SUMMARY OF RESULTS OF MEASUREMENTS AND TESTS RELATED TO RF INTERFERENCE AT BATH, MAINE

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PREFACE

Certain commercial equipment and software are identified in this report to adequately describe the measurements. In no case does such identification imply recommendation or endorsement by the National Telecommunications and Information Administration, nor does it imply that the equipment or software identified are necessarily the best available for the application.

ACKNOWLEDGMENTS

The measurements and tests described in this Technical Memorandum required the dedicated efforts of a large group of people. In addition to the authors, the Bath Test Team consisted of personnel from the U.S. Navy, the Illinois Institute of Technology Research Institute (IITRI), and Lockheed Martin. Lieutenant Commander Arthur Harris, AEGIS Test Officer, SUPSHIPS Bath, provided us with all support and access necessary to accomplish the measurements at the shipyard. Mr. Len Lieb of IITRI assisted in the preparation of the test plan, and was a key figure in the measurements, tests, and on-site analysis of results. Mr. Scott Freiberger (Lockheed Martin) of the AEGIS Test Team (ATT) provided guidance during the measurements, tests, and analysis, and also supported the Test Team with office facilities during the tasks at the shipyard. Mr. David Murray of Lockheed Martin provided critical guidance and evaluation for the team during and after the measurements and tests at the site. Mr. Michael Kelley of TRACOR (in support of PMS-400) also provided critical coordination among the ATT members before, during, and after the work at Bath.

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The National Telecommunications and Information Administration (NTIA) is responsible for managing the Federal Government's use of the radio spectrum. In discharging this responsibility, NTIA uses a variety of spectrum measurement system to collect data for spectrum management support. Such spectrum management support can involve technical analysis of radio interference that involves Federal Government radio systems. Such an interference situation has occurred at Bath, Maine, involving the U.S. Navy and a private-sector earth station operator. This report details a data collection effort directed at determining the mechanism of interference to the earth station. Based upon the assessment of the interference mechanism, technically feasible mitigation options are proposed and described.

Key words: electromagnetic compatibility (EMC); fixed-satellite earth stations; forward error correction; front-end overload; interference mitigation; low-noise amplifier; radar interference; radar spurious emissions; radar stations; radio frequency interference (RFI); television receive-only (TVRO) systems.

1. INTRODUCTION

1.1 Background

The National Telecommunications and Information Administration (NTIA) is responsible for managing the Federal Government's use of the radio spectrum. Part of this responsibility is to establish policies concerning spectrum assignment, allocation, and use; and to provide the various departments and agencies with guidance to ensure that their conduct of telecommunications activities is consistent with these policies [1, part 8.3]. In discharging this responsibility, NTIA 1) assesses spectrum utilization, 2) identifies existing and/or potential compatibility problems among the telecommunication systems that belong to various

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departments and agencies, 3) provides recommendations for resolving any compatibility conflicts that may exist in the use of the frequency spectrum, and 4) recommends changes to promote spectrum efficiency and improve spectrum management procedures.

NTIA responsibility for item (3), above, sometimes requires that NTIA personnel perform diagnostic measurements and tests at locations where radio frequency interference (RFI) is reported, when such interference appears to involve Federal Government radio systems. The purpose of such tests and measurements is to determine the physical mechanisms that may be causing electromagnetic compatibility (EMC) problems between systems. The determination of these mechanisms then leads to recommendations by NTIA personnel of technical solutions to the observed EMC problems.

This report describes a set of measurements and tests performed by NTIA and other personnel at a restaurant near the Bath Ironworks (BIW) at Bath, Maine during June 30-July 2, 1997. BIW builds Navy ships, and some testing of Navy radars is performed at BIW in connection with the shipbuilding activities. Currently, AEGIS (AN/SPY-1) radars are tested at BIW. A neighboring restaurant that operates a television receive-only (TVRO) system has complained that the shipborne radar test operations are interfering with its TVRO signal reception, and has asked for an analysis and possible solution to the problem.

These tasks were performed in response to an ongoing interference problem between U.S. Navy radiolocation systems (radars) operated at BIW and a private-sector earth station operator whose facility is located directly adjacent to the BIW facility. In this report, the measurements and tests at Bath are described, the results of the data analysis are summarized, and technically feasible solutions to the interference problem are proposed.

1.2 Authority

NTIA maintains and operates the Radio Spectrum Measurement System (RSMS), and derivative, air-transportable measurement systems called suitcase measurement systems. The RSMS and derivative suitcase systems are under the administrative control of the Director of the Institute for Telecommunication Sciences (ITS). The Deputy Associate Administrator of the Office of Spectrum Management (OSM) is responsible for meeting the spectrum measurement requirements of NTIA, as transmitted to him by the Associate Administrator of OSM. Spectrum measurement activities

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[2]Organizations that participated in these tests and measurements included: NTIA, U.S. Navy, Illinois Institute of Technology Research Institute (IITRI), and Lockheed Martin.

are authorized by the Deputy Associate Administrator of OSM in consultation with the Director of ITS. Federal agencies with spectrum management problems can request support of the RSMS and derivative suitcase measurement systems through the Deputy Associate Administrator of OSM. An NTIA/ITS suitcase measurement system was used for the measurements at Bath.

1.3 Major Objective

The major objective of the measurements and tests performed at Bath was to determine the mechanism by which interference is occurring, and to recommend technically feasible solutions to the interference problem. Technical feasibility of a solution does not necessarily mean that the solution will be considered to be practical or desirable from a standpoint of cost or other non-technical considerations; it only means that the solution will work under the limits of known laws of physics and current state-of-the art knowledge of electrical engineering principles. Our purpose in performing the tasks at Bath, performing analysis of the data from Bath, and in writing this report is to set forth all possible technical solutions that meet these criteria. The parties to the interference problem may use these recommendations to attempt to resolve the interference problem on a technical basis.

1.4 Approach

Radar spurious emissions from the type of radar operated at BIW have previously been measured by NTIA personnel[2], and have been found to meet the Radio Spectrum Engineering Criteria (RSEC) emission mask [1, Part 5]. In addition, the radars at BIW operate under the control of software that prevents radar main beam energy from directly illuminating buildings and other structures, including the earth station, at Bath. Thus, the work at BIW was devoted to determining the mechanisms by which interference was occurring at BIW.

Prior to the measurements, a test plan was developed by NTIA personnel at ITS and OSM. The plan was finalized prior to the

[3] Referred to technically as in-port adaptation data for high-power radiation, and described more informally as cut-outs, the radar operations are restricted by NO-RADIATE zones and angles that are, in effect, a database of information on objects near the BIW facility. The radiation-limit zones are tailored to the specific pier at which a ship’s radar is transmitting. Radar control software constrains objects in the cut-out database, including the Bath earth station, from being directly illuminated by radar main beam energy.

measurements, and four major sets of measurements and tests were developed and described in the plan. These four tasks were deemed necessary and sufficient to achieve the major objective described in 1.3, above.

The measurements and tests were performed by personnel from NTIA, the Bath Ironworks Office of the Supervisor of Shipbuilding (Supships), and Lockheed Martin, the company that produces the radars operated at BIW. A written data log was maintained in a bound notebook during the measurements and tests by NTIA personnel, and data results of the measurements and tests were recorded in electronic files on a laptop computer. The electronic file data were subsequently analyzed by ITS in Boulder, CO. The laptop computer was also the controller for the suitcase measurement system.

At the conclusion of the measurements and tests at Bath, on July 2, 1997, it was agreed that a report on the results of the measurements and tests would be prepared by ITS. The report would describe and summarize the measurements and tests, the results of the data analysis, and the conclusions and recommendations for interference mitigation that would result from the NTIA analysis.

2. MEASUREMENTS AND TESTS

2.1 Introduction

As described in detail below, the measurements and tests conducted at Bath were intended to explicate clearly the interference mechanisms that were occurring, and hence the options that would be available for interference mitigation by technical means. The measurement system was provided by NTIA/ITS, and consisted of the following major equipment and software elements:

1) Hewlett Packard 8563E portable spectrum analyzer;
2) ITS-designed RF front-end, containing 0-70 dB attenuator, YIG and bandpass preselection, and low-noise preamplification ;
3) Pentium laptop computer operating ITS-written measurement software for acquiring spectrum data, time waveforms, and related data required to produce amplitude-probability pulse data results;
4) EMCO model 3115 dou ble-ridged waveguide horn antenna;
5) phenolic antenna tripod;
6) miscellaneous connectors, cables, attenuators, and filters.

The earth station consists of the following components:

1) Four dish antennas, 9 ft. diameter, mounted on the roof of the operator’s building, at a height of about 20 ft above the ground at the center of the antennas. Three of these dishes are receiving objectionable levels of interference on digital channels;

2) An RF front-end on each of the operator’s antennas, consisting of a feed horn, a 3700-4200 MHz bandpass filter (intended to reject radar signals in the 3100-3700 MHz radiolocation band, and thus prevent front-end overload from occurring in the earth station system), and a low-noise block downconverter (LNB) that provides low-noise preamplification of the satellite transponder signals, followed by downconversion of the transponder signals to the 950-1450 MHz band.

3) A length of coaxial line sufficient to connect each antenna front-end to the receiver room, downstairs in the operator’s establishment;

4) Signal splitters in the receiver room that provide several outputs for each antenna coaxial line;

5) A set of receivers that process the transponder signals and produce outputs that are sent to television sets in the establishment.

The earth station operator’s system configuration is a television receive-only (TVRO) for transponder signals originating on geosynchronous satellites. The operator receives signals from several satellites. Most of the tests and measurements were performed through the system that has evidenced the worst EMC problems; this is satellite G6, vertical feed. The other earth station satellite feeds experience similar, but somewhat less severe problems. G6 probably experiences the worst problems due to its low pointing angle above the horizon.

Four major tasks were identified and described in the test plan, and these were carried out at Bath. In this Section, each of these objectives is described, and the analyzed data results are presented.

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[4] The LNB output frequency range of 950-1450 MHz can be converted to RF signals in the 3700-4200 MHz satellite transponder band by the following equation: $f_o = -(f - 5150)$. Therefore, 1450 MHz at the LNB output equates to 3700 MHz, and 950 MHz at the LNB output equates to 4200 MHz.

2.2 Objective 1: Determination of the Possible Presence of Direct Case Penetration by the Radar Emissions

Objective 1 Description : Objective 1 was designed to determine whether the interference coupling mechanism was occurring via the earth station antenna or via direct case penetration of the earth station receiver, or whether both interference mechanisms were present. This determination is crucial to further determining what interference mitigation options may reasonably be expected to be successful.

To meet this Objective, it is necessary to perform the following tasks:

a) Observe the interfering signal in the earth station receiver at the IF stage (70 MHz), the detected video stage, or some equivalent post-RF receiver stage. The radar should be operating at maximum power and in an operational band that has been previously determined to produce the most severe interference.
b) While the interfering signal is being observed in the receiver, disconnect the earth station antenna and replace it with a 50-ohm or 75-ohm (depending upon cable impedance) dummy load.
c) Observe the effect, if any, in the receiver stage that is being monitored. If no interference is observed, then the coupling must be through the antenna. If the interference persists, then the interference is being coupled via case penetration. It will then be necessary to determine whether the coupling is occurring in the LNB or in the receiver inside the restaurant. This determination will be performed by examining the outputs of individual parts of the earth station receiver (e.g., the output of the LNB). A spectrum analyzer operating in the +peak detector mode, at 0-Hz-span, will be used for these observations.

Note that, if Objective 1 results indicate that case penetration is occurring, alternative methods of mitigating case penetration must be addressed, and results of the following Objectives (below) may not be meaningful.

Performance of Objective 1 Measurements and Tests : Measurements were performed as described above to determine if interfering signals were being coupled into the earth stations receiver via direct case penetration. These measurements were conducted in two phases: 1) via case penetration through the system front-end components (RF filter and low noise block (LNB) downconverter), and 2) via case penetration through the receiver. The phase one measurements were conducted by disconnecting the RF filter from the antenna port and placing a 50 ohm load on the input to the RF filter. The output of the LNB was observed using a spectrum analyzer to observe if any radar signals were exceeding the LNB inherent noise level. The spectrum analyzer was set for the + peak detector mode. There were no test points in the digital receivers to observe case penetration in the receiver unit. For these tests it was desirable to radiate the maximum radar signal level. Therefore, the AEGIS radar at pier 1 was used and the radar was operated in the high power mode, bands 1 through 10.

In the course of the measurements, it was observed that the earth station LNB front-end gain appeared to be about 25 dB in excess of what was required for optimal station operation. To test this hypothesis, we added an experiment in which we inserted attenuation into the earth station system at the receiver input. Attenuation values of 10 dB, 13 dB, 16 dB, 20 dB, 23 dB, 26 dB, 30 dB, and 40 dB were inserted, and performance was checked as a function of those attenuation values.

Objective 1 Data Analysis and Results: Figure 1 (VFR:001:001:001) shows the satellite transponder band for satellite G6 (vertical) as received through the system's front-end LNB and input to the receiver. This measurement was produced by attaching the NTIA spectrum analyzer to one output of an earth station signal splitter, while another splitter output fed the same signals to a receiver box. Thus, this measurement shows the same spectrum features as are routed to the earth station receiver. The noise floor displayed, at about -65 dBm to about -73 dBm, represents the inherent noise of the front-end LNB. Therefore, the LNB's inherent noise level is the limiting inherent noise for the entire system. The peaks in the measurement are the satellite transponder signals.

Figure 2 (VFR:001:001:008) shows the LNB output inherent noise level over the frequency range of 950-1450 MHz. To eliminate the satellite transponder signals from the receiver, the satellite antenna was directed away from the satellite (G6, vertical), and down toward the horizon. The noise displayed in this scan is generated by the satellite earth station LNB output on this antenna. Note that the noise level in this measurement is about 5 dB higher than was observed when the antenna was directed toward the satellite.

In Figure 3 (VFR:001:001:009), a 50-ohm load termination has been attached to the LNB input, effectively isolating the LNB input from the outside world. With this termination in place, the radar was operated at pier 1 of the BIW. This figure shows the LNB output measured when the radar at pier 1 was radiating in the high power mode, radar bands 1 through 10. The figure shows signal levels in the order of 10-13 dB greater than inherent LNB output noise in the 1250-1450 MHz (corresponding to 3700-3900 MHz) frequency range. Since the measurements were made with the spectrum analyzer in the + peak detector mode, this equates to I/N_{rms} ratios of 22-25 dB.

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[5]This designates to the volume, file, and record of the original data, as recorded in the ITS electronic file structure.

Therefore, the measurements showed that the high signal levels of the AEGIS radar caused case penetration in the receiver front-end (which consisted of an RF 3700-4200 MHz bandpass filter and the LNB). (See 2.1, above, for description of the earth station RF front-end.)

To further isolate the location where the front-end case penetration was occurring, additional measurements were made with the 3700-4200 MHz RF bandpass filter removed. That is, the measurements were performed with the dummy load connected directly to the LNB input. Figure 4 (VFR:001:001: 011) shows the LNB output with the earth station front-end RF filter removed, and with the AEGIS radar at pier 1 radiating in the high power mode, radar bands 1 through 10. Since Figure 4 is nearly identical to Figure 2, with only a few spikes above the inherent LNB noise level, forcing the conclusion that the case penetration was occurring mostly as a result of the presence of the RF filter. Comparison of Figures 3 and 4 indicates that case penetration was not occurring directly through the dummy load inserted to perform these tests since the figures show no similarity in signals that appear above the LNB inherent noise level.

There was no easily accessible test point in the receiver to test for receiver case penetration. However, the receiver room in the restaurant was down in the basement, which should provide substantial additional shielding. On that basis, it was concluded that case penetration directly into receiver units inside the earth station was unlikely.

In contrast to the levels of case penetration observed in Figure 3, Figure 5 (VFR:001:001:014) shows the level of radar emissions measured at the LNB output when the antenna was reconnected. Figure 5 measurements were made when the radar was operating in its high power mode, at the nearest pier (pier 1), in all of its bands (bands 1-10). Peak radar levels in the receiver were measured at -20 dBm, as compared to peak levels of -48 dBm when the only coupling mechanism was case penetration. This difference of 28 dB implies that, although case penetration needs to be addressed (probably by improving the grounding in the earth station RF system, see Conclusions, below) the radar energy that is coupled into the earth station via the antenna feed is also a major problem that must be addressed if the interference problem is to be effectively mitigated.

It is important to note, however, that all the measurements performed when the antenna was either directed away from the satellite with the feed connected (Figure 2), or when the feed was disconnected and a dummy load inserted in its place (Figures 3-4) all show LNB output noise levels that are 5-8 dB HIGHER than were observed when the antenna was aimed at the transponder signals on satellite G6. This difference is illustrated in Figure 6, which graphs the curves of Figures 1 and 4 together. If the environmental temperature is assumed to be 290 K, and if the noise temperature of the LNB is 25 K, then the total noise temperature of the LNB device is 315 K. Attaching a 50-ohm load at a temperature of 290 K to the LNB input will thus result in an overall noise power increase of 10 log(((290+25)+290)/(290+25)) = 2.8 dB in the LNB output noise level. This, indeed, is the difference between the noise level in Figure 2, where the antenna has no load connected, and Figures 3-4, where a load is connected. Thus, there is a residual 5 dB of LNB output noise decrease that cannot be accounted for. The only known effect that can cause such a decrease in noise output when the antenna is directed at the desired signal is gain compression due to overload by the desired signal. The conclusion is that this LNB may well be operating a gain level that is higher than required to adequately receive the transponder signals, and is in fact so high that the transponder signals are themselves overloading the LNB front-end, resulting in gain compression.

It is also observed that the peak-detected LNB noise output level (at the earth station receiver input) of approximately -54 dBm to -64 dBm in a 1-MHz measurement bandwidth (Figure 4) significantly exceeds the level of noise produced by thermal electrons (similarly peak-detected and measured in a 1-MHz bandwidth). That inherent noise level (at 290 K) is -174 dBm/Hz, plus 60 dB (for 1 MHz bandwidth), plus 10 dB (for peak detection), for a total of -104 dBm. The difference between -104 dBm and -54 to -64 dBm is 40-50 dB. Since most earth station receivers (that is, the signal-processing boxes) have noise figures of only about 10-20 dB (as opposed to the low-noise RF front-ends, which usually have 0.5-dB noise figures), this implies that the earth station operator is not only gain-compressing his RF front-end with his desired transponder signals, but also may be using about 20 dB more gain than necessary in the LNB on the G6 system. (This value is computed by subtracting a maximum 20-dB receiver noise figure from a minimum of 40 dB of LNB out put noise at the receiver input.)

To test the hypothesis that the front-end was being operated with about 25 dB more gain than necessary, we added an experiment in which we inserted attenuation into the earth station system at the receiver input. Attenuation values of 10 dB, 13 dB, 16 dB, 20 dB, 23 dB, 26 dB, 30 dB, and 40 dB were inserted, and performance was checked as a function of those attenuation values. The result was that, with up to 20 dB of attenuation inserted at the receiver input, no noticeable degradation in the television pictures was noted. At 23 dB, some members of the team thought that the pictures were degraded. At 30 dB, definite degradation was observed, and at 40 dB, the pictures were lost entirely. These results again indicate that the earth station front-end LNB, at least of the G6 system, is using about 20 dB too much gain.

The summary result of the Objective 1 measurements, tests and analysis was this: Case penetration at the LNB does exist at low levels, and may well be present in conjunction with the installation of the 3700-4200 MHz RF bandpass filter at the LNB input. However, the coupling levels are substantially lower (28 dB lower) than the levels coupled via the antenna feed. Thus, the problem of case penetration can be discounted as a major interference coupling mechanism for this earth station. However, steps to mitigate case penetration may be necessary. In general, case penetration can be reduced by improved connections to ground, and this needs to be done by the earth station operator to reduce the case penetration. It was the view of the Bath Test Team that mitigation of front-end case penetration would be easier with a conical horn antenna than a dish antenna since there is more flexibility in options to reduce the case penetration without disturbing the main beam antenna pattern and gain.

However, the measurements also indicate that the LNB front-end is operating a gain level that is substantially higher (by about 20 dB) than is probably optimal for this earth station. The excess gain will cause the earth station to be more susceptible to interference than if it were optimized in accordance with standard electrical engineering principles for receiver design. (See Section 3, Conclusions, for further discussion of this problem, and how its correction may assist in mitigating the interference effects of the radar operation.)

2.3 Objective 2: Measurement of the Amplitudes of Radar Pulses and of Pulse Amplitude-Probability Distribution in the Earth Station Receiver

Objective 2 Description : a) Determine the amplitudes of the radar signals that are occurring in the earth station receiver, relative to either the earth station receiver inherent noise ((I+N)/N) or the amplitude of the desired signal ((C+I)/I), more conventionally written as (I/N) and (C/I). Determination of one or both of the these ratios is critical to determining the amount of suppression of the radar signal that will be required to mitigate the interference. Note that these ratios are physically meaningful only if the interference is determined to be occurring via coupling through the earth station antenna. Consideration of the independent variables of ship location and crane position will be included.

b) Measure number of pulses per second exceeding threshold(s), to determine the distribution of pulses in time.

To meet this Objective, it is necessary to perform the following tasks:

a) With the radar operating in a mode that has been determined to produce the most objectionable interference, the interference will be monitored in the receiver input to determine the I/N and C/I ratios that are occurring. These ratios will determine the amount of reduction that must be achieved in radar signal level in the receiver circuitry to eliminate interference. The carrier and interference signal levels will be measured as a function of measurement bandwidth, so that extrapolations up to bandwidths wider than 3 MHz (the maximum ITS measurement system bandwidth) can be performed. Consideration of the independent variables of ship location and crane position will be included.

b) Time scans will be recorded, and number of pulses occurring above a threshold (or several thresholds) per unit time will be determined. A spectrum analyzer will be used for these measurements (0-Hz span mode, +peak detector, DA stepped mode program, spectrum analyzer tuned to worst channel, as determined in (a) above or from).

Performance of Objective 2 Measurements and Tests: The time waveforms of the radar pulses at the receiver input for satellite G6 were measured while television programming was simultaneously viewed, so that correlation of radar pulse densities could be made with the quality of the television displays. The time waveforms were recorded in 50 ms segments, each segments being recorded as a separate record. Twenty such records were produced for each combination of radar power level, radar location, and radar band selection that was tested. These 20 records for each radar permutation were later analyzed to produce amplitude-probability distributions (APD) which could be correlated with television picture quality. By comparing the APD for the worst case to the APD for the case where interference first became noticeable, it was possible to determine the reduction in coupling levels that will be necessary to eliminate the interference.

Maximum radar interference was achieved by operating at pier 1, in high power mode, in radar bands 1-10, as shown in Figure 5. In this operational mode, the radar caused a blacked-out television screen in the TVRO. In later tests, the earth station was completely disabled by operating the radar at pier 3 in high power mode, bands 8-10. APD data were taken while the radar was at pier 3, at a frequency of 1313 MHz in the IF (corresponding to 3837 MHz RF frequency). The maximum amplitude at 1313 MHz when the radar was in high power, bands 8-10, at pier 3 was the same as when the radar was at pier 1, high power, bands 1-10. In both cases, -32 dBm was the maximum pulse amplitude at the earth station.

The data taken when the radar was operated at pier 3 (and which were later converted into an APD curve) are shown in Figure 7 (VFR:001:001:024-043). Other combinations of radar band selection, radar location, and radar power level were tested, until a

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[6]This implies that future tests can be run at pier 3 as readily as at pier 1.

combination was found that produced effects that were deemed by television viewers at the earth station establishment to be just at the threshold of interference. This combination of parameters was: pier 3, low power mode, bands 8-10. This APD curve is shown in Figure 8 (VFR:001:001:071-090).

Objective 2 Data Analysis and Results: Figure 7 (VFR:001:001:024-043) shows the APD for the worst-case condition that can be generated at the earth station location. Figure 8 (VFR:001:001:-71-090) shows the APD for the threshold at which interference appears/disappears. The difference, in decibels between these two APD curves (maximum pulse amplitudes in Figure 7 vs maximum pulse amplitudes in Figure 8) is the difference that must be achieved in coupling levels to mitigate the interference. **This difference is 20 dB**.

2.4 Objective 3: Determination of the Existence of and Direction-of-Arrival of Signals from Navy Radars

Objective 3 Description : Determine the existence of and direction-of-arrival of signals from Navy radars. This information will be necessary in determining the directions from which the maximum attenuation of the radar signal must occur.Consideration of the independent variables of ship location and crane position will be included.

To meet this Objective, it was necessary to perform the following tasks:

With the radar operating in a high-power mode, a directional antenna was used to determine the direction(s) from which high incident field levels originate, relative to the pointing direction of the earth station antenna. The methodology was to move the DF antenna +/-15 degrees in azimuth/elevation relative to the normal pointing direction of the earth station, and also to DF in other sectors, as determined by inspection of the site. The direction-finding was performed while taking a 0-Hz span measurement on a spectrum analyzer. The spectrum output was monitored for any signals within the DF antenna scan cone that exceed the amplitude measured along the earth station antenna axis. The antenna will then pointed directly at the radar, and the level was observed. This would indicate whether or not radar signal multipaths were occurring within the main sidelobes of the earth station antenna. Consideration of the independent variables of ship location and crane position was included in this task.

Performance of Objective 3 Measurements and Tests: These measurements were performed with an EMCO 3115 double-ridged waveguide horn antenna. The antenna was used to measure received radar signal level as a function of azimuth for locations on the roof (adjacent to the existing earth station antenna positions), and in the parking lots on the north and south sides of the earth station establishment. The horn was also used to measure radar signal amplitudes when aimed at the sky, in the direction of the earth station antennas. The data were recorded as time waveforms, in 50 ms segments. The radar was operated at pier 1, high power, bands 1-10. Thus, these APDs represent the worst-case interference that can occur at the earth station location.

Scans performed on the rooftop from azimuths of 150° to 255°, in increments of 15°, which included the radar azimuth at pier 1, as well as the azimuths of the large shipyard cranes. The resulting APDs for these scans are shown in Figure 9. Scans were also performed on the line-of-sight of the earth station antennas to satellites G3, G6, and G5. The APDs from these scans are shown in Figure 10. The APD for the direction of the shipyard cranes is shown in Figure 11.

APD results for the north parking lot next to the earth station building (135° to 240° azimuth) are shown in Figure 12. APDs from scans in the same parking lot, at the northwest corner of the lot (105°-225° azimuth), are shown in Figure 13.

APD results for the south parking lot measurements (150°-240° azimuths) are shown in Figure 14. Line-of-sight APDs for satellite G6, G3, and G5 are shown in Figure 15.

Objective 3 Data Analysis and Results: For the rooftop measurements, the APD curves for azimuths of 150°-255° (Figure 9) all have essentially the same shape, and the maximum deviation between the curves is only about 8 dB. This indicates that the pulse environment changes very little as a function of azimuth for an antenna on the rooftop. The pulse environment looks almost the same when the antenna is pointed in the direction of the ship at pier 1 as it does when aimed almost directly away from it. This is not surprising, as the radar at pier 1 (and also at piers 2 and 3) does not illuminate the earth station via direct line-of-sight, but rather indirectly, due to structures that are located directly between the radars at piers 1-3 and the earth station.

The implication of this result is that the pulses reaching the earth station antennas on the rooftop are being diffracted around structures that lie directly on the line-of-sight between the earth station and the radars, and that the pulses are also scattered off the buildings and structures in the area, and then into the earth antenna side lobes and back lobes. Indeed, the environment around the earth station is extremely cluttered in terms of being surrounded by buildings, shipyard cranes, and a large bridge. All these structures exceed the earth station in height.

The effect is the same as if the earth station were rather uniformly illuminated from all directions by radar pulses. Because the main beams of the earth station antennas are aimed skyward, and do not intersect terrestrial objects, coupling of radar pulses into the main beams of the earth station antennas does not occur.

As for the results of the measurements in the earth station parking lots, some reductions in the APD curves did occur, especially when the test antenna was aimed in the same direction as the earth station antennas. When pointed in the direction of the earth station antennas in the north parking lot, the reduction in the APD curve was about 5 dB. The reduction observed for the south parking lot (Figure 14) was 8-10 dB, on the azimuths of the earth station antennas.

For a reduction of 20 dB in sidelobe and back lobe coupling levels, simply moving the antennas into one of the parking lots will not be sufficient to solve the problem. However, the 5-10 reduction in coupled signal levels in the parking lots may be of use in other mitigation schemes, such as conical horn antennas (see Section 4, Technical Mitigation Options).

2.5 Objective 4: Additional Testing for Presence of Front-End Overload at the Navy Radar Fundamental Frequencies

Objective 4 Description: Because it is understood that interference has persisted after installation of a 3.7-4.2 GHz bandpass filter on the earth station RF front-end, it may be desirable to perform additional tests to examine the interference coupling mechanism. As time permits, perform tests to determine whether front-end overload or spurious radar emissions are the source of the interference problem. These tests would be conducted in accordance with procedures described in an NTIA Report [3].

To meet this Objective, it is necessary to perform the following tasks:

Perform tests for interference coupling mechanism in accordance with the descriptions in the NTIA Report 94-313, "Analysis of Electromagnetic Compatibility Between Radar Stations and 4 GHz Fixed-Satellite Earth Stations," or by observing the earth station carrier level at the LNB output with the interference turned off and on. Test equipment includes a spectrum analyzer and a digital oscilloscope. A 3.7-4.2 GHz filter will be present in the front-end of the earth station for this test. The simplest method will be to observe the desired carrier level with a spectrum analyzer in a 0-Hz-span, +peak detector mode, while the radar is turned off, and again when the radar is turned on. A decrease in carrier level with the radar on will indicate the presence of front-end overload in the receiver

If front-end overload is observed, the reduction in radar signal level required to mitigate the front-end overload condition will be determined as follows: The earth station front-end filter will be disconnected from the LNB, and the NTIA measurement system will be connected to the output of the RF front-end filter. The amplitude of the radar will then be measured at the output of the earth station RF filter. This amplitude will be compared to the theoretical value of the overload threshold for the LNB (see NTIA Report 94-313, page 11). The difference between these values will be the suppression required on the radar signal to prevent front-end overload in the earth station receiver.

Performance of Objective 4 Measurements and Tests: Measurements were performed to determine if the AEGIS radar signals could cause receiver front-end overload even with the RF filter installed ahead of the LNB. Both the radar fundamental and in-band spurious emissions (3700-4200 MHz) were investigated for the potential for receiver front-end overload. Observations for the potential for receiver front-end overload were limited to the LNB output since there was no IF test point available at the back of the receiver units. Therefore, a single video digital channel could not be observed complicating the verification of receiver front-end overload. Also, a digital oscilloscope was not available to capture and retain single sweep in time of the radar fundamental and LNB output.

Measurements were made from the rooftop of the restaurant using the horn antenna and measuring the AEGIS signal level in the 3700-4200 MHz band. The AEGIS radar was operating from pier 3 in the high power mode, bands 8 through 10. Figure 16 (VFR-001:010:031) measurements.

Objective 4 Data Analysis and Results: The potential for receiver front end overload was calculated using the data in Figure 16 and calculating the receiver power (P_r) at the earth station antenna input:

P_r = -53 dBm @ 3725 MHz in a 1 MHz bandwidth

Correcting for the horn antenna gain, 12 dB, the receiver power is

P_r = -65 dBm in a 1 MHz bandwidth for a 0 dBi antenna gain

P_r = -41 dBm for a 250 MHz bandwidth

The LNB saturation level is given by:

S_{LNB} = +10 dBm - G_{LNB} = +10 dBm -60 dB = -50 dBm

Therefore, calculations show the potential for interference to occur via the coupling mechanism of receiver front-end overload from the radar spurious emissions in the 3700-4200 MHz band. This was not verified through measurements due to the difficulties discussed above. Since the AEGIS signal was calculated to be only 9 dB into saturation, the conical horn reflector should attenuate the radar signals sufficiently to mitigate any front-end overload.

3. CONCLUSIONS

Based on the results of the measurements and tests at the Bath, Maine, earth station location, the following technical conclusions have been reached:

1) Case penetration at the LNB does exist at I/N levels of 22-25 dB, and may be present in conjunction with the installation of the 3700-4200 MHz RF bandpass filter at the LNB input. However, case penetration coupling levels are substantially lower (28 dB lower) than the levels coupled via the antenna feed. No case penetration is occurring directly into the receiver boxes inside the earth station building. However, steps to mitigate case penetration may be necessary. Case penetration can be reduced by improving the grounding of the RF system (LNB or RF filter) in the earth station. It was the view of the Test Team that mitigation of front-end case penetration would be easier with a conical horn antenna than a dish antenna since there is more flexibility in options to reduce the case penetration without disturbing the main beam antenna pattern and gain.

2) The measurements i ndicate that the LNB front-end(s) is/are operating at a gain level that is substantially higher (by at least 20 dB) than is optimal for this earth station. The excess gain causes the earth station to be more susceptible to interference than if it were optimized in accordance with standard electrical engineering principles for receiver design. **This gain should be optimized in accordance with the instructions included in the earth station documentation [4].** See Extended Comments on Conclusion 2, below.

3) Based on the difference between worst-case APD and interference threshold APD curves, the difference that must be achieved in coupling levels to mitigate the interference is 20 dB. See Section 4 for technical mitigation options that should provide this level of decoupling.

4) The pulses reaching the earth station antennas are being diffracted around structures that lie directly on the line-of-sight between the earth station and the radars, and the interference pulses are also scattered off the buildings and structures in the area, and then into the earth antenna side lobes and back lobes. The environment around the earth station is extremely cluttered in terms of being surrounded by buildings, shipyard cranes, and a large bridge. The effect is

the same as if the earth station were rather uniformly illuminated from all directions by radar pulses. Thus, the radar pulses are coupling into the earth station antennas via the side lobes and backlobes of those antennas. Because the main beams of the earth station antennas are aimed skyward, and do not intersect terrestrial objects, coupling of radar pulses into the main beams of the earth station antennas should not occur.

5) Some reductions in the APD curves do occur in the parking lots adjacent to the earth station building, especially when the test antenna was aimed in the same direction as the earth station antennas. When the test antenna was pointed in the same direction of the earth station antennas, but was located in the north parking lot, the reduction in the APD curve relative to the rooftop was about 5 dB. The reduction observed for the south parking lot location relative to the rooftop location was 8-10 dB, on the azimuths of the earth station antennas.

6) For a reduction of 20 dB in sidelobe and back lobe coupling levels (as indicated by Conclusion 3, above), simply moving the antennas into one of the parking lots will not be sufficient to solve the problem. However, the 5-10 reduction in coupled signal levels in the parking lots may be of use in other mitigation schemes (see Section 4).

7) Calculations show the potential for interference to occur via the coupling mechanism of receiver front-end overload from the radar spurious emissions in the 3700-4200 MHz band. This was not verified through measurements due to the difficulties discussed above. Since the radar signal was calculated to be saturating the receiver by 9 dB, attenuation of the radar signals by 9 dB or more should be sufficient to mitigate any front-end overload that may still be occurring.

<u>Extended Comments on Conclusion 2:</u> The most critical parameters for any receiver system front-end are the gain and the noise figure. The noise figure is usually made as low as possible, limited only by the economic trade-off of lower noise figure vs. the minimum signal level that will be present at the antenna output. The front-end gain should be just sufficient to amplify the front-end noise to a level at which it exceeds the inherent noise level (the noise figure) of the receiver. At that point, the gain is optimized, in that any signal that is received above the noise level of the front-end will be present in the receiver at the same signal-to-noise ratio (SNR) as was present in the RF front-end. To put it another way, the optimum front-end gain is just sufficient to make the noise figure of the RF front-end the limiting noise figure of the entire system.

If the gain of the front-end exceeds this optimum value, no additional improvement in the SNR will occur; no improvement in receiver performance will be achieved. In fact, the presence of more than the optimum amount of front-end gain has a deleterious effect: the dynamic range of the receiver system is reduced. This is because the saturation point of the system remains the same, regardless of the amount of gain in the front-end, while the noise level and the signal level produced by the front-end goes up with increasing gain in the front-end. The effect is like the floor of a room being pushed up into the ceiling. The floor-to-ceiling distance represents the dynamic range of the system, and increasing gain beyond the optimum value just squeezes that distance.

If dynamic range is compressed too much, the dynamic range may become so small that the presence of even relatively low-level signals may result in enough signal power in the system to cause saturation to occur. When saturation occurs, the gain value of the amplifier decreases, and the result is that the front-end-generated noise in the receiver drops. It means that the system is being driven into a non-linear type of operation, in which interference effects are far more likely to occur than they otherwise would.

Based upon the collected data and on the attenuator testing results (described in Section 2, Objective 1), we believe that some front-end saturation is occurring in the G6 system at the earth station due to excessive gain in the LNB front-end, and that excessive front-end gain may be exacerbating interference effects in the earth station receivers, as well. The evidence for this saturation is the decrease in the front-end noise seen at the receiver input when the system is aimed at the transponders.

Furthermore, the high gain value of the front-end LNB is apparently reducing the dynamic range of the receiver boxes inside the earth station building. The evidence for this is the fact that, at the receiver input, the front-end noise output appears to exceed the receiver noise figure by 20-25 dB, as indicated by the attenuator tests that the team performed (see Section 2, Objective 1).

<u>Implications of Using Excessive Gain in the Earth Station RF Front-End:</u> With regard to the existing interference at the earth station, how does the apparently excessive gain of the front-end contribute to the overall interference problem, if at all? The presence of too much gain in the front-end has two effects that can contribute to the interference problem:

1) By causing the LNB to saturate on even the desired transponder signals, the excessive gain keeps the LNB amplifier in a constant state of gain compression. In this state, even relatively low-amplitude interference pulses can drive the LNB amplifier into even deeper gain compression, resulting in loss of signal at the receiver input that would otherwise not occur,

or would occur for shorter periods of time if the gain in the LNB were not so high.

2) Even if the LNB front-end amplifier escapes the amount of gain compression that leads to loss of signal at the receiver input, trouble can still occur in the receiver box inside the earth station building. The receiver is itself made more susceptible to the interference because its available dynamic range is reduced by the excessive gain. This is because every interfering pulse is 20 dB closer to saturating the receiver than it would be if the LNB gain were optimized. Because every pulse is 20 dB closer to saturation in the receiver, a much larger number of interfering pulses actually do hit the saturation level than would hit that level if the LNB gain were 20 dB lower.

But, given that the APDs measured at the station show a wide distribution of pulse levels to be coupling into the receivers, why should the high-level pulses be of special concern? The answer is that most of the interference effects are probably being caused by the highest-level pulses. Our reasons for inferring this are that the signals being processed by the receivers are digital, and are being processed with Reed/Solomon forward error correction (FEC) coding with interleaving. If the parameters provided in the earth station manuals and by technical personnel at the manufacturer's facilities are correct , the FEC used at the earth station should be sufficient to restore the information lost from AEGIS radar pulsed interference. This has turned out, however, to not be true at the Bath earth station; the radar interference causes severe degradation to the station's television outputs. The solution to this paradox appears to be that the FEC is not effective because the radar pulse levels are high enough to

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[7]Scientific Atlanta (S/A) and National Instruments (N/I) receivers are in use at the earth station. Both types use Reed/Solomon FEC with interleavers. The S/A systems can correct for up to 80 μs of lost data with a 5.5% duty factor, and the N/I systems can correct for up to 43 μs of lost data with a 4% duty factor. The Navy radar should only cause 52 μs or less of data to be lost during any radar pulse event; therefore, the S/A should be capable of completely mitigating the interference, and the N/I receiver should show marginal performance for the 52-μs pulses. But, at Bath, the radar is normally operated in a mode in which most of the radar pulses are substantially shorter than 52-μs, and usually less then the N/I unit's 43-μs limitation. Thus, the N/I receiver should perform well, but not as well as an S/A receiver, at processing out the radar interference. The paradox, then, is why do the receivers not perform well with the FEC that they are known to utilize?

cause the IF stages (e.g., the receiver tuner section) in the decoders to saturate, resulting in either stretching of the radar pulses or some other effects that disable the capacity of the FEC to restore the information lost during the interference pulse events. To put it more simply, the FEC appears to fail due to effects generated by the highest-amplitude radar pulses, while probably adequately processing out the interference effects of the low-level pulses. This implies that mitigation efforts at Bath must focus on the elimination of the highest-amplitude pulse events in the earth station receivers, so that the FEC can do its job properly on the remaining, lower-amplitude radar pulses.

To test this hypothesis, a test was run in which attenuation was inserted between the output of the LNB and the inputs to two different types of receiver/decoder units. The degree of performance degradation from radar pulses was significantly reduced for one of the systems, indicating that IF stage saturation effects may be reducing the effectiveness of the FEC to mitigate the radar interference. Therefore, a possible solution to the EMC problem may be to install a limiter between the output of the LNB and the input to the IF stage (see Mitigation Options in Section 4, below). If the hypothesis that saturation pulses are far more likely to cause loss of the digital signal in the receiver than are the low-amplitude pulses (which are more likely to be processed out by the receiver's FEC) is correct, this loss of dynamic range only creates a larger number of saturation hits in the receiver, and consequently a larger of drop-outs on the television monitors.

But, what about the automatic gain control (AGC) circuitry in the receiver? Won't it compensate for the excessive gain from the front-end LNB? Unfortunately, the answer is No, because the AGC can add gain if the signal level into the receiver is too low, but it cannot go to less than zero gain. The problem with this AGC limitation is this: To compensate for the excessive gain from the LNB, going to less than zero gain is exactly what the AGC needs to do. This is what we did, in effect, by adding the attenuators at the receiver input during our Objective 1 testing.

The bottom line to the LNB gain discussion is this: Although the interference will not be entirely mitigated by optimizing the front-end gain of the earth station LNB, the apparently excessive amount of gain in the earth station front-end LNB is tending to make the earth station more susceptible to interference than it

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[8]Also, to be effective, the AGC would have to respond within microseconds; in reality, the AGC response time is much longer than this.

would otherwise be, and the front-end LNB gain **should be optimized** as part of an additional attempt at interference mitigation (see Mitigation Options in Section 4, below).

It should be noted that, as part of the User's Manual documentation supplied with the earth station equipment, there is an Application Brief [4] that describes steps that the user should take if interference occurs. The first expedient listed in that document is to optimize the front-end gain at the LNB. The document recommends doing this by inserting attenuators between the LNB output and the receiver input.

4. TECHNICAL INTERFERENCE MITIGATION OPTIONS

Technical feasibility of a solution does not necessarily mean that the solution will be considered to be practical or desirable from a standpoint of cost or other non-technical considerations; it only means that the solution will work under the limits of known laws of physics and current state-of-the art knowledge of electrical engineering principles. Our purpose in performing the tasks at Bath, performing analysis of the data from Bath, and in writing this report is to set forth all possible technical solutions that meet these criteria. The parties to the interference problem may use these recommendations to attempt to resolve the interference problem on a technical basis.

Preliminary Mitigation Requirement to Prevent LNB Case Penetration: Regardless of any other technical mitigation options that may be undertaken, Conclusion 1 (Section 3, above) requires that the earth station operator undertake all practicable technical efforts to ensure that the earth station RF front-end filter and LNB are thoroughly and securely grounded. The earth station operator can have this work done by a technical expert of his choosing.

The following mitigation options are available and are considered to be technically feasible for this earth station. Pro and con arguments are presented for each option.

Mitigation Option #1: Move the Earth Station Front-End to Another Location. If the earth station front-end is moved far enough from the current location to achieve terrain shielding of 20 dB or more, the interference will be eliminated.

Pro: This solution will unequivocally solve the interference problem due to the radars at BIW, provided that the new site provides at least 20 dB of RF attenuation of the BIW radar signals.

Con: Data from the front-end would have to be sent to the earth station premises via a cable link, a modem, or some equivalent information channel. This option would obviously involve substantial costs, including initial planning, engineering, and maintenance costs. Earth station operations will probably be less convenient than they are now. And, although this option will unequivocally solve the interference problem due to the radars at BIW, any new location always carries the risk that a new interference source may occur later at that location.

Mitigation Option #2: Reduce the Sidelobes and Backlobes of the Earth Station Antennas by 20 dB or More. Implementation of this option will necessitate the replacement of three existing earth station parabolic dish antennas. The only antennas that will suffice to reduce the sidelobes and backlobes by at least 20 dB are conical horn antennas. The gain of conical horn antennas vs. conventional parabolic antennas such as are being currently used at the earth station is shown in Figure 17. If the median value between the conical horn VV and the conical horn HH curves is used, the sidelobe and backlobe gain reduction relative to the parabolic antenna exceeds 20 dB at off-axis angles of greater than $\pm 27°$.

Pro: Since there are no terrestrial scatterers observed to be within the $\pm 27°$ angular range of the earth station antennas, this solution will almost certainly work to effectively eliminate the interference. Not only will the antennas have lower sidelobe and backlobe coupling levels, but their location in the parking lot (see Con, below) will provide them with another 5-10 dB of RF shielding from the BIW radars. It was also the view of the Test Team that mitigation of front-end case penetration would be easier with a conical horn antenna than a dish antenna since there is more flexibility in options to reduce the case penetration without disturbing the main beam antenna pattern and gain.

Con: As can be seen by examining the conical horn data in the Appendix, conical horns are neither small nor lightweight. They also are relatively expensive. A conical horn measures over 10 feet in diameter, and is on the order of 15 feet tall if mounted to receive earth station signals.

The footprint size is important, because these antennas weigh so much that the present earth station roof will probably not support one of these, much less three: each antenna will weigh more than 1,000 lb, and the mount will weigh over 500 lb., for a total of more than 1,500 lb per antenna, or more than 4,500 lb for a set of four. Therefore, conical horns would have to be located in one or both of the parking lots adjacent to the earth station building. Since each conical horn will effectively occupy about 10x10 = 100 sq ft of space, an array of three will occupy at least 300 sq ft of space in the parking lot(s).

The antenna mounting is also an issue, because the cheapest and easiest mounting arrangement is fixed-axis. That is, once the conical horn is aimed at a satellite, a major effort is required to position it on a new satellite. And, unlike lower-gain parabolic antennas that can often acquire signals from two satellites that occupy adjacent locations in the sky without being slewed from one to the other, a conical horn antenna must be re-aimed to acquire signals from another satellite, even if it is adjacent in the sky. Steerable mountings are available, but they weigh at least 50% more than a fixed mount, and they are considerably more expensive, utilizing such additional features as pivot joints and heavy-duty motors. It is not clear that any currently available antenna positioning controllers for 3-meter parabolic dish antennas can drive these mounts. If not, then a new set of antenna positioning controllers will also have to be purchased.

Mitigation Option #3: Attempt to Use Existing Antennas in the Parking Lot, with Front-End LNB Gain Properly Optimized. This option relies on the effect of front-end LNB gain optimization, combined with the measured attenuation of the radar signals in the parking lot to substantially mitigate the interference problem. The implementation is as follows: A parabolic dish antenna, either one that is currently on the rooftop, or another one of the same size and electrical characteristics that is temporarily provided by the earth station operator’s technical expert, is temporarily installed in one of the parking lots. With the antenna installed, the dish is equipped with an LNB that produces enough output gain to overdrive the receiver input, and no more. I.e., it is optimized in accordance with recognized electrical engineering principles. The earth station’s technical expert can optimize the gain by the following method:

1) **As described in the product Application Brief [4]**, verify that the receiver is configured in the low-gain mode;

2) **As described in the product Application Brief [4]**, insert attenuator(s) BETWEEN the LNB output and the receiver input. (The input to the receiver may be most convenient location, in terms of access.) Based on our test results, 10 dB, 16 dB, and 20 dB of attenuation should be attempted. The highest-level attenuator that provides adequate television viewing should be used for the remainder of the test.

By taking advantage of 5-10 dB of parking lot shielding and the 10-20 dB increase in dynamic range in the receiver that the lower front-end gain will provide, this solution may well solve the interference problem to a sufficient extent to permit non-objectionable television viewing.

Mitigation Option #3(a): Add a Wire Mesh Screen at the Antenna in the Parking Lot. In the event that the combined measures of parking lot location and front-end gain optimization do not provide adequate television viewing, a final measure may be implemented which should nearly guarantee success: construction of a wire-mesh screen around the antenna in the parking lot. Although precise quantification of the attenuation that such a screen will provide is essentially impossible to calculate, previous experience with such screening indicates that a 10-dB coupling reduction is likely. This option was previously attempted on the rooftop, but failed. However, we now know why: 20 dB of sidelobe decoupling is required to mitigate the interference, but screening, implemented on the rooftop, would only have provided about 10 dB of decoupling, based on past experience with screens.

As explained below under Con, this mitigation option is not as likely as the other two options to completely solve the earth station interference problem. However, testing this solution will involve relatively small expense (compared to the other mitigation options), and if it works, it will be a more practical solution than either of the other two options.

Pro: This solution is relatively inexpensive to test. It will be relatively easy to implement for all three earth station dishes.

Con: This solution, while it may not provide 100% error-free viewing, will probably provide viewing that is not considered objectionable by most people (i.e., some intermittent freeze-frame events, but probably 90% fewer than are currently occurring during interference episodes).

Mitigation Option #4: Use RF Limiters at the Inputs of the Earth Station Receivers. As with Option 3, this mitigation option is predicated on the highly likely but not completely proven hypothesis that the bulk of the EMC problem is being caused by the incapacity of the FEC in the earth station receivers to compensate for the highest-level pulses that occur in the receivers. If this hypothesis is correct, the use of limiters at the inputs of the receivers (that is, between the LNB output and the receiver input) should prevent any pulses from reaching the level in the receiver at which the FEC fails. The FEC will then compensate for the low-level pulses, and the interference will be mostly or entirely mitigated.

To work effectively, the limiter threshold level should be set just below above the desired signal levels. A test could be run with a modulated noise source to determine the effectiveness of the FEC for radar pulses, where the pulse repetition frequency, pulse width, and the amplitude of the modulated noise source could be controlled.

Limiters are normally used to protect systems from physical damage, rather than from interference, and as a result the current off-the-shelf limiter products only provide limiting at power levels of about 0 dBm or above. We need limiters that work at levels of about -30 dBm to -50 dBm. Five of the top limiter suppliers in the U.S. were contacted. Of these, none supply limiters at the low

[9]These were: M/A-COM of Lowell, MA; Mica Microwave of San Jose,

thresholds that we need. Thus, the limiter option, while technically attractive, appeared at first to be unavailable due to lack of the required hardware components from manufacturers.

However, recent information from some Department of Defense contractors indicates that a type of limiter solution may be feasible to design and construct. This solution, outlined by a private-sector manufacturer, is as follows: a configuration of amplifiers and attenuators is used in the following sequence:

AMP -------- ATTEN -------- AMP -------- ATTEN

The amplifiers would utilize FET technology, with a noise figure of 2 dB, a gain value of 37 dB, a 1 GHz bandwidth, and a 1-ns recovery time. The first attenuator adjusts the saturation level. (Note, however, that this attenuator could also be inserted, and would be more effective, at the input to the LNB.) The second attenuator is used to readjust the signal level. The recommended amplifiers would be Miteq JS2-00950125-10-SP for the 950-1250 MHz earth station receiver input.

The engineering costs for this solution are not yet known, but they will be substantial. The time-frame for preparing this device, even if the costs could be covered, will also be substantial, on the order of at least many months.

<u>Pro:</u> If the hypothesis that interference due to high-level pulses is defeating the built-in FEC in the receivers is true, then this solution should work. This solution might enable the earth station operator to leave his dish antennas on the roof, in their present locations. The operator would have to procure and insert these limiter-type devices at the input of each receiver.

<u>Con:</u> This option involves a significant engineering design effort; **it is not an off-the-shelf solution**. The cost of designing and procuring this solution will be substantial, and the amount of time required to pursue this option could be quite long, on the order of at least several months, and perhaps longer, depending upon the funding and staffing levels that would be devoted to it, and depending upon the responsibilities within the Navy and the earth station operator for supporting this effort. Uncertain variables include such issues as: who will perform such design and procurement work, and who will bear the costs of design and testing of these devices.

CA; Mini-Circuits of Brooklyn, NY; Vectronics MW Corp of Middlesex, NJ; and Herley MDI of Woburn, MA.

5. REFERENCES

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