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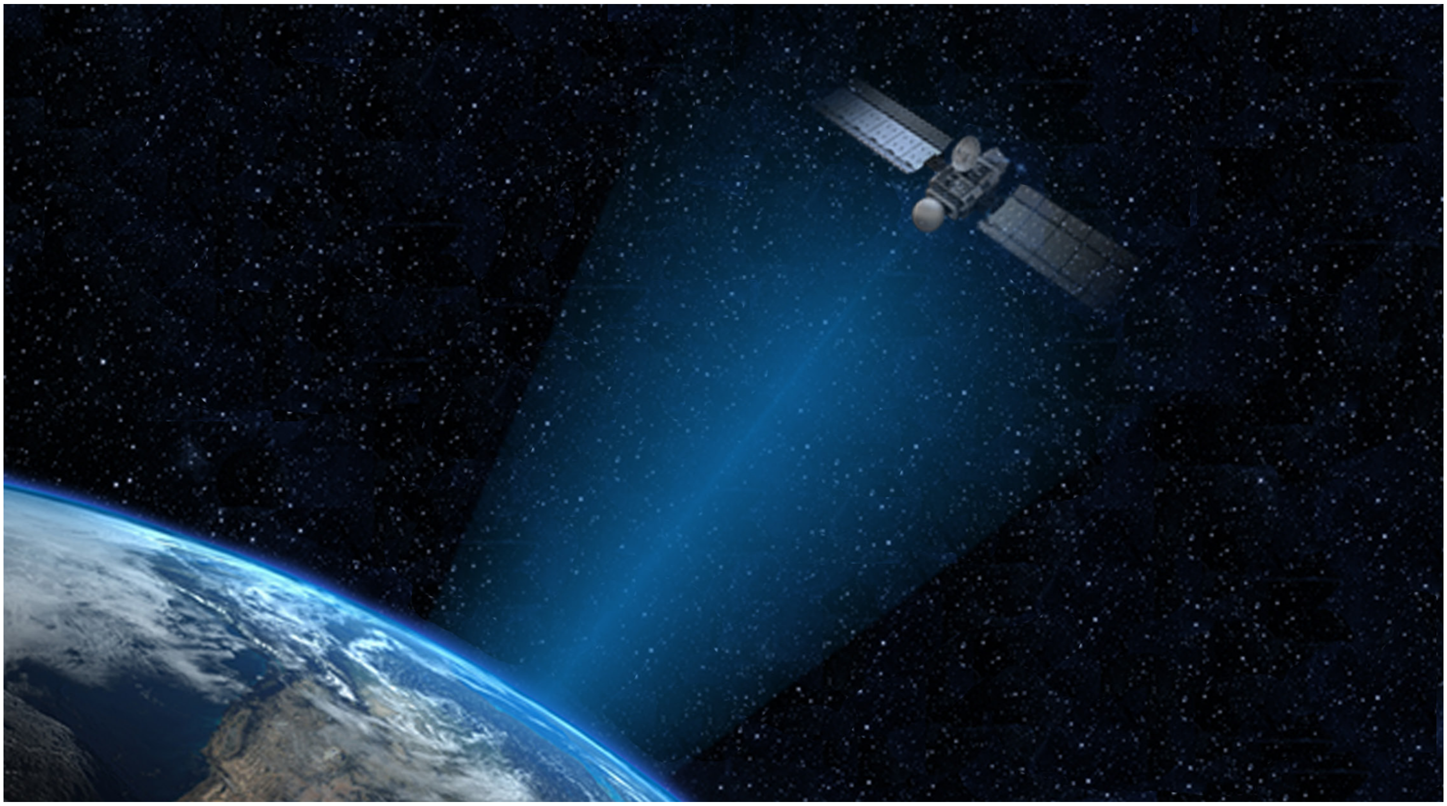
# Towards Complete Space Domain Awareness

*How RF Data Fills the Gaps in Orbital, Link and Terrestrial SDA*



# Towards Complete Space Domain Awareness

## *How RF Data Fills the Gaps in Orbital, Link and Terrestrial SDA*

*When a Russian satellite recently parked close between two commercial satellites, then moved near a third months later, its actions were deemed reckless and irresponsible by the international community. Maneuvering within kilometers of one satellite, its unknown mission raised alarms and intensified concerns. Absent information about the Russian satellite's planned maneuvers, payload use or intent, operators could not know how to maintain safe distance or take other appropriate actions. The risks in space are growing, especially alongside the marked rise in the sophistication and intent among nation-states such as Iran and North Korea to disrupt space operations.*

> *In January of 2022, the U.S. Space Force expanded the scope of SDA to include activities in all three segments of space operations:* ***Orbital, Link*** *and* ***Terrestrial.***

As space operations have become essential to applications, ranging from global communications and commerce to enabling defense and intelligence operations, Space Domain Awareness (SDA) has taken on heightened importance. Given the pace of emerging threats and a more cluttered and collision-prone environment, SDA is challenged to stay ahead of a mounting array of vulnerabilities.

This paper addresses how the addition of Radio Frequency (RF) data can enhance the speed, accuracy, and insight of SDA, filling in the gaps of traditional techniques. The addition of the RF data domain—the information about satellite signals—can provide a more thorough and predictive awareness of the space environment.

### *The Limits of Traditional SDA*

Space Domain Awareness provides the foundation for all space doctrine, from protecting and defending spacebased capabilities, to de-conflicting space traffic, to battle damage assessment. This operational picture requires that SDA effectively detect objects, examine the health of RF communication links and geolocate terrestrial sources impacting satellite operations.

As with any domain, gaining an 'awareness' or understanding of active space is predicated on completeness of information. To date, SDA has relied primarily on two main sensor types for data; Ground-based Radar and Electro-Optical (EO). Each offers respective strengths, but also limitations and gaps.

- **Ground-based Radar** excels at capturing objects moving through low earth orbit, extending to approximately 1,200 miles above the earth's surface. However, given power considerations, few radars can detect objects in geosynchronous (GEO) orbit (22,000 miles).

- **Electro-Optical**, or telescopic observation, can observe satellites in the geosynchronous orbit, however, only at certain times and optimal conditions— that is, at night, against a clear dark sky free of clouds and other obscuring weather.

Radar and EO observations are limited to the Orbital segment of space operations.

### Enhancing SDA with RF Data

Radio Frequency (RF) data— the electromagnetic spectrum used by space systems to communicate—can be used to enhance traditional SDA, offering a wealth of information spanning the Orbital, Link and Terrestrial segments with data absent from other sensors. For example, a satellite maneuvering in geostationary orbit is beyond the detection of radar, and goes unseen by telescopes in the bright light of day. However, its RF transmission can be used to detect maneuvers and anomalies, day or night and in all weather conditions. Further, RF can characterize behaviors, attributing whether an unexpected maneuver represents the patterns of adversarial intent, or the drift caused by an onboard system malfunction. These RF capabilities fill the blindspots of existing SDA sensors, while providing additional knowledge to enrich insight.

RF data has been in use for years to support space operations, from monitoring payload performance and usage, to detecting and geolocating interference, and to supplementing government monitoring networks. In theory, this data always held significant value for SDA, but in practice wasn't available at scale due to limited sensor coverage and spotty infrastructure. Now, with commercial global monitoring available, RF data can be collected for the complete geosynchronous arc at all times, 24/7/365, providing unique insights that elude detection or characterization by traditional sensors.

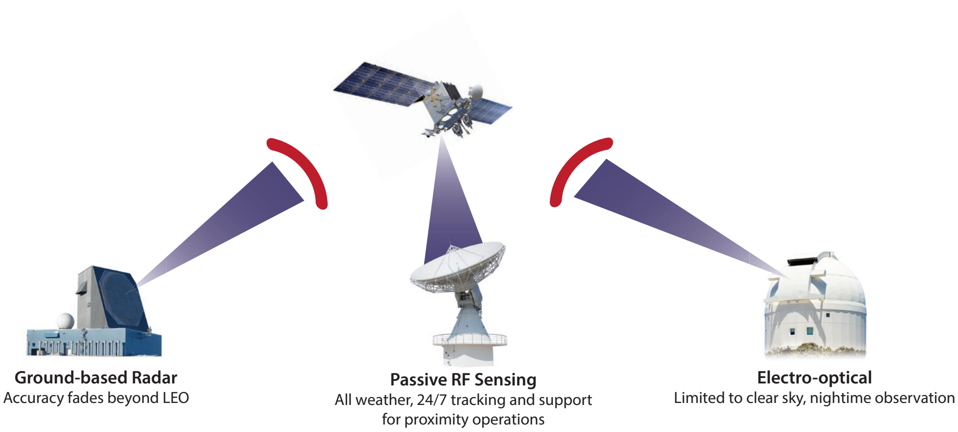
RF data improves current SDA capabilities by:

- delivering persistent surveillance of GEO and non-GEO satellites and maintaining chain of custody of high interest systems.
- detecting satellite maneuvers in real-time and identifying their accurate location for conjunction assessment, collision avoidance, and safety of flight.
- identifying anomalies in RF system performance, including jamming or unintentional interference determining the capabilities of friendly and adversarial space assets.
- characterizing satellite patterns and behaviors, and identifying aberrations that can be alarmed and acted upon.

When fusing information across all three operational segments (Orbital, Link and Terrestrial), the RF-inclusive combination offers a more complete and accurate real-

| RF Data | | |
|---|---|---|
| Power Equivalent Bandwidth | Modulation Type | Error Bit Rate |
| Data Rate | Backoff Power | EIRP |
| C/N: Carrier to Noise | Bandwidth | Es/No |
| Symbol Rate | Center Frequency | Eb/No |
| FEC Detection | C/I | |

*RF data monitored and collected for multiple bands and frequencies by a worldwide network of sensors and antennas can be used to determine the Location, Health, Usage and Attribution of space assets.*




*The two main sensor types for SDA data: Radar and Electro-Optical (EO). Each offers strengths, but also limitations. RF data can fill the gaps to enhance SDA.*

## RF Signal measures provide a new data domain for SDA:

*What's Required to Convert RF data into SDA Intelligence?*

***a global sensor network** to collect RF data in multiple bands/frequencies across the complete geosynchronous arc.*

***a well-staffed, state-of-the-art RF operations center** to aggregate and integrate that data.*

***advanced analytics**, including machine learning and AI, to enhance the data for real-time awareness, predictive insights, historical trending and patterns of life.*

time picture of satellites, their activities, and the impact to users of these systems.

### Inside the Unique RF Footprint

RF data is monitored and collected from satellite uplinks and downlinks from sensors and antennas networked worldwide in S, L, C, X and Ku bands. The phenomenology of the signal externals—or waveforms—is represented by over a dozen measures. These include: directional RF power, center frequency, signal-to-noise, carrier-to-noise and many more. These signal metrics can be interpreted to determine the *Location*, *Health*, *Usage* and *Attribution* of space assets, supporting the functional requirements of SDA.

### RF Applications to SDA: Orbital Segment

By rapidly scanning the geostationary arc in multiple bands, RF supports a variety of orbital insights including a new object discovery and threat awareness. Whereas optical sensors (telescopes) can only locate and measure range from other point of light references, i.e., against stars in the night sky, RF data can detect maneuvers and locate transmitting objects at all times and in all weather conditions. This persistent monitoring of the geosynchronous orbit, similar to a 'neighborhood watch,' maintains chain of custody for satellites and systems of interest that can evade other sensors.

### How RF 'Detects, Tracks & Identifies'

As a satellite moves, its RF signals exhibit a small Doppler shift. This change in the signal's Center Frequency indicates movement and positional change. By monitoring these frequency shifts, satellite maneuvers can be detected as they occur in real-time. Satellite position and range can then be determined by both passive and active ranging techniques that compare the time it takes for signals to reach sensors at multiple locations. These highly accurate RF methods enable new orbits to be determined and propagated for conjunction assessment and awareness of other proximate objects.

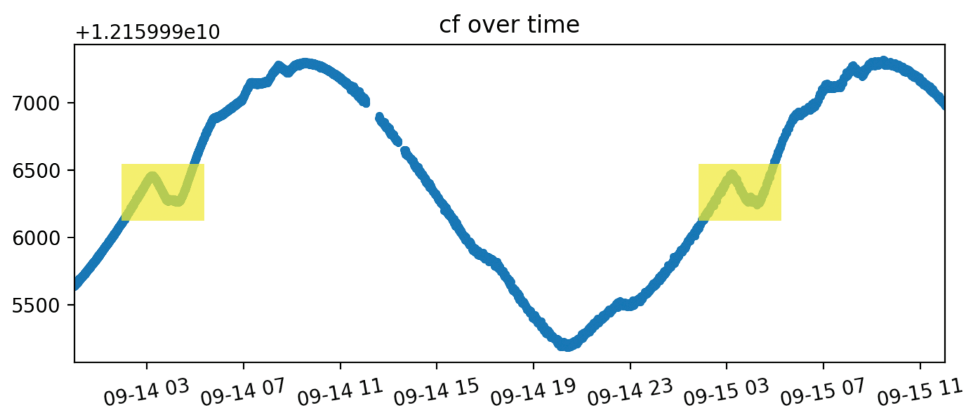
RF location updates like these, combined and correlated with optical and radar sensor data, help maintain the accuracy and currency of the space catalog for collision avoidance and safety of flight.

### Predictive Analytics to Uncover the Unexpected

Using machine learning and pattern recognition algorithms, RF data can be used to establish the normal, expected behaviors of space objects, such as routine station-keeping and the frequency of maneuvers. By monitoring deviations from these patterns, those that are atypical or anomalous can be detected and alerted for more pre-emptive threat awareness and space traffic management.

### RF Applications to SDA: Link Segment

RF measurement is the only SDA technique to offer insights about payload performance and status, that is: when systems are operating nominally, when they've changed or degraded and to what degree. Insight on payload use and the ability to detect and characterize the patterns in their use




*Doppler shifts detected in the RF signal of a satellite indicate its movement at specific times.*

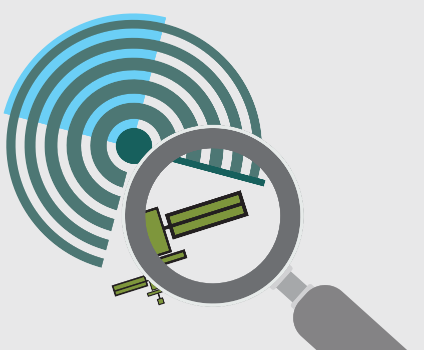
offers unique additive value absent from traditional sensor data.

### *Detecting Anomalies & Cause*

RF metrics can reveal the extent of a performance anomaly and its cause. For example, slow, gradual variations in normal baseline measures might indicate equipment wear or changes in user requirements. More sudden or severe RF signal deviations, on the other hand, may uncover a polarity issue, adjacent satellite interference, payload system failure, jamming or a directed energy attack. This ability to detect payload or other operational irregularities and their origin accelerates response and resolution. For example, operators would know whether to re-route traffic to bypass an equipment issue, or to focus efforts on geo-locating an unauthorized broadcaster to eliminate interference.

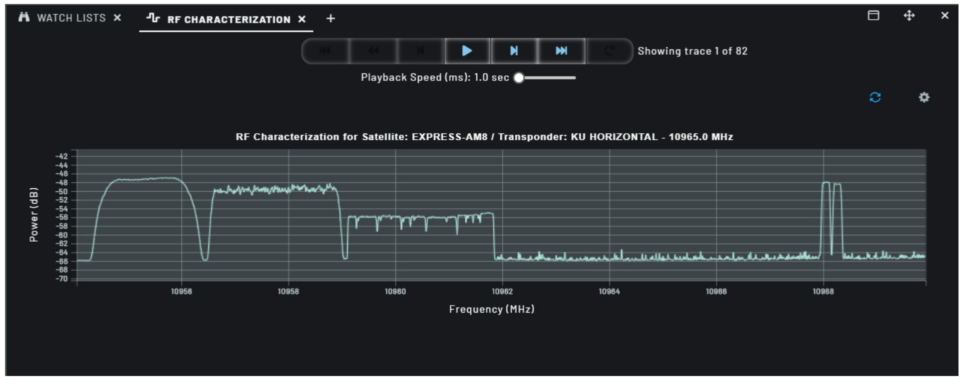
### *Insights on Satellite Use*

RF data about transponder and communication links provides a unique



## *The Power of Combined RF + Optical Sensors:*

*RF monitoring recently detected a performance anomaly, where all carrier traffic disappeared from a satellite's transponders. Optical sensors later visually confirmed field debris from an onboard event.*




*RF data is collected and analyzed over a period of time. This chart indicates activity following a satellite anomaly affecting the services of a global satellite operator.*

understanding of the amount, type, and nature of traffic on payloads. Metrics about a transponder's capacity and loading helps users and operators conduct more efficient payload operations. Additional signal characterization can help determine the nature of an asset's transmission, whether its mission supports video broadcast or UAV operations, for example, and whether a large spike in bandwidth and upload of a certain traffic type is an indication or warning.

### *Assessing Capabilities*

In addition to detecting performance issues, these insights also inform battle damage assessment. This helps characterize the capabilities of friendly, neutral, and enemy space systems, including the impact and effect of offensive or counterspace operations. For example, a transponder's change in signal power, carrier-to-noise, and symbol rate would reveal its reduced traffic-carrying capacity, and as a consequence, the satellite's diminished mission capabilities.

## *RF Applications to SDA: Terrestrial Segment*

RF monitoring immediately detects any disruption to satellite signals whether intentional or inadvertent and offers actionable insight about ground-based causes and resolution steps. While there are a realm of threats to satellites, accidental interference is the most common disruption. RF techniques can characterize, identify and locate the ground-based transmission source of interfering activities. The RF data contains clues which attribute the cause of interference to the congestion of proliferating VSAT terminals, mis-configured gateways, intruding signals from neighboring satellites, or the 'blue' or friendly interference that can often happen in naval fleets or on the battlefield. RF can also proactively measure the frequency 'noise' of an orbital slot prior to moving a satellite to it, so it can be adequately prepared to avoid subsequent interference.

### *Determining Cause & Intent*

RF techniques such as Time Difference of Arrival and Frequency Difference of Arrival are becoming increasingly more accurate, geo-locating interference to within a few kilometers. With additional signal characterization, using measures such as Modulation Type and Symbol Rate, the type of modem can be fingerprinted and the carrier identified to help narrow attribution to an entity or organization. In the case of inadvertent interference, resolution often entails simple coordination with an owner or operator to reconfigure an antenna or terminal; whereas intentional jamming


*Geolocation services leveraging a global sensor network provide worldwide awareness to satellite operators without additional CAPEX.*

can employ RF capabilities to mitigate and cancel out the interfering beam.

## Adding Value with Data Science and Algorithm Development

Just as RF methods have been honed over the years to support satellite mission performance and interference detection, new RF techniques are being developed to exploit its value for SDA. With the right analytics, machine learning, and artificial intelligence tools, skilled scientists and professionals can characterize RF data to identify the attributes of satellites, predict the maneuvers or actions they may undertake, and discern intentions.

For example:

- Machine learning applied to payload, usage, and maneuver data can detect anomalous conditions and patterns of interest.
- Long-term trending and characterizing of RF signals can establish patterns and changes in satellite and interference locations, including the terminal types, waveforms, and recurring violators involved.
- Analyzing payload performance baselines and systems status can identify the capabilities and status of friendly and adversary satellites.
- Automated classification of bandwidth use, transmission type, and timing can help identify satellite modems, payload activities, and attribute behavior.

This type of machine-speed data collection and analysis supports more predictive warning, extending lead times and knowledge for appropriate response. For example, early detection of satellite interference from RF, correlated with other events, such as cyber disruptions and upticks in social media activity, could indicate precursors of hostile actions by rogue states. Fusing these RF analytics with other sensor, open source, and intelligence data can provide decision-makers the information to get ahead of mission threats, such as triggering maneuvers to avert a collision, or to counter an expected RF attack.

## RF Advances SDA for a New Space Era

Space systems are exposed to a growing array of threats; from potential collisions and spectrum interference as more satellites are launched and activated, to adversaries developing new techniques to disrupt and disable US and ally space operations. These challenges have placed more urgency on advancing the timely, complete picture required of SDA.

Now with the unique capabilities of RF to persistently detect, locate, and characterize space systems, new levels of insight can be added beyond what's possible with traditional sensors and data. As space continues to undergo profound change, RF can enhance SDA to support the more predictive and pre-emptive posture needed for this new era.

### Unified Data Library (UDL) and Kratos

*Kratos global sensor network publishes Space Awareness Data directly into the Unified Data Library (UDL). Traditionally, military SDA data has been stored in isolated systems, limiting the operator's ability to access data needed for a mission. The UDL solves this problem by aggregating multiple data types from multiple data providers and creating a comprehensive picture of the space domain. Data access is securely controlled to feed relevant end-users, security classification levels, and mission domains. This architecture decreases unique interfaces and improves the efficiency of data capture, storage and dissemination.*

# Kratos SDA Services Fill the Gaps

## Supports Multi-Domain Command and Control (C2)

*Kratos operates the most extensive, fully-integrated, commercial global RF monitoring network, which has been helping government and commercial customers detect and resolve RF spectrum challenges for years. This custom developed infrastructure includes:*

- ***Global Sensor Network:** Kratos' extensive global network currently consists of over 20 worldwide RF monitoring sites, hosting more than 140 antennas in L, S, C, X and Ku bands. Using unique state-of-the-art sensors the network is tuned for high-speed, accurate RF signal collection and measurement.*

- ***Advanced Network Operations Center:** Kratos' 24/7/365 Network Operations Center (NOC) is the central hub for monitoring and integrating raw RF data from its global sensor network. The NOC incorporates automated workflows, tasking, and visualization that support Kratos' dedicated, experienced workforce skilled in RF spectrum management and SDA techniques.*

- ***Data Science & Algorithm Development:** Kratos' advanced analytics and AI tools process RF data for real-time SDA awareness, predictive insights, historical trending, and patterns of life. Fused and correlated with data from optical/radar/ terrestrial and space-based sensors, this provides more timely, accurate, and complete SDA.*

*Advanced technologies developed by and exclusive to Kratos have been integrated into all levels of this cutting-edge infrastructure, from custom algorithms employed in the sensor network, to industry-leading commercial applications used in the NOC for data monitoring, correlation and geolocation, to specially-developed analytics that provide the real meaning behind the raw data.*

*Underlying these capabilities, Kratos employs a robust cloud-based architecture, offering the highest levels of enterprise security, transport, and analytic computing to support global reach for SDA networking, analyses and data integration. Kratos helps you leverage a complete commercial enterprise infrastructure without the maintenance and operational costs and concerns.*

*Market leading products such as **Monics®**, **SatGuard®**, **satID®** and **Compass®** are integrated with specially developed analytics to create Enhanced SDA Services for both government and industry.*

*Enhanced RF SDA Services from Kratos include:*

- *Tracking and Maneuver Detection*
- *Signal Geolocation*
- *RF Signal Survey and Characterization*
- *RF Interference Mitigation*
- *Correlative/Predictive Analytics*
- *Bandwidth Utilization*

*For more information, contact: Space@KratosDefense.com.*

**Worldwide presence**
**L/S/C/X/Ku coverage**
**140+ sensors**
**20+ sites**

***Kratos' services are operated and powered by their own world-wide network.***

## About Kratos

Kratos Defense & Security Solutions, Inc. (NASDAQ:KTOS) develops transformative, affordable technology for the Department of Defense and commercial customers. Kratos is changing the way breakthrough technology for these industries are brought to market through proactive research and a streamlined development process. Kratos specializes in unmanned systems, satellite communications, cyber security/warfare, microwave electronics, missile defense, training and combat systems. For more information, go to www.KratosDefense.com.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