancement

To assist the operator to spot small targets, most modern radars have the ability to expand them. Usually named echo stretch or expansion, its sole object is to make small targets look bigger. This can at times be a great benefit, but it also tends to distort the picture and reduces range and bearing discrimination. Expansion may be useful at times but should be switched off when not required. There is no IMO symbol for echo expansion.

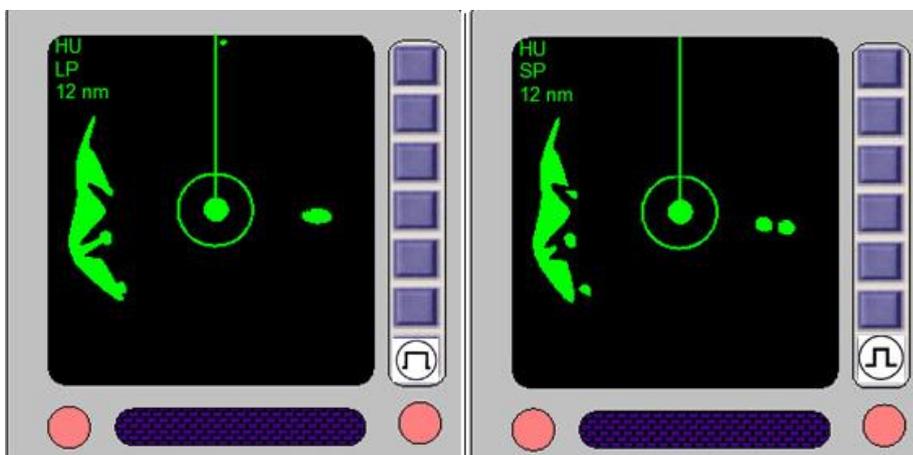
### Heading marker and range rings

The heading marker and the range rings can obscure small targets. So it's a good idea to have the range rings turned off when they are not in use and to delete the heading marker every few minutes to see if it is masking a small target, dead ahead. The heading marker delete control is usually self cancelling; that is the heading marker will reappear as soon as the button is released.

### Pulse Length Control



The pulse length is normally selected automatically with the range scale. On most sets however, in the mid ranges (6 mile to 48 mile on a 72 mile radar), it is possible to manually select the pulse length, which will have a significant effect on radar performance. A long pulse length increases the chance of detecting targets at long range. Selecting a short pulse length will increase range discrimination, making it possible to distinguish between a tug and its tow for instance.



In the PPIs shown it can be seen that when long pulse is selected the small target almost dead ahead is visible, but the tug and tow are merged and shown as a single contact. Also, on the left the land mass has merged with the islands. When short pulse is selected the small target ahead is lost, but the tug and tow are shown as separate and the islands have separated from the land mass.

### **Off-Centring**

By using the off-centring control the centre of the picture can be moved downwards or upwards and on some newer sets it can also be moved sideways. Moving the centre of the picture downwards expands the effective range of the radar forwards at the expense of range astern for instance on a six mile range, off-centring would enable you to see nine miles ahead but only three miles astern. This could be an advantage when piloting but may be a disadvantage when using radar for collision avoidance as a faster vessel can catch up to your ship very quickly and you may be unaware of its presence until you see it overtaking through the wheelhouse window.

## **3.Tuning the radar**

### **Turning on, tuning in, switching off**

Watchkeepers should be aware that masters may pre-tune and lock off the controls of their radars (a function enabled by depressing the knobs) in order to stop fiddlers. However, the following instructions apply to most radars, though the procedure may differ on more complex models.

First check that the scanner is free to rotate so as not to foul rigging and that no crew members are working in the vicinity to avoid soft tissue damage from the harmful microwave emissions.

It is particularly important with older analogue display radars before switching on the radar to first turn the brilliance and gain controls right down. Analogue displays produce the picture by directing a stream of electrons onto a delicate florescent coating inside the screen.

When the set is first turned on, this beam of electrons is directed at the very centre of the screen, over time this would result in burning out the centre portion of the display. Turning down the brilliance and gain first will reduce the intensity of the beam and prevent damage to the screen. For the same reason it's a good practice at sea, to always have some sea clutter employed so as not to burn out the centre of the screen.

Many raster scan radars will automatically tune for optimum performance. However, operators often prefer to tune manually to ensure top locally relevant performance, so all radars have provision for manual tuning. The best practice for an optimised manual tuning is by an alphabetical order. After switching on then adjust the scale

**Brilliance.** Next, after selecting transmit adjust the **Gain**, then **Heading marker**, then **Range** and then **Tuning**.

### Turning on and tuning in sequence

Turn all controls to minimum, press the power button and when the set warms up and notifies its standby status (up to 120 seconds), then switch to transmit



After switching power on you will then have to wait until the set warms up, this is usually 120 seconds. With a raster scan display you can set the brilliance to suit the conditions at this stage.



While you are waiting most sets will give a countdown, or an indicator light will come on after the warm up period is completed. Once warm up is completed the set will be in standby mode, the transmitter can now be turned on.



When the set is transmitting you will get a picture of some sort. If necessary re-adjust the brilliance. With an analogue the brilliance/gain should have been set to zero, so you must turn up the brilliance so the time-base trace is just visible.



Next, with an analogue display adjust the gain up to about 70% or until background noise (speckle) can just be seen, this will ensure that weak echoes will be seen.



With a raster scan display adjust the gain up until background noise is just seen across the entire screen, then turn it down until it just disappears.



The heading marker and the range rings can obscure small targets. So it's a good idea to have the range rings turned off so far and to check if the heading marker is

masking a small target, dead ahead. The heading marker on/off control is usually self cancelling and will reappear as soon as the button is released.



You will have spent some time with your eyes in the radar rather than out the windscreen so now a visual check for unnoticed targets is prudent. Compare the visual with the radar at the appropriate range scale. Re-adjust the gain if sighted targets are not displayed. Next select a suitable range for use. This is dependant on your manoeuvrability but at sea will usually be one of the middle ranges. For a 72 nm radar the 12 mile range would be selected and at the same time checks ensure that other controls such as, rain clutter and interference rejection (IR) are turned off.



Next the tune is adjusted. To do this you have to be receiving something, even if it's only sea clutter. Preferably choose a distant weak target, as the effect of tuning will be more obvious. Then adjust the tuning knob for the clearest and brightest picture. If you are at sea, with no targets visible, adjust the set for maximum sea clutter.

Adjust the tuning control slightly then wait for a few sweeps to see the result. Continue fine tuning for the clearest picture with most targets displayed. Most radars have a tuning indicator to assist. Tune for the maximum number of tuning lights but don't totally rely on the meter as your eye is the superior indicator. After tuning readjust the gain for a light noise background.



Next, return to the desired range scale and adjust the anti-clutter controls. Then check the VRM against the range rings and the alignment of the heading marker against the ship's head. If a performance monitor is fitted, check that performance is satisfactory. The radar is now ready for operation. After 10 minutes recheck the gain control and retune the set, because as the set warms up the transmitter frequency is likely to have changed slightly. Check gain, clutter controls and tuning again after every hour or so of operation as the set may gradually drift out of tune.



Remember the alphabetical start up sequence - after you have switched on, adjust the **Brilliance, Gain, Heading marker, Range** and **Tuning**. Before shutting down the radar set turn the brilliance and gain, to the minimum and turn off the anti-clutter controls. This will extend the life of the display and allow the next operator to set up the radar using standard procedure in the minimum time.

### Incorrect adjustment of controls

If the radar controls are incorrectly adjusted the performance of the radar will be adversely affected. This could result in small and weak targets remaining undetected and larger targets being detected at a reduced range. Good watchkeeping procedure should ensure that the radar is carefully monitored, checked against the visual watch whenever the opportunity arises and always tuned for optimum performance.

## 4. Radar presentations

### Relative motion unstabilised display

Most small vessels are equipped with a relative motion unstabilised display. This display shows the picture and not the vessel in motion. The ship is at the display's centre and the heading marker is aligned with 000° on the azimuth ring head-up.

Having your own vessel at the centre of the display is easy for relating the real world to the radar image, as the right hand side of the screen corresponds to the view to starboard and left hand side to port of your vessel.

When the vessel's course is altered, the heading marker remains upward at 000°, while the whole picture rotates in the opposite direction by the amount of the course alteration. All bearings are therefore relative to the vessel's fore and aft line. During the time the vessel is altering course, the whole radar picture is rotating, making the radar useless until the vessel settles on its new heading. This time lag is a severe disadvantage during pilotage manoeuvres.



The ship's head up (SHU) displays above show the sequence of events as when your own vessel alters course in relative motion unstabilised displays. The left shows your own vessel on a course 000°Rel & 270°T. The true target bearing is:

$$270^{\circ}\text{T} + 330^{\circ}\text{Rel} = 600^{\circ} - 360^{\circ} = 240^{\circ}\text{T} \text{ target bearing.}$$

Your own vessel then alters course by 30° to starboard (to 300°T). The middle display shows your vessel half way through the course change (15°).

The right shows the display after your own vessel has settled on the new heading of 300°T. The target's true bearing is now  $300^{\circ}\text{T} + 300^{\circ}\text{Rel} = 600^{\circ} - 360^{\circ} = 240^{\circ}\text{T}$ .

### Relative motion course-up stabilised display

The course up (CU) displays below show use the heading information from the vessel's electronic compass. This could be a magnetic fluxgate compass or a gyro compass but generally a gyro compass would be employed for this purpose as all

courses and bearings will then be true bearings and courses. The heading marker will appear at the top of the screen and will indicate the vessel's true heading. The true bearings of targets can be read from the azimuth ring. The radar is then said to be **stabilised**.

As it is still the picture that moves and not the vessel, the display is still **ship's head-up**, which means that the whole picture will move when the vessel alters course. However, the display will not be affected by yaw which makes the course-up stabilised display ideal for collision avoidance purposes.



The displays above show the same sequence of events this time with a ship's course-up (CU) stabilised display. The vessel's true course is shown at the top of the display. Therefore the bearing of the target will be a true bearing.

*Note: that it is still the picture that moves.*

### Relative Motion North-Up Display

The navigator can also choose to operate the stabilised display in the north-up mode (NU). In NU mode the display is stabilised with north at the top of the screen. When the vessel alters course only the heading marker moves. This display makes comparison with the chart easier and allows continuous observation of targets, even while altering course which makes this display ideal for pilotage purposes.



The displays above show the same sequence of events on a relative motion north-up display.

*Note:* that only the heading marker moves.

### True motion display

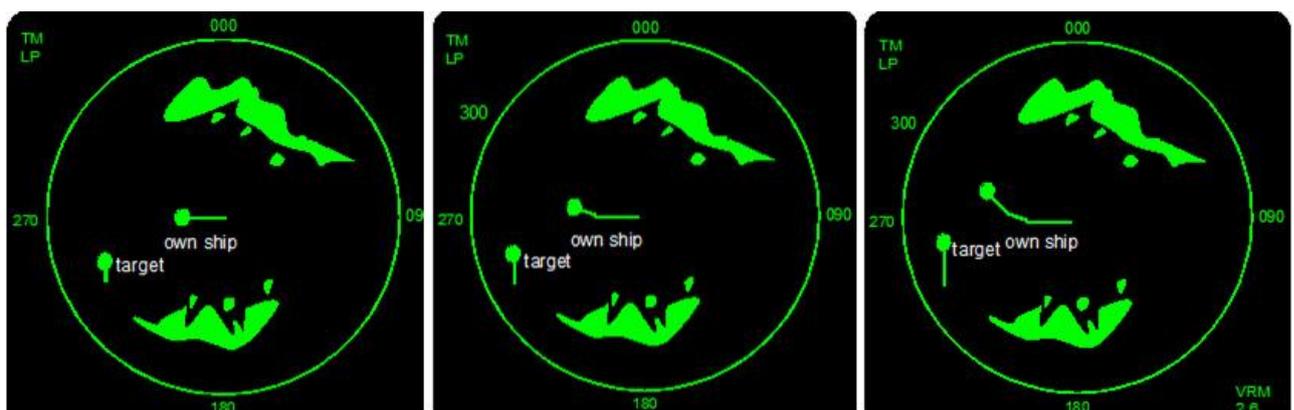
With the addition of information from the vessel's log as well as the gyro or fluxgate compass, most modern radars can be switched to show true motion. In a true motion display the centre of the picture moves across the screen in time with the actual movement of the vessel. The vessel is then seen to pass the coastline rather than the coastline pass the vessel, stationary objects like buoys will appear stationary on the display.

True motion (TM) is the preferred choice of many operators for pilotage operations as you can watch your vessels progress on the display in the same manner as you would with a GPS plotter. True motion also has the advantage that echoes of vessels under way can be distinguished at once by their trails, indicating their true courses, while the echoes of stationary objects can be readily identified by the absence of echo trails. To achieve this the radar must be ground stabilised.

True motion displays can be either **sea stabilised**, or **ground stabilised**. With a sea stabilised display, information concerning the vessel's heading and speed through the water are fed to the radar. In a ground stabilised display additional information concerning the set and rate of the tide is also applied.

Your ship's cursor can be made to start at any point on the screen and then moves outwards towards the edge. It will automatically reset itself when your ship's cursor has traversed two thirds of the radius of the screen, or it can be reset manually.

For collision avoidance purposes however, a relative motion display is preferred as calculating the closest point of approach (CPA) in true motion is a more complicated process.



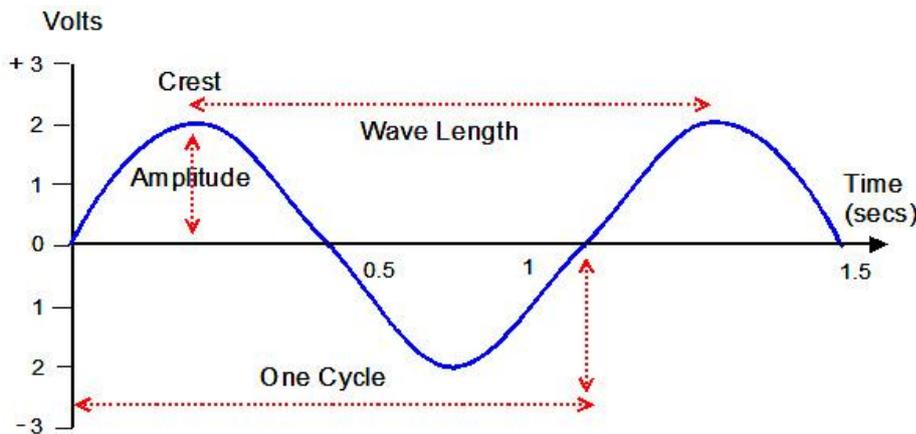
The displays above show again the same sequences of events this time with a true motion display.

*Note:* that moving objects display echo trails.

## 5. Radio propagation and radar performance

### The radio wave

To best interpret radar information an understanding of radio wave propagation and how that limits radar performance is required. It is vital for the mariner to understand how a radar operates, what information you can obtain from it and more importantly how it can deceive the unskilled operator.



**cycle**            *One complete oscillation*

**frequency**      *The number of cycles passing a given point per second. The unit of frequency is the Hertz (Hz)*

**wavelength**    *The distance between successive crests*

**amplitude**      *The vertical height of the wave from crest to centreline*

Radar uses electromagnetic energy in the form of radio waves. In marine radars, the waves are not transmitted continuously but in pulses. The pulses travel outwards in a directional beam at a constant speed of 300 million metres per second (161,987 nautical miles). When the radar pulse strikes a reflective surface, part of the wave bounces back from the object, the way sound waves bounce back from an object, and produces an echo. We can calculate the range of the target with the formula:

$$\text{Range} = \frac{T \times S}{2}$$

where:

T = Elapsed time

S = Speed of radar wave

## Marine radar types

### ***X Band or 3 cm radar***

Radar wavelengths are expressed in centimetres, the commonest commercial marine radar being 3 cm (actually 3.1 to 3.2 cm). This corresponds to a frequency of 9300 to 9500 megahertz (millions of cycles per second) and is called X-band radar.

A 3 cm radar requires a smaller scanner to achieve the desired beamwidth and definition as compared with a 10 cm radar. X-band radars are particularly suited to coastal navigation and pilotage due to their high picture definition and quality. On the negative side a 3 cm radar produces more side lobes than a 10 cm radar and the radio waves are not as refracted to the same extent. Therefore they will not achieve the same range as a 10 cm radar.

### ***S Band or 10 cm radar***

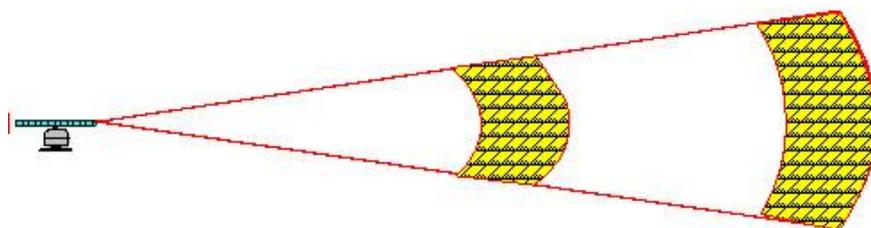
Another common marine radar wavelength is 10 cm (actually 9.2 to 10 cm) with a frequency of 3000 to 3246 megahertz. This is known as S-band radar. A 10 cm radar will require a scanner up to 5 metres long to focus the beam. However, once produced the beam will produce fewer side lobes and travel further along the surface, resulting in a greater maximum range. Another advantage of S-band radars because of their longer pulse length and greater power is that they will be less affected by attenuation than X-band radars.

S-band radars are suited to long range landfall navigation and early detection of targets for collision avoidance, due to their superior range and the cohesive quality of their pulses. On the negative side 10 cm radars require a larger scanner, greater power and often a longer pulse length resulting in a loss of definition at short ranges.

A 3 cm radar is nearly always the preferred choice for small craft due to the greater power and scanner size requirements of 10 cm radar.

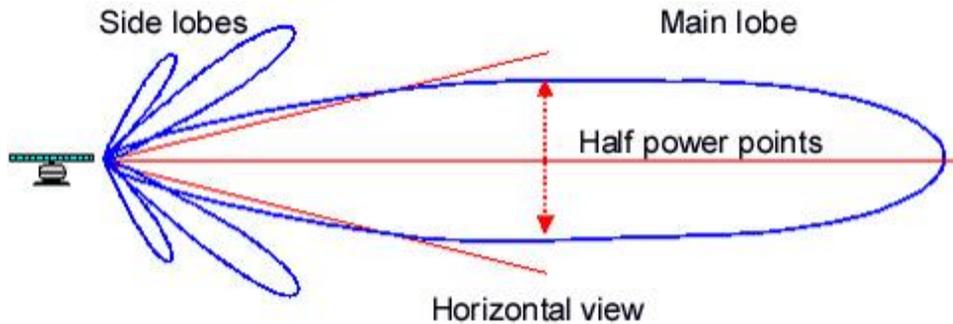
## Radar transmissions

### ***Echo Strength***



As the radar beam spreads out with increasing range, due to the wide vertical beamwidth, power decreases rapidly. The radar's energy is inversely proportional to the fourth power of the distance from the scanner.

## **Horizontal Beam**



In the horizontal plane the radar beam consists of a strong narrow main lobe and smaller side lobes. The width of the horizontal beam (measured between the half power points of the main lobe) is equal to  $70 \times \text{wavelength}$  divided by scanner width.

$$\theta = \frac{70 \times \lambda}{d}$$

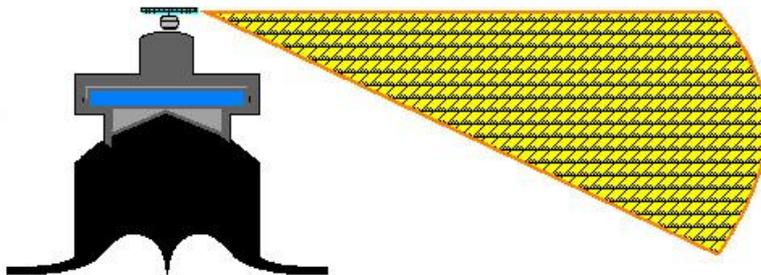
where:

$\theta$  = width of horizontal beam (HBW)

$\lambda$  = wavelength

$d$  = scanner width

## **Vertical Beam**



The vertical beam width (VBW) is determined by the width of the scanner. It must be wide enough to give good target echoes when the vessel is rolling or pitching heavily, and is usually between  $20^\circ$  and  $30^\circ$ .

## **Maximum Range & Minimum Range**

The maximum range of the radar depends on various factors including wavelength, pulse repetition frequency (PRF), power output, HBW, receiver sensitivity and scanner height. Experience and the radar log will tell you typical detection ranges for various types of targets. The theoretical maximum range can be calculated by using the following formula found in nautical tables.

Range in nautical miles =  $2.21\sqrt{h} + 2.21\sqrt{H}$

where:

$\sqrt{\quad}$  = square root

h = height of the scanner in metres

H = height of the target in metres

The minimum range of a radar depends mainly on the pulse length, and is slightly more than half the shortest pulse length, a typical figure would be 25 metres.

### ***Range & bearing accuracy***

The range accuracy depends mainly on the accuracy of the timebase and the range markers. It should not exceed 1.5% of the maximum range of the range scale in use, or 70 metres, whichever is greater. It should be calibration at suitable opportunities.

The bearing accuracy of a radar depends mainly on HBW, the narrower the beam, the better the bearing accuracy. The bearing accuracy will be quoted in the manufacturer's manual, but should not exceed 1°.

Misalignment of the heading marker contacts will cause bearing errors and these alignments should be frequently checked. On most sets with the radar in ship's head-up presentation, the heading marker can be adjusted so that it indicates 000° on the bearing scale by an adjusting screw in the scanner unit. This is best done by bringing a target dead ahead visually and checking to see that the same target is bisected by the heading marker on the display. On an unstabilised display, yaw error will result, unless the ship's head is noted at the instant of taking a bearing.

### ***Range measurement***

In analogue radars, target range is measured electronically by a beam of light that is continually moving across the screen from the centre to the edge at a speed equivalent to half that of the radar wave. The light beam forms a line called the timebase or trace on which the target echoes appear.

In more modern rasterscan radars range is measured electronically. When the pulse is transmitted a very precise clocklike timebase signal is produced in the switch register, corresponding to the speed of the transmitted pulse. If a returning echo is received at precisely the same time as the timebase signal is produced a switch is turned on and the returning echo displayed. The range is measured by either fixed range rings or a variable range marker (VRM).

### ***Pulse length***

As mentioned earlier, radar does not transmit continually, because weak echoes and close targets would be masked by the noise of transmission, but transmits in very short bursts called pulses. The pulse is transmitted and then the receiver listens for a returning echo from the pulse before another pulse is transmitted.

The beginning of the pulse is called the leading edge and the end of the pulse is called the trailing edge. For a pulse of one second duration the leading edge would travel 300,000,000 metres before the trailing edge leaves the transmitter. That is 150,000,000 outbound and 150,000,000 bounces off an object to returns to the

transmitter. If there were targets closer than 150,000,000 metres (80,994 nm) the trailing edge of the transmission would not have cleared the transmitter preventing the weaker leading edge being received - had the target being further away than 80,994 nm the trailing edge would have cleared the transmitter leaving it ready to receive. So a radar with a pulse length of one second would have a minimum range of 80,994 nm. Of course there are no radars with a pulse length of one second and a minimum range of 80,914.5 nm. Marine radars operate between 0.8µs and 1.2µs

### **Example**

*What would be the minimum range of a radar with a pulse length of one 1µs (one millionths of a second)?*

$$\text{Range} = \frac{300,000,000}{1,000,000} = 300 \text{ mtrs}$$

to find minimum range divide by 2:

$$\text{Minimum range} = \frac{300}{2} = 150 \text{ mtrs}$$

*What is the minimum range of a radar with a pulse length of 0.8µs?*

$$\text{Minimum range} = 0.8 \times 150 = 120 \text{ mtrs}$$

A long radar pulse uses more energy than a short pulse of the same power. It will also travel further and the returning echo will produce a more conspicuous echo on the radar screen. However a short pulse will achieve better range discrimination and definition resulting in a clearer radar picture.

So a long pulse is required to detect targets at long range and a short pulse is required for definition and good range discrimination. To overcome this contradiction most radars are equipped with typically 3 to 5 different pulse lengths, from 0.08 to 1.2 µs (millionths of a second). The pulse length on most radars is a function of range. If you select a short range, a short pulse length will be selected automatically, if you select a long range, a long pulse will be selected automatically.

### **Pulse repetition frequency (PRF)**

Pulse repetition frequency (PRF) is the number of pulses transmitted per second. While minimum range is affected by the duration of the pulse the maximum range is affected by the PRF. There must be a null period between the transmission of each pulse to allow the weaker returning pulse to return without colliding with and cancelling out the next outgoing pulse. Most radars will have a different PRF corresponding to each pulse length. A typical PRF is 500 pulses per second for long pulse and 3000 pulses per second for short pulse.

### **Bearing measurement**

To obtain an accurate bearing, the radar pulse is concentrated in a narrow beam in the horizontal plane, and is rotated continuously through 360° in synchronisation with the trace in an analogue radar. The radar assumes that if it receives an echo, its beam must be pointing straight at the target in question. A line on the screen called the heading marker provides a bearing reference, and target bearings are measured by an electronic bearing line (EBL) or in older radars a bearing cursor.

### **Wavelength and frequency**

The wavelength ( $\lambda$ ) and frequency ( $f$ ) of the radar wave are inversely proportional to each other, and are related by the formula:

$$c = \lambda \times f$$

or:

$$f = \frac{c}{\lambda}$$

where:

$c$  = The constant speed of the wave

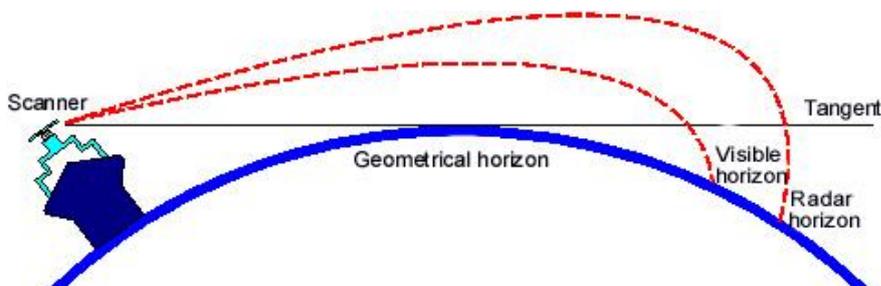
### **Example**

With a wavelength of 3 cm at a constant speed of 300 m/ $\mu$ s, what is the frequency?

$$f = \frac{c}{\lambda} = \frac{300,000,000}{0.03} = 10,000,000,000 \text{ Hz} = 10,000 \text{ MHz}$$

### **Refraction**

If the radar wave travelled in straight lines, the distance to the radar horizon would only be dependent on the radar's power output and the height of the scanner. In other words, the distance to the radar horizon would be the same as that of the geometrical horizon for the scanner height. However, both light and radar waves are subject to downward bending as they pass through the atmosphere, the amount of bending being greater for longer wavelengths. This bending is known as refraction.



### **Radar horizon**

Radar waves are longer than light waves, so bending due to refraction will be greater, resulting in the radar horizon lying beyond the visible horizon. The radar horizon under normal atmospheric conditions is about 6% greater than the visual horizon.

### **Effects of weather**

Weather conditions affect radar performance, in three ways:

- non-standard atmospheric conditions
- attenuation
- unwanted echoes

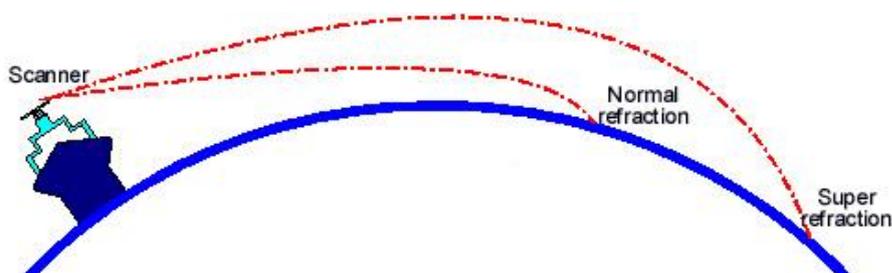
The radar horizon assumes standard atmospheric conditions of:

- pressure = 1013 hpa decreasing at 36 hpa / 1000 feet of height
- temperature = 15°C decreasing at 2°C / 1000 feet of height
- relative humidity = 60% and constant with height.

In the standard atmosphere the temperature and moisture content decrease relatively slowly with height and the radar's range will be normal. In non-standard atmospheric conditions the radar's range will differ from normal.

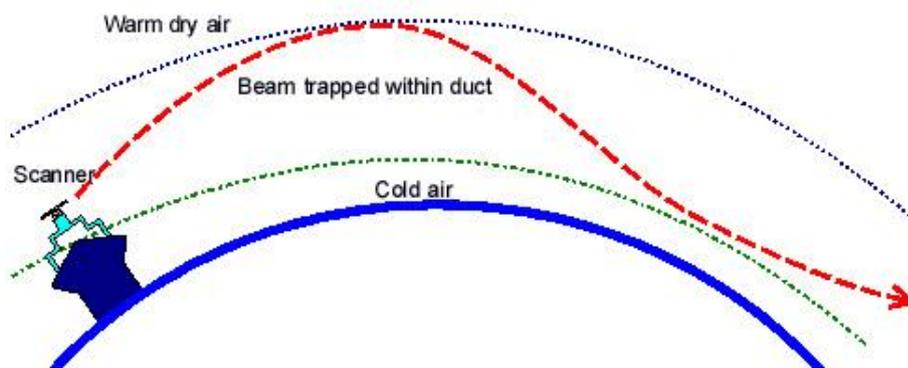
### **Super-refraction**

Super-refraction will occur when a warm air layer overlies a cooler sea surface (i.e. temperature inversion). The radar beam is refracted more than normal causing considerably increased target detection ranges, typically up to 25%.



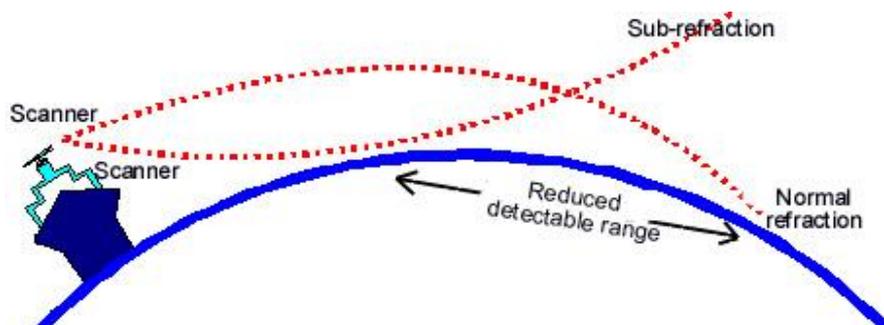
### **Ducting**

An extreme form of super-refraction is known as ducting, when the radar beam is conducted for long periods within a duct formed by air layers. When this occurs, unusually long detection ranges of targets may be experienced. It is during periods of ducting that second trace echoes may appear.



### ***Sub-refraction***

Sub-refraction occurs when a cold layer of air overlies a warmer sea surface. The radar beam is refracted at less than normal, causing reduced target detection range.



### ***Attenuation***

Attenuation occurs when part of the radar energy is absorbed by water vapour in the atmosphere. It is greatest in heavy rain and can cause severe reduction in detection ranges but may also occur in hail, snow, sleet and, to a lesser extent, in fog. A 10 cm radar because of its greater power will be less affected by attenuation than a 3 cm radar.

### ***Rain clutter***

Echoes from precipitation have much the same effect as sea clutter. It looks like cotton wool and the strength of the echo depends on the amount of precipitation. Heavy rain will completely mask out target echo, especially on older style colour radars where everything turns red.

### ***Other causes of attenuation***

Clouds may cause echoes similar to rain clutter if they are low and have precipitation within them. Other conditions such as sand and dust storms, smoke and haze do not usually cause echoes.

## Target acquisition

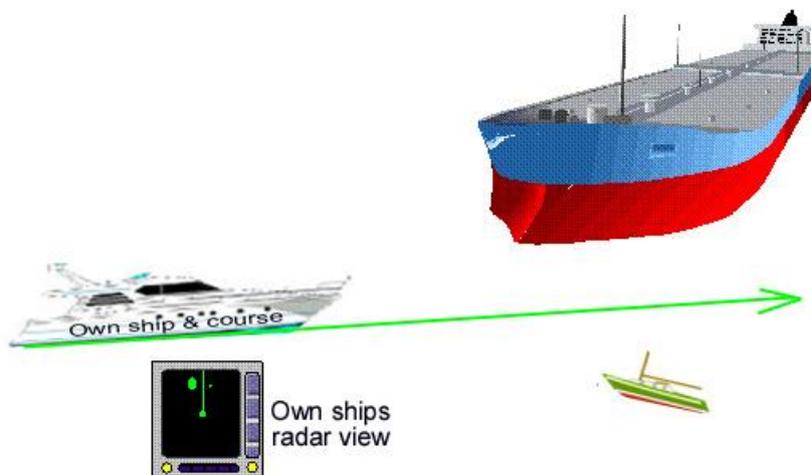
The ability of a radar to detect a target depends on two factors, the peak power of the transmitted pulse and the reflective properties of the target.

The maximum range of a radar set will depend on the peak power of the radar, scanner height, weather conditions and the reflective properties of the target. Peak power for a x-band radar varies from about 1.5 kW for a 12 nm radar to 25 kW for a 120 nm radar. A minimum of 3 kW is required to pierce fog, 4 kW will be more effective. Considerably greater power is required to transmit in the S-band.

The reflective properties of the target include its:

- size
- material
- aspect
- surface texture

### **Target size**

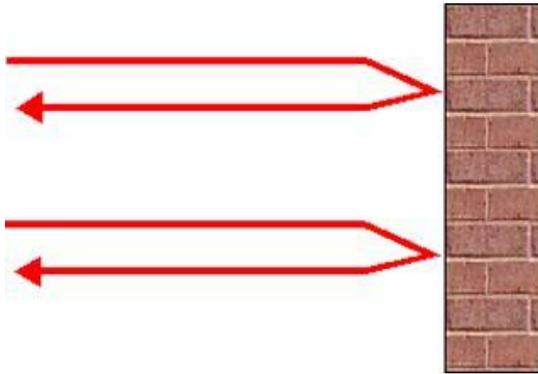


All other things being equal, a large target will reflect more of microwave energy than a small one. So it will produce a stronger echo, and show up on the screen as a brighter image at a longer range.

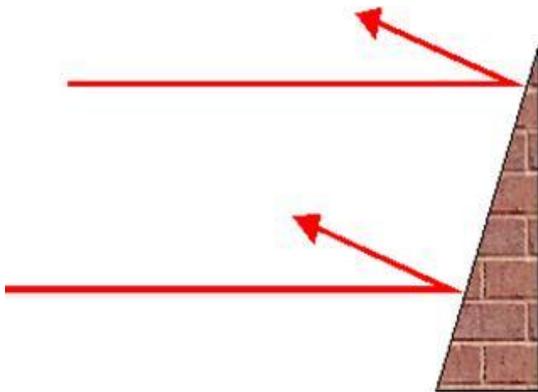
### **Target material**

Targets of hard, dense material with good conducting properties give the strongest echoes. Rock and concrete are good reflectors but the best reflector is metal. Wood is almost invisible to radar, because wood tends to absorb the microwaves instead of reflecting them. Sand and mud will also produce a very weak echo. GRP and plastics are poor reflectors because the microwaves will go straight through them.

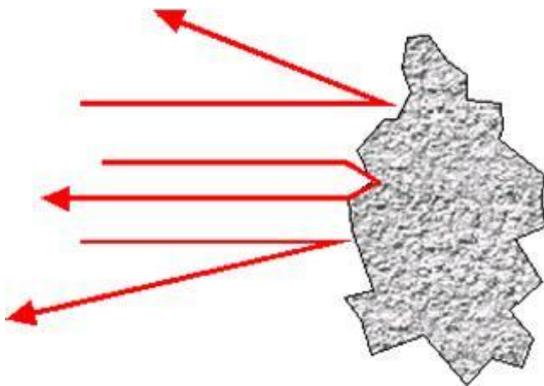
**Target aspect**



A target at 90° aspect to the radar beam will reflect most of the microwaves back to the scanner and produce the strongest echo.

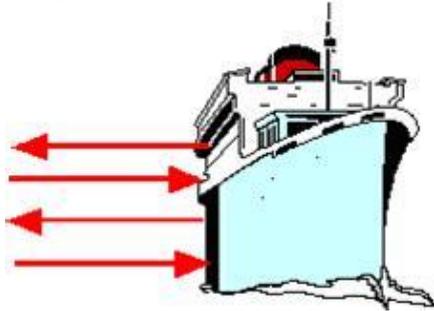


Targets at oblique angles will reflect most of the energy in other directions and return a weak echo.

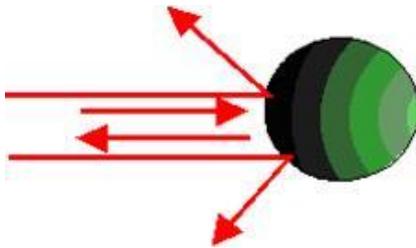


If the target's surface is uneven at least some of the microwave energy will be reflected back.

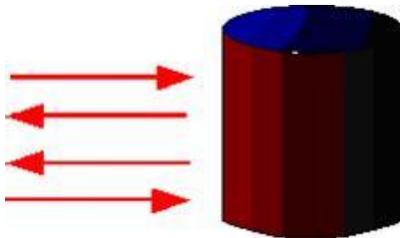
### **Target shape**



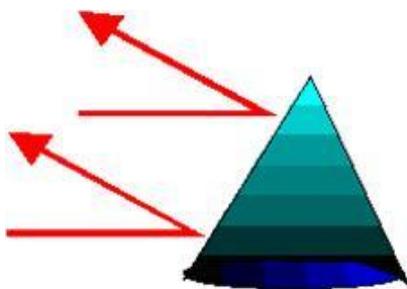
Generally speaking flat surfaces are better radar reflectors than curved or pointed ones. So the best reflector will be a perpendicular plane surface, like a ship's side.



A sphere is a poor reflector as it will only return an echo from that part which is at right angles to the beam, which is a very small reflecting point in the centre. The rest of the microwaves will be reflected outwards and lost.



A cylinder is a moderate radar reflector. Like a sphere it will only reflect from the part which is end on to the radar beam.



A cone is a very poor reflector. It reflects all the energy upward and away.

### **Surface texture**

A perfect, mirror like smooth surface would produce a very weak echo unless it was perfectly aligned at right angles to the radar pulse. In practice this rarely occurs, almost everything includes surface irregularities, which scatter the pulse, so that some of it will return to the scanner. Therefore, a target with a rough surface scatters energy evenly and gives a fair echo at any aspect.

### **Practical targets**

The echo strength and detection range of practical targets such as coastlines, beacons and other vessels depends on a combination of all previously mentioned characteristics, the most important factor being aspect. A large tanker, at an acute angle to you may not give as a strong return as a small fishing vessel beam on to the radar pulse. A cylindrical object like a lighthouse (unless fitted with a radar reflector), may give a very poor echo, despite the fact that it can easily be seen with the naked eye. Mountains and coastlines will show up because of their shape rather than their height. You can never be sure which part of the landmass is reflecting the best and, therefore, you cannot be sure of exactly what you are seeing on the display. Experience will tell what detection range to expect for each type of target. The weakest echoes, or those unseen may be the most dangerous.

*Note: that from a ship underway, a target presentation on the screen can alter as the aspect changes.*

## **Navigational aids**

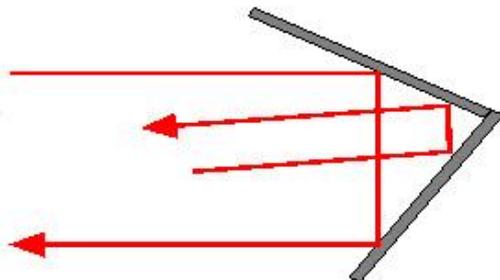
### **Radar reflectors**

Radar reflectors are fitted to vessels or navigational buoys or other charted features to improve their reflective properties so as to make them visible to searching radar. There are two types of radar reflectors:

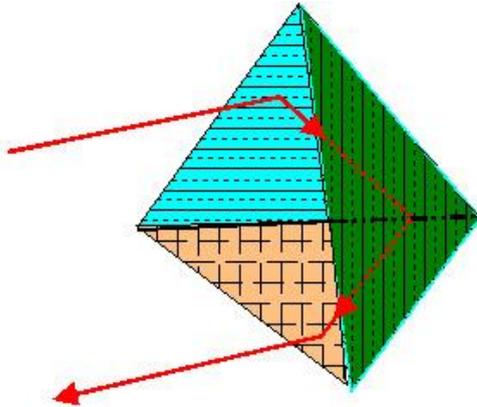
- passive
- active

### **Passive radar reflectors**

Vessels or other objects constructed of wood or GRP are almost invisible to radar. If these craft are to show up on another vessel's radar they must be equipped with a radar reflector. All radar reflectors work on the principle of the corner reflector,

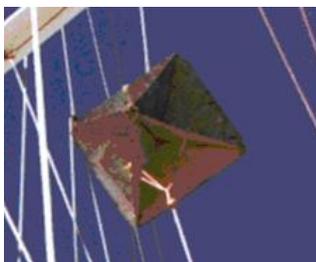


when two flat plane plates form a corner, the corner has the ability to reflect directly back to wherever the signal is coming from.



Most radar reflectors are improvements on this principle, the basis of which is that three plates at right angles to each other will give the reflector the ability to reflect a strong signal over a wide angle, both horizontally and vertically. In order to cover all angles, radar reflectors are usually arranged into clusters, the most common type being the octahedral (8 corner reflectors).

Octahedral clusters work well if they are mounted correctly. It should never be attached to a halyard by any of its points. This destroys a large part of the reflecting capability. It is best rigidly mounted with one of its open faces uppermost, so that the device could retain water in the cup. This is known as the rain catch position.



Shown above is an octahedral radar reflector. The radar reflector would perform better if it were rigidly mounted in the 'rain catch' position and below the newer encapsulated type of radar reflector can be hauled up the mast on a halyard.



### **Active radar reflectors**

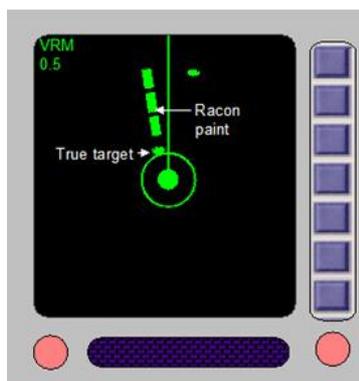
There are two types of active radar reflectors or radar transponders which are used to assist the navigator to identify charted objects:

- racons
- ramarks

### **Racons**

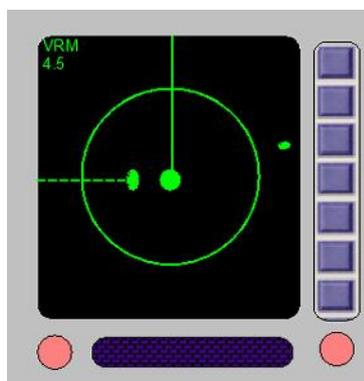
A small pulse transmitter is mounted on the beacon, which when triggered by the radar pulse of a vessel radiates an identifying signal in all directions. The ship's scanner can only receive this signal when the scanner is pointed in the direction of the beacon. So the pulse will be displayed on the screen at the correct bearing, but because of the slight delay in transmission, the beginning of the pulse will be displayed at a greater range than the true echo.

Due to the system of scanning used, the mark will be displayed on the screen only intermittently or every few sweeps. The true echo of the beacon will appear on the screen in front of the identification signal, when it is in range.



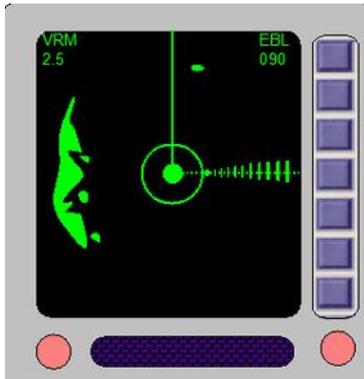
The above figure shows a Racon (morse code O). Racons are particularly useful for showing up objects which otherwise may be difficult to identify, for instance an important navigation mark in a busy traffic area, an isolated point on a featureless coastline or the entrance to an important navigational channel.

### **Ramarks**



The above figure shows a ramark (*radar marker*). Ramarks transmit pulses continuously or to special time schedules, rather than on receipt of a vessel's radar pulse. They appear on the display as a bright radial line from the centre of the display to the edge and are identified by breaking up the radial line into a series of dots or dashes. Their major disadvantage is that they may mask other important echoes on the screen. Ramarks are now rare, there are none in Australian waters.

### **Search and rescue transponders (SART's)**



A SART is a portable battery powered radar transponder which operates on “x-band or 3 cm radar”. In an emergency situation when the SART detects the incoming radar pulse from a searching aircraft or ship it responds by transmitting a distinctive signal which shows up on the radar screen of the searching vessel as a series of 12 blips extending approximately 8 nautical miles outward from the SART's position along its line of bearing. Figure 35.

When a SART is not being interrogated by searching radar, the SART's receiver is rapidly sweeping the radar band, searching for radar signals. As all marine radars do not operate on exactly the same frequency within the “x-band”, there may be a small delay in SART response as the SART locks on to the searching radar signal. When the SART receiver has locked on to the searching radar there will be a delay as the SART switches from receive to transmit mode.

These delays will result in a slight range error, and therefore the first blip of the SART response may be some distance outside the position corresponding to the actual location of the SART. At medium ranges of about 6 nm the range delay may be between 0.6 nm to 150 metres. As the SART is approached by the searching radar the range delay should be no more than 150 metres.

When searching for a SART the IMO recommends that a range scale of 6 or 12 miles (with short pulse selected) be used because the spacing between the SART responses is about 0.6 nm or 1125 metres and it is necessary to see a number of responses to distinguish the SART from other responses.

A search and rescue transponder (SART) is shown below.



### ***Anti-collision radar transponders***

Anti-collision radar transponders will produce a line of five blips over 1 nm on an interrogating vessel's radar screen. A vessel carrying the transponder will also be alerted to the other vessels presence by a visual or audible warning signal when it is being interrogated by the other vessel's radar signal.

### **Performance monitoring**

A performance monitor informs the radar operator whether the radar is operating at full efficiency or not. It should be used when the set is first turned on and at frequent intervals thereafter when no targets are present on the screen. A lack of targets may be due to a lack of targets but may also be due to poor radar performance.

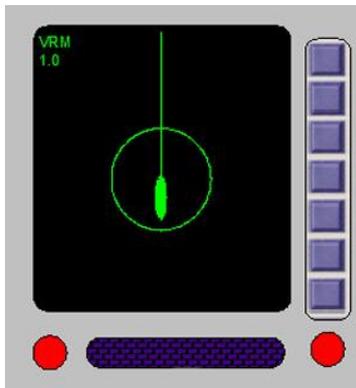
There are two types of performance monitors, external and built-in. Both types both utilise a metal echo box mounted behind the scanner and resonant to the radar's frequency to capture some of the radar's transmitted energy.

The external type makes a long plume like line on the screen in the direction of the echo box. The length of the plume depends upon the following:

- transmitted power
- receiver sensitivity
- correct tuning

The monitor gives an indication of the efficiency of the set. The length of the plume is measured when the set is installed and known to be performing well. If at any time the plume is shorter, one or more of the above factors may have deteriorated and allowance for this made, or the fault rectified. The built-in type is used in the same manner, but produces a circular pattern the radius of which is measured.

The figure on the left shows the plume from an external performance monitor. The length of which according to the radars logbook should be 1 nm. Some readjustment of the radar is required.



### ***The radar logbook***

The radar logbook serves two functions one technical and the other operational. On the technical side, information recorded in the logbook would include: maintenance and repairs carried out, spares on board and their part numbers, technical and performance details and information concerning arcs of shadow and blind sectors. On the operational side, information recorded in the logbook would include: details of detection ranges for various types of targets and information concerning detection ranges of conspicuous objects.

### ***Performance standards***

Recommendations on performance standards for radar equipment can be found in IMO, Class and AMSA guides for radar equipment, referred to as type tested.

### ***Installation, maintenance and safety precautions***

Today, a technician is no longer required to install a radar. It's just a matter of securing the radar and scanner with a few bolts, plugging the cables together, earthing the set and connecting up to the power supply. The cable connecting the display unit to the scanner can be provided in custom lengths to fit the specific installation. The cable should never be cut.

When installing a radar, the scanner unit should be positioned as high as practical to give the best possible range and clear of obstructions to avoid shadow sectors. It should also not be so close to other electromagnetic equipment as to cause interference and should be away from excessive heat or vibration, but accessible for maintenance. Once installed the range and heading marker accuracy should be checked by competent personnel and the limits of any shadow sectors established and recorded in the radar logbook and displayed on a card near the radar.

The display unit should be positioned so that it is in easy reach of the navigator and facing forward to facilitate lookout. It should be at a convenient level and position for observing and servicing, away from the magnetic compass, other electromagnetic equipment, and exposure to weather. If the radar is flush mounted ensure that there is good ventilation to the rear of the set.

### ***Maintenance and troubleshooting***

Maintenance of modern radars is a relatively simple affair. Firstly, read and follow the instructions in the manufacturer's operator's guide. Keep a radar log, and record in it maintenance, service, faults and repairs, as these could be invaluable to assist the radar technician to diagnose a problem.

Radars are generally very reliable and need only to be protected from water, heat and physical damage. A regular maintenance program would consist of periodically checking mounting bolts and brackets, keeping wiring connections clean, tight and external wiring connections smeared with a thin coating of petroleum jelly. The set itself should be kept clean and free of salt spray.

Troubleshooting would first involve checking that the unit is receiving power and that the correct start-up procedure has been followed. If the power supply is OK, all connections are clean and tight, the main circuit breaker or fuse is OK, the internal fuses are all right and the scanner is free to rotate and the set still does not work, then it is probably time to call a technician.

### ***Safety precautions***

Personnel should avoid microwave radiation hazard by keeping clear of an operating scanner. If working aloft on the scanner unit or other equipment near the scanner unit. Ensure that:

- the radar unit is turned off, the power disconnected and a sign placed on the display informing others that you are working aloft
- clip on a safety harness
- tie on a tool bag that won't spill if inverted
- don't raise or lower power tools by their cord
- if at all possible have someone assist you

The high voltage circuits inside the display unit can cause electrocution and must not be touched except by qualified personnel with the radar switched off. The display unit has potentially lethal voltages inside the unit even after it has been turned off.

*Note: A good rule to remember is if the back has to be removed, leave it to the experts.*

### ***Where to site the scanner***

Siting of the scanner unit requires careful consideration so that a compromise can be reached between the effect of height on range performance and sea clutter and the need to minimise shadow sectors and false echoes. The higher the scanner is placed the more pronounced the sea clutter return.

The scanner should be mounted on a structure which will not twist and cause bearing errors. To ensure that the heading marker indicates the true fore and aft line

of the vessel the scanner should be sited as near as possible to the centre line of the vessel.

***Where to site the display***

The following should be considered when siting the display unit:

- under marine regulations, installation instructions include the minimum safe distance that the display should be mounted from the magnetic compass..
- light issuing from the display unit should not interfere with visual lookout when the bridge is in darkness.
- it should be possible for two observers to view the display simultaneously with any fitted display visor removed.
- the display should be mounted so that an observer faces forward when viewing it so as a visual lookout ahead can be maintained.
- the display should be mounted sufficiently rigidly so as not be adversely affected by vibration and away from excessive heat and fumes.
- when compass adjustments are being made, the radar set should be in operation.

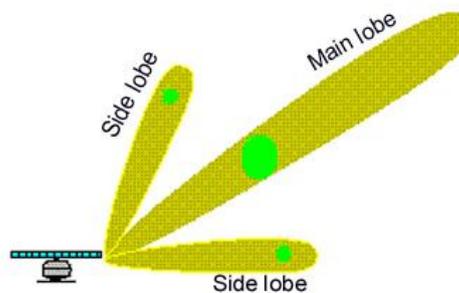
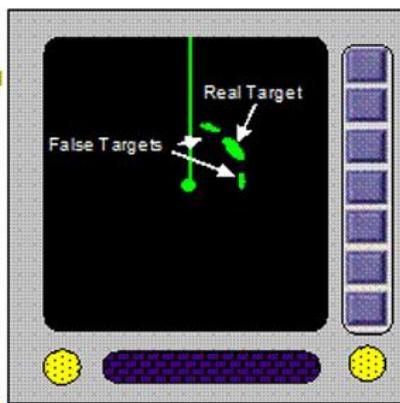
## 6. False radar information

### False echoes

Radar can deceive us by displaying targets that may not exist at all. These are called false echoes.

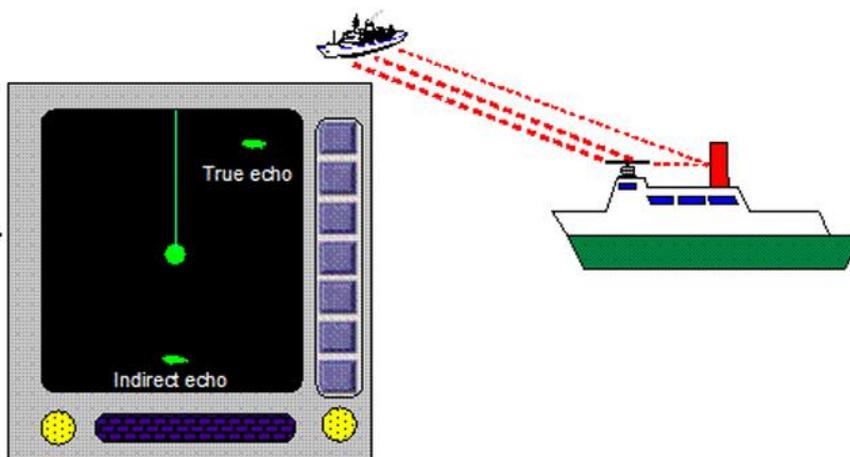
### Side echoes

Squeezing a naturally an multi-directional radio wave into a directional radar wave is never fully achieved. Not all of the radar wave can be focused by the radar aerial into the main lobe. Some escapes into what are known as side lobes. Side echoes are caused by reflections from the side lobes of the radar beam. They are likely to appear when a target is a good radar reflector and in range of the weaker side lobes.



The true target will always be the stronger echo in the centre of the pattern. Side echoes can be removed by reducing the gain, or by using the sea clutter control.

### Indirect echoes



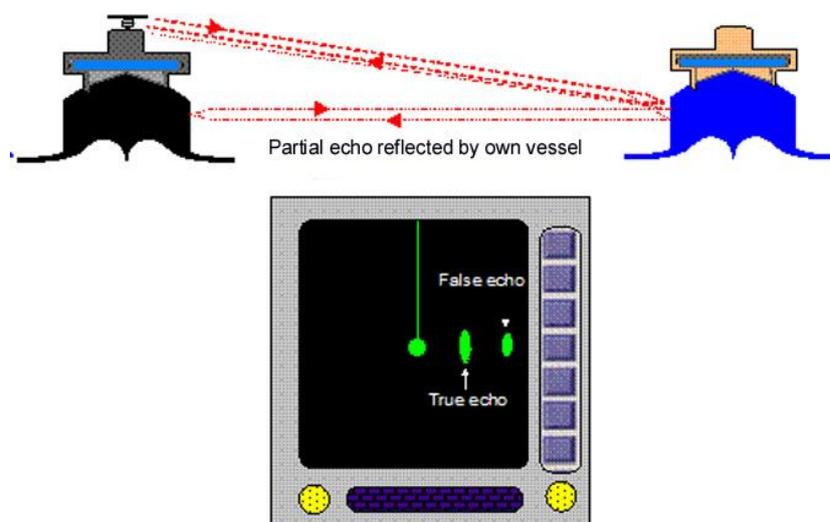
Indirect echoes are caused when some of the outgoing radar energy is reflected from an object close to the scanner such as a funnel or mast. The echo may return by the same path or directly to the scanner. The false echo will appear (usually intermittently) on the display at the correct range because the additional distance between the scanner and the reflecting object will be negligible, but on the bearing of the obstruction. The true target will also appear on the display at the correct range and bearing.

Indirect echoes usually occur in shadow sectors however, they can appear on bearings where there are no shadow sectors. Indirect echoes are usually associated with funnels and other large objects close to the scanner.

Although the bearing of the real target may change, the bearing of the deflected target will remain constant and may if the range is decreasing, appear to be on a collision course. To determine if the target is an indirect echo or not, alter course about 10°, if the relative bearing of the echo remains constant, then the echo is a false one. Alternatively the gain can be reduced, or if the echo appears in a known blind sector it can be ignored.

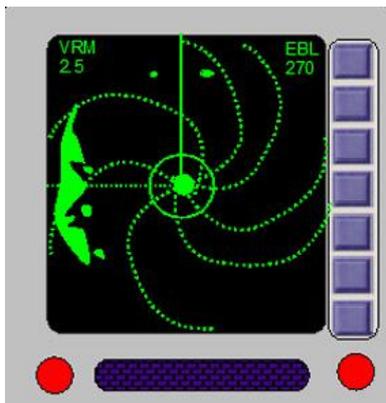
The other form of reflected or indirect echoes uses strong targets such as buildings, bridges or large ships usually when navigating in rivers or harbours. While some of the radar beam is returned to the scanner, much of it is deflected in other directions but at close range it can produce a beam which will be reflected from the secondary target. This will show on the display on the same bearing as the strong target but at an increased range. It will also show up in its correct position so it should not be too much of a problem.

### **Multiple echoes**



Multiple echoes are caused when a strong echo arrives back at your vessel and bounces off it, effectively retransmitting the signal. For this to occur the other target must be large and close, and both the target, which may be a land target such as a bridge or headland or another vessel, and your ship must be good radar reflectors. The false echoes (which may be any number) will appear at multiples of the true range on the same bearing. Multiple echoes can be removed by reducing the gain.

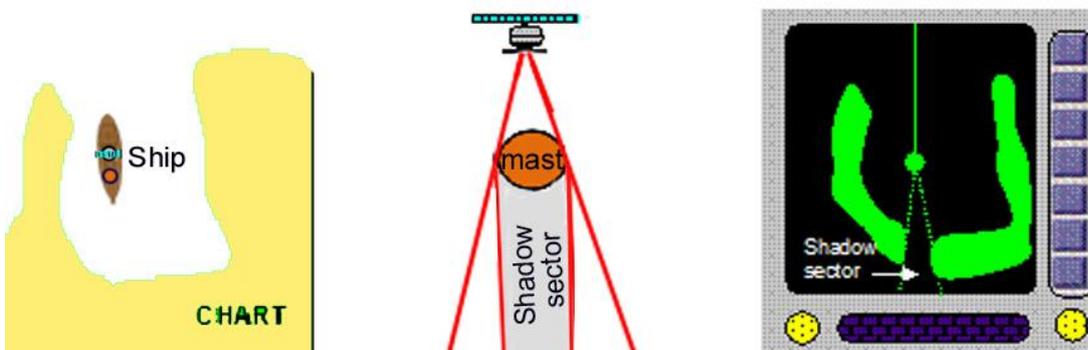
**Interference**



Radar transmissions from another vessel in the locality on a similar frequency to your vessel's radar can cause interference similar to the figure above. In most radars this interference can be eliminated by switching on the IR control.

**Shadow and blind sectors**

Obstructions such as funnels, masts, or trawl gear in the path of the scanner can cause shadow or blind sectors on the display, in which targets may be lost or only detected at reduced range or not detected at all. As the radar wave will bend to some extent bend around obstructions by diffraction, some targets in shadow sectors will be displayed at times, while targets in blind sectors will not be detected at all. The radar aerial should always be placed to minimise shadow and blind sectors.



A good method to check for blind or shadow sectors is to find a section of slightly choppy water and turn off the sea clutter control. If no blind or shadow sectors are present the display will fill over an arc of 360° with a mass of small contacts, caused by the echoes returned from the waves. Any dark streaks radiating outwards from the centre represent blind or shadow sectors.

If blind sectors or shadow sectors are present their limits must be determined and recorded in the vessel's radar log. Sea clutter is one way to determine these limits, or a sextant could be used. The best method however, is to observe a small target vessel at the edge of a short range, as your vessel's course is altered. Note: the bearing when the target disappears and then reappears.

### ***Second trace echoes***

Second trace echoes will appear at times during periods of severe super-refraction or ducting. Targets at very long range will appear at a false range on the correct bearing, on the second sweep of the timebase. In other words, an echo may return from a distant target after a second pulse has been transmitted and the receiver is open.

The higher the PRF, the more likely that second trace echoes will occur as more pulses are transmitted and the corresponding silence period is reduced. Second trace returns can usually be made to disappear by changing the range scale in use.

### ***Other causes of false echoes***

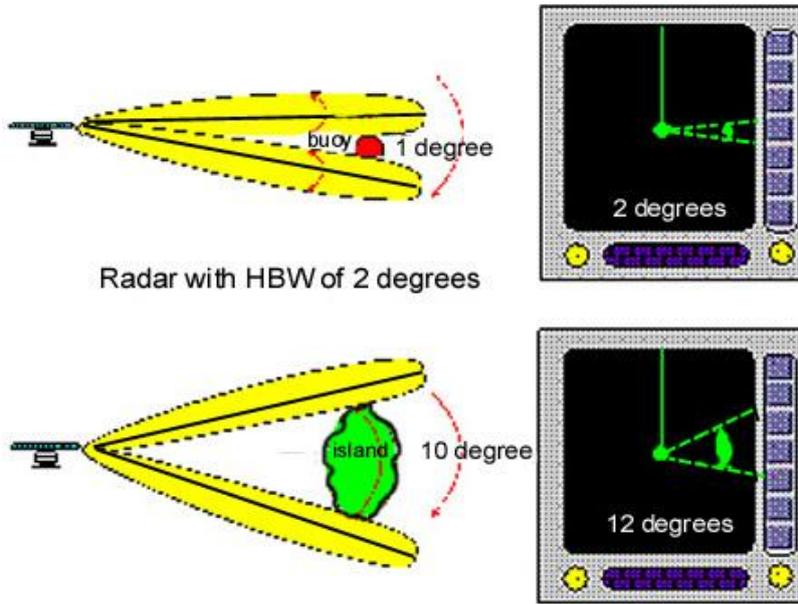
When navigating in rivers and harbours overhead power cables at close quarters can return an echo from the direction where the cable is at right angles to the radar beam, the effect on the display is a small echo which is closing on a collision course. The echo disappears when the vessel is close to the overhead cable as the radar beam is no longer in contact with the target.

### **Beamwidth distortion**

Beamwidth distortion is directly related to the radar's beamwidth which is largely determined by the scanner's length. A small 60 cm scanner will have a beamwidth of about 7° while a 2 metre scanner will produce a beamwidth of about 1.2°

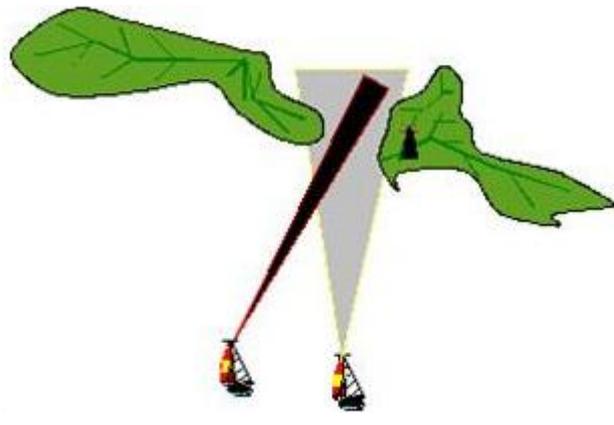
A target echo will be painted on the display the whole time the radar beam takes to sweep the target. This will have the effect of enlarging all targets, extending each side by an angle equal to half the beamwidth of the radar. Therefore radar with a beamwidth of 2° will show a small target such as a buoy to be as an arc 2° wide. An island 10° wide will appear to be 12° wide and a headland will appear to extend 1° further to sea than it really does.

Shown below the small buoy may only be ½° wide but as the radar beam rotates it will paint the buoy from the moment the leading edge of the beam first touches the buoy and during the whole time it sweeps across the buoy until the trailing edge is clear of the buoy. Therefore on the radar display the buoy will appear to be 2° wide.



Radar with HBW of 2 degrees

The advantage of larger beamwidths is that smaller weaker targets will be painted larger on the screen, therefore they will have a better chance of being detected from a small vessel as it moves around in a seaway. The down side is less bearing resolution and poor bearing discrimination.



Beamwidth is very important when you are looking for a narrow passage between islands, a narrow harbour entrance or a river entrance. Because of beamwidth distortion, a radar with a large beamwidth will not be able to see the gap until very close.

Shown above, the yacht with narrow beamwidth radar will be able to see the entrance to the harbour on the radar display as the beam can fit entirely between the headlands. However, to the yacht with the wide beam width radar the entrance will remain hidden and the coast appears continuous until the yacht is much closer.

The effect of beamwidth distortion can be improved somewhat by reducing the gain but, remember to turn it up again afterwards.

The range at which it would be possible for a narrow gap to be visible on radar can be found by the formula:

$$\text{Range} = \frac{\text{distance}}{\sin \text{BW}}$$

where:

distance = size of the gap

BW = beamwidth

### **Example**

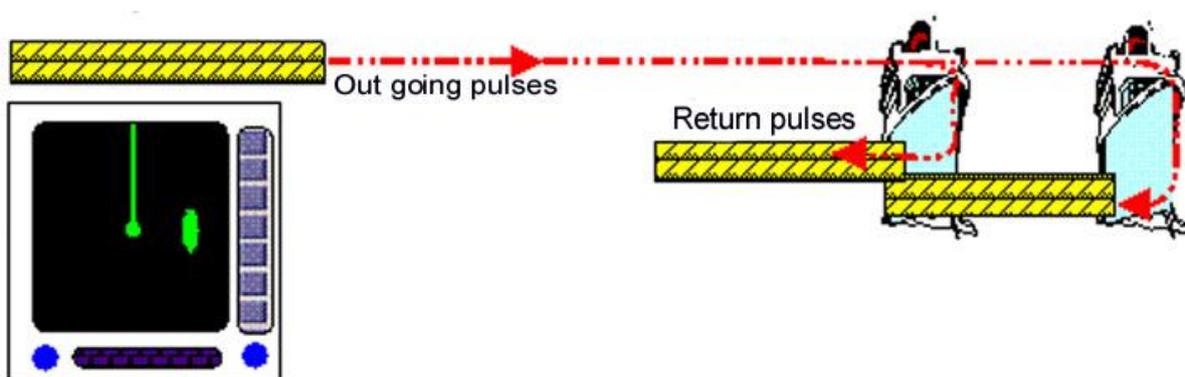
You are approaching a harbour from seaward, the entrance of which is 0.07 nm wide, your radar has a beamwidth of 6°. At what range would you expect to see the entrance on radar?

$$\text{Range} = \frac{\text{distance}}{\sin \text{BW}} = \frac{0.07}{0.104528} = 0.67 \text{ nm}$$

## **Range and bearing discrimination**

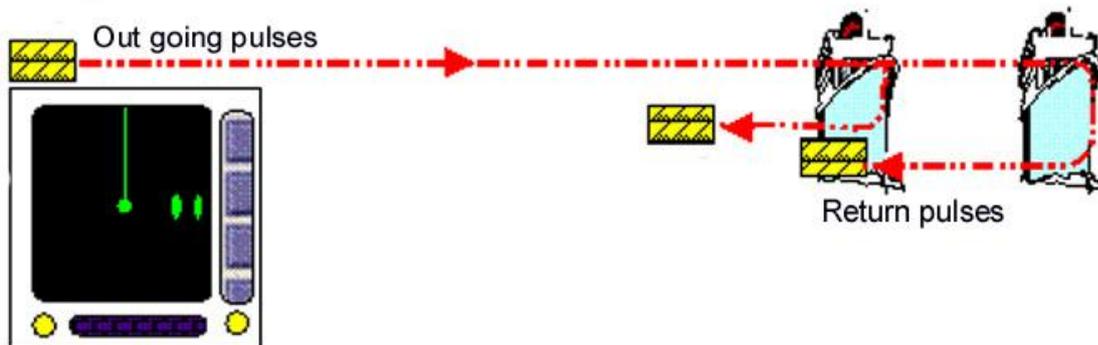
### **Range discrimination**

Range discrimination is significant, as it can have an effect on the useful operating range of the radar. A long pulse uses greater power and will detect a target at a longer range. However, a long pulse has a down side too. Shown below a radar transmitting on long pulse may have a pulse length of 300 metres, after it travels outwards for a distance it comes upon two vessels 150 metres apart. Part of the leading edge of the pulse will be reflected off the nearer ship while part will carry on to be reflected off the second ship. Before the trailing edge of the pulse has reached the first ship, the leading edge will be already on its way back, so that the echoes from the two ships will merge. Instead of seeing the two ships separately on the display they will appear as a single target.



If the pulse length is more than twice the distance between two targets, the echoes will merge.

A shorter pulse length, of say 100 metres, will keep the echoes separate.

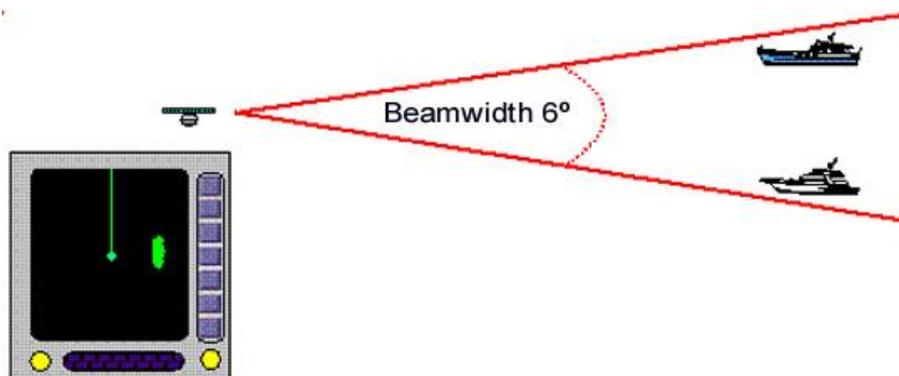


So a short pulse is required for good range discrimination, and a long pulse length is required to detect weak targets at long range.

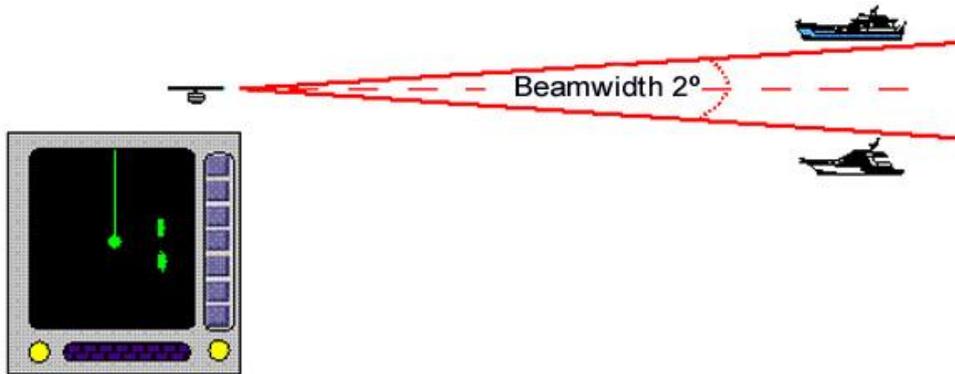
To overcome this contradiction most radars are capable of operating at different pulse lengths in the mid ranges. For example; you may be having difficulty distinguishing a isolated rock just off the coast from the coastline itself (as the two objects have merged) on long pulse at a range of 24 miles. By switching to short pulse the rock may now appear on the display as a separate object.

### ***Bearing discrimination***

Bearing discrimination is similar to range discrimination in that it governs the radar's ability to discriminate between two close targets, but this time to distinguish between two targets close together at the same range. The radar beam can be likened to a rotating pie slice, a small target will be painted on the screen the whole time it takes the beam to pass over it. So that if two targets close together can both be covered by the beam at the same time, they will appear on the display as one target. Bearing discrimination depends on HBW, the narrower the beam the better the bearing discrimination.



A wide HBW radar will receive echoes from both targets at once as both are within the beam. They will appear on the screen as one target.



A narrower HBW radar will pass between the targets and therefore the echoes will appear separately.

HBW is dependent on the scanner size, a small 60 cm wide scanner will produce a beamwidth of about  $7^\circ$ , while a 1800 cm foot open array scanner will produce a beamwidth of  $2^\circ$ . Bearing discrimination can be improved somewhat by reducing gain.

## 7. Navigating with radar

### Bearings

#### ***Bearing measurement***

The crucial factor in radar navigation is to correctly identify radar conspicuous features that are recognisable on the chart as well as on the radar screen. Towers, monuments, buildings and other prominent features that are favourites with compass navigation will not be visible on radar. However, objects such as headlands, islands, buoys and beacons will, with the added advantage that they will be equally useable by day or night.

Your ship is always at the centre of the display (except in a true motion display) and bearings are read off from the graduation scale around the circumference of the display.

With a **North-up** or **Course-up** stabilised display, where the radar is interfaced with a gyro compass the heading marker will always point to the true course being steered. Therefore, all bearings of targets read from the graduation scale around the circumference of the display will be **True Bearings**.

In a **Ship's Head-up** display where the heading marker always points straight up to the 000° on the graduation scale. All bearings will be **Relative Bearings**, that is, relative to the ship's head or the fore and aft line of the vessel.

Relative bearings can be represented by two methods:

- Red 0° to 180° or Green 0° to 180° depending whether they are to Port or Starboard of the heading marker. Echoes to Port would be read as Red 0° to 180° and echoes to Starboard would be read as Green 0° to 180°.
- Circular configuration 000° to 360°. Measured from ship's head (000°) in a clockwise direction. An echo bearing 30° to Starboard would be read as 030° Rel. and an echo 30° to Port would be read as 330° Rel.

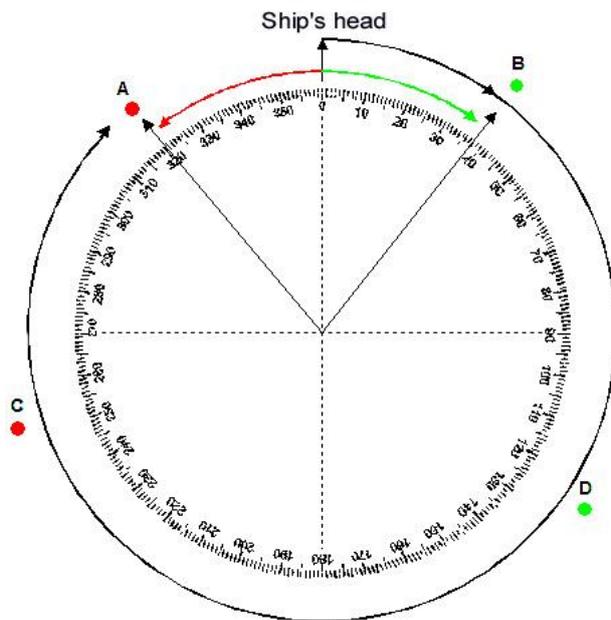
*Note: to avoid confusion all bearings are identified as follows. Colours always proceed the degrees:*

**G90° = Green 90°**

**R90° = Red 90°**

*For relative bearings Rel will follow the degrees and all relative bearings will be in three figure configuration:*

**090°Relative = 090° Rel.**



In the figure above:

Target A would be called; R40° or 320° Rel.

Target B would be called; G38° or 038° Rel.

*What would targets C and D be called?*

*Note : all radars that have EBL's use the circular configuration 000° to 360° relative method.*

Before relative bearing can be used for radar navigation or collision avoidance the vessel's true course must be known. The true course being steered is found by applying the sum of deviation and variation (compass error) to the compass course being steered.

Next the relative bearing of the target must be converted to a true bearing. This is done by adding the relative bearing to the vessel's true course. If this value exceeds 360° which means that you have passed through north, then 360° must be subtracted from the answer.

When using Red or Green relative bearings Green bearings will be added to the true course and Red bearings will be subtracted. So:

***True course + Rel. bearing = True bearing***

***True course + Green bearing = True bearing***

***True course - Red bearing = True bearing***

### **Example**

Your ship steering 035° Compass - Variation 7° East - Deviation 4° West.  
Target bearing 030° Rel. Find the true bearing of the target?

Your ship 035° compass

Deviation 4° West	Dev. 4° West
Magnetic 031°	Var. 7° East
Variation 7° East	CE. 3° East

True course 038°T

True bearing of target.

Ship's head true + Relative bearing = True bearing

$038^\circ + 030^\circ = 068^\circ$

True bearing of target = 068°T

### **Using the electronic bearing marker (EBL)**

The EBL is a straight line from the centre of the display to the edge of the display which is used to measure bearings of objects from your ship, in much the same way as a compass would. In a stabilised display bearings taken with the EBL will be true bearings and with an unstabilised display the bearings will be relative to the ship's fore and aft line.

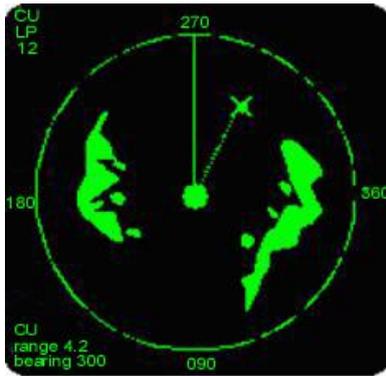
To take the bearing of an object simply adjust the EBL until it cuts through the centre of the object and read off the bearing from the EBL readout on the display.

Modern radars incorporate an improvement on the EBL by using a electronic cursor. The cursor is usually a cross which can be moved around the screen by using a trackball or other pointing device. Simply place the cursor over the chosen object and read out the range and bearing of the object from the cursor information displayed on the screen.

### **Using a bearing cursor**

Older analogue radars generally do not have an EBL instead bearings are measured by a bearing cursor. This is a line inscribed on a clear plastic screen, laid over the top of the radar screen. This line can be moved around mechanically to obtain a bearing. The use of a mechanical cursor may produce the following errors:

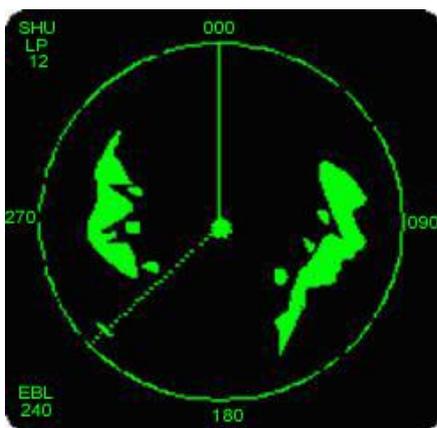
- If the centre spot of the radar is not directly under the centre mark of the bearing cursor, the bearings obtained will be inaccurate. This is called centring error.
- The operator must view the radar in such a way as to always view the bearing cursor passing through the centre spot. Because the screen of the bearing cursor is not hard up against the radar screen, if you step back a little for example, the cursor line will appear to move off the centre, causing an error in bearing. This is called parallax error.



The top CU display above shows a target measured by the *cursor* as being on a bearing of 300° at a range of 4.2 miles. As the radar is a stabilised *course up* display the bearing will be a true bearing.

The bottom display above shows a target on a bearing of 240° as measured by the *EBL*. When measuring a bearing with the EBL, it should cut the target's centre.

With an unstabilised SHU display any bearing taken will be a relative to the vessel's fore and aft line and not to the true compass. So to find the true bearing, the relative bearing must be added to the ship's true heading.



Shown above, the vessel's heading is 345°T. The target as measured by the EBL is on a relative bearing of 240°. To find the target's true bearing the target's relative bearing is added to the vessel's heading.

To find the true bearing:

Ship's heading	345°T
Relative bearing	+ 240° Rel
	= 585°
	- 360°
<b>True bearing</b>	<b>225°T</b>

### ***Yaw Error***

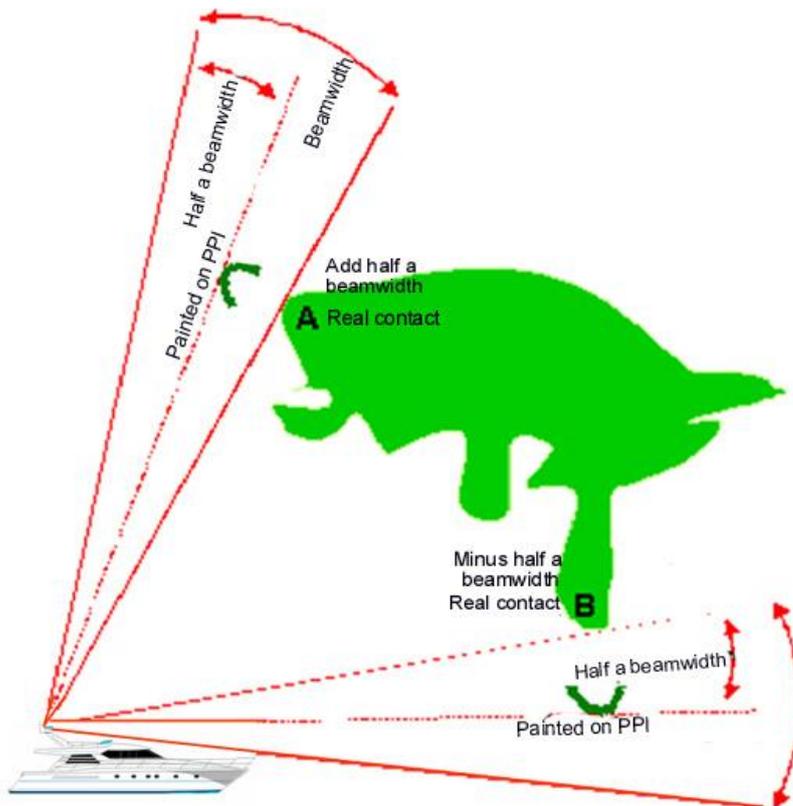
With unstabilised displays the greatest source of error is **yaw error**. As a vessel moves in a seaway the vessel's head will be continually drifting a few degrees either side of the intended course before the helmsman or the autopilot can correct the movement. So it is paramount that the exact heading of the boat is noted at the moment the radar bearing is taken. A 3° yaw at the wrong moment will produce a 3° error in the radar bearing.

This problem can be overcome by the helmsman noting the compass course at the instant the navigator takes the radar bearing. But this can only be managed if you have the luxury of a helmsman, a rarity. If you have two EBL's it's possible to line one of EBL's up with an object nearly dead ahead, while using the second EBL to take the bearings. If the vessel yaws the navigator will see this immediately and adjust the radar bearing accordingly.

### ***Beamwidth Error***

A second source of error is beamwidth error. The radar assumes that the scanner must be pointing straight at the target in order to receive an echo, it will start to "paint" a target on the screen as soon as the leading edge of its beam first touches the target, and go on painting until the trailing edge of the beam has passed clear of it. So a radar with a beamwidth of 5° will show a small target such as a buoy as though it were 5° across, while a radar with a beamwidth of 2° would show it as 2° across. So if you are taking a radar bearing of a small contact, the EBL should cut right through the centre of the target.

The radar will enlarge larger targets like headlands; the edges of the headland will cause an echo to paint while they are illuminated by any portion of the beam. When the leading edge of the beam is touching the headland, the edge of the echo on the display will appear on the bearing of the centre of the beam at that instant. The error will, therefore be half the beamwidth in the direction of the land.



### Example

Above, the vessel's radar has a beamwidth of  $6^\circ$  and the vessel's course is  $090^\circ\text{T}$ . The EBL shows a true bearing of headland "A" to be  $015^\circ\text{T}$  and headland "B" to be  $080^\circ$ . Find the true bearing of both headlands?

The beamwidth of this radar is  $6^\circ$  the contact will be extended a distance equivalent to half the beamwidth to seaward, therefore a correction of  $3^\circ$  towards the land will need to be applied.

Headland A  $015^\circ$  (correction of  $\frac{1}{2}$  beamwidth towards the land) +  $3^\circ = 018^\circ$

Headland B  $080^\circ$  (correction of  $\frac{1}{2}$  beamwidth towards the land) -  $3^\circ = 077^\circ$

With a unstabilised display, yaw error and beamwidth error combine to make radar bearings at best unreliable and should only be used with extreme caution. A stabilised display will eliminate yaw error, so you only have beamwidth to worry about. Bearing in mind the effects of adjusting gain, tuning, sea and rain clutter controls and echo expansion, radar bearings taken with allowance for beamwidth will produce reasonably satisfactory results.

### Ranges

#### Measuring radar ranges

Radar is inherently better at measuring range than it is at measuring bearings: after all, measuring ranges is what it was specifically designed for. Also, as the heading of

the vessel is irrelevant when taking a range, the biggest source of error, yaw error, is eliminated. Typically, radar range accuracy is better than 1%, of the range scale in use.

### ***Using the variable range marker (VRM)***

All radars are equipped with fixed range rings and the ranges of targets can be estimated by using the fixed range rings. However, most navigators prefer to switch off the fixed range rings, (because they tend to clutter the screen), and use the variable range marker, (VRM).

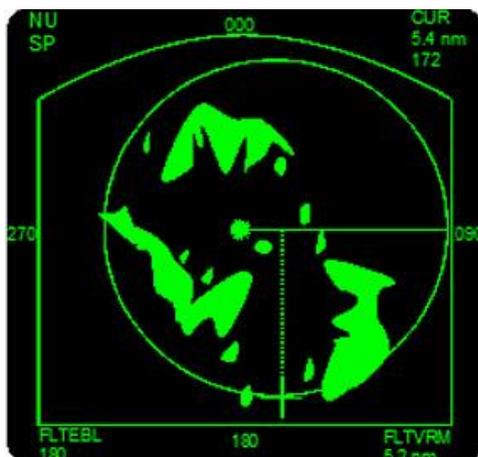
The VRM is an adjustable range ring whose distance from the centre of the screen can be varied by the operator. The radius of the VRM is indicated on the VRM display on the screen. Many radars now offer a cursor controlled VRM which will measure both bearing and range at the same time.

The accuracy of the VRM can be checked by placing the variable ring exactly over several of the fixed rings in turn, and noting any discrepancy in the readings indicated. Such discrepancies can be taken as VRM error, and can differ at different distances from the centre.

Whether you use a traditional controls or a trackball, the method of use is the same. The range of a target is measured by moving the VRM strobe or cursor until it just touches but does not cut the closest edge of the target. To obtain the best possible accuracy always use the shortest range scale available. Any combination a radar bearings and radar ranges (and other means) may be used to fix your position.

### ***Floating EBL and VRM***

Many modern radar sets are equipped with floating EBL's and VRM's. Used in conjunction with the cursor they can measure the bearing and range from any two points on the display. This is a very useful feature when using radar for blind pilotage as the floating cursor with practise can substitute for drawing chinagraph lines on the face of the display.



In the figure on the left the vessel is on a course of 090°T. The position of the cursor is given from the centre of the display as, on a bearing of 172° at a range of 5.4 nm.

The floating EBL and VRM origins have set for the vessel's turn point just ahead of the island on the vessel's starboard side. For the next leg of the vessel's passage the course will be 180° and the distance 5.2 nm as measured by the floating cursor.

**Distance to the radar horizon**

As mentioned earlier, radar, due to refraction radar can see about 6% further than we can see visually.

It is possible, to work out just how far away, you could expect to detect a target using a simple mathematical formula. The formula assumes the following:

- standard atmospheric conditions
- radar pulses are sufficiently powerful
- target will return detectable echoes
- weather conditions (e.g. rain) will not attenuate signal

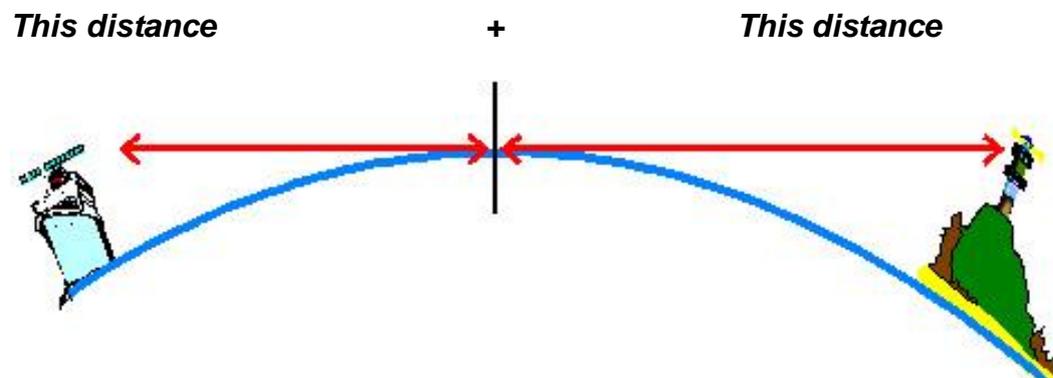
$$\text{Range in nautical miles} = 2.21\sqrt{h} + 2.21\sqrt{H}$$

where:

$\sqrt{\quad}$  = square root

h = height of the scanner in metres

H = height of the target in metres



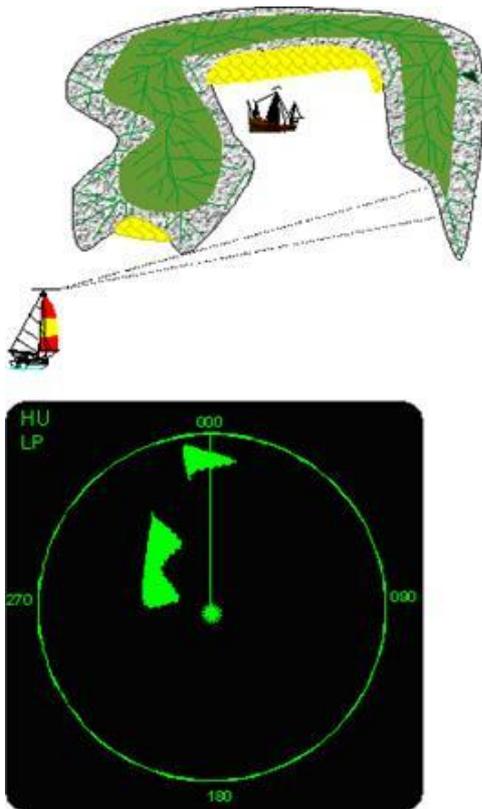
**Example**

What would be the theoretical detection range of an object 16 metres high, from a ship with an aerial height of 4 metres?

$$\begin{aligned} \text{Range in nautical miles} &= 2.21\sqrt{h} + 2.21\sqrt{H} \\ &= 2.21 \times 4 + 2.21 \times 2 \\ &= 8.84 + 4.42 \\ &= 13.3 \text{ nautical miles} \end{aligned}$$

### **Shadow sectors**

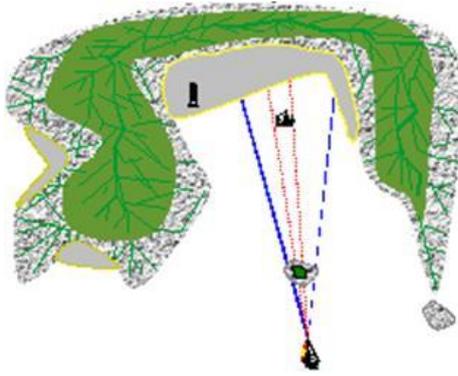
Radar works very much like a flash camera in that it provides its own light (in the form of radio waves) to take a snapshot image. Like a camera and lens the radar snapshot will only see what is reflected back towards the radar antenna. So anything that is behind the object that is the reflector, or in other words, in its shadow, will be invisible to the radar.



On the radar display on the left both the vessel and the bay in which it is anchored will not be visible on the radar screen.

Both are in the shadow area cast by the island's headland

A good example of this is a headland, the radar cannot see through the headland just as you can't, so anything behind the headland will be hidden in the radar's shadow area. On the radar display above both the vessel and the bay in which it is anchored will not be visible both are in the shadow area cast by the islands headland.



The display shown above represents an island with a smaller island in the bay and a monument on the beach. The solid lines originating from the sailing vessel represent the radar beam and the dotted lines indicate the extent of the shadow area cast behind the smaller island. In the radar view the low lying beaches are not visible, but the monument is, however it appears to be a small island or a vessel at anchor.

The small island on the right hand side has merged with the peninsula due to beam width distortion. The anchored vessel is not visible at all as it lies in the shadow area of the cruise liner. Only the tops of the mountains behind the beach appear in the shadow area.

### Position fixing

Radar navigation is similar to traditional navigation in that you have to identify landmarks, measure their position relative to your own and use those measurements to establish a position on the chart. Radar fixing is often quicker than taking bearings with a magnetic compass and is a more professional technique than simply transferring a latitude and longitude from the GPS.

The accuracy of the fix depends on many factors, including the ability of the operator, environmental factors, and the equipment used. Accuracy will improve as the operating range decreases, so the closer you are to the targets the more accurate the fixing, when you need it the most.

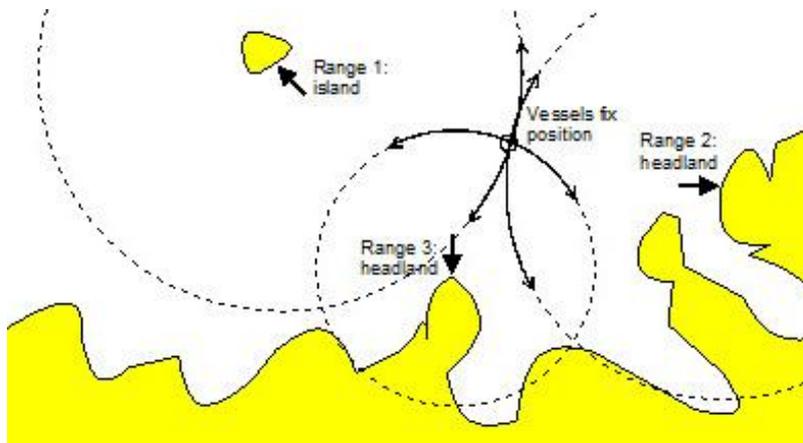
### ***Fixing by radar bearings***

The crucial factor in radar navigation is to correctly identify radar conspicuous features that are recognisable on the chart as well as on the radar screen. Towers, monuments, buildings and other prominent features that are favourites with compass navigation will not be visible on radar. However, objects such as headlands, islands, buoys and beacons will, with the added advantage that they will be equally useable by day or night.

### ***Fixing by radar ranges***

Radar is inherently better at measuring range than it is at measuring bearings: after all, measuring ranges is what it was specifically designed for. So the heading of the vessel is irrelevant when taking a range, the biggest source of error, yaw error, is eliminated. Typically, radar range accuracy is better than 1%, of the range scale in use.

The usual method of obtaining a fix on the chart from radar ranges is to use a pair of compasses and draw “position circles” of at least three, widely-spaced identified conspicuous objects. Choose objects that are close to the boat, since this will improve accuracy. Then measure the ranges with the VRM. Note the ranges, then take a pair of compasses and mark each range on the chart, with the metal compass point on the contact in each case. Short arcs near your DR position are sufficient, label the arcs with an arrowhead at each end. The point where these circular position lines cross marks your position.



### ***Long range position finding***

Experience and skill are the prerequisites required when making a landfall by radar after an ocean passage. At long range when the coastline is below the radar horizon, the identification of inland topographical features with echoes on the display is a matter of some difficulty and requires considerable pre-planning.

The range at which land features will appear on the display will depend upon many factors discussed in earlier sections, such as height of the feature and of the scanner, the weather conditions and the direction from which the land is viewed. Some preparation is therefore required when intending to make a landfall with the aid of radar.

The navigator should have a thorough knowledge of the capabilities and limitations of his radar. Meteorological conditions will need to be taken into account when calculating the radar range at which various land features could be expected to appear on the display. The preparation should begin by first studying the character of the coast within a reasonable distance either side of your estimated position and highlighting features likely to return the first echoes. Without previous local experience a position obtained from any less than three positively identified echoes should be treated with scepticism. Remember that the strongest echo is not necessarily the highest mountain, nor need the first echo seen necessarily be the highest object above the radar horizon.

In many cases however, the first indication of land will be a single indistinct echo on the display. With a single echo, if any sort of position is to be obtained then both range and bearing will have to be used. Apart from the bearing accuracy there must always be considerable doubt about any position obtained from a single echo. Don't just assume that the echo that appears on the display is the target that you are looking for. Soundings in particular can provide a useful check on any position obtained from a signal echo. Treat the fix with scepticism until more echoes appear.

One method to plot a position on the chart once three or more objects appear on the display is to use a sheet of tracing paper. With the ship's position marked at the centre of the sheet transfer the true bearing and range of the echoes on the display to the tracing paper using the latitude scale from the chart. Place the tracing paper over the chart with the marked ship's position near the DR position of the ship and orientate the tracing paper to true north. Then move the tracing paper around until all the plotted echoes correspond with the charted features expected to give responses. The ship's position is then marked on the chart by pricking through the tracing paper onto the chart.

A clear plastic plotting sheet known as a radar station pointer has been specially produced as Admiralty Chart 5028 for this purpose.

## **Pilotage**

### ***Using radar for coastal navigation***

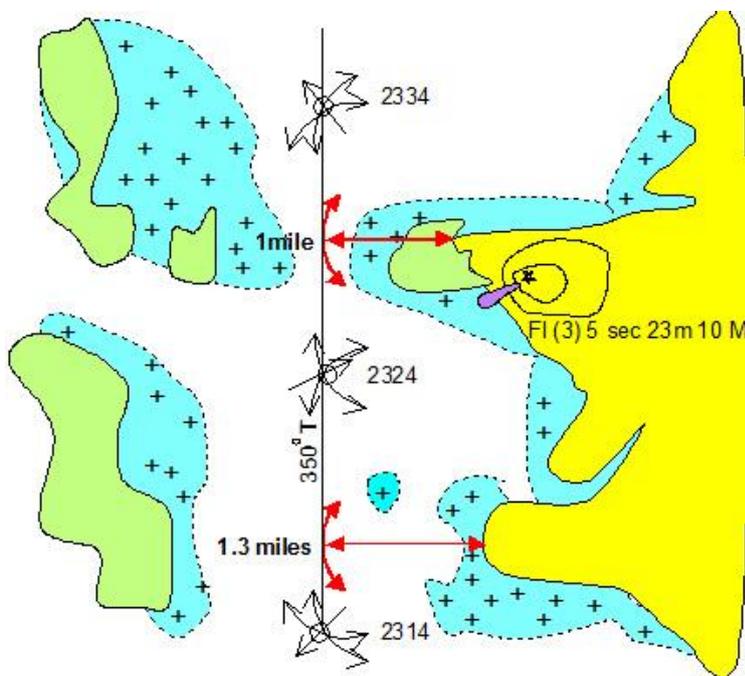
While radar range accuracy is high radar bearing accuracy is low when compared with visual observations. Therefore the most accurate radar assisted fixes are obtained in descending order by:

- a combination of visual bearings of prominent objects and radar ranges
- radar ranges of at least three prominent objects
- radar range and radar bearing of a single prominent feature.

When selecting prominent coastal features for a radar range an object which is high and steep to in the direction of the observer is the best choice and the radar range obtained can be related directly to the chart with little or no error. Three such objects separated in bearing by about 45° will produce the most accurate fixes.

No coastal feature should be used in a radar fix until the feature has been positively identified on the chart. In practice when coasting what is done is to obtain a fix using three known ranges and at the same time take a couple of ranges of other points on the display which are thought to be prominent features. After the three identified objects are plotted, the others are plotted and if they pass through the position it gives reasonable proof of identification. After the new objects have been checked in this way a couple of times they can be used with confidence.

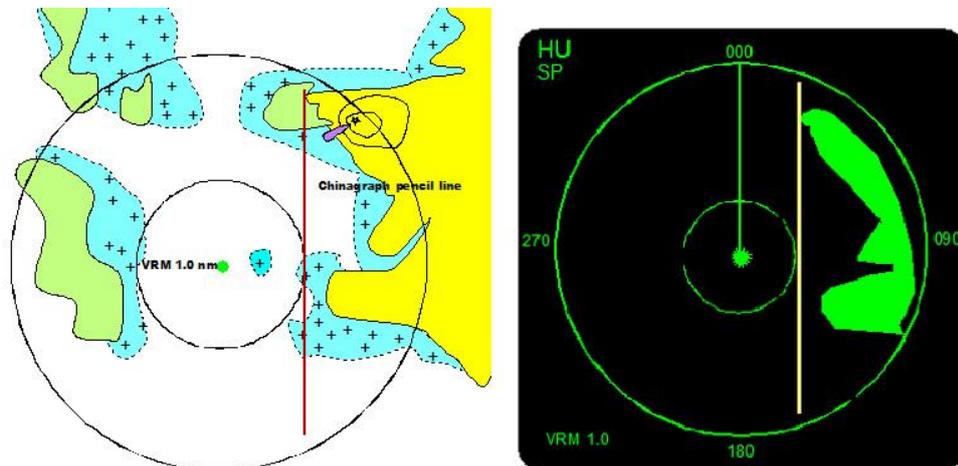
When passing along coasts with off lying dangers a radar range can be used to pass a danger at a safe distance. This is done by drawing a range circle on the chart from a prominent feature such as a headland, then drawing in your DR line tangentially to the danger circle. With the VRM set at the required distance the vessel can be kept on the intended track by keeping the heading marker that distance off the headland. This is even easier to do if you draw a chinagraph line across the screen, the right distance away from the heading mark and parallel to it. See figure 10.



In the chart shown above the navigator is fixing his vessel by using a combination of radar ranges and visual bearings. The navigator has also taken the added precaution when passing through the narrow sections between the reefs of plotting range circles from the headlands. By setting the VRM to the required distance and keeping the radar heading marker that distance off the headland or even better drawing a line with a chinagraph pencil parallel to the heading marker, the vessel is assured to travel along the intended track. This technique is known as blind pilotage or parallel indexing.

Shown below, the navigator has planned his approach to negotiate the narrow passage between the reefs. The left diagram shows the radar display superimposed over the chart. The right diagram shows the radar display (ship's head-up) as the

navigator sees it. In the right diagram the VRM has been set to 1 mile and the navigator has drawn a line with a chinagraph pencil on the screen just touching the VRM and parallel to the heading marker on the radar screen. To safely negotiate the passage all the navigator must do is to con his vessel so as to keep the VRM just touching the pencil line.



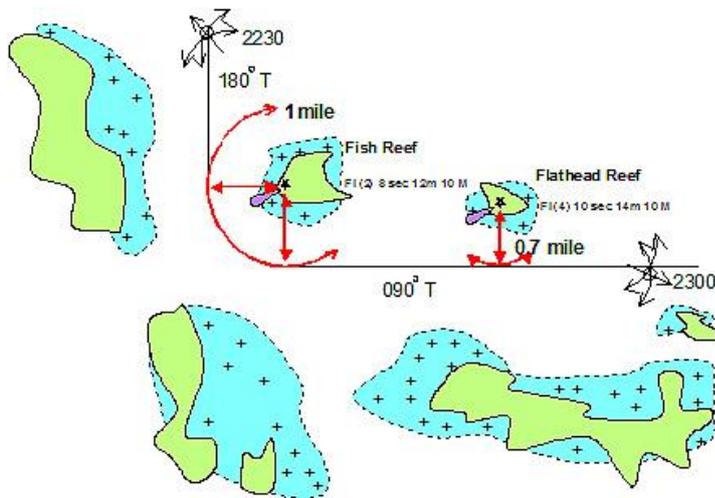
### ***Blind pilotage or parallel indexing***

Blind pilotage or parallel indexing involves navigating a vessel along a pre-planned track in waters so confined that conventional methods of navigating (transferring visual bearings and radar ranges to the chart) is impractical because it cannot not be done quickly enough. Here radar comes into its own, with some pre-planning, its graphic presentation, showing the vessels position in the context of its immediate surroundings can be interpreted by the navigator instantly and the vessel conned directly from the radar display in daylight or darkness.

A north-up presentation is far superior to ship's-head up display for pilotage purposes for the following reasons:

- the display is orientated to look the same as the surroundings
- the display is stabilised so you do not lose the picture when altering course, only the heading marker moves
- the pre-planning process is simplified.

The key to successful piloting is meticulous planning, preparing well in advance the pilotage plan of what should happen, what might happen and being prepared for both contingencies.



Above is shown a pilotage plan for negotiating a 90° course change between the reefs. The vessel's intending track has been drawn on the chart and the vessel's position will be fixed in the normal manner until about one mile from Fish Reef Light. Radar pilotage techniques will be employed from this point. VRM 1 is set to 1 mile and the heading marker kept that distance off Fish Reef Light or a chinagraph pencil line drawn parallel at a distance of 1 mile to the heading marker, until the vessel is abeam of Fish Reef Light.

The helm is then put over to port and the vessel kept at a distance 1 mile off Fish Reef Light until the heading marker with VRM 2 set at a distance of 0.7 miles is that distance off Flathead Reef Light. If your radar only has one VRM the VRM will have to adjusted continually between the two settings. Alternatively a chinagraph pencil line can be drawn on the radar screen.

When abeam of Flathead Reef Light the vessel's position will again be fixed in the normal manner.

## 8. Collision Avoidance

Radar is one of the mariners' most effective tools, its immense value rests with its twofold purpose of radar navigation and collision avoidance. In order to get the greatest value from the radar's detecting ability, radar plotting is necessary, rather than just eyeballing the screen and making assumptions as to the intentions of the other vessel.

By the 1950's radar was developed widely fitted to most of the larger commercial vessels. At first, given radars ability to see through darkness, fog and rain, many mariners believed that there was no longer a need to reduce speed in restricted visibility. This misconception resulted in radar assisted collisions, such as the one between the *Andrea Doria* and the *Stockholm* and has continued as in the Tricolor.

These series of collisions demonstrated that the mariner's ability to interpret and use the radar information was as important as the radar itself. At the core of using radar effectively, the operator must have both, an understanding the radars principles of operation, as well as an understanding of relative motion.

### Early warning of risk of collision

#### ***EBL and VRM***

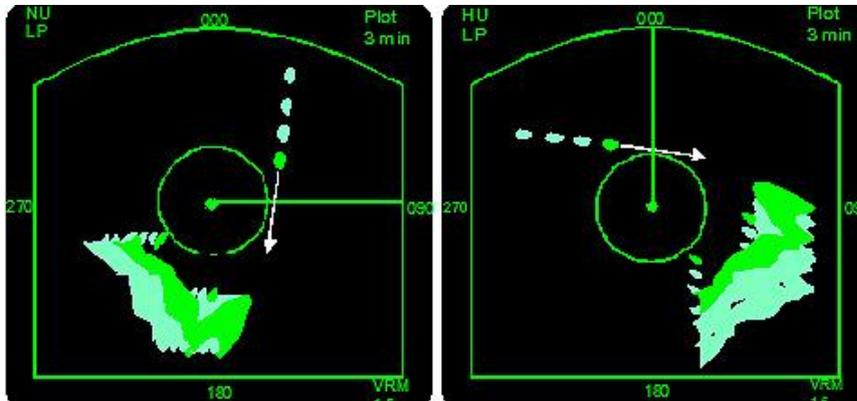
A quick and easy method to establish whether or not a risk of collision may be developing with another vessel on radar, is to position the EBL over the centre of the contact, as if to take a bearing of it. If after two or three minutes the contact appears to be moving towards the centre of the display and along the EBL, a risk of collision maybe developing. A radar plot should then be started or the target captured by the Automatic Radar Plotting Aid (ARPA).



In the sequence above a contact approaching on a steady relative bearing of 215° is shown. A risk of collision is developing.

### **Echo Trails**

Most modern radars have a feature called echo plotting or plot. This feature shows the past position of echoes and therefore the movement of each echo by displaying their previous positions at regular intervals. The plotting interval can be selected by the operator usually beginning at 15 seconds to continuous plotting.

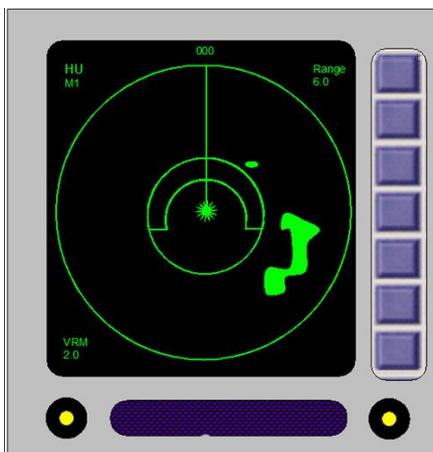


The display on the left represents a north-up stabilised display and shows a vessel on a course of 090° and a target being plotted at three minute intervals. Mentally or by using a chinagraph pencil directly onto the screen, extrapolating the line that the past echoes have made and adjusting the VRM will give the closest point of approach (CPA), of the target, in this case 1.5 nm.

The display on the right shows the same situation but this time with a unstabilised ship's head-up display. At times this method of plotting can be very effective, but at other times particularly with a cluttered display, the picture can become confusing. Experience is invaluable in assessing the most threatening targets before commencing plotting.

### **Guard Zones**

Most modern radars have a facility to incorporate a guard zone on the display which sounds an alarm whenever a contact enters a predetermined section of the display. The guard zone is set up using the EBL and VRM. Guard zones can be set up for many reasons, but a common one would be to give early warning of the approach of another vessel.



A guard zone has been set up to detect targets at a distance of 2 nm from right ahead to  $22\frac{1}{2}^\circ$  abaft the beam on either side of the vessel.

As the target on the starboard side enters the zone, the alarm will sound alerting the operator to a potentially dangerous situation.

### ***Reflective Plotter***

A reflective plotter is a removable device that fits tightly over the radar screen which is then viewed through the plotting surface with minimal parallax error. The semi-silvered surface reflects the image of a chinagraph pencil so that it always appears directly above the target. The device can be used to advantage when using parallel indexing techniques in coastal navigation. It can also be used with a north-up radar when plotting to draw the OA track of a target directly onto the display. The reflective plotter has the advantage that the navigator need not measure ranges and bearings and transfer them to another plot, improving plotting time and avoiding some risk of error.

### ***Relative Motion***

The navigator's primary concern is the safe navigation of his/her vessel to its destination. To accomplish this, fixed hazards such as reefs must be avoided. To do this, the actual or geographical position of the vessel must be known.

Also during the course of a voyage, other moving hazards, such as vessels will be encountered, and the navigator will have to deal with a second type of motion during the voyage. This second type of motion deals with the apparent movement of moving objects and is known as relative movement.

Relative movement is motion measured with respect to a specified object, which may or may not be moving itself. For example, if two vessels are proceeding on the same course and at the same speed. Both vessels will have actual (geographical) movement, but relative to each other they will appear to be stationary.

# Relative Motion

## Ship's Head-up Display

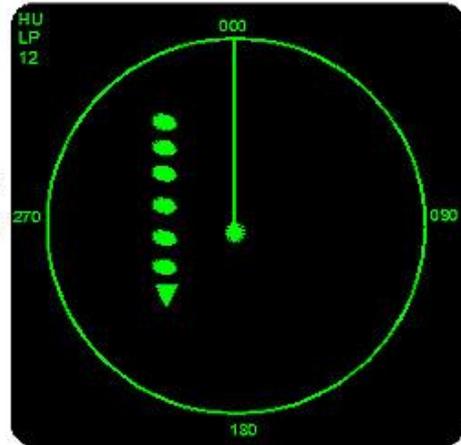


Other vessel stopped



Own vessel course  $090^{\circ}$ T speed 12 kts

Echo movement on display  $180^{\circ}$  12 knots. The relative motion line of the target will run parallel and opposite to own ship's course.

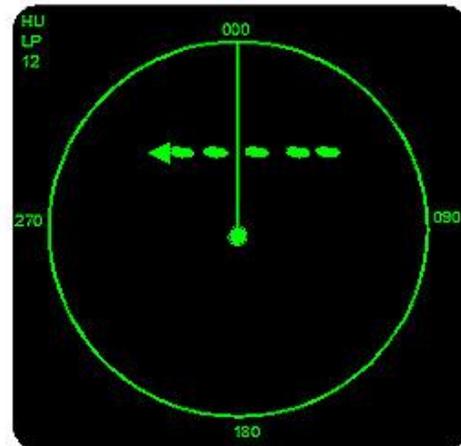


Own vessel stopped



Other vessel course  $000^{\circ}$ T speed 12 kts.

Echo movement on display  $270^{\circ}$  12 knots. When own vessel is stopped the relative motion line of the target will be the same as true motion.

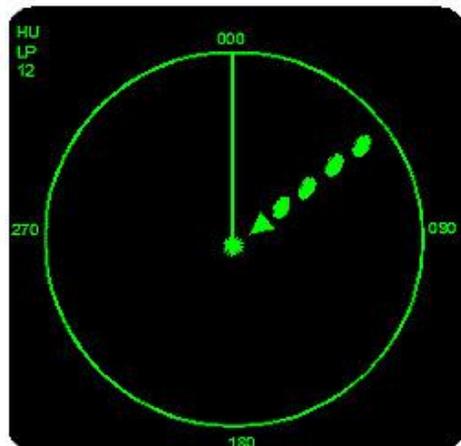


Own vessel course  $090^{\circ}$ T speed 12 kts



Other vessel course  $000^{\circ}$ T speed 12 kts.

The relative motion line is the apparent motion of the other vessel relative to own vessel which is at the centre of the display



## **Relative motion summary**

- Stationary floating objects will move on the radar screen parallel with our course, in a reverse direction, and at our speed.
- Moving objects will not show their true movement on the radar screen.
- Moving targets on the radar screen will have a movement which is a combination of their course and speed and our own ship's course and speed.
- Vessels on collision courses will have a movement towards the centre of the radar screen.

The navigator, primarily to avoid collision, must accurately and quickly solve the problem of the relative movement of other vessels underway and relate that movement to the chart. This could be done by trigonometry, but is quicker and easier to do by geometry.

## **Radar Plotting**

Radar plotting instruction is found in the companion text found at:

<http://www.splashmaritime.com.au/Marops/data/text/Radartex/Radarplottex.htm>