MEOSAR-NG Study

Executive Summary Report

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1 INTRODUCTION & SCOPE

1.1 Scope

This document contains an summary overview of outcomes of the MEOSAR NG study conducted by OHB System with RUAG Space Austria and FFI Norway.

1.2 Study overview

MEOSAR is a system designed to locate emergency beacons anywhere on the Earth in order to coordinate rescue efforts for people, vehicles and facilities in distress. It works by evaluating the time and the frequency of the beacon signal upon arrival at the receiver. From these the relative distance and velocity of the sender can be calculated if sufficient data points have been collected. It is beneficial to receive the beacon on several different spacecraft to optimise the accuracy of the trace.

In the current MEOSAR system, the signal is rerouted to a ground station via the MEO satellite. In the next generation system TOA and FOA are evaluated on-board and then forwarded to the ground segment. This vastly reduces message size. Two scenarios were be analysed:

- Scenario A is similar to the architecture of the existing MEOSAR system. The payload is self-contained only receiving power from the satellite and exchanging TMTC with the on-board computer.
- In Scenario B the system makes use of the G2G infrastructure and capabilities by routing the beacon data (TOA, FOA + auxiliary data) through the platform. This way they may be downloaded to a Galileo ground station (GALLUT) instead of a dedicated MEOSAR ground station (MEOLUT).

The objective of the MEOSAR-NG study was to assess, develop and evaluate several possible architectures for a next generation MEOSAR system resulting in the selection of the baseline concepts presented in this report. The overarching aim was to reduce costs of the Search-And-Rescue system by moving part of the system intelligence from ground to space leading to a reduction in complexity of the MEOSAR ground infrastructure.

The use of a MEO-based SAR-system instead of a classical LEO-based system improves satellite-to-ground station visibility and contact time, which increases the overall system reliability and response time. Thus, a significant progress in terms of reduced cost and complexity and improved SAR-system performance may be achieved, in case this new SAR processor payload technology would be implemented on the Galileo-2G (G2G) satellites. There is an option to run both systems, the current SART transponders and the next generation SARP processors in parallel.

1.3 Abbreviations and acronyms

BDP	Burst Data Package
CLOP	Central Location Processor
D/L	Downlink
ELT	Emergency Locator Transmitter
EPIRB	Emergency Position Indicating Radio Beacon
FGB	First Generation Beacon
FOA	Frequency of Arrival
G2G	Galileo Second Generation
GCC	Galileo Control Centre
HW	Hardware
I/F	Interface
ISL	Inter-satellite Link
LUT	Local User Terminal
MCC	Mission Control Centre
OBC	On-board Computer
OBDH	On-board Data Handling
P/F	Platform
P/L	Payload
PLB	Personal Locator Beacons
S/C	Spacecraft
SAR	Search and Rescue
SARP	SAR Processor
SART	SAR Transponder
SGB	Second Generation Beacon
SIT	Standard Indicator Type
SW	Software
TC	Telecommand
TM	Telemetry
TOA	Time of Arrival
TT&C	Telemetry, Tracking and Command
U/L	Uplink
ULS	Uplink Station

2 MISSION OVERVIEW

Different scenarios can be derived to meet the requirements set forth in the study statement of work. In the current MEOSAR system, the signal is rerouted to a ground station via the MEO satellite. In the next generation system TOA and FOA will be evaluated on-board and then forwarded to the ground segment. This vastly reduces message size. Two scenarios are analysed:

- Scenario A is similar to the architecture of the existing MEOSAR system. The payload is self-contained only receiving power from the satellite and exchanging TMTC with the on-board computer. The main advantage of scenario A is that it is platform independent. Therefore, impacts on the SAR payload by changes in the capability and design of the Galileo Second Generation (G2G) mission and system can be minimised. Also, similar systems can be developed to be embarked on other MEO satellite constellations. Scenario A is unaffected by the final decision to include/exclude ISL. The disadvantage of Scenario A is that it needs to be self-sufficient in data handling and download and synergies with the platform cannot be exploited. This makes the system more complex/costly compared to Scenario B while potentially offering lower performance, e.g. in terms of downlink data rate.
- In Scenario B the system makes use of the G2G infrastructure and capabilities by routing the beacon data (TOA, FOA + auxiliary data) through the platform. This way they may be downloaded to a Galileo ground station (GALLUT) instead of a dedicated MEOSAR ground station (MEOLUT). This scenario allows an efficient use of the platform resources by the payload leading to a smaller/lower cost system without impacting (possible even improving) the performance. The disadvantage is the dependence of the system on the capabilities of the G2G satellites, in particular inter-satellite link (ISL), which is of vital importance for scenario B.

The following features are optional as they are not necessary to fulfil the mission requirements but can add some interesting additional functionality. All features are applicable to both scenarios.

Beacon archive on the platform

In order to make best use of the allocated bandwidth for the downlink of processed beacons a filtering and prioritisation is implemented on-board. This means that in times of high beacon traffic lower priority beacons such as self-test messages and orbitography messages are not forwarded. As an optional feature the G2G platform will save all received messages in a repository that can be downloaded upon ground command when the satellite is in direct contact with the ground station.

Location broadcast in the NAV message

This implementation option is based on the functionality that after generation of a SIT, the beacon position will be uplinked back to the space segment and subsequently broadcast. Such function might be worthwhile for rescue teams in very remote areas, as it will keep them up-to-date on the latest beacon position and the information can be received on a hand-held GNSS receiver. In order to successfully broadcast the beacon positions, this information will be integrated in the mission data as a service. After checking the Galileo-2G SISICD for available services / data fields, the recommendation is to select the Real-Time Data service in the I/NAV component for the beacon position broadcast function. As alternatives, the data field for a Spare Word can be used or in its extreme case, the signal structure can be modified.

SART and SARP in parallel

In addition to the SARP as an option a heritage SART will in implemented on Galileo SG spacecraft. SART is a transparent transceiver which does not perform any digital processing on the received signal. This way existing MEOLUT station will be able to receive the beacon messages without any modification. Modified MEOLUTs may receive both the original beacon and the BDP and can then gain even better accuracy on the location by using the TOA and FOA computed on board and their own computation.

2.1 Ground segment

The following diagrams shows the necessary functions of platform and payload for the handling of beacon messages. The diagram is not showing the SAR RTN link pathway, which consists of a message imbedded in the NAV signal and uploaded to the satellite in the usual way via the uplink stations of through the ISL network and requires no involvement of the payload.

In scenario A the ground dissemination of the data is handled the same as in the current MEOLUT system as the receiver for the BDPs is just a modification to the receive function of the station. Additional OMNILUTs will follow the same dissemination strategy.

In scenario B, all data is downlinked to the Galileo Control Centre where it will be identified as SAR data and automatically forwarded to the GALLUT system. The GALLUT will process the BDPs, computing locations and sending the processed data to the Galileo-MCC. This MCC then uploads all information to a global server to be accessed from any other COSPAS-SARSAT member.

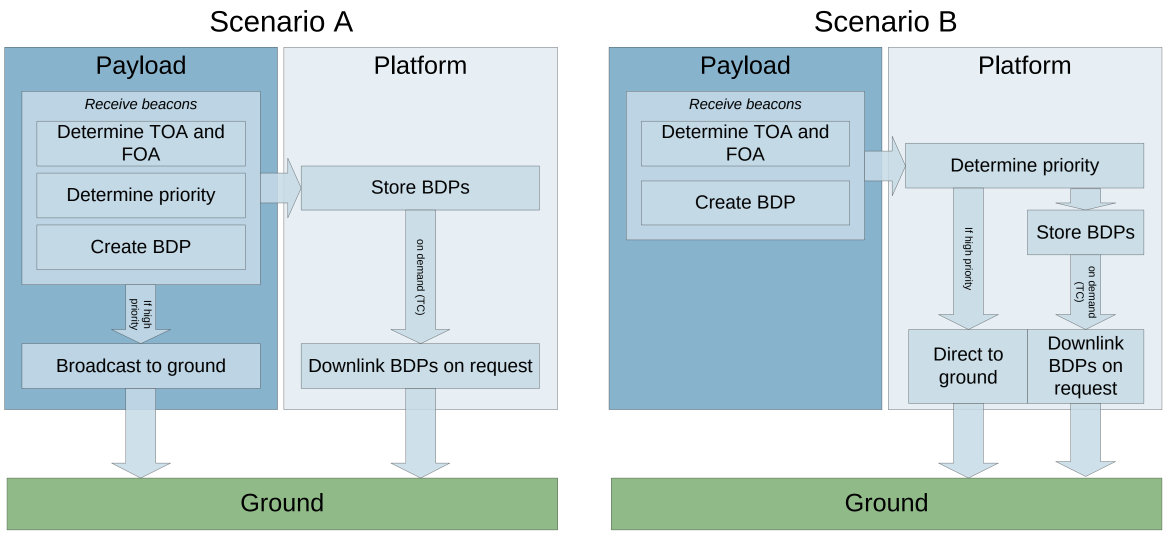

Figure 2-1: Functions of the on-board data management of beacon messages

3 SARP DESIGN

3.1 SARP overview

The core functionality of the SARP is to receive and precisely analyse beacon transmissions by determining Time Of Arrival (TOA) and Frequency Of Arrival (FOA) parameters, and to forward the results in form of Burst Data Packets (BDPs).

Table 3-1: SARP Overview

SARP Function	Scenario A	Scenario B
Detection, reception and processing of FGB and SGB bursts	X	X
Precise determination of the TOA based on Galileo System Time (GST)	X	X
Precise determination of the FOA	X	X
One FGB detector covering all SAR channels	X	X
[confidential] parallel SGB detectors	X	X
Individual PRN-code for each SGB detector	X	X
Advanced digital signal processing (DSP) for accurate estimation of TOA and FOA	X	X
Full digital data regeneration incl. BCH decoding	X	X
Generation and forwarding of BDPs	X	X
Configurability via TMTC	X	X
Beacon filter capabilities based on beacon HEX-IDs	X	
L-Band downlink with [confidential] bps	X	
Redundancy concept backward compatible with SART	X	X

The SARP core functionality does not vary with different mission scenarios, so the majority of functionality is covered by both SARP variants (Scenario A and B). For Scenario B however, the dedicated L-Band downlink is removed from the design.

3.2 SARP design description

Besides the antenna assembly (incl. harness) and the *band-pass filter* (BPF) stage, the hardware of the SARP is partitioned onto three modules:

- *Radio Frequency* (*RF*) Module (RFM)
- Processing Module (PM)
- Power and Interface Module (PIM)

For the redundant configuration of the payload, each of the modules is provided twice. The individual modules are accommodated in a single box and interconnected via a common backplane.

The architectural overview of the SARP in Figure 3-1 shows the relationship and interfaces between the individual modules, and indicates the core components of each of them. Two RF switches (shown on the left side of Figure 3-1), allow to switch in-between the nominal and redundant unit. In case of Scenario B, all components following and including the DAC are removed.

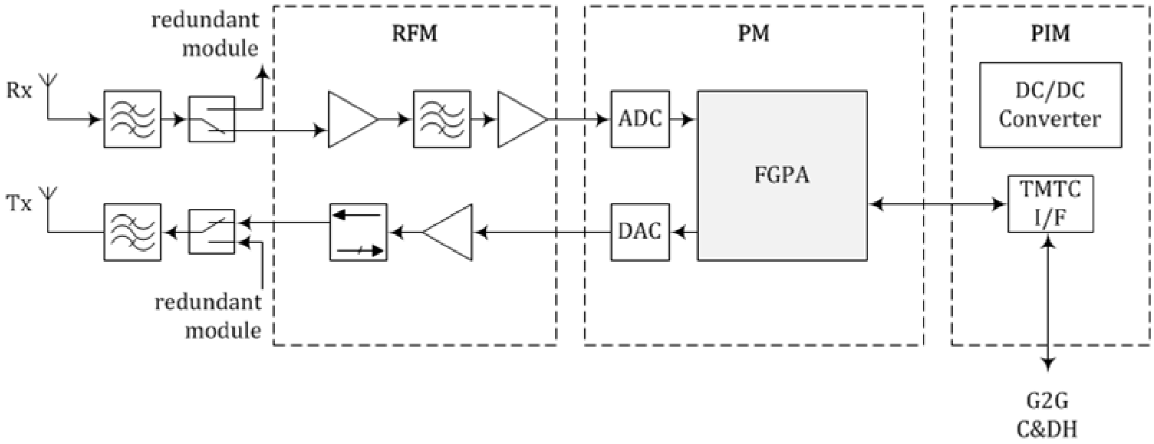

Figure 3-1: SARP Architectural Overview

The DSP architecture of the SARP distinguished between FGB and SGB bursts. The continued detection and acquisition processes operate on the live data stream coming from the RFM. A full Parallel Code Phase Search Acquisition (PCPSA) allows the simultaneous and uninterrupted search for FGB and SGB bursts, for up to [confidential] different PRN codes.

The major driver in terms of complexity, performance and resource demands is the full parallel and persistent processing in the SGB processing blocks. Their share in total DSP, memory and logic demands is approx. 80%, based on an evaluation and of the preliminary DSP design of the SARP.

3.3 SARP budgets

Table 3-2 provides a summary of the technical budgets of the SARP. Accurate values partially have been replaced by a bound or range approximate.

Table 3-2: SARP Technical Budgets Overview

Parameter	Unit	Scen. A	Scen. B	Comment
Mass	kg	< 22	< 19	Incl. antenna
Exterior Volume	mm^3	1200 x 700 x 273		Dual-band antenna (Rx & Tx)
Equipment Bay Volume	mm^3	230 x 224 x 284		SARP processor box, W x D x H (w/o connectors)
Communication link	kbps	< 10 kbps		
Power	W	< 100	< 70	
Memory	Mbit	32 to 64	32 to 64	
Reliability	FIT	123	<123	Redundant configuration
Dynamic Signal range	dBFS	> 55		

3.4 SARP technology

Table 3-3 shows the SARP technology matrix, indicating the Technology Readiness Level (TRL) and criticality of the key technologies.

Table 3-3: SARP Technology Matrix

Unit/Module	Technology	TRL	Comments
PM	ADC	5 to 6	Considered critical
PM	FPGA	2 to 3	Considered critical
PM	DAC	4 to 5	Considered critical
PM	Memory	5 to 6	
RFM	RF Switch	6 to 9	
RFM	BPF	6 to 9	
RFM	LNA	6 to 9	
RFM	VGA	6 to 9	
PIM	DC/D Converter	8 to 9	
PIM	Connectors	8 to 9	
ANT	Rx & Tx Antenna	9	

Three technologies used in the preliminary SARP design have been identified as critical. The analog-to-digital converter (ADC), the Field Programmable Gate Array (FPGA) and the *digital-to*-analog converter (*DAC*) (Scenario A only).

Table 3-4: Summary of Critical Aspects

Technology	Critical Aspect	Comment
ADC	Radiation Effects	Sensitivity to Single Event Upsets (SEU) / Single Event Transients (SET).
FPGA	Performance	High resource and performance demands due to high-speed DSP.
	Packaging	Mounting qualification of high-density Package.
	Radiation Effects	SRAM-based FPGA technologies are prone to SEU.
	Legal Aspects	ITAR / EAR
DAC	Radiation Effects	Sensitivity to SEU/SET.

Radiation effects

- Rigorous consideration of this sensitivity throughout all project phases, in particular during the reliability analysis and detailed design.

Particular mitigation techniques in the FPGA design comprise:

- Fail-safe and deadlock-free finite state machines (FSM)
- Error Detection And Correction (EDAC)
- Global, large grain or local Triple Modular Redundancy (TMR)
- Reliability-oriented Synthesis and Place and Route Configuration

3.5 SARP performance

Figure 2 shows the SARP performance simulation results for the TOA and FOA parameters as a function of carrier to noise density (C/No). The simulations are carried out for the nominal case and under worst case conditions such as a high transmitter instability, high Doppler rates and high symbol rate variation.

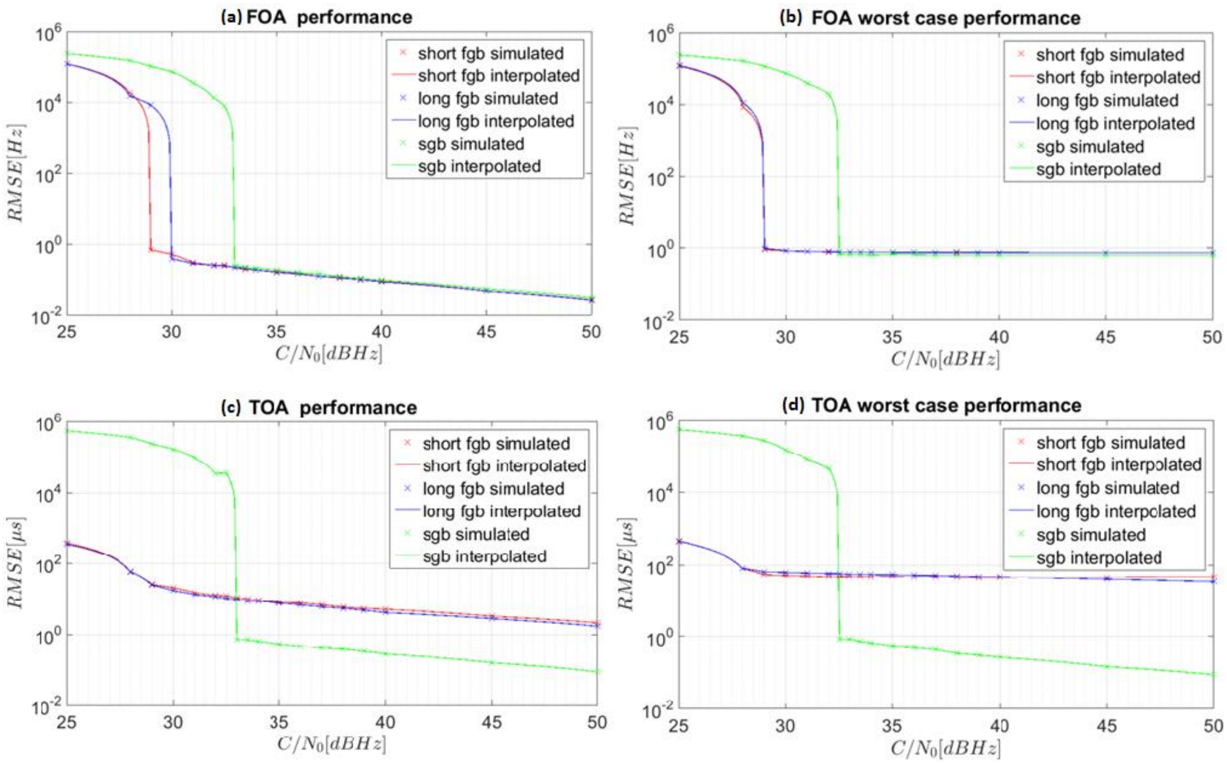

Figure 2 - SARP Performance Simulation Results (left - nominal, right - worst case)

The results in (a) show an offset of the detection threshold between FGB and SGB. This results to some extent from the signal structure and in particular the initial part of a burst, i.e. pure carrier in case of FGB and a preamble (*Direct Sequence Spread Spectrum* (*DSSS*)) in case of SGB, but also from the differences in-between the DSP architectures for FGB and SGB. For both architectures, the results of the link budget calculation served as reference point in performance vs. resources/complexity trade-off, carried out in the study. In both cases, the targeted detection threshold is achieved.

In accordance to the results for the FOA parameter, the results for the TOA parameter show the same offset of the detection threshold in-between FGB and SGB. The achieved performance for SGB however, is substantially improved if compared to FGB. This improvement results from the signal structure of SGB, and in particular the specified low chip rate short term frequency variation.

4 SYSTEM PERFORMANCE SIMULATION

This section summarises only the most relevant geolocation performance results.

For example, an ionospheric scintillation event during solar maximum increase the packet error loss, but with little effect on overall geolocation accuracies. Similarly, there is not much difference between first generation beacons transmitting short messages and first generation beacons transmitting long messages.

4.1 Geolocation results for second generation beacons

COSPAS-SARSAT defines the operational requirements for second generation beacons as:

- At least one valid beacon message within 30 seconds 99.9% of the time
- First burst 2 dimensional independent location accuracy within 5 km, 90% of the time
- 5 km, 95% of the time, within 30 seconds after beacon activation
- 1 km, 95% of the time, within 5 minutes after beacon activation
- 100 m, 95% of the time, within 30 minutes after beacon activation

These simulations ran for 30 days with ionospheric conditions corresponding to solar minimum. We used an elevation mask of 5 degrees. I.e. no messages were received by a satellite less than 5 degrees above horizon. Of the remaining messages, there was an overall packet loss of 0.013%, which is well within the operational requirements since a beacon message lost by one satellite is still received by multiple other satellites.

Figure 4-1 shows the cumulative error distributions after 30 seconds and how the geolocation performance varies with the data types used to locate the beacons. Figure 4-1 demonstrates that the FOA observables have negligible effect on the final geolocation results, but the FOA observables helps the geolocation routine to find a unique solution. The curves show the performance when combining both TOA and FOA and when using only one of these data types.

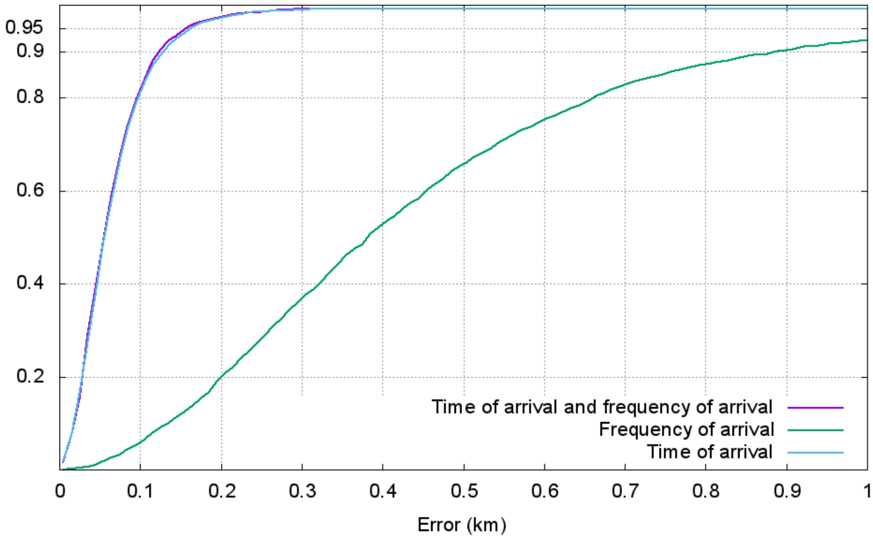

Figure 4-1: Cumulative geolocation accuracy for second generation beacons after 30 seconds assuming nominal beacon oscillator stability.

4.2 Geolocation results for first generation beacons

These simulations used the same geographical distribution and the same activation probabilities as the previous simulations, but with appropriate repetition rates and message lengths for first generation beacons. We only provide one set of results, since the performance did not vary significantly between the simulations.

Figure 4-2 shows cumulative geolocation accuracy for first generation beacons transmitting short messages near solar minimum.

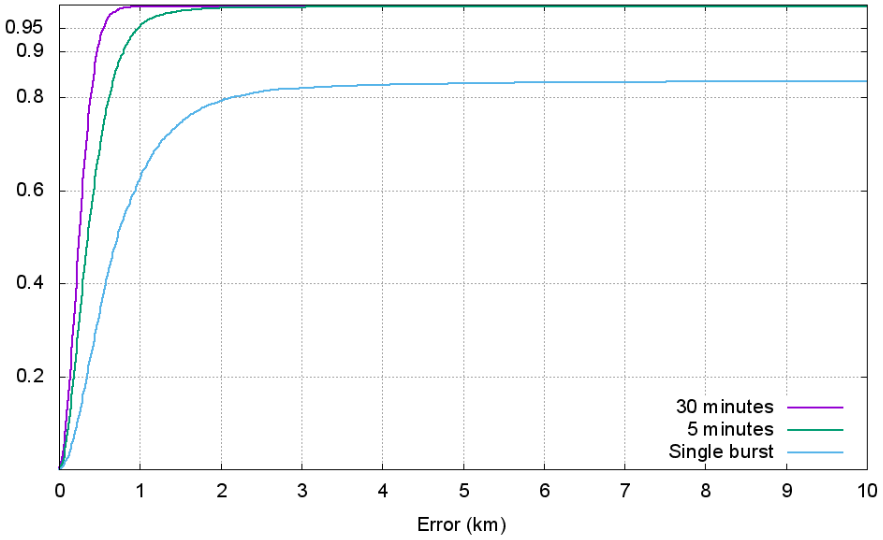

Figure 4-2: Cumulative geolocation accuracy for first generation beacons transmitting short messages near solar minimum.

5 CONCLUSIONS AND OUTLOOK

5.1 Study summary

This report presents a summary of the findings of the MEOSAR-NG study performed by OHB System, RUAG Space Austria and FFI. A concept for a new SAR payload was developed which processes received beacons and computes TOA and FOA on-board. Two different system options were investigated.

Scenario A is a self-sufficient payload which downlinks the received beacons to modified MEOLUT stations and new OMNILUT stations. OMNILUTs are a lot less complex and costly to build than current MEOLUTs, while MEOLUTs can be amended to receive both SART and SARP signals.

Scenario B makes maximum use of the G2G infrastructure by forwarding the received beacons to the platform for filtering and data handling including downlink via inter-satellite link to the Galileo Control Centre.

Additional options for both scenarios include archiving of all received beacons on the Galileo satellite for later bulk download, broadcast of selected SITs in the NAV message and flying the SARP in addition to the SART to be fully backward compatible.

5.2 Comparison with existing MEOSAR system

When comparing the investigated system scenario for the next generation MEOSAR system with the contemporary MEOSAR system using MEOLUTs, the following advantages and disadvantages can be distinguished:

Scenario A:

- Decentralized and flexible system: Every entity / nation can independently receive SAR messages
- OMNILUT terminals are significantly less complex than existing MEOLUT terminals → handheld receivers might become an option
- On satellite level: no significant change with contemporary SART system, except for slightly higher mass and higher power requirements
- No change in interface to COSPAS-SARSAT, i.e. LUT → MCC interface. In this case, a MEOLUT is simply exchanged by an OMNILUT

Scenario B:

- Centralized system with GCC is responsible for receiving SAR messages
- No extra ground station terminals required, as GCC is already in place and available
- On satellite level: omission of L-band downlink chain, but introduction of slightly higher complexity on software level (data multiplexing, SAR data handling)
- Simple interface to COSPAS-SARSAT, i.e. GCC/GALLUT → MCC interface with very limited amount of GCCs
- Disadvantage: ISL is required on G2G satellites to guarantee global coverage and low latency
- Without ISL, the latency requirements will not be compliant to the specification

Recommendation for the implementation plan is Scenario A, as it allows for a high amount of flexibility and maintains the sovereignty of nations in receiving their SAR messages. Furthermore, a significant reduction in complexity, and as such both investment and operational costs, of the ground stations can be expected.

In order to have full backwards compatibility with the existing MEOLUT network, it is recommended to fly the SARP payload in parallel with a SART payload. This functionality can be either realized by an independent SART unit, a switchable SART chain in the SARP payload or by implementing SART mimicking (see next section).

5.3 Outlook: SART mimicking

One interesting concept that arose from this study is “SART-mimicking” in which a SARP transmits a backward compatible signal mimicking that of a transparent transponder but adding the on-board calculated values for FOA and TOA to be read-out by compatible ground stations. Current beacon messages do not foresee fields for measured TOA, FOA and spacecraft ID. In order to allow simple ground stations to interpret the signal, two solutions have been found:

- In addition to the SART mimicking broadcast, BDPs are broadcast. This way, full SARP functionality exists in addition to the backwards-compatibility. This solution requires double the transmit power.
- The second option requires a modification of the planned SGB standard. Three fields are entered: TOA, FOA and spacecraft ID which are transmitted as blanks by the beacons. SART systems will just relay this blank message, however SART mimicking systems will fill these fields with on-board computed values and its spacecraft ID. This way even old MEOLUTS could easily be adapted to read out the transmitted TOA and FOA values, but can also interpret the message without this update. One disadvantage of this option is that it requires the use of SGB as a downlink format which has a longer transmit duration and thus takes more bandwidth than FGB. Impact on SGB message format: Space Vehicle ID (6 bit), TOA (64 bit), FOA (32 bit). In total: +102 bit (without FEC). This equals a plus of 140.8 % of the number of bits contained in a SGB burst, or +34 ms at 300 bps.

The additional fields could be defined as optional. So they will not be part of the bursts issued by a beacon, but can be appended by any COSPAS-SARSAT payload, capable of providing this information (like the SARP).

A number of other issues were identified with the concept which could not be investigated further within the scope of this study. However, the option of SART mimicking looks like a promising way to combine the advantages of a processor payload with full backward compatibility to the current system.

It is recommended to look further into this topic in a follow-on study.