The accuracy of positions

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Navigation

- Navigation is a branch of science that deals with driving a ship along a safe and an optimal route. Knowledge of navigation allows you to determine your own position and assists you reach your destination.
- Nowadays, the task of navigation is to determine the position of a mobile unit - a human, a vehicle, a ship or an airplane.
- This task can be accomplished by observing the passing of a characteristic landmark, counting the movement parameters from a known position or by determining lines of position.

to provide navigation following elements are required:

- The method of determining the position
- Chart (up to date)
- The method of determining the direction and distance to the destination point or a next waypoint

Type of positions

- FIX – obtained on a intersection of lines of position, which means that navigational measurements to reference objects need to be performed
- Dead reckoning – obtained on the end of vector (COG, SOG) drawn from the last position (fix or dead reckonnig). An accuracy of such a position becomes worse in time function from last fix position
- Simulated - position determined basis on following data, introduced by user of radio-navigation receiver: start position, COG, SOG and related to simulation time. Result of special function of radio-navigation receiver in order to demonstrated operation of the receiver

Line of position LOP

- It is a set of points of possible positions of the object, determined by the fixed value of the measured physical quantity, which determines this line in a unambiguous way.
- The shape of the line of position depends on the measured physical quantity. Measurement of this quantity (navigation parameter), from any point of it, always gives the same result
- Lines of position can be determined on the basis of observations of:
  - natural quantities such as Earth's magnetism, location of celestial bodies, isobaths etc., or
  - by measuring radio navigation parameters, i.e. using the properties of radio waves.

Navigation systems

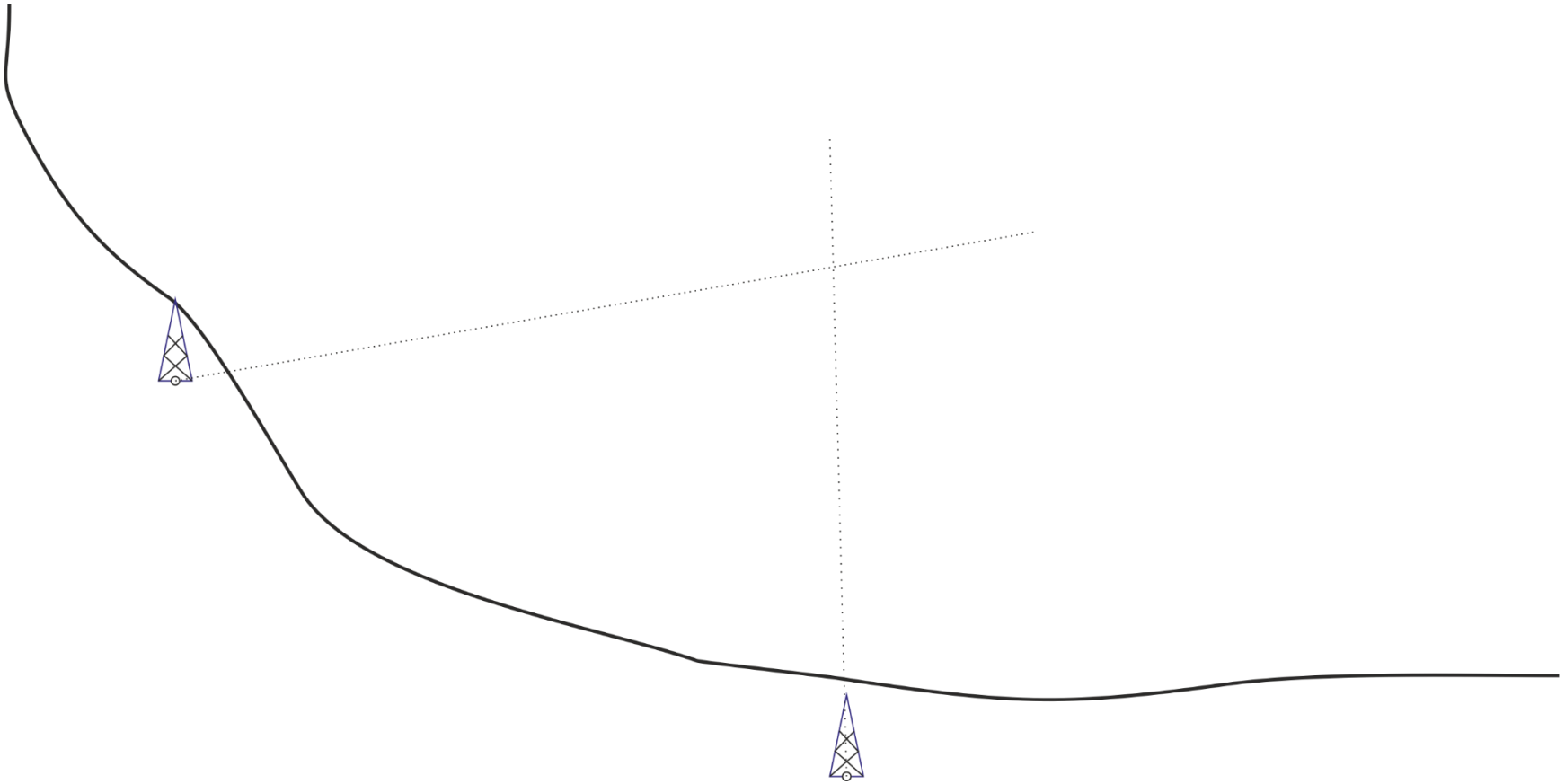
Due to the method of determining the position, the navigation systems can be divided into:

- Angular - measurement of two angles (radio direction finding)
- distance-angle - measurement of angle and distance (polar coordinates, radar)
- Distance - measurement of two distances
- Hyperbolic - measuring the difference in distance from the ship to at least two beacons

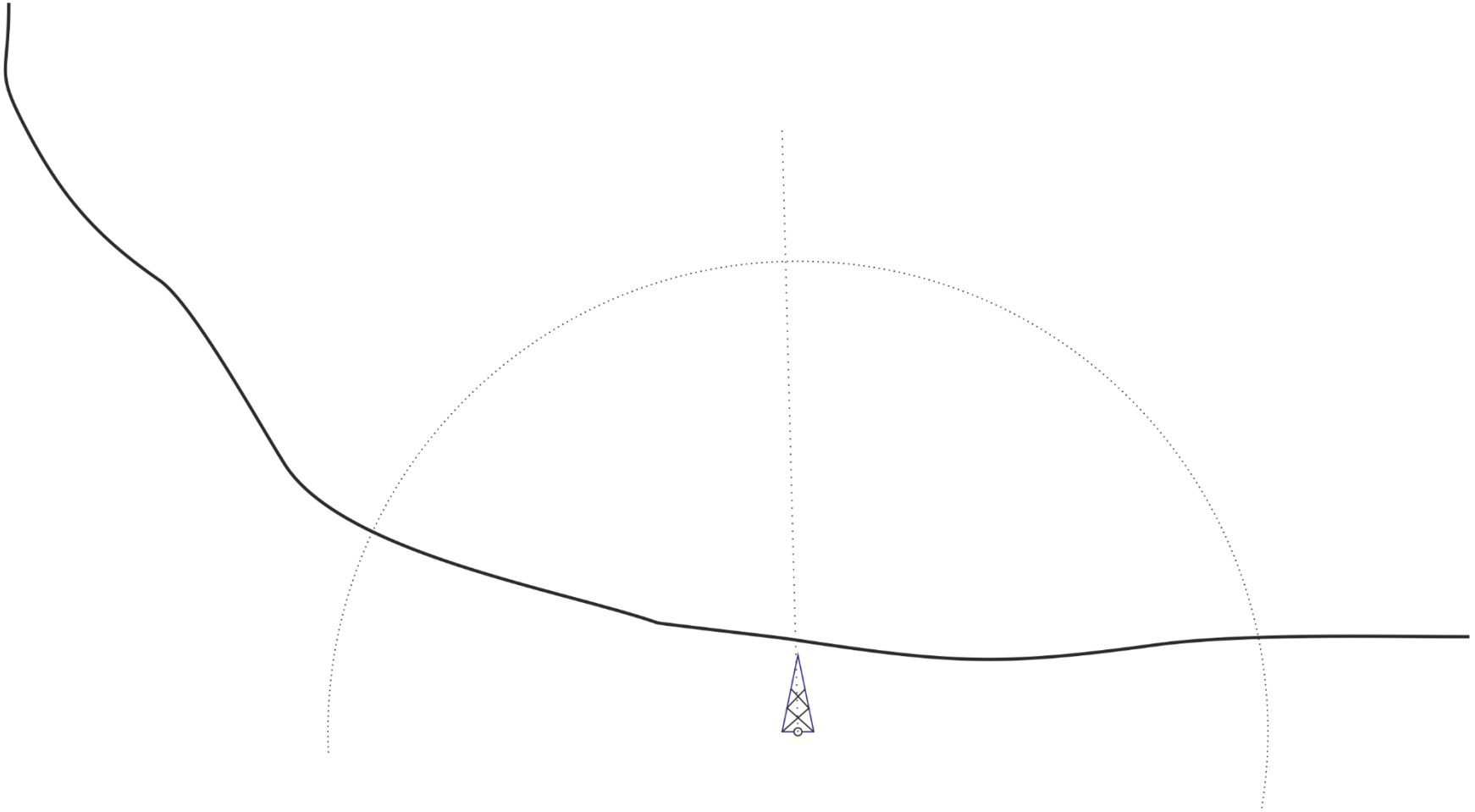
Fix positions

- Bearings (at least two – 2D)
- Distance and bearing – 2D
- Distances (at least 3 for 2D, at least 4 for 3D)
- Distance differences (at least two – 2D)

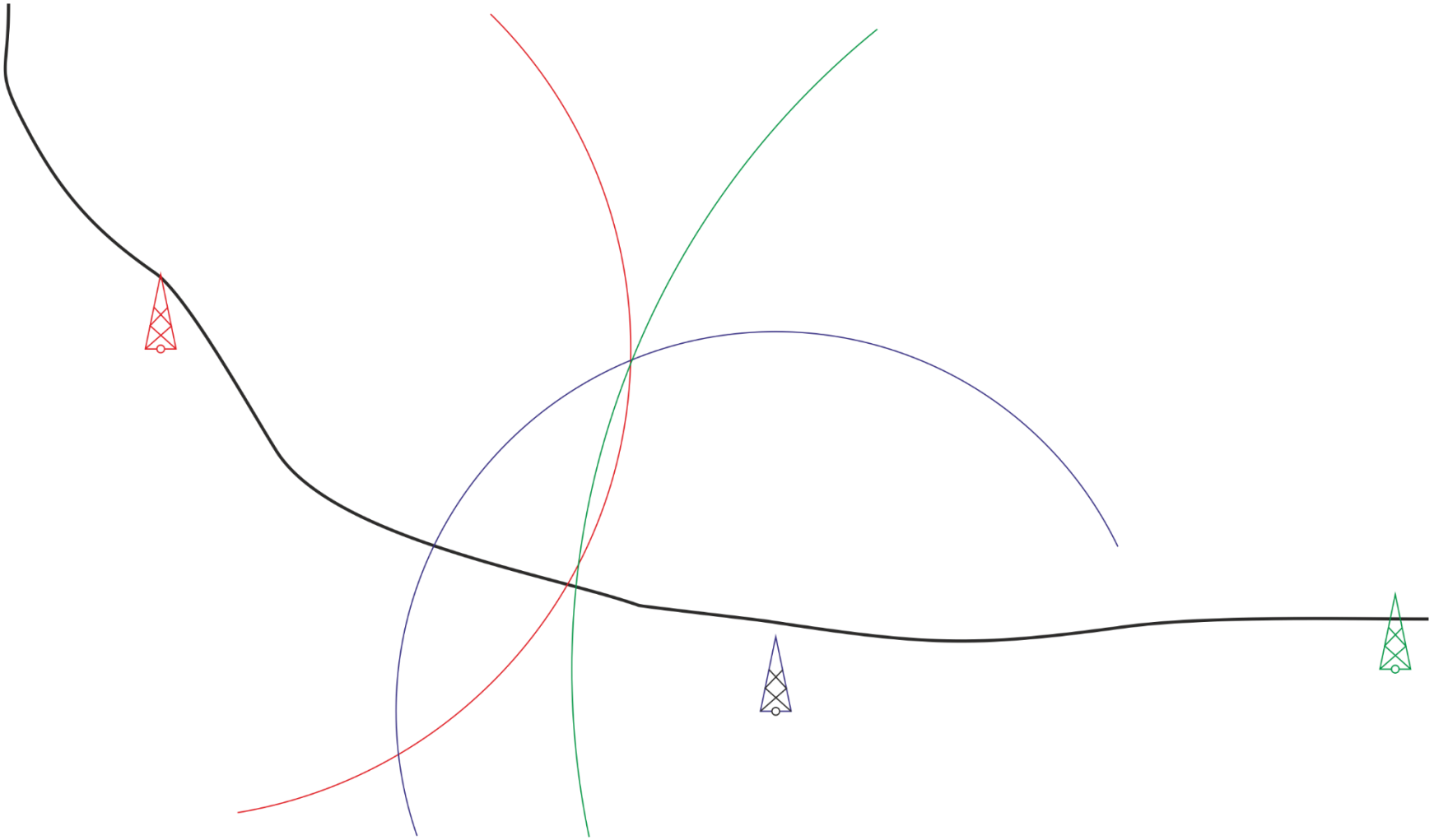
Two bearings



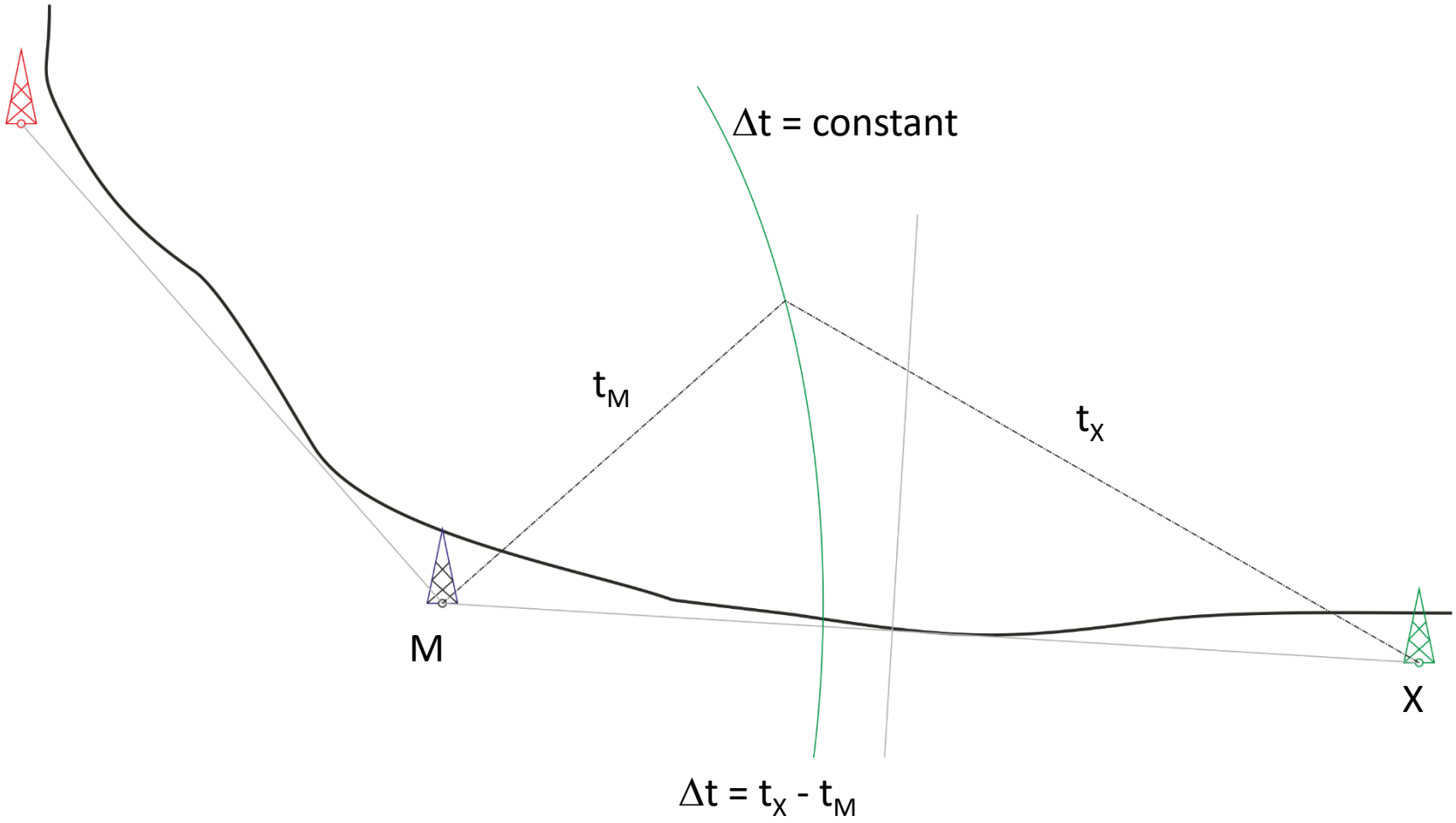
Distance and bearing



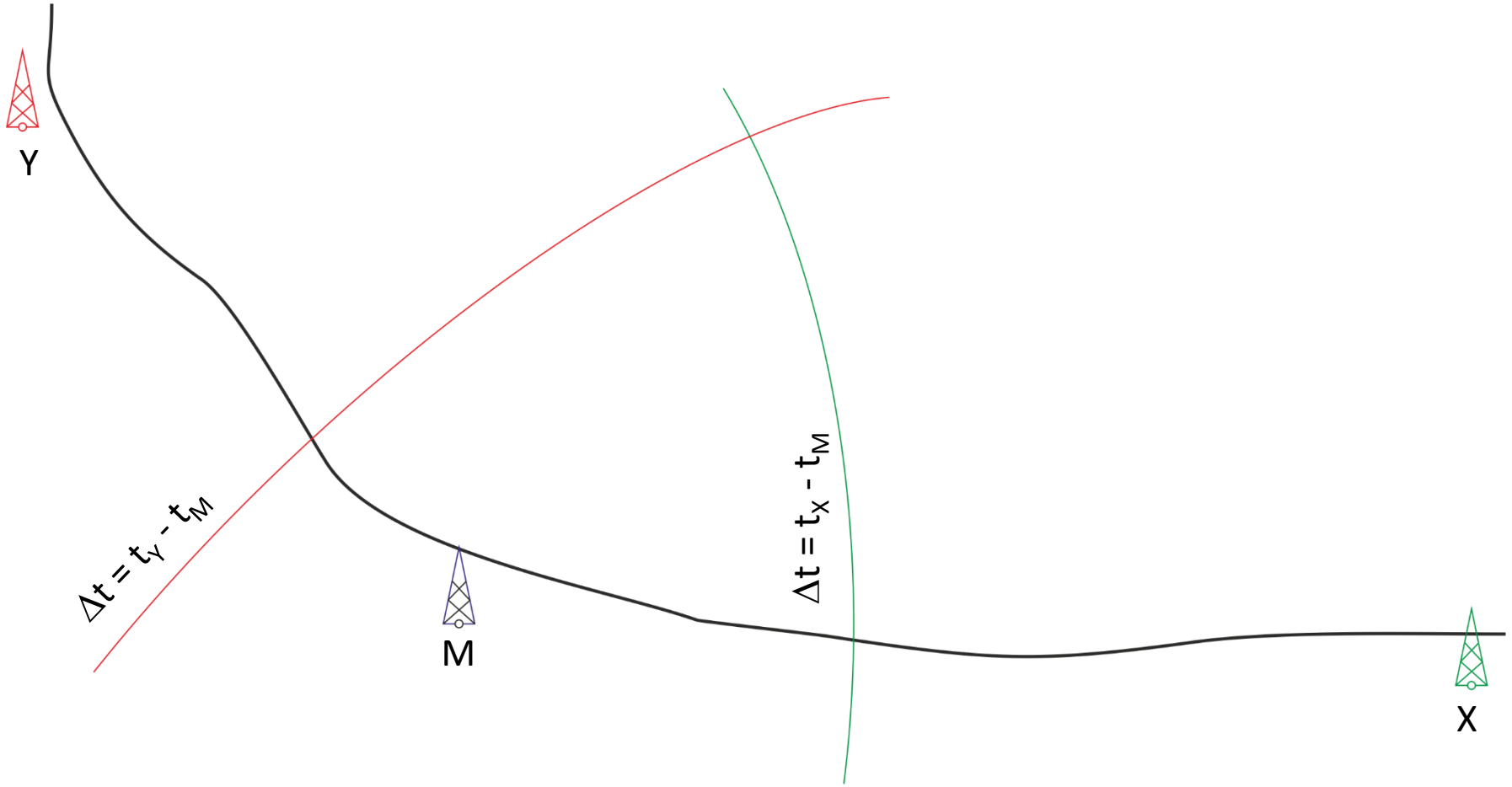
Distances



Hyperboles



Hyperboles



Accuracy

The level of accuracy depends on a purpose of positioning:

- Open sea navigation: miles or cables
- Dynamic Positioning (DP) : up to 5 meters
- On determining geodesy mark (on a land): up to 5 cm

Accuracy Res. A.915(22):

- Absolute accuracy – The accuracy of a position estimate with respect to the geographic or geodetic co-ordinates of the Earth
- Predictable accuracy – The accuracy of the estimated position solution with respect to the charted solution
- Relative accuracy – The accuracy with which a user can determine position relative to that of another user of the same navigation system at the same time
- Repeatable accuracy – the accuracy with which a user can return to a position whose co-ordinates have been measured at a previous time using uncorrelated measurements from the same navigation system

Errors

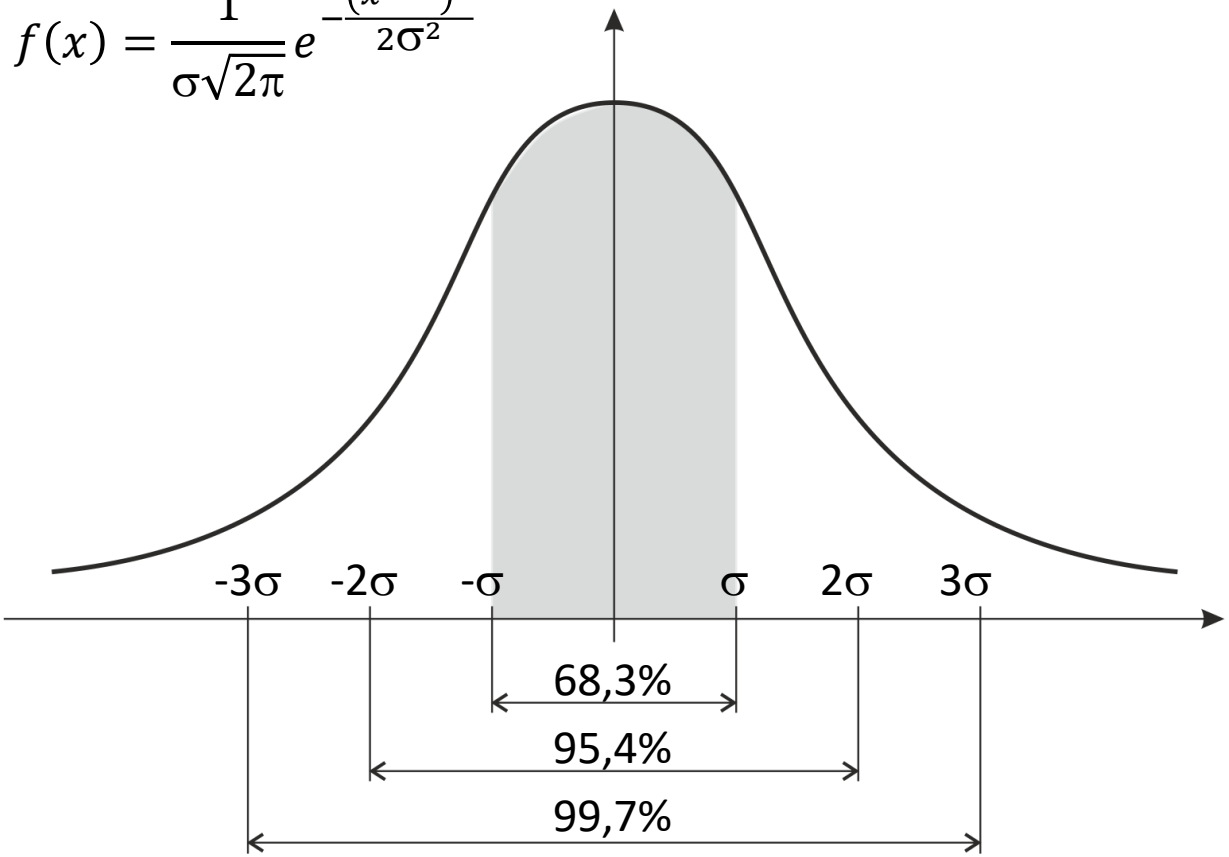
Always is necessary to describe the probability of accuracy because of a statistical nature of errors.

We can distinguish following errors:

- Systematic (fixed) – errors that can be constant or follow a pattern; over time can be calibrate away; mostly come from measuring instruments; mean not equals to zero
- Random (variable) – have a random size and are distributed according to normal distribution with average value equals to zero
- Big (mistake) - when one of the measurement results deviates significantly from the others, it can be assumed that an event occurred that caused distortions in measurements. These results are often rejected during statistical analysis

Normal distribution of measurements

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\ )^2}{2\sigma^2}}$$



x – measured value

μ – mean value

$$\mu = \frac{\sum_{i=1}^{n} x_i}{n}$$

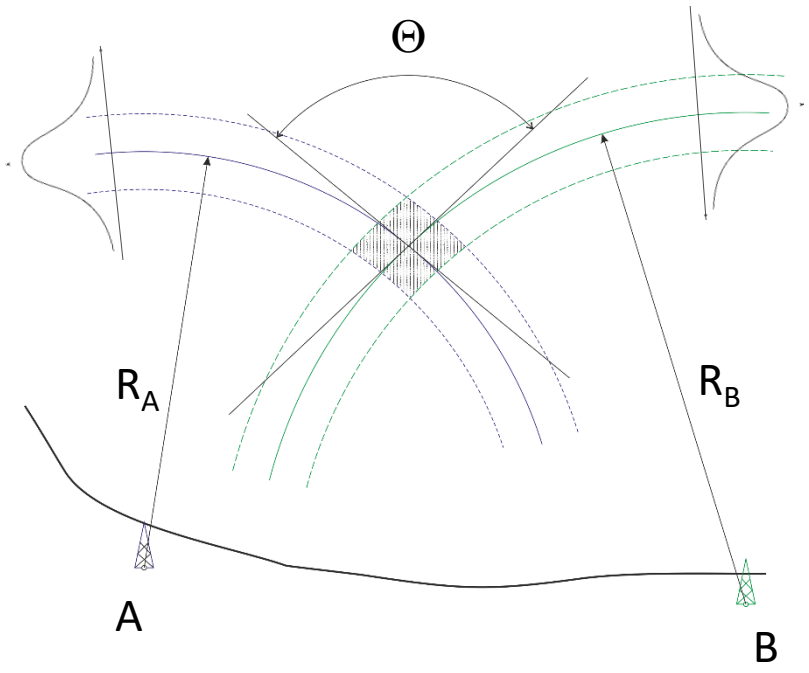
σ^2 – variance

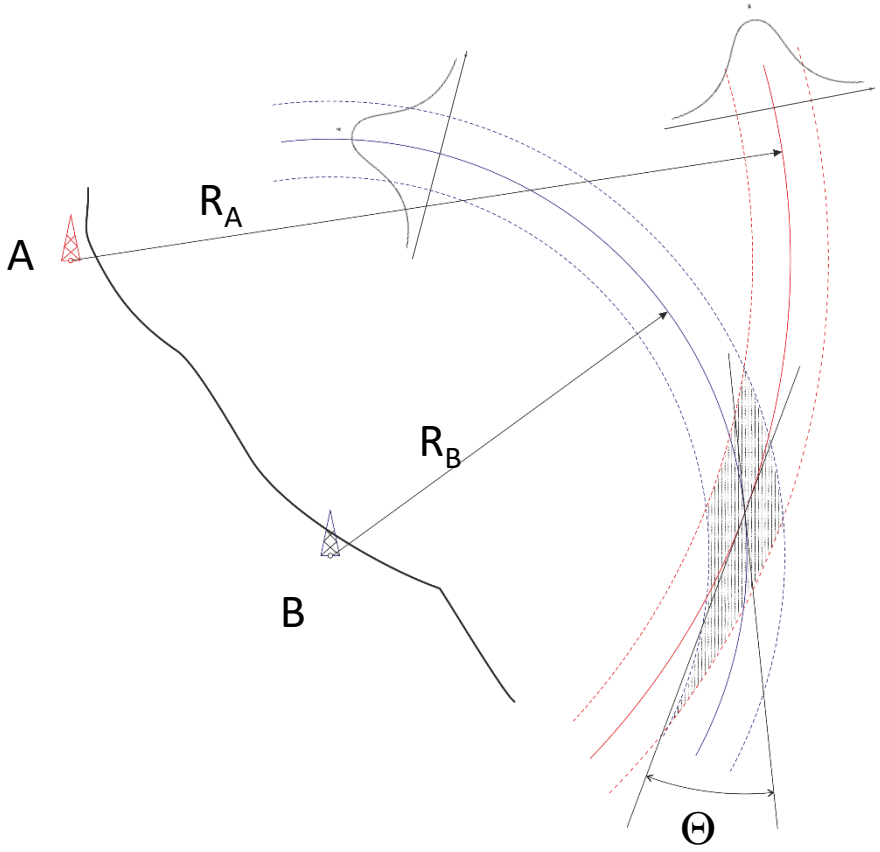
$$\sigma^2 = \frac{\sum_{i=1}^{n} (x_i - \mu)^2}{n}$$

σ – standard deviation

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \mu)^2}{n}}$$

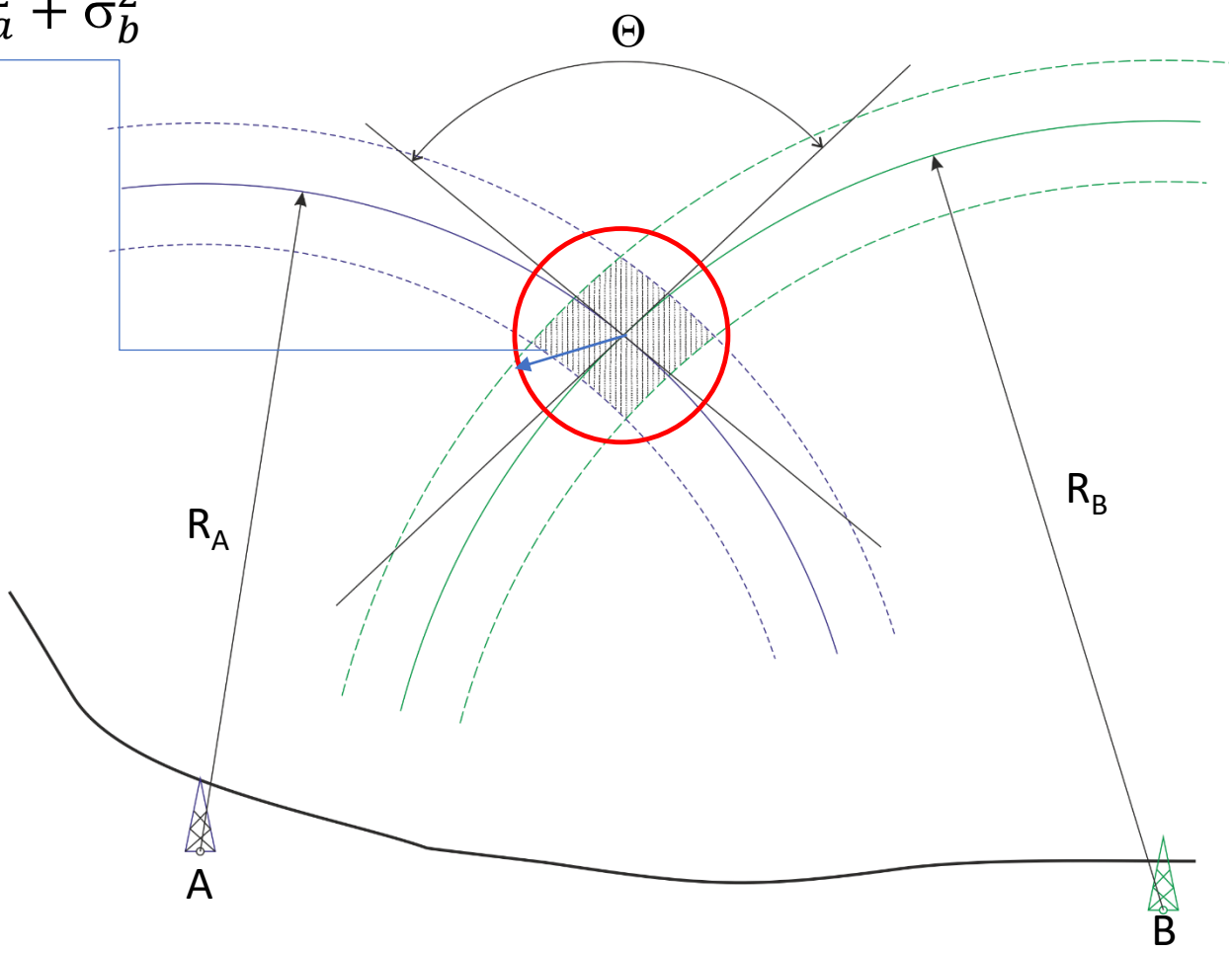
Geometry of LOP





Circular error distribution - d_{RMS}

- $d_{RMS} = \frac{1}{sin\Theta}\sqrt{\sigma_a^2 + \sigma_b^2}$
- $d_{RMS} = \sigma\, DOP$



DOP – dilution of precision

- Horizontal DOP

$$\mathrm{HDOP} = \frac{1}{\sigma}\sqrt{\sigma_x^2 + \sigma_y^2}$$

- Vertical DOP

$$\mathrm{VDOP} = \frac{\sigma_z}{\sigma}$$

- Position DOP

$$\mathrm{PDOP} = \frac{1}{\sigma}\sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2}$$

- Time DOP

$$\mathrm{TDOP} = \frac{\sigma_t}{\sigma}$$

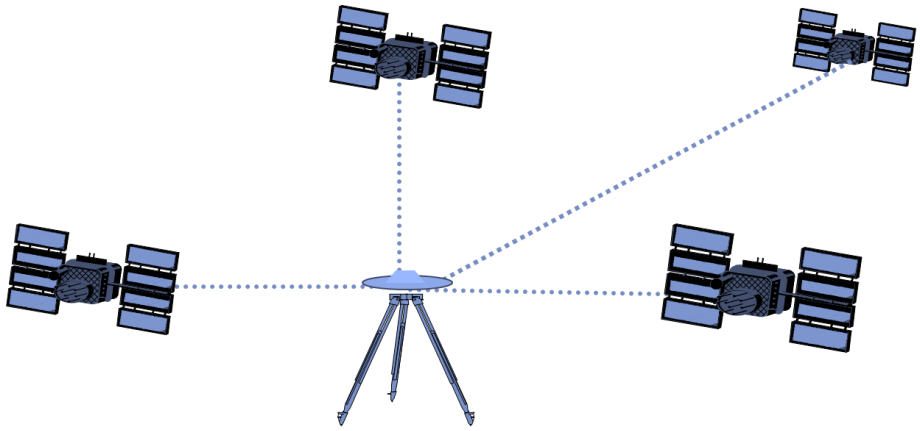
- Geometric DOP

$$\mathrm{GDOP} = \frac{1}{\sigma}\sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_y^2 + \sigma_t^2}$$

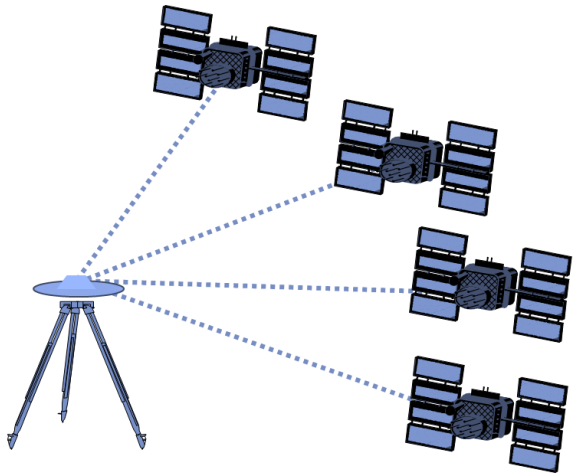
σ - measurement error of navigational parameter (distance)

σ_x , σ_y , σ_y , σ_t - mean squared error of obtained position in 3 directions x,y,z and time

DOP – dilution of precision



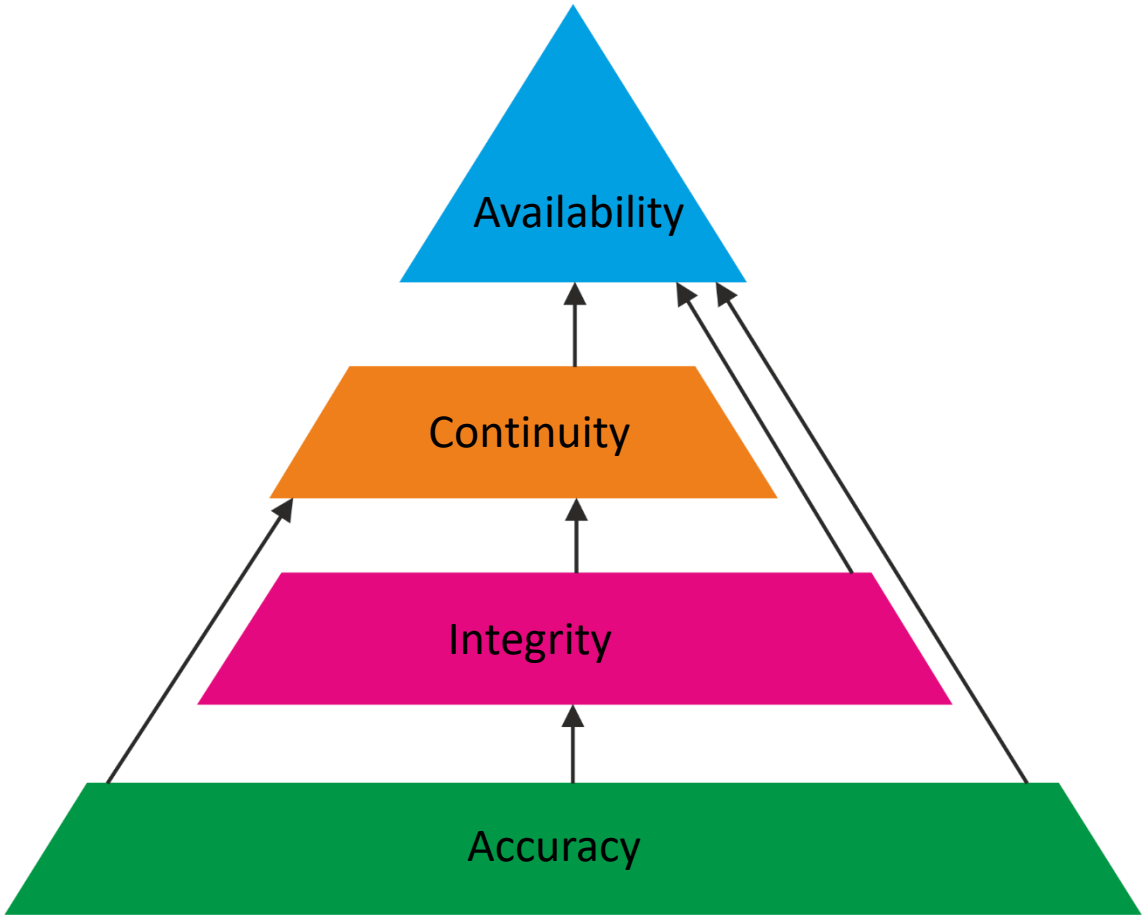
Good DOP



Poor DOP

QUALITY	DOP
Very Good	*1-3*
Good	*4-5*
Fair	*6*
Suspect	*>6*

Quality of positioning systems



Quality of positioning systems

- **Integrity** – the ability to provide users with warnings within a specified time when the system should not be used for navigation; RAIM – receiver autonomous integrity monitoring
- **Continuity** - the probability that, assuming a fault-free receiver, a user will be able to determine position with specified accuracy and is able to monitor the integrity of the determined position over the (short) time interval applicable for a particular operation within a limited part of the coverage area
- **Availability** - the percentage of time that an aid, or system of aids, is performing a required function under stated conditions. Non-availability can be caused by scheduled and/or unscheduled interruptions.
  - *Signal availability.*
    The availability of a radio signal in a specified coverage area.
  - *System availability*
    The availability of a system to a user, including signal availability and the performance of the user' s receiver.

Quality of positioning systems

- *Coverage* –
  *t*he coverage provided by a radionavigation system is that surface area or space volume in which the signals are adequate to permit the user to determine position to a specified level of performance.

Appendix 2

Table of the minimum maritime user requirements for general navigation

	System level parameters				*Service level parameters*			
	Absolute accuracy	Integrity			Availability % per 30 days	Continuity % over 3 hours	Coverage	2 Fix interval seconds
	Horizontal (metres)	Alert limit metres	2 Time to alarm - seconds	Integrity risk (per 3 hours)				
Ocean	10	25	10	10^{-5}	99.8	N/A[1]	Global	1
Coastal	10	25	10	10^{-5}	99.8	N/A[1]	Global	1
Port approach and restricted waters	10	25	10	10^{-5}	99.8	99.97	Regional	1
Port	1	2.5	10	10^{-5}	99.8	99.97	Local	1
Inland waterways	10	25	10	10^{-5}	99.8	99.97	Regional	1

Notes:

[1] Continuity is not relevant to ocean and coastal navigation.

[2] More stringent requirements may be necessary for ships operating above 30 knots.

The end