



TECHNICAL REPORT

**System Reference document (SRdoc);  
Short Range Devices (SRD) using Ultra Wide Band (UWB);  
Technical characteristics and spectrum requirements for  
Ground Based Synthetic Aperture Radars  
within 33,4 GHz to 35,2 GHz tuning range**

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**Reference**

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**Keywords**

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650 Route des Lucioles  
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - APE 7112B  
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# Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM).

The present document has been developed to support the co-operation between ETSI and the Electronic Communications Committee (ECC) of the European Conference of Post and Telecommunications Administrations (CEPT).

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# Modal verbs terminology

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# Executive summary

The present document outlines the evolutionary rationale, market needs, technical specifications, and operational scenarios for the next generation GBSAR system, the Multiple Input Multiple Output Ground-Based Synthetic Aperture Radars (MIMO-GBSAR). It highlights the advantages of this innovation and the technical challenges addressed in comparison to traditional HD-GBSAR and GBSAR systems. MIMO-GBSAR extends the applicability of the technology to use cases that require a transportable solution and a range capability of up to 2 km.

The MIMO-GBSAR system, featuring a 1 GHz bandwidth, delivers the same resolution performance and retains the compactness and transportability of the HD-GBSAR. At the same time, the MIMO-GBSAR 34 GHz operating frequency, it more than doubles the monitoring range, enabling early detection of displacement trends, such as those that precede ground collapses, in scenarios where traditional GBSAR and HD-GBSAR systems are not applicable.

Despite its advanced capabilities, the MIMO-GBSAR remains a niche, highly specialized tool intended for use exclusively by trained professionals. Market forecasts, based on extrapolated trends from GBSAR and HD-GBSAR systems, suggest that demand for MIMO-GBSAR units across Europe will likely not exceed 300 units over the next five years. A significant portion of these units is expected to be deployed in shielded terrains, such as quarries, mines, or remote mountainous areas, where electromagnetic emissions are naturally confined within the surveyed space. As a result, only a small fraction of MIMO-GBSAR systems will operate in open environments where they could potentially affect other radio spectrum users. Therefore, the sharing profile of MIMO-GBSAR equipment, defined by its deployment density, visibility to other radiocommunication systems, and potential for interference is very low.

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# 1 Scope

The present document describes the MIMO Ground Based Synthetic Aperture Radar (MIMO-GBSAR) system, which may require a change of the present frequency designation/utilization within the EU and CEPT. A total of 1 GHz bandwidth is required for operation of MIMO-GBSAR, which could be accommodated in the frequency range between 33,4 GHz and 35,2 GHz.

The provided description of MIMO-GBSAR in the frequency range between 33,4 GHz and 35,2 GHz includes in particular:

- Market information;
- Technical information including expected sharing and compatibility issues;
- Regulatory issues.

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# 2 References

## 2.1 Normative references

Normative references are not applicable in the present document.

## 2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long-term validity.

The following referenced documents may be useful in implementing an ETSI deliverable or add to the reader's understanding, but are not required for conformance to the present document.

- [i.1] ETSI TR 102 522 (V1.1.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Equipment for Detecting Movement; Radio equipment operating in the frequency range 17,1 GHz to 17,3 GHz; System Reference Document for Ground Based Synthetic Aperture Radar (GBSAR)".
- [i.2] [ERC Recommendation 70-03](#): "Relating to the Use of Short Range Devices (SRD)".
- [i.3] ETSI TR 103 594 (V1.1.1): "System Reference document (SRdoc); Short Range Devices (SRD) using Ultra Wide Band (UWB); Technical characteristics and spectrum requirements for High-Definition Ground Based Synthetic Aperture Radars (HD-GBSAR) operating in 1 GHz band within 74 GHz to 81 GHz tuning range".
- [i.4] [ECC/DEC/\(21\)02](#): "The harmonised frequency band 76-77 GHz, technical characteristics, exemption from individual licensing and free circulation and use of High Definition Ground Based Synthetic Aperture Radar (HD-GBSAR)".
- [i.5] [ETSI EN 300 440 \(V2.2.1\)](#): "Short Range Devices (SRD); Radio equipment to be used in the 1 GHz to 40 GHz frequency range; Harmonised Standard for access to radio spectrum".
- [i.6] [ERC Recommendation 74-01](#): "Unwanted emissions in the spurious domain".
- [i.7] [ERC Report 111](#): "Compatibility Studies between Ground Based Synthetic Aperture Radar (GBSAR) and existing services in the range 17.1 GHz to 17.3 GHz".
- [i.8] [ERC Report 25](#): "The European Table of Frequency Allocations and Applications in the frequency range 8.3 kHz to 3000 GHz (ECA Table)".

- [i.9] Recommendation ITU-R K.136 (11/2022): "Electromagnetic compatibility requirements for radio telecommunication equipment".
- [i.10] [ECC Report 315 \(05/2020\)](#): "Feasibility of spectrum sharing between High-Definition Ground Based Synthetic Aperture Radar (HD-GBSAR) application using 1 GHz bandwidth within 74-81 GHz and existing services and applications".
- [i.11] [ECC Report 166 \(05/2011\)](#): "Coexistence between zenith-pointing meteorological radars at 24 GHz and 35 GHz and other systems in other radio services".
- [i.12] Loew, S., Gschwind, S., Gischig, V. et al.: "Monitoring and early warning of the 2012 Preonzo catastrophic rockslide failure. Landslides" 14, 141-154, 2017.
- [i.13] A. Serrano-Juan, E. Vázquez-Suñe, O. Monserrat, M. Crosetto, C. et al.: "Gb-SAR interferometry displacement measurements during dewatering in construction works. Case of La Sagrera railway station in Barcelona, Spain", Engineering Geology 205, 2016.
- [i.14] ETSI EN 303 661 (V1.1.1): "Short Range Devices (SRD); Ground Based Synthetic Aperture Radar (GBSAR) in the frequency range 17,1 GHz to 17,3 GHz and High Definition Ground Based Synthetic Aperture Radar (HD-GBSAR) in the frequency range 76 GHz to 77 GHz; Harmonised Standard for access to radio spectrum".
- [i.15] Market Size and Trend: "[Dam Monitoring Market Overview](#)", 2025.
- [i.16] Dataintel: "[Landslide Monitoring System Market](#)", 2025.
- [i.17] Agenzia Spaziale Italiana: "[COSMO-SkyMed Seconda Generazione: System and Products Description](#)", 2021, table 8, page 22.
- [i.18] Recommendation ITU-R P.676-9 (2012): "Attenuation by atmospheric gases".
- [i.19] Recommendation ITU-R P.838-3 (2025): "Specific attenuation model for rain for use in prediction methods".
- [i.20] [ITU Radio Regulation 2024](#).
- [i.21] Peng Wang, Cheng Xing, et al.: "Microdeformation monitoring by permanent scatterer GB-SAR interferometry based on image subset series with short temporal baselines: The Geheyan Dam case study", Elsevier, Measurement 184 (2021).
- [i.22] Luzi, G., Monserrat, O., Crosetto, M., et al.: "Ground-Based SAR Interferometry Applied to Landslide Monitoring in Mountainous Areas", International Conference "Mountain Risks: Bringing Science to Society", 24-26 November, 2010.
- [i.23] M. Rebmeister, et al.: "Ground-based InSAR and GNSS integration for enhanced dam monitoring", Applied Geomatics 17 (2025).
- [i.24] Antonello, G., Casagli, N., Farina, P., et al.: "Ground-Based SAR Interferometry for Monitoring Mass Movements", Landslides, 1(1), 21-28 (2004).

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## 3 Definition of terms, symbols and abbreviations

### 3.1 Terms

For the purposes of the present document, the following terms apply:

**Ground Based Synthetic Aperture Radar (GBSAR):** Short Range Device application intended for safety critical deformation monitoring of natural as well as man-made objects and structures operating in the frequency range 17,1 GHz to 17,3 GHz

**High Definition evolutionary version of GBSAR (HD-GBSAR):** High Definition evolutionary version of GBSAR operating in the frequency range 76 GHz to 77 GHz

**Multiple Input Multiple Output GBSAR (MIMO-GBSAR):** Multiple Input Multiple Output GBSAR operating in the frequency range 33,4 GHz to 35,2 GHz

**professional equipment:** equipment for use in trades, professions, or industries which is not intended for sale to the general public

NOTE: See Recommendation ITU-R K.136 [i.9].

**professional installation:** installation and maintenance of equipment by professional(s) with sufficient knowledge to employ Electromagnetic Compatibility (EMC) mitigation measures according to the installation instructions

NOTE: See Recommendation ITU-R K.136 [i.9].

**target's surface point illumination time:** time interval during which a given point on target surface is being illuminated by the HD-GBSAR transmitting antenna, while it is rotating on the horizontal plane

NOTE: The illumination time depends on the antenna horizontal half power beam width and the antenna horizontal rotation speed.

## 3.2 Symbols

For the purposes of the present document, the following symbols apply:

dBi	antenna gain in decibels relative to isotropic radiator
dBm	transmit power in decibels relative to mW
C/I	carrier to interference ratio
Gbps	Gigabits per second

## 3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

EESS	Earth Exploration Satellite Services
EIRP	Effective Isotropically Radiated Power
ERC	European Radio communication Committee
EUT	Equipment Under Test
FWA	Fixed Wireless Access
GBSAR	Ground Based Synthetic Aperture Radar
HD	High Definition
LFMCW	Linear Frequency Modulated Continuous Wave
MIMO	Multiple Input Multiple Output
NESZ	Noise-Equivalent-Sigma-Zero
OOB	Out-Of-Band
RF	Radio Frequency
SAR	Synthetic Aperture Radar
SNR	Signal-to-Noise Ratio
SRD	Short Range Device
TRP	Total Radiated Power
TX	Transmitter

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## 4 Comments on the System Reference document

No comments have been received from other ETSI groups.

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## 5 Presentation of MIMO-GBSAR system

The first-generation of Ground Based Synthetic Aperture Radars (GBSAR) operating in the band 17,1 GHz to 17,3 GHz [i.1] and [i.2] was introduced in the market in 2007. It utilized channel bandwidth of 100 MHz to 200 MHz which allowed it achieving spatial resolution of 0,75 m with displacement measurement accuracy of 1 mm.

In order to overcome some of the limitation of GBSAR and extend the applicability of the technology to more potential applications that require an easily transportable and compact system providing a finer resolution, in it was introduced into the market the second generation of GBSAR, named HD-GBSAR, operating in the band 76,0 GHz to 77,0 GHz [i.3] was introduced in 2021 [i.4].

GBSAR and HD-GBSAR technologies have been widely adopted across Europe and globally for safety-critical deformation monitoring applications. These include landslide monitoring, glacier monitoring, dam monitoring, tunnel monitoring, building monitoring and in general, and other scenarios requiring real-time deformation analysis. The usage of GBSAR is a standard practice in open pit mine operations, as safety tool capable to provide early warning in case of deformation indicative of impending slope failure, improving the safety standard of people working in mining environment.

The high resolution and compact design of HD-GBSAR have enabled its use in a broader range of applications compared to traditional GBSAR systems. However, its operating frequency limits the maximum measurable distance to approximately 800 meters, which restricts its applicability in certain scenarios. To overcome this limitation, a third-generation GBSAR system has been developed, operating at frequencies slightly above 30 GHz. This advancement preserves the system's compactness and portability while extending its effective range to up to 2 km. The increased range is made possible by reduced propagation losses, particularly in rainy conditions, and minimized atmospheric effects, which are critical factors influencing displacement measurement accuracy.

The availability of compact and transportable GBSAR systems with a range of up to 2 km is crucial for emergency monitoring applications. These scenarios often require access to remote or difficult-to-reach areas while maintaining a safe distance from hazardous zones. Similar considerations apply to landslide monitoring in mountainous regions, where road access is limited or non-existent.

The new generation of GBSAR systems is referred to as MIMO-GBSAR. In addition to operating within a different frequency range, this system performs SAR acquisition through electronic scanning, utilizing an array of multiple transmitting and receiving antennas. The MIMO technique offers significant improvements over conventional GBSAR systems, including faster data acquisition allowing the monitoring of dynamic events like vibrations.

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## 6 Market information

The following main use scenarios are intended for the MIMO-GBSAR, enabled by the compact portable size and increased measurement range and fast acquisition time. For further details see clause A.1:

- **Dams and large structure monitoring**  
MIMO-GBSAR can be employed to monitor the deformation of civil structures, such as dams, either to assess their structural stability or to detect instabilities that may be triggered due to external factors, such as seismic activity or nearby construction.
- **Landslide Monitoring**  
Like its predecessor, MIMO-GBSAR can be used to monitor landslide displacements and provide early warnings in the presence of precursory failure movements. Its key advantage lies in its portability, allowing deployment in remote or hard-to-reach areas. This is particularly valuable in mountainous regions, where transporting the radar system may require manual carrying or even helicopter assistance. Additionally, MIMO-GBSAR can be installed at a safe distance from the hazardous zone, reducing the risk to equipment and personnel while still ensuring effective monitoring.
- **Quarry monitoring**  
Monitoring superficial ground deformation in active quarries is essential for providing early warnings in the presence of precursory failure movements. The extended range of MIMO-GBSAR significantly broadens its applicability in this context compared to HD-GBSAR, enabling effective surveillance over larger areas and from safer, more distant observation points.

- Construction site  
MIMO-GBSAR can be effectively used to monitor ground instabilities caused by the construction of new roads or railways, providing real-time displacement measurements to issue timely alerts. This capability helps reduce risks for workers and machinery operating within the construction site.

In all the use cases mentioned, the small size and light weight of the MIMO-GBSAR system, along with its longer operating range, significantly enhances the applicability of this highly valuable and life-saving technology in a broader array of environments and situations.

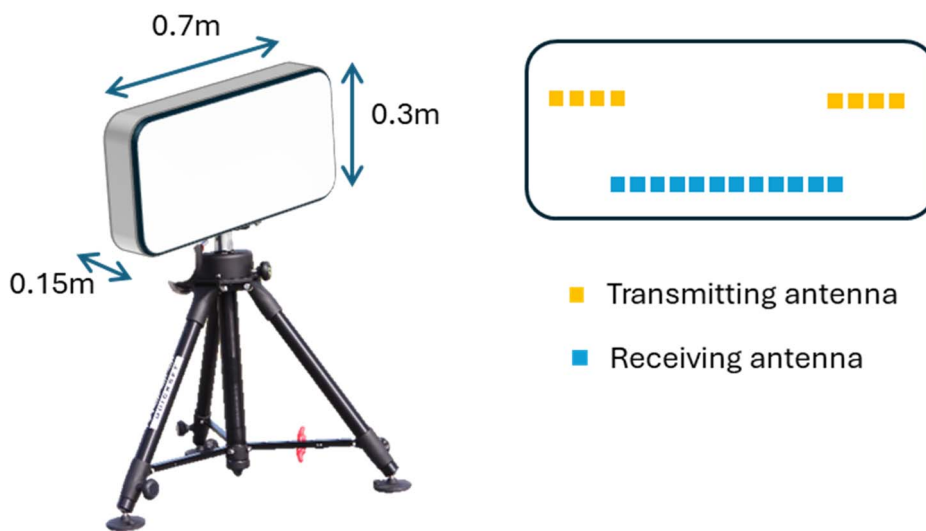
Detailed estimates of different segments of MIMO-GBSAR market are outlined in clause A.2.

## 7 Technical information

### 7.1 Detailed technical description

The MIMO-GBSAR system, as depicted in Figure 1, is an advanced interferometric radar designed for real-time monitoring of surface deformations across wide areas with sub-millimetre accuracy. Technically, it consists of a compact module integrating multiple transmitting and receiving antennas. This module handles both radar data acquisition and onboard processing to generate precise displacement measurements.

Measurements can be visualized directly in the field by connecting a tablet or computer to the MIMO-GBSAR system. For long-term monitoring applications, data can also be automatically transmitted to a remote server via the internet. The system is versatile in terms of power supply, operating either from mains electricity or a battery pack.



**Figure 1: MIMO-GBSAR system composition**

Signal transmission in the MIMO-GBSAR system is time-multiplexed, meaning that only one antenna transmits at any given moment, while all receiving antennas simultaneously capture the backscattered signals from the observed scenario. This configuration enables the formation of a synthetic aperture, created by combining all transmit-receive antenna pairs. The length of this synthetic aperture directly determines the system's horizontal resolution.

To achieve horizontal resolution comparable to that of the HD-GBSAR system, the physical length of the MIMO-GBSAR module is approximately 0,7 meters. In contrast, the range resolution is governed by the bandwidth of the transmitted signal. To match HD-GBSAR performance, a bandwidth of 1 GHz is required.

The system is capable of completing a full acquisition in less than one minute, delivering a displacement heat map of the monitored area. This displacement data is crucial for early warning applications, particularly in scenarios where the magnitude and rate of deformation may indicate potentially hazardous instabilities.

A more detailed technical explanation of the MIMO-GBSAR operating principles, with emphasis on the newly proposed frequency range, is provided in Annex B.

## 7.2 Technical parameters and implications on spectrum

### 7.2.1 General

Table 1 contains the summary of main technical parameters of MIMO-GBSAR systems in the frequency range between 33,4 GHz and 35,2 GHz.

**Table 1: MIMO-GBSAR technical specifications, 33,4 GHz to 35,2 GHz**

Parameter	Value
Modulation	LFMCW
Central frequency	Tuneable between 33 GHz to 36 GHz
Emissions Bandwidth	1 GHz
Sweep Duration	1 ms
Duty Cycle per 1 GHz	50 %
Duty Cycle per 50 MHz	2,5 %
Power at the antenna connector	27 dBm (-3 dBW)
Maximum Equivalent Isotropic Radiated Power (EIRP)	37 dBm (7 dBW)
Maximum mean Spectral Power Density e.i.r.p.	7 dBm/MHz (-23 dBW/MHz)
Total Radiated Power spectral density ( $TRP_{sd}$ )	-3 dBm/MHz
Antenna Type	Patch antennas
Antenna Gain	10 dBi
Antenna Half Power Beamwidth	Horizontal 120° Vertical 40°
Antenna Polarization	Linear Vertical
Weight	10 kg
Size (Height × Depth × Width)	700 mm × 300 mm × 150 mm

### 7.2.2 Status of technical parameters

#### 7.2.2.1 Current ITU and European Common Allocations

Annex C of the present document contains the analysis of current frequency allocations in the target frequency range between 33,4 GHz to 35,2 GHz to the up-to-date relevant provisions of Article 5 of ITU Radio Regulations [i.20] and those of the European Common Frequency Allocations Table defined in ERC Report 25 [i.8].

Considering the information on current spectrum allocations and its analysis provided in Annex C, it is conceived that the most promising candidate band for MIMO-GBSAR operations may be found in the mid part of the target range, i.e. 33,4 GHz to 35,2 GHz, which is allocation to the Radiolocation services are primary service.

#### 7.2.2.2 Sharing and compatibility studies already available

The original sharing and compatibility study for first-generation GBSAR technology was developed by CEPT and provided in ECC Report 111 (2011) [i.7]. However, that study considered the operation of 200 MHz bandwidth GBSAR application in the band 17,1 GHz 17,3 GHz. ECC Report 315 [i.10] addressed the second-generation HD-GBSAR technology addresses the proposed use of 1 GHz bandwidth within the 74-81 GHz range. In these reports an overview over the already deployed GBSAR systems and applications can be found.

In 2011 a sharing study covering the use of Cloud Radars (Coexistence Between Zenith-Pointing Meteorological Radars at 24 GHz and 35 GHz and Systems in other Radio Services) has been published as ECC Report 166 [i.11]. This report concluded that the operation of cloud radars in the band 33,4 GHz to 35,2 GHz is compatible with other services in the band and in adjacent bands. In order to protect the operation of EESS (active) systems in the band 35,5 GHz to 36,0 GHz a maximum mean e.i.r.p. out-of-band limit of 6,2 dBW/MHz (36,2 dBm/MHz) has been proposed. To protect the EESS (passive) services in the band 36,0 GHz to 37,0 GHz a maximum mean e.i.r.p. out-of-band limit of -2 dBW/MHz (28 dBm/MHz) is specified.

The provisional spectrum sharing study to verify the feasibility of deploying MIMO-GBSAR in the frequency band 33,4 GHz to 35,2 GHz had been carried out within ETSI ERM as part of developing the present document and is provided in Annex D.

### 7.2.2.3 Sharing and compatibility issues still to be considered

The band 33,4 GHz to 35,2 GHz is allocated to the Radiolocation services as the only primary allocation. The only known applications in the band are military radiolocation applications [i.8]. Technical details of these applications are not yet available.

## 7.2.3 Transmitter parameters

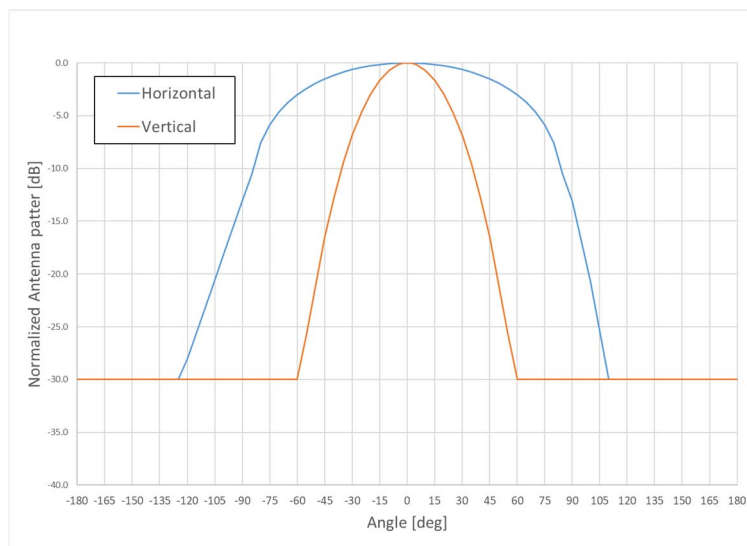
### 7.2.3.1 Transmitter Output Power / Radiated Power

The maximum mean e.i.r.p. value is 37,0 dBm (7 dBW).

The maximum mean Power Spectral Density is 7 dBm/MHz (-23 dBW/MHz) across the maximum operating bandwidth of 1 GHz in frequency band 33,4 GHz to 35,2 GHz.

### 7.2.3.2 Antenna Characteristics

Typical MIMO-GBSAR antenna radiation patterns is depicted in Figure 2. The antenna gain is 10 dBi and the Half Power Beamwidth is approximately 120° in azimuth and 40° in elevation.



**Figure 2: MIMO-GBSAR antenna radiation pattern**

### 7.2.3.3 Total Radiated Power spectral density ( $TRP_{sd}$ )

The total radiated power spectral density represents the average interference potential around the operational device. This parameter is directly related to the antenna characteristics.

Based on the available antenna radiation pattern in Figure 2 the  $TRP_{sd}$  value will be -3 dBm/MHz or below.

### 7.2.3.4 Operating Frequency

Any 1 GHz wide portion within the range 33,4 GHz to 35,2 GHz is a possible allocation. This 1 GHz wide band would be used as a single channel for transmitting Linear Frequency Modulated Continuous Wave signal, as explained in Annex B.

### 7.2.3.5 Bandwidth

Necessary bandwidth is 1 GHz, typical maximum occupied bandwidth is 980 MHz.

### 7.2.3.6 Unwanted emissions

The emission limits in the out-of-band domain are given in ETSI EN 303 661 [i.14] for the GBSAR systems. The emission mask is depicted in Figure 3.

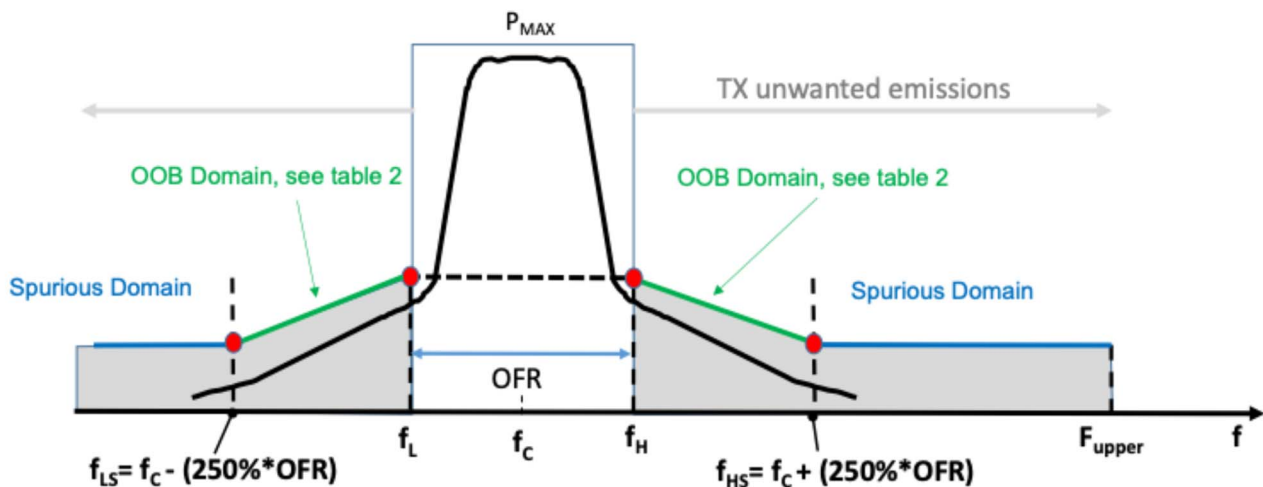


Figure 3: TX unwanted emissions within the OOB and Spurious Domain for GBSAR EUT

The proposed limits are given in Table 2.

Table 2: MIMO-GBSAR emission mask in the OOB domain

Frequency range	Emission limits (EL) [dBm] (note 1)	Measurement bandwidth
$f_{LS} \leq f < f_L$ (note 2)	$EL = \left( \frac{P_{MAX} + 10}{f_L - f_{LS}} \right) \times (f - f_{LS}) - 30$	1 MHz
$f_L$	$P_{MAX} - 20$	1 MHz
$f_H$	$P_{MAX} - 20$	1 MHz
$f_H < f \leq f_{HS}$ (note 2)	$EL = \left( \frac{P_{MAX} + 10}{f_{HS} - f_H} \right) \times (f_{HS} - f) - 30$	1 MHz

NOTE 1:  $P_{MAX}$  (dBm) is the maximum mean e.i.r.p. as measured in ETSI EN 303 661 [i.14], clause 4.3.2.  
 NOTE 2:  $f_L/f_H$  are the lowest/highest frequency of the operating frequency range as measured in ETSI EN 303 661 [i.14], clause 4.3.1.

Where  $f$  is the frequency of the spurious domain emission while  $F_{UPPER}$  is defined as the 2<sup>nd</sup> harmonic of the fundamental frequency (as defined in CEPT/ERC/REC 74-01 [i.6]).

To protect the operation of EESS (active) in the band 35,5 GHz to 36,0 GHz and EESS (passive) in the band 36,0 GHz to 37,0 GHz no specific out-of-band limits for MIMO-GBSAR systems are necessary. The in-band limits are already significantly below the protection limits calculated in ECC Report 166 [i.11]. The proposed limits for the mean spectral density (e.i.r.p.) in the out-of-band domain are at least -13 dBm/MHz as depicted in Table 2.

### 7.2.4 Channel access parameters

During measurements, the MIMO-GBSAR continuously transmits and receives radar signals. However, these measurements occur periodically, with acquisition intervals longer than the actual measurement duration. From the perspective of other devices operating in the same frequency band, the MIMO-GBSAR signal appears with a duty cycle of 100 % during the measurement duration depicted Figure 4. During the measurement duration (blue rectangular in Figure 4) the signal sweeps through the operational bandwidth of up to 1 GHz leading to a duty cycle per 50 MHz frequency bin of 5 % (a victim system with 50 MHz bandwidth would only see 5 % of the time a potential interference).

The effective overall duty cycle DC is defined as the ratio of the measurement duration to the acquisition time interval which is in a typical range of 50 %. Combined with the duty cycle per frequency bin during the measurement period it leads to an effective duty cycle per 50 MHz frequency bin of 2,5 %.

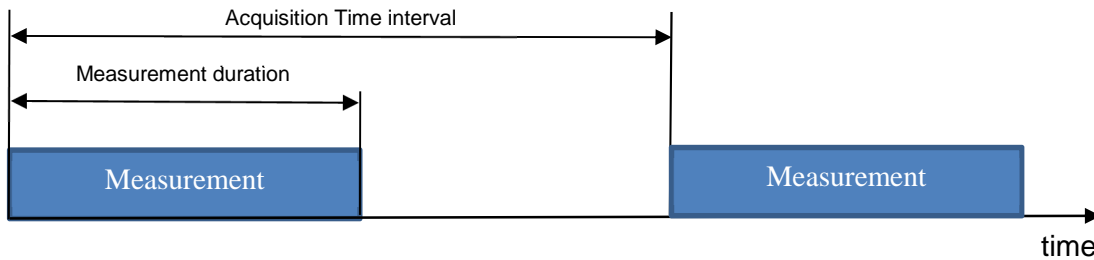


Figure 4: MIMO-GBSAR acquisition cycle

## 8 Radio spectrum request and justification

The analysis of the MIMO-GBSAR system description and its technical parameters and operational scenarios results in the following observations and conclusions that have implications for categorizing and regulating spectrum access for such systems:

- MIMO-GBSAR may be characterized as Ultra-Wide Band Short Range Device, belonging within the family of Radiodetermination applications;
- Accordingly, the MIMO-GBSAR should be considered within the family and framework of SRD regulations contained in Annex 6 of the CEPT ERC/REC 70-03 [i.2];
- The MIMO-GBSAR system, with its 1 GHz bandwidth, offers the same resolution and compact design as HD-GBSAR systems, while also providing a longer range and faster data acquisition. This makes it possible to detect early signs of ground movement, such as those that may occur before a collapse, even in situations where traditional GBSAR or HD-GBSAR systems cannot be used;
- MIMO-GBSAR remains a highly specialized professional application to be used only by trained professionals, like in the case of first-generation GBSAR and second-generation HD-GBSAR systems. The market forecasts provided in clause A.2 show that based on extrapolation of GBSAR and HD-GBSAR market trends it may be expected that the total market demand for MIMO-GBSAR would not exceed 300 units over 5 years for the entire European area;
- MIMO-GBSAR spectrum designation should be made for the entire operating band of 1 GHz without specifying channel bandwidth.

An alternative solution could be to operate the MIMO-GBSAR systems under the Radiolocation allocation in the band 33,4 GHz to 35,2 GHz. This solution has been chosen for the cloud radar operation in the 35 GHz band [i.11].

Clause 9 provides further details of regulatory analysis and considerations regarding spectrum designation for MIMO-GBSAR systems and recommends a specific action in that regard.

## 9 Regulations

### 9.1 Current regulations

The first-generation GBSAR [i.1] was recognized as Radio determination SRD application and was designated frequency band 17,1 GHz to 17,3 GHz in Annex 6 of ERC Recommendation 70-03 [i.2].

It was specified that GBSAR could operate without restrictions on channel bandwidth, i.e. utilizing up to entire 200 MHz of bandwidth in the 17 GHz range. The total power is limited to 26 dBm e.i.r.p. and it was mandated that the GBSAR using this band should employ Detect-And-Avoid interference mitigation technique as detailed in Annex E of ETSI EN 300 440 [i.5]. This mitigation technique is mandatory to minimize risk of interference from GBSAR to primary service radiolocation systems utilizing the subject frequency band of 17,1 GHz to 17,3 GHz.

In order to overcome some of the limitation of GBSAR and extend the applicability of the technology to more potential applications that require an easily transportable and compact system providing a finer resolution, in it was introduced into the market the second generation of GBSAR, named HD-GBSAR, operating in the band 76,0 GHz to 77,0 GHz [i.3] was introduced in 2021 [i.4].

The current regulations provide a sufficient and satisfactory regulatory conditions for deployment of first-generation and second-generation GBSAR equipment providing mm-range accuracy for displacement measurements.

However, they are not adequate to allow deployment of MIMO-GBSAR equipment described in clause 7.

## 9.2 Proposed regulation and justification

Matching of MIMO-GBSAR operational requirements vis-à-vis technological capabilities of suitable RF element base has directed the search of suitable operating band of at least 1 GHz to the range of 33,4 GHz to 35,2 GHz. Annex C of the present document contains the analysis of current frequency allocations in this target frequency range according to the up-to-date relevant provisions of Article 5 of ITU Radio Regulations [i.20] and those of the European Common Frequency Allocations Table defined in ERC Report 25 [i.8].

Specifically, it is proposed that regulatory designation of 1 GHz band in the 33,4 GHz to 35,2 GHz tuning range for MIMO-GBSAR may be done by making the following addition to Annex 6 "Radiodetermination applications" of ERC/REC 70-03 [i.2].

**Table 3: Proposed designation of MIMO-GBSAR band in the 33,4 GHz to 35,2 GHz in Annex 6 of ERC/REC 70-03 [i.2]**

#	Frequency Band	Power/Magnetic Field	Spectrum Access and Mitigation Requirements	Modulation/Maximum Occupied Bandwidth	ECC/ERC Deliverable	Notes
n	1 GHz in the 33,4 GHz to 35,2 GHz tuning range	37 dBm mean e.i.r.p.	No	Not specified		For Multiple Input Multiple Output Ground Based Synthetic Aperture Radar (MIMO-GBSAR)

Based on the analysis provided in Annex C, it is assumed that the band 33,4 GHz to 35,2 GHz might be the most promising band and thus the preferred candidate for locating 1 GHz operational band for MIMO-GBSAR.

Alternatively, MIMO-GBSAR systems could be operated under the Radiolocation Allocation in the band 33,4 GHz to 35,2 GHz, see cloud radar [i.11].

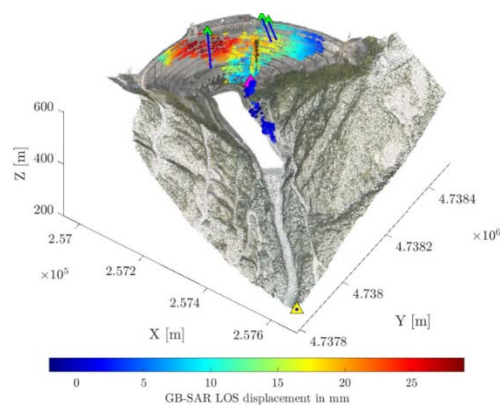
## Annex A: Detailed use case examples and market information

### A.1 Use Case Examples

#### A.1.1 Dam and large structure

MIMO-GBSAR systems can be effectively used to monitor the deformation of large civil structures, such as dams, to assess their structural stability or to detect changes induced by external factors like earthquakes or repair activities. GBSAR technology has already been applied in dam monitoring as presented in [i.21] and [i.22], although its use remains limited due to the challenging deployment requirements, primarily stemming from the system's large physical dimensions. Similarly, HD-GBSAR applications in dam monitoring are constrained to scenarios where the system can be positioned within 800 meters of the structure, limiting its practicality in many real-world cases.

Figure A.1 illustrates an example of displacement measurements obtained using GBSAR, superimposed on a 3D model of the dam as a coloured point cloud. Each colour represents the Line-of-Sight displacement measured over a specific time interval. For every measurement point, it is possible to visualize the temporal evolution of deformation and configure threshold values to trigger alarms, enabling early detection of potential structural damage. MIMO-GBSAR, like conventional GBSAR, provides similar results but with enhanced spatial resolution and greater deployment flexibility. In this case, the system was installed approximately 1 km from the dam and oriented directly toward the structure.

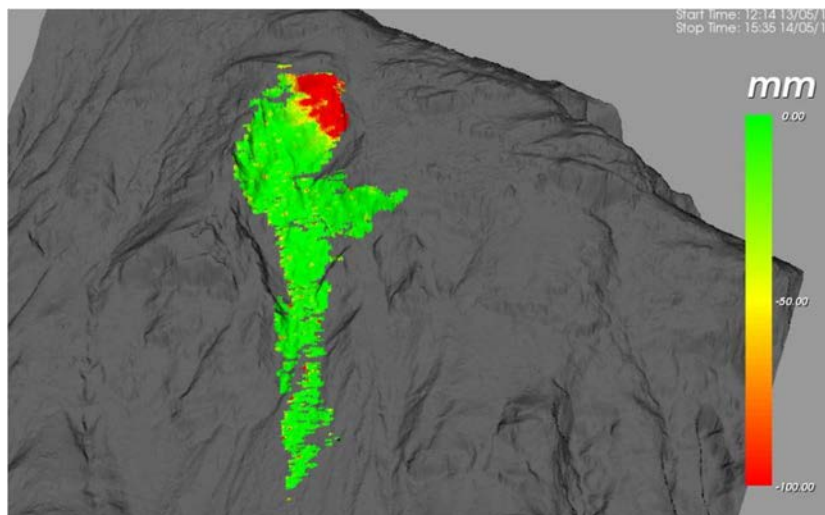


**Figure A.1: Examples of dam displacement measurement provided by GBSAR [i.23]**

In both examples presented above, the GBSAR system was positioned over 1 km from the dam. Its considerable physical size posed significant challenges for deployment and operation, particularly in constrained or remote environments. In such scenarios, the compact and highly portable design of the MIMO-GBSAR system offers clear advantages. Its reduced dimensions enable deployment in areas with limited access or space restrictions. Moreover, emergency monitoring situations, such as those triggered by sudden structural anomalies, often require rapid setup and deployment on safe area sufficiently away from the structure. This need is effectively addressed by the system's lightweight design (weighing less than 10 kg), which allows for quick installation and relocation, even by a single operator. The spatial resolution of MIMO-GBSAR (0,15 m) also plays a crucial role, as it enables detailed mapping of displacement patterns across the structure. This enhanced resolution supports a deeper understanding of the structural health, thereby improving the capability to identify potential issue and implements preventive maintenance actions.

## A.1.2 Landslide

GBSAR technology is widely adopted for landslide monitoring [i.24] and [i.22], enabling accurate detection of displacement patterns and providing early warnings when precursory failure movements occur. Figure A.2 illustrates an example from the 2012 Preonzo landslide [i.12], where GBSAR measurements were used to track slope movements in real time. The displacement data are visualized as a color-coded heat map, overlaid on a digital terrain model of the monitored area, representing cumulative displacements over a defined time interval. This monitoring approach allowed authorities to control and assess slope dynamics effectively, leading to the timely evacuation of the at-risk zone several days before the eventual collapse.



**Figure A.2: Examples of landslide displacement measurement provided by GBSAR at Preonzo [i.12]**

Similarly, MIMO-GBSAR can be employed for the same purpose, offering enhanced portability as its key advantage. This feature makes it particularly suitable for deployment in remote or hard-to-access areas, such as mountainous regions, where transporting the radar system may require manual carrying or even helicopter assistance, extending the applicability of interferometric radar technology to more cases. Furthermore, MIMO-GBSAR can be positioned at a safe distance from the hazardous zone, minimizing risk to both equipment and personnel while maintaining effective monitoring coverage.

## A.1.3 Construction Site

The high mobility and flexibility of MIMO-GBSAR make it particularly well-suited for dynamic environments such as new roads, railways, or tunnels construction sites. It enables continuous monitoring of slope or structural stability directly impacted by construction activities which may involve excavation or earthworks. In this context, MIMO-GBSAR can deliver real-time early warning based on displacement measurements, helping to mitigate risks for workers and machinery operating within the construction area.

Figure A.3 illustrates the application of GBSAR during the construction of the future La Sagrera railway station in Barcelona (Spain) [i.13]. In this project, GBSAR was employed to accurately quantify wall displacements induced by dewatering operations. The system proved essential for understanding structural deformation patterns and identifying vulnerable areas, supporting informed decision-making throughout the construction process.



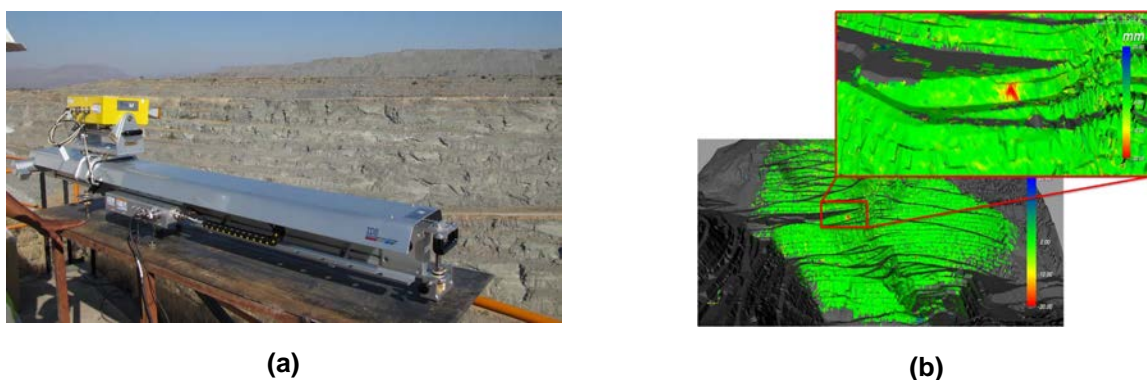
Figure A.3: Examples of GBSAR deployment in a construction site [i.13]

GBSAR technology is widely employed for real-time monitoring of slopes near highways, tunnels, and large-scale construction projects for the same purpose. However, the traditional systems present challenges due to their size, which complicates deployment and handling. Additionally, as construction progresses, frequent relocation may be required to monitor newly identified hazardous areas.

HD-GBSAR systems address the flexibility issue by offering higher mobility, but their limited range necessitates positioning within the construction site itself. This can interfere with ongoing activities and restrict the area that can be effectively monitored, reducing overall operational efficiency.

### A.1.4 Open pit mine and quarry

Open-pit mine slope stability monitoring represents the most common application of GBSAR and HD-GBSAR technology, thanks to their ability to deliver real-time, wide-area coverage with millimetre-level accuracy for detecting slope movements and enabling early warning of potential failures. Currently, GBSAR systems are primarily deployed to monitor the main pit slopes from permanent or semi-permanent installations, ensuring continuous observation of critical areas.



NOTE: (a) Deployment, (b) Displacement heat map.

Figure A.4: Example of GBSAR used in open-pit mine

The high transportability and extended range of MIMO-GBSAR significantly broaden its applicability in open-pit mining operations. Unlike conventional GBSAR and HD-GBSAR systems, which face limitations in flexibility and coverage, MIMO-GBSAR can effectively monitor secondary assets such as leaching piles, waste dumps, and underground mine tunnel portals (Figure A.5). These areas are often difficult to cover with existing solutions due to range constraints or frequent repositioning requirements. By enabling reliable monitoring of these critical zones, MIMO-GBSAR contributes to further improving safety standards in open-pit mining operations.

Similar advantages apply to active quarry environments, where the monitored scenario is highly dynamic and evolves rapidly. In such cases, MIMO-GBSAR's mobility enables quick redeployment to new vantage points, ensuring continuous monitoring despite frequent changes in excavation geometry and operational layout.



Figure A.5: (a) Leaching pile, (b) Waste dump, (c) Underground mining tunnel portal

## A.2 Market Information

### A.2.0 General

This clause provides a detailed analysis of the MIMO-GBSAR market size and value, segmented into four key market areas identified by the primary use cases outlined in clause A.1. The market assessment is based on real-world deployment experiences and historical data from first- and second-generation GBSAR deployments within similar segments. Future projections are derived from publicly available market research, providing a forward-looking perspective on potential growth and adoption trends.

Table A.1 and Table A.2 summarize the estimated market size and value of MIMO-GBSAR systems at both global and European levels, with a breakdown across the key market segments. The following sections detail the underlying assumptions, rationale, and calculation methodologies used to derive these estimates.

Table A.1: Estimated global MIMO-GBSAR market size and value

Market segment	Global market estimates for 2028-2032	
	Number of Units	Value
Dam and large structure (see clause A.2.1)	80	8,0 M€
Landslide monitoring (see clause A.2.2)	250	25 M€
Construction site (see clause A.1.3)	250	25 M€
Quarry and open pit mine (see clause A.2.3)	600	60 M€
<b>Totals</b>	<b>1 180</b>	<b>118,0 M€</b>

Table A.2: Estimated European MIMO-GBSAR market size and value

Market segment	European market estimates for 2028-2032	
	Number of Units	Value
Dam and large structure (see clause A.2.1)	32	2,0 M€
Landslide monitoring (see clause A.2.2)	100	4 M€
Construction site (see clause A.1.3)	100	5 M€
Quarry and open pit mine (see clause A.2.3)	60	6 M€
<b>Totals</b>	<b>292</b>	<b>29,2 M€</b>

## A.2.1 Dam and large structure monitoring

Global dam monitoring market size is projected to grow from **\$1,2 billion** in 2024 to **\$2,4 billion** by 2032, reflecting an annual growth rate (CAGR) of around **9,5 %**. The primary factors contributing to this growth include the integration of advanced monitoring technologies, increased government regulations to ensure dam safety, and the growing awareness of environmental sustainability. As aging infrastructure continues to pose challenges, there is an urgent need for reliable monitoring solutions to prevent potential disasters (source: Market Size and Trend [i.15]).

The first-generation GBSAR systems achieved limited market penetration in the dam monitoring segment. For example, a European manufacturer reports approximately 40 units sold for this application between 2007 and 2025, with the current global installed base estimated at around 80 units. This restricted adoption was primarily due to the complexity of deployment and the large size of the equipment, which made periodic monitoring of multiple dams with a single device impractical, confining usage mainly to permanent installations. In addition, HD-GBSAR systems, despite improved portability, were constrained by their 800 m range capability, significantly limiting the number of dams that could be effectively monitored.

MIMO-GBSAR is aimed to address the above-mentioned limitations, in order to gain a more significant dam monitoring market share. The forecasted MIMO-GBSAR market size and volume for dam monitoring application is reported in Table A.3 and is based on the following assumptions:

- About 10 MIMO-GBSAR units sold in 2028 and a constant growth rate of 20 % in the forecasted period;
- An average cost unit of 100 k€
- European market share remaining at approx. 40 % of the global market.

**Table A.3: Estimated MIMO-GBSAR market size and value for Dam monitoring segment**

	<b>Global market 2028-2032</b>	<b>European market 2028-2032</b>
Value	8,0 M€	3,0 M€
Number of units	80	32

## A.2.2 Landslide monitoring

The global landslide monitoring system market size reached USD 1,24 billion in 2024, reflecting robust adoption across diverse sectors. The market is poised to grow at a promising CAGR of 8,7 % from 2025 to 2033, with the total market value expected to reach USD 2,73 billion by 2033. This dynamic growth is primarily driven by increasing awareness of natural disaster risks, rapid urbanization in vulnerable regions, and the integration of advanced technologies for real-time monitoring and early warning systems (source: Dataintelco [i.16]).

The current radar-based landslide monitoring market is estimated at approximately 100 units per year, with an annual growth rate of 10 %, aligned with the overall global landslide monitoring systems market. The introduction of MIMO-GBSAR is expected to increase this market by at least 40 %, corresponding to an additional 40 units per year, while maintaining the same CAGR of around 10 %. Table A.4 presents the projected MIMO-GBSAR market size based on these assumptions and an average unit price of 100 k€. The European market accounts for around 40 % of the global market.

**Table A.4: Estimated MIMO-GBSAR market size and value for Landslide monitoring segment**

	<b>Global market 2028-2032</b>	<b>European market 2028-2032</b>
Value	25 M€	10 M€
Number of units	250	100

## A.2.3 Open pit mine and quarry

GBSAR technology has been extensively deployed in large and medium-sized open-pit mining operations worldwide, playing a fundamental role in improving safety standards over the past two decades. The overall global market is estimated at approximately 3 000 radar units installed at around 600 sites.

MIMO-GBSAR is expected to further expand radar adoption by addressing secondary monitoring applications within open-pit mines and increasing penetration in the quarry segment, where higher deployment flexibility is critical. The estimated market size for MIMO-GBSAR, as shown in Table A.5, is based on the following assumptions:

- 50 % of sites currently using radar for primary slope monitoring will adopt the new technology for secondary applications within five years, with an average of two MIMO-GBSAR units per site.
- An average unit price of 100 k€
- A European market share of approximately 10 % of the global market.

**Table A.5: Estimated size and value of MIMO-GBSAR market for quarry monitoring**

	<b>Global market 2028-2032</b>	<b>European market 2028-2032</b>
Value	60 M€	6 M€
Number of units	600	60

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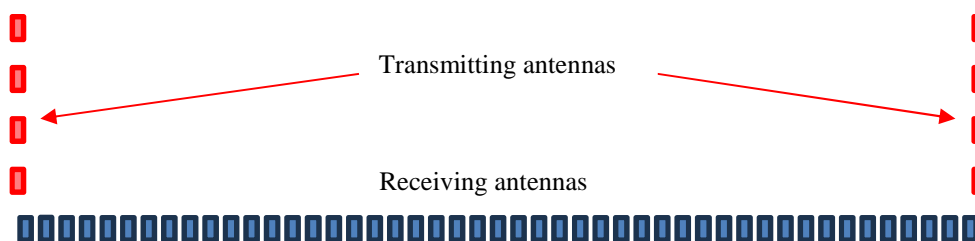
## A.3 System deployment and activity factor considerations

For all the applications mentioned in clause A.1 the use of MIMO-GBSAR is used for continuous or for time-discreet monitoring sessions: in the first case the system is permanently installed in front of the area to be monitored (dam, landslide, slope), while in the second case it will be used as a nomadic system, used for performing several different surveys in different time-period. In the case of a time-discreet nomadic use, one survey would usually last for about 1 to 2 weeks with a time repetition interval of some months. In case of construction site, the relocation of the system could be more frequent, and the average duration of the monitoring activity of the same area will rarely exceed 2 weeks. During the monitoring phase the activity factor is around 25 %, as MIMO-GBSAR will perform an acquisition in 30 seconds and repeat the acquisition every 2 minutes, as the main purpose is to monitor slow displacement trend.

## Annex B: Technical information on MIMO-GBSAR signals and operation

### B.1 Technical Fundamentals

The MIMO-GBSAR transceiver emits a Linear Frequency Modulated Continuous Wave (LFMCW) signal through an array of patch antennas (see Figure B.1) and receives the signal backscattered from the observed object/landscape with similar array of patch antennas.

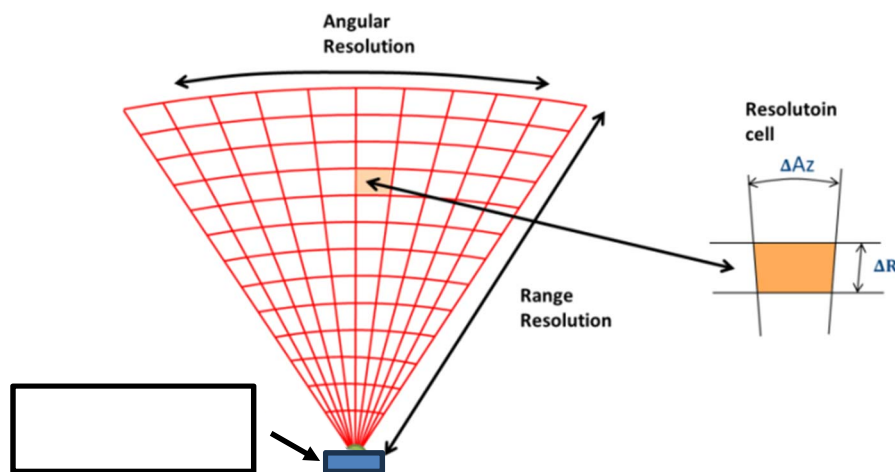


**Figure B.1: MIMO-GBSAR antenna array**

The radar signal is a saw tooth wave in frequency sweeping a bandwidth of 1 GHz tuneable between 33 GHz and 36 GHz.

The RF signal is transmitted by one of antenna patches at a time and received simultaneously by a subset of the receiving patches. Compared to first and second generation GBSAR, this technique allows the acquisition of an array of channels with no mechanical movement of the equipment hence the whole scene can be constantly monitored (compared to the circularly scanned HD-GBSAR) and re measured at a very fast rate ( $< 1$  s compared to 30 s of GBSAR and HD-GBSAR) thus allowing much better separability of fast moving targets (e.g. vehicles, people, machinery) and the much slower movement of soil.

MIMO-GBSAR provides a bi-dimensional image of the monitored scenario by the very same imaging principle of mechanically linearly scanned GBSAR (see Figure B.2).



**Figure B.2: MIMO-GBSAR spatial resolution (top view)**

The range resolution  $\Delta R$  is determined by the bandwidth of the emitted signal ( $\Delta R = c/2B$ ) and is 0,15 m, whereas the angular resolution  $\Delta Az$  is around 7 mrad assuming a horizontal dimension of the array of dimension of 0,64 m.

The combination of range and angular resolution allows the creation of a bi-dimensional image (see Figure B.2), where each resolution cell is a measurement point providing a real-time displacement information with sub-millimetre accuracy thanks to the interferometric technique.

## B.2 Choice of the Frequency Range

This clause will analyse the choice of the frequency range 33,2 GHz to 35,4 GHz for the third-generation MIMO-GBSAR application described in the present document.

To this end a comparison among a MIMO solution implemented at 17 GHz, 34 GHz or 77 GHz having the same desired application requirements defined by Table B.1 will be performed.

**Table B.1: Typical operational requirements for MIMO-GBSAR**

Requirement	Value
Maximum range	2 000 m
Range resolution	0,4 m
Azimuth resolution	7 mrad
Total integration time (Time on Target)	30 s
Sensitivity (Noise Equivalent Sigma Zero)	-20 dBsqm/sqm
Resilience to rain precipitation	10 mm/hour
Portability (maximum size)	< 1 m

A sensitivity (NESZ) between -20 dBsqm/sqm to -25 dBsqm/sqm is a typical value for Earth observation SAR satellites [i.17]. These values are confirmed also in the domain of GBSAR by extensive experience on natural and open-pit mine scenarios at 10 GHz, 17 GHz and 77 GHz. In fact, comparative measurements confirm that:

- there is almost no difference of soil reflectivity in this range of frequencies;
- in this range of frequencies soil reflectivity varies between -4 dBsqm/sqm and 1 dBsqm/sqm (depending on soil type) for bare soil and 10 dB lower for vegetated areas.

To guarantee a typical sub-millimetre interferometric sensitivity of 0,1 mm a 20 dB Signal-to-Noise Ratio (SNR) which yields the -20 dBsqm/sqm is needed.

Based on these requirements, a solution at 17 GHz cannot jointly meet the portability / azimuth resolution requirements since the array should be at least 1,3 m long to guarantee 7 mrad resolution, nor range resolution since only a 200 MHz bandwidth is allowed for 17 GHz GBSAR (0,75 m resolution).

A 77 GHz solution would be feasible assuming no rain and a 30 dBm transmitter and an EIRP of 40 dBm which is permitted by the HD-GBSAR regulations. However, the 77 GHz solution would be able to withstand only a very slight rain (2 mm/h) while only a moderate rain (10 mm/h) would increase the atmospheric loss by 30 dB.

The following table shows the atmospheric loss for the 3 frequencies considered at different rain rates computed following Recommendations ITU-R P.676-9 [i.18] and P.838-3 [i.19].

**Table B.2: Atmospheric losses in dB at 2 000 m range for different frequencies and rain rates [i.18]**

		Frequency [GHz]		
		17	34	76
Rain rate [mm/h]	0	0,2	0,4	1,6
	2	0,8	2,5	7,9
	10	3	11	33
	30	9	33	96

While an increase of atmospheric loss of some 10 dB can be somehow tolerated accepting some reduction of performance of the system during such precipitation occurrences, a 30 dB increase would completely disrupt its operativity.

Since at 34 GHz the attenuation of 10 mm/h rain at 2 000 m range is 11 dB, this solution can meet all requirements assuming a transmitted power of 27 dBm with a maximum mean EIRP of 37 dBm and a Noise Figure of 8 dB.

Finally, it will be also mentioned that wavelength affects both the maximum measurable velocity and the impact of atmospheric effects on measurement accuracy. Both these effects reduce by a factor of 2,2 by reducing the frequency from 77 GHz to 34 GHz.

## Annex C: Relationship to the existing spectrum regulation

Based on technological requirements and capabilities, it was proposed that the range of 33,4 GHz to 35,2 GHz may provide a suitable candidate band to accommodate spectrum designation for proposed MIMO-GBSAR application. This annex reviews the current frequency allocations in this target frequency range with the objective of identifying the band(s) of at least 1 GHz width that could accommodate MIMO-GBSAR while minimizing potential regulatory and electro-magnetic compatibility impact on existing spectrum users.

Table C.1 lists the existing spectrum allocations and applications that are in major use in Europe according to the up-to-date relevant provisions of Article 5 of ITU Radio Regulations [i.20] and those of the European Common Frequency Allocations Table defined in ERC Report 25 [i.8].

**Table C.1: Spectrum allocations and major European uses  
in candidate frequency range 33,4 GHz to 35,2 GHz and adjacent bands**

Frequency band	Allocations	Main Applications
33,0 GHz to 33,4 GHz	FIXED 5.547A RADIONAVIGATION 5.547 5.547E	FWA, Fixed, Radiolocation (military)
33,4 GHz to 34,2 GHz	RADIOLOCATION 5.549	Radiolocation (military)
34,2 GHz to 34,7 GHz	RADIOLOCATION SPACE RESEARCH (deep space) (Earth-to-space) 5.549	Radiolocation (military)
34,7 GHz to 35,2 GHz	RADIOLOCATION SPACE RESEARCH 5.550 5.549	Radiolocation (military)
35,2 GHz to 35,5 GHz	METEOROLOGICAL AIDS RADIOLOCATION 5.549	Radiolocation (military)
35,5 GHz to 36,0 GHz	METEOROLOGICAL AIDS EARTH EXPLORATION-SATELLITE (active) RADIOLOCATION SPACE RESEARCH (active) 5.549 5.549A	EESS (active)
36,0 GHz to 37,0 GHz	EARTH EXPLORATION-SATELLITE (passive) FIXED MOBILE SPACE RESEARCH (passive) 5.149 5.550A	EESS (passive)

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## Annex D: Preliminary spectrum sharing feasibility analysis

### D.0 General

In this clause some preliminary sharing considerations are summarized.

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### D.1 In-band sharing feasibility between 33,4 GHz to 35,2 GHz

**Military Radiolocation application:** The proposed operational conditions including the proposed TX power levels of a MIMO-GBSAR system are in the range of or slightly below the typical levels of radiolocation devices in the band, see ECC Report 166 [i.11]. Thus, no specific in-band compatibility issues are assumed for the controlled operation of MIMO-GBSAR in the band.

In Germany a specific allocation for police enforcement radars is in place in the band 34,2 GHz to 34,5 GHz. Due to the nature of the use case (road monitoring and speed limit enforcement) no specific interference issues are envisaged towards these systems.

No other applications are known.

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### D.2 Out-of-band sharing feasibility below 33,4 GHz

Based on the allocation below 33,4 GHz (mainly fixed services) and the emission characteristics of the MIMO-GBSAR systems in the band 33,4 GHz to 35,2 GHz no compatibility issues are assumed under the condition that the MIMO-GBSAR systems comply with the proposed out-of-band limits of below -13 dBm/MHz.

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### D.3 Out-of-Band sharing feasibility with EESS in the band 35,2 GHz to 37,0 GHz

Based on the proposed out-of-band limits in the frequency band 35,2 GHz to 37,0 GHz of below -13 dBm/MHz mean e.i.r.p. and the results given in ECC Report 166 [i.11] full compatibility can be assumed.

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## Annex E: Bibliography

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- ETSI EN 302 217-4: "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 4: Antennas".
- [ECC Recommendation \(02\)05 \(03/2012\)](#): "Unwanted Emissions".

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## History

<b>Version</b>	<b>Date</b>	<b>Status</b>
V1.1.1	July 2026	Publication