Radar and Remote Sensing

Range Doppler Radar

Range doppler is a technique that radar use to estimate Doppler.

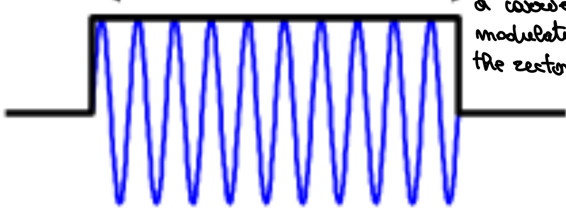
→ How we said this technique that can be used with any waveform

Possible radar waveforms

1) Square Pulse

Pulse Width, T

Total duration of the pulse and there is a carrier frequency modulated by the rectangular pulse



Bandwidth = 1/T

Detectability gain

Time × Bandwidth = 1

We have a problem because τ an B are not independent infact the time - bandwidth product is equal to 1

$\Delta R = \frac{c}{2B}$

$R_{MAX} = \frac{c}{2 f_r}$ → depends on the maximum anambigus rang

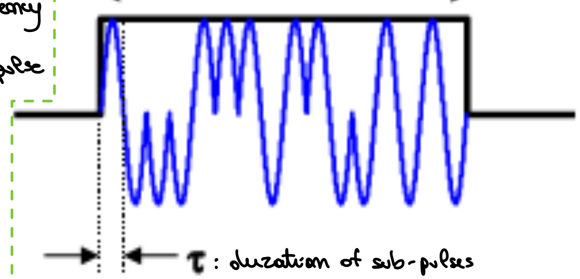
This type of waveform is very limited because one of the main issue to choose a waveform is the possibiliti to have a ΔR and the capability to detect target

But here if we want to increase ΔR we have to increase B a lot but reducing B we reducing time (τ). And if we reduce τ we still want to maintain a certain energy of the signal a lot of power is needed

Digitally modulated waveform

Binary Phase Coded Waveform

Pulse Width, T → Is divided in sub-pulses



τ : duration of sub-pulses

τ can be set in the limit because the PRI is at the minimum that is = T_r

Bandwidth = 1/τ

Time × Bandwidth = T/τ

$R_{MAX} = \frac{t_{d\,max}\, c}{2}$

$\Delta R = \frac{c}{2B}$

→ The limit is give to our system to process data, because in the radar receive block diagram we down convert the signal and convert the I/Q component and we do the correlation. So we have a buffer of data $(w_1, \dots, w_N)$

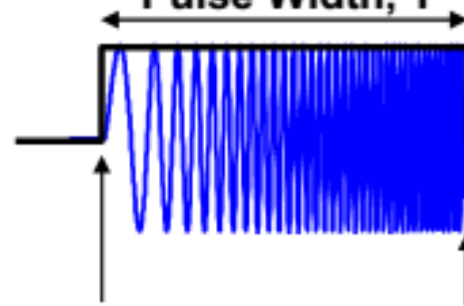
The lenght of the buffer depend on the processing system to elaborate τ before to the nex pulse

Analog modulation → Linear frequency modulated waveform

- We have introduce a modulation in a Bandwith $\Delta f = f_2 - f$
- Advantage: We can set indipendently Δf and T and so other advantages:
  1) $\tau \cdot B$ is much larger than 1 so the detectability (SNR) is much larger than SNR to the macth filter

Linear Frequency Modulated Waveform

Pulse Width, T



Range of target

$\frac{\Delta t}{\Delta f} \frac{c}{2} f$

$= \frac{\Delta t}{\Delta f} \frac{c}{2} \frac{f_s}{2}$

$= \frac{\Delta t\, c}{4 \Delta f} f_s$

Frequency F_1 Frequency F_2

Bandwidth = ΔF = F_2 - F_1

Time × Bandwidth = TΔF

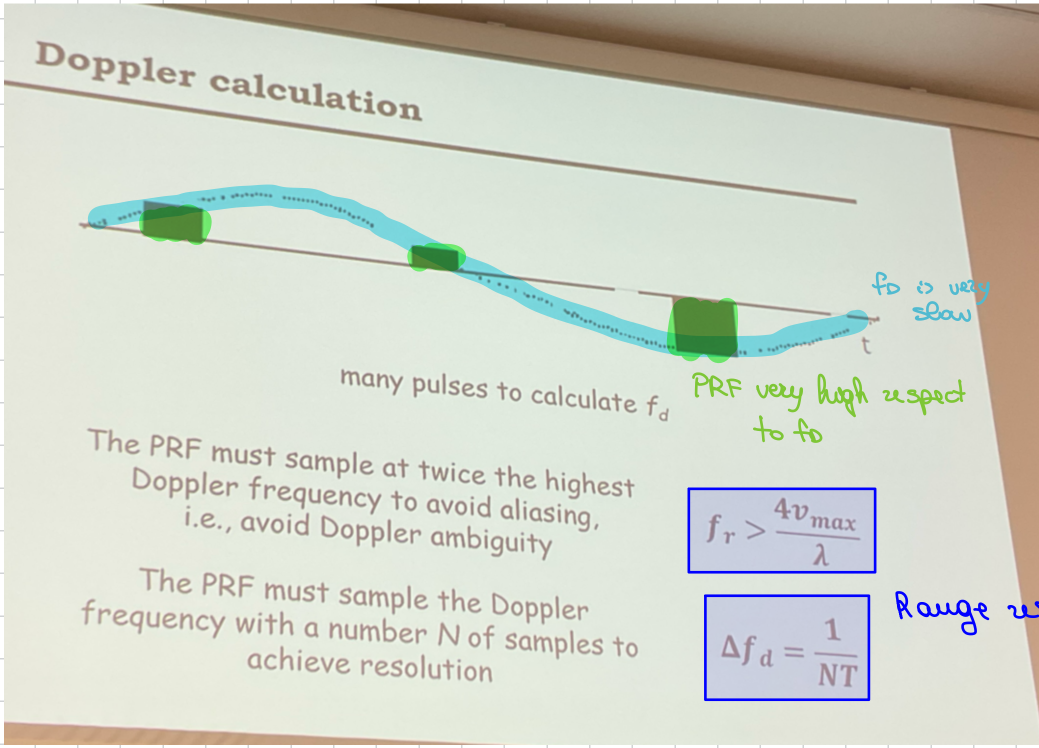
$R_{MAX} = \frac{\Delta t\, c}{4 \Delta f} \cdot f_s$

$\Delta R = \frac{c}{2B}$

Is different from the rectangular pulse, but it depend on f_s of beat frequency because we have to sampling the output of the mixer

2) ΔR → we can fix B to get a certain resolution and the we can fix the τ to have $B \cdot \tau > 1$

- We can have Idle time between pulses so we can can PRI ando so in decrease The PRF → Problem for doppler



Range resolution

▷ Radar is called a four dimentional system because is capable to detect at the same time the range, azimut, elevation and velocity of target

• The classical way to detect doppler is use many pulses to calculate fo because fo is much lower than PRF.

So we have pulses modulated pulse by the fo

• PRF is a sampling frequency for the doppler and PRF must sample twice the highest fo

Problem → PRF has a value according to the Vmax of target and so the largest is Vmax ⟹ the largest PRF must be

If PRF is larger the PRI is smaller

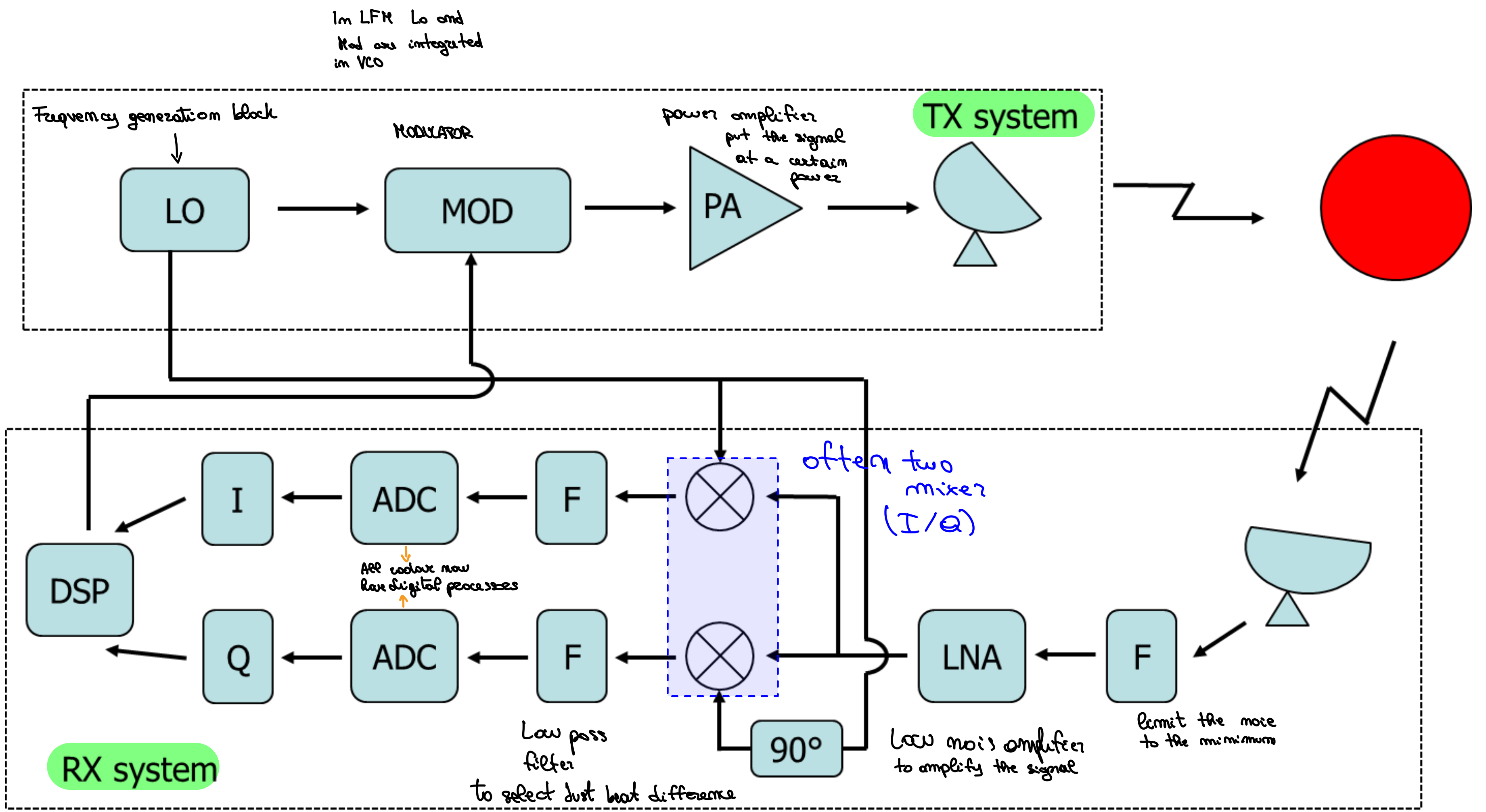
If we have large Bandwith we want to have large duration of the signal to increase energy but we have a limit because if we want a very fast target we have to reduce the duration of the signal to improve PRF

▷ Every time we sample thanks to PRF the fo → Obviously: to estimate fo we have to do an FFT of the data

↳ Every time we do this we must sample the fo with a certain N = # of sample that we collect to estimate fo to obtain a certain Doppler resolution.

From Δfo we want N >> 1 but if we collect a lot of data we delay the calculation so we limit the number of observation per second (for car we have to sample 20 observation per second)

Range Doppler radar implementation

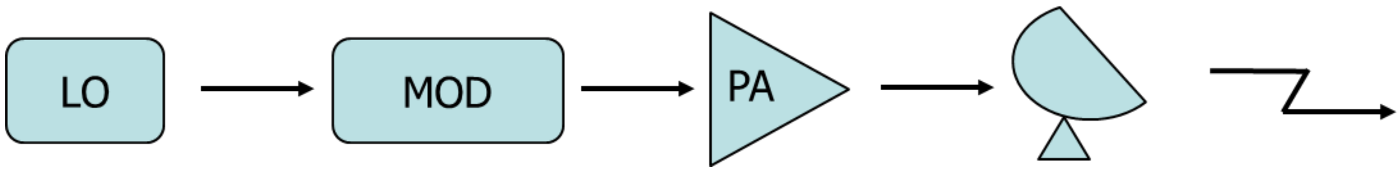


In this case we have a system available for mono/bi-static radar

In a monostic we have to put the T/R module

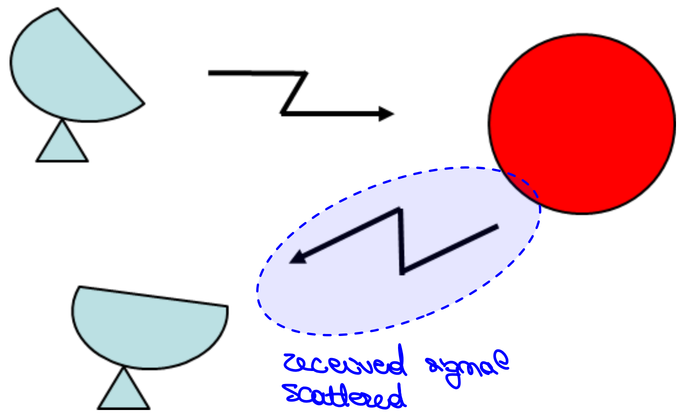
TX system

Usually we have a continuous trasmission but we can have an idle interval between the pulses to get PRI that we've choosen



- ✓ A modulated signal is generated considering the given pulse length, the pulse repetition interval (PRI), the carrier frequency, and the bandwidth.
- ✓ The transmitted signal is made up of a modulated pulse and, if needed, a zero interval up to the required PRI. Idle
- ✓ Extra signals are also generated by the local oscillator to provide the input for the mixers at the coherent receiving stage.

Received signal



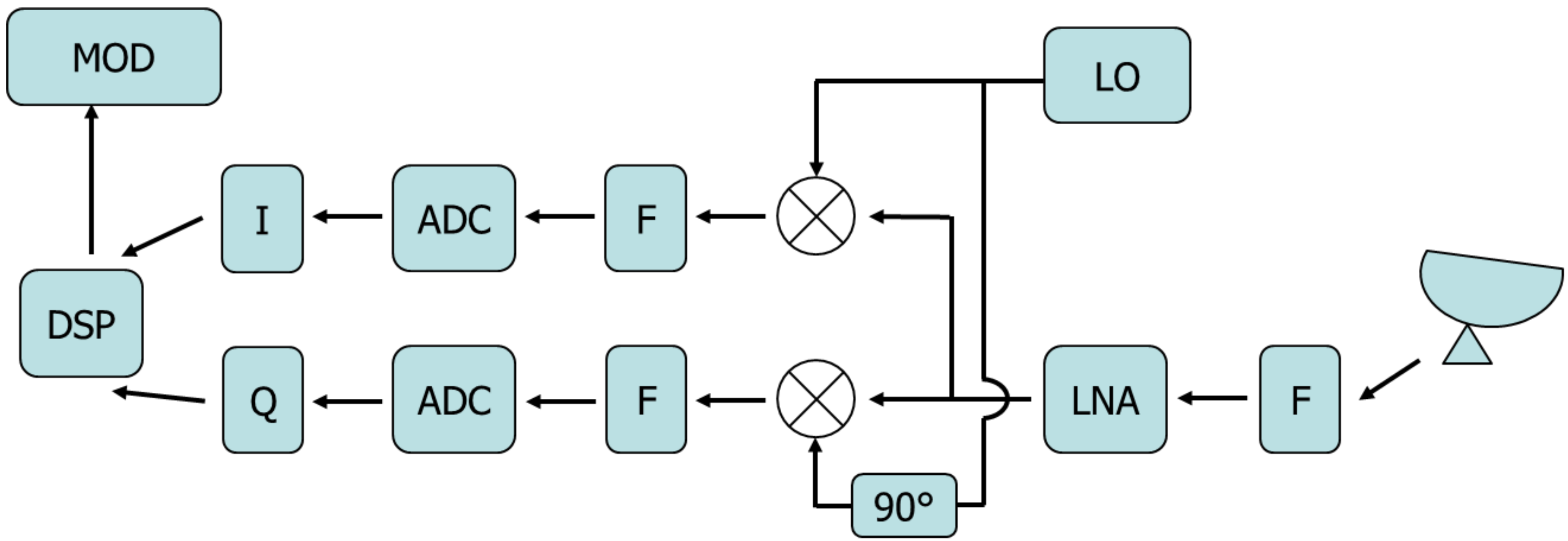
- ✓ The received signal can be approximated applying attenuation, delay, and frequency shift to the transmitted one, due to the target RCS, position and relative speed.

  ↳ f_0 scalte

- ✓ By means of the radar equation, the transmitted power, the antenna gain (TX and RX), the free space attenuation, the losses and the radar cross section of the target introduce an amplitude scaling factor.

- ✓ Additional white Gaussian noise is calculated to get to the received Signal to Noise Ratio (SNR).

RX system



- ✓ The RX signal is filtered, amplified, splitted, and mixed with two replicas of the original signal coming out of the LO (with 90° phase difference between the two).

- ✓ The obtained signals are then sampled through the analog-to-digital converter to get the I and Q samples.

We have a vector of data every PRI and so we have to organize this vector → We use a matrix which every line is a vector data. Then, after a certain number of vector we moving toward the following observation

Range Doppler radar implementation

✓ Once I and Q are stored for a certain number of pulse repetition intervals (train or frame), the complex samples I+jQ are organized into a matrix of data.

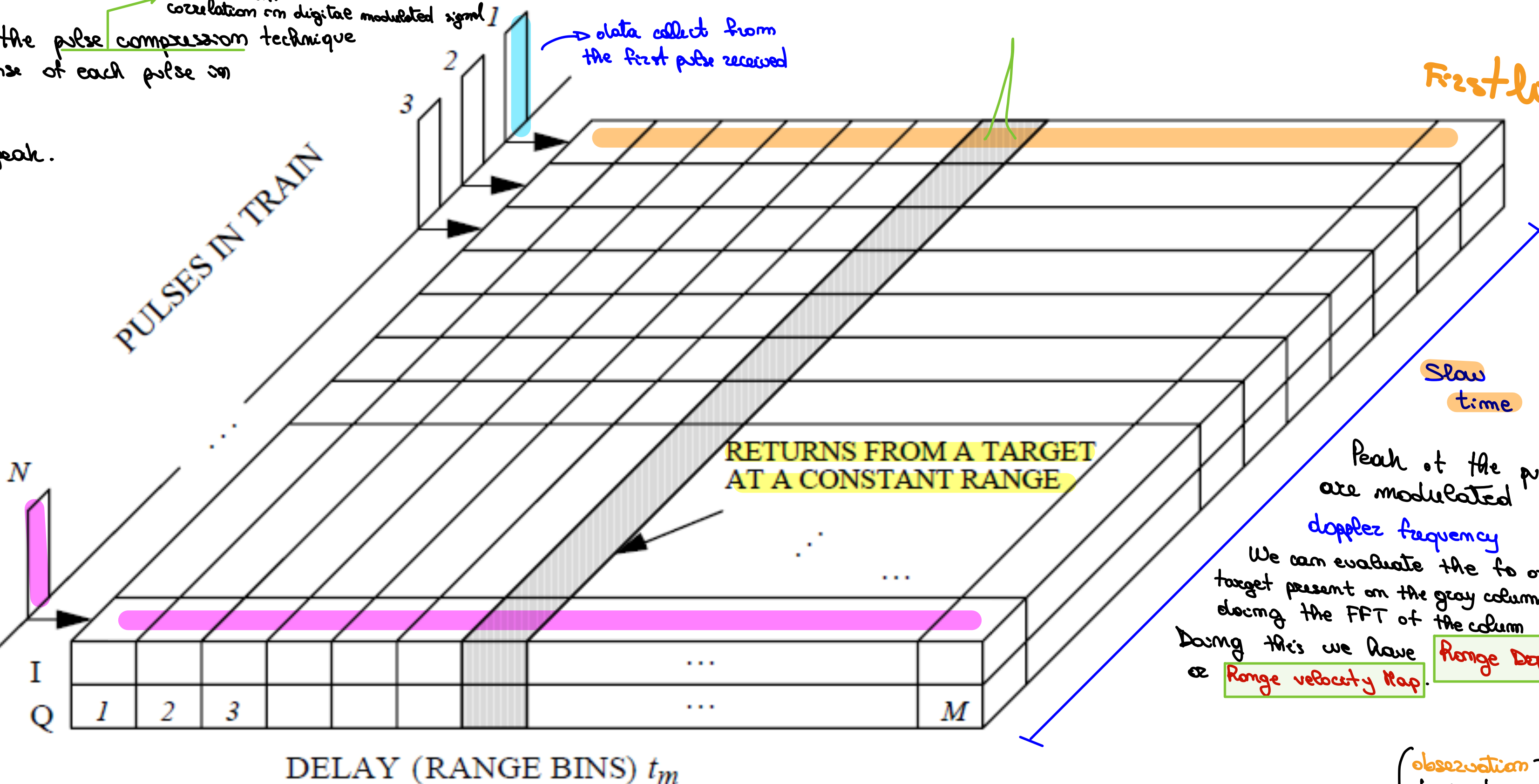
Can be:
FFT in LMF
correlation in digital modulated signal

• if we implement the pulse compression technique here we have the response of each pulse in range. (of I/Q sample)
↳ Response with peak.

▷ We send a certain number of pulses called **frame** or **traini** of pulses. After we collect each line for each pulse. After obtained the Matrix this are in the fbga memory.
When we do the pulse compression in range for each line we do the pulse compression for specific data of the I/Q sample for ex ampli by doing the correlation of the trasmitted signal. And we obtain the range range for the different present pulses.
If we have One peak we now do the FFT of the Columbia we obtain a peak corrisponding to the doppler shift of the target.

→ data collect from the first pulse received

First line



fast time

Slow time

Peak of the pulses are modulated by the doppler frequency
We can evaluate the fd of this target present on the gray column by doing the FFT of the colum
Doing this we have Range Doppler Map or Range velocity Map.

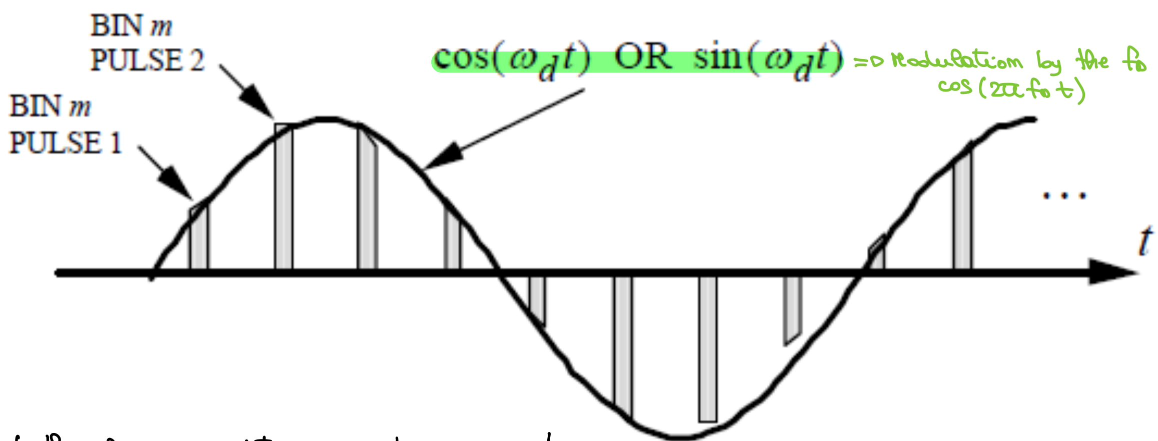
• We have to wait N pulses to have one observation.

observation time depend on the application
Ex: missile or car

Range Doppler radar implementation

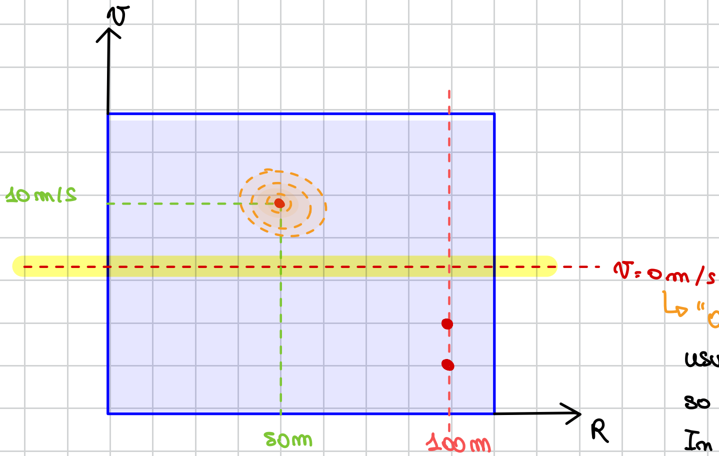
Here if we consider the grey column of the previous slide

Returns for a target that remains in a single range bin (for example, bin m)



$\Rightarrow$ modulation by the f_D $\cos(2\pi f_D t)$

If we do the FFT of the column we obtain a peak corresponding to f_D that is proportional to the velocity of the target.



↳ "0 doppler" considered a region of clutter because usually radar want to detect moving target and so are away from this region

{ Upper part: target are closing
Lower part: target are opening

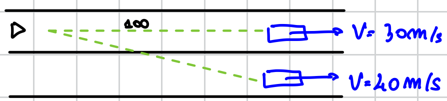
In this case we have echo radar because our radar is not moving

Otherwise, if the radar is moving this are the target at the velocity of the radar

↳ Just to see the response of the stationary target

- Zero doppler cut is an important plot where we cut the matrix at v=0 and plot what there are on the bottom or below.

Ex:



} I can't separate the target in range but also in velocity

▷ There are different waveform and we can set the artificial intellegence to decide

Ex: if I moving by feet avanti e dietro we will have a circular shape because i start from v=0 to v=max e viceversa.

Range Doppler radar implementation

sampling is fast

- ✓ The time delay or range (represented along one dimension of the matrix called fast time) and Doppler frequency shift or speed (represented by means of a Fourier transform along the other dimension of the matrix called slow time) allow to derive the range and speed of the target. In case of FMCW a two-dimensional Fourier transform is performed.

samples slower

Once we get the complete matrix the algorithm implemented in the DSP is the two-dimensional Fourier transform.

In this example the target is moving toward the radar at about 100m/s.

The position of the target with respect to the radar is approximately 400m range.