# EVENT DETECTION FROM RF SENSING

**Matthew Prechtel**
Kratos | RT Logic
mprechtel@rtlogic.com

## ABSTRACT

RF sensing is currently underutilized in today's Space Situational Awareness architectures. Providing RF situational awareness is critical to protecting C2 and mission data satellite links. According to Air Force Doctrine, SSA includes components of intelligence, surveillance, and reconnaissance (ISR), space environmental monitoring, and space warning functions.

Monitoring of the local RF environment near a ground station can aid in determining if the C2 links are being affected by unintentional or intentional interference. When interference is detected, analysis can characterize whether the signal is CW, broadband noise, or a modulated signal. By determining the type of interference, the ground system can avoid the contended frequency bands or switch to another ground system that is not affected thus providing resiliency in the ground enterprise. SATCOM monitoring, with examples of interference detection attributed to piracy and jammers along with mitigation techniques will be presented.

With respect to supporting Space Situational Awareness, there are primarily two technologies used to observe and measure and characterize Resident Space Objects (RSOs); ground based radar and optical telescopes. RF can also be used to measure and characterize RSOs. RF sensing is largely underutilized; however, identification of an event from a passive RF collection system that is intentionally monitoring a commercial SATCOM transponder or other transmitting RSO is useful. By observing changes in the frequency characteristics from RF sensors, direction of maneuvers can be inferred. Finally, machine learning (ML) has often been applied to imagery and image recognition; the application of ML to RF signal identification and characterization from SATCOM collections will be introduced reducing the complexity, cost, and training necessary to effectively deploy passive RF sensing in a comprehensive SSA strategy.

## INTRODUCTION

As space operations have become increasingly critical to applications, ranging from global communications and commerce to enabling defense and intelligence operations, RF Sensing and Space Situational Awareness (SSA) has taken on heightened importance. Given the rapid pace of developing threats and a more cluttered and collision-prone environment, SSA 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 SSA and RF Event Detection, filling in the gaps in traditional techniques. The addition of the RF data domain to SSA, which utilizes information from satellite signals, can provide a more thorough and predictive awareness of the space and RF environments.

## LIMITS OF TRADITIONAL SSA

Space Situational Awareness provides the foundation for all space doctrine, from protecting and defending space-based capabilities, to regulating spectrum, to de-conflicting space traffic, to battle damage assessment. This Common Operational Picture requires that SSA effectively detect objects, determine the intent of their activities, and identify all potential high-risk conjunctions and other threat behaviors.

 

As with any domain awareness, gaining an understanding of active space is predicated on completeness of information. To date, SSA has relied primarily on two main commercial sensor types for data; 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 radar systems can detect objects in geosynchronous (GEO) orbit (22,000 miles).

***Electro-Optical***, or telescopic observation, can image satellites in the geostationary 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.

In contrast, as the part of the electro-magnetic spectrum used by space systems to communicate, RF data can be used to fill in the gaps left by these traditional sensor types. RF adds a unique data domain to SSA, offering a wealth of information 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 signature can be used to immediately 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 malfunction. These RF capabilities fill the blind spots in existing sensors, while providing additional knowledge to enrich SSA.

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

## RF SENSING DATA

RF data is monitored and collected from satellite uplinks and downlinks from sensors and antennas networked worldwide in L, S, C, X, Ku, and Ka 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, bit rate, and modulation and much more. This RF data provides numerous insights on payload performance and status— when systems are operating nominally, when they've changed, been degraded, and to what degree. Insight on payload use, and the ability to detect and characterize the patterns in their use, offers unique additive value absent from traditional sensor data.

### *Interference, Geolocation & Attribution*

Continuous monitoring of satellite payload signals gives way to a rich data set that is used to understand the RF environment around every transmitting satellite. When interference is detected on a transponder channel, the RF data supports techniques such as Time Difference of Arrival and Frequency Difference of Arrival for geolocation purposes. Additional signal characterization that uses measures such as Modulation Type and Symbol Rate, can identify or fingerprint the type of modem and carrier to help narrow attribution to an entity or organization. In combination with other multi-domain data, such as mapping software, attribution can be further refined and accelerated. In the case where the monitoring data indicates inadvertent interference, resolution often entails simple coordination with an owner/operator to reconfigure an antenna or terminal; whereas intentional jamming can employ RF capabilities to cancel out the interfering beam. Sometimes, these sources of interference are nefarious at best. Exhibit 1 is an example of where an intentional jammer followed all active carriers in a monitored satellite communications channel. The actor used advanced techniques to monitor the bandwidth of active users and then placed narrowband power spikes centered on the authorized signals. This technique serves to saturate the user's receiver power system and deny access to the transmitted signal.

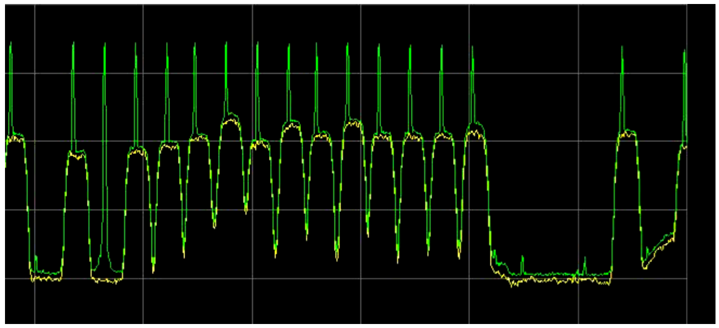

**Exhibit 1:** Intentional Jamming of SATCOM Users. In this particular case, the illegal action was attributable to a nation-state exercising and testing their capability to interfere with satellite communications. The ability to intelligently interfere with satellite communications has moved well beyond 1st world militaries such as China and Russia, and now exists in North Korea, Iran, and Syria and continues to proliferate in the third world often through the use of Russian made jamming equipment.

In addition to jamming, piracy is another example of misuse of satellite spectrum, as shown in the following two exhibits. The first exhibit is an example where Iraqi based pirates inserted a propaganda video broadcast on top of a Eutelsat authorized payload. The next exhibit shows the pirate narrow band video broadcast signal sitting on top of a wideband signal.

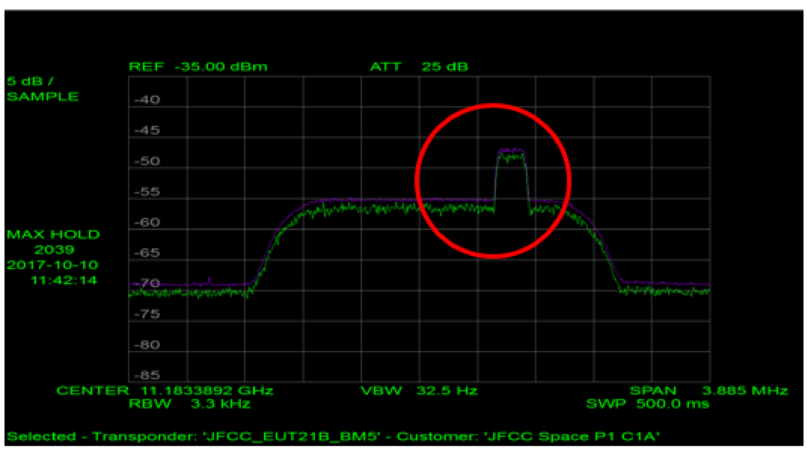


**Exhibit 2:** Pirate Signal on top of an Authorized SATCOM User. When a receiver was placed into the RF circuit and tuned to the center frequency of the pirate signal, the video from Exhibit 3 was obtained. The pirate realized very quickly that they were being monitored when the owner-operator blocked their pirate signal. Realizing the authorities were onto them, the pirate quickly disappeared from the channel before geo-location could occur.


**Exhibit 3:** Demodulated Pirate Video Broadcast. Piracy not only takes up leased bandwidth for illegal access, but also interferes with the authorized user by placing a high power carrier over top of the legitimate spectrum user, also denying the authorized user of their transmissions.

***Satellite Bandwidth Insights***

Whether the interference is intentional, piracy, or accidental, the monitoring and collection of RF data on spectrum usage becomes invaluable in identifying, attributing, and locating sources of interference. In addition, the RF data about transponder and communication links provides an understanding of the amount, type, and nature of traffic on payloads. Usage metrics, and data about a transponder's capacity and loading help users and operators conduct more efficient payload operations and management.

## DETECTION OF MANEUVERING SATELLITES

RF sensing and data collection has uses beyond SATCOM operations; RF data and the evaluations of signal externals can be used to help inform position and space activities of Resident Space Objects. Timely identification of a maneuver event from RF passive collection systems on geosynchronous vehicles is one example and important in informing the SSA mission area.

Satellites typically maneuver for small adjustments in station keeping or larger adjustments when changing orbital planes or other orbital parameters. In the SSA domain today, detection of a maneuvering geosynchronous satellite is difficult, as the primary means of doing so is from ground-based radars or optical telescopes. Often these resources are not available to support persistent monitoring, are unavailable during daytime, or are not geographically located where they can apply their capabilities. Passive RF sensors provide an excellent gap filling capability in that they are 24/7 capable and not affected by adverse weather.

During an experiment where EMI collection systems were processing differential frequency measurements from multiple antenna sources on a single satellite, a sudden shift in center frequency (observed Doppler) from all four of the collecting sensors was observed at the same time. The data plot in Exhibit 4 highlights a discontinuity in the Differential Frequency Offset (DFO) measurements that is indicative of the RSO applying its thrusters to maintain its orbital station.

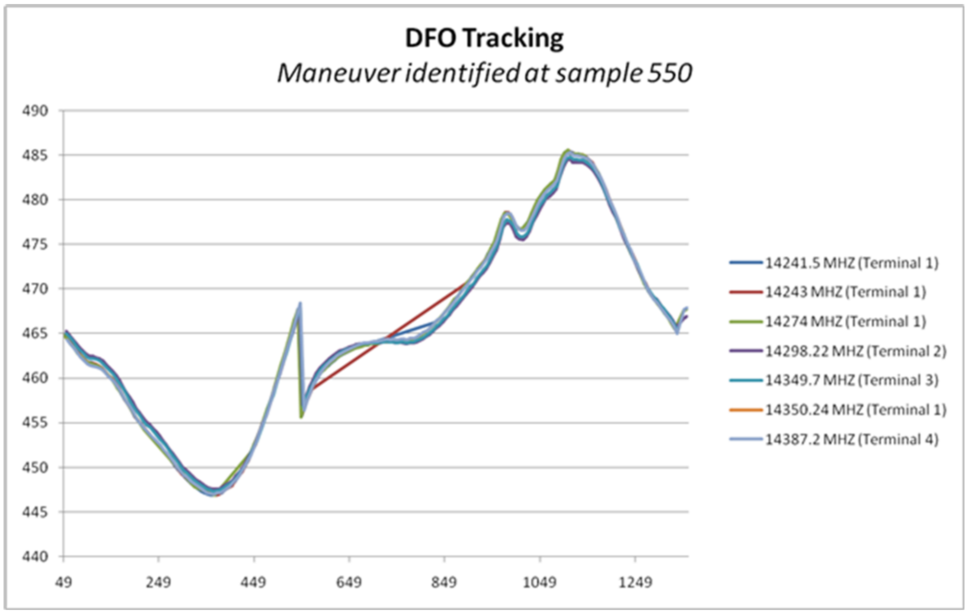


**Exhibit 4**: Maneuver Detection using Differential Frequency Offset Processing. This discontinuity was attributable to the Doppler induced along the range vector from the collecting systems to the maneuvering satellite. The experiment was later repeated with the intent of seeing whether the event was reproducible from observations collected from single antenna measurements. While multiple antennas were used, differential processing was not employed. Exhibit 5 contains the normalized center frequency observations for six individual carriers within a transponder plus a ranging signal (dark blue). The ranging signal (a spread spectrum transmitted signal over the observed satellite's payload channel) indicates a change in the measured range

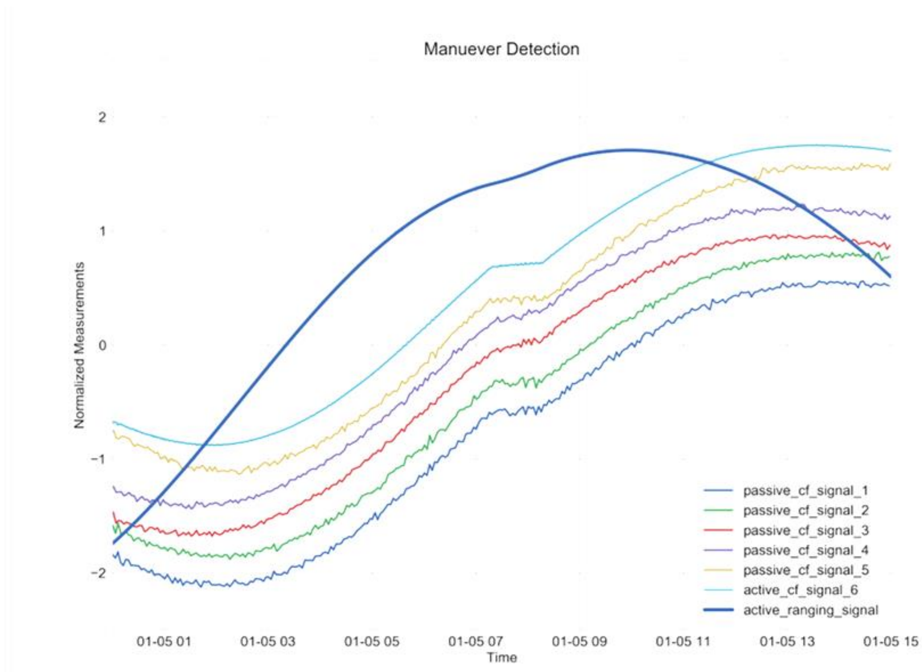


**Exhibit 5:** Maneuver Detection using Center Frequency Measurements. The observations in this chart reinforced that maneuvers are visible by a single antenna to which additional detection processing (analytics) are applied to provide indications of a maneuvering satellite.

## RF PATTERNS AND DATA ANALYTICS

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 SSA and RF situational awareness. With the right tools in the hands of skilled scientists and professionals, analytics, machine learning, and artificial intelligence can characterize RF data to identify the attributes of satellites, predict maneuvers or actions they may undertake, and discern intentions.

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

Kratos|RT Logic is actively applying analytics in support of:

- Machine learning applied to payload, usage, and maneuver data to detect anomalous conditions and patterns of interest.
- Long-term trending and characterizing of RF signals to 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 to 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.
- Integrating these event feeds with other sensor, open source, and intelligence data provides real time situational awareness of space system assets and events.

This type of machine-speed data collection and analysis supports more predictive warning, extending lead times and knowledge for appropriate response. For example, early patterns of satellite interference detected from RF SSA can be correlated with other events, such as cyber disruptions and upticks in social media activity, as precursors of hostile actions by rogue nation-states. Synthesizing RF-inclusive analytics with other data sources can provide decision-makers the information needed to get ahead of threats to missions, whether to trigger maneuvers to avert satellite collisions or to deploy waveforms to counter an expected RF attack.

### *Satellite Usage Classification*

RF data 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 certain traffic type is an indication or warning. This process of characterization falls into the category of spectrum classification. One approach at classification involves the clustering of similar signals into groups and then organizing them in such a way where their common features cluster them together. Exhibit 6 is a sample of RF spectrum waterfall collections along with preliminary clustering of the individual bursts of signal transmissions applied:

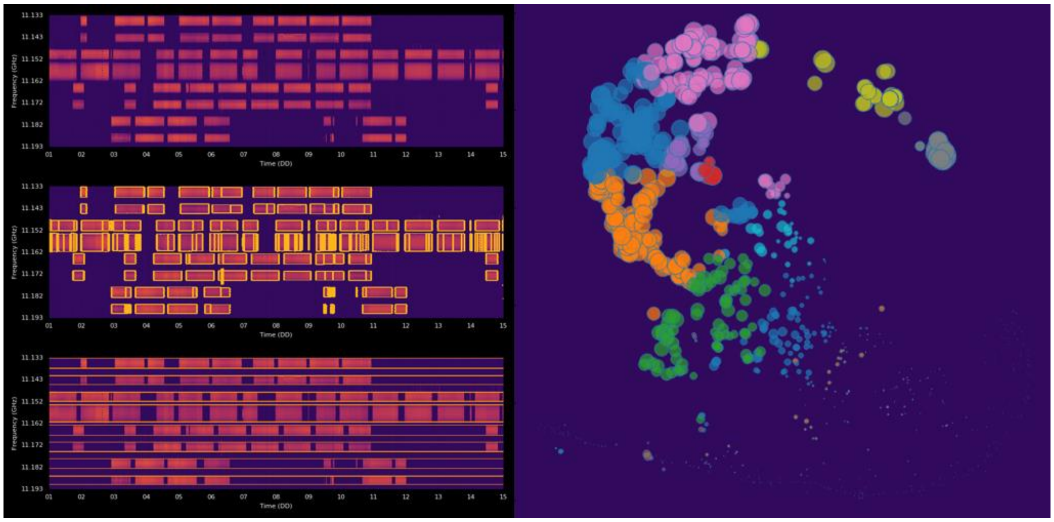

**Exhibit 6:** Satellite Usage Patterns. This clustering of the spectrum access uses machine learning algorithms and has the goal of being able to uniquely identify and label RF channel accesses that have the same sets of features. For example, if a particular type of unmanned aerial vehicle exhibits a particular RF signature, that signature can be decomposed into features (time, duration, center frequency, location, modulation type, etc.) and then labeled. Every occurrence of that label becomes searchable from a larger database of accesses and extractable for additional pattern recognition. The additional patterns may be correlated to operations tempo, troop deployments, global crisis, or predicators to missile test events. The end result is that the analytics and classification of spectrum give way to larger and broader understandings of global activities

***Anomaly Cause & Attribution***

RF performance metrics can detect and reveal the extent of an anomaly and its cause. Slow, gradual variations in normal baseline measures might indicate equipment wear or changes in user requirements. More sudden or severe RF signal deviations may uncover a polarity issue, adjacent satellite interference, payload system failure, jamming or a directed energy attack. The ability to detect payload 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 mitigate interference.

One recent and highly relevant example of how RF supports anomaly detection was the June 2017 catastrophic event that befell SES's AMC-9 satellite. RF sensing systems detected a complete de-allocation of carriers near simultaneously across the satellites transponders. The waterfall plot in Exhibit 7 demonstrates this sudden departure from active carriers.

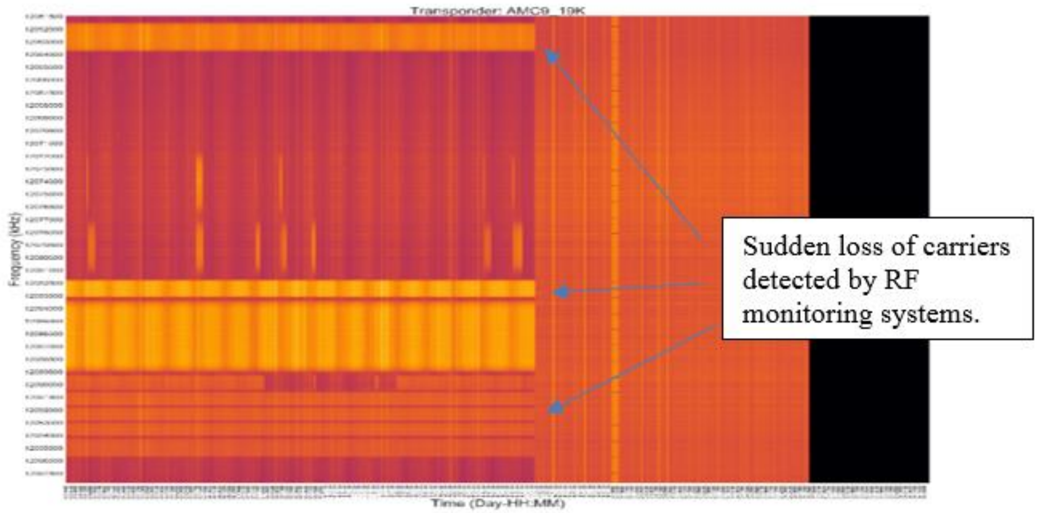


**Exhibit 7:** AMC-9 Catastrophic Loss of Carriers. The event was later collaborated with optical telescope observations though the RF observations were one of the first indications of the satellite experiencing issues. In this case, the event occurred at nighttime which allowed telescopes to collect immediately. However, had this event occurred during sun exclusion times, hours would have passed before optical systems could report on the event. RF sensing, when combined with analytics provides an immediate notification of an anomaly.

## CONCLUSION

RF sensing is an important means to understanding the RF and space environments such that users of space can have the insight they need to operate safely in an increasingly contested and congested space environment. RF sensing serves an important role in augmenting other sensors types in the understanding of SSA as a third and complementary phenomenology to existing optical and radar systems. This paper has described summarized details around electromagnetic interference from hostile operators and pirates, the ability for RF sensing to identify maneuvering satellites, classification of RF spectrum use, and anomaly event detection. The common element for these activities is the sensing and collection of RF data from passive collection systems. By collecting, processing, and analyzing rich data sets of RF data, the space environment and RF environments are raised to new levels of awareness.