CGMS Agency Best Practices in Planning, Monitoring, Mitigating, and Removing Radio Frequency Interference in Data Collection Systems (DCSs)

For endorsement by CGMS-54, 4 June 2026

v1.5, Final Draft, 13 April 2026

Document Change Record

Issue / Revision	*Date*	*DCN. No*	*Summary of Changes*
Final Draft, revision 1.5	23Apr26		

TABLE OF CONTENTS

1. INTRODUCTION

This document presents the CGMS agency discussion and best practices (BP) to address Radio Frequency Interference (RFI) through the lifecycle of a satellite-based Data Collection System (DCS) that relies on radio spectrum to relay data. The discussion in the document primarily refers to a DCS with terrestrial, in-situ, data collections platforms (DCPs) that send information via radio frequency (RF) to a geostationary satellite, which in turn, sends that information back to earth ground stations. For simplicity's sake this document will refer to the system as a DCS, but the discussion and best practices may be applicable to other radio-based data communication systems as well.

RFI, as discussed in this paper, refers to any human (anthropogenic) or natural caused electromagnetic energy (e.g. due to space weather) that negatively affects the desired performance of a system. The scope of this "best practice" document includes the end-to-end movement of data through the system from a terrestrial data collection source to ingestion of a terrestrial data distribution system via satellite relay. These best practices exclude interference that may occur directly to sensors at the data collection point and interference that may occur in systems that are part of the downstream data distribution capability. These best practices may apply to multiple components of any data collection system and supporting subsystems, depending on the overarching infrastructure. Note that this document does not consider interference from a source with the intent to intentionally disrupt communication.

This document is organized into the following sections:

- Planning for RFI in system design
- Implementing system monitoring and RFI identification in system operations
- Characterizing RFI and Communicating the impact of RFI
- Mitigating RFI
- Removing RFI

2. Planning for Radio Frequency Interference in System Design

Considering RFI From a Satellite Communication Model Perspective

It is useful to consider standard communication models and where interference may be present when designing a satellite-based data communication system. For example, the Shannon-Weaver[1] model of communication, figure 1, can provide a starting point of identifying the elements of a satellite data collection system and then be amended to omit or add relevant components.

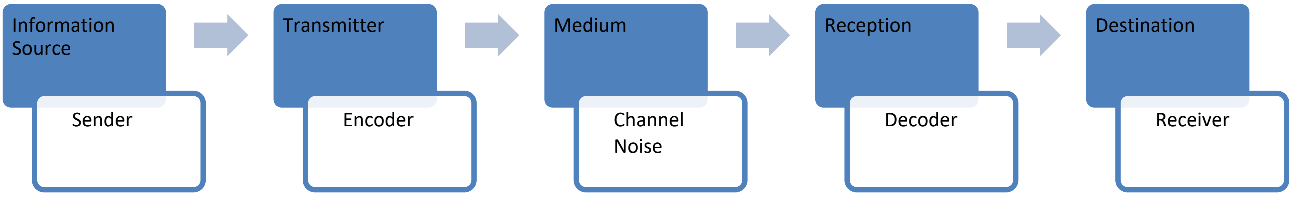

Figure 1 – Basic Shannon-Weaver Model of Communication

This model modified for satellite relay data communication, figure 2, can assist in identifying specific attributes of each component to view the communication model from an RFI perspective.

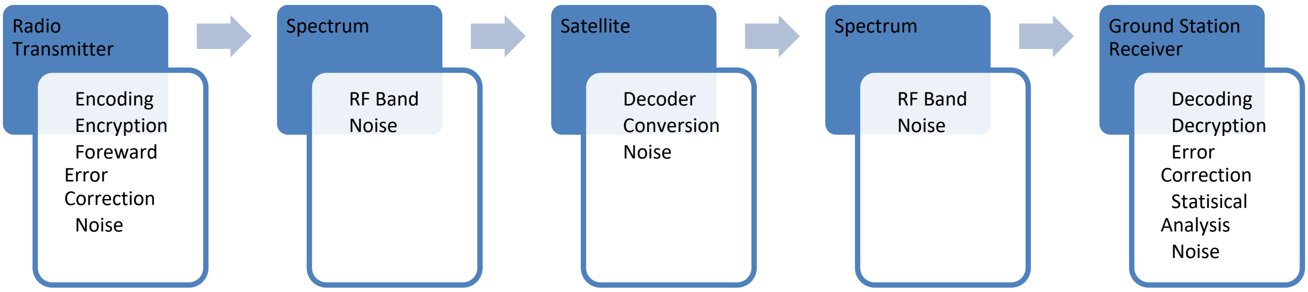

Figure 2 - Shannon-Weaver Model Modified for Satellite Communication

Of the many variables to address in this communication process the satellite vehicle and spectrum frequencies (uplink and downlink) are paramount. The ability to influence a satellite vehicle design has a limited window of time for it to be made. The ability to modify satellite hardware after launch is unlikely or impossible. Decisions on selecting radio spectrum architectures are typically conducted as part of satellite design as well. Spectrum is finite, advocating for the best performing spectrum for the application should be done during satellite design and approval. A DCS operator needs to take an active part in satellite acquisition to ensure that RFI is factored into system design and spectrum filing.

RFI planning for the rest of the communication system becomes more tangible once the satellite vehicle and approved spectrum are known. Spectrum assignments will drive radio transmitter and satellite ground receiver designs. Spectrum assignments will also result in knowledge of other *known* operations in the same or adjacent bands and whether spectrum sharing will be required. This information may also influence what type of signal modulation and communication techniques are the most applicable or best performing.

[1] Shannon, C. E. and Weaver, W., 1949. The Mathematical Theory of Communication, Urbana: University of Illinois Press

Planning for RFI in design should be a recursive effort. Once a variable or capability has been addressed in one component of the chain of communication, the impact to the others should be assessed.

The final key component in RFI planning for a DCS system to include performance monitoring. The DCS operator needs to have the ability to identify what is considered nominal performance and what is considered degraded performance.

DCS monitoring can be grouped into at least three categories: monitoring the performance of the supporting infrastructure, monitoring the data, and monitoring the spectrum. The DCS monitoring system should be capable of monitoring individual components and generating useful statistics or metadata regarding the data flow. Spectrum monitoring in the uplink and downlink RF bands is a critical capability when it comes to identifying and confirming RFI and should be considered a fundamental requirement when planning for RFI in monitoring system design.

Specific Design Considerations and Discussion

Radio Transmitter - Many of the techniques to mitigate RFI start at the transmitter itself. There are several attributes that should be considered when planning for design:

- The transmitter should be designed and built to industry standards that prevent the transmitter from interfering with itself or external receivers. Spurious emissions, grounding, filtering, stable oscillators, etc. are all part standard industry practice, but should be confirmed with a design specification for the data communication system and verification process by the DCS operator.
- The transmitter should be designed with the ability to have parameters reprogrammed without significant hardware changes to adapt to new RFI avoidance techniques. DCS data collection platforms (DCP) are widely distributed and subject to the resource limitations of the DCP operator. Firmware or software updates can be performed at minimal cost during routine maintenance. Hardware changes may take months or years, which may be infeasible system wide.
- If possible, the transmitter should have remote commanding capability, also referred to as backhaul, to perform remote configuration changes (e.g. broadcast time changes, channel changes, etc.) to avoid or mitigate RFI.
- The transmitter should send data on its performance, configuration, location, or other important data, so it can be remotely monitored. Each transmission provides the opportunity to obtain information about the communications signal path in addition to the actual data being transmitted. A malfunctioning DCP can cause RFI, and some malfunctions can be predicted, as opposed to operating to a failure mode, if transmitter performance can be monitored.

Spectrum (Uplink and Downlink) – the frequency band allocated for the communication system is critical for system design.

- Planning should ensure that operational requirements, mission parameters, etc. can be met in the planned spectrum assignment.
- The design should consider spectrum limitations related to approval as a primary user, shared users, or secondary user.

Satellite – satellites, especially geostationary satellites with a near hemispheric field of view, can receive RFI from multiple locations.

- The satellite receiver design should consider signal selectivity, signal rejection, and other RF attributes to maximize the reception of desired signals and exclude undesired signals.
- The satellite design should consider space weather effects.
- Satellite planning should include multiple data paths (e.g. multiple satellites, satellite-to-satellite relays, rebroadcasts, etc.) to avoid single data path points of failure.
- The satellite should be designed so the original uplink signal can be analysed via the downlink signal (transparent transponder).

Ground Station Receiver and Operational Support –

- The receiver demodulation system should reject pure RF energy that does not comply with the communication modulation or protocol scheme(s).
- The receiver demodulation system should be designed with the flexibility to have parameters programmed to adapt to new RFI avoidance techniques.
- The downlink and demodulation system should be designed to process metadata about each specific message to help characterize the spectrum and system performance during the time of the broadcast. For example, signal strength, signal variability, signal timing, data corruption, etc.
- The DCS operator should plan for the need to obtain RFI geolocation services for the spectrum in which it operates.
- The DCS system should have a full development system for end-to-end testing of system updates related to RFI. The scope of system update should include all components from the DCP to the data dissemination point.

Signal Modulation, Communication Protocols, and Spectrum Management Techniques - Modulation and communication protocols can vary widely based on the application, available spectrum bandwidth, data size, broadcast time, etc. RFI risk should be considered when a modulation and communication protocols are selected.

- Modern, low-power microprocessors and GNSS timing are now readily available and may be feasible for more robust communication available for transmitter applications.

DCS planning for RFI should include market research on the state of technology to update transmitter specifications to take advantage of new RFI-resistant capability.

- Multiple communication protocols should be considered, as opposed to a single solution, in order to expand system user options to mitigate RFI in various scenarios. Various types of modulation, error correction, data rates, etc. should be reviewed.
- RFI planning should include spectrum management techniques that include such things as limiting broadcast lengths, providing alternate broadcast channels, authorizing redundant/repeated message transmissions or other techniques that strategically avoid high probability RFI.

Performance Monitoring - Baselines of normal performance need to be identified so that any abnormal performance can be identified.

- The ground-receive station and operational support should be able to monitor the individual system components and overall performance.
- The ground-receive station and operational support should be able to monitor the data communication stream to identify data loss, interruptions, and analyse signal metrics that allow analysis of data flow.
- The ground receive station should have spectrum monitoring to identify and capture signal characteristics from local RFI senses at the satellite and RFI local to the ground-receive station interference. Monitoring should have extended storage capability so that historical analysis can be conducted and RFI trends can be identified.
- Planning for RFI should include allocating resources and capability to make data analysis and RFI response effective. For example, a system can capture all the necessary performance data but if there are not proficient personnel to interpret the data, dealing with RFI may be difficult. Likewise, a highly automated system that is easy to use is only effective when there are personnel resources to take action on the information. The quantity of data for a DCS lends itself to the application of Artificial Intelligence/Machine Learning. The merger of current system performance metrics with spectrum In-Phase Quadrature (IQ) data offers significant potential for DCS RFI monitoring.

Best Practices

DCS RFI Best Practices for Planning for RFI in System Design	
DCS RFI BP 1.1	
DCS RFC BP 1.2	

3. Monitoring System Operations and Identifying RFI

Total system monitoring is complex and has a wide range of different monitoring systems located throughout the satellite system architecture and won't be discussed further in this document. With respect to the DCS, the DCS operator should monitor what parts of the system are nominal and what parts may be degraded in performance and data. Satellite communication systems are IT intensive so there are a number of connectivity, software or hardware issues that contribute to data loss. An operator must be able to assess the status of the DCS to deduce that the cause of data loss is coming from outside the system.

The following list of attributes supports monitoring and identification of RFI:

- Dedicated monitoring (automated or human) that detects data loss or corruption and allows the monitor to conclude the communication system itself (i.e. satellite, receiver, etc.) is not the source.
- Data communication metrics, statistics, or dashboards that provide details on the expected signals and stores that data for analysis.
- Spectrum data, storage, and analytical tools that allow the DCS operator to confirm the presence of non-DCS RF energy in the DCS RF spectrum and correlate that data to system performance metrics. Analytical tools should have the ability to provide rapid, system-wide analysis as well as highly specific analytical capability on the performance of individual DCPs, channels, users, etc. This system should include the ability to identify and isolate RFI trends over time that are useful for RFI mitigation and removal activities discussed in sections 5 and 6 of this document.
- Geolocation or Radio Direction Finding capability. This may not be part of the data communication system, but this capability may be necessary for locating the source of RFI.

DCS RFI Best Practices for Planning for RFI in System Design	
DCS RFI BP 2.1	
DCS RFC BP 2.2	

4. Characterizing RFI and Communication Impact

Once RFI has been identified, the next step is to gather all the signal information and characterize it in a way it can be communicated to the appropriate entities. These entities may include the communication system organization, the data user or a regulator.

Characterizing RFI

Data needed to characterize an RFI signal may vary by organization. The International Telecommunication Union (ITU) Satellite Interference Reporting and Resolution System (SIRRS) provides an excellent source for what information is needed to file a report and would be useful both in communicating the impact and identifying what data you should capture during normal monitoring (see section 3 above). This information includes but is not limited to the following:

- Station causing interference, if known, with details on the source and measured signal characteristics and location
- Station interfered with and the interfering scenario (e.g. uplink or downlink) along with location
- Frequency Assignments
- Supporting documentation (scan plots, geolocation plots, etc.)

Geolocation services need to know what to look for as well as when to look for it. Characterizing RFI in the greatest detail possible and developing patterns on RFI is important when trying to obtain geo-location services.

Communicating the Impact of RFI

The initial report of RFI within an organization will likely need to have enough information to confirm the presence of RFI and to communicate the resulting impact of data loss. In proceeding with the RFI reporting process, determining the location and source of the RFI may be time consuming and expensive. In some cases, data loss may be reported by the users themselves. In these cases, after confirming the issue is not related to the transmitter or the satellite communication infrastructure, it is important to document the impact of RFI to the user's operations.

The DCS operator should use their organizational reporting process to initiate an RFI report. This process may lead to various external spectrum organizations. It is important to note that in any event the location or source of interference is the most critical piece of information. Spectrum regulators may not be able to report or support the DCS administrator if the source and location of RFI is unknown. This highlights the importance of system monitoring and RFI detection capabilities as discussed here and in section 3.

Unreported RFI is equivalent to "no RFI" in the eyes of a regulatory body.

DCS RFI Best Practices for Planning for RFI in System Design	
DCS RFI BP 3.1	
DCS RFC BP 3.2	

5. Mitigating RFI

Mitigation is focused on limiting data loss by changing behavior, implementing updates, or seeking alternatives to the existing data communication system while RFI is still present. The DCS operator should look at every aspect of the communication model to ascertain what components have the capacity for mitigation actions. In some RFI cases mitigation may be the only option available because RFI removal is impossible. The following list includes some potential mitigations to consider:

- Optimize transmitter operators or change transmitter behaviour. The DCP operator should confirm the DCP is operating at peak performance. Repointing the antenna, verifying transmitter power, or updating to a more modern DCP model might optimize performance. Employing alternative broadcast times, redundant broadcasts, channel selection or selecting a different communication protocol might avoid or mitigate the impact of RFI.

- Implement new transmitter technology or communication protocol improvements based on the state of current technology beyond the original design (e.g. error correction, more robust modulation)
- Increase data paths. Transmitters may reach multiple satellites with redundant downlinks that could be demodulated and added to the data stream. Supplementary or complementary commercial services may be available.
- Employ improved digital signal processing to recover data
- If the RFI source has been identified and it is possible to establish communication, explore any options where the RFI source can change its operation to deconflict with the DCS operations. This may not result in removal of the RFI, but it may result in both operators coexisting without affecting system performance.

DCS RFI Best Practices for Planning for RFI in System Design	
DCS RFI BP 4.1	
DCS RFC BP 4.2	

6. Removing RFI

RFI may be removed as part of the formal regulatory process or as the result of a more informal process. This document cannot provide examples for the myriad RFI scenarios but removing RFI will likely require three components:

1. A clearly characterized signal that shows the signal negatively impacts operations. This impact is particularly important if it involves life and property protection.
2. A high degree of certainty of where the signal is and who is the operator
3. Organizational relationships that foster change to the RFI signal

Paragraph bullet one and two of this section have been covered in this document sections two through four. This section will focus on bullet three.

When the DCS operator reaches the stage where they are attempting to remove RFI, it is highly likely that they know where it is coming from or who is operating the signal, or both. The organizational relationship between the DCS spectrum administrator and the RFI source may result in forced compliance via regulatory or legal action. In those cases, the DCS operator may have a role limited to submitting an interference report and providing supporting analysis.

In other scenarios there may be no need to involve the regulator by the DCS operator. For example, NOAA has found several international RFI sources that were unaware their operation was causing interference and were operating well within their national spectrum rules. In those cases, an informal and collaborative approach can be effective in influencing a change in the operations of an RFI source, particularly if the impact to the DCS is critical for safety of life and property.

A DCS operator or spectrum manager may have both formal and informal organizational relationship options with operators of an RFI source. It is recommended that a direct and informal engagement strategy be utilized if possible and permissible. When an RFI source is located, and if conditions permit, a radio system operator to radio system operator engagement may be the fastest and most effective way to remove the RFI.

DCS RFI Best Practices for Planning for RFI in System Design	
DCS RFI BP 5.1	
DCS RFC BP 5.2	

7. Conclusion

These best practices demonstrate and characterize a comprehensive, lifecycle-based framework for managing RFI in satellite-based DCS. It establishes that ensuring operational resilience is not merely a reactive task, but a strategic imperative that must be integrated from the initial system design through ongoing operations and response. The best practices outlined across the key stages—planning, monitoring, characterization, mitigation, and removal—equip system operators and designers with a structured methodology to proactively address and resolve interference.

A core takeaway is that a proactive posture during the design phase is the most effective and cost-efficient strategy for managing RFI. By embedding robust monitoring capabilities, flexible hardware and software, and sound spectrum management techniques into the system architecture from the outset, operators are better positioned to detect, analyze, and counteract interference events. The document underscores that capabilities such as spectrum monitoring and geolocation are not auxiliary functions but fundamental requirements for maintaining data integrity.

Ultimately, the strategies presented serve as a vital blueprint for ensuring the reliability and long-term viability of critical data collection services in an increasingly congested and contested radio spectrum. By adopting this holistic approach, organizations can move from a position of simply reacting to data loss to one of actively managing the RF environment, thereby safeguarding mission-critical data flow and enhancing overall system performance. The successful removal of RFI, as highlighted, often depends as much on well-established organizational relationships and clear communication as it does on technical characterization.

Enclosure