JPL PUBLICATION 81-34

Radio Frequency Interference At The Geostationary Orbit

Final Report

M. K. Sue

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ABSTRACT

Growing demands on the frequency spectrum have increased the possibility of radio frequency interference (RFI). For years, NASA has been concerned about the possible harmful interference to a satellite in the geostationary orbit due to terrestrial transmitters sharing the same frequency bands. RFI did exist in the past and is very likely to continue in the future; this is substantiated by past RFI incident data and potential terrestrial RFI sources obtained from a recent survey. Various approaches to obtain in-orbit RFI data are compared; this comparison indicates that the most practical way to obtain RFI data for a desired orbit (such as a geostationary orbit) is through the extrapolation of in-orbit RFI measurements by a low-orbit satellite. It is concluded that a coherent RFI program that uses both experimental data and analytical predictions provides accurate RFI data at a minimal cost.

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SECTION I

SUMMARY

For years, NASA has been concerned about the possible harmful effects of radio frequency interference (RFI) with satellites in a geostationary orbit due to terrestrial transmitters sharing the same frequency bands. The purpose of this study is to examine the problem and determine if appropriate actions are necessary. Even though the uplink RFI is of major concern to NASA, the downlink RFI should also be of concern because of the close relationship of the two.

As a part of our study, past works including related RFI experiment proposals, analyses, and experiment reports have been reviewed, as well as an analysis performed by the Electromagnetic Compatibility Analysis Center (ECAC) to estimate the RFI levels at the geostationary orbit. Using the ECAC data base, the analysis focused on transmissions from the North American Continent in the 806- to 890-MHz, 2.5- to 2.69-GHz, and 27.5- to 30.0-GHz bands as the sources of RFI. Based on our study, it can be concluded that:

(1) Potential RFI sources exist in certain frequency bands such as the 806- to 890-MHz, 2.5- to 2.69-GHz, and 5.9- to 6.4-GHz bands.

(2) There is a basic need to gain better and more accurate knowledge about the RFI situation at orbital altitudes, including geostationary orbit, in order to maximize frequency utilization, to determine actual spectral occupancy, and to minimize harmful interference.

(3) The proper approach to obtain the needed knowledge about RFI at orbital altitudes is to measure RFI with a low-orbit satellite and then extrapolate the data to the desired orbits, including the geostationary orbit. This is the most cost-effective way. An analytical approach is not practical because of its inaccuracy as evidenced by ATS-6 satellite results.

(4) For the downlink RFI, an earth-station measurement of sky noise as a function of time, elevation angle, and azimuth angle is sufficient to characterize the downlink RFI environment. Again, the analytical approach is not recommended.

The seriousness of the RFI situation cannot readily be determined from available data. Consequently, no immediate orbital RFI measurements are recommended. Instead, it is recommended that an RFI incident data base, which contains past RFI incidents experienced by various satellites, be created and that the decision on the timing of an RFI measurement project be postponed until such data base has been created and analyzed. In addition, it is recommended that a coherent RFI program be established to handle RFI problems. This program should emphasize the RFI modeling, prediction, measurement, incident data collection, and coordination.

SECTION II

INTRODUCTION

Communications systems and microwave sensors of existing and planned space missions are susceptible to radio frequency interference (RFI) from ground, airborne and spaceborne emitters. This problem has been of concern to NASA for years. Some work has been performed in this area. Most of the work, however, is in the form of proposals for a direct measurement of RFI. For various reasons, most of the proposals were shelved; only a few proposed experiments were actually carried out. Consequently, only a very limited knowledge was gained by NASA and concern for this problem remains. The objectives of this study are: (1) to determine if better knowledge of the RFI at the geostationary orbit is necessary, and (2) the appropriate approach necessary to obtain such knowledge when needed.

Even though it is the in-orbit RFI that is of interest to NASA, it is felt that RFI as seen by an earth-based station should also be considered because of the close relationship of the two. The RFI as seen by a satellite usually is called "uplink RFI," while that seen by a ground station is called "downlink RFI."

Most of the previous work reviewed emphasized the technical aspects of designing an RFI measurement system. Some did attempt to rationalize the need for such a system, but the arguments are not all convincing. In the following paragraphs the following basic questions will be reexamined:

(1) What effects would RFI have on a satellite system?

(2) Are there any potential RFI sources?

(3) Is it really necessary to gain better knowledge of RFI?

(4) What are the possible approaches to obtain the needed RFI knowledge?

(5) What is the proper approach?

(6) When is it necessary to measure the RFI?

(7) What are the requirements for the experiment?

Finally, an RFI program aimed at handling the RFI problems in general will be discussed.

SECTION III

SOME BASIC RFI QUESTIONS REEXAMINED

In this section, we will reexamine some of the basic questions regarding the RFI effects on a satellite, the existence of RFI sources, and the justification for obtaining more and accurate RFI knowledge. In other words, we will try to answer the first three questions raised in Section II.

A. WHAT EFFECTS WOULD RFI HAVE ON A SATELLITE SYSTEM?

RFI, when it occurs, can have various effects on a communications system and microwave sensors. These effects range from a simple degradation of data to a total loss of data, from a single glitch on the receiver AGC to the malfunction of a sensor, or from a loss of command capability to a loss of mission. NASA has had some experience with RFI in the past. These RFI incidents are shown in Table 3-1, which was obtained from Ref. 3-1. Fortunately, none of these incidents were catastrophic. However, with the growing number of satellites and terrestrial transmitters, the odds of having a catastrophic incident cannot be totally discounted. Figure 3-1 shows the satellites in the geostationary orbit visible from Clarksburg, Maryland, for 1977 and the projected picture for 1981 (Ref. 3-2).

B. ARE THERE ANY POTENTIAL RFI SOURCES?

The existence of potential RFI sources in certain frequency bands is unquestionable as evidenced by the RFI incidents observed on different satellites (Table 3-1). In addition, there are a number of potential RFI sources that have either been predicted or measured by satellites or airplanes performing RFI measurement experiments (Refs. 3-3, 3-4, 3-5, and 3-6).

Examples of some of these potential RFI sources are given below.

(1) Signals as strong as -90 dBm in the 255- to 280-MHz band were detected by LES-5 at a subsynchronous orbit (Ref. 3-3). These signal levels are strong enough to be of concern.

(2) Maximum man-made radiation levels corresponding to an equivalent noise temperature of 280,000 to 450,000 K were measured at 121.5 MHz by an RFI measurement airplane at 25,000 feet above New York City. Even higher levels (700,000 K at 243 MHz) were reported for Chicago, Illinois (Ref. 3-4).

(3) Based on frequency assignment data, a study performed by Electromagnetic Systems Laboratories (ESL) has revealed that there are a number of transmitters on earth capable of producing signal levels as strong as ~-70 dBm at a synchronous satellite in the 136- to 138-MHz and 148- to 155-MHz bands (Ref. 3-5). Similar signal levels are estimated for a low-orbit satellite. The estimated RFI power levels as a function of frequency obtained from Ref. 3-5 are shown in Tables 3-2 and 3-3 for synchronous satellites and low-orbit satellites, respectively.

Table 3-1. RFI Incidents[a]

Spacecraft	Link	Frequency, MHz	Problem
ATS-3	Down, OPLE; data	136.47	OPLE platform dropouts, hydrologic data loss
	Up, OPLE	149.22	OPLE signal losses
EOLE	Up, balloon data	401.7	Data loss and degradation
ERTS-1	Up, platform data	401.55	Data loss
GRS-1	Up, command	148.25	Unknown
IMP-4	Down, telemetry	136.	Loss and degradation 3% of time
Nimbus-2	Up, command	149.52	Spurious tone commands
Nimbus-3	Up, command	148.98	Spurious tone commands
Nimbus-4	Down, IRLS	401.5	Spurious interrogations
	Up, IRLS	466.0	Interrogation response losses
OAO-2	Up, command	149.52	Execution inhibition
OGO-6	Up, command	148.98	Spurious tone commands
OSO-4	Up, command	149.52	Low command response and spurious commands
OSO-6	Up, command	149.52	Spurious commands
SAS-2	Down, telemetry	136.68	Data loss
OSO-5	Up, command	149.52	Spurious commands

[a]Based on Ref. 3-1.

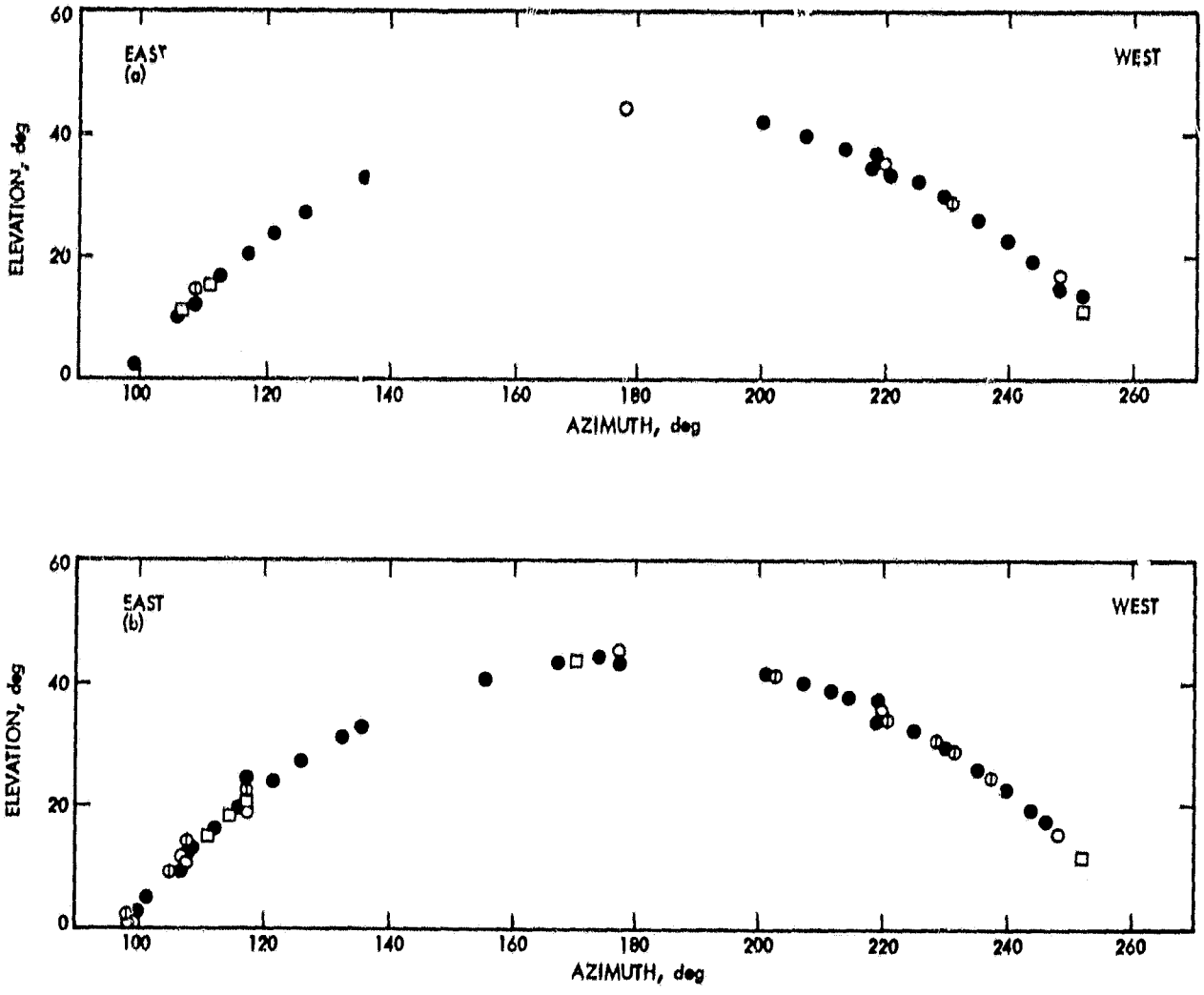

Figure 3-1. Geostationary Satellites Visible From Clarksburg, Md. (From Ref. 3-2): (a) 1977, (b) Projection for 1981

Table 3-2. Estimated RFI Power at the Geostationary Satellite 136- to 138-MHz and 148- to 155-MHz Bands (from Ref. 3-5)

SATS Location Synchronous Altitude						
Band, MHz	11°W		143°W		112°E	
	Power, dBm	Number of Emitters	Power, dBm	Number of Emitters	Power, dBm	Number of Emitters
136 to 137	-81.3	132	-87.8	56	-99.4	5
137 to 138	-79.4	235	-84.3	100	-91.8	10
148 to 149	-75.1	114	-70.8	789	-79.3	25
149 to 150	-81.0	70	-72.9	852	-76.9	58
154 to 155	-80.6	252	-79.9	216	-89.5	46

Table 3-3. Estimated RFI Power at the Low-Altitude Satellite 136- to 138-MHz and 148- to 155-MHz Bands (from Ref. 3-5)

Band, MHz	SATS Location (Altitude, 1000 km)			
	38°N-88°W		50°N-30°E	
	Power, dBm	Number of Emitters	Power, dBm	Number of Emitters
136 to 137	-86.7	5	-71.0	130
137 to 138	-79.4	25	-70.0	178
148 to 149	-68.7	80	-69.0	15
149 to 150	-75.2	53	-97.0	2
154 to 155	-74.0	127	-89.6	6

(4) Signals in the 5925- to 6424-MHz band having a spectral density ranging from approximately -124 to -146 dBW per 100 kHz with the majority centered at ~-140 dBW/100 kHz had been detected by ATS-6 when surveying Ithaca, New York, and Columbus, Ohio (Ref. 3-6). An interference with a power level of -140 dBW in a 100-kHz bandwidth is strong enough to cause problems to many satellite systems such as those using passive microwave sensors. A list of interference thresholds for passive microwave sensors obtained from Ref. 3-7 is shown in Table 3-4. Based on Table 3-4, the interference threshold for a passive sensor near 6 GHz with a bandwidth of 400 MHz is -158 dBW. An interference having -140 dBW in 100 kHz near 6 GHz would exceed the allowable interference power by at least 18 dB. This kind of interference is certainly intolerable. The number of assignments and the distribution of effective isotropically radiated power for these assignments are based on the U.S. data base used for the ATS-6 prediction program and are shown in Fig. 3-2 and Fig. 3-3, respectively. In addition, the 10 most frequently occurring transmitter powers and the 10 highest transmitter powers for assignments in this band are given in Table 3-5. (Figures 3-2 and 3-3 and Table 3-5 were obtained from Ref. 3-6.)

Some of these potential RFI sources may not be directly applicable to a satellite in the geostationary orbit; they indicate, however, that such a possibility exists. A recent study performed by ECAC to estimate the RFI levels as seen by a geostationary satellite at 100°W longitude overlooking the North American Continent further confirms the existence of such potential RFI sources (Ref. 3-8). Three frequency bands have been examined: 806 to 890 MHz, 2500 to 2690 MHz, and 27.5 to 30.0 GHz. The 806- to 890-MHz band is being considered for the Land Mobile Satellite Service (LMSS), the 2500- to 2690-MHz band is for educational TV broadcasting, and the 27.5- to 30.0-GHz band is allocated for fixed, mobile, fixed satellite, and mobile-satellite services.

Results of the ECAC study can be summarized as follows:

(1) 806- to 890-MHz band: There are a number of transmitters (approximately 18) located in Alaska and the Continental United States capable of producing a power level of -120 dBm or stronger at the satellite. A plot of the power level as a function of frequency obtained from Ref. 3-6 is shown in Fig. 3-4. It is noted that the frequency scale in Fig. 3-4 is divided into increments of 3 and 6 MHz. The 3-MHz increment is used for the portion of the band occupied by land-mobile equipments and the 6-MHz increment is used for the portion occupied by television transmitters. The power level for a given frequency increment represents the power that a geostationary satellite would see assuming that the satellite has an isotropic antenna and a receiver bandwidth comparable to the transmitter bandwidth. The typical transmitter bandwidth is 16 kHz for the land-mobile equipments and 6 MHz for the television transmitters. In addition, there are a number of tunable equipments in the lower half of this band that can produce a power level of -104.7 dBm at the satellite, and there are a number of shipboard equipments, tunable at the upper half of this band, that can produce a power level of -97.2 dBm. These signal levels are strong enough to cause significant performance degradation of radio systems using this frequency band.

Table 3-4. Passive Microwave Sensor Interference Thresholds (from Ref. 3-7)

Frequency, GHz	Interference Threshold, dBW	Bandwidth, MHz
Near 1.4	-165	100
Near 2.7	-166	60
Near 5	-158	200
Near 6	-158	400
Near 11	-156	100
Near 15	-160	200
Near 18	-160	200
Near 21	-160	200
22.237	-155	300
Near 24	-157	400
Near 30	-156	500
Near 37	-146	1000
Near 55	-157	250
Near 90	-138	6000
Above 100	-150	2000

Table 3-5. Frequency of Occurrence of Transmit Powers in the 5900- to 6450-MHz Band (from Ref. 3-6)

Ten Most Frequent Entries		Ten Highest Powers	
Power, dBW	Number of Assignments	Power, dBW	Number of Assignments
10.0	24,477	40.0	11
-10.0	12,625	39.1	2
0.0	12,571	37.6	1
11.1	11,118	37.3	1
7.0	8,562	37.0	5
3.0	3,936	35.7	1
1.8	1,160	35.5	1
2.0	931	34.8	118
- 7.0	789	34.5	37
- 3.0	693	33.4	2

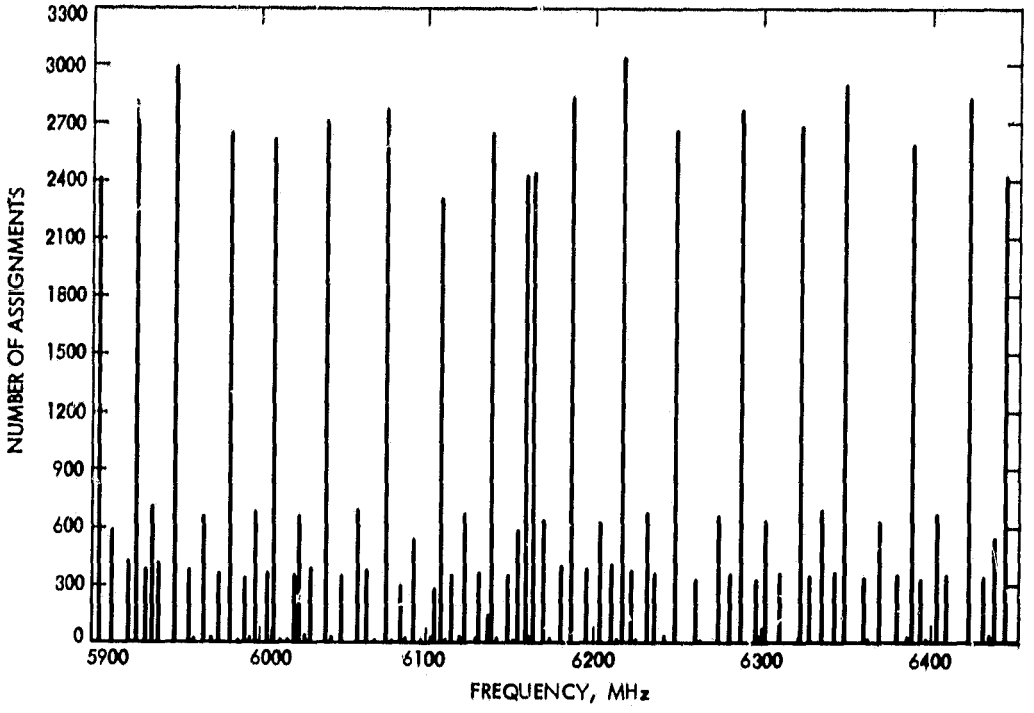

Figure 3-2. The Distribution of Frequency Assignments Within the U.S. Data Base for 5900- to 6450-MHz Band (From Ref. 3-6)

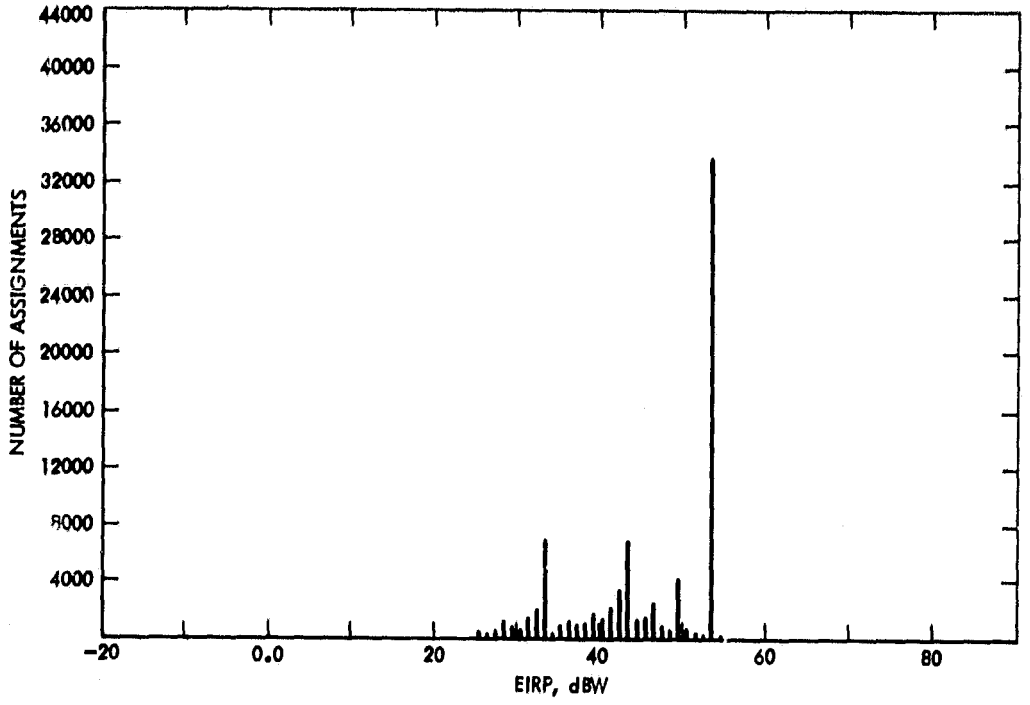

Figure 3-3. EIRP Distribution of the Terrestrial Transmitters in the 5.926- to 6.425-GHz U.S. Data Base (From Ref. 3-6)

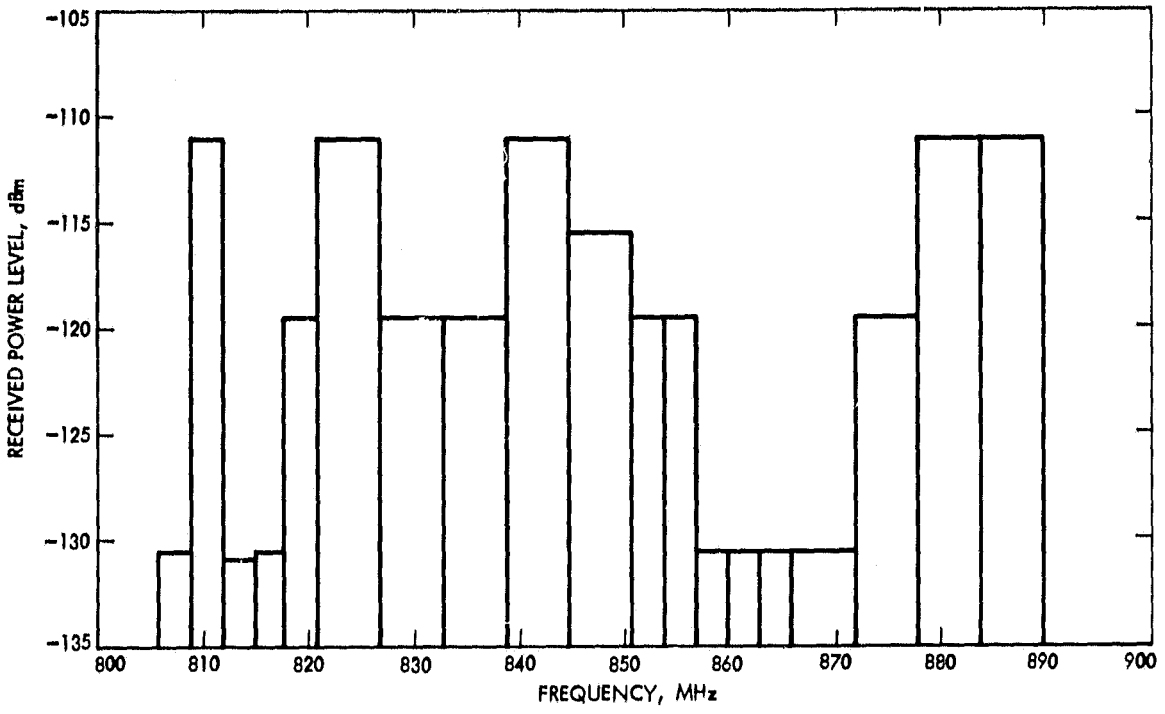

Figure 3-4. Power Level due to Terrestrial Transmitters in the 806- to 890-MHz Band as Seen by a Geostationary Satellite at 100°W Longitude Overlooking the North American Continent With an Isotropic Antenna and a Receiver Bandwidth Comparable to the Typical Transmitter Bandwidth. Assume Only a Single Transmitter is in the Receiver Bandwidth.

(2) 2500- to 2690-MHz band: The power level at the geostationary orbit is approximately -150 dBm for most of the band except for the portion approximately from 2565 MHz to 2375 MHz where the power level is approximately -130 dBm. A plot of the power level as a function of frequency obtained from Ref. 3-8 is shown in Fig. 3-5. A 6-MHz increment is used throughout this band. The power level for a given increment is the power level due to a typical equipment within this increment. The satellite is again assumed to have an isotropic antenna and a receiver bandwidth comparable to the transmitter bandwidth, typically 6 MHz for this band. An interference of -150 dBm is generally not strong enough to cause problems on communication satellites at the geostationary orbit. Since this frequency band is shared by Earth Exploration Satellites (WARC-79), this RFI level can, however, be detrimental to passive microwave sensors on board a low-orbit satellite with altitudes of the order of 1000 km (Seasat and Landsat type of orbits). The -150 dBm power level at the geostationary orbit corresponds to about -150 dBW at a 1000-km orbit which is approximately 16 dB above the interference threshold for passive microwave sensors near these frequencies. (See Table 3-4 for microwave sensors interference threshold for this frequency band.) In addition, a number of tunable experimental equipments located in California and New Mexico are capable of producing a power level of -142 dBm at the geostationary satellite. This equipment surely would cause problems on passive microwave sensors on board a low-orbit satellite if they were in the main beam of the satellite antenna.

(3) 27.5- to 30.0-GHz band: There is very little usage in this band at present. The maximum power at the satellite is estimated to be -173 dBm, which probably should not be a cause of concern.

Although there may be some uncertainty in magnitudes, exact frequencies, and geographical locations of the potential RFI sources, it is clear from the ECAC study and other studies mentioned above that potential RFI sources exist.

C. IS IT REALLY NECESSARY TO GAIN A BETTER KNOWLEDGE OF RFI?

Better RFI knowledge is necessary:

(1) To determine the seriousness of RFI problems. Knowing that potential RFI sources exist is not enough; to perform effective frequency management and to minimize harmful interference, more detailed and more accurate information regarding RFI frequencies, magnitudes, and locations is necessary.

(2) To derive temporal, spatial, and spectral statistics, which are essential for the following purposes:

(a) Satellite system design: It is possible to minimize performance degradation if the RFI situation is known.

(b) Earth-based station siting and satellite spacing: It is possible with the aid of RFI data to avoid placing an earth-based station or satellite in a location where unacceptable RFI exists.

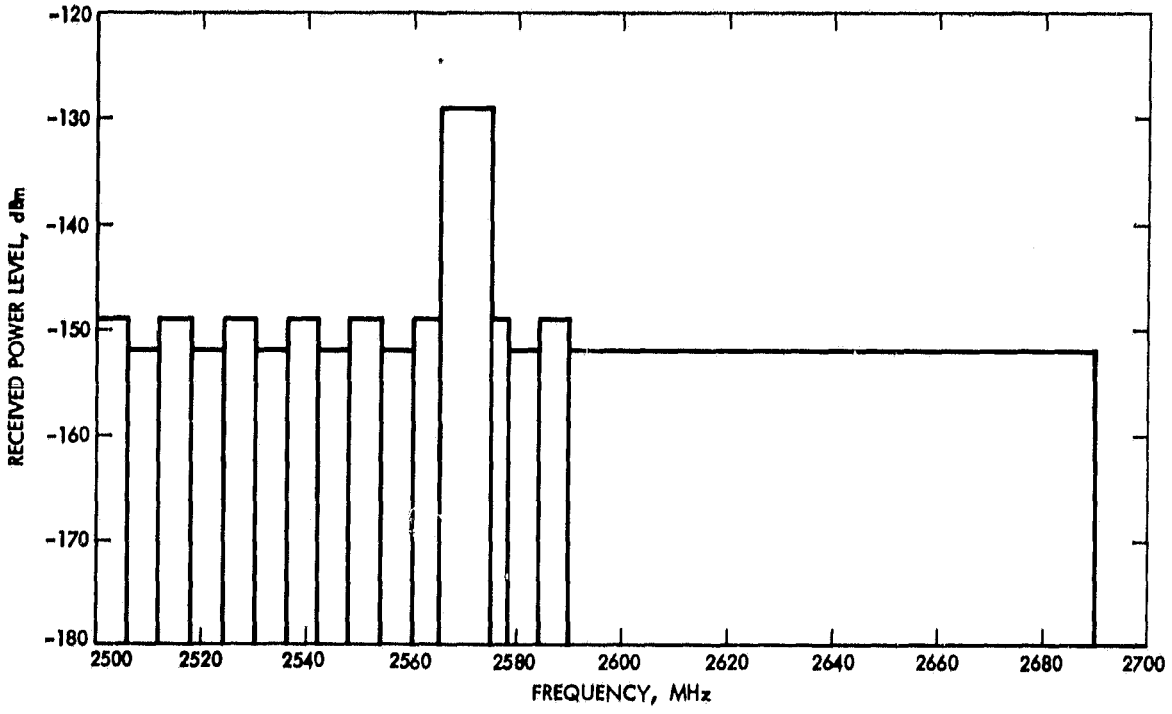

Figure 3-5. Power Level due to Terrestrial Transmitters in the 2500- to 2690-MHz Band as Seen by a Geostationary Satellite at 100°W Longitude Overlooking the North American Continent With an Isotropic Antenna and a Receiver Bandwidth Comparable to the Typical Transmitter Bandwidth (6 MHz). Assume Only a Single Transmitter is in the Receiver Bandwidth

(c) Frequency management: As demands on the spectrum increase, more efficient use of the spectrum is necessary. With the aid of RFI data, frequency allocation and sharing for maximum use can be determined.

On the other hand, the lack of RFI knowledge can have the following adverse effects:

(1) It may be necessary to accept performance degradation as a way of life.

(2) Experiments may be overdesigned to compensate for RFI uncertainties, or even deleted.

(3) An inefficient use of the spectrum may result because theoretical spectral occupancy may be quite different from actual spectral occupancy. As an example, experiments performed on LES-5 indicated that portions of the band surveyed (255 to 280 MHz) showed, in contrast to normal belief, very little usage (Ref. 3-3). Similar situations may occur in other frequency bands.

(4) Erroneous data might be returned from passive microwave sensors. Based on the ECAC study (Ref. 3-8) and the RFI measurement experiment performed on ATS-6 (Ref. 3-6), potential interference sources of power levels significantly above the CCIR sensor interference thresholds established by the International Radio Consultative Committee (CCIR) exist near 2.7 GHz and 6 GHz. These two frequencies are used by remote sensors for salinity, soil moisture, and ocean temperature measurements.

The need to obtain a better RFI knowledge is clear. The approach and timing to obtain such knowledge is, however, not all that obvious.

SECTION IV

POSSIBLE APPROACHES TO OBTAIN NEEDED RFI KNOWLEDGE

Basically, all possible approaches to obtain RFI data can be divided into two approaches: analytical and experimental. A brief description is given for each together with its relative advantages and disadvantages.

(1) Analytical approach: An analytical model can be developed and used to generate the needed RFI data by using the available data on all known transmitters. ECAC maintains a file that contains the characteristics of most of the known transmitters. The advantage of this approach is economy. The disadvantages are:

  (a) Not all transmitters are known.

  (b) Data available for a transmitter are not always accurate.

(2) Experimental approaches — uplink RFI: Most of the previous work reviewed used this approach. This approach involves measuring the RFI directly by either a high-altitude aircraft or an earth-orbiting satellite. The advantage and disadvantages are discussed below.

  (a) Aircraft measurement: This offers better accuracy than the analytical approach. It has, however, the following disadvantages:

    (i) Expensive.

    (ii) Time consuming.

    (iii) Almost impossible on a global scale due to possible political implications.

  (b) Earth-orbiting satellite measurement: This approach offers the most realistic results. The disadvantage is the cost.

(3) Experimental approaches — downlink RFI; Downlink RFI measurement was discussed in a report written by National Scientific Laboratories, Inc. (Ref. 4-1). There are various ways of doing this experiment by using up to two satellites.

  (a) Method A: This method employs two satellites; one transmits a signal and the other the interference. This is the most complicated experiment as it is necessary to maneuver these two satellites in various ways to accomplish the experiment objectives.

  (b) Method B: This method uses only one satellite. The desired signal comes from the satellite and the undesired signal comes from a nonsatellite source.

(c) Method C: This method also uses one satellite. The desired signal is simulated and injected at the earth-station receiver while the interference is coming from the satellite.

(d) Method D: This method measures the interference from a satellite without desired signals.

(e) Method E: This method uses no satellite. Sky noise is measured. This is the simplest approach.

SECTION V

THE PROPER APPROACH TO OBTAIN NEEDED RFI KNOWLEDGE

To obtain the needed uplink RFI knowledge, the first approach, the analytical, is least expensive. If it were not for its inaccuracy, this would be the best choice. It is, in general, possible to predict the radiation levels at orbital altitudes due to terrestrial transmitters based on a data base that contains information on terrestrial transmitters. Accuracy of the prediction, however, depends on the accuracy of the data base.

It is difficult to maintain an accurate, up-to-date data base for several reasons, some of which are:

(1) Unauthorized transmission.

(2) Inaccurate information provided by operators.

(3) Failure to report an inactive transmitter to proper authorities.

(4) Inaccessible information, such as classified information.

The Radio Frequency Interference Measurement Experiment (RFIME) performed on ATS-6 can best illustrate the inaccuracy of the analytical approach. The RFIME revealed the following problems:

(1) Discrepancy in data base (Ref. 3-6 and Ref. 5-1): In the course of generating predictions for RFIME, data files that contained information of terrestrial transmitters located in the U.S. were obtained from ECAC and FCC (Federal Communications Commission). Test runs were performed to estimate the signal levels emanating from part of California using these data files. A comparison of these two predictions showed that prediction based on an FCC data file had a much lower signal level than prediction for the same area using the ECAC data file. These two predictions and areas examined are shown in Fig. 5-1 (obtained from Ref. 5-1). In addition, errors in transmitter locations and transmitter antenna gains had been discovered. While some of these problems have been corrected, the uncertainty of the accuracy of the data file remains.

(2) Discrepancy in signal frequency between experimental and analytical data: A comparison was made in Ref. 3-6 between experimental data and analytical predicted data for two of the many sites surveyed by ATS-6. These two sites are Ithaca, New York, and Columbus, Ohio. Both experimental and analytical data are shown in Tables 5-1 and 5-2, which were obtained from Ref. 3-6. The measured data were placed into three groups (A, B, and C) according to the confidence levels associated with the measurements; group A had the highest level of confidence. The comparison showed that a number of signals detected by ATS-6 were not in the data base. Similarly, the comparison also showed that a number of signal frequencies were predicted but not detected. Using a bandwidth of 100 kHz, 45% of the measured type-A data for Ithaca and 89% of the type-A data for Columbus were not in the data base. The

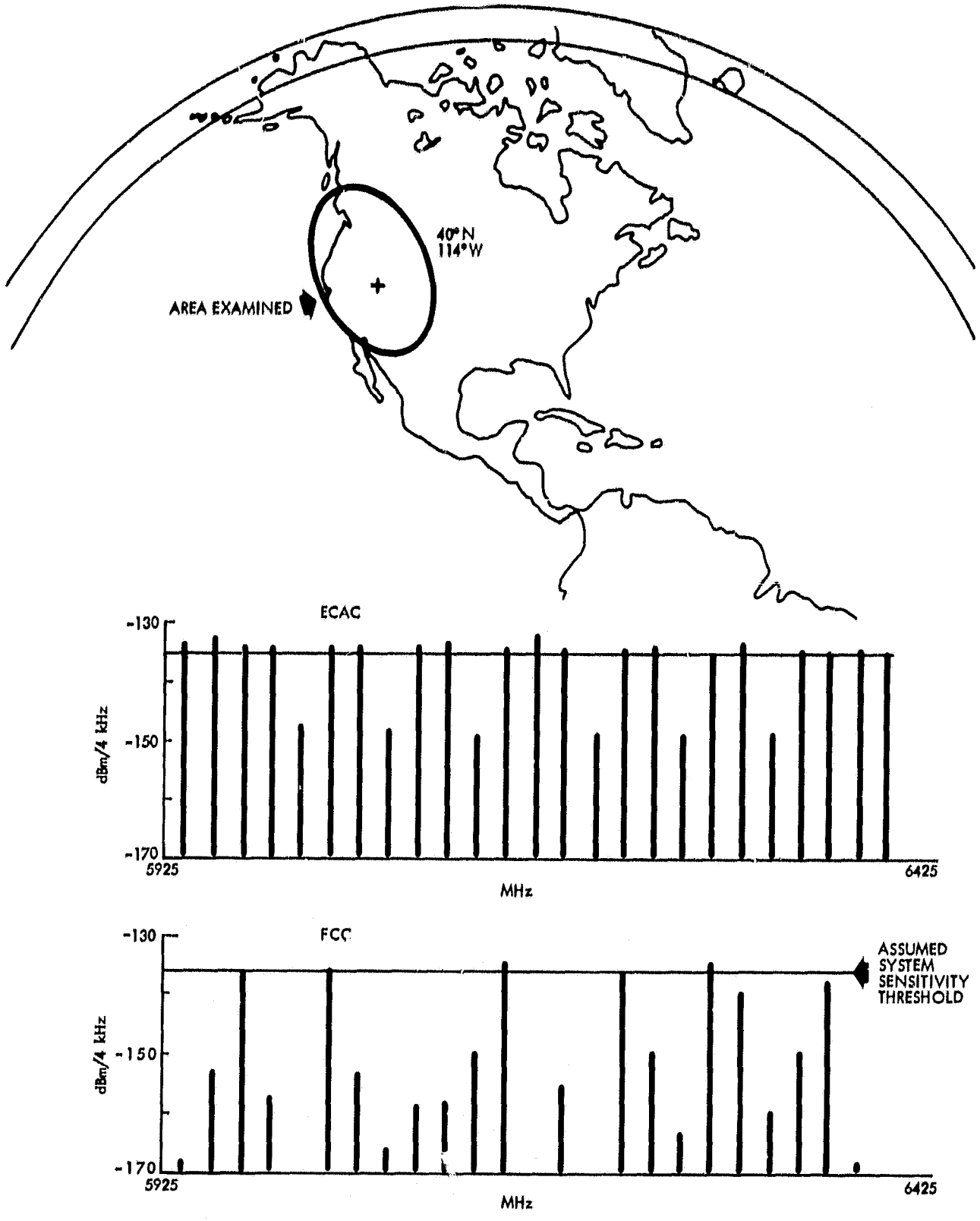

Figure 5-1. Comparison of Predictions Made With ECAC and With FCC Data Bases (From Ref. 5-1)

Table 5-1. Ithaca, New York, Data Summary (from Ref. 3-6)

Bandwidth, kHz	Measured Data Type	Total Measured Data	No. of Matched Frequencies	Total Matched to Frequency	Measured Signals Not in Data Base	Predicted Signals Not Detected	δ, %[a]	α, %[b]
100	A	101	13	56	45	31	45	70
	A,B	267	17	96	171	27	64	61
200	A	101	14	81	20	30	20	68
	A,B	267	18	139	128	26	48	53
300	A	101	14	93	8	30	8	68
	A,B	267	18	170	97	26	36	53

[a] δ = percentage of measured data not in data base.

[b] α = percentage of predicted signal frequencies not measured.

Table 5-2. Columbus, Ohio, Data Summary (from Ref. 3-6)

Bandwidth, kHz	Measured Data Type	Total Measured Data	No. of Matched Frequencies	Total Matched to Frequency	Measured Signals Not in Data Base	Predicted Signals Not Detected	$\delta, \%^a$	$\alpha, \%^b$
100	A	614	15	68	546	10	89	40
	A,B	631	15	70	561	10	89	40
	A,B,C	928	17	100	828	8	89	32
200	A	614	15	98	516	10	84	40
	A,B	631	15	100	531	10	84	40
	A,B,C	928	17	142	786	8	85	32
300	A	614	15	112	502	10	82	40
	A,B	631	15	114	517	10	82	40
	A,B,C	928	17	163	765	8	82	32

[a] δ = percentage of measured data not in data base.

[b] α = percentage of predicted signal frequencies not measured.

percentages of predictions that were not detected were also surprisingly high: 70% for Ithaca and 40% for Columbus based on type-A data using a 100-kHz bandwidth. Most of these discrepancies are believed to have been caused by an inaccurate data base rather than measurement errors because type-A data have the highest confidence levels.

(3) Discrepancy in signal levels for matched frequency data: In addition to the mismatch of signal frequencies, there is also a discrepancy in signal levels among the matched frequency data. The matched frequency data are those where the measured frequency agrees with the predicted signal frequency within a given tolerance or bandwidth. It was pointed out in Ref. 3-6 that "predicted signal levels for those predicted on the same frequency as those measured appear 8 to 10 dB lower than those measured." This discrepancy has not yet been fully explained. Since the measured data were calibrated against a precisely known reference, this discrepancy is more likely related to either the accuracy of the analytical model in such areas as propagation path and antenna pattern models, or the accuracy of the data base, or a combination of both. A discrepancy of 8 or 10 dB is not really too large to be unreasonable, but the fact that measured data were consistently stronger than predicted clearly points out the need for experimental verification of analytical models. A plot of experimental and analytical data for the matched frequency data is shown in Figs. 5-2 and 5-3 for Ithaca and Columbus, respectively. These plots are based on data obtained from Ref. 3-6.

In addition to the RFIME on ATS-6, there are other experiments that tend to indicate the possible inaccuracy of analytical models. One such experiment is the LES-5 experiment performed by Lincoln Laboratory to survey radiation levels in the 255- to 280-MHz band (Ref. 3-3). Results of this experiment indicate that "many unidentified signals of amplitude sufficient to cause concern are seen." The RFIME and LES-5 experiments clearly point out some of the problems inherent in the analytical approach. Even though there has been some improvement in existing data bases, whether these data bases are accurate enough to provide accurate RFI predictions remains to be proven. It is for this reason that the analytical approach is not recommended. (It is noted that the U.S. Air Force has recently taken steps to develop a Space Environment Data Base. One of the possible uses of such a data base is to estimate man-made radiation levels at orbital altitude. Whether experiments are planned to verify the accuracy of the data file is not known.)

The second approach to obtain the needed uplink RFI knowledge is that part of the experimental that involves high-altitude measurements by an aircraft. This approach has been demonstrated to be feasible on a small local scale (Refs. 3-4, 5-2, and 5-3). Extrapolation techniques can be used to estimate the RFI power level at different orbital altitudes (Refs. 5-4 and 5-5). Unfortunately, this approach is limited to a local scale. To make a global coverage using an airplane would be very time-consuming, expensive, and, most of all, would run into formidable political obstacles. Since our concern is on a global scale, this approach is not practical.

The remaining approach is to measure the actual RFI level by an earth-orbiting satellite. There are two options: to perform RFI measurements at the geostationary orbit using a geostationary satellite, or to perform the measurement

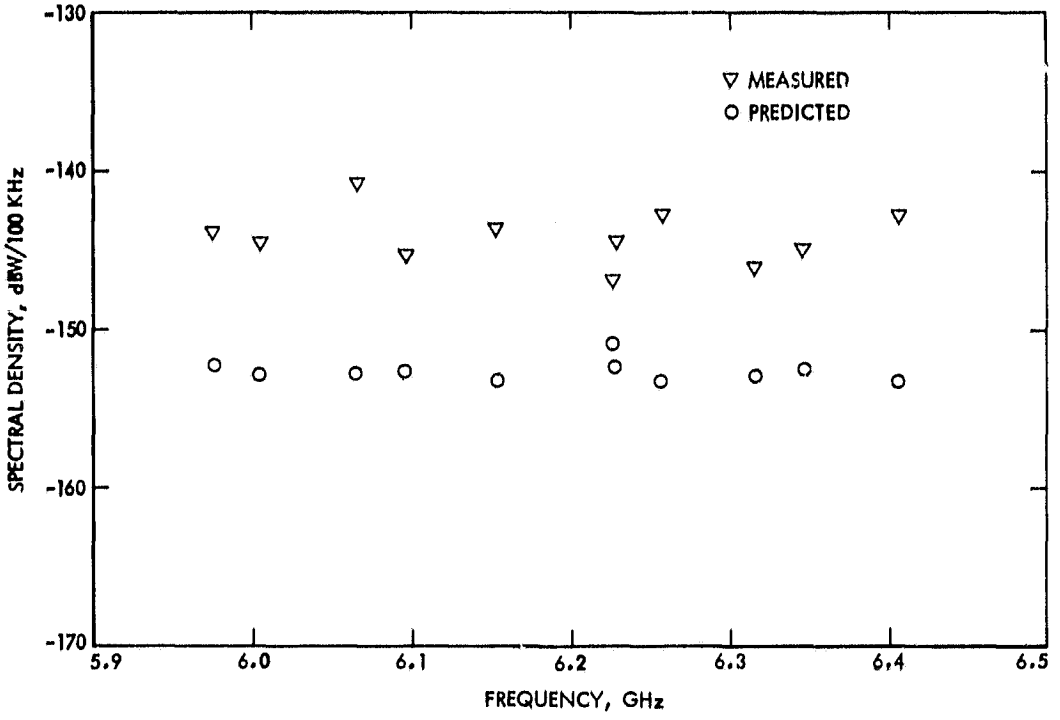

Figure 5-2. Matched Frequency Data for Ithaca, New York. 100-kHz Bandwidth, ATS-6 (From Ref. 3-6)

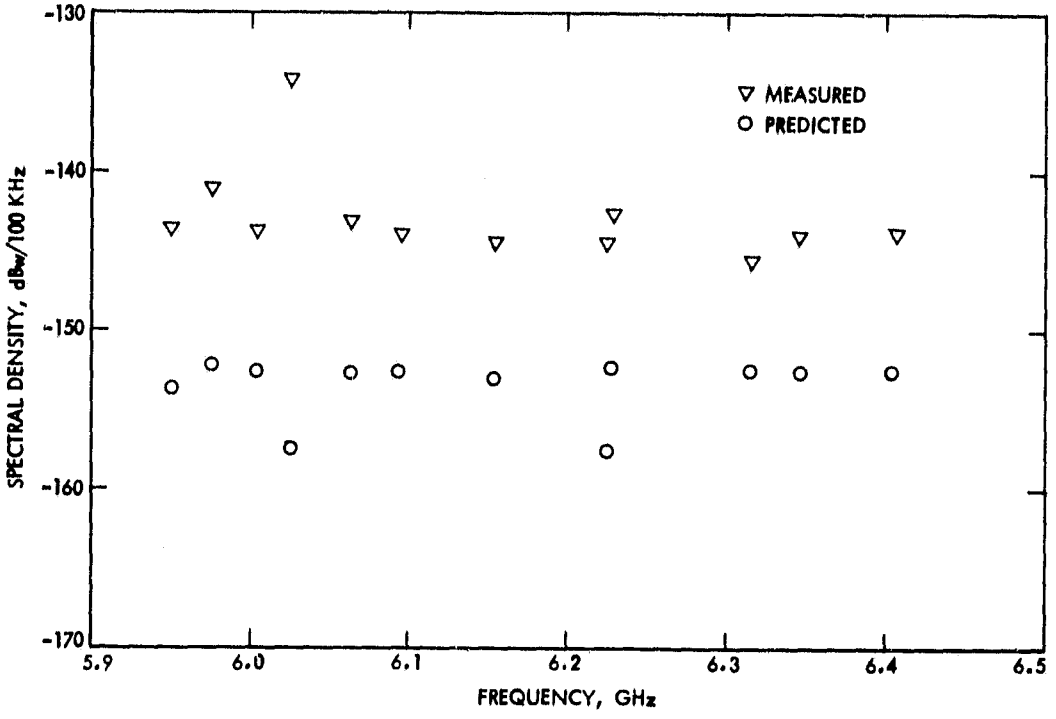

Figure 5-3. Matched Frequency Data for Columbus, Ohio. 100-kHz Bandwidth, ATS-6 (From Ref. 3-6)

by a low-orbit satellite and apply extrapolation techniques to derive RFI data for the desired orbits, including the geostationary orbit. Both techniques seem feasible (Refs. 3-5, 3-6, 5-4 and 5-6). The use of a low-orbit satellite, however, is preferable for the following reasons:

(1) Cost effectiveness: Even though it is the RFI at the geostationary orbit that is of major concern to NASA, satellites in lower orbits are equally susceptible to RFI. NASA has had satellites in the geostationary orbits as well as other lower orbits and this is expected to continue in the future. It is therefore necessary to have RFI data for all orbital altitudes of interest. A cost-effective way to obtain such data is to extrapolate measurements from one orbital altitude to another. A low-orbit satellite offers the opportunity of better spatial resolution, hence making it easier to extrapolate the RFI measurements from one orbit to another.

(2) Global coverage: Because a low-orbit satellite can pass a given point on earth from different directions, a complete survey of upward rotation at different elevation and azimuth angles is possible. Consequently, near-global coverage can easily be obtained by a low-orbit satellite. A satellite at the geostationary orbit, on the other hand, does not have this capability.

(3) Lower detectable signal level: The distance from a terrestrial transmitter to a low-orbit satellite is considerably less than that from the same transmitter to a satellite in the geostationary orbit. For the same receiver sensitivity, the minimum detectable signal level is much lower for a low-orbit satellite than that for a geostationary satellite.

Based on the above reasons, a low-orbit satellite is believed to be more suitable for uplink RFI measurements than a geostationary satellite.

For downlink interference, Method E of the five approaches outlined in Section IV is preferred. By using a ground station, sky noise (including nonsatellite and satellite sources) can be measured as a function of elevation angle, azimuth angle, and time. Statistical data can then be derived and used by different users.

SECTION VI

THE TIMING AND REQUIREMENTS OF AN RFI MEASUREMENT EXPERIMENT

We have thus far examined the first five of the seven basic RFI questions raised in Section II, and established the following regarding RFI at orbital altitudes:

(1) Potential RFI sources exist.

(2) There are basic needs for more and accurate RFI data.

(3) The best approach to satisfactory RFI measurements is with use of a low-orbit satellite.

The question of when RFI measurements should be made can be answered on the basis of two factors:

(1) The seriousness of the RFI problem.

(2) The penalty for not having RFI data.

The RFI incidents observed by NASA were well documented prior to approximately 1974. These data make an estimate of the RFI situation possible. Unfortunately, no such data is available for the last five or six years. It is believed that an RFI incident data base, which consists of all RFI incident data, should be created. These data can give clues to (a) the extent of RFI, and (b) the characteristics of RFI in terms of frequency bands and geographical locations. With the aid of this information, an RFI measurement experiment can be implemented in a timely and cost-effective manner.

The effort to create such a data base is believed to be minimal, and the time required is estimated at six to twelve months. The cost of creating such a data base is also insignificant compared to the cost of an RFI measurement program. It is therefore recommended that the RFI measurement project be postponed until an RFI incident data base can be created and analyzed.

While it is difficult to schedule an RFI measurement experiment that is based on available data, it is possible to state the general requirements of such an experiment. Based on the nature of the RFI environment and the intended use of the results, the design for an RFI measurement experiment should embody the following criteria:

(1) Low cost: The nature of RFI may require costly multiple measurements of the RFI environment. To make the measurement project financially feasible, the experiment should be a secondary payload on a suitable primary mission.

(2) Minimum wait-time: Because measurement gathering and data processing are time consuming, results of the RFI measurement are not immediately available for use. The RFI environment, however, may change, and it

is imperative to minimize the wait time for a useful result. The amount of data processing is directly proportional to the number of frequency bands monitored, and the geographical area covered. It may be necessary, therefore, to establish measurement gathering and data processing priorities among the different frequency bands and geographical locations.

(3) Repeated measurements: Parameters affecting the RFI environment may change from time to time. In particular, daytime and nighttime activities of terrestrial transmitters are believed to be quite different. An RFI experiment, therefore, must be able to make repeated measurements over a particular area and a particular frequency band to derive long-term statistics and provide information about diurnal variations. Only long-term data are meaningful to satellite designers and frequency management.

(4) Determination of transmitter locations and direction of transmission: One of the many possible uses of RFI measurement data is to verify and modify existing RFI predictive models, or even develop new models. To achieve these goals, an RFI measurement system must provide information on the location of an RFI source and the direction of transmission. In addition, this information will allow extrapolation of measurements from one altitude to another. This combination of low-orbit measurements and extrapolation techniques make RFI data for all orbits of interest possible in a cost-effective way.

(5) High inclination angle: The distribution of terrestrial transmitters is more or less related to the distribution of population on the surface of earth. Therefore, a suitable orbit for RFI measurements should cover a major portion the population. A plot of the percentage of population and land surface covered by a satellite as a function of the orbit inclination angle obtained from Ref. 5-5 is shown in Fig. 6-1. Based on Fig. 6-1, an orbit with an inclination angle of about 50 deg would cover a large portion of land surface and population.

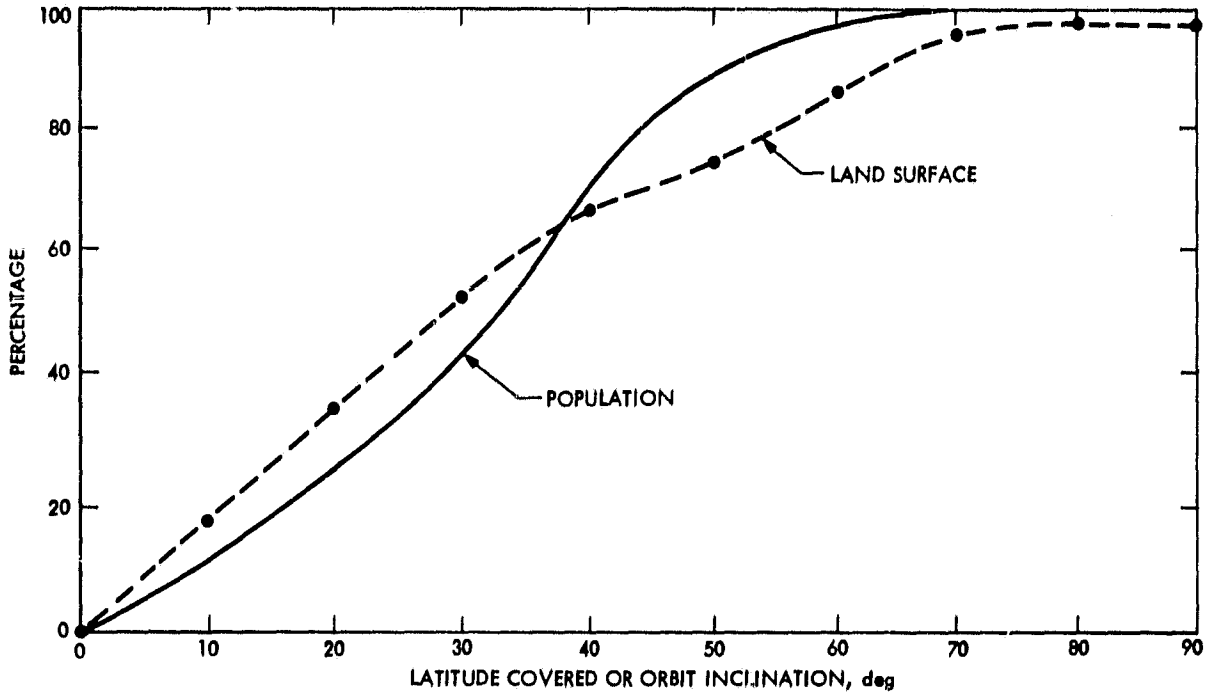

Figure 6-1. Percentage of Population and Land Surface Coverage by a Satellite as a Function of Orbit Inclination (From Ref. 5-5)

SECTION VII

A PROPOSED RFI PROGRAM

Both uplink and downlink RFI environments are subject to constant change. It is imperative to know whether an RFI measurement will be valid some years later. One obvious assurance is frequent RFI measurements on a regular schedule. The cost, however, would be prohibitive. To achieve this goal in a cost-effective way, it is necessary to create a coherent RFI program that emphasizes equally RFI incident data collection, measurements, modeling/prediction, and coordination (Fig. 7-1). This program involves the creation of a centralized RFI incident data base, the establishment of a coordination committee, and the use of predictive models and RFI measurements. Each of these elements functions as follows:

(1) RFI incident data base (because of the intended use of this data base, early establishment would be necessary):

   (a) It provides clues to the seriousness of the RFI situation, and the geographical and spectral characteristics. This information is useful for planning an RFI measurement project.

   (b) It serves as verification of RFI predictive models. If models are proven incorrect by observed RFI incidents, it may be necessary to modify the models or even perform direct measurements. This data base allows constant monitoring of the validity of predictive models without regular, expensive measurements.

(2) RFI measurement: The RFI data base can be analyzed to give information on the extent, trends, and other characteristics of RFI activity. This information would determine the appropriate time for an in-orbit RFI measurement. The results of the measurement can be used to verify, modify, or even develop predictive models.

(3) RFI predictive models: Upon verification by measurements, these models can be used to predict RFI occurrence for as long as the models remain valid. If the models fail to predict the observed RFI, remodeling or more measurements may be necessary.

(4) Coordination committee: Because parameters affecting the RFI environment may change, the possibility of serious interference exists regardless of the measures taken to prevent it. It is therefore important to establish a means to avoid such interference when it is predicted or even being observed. An international coordination committee can achieve this goal.

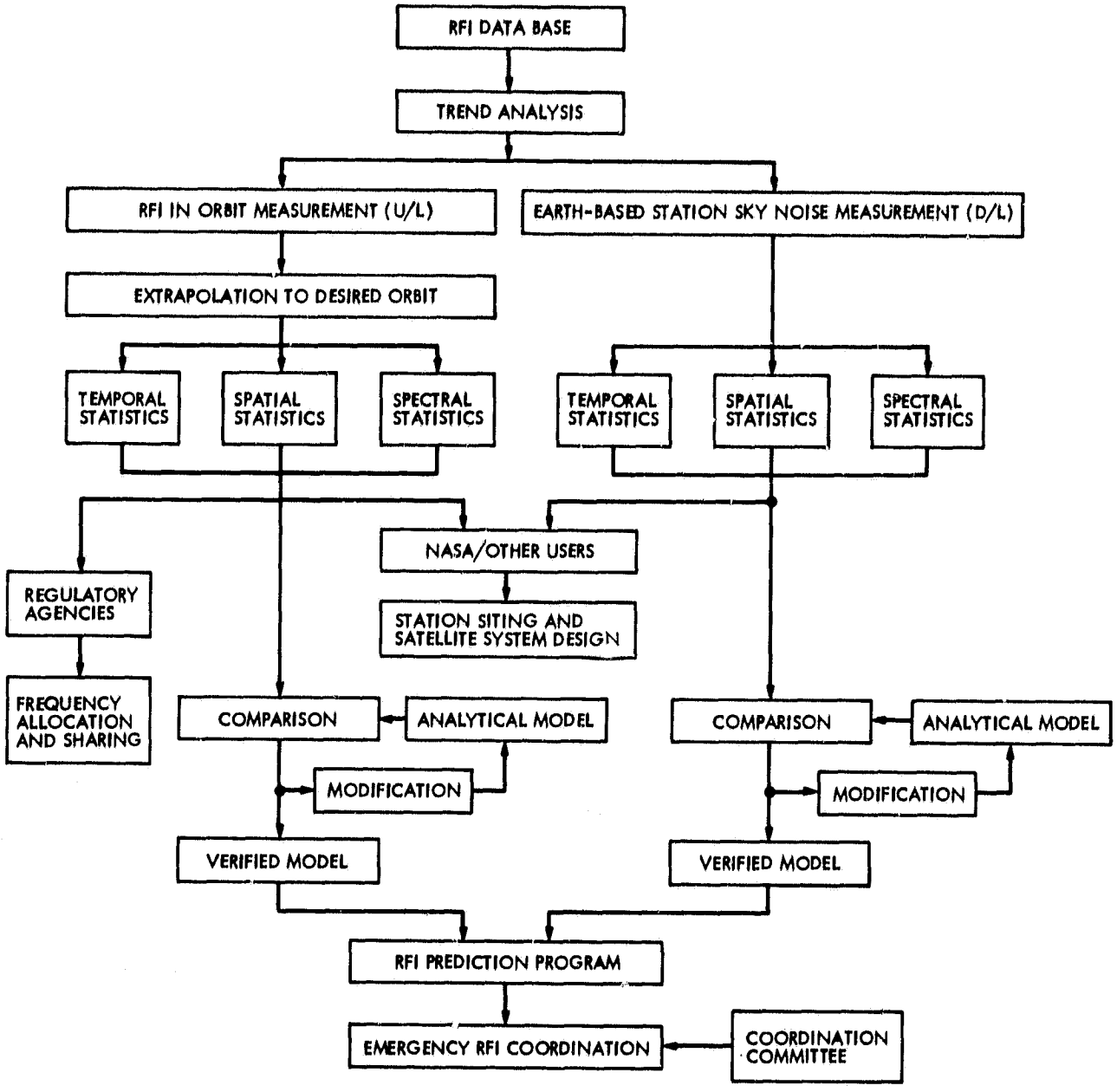

Figure 7-1. A Proposed RFI Program

SECTION VIII

CONCLUSION

The RFI problem at the geostationary orbit has been examined. It has been shown that potential RFI sources exist in certain frequency bands. It is fortunate that there have been no catastrophic RFI incidents. With the development of the new space transportation system (Shuttle) and the Tracking and Data Relay Satellite System (TDRSS), space activities are bound to increase in the future. This, coupled with the demand for higher data rates and, hence, wider bandwidths, will certainly increase the possibility of harmful interference. To minimize such interference, to maximize the utilization of the frequency spectrum, and to avoid unnecessary overdesign of satellite systems, a RFI program is recommended.

This program utilizes in-orbit RFI measurements and computer models to achieve these goals cost-effectively. This program, when implemented, will be adequate to handle the RFI problem at the geostationary orbit, as well as other orbits.

The first step in implementing the program is the creation of a centralized RFI incident data base. This data base is essential in providing information for defining further actions. Early establishment of this data base is recommended.

The proposed RFI program partly involves the measurement of RFI levels at orbital altitude. This can be a very sensitive area because it may involve classified information. It will probably be necessary to coordinate the measurement activity with the Department of Defense (DOD), the Federal Communications Commission (FCC), and foreign countries.

REFERENCES

3-1. RFI Experiment Definition Project Report, National Scientific Laboratories, Inc., McLean, Va., June 1974.

3-2. Morgan, W. L., "Multi-Mission Space Stations," Satellite Communications, Vol. 2, No. 4, April 1978.

3-3. Ward, W. W., Sicotte, R. L., Hurlbut, K. H., and Zamites, C. J., Jr., The Results of the LES-5 and LES-6 RFI Experiments, Technical Note 1970-3, February 6, 1970, MIT Lincoln Laboratory.

3-4. Taylor, R. E., and Hill, J. S., "Airborne East Coast/Mid West Urban Survey at 121.5/243 MHz," IEEE Transaction on Electromagnetic Compatibility, Vol. EMC-21, No. 2, May 1979.

3-5. Birch, J. N., and French, R. H., Definition of Multipath/RFI Experiments for Orbital Testing with a Small Application Technology Satellite, Final Report, December 1, 1972, The Magnavox Company.

3-6. Adams, J. E., and Vandermade, D. W., A Revised Model For Predictions of Interference Power in the Geostationary Orbit and Some Comparisons to ATS-6 Measured Data, July 1978, Institute of Telecommunications Science (Preliminary Draft).

3-7. International Radio Consultative Committee, XIVth Plenary Assembly, Recommendations and Reports of CCIR, 1978, Vol. II, Report 694.

3-8. Harper, J. G., and Dean, G., NASA RFI Emission Levels, IIT Research Institute, October 1980 (ECAC-CR-80-105).

4-1. Satellite Spacing Experiment Design Study, Second Status Briefing, National Science Laboratories, Inc., Westgate Research Park, McLean, Va., March 11, 1971.

5-1. Bergman, R. R., Rice, P. L., and Miles, M. J., "Mathematical Computer Model and Predictions for ATS-F Radio Interference Experiment at 6 GHz," Telecommunications Technical Memo, Institute of Telecommunications Sciences, OT TM-107, August 1972.

5-2. Airborne Interference Measurement Systems (AIMS) Experiment, National Scientific Laboratories, Inc., June 3, 1974.

5-3. Taylor, R. E., and Hill, J. S., The Plan and Preliminary Report of Airborne Electromagnetic Environment Survey over U.S.A. Urban Areas 0.4 to 18.0 GHz, NASA CR-2640, National Aeronautics and Space Administration, Washington, D.C., December 1975.

5-4. Proposal to Measure Electromagnetic Field Intensity In Orbit Using SATS-A Spacecraft (Part 1, Technical), December 1, 1972, Goddard Space Flight Center.

5-5. Feasibility Study of Man-Made Radio Frequency Radiation Measurement From A 200-Mile Orbit, General Dynamics Report No. 22K68-007, 15 February 1968.

5-6. AAFE Proposal for An RFI Measurement Extrapolation Experiment, Electromagnetic Systems Laboratories, May 5, 1972.

NASA–JPL–Coml., L.A., Calif.