WHITE PAPER

AUGMENTING BORDER SECURITY & DEFENSE

with Radio Frequency (RF) sensor technology

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CRFS

EXTRAORDINARY
RF TECHNOLOGY

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INTRODUCTION

To protect the integrity of their borders and safeguard their citizens, border forces and border security agencies focus on two missions: border security and homeland defense. Traditionally, border defense has depended on military force, while border defense is ensured by a combination of patrols and physical security.

However, to operate effectively, both must achieve complete situational awareness, stemming from an informational advantage garnered from a variety of sources:

- Radar systems
- Fixed ground sensors with seismic, acoustic, or infrared technology
- High-resolution and infrared cameras and night-vision equipment
- Unmanned aerial vehicles and aerostats
- Intelligence, security, and reconnaissance (ISR)
- Communications intelligence and signal analysis
- Integrated communication systems
- Mobile surveillance systems

As no one solution provides complete situation awareness, robust border security involves combining as many technological solutions as possible. Taking a layered approach means that one solution's weaknesses will be enhanced by another's strengths.

Together with cameras and radar, RF technology is an essential element of border security and defense. Its distinct advantage is the ability to provide passive surveillance and early warnings of potential criminal activity, or threats to national security—which can then be closely investigated and addressed with the appropriate resources.

This white paper was guided by the results of a border security survey aimed at border control, border security, and military personnel tasked with national security and defense. It examines how RF sensor technology can be used to tackle modern border security threats, adds to the greater detection ecosystem, and shortens warning and response timelines for border forces. It also details current, real-world deployments.

INCREASE YOUR **DETECTION RANGE**

An RF sensor network can act as an early warning system that provides border forces with enhanced situational awareness.

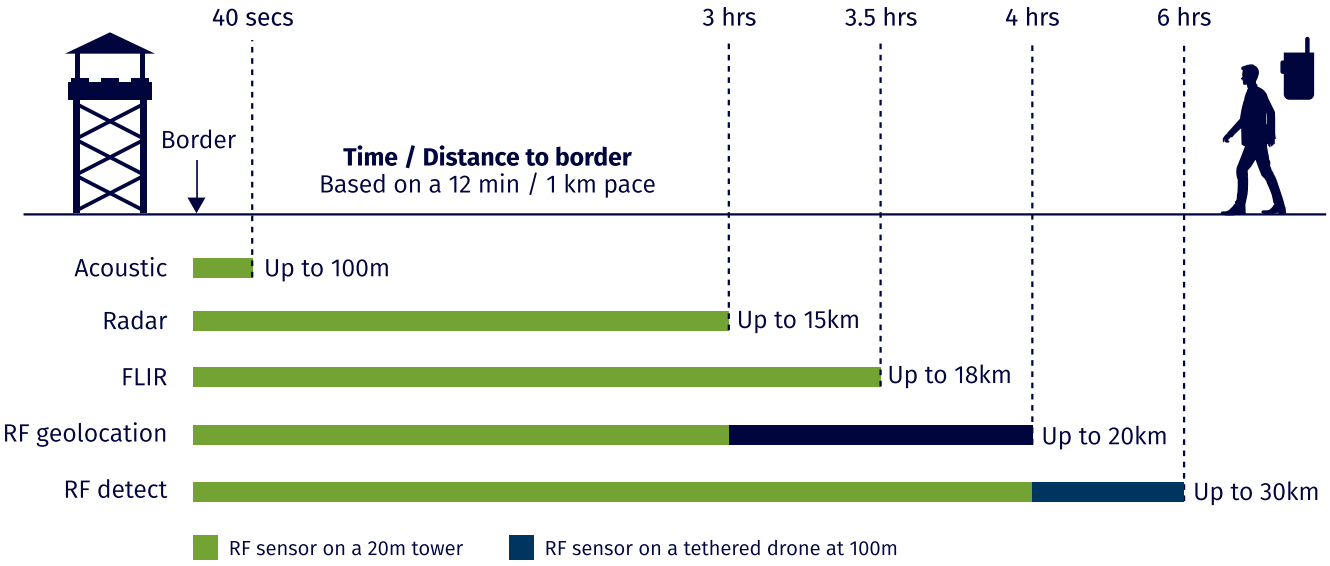


Figure 1 illustrates the approximate detection range of several commonly deployed sensors. On average, acoustic sensors can operate up to 100m, ground-based radar up to 15km, and Forward Looking Infrared (FLIR) up to 20km.

RF sensors can detect a PTT (Push-to-Talk) radio transmitting at 50MHz at a distance between 20–30km and can geolocate the signal between 15–20km. However, the precise distance depends on the height of the sensor, the terrain, and the environment.

Assuming a person averages 12 minutes per kilometer, this information provides commanders with about two hours of decision space before employing the next sensor. RF sensors act as an early warning system, allowing decision-makers to proactively send resources to the areas of concern.

Figure 1: Graphic showing the detection range of several commonly deployed sensors.

SURVEY: **ENHANCING BORDER SECURITY WITH RF TECHNOLOGY**

CRFS sent border security agencies and forces across the globe a survey to understand their perspectives on integrating radio frequency (RF) technology into their operations. The audience was intended to be as diverse as possible.

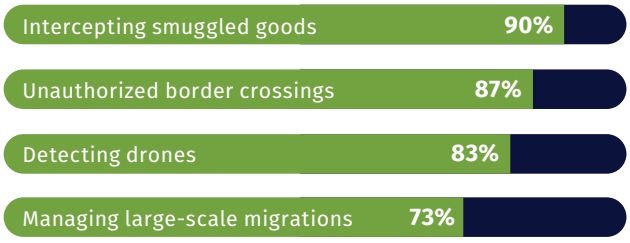
The results from this survey provide valuable insights into the current state and future potential for RF technology in border security operations, highlighting key stakeholders' opportunities and challenges.

Respondents from thirty-eight border security agencies completed the survey in April 2024.

KEY SURVEY INSIGHTS

Most respondents expressed a desire to understand more about how RF technology can help address their challenges—specifically the most significant ones, which include intercepting smuggled goods, unauthorized border crossings, detecting drones, and managing large-scale migrations.

BORDER SECURITY CHALLENGES RESPONDENTS RANKED AS MODERATE TO SIGNIFICANT IN SEVERITY

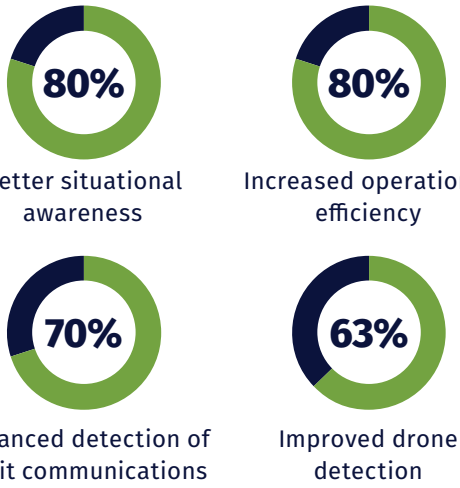


Respondents report comparatively lower usage of RF detection equipment compared to more traditional forms like surveillance cameras, radars, infrared cameras, and UAVs; however, approximately a third report using the technology for electronic surveillance, with slightly less than a third reporting using it for drone detection and communications interception.

Regarding the perceived benefits of RF technology, the most valuable benefits relate to detecting illicit communications and enhancing both situational awareness and operational efficiency.

This suggests a strong interest in RF technology to improve overall security efficacy and highlights the importance of intelligence gathering and real-time awareness in border security operations.

PERCEIVED BENEFITS OF INCORPORATING RF TECHNOLOGY INTO BORDER SECURITY OPERATIONS



The survey acknowledges respondents' interest in using the electromagnetic spectrum in modern security operations. The emphasis on cost-effectiveness and proven effectiveness indicates a cautious investment approach, where decision-makers seek reliable, efficient solutions that offer good value. Moreover, the importance placed on ease of integration, support, and training suggests that organizations are not only looking for effective solutions but also for technologies that can be adopted without significant disruption to current operations and with adequate resources to enable their personnel to use new tools effectively.

93% of respondents interested in including RF technology in their border security operation

MODERN BORDER SECURITY THREATS AND SOLUTIONS

Borders demonstrate a nation's ability to protect and define itself. Yet, their vulnerability lies in the fact that border terrain is often difficult to patrol, a corridor of illicit activities, and a nexus for humanitarian crises.

Countries cannot build walls to keep everyone out, and there will never be enough border agents to patrol every section of a remote border. No single technology or strategy can offer complete protection against the most significant modern threats to the nation-state:

- Human trafficking by land and sea
- Organized crime involving drug trafficking and weapons smuggling
- Hostile neighbors and protection from terrorism

AN ADVANCED RF SOLUTION TO SECURITY THREATS

Border security agencies need technology to cover large areas, decrease timelines, and provide accurate situational awareness in all domains, including the radio spectrum.

Integrating RF sensor technology with existing surveillance technologies provides a complementary layer of security that enhances capabilities to create a comprehensive, multi-layered approach to border security and management. Specific detection includes Push-to-Talk radios, drone signals, and aircraft.

RF sensor technology has sophisticated detection and surveillance capabilities, enabling agencies to geolocate electronic devices used in illicit border activities. Continuously scanning the electromagnetic spectrum for unauthorized transmissions can bolster real-time threat detection and response. The technology can be used as an early warning detection system, alerting agencies to potential threats before the situation becomes critical.

In terms of deployment, RF sensors are highly flexible:

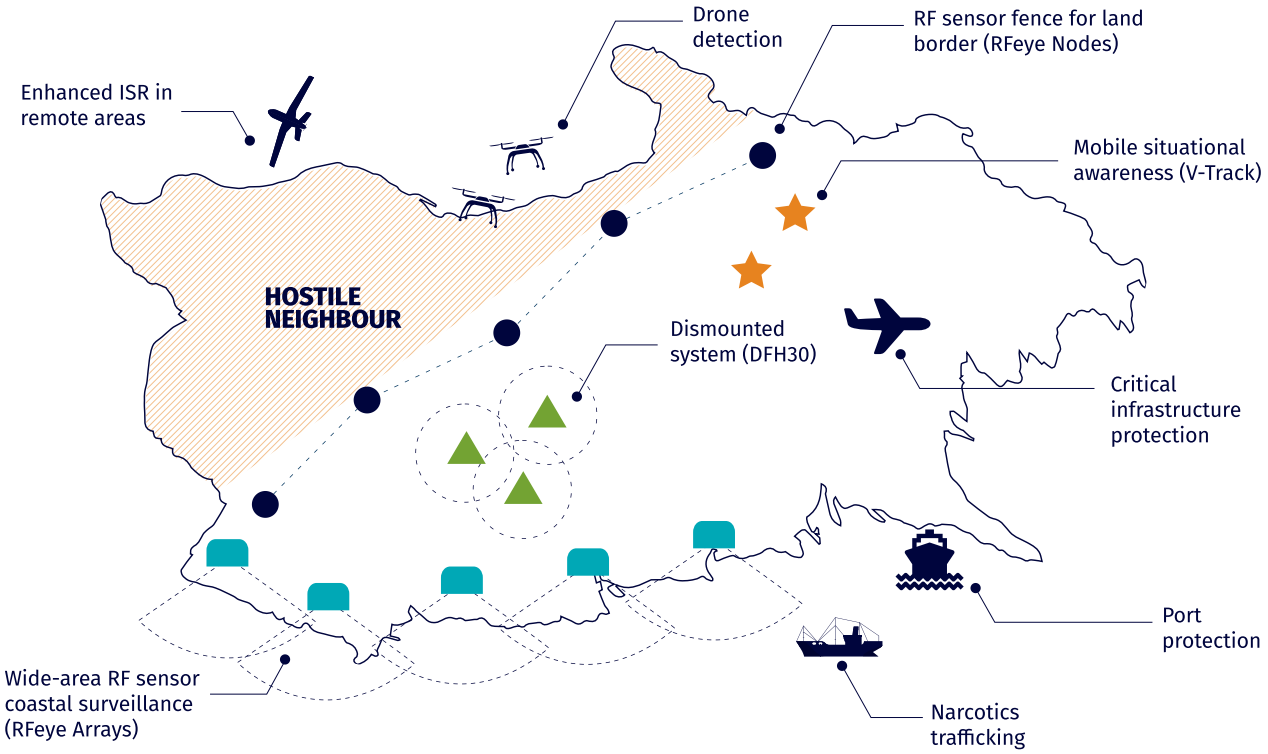
- Fixed on towers to monitor critical infrastructure
- Man-portable in a robust Peli Protective Case
- Vehicle-mounted on a fleet of specially designed tactical vehicles
- As an airborne payload (drone/aerostat)

This adaptability is helpful for a wide array of border applications—from protecting critical infrastructure to operations in remote, challenging terrains.

By building an RF sensor 'wall' across a border, agencies and forces are establishing a dynamic, intelligent surveillance and detection solution.

RF SENSOR APPLICATIONS FOR BORDER SECURITY MONITORING

Figure 2: Graphic showing the different RF sensor deployment options to address diverse border security challenges.



Creating a fixed infrastructure of RF sensors along a land border creates an invisible barrier, early warning, and passive surveillance and intelligence system to support COMINT, SIGINT, and EW activities.

Mobile situational awareness (V-Track) systems can be used to fill in gaps or blind spots in the sensor wall. Dismounted systems can be deployed from vehicles to create short-range TDoA and geolocation networks.

Small localized sensor networks can be used to protect critical infrastructure and ports.

Wide-area coastal surveillance using omnidirectional antennas can monitor, detect, and perform automatic geolocations of acquired targets and signals of interest.

RF sensors fitted as payloads to rotary, tethered, or fixed-wing UAVs (drones) can link to ground-based sensors to create 3D TDoA networks for air defense and drone detection while supporting ISR.

ENHANCED ISR IN REMOTE AREAS

Mobile (vehicle and drone-mounted) RF sensors can be deployed to detect and geolocate unusual signal activity in remote or infrequently patrolled areas where installing permanent surveillance equipment is complicated. The RF sensors becomes a "digital patroller" for border agents.

Spectrum monitoring is a critical element of ISR missions. Knowing who is operating in the electromagnetic spectrum (voice, data, sensors such as radar), what they are transmitting, and where they are located are all extremely valuable data points.

Spectrum monitoring is integral to SIGINT—intercepting and analyzing electronic communications and signals to gather intelligence. Monitoring specific frequencies allows SIGINT operations to uncover valuable information about adversaries' movements, intentions, and capabilities without physical intrusion.

However, spectrum monitoring in remote areas can be challenging. If line-of-site is affected by complex terrain such as mountainous areas, spectrum monitoring can be affected. Adding RF sensors to assets such as surveillance drones and all-terrain vehicles allows border forces to detect radio signals from a more extensive collection cone.

ISR MISSIONS AT SEA & ACROSS HOSTILE BORDERS

PROBLEM: Large geographical areas need protection from hostile threats, and traditional spectrum monitoring is limited by radio horizon and geography.

SOLUTION: Combining ground-based RFeye Direction Finder Arrays with air-based RFeye Nodes on drones to overcome coverage issues and expand signal detection range.

RESULTS: Enhanced ISR missions over thousands of kilometers with AoA and TDoA geolocation capabilities.

WIDE-AREA RF SENSOR WALLS

Smart walls across coastlines or land borders using fixed and deployable RF sensors can act as a visual deterrent and support traditional surveillance by alerting a command and control center to suspicious signals. Land or maritime border patrols can then be dispatched to precise locations.

Along geographically complex borders, maintaining national security is a critical concern. Building fences across thousands of kilometers up mountains and through jungles is often unrealistic.

However, implementing a smart border that acts as an intelligence-gathering solution is viable in any environment. Smart walls equipped with RF and other sensor technologies can extend surveillance capabilities to remote and rugged terrains where traditional patrol methods are less effective or feasible. This ensures a continuous monitoring presence across vast borders.

By building wide-area smart walls, border security forces can monitor remote areas for suspicious signals from push-to-talk radios using narrowband signals. They can then geolocate, decode, and demodulate signals of interest—gaining the intelligence required to deploy resources to the area (if necessary).

A smart wall can integrate RF technology that trips and cues other sensor systems, such as thermal imaging for nighttime surveillance and high-resolution cameras for visual identification. This multi-layered approach enhances the overall detection capabilities.

MOD BORDER SURVEILLANCE IN THE MIDDLE EAST

PROBLEM: A Ministry of Defense in the Middle East needed to enhance electronic surveillance across extensive, remote border regions to counteract various threat vectors.

SOLUTION: They implemented an RF hardware and software ecosystem, including RFeye Nodes and Arrays, for continuous automated spectrum monitoring and intelligent mission management.

RESULTS: Over a decade of successful multi-mission deployments has led to robust spectrum intelligence capabilities, enabling real-time detection and management of diverse threats.

DRONE DETECTION

Military and civilian drones contain many RF-emitting components, including transmitters, video downlinks, and telemetry modules. Each component can be detected, and the drone geolocated using a signal geolocation method: 3D Time difference of arrival (TDoA).

Commonly used in smuggling operations, reconnaissance missions, and acts of aggression, criminal drone use is prolific.

As most drones contain many RF-emitting components, including transmitters, video downlinks, and telemetry modules, adding RF sensors to a border security operation is beneficial to increase security. These sensors can be used either as standalone sensors or as part of a larger counter unmanned aerial vehicle (c-UAS) solution with additional sensors (electro-optical, infrared, acoustic).

RF sensors can identify drones and discriminate them from other targets and signals. However, they must include advanced software-defined radio (SDR) technology that provides wide spectrum capability, detecting a broad range of threat vectors—from COTS to MALE and modified drones.

Detecting the specific signal rather than the type of drone is also essential. Library-based systems are more fallible as, if the incoming drone is not in the library, the system will not recognize it. Conversely, RF signal detectors that hunt for specific signals of interest are a more precise solution.

When an RF sensor detects a specific signal, it immediately performs a 3D geolocation—through (at least) four networked sensors, providing individual border security agents or C2 centers with real-time intelligence.

ACHIEVING SPECTRUM DOMINANCE ACROSS MULTIPLE MILITARY AIRBASES

PROBLEM: NATO airbase spectrum managers were overextended, trying to cover multiple locations and responsibilities with insufficient resources.

SOLUTION: They installed a network of RFeye Nodes across multiple airbases, which could be centrally controlled and operated, enhancing efficiency and spectrum management.

RESULTS: The system ensured spectrum dominance with improved situational awareness and operational security, allowing for centralized, automated monitoring, and efficient use of expert resources.

GATHERING SIGNALS INTELLIGENCE

By conducting wideband spectrum monitoring, border forces can detect, record, and analyze a vast range of signals—from maritime radio signals to standard cellular signals, up to radar signals and even some satellite communications.

In areas with concentrated criminality, border security forces may need to gather intelligence on illegal operations.

By conducting wideband spectrum monitoring (frequencies from 30 KHz – 40 GHZ in the VLF, LF, MF, HF, VHF, UHF, and SHF bands), border forces can detect and record a vast range of signals—from maritime radio signals to standard cellular signals, up to radar signals and even some satellite communications.

Gathering advanced signals intelligence by recording high-fidelity In-phase and Quadrature-phase (I/Q) data of these signals over long durations can help provide a complete intelligence picture. I/Q is the gapless capture of a signal enabling decoding and decryption.

Forensic analysis of I/Q data can uncover header data, country codes, and other information payloads, including voice. Over time, networks can be created and further exploited using cyber technology or monitored to establish patterns for a surveillance target.

REAL-TIME I/Q DATA CAPTURE FOR ENHANCED INTELLIGENCE

PROBLEM: A national border force needed to modernize its outdated spectrum monitoring equipment for better security against a hostile neighbor.

SOLUTION: CRFS co-engineered the RFeye SenS Remote, a custom solution combining the capabilities of the RFeye Sens Portable and RFeye Node 100-18 for enhanced I/Q data capture and flexible signal detection.

RESULTS: The force achieved enhanced intelligence and security through the ability to capture and analyze a wide range of signals.

NARCOTICS TRAFFICKING

RF technology can detect signals emitted by drones and monitor communications signals of vessels and USVs suspected of drug smuggling. Criminals are constantly finding new ways to smuggle narcotics across borders and in-shore.

DRONES

On the Mexico-US border, inexpensive quadcopters converted into narcodrones carry 16 kg (35 lb) narcotic payloads. The sheer volume of drones that criminals fly over the border at night in remote areas makes border forces' job more difficult. RF sensors can identify many RF signals emitted by drones' control and communication systems. The drone can be geolocated using 3D TDoA, and action taken to ensure the narcotics do not end up in the hands of criminals.

VESSELS

Using RF sensor technology that monitors navigation systems, border security forces can monitor vessels suspected of being involved in drug trafficking. Monitoring the emitters associated with unknown or unexpected vessel signals can provide insights into smuggling routes and drop-off locations.

NARCOTICS DROPS

Advanced screening technology in ports has led to an increase in small vessels dropping narcotics at informal landing sites or leaving packages in the water attached to buoys that communicate their position. RF monitoring and geolocation of transmitters can assist border forces in locating vessels and buoys.

INCREASING LINE OF SIGHT & GEOLOCATING GROUND-BASED TARGETS FROM A LONG DISTANCE

PROBLEM: The difficulty in geolocating targets from a distance due to the curvature of the Earth limiting the line of sight.

SOLUTION: Integrating highly-sensitive RF sensors on unmanned aerial systems (UAS) to extend the geolocation range and enhance situational awareness.

RESULTS: Improved ability to geolocate targets beyond the horizon, and facilitating advanced passive ISR over extensive areas.

CRITICAL INFRASTRUCTURE PROTECTION

Critical infrastructure, such as airports, ports, or offshore facilities, can be monitored to ensure critical communications are not being intercepted or jammed by criminals.

A nation's critical infrastructure is inherently vulnerable to attacks from terrorist actors or hostile states. Nefarious actors can attack critical infrastructure in many ways:

- Drones can be used for illicit surveillance, for direct attacks, or to cause disruption
- Cyber attacks may jam essential wireless communications
- RF devices can be used for illegal surveillance of sensitive facilities
- Remote-controlled devices may be used to detonate remotely
- Actors can carry out deliberate signal interference by broadcasting on known channels
- Sensitive data can be stolen by actors monitoring RF transmissions within sensitive facilities

RF monitoring addresses these threats by providing real-time awareness and the ability to respond rapidly to potential security breaches.

By continuously scanning the radio frequency environment, operators can detect unusual or unauthorized signal activities that may signify various security risks. Early detection of these activities allows for timely countermeasures, preventing potential attacks or disruptions.

It is a critical component of a comprehensive security strategy for protecting critical infrastructure from sophisticated and evolving threats.

KEY PRINCIPLES

1. TARGETED MONITORING

Determine the specific targets and threats you need to monitor and detect. Then, tailor your approach by using propagation and simulations—ensuring you select the right Radio Frequency (RF) sensor and place it strategically. Ensure that the sensor is close enough to both the threat and other sensors in the network to provide dependable operational support.

2. SCALABLE DEPLOYMENT

Establish a small yet effective network of RF sensors. As networks are expandable, they can be connected to form a more extensive system to support reliable AoA, PoA, TDoA or 3D TDoA monitoring and geolocation.

Geolocation techniques

- AoA – Angle of Arrival
- PoA – Power of Arrival
- TDoA – Time Difference of Arrival
- 3D TDoA – calculates a signal's altitude, latitude and longitude

3. INCREMENTAL EXPANSION

Over time, expand your monitoring capabilities to cover any gaps or blind spots by investing in second-phase developments or adding vehicle or vehicle and dismounted systems. This may include integrating mobile units such as the V-Track system, which enables secure vehicle-to-vehicle, secure vehicle-to-mobile ground force, and secure ground-to-air ISR and geolocation operations.

4. CUSTOMIZED DRONE DETECTION

Tailor your drone detection systems to the specific needs of each site, taking into account local terrain, ambient noise, and the range of detection required. It is more effective to use sensors designed to seek out specific threats than to rely on pre-existing drone signal databases, which may become outdated quickly.

5. FLEXIBLE SENSOR PLACEMENT

Adding RF sensors as payloads to fixed-wing drones, rotary, or tethered drones supports 3D TDoA and provides variable height antenna solutions where no fixed infrastructure is available.

CONCLUSION

Radio Frequency (RF) sensor technology is a critical component of a modern border security and defense system. Borders often span remote and complex terrain, and RF sensors can flexibly extend the reach of traditional security measures. The technology serves as an early warning system—feeding into a multi-layered surveillance and intelligence-gathering solution. Its integration into existing systems is an enhancement rather than a complete overhaul, ensuring operational continuity while strengthening capabilities.

By integrating RF sensor technology, border security agencies and forces can improve their operations in the following ways:

Enhanced ISR: RF sensors can act as digital patrols, especially in remote areas, contributing greatly to intelligence, surveillance, and reconnaissance (ISR) missions and signal intelligence (SIGINT) operations.

Smart walls: Building a smart wall using RF sensors extends surveillance capabilities to complex terrains and integrates with other technologies for comprehensive spectrum monitoring.

Drone detection: RF technology can help detect and geolocate drones used for illicit activities using methods like 3D TDoA.

Detecting illegal activities: Whether the problem is unauthorized border crossings or narcotics trafficking, RF sensors help in monitoring and geolocating vessels, drones, people, and packages used in illegal activities.

RF sensors are flexible and efficient and add value to existing security measures. Also, unlike radar and other ground-based sensors, they are passive, meaning targets or operators are unaware they are being monitored.

Adopting the technology is a significant enhancement to border security operations, providing an intelligent approach to contemporary security challenges.

FIND OUT MORE ABOUT CRFS **PRODUCTS & SOLUTIONS**

RFeye® Receiver (Node)

High-performance spectrum sensor (receive / record) to 40GHz

RFeye® Array

Direction finding from 20MHz to 40GHz

RFeye® Site

Real-time spectrum monitoring & geolocation toolkit

RFeye® Mission Manager

Automated monitoring & mission management

RFeye® DeepView

Forensic signal analysis software with 100% probability of intercept

RFeye® SenS Remote

High fidelity RF Recording (I/Q data) for enhanced intelligence

RFeye® Integrated Vehicles

Mobile spectrum monitoring, geolocation & tactical deployments

RFeye® Integrated Drones

Lightweight, rugged RF sensors fitted onto drones

CRFS

EXTRAORDINARY
RF TECHNOLOGY

CRFS is an RF technology specialist for the defense industry, national security agencies, and systems integration partners. We provide advanced capabilities for real-time spectrum monitoring, situational awareness, and electronic warfare support to help our customers understand and exploit the electromagnetic environment.

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