A New Radar Technology – "Broadband" Radar Explained

by Bill Johnson

The landscape of small boat radar has just changed. Until two months ago, all the radars for the leisure marine market worked in pretty much the same way, but earlier this year a significant innovation became available from one group of manufacturers.

Named "Broadband" (no connection with the internet use of the term), these radars operate using continuous transmission of microwaves – as opposed to the traditional pulse transmission. Clearly, anyone who is considering buying a radar system will want to know how the new technology differs from the old, how it works, and what the advantages – and disadvantages – are likely to be.

How the New Technology Works

Those who have studied radar, and/or who have read Chapter 2 of my book *Essential Boat Radar*, will know that radars transmit microwaves, and detect returning echoes of those waves from objects in their path. They will also know that the radar needs to calculate the range of those objects.

Up until now, all small boat radars did this in the same way, using a method which dates to the earliest days of radar. What they do is use *pulses* of microwave radiation rather than a continuous transmission, and measure the *time interval* between sending out the pulse and receiving its echo from the object. The distance travelled by the pulse and its echo (out to the object and back) can be calculated by the formula:

distance = speed x time

where "speed" is the speed of light: 3×10^8 metres per second. The *range* of the object is, of course, half this distance.

Now there is a second method for calculating the range. "Broadband" – or Frequency Modulated Continuous Wave (FMCW) – radars use a *continuous* transmission of microwaves. They also listen continuously, for echo returns. But the *frequency* of the microwave transmission is not constant: it increases at a steady rate, in a "sawtooth" pattern (see figure 1).

So even though there isn't a pulse, we still have a method of timing the interval between the transmission of the microwaves and the detection of their echo. Once the waves have left the transmission antenna, their frequency doesn't change. They continue to the object, reflect off it, and return to the radar's receiver antenna. By then the radar is transmitting a higher frequency. The radar looks at the difference between the frequency it is currently transmitting, and the frequency of the echo it is receiving: and knowing the rate at which the transmission frequency is increasing, it can work out the time delay. From then on, the calculation is exactly the same as before. See Figure 2.

FIGURE 1 FMCW radar transmission frequency pattern

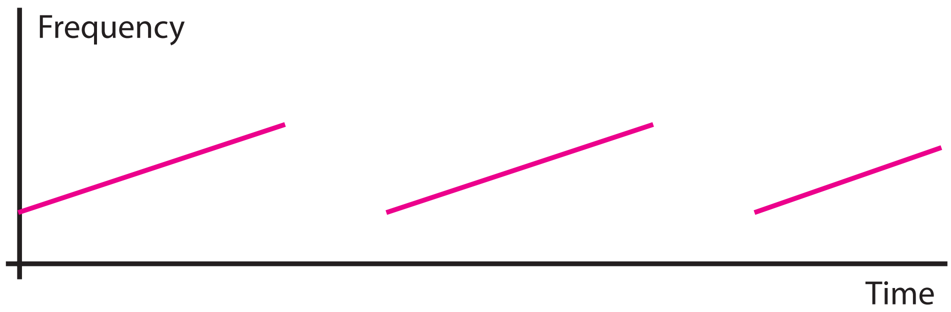
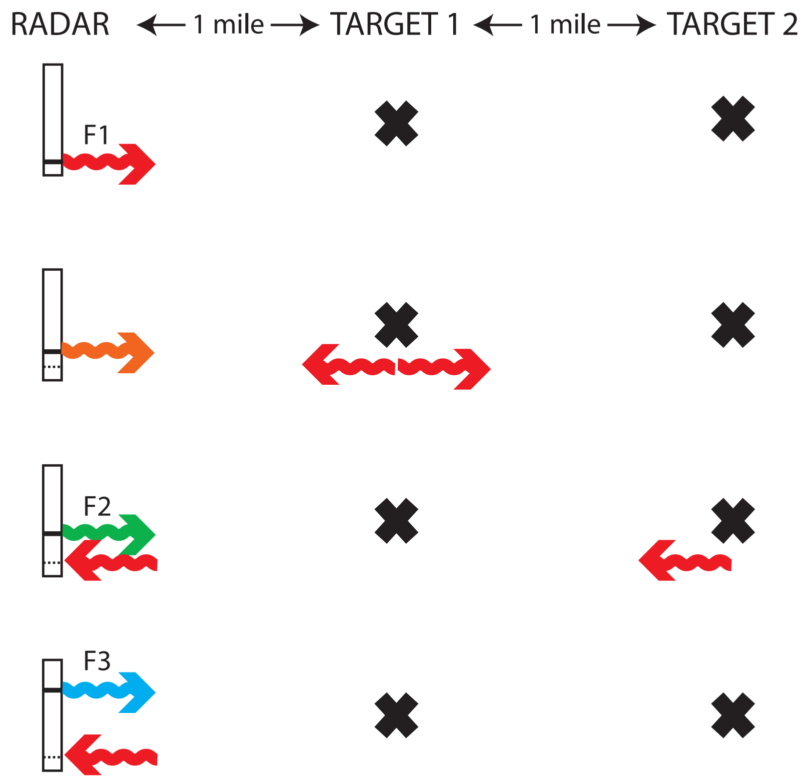


FIGURE 2 How FMCW radars calculate target range



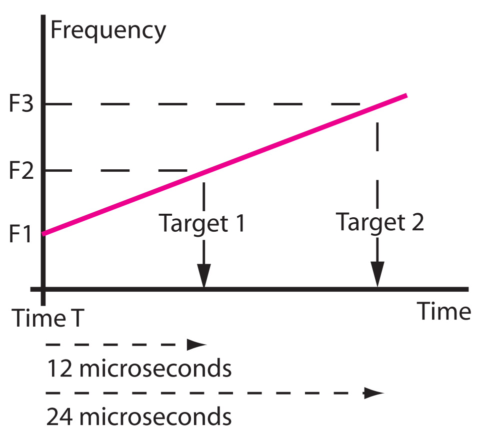
Time T: Waves transmitted at frequency F1 and travel at speed of light.

T+6 microseconds: F1 waves reach Target 1, and echo returns. F1 waves continue towards Target 2. Radar is now transmitting at higher frequency.

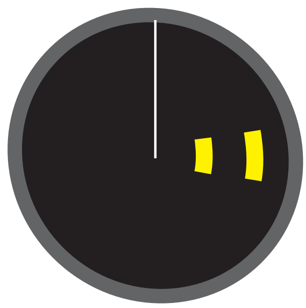
T + 12 microseconds: First F1 echo reaches scanner. Echo returns from Target 2. Radar is now transmitting at F2. By comparing F2 with F1 it calculates time interval for Target 1 (see graph).

T + 24 microseconds: Second F1 echo reaches scanner. Radar is now transmitting at F3. By comparing F3 with F1 it calculates time interval for Target 2 (see graph).

TRANSMISSION FREQUENCY GRAPH



RADAR DISPLAY



Radar calculates distances from time intervals:

12 microseconds = 2 miles travel = 1 mile target range
24 microseconds = 4 miles travel = 2 miles target range

Note that with FMCW, the transmitter and receiver operate continuously, requiring separate antennae contained in the same dome. Pulse radars switch from transmit to receive, so they can use the same antenna for both functions. The technology for producing the microwaves is also radically different, and this has several consequences which are described below.

What Are the Differences Between Pulse Radar and FMCW / "Broadband"?

The first thing to note is that most of the radar system, and very nearly all of what you have learned about using radar, is entirely unchanged by the new technology. The picture will still look the same; you still use it in the same way; all the technical facts about beam width, side lobes, multiple echoes etc are the same; and the functionality available from integration with other instruments is identical (see *Essential Boat Radar* for this information).

The areas of difference that a user needs to know about are identified and discussed below. They are:

- warm-up time and tuning
- range discrimination and target detection
- sea clutter
- transmission characteristics

It's also fair to note that, being completely new on the market, much is not yet known about how the new systems actually perform. We expect that they will benefit from the inherent advantages of the new technology, but there are also disadvantages to overcome. The unknown factor is how well the new technology has been implemented by the manufacturer.

There are plenty of extremely good radars using the "proven" pulse (magnetron) technology, and I doubt they will all be swept aside by FMCW in the short term. (Perhaps a reasonable analogy is digital photography: undoubtedly the technology of the future, but it took quite a long time for it to equal or out-perform the well-established chemical film.)

Warm-up Time and Tuning

The device that does the microwave pulses is called a magnetron. One feature of the magnetron is that it takes time to warm up, and another is that its transmission frequency varies a bit.

For the user on a boat (see Chapter 3 of *Essential Boat Radar*) the warm up period means that when you turn the radar on, you have to wait a couple of minutes before you can use it. Radar systems generally have a low power-consumption "Standby Mode", so that you can get the picture immediately by selecting "Transmit" when you need it.

The variation of frequency means that the receiver has to be fine-tuned to the transmit frequency, and there is a Tuning control to do this. (This is not much of a burden to the user with modern systems, because they can perform the tuning function automatically.)

In contrast, FMCW uses solid state transmitters which do not require a warm-up time and whose frequency is stable, so the systems are available pretty well straight away when turned on, and do not require any Tuning function.

Range Discrimination and Target Detection Performance

a) Short Range

This is the most exciting benefit of FMCW technology.

The range discrimination of pulse radar depends on the pulse length (see page 71 & 72 of *Essential Boat Radar* for a full explanation of this), whereas there is no theoretical limit to the range discrimination available to a FMCW radar. This leads to pictures that are very much sharper in range with FMCW radars than the equivalent picture with pulse radar, particularly at short range. Added to this, pulse radars have a substantial *minimum* range below which they can't detect anything (perhaps 40 – 50 metres) because they have to switch from transmit to receive, but FMCW radars can detect targets a very short distance from the boat.

Another factor is that, at short range, FMCW is able to transmit more energy to illuminate targets, and needs less receiver bandwidth, than pulse radar. This means that target detection is inherently better with FMCW at short range.

So the short range pictures are undoubtedly better with FMCW radars. There is an important point to note however: FMCW offers no intrinsic gain in *bearing* discrimination, because beam width will have the same relation to antenna size with both types of radar.

b) Long Range

At longer range, FMCW still discriminates range with extraordinary precision compared to pulse radars (particularly when the latter are using longer pulses, which they do for longer ranges). However, the difference isn't nearly so obvious on the display when you are looking at targets several miles away. In any case, you are not so interested in precise range discrimination of a few metres when the target is a few miles away, is moving (a vessel), or perhaps partly obscured below the horizon (a coastline).

The chances of *detecting* a target depend on how much energy you can illuminate it with.

Pulse radars have a very high transmission power available (typically 2 or 4 kW for a small boat system) which they use for a very short period of time: the duration of the pulse. FMCW radars, on the other hand, transmit continuously at a much lower power (around 1 or 2W, i.e. about a thousand times less).

At short range, FMCW "wins" over pulse radar – it can transmit more energy to illuminate targets. Pulse radar has to use very short pulses for range discrimination, and this means less energy per pulse. But at long range, pulse radar can use longer pulses (albeit fewer of them per second), and therefore, with its very high transmission power, it can get more energy out to illuminate targets.

There are other factors besides transmitted energy (receiver bandwidth and noise, spectral purity) that also work against FMCW at longer ranges. We won't know how well the new radars perform in relation to the old technology until there are more of them out there being used, but long range target detection is an area where pulse radar retains inherent advantages.

Sea Clutter

Sea clutter is the radar detecting perfectly valid targets – wave surfaces – that we don't happen to be interested in. At closer range the radar is "looking at" the sea at a steeper vertical angle, so the clutter problem tends to be greatest at close range (see page 29 of *Essential Boat Radar*).

As discussed above, FMCW radar is particularly good at resolving individual small targets at close range, so sea clutter will tend to be displayed as a speckle of small targets: whereas with pulse radar it is likely to be shown as a larger blob of joined-up returns. Thus with FMCW, it should be easier to spot a larger, or stronger, target amongst the clutter, not least because its position should be more constant than the speckle of wave face returns.

If you suppress the clutter – usually by reducing the receiver's gain at short range – you are in danger of suppressing real targets too, and this is just as true of FMCW radar as it is of pulse.

Transmission Characteristics

Pulse radar has a very high peak transmission power, and this is regarded as hazardous. By contrast, FMCW transmits at a much lower power (more akin to mobile phones) and does so continuously. It is considered, therefore, that FMCW can be operated safely close to personnel.

It is interesting to note that there is very much less difference between the respective *mean* transmission powers (because pulse radar only transmits for a short time, during pulses).

Other Factors

For completeness, I will mention two other areas where the difference between the technologies is probably not of very much consequence to the user.

Interference

Potentially, FMCW can suffer from interference from strong microwave transmissions e.g. from pulse radars, and they can suffer from on-board reflections from superstructure etc. No doubt the manufacturers will have worked to overcome these problems.

Power Utilisation

Whilst there may be perfectly valid claims regarding the lower power utilisation of particular FMCW systems, it is difficult to equate this to any inherent advantage of the technology.

When considering power utilisation it is not relevant to compare *peak* power transmission (which is of course very much higher in pulse radar).

It is the energy – or *mean* power – transmitted by the radar that enables targets to be seen, and that is what the boat's batteries have to provide. As explained above, FMCW owes part of its superior short range performance to the fact that at short range it is transmitting at *greater* mean power than the equivalent pulse radar. At longer range this situation is reversed. Overall the mean power transmission is similar in the two types of radar, with systems of similar performance.

Transmitted power is, of course, only one component of the power needed to run the system. Perhaps the full validity of any claims will be established when the new systems are independently trialled.

Conclusion

The new technology is impressive and represents a genuine change in radar technology. Up until now most of the advances have been in the part of the system which processes and displays the picture, but this is different: FMCW is a real technological change in the part of the radar which gets the information.

One would expect that this will be the way forward for future systems, but as explained above FMCW does not have all of the advantages. If you are choosing which to buy, perhaps the best advice is to have a good look at what you want your radar *for*. The major strength of FMCW is better performance and clarity at very short range, and perhaps suitability for smaller vessels. Vessels whose primary use of radar is collision avoidance at sea (a relatively long range application) will – for the moment anyway – be just as well off with pulse radar.

For the user, both types of radar do the same thing and are used in the same way. The only difference with “Broadband” systems is that there is no warm-up time (and so no need for Stand-by / Transmit), no Tuning function (something you probably won’t notice, as it is automated in modern pulse systems), and shorter range scales will be available.