DSN RFI Susceptibility Models Development Program Overview

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Earth stations employed for space exploration are often operated in an environment of man-made electromagnetic radiation. Such an environment can have the potential of radio frequency interference (RFI). To analytically determine and predict the effects of RFI it is necessary to have models that describe the response of the earth station receivers to various types of interference. The RFI model development described in this article is intended to provide an understanding of the interference susceptibility of DSN receivers. The article presents an overview of interference types and effects, analytic modelling and experimental verification, and work accomplished and work to be done.

I. Introduction

Growing usage of the radio frequency spectrum has increased the potential for interference to deep space communications. To allow successful operations in an environment of man-made electromagnetic radiation, it is necessary to know the susceptibility of the DSN stations to various forms of RFI. RFI model development is in response to this need and to the following specific requirements:

(1) The obligation to provide the Department of Defense (DOD) with DSN RFI susceptibility data under the Memo of Understanding agreed upon by NASA and DOD.

(2) The need to be capable of DSN operational RFI prediction.

(3) The need for susceptibility information and protection criteria used in band and frequency sharing studies.

The RFI effects on the DSN receiving systems, the scope and approach of the model development, past achievements, and future direction are discussed in this article.

II. Types of RFI and Their General Effects

For the purpose of developing RFI models, three types of interference may be considered:

(1) CW interference.

(2) Pulsed sinusoidal interference.

(3) Wideband interference.

Most of the interference in the Fort Irwin-Goldstone area is of the pulse type. The source of this type of interference is a wide variety of radar equipment. All the RFIs considered are unintentional; the special problems that result from the characteristics of intentional jamming are not considered.

RFI can have various effects on the receiving system, depending on the power level and the frequency range of the interference. At weak-to-moderate power levels, an in-band[1] interference can result in an increase in the static phase error and the phase jitter of the carrier tracking loop, an increase in the telemetry bit error rate, or a loss of synchronization. These effects are referred to as performance degradation. Performance degradation caused by RFI can generally be expressed as an equivalent reduction in the signal-to-noise ratio and can be compensated by increasing the power level of the desired signal. At strong levels, an interference can result in a performance degradation and simultaneously drive one or more of the receiver components into a nonlinear region, resulting in gain compression and the generation of harmonics, spurious signals, and intermodulation products. These nonlinear effects are collectively referred to as saturation effects. Unlike performance degradation, saturation effects generally cannot be compensated by simply increasing the power level of the desired signal.

An interference with a strong power level and with a large frequency offset from the carrier of the desired signal generally tends to produce saturation effects. For an interference with a small frequency offset, the predominant effect is performance degradation, such as an increase in the telemetry bit error rate.

III. RFI Effects to be Modeled

There are two classes of RFI effects that must be considered in model development, i.e., saturation and performance degradation. The subsystem that is responsible for saturation is the maser. It is the first element in the entire system to be saturated at strong interference levels (Ref. 1). Other parts of the system are not likely to have saturation because severe performance degradation would take place much before saturation effects became noticeable. A strong interference can cause the maser to saturate if the interference frequency is (Ref. 2): (1) in the maser passband, (2) near the maser passband, (3) in the maser mixing range, or the idler frequency range.

The second class of RFI effects includes the performance degradation of various receiver functions. RFI can result in: (1) telemetry channel performance degradation, (2) ranging channel performance degradation, and (3) doppler channel performance degradation. In order to evaluate these effects, it is necessary to also examine the performance of the carrier tracking loop because it directly affects the performance of the telemetry, ranging and doppler systems.

[1] An in-band interference is one that falls inside the desired channel bandwidth.

Carrier channel degradation occurs in the presence of an interference at or near the carrier frequency. Degradation to the telemetry channel can be caused by an interference in the telemetry channel, near the telemetry subcarrier odd harmonics, or in the carrier channel. Degradation to the ranging channel can be a result of an in-band interference or a carrier interference. Doppler channel degradation is directly caused by a carrier interference.

In addition, interference in the maser idler frequency range or mixing range can mix with the maser pump frequency and produce a mixing product at the desired signal frequency. This product, being frequency-modulated, is wide band and can produce one or more of the four possible performance degradations.

The response of the receiving system to an interference is a function of the interference type, interference power, interference frequency and the operating condition of the system. It is not feasible to completely specify the RFI characteristics of the system by a single model. Different models, each developed for a particular type of interference and a particular part of the system under a particular condition, are necessary.

IV. Required RFI Models

Based on the RFI types and effects, three system level models are needed to completely define the RFI susceptibility characteristics of the receiving system: (1) CW RFI model, (2) pulse RFI model, and (3) wideband RFI model. Each of these system models contains two parts, one for the saturation effects and the other the performance degradation effects. The saturation part of the model contains a subsystem model that defines the saturation characteristics of the maser, i.e., maser saturation model. The performance degradation part of each system model contains five subsystem models: (1) carrier channel degradation, (2) telemetry channel degradation, (3) ranging channel degradation, (4) doppler channel degradation, and (5) maser mixing/conversion.

The first four subsystem models define the performance degradation of the four functions performed by the receiving system. The last subsystem model accounts for the possible performance degradation caused by interference having a frequency in the maser idler frequency range. An interference in idler frequency range or mixing range can mix, or multiply and mix, with maser pump frequencies and create an in-band interference through two mechanisms: electron spin resonances and reaction with linear elements in the maser.

The relationships between the interference frequency, the power level, the affected subsystems, the degradation effects, and the necessary models at the system and subsystem levels are shown in Fig. 1 for the three types of interference. Since the system can operate in both S-band and X-band, each model in Fig. 1 generally has both S-band and X-band versions. A summary of the required models is shown in Table 1. These models are needed for all three interference types.

V. Current Status and Future Direction in Model Development

Most of the model development effort in the past has been directed to CW interference. Table 2 shows the current status in CW RFI model development. Column 1 lists the subsystem models that make up the system model. Column 2 lists specific interference effects to be modeled for each subsystem model. Column 3 shows the required frequency bands and column 4 shows the current status. To complete the CW RFI model, several effects remain to be included:

(1) Maser conversion loss in converting interference in the maser idler or mixing range to in-band interference due to nonlinear elements in the maser.

(2) Ranging channel degradation due to RFI in (a) the carrier loop, and (b) the ranging channel.

(3) Telemetry degradation due to interference (a) in the telemetry channel, and (b) in or near telemetry subcarrier odd harmonics.

The model development for the CW RFI, pulse RFI and wideband RFI in theory can be handled simultaneously. In practice, it is convenient to complete the model development for the CW case, then the pulse case followed by the wideband case. There are two reasons that the CW case should precede the pulse case:

(1) Effects of a pulse RFI can be approximated by a CW RFI under certain conditions.

(2) Insight gained in developing CW RFI models may be helpful for the pulse case.

Effects of a wideband interference can be estimated by the traditional noise conversion technique where the interference is treated as extraneous noise. Models for this type of RFI are relatively simple and will be treated last.

The plan for the immediate future is to complete the model for the CW RFI case. Modelling for pulse RFI can then begin. The effects of pulse RFI are a function of pulse width, repetition rate and pulse carrier frequency. To bound the scope of modelling, it is necessary to determine these characteristics for the typical pulse interference encountered by DSN. Having determined these characteristics, pulse RFI models for the degradation of carrier loop, telemetry, ranging, doppler and saturation can then be developed in the order mentioned.

VI. Model Application

The saturation model developed is based on a 1-dB gain compression criterion. This model allows one to predict whether a given interference violates the 1-dB gain compression criteria. This model does not predict the degree of performance degradation.

Unlike the saturation model, all performance degradation models are capable to predict for a given interference the degree of degradation. Performance degradation is measured by a variety of parameters and they are discussed in the following subparagraphs.

(1) Carrier Channel Performance Degradation Model. This model allows one to predict the amount of static phase error and phase jitter in the tracking loop due to the presence of a CW interference in the carrier channel. It also predicts the lock and unlock behavior of the loop under strong interference.

(2) Telemetry Channel Performance Degradation Model. Development of this model is yet to be completed. Upon completion, it will allow one to determine the error probability for the coded as well as the uncoded cases. Alternatively, it will predict the equivalent reduction in the signal energy to spectral density ratio. Currently, it is not planned to include the lock and unlock behavior of the telemetry system. It may be necessary to expand the model to include these effects in the future as needs arise.

(3) Ranging Channel Performance Degradation. This model will determine the variance of range delay estimate and the equivalent reduction in signal-to-noise ratio.

(4) Doppler Channel Degradation Model. This model can be derived directly from the carrier channel degradation model and it allows one to determine the equivalent doppler noise.

(5) Maser Mixing/Conversion Model. This model will predict the amount of degradation on the carrier channel, telemetry channel, ranging channel and doppler channel due to interference in the maser idler frequency range or mixing range.

VII. Conclusion

Efforts taken under the RFI susceptibility model development program in recent years have produced some limited but useful results. Further efforts are necessary to obtain a full set of RFI susceptibility data for the receiving system. In addition to fulfilling NASA's obligation to DOD, these data can be useful in a variety of ways such as in the development of protection criteria for deep space communications and in the selection of frequency channels for future missions. They can also be applied to upgrade DISSIP2, an operational computer program used by DSN to predict interference from earth-orbiting satellites.

The use of RFI susceptibility models to protect deep space stations from harmful interference through coordination and control is only a first step to obtain RFI protection. In the future, it may be necessary to consider design changes in order to obtain RFI immunity, such as filtering and the use of different modulation techniques and coding schemes.

References

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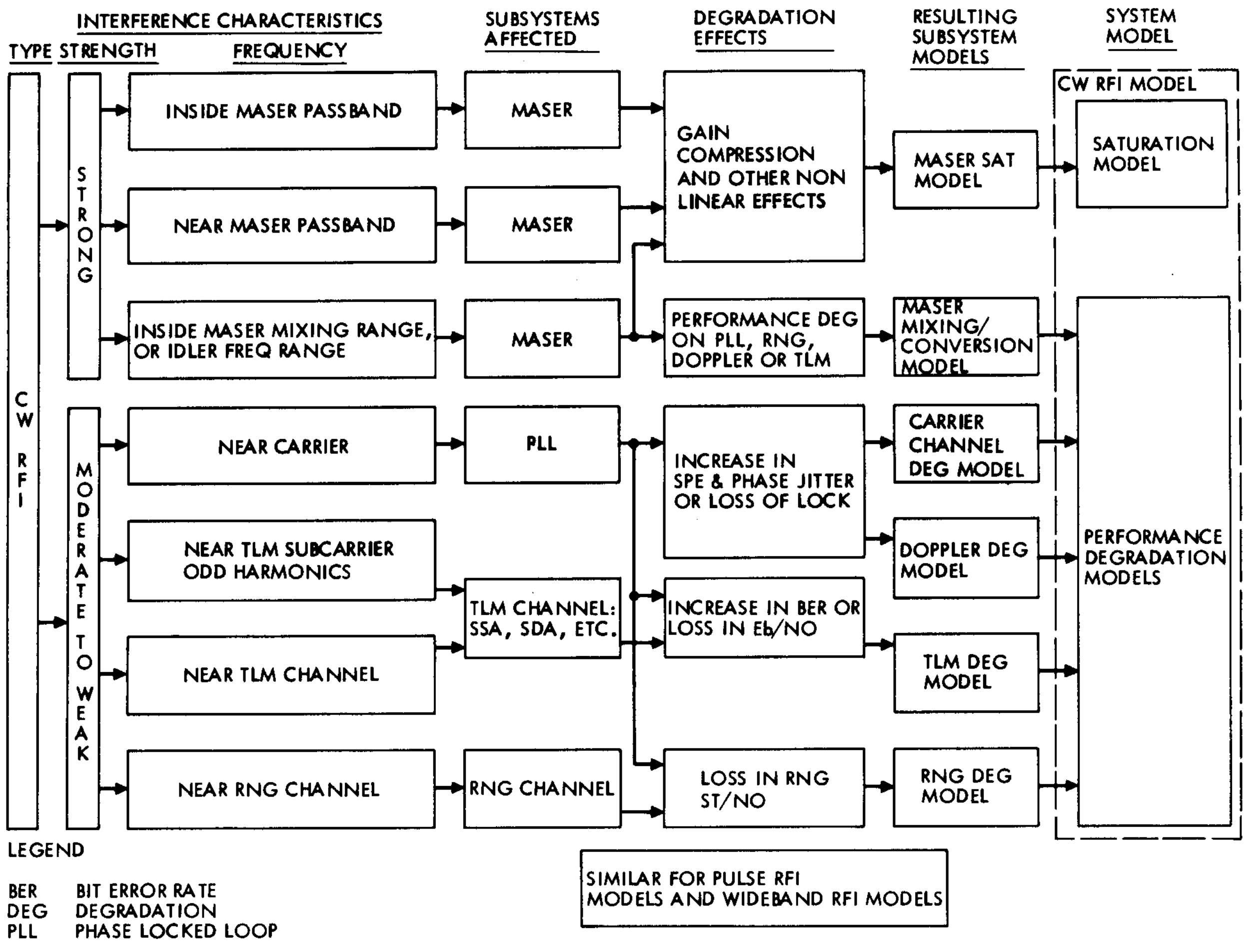
Table 1. Required RFI susceptibility models (for a given type of interference)

Type of system models	Subsystem models	Interference frequency
Saturation model	Maser saturation model	In or near maser passband Inside maser mixing range Inside maser idler frequency range or mixing range
Performance degradation models	Carrier channel degradation	Near carrier
	Telemetry channel degradation	Near carrier Near TLM subcarrier odd harmonics Near telemetry channel
	Ranging channel degradation	Near carrier Near ranging channel
	Doppler channel degradation	Near carrier
	Maser mixing/ conversion model	Inside maser idler frequency range or mixing range

Table 2. Model development status for CW RFI

Required subsystem models	Interference effects to be modeled	Required frequency bands	Status
Maser saturation	Maser saturation characteristics for X-band (BLK 1, 2) and S-band (BLK 3, 4):		
	(a) RFI in or near maser passband	S&X	Available in Refs. 1-3
	(b) RFI in the maser mixing range	S&X	Available in Refs. 1-3
	(c) RFI in the maser idler frequency range or mixing range	S&X	Available in Refs. 1-3
Maser mixing/ conversion loss	Loss incurred in converting idler frequency interference to in-band interference	S&X	Partially available in Refs. 2, 3. Conversion loss due to non-linearities not available.
Carrier channel degradation	PLL degradation due to RFI near the carrier	S&X	Completed (Ref. 4)
Doppler channel degradation	Doppler channel degradation due to interference in the carrier channel	S&X	Completed (Ref. 4)
Ranging channel degradation	Ranging channel degradation due to:		
	(a) carrier interference	S&X	TBD
	(b) ranging channel interference	S or X	TBD
Telemetry channel degradation	Telemetry channel degradation due to:		
	(a) carrier interference	S&X	Completed (Ref. 5)
	(b) interference in the telemetry channel	S or X	Currently under study
	(c) interference near telemetry subcarrier and harmonics	S or X	TBD



LEGEND

BER BIT ERROR RATE
DEG DEGRADATION
PLL PHASE LOCKED LOOP
RNG RANGING
SDA SUBCARRIER DEMODULATION ASSEMBLY
SPE STATIC PHASE ERROR
SSA SYMBOL SYNCHRONIZATION ASSEMBLY

Fig. 1. RFI models