

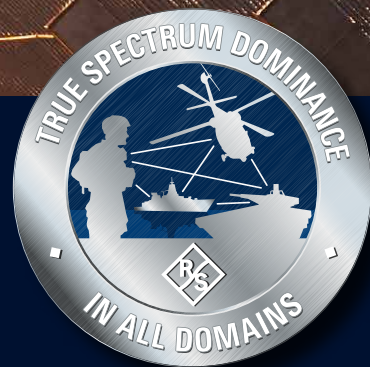
EXPERT PAPER

A Wall of RF Sensors

SECURING NATIONAL BORDERS IN THE DIGITAL AGE

ROHDE & SCHWARZ

Make ideas real



EXECUTIVE SUMMARY

Global security is at a critical juncture, with international borders exposed to an unparalleled array of threats. The converging forces of terrorism, transnational organized crime and large-scale migration are straining national capacities, testing the resilience of infrastructure and societal frameworks. Meanwhile, increased dependence on digital solutions has introduced new vulnerabilities, rendering borders increasingly susceptible to risks from cyber infiltration, sensitive data compromises and covert intelligence gathering.

Escalating geopolitical tensions underscore the need to fortify borders as a safeguard against hostile infiltration, espionage and aggressive maneuvers.

In this high-stakes environment, technology’s role in bolstering border security has reached a critical juncture. Conventional measures, such as perimeter fencing and ground patrols, have failed to keep pace with the sophistication and breadth of contemporary threats. But the digital era presents transformative opportunities. Cutting-edge sensor technologies have emerged as a linchpin of modern border protection frameworks. Radio frequency (RF) sensors stand out for their demonstrated significant potential to provide instant situation insights that boost the effectiveness of border management.

This expert paper explores how RF sensors can mitigate the complex challenges of border security in the digital landscape. Through detailed, comprehensive analysis, this publication offers insights and support for defense and security stakeholders in their efforts to reinforce border resilience and shield their communities from the evolving threat matrix.

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BORDER SECURITY CHALLENGES



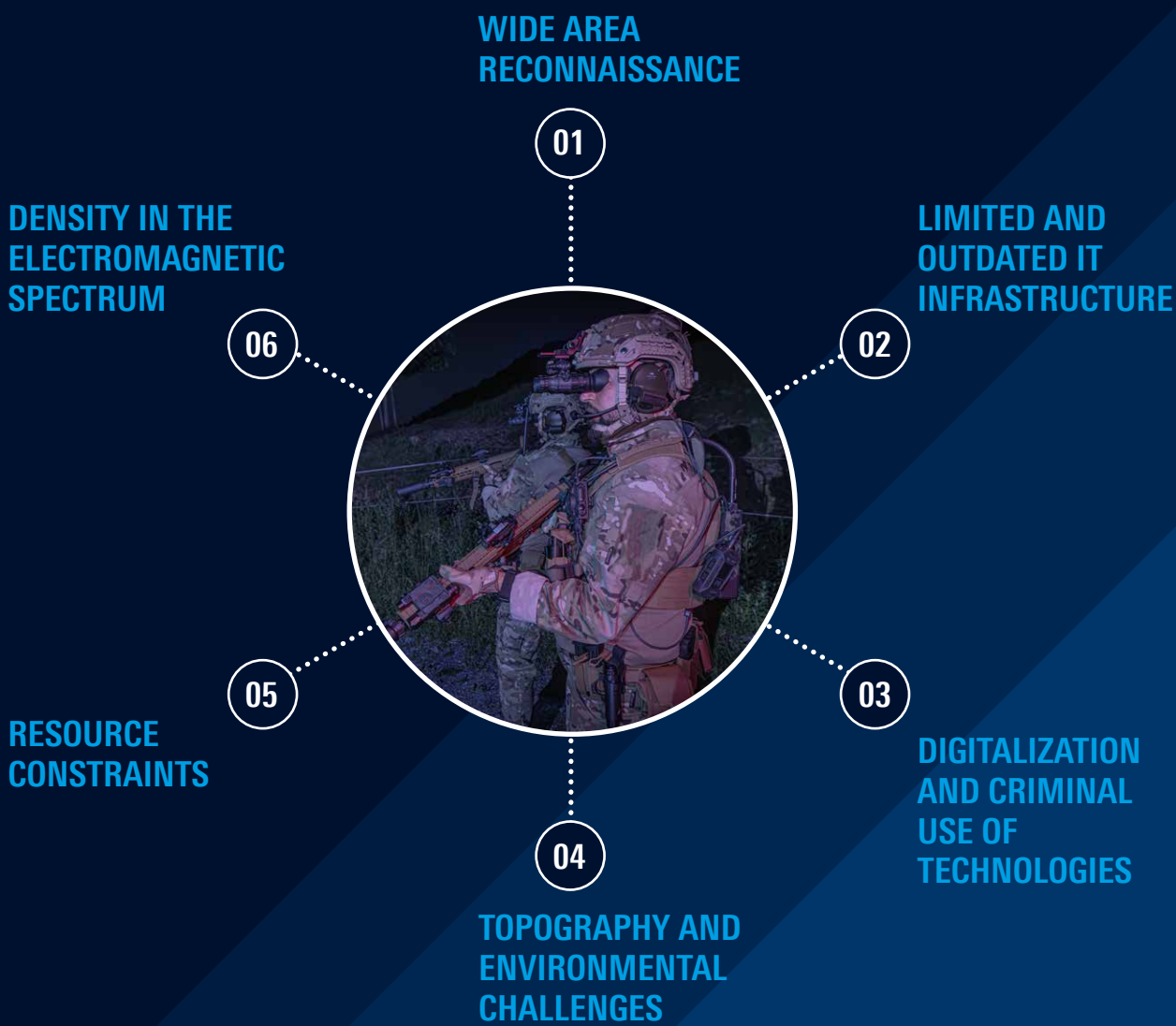
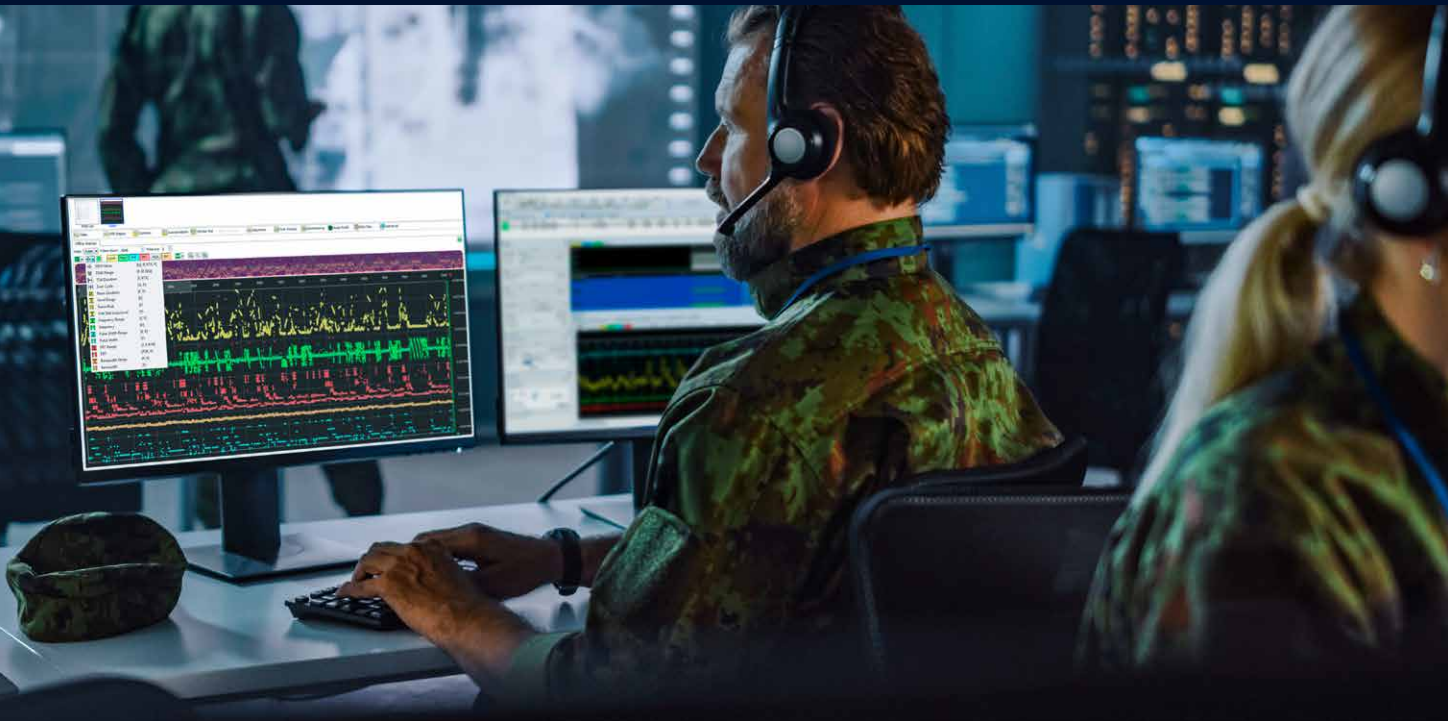
A country's borders are crucial to its national security, economy and sovereignty but pose significant security challenges due to their vast length, diverse geography, and the infrastructure required to monitor them effectively.

Today's threat landscape is more complex and dynamic than ever, with myriad emerging dangers posing a risk to both people and critical infrastructure. Current threats include piracy, terrorism, migrant smuggling, illicit hazardous materials trafficking and a broad spectrum of transnational criminal activities.

Traditionally, border security strategies have focused on terrestrial surveillance, monitoring the ground-level movement of individuals and associated vehicles engaged in smuggling, terrorism and illegal migration. However, the proliferation of drones has upended the threat paradigm, necessitating an evolution to three-dimensional surveillance capabilities.

Drones with extended ranges, heightened speeds, and enhanced payload capacities have become omnipresent. Criminal enterprises are agile adopters of disruptive technologies and leverage advanced communication platforms like satellite communications to coordinate their operations. Digital transformation is another force profoundly changing the threat landscape and has necessitated a rethink of border security in order to adapt and counter these novel challenges.

To effectively mitigate these emerging threats, it is crucial to deploy advanced technologies. These solutions must be capable of detecting a wide array of entities – vehicles, individuals, drones, and marine vessels – at considerable distances, even within dense signal environments and under extreme climatic conditions.



STRATEGIC INTEGRATION OF RADIO FREQUENCY (RF) SENSORS IS REVOLUTIONIZING BORDER SECURITY OPERATIONS, PROVIDING UNPARALLELED SITUATIONAL AWARENESS AND A DECISIVE EDGE IN COMBATING EMERGING THREATS.

BORDER SECURITY CHALLENGES

1 WIDE-AREA RECONNAISSANCE

Countries with extensive coastlines and land borders face significant security challenges. The sheer length and diversity of these borders are a vulnerability that can be exploited by malicious actors. Rapid technological advancements have increased the complexity of border security and made it easier for individuals or groups to engage in illicit activities. New technologies and wide-area reconnaissance capabilities that enable real-time monitoring can counter emerging threats to achieve the effective border security that is crucial for maintaining national sovereignty, economic stability and citizen safety.

2 LIMITED AND OUTDATED IT INFRASTRUCTURE

RF sensors hold huge potential for border security, but they generate vast amounts of data that can be an obstacle to their deployment in places with outdated or limited IT infrastructure that is ill equipped to handle the vast amounts of data the sensors generate. When properly integrated, however, RF sensors can be a transformative force, not only to enhance border surveillance but also as a catalyst to modernizing legacy IT systems to bridge the technology gap in border security operations.

3 DIGITALIZATION AND CRIMINAL USE OF TECHNOLOGY

Criminals leverage cutting-edge technologies to conceal and spread the reach of their illicit operations. They use satellite communications, encryption, the dark web and social media to their advantage. This digitalization of crime also poses a significant threat to border security. Commercial drones are increasingly used by criminal entities for smuggling, surveillance and attacks. Their small size, agility, and wide availability make them a growing border security challenge, complicating detection and tracking efforts.

4 TERRAIN AND CLIMATE HURDLES

Border security operations are severely impeded by the forces of nature and vast, inhospitable terrain. Harsh weather conditions, coupled with expansive sea borders and landscapes with dense forests and mountains add uncertainty to surveillance efforts. Extreme weather events further complicate patrolling operations, while the sheer scale of maritime environments creates vast blind spots. Collectively, these environmental and topographical challenges constrain border security agencies and defense forces in their efforts to craft effective responses to emerging threats.

5 LIMITED RESOURCES

Border security agencies and defense forces are frequently confronted with the dual hurdles of personnel shortages and tight budgets. The lack of manpower and finances also has knock-on effects when it comes to operational focus, technological capability and legal frameworks. Together, these constraints can significantly erode the effectiveness of border monitoring and response. To bridge this gap, a multifaceted strategy is essential, one that includes sustained investment with the funding required to meet operational needs, strategic alignment through focused planning to maximize resource utilization, and unified effort through interagency cooperation to leverage joint strengths and enhance overall border security posture.

6 DENSITY IN THE ELECTROMAGNETIC SPECTRUM

In the densely populated electromagnetic spectrum, consistently monitoring threats is a daunting task. Adversaries employ tactics to overwhelm and distract, creating a landscape that is deliberately cluttered with fake sensors, jamming devices and other signal-emitting decoys. This „signal overload“ strategy, observed in both drone deployments and jamming operations, aims to saturate the spectrum and make it difficult for operators to pick out genuine signals from false ones and discern friend from foe. Effective monitoring and detection rely on sophisticated technologies capable of filtering out this electromagnetic noise and pinpointing legitimate threats to ensure national security.

BORDER SECURITY CHALLENGES

Threats adapt, security evolves

Individuals or groups attempting to bypass border security are driven by a single goal: to evade detection and successfully smuggle or breach security.

To achieve this goal, they employ a range of tactics, techniques and procedures to conceal their activities, hide prohibited items and exploit system limitations to overwhelm or saturate security measures. Human intelligence (HUMINT) is a further tool they use to manipulate or deceive security personnel and employ technical countermeasures to disrupt or interfere with security systems.

These adversaries are adaptive, resourceful and always looking for vulnerabilities in security measures. They often possess in-depth knowledge of the very systems they aim to breach.

Adversary actions have resulted in continuous, dynamic threat-countermeasure iterations, driving the development of new security technologies and protocols. With each subsequent iteration, security solutions become increasingly sophisticated. To stay ahead of the adversary, it is crucial to continuously monitor and assess potential threats, share intelligence, and invest in research and development. Effective border security in this complex landscape demands cutting-edge technologies that can detect and track targets in harsh conditions and dense EM environments. With high-end sensors and effectors, countries can ensure a secure and prosperous environment while balancing the need to facilitate legitimate trade and travel and safeguarding sovereignty, economic vitality, and national security.

CONCEALMENT TECHNIQUES

- ▶ Using creative hiding spots or compartments to evade detection
- ▶ Employing materials or methods to mask the presence of prohibited items

EXPLOITING SYSTEM LIMITATIONS

- ▶ Researching and identifying vulnerabilities in security screening technologies
- ▶ Attempting to overwhelm or saturate the system with multiple, simultaneous threats

HUMINT

- ▶ Manipulating or deceiving security personnel to gain unauthorized access
- ▶ Creating diversions to deflect attention from the actual security breach

TECHNOLOGICAL COUNTERMEASURES

- ▶ Developing or acquiring devices that can interfere with or disrupt security equipment
- ▶ Using encryption or other methods to conceal digital evidence

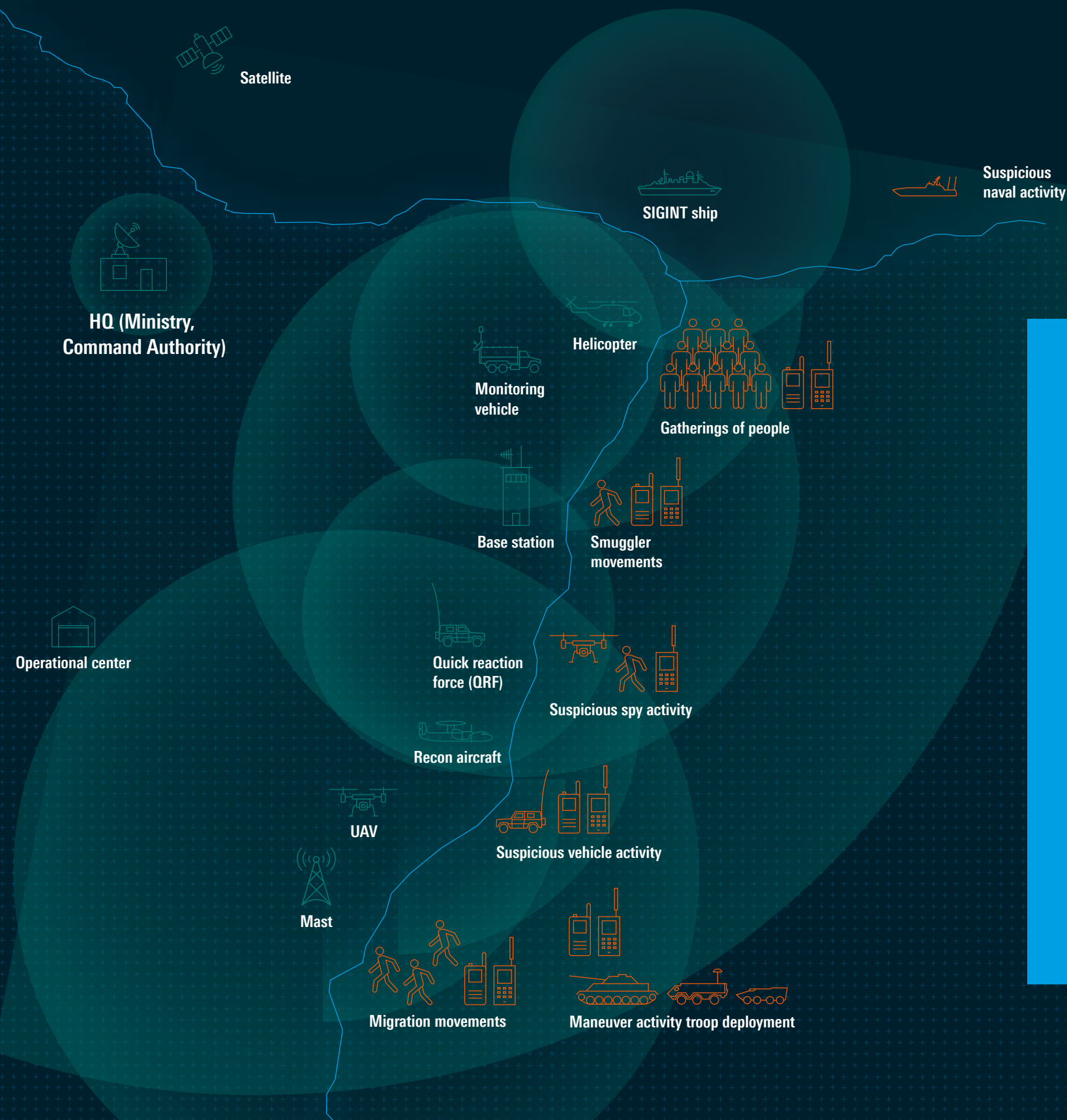
ALTERNATIVE SMUGGLING METHODS

- ▶ Utilizing non-traditional, hard-to-detect methods, such as hiding items within the human body
- ▶ Employing unsuspecting third parties to transport prohibited items

INTELLIGENCE

- ▶ Collecting information on security protocols, personnel, and system vulnerabilities
- ▶ Analyzing security measures to identify potential weaknesses

THE PIVOTAL ROLE OF RF SENSORS



RF sensor technology plays a vital role in augmenting surveillance and defense capabilities for border security. RF sensors overcome the limitations of traditional measures, acting as a proactive early warning system, particularly in complex, hard-to-monitor terrains. They can detect and pinpoint the location of unauthorized communication devices, such as cell phones and radios often associated with illicit activities like smuggling.

RF sensors provide continuous, passive monitoring around the clock and enhance situational awareness in a way that is subtle and non-intrusive. By collecting data for real-time signal analysis, RF sensors give border control agents a tool they can employ to anticipate and counter threats from drones and ships that evade detection by disabling their transponders.

RF sensors are a flexible, cost-efficient solution for optimizing border management and security.

THE PIVOTAL ROLE OF RF SENSORS

Border security sensor solutions: A comprehensive overview

There are many different types of sensors used for border security, each with its own strengths and weaknesses. Some of the most common sensors include

GROUND SENSORS, also known as seismic sensors, buried in the ground and able to detect vibrations caused by people or vehicles; often used to detect illegal crossings and smuggling attempts.

RADAR SENSORS can detect people and vehicles at long distances, even in poor visibility conditions and are often used to monitor large areas of land or sea.

ELECTRO-OPTICAL/INFRARED SENSORS can detect heat signatures to identify people and vehicles at night or in other low-light conditions.

ACOUSTIC SENSORS can detect sounds, such as vehicles or gunfire; often used in conjunction with other sensors to provide a more complete situation picture.

FIBER-OPTIC SENSORS can be used to detect a variety of different things, including vibrations, temperature changes, and chemical leaks; often used in conjunction with other sensors to augment the situation picture.

RF SENSORS can detect radio frequency signals, such as those emitted by cell phones and other electronic devices; used to identify and track people using devices to communicate or who are attempting to exploit the electromagnetic spectrum, e.g. with IMSI catchers.

The type of sensor used in a particular border security application depends on several factors such as the type of threat, the terrain and the available budget.

Feature	RF Sensors	Cameras (optical/thermal)	Motion sensors	Radar
Night detection	Any lighting conditions because they analyze radio signals	Thermal cameras work at night, a limited ability to detect concealed targets, e.g. people hiding under blankets or in soft-sided vehicles. Optical cameras require light or illumination	Operate in any light but limited to movement	Any lighting conditions
Range	Can detect and locate signals over long distances	Range limited by lens type, environmental conditions and line of sight	Very short range	Long range, depending on frequency band and terrain
Detection of hidden targets	Can identify concealed communication devices or radio signals	Thermal cameras have a limited ability to detect concealed targets, e.g. people hiding under blankets or in soft-sided vehicles Optical cameras are not effective for hidden targets	Not effective for hidden targets	Effective for most physical objects, but not for radio signals
Geolocation function	Can triangulate signal sources to identify precise locations - - -	Can be combined with laser range finder (LRF), navigation data (e.g. built -in GPS, accelerometer, etc.) or other onboard sensors to geolocate targets with high accuracy.	Unattended ground sensors can provide location via onboard GPS and can thereby provide static geolocation	Can locate physical objects, but not radio communications
Threat analysis	Identifies specific radio signatures, analyzes signals, and can differentiate between various types of threats -	No signal processing or specific threat analysis capability, except for facial/gait recognition.	Can distinguish between wheeled/tracked vehicles & human/animal targets	Identifies radar signatures
Environmental resistance	Operates in any weather conditions	Optical cameras strongly affected by fog, rain, and snow	Operates under most weather conditions but sensitive to environmental vibrations	May be limited by weather conditions (rain, fog)
Detection capability	Communication devices (radios, mobile phones, drone controllers), radar, and other radio signal sources	Limited to visible threats or threats with a thermal signature	Limited to physical movement	Detects physical objects, but not radio communications



Advantages of RF sensors over other types of border security sensors

RF sensors that passively detect RF signals emitted by electronic devices offer numerous benefits for border security (see below) and are a valuable tool when combined with other sensor technologies.

Passive detection of RF signals emitted by electronic devices such as cell phones, push-to-talk radios, or even radio-frequency improvised explosive devices (RFIED). This means they do not require active illumination or triggering, making them less detectable and more reliable.

Detection of signals over long distances, allowing RF sensors to monitor large areas with fewer sensors than other technologies. Not affected by environmental conditions like fog, rain or darkness, ensuring continuous surveillance. Real-time detection and geolocation,

providing real-time alerts and precise geolocation of the source of the signal, enabling rapid response and intervention.

Detection and tracking of targets at a significantly longer range than other sensor types, enabling border security forces to respond more effectively to potential threats and giving them early warning to assess and react to situations.

Can be used for a wide range of applications, including detecting illegal border crossings, tracking smugglers, and identifying potential threats.

While RF sensors offer these benefits, it is important to note that they are most effective when used in conjunction with other sensor technologies. A multi-layered approach that combines RF sensors with other technologies like ground sensors, thermal imaging cameras, and acoustic sensors can provide a more comprehensive and robust border security solution through heightened situational awareness.

SENSOR TECHNOLOGIES FOR BORDER SECURITY

RF sensors play a crucial role in today's border security, serving as an early warning system to detect and geolocate unauthorized communication devices linked to illegal activities. These sensors provide passive, 24/7 monitoring and enhance situational awareness. RF sensors offer a scalable and cost-effective solution for effective border management by analyzing signal transmissions in real-time to enable border control teams to pre-empt threats from drones and "dark ships" that turn off their transponders.

Rohde&Schwarz offers a range of solutions for border security and protection based on RF sensor technologies that detect and analyze various types of signals. These solutions are designed to provide border control and defense forces with a comprehensive and effective means of detecting and responding to security threats while also ensuring the integrity and confidentiality of sensitive data.

“IN THE FACE OF INCREASINGLY SOPHISTICATED THREATS TO NATIONAL SECURITY, EFFECTIVELY SAFEGUARDING OUR BORDERS DEMANDS MORE THAN JUST TRADITIONAL MEASURES. IT REQUIRES SWIFT ADOPTION AND SEAMLESS INTEGRATION OF CUTTING-EDGE SENSOR TECHNOLOGIES.”

COMINT SYSTEMS enable information gathering from all communications in the electromagnetic spectrum containing speech or text including terrestrial communications as well as non-terrestrial satellite communications.

SATELLITE INTELLIGENCE SOLUTIONS offer scalable monitoring solutions – from transportable to strategic – for analyzing unknown satellite-based communications, enabling efficient signal processing and metadata analysis across diverse satellite networks.

ELINT SYSTEMS collect electromagnetic non-communications transmissions – primarily in the form of radar signals – to detect, analyze and locate specific targets and determine the operational patterns of their systems in order to generate what is commonly called an electromagnetic order of battle (EOB).

SPECTRUM MONITORING SOLUTIONS provide real-time monitoring and analysis of the RF spectrum, allowing border control agencies and defense forces to detect and identify unauthorized signals, including those from drones and other aerial threats. They also map spectrum occupancy, hunt for radio interference, verify of operation of friendly networks and detect illegal transmitters.

CELLULAR NETWORK ANALYSIS tools swiftly detect, identify, and mitigate potential threats by providing unparalleled situational awareness, automated real-time analysis of the electromagnetic spectrum and enhanced flexibility for deployment.

COUNTER-DRONE SYSTEMS can be deployed along extensive borders where drones are used for smuggling contraband, identifying weak points in border security to enable illegal border crossings or for other hostile purposes. These systems can also be used to enhance force protection and base security against the threat of airborne IEDs.

DIRECTION-FINDING SYSTEMS use advanced algorithms and antenna arrays to determine the direction of signal transmissions, enabling border control agencies to pinpoint the location of suspicious signals.

SECURITY SCREENING SOLUTIONS leverage cutting-edge millimeterwave (mmWave) technology and AI-based algorithms to provide comprehensive threat detection and forensic insights for border control and customs agencies, enhancing national security and facilitating the safe passage of people and goods across international borders.

SECURE COMMUNICATIONS through software-defined radios (SDR) enable agencies and defense forces to transmit and receive reliable, high-fidelity video, voice and data with uninterrupted broadband wireless connectivity in real-time.

CYBERSECURITY SOLUTIONS help protect border security systems from cyber threats, ensuring the integrity and confidentiality of sensitive data.

TEST & MEASUREMENT SOLUTIONS for radar/EW and military communications testing

FUSING SENSOR DATA INTO ACTIONABLE INTELLIGENCE



In today's complex world, despite immense information resources, authorities are often at a loss to gain timely actionable insights. This disparity is particularly relevant in the realm of border security, where the integration of diverse information sources is crucial for enhancing situation awareness and decision making. Vast amounts of data from diverse sources have to be fused into actionable intelligence to enable a swift response to emerging threats in real time.

In border security, multiple sensors yield huge numbers of data points. This data is also complex, varying in format, frequency and quality, which further complicates the integration process. The need for swift analysis and response to emerging threats demands powerful real-time processing capabilities.

A unified platform that aggregates data from all sensor sources is essential to obtain a comprehensive view of the border environment. Advanced analytics use AI, machine learning and data mining techniques to identify patterns, predict potential threats and highlight anomalies. Real-time processing enables an immediate response to detected threats, minimizes response time and maximizes the effectiveness of border control measures.

Artificial intelligence (AI) and machine learning (ML) are crucial for advanced pattern recognition and predictive analytics. Internet of things (IoT) integration enables the seamless connection of diverse sensor technologies. Cloud computing provides scalable, secure real-time data processing capabilities, while robust cybersecurity measures protect sensitive data and prevent potential cyber threats.

Fusing sensor data to obtain actionable intelligence is crucial for border security and offers enhanced situational awareness, improved threat detection and an optimized response. Border security agencies that adopt this integrated approach can more effectively safeguard national interests, ensure public safety and facilitate the secure movement of legitimate travelers and goods.



SENSOR DATA FUSION ENHANCES SITUATIONAL AWARENESS, IMPROVES THREAT DETECTION AND ENABLES A TARGETED RESPONSE.

CHALLENGE

- ▶ **Multiple sensor sources:** radar, cameras, acoustic sensors, seismic and other sensors all generate vast amounts of data.
- ▶ **Data complexity:** variations in format, frequency and quality complicate integration.
- ▶ **Real-time requirements:** response to emerging threats demands rapid analysis.

SOLUTION: SENSOR DATA FUSION FOR ENHANCED BORDER SECURITY

- ▶ **Integrated platform:** unified system that aggregates data from all sensor sources and provides a comprehensive view of the border environment.
- ▶ **Advanced analytics:** AI, machine learning and data mining techniques identify patterns, predict potential threats and highlight anomalies.
- ▶ **Real-time processing:** enables immediate response to detected threats, minimizing reaction time and maximizing effectiveness of border control measures.

KEY BENEFITS:

- ▶ **Enhanced situational awareness:** comprehensive, real-time picture of the border environment facilitates decision-making.
- ▶ **Improved threat detection:** increased capability to identify and predict potential security breaches, reducing the risk of incursions.
- ▶ **Optimized resource allocation:** data-driven insights enable efficient deployment of personnel and assets, maximizing the impact of border security efforts.
- ▶ **Streamlined response:** swift, coordinated threat response ensures the safety of border control personnel and the public.



Fusing sensor data to obtain actionable intelligence is crucial for modern border security and offers enhanced situational awareness, improved threat detection and an optimized response. Border security agencies that adopt this approach can more effectively safeguard national interests, ensure public safety and facilitate the secure movement of legitimate travelers and goods.

ROHDE & SCHWARZ:

TRUSTED PARTNER FOR BORDER SECURITY



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SAFE BORDERS, STRONGER FUTURES: UNLOCK THE POTENTIAL OF ADVANCED BORDER SECURITY SOLUTIONS! BY HARNESSING THE POWER OF CUTTING-EDGE BORDER SECURITY TECHNOLOGIES, WE CAN EFFECTIVELY SAFEGUARD OUR BORDERS AND CREATE A MORE SECURE ENVIRONMENT FOR FUTURE GENERATIONS AND A MORE RESILIENT AND PROSPEROUS NATION WHERE SAFETY AND OPPORTUNITY THRIVE.

Rohde & Schwarz provides both high-performance sensors and powerful software for sensor fusion and signal analysis to increase border security. Procuring everything from a single source streamlines integration and maximizes efficiency.

One major advantage of getting both hardware and software from the same provider is the seamless collaboration between R&D departments.

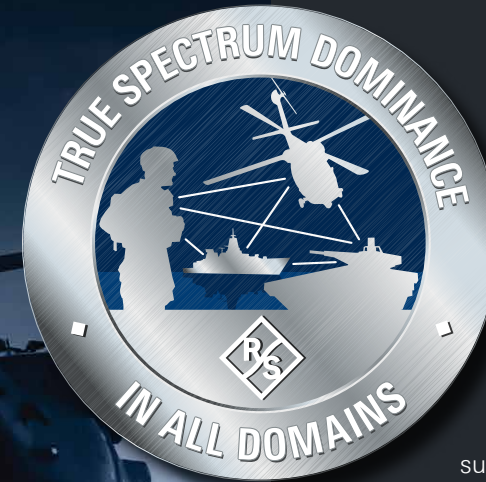
Rohde & Schwarz is an ideal partner. Its comprehensive portfolio of innovative, reliable, and secure solutions – including communications, surveillance and monitoring systems – effectively bolsters border protection to counter a range of threats. With decades of experience in providing cutting-edge technology to government agencies and security forces around the globe,

Rohde & Schwarz offers unparalleled expertise and tailored support to enhance border security operations.



Effective border security demands integration of advanced technologies to enhance situational awareness and a rapid response. Rohde & Schwarz, with its comprehensive portfolio of innovative solutions, is ideally positioned to support border security operations, leveraging its expertise in communications, surveillance and monitoring systems. By partnering with Rohde & Schwarz, border security agencies can optimize their defenses against various threats to ensure the safety and security of their borders and the people they protect.

TRUE SPECTRUM DOMINANCE IN ALL DOMAINS



Today's military missions increasingly rely on information superiority and advanced command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) systems. Control over the electromagnetic spectrum has become essential in achieving strategic military dominance.

Rohde & Schwarz develops, designs, manufactures and implements turnkey end-to-end solutions for secure communications, SIGINT/ EW, intelligence, test & measurement and security in modern warfare. Our solutions contribute to effective C4ISR, enabling customers to achieve dominance in the electromagnetic spectrum for a decisive edge in modern warfare.

SIGNAL MASTERY

Signal testing and generation, secure communications, encryption, signal detection, location, analysis and interception from a single source.

VERTICAL INTEGRATION

Rohde & Schwarz maintains a high degree of vertical integration with nearly its entire value chain inside the company. All products are developed and manufactured in its own factories.

ONE-STOP SHOP

Rohde & Schwarz provides a one-stop shop with the full range of turnkey solutions, from sensors and analysis to effectors across the electromagnetic spectrum.

TRUSTED PARTNERSHIP

As an independent, privately-owned company, Rohde & Schwarz finances its growth with its own resources. The company is not beholden to capital markets or stock market expectations.



NON-TERRESTRIAL
MONITORING



MONITORING
SOLUTIONS



COUNTERING
DRONES



ELINT/RESM



COMINT/CESM



CYBERSECURITY



MOBILE
NETWORK
TESTING



NAVAL
COMMUNICATIONS
SYSTEMS



CELLULAR
NETWORK AND
IP ANALYTICS



TEST &
MEASUREMENT



TACTICAL
COMMUNICATIONS



AIRBORNE
COMMUNICATIONS

Service at Rohde & Schwarz You're in great hands

- ▶ Worldwide
- ▶ Local and personalized
- ▶ Customized and flexible
- ▶ Uncompromising quality
- ▶ Long-term dependability

Rohde & Schwarz

The Rohde&Schwarz technology group is among the trailblazers when it comes to paving the way for a safer and connected world with its leading solutions in test&measurement, technology systems and networks&cybersecurity. Founded 90 years ago, the group is a reliable partner for industry and government customers around the globe. The independent company is headquartered in Munich, Germany and has an extensive sales and service network with locations in more than 70 countries.

www.rohde-schwarz.com

Sustainable product design

- ▶ Environmental compatibility and eco-footprint
- ▶ Energy efficiency and low emissions
- ▶ Longevity and optimized total cost of ownership

Certified Quality Management
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