COSPAS-SARSAT

MEOSAR Presentation

Yoan GREGOIRE – 14/11/2018

SUMMARY

Introduction to Cospas-Sarsat and current status

- General introduction and history
- User, space and ground segment status

MEOSAR Highlights

- MEOSAR benefits compared with LEOSAR
- Location processing and moving beacons issue
- Second generation beacon standard

System evolution: RLS and ELT(DT)

Introduction to Cospas-Sarsat and current status

Introduction to Cospas-Sarsat and current status

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Russian COSPAS acronym can be translated in: “Space System for the Search of Vessels in Distress”

Introduction to Cospas-Sarsat and current status

Cospas-Sarsat is an international space system to detect and localize users in distress.

Overall statistics:

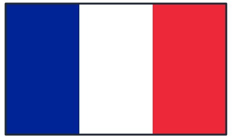
- **12 000** SAR events and **42 000** rescued people since 1982
- An average of **6 people/day** are rescued since 2010

Introduction to Cospas-Sarsat and current status

Cospas-Sarsat: an international cooperation

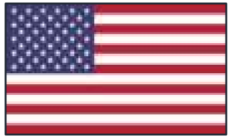
- 4 Parties (founding members)
- 29 Ground segment providers
- 9 User States
- 2 Organisations

Canada



France

Russia



United-States

Introduction to Cospas-Sarsat and current status

Cospas-Sarsat: missions of the system

- The International Cospas-Sarsat Programme provides **accurate, timely, and reliable distress alert and location data** to help search and rescue authorities assist persons in distress.

- To achieve this objective, **Cospas-Sarsat Participants implement, maintain, co-ordinate and operate a satellite and ground system capable of detecting distress alert transmissions from radiobeacons** that comply with Cospas-Sarsat specifications and performance standards, and of determining their position anywhere on the globe. The distress alert and location data is provided by Cospas-Sarsat Participants to the responsible SAR services.

- **Cospas-Sarsat co-operates with** the International Civil Aviation Organization (**ICAO**), the International Maritime Organization (**IMO**), the International Telecommunication Union (**ITU**) and other international organizations to ensure the compatibility of the Cospas-Sarsat distress alerting services with the needs, the standards and the applicable recommendations of the international community.

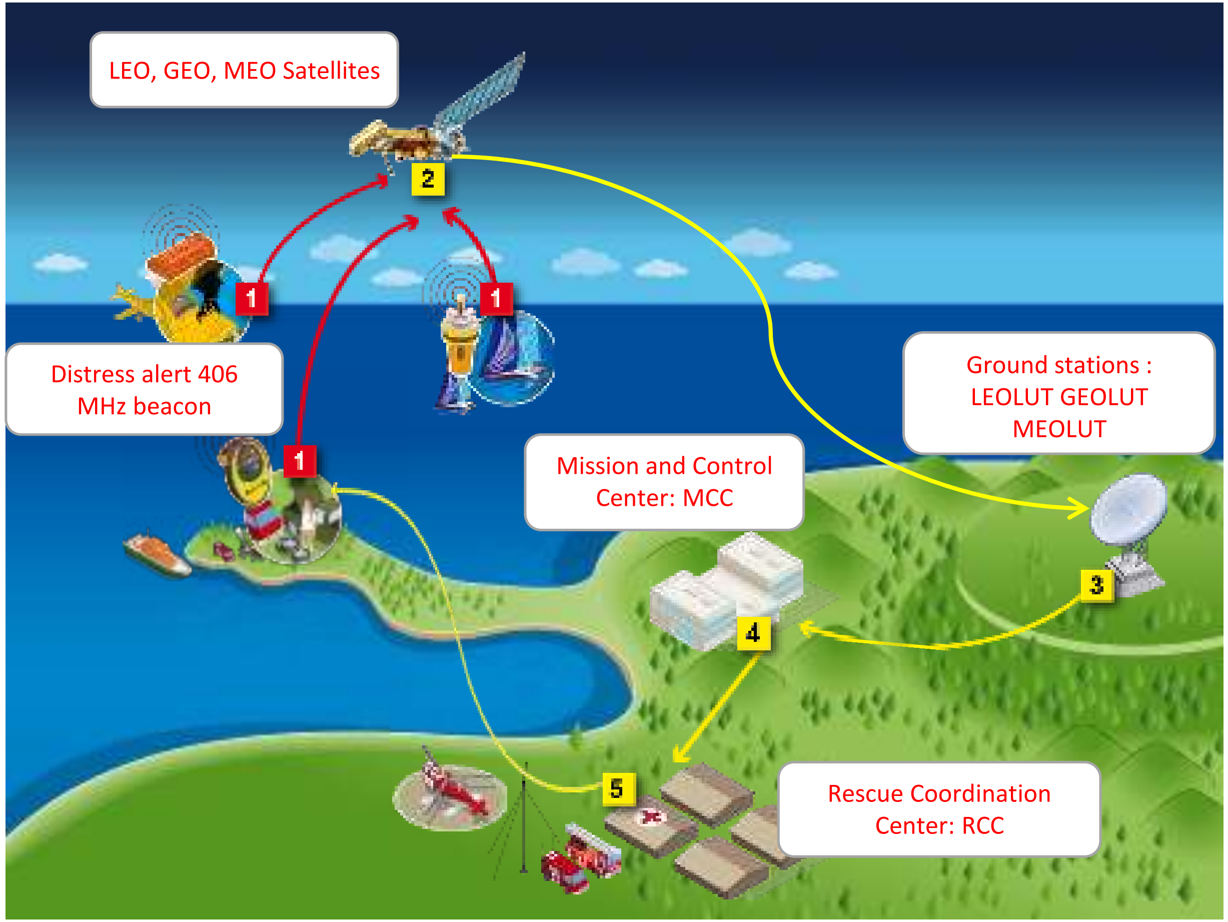
Introduction to Cospas-Sarsat and current status

Cospas-Sarsat: history

- **1979** : a Memorandum of Understanding covering the system development was signed between the space agencies of four founder states : the former USSR, USA, France and Canada
- **1982** : first Soviet instrument mounted on Cosmos 1383 satellite and in March 1983 first French and Canadian instrument mounted on the American NOAA-8 satellite
- **1982** : first rescue in Canada after an aircraft crash
- **1987**: launch of the first GEOSAR satellite
- **1988** : the 4 founder states sign an International Cospas-Sarsat Programme Agreement (ICSPA) which ensures service continuity and availability of the system to all States on a non-discriminatory basis
- **2005** : Cospas-Sarsat Secretariat moves to Montréal, Canada (status as an International Organization)
- **2010** : 1 million of 406 MHz beacons are deployed
- **2012** : first GALILEO spacecraft launch with a SAR payload (GSAT0103 and GSAT0104)
- **2016** : broadcasting of the first MEOSAR operational alerts (Early Operational Capability phase)
- **2019**: MEOSAR enters Initial Operational Capability ?

Introduction to Cospas-Sarsat and current status

Overview



Introduction to Cospas-Sarsat and current status

Distress beacons

3 types of beacons (currently)

- ELT for aeronautics
- EPIRB for maritime
- PLB for personal use

Yearly Production : around 200,000 beacons

- 70,000 only in 2005
- 44% EPIRBs, 15% ELTs, 41% PLBs

Geographical Distribution of manufacturers :

- Europe: 49 %
- USA et Canada: 30 %
- Asia et Australia: 21 %

Population:

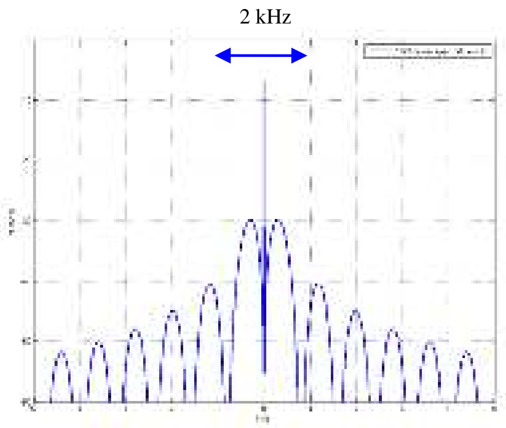
- End of 2017: 1.6 millions of registered beacons, 2.1 millions estimated population

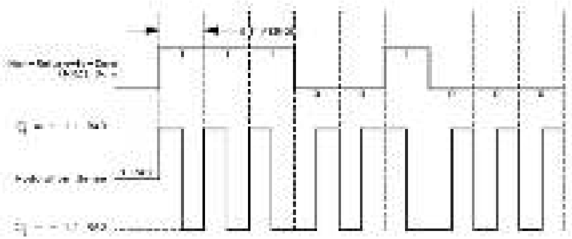
Introduction to Cospas-Sarsat and current status

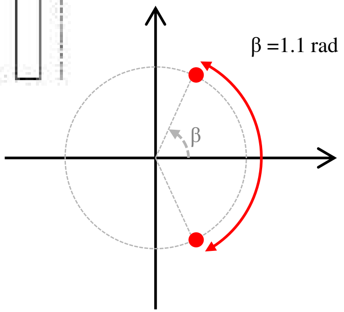
Distress beacons

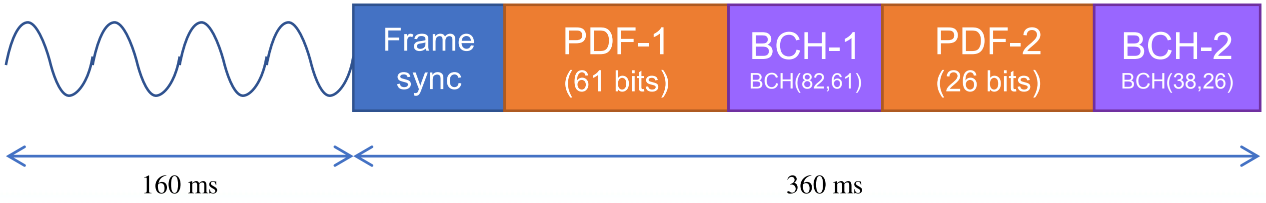
Main beacon signal characteristics

- A pure carrier preamble (160ms), total burst length = 520 ms
- A distress message (bi-phase L, 1.1 modulation index) at 400 bps composed of 144 bits
- One burst transmitted every 50s
- Uniquely identified (15 HexID)





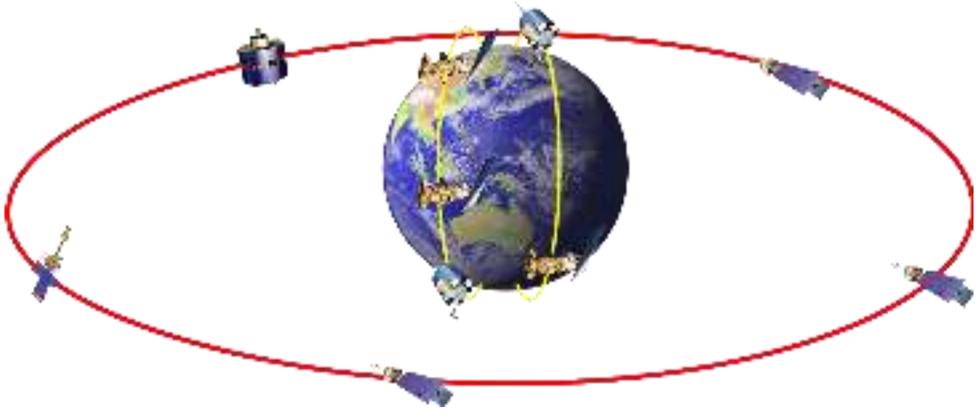




How Cospas-Sarsat system works

Space segment

- LEO satellites: Low Earth Orbit (altitude = 800 km typically, polar orbits)
- GEO satellites: Geostationary Earth Orbit (altitude = 36000 km, equatorial orbits)



- MEO satellites : Medium Earth Orbit → GNSS satellites at 20000 km typically

Introduction to Cospas-Sarsat and current status

Current status of space segment:

- 5 operational LEO satellites (NOAA-15, NOAA-18, NOAA-19, MetOp-A, MetOp-B)
  - Equipped with both SARR (SAR Repeater) and SARP (SAR Processor)
  - SARP measures FoA (Frequency of Arrival) upon successive transmitted signals in order to compute the beacon location
- 6 operational GEO satellites (GOES-13, GOES-15, MSG-1, MSG-2, MSG-3, INSAT-3D)…
  - … and satellites in orbit spare or under testing (GOES-14, MSG-4, GOES-16, GOES-17, Electro-L 2, Louch-5A, Louch-5V, INSAT-3DR, GSAT-17)
  - Equipped with SARR repeater only, no independent location possibility

Introduction to Cospas-Sarsat and current status

Current status of MEO space segment:

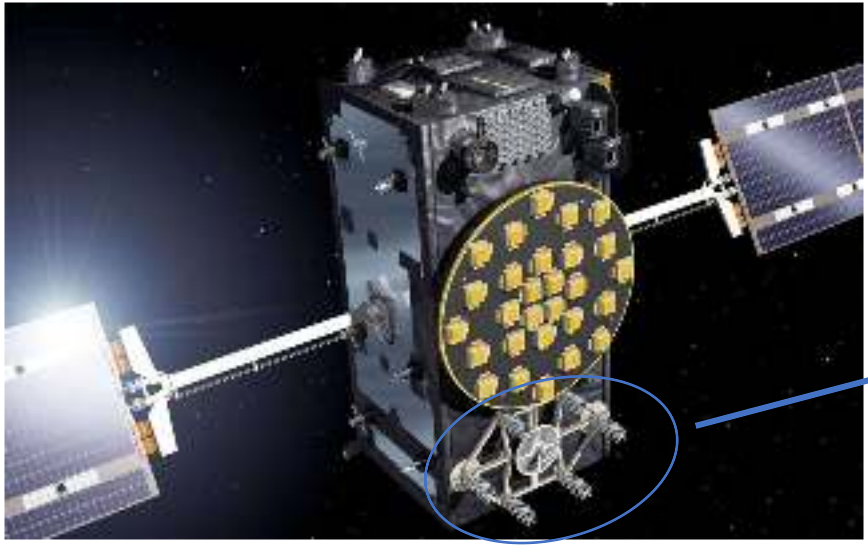
- 16 Galileo SAR payloads commissioned at FOC level + 4 to be approved soon
  - Equipped with nominal L-band payload (downlink at 1544.1 MHz), SART (SAR Transmitter)
- 19 GPS/DASS SAR payloads
  - Equipped with non-nominal S-band payloads (downlink at ≈2.3 GHz)
  - Initially planned for testing purpose but now used operationally
- 1 GLONASS SAR payload used for testing purpose

Introduction to Cospas-Sarsat and current status

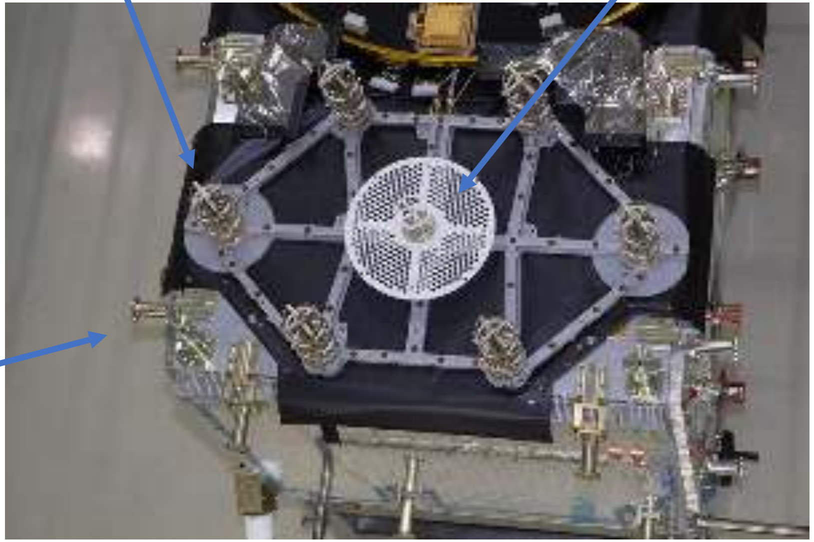
MEOSAR payload example

Transmitting antenna (1544.1 MHz)

Receiving antennas (406 MHz)



Galileo FOC (Copyright ESA)



Galileo FOC SAR antenna (Copyright ESA)

Introduction to Cospas-Sarsat and current status

Ground segment

- LUT: Local User Terminal
  - LEOLUT: tracks, receives data from LEO satellites (successively), and computes Doppler locations → 56 operational LEOLUTs distributed worldwide
  - GEOLUT: tracks and receives data from GEO satellite → 26 operational GEOLUTs distributed worldwide
  - MEOLUT: tracks, receives data from MEO satellites (simultaneously), and computes independent location based on TOA/FOA measurements
    - 12 MEOLUT commissioned at EOC level
    - 15 additional MEOLUT planned to be available or commissioned in 2019
    - and more in the coming years…

Introduction to Cospas-Sarsat and current status

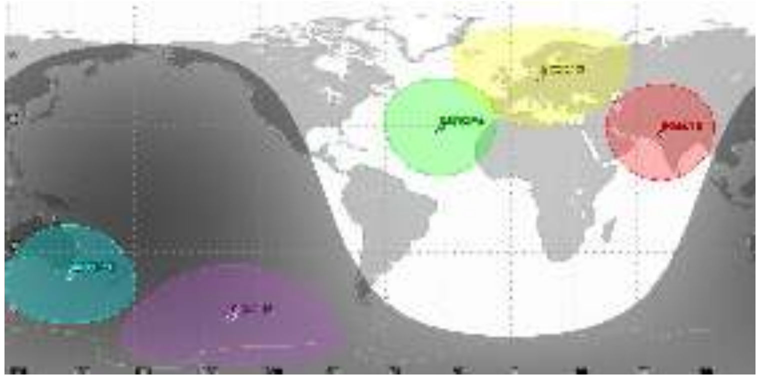
MEOLUT Illustration

« Classical » MEOLUT architecture
1 dish antenna tracks 1 MEO satellite

« Innovative » MEOLUT architecture
1 phase array antenna tracks all in view MEO satellites

MEOSAR highlights

MEOSAR highlights



LEOSAR coverage example

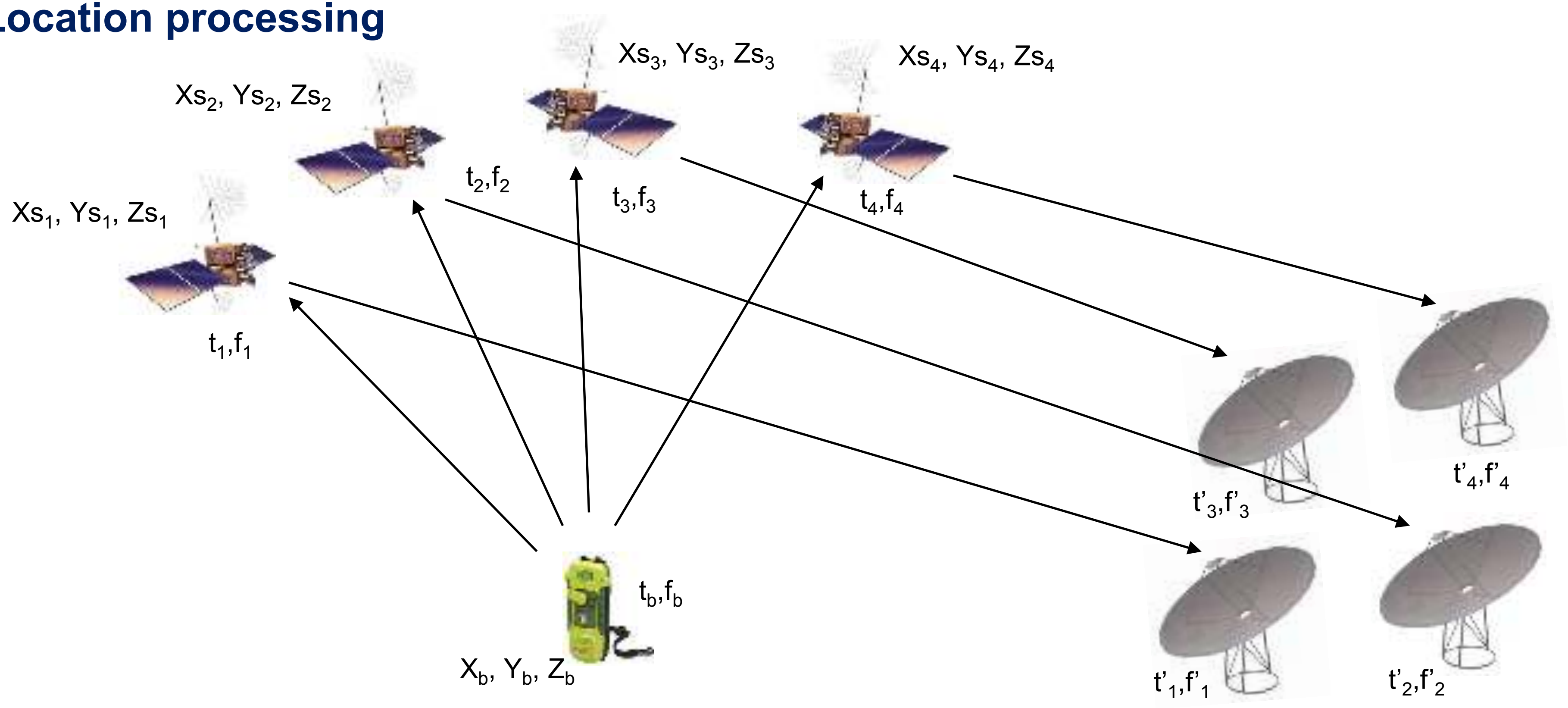
MEOSAR benefits compared to LEOSAR:

- Instantaneous location capability
  - With a sufficient number of MEO satellites and MEOLUTs, a beacon can be located on a single burst
- Instantaneous global coverage
  - With a sufficient number of MEO satellites and MEOLUTs, beacons can be located everywhere on Earth, at every time

In brief: MEOSAR greatly enhances the time to locate a distress (few minutes instead of up to 2 hours with LEOSAR)

MEOSAR highlights

Location processing



MEOSAR highlights

t_t: time of beacon burst transmission,
f_t: frequency of beacon burst transmission,
$\overrightarrow{X_s^i} = [x_s^i, y_s^i, z_s^i]$: the position vector of the i[th] satellite,
$\overrightarrow{V_s^i} = [vx_s^i, vy_s^i, vz_s^i]$: the velocity vector of the i[th] satellite,
$\overrightarrow{X_b} = [x_b, y_b, z_b]$: the position vector of the beacon,
$\overrightarrow{V_b} = [vx_b, vy_b, vz_b]$: the velocity vector of the beacon.

Location processing

- MEOSAR localization technique uses:
  - Frequency of Arrival (FoA), same as LEOSAR

$$FOA_i = f_t - \frac{f_t}{c} . \left(\overrightarrow{V_s^i} - \overrightarrow{V_b}\right) \cdot \frac{\left(\overrightarrow{X_s^i} - \overrightarrow{X_b}\right)}{\left\|\overrightarrow{X_s^i} - \overrightarrow{X_b}\right\|}$$ (typical measurement noise σ_{FOA} = 0.2 Hz)

  - Time of Arrival (ToA) → estimation of ToA is performed at the MEOLUT

$$TOA_i = t_t + \frac{\left\|\overrightarrow{X_s^i} - \overrightarrow{X_b}\right\|}{c}$$ (typical measurement noise σ_{TOA} = 20 µs)

MEOSAR highlights

Location processing

- Generally used assumptions
  - Use of TDOA/FDOA instead of TOA/FOA as the time/frequency of transmission are no known (this process also simplifies multi-burst processing)
  - Beacon is on the ground → 2D location only (latitude, longitude)
  - Beacon velocity is small compared to satellite velocity → Vb_x, Vb_y, Vb_z = 0 ? not so easy…

- While MEOSAR nominal performance was extensively studied with static beacons, it was quickly realized that moving beacons were located with a significantly degraded performance (even slow moving beacon, such as a beacon bobbing in waves…).

MEOSAR highlights

Location processing

- Moving beacon issue: theory
  - Location is generally computed with a classic iterative approach:

$$X_b^{n+1} = X_b^n + (H^T.W.H)^{-1}.H^T.W.\Delta Y$$

  - With:

X_b^n: the estimated beacon location produced from iteration n,

H: the Jacobian matrix, containing partial derivatives,

W: a weighting matrix (weighting coefficients for TOA and FOA measurements),

ΔY: the difference vector between the TOA/FOA measurements and the TOA/FOA values that would have resulted from the beacon location as evaluated at the last iteration (n).

MEOSAR highlights

Location processing

- Moving beacon issue: theory
  - If assuming the beacon to be static in the location process, the beacon motion creates a bias that depends on beacon velocity, satellite geometry and relative weights on ToA/FoA measurements:

$$\Rightarrow \Delta x = \frac{f_t}{c} . \sum_{j=1}^{N} p_{1,j} . (\overrightarrow{V_b} . \overrightarrow{U_j})$$

$$\Rightarrow \Delta y = \frac{f_t}{c} . \sum_{j=1}^{N} p_{2,j} . (\overrightarrow{V_b} . \overrightarrow{U_j})$$

$$\Rightarrow \Delta z = \frac{f_t}{c} . \sum_{j=1}^{N} p_{3,j} . (\overrightarrow{V_b} . \overrightarrow{U_j})$$

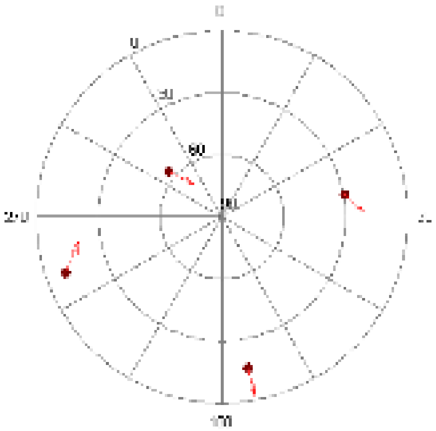
P: a projection matrix, $P = (H^T . W . H)^{-1} . H^T . W$,
$p_{i,j}$: the value in matrix P in the i^{th} row and j^{th} column,
$\overrightarrow{V_b} = [vx_b, vy_b, vz_b]$: the velocity vector of the beacon,
$\overrightarrow{U_j}$: the unit vector pointing from the beacon towards the j^{th} satellite,
N: the number of satellites.

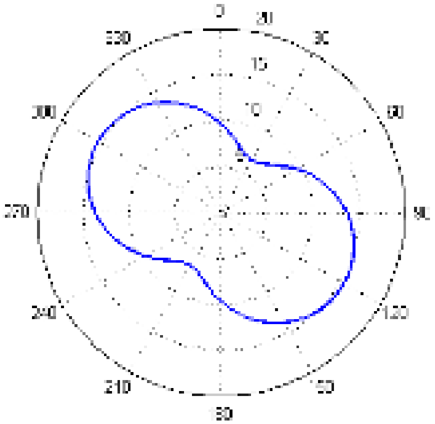
MEOSAR highlights

Location processing

❖ Moving beacon issue: theoretical example

- Typical location accuracy for static beacons: 5km @ 90% (single burst, using ToA and FoA)
- Effect of a motion of 1 m/s





Minimum bias error resulting from the beacon motion = 6.6 km (for beacon headings towards 30 and 210 deg, at 1m/s)

Maximum bias error resulting from the beacon motion = 15.5 km (for beacons headings towards 120 and 300 deg, at 1m/s)

MEOSAR highlights

Location processing

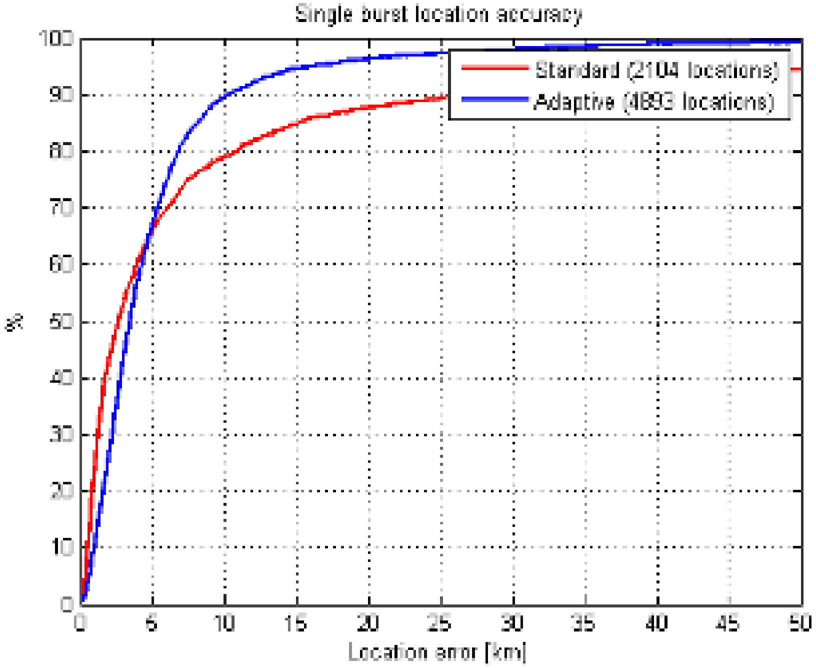
- Moving beacon issue: solutions
  - It is important to detect if a beacon is moving or not (from velocity estimation from FoA measurement or FoA residuals)
  - If it is detected that the beacon moves with a sufficient speed, 2 possible different strategies:
    - Decrease the weight on FoA measurements (compromise bias vs noise to get the best location accuracy)
    - Use a joint position+speed estimation

- Location processing has to be adaptive to the beacon speed to get the best location accuracy.

MEOSAR highlights

Location processing

- Moving beacon issue: improvement due to adaptive algorithm



Results obtained during a test conducted by Norway in March 2016, involving a boat with moving and static phases.

MEOSAR highlights

Location processing

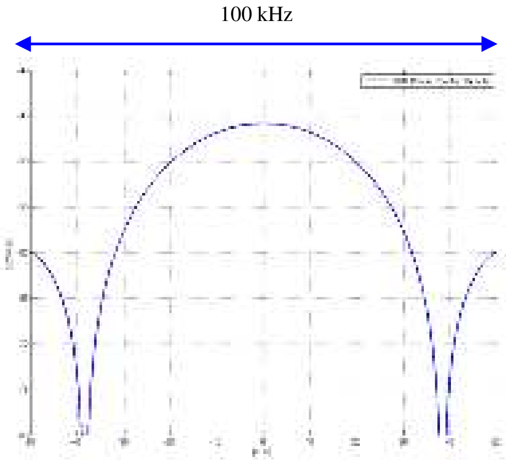
- Moving beacon issue: way forward
  - Additional work is needed to improve location performance of moving beacons using multi-bursts
    - Trajectory estimation with simple trajectory model ?
    - Kalman filter ?

MEOSAR highlights

Second Generation Beacon standard

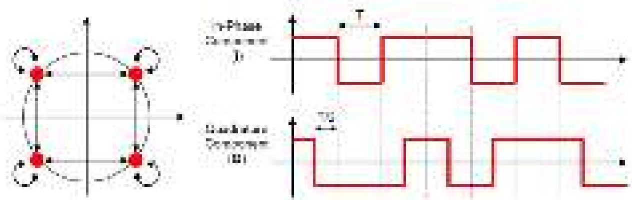
- In parallel to MEOSAR deployment, a second generation of beacon is being developed
- Objective: answer to more stringent operational requirements
  - Better detection performance: 99.9% after 30s of activation
  - Better localization performance:
    - 5km, 90% of the time for first burst
    - 5km, 95% of the time after 30s of activation
    - 1km, 95% of the time after 5min of activation
    - 100m, 95% of the time after 30min of activation
  - Increased content of transmitted message

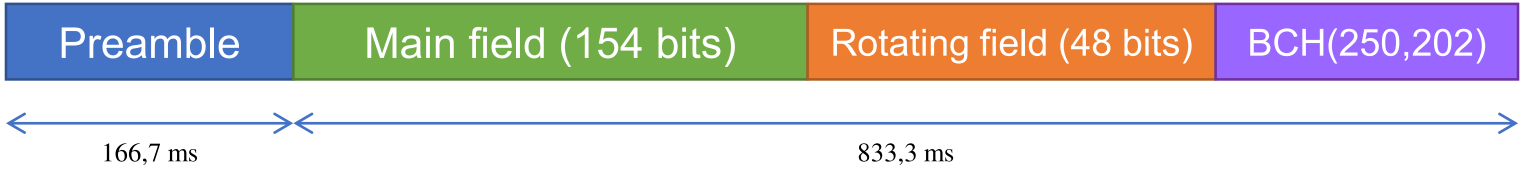
MEOSAR highlights



Second Generation Beacon standard

- Second Generation Beacons signal characteristics:
  - Waveform: OQPSK with spread spectrum at 38400 chips/s
  - Message: 202 useful bits, 300 bits/s, 1s duration
  - Error correction code: BCH(250,202)
  - Introduction of “Rotating field”: transmission of different information on each burst
  - Cancellation capability





MEOSAR highlights

Second Generation Beacon standard

- Performance improvement

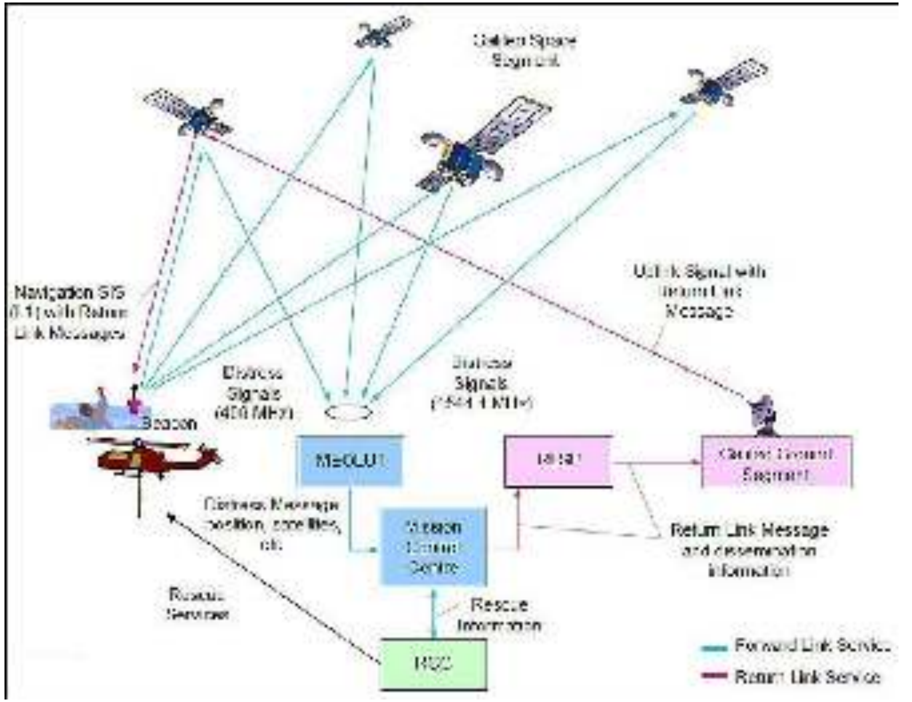
	FGB	SGB
Detection threshold	34.7 dBHz	31.7 dBHz
σ_{FOA}	0.2 Hz	0.15 Hz
σ_{TOA}	20 µs	1 µs
Location performance (static beacon, single burst)	~ 5 km	~ 1 km
Location performance (moving beacon, single burst)	~ 20 km	~ 1km

System evolutions: RLS and ELT(DT)

System evolutions: RLS and ELT(DT)

Return Link Service

- A Galileo service which allows to send a acknowledgement to user in distress
- An RLM is sent through the Galileo E1 signal
- The RLS service should be declared operational in 2019 by EC
- RLSP (Return Link Service Provider) is operated by CNES



System evolutions: RLS and ELT(DT)

Return Link Service

- Currently, only the automatic acknowledgement has been agreed but additional uses of RLS are being discussed:
  - Remote activation : a beacon that listen to Galileo signals could be activated from the ground. Useful to track an aircraft that disappears from air traffic control (ex: MH370)
  - Remote command: change beacon transmission characteristics (ex: reduce repetition rate to save battery)
  - Two-way messaging: give more details to SAR forces about the distress situation (ex: number of people involved, type of distress)

System evolutions: RLS and ELT(DT)

Beacons activated in flight: ELT(DT)

- Following accidents of AF447 and MH370, ICAO has imposed a requirement for new aircrafts being operated after 1st January 2021, to be equipped with a system able to locate the aircraft accident site. The system has to transmit signals from which a location can be retrieved at least once every minute.
- Cospas-Sarsat answer was the development of the ELT(DT) standard:
  - A beacon activated in flight upon detection of distress situation (total loss of propulsion, unusual attitude, unusual speed, unusual altitude, ground proximity)
  - A GNSS encoded location as primary mean of location
  - Independent location with speed estimation (coarse location accuracy with FGB, enhanced location accuracy with SGB).

Thank you for your attention !

Question ?