Blind Speed

At the comparison of the echoes between two or more pulse periods the fall can appear, that the airplane flies with exactly this one radial speed, some a phase shifting of correct 360° causes. In accordance with the periodicity of the sine function this fall can appear even at all integral multiples of *±n · 360°*. The value of phase shifting is zero in these falls too. Well, the target isn't recognized as a moving target therefore. It flies with a so-called **blind speed** and the MTI system won't report it like a ground clutter.

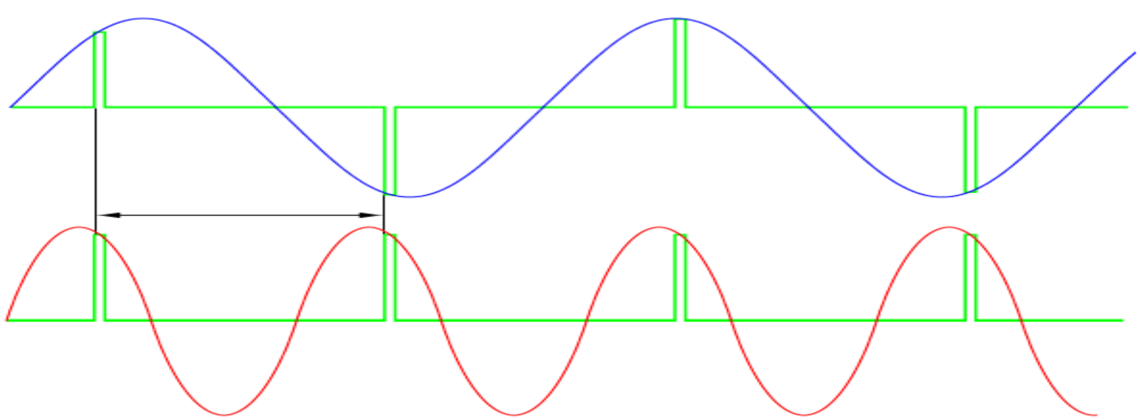
The blind speed is dependent on the transmitted frequency and on the pulse repetition frequency of the radar unit.

$$v_{blind} = \lambda / 2 \cdot T_s \qquad (1)$$

where:

v_{blind} = one of the blind speeds
λ = wavelength of the transmitted pulse
T_s = pulse repetition time (PRT)

With reference to the lower diagram on the figure 1:



If the Doppler frequency produced by a moving target is exactly the same as the PRF ($f_D = PRF$) then "sampling" occurs at the same point on each Doppler cycle. As far as the signal processor is concerned, it is as if the target were stationary. The same effect occurs if f_D is an integer multiple of PRF. Hence targets with certain radial velocities tend to be invisible to an MTI pulse radar.

The blind speed is a radial speed of the airplane at which the phase shifting of the echo-signal has the value *±n · 360°* between two pulse periods. With blind speeds moving targets are suppressed by a MTI system like ground clutters.

Example:
A radar unit works with the tx-frequency of 2.8 GHz and a puls repetition time of 1.5 ms. Under these conditions the first blind speed has got the value:

$$v_{blind} = \frac{\lambda}{2 \cdot T_s} = \frac{c_0}{2 \cdot f \cdot T_s} = \frac{3 \cdot 10^8}{2 \cdot 2{,}8 \cdot 10^9 \cdot 1{,}5 \cdot 10^{-3}} = 35{,}72\ {}^{m}/_{s} \qquad (2)$$

c_0 = speed of light

This speed of converted about 130 km/h and all integral multiples of this also well cause that the target isn't visible in the range of the effectiveness of the MTI system.

Due to the periodicity of a measured Doppler frequency is only in the period from zero to the first maximum of the sine wave in Figure 1 (representing the Doppler frequency) unambiguously assigned to a velocity. The doppler frequency must be lower than the pulse repetition frequency. This ambiguity in measurements of velocity is called Doppler Dilemma.

Simple **measures against the appearance of blind speeds** are:

- Using of the coherence channel only if it is necessary
  This demand also arises that the amplitude channel ("Normal Video") has a better maximum range than the "Coho-channel".
- constantly changing of the TX- frequency (Frequency-Diversity)
  It is demanded a sufficiently large frequency spacing.
- constantly changing of the pulse repetition time (Staggered PRT)
  Most effective resource: no airplane can change its speed so fast and synchronous still to this!

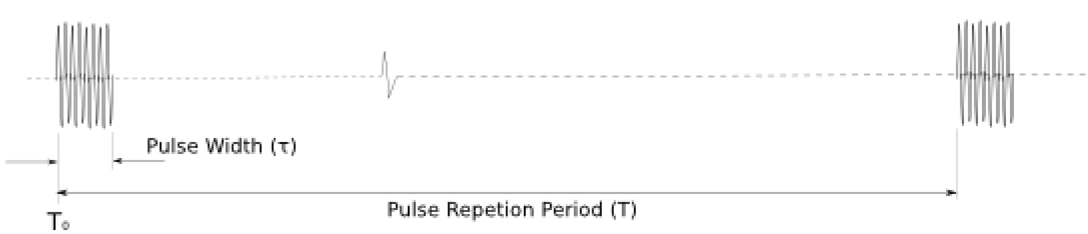
However, all these measures are part of the standards of air-surveillance radar sets already.

Radar signal characteristics

A radar system uses a radio-frequency electromagnetic signal reflected from a target to determine information about that target. In any radar system, the signal transmitted and received will exhibit many of the characteristics described below.

The radar signal in the time domain

The diagram below shows the characteristics of the transmitted signal in the time domain. Note that in this and in all the diagrams within this article, the x axis is exaggerated to make the explanation clearer.



Carrier

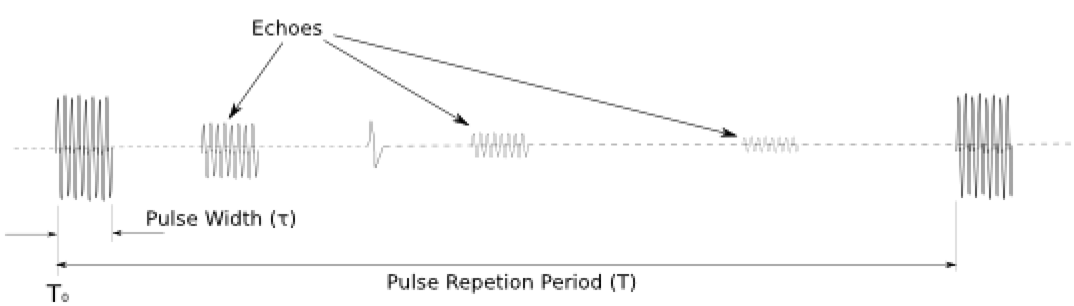
The carrier is an RF signal, typically of microwave frequencies, which is usually (but not always) modulated to allow the system to capture the required data. In simple ranging radars, the carrier will be pulse modulated and in continuous wave systems, such as Doppler radar, modulation may not be required. Most systems use pulse modulation, with or without other supplementary modulating signals. Note that with pulse modulation, the carrier is simply switched on and off in sync with the pulses; the modulating waveform does not actually exist in the transmitted signal and the envelope of the pulse waveform is extracted from the demodulated carrier in the receiver. Although obvious when described, this point is often missed when pulse transmissions are first studied, leading to misunderstandings about the nature of the signal.

Pulse width

The pulse width (or pulse duration) of the transmitted signal is the time, typically in microseconds, each pulse lasts. If the pulse is not a perfect square wave, the time is typically measured between the 50% power levels of the rising and falling edges of the pulse.

The pulse width must be long enough to ensure that the radar emits sufficient energy so that the reflected pulse is detectable by its receiver. The amount of energy that can be delivered to a distant target is the product of two things; the peak output power of the transmitter, and the duration of the transmission. Therefore, pulse width constrains the maximum detection range of a target.

Pulse width also constrains the range discrimination that is the capacity of the radar to distinguish between two targets that are close together. At *any* range, with similar azimuth and elevation angles and as viewed by a radar with an unmodulated pulse, the range resolution is approximately equal in distance to half of the pulse duration times the speed of light (approximately 300 meters per microsecond).



Pulse width also determines the radar's dead zone at close ranges. While the radar transmitter is active, the receiver input is blanked to avoid the amplifiers being swamped (saturated) or, (more likely), damaged. A simple calculation reveals that a radar echo will take approximately 10.8 µs to return from a target 1 statute mile away (counting from the leading edge of the transmitter pulse (T_0), (sometimes known as transmitter main bang)). For convenience, these figures may also be expressed as 1 nautical mile in 12.4 µs or 1 kilometer in 6.7 µs. (For simplicity, all further discussion will use metric figures.) If the radar pulse width is 1 µs, then there can be no detection of targets closer than about 150 m, because the receiver is blanked.

All this means that the designer cannot simply increase the pulse width to get greater range without having an impact on other performance factors. As with everything else in a radar system, compromises have to be made to a radar system's design to provide the optimal performance for its role.

Pulse repetition frequency (PRF)

In order to build up a discernible echo, most radar systems emit pulses continuously and the repetition rate of these pulses is determined by the role of the system. An echo from a target will therefore be 'painted' on the display or integrated within the signal processor every time a new pulse is transmitted, reinforcing the return and making detection easier. The higher the PRF that is used, then the more the target is painted. However, with the higher PRF the range that the radar can "see" is reduced. Radar designers try to use the highest PRF possible commensurate with the other factors that constrain it, as described below.

There are two other facets related to PRF that the designer must weigh very carefully; the beamwidth characteristics of the antenna, and the required periodicity with which the radar must sweep the field of view. A radar with a 1° horizontal beamwidth that sweeps the entire 360° horizon every 2 seconds with a PRF of 1080 Hz will radiate 6 pulses over each 1-degree arc. If the receiver needs at least 12 reflected pulses of similar amplitudes to achieve an acceptable probability of detection, then there are three choices for the designer: double the PRF, halve the sweep speed, or double the beamwidth. In reality, all three choices are used, to varying extents; radar design is all about compromises between conflicting pressures.

Staggered PRF

Staggered PRF is a transmission process where the time between interrogations from radar changes slightly, *in a patterned and readily-discernible repeating manner.* The change of repetition frequency allows the radar, on a pulse-to-pulse basis, to differentiate between returns from its own transmissions and returns from other radar systems with the same PRF and a similar radio frequency. Consider a radar with a constant interval between pulses; target reflections appear at a relatively constant range related to the flight-time of the pulse. In today's very crowded radio spectrum, there may be many other pulses detected by the receiver, either directly from the transmitter or as reflections from elsewhere. Because their apparent "distance" is defined by measuring their time relative to the last pulse transmitted by "our" radar, these "jamming" pulses could appear at any apparent distance. When the PRF of the "jamming" radar is very similar to "our" radar, those apparent distances may be very slow-changing, just like real targets. By using stagger, a radar designer can force the "jamming" to jump around erratically in apparent range, inhibiting integration and reducing or even suppressing its impact on true target detection.

Without staggered PRF, any pulses originating from another radar on the same radio frequency might appear stable in time and could be mistaken for reflections from the radar's own transmission. With staggered PRF the radar's own targets appear stable in range in relation to the transmit pulse, whilst the 'jamming' echoes may move around in apparent range (uncorrelated), causing them to be rejected by the receiver. Staggered PRF is only one of several similar techniques used for this, including jittered PRF (where the pulse timing is varied in a less-predictable manner), pulse-frequency modulation, and several other similar techniques whose principal purpose is to reduce the probability of unintentional synchronicity. These techniques are in widespread use in marine safety and navigation radars, by far the most numerous radars on planet Earth today.

Clutter

Main article: Clutter (radar)

Clutter refers to radio frequency (RF) echoes returned from targets which are uninteresting to the radar operators. Such targets include natural objects such as ground, sea, precipitation (such as rain, snow or hail), sand storms, animals (especially birds), atmospheric turbulence, and other atmospheric effects, such as ionosphere reflections, meteor trails, and three body scatter spike. Clutter may also be returned from man-made objects such as buildings and, intentionally, by radar countermeasures such as chaff.

Some clutter may also be caused by a long radar waveguide between the radar transceiver and the antenna. In a typical plan position indicator (PPI) radar with a rotating antenna, this will usually be seen as a "sun" or "sunburst" in the centre of the display as the receiver responds to echoes from dust particles and misguided RF in the waveguide. Adjusting the timing between when the transmitter sends a pulse and when the receiver stage is enabled will generally reduce the sunburst without affecting the accuracy of the range, since most sunburst is caused by a diffused transmit pulse reflected before it leaves the antenna. Clutter is considered a passive interference source, since it only appears in response to radar signals sent by the radar.

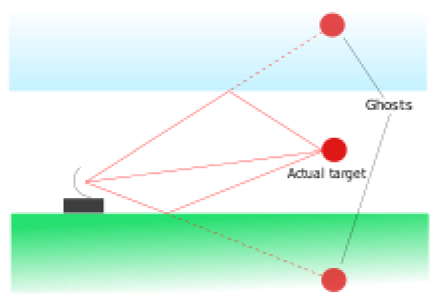
Clutter is detected and neutralized in several ways. Clutter tends to appear static between radar scans; on subsequent scan echoes, desirable targets will appear to move, and all stationary echoes can be eliminated. Sea clutter can be reduced by using horizontal polarization, while rain is reduced with circular polarization (note that meteorological radars wish for the opposite effect, and therefore use linear polarization to detect precipitation). Other methods attempt to increase the signal-to-clutter ratio.

Clutter moves with the wind or is stationary. Two common strategies to improve measure or performance in a clutter environment are:

- Moving target indication, which integrates successive pulses and
- Doppler processing, which uses filters to separate clutter from desirable signals.

The most effective clutter reduction technique is pulse-Doppler radar with Look-down/shoot-down capability. Doppler separates clutter from aircraft and spacecraft using a frequency spectrum, so individual signals can be separated from multiple reflectors located in the same volume using velocity differences. This requires a coherent transmitter. Another technique uses a moving target indication that subtracts the receive signal from two successive pulses using phase to reduce signals from slow moving objects. This can be adapted for systems that lack a coherent transmitter, such as time-domain pulse-amplitude radar.

Constant False Alarm Rate, a form of Automatic Gain Control (AGC), is a method that relies on clutter returns far outnumbering echoes from targets of interest. The receiver's gain is automatically adjusted to maintain a constant level of overall visible clutter. While this does not help detect targets masked by stronger surrounding clutter, it does help to distinguish strong target sources. In the past, radar AGC was electronically controlled and affected the gain of the entire radar receiver. As radars evolved, AGC became computer-software controlled and affected the gain with greater granularity in specific detection cells.



Radar multipath echoes from a target cause ghosts to appear.

Clutter may also originate from multipath echoes from valid targets caused by ground reflection, atmospheric ducting or ionospheric reflection/refraction (e.g., Anomalous propagation). This clutter type is especially bothersome since it appears to move and behave like other normal (point) targets of interest. In a typical scenario, an aircraft echo is reflected from the ground below, appearing to the receiver as an identical target below the correct one. The radar may try to unify the targets, reporting the target at an incorrect height, or eliminating it on the basis of jitter or a physical impossibility. Terrain bounce jamming exploits this response by amplifying the radar signal and directing it downward.[1] These problems can be overcome by incorporating a ground map of the radar's surroundings and eliminating all echoes which appear to originate below ground or above a certain height. Monopulse can be improved by altering the elevation algorithm used at low elevation. In newer air traffic control radar equipment, algorithms are used to identify the false targets by comparing the current pulse returns to those adjacent, as well as calculating return improbabilities.

Sensitivity time control (STC)

STC is used to avoid saturation of the receiver from close in ground clutter by adjusting the attenuation of the receiver as a function of distance. More attenuation is applied to returns close in and is reduced as the range increases.