Radio Frequency Interference Protection of Communications Between the Deep Space Network and Deep Space Flight Projects

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The increasing density of electrical and electronic circuits in Deep Space Station systems for computation, control, and numerous related functions has combined with the extension of system performance requirements calling for higher speed circuitry along with broader bandwidths. This has progressively increased the number of potential sources of radio frequency interference (RFI) inside the stations. Also, the extension of spectrum usage both in power and frequency as well as the greater density of usage at all frequencies for national and international satellite communications, space research, earth resource operations and defense, and particularly the huge expansion of airborne electronic warfare (EW) and electronic countermeasures (ECM) operations in the Mojave area have greatly increased the potential number and severity of radio frequency interference incidents. This article describes the various facets of this problem and the efforts to eliminate or minimize the impact of interference on Deep Space Network support of deep space flight projects.

I. Introduction

At the inception of the Deep Space Network (DSN), one of the prime criteria considered in the location of a network communications station was the requirement for a completely radio frequency (RF) noise free environment. In the past several years the DSN capability to operate at progressively weaker signal levels, coupled with the greater use of the entire radio frequency spectrum by aircraft, satellites, etc., has resulted in an increasing number of radio frequency interference (RFI) incidents experienced by the Network. At the Goldstone Deep Space Communications Complex (Mojave desert, California), the DSN currently operates what are probably the most sensitive receivers and antennas in the world to extract intelligence from extremely weak radio signals. When it is realized that the Goldstone Complex is located in the center of one of the largest restricted areas in the United States, which is now used as a test and proving ground for intensive operations of the most sophisticated electronic warfare (EW) and electronic countermeasures (ECM) equipment specifically designed to prevent intelligence from being extracted from any radio/radar signals, it is surprising that the Deep Space Stations can operate at all.

Other common sources of RFI to the Network are military and civil aircraft communications and navigation transmitters, point-to-point microwave links, military ground radars and vehicles, military and other earth-orbiting satellites, as well as interference generated inside the Network Complex or the Deep Space Station (DSS) itself.

II. United States Department of Defense and Goldstone Complex Compatible Operations

The original selection of Goldstone, in 1958, as the site for the NASA/JPL/DSN communication stations was influenced mainly by the remote location in valleys which were out of the "line of sight" of any other manmade dwellings or structures. The closest domestic dwellings were over 80 km away, and the barren desert terrain, in the Ft. Irwin restricted area, made the building of new domestic or commercial radio noise sources a very remote possibility. The Department of Defense (DOD) activities at that time consisted mainly of occasional ground vehicle and troop exercises at Ft. Irwin, sporadic aircraft bombing and gunnery exercises at Edwards Air Force Base (EAFB) and China Lake Naval Weapons Center gunnery and bombing ranges.

The 20 years between 1958 and 1978 saw a vast change in the Mojave area activities. The very reasons NASA used in selecting the Goldstone location were the same reasons used by DOD to move the bulk of their research and development, testing and training to the same area. The result was that the number and scope of the defense exercises increased as did the number and severity of interference incidents at the Goldstone complex. On many occasions, visiting aircraft using the ranges were not even aware of the existence of the Goldstone complex and inadvertently radiated the stations.

The big problem, however, was that the DSN did not have the communications, points of contact or monitoring equipment to determine what the interfering source was, and each interference event ended on many occasions in numerous fruitless phone calls trying to identify the culprit. These exercises also uncovered the fact that the Network was often not the only victim and that interference between the various branches of DOD was becoming more prevalent.

In December 1978, a Memorandum of Understanding was signed by DOD and NASA. Summarizing, the memorandum states in part:

"a. DOD and NASA jointly will:

(1) Establish a Mojave Coordinating Group (MCG), with DOD and NASA membership, for operational coordination, scheduling, and problem resolution."

It also states in part that . . . "NASA will:

c. (4) Pursue a program to reduce the electromagnetic interference susceptibility of the Goldstone facility.

(5) Pursue a program to enhance the capability to detect, classify, and identify electromagnetic interference."

The Mojave Coordinating Group was formed and composed of representatives from each of the military bases and ranges, NASA, JPL, Goldstone Deep Space Communications Complex, Department of Energy (DOE), Federal Aviation Authority (FAA), and the Electromagnetic Compatibility Analysis Center (ECAC). The MCG meets at six-week intervals to coordinate DOD and NASA scheduled events to ensure compatible, interference-free operations in the area. During 1979-1980 the MCG has proved to be extremely effective, as demonstrated during the last three quarters of 1980 when relatively few interference events occurred during routine spacecraft cruise operations and no interference was experienced during any critical or semicritical operations.

The functions of the MCG, the classification of DSN events, and the analysis and real-time coordination of RFI events are dealt with in some detail in Ref. 1.

III. Radio Spectrum Surveillance Station

A. Background

In mid 1978, prior to the signing of the NASA-DOD Memorandum of Understanding, the RFI situation at Goldstone indicated a strong requirement for some form of monitoring or detection of interference signals to facilitate their identification and prevent their recurrence.

A relatively small, low-cost surveillance station was designed, built, and installed at Goldstone. The initial installation consisted basically of a rotating horn antenna, mounted on top of the Goldstone 26-meter antenna station collimation tower. The tower, approximately 4 km from the 26-meter site and normally used as a calibration target for the station, is located on a hilltop overlooking the Complex and surrounding area. The antenna was connected to a preamplifier, downconverter and spectrum analyzer at the collimation tower site. This original model was equipped with a camera which was triggered whenever a signal was observed above a preset amplitude threshold. Each time the camera was triggered, the time and azimuth were recorded on the photo, and a counter in the Frequency Coordinator's office at the 26-meter station site was updated.

B. Operations

The prototype radio spectrum surveillance station became operational in late 1978 and immediately proved to be an extremely effective tool to detect and identify interfering signals, particularly when the spectrum photos were used in conjunction with the MCG meetings. On many occasions, a group member could identify the interfering signal source as coming from a particular aircraft, emitter, frequency and operational mode. The type of aircraft and configuration would then be listed as a definite DSN interference threat with the understanding that future scheduled operations would be coordinated with the DSN operations to prevent a recurrence. Spectra not identified by the MCG would be submitted to the Electromagnetic Compatibility Analysis Center for identification by their Annapolis computer facility; results were reported back to the MCG.

On many occasions, Defense Department agencies were subjected to the same interference as the DSN. When identified, the interference proved to have originated either unknowingly from one of the Mojave agencies' equipment (spurious, harmonics, etc.) or from agencies outside the Mojave area, sometimes hundreds of miles from Goldstone. Thus the Surveillance System has proved to be beneficial to the total Mojave Coordination Group membership and has resulted in a much closer working relationship within the group.

C. Radio Spectrum Surveillance System Enhancement

As noted above, the prototype Radio Spectrum Surveillance System was equipped with a camera to record an event. This was effective but extremely cumbersome and time consuming. When the counter updated (indicating the receipt of an interference event) or RFI was experienced at a station, or both, the Interference Coordinator would drive to the collimation tower site, remove the film cassette, and have it developed and printed before he could start to analyze and identify it.

In early 1979, a Radio Spectrum Surveillance System redesign was initiated to enhance system capabilities. Redesign was completed in mid-1979 and currently the radio spectrum analyzer signal is converted to a digital format, automatically transmitted to the 26-meter site, stored on magnetic tape and printed on a hard copy page print. It can be replayed and displayed on a cathode ray tube or printed on a page printer. The system was moved from the collimation tower site, to a more suitable location, previously occupied by a surveillance radar installation.

A decision will be reached in 1982 as to whether the final model will also be installed at the overseas DSN Complexes. A very detailed technical description of the Radio Spectrum Surveillance System is contained in Ref. 2.

IV. Deep Space Network Susceptibility to Radio Frequency Interference

A. Background

The DSN S-band masers are intended to support spacecraft downlinks in the *deep space only* portion of the S-band spectrum between 2290 and 2300 MHz. However, they were originally designed to also accommodate Apollo mission frequencies from 2270 to 2290 MHz. As DSN spacecraft downlinks usually operate at extremely low received signal power, the ground stations are very susceptible to interference not only from other in-band signals but also from some specific out-of-band signals. Previous analysis has discovered that RFI at several out-of-band frequencies can resonate with the maser pump and cause in-band interference. The problem to date has been most severe at S-band but with the increasing use of X-band, the problem is expected to increase with time at the higher frequencies.

It should be borne in mind that in the current Memorandum of Understanding with the Department of Defense, NASA agreed to substantially decrease the DSN susceptibility to RFI.

B. Cryogenic Filters

Current thinking is that the best approach to this problem is to design some form of RF filter to reject any other signals except the spacecraft downlink signal of interest at any given time. In late 1979 funding was made available to initiate an R&D task to produce a design for:

(1) Fixed passband filters ahead of the masers to avoid in-band interference caused indirectly by interfering sources whose prime frequency is outside the maser passband.

(2) Tunable bandpass filters ahead of the masers to reject interference signals inside the maser pass band. Both types of filter must be cryogenically cooled to avoid raising the system noise temperature and degrading the receiver threshold.

Work is presently concentrated on yttrium iron garnet (YIG) wafer filters and involves one engineer at JPL and one at MIT. However, this is very much in the field of new technology and an answer as to whether or not low-loss, cooled YIG filters are feasible will not be known until late 1981 at the earliest.

V. Deep Space Network Radio Frequency Interference from Non-Deep-Space Sources

A. Background

The S-band spectrum from 2290 to 2300 MHz is allocated to deep space only downlinks by the International Telecommunications Union (ITU) and the Consultative Committee for

International Radio (CCIR) with deep space defined as lunar distance from earth and beyond. The 2200 to 2290 MHz portion is shared by many users including earth-orbiting satellite downlinks used for space operations and research. This includes government uses such as military satellite communications, military surveillance, earth resources satellites as well as terrestrial fixed and mobile communications, and aircraft electronic warfare, electronic countermeasures and telemetry.

Most of these downlinks are comparatively powerful, with the signal strength at times in excess of −90 dBm at the output of a DSN 64-meter (62 dBi gain at S-band) antenna on boresight. So although a satellite may be radiating on a center frequency outside the deep space spectrum, its associated harmonics, subcarriers and spurious radiation often fall within the deep space band at a level much stronger than the spacecraft earth-received signal.

The effort expended by JPL in the field of RFI avoidance is intended to ensure that no interference is experienced by the DSN during mission-critical or semicritical events, and that interference during routine operations is minimized or coordinated so as to minimize the impact on operations.

The terms "critical" and "semicritical" are often referred to in the following text so they are defined here for better understanding:

Critical or Class I events are of such science-mission importance that failure to execute them exactly as planned would result in catastrophic loss of scientifically unique data or destruction of the spacecraft with complete or near-complete failure to meet the mission objectives. Class I (critical) events are typically of short duration (hours), though longer periods are possible, and are inflexibly fixed in time dictated by launch constraints or celestial geometry, e.g., planetary flyby, planetary landing, launch critical pass.

Semicritical or Class II events are extremely important in terms of science-mission objectives and are defined as periods when loss or interruption of communications with the spacecraft could severely impact the mission objectives or cause extended disorientation of the spacecraft. Class II (semicritical) events fall into two main categories: (1) relatively long periods (days or hours) prior to and immediately following a Class I critical flyby or landing, and (2) relatively short periods required to execute a station-keeping or trajectory correction maneuver. In the case of Class IIA, it is sometimes possible to move sequences within the total period, if necessary, to avoid predicted interference, or in the case of Class IIB, to reschedule the entire event.

B. Deep Space Network Radio Frequency Interference from Earth-Orbiting Satellites Supported by the NASA Goddard Space Flight Center, Space Tracking and Data Network

For many years, JPL and Goddard Space Flight Center (GSFC) have had an informal working interface whereby GSFC passes to JPL prelaunch frequency, spectrum and trajectory information in a form which the DSN then uses as an input to the Deep Space Interference Prediction Program (DSIP2) to predict interference to the Network. The DSIP program is discussed in VI below. This interface has been working very satisfactorily, with only occasional occurrences of predicted and actual interference to the Network and no occurrence during Network critical or semicritical events. A formal Memorandum of Understanding between GSFC and JPL is currently being prepared.

C. Deep Space Network Radio Frequency Interference from European Space Agency Earth Orbiting Satellites

On June 29, 1976, the European Space Agency and NASA agreed upon a formal document titled "Working Arrangement for Radio Frequency Coordination Between ESA and NASA." Comprehensive working agreements and procedures were published in the "ESA/NASA Frequency Coordination Manual" in September 1978. Representatives from both agencies formed the "ESA/NASA Frequency Coordination Group" which initially met frequently, and now meets annually, to discuss and resolve ESA/NASA RFI matters. Prelaunch satellite parameters are received by JPL from ESA and are used by the Deep Space Interference Prediction Program.

These agreements, procedures and relevant interfaces have been operating very satisfactorily, with very rare interference occurrences predicted.

D. Deep Space Network Radio Frequency Interference from US Department of Defense Satellites

A formal Memorandum of Understanding between the Air Force Satellite Control Facility (AFSCF) Sunnyvale, California, and JPL was originated in December 1979. Comprehensive operating procedures have been in use since that time, and they were finalized in February 1980. In this instance, because of the classified nature of the satellite parameters, JPL supplied the Air Force Satellite Control Facility with software modules and training, and routinely supplies the Facility with DSN spacecraft parameters and updates; the Facility runs a prediction program. JPL also supplies the Satellite Control

Facility with schedules of DSN critical and semicritical events to enable their satellite operational sequences to be modified to avoid causing interference during a Network critical event.

This Memorandum of Understanding and interface have been operating very satisfactorily, particularly during 1980 when there have been only two instances of Air Force Satellite originated interference resulting in minimal Network data degradation, and no instances during Network critical or semicritical events. This is a significant improvement over years prior to the advent of the Memorandum.

E. Deep Space Network Radio Frequency Interference from USSR Earth-Orbiting Satellites

The only USSR satellites known to pose a potential interference threat to the Network are highly elliptic vehicles which compose a subset of early warning satellites in the overall Cosmos series. These satellites operate at various frequencies, some of which have extremely powerful spectral components in the 2290 to 2300 MHz band.

It has not been possible to establish a Memorandum of Understanding, procedures or interface between the USSR and NASA, similar to those with other agencies discussed in this section. When the DSN becomes aware of the launch of a satellite in this category, trajectory information is requested and supplied through established channels, and a NASA station is scheduled to perform a short tracking pass of the satellite to obtain the downlink spectral characteristics. These are then input to the Deep Space Interference Prediction Program and interference predicts generated as for any other satellites.

If interference is predicted during routine or semicritical Network events, the spacecraft project personnel concerned are notified and the spacecraft operational sequences rescheduled, if possible, to avoid the predicted interference. If interference is predicted during a Network Class I critical event, e.g., Voyager Saturn encounter, where the prime mission objectives would be jeopardized, the event time, station location and frequencies are passed to the USSR from JPL via NASA Headquarters and the US State Department with a request for protection. This has occurred on three occasions to date: Pioneer Venus encounter, Pioneer 11 Saturn encounter and Voyager Saturn encounter, and on each occasion the USSR has complied with the request.

Efforts are still being made to establish a more direct and more easily exercised interface with the USSR, though very little progress has been made to date.

F. Deep Space Network Radio Frequency Interference from Japanese Satellites

To date there have been no DSN interference incidents caused by Japanese satellites, mainly because Japan has not operated satellites in the S-band spectrum. In the past, an informal ad hoc interface was successfully established between Japan and NASA/JPL in which the DSN was informed of the status of a Japanese launch vehicle second-stage (battery powered) transponder operating at S-band. This signal was "in view" of the Australian DSN stations for very short periods of time and caused no Network interference.

Recently, Japan announced two launches in the future (one a Deep Space Comet Mission – Planet A) which will operate at S-band frequencies. Japanese-NASA meetings have taken place and it is hoped that a Memorandum of Understanding and formal working interfaces may be achieved in 1981.

VI. The Deep Space Interference Prediction (DSIP2) Program

Briefly, the Deep Space Interference Prediction Program provides the capability to predict degradation to a deep spacecraft S-band downlink, caused by an interfering S-band CW signal from an earth-orbiting satellite. When predicted, the degradation is output in terms of telemetry signal-to-noise ratio degradation and for receiver loss of phase lock. The program will currently handle up to 10 DSN stations, 10 interfering satellites and any number of spacecraft for any one run (see Refs. 3, 5 and 6).

This program has been operating successfully since 1977; however, continuing effort is needed to keep pace with expanding requirements, and need for prediction accuracy. For instance, if the prediction errs on the conservative side this could result in the unnecessary request to turn off an internationally used earth resources satellite, causing loss of revenue and/or data to many countries. On the other hand, no predicted interference indicated in the case where an event will actually occur could result in the loss of a mission's prime objectives.

Future plans include examining the need to predict "X", "K_u" and "K_a" band interference from spread spectrum and pulse types of interfering signals.

This is a rather large and quite complex program and a technical description detailing the functions and techniques used will be published in a future TDA Progress Report.

VII. Deep Space Station Internal Radio Frequency Interference

The modern 64-meter-diameter-antenna Deep Space Station is an extremely large and complex facility bearing no resemblance to its humble ancestors of 20 years ago which comprised a few racks of equipment in a trailer. When one realizes that not only does a 64-meter station control room contain more than 100 RF oscillators but also numerous computers, etc., which operate at speeds into the GHz range, the 60-cycle hum-type problems of early years seem very insignificant.

It appears that the interference characteristics of "off-the-shelf" or Laboratory-designed equipment have not been formally factored into equipment design as the stations have grown, so that currently there is no comprehensive picture of the electromagnetic environment inside a Deep Space Station. Commercial or domestic interference specifications and standards are basically intended to protect the commercial broadcast industry and are completely unsuitable for Deep Space Network use. With a few exceptions, military specifications and standards have also been found unsuitable.

This means that the only Radio Frequency Interference qualifications applied to Network equipment from either a "victim" or "culprit" aspect, have been the application of good engineering practice based on past experience. However, the density and new technology of Network equipment is beginning to require something more than the application of past experience to optimize design from the aspects of susceptibility to, or generation of, RFI. Radio frequency interference specifications are required to qualify most of the various types of equipment already implemented or planned to be implemented in the Network. A proposal to generate specifications, make an inventory and validate all the equipment, as part of the Network's consolidation implementation, is under consideration at this time.

VIII. Search for Extraterrestrial Intelligence Impact on Radio Frequency Interference Studies

All of the foregoing has discussed RFI avoidance for Network support of Deep Space Missions. The object here simplistically is to reject and avoid or predict and detect all other signals to ensure good reception of a single well-known downlink frequency. The Network will be starting to support Search for Extraterrestrial Intelligence (SETI) program operations in the near future, and this will involve scanning the spectrum initially from 1 to 10 GHz (eventually 25 GHz) to ensure reception of a *single* and completely *unknown* signal, and rejecting all the known signals. Obviously, current RFI avoidance thinking and techniques will not apply to the SETI operation. It is only in recent months that this task has received attention, and at this time it is still under discussion.

IX. Human Factors in Radio Frequency Interference Avoidance

The major requirement to ensure effective avoidance of interference is good (personal) relations between the parties concerned, and this applies equally at the local, national and international levels, i.e., the ITU/CCIR/WARC. Participating nations agree that a specific portion of the spectrum will be allocated for a certain type of activity. However, each nation has authority to allocate blocks of frequencies inside their own country, and their numerous agencies, and to assign specific frequencies to government or industry.

When one considers the use of radio communications and navigation on international aircraft flights, it quickly becomes apparent that without extremely tight international, national and local frequency agreements, regulations and management there would be chaos. Satellites, radiating while they pass over many countries every 90 minutes, could increase the chaos without proper frequency management. However, constant coordination between the participants is essential to make the agreements effective, and the preparation for and issuance of the agreements and regulations require dedicated, qualified people working on behalf of the DSN to ensure reasonable protection and to carry out highly technical analyses to provide data for the negotiations and coordinators (Refs. 3-6).

X. Conclusions

Radio frequency interference is here to stay. The potential for interference has been growing over the past 20 years, and the potential for interference to the Deep Space Network will increase with time. This author feels that JPL has recognized the external interference problem and has taken corrective action, with the result that the number of external interference events have been decreasing, none being experienced during a deep space mission critical event in recent years. Unfortunately, internal interference prevention has not enjoyed the same attention and there have been several cases recently in which several months of troubleshooting have been expended to cure interference problems with new equipment. However, with sufficient qualified personnel and the proper tools to negotiate, coordinate, analyze, predict, detect and identify radio frequency interference, the Deep Space Network should be able to continue to operate compatibly with all the other users of the radio frequency spectrum.

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