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AFAL-TR-75-252

SUMMARY OF SHF SATCOM INTERFERENCE STUDY

System Avionics Division (AA)
System Development Branch (ASD)

DECEMBER 1975

TECHNICAL REPORT AFAL-TR-75-252

Summary of Final Technical Report May 1974 - June 1975

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20. (Continued)

Resource Assessment of the 7.25-8.40 GHz band conducted by the Department of Commerce, Office of Telecommunications. The Advanced Airborne Command Post plans to implement an airborne SHF SATCOM terminal aboard its E-4 aircraft to provide reliable command and control communications. Since the SHF frequency band (7.9-8.4 GHz) is allocated for terrestrial microwave and space system use, it was necessary to experimentally verify the interference potential of the airborne terminal and to identify spectrum sharing options. To assure this, a detailed analysis was performed to identify tolerable interference levels for a number of terrestrial microwave and space systems. Next, a series of ground and flight test measurements were made against representative terrestrial microwave terminals and the NASA Goldstone deep space tracking station. These results determined the mutual coupling levels between the airborne SHF SATCOM antennas the the terrestrial microwave and space system antennas. Received power levels and interference modes were investigated. The results of these tests were analyzed and conclusions drawn as to the probability of interference between the two systems under various conditions. Conclusions and recommendations were drawn from the analysis which would reduce the interference between the airborne SHF SATCOM terminal and terrestrial microwave systems to a tolerable level if a number of specific spectrum sharing options are implemented. Recommendations are presented regarding a course of action to assure that the options are considered.

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FOREWORD

This Technical Report presents a summary of the findings of an investigation to experimentally evaluate the interference potential of an airborne SHF SATCOM terminal on terrestrial microwave and space systems that operate in a common frequency band. This effort resulted from concerns voiced by the Office of Telecommunications Policy (OTP) as a result of a Spectrum Resource Assessment of the 7.25-8.40 GHz frequency band conducted by the Department of Commerce, Office of Telecommunications. Because of the broad implications of the potential interactions, the USAF, as developer of the airborne SHF SATCOM terminal, was identified by DOD to lead the investigation. The USAF in turn delegated this responsibility to the Air Force Avionics Laboratory (AFAL). AFAL called upon the expertise of the Department of Commerce, Office of Telecommunications (OT) and the Department of Defense, Electromagnetic Compatibility Analysis Center (ECAC) for direct support in performing the necessary study. In the conduct of the study, a large number of other agencies and individuals were called upon to assist in the various phases of the study. The authors wish to thank the following organizations without whose tremendous support the effort could not have been accomplished:

- Office of Telecommunications Policy (OTP)
- Energy Research and Development Administration (ERDA/AEC)
- Department of the Interior (DOI)
- Department of Commerce (DOC)
- National Aeronautics and Space Administration (NASA)
- NASA/Jet Propulsion Laboratory (JPL)
- Defense Communication Agency (DCA)
- Federal Aviation Administration (FAA)
- Tennessee Valley Authority (TVA)
- Bonneville Power Administration (BPA)

USAF/Frequency Management
USAF/E-4 System Program Office
Electronic System Division
Strategic Air Command (SAC)
Air Force Communication Service (AFCS)

This effort was accomplished during the period May 1974 through June 1975 under Project 1227, "Advanced Microwave Communications," task 12272205, "SATCOM Testing."

The project leader was Allen L. Johnson. Testing was under the direction of Roger L. Swanson (AFAL), Robert Mayher (OT), Richard Parlow (OT), Michael J. Kelly (ECAC/IITRI) and Paul Groot (ECAC/IITRI). Special thanks is extended to Major Robert L. Wasson who was in charge of AFAL's test effort from the project inception until his transfer in April 1975.

TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
I	GENERAL	1
II	ANALYSIS APPROACH	9
III	SHF SATCOM OPERATIONAL CONSIDERATIONS	14
IV	CONCLUSIONS	19
V	REFERENCES	25

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Airborne SHF SATCOM Interference Geometry	2
2	DSCS II Satellite Frequency Plan	17

SECTION I

GENERAL

INTRODUCTION

The Department of Defense (DOD) plans to implement a Super High Frequency (SHF) satellite communication (SATCOM) capability aboard the E-4 (Advanced Airborne Command Post) in order to provide reliable, jam-resistant communications for the command and control purposes. The airborne SHF SATCOM system is designed to communicate over the Defense Satellite Communications System (DSCS) which operates in the 7.25 to 8.4 GHz frequency band. In the DSCS Phase ~~I~~² satellites a portion of this frequency band from 7.25 to 7.30 GHz (downlink) and from 7.975 to 8.025 GHz (uplink) has been allocated exclusively for satellite use. The remainder of the DSCS ~~I~~² frequency band has been allocated as a shared band for ground terrestrial microwave use and other space systems. The users of this shared portion of the band are various government agencies which operate point-to-point microwave links plus other space systems.

Use of the exclusive satellite band by SATCOM terminals does not represent a significant interference threat to ground terrestrial microwave. However, airborne SHF SATCOM terminals in the shared portion of the DSCS ~~II~~² band represent a potential threat to the point-to-point terrestrial microwave users and other space systems. Most ground based SATCOM terminals are specifically located to avoid interference with other terrestrial microwave users. However, due to its mobility, the incorporation of a SHF SATCOM terminal in an airborne command post represents a potential interference to terrestrial microwave users operating in the shared frequency band under the

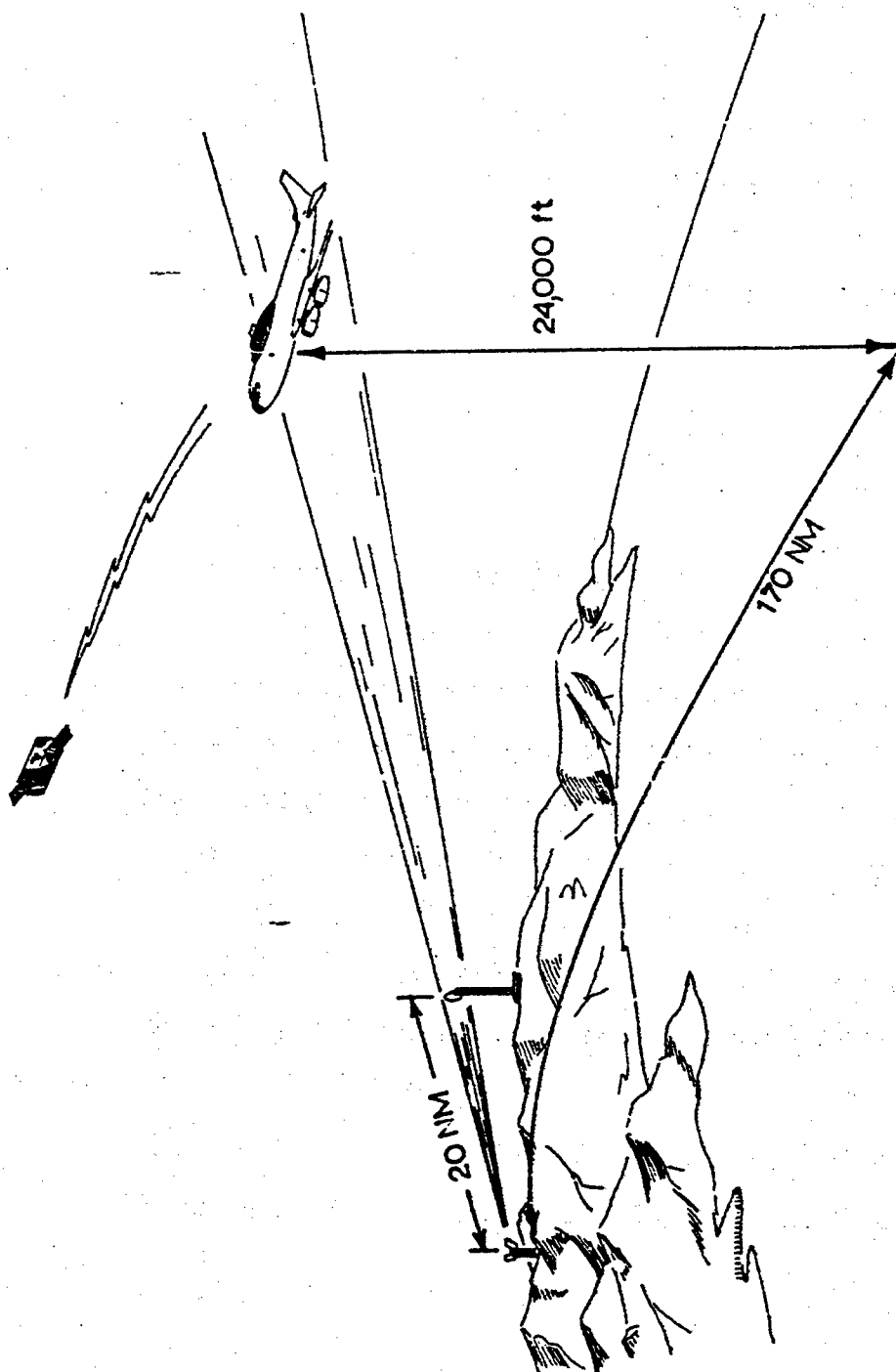


FIGURE 1 AIRBORNE SHF SATCOM INTERFERENCE GEOMETRY

situation shown in Figure 1. This figure depicts potential interference coupling between the sidelobes of the airborne SHF SATCOM terminal and the main beam of a terrestrial microwave receiver.

The airborne SHF SATCOM terminal developed for use on the E-4 (AN/ASC-18) can transmit at 1 watt to 10 kilowatts continuous power and utilizes a 32 dB directive antenna to communicate via the satellite.

In view of the potential interference threat which this airborne SHF SATCOM terminal represents when it flies near a terrestrial microwave user the Office of Telecommunications Policy (OTP) requested that the Air Force perform a detailed investigation to determine the seriousness of the interference threat prior to implementation of the operational airborne SHF SATCOM system.

OBJECTIVE

The U.S. Air Force directed that the Air Force Systems Command (AFSC), who is responsible for both the AN/ASC-18 development and the E-4 program, perform the detailed study necessary to answer the interference question. AFSC designated the Air Force Avionics Laboratory (AFAL) as the Office of Primary Responsibility for conducting the interference investigation. AFAL hosted an initial meeting in May 1974 to define the objective of the test and the approach. The meeting was attended by those government agencies which operated terrestrial microwave links in the SHF shared satellite band and by organizations which intended to participate in the interference study. At this meeting it was decided that the objective of the SHF SATCOM Interference Study would be to "Determine the interference level generated in the terrestrial microwave terminals and space systems in the band by the airborne

SHF SATCOM terminal, then evaluate the effect of this interference on the performance of the terrestrial microwave system and identify alternate solutions."

APPROACH

In order to accomplish the objectives the following approach was selected:

A. Identification of Terrestrial Microwave Users. The objective of this effort was to identify those agencies with systems operating in the 7.25 to 8.4 GHz band. This involved not only current users, but agencies which might be operating on that band in the future. The Office of Telecommunications Policy (OTP) accepted the chairmanship of this task. They accomplished this task by reviewing the computer listings for frequency assignments within the desired frequency band. They also polled agencies for potential future users who expected to operate in this band.

B. Terrestrial Microwave System Characteristics. The objective of this task was to identify the characteristics of the terrestrial microwave systems and other space systems operating within the selected frequency band. The Electromagnetic Compatibility Analysis Center (ECAC) accepted the chairmanship of this task. Their approach was to use the computer listings of the various band users to identify basic equipment types. Further discussions with each individual users to verify, clarify and add to the computer information was necessary in order to obtain the technical characteristics of the terrestrial microwave systems of interest. One of the characteristics to be determined was the expected fading outage. Since the total elimination of interference may not be possible there is a need

to establish a tolerable level of interference. In general, if the interference occurs for a small percentage of the normal fading outage time, it would appear to be tolerable. The characteristics of the users' terminals are included in the complete report.¹

C. Establish Signal-to-Interference Ratios. The objective of this task was to establish signal-to-interference levels which would provide criteria for protection of terrestrial microwave system operation. The Office of Telecommunication (OT) accepted chairmanship of this task.

Their approach to this task was to develop signal-to-interference (S/I) ratios which could be applied by each of the microwave users. They then assisted the users in evaluating their systems and in developing the necessary S/I ratios and associated maximum probability of occurrence values. These ratios provided the basis for the test analysis criteria and are contained in Reference 2.

D. Define Expected SHF SATCOM Operation on E-4. The objective of this task was to define the expected operational use of the airborne SHF SATCOM system aboard the E-4. This would include the expected frequency, power and data rate to be used in addition to expected time and geographical location of airborne operations. The E-4 SPO at ESD accepted the chairmanship of this task.

Their approach to this task was to quiz the potential E-4 users (SAC and NEACP) to determine their expected operational scenario. They tried to determine who the command post would be operating with, at what data rates, what geographic locations, what satellite modes, what power, and during what times. The results of this effort are in SECTION III.

E. Interference Probability Analysis. The objective of this task was to determine the likelihood of interference being generated in the terrestrial microwave by the airborne SHF SATCOM system. ECAC accepted the chairmanship of this task.

Their approach was to conduct a general study of the airborne SHF SATCOM terminal's impact on point-to-point microwave and other systems which share the common operating band. Guidelines were developed that aided in the identification of spectrum sharing options. Factors such as desired signal levels, fade margins, typical system characteristics, expected interference signal levels and aircraft overflights were considered. Their analysis is contained in References 3 and 4.

F. Data Collection. The objective of this task was to develop procedures for ground and airborne tests to collect the necessary test data. This included the task of providing the necessary monitoring and interfering equipment for the ground and airborne test. Final effort in this task was to actually perform the ground and airborne flight test. Air Force Avionics Laboratory (AFAL) accepted the chairmanship of this task.

The approach was to first examine the interference criteria and determine what testing needed to be done. Next the test equipment required was defined and collected. A ground test was performed at each site to verify the system parameters and establish a baseline for the flight test. The plan for the flight test was established and actual data collection accomplished by flying the interfering system in the vicinity of the terrestrial microwave link. The test plans and test reports were published in References 5 through 13.

G. Analysis and Evaluation. The objective of this task was to evaluate the data obtained from the previous six tasks and formulate recommended operational and management procedures for compatible operation of the airborne SHF SATCOM system and the terrestrial microwave systems. AFAL was chairman of this group.

The approach was to review all the data collected under the previous six tasks and provide a detailed analysis of the interference problem. The details of the evaluation are contained in AFAL-TR-75-251.¹ In order to cover extensions of these techniques to the more general interference problem, a third report has been prepared.¹⁴ That report considers the changes in bandwidths, powers, signal-to-noise or modulation techniques to be taken into account when applying these evaluation techniques to other systems.

It was agreed that the potential interference problem was a world-wide problem. However, it was decided to limit the study to the CONUS (48 contiguous states plus the District of Columbia). Once those problems were solved the effort could be expanded as required.

An initial look at the problem indicated that it would not be possible to perform an actual test against all microwave sites. It was decided to try to group the types of sites and pick representative sites for the actual test. As a result of the grouping six test sites were selected as typical. These were:

- a. TVA's McEwen, Tennessee 600 Channel FM Voice Link
- b. AEC's Nevada Test Site Close Circuit TV Link
- c. AEC's Nevada Test Site Digital Link (NADS)
- d. FAA's Jacksonville, Florida RML-4 Radar Remoting Link

e. FAA's Jacksonville, Florida RML-6 Radar Remoting Link

f. JPL's Goldstone, California 210' Space Track System

In selecting an approach for the study it was agreed to attempt to set up and validate an analysis procedure so that as future terrestrial microwave sites are added the interference problem can be satisfied by analysis. Testing against each new site is obviously not practical.

SECTION II

ANALYSIS APPROACH

GENERAL

The basic concept of the analysis effort was to make a series of measurements and calculations which could be applied to the general problem of interference between an airborne SHF SATCOM system, terrestrial microwave systems and other space systems. This required a series of predictions, calculations, ground (closed-system) measurements, and airborne (open-system) tests. Obviously, it is not possible to test all links nor to test under all possible conditions. Therefore, the plan was to test a representative sample of the types of links in use under realistic conditions.

In order to analyze the interference between the airborne and other systems sharing the band it is necessary to define the system parameters which may interact. These parameters include:

- (1) modulation characteristics
- (2) system frequencies and bandwidths
- (3) type of information being transmitted
- (4) link characteristics, including geometric considerations
- (5) operational periods and data perishability
- (6) design options

ANALYSIS PROCESS

The analysis process to be used in this report includes the following steps:

- (1) Development of basic system equations.
- (2) Application of predicted and measured link parameters.

- (3) Calculation of predicted interference levels.
- (4) Comparison of predicted and measured interference levels.
- (5) Application of probability theory to determine probabilistic aspects of link outage times.

TYPE OF TESTS

In general, two types of tests (a closed-system test and an open-system test) are required to completely characterize the potential interference. The closed-system tests are done to provide a baseline for performance. They determine system response to known interference signal. These tests are run on the ground with an interference signal inserted directly into the receiving system along with the desired signal. In this way known levels of interference can be generated and the effects of this interference on the AGC, squelch, processing gain and signal quality can be made.

The first step in the closed test is to calibrate the AGC signal with a known input CW signal. Next the input interference level is measured. Then the modulated desired signal is fed to the receiver along with the known interference. The $(S/I)_{IN}$ is varied and the $(S/I)_{OUT}$ is measured. In this way the processing gain is derived and can be used during actual measurements.

Following the closed-system test actual airborne open-system tests were made using an interference source in the test aircraft. These tests were done to confirm the predicted antenna coupling and microwave system interference. Since the interfering signal overlaps in frequency with the desired signal, it is not possible in the open-system test to directly measure interference power. However, from the baseline closed-system tests the input interference power level can be determined by measuring $(S/i)_{OUT}$. Since the

processing gain was determined in the closed-system test, $(S/I)_{IN}$ can be derived. Using this technique the S/I ratios were determined as the aircraft flew through the test area and radiated the potential interfering signal.

To simulate a 600 channel FM microwave system the baseband channel was noise loaded. A series of slots were notched out using 3 kHz slot filters. In this way the effect of the interference signal could be measured on the receiver by noting the rise in the noise in the slot. For the digital link and video link slots were available. The interference could be measured by noting the power rise in these slots.

FLIGHT PATTERNS

For the open-system test several flight patterns were used to investigate the possible antenna coupling. The first flight pattern consisted of inbound or outbound legs where the aircraft flew from over-the-horizon to directly over the terrestrial microwave station, trying to define the beam pattern of the terrestrial microwave.

The second series of flights were over-flights in the area of the terrestrial microwave system. These flights tested the overhead coupling of the terrestrial microwave system with the aircraft.

A third type of flights were an orbit pattern flown in the main beam of the terrestrial microwave system at a distance of 150 to 200 miles from the terrestrial microwave antenna. The purpose of these flights was to determine degradation from the worse case main beam coupling.

These three types of flight patterns provided samples of all possible mutual antenna coupling.

MEASURE OF DEGRADATION

The degradation experienced by a terrestrial microwave system depends upon the type of information being transmitted and the display or output equipment characteristics. For a 600 channel FM terrestrial microwave system with diversity the degradation caused by an interfering signal appears as the squelching of one receiver channel as the interfering noise rises above a preset threshold.

If squelch or diversity are not available, the interference is noted as a rise in the baseband noise level as the interference increases. For a digital link the interference is measured as a change in the bit error rate.

For a video system the degradation is noted as a change in the video quality.

The FAA conducts air traffic control operations using both broadband and narrowband control systems. For the broadband system the display is a PPI scope. Degradation to the PPI display consisted of white wedges that mask the desired targets. For the narrowband control system the data is digital and the degradation experienced is an increase in the error rate.

ANTENNA PATTERNS

A variety of antennas are used for the various terrestrial microwave links. The patterns of these ground antennas are similar. Therefore, for the purpose of this report a CCIR standard ground antenna pattern was used.¹

The airborne antenna pattern is influenced by the direction the antenna is pointed relative to the nose of the aircraft. After a series of antenna measurements an envelope antenna pattern was established.¹ This pattern describes the peak gains measured for various angles off the main beam.

EFFECTS OF FADING

Terrestrial microwave systems may experience signal fading due to several causes.^{15,16} During a signal fade the terrestrial microwave system may be more vulnerable to interference. However the susceptibility depends upon the cause of the fading.

Ducting or inversion layers can cause fading. However, ducting or inversion layers are more likely to occur between the aircraft and the terrestrial terminal, thereby providing additional shielding rather than additional interference.

The effect of rain cell attenuation between terrestrial microwave transmitter and receiver will cause the same or greater attenuation of the aircraft interfering signal. Therefore, fading due to rain cell attenuation should not affect the signal-to-interference ratio generated by the airborne interference.

Multipath fades may result from gradual changes in refractive index along the propagation path, especially during the evening or morning hours. The fades between the two terrestrial terminals are not expected to be correlated with the multipath fades between the aircraft and the terrestrial receive terminal. Therefore, the terrestrial link will be more susceptible to interference during periods of multipath fading.

SECTION III

SHF SATCOM OPERATIONAL CONSIDERATIONS

INTRODUCTION

The E-4 is being implemented to provide a survivable DOD command center. One use of the E-4 is to support the National Emergency Airborne Command Post (NEACP) operating presently out of Andrews Air Force Base, Maryland. NEACP has the responsibility of providing an emergency command and control system which the National Command Authority (NCA) can use to direct military forces in the time of a national emergency. The other use of the E-4 is the operation of the Command-in-Chief of SAC. The SAC command post operates out of Offutt Air Force Base, Nebraska to provide directions to the worldwide US forces in time of emergency.

The E-4 system is presently in the initial implementation phase. Only one test aircraft is expected to be equipped with the airborne SHF SATCOM system by 1978. Additional aircraft will probably not be equipped prior to 1980. Even when all six E-4 aircraft are equipped with the airborne SHF SATCOM system, only two are likely to be flying at any one time.

FLIGHT PARAMETERS

The normal flight routes of the NEACP aircraft in peacetime can be anywhere in the United States. They normally fly direct point-to-point, but may fly airways. The flight altitudes are from 24 to 35 thousand feet. The normal peacetime flight orbit for the SAC airborne command post is in the area around Offutt AFB which covers portions of Nebraska, Iowa, Minnesota and South Dakota.

Prior to completion of the study it was not possible to determine the planned maximum transmit power level, time or duration of SATCOM operations. Therefore, the results of this report are structured to allow the users of the E-4 or others to evaluate the effect of various transmit power levels or transmit duration on the probability of causing interference.

SHF SATCOM PARAMETERS

The airborne SHF SATCOM system (ASC-18) has been designed to provide a reliable jam-resistant communication system for high priority traffic between E-4's and other airborne or ground command centers.¹⁷ The ASC-18 utilizes 1W to 10 kW transmitter and a 32 dB gain parabolic antenna to achieve a high effective radiated power to overcome potential jamming threats. The ASC-18 receiving system utilizes the 32 dB gain dish and a low noise parametric amplifier to provide a sensitive receiving system. The SHF antenna can be passively pointed towards the satellite using a computer pointing group which converts the satellite ephemeris and directional information from an inertial navigation system into a pointing vector.

An active tracking capability also exists where the antenna senses down-link energy from a beacon signal transmitted by the DSCS II satellite. The ASC-18 interfaces with the modulation/demodulation system at a 70 or 700 MHz interface.

MODULATION

The planned modulation system for the E-4 is a USC-28 pseudo noise (PN) modem. This modem utilizes band spreading to achieve jam protection. This protection is provided by spreading the relatively low data rate of the information signal to be transmitted over a 40 MHz bandwidth using direct

sequence pseudo random noise. The basic modulation/demodulation technique is phase-shift keying.

A narrowband FM voice modulation may be used for test coordination purposes over the satellite. Since the interference of a narrowband FM is similar to that of CW, it was decided to include CW modulation in the interference test.

DSCS SATELLITES

The SHF satellite to be used initially is the DSCS II satellite. These satellites operate on the uplink frequencies of 7.9 to 8.4 GHz. The satellites have an earth coverage horn-type antenna and a spot-beam or narrowbeam parabolic antenna. The 500 MHz uplink band is broken into four satellite bands which are from 50 to 185 MHz wide, as shown in Figure 2. By proper selection of frequencies the uplink signal can be received and retransmitted from the following combinations of bands: receive earth coverage, transmit narrowbeam; receive earth coverage, transmit earth coverage; receive narrowbeam, transmit earth coverage; receive narrowbeam, transmit narrowbeam.

An exclusive satellite band has been established in the 7.975 to 8.025 GHz uplink band. This falls within the earth coverage - earth coverage mode of the DSCS II.

The DSCS II satellites are in a synchronous equatorial orbit. The two satellites in operation at this time are located at 13°W 0°N (#9433) and 175°E 0°N (#9434). Other Phase II satellites are planned with one to be located at 135°W. Due to the non-isotropic pattern of the airborne SHF SATCOM antenna, the potential interference level at a ground site is dependent upon which satellite the E-4 is communicating with.

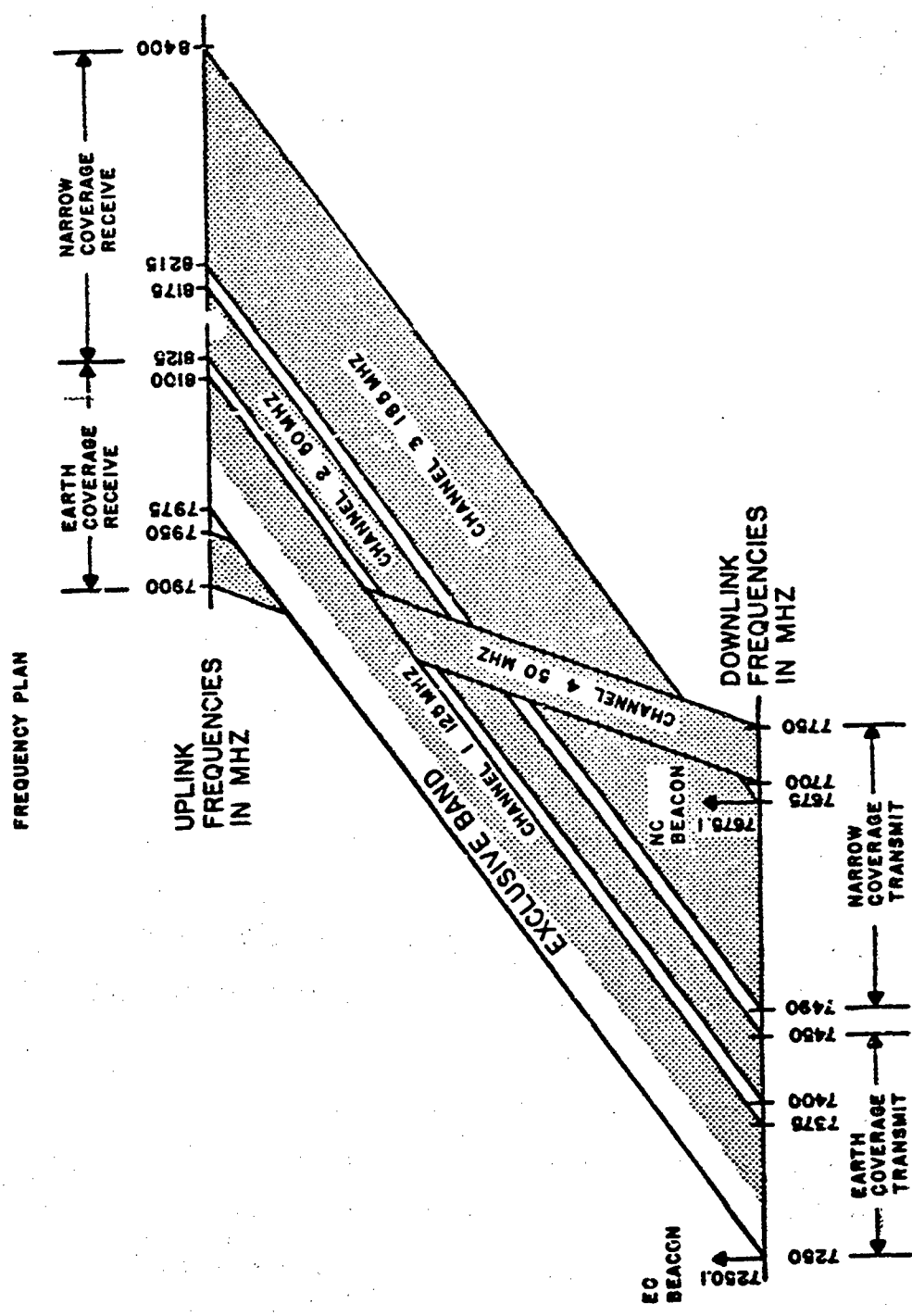


Figure 2. DSCS II Satellite Frequency Plan

By approximately 1980 the third phase of the Defense Satellite Communication System (DSCS III) is expected to be in operation. For these satellites a different frequency plan is being selected which allows operation of the narrowbeam - narrowbeam mode in the exclusive band (7.975-8.025 GHz uplink).

FREQUENCY

While the E-4 will have the capability of operating its airborne SHF SATCOM terminal on any frequency within the 500 MHz satellite authorization, the present plans are for normal operation to be at the narrowbeam - narrowbeam or narrowbeam - earth coverage frequencies. For DSCS II the planned uplink frequencies [8.215-8.265 GHz (NB-NB), 8.125-8.175 GHz (NB-EC)] are in the shared part of the band. For the planned DSCS III the narrowbeam - narrowbeam capability will be available in the exclusive band which should minimize the interference problem.

SECTION IV

CONCLUSIONS

GENERAL

At the completion of the data collection and analysis the following conclusions were drawn relative to the potential interference between the airborne SHF SATCOM, the terrestrial microwave and other space systems.

A more complete discussion of these conclusions is contained in AFAL-TR-75-251.¹

ASSUMPTIONS

The conclusions are based on the following set of assumptions:

1. The analysis was based on the SHF band utilization contained in the IRAC file as of May 1974 updated by information on FAA, TVA, BPA, ERDA and JPL links late in 1975. Future changes to the SHF population will have to be considered to evaluate their susceptibility using the calculation techniques presented in this report.
2. The E-4 aircraft will be equipped with the airborne SHF SATCOM system (ASC-18) in the late 1970s. A total of six aircraft are planned for the E-4 fleet. There would seldom be an occasion for more than two of the six E-4s to be airborne at any one time.
3. The airborne SHF SATCOM system will be operated at the lowest power which will provide the required communication capacity (expected to be 100 to 1000 watts).
4. The planned E-4 SHF frequency utilization envisions two fifty megahertz bands centered at 8.150 and 8.240 GHz. The modulation is a direct sequence pseudo random noise with phase shift keying. All terminals will use the same center frequencies and multiple access will be accomplished by code division.

5. While any interference with terrestrial microwave or other space systems is undesirable, it is assumed that statistically derived levels of interference that produce a finite increase in outage over that caused by nature alone could be defined and recommended to the effected agencies.

6. The increase in outage time identified in the probability interference analysis was based on the assumption that the aircraft would be present within a specified set of signal-to-interference contours a given number of minutes per day. For any specific flight scenario, the actual flight time within these regions could be less and hence reduce the predicted increase in outage time. During this investigation, insufficient flight scenario data was available to allow the evaluation of flight time constraints in any given area, hence maximum limits have been identified.

7. The main beam of the airborne SHF SATCOM antenna will not be pointed lower than $+10^\circ$ elevation. The only coupling to the terrestrial microwave or other space systems will be through the sidelobes of the airborne antenna.

8. Initial calculations were done assuming an unfaded microwave link. Following that analysis the fading probabilities were evaluated to see what effect the airborne SHF SATCOM system would have on a microwave link during fading. For space systems in or planned for the band, typical receiver noise temperatures and/or expected signals were considered.

100 WATT OPERATION

Cochannel operation of the airborne SHF SATCOM system at a reduced power of 100 watts reduces the interference to what is judged to be a tolerable level for all systems as long as the main beam of the JPL, ERSOS and ERDA/NADS systems are avoided. The JPL and ERSOS systems have a main

beam which is very narrow, 200 to 1000 feet diameter at expected flight altitudes (24,000 to 35,000 ft msl). The probability of main beam interception is very small, i.e., = one in a million. For the ERDA/NADS protection can be provided by avoiding the main beam within 80 nm of the receiver or by tuning to a center frequency at least 45 MHz from the NADS. Use of the planned frequencies (8.150 and 8.240 GHz) would provide the required frequency separation for the JPL, ERSOS and ERDA/NADS systems.

1 kW OPERATION

Cochannel operation of the airborne SHF SATCOM system at a power of 1 kW increased the probability of outage to the FAA and one BPA link near Seattle due to interference only slightly from that presently experienced due to natural causes. For example, if the expected outage were presently 1×10^{-3} it might be increased to 1.5×10^{-3} . This probability assumes a limited number of flights through certain high probability areas, such as three hundred flights per year through certain main beams. Interference would not occur unless the FAA or BPA link were in a faded condition. It would still be necessary to avoid main beam interception of the JPL (Goldstone), ERSOS (Sioux Falls) and NADS (Nevada Test Site) systems. Center frequency separations of 100 MHz for JPL, 40 MHz for ERSOS and 48 MHz for NADS would reduce the probability of interference to what is judged to be a tolerable value. Use of the planned frequencies (8.150 and 8.240 GHz) would provide the required frequency separation for JPL, ERSOS and ERDA/NADS systems.

10 kW OPERATION

Operation of the airborne SHF SATCOM terminal at its full 10 kW power output using PN modulation could cause interference to FAA (continental),

BPA (one link near Seattle), ERDA/NADS (Nevada Test Site), JPL (Goldstone) and ERSOS (Sioux Falls) systems if the aircraft were to fly through the main beam of the microwave system while operating on the same channel. Other systems such as TVA, BPA (other than one link near Seattle) and ERDA-CCTV have sufficient link margin that there is only a very small probability that they would be interfered with. For example, the TVA outage probability might increase from $.4 \times 10^{-5}$ to $.6 \times 10^{-5}$. Outage would only occur if the TVA link were experiencing fading. If center frequency offsets of approximately 40 to 50 MHz (100 MHz for JPL) are provided between the airborne SHF SATCOM terminal and the affected system or if main beam interception is avoided, there is only a very small probability that interference would be encountered. Use of the planned frequencies (8.150 and 8.240 GHz) would provide the required frequency separations for the JPL, ERSOS and ERDA/NADS systems.

GROUND OPERATIONS

The airborne SHF SATCOM system will be operated on the ground while the E-4 is on alert. Calculations were performed to evaluate the potential interference to terrestrial microwave or other space systems located near the airport. The general conclusion was that there is a potential interference problem to microwave systems operating on nearby frequencies. It appears that each site where ground operation is planned will have to be analyzed on a case-by-case basis to assure power levels and operating frequencies are selected which will preclude interference to the local terrestrial microwave users.

EXCLUSIVE BAND OPERATION

Operation of the airborne SHF SATCOM system aboard the E-4 will utilize a DSCS II satellite up until approximately 1980. During this time period the prime frequencies for operation (8.150 to 8.240 GHz) of the airborne SHF SATCOM system will be in the frequencies shared with terrestrial microwave and other space system users. Therefore, interference problems between the airborne SHF SATCOM system and the other users must be addressed. However, the planned development of a DSCS III satellite includes the ability to shift the narrowbeam operation from the shared portion of the band to the exclusive frequency band. The DSCS III satellite is planned for operation in approximately 1980. At that time if the prime mode of operation of the airborne SHF SATCOM system on the E-4 shifts from the shared band to the exclusive satellite band, possible interference generated by the joint use of the shared portion of the satellite band should no longer be a problem. Operation at that time in the exclusive portion of the satellite band should preclude the possibility of serious interference problems between the airborne SHF SATCOM system, terrestrial microwave systems and other space systems. However, if the prime mode of operation is not shifted to the exclusive band serious restrictions on geographic location and/or frequency assignments of future systems will exist.

RECOMMENDATIONS

The following recommendations are offered:

1. As a long term solution to the interference problem, operation of the airborne SHF SATCOM system should be moved to the exclusive satellite band. This should be implemented in the DSCS III satellite planned for the 1980 period. During the interim period operation of the airborne SHF

SATCOM system in the shared band should be maintained at the lowest power which satisfies the communication requirements.

2. Main beam interception of the other users should be avoided where practical.

3. Procedures should be established to assure that operation of the airborne SHF SATCOM system be accomplished without causing intolerable amounts of interference to other users.

4. Procedures should be established to assure that changes in the frequency assignment or user population will be evaluated to assure continued compatibility.

5. Potential interference problems should be coordinated with the agencies involved.

SECTION V

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