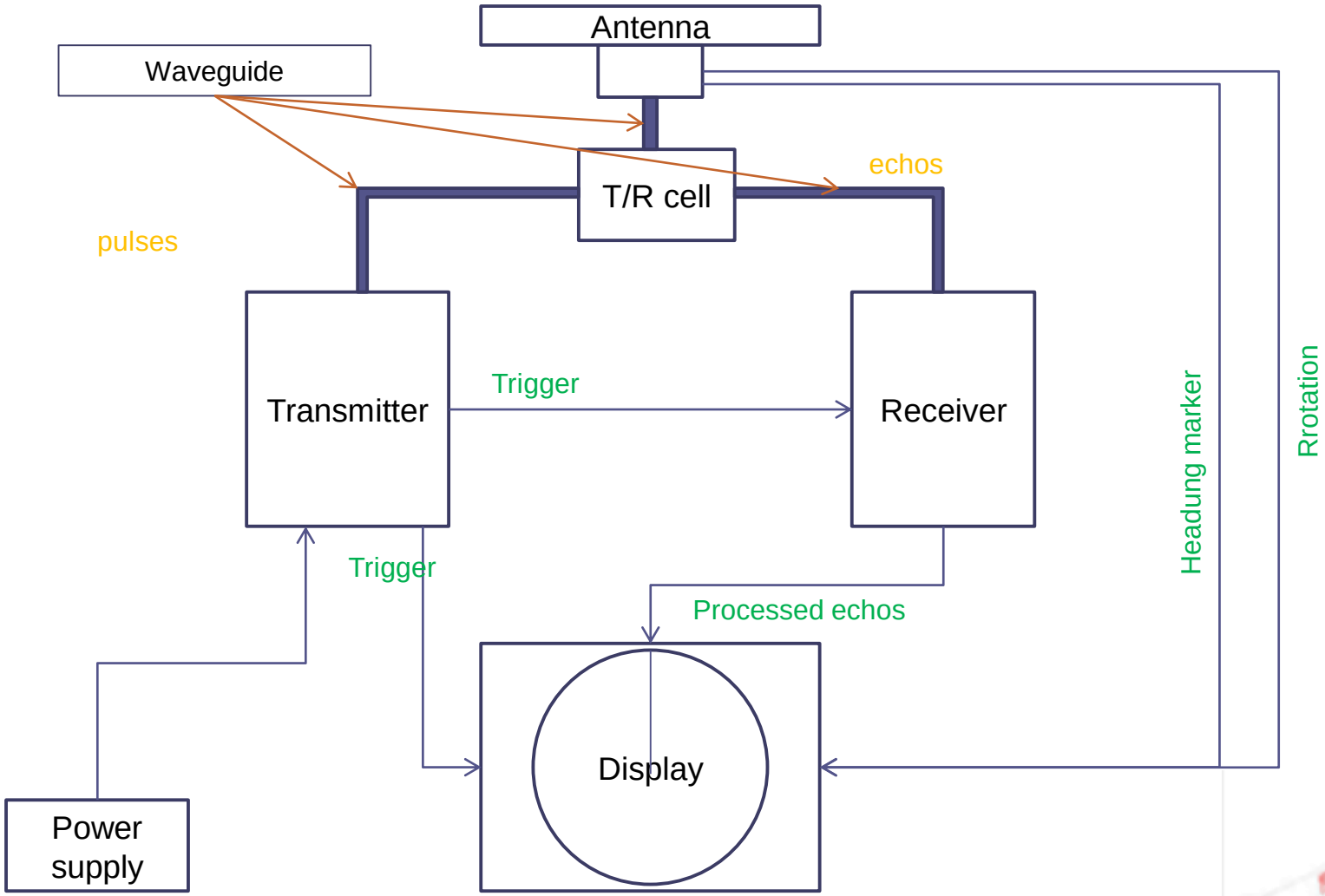
Radiolocation 2

Transmitter, receiver, display, antenna and waveguide arrangement, and their controls

Radar design

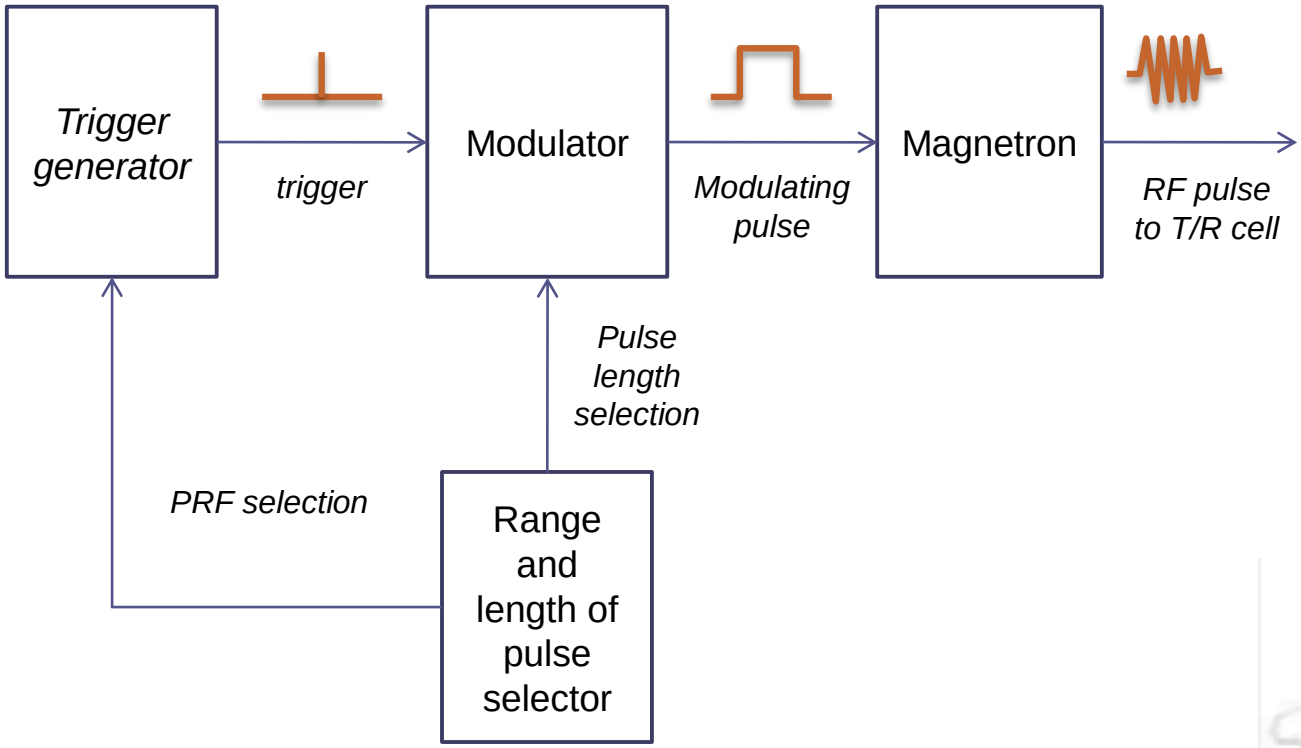


Transmitter

The transmitter comprises three main elements:

- Trigger generator – controls the number of radar pulses transmitted in one second PRF;
- Modulator – together with pulse forming network produces a pulse of the appropriate length, power and shape when is activated by the trigger;
- Magnetron – determines electromagnetic wave frequency of pulse which is sent then to the antenna by waveguide.

Transmitter design



Trigger generator

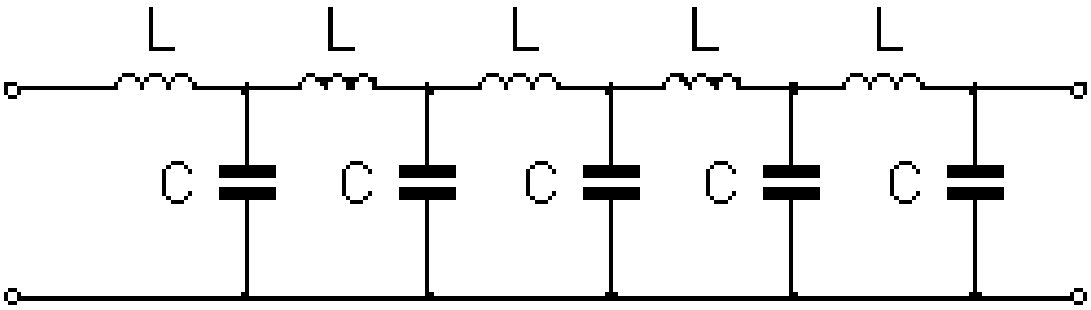
- is a free-running oscillator which generates a continuous succession of low voltage pulses known as synchronizing pulses, or trigger pulses
- Synchronization covers all systems that participate in the distance measurement process and therefore their synchronization is required to obtain a high accuracy of the measured distances.
- These pulses control e.g. madulator, time base (memory cells selection), A/C Sea etc.

Modulator

- Forms a rectangular shaped electric pulses with great power (very high voltage tens of thousand volts and the current of hundreds of ampere).
- Pulse forming network PFN is used, which consists of series connected cells of power storage components as capacitors and inductors.
- They are charged relatively slow (about 1000 μs), but discharging of the energy is very rapid (about 1 μs).
- It allows to use a low energy source to produce a high energy pulse.

PFN – ladder network

- The selection of the pulse length is performed by selecting an appropriate number of PFN cells.



Magnetron

Very high electromagnetic wave frequency generator

Under the influence of the energy of the modulating pulse generates a high-power electromagnetic wave pulse with a specific frequency and duration.

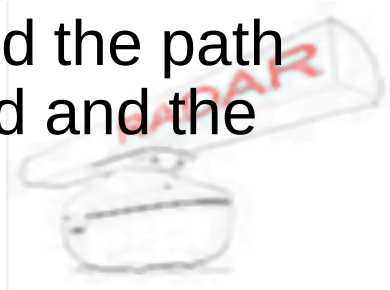
Duration of the microwave impulse ranges from 0.02 to 1.0 μs, and its power from several to several dozen kW.

The frequency of the microwaves, called radar frequency, belongs to the frequency of bands S or X. The X band most commonly used in marine radars, covers the frequency range 9200-9500 MHz, and the S band includes 2900-3100 MHz.

As the microwave generator a special type of microwave valve called a magnetron is used. The magnetron produces electromagnetic waves of a specific frequency. This energy impulse is then transmitted through the waveguide to the antenna.

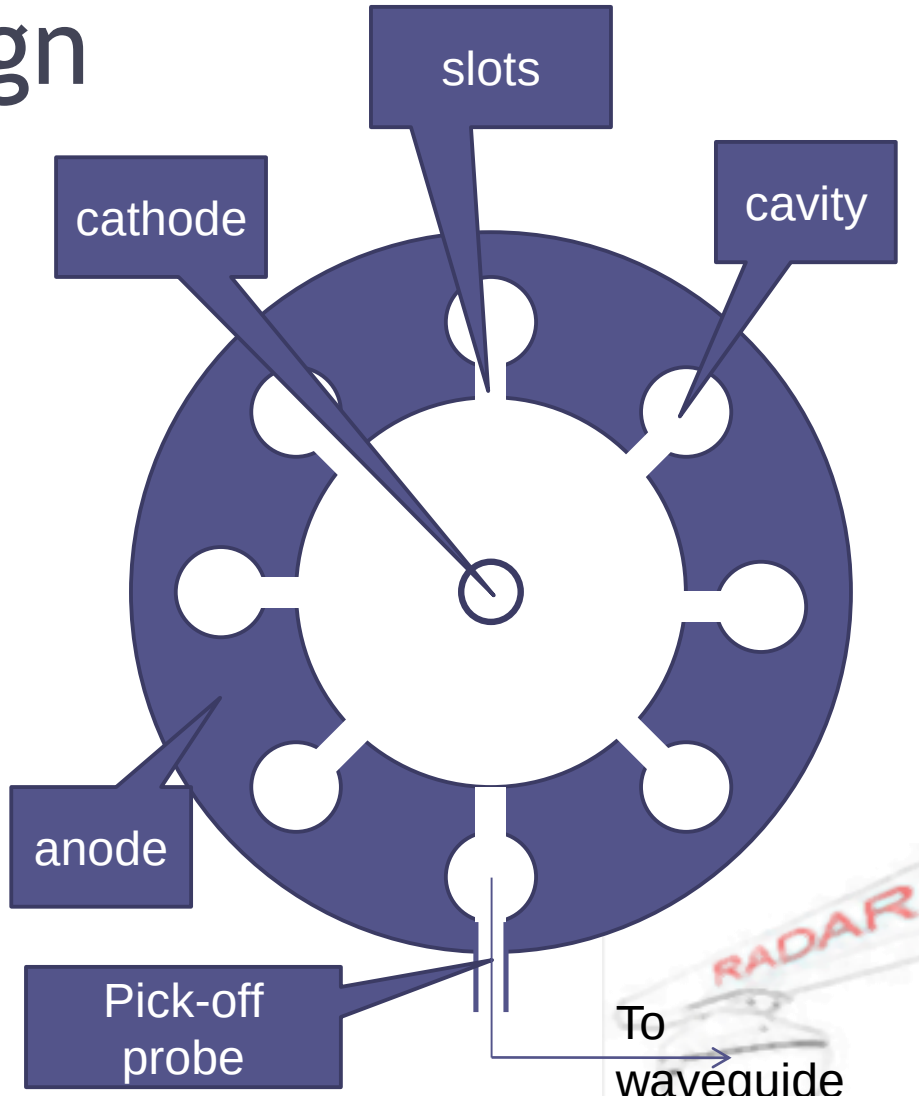
Magnetron

- self-induced oscillation device based on the phenomenon of resonance, which converts input DC (direct current) energy into high frequency electric energy.
- The magnetron is essentially a diode valve in which the anode is a copper cylinder into which are cut cavities (in the form of holes and slots) of very precise dimensions. The cathode is a pillar located along the central axis of the cylinder.
- A horseshoe magnet applies an extremely powerful magnetic field which acts along the axis of the cylinder
- The electrons flow from the cathode to anode, and the path and their speed are modified by the magnetic field and the shape of the anode chamber.



Magnetron - design

- A copper cylinder with cavities
- The source of electrons in the form of an oxide cathode heated (anneal) by a resistance element
- Vaccum



Range scale – pulse length

	Short pulse		Long pulse	
Range [Mm]	PRF [Hz]	PL [μs]	PRF [Hz]	PL [μs]
0.25	2000	0.05	2000	0.05
0.5	2000	0.05	1000	0.25
0.75	2000	0.05	1000	0.25
1.5	2000	0.05	1000	0.25
3.0	1000	0.25	500	1.0
6.0	1000	0.25	500	1.0
12	1000	0.25	500	1.0
24	500	1.0	500	1.0
48	500	1.0	500	1.0

Short and long pulses – comparison

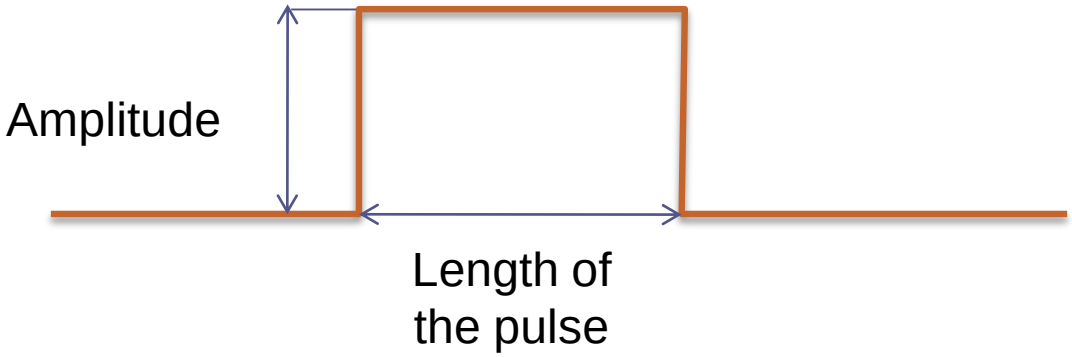
Feature	Impuls krótki	Impuls długi
Long range target detection	Poor. Use when short range scales are selected	Good. Use when long range scales are selected and for poor response targets at short range.
Minimum range	Good. Use when short range scales are selected	Poor. Use when long range scales are selected and minimum range is not a major consideration.
Range discrimination	Good	Poor.
Effect on echo paint	Short radial paint. Produces a well defined picture when short range scales are selected.	Long radial paint when short range scales are selected but the effect is acceptable when long range scales are selected.
Effect on sea clutter	Reduces the probability of the masking of targets due to saturation	Increases the probability of the masking of targets due to saturation
Effect in precipitation	Reduces the probability of the masking of targets due to saturation	Increases the probability of the masking of targets due to saturation. However the use of long pulse helps to combat the attenuation caused by precipitation and will increase the probability of detecting targets which lie beyond rain.

Pulse power

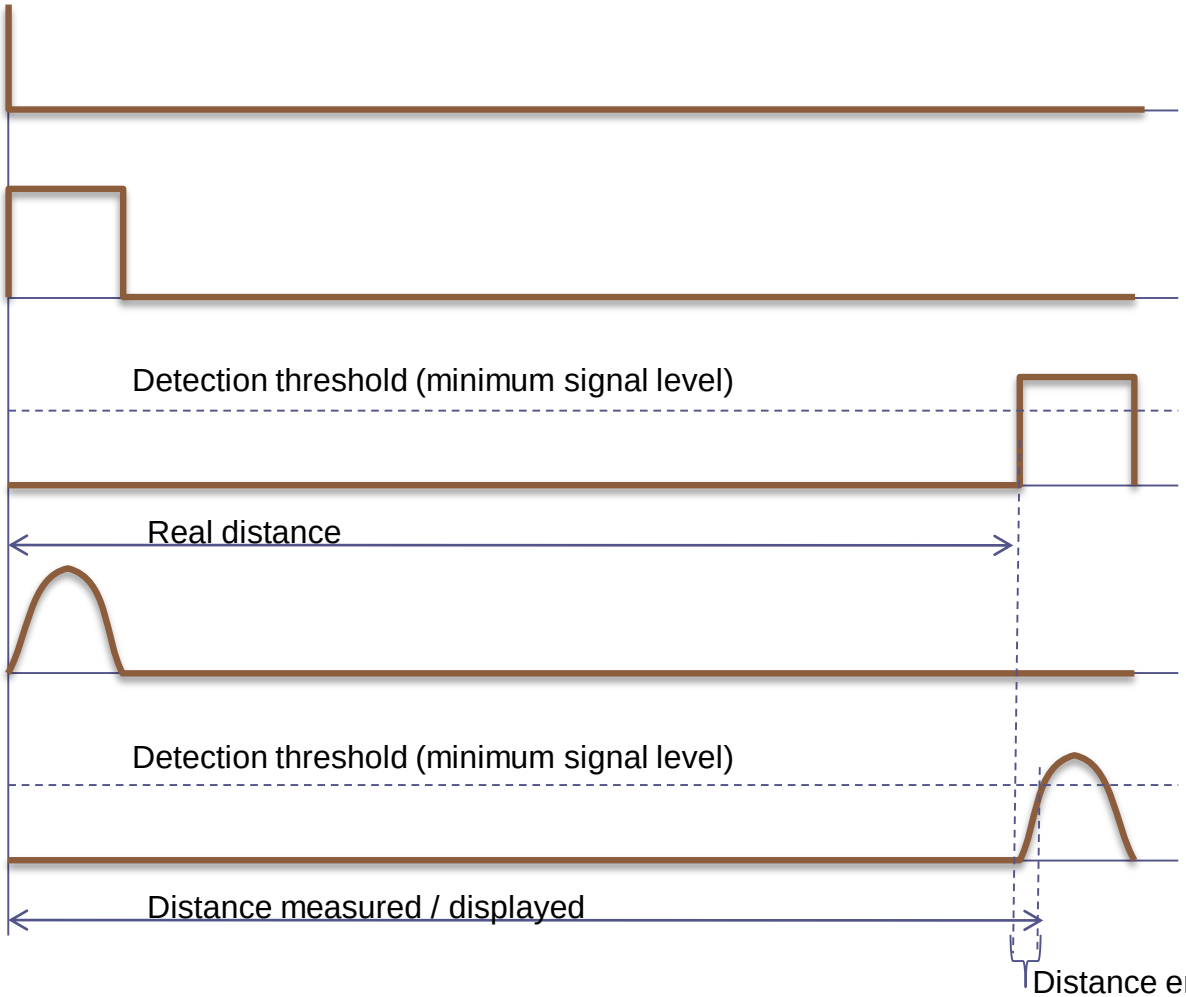
- It is one of the factors determining the maximum radar range.
- It depends on the amplitude of the pulse.
- On small vessels, transmitters with a power not exceeding several kW are used.
  For commercial ships with an unlimited sailing range, up to several dozens of kW are used.

Pulse shape

- The shape of the pulse is particularly important when measuring the distance. Perfect - rectangular.

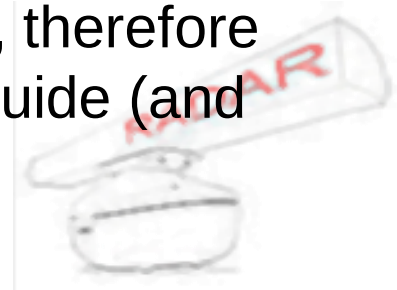


Pulse shape


Trigger
The perfect pulse
Detection threshold (minimum signal level)
The perfect pulse - response
Real distance
The real pulse
Detection threshold (minimum signal level)
The real pulse - response
Distance measured / displayed
Distance error

Waveguide

- Line of the pulse energy transmission from the transmitter to the antenna, as well as the energy of the reflected pulses (echoes) from the antenna to the receiver.
- For the X-band, the waveguides are metal pipes with a rectangular cross-section of the appropriate dimensions ensuring the transfer of RF energy with the lowest possible losses.
- For the S-band, as the transmission line coaxial cables of appropriate design are also used.
- Since the antenna is a moving element in the radar, therefore in order to transfer the energy from the fixed waveguide (and vice versa) a rotary connector is to be used.



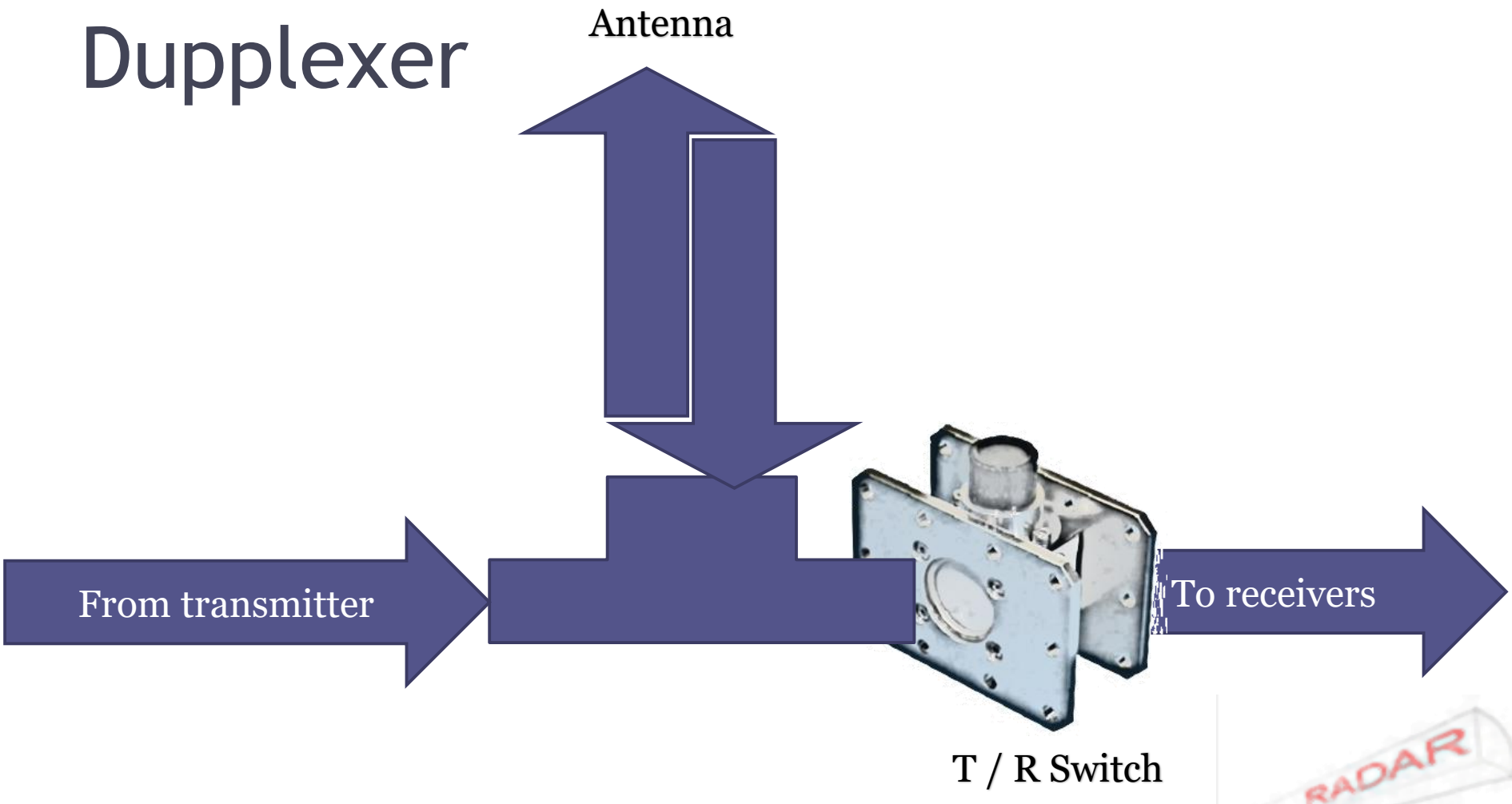
Duplexer

Transmit / receive switch or cell,

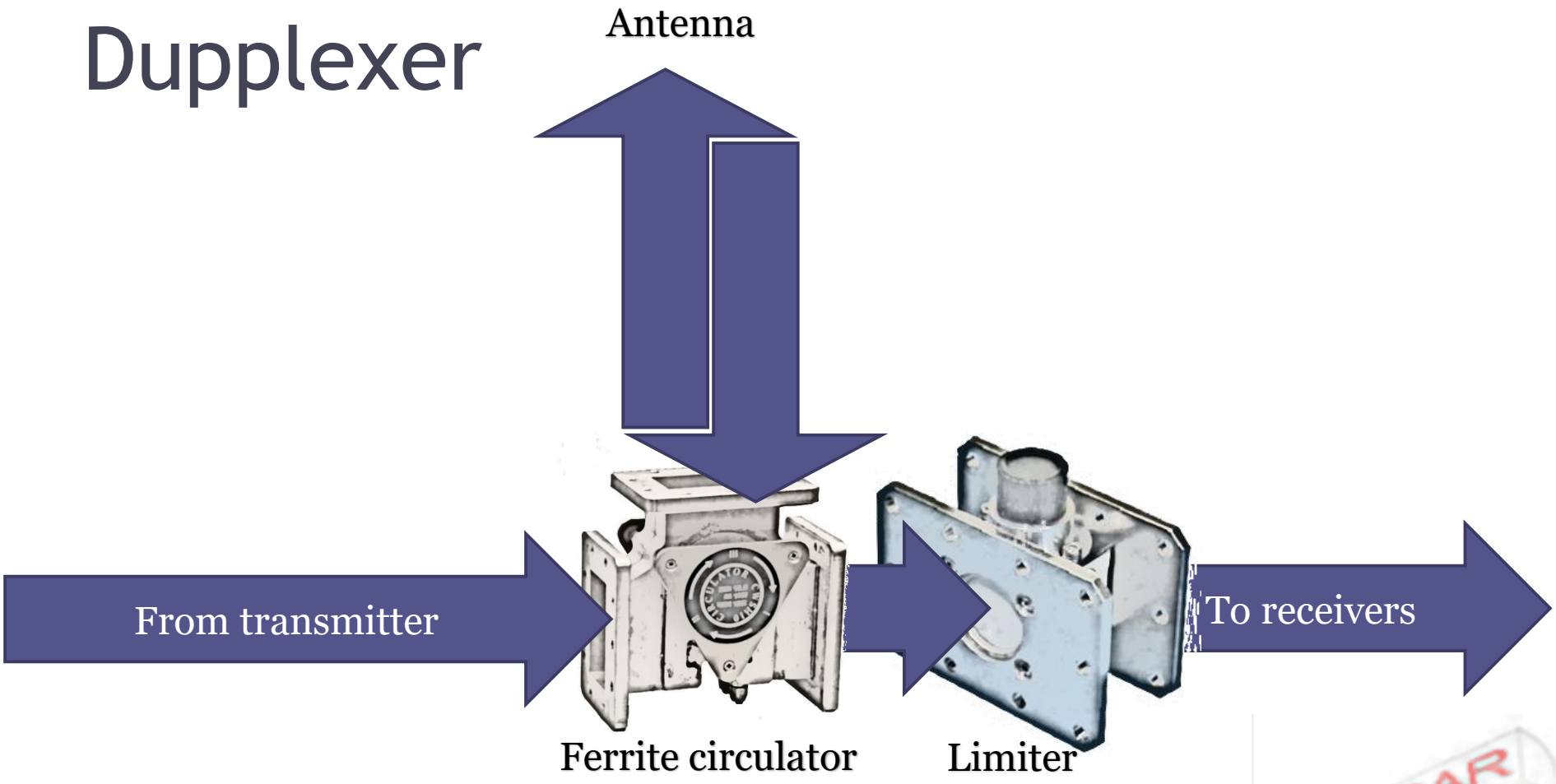
The purpose of this switch is to block the input circuits of the receiver while the transmitter is in operation. The sensitive input circuits are then protected against being damaged by the high power of RF impulse.

Mostly the T/R switch (gas-tube dupplexer) is a kind of tube filled with a low-breakdown-voltage gas. The gas during high power pulse transmissions is fired (ionisazated) and blocking the part of waveguide leading to the receiver.

Dupplexer



Dupplexer


Antenna
From transmitter
To receivers
Ferrite circulator
Limiter

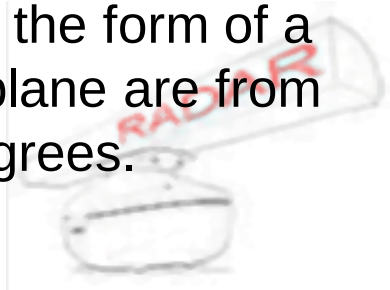
Antenna

Antenna radiates directionally and receives pulses of electromagnetic waves and simultaneous is rotated by an electric motor in a horizontal plane. Mostly are used two types of antennas: slot antenna and parabolic antenna.

Slot antennas (used most often by civil vessels) are made of a waveguide segment, in whose shorter wall are cut out a number of slots at precisely defined distances, and inclined to the axis of the waveguide at an angle greater than 70 degrees.

The parabolic antenna consists of a reflector being a segment of a parabolic mirror in whose focus the end of the waveguide. The waveguide is ended with a horn which is acting as a radiating element.

The EM pulses are transmitted (and received) in the space in the form of a lobe. The angular dimensions of the lobe in the horizontal plane are from 0.5 to 2 degrees, and in the vertical plane from 20 to 45 degrees.



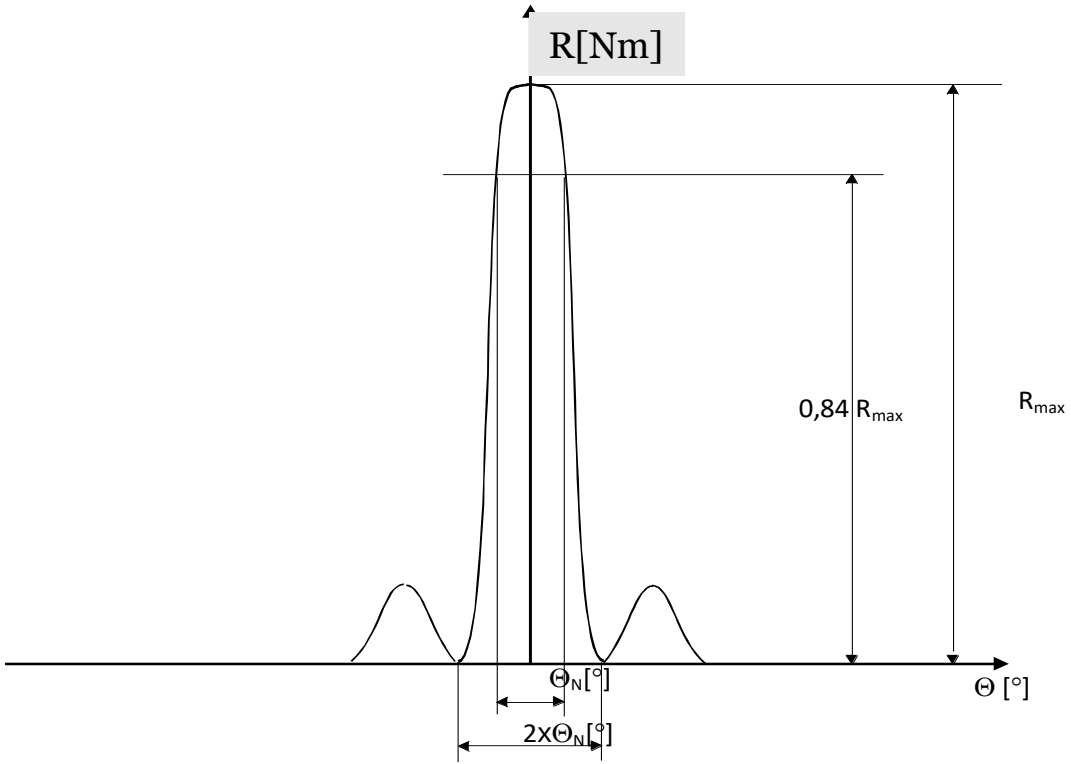
Antennas

$$\Theta[^\circ] = K\frac{length\ of\ EM\ wave[m]}{width\ of\ aperture[m]}$$

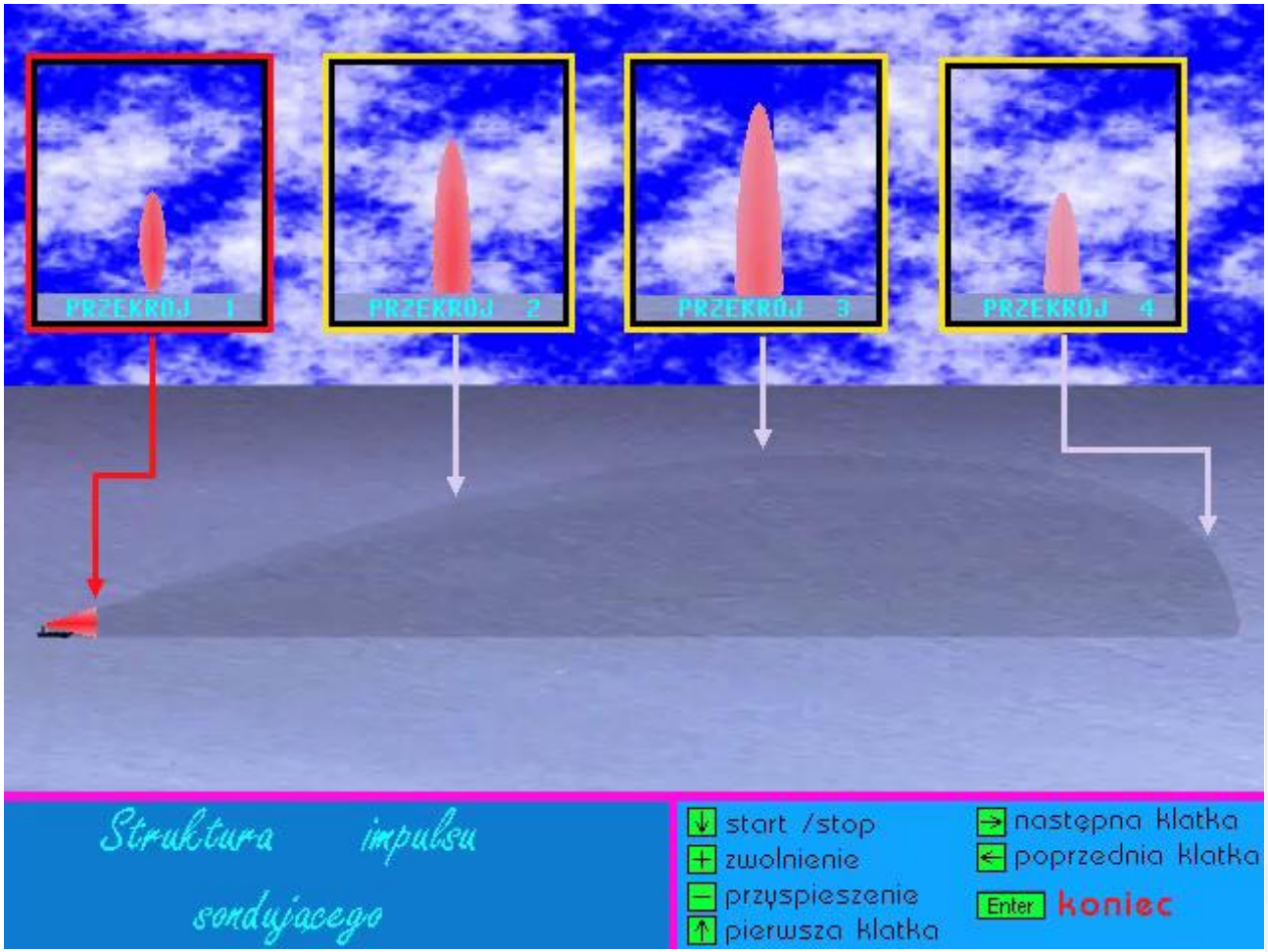
K – constant number;
theoretical value is equal to 51.
In practice, the value of the constant varies depending on the design of the antenna.
For modern slot antennas it is equal to 70.

Slot antenna

- The shape of the horizontal cross-section of the antenna radiation pattern at the level of the antenna axis in a rectangular (Cartesian) pattern.
- Θ_N - nominal value Θ at a distance of 0,84 R_{max} [°];
- R_{max} - maximum range of object detection at the antenna axis level [Nm];



Antena szczelinowa

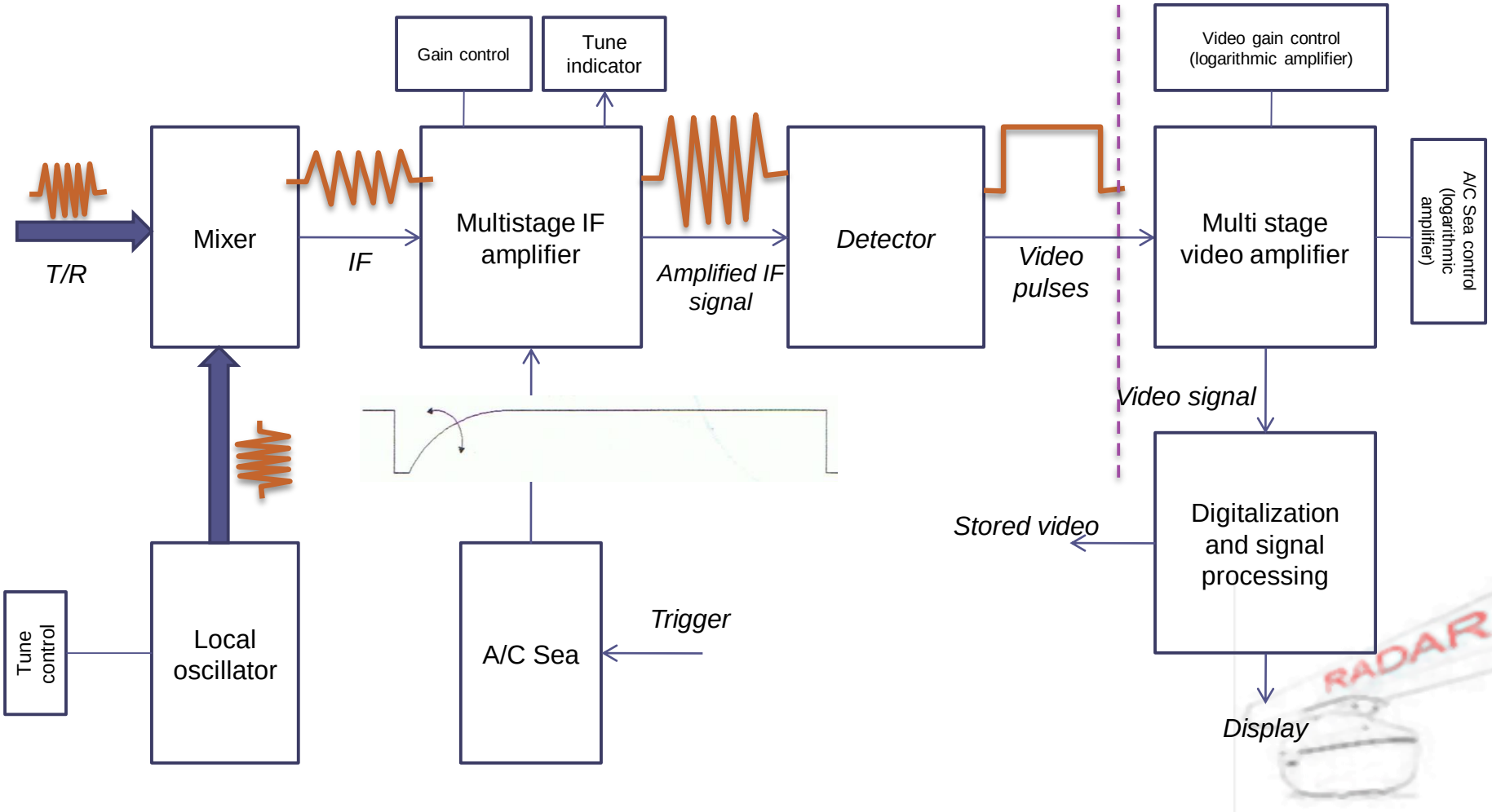


Antena szczelinowa

Receiver

- The task of the radar receiver is to receive the reflected pulse, amplify it and transfer it in a suitable form to the radar indicator.
- The basic elements of the receiver are:
  - Mixer
  - Local oscillator
  - Intermediate frequency amplifier
  - Detector

Receiver design



Mixer

- Due to the high frequency of the echo pulses received by the antenna, they are transmitted to the mixer system before they are amplified.
- In this system, the frequency of the received pulses is reduced as a result of interference with the signal from the local oscillator.
- In this way, intermediate frequency pulses are created, which are amplified in further receiver systems.
- Radar receivers use mixers working on silicon crystal diode.

Local oscillator

- Its task is to generate a continuous low power radio frequency signal at microwave frequency.
- The difference between the magnetron generated microwave frequency and that of the local oscillator is equal to IF (intermediate frequency)
- The determined and constant value of the intermediate frequency necessary to ensure the proper operation of the IF amplifier, and thus the achievements of the highest detection capability of the radar, is obtained by tuning the local oscillator with the help the Tune control.

IF amplifier

- Weak pulses at the intermediate frequency are then amplified in a multi-stage amplifier with adjustable gain.
- The gain amount of all incoming pulses on the input is determined by means of a Gain control.
- In addition, the amplification of signals coming from close proximity may be modified by the A/C Sea system.
- IF amplifier it is characterized by a sufficiently high gain, selectivity and width of the transmitted band.
- The intermediate frequency used in radars is constant and is conteined within 30-80 MHz (IF depends on a manufacture).

A/C Sea

- this system works by reducing the gain of the IF amplifier in the initial period of each radar cycle.
- The A/C Sea regulator determines the efficiency and range of the system.
- The A/C Sea system is controlled by trigger pulses.

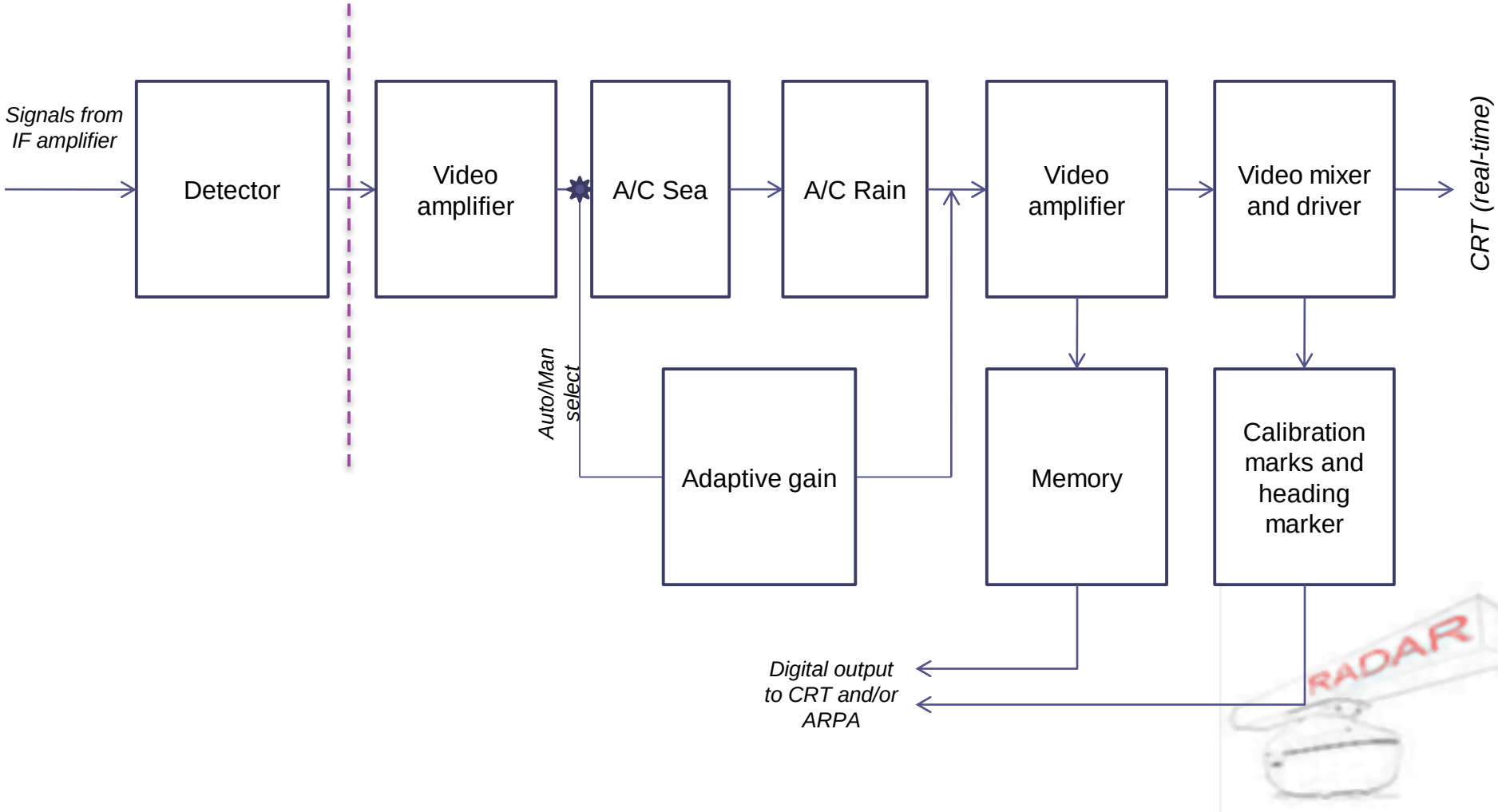
Tune indicator

- The task of this system is to indicate to the operator the tuning degree of the local oscillator.
- This system measures the amplitude of the intermediate frequency. The maximum tuning point corresponds to the largest amplitude of the intermediate frequency.

Detector

- The task of the circuit is to transform the pulses coming from the IF amplifier into DC video pulses

Display design

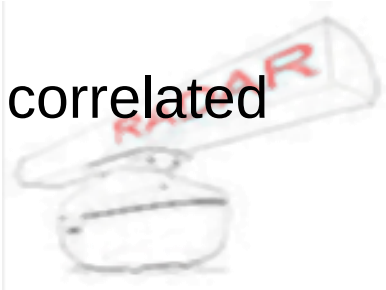


Signal processing

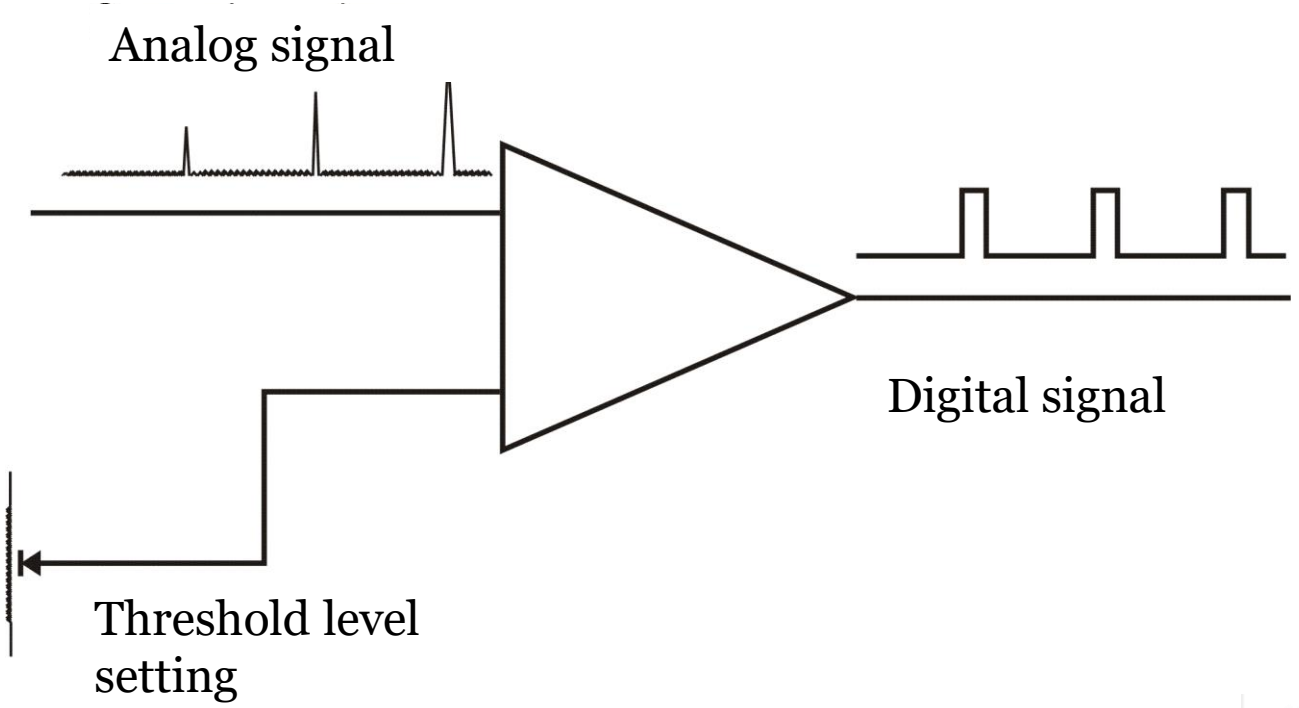
The following signal processes are available:

- Analog-Digital Conversion – in radars, digital video signal processing systems operating on the principle of single or multi-level threshold detection are used.
  The video signal is digitalized in the state and in time. The obtained digital signal is stored in memory then.
  Moreover, the digitalization allows to get the same brightness of echoes on the screen regardless of the echo amplitude and regardless of the scope of observation.

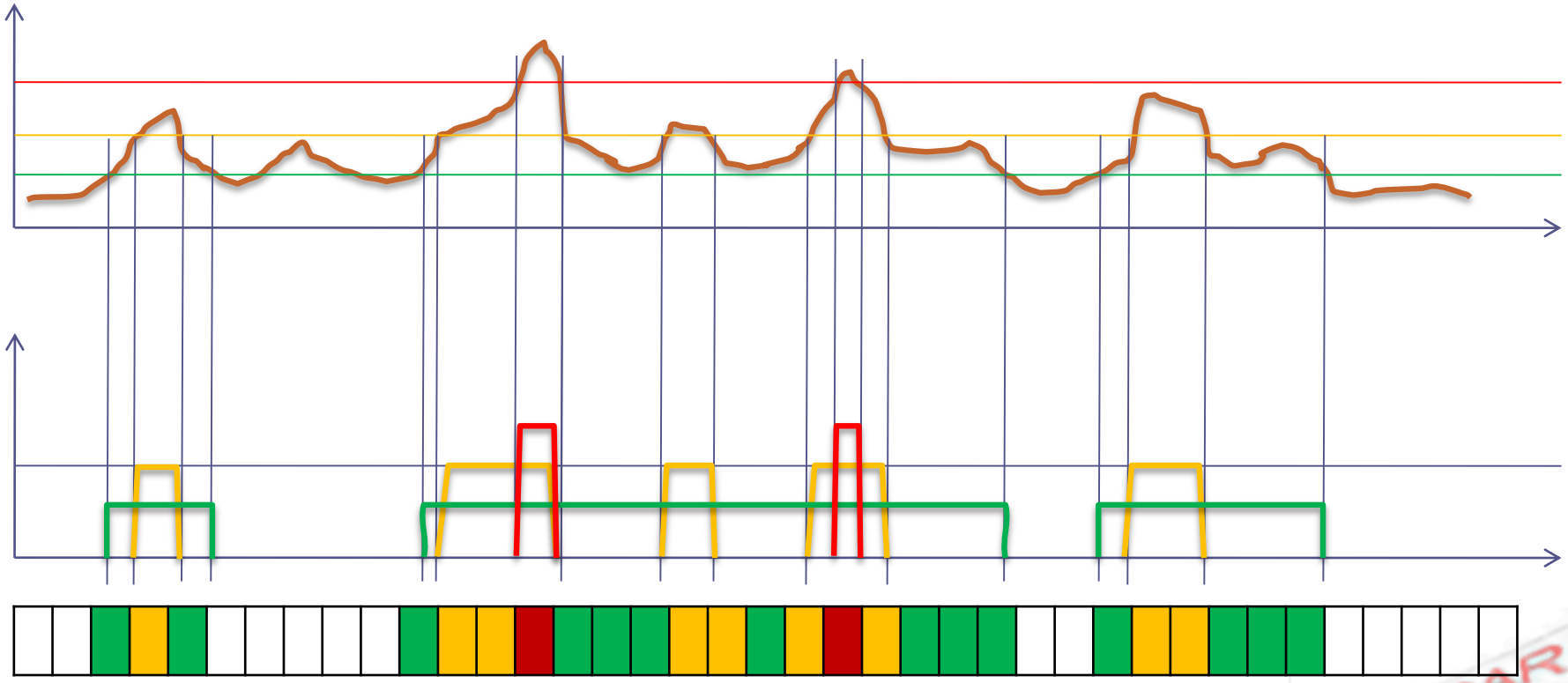
- Interference rejection – this process remove all non correlated signals.



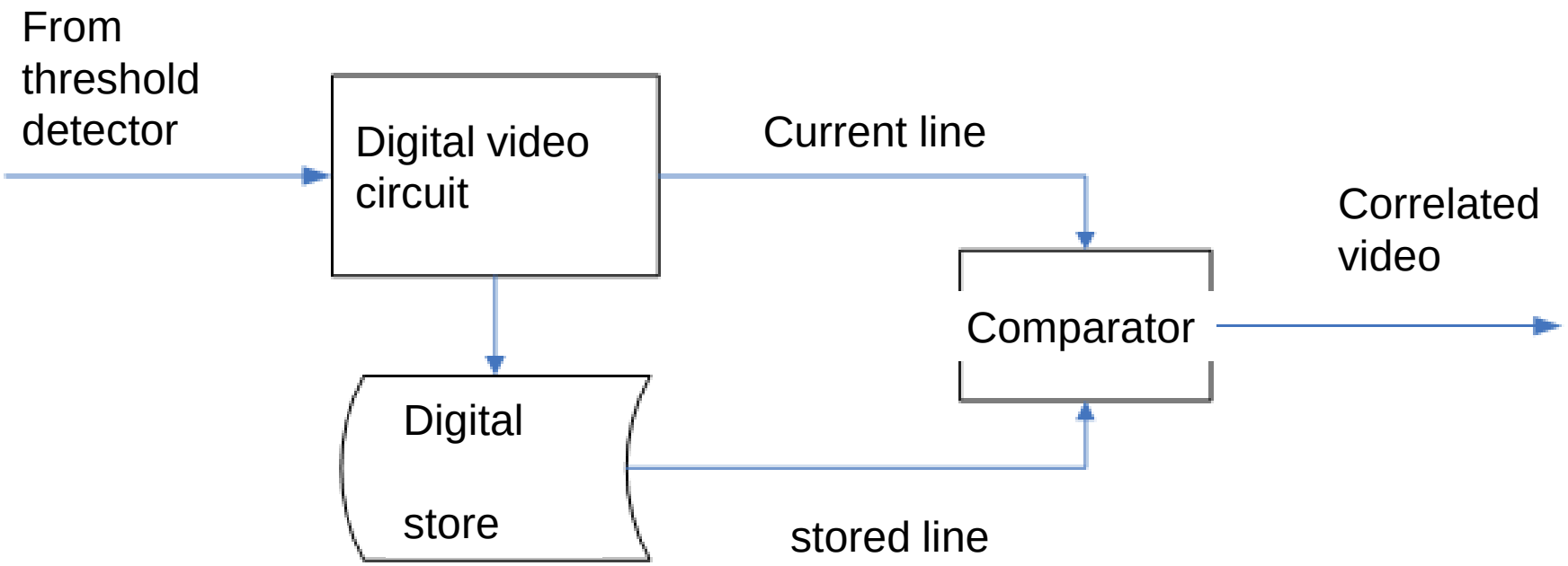
Analog-Digital Converter



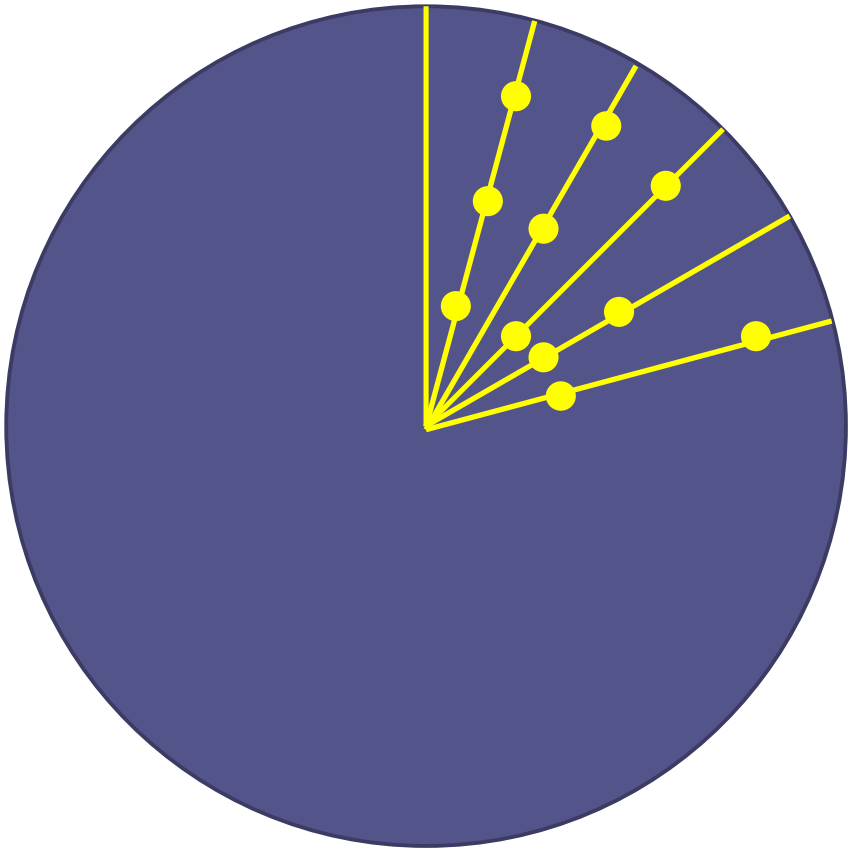
Multi-level detection

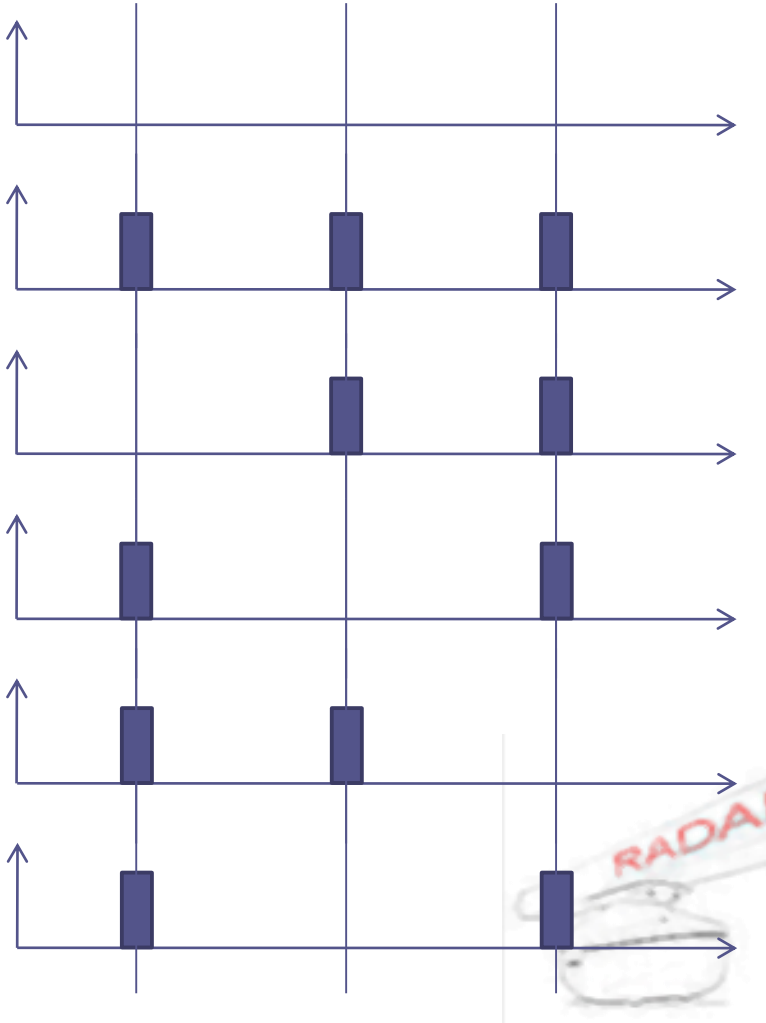


IR circuit design



IR – interference reject

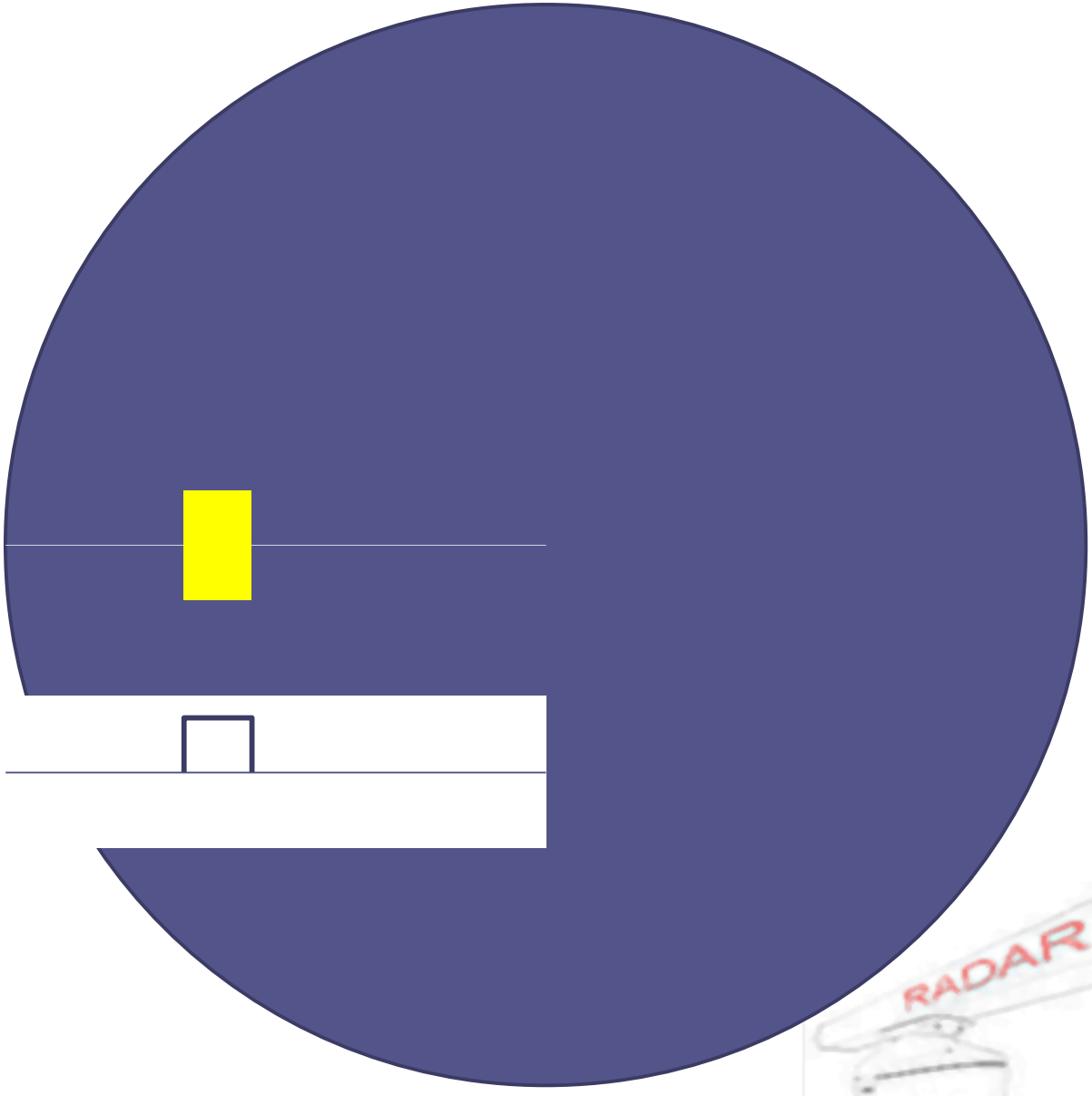




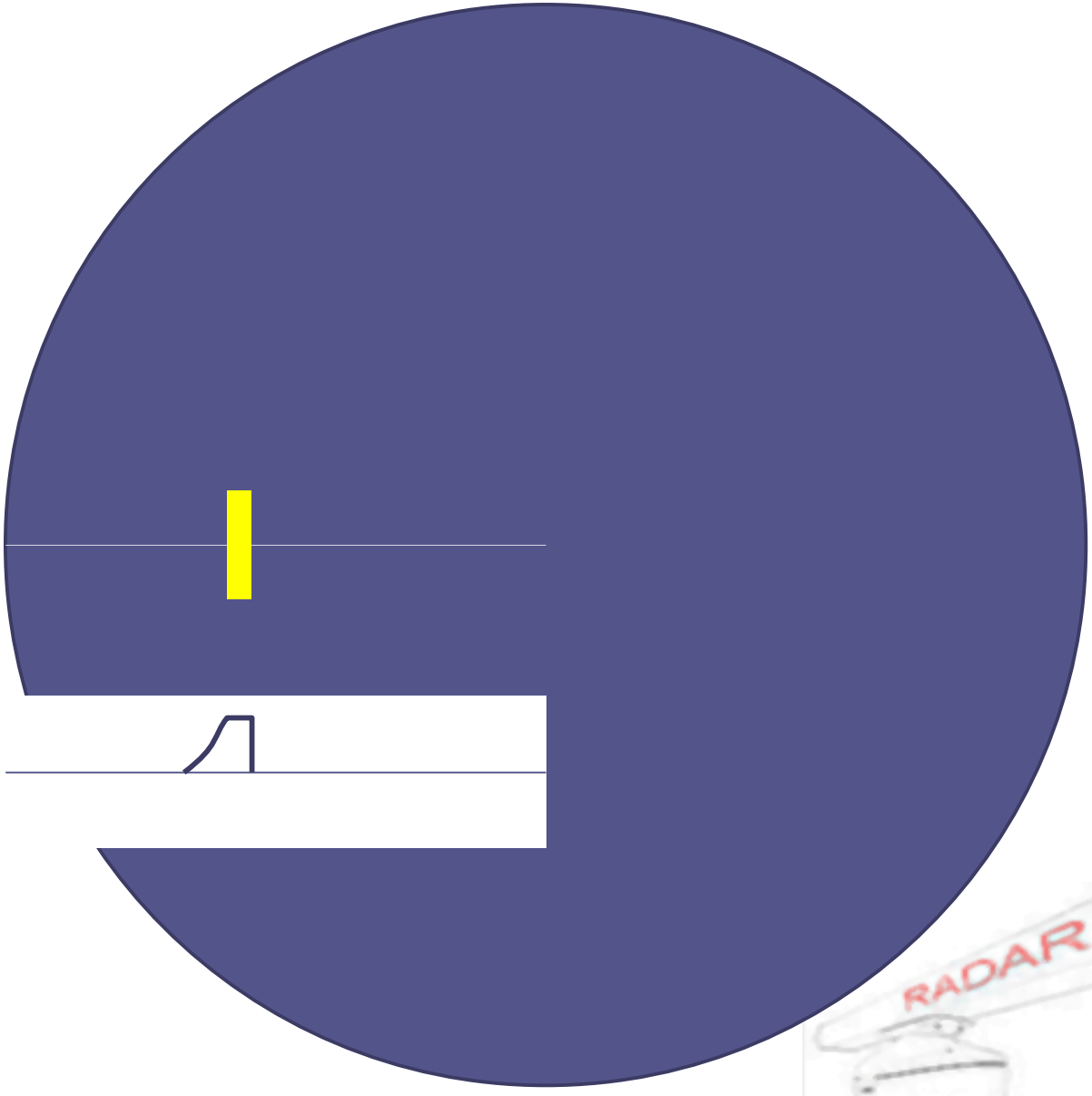
A/C Rain circuit

- Differentiator – the task is to shorten the duration of received echo pulses in order to increase radial discrimination and to eliminate some (rain) clutter of the radar image.
- Due to the reduction of the amplitude and energy of the differentiated pulses (related to the time), the dimensions of the echoes on the display are reduced, which eliminates weak echoes and reduces the maximum radar range.
- The differentiator can be switched on by a potentiometer, which allows for a smooth adjustment of the duration of differentiating pulses.

A/C Rain



A/C Rain



Video amplifier

- the amplifier's task is to amplify and combine video signals and pulses of distance and course markers into one signal

Screen

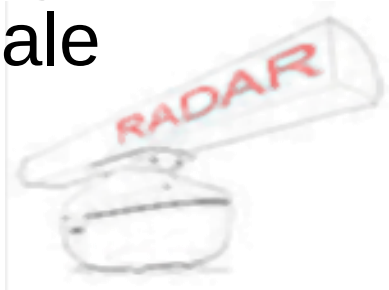
- Nowadays mostly the raster-scan radars with CRT (cathode ray tube) or LCD (liquid-crystal display) are used. The image is drawn in a rectangular coordinate system with a refresh frequency at least equals 60 Hz.
- Due to very short time of glow of such a screen (less then 1 ms), the glows of moving echoes (trails) on the screen are obtained artificially.

The pulse length

- Measured in μs, and defined as the time in which the radar transmits the pulse.
- The longer the pulse, the more probable the detection of a target. This is due to the fact that radar receiver amplifies long pulses more effectively than short ones.
- The longer the pulse, the longer the minimum range is, which may result in not detecting objects in the immediate vicinity of the radar antenna.
- In some situations (difficulty in detecting an echo from an object against the background of interference from sea waves) shortening the pulse may cause weakening of the clutter and thus detection of useful echoes (targets).

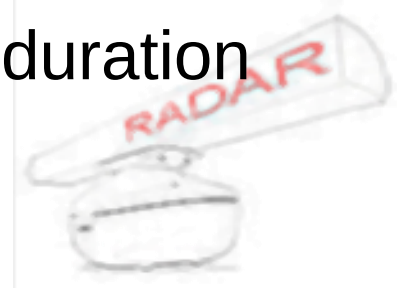
Długość impulsu

- The number of possible pulse lengths is from 2 to 5 or even 7 and depends on the design of the radar.
- The pulse length is within 0.05 to 1.3 μs.
- The semi-automatic choice of pulse length is realized by a range scale selection.
- The length of the selected pulse depends on the observer's requirements, hydrometeorological conditions, sailing area and the range scale used in the radar.



Range scale, max and min ranges

- *Range scale* is the radius in Nm of the area shown on the radar screen (operational display area).
- *Maximum range* is the max detection distance of certain object by given radar. Depends on a reflect properties of the object (RCS) and properties of radar (pulse energy, antenna aperture and sensitivity of receiver).
- *Minimum range* is the min distance in which a radar can detect any object. Depends on a pulse duration and a T/R switch inertia.



Range discrimination

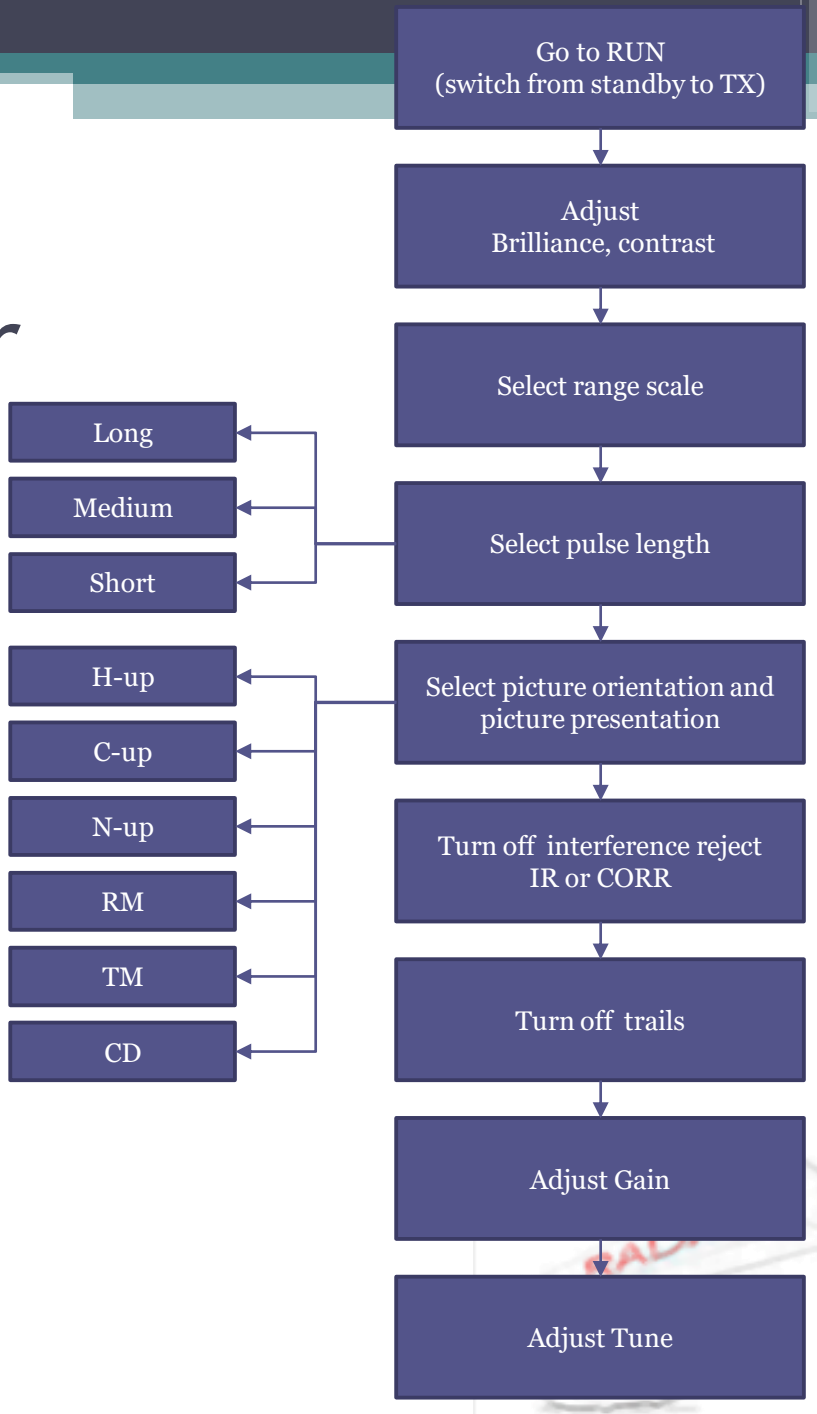
- The ability of the radar to display separately two echoes of objects located in the same bearing and in close proximity.
- This is an absolute measure expressed in meters, which specifies what distance must be between the objects to be displayed on the screen as separate echoes

Bearing discrimination

- The ability of the radar to display separately two echoes of objects located at the same distance and in close bearings.
- This is an absolute measure expressed in degrees, which defines the angular distance between this objects so that their echoes are displayed separately.

Adjustment of radar

1. Turn the power on
2. Awaiting for standby mode
3. Basic adjustment
    1. Brightness
    2. Gain
    3. Tune
4. Advance adjustment
    1. Iinterference reject IR
    2. Anti-Clutter Rain
    3. Anti-Clutter Sea



Comparison of X and S radars

- Target response
  - For a target of a given size, the response at X-band is greater than at S-band
- Bearing discrimination
  - For a given aerial width the horizontal beamwidth effect in an S-band system will be approximately 3.3 times that of an X-band system
- Vertical beam structure
  - The vertical lobe pattern produced by an S-band aerial is about 3.3 times as coarse as that from an X-band aerial located at the same height
- Radar horizon
  - The radar horizon with S-band is slightly more distant than with X-band

Comparison of X and S radars

- Sea clutter response
  - The unwanted response from sea waves is less at S-band than at X-band, thus the probability of targets being masked due to saturation is less
- Precipitation response
  - The probability of detection of targets which lie within an area of precipitation is higher with S-band transmission than with X-band transmission
- Attenuation in precipitation
  - In any given set of precipitation conditions, S-band transmissions will suffer less attenuation than those at X-band

The end