THE ATS-F RADIO FREQUENCY INTERFERENCE MEASUREMENT EXPERIMENT

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Introduction

Electromagnetic incompatibility and spectrum pollution resulting from the proliferation of new communication systems has prompted the need for more efficient use of the radio spectrum. Experience with operational satellite systems and planning for domestic satellite systems with optimum utilization of the frequency spectrum has shown the need for empirical data on mutual RF interference between satellite and terrestrial systems.[1]

The National Aeronautics and Space Administration is currently implementing an experiment to provide data on the feasibility of expanded spectrum sharing.[2] The ATS-F Radio Frequency Interference Measurement Experiment (RFIME) is designed to measure and evaluate the amount of up-link carrier power interference between synchronous satellite and terrestrial microwave relay systems in the shared common carrier band of 5.9 to 6.4 GHz. Parametric measurements will include transmitted and received power levels, propagation path loss and interference signal variations as a function of range, elevation angle, rf polarization, and geographical location of interference sources. This experiment is scheduled to acquire data for a period of one year following the launch of ATS-F in 1974.

Following a statement of the technical objectives for the experiment the remainder of this paper contains an abbreviated system description, system performance characteristics and a generalized measurement plan.

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[1] "The Radio Frequency Spectrum - U.S. Use and Management", Office of Telecommunications Policy, January 1973.

[2] V. F. Henry and J. J. Kelleher, "Radio Frequency Interference Experiment Design for the Applications Technology Satellite", NASA TN D-5041, May 1969.

Technical Objectives

The technical objectives of the uplink interference tests and measurements are:

- Determine the integrated interference power from all 6 GHz terrestrial sources sharing the common carrier band within the RF field of view of the ATS-F satellite;
- Establish practical G/T (receiver antenna gain/noise temperature ratio) limits for satellites sharing the 6 GHz common carrier band;
- Determine the geographical and frequency distribution of 6 GHz terrestrial sources sharing the common carrier band;
- Establish a protection ratio - wanted to unwanted carrier power (C/X) at the satellite receiver;
- Investigate mathematical modeling for predicting RP interference.

Uplink tests (Figure 1) are designed to measure and identify the RF carriers of ground transmitters radiating in the 6 GHz band which are potentially capable of interfering with uplink transmission. These tests represent the only realistic method of determining the integrated interference power generated in the large peographic area that can be seen by a satellite. Because of potential uplink interference, there will be a practical lower limit to earth station radiated power. This limit can be established by using the results of the uplink tests to determine the distribution of interference power or to determine the distribution of interference power with geographic location. This will be done to the accuracy permitted by the satellite antenna pattern and pointing. Location information will be of use in the event of unexpected sources of interference. It may also be useful in designing future satellite system , since parameters can be based on interference levels in the particular geographic areas in question.

System Description

The RFI measurement system is capable of examining uplink interference over the entire shared frequency band of 5925 to 6425 MHz. This required that the datellite have wither a 500 MHz repeater bandwidth or a scanning receiver capable of sweeping across the 500 MHz band. If the system link is basically uplink-limited, as it is here, then narrowband filtering in the satellite offers no improvement in performance. Furthermore, satellite repeater simplicity is maintained with the narrowband filtering at the ground terminal. The 6 GHz interference signals of interest here are RF carriers of microwave relay stations. Since the carriers are not ideal spectral lines but extend over several voice channels, a practical reciever bandwidth of 10 kHz has been chosen. Assuming a carrier-to-noise ratio of 10dB for 10 kHz bandwidth, the required carrier-to-noise power density (C/N_o) in the satellite receiver is 50dB (Hz). The satellite transponder developed for this experiment consists of a 6 to 4 GHz linear repeater with a noise bandwidth of 500 MHz. The

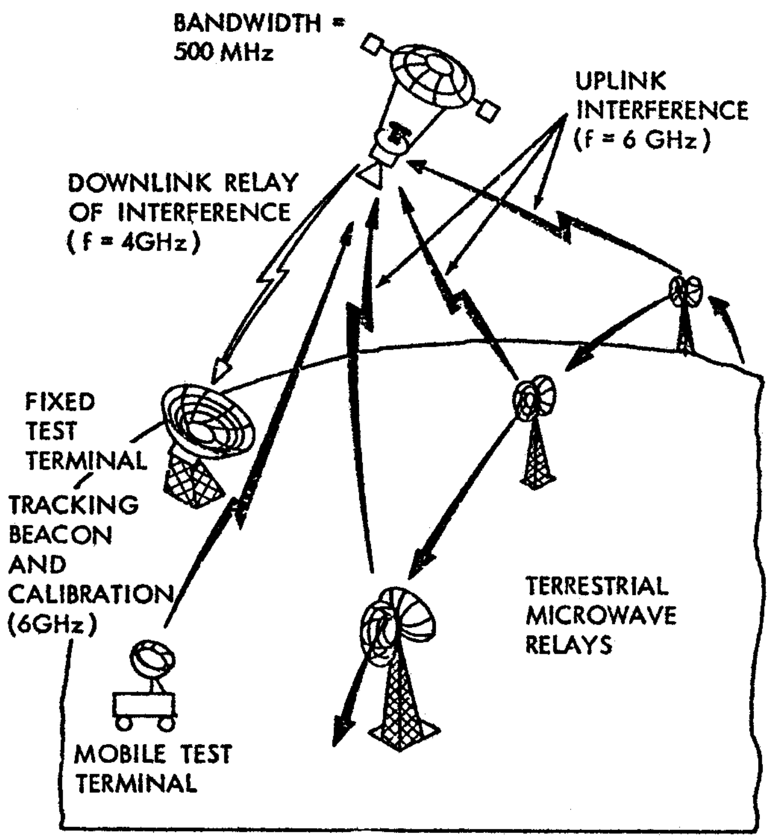

FIGURE 1. 6 GHz RFI Experiment

interference vulnerability of a satellite is determined primarily by its receiver sensitivity, which may be specified in term of its receiver antenna gain/noise temperature ratio (G/T). The G/T for the ATS-F satellite is 19dB/°K, which requires an interference EIRP from an earth source of 8 dBw to satisfy the C/N_o requirement of the satellite.

Equipment System Description

The experiment hardware consists of three major subsystems, Figure 2,the spacecraft transponder, the RFI receiver/analyzer subsystem, and the portable calibration terminal. The spacecraft intercepts the terrestrial interference radiation in the 5.925 to 6.425 GHz band through its 30 foot parabolic antenna and transponds this radiation back to the Rosman terminal in the 3.70 to 4.20 GHz band , where the interference spectrum is scanned by the RFI receiver. A narrow frequency filter or window is moved across the band. The output signal is stored on analog tape and in parallel is detected, processed, and stored on digital tape for permanent record. The analog tape is used to provide storage of the raw data and enable reruns of the detection process and to minimize the required satellite access time.

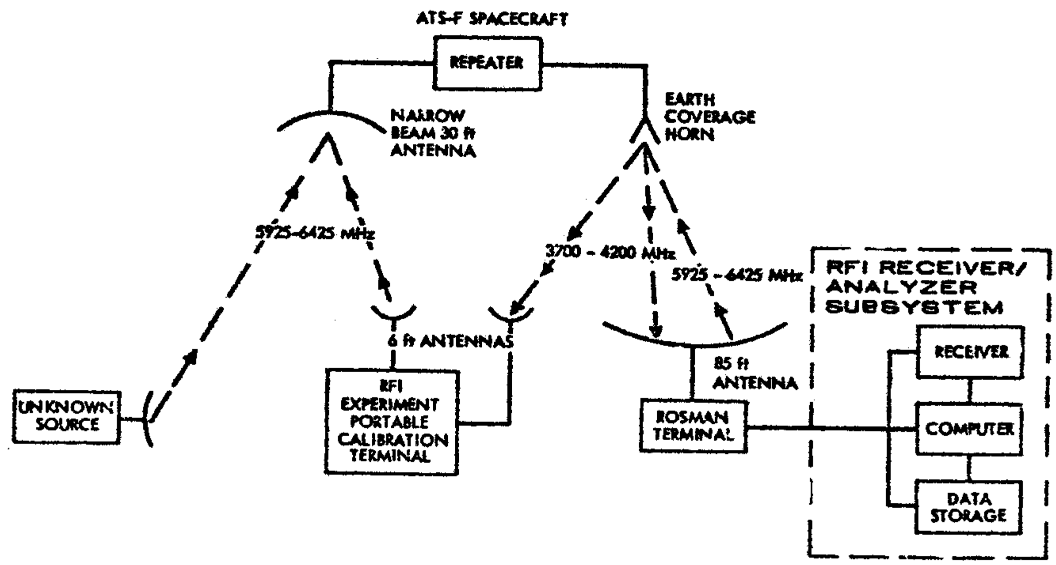

FIGURE 2   RFI Measurement System

Spacecraft Subsystems

The RFIME repeater developed for ATS-F consists of four subs stems:

(1) a low noise preamplifier, (2) wideband frequency transponder, (3) redundant transmitters, and (4) RF transmission lines, couplers, mixers, and switches. In addition to the 30-foot parabolic antenna, a low gain, earth coverage transmit-receive antenna is required. This antenna can be switched to the RFI transponder input for use in determining the location of very strong interference signals. The RFI transponder characteristics are summarized in Table 1.

Portable Calibration Terminal

The portable calibration terminal provides a calibration transmitter and a beacon for accurate spacecraft antenna pointing. During the period of diagnostic tests, it will be located at Rosman to transmit low level signals to the satellite. It is equipped with transmit and receive antennas, control data communication capability, and with an accurately controlled calibration transmitter. The portable calibration terminal is normally located in the center of the narrow beam (30-foot antenna pattern). A data link between it and Rosman provides fast calibration of the spacecraft-Rosman link.

Table 1.

TRANSPONDER CHARACTERISTICS	
Transmitter type	Traveling-wave tube
Transmitter power output	20 watts
Transmitter Frequency	3950 ± 250 MHz
Receiver type	Linear, single conversion
Receiver noise figure	8.0 dB
Receiver frequency	6175 ± 250 MHz
Receiver dynamic range	40 dB
Polarization diversity	Horizontal, vertical, or circular

RFI Receiver/Analyzer Subsystem

Design details of the RPIME receiver/analyzer were recently published in Reference [3]. The functional operation of this subsystem is summarized in the following paragraphs.

RF signals in the 500 MHz band from 3.7 to 4.2 GHz enter the RFI receiver after amplification by the Rosman low-noise pre-amplifier. Narrow frequency bands are selected from the 500 MHz input bandwidth automatically. That is, the RFI receiver is tuned by means of digital signals from the RFI computer, thereby performing the first step in the spectral and time analysis of the RFI signals.

Analog processing is performed by a variety of filtering and detection circuits. Switches are automatically controlled to change gain, bandwidth, sweep rates and filters, etc. when required. For the principal experimental modes, the processed analog data is converted to digital funn for further processing in the RFI computer. An analog tape recorder provides a record of the experimental data before they have been converted to digital form. The analog recording will be played back for off-line digital processing.

[3] V. F. Henry and G. Schaefer, "System Design of the ATS-F RFI Measurements Experiment" IEEE National Telecommunications Conference Record Dec. 1972

Test and Measurements Plan

The RFIME system parameters are listed in Table 2. The detailed test procedures are currently under development. In general, the tests and measurements for the experiment will be conducted as follows.

Table 2

6 GHz RFIME System Parameters	
Satellite transmit power (4 Ghz)	13 dBw
Satellite transmit antenna	17 dB
Satellite EIRP	30 dBw
Satellite bandwidth (500 MHz)	87 dB/Hz
Ground station antenna gain (4 GHz) - 85' dish	56 dB
Ground station receiver noise temperature (50° K)	17 dB/°K
Ground station receiver G/T	39 dB/°K
Satellite receiver antenna gain (30' dia., 6 GHz, 45%)	49 dB
Satellite receiver noise temperature (1000° K)	30 dB/°K
Satellite receiver G/T	19 dB/°K

Following the establishment of the ATS-F satellite "on station", a series of diagnostic tests will be performed to calibrate the antenna system, including patterns, axes orientation, attitude stability, and orbital position. Additional measurements will be made to determine overall system performance, including transmit-receive gain, polarization, pointing accuracy, noise temperature, and EIRP of both the satellite and ground terminals. With the earth terminal configured in a back-to-back loop through the satellite and transmitting up at 6 GHz and receiving at 4 GHz, the overall noise performance of simulated satellite communications system will be measured. The simulated system will represent a fully loaded system with 60 to 1200 channels of FDM/FM multiplexed voice channels across the baseband. All of these n.p.r. measurements (which will be used for comparison with the experimental measurements) will be made using the earth coverage (low gain) antenna pointed to a "quiet spot" on the earth. Similarly, using the same configuration, reference data will be established from measurements of the system configuration, reference data will be established from measurements of the system carrier-to-noise and baseband signal-to-noise ratios. Carrier frequencies for the simulated system will be variable to allow calibrations in regions of the allotted common carrier band where interference is most likely to occur. Then the main beam of the high gain antenna will be pointed toward a high density population area such as the northeastern coastal region of the United States. The satellite receiver terminals will be coupled to the high gain antenna while the transponder output (transmitter) terminal will remain connected to the low gain antenna for transmission at 4 GHz to the tests and measurements earth terminal. The earth terminal remains in the simulated back-to-back loop configuration. Thus the measurement system now contains both the simulated desired signals (and basic noise) plus the real (unwanted) noise signals from all earth sources within the field of view. These unwanted noise signals, sharing the same common carrier frequency as the simulated system, can now be determined by remeasuring the system n.p.r. and carrier-to-noise (C/N) and baseband signal-to-noise (S/N) ratios.

The procedures described above for the uplink interference measurements will be repeated for different areas to determine the geographical distribution of interference sources. The sweep-frequency receiver technique described earlier will be used to determine the frequency distribution of interference sources across the 500 MHz bandwidth of the common carrier band. Statistical time variations of noise will be determined by selecting and adjusting the duration and time of day, week, and season of interference measurements.

The actual RFI Experiments tests will be preceded by calibration of the portable terminal and by 4 GHz RFI measurements of the Rosman receiving terminal pointing at the nominal space station location while the spacecraft is not transmitting. Once the spacecraft is on station, the link from portable terminal to the spacecraft to Rosman will be carefully calibrated. The total link noise will be measured; and, from these measurements, noise coefficients will be derived.

The initial measurement phase of the experiment will consist of an eastwest raster scan of continental United States. Allowing for overlap of successive scans at the narrow beam antenna 3dB contour, the total U.S. can be covered in nine parallel scans. For each resolution cell, the frequency of the receiver is stepped across the 500 MHz band in steps determined by filter bandwidth. The time required for a complete U.S. scan varies from 7.8 hours to 70 hours, depending on the accuracy desired and how rapidly the output of processed data is desired. When data processing is done in real time, the scan time is determined by the settling time of the narrowband (10 kHz) filter and detector assembly and the requirement for frequency scanning in 10 kHz steps across the 500 MHz band. When the raw data is stored in analog form and later processed off-line, a wider band filter will be used with correspondingly reduced settling time and a smaller number of frequency steps to traverse the 500 MHz band.

From the above data, taken in a relatively short time, power flux density contours can be drawn indicating those areas where the flux density is high and, conversely, those where it is low. Both are of interest and can be investigated more closely using the spot mode. In this mode, the spacecraft is pointed to a particular area of interest for more detailed examination. By means of small orthogonal scans across the area, each source that can be resolved in amplitude, space, and frequency can be located to within approximately 0.06 degree of the spacecraft boresight axis.

Mathematical Model

An elementary model of the expected RF interference power levels has been developed.[4] The model has an estimated accuracy of 5 dB, and is adaptable to other frequency bands. It utilizes computerized data bases permitting rapid up-dating and improved accuracy of RFI predictions as better data bases become available. The model predicts that a RFIME sensitivity of -117dBm/110kHz is expected to "see" about 6 possible RFI areas in the U.S. compared to about 300 such locations for a sensitivity level of -127dBm/10kHz. In addition to the above, data are included for expected spectral power flux density levels emanating from 41 U.S. locations. These predictions permit application of different satellite antenna patterns for evaluation purposes.

A study of the impact on received signals as satellite orbital position is shifted and transmitters in the target area approach the optical horizon showed a 23 dB signal increase for Canadian stations as the satellite position was changed from 40° to 10° west longitude.

[4] Bergman, Rice, Miles, Henry, "Advanced Computer Model and Predictions for ATS-F/G Radio Interference Experiment at 6 GHz", IEEE G-AP International Symposium, 7IC39-AP, September 1971.