RAdio Detection And Ranging (RADAR)

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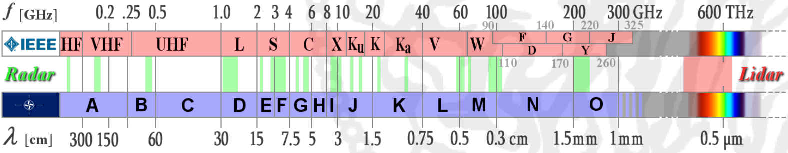
RADAR

When Radio Frequency (RF) signals hit an object they are usually reflected or scattered in many directions, although some of them will be absorbed and penetrate into it.

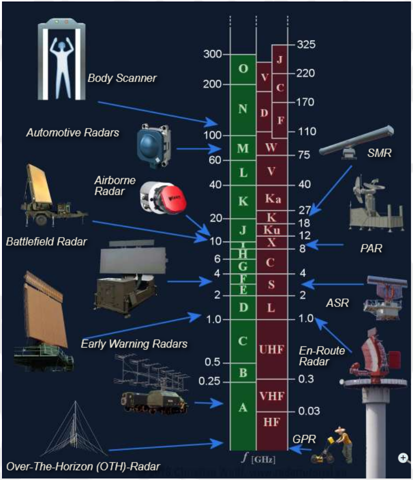
A RADAR is a system that determines the position and possibly velocity of non-cooperative objects by transmitting RF signals and processing the back-reflected received echo(es).

Operating frequency of RADARs is strongly dependant on the particular application requirements.



RADAR

- Surface Movement Radar (SMR)
- Precision Approach Radar (PAR)
- Airport Surveillance Radar (ASR)
- Ground Penetrating Radar (GPR)
- Over The Horizon (OTH) Radar



Range Equation

Assumptions

- Radio signals propagate in air at the speed of light in vacuum.
- Radio signals propagate in Line Of Sight (LOS).

Measurement process:

- A single, high power radio frequency pulse is transmitted and concurrently time measurement is started.
- Transmitter is switched off and receiver is switched on.
- Round-trip time t_i is measured for every single echo received.

Range R_i of the i-th detected target is then calculated as:

$$R_i = \frac{ct_i}{2} \tag{1}$$

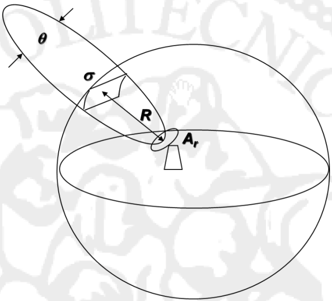
Radar Equation

Power density $\hat{P}_{dt}$ at a distance R from an isotropic transmitter is given by

$$\hat{P}_{dt} = \frac{P_{tx}}{4\pi R^2} \tag{2}$$

where P_{tx} is the transmitted power.
In case of a transmitter antenna with a gain G_{tx}, power density P_{dt} is:

$$P_{dt} = G_{tx}\hat{P}_{dt} = \frac{P_{tx}G_{tx}}{4\pi R^2} \tag{3}$$



Assumptions

The above formulas are valid under the hypothesis that no attenuation is caused by the transmissive medium (air).

Radar Equation

Power density P_{dt} hits the target and is reflected back with an intensity P_r that depends on a number of target characteristics (shape, material, surface finishing, geometry, etc.) usually condensed in its *radar cross section* $\sigma \left[m^2\right]$

$$P_r = P_{dt}\sigma = \frac{P_{tx} G_{tx}}{4\pi R^2}\sigma \tag{4}$$

The echo propagates back finally hitting the antenna with a density P_{dr}

$$P_{dr} = \frac{P_r}{4\pi R^2} = \frac{P_{tx} G_{tx}}{4\pi R^2}\sigma\frac{1}{4\pi R^2} = \frac{P_{tx} G_{tx}}{(4\pi)^2 R^4}\sigma \tag{5}$$

Radar Equation

The receiving antenna *effective aperture* $A_r\left[m^2\right]$ is defined as:

$$A_r = \frac{G_{rx}\lambda^2}{4\pi} \tag{6}$$

where G_{rx} is the antenna gain in reception and $\lambda\,[m]$ is the wavelength.

Power density P_{dr} is then eventually captured by A_r yielding received power P_{rx}:

$$P_{rx} = P_{dr}A_r = \frac{P_{tx}G_{tx}}{(4\pi)^2R^4}\sigma\frac{G_{rx}\lambda^2}{4\pi} \tag{7}$$

Radar Equation

Rearranging eq. (7) and remembering that most antennas exhibit symmetrical gain $G_{tx} = G_{rx} = G$ we obtain

$$P_{rx} = \frac{P_{tx} G^2 \lambda^2 \sigma}{(4\pi)^3 R^4} \tag{8}$$

Radar Equation

Equation (8) is often refered to as *The Radar Equation*.

Defining P_{rxm} the minimum signal power that can be processed by the receiver we can obtain the maximum target range R_{max}

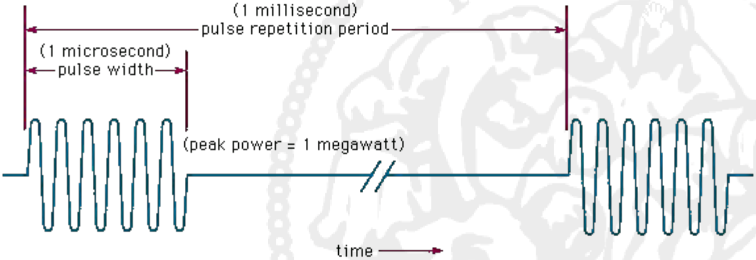
$$R_{max} = \sqrt[4]{\frac{P_{tx} G^2 \lambda^2 \sigma}{(4\pi)^3 P_{rxm}}} \tag{9}$$

Primary Radar

A *Primary Surveillance Radar (PSR)*, a.k.a. *Primary Radar*, controls a large portion of air space to detect and localise both cooperative and non-cooperative targets within its operating range.

Primary Radar

Primary Radar is a pulsed radar: it periodically transmits high-power RF pulses and listens for echoes.



Primary Radar: Observables

For every detected target, Primary Radar observables include:

- Range.
- Bearing.
- Slant speed (possibly).

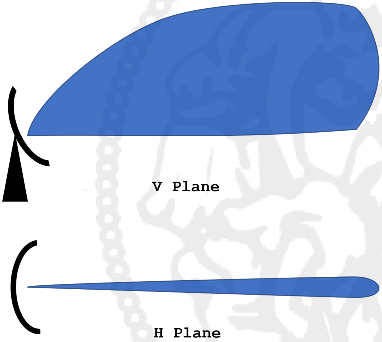
Range is determined by measuring round-trip pulse time and applying (1).

Bearing is determined using an antenna with a highly directional radiation pattern in the horizontal plane.

Slant speed is determined measuring the Doppler frequency shift of the received echo.

Primary Radar: Antenna

Primary Radar antenna is designed to have a very directional radiation pattern in the horizontal plane and a wide radiation pattern in the vertical plane.



Primary Radar: Antenna

Primary Radar antenna is rotated about a vertical axis at a speed of approximately 5 to 20 rpm.

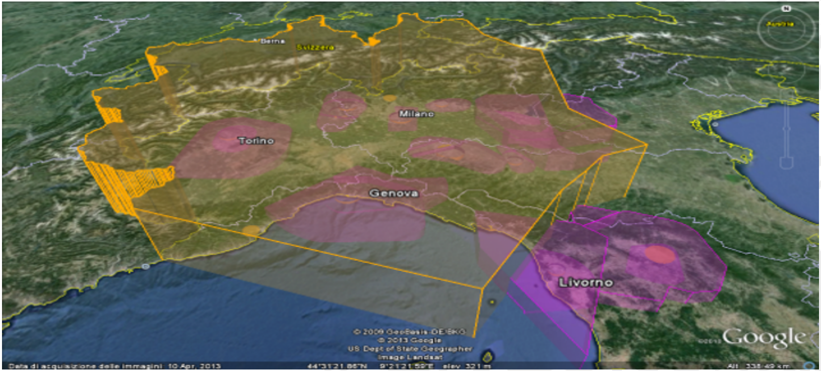
The bearing associated to every received echo is derived from the angular position of the antenna at the moment that particular echo is received, measured on the antenna mast with an angular resolver.

The wide radiation pattern in the vertical plane permits Primary Radar to scan the entire volume around it position for every revolution.

The consequence of such choice is that no information on target elevation is obtained.

Primary Radar: Example

Milano Area Control Center (ACC) controlled airspace.

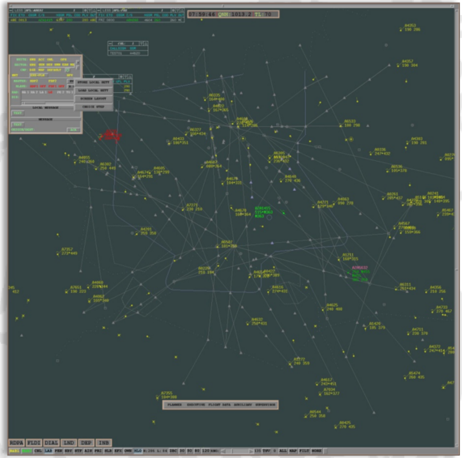


Primary Radar: Example

Primary Radar stations within Milano ACC

Primary Radar: Human Machine Interface (HMI)

Primary Radar information is never presented "as is", but is heavily post-processed and blended with other sources of information (e.g. Secondary Surveillance Radar, Eurocontrol traffic database, etc.) before being displayed on the operator's screen



List of Acronyms

ACC	Area Control Center
ASR	Airport Surveillance Radar
GPR	Ground Penetrating Radar
HMI	Human Machine Interface
LOS	Line Of Sight
OTH	Over The Horizon
PAR	Precision Approach Radar
PSR	Primary Surveillance Radar
RADAR	RAdio Detection And Ranging
RF	Radio Frequency
SMR	Surface Movement Radar