NTIA REPORT 80-38

SPECTRUM RESOURCE ASSESSMENT IN THE 2.7 TO 2.9 GHz BAND PHASE II: LSR DEPLOYMENT IN THE LOS ANGELES AND SAN FRANCISCO AREAS

(Report No. 3)

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ABSTRACT

The National Telecommunications and Information Administration (NTIA) in the Department of Commerce undertook a detailed program to investigate the feasibility of deploying the Limited Surveillance Radars (LSR) in the 2.7-2.9 GHz band in the Los Angeles and San Francisco areas. The LSR is a Federal Aviation Administration (FAA) air traffic control radar planned for use at general aviation airports with high traffic density that do not qualify for the longer range Airport Surveillance Radars (ASR). This investigation was the third in a series of tasks undertaken by NTIA as part of a spectrum resource assessment of the 2.7-2.9 GHz band. The overall objective of the spectrum resource assessment was to assess the degree of congestion in the band in designated areas in the United States, and to promote more effective utilization of the band.

The investigation showed that the 2.7-2.9 GHz band is congested in both the Los Angeles and San Francisco areas. Major factors contributing to congestion are the Military height-finding radars and the occurance of ducting (superrefraction) propagation conditions. However, the LSR radars can be accommodated in the present environment at the proposed sites in these areas, but it was necessary to conduct a detailed frequency assignment investigation. Due to the high degree of congestion in these areas, it may be necessary, in order to accommodate all the proposed LSR deployments, to retrofit a few existing radars in the envirorment with waveguide filters or receiver signal processing techniques to suppress asynchronous pulsed interference.

KEY WORDS

Limited Surveillance Radar
Deployment
Frequency Assignment
Electromagnetic Compatibility

SECTION 1

INTRODUCTION

BACKGROUND

During the period of August 1971 through April 1973, the Interdepartment Radio Advisory Committee (IRAC) had under study the accommodation of Department of Defense (DoD), Federal Aviation Administration (FAA), and Department of Commerce (DoC) radar operations in the band 2.7-2.9 GHz. A series of meetings were held between the agencies (Summary Minutes of the First (October 1972) and Second (December 1972) OTP Meetings) to determine if new FAA air traffic control radars could be accommodated in this band without degrading their performance, and what impact these radars would have on the performance of existing radars in the band. An initial assessment of the problem (Maiuzzo, 1972) determined that the addition of new radars to the band could create a potential problem. To resolve the immediate problem of accommodating the new FAA Air Traffic Control Radars, the following actions were taken:

a. The band 3.5-3.7 GHz was reallocated by footnote to provide for co-equal primary Government use by both the Aeronautical Radionavigation and Radiolocation Services. The footnote reads as follows:

> G110 - Government ground-based stations in the aeronautical radionavigation service may be authorized between 3.5-3.7 GHz where accommodation in the 2.7-2.9 GHz band is not technically and/or economically feasible.

Agencies were requested to cooperate to the maximum extent practicable to ensure on an area-by-area, case-by-case basis that the band 2.7-2.9 GHz is employed effectively.

b. The Spectrum Planning subcommittee was tasked to develop a long-range plan for fixed radars with emphasis on the 2.7-2.9 GHz and 3.5-3.7 GHz bands. The SPS plan (SPS Ad Hoc Committee, 1974) was completed and approved by the IRAC.

The Office of Telecommunications Policy (OTP)* subsequently tasked the Office of Telecommunications (OT)* to perform a spectrum resource assessment of the 2.7-2.9 GHz band. The intent of this assessment was to provide a quantitative understanding of potential problems in the band of concern as well as to identify options available to spectrum managers for dealing with these problems. One of the primary reasons for initiating the assessment was to ensure identification of problems during the early phases of design and planning rather than after-the-fact, i.e., after a system has been designed and hardware fabricated. By making these band assessments early, necessary actions can be taken to assure that appropriate communication channels are established between agencies whose systems are in potential conflict. This will enhance the early identification of solutions which are mutually satisfactory to all parties involved.

*OTP and OT have been reorganized into the National Telecommunications and Information Administration (NTIA) within the Department of Commerce.

A multiphase program to the solution of the 2.7-2.9 GHz Spectrum Resource Assessment task was undertaken by NTIA.

Phase I - The first phase involved the identification of systems existing in and planned for the band in question, determination of available technical and operational data for each system, identification of the potential interactions between systems, and the generation of a plan that leads to an overall assessment of the band's potential congestion. A Phase I report (Hinkle and Mayher, 1975) for the 2.7-2.9 GHz Spectrum Resource Assessment was completed.

Phase II - The second phase encompassed several tasks:

1. A detailed measurement and model validation program in the Los Angeles and San Francisco areas. The objective of this task was to validate models and procedures used to predict radar-to-radar interference, and assess the capability of predicting band congestion. This task was completed and the findings given in a report by Hinkle, Pratt, and Matheson (1976).

2. Investigation of the signal processing properties of primary radars in the 2.7-2.9 GHz band and the Automated Radar Terminal System (ARTS-IIIA) to assess the capability of the Radars to suppress asynchronous interference and the trade-offs in suppressing asynchronous signals. This task was completed and the findings given in a report by Hinkle, Pratt and Levy (1979).

3. Investigation of the feasibility of accommodating new radar systems in the 2.7 to 2.9 GHz band in eight designated congested areas (Los Angeles, San Francisco, New York, Philadelphia, Atlanta, Miami, Chicago, and Dallas).

4. Development of engineering and management aids to assist the frequency manager in determining if new radars can be accommodated in the 2.7-2.9 GHz band, and a methodology for assessing how efficiently the band is being utilized.

This report is the third Phase II report in a series of reports related to the Spectrum Resource Assessment of the 2.7-2.9 GHz band. The report contains an investigation of the feasibility of accommodating the Limited Surveillance Radar (LSR) in the Los Angeles and San Francisco areas in the 2.7-2.9 GHz bands without degrading the performance of existing radars, or the LSR radars.

ENVIRONMENT

The Government Master File (GMF) currently lists 642 frequency assignments in the 2.7 to 2.9 GHz band. Major systems in the band include the FAA Airport Surveillance Radars (ASRs), DoD Ground Control Approach (GCA) radars, and DoC National Weather Service (NWS) radars. TABLE 1-1 lists the number of frequency

TABLE 1-1

FREQUENCY ASSIGNMENTS IN 2.7 TO 2.9 GHz BAND

AGENCY/SERVICE	NUMBER OF ASSIGNMENTS	PERCENTAGE OF ASSIGNMENTS
FAA	212	33.0
NWS	68	10.6
Army	18	3.0
Navy	67	10.4
Air Force	261	40.6
NSF	3	0.4
NASA	2	0.3
Non-Gevernment	11	1.7

assignments for each Government agency and the non-Government assignments for March, 1980. The location of the frequency assignments in CONUS are shown in Figure 1-1. There is a high level of usage in this band along the East and West coast megalopolis areas (New York, Philadelphia, Los Angeles and San Francisco) as well as the Atlanta, Miami, Chicago and Dallas areas.

In these congested areas, potential Electromagnetic Compatibility (EMC) problems could occur in accommodating new radar systems planned for the band. Therefore continued coordination among Government agencies planning major new radar procurements is required in order to assure that new radar systems are properly engineered to enhance their accommodation in the band.

New Systems

Several new major radar systems are being considered for deployment in the 2.7 to 2.9 GHz band. These systems include: 1) FAA Limited Surveillance Radar (LSR), 2) FAA Airport Surveillance Radar (ASR-9), and 3) Joint FAA, National Weather Service (NWS) and Air Force next generation weather radar (NEXRAD).

LSR

The Limited Surveillance Radar (LSR) system is an air traffic control radar planned for use by the FAA at general aviation airports with high density traffic. This system was developed as a cost-effective sensor to improve safety procedures and increase operational efficiency at airports that do not require the control area size or have the traffic density to warrant a highly sophisticated Airport Surveillance Radar/Radar Beacon System (ASR/RBS). The LSR system is a single channel radar which uses doppler signal processing similar to the Moving Target Detection (MTD-II) radar developed by the FAA at the National Aviation Facility Experimental Center (NAFEC). A study by the FAA (Paul S. Rempfer, 1977) identifies 17 proposed locations for LSR system installations based on a cost/benefit analysis. However, the LSR system may be installed at any number of airports in CONUS.

In October 1978, the FAA requested the IRAC Spectrum Planning Subcommittee (SPS) to provide spectrum support for deployment of the LSR system in the 3.5 to 3.7 GHz band based on allocation footnote G110 (SPS-3341/1-1.14.10). The NTIA preliminary review of the LSR system (SPS-3388/1-1.14.10) recommended that spectrum support in the 3.5 to 3.7 GHz band appears warranted only if the FAA can demonstrate that the LSR cannot be technically or economically accommodated in the 2.7 to 2.9 GHz band. The FAA has considered the band 2.7 to 2.9 GHz for the LSR, but has not requested spectrum support in that band.

As a result of the 1979 World Administrative Radio Conference (WARC), the radiolocation service in the 3.5 to 3.7 GHz band was changed from primary to secondary status. Because of the reallocation of radiolocation to secondary status, the deployment of the LSR system which is a safety-of-life service in the 3.5 to 3.7 GHz band may not be desirable. The concern over congestion in the 2.7 to 2.9 GHz band necessitated the requirement of a detailed study by NTIA into the feasibility of accommodating the LSR system in the 2.7 to 2.9 GHz band.

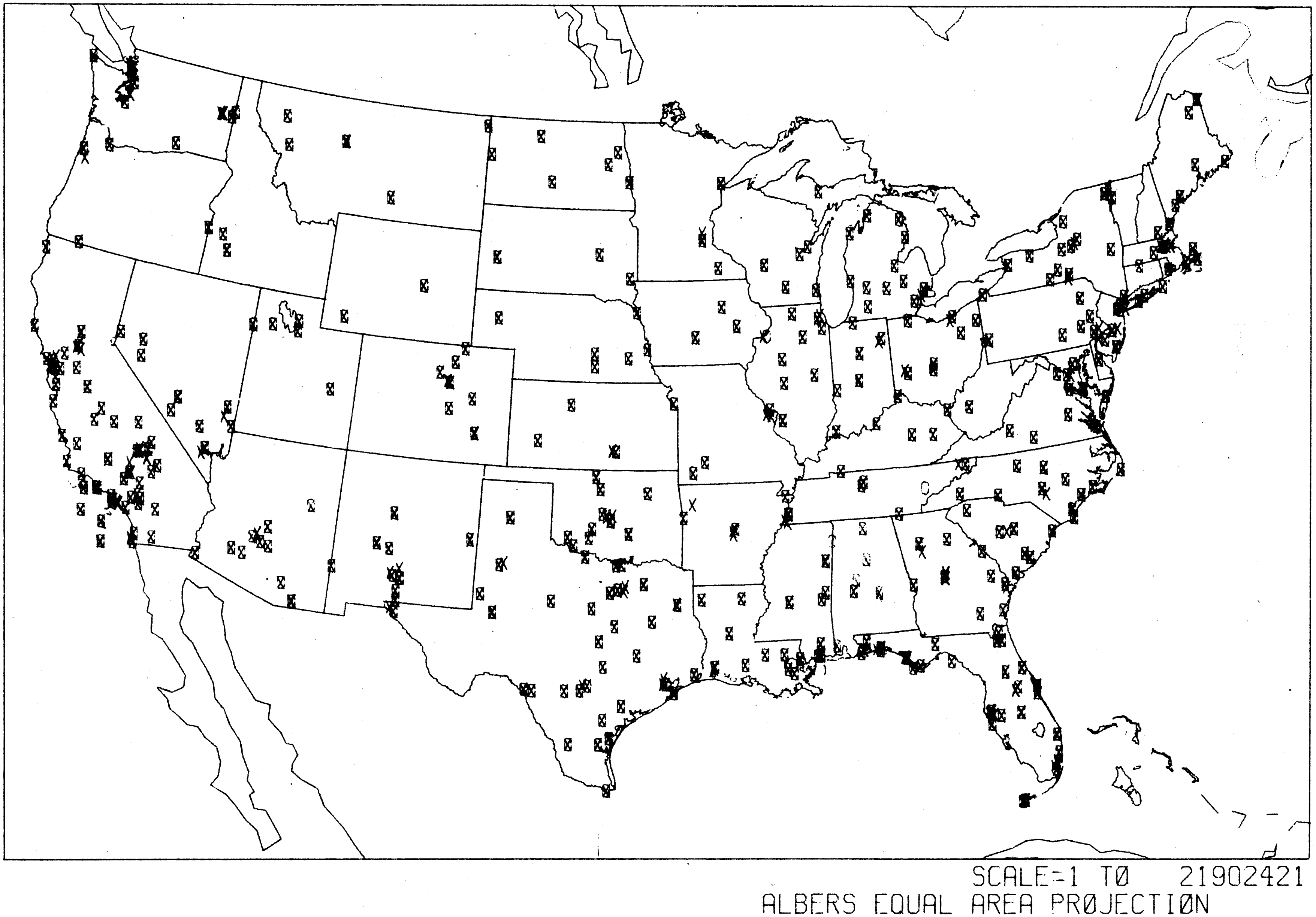

Figure 1-1. Radar Locations in 2.7 to 2.9 GHz Band

ASR-9

The Airport Surveillance Radar (ASR-9) is being developed by FAA for replacement of the ASR-4, ASR-5, and ASR-6 analog radars. The radar will be a dual channel radar, but will not operate in the frequency diversity mode. The ASR-9 transmitter will use a klystron output tube. The ASR-9 receiver will also use doppler signal processing similar to the MTD-II radar.

The FAA has tentative long range plans for procurement of 92 ASR-9 radars. The military requirements for the ASR-9 radar system are not known at this time. In March 1980, the FAA requested the IRAC Spectrum Planning Subcommittee (SPS) to provide spectrum support for deployment of the ASR-9 system in the 2.7 to 2.9 GHz band (SPS-4440/1-1.14.10).

NEXRAD

The next generation weather radar is being developed jointly by the FAA, NWS, and Air Force. Present plans are for the radar to have two transmit/receive channels; one for doppler information processing, and one for range information processing. Therefore, each radar may require two operating frequencies if some form of batch processing of the two types of information on a single frequency cannot be achieved. An experimental version of the NEXRAD radar is being developed by the Air Force. This experimental version is called the Dual Frequency Self-Cal Radar. The Air Force submitted to the IRAC Spectrum Planning Subcommittee for spectrum support in October 1979 (SPS-4203/1-1.14.10). In February 1980, stage 3 approval of the Dual Frequency Self-Cal Radar was granted by NTIA (SPS-4294/2-1.14.10).

National coverage requirements for NEXRAD system may result in as many as 200 systems being deployed. The FAA has, tentatively, identified 76 locations within CONUS for weather information. The NWS and Air Force have not identified their requirements for the NEXRAD system.

Because of the uncertainty of the DoD requirements for the ASR-9 system and the NWS and Air Force requirements for the NEXRAD system, these systems were not taken into consideration in assessing the feasibility of accommodating the LSR in the 2.7 to 2.9 GHz band in the Los Angeles and San Francisco areas.

OBJECTIVE

The objective of this Task was to determine if the LSR radars can be accommodated in the Los Angeles and San Francisco areas in the 2.7-2.9 GHz band without degrading the performance of existing radars in the band, or the LSR radars.

APPROACH

In order to accomplish the objective related to the task, the following approach was taken:

1. The Government Master File (GMF) was used to identify

existing radars and their operating frequencies in the 2.7-2.9 GHz band in the Los Angeles and San Francisco areas. The GMF information was then verified with the FAA and DoD Western Region frequency coordinators.

2. Use information provided by FAA in identifying proposed site locations for LSR radar system deployments in the Los Angeles and San Francisco areas.

3. Establish an appropriate Interference-to-Noise Ratio (INR) performance criterion for the LSR system.

4. Assess the feasibility of accommodating the LSR radars in the 2.7-2.9 GHz band by using the procedure outlined in the report by Hinkle, Pratt and Matheson (1976), and taking into consideration propagation phenomena related to building attenuation and ducting.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

This section contains a summary of the conclusions and recommendations resulting from an investigation into the feasibility of accommodating the Limited Surveillance Radars (LSRs) in the 2.7 to 2.9 GHz band in the Los Angeles and San Francisco areas. The investigation did not take into consideration the deployment of the ASR 9 and NEXRAD radar systems planned for the band because of unknown requirements for these systems.

The conclusions and recommendations are based on the LSR system characteristics and performance criterion given in Section 3. Final specifications for procurement of the LSR system have not been determined, and any changes to the LSR system specifications as given in Section 3 may necessitate changes in the findings of this investigation. The procedure used for determining possible operating frequencies at proposed LSR sites is discussed in Section 4.

CONCLUSIONS

A detailed frequency assignment procedure was used to determine the feasibility of accommodating the LSR system at six proposed sites in the Los Angeles area and eight proposed sites in the San Francisco area. This led to the following conclusions, which are discussed in detail in Section 5 for the Los Angeles area and Section 6 for the San Francisco area.

General

General conclusions resulting from the LSR deployment investigation are:

1. The 2.7 to 2.9 GHz band is congested in both the Los Angeles and San Francisco areas. However, a detailed frequency assignment investigation indicates that the Limited Surveillance Radars (LSRs) can be accommodated at the proposed sites in these areas.

2. Due to the high degree of congestion in these areas, it may be necessary, in order to accommodate all the proposed LSR deployments, to retrofit a few existing radars in the environment with waveguide filters or receiver signal processing techniques to suppress asynchronous pulsed interference. However, the cost of retrofitting existing radar systems to eliminate interference must be weighed against the problems created by the interference, and the scheduled replacement of the existing radar systems.

3. Previous investigations (Hinkle, Pratt and Levy, 1979) have shown that existing digital radar receivers have the signal processing circuitry to suppress asynchronous pulsed interference. At this time, tests have not been conducted to determine if the analog radar receivers have the signal processing circuitry to suppress

asynchronous pulsed interference.

4. The height-finding radars are a major contributor to congestion in the band. Measurements made with the Radio Spectrum Measurement System (RSMS) van show that the coaxial magnetron output tube used in the height-finding radars have spurious modes which produce high level emissions in the band thus denying the use of a large percentage of the band to other potential users. Other height-finding radar characteristics which contribute to congestion are their site location (generally on top of hills and mountains), and their relatively high transmitter power and antenna gain.

5. The occurrence of ducting (superrefraction) propagation conditions along the coast of Southern California also contributes to congestion in the Los Angeles and San Francisco areas. The ducting propagation phenomenon occurs approximately 50 percent of the time during the summer, and must be taken into account in determining frequency assignments which will result in compatible operations.

6. Because of the degree of congestion in the 2.7-2.9 GHz band in some areas, new radar procurements for the Aeronautical Radionavigation service as well as the Meteorological Aids service will have to contend with asynchronous pulsed interference in performing their operational requirements. Emphasis must be placed upon the design standards of new equipment requiring low transmitter emission spectrum sideband levels to minimize adjacent channel interference, and receiver signal processing circuitry to suppress asynchronous pulsed interference. The use of these spectrum conservation techniques would more readily permit the accommodation of new radar deployments in the band.

7. Reallocation of the radiolocation service in the 3500-3700 MHz band from primary to secondary status by the 1979 WARC requires that further consideration be given to the desirability of deploying the LSR system in the 3500-3700 MHz band.

8. An analytical investigation of the developmental LSR system (MTD-II) showed that an Interference-to-Noise Ratio (INR) criterion of 5 dB or less would preclude asynchronous pulsed interference from causing false reports and raising the adaptive threshold by more than one dB.

Los Angeles Area

The following is a summary of conclusions resulting from an investigation into the feasibility of deploying Limited Surveillance Radars (LSRs) at six proposed sites in the Los Angeles area:

1. Table 2-1 shows the available operating frequencies and

TABLE 2-1

AVAILABLE OPERATING FREQUENCIES AND PERCENTAGE OF BAND AVAILABLE FOR ASSIGNMENT IN THE LOS ANGELES AREA

Proposed LSR Site	Available Operating Frequencies (MHz)	Percentage of Band Available for Assignment
Imperial	2700 - 2740	20
Brown	2812 - 2818 2861 - 2866 2875 - 2878	7
Gillespie	2809 - 2822 2860 - 2863 2876 - 2878 2882 - 2884	10
El Monte	None *	0
Palmdale	2702 - 2746	22
Santa Maria	2772 - 2786 2806 - 2824 2852 - 2900	40

* The proposed El Monte LSR site can be accommodated in the band by using a waveguide filter on the Los Angeles ASR-4 radar.

percentage of the 2.7 to 2.9 GHz band usable for frequency assignment for each of the proposed LSR sites. LSRs can be deployed at five of the six proposed LSR sites without performance degradation to the existing radars in the environment, or the LSRs. The proposed LSR site at El Monte could potentially receive interference from radars in the Los Angeles area regardless of its operating frequency in the 2.7 to 2.9 GHz band.

2. Several factors make it very difficult to deploy an LSR at El Monte. These factors include: 1) The close proximity of the proposed El Monte LSR site to existing radars in the Los Angeles basin, and 2) Possible ducting conditions between the El Monte LSR and other radars in the basin as well as radars off the coast. One method of accommodating an LSR located at El Monte is to install a waveguide filter in the Los Angeles Airport ASR-4. This would permit the operation of an LSR at EL Monte in the 2716 to 2723 MHz band.

San Francisco Area

The following is a summary of conclusions resulting from an investigation into the feasibility of deploying Limited Surveillance Radar (LSRs) at eight proposed sites in the San Francisco area:

1. TABLE 2-2 shows the available operating frequencies and percentage of the 2.7 to 2.9 GHz band usable for frequency assignment for each of the proposed LSR sites. LSRs can be deployed at seven of the eight proposed sites without performance degradation to the existing radars in the environment, or the LSRs. The proposed LSR site at Napa County could potentially receive interference from radars in the San Francisco area regardless of its operating frequency in the 2.7 to 2.9 GHz band.

2. The proposed LSR site at Napa County Airport is located near the North end of the San Francisco/San Pablo Bay. Propagation ducting phenomena, which occurs approximately 50 percent of the time in the summer in the Bay area, significantly decreases the percentage of the band available for operation of an LSR at the Napa County Airport. Also the Mt. Tamalpais height-finding radar, which is line-of-sight with the proposed LSR site, denies the Napa County Airport LSR approximately 79.5 percent of the 2.7 to 2.9 GHz band. In order to accommodate an LSR at the proposed Napa County Airport site, it is anticipated that a waveguide filter may be required on the Mt. Tamalpais height-finding radar.

TABLE 2-2

AVAILABLE OPERATING FREQUENCIES AND PERCENTAGES OF BAND AVAILABLE FOR ASSIGNMENT IN THE SAN FRANCISCO AREA

Proposed LSR Site	Available Operating Frequencies (MHz)	Percentage of Band Available For Assignment
Merced	2735 - 2765 2805 - 2900	60
Modesto	2700 - 2707 2723 - 2777 2779 - 2823 2827 - 2900	76
Livermore	2700 - 2712 2859 - 2900	26.5
Stockton	2700 - 2774 2783 - 2789 2798 - 2817 2829 - 2888 2892 - 2900	81
Concord	2700 - 2718 2732 - 2748 2832 - 2879	40.5
Napa County	None *	0
Santa Rosa	2834 - 2900	33
Chico	2700 - 2900	100

* The proposed Napa County LSR site can be accommodated in the band by using a waveguide filter on the Mt. Tamalpais AN/FPS-90 radar.

RECOMMENDATIONS

Considering the findings resulting from the Los Angeles and San Francisco area LSR deployment investigation, the following action is recommended:

1. Because of the level of usage of the 2.7 to 2.9 GHz band in certain areas within CONUS and the uncertainty in requirements of new systems in the band, an investigation of the feasibility of accommodating the combined requirements of the ASR-9, NEXRAD, and LSR should be conducted. This investigation should be based on Government agency projected requirements in the 2.7 to 2.9 GHz band.

2. An IRAC Technical Subcommittee (TSC) Ad Hoc group should be established to determine system performance guidelines required for new procurements in the 2.7 to 2.9 GHz band. These performance guidelines should be directed towards:

    a. Identifying more stringent RSEC criteria for radar transmitter emission spectrum sideband levels in order to minimize adjacent channel interference.

    b. Defining the environmental signal characteristics which new radar systems may have to contend with in performing their operational requirements. The environmental signal characteristics should be in terms such as: pulse width, Pulse Repetition Frequency (PRF), and expected signal levels. This information can then be used as a performance guideline in developing receiver interference suppression techniques.

    c. Developing a compendium for reference of interference suppression techniques and their significant charactristics.

3. An IRAC Spectrum Planning Subcommittee (SPS) Ad Hoc group should be established to assure that new systems are properly engineered to enhance their accommodation in the 2.7 to 2.9 GHz band. The SPS Ad Hoc group activities should be directed towards:

    a. The identification of Government agency procurement plans in the 2.7 to 2.9 GHz band through 1985.

    b. The over-sight of the implementation of the performance guidelines established by the TSC Ad Hoc group in new systems.

4. An investigation into the spurious emission characteristics of the coaxial magnetrons used in the height-finding radars should be conducted to determine why the coaxial magnetron emission spectra are not as clean as purported.

5. In congested areas, the secondary radiolocation height-finding radar transmitters should use some method (waveguide filter, etc.) of controlling their spurious emission spectra levels in order that they do not deny a large percentage of the band to other users.

6. A measurement program should be conducted to determine the capability of doppler radars planned for the 2.7 to 2.9 GHz band to suppress asynchronous pulsed interference under actual field operating conditions.

7. The NEXRAD radar should be designed, if practical, to operate on a single frequency. In view of the congestion in this band, it is believed that the joint development group should seriously consider this possibility before they proceed with a dual frequency system. A single frequency system is much more likely to be accommodated in heavily used areas.

8. Priority be given to replacing the ASR-4, ASR-5, and ASR-6 radars in congested areas with the ASR-9 system.

9. Because of the congestion being experienced in this band and because of the safety-of-life nature of the aeronautical radionavigation service, all new or replacement radars operating in the 2700 to 2900 MHz band in the primary aeronautical radionavigation or meteorological aids services or the secondary radiolocation service should be reviewed in the SPS.

10. All new radar procurements in the 2.7 to 2.9 GHz band be required to submit measured data on Form OT-33, 34, and 35 for stage 4 Systems Review approval.

SECTION 3

LSR SYSTEM CHARACTERISTICS AND DESCRIPTION

INTRODUCTION

This section contains a discussion of the LSR system characteristics, and system description. An analysis of the signal processing of asychronous pulsed interference through the LSR receiver, and appropriate performance criteria for the LSR in an asynchronous pulsed interference environment are given in Appendix B.

BACKGROUND

Present design plans for the LSR are to use the Moving Target Detection (MTD) signal processing technique. In 1975, a hard-wired version of the MTD was tested extensively at the National Aviation Facilities Experimental Center (NAFEC) near Atlantic City. The subclutter visibility performance of the MTD on controlled aircraft flying in heavy rain and ground clutter was measured to be about 100 times (20dB) greater than conventional Moving Target Indicator (MTI) performance. The MTD employs coherent, linear doppler filtering, adaptive thresholding, and a fine grained clutter map to reject ground clutter, rain clutter, angels (birds) and interference. A detailed discussion of the original MTD radar (MTD-I) signal processing is given by O'Donnell, Muehe, Labitt, Drury and Cartledge (1974); Drury (1975) and Cartledge and O'Donnell (1977).

In June 1979 a second generation MTD radar (MTD-II) was installed at Burlington Vermont for operational field evaluation. The major difference between the MTD-I and MTD-II radars are the methods used to implement the doppler filtering. The MTD-I used an eight point Discrete Fourier Transform (DFT) for the doppler filters, while the MTD-II uses Finite Impulse Response (FIR) filters, often called transversal filters. A discussion of the MTD-II is given by O'Donnell and Muehe (1979).

SYSTEM CHARACTERISTICS

TABLE 3-1 shows a list of the basic system characteristics proposed for the LSR. Since the LSR system is still in the developmental phase, and the MTD-II signal processing technique is still undergoing operational field evaluation, the LSR system characteristics shown in TABLE 3-1 may not be representative of the final procurement specifications for the LSR system.

The major difference between proposed LSR characteristics and the MTD-II being evaluated at Burlington is the implementation of 16 doppler filters rather than eight doppler filters. Other possible changes to the MTD-II processor which may be incorporated in the LSR are discussed in the following system description. Since the threshold criteria for a 16 doppler filter MTD radar have not been determined, the following system description is for the eight doppler MTD-II system.

TABLE 3-1

LSR SYSTEM CHARACTERISTICS

ANTENNA:	
Antenna Gain (G)	29.2 dBi
Azimuth Beamwidth	3.4°
Antenna Scan Period/Rate	4 sec/15 RPM
Antenna Height	25 ft.
TRANSMITTER:	
Transmitter Peak Power (Pt)	100 kW
Pulsewidth	2.0 us
PRF (average)	2000 pps
RECEIVER:	
Receiver IF Bandwidth (B)	0.6 MHz
Noise Figure (NF)	5.0 dB
Coherently Processed Intervals (CPI) per 2-way Beamwidths	2.2
Coherently Processed Points or Doppler Filters (I)	16
CPI's per scan	336
Range bins	256 (1/8 mi)
Range Azimuth bins	86016
Range Azimuth Doppler bins	2.06×10^6
False Alarms per Scan	40
False Alarms per bin (PFA)	1.94×10^{-5}
Probability of Detection (PD)	0.75
Instrumented Range	32 nmi

SYSTEM DESCRIPTION

A block diagram of the MTD-II radar system is shown in Figure 3-1. Analog signals from the radar's linear receiver (which is linear over 60 dB dynamic range) are sent to the MTD signal processor where MTD signal processing algorithms are performed. Doppler threshold crossings are sent over the IEEE bus to the post-processor. In addition, post MTD area thresholding and scan-to-scan correlation are performed in the post-processor to remove the false hit reports, passed by the MTD processor. Aircraft position reports are then sent from the post-processor to an intelligent graphics display and over an interface to the user display.

MTD Analog Hardware

The MTD radar uses a conventional radar receiver front end up to the Intermediate Frequency (IF) amplifier stage input. The analog portion of the MTD from the IF amplifier input is shown in Figure 3-2. It contains both IF and Coherent Oscillator (COHO) amplifiers and double balanced mixers. The use of these amplifiers and mixers result in Inphase (I) and Quadrature (Q) video detectors with a linear dynamic range that is only limited by the Analog-to-Digital (A/D) converters which follow.

MTD Digital Processor

A block diagram of the MTD-II digital processor is shown in Figure 3-3. The I and Q (Inphase and Quadrature) signals from the A/D converter are added coherently, two at a time. Then consecutive samples of both the I and Q channels for each of the range bins are stored in word memory. These words are then processed sequentially (eight time samples for each range bin) by a two-pulse MTI canceller. Each group of eight pulses which are processed coherently together is called a Coherent Processing Interval (CPI). The I and Q channels are processed by separate hardware in the two-pulse canceller section of the processor. Note that the eight pulses of the I and Q channel samples exist after the two-pulse canceller as seven pulses. The output of the two-pulse canceller for both the I and Q channels (real and imaginary parts of the signal) is fed to seven transversal filters. Weighting of the I and Q channel signals to reduce the filter sidelobe level is done after filtering. Consideration is being given to eliminating the two-pulse canceller prior to the transversal filters in the LSR.

Since the two-pulse canceller has a poor low doppler velocity response, a Zero Velocity Filter (ZVF) is employed to see low radial velocity targets. The low pass filter is implemented by using an FIR filter. A recursive filter is used to update on a scan-to-scan basis the average signal level stored in the memory. On each scan one 8th of the stored clutter level is subtracted from the stored level. One 8th of the signal level output from the ZVF is added to the value remaining after subtraction. This new level is then stored in the memory for thresholding on the next scan.

An interference eliminator circuit has been hard-wired into the MTD-II to eliminate asynchronous pulsed interference. The magnitude of sixteen pulses in the same range bin in consecutive azimuth change pulses is taken by adding the absolute values of the I and Q channels. The sixteen magnitudes are also stored until the average has been computed. Each range bin is then compared

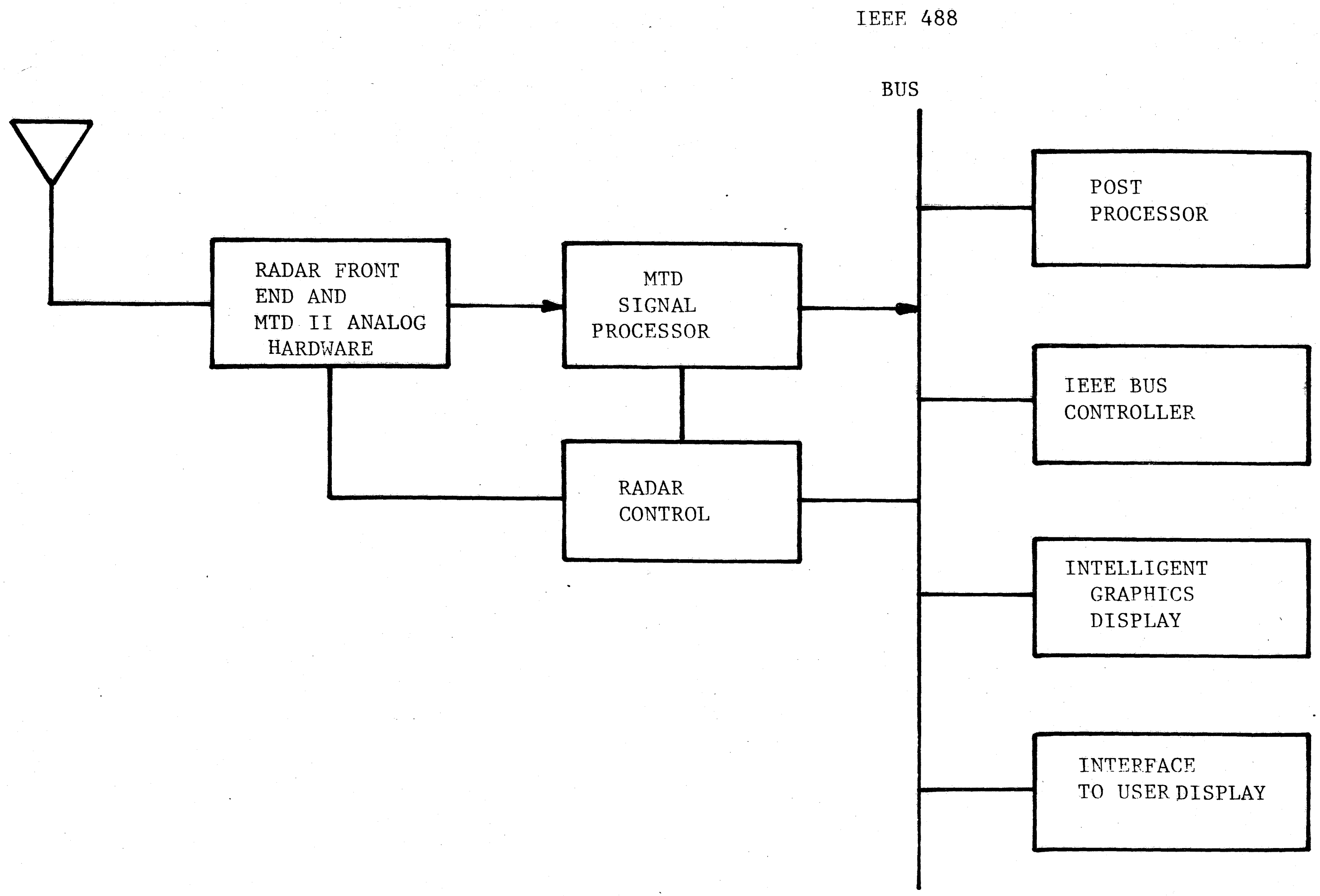

Figure 3-1. Block Diagram of MTD-II Radar System

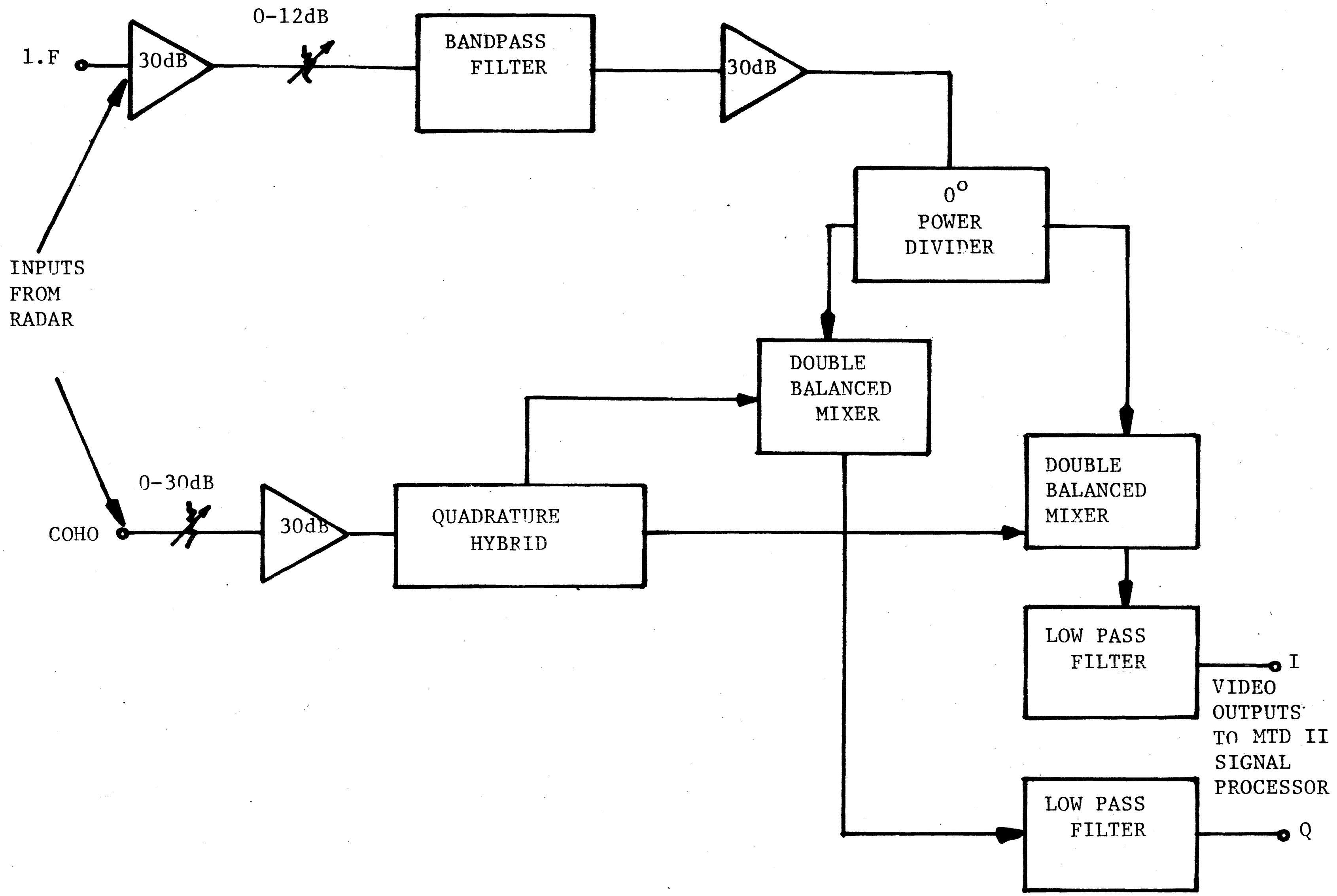

Figure 3-2. MTD-II Analog Hardware

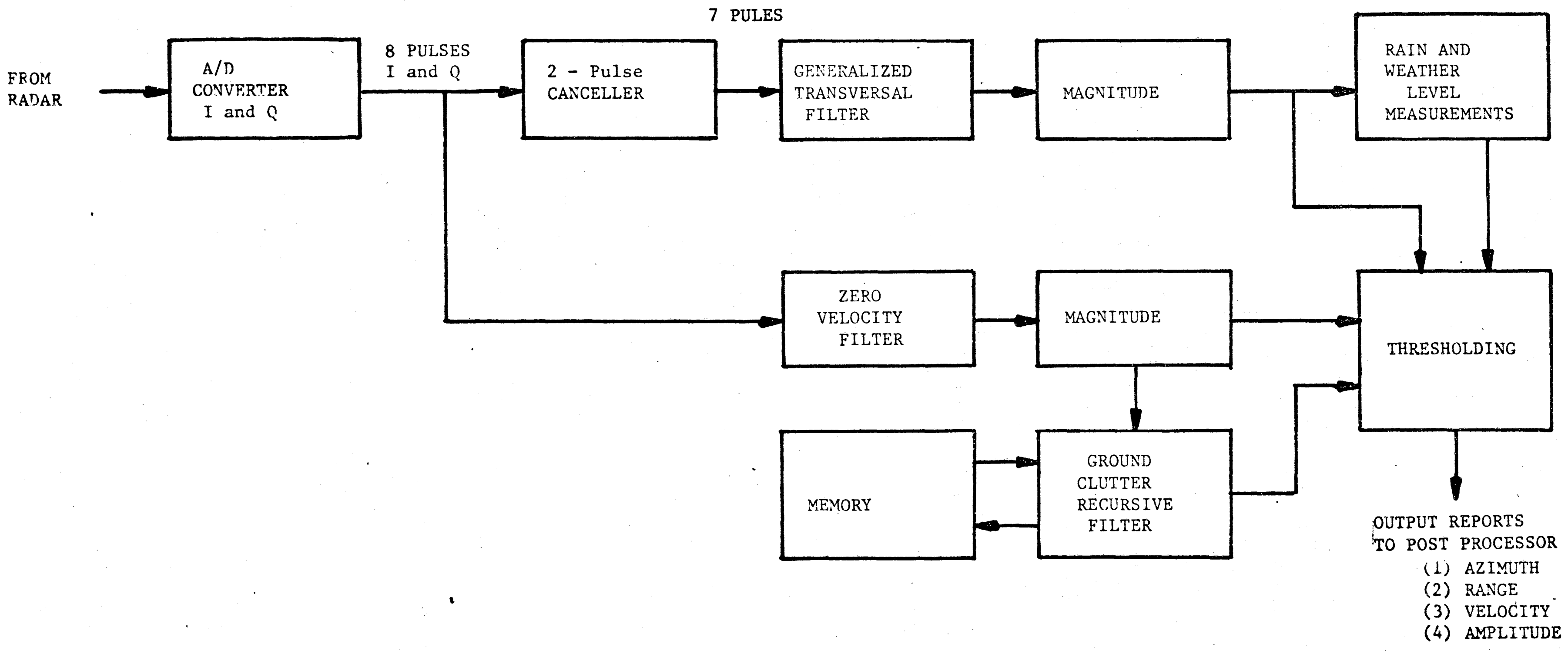

Figure 3-3. Block Diagram of MTD-II Signal Processor

sequentially with four to five times the average. If any one range bin exceeds this number, it is replaced by the average of the sixteen range bins.

A more detailed discussion of the doppler filtering technique and interference eliminator circuit is given in the report by O'Donnell and Muehe (1979).

MTD Threshold

After magnitudes are taken, adaptive background clutter levels and thresholds are set for each range-azimuth-doppler bin, and threshold crossings are noted and output to the post processor. The adaptive background levels and threshold settings are dependent upon the clutter phenomena which are present. The doppler domain is divided into three domains, doppler filter 0, doppler filters 2 through 6 and doppler filters 1 and 7.

In doppler filter 0 (ZVF channel) the clutter is generally due to ground backscatter. The average ground backscatter cross section varies from range-azimuth bin to range-azimuth bin. The average backscatter signal level for each bin is measured and stored in the memory. The threshold for the zero doppler filter is a fixed value between four and eight times the level stored in the memory. This fixed value may be altered by the use of a wire jump on the hardware.

In doppler filters 2 through 6, the clutter is due chiefly to rain. For each doppler filter and azimuth bin, the average signal level is measured by averaging the receive signal over 16 range bins centered on the range bin of interest. The range bin of interest and the guard range bins on both sides of the range bin of interest are excluded in determining the average signal level. The threshold for these filters is a fixed value set at four to eight times the measured average signal level.

Doppler filters 1 and 7 can contain clutter due to rain and spillover from the ground backscatter in doppler filter 0. The threshold in these filters is set as the greater of two thresholds; (a) the threshold set as in doppler filters 2 through 6, or (b) a fixed binary fraction of the threshold set in doppler filter 0.

Threshold crossings in the MTD processor are noted, and reports sent to the post processor. These MTD reports contain the following information: aximuth, range, doppler velocity and voltage amplified.

Post-Processor

Figure 3-4 shows a block diagram of the post processor. The post-processor algorithms perform three functions: report correlation and interpolation, post MTD thresholding, and scan-to-scan correlation. post MTD thresholding is an area Constant False Alarm Rate (CFAR) thresholding algorithm which deletes false alarms. It is the function of correlation and interpolation to cluster (combine) all range azimuth doppler threshold crossings, which are caused by the same aircraft, and combine them together into a single report with the most accurate radar observables (range, azimuth, doppler velocity, strength). Finally, scan-to-scan correlation deletes those uncorrelated radar reports due to noise, automobile traffic, angels and

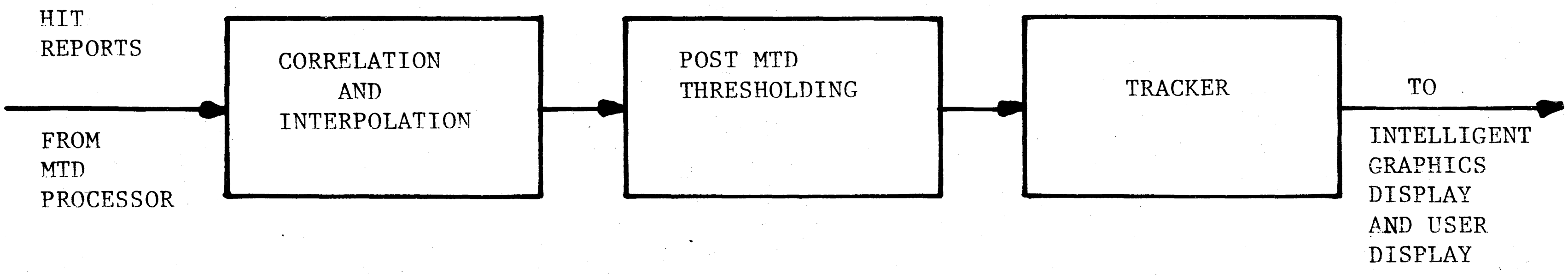

Figure 3-4. Block Diagram of Post-Processor

asynchronous pulsed interference whose scan-to-scan histories indicate characteristics unlike those of aircraft (i.e., low speeds or lack of spatial correlation from scan-to-scan).

Correlation and Interpolation

It is the purpose of these algorithms to cluster those range-azimuth-doppler threshold crossings which are due to one target (i.e., a bird, aircraft, or automobile) and then to calculate from the data of the cluster the best value of radar observables for the target. These radar observables are range, azimuth, doppler velocity, and strength. The criteria used for clustering is range and azimuth adjacency of the threshold crossings. The strength of each threshold crossing is normalized depending on the gain of the doppler filter from which it came. The range and azimuth are calculated by weighting both range and azimuth by the strength (voltage) associated with that threshold crossing. The doppler velocity is calculated by interpolating between the doppler of the cell with the largest strength and its adjacent doppler cell with the second greatest strength. This interpolation is done to one part in 64 across the band of eight doppler filters.

Post-MTD Thresholding

Post MTD thresholding is an area CFAR technique to delete single CPI false alarms due to residual angels, interference, and weather clutter that are not removed by signal processing algorithms in the MTD signal processor. Early in the testing of the MTD-I at NAFEC it became evident that several environmental phenomena were causing more false alarms than initially predicted. Furthermore, these false alarms were partially correlated both spatially and temporally and, thus, were causing false tracks to be initiated by the tracker. Typically, there were 50 to 100 false alarms per scan due to noise and as many as several hundred false alarms per scan from all environmental phenomena when they were present.

A series of thresholding algorithms, developed by W. Goodchild at NAFEC, have been particularly successful in eliminating almost all of the non-noiselike false alarms. These algorithms have been incorporated in the post processor software before the radar reports are sent to the tracker. A detailed discussion of these algorithms are given in the report by Cartledge and O'Donnell (1977), and O'Donnell and Muehe (1979).

Scan-to-Scan Correlation

The scan-to-scan correlator is a radar report editing process. It does not change any radar report data, it only deletes some of the data which are input to the scan-to-scan correlator. It is the purpose of these algorithms to delete all reports due to nonaircraft phenomena such as interference and pass all reports which are due to aircraft. A detailed discussion of these algorithms is given by O'Donnell and Muehe (1979).

PERFORMANCE CRITERIA

In order to assess the feasibility on an electromagnetic capability (EMC) basis of deploying the LSR radars in the Los Angeles and San Francisco area, it is necessary to establish a peak Interference-to-Noise Ratio (INR) which will preclude performance degradation of the LSR System. For this investigation, the criteria used to establish an appropriate peak INR was:

1. The level of interference should not cause false hit reports to be sent to the MTD post-processor which could result in overloading of the post-processor.

2. The level of interference should not cause the MTD threshhold level to be increased by more than 1 dB.

An analysis of the signal processing of asynchronous pulsed interference through the LSR receiver, and appropriate performance criteria for the LSR in an asynchronous pulsed interference environment are given in Appendix B. It is shown in Appendix B that a peak INR of 5 dB will preclude performance degradation to the LSR.

SECTION 4

FREQUENCY ASSIGNMENT PROCEDURE

INTRODUCTION

This section contains an outline of the approach used to assess the feasibility of deploying the LSRs in the 2.7 to 2.9 GHz band in the Los Angeles and San Francisco areas. A discussion of the procedure used to determine possible frequencies at which the LSR can operate without performance degradation to the radars presently in the environment or the LSRs is given. Also contained in this section is a brief discussion of the analytical models (antenna pattern characteristics, Off-Frequency-Rejection (OFR) and propagation loss) and system parameter values used in establishing possible operating frequencies for the LSRs.

FREQUENCY SEPARATION

The first step in establishing possible operating frequencies for the LSR deployment is to determine the required frequency separation which will assure electromagnetic compatible operations between proposed LSR sites and existing radars in the environment. Because of the characteristics of the LSR system and existing radars in the environment, it was only necessary to calculate the required frequency separation in one direction to assure mutually compatible operations. That is, it was only necessary to calculate the required frequency separation based on potential interference to the LSR receiver because:

1. The peak transmitter output power of the LSR is 6 to 17 dB lower than existing radars in the band.
2. The mainbeam antenna gain of the LSR is 2.8 to 9.8 dB less than existing radars in the band.
3. The emission spectrum bandwidth of the LSR is in most cases narrower than other radars in the band because the LSR transmitted pulse width (2.0µs) is generally wider than other radars in the band. Only height-finding radars and weather radars have a wider transmitter pulse width than the LSR.
4. The TWT transmitter output tube of the LSR has a sharper emission spectrum skirt fall-off than radars with magnetron transmitter output tubes.

The required frequency separation between proposed LSRs and existing radars in the environment was determined using the following calculation:

$$\mathrm{OFR} = P_t + G_t + G_r - \mathrm{OTR} - L_p - I_1 - \mathrm{INR} - N \qquad (4\text{-}1)$$

where:

OFR = The required off-frequency-rejection between the LSR receiver and the potential interfering radar, in dB (OFR > 0)

P_t = The peak transmitter power of the potential interfering radar, in dBm

G_t = The nominal mainbeam gain of the potential interfering radar minus correction for antenna tilt angle (mainbeam gain -5 to -12 dB), in dBi

G_r = LSR antenna median backlobe level, -12 dBi

OTR = The on-tune rejection of the interfering signal due to the LSR receiver bandwidth being narrower than the interfering signal emission bandwidth, (OTR = 20 log $B\tau$) in dB (B = LSR IF bandwidth, and τ = interfering pulse width)

L_p = Median propagation path loss between LSR and potential interfering radar, in dB

I_1 = Waveguide and coupler insertion losses of both LSR and potential interfering radars. A 2 dB insertion loss was used at both ends (Offi and Herget, 1968).

INR = Maximum allowable peak Interference-to-Noise Ratio at the LSR receiver input to preclude LSR performance degradation, 5 dB (See Appendix B)

N = LSR receiver inherent noise level referred to the RF input, (N = -114 + 10 log B(MHz)+ NF) = -111 dBm)

Using the fixed parameter values discussed above, Equation 4-1 can be expressed as:

$$OFR = P_t + G_t - OTR - L_p + 90 \qquad (4\text{-}2)$$

Equation 4-2 was used to calculate the Off-Frequency-Rejection (OFR) except in some cases of mainbeam coupling from height-finding radars. Generally height-finding radar mainbeam antenna coupling to aeronautical radionavigation radars does not occur periodically because the antenna on height-finding radars does not rotate 360 degrees at a constant RPM rate. However, height-finding radar mainbeam coupling to aeronautical radars does occur occasionally. Because of the high power and antenna gain of height-finding radars, in some cases it is difficult to preclude performance degradation from height-finding radars without denying an LSR a large percentage of the 2.7 to 2.9 GHz band. Therefore, in some cases antenna coupling of the LSR mainbeam to the height-finding radar backlobe was used. For this situation, an LSR mainbeam antenna gain (G_r) of 22.2 dBi (29.2 dBi -7 dB for tilt angle) and a height-finding backlobe antenna gain (G_t) of -13 dBi was used.

Once the required OFR was calculated, the required frequency separation between the LSR operating frequency and the operating frequency of the potential interfering radar was determinded using an analytical OFR model (CCIR Report 654). After the required frequency separation between the LSR and radars presently in the environment was determined, appropriate operating frequencies for the LSR to operate were indicated in a bar graph along with the percentage of the 2.7 to 2.9 GHz band available for LSR operation.

ANALYTICAL MODELS

The following is a brief discussion of the analytical models (antenna pattern characteristics, Off-Frequency-Rejection (OFR) and propagation loss) used in establishing possible operating frequencies for the LSR.

Antenna Patterns

A three level antenna pattern statistical model for an average clutter area was used to determine operating frequencies for the LSR in the Los Angeles and San Francisco areas. The statistical antenna characteristics were obtained by measuring antenna patterns of radars in the 2.7 to 2.9 GHz band using the NTIA Radio Spectrum Measurement System (RSMS) van (Hinkle, Pratt and Matheson, 1976). The statistical median antenna gain, standard deviation (σ) and degrees for each of these regions are:

Mainbeam Region: Gain: Nominal mainbeam gain minus correction for antenna tilt angle

Degrees: 357° to 3°

Sidelobe Region: Gain: -7 dBi, σ = 3 dB

Degrees: 3° to 25° and 335° to 357°

Backlobe Region: Gain: -13 dBi, σ = 3dB

Degrees: 25° to 335°

Surveillance radars with cosecant squared elevation antenna patterns normally tilt the mainbeam of the radar above the horizon to reduce ground clutter, therefore, the antenna gain at an elevation angle of zero degrees may be typically 5 to 12 dB below the actual mainbeam gain. For example, the FAA Airport Surveillance Radars (ASRs) have a nominal mainbeam gain of 34 dBi, and a typical antenna tilt angle of 3.0 to 3.5 degrees. The antenna gain along the horizon for an antenna tilt angle of 3.0 to 3.5 degrees is approximately seven dB down from the nominal mainbeam gain. Thus, the mainbeam antenna gain along the horizon for ASRs is typically 27 dBi.

The mutual antenna gain coupling considered for this investigation was mainbeam-to-backlobe. Mainbeam-to-mainbeam antenna gain coupling may occur in the environment. However, the percentage of time mainbeam-to-mainbeam coupling may occur is less than .01 percent. Because the present radars in the environment have a mainbeam gain of 2.8 to 9.8 dB greater than the proposed LSR antenna, the mainbeam of the radars in the environment (interfering radars) to the LSR median backlobe level of -12 dBi was used. The LSR median backlobe level of -12 dBi was based on a measured median backlobe level of -13 dB for the larger ASR antennas. For example, the mutual antenna gain coupling for mainbeam of an ASR to the backlobe of the LSR would be +15 dBi (+ 27 dBi - 12 dBi). The probability of the coupled mutual antenna gain exceeding + 15 dBi is approximately 1.3 percent (Hinkle, Pratt, Matheson, 1976). This is a conservative mutual antenna gain coupling criteria since it implies that only 1.3% of the time the interfering signal level will exceed the INR = 5 dB performance criterion.

Off-Frequency-Rejection

The Off-Frequency Rejection (OFR) model accounts for the energy coupling loss of an undesired signal in a victim receiver due to the frequency separation between the interfering radar transmitter operating frequency and the victim radar receiver tuned frequency. Therefore, the OFR model is a necessary component in predicting the level of interference at a radar receiver IF output. The factors which affect the OFR of a victim receiver are the victim receiver IF selectivity, interfering signal emission spectrum characteristics and the frequency separation between the interfering and victim radars.

Appendix A contains a detailed discussion of the OFR model, LSR receiver IF selectivity and the emission spectrum characteristics used to represent radars in the 2.7 to 2.9 GHz band. An analytical model (Newhouse, 1969) was used to obtain the emission spectrum characteristics of radars using conventional magnetron transmitter output tubes. Measurements made with the RSMS van were used to validate the conventional magnetron emission spectrum model (Hinkle, Pratt, Matheson, 1976). The RSMS van was also used to measure emission spectrum characteristics of new radars in the 2.7 to 2.9 GHz band which use diplex filtered conventional magnetrons, coaxial magnetrons and klystron transmitter output tubes.

A compendium of OFR curves used to determine the feasibiliy of deploying the LSR in the 2.7 to 2.9 GHz band in the Los Angeles and San Francisco areas are also contained in Appendix A.

Propagation

The prediction of the propagation path loss between the potential interfering transmitter radar sites and the proposed LSR sites was obtained using the Terrain Integrated Rough Earth Model (TIREM) (Weissberger and Baker, 1978). The TIREM propagation model is a batch program normally used to compute basic propagation loss when the specific coordinates of antenna locations are known. The program automatically addresses a terrain data base, extracts the terrain profile along the great circle path, computes geometric terrain parameters, and selects the lowest loss propagation mode for calculation of the basic propagation loss. Previous propagation loss measurements (Hinkle, Pratt, Matheson, 1976) made in the 2.7 to 2.9 GHz band in the Los Angeles and San Francisco areas indicated that the TIREM propagation model and terrain data base did not consider all environmental factors that affect propagation loss. Environmental factors which must be considered in propagation loss predictions include: ducting, man-made clutter, foliage and terrain multipath. The following is a discussion of these environmental factors, and how they were taken into account in predicting the basic propagation loss.

Ducting

Evaporation of moisture from water creates a refractive index gradient at low heights that can refract microwave energy downward to create a "guiding" effect or duct. Propagation of electromagnetic waves in such a duct can vary from a near lossless situation, to signal enhancement, depending on the frequency and intensity of the evaporation duct. The intensity of the evaporation duct is most often described in terms of "duct height" which is defined as the height at which the modified refractivity is minimized.

Many researchers have investigated the ducting phenomenon in the Southern California area. Bean (1959) noted that during the summer months at San Diego and Oakland that an elevated duct is observed about 50 percent of the time. Rosenthal (1972, 1973) and Crain (1953) States that much of the coastal area of California is usually in a moist marine layer capped by a dry inversion layer. The inversion layer produces ducting conditions throughout the year and is most frequent in the summer months. Meterological parameters were measured by Naval Electronics Labratory Center (NELC) over a five year period, for all seasons and times of the day, in the off-shore San Diego area. These studies indicated that radar range enhancement occurs 30% of the time. Bean and Cahoon (1959) report rapid horizontal changes in refractive index associated with land-sea breezes, storms and frontal passages. Other researchers have noted large diurnal variations due to land-sea breeze circulation. In the Los Angeles area, Neiburger (1944) noted that the inversion layer undergoes significant diurnal changes in elevation. Edlinger (1959) also reported rapid changes in the marine layer with time of day.

Chang (1971) concludes that when both antennas are above or within the duct, the received field is 10 to 20 dB above free space. When one or both terminals are below the duct, the field is 10 to 25 dB below free space, even at distances up to 1200 km. Oversea paths are more likely to be affected by superrefraction and elevated layers than land paths, and so give greater variation in path loss. This may also apply to low, flat coastal regions in maritime zones such as the Los Angeles and San Diego Basins. Figure 4-1 shows the variation in transmission loss with effective distance for an oversea path in a maritime temperate climate (CCIR Report 238-3).

During measurements made in the Los Angeles and San Francisco areas in 1975 in the 2.7 to 2.9 GHz band (Hinkle, Pratt, Matheson 1976), it was observed that in ducting conditions the measured propagation path loss was intermittently 40 dB less than the predicted propagation loss, and sometimes approached 10 dB less than free space loss. These findings were in agreement with previous investigations and CCIR Report 238-3. Based on these measurement findings, the procedure used in this report to take into account ducting

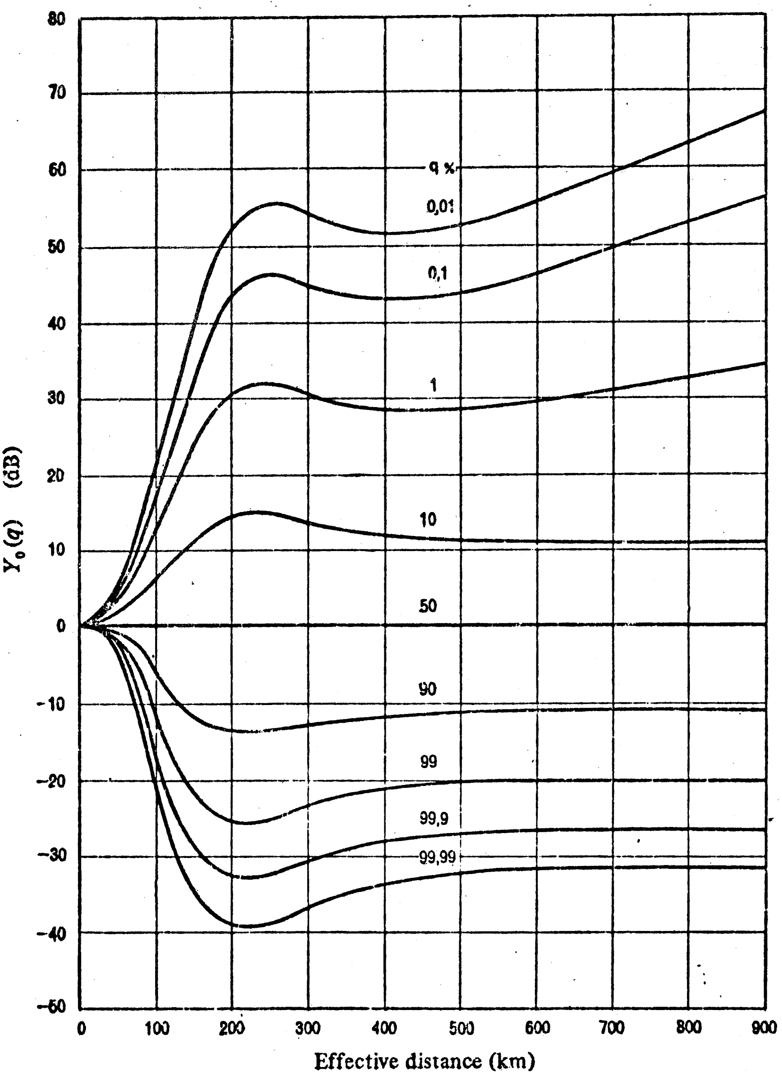

Figure 4-1. Variation of Propagation Loss with Effective Distance for an Oversea Path in a Maritime Temperate Climate

phenomena over potential ducting paths was to reduce the TIREM model predicted loss by as much as 40 dB to account for the potential of ducting propagation, but not to exceed 10 dB below free space. Figure 4-1 shows that a propagation loss of 40 dB less than the median level may occur about 0.2 percent of the time for oversea paths in a maritime temperate climate. Since 0.2 percent of the time corresponds to less than one day a year, the 40 dB correction for potential ducting paths is a conservative correction for ducting conditions.

Man-made Clutter

The propagation path loss through urban and surburban areas is predominately caused by the many multipaths due to signal reflection and diffraction from the man-made obstacles such as buildings. The TIREM propagation prediction model that uses the topographical file only considers the terrain profile in the vertical plane between the two path end points, and consequently does not consider multipath effects due to building reflections and diffractions.

It is believed that the most practical approach is to employ empirical results in selecting a man-made obstacle attenuation factor for addition to the propagation model loss prediction. The result of the propagation loss measured by other investigators for various degrees of built-up areas were summarized in the report by Hinkle, Pratt and Matheson (1976).

Propagation loss measurements for various degrees of building congestion in the San Francisco area were reported by Turin (1972). The environmental description geometry of the test set-up, and measured median loss below free space with standard deviation, are indicated in TABLE 4-1. These measurements were made to support development of a statistical urban propagation model for evaluating mobile radio location performance. The paths described would have been line-of-sight if man-made obstacles were not present. Therefore, it is assumed that the propagation losses below free space shown in TABLE 4-1, can be attributed mostly to attenuation due to buildings. The measurement results shown in the TABLE were made at 1280 MHz but are reported to be very close to values obtained at 2920 MHz.

The results of measurements by Turin were employed in the San Francisco area propagation loss predictions by Hinkle, Pratt and Matheson (1976). It resulted in a 7 dB improvement over the Los Angeles area predictions. The average difference between predicted and measured loss for San Francisco was only -3 dB. Based on these findings, the results by Turin were also used in the LSR deployment investigation in the Los Angeles and San Francisco areas.

Foliage

The propagation loss measurements in man-made clutter environments, referenced in the preceding section, included sparse foliage. Precise propagation loss prediction due to trees is difficult because of variations in tree type, heights, shape, and distribution. In addition, foliage density which changes with seasons of the year also affects attenuation. The report by Hinkle, Pratt and Matheson (1976) summarizes measurements of foliage attenuation. However, for this investigation adjustments to the predicted propagation loss values for foliage attenuation were not taken into account.

TABLE 4-1

PROPAGATION LOSS BELOW FREE SPACE DUE TO VARIOUS URBAN ENVIRONMENTS

ENVIRONMENTAL DESCRIPTION	LOSS BELOW FREE SPACE (dB)
WORST CASE - MODERN METROPOLIS Transmitter on 120 foot high roof, reception area 1 mile away and consisting of densely packed skyscrapers (up to about 50 stories high).	μ = 51 dB σ = 8 dB
DOWNTOWN DISTRIBUTION OF MEDIUM SIZED CITY Transmitter on roof of building located on 1300 foot hill, reception area 5.5 miles away and consisting of clustered sky scrapers up to 40 stories, interspersed with 2-3 story metal frame buildings.	μ = 18 dB σ = 8 dB
DOWNTOWN AREA OF SMALL-TO-MEDIAN SIZED TOWN Transmitter on roof of building located on 1300 foot hill, reception area 1.5 miles away and consisting of a few 10-20 story buildings, many 2-5 story metal frame buildings, and some small 1-2 story wood frame buildings.	μ = 12 dB σ = 7 dB
ENVIRONMENTAL DESCRIPTION PRIVATE-RESIDENCE SUBURBS OF MOST TOWNS AND CITIES Transmitter on roof of building located on 1300 foot hill, reception area 1-1.5 miles away consisting of 1-2 story wood-frame housed, trees, supermarkets, etc.	μ = 12 dB σ = 5 dB

NOTE: (1) The receiver for above measurement was located at street level
(2) μ average of Log Normal distribution
(3) σ standard deviation of Log Normal distribution

Terrain Multipathing

The TIREM point-to-point propagation model considers only the terrain profile in the vertical plane defined by the great circle path between the transmitter and receiver. However, other propagation paths due to off-path reflections and diffraction through mountainous or hilly terrain may result in less loss than the great circle path. Terrain multipath can be categorized into two types:

a. Isolated multipath - multipath signals caused primarily by mountain reflections that arrive from vastly different directions from the direct path.

b. Direct multipath - multipaths that occur at azimuths around the direct path bearings caused primarily by mountain or hill diffraction.

Such multipath reflections were observed during measurements made in the Los Angeles area with the RSMS van. A detailed discussion on terrain multipath and procedures for taking it into account are given by Hinkle, Pratt and Matheson (1976). In general, it was found that the multipath propagation loss was greater than the direct path. Only on one path (Ontario to Los Alamitos) was the measured multipath propagation loss less than the predicted propagation loss. For that path, the measured propagation path loss was 6 dB less than predicted. However, the 6 dB difference was within the variability of the propagation model.

The major affect of multipathing is to cause stretching of the interfering radar pulse width, and additional interfering pulses when the difference in distance between the direct and reflected path exceeds the distance (0.3 km) that a signal can travel in one pulse width. Thus multipath propagation may add to the severity of interference from pulsed radars. For this investigation, no adjustment was made to the predicted propagation loss value for terrain multipath phenomena.

SECTION 5

LOS ANGELES ENVIRONMENT

INTRODUCTION

This section discusses the feasibility of deploying the Limited Surveillance Radar (LSR) at six proposed sites in the Los Angeles area in the 2.7 to 2.9 GHz band. The LSR system characteristics and Interference-to-Noise Ratio (INR) criterion used in the investigation are discussed in Section 3. The procedure used to identify frequencies in the 2.7 to 2.9 GHz band at which the LSR can operate without performance degradation to the radars presently in the environment, or the LSR, is discussed in Section 4.

RADAR ENVIRONMENT OF 2.7 to 2.9 GHz BAND

The present radar environment for the Los Angeles area was determined using information obtained from the Western Region FAA Frequency Manager, and the Government Master File. Comparison was made between these two sources, and differences resolved by contacting the FAA and DoD area frequency coordinators. It was determined that there are a total of 33 radars within the Los Angeles area operating in the 2.7 to 2.9 GHz band. TABLE 5-1 lists the location, nomenclature and function of these radars. Figure 5-1 shows the location of these radars on a Los Angeles area map. The equipment characteristics of the radars are given in TABLE 5-2.

LSR ENVIRONMENT

Six potential Limited Surveillance Radar (LSR) sites have been identified in the Los Angeles area. TABLE 5-3 shows the approximate Latitude/Longitudal locations for the LSR sites, and Figure 5-2 shows the location of the LSR radars in the Los Angeles area.

LSR DEPLOYMENT

The following is a discussion of the feasibility of deploying LSRs at the six proposed sites in the Los Angeles area (see TABLE 5-3 and Figure 5-2) without degrading the performance of existing radars in the environment, or the LSR radars.

Imperial LSR

There is only one potential interfering radar to the Imperial LSR. The Mt. Laguna AN/FPS-90 radar (Radar No. 29) could potentially cause performance degradation to the LSR no matter what frequency it is assigned in the 2.7 to 2.9 GHz band when the height-finding radar is nodding at the Imperial LSR bearing. This is because the Mt. Laguna AN/FPS-90 radar is line-of-sight with the proposed Imperial LSR. For LSR antenna mainbeam coupling to the height-finding radar antenna backlobe, approximately 20 percent of the band can be used for operation of the Imperial LSR. TABLE 5-4 shows the usable frequencies for the LSR operation.

TABLE 5-1

LOCATION OF 2.7-2.9 GHz RADARS IN LOS ANGELES AREA

RADAR No.	CITY/BASE	NOMENCLATURE	LATITUDE			LONGITUDE		
	FAA		Airport Surveillance Radars					
1	Miramar*	ASR-5	32	52	29	117	08	23
2	El Toro	ASR-5	33	39	46	117	42	43
3	Long Beach	ASR-8	33	49	09	118	08	16
4	Palm Springs	ASR-5	33	50	05	116	30	20
5	Los Angeles Int.	ASR-7	33	55	57	118	24	23
6	Los Angeles Int.	ASR-4	33	57	12	118	24	00
7	Ontario	ASR-5	34	03	15	117	35	41
8	Burbank	ASR-6	34	12	15	118	21	14
9	Edwards AFB*	ASR-5	34	52	22	117	54	38
10	Bakersfield	ASR-5	35	26	28	119	03	32
11	Santa Barbara	ASR-4	34	25	26	119	50	29
	FAA/Military		Test Range Surveillance Radars					
12	Velvet Peak	ASR-8	35	03	37	117	00	49
13	Fremont Valley	ASR-8	35	13	30	117	59	16
14	Indian Wells Ky.	ASR-8	35	39	21	117	50	04
15	Searles Valley	ASR-8	35	48	13	117	20	40
	Army		Ground Control Approach Radars					
16	Los Alamitos	CPN-4	33	47	24	118	03	04
	Navy		Ground Control Approach Radars					
17	Imperial Beach	CPN-4	32	33	37	117	07	11
18	North Island	ASR-8	32	42	09	117	12	57
19	San Clemente Is.	CPN-4	33	01	22	118	35	42
	Navy		Missile Range Clearance					
20	San Nicolas Is.	ASR-7	33	14	57	119	31	16
21	Santa Cruz Is.	APS-20	33	59	40	119	37	56
22	Laguna Peak	APS-20	34	06	28	119	03	51
23	Point Mugu	ASR-8	34	07	06	119	07	25
	Air Force		Ground Control Approach					
24	March AFB	TPN-19	33	53	04	117	157	35
25	Norton AFB	MPN-15	34	05	45	117	14	12
26	George AFB	GPN-12	34	35	54	117	23	02
27	Vandenberg AFB	MPN-14	34	43	42	120	34	31

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*Joint FAA Military

TABLE 5-1 (Continued)

RADAR No.	CITY/BASE	NOMENCLATURE	LATITUDE			LONGITUDE		
	Air Force	Tracking Radars						
28	Edwards AFB	MPS-19	34	56	43	117	54	45
	Air Force	Height Finding Radars						
29	Mt. Laguna	FPS-90	32	52	33	116	24	49
30	San Pedro Hill	FPS-90	33	44	48	118	20	09
31	Cambria	FPS-6	35	31	21	121	03	46
32	Paso Robles	FPS-6	35	32	42	120	21	12
	NASA							
33	Goldstone	FPS-18	35	18	09	116	51	15

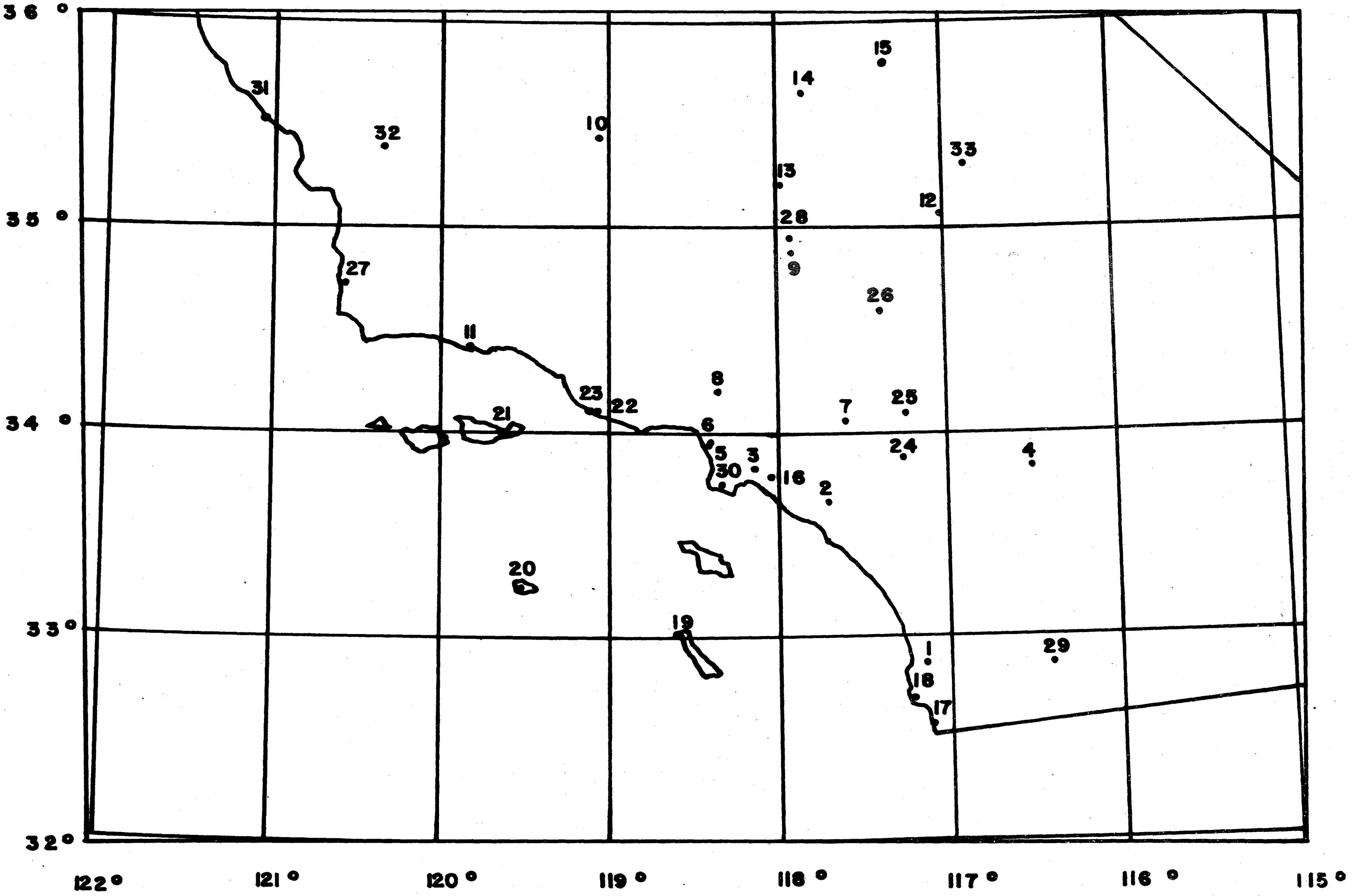


Figure 5-1. Location of Radars in the 2.7-2.9 GHz Band in the Los Angeles Area

TABLE 5-2

CHARACTERISTICS OF 2.7-2.9 GHz RADARS IN LOS ANGELES AREA

RADAR NO.	CITY/BASE	EQUIPMENT NOMENCLATURE	ASSIGNED FREQUENCY (MHz)	PEAK POWER (kW)	OUTPUT TUBE TYPE	P.W. (μS)	PRF (PPS)	IF Bw (MHz)	NOISE LEVEL (dBm)	ANTENNA GAIN (dB)	ANTENNA HEIGHT (FT.)	ANTENNA TILT ANGLE (DEGREES)	ANTENNA SCAN RATE (RPM)	SCOPE RANGE (NM)	SITE ELV. (FT.)
1	Miramar	ASR-5	2710 - 2720	400	5586+	0.833	700	2.7,5*	-106	34.0	74		13.0	60	451
2	El Toro	ASR-5	2730 - 2740	600	5586+	0.833	780	2.7,5*	-106	34.0	44	3.5	13.0	60	404
3	Long Beach	ASR-8	2775 2845	1000	VA-87E	0.6		1.1,5*	-110	33.5 32.5	26		12.5	60	31
4	Palm Springs	ASR-5	2770 - 2780	750	5586+	0.833	830	2.7,5*	-106	34.0	55	3.75	13.0	60	436
5	Los Angeles Int.	ASR-4	2750 - 2760	450	5586+	0.833	810	2.7,5*	-106	34.0	26	3.0	13.0	60	116
6	Los Angeles Int.	ASR-7	2705 - 2855	450	DX 276	0.833	852	2.7,5*	-106	34.0	46	3.5	15.0	60	115
7	Ontario	ASR-5	2810 - 2820	600	5586+	0.833	900	2.7,5*	-106	34.0	53	3.5	13.0	60	995
8	Burbank	ASR-6	2785 - 2795	400	5586+	0.833	1125	2.7,5*	-106	34.0	70	3.5	10.0	60	743
9	Edwards AFB	ASR-5	2870 - 2880	400	5586+	0.833	1140	2.7,5*	-106	34.0	26		15.0	60	2350
10	Bakersfield	ASR-5	2760 - 2770	400	5586+	0.833	870	2.7,5*	-106	34.0			13.0	60	
11	Santa Barbara	ASR-4	2865 - 2875	400	5586+	0.833	975	2.7,5*	-106	34.0	26		13.0	60	10
12	Velvet Peak	ASR-8	2700	1000	VA-87E	0.6	1020	1.1,5*	-110	33.5 33.5	26		12.5	60	4430
13	Fremont Valley	ASR-8	2700	1000	VA-87E	0.6	1025	1.1,5*	-110	33.5 33.5	26		12.5	60	2225

* Normal and MTI IF Bw, respectively

\+ FAA ASR radars may use 5586, DX276 or QK1643

TABLE 5-2 CONTINUED

CHARACTERISTICS OF 2.7-2.9 GHz RADARS IN LOS ANGELES AREA

RADAR NO.	CITY/BASE	EQUIPMENT NOMENCLATURE	ASSIGNED FREQUENCY (MHz)	PEAK POWER (kW)	OUTPUT TUBE TYPE	P.W. (μS)	PRF (PPS)	IF Bw (MHz)	NOISE LEVEL (dBm)	ANTENNA GAIN (dB)	ANTENNA HEIGHT (FT.)	ANTENNA TILT ANGLE (DEGREES)	ANTENNA SCAN RATE (RPM)	SCOPE RANGE (NM)	SITE ELV. (FT.)
14	Indian Wells Valley	ASR-8	2705	1000	VA-87E	0.6	1015	1.1,5*	-110	33.5 32.5	26		12.5	60	2450
15	Searles Valley	ASR-8	2710 2805	1000	VA-87E	0.6	1035	1.1,5*	-110	33.5 32.5	26		12.5	60	1692
16	Los Alamitos	AN/CPN-4	2800	600	5586	0.5	1200	2.25	-102	31.0	14	3.0	20.0	30	35
17	Imperial Beach	AN/CPN-4	2780	250	5586	0.5	1500	2.25	-102	31.0	14		20.0	30	12
18	North Island	ASR-8	2755 2825	1250	VA-87E	0.6		1.1,5*	-110	33.5 32.5	26		20.0	30	18
19	San Clemente Island	AN/CPN-4	2800	600	5586	0.5	1500	2.25	-102	31.0	14		20.0	30	168
20	San Nicolas Island	ASR-7	2785	400	DX 276	0.833	1002	2.7,5*	-106	34.0	35			60	500
21	Santa Cruz Island	AN/APS-20	2871	1000	4531	2.0	309	1.0	-111	30.0	35		10.0	200	50
22	Laguna Peak	AN/APS-20	2880	1000	4531	2.0	311	1.0	-111	30.0	30		10.0	200	20
23	Point Mugu	ASR-8	2730 2830	1000	VA-87E	0.6		1.1,5*	-110	33.5 32.5	26		12.5	60	13
24	March AFB	AN/TPN-19	2765 2877	500	8798	1.0	1050	1.0	-111	33.6	20		15.0	60	1507
25	Norton AFB	AN/MPN-15	2795	750	8798	0.7	1100	2.25	-106	32.0	14	4.25	15.0	30	1156
26	George AFB	AN/GPN-12	2800	425	8798	0.833	1200	2.7,5*	-106	34.0	26		15	60	2875

* Normal and MTI Bw respectively.

TABLE 5-2 CONTINUED

CHARACTERISTICS OF 2.7-2.9 GHz RADARS IN LOS ANGELES AREA

RADAR NO.	CITY/BASE	EQUIPMENT NOMENCLATURE	ASSIGNED FREQUENCY (MHz)	PEAK POWER (kW)	OUTPUT TUBE TYPE	P.W. (μS)	PRF (PPS)	IF Bw (MHz)	NOISE LEVEL (dBm)	ANTENNA GAIN (dB)	ANTENNA HEIGHT (FT.)	ANTENNA TILT ANGLE (DEGREES)	ANTENNA SCAN RATE (RPM)	SCOPE RANGE (NM)	SITE ELV. (FT.)
27	Vandenberg AFB	AN/MPN-14	2800	700	5586	0.7	1100	2.25	-106	32.0	14		15.0	30	336
28	Edwards AFB	AN/MPS-19	2800	325	5586	0.8	320	3.0	-105	37	26	N.A.	0-20		2350
29	Mt. Laguna	AN/FPS-90	2840	3700	VSM-1143	2.0	330	0.8	-106	39	40	N.A.	7.5RPM 20-30 CPM	200	6200
30	San Pedro Hill	AN/FPS-90	2895	5000	VSM-1143	2.0	370	0.8	-106	39	50	N.A.	7.5RPM 20-30 CPM	200	1480
31	Cambria	AN/FPS-6	2800	5000	VSM-1143	2.0	328	0.8	-106	39	50	N.A.	7.5RPM 20-30 CPM	200	780
32	Paso Robles	AN/FPS-6	2760	5000	VSM-1143	2.0	280	0.8	-106	39	69	N.A.	7.5RPM 20-30 CPM	200	3665
33	Goldstone	AN/FPS-18	2835	1000		1.0	1200			35	50				3976

* Normal and MTI IF Bw respectively.

TABLE 5-3

PROPOSED LOCATIONS OF LSRs IN LOS ANGELES AREA

RADAR NO.	CITY	LATITUDE	LONGITUDE
34	Imperial	32 50 --	115 34 --
35	Brown	32 34 --	116 59 --
36	Gillespie	32 50 --	116 58 --
37	El Monte	34 50 --	118 02 --
38	Palmdale	34 38 --	118 06 --
39	Santa Maria	34 54 --	120 27 --

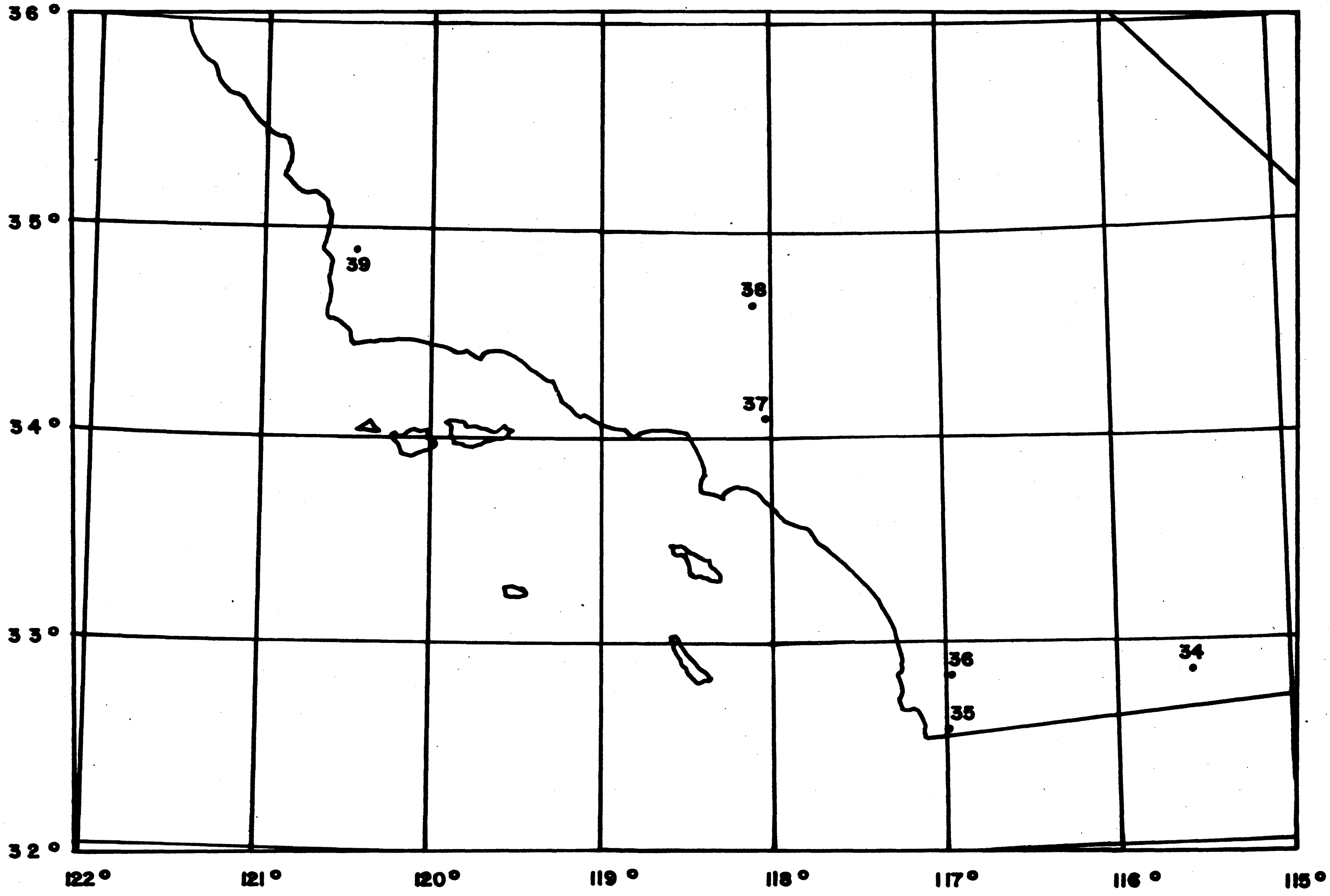


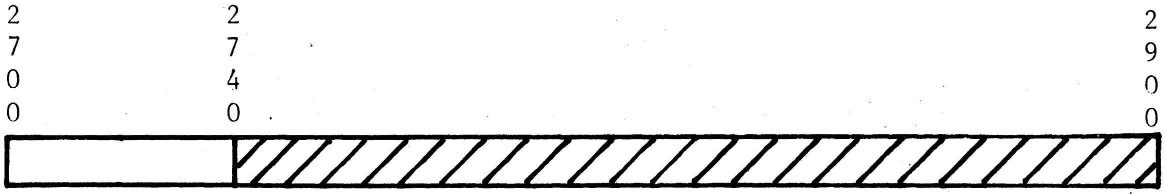
Figure 5-2. Proposed Location of Limited Surveillance Radars (LSRs) in the Los Angeles Area.

TABLE 5-4

IMPERIAL LSR SITE

RADAR NO.	P_t (dBm)	G_t (dBi)	OTR (dB)	L_p (dB)	REQUIRED OFR (dB)	**DENIED FREQUENCY** BAND (MHz)
29	96	-13*	0	139.8	67.4	2740-2900

*Height-finding radar backlobe to LSR mainbeam.



☐ Usable Frequency Band 20%.

Brown LSR

The proposed Brown LSR site is located south of San Diego near the Mexican border. There are 15 radars in the Los Angeles area which could potentially interfere with an LSR located at Brown. TABLE 5-5 lists the potential interfering radars, and the denied frequency band for each of the potential interfering radars. Ten of the potential interfering radars listed in TABLE 5-5 were identified as potential ducting paths, and would only interfere during ducting conditions. The AN/FPS-90 height-finding radar at Mt. Laguna (Radar No. 29) is line-of-sight with the Brown LSR, and could potentially exceed the 5 dB INR performance degradation criteria of the LSR no matter what frequency it is assigned in the 2.7 to 2.9 GHz band when the height-finding radar is nodding at the Brown LSR bearing. Also, the AN/FPS-90 height-finding radar at San Pedro Hill (Radar No. 30) could also cause frequency assignment problems during superrefraction (ducting) conditions in the case where the height-finding radar is nodding at the bearing of the Brown LSR. Therefore, the required frequency separation from the height-finding radars (Radars No. 29 and 30) was based on the height-finding radar antenna backlobe coupling to the LSR antenna mainbeam. When considering all the potential interfering radars, only 7 percent of the 2.7 to 2.9 GHz band can be used for operation of the Brown LSR. TABLE 5-5 shows the usable frequencies for an LSR located at Brown.

Gillespie LSR

There are 13 radars in the Los Angeles area which could potentially interfere with an LSR located at Gillespie. TABLE 5-6 lists the potential interfering radars, and the denied frequency band for each potential interfering radar. Ten of the potential interfering radars listed in Table 5-6 were identified as potential ducting paths, and would only interfere during periods of superrefraction. The AN/FPS-90 height-finding radars at San Pedro Hill (Radar No. 29) could potentially exceed the 5 dB INR performance degradation criteria of the Gillespie LSR during superrefraction conditions no matter what frequency it is assigned in the 2.7 to 2.9 GHz band when the height-finding radar is nodding at the LSR bearing. When considering all the potential interfering radars, 10 percent of the 2.7 to 2.9 GHz band can be used for operation of an LSR at Gillespie for an INR criterion of 5 dB or less. TABLE 5-6 shows the available frequencies for operation of an LSR at Gillespie.

El Monte LSR

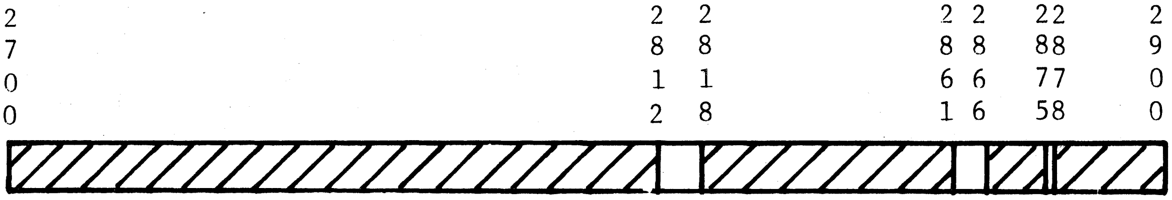
The El Monte LSR site is in the Los Angeles basin. Because of its close proximity to other radars in the basin, and possible ducting conditions from the radars in the basin as well as the radars off the coast, the El Monte LSR site has the potential to receive very high level interfering signals from 13 radars in the Los Angeles area (see TABLE 5-7). Ten of the potential interfering radar propagation paths are either oversea or within the Los Angeles basin where ducting could occur. Also the height-finding radar at San Pedro Hill (Radar No. 30) is line-of-sight to the proposed El Monte LSR site. Line-of-sight coupling from the AN/FPS-90 radar at San Pedro Hill results in extremely high interfering signal levels at the LSR site making it difficult to preclude performance degradation to an LSR located at El Monte if the height-finding radar nods at the LSR site. Even for LSR antenna mainbeam coupling to the height-finding radar antenna backlobe, the required frequency

TABLE 5-5

BROWN LSR SITE

RADAR NO.	P_t (dBm)	G_t (dBi)	OTR (dB)	L_p (dB)	REQUIRED OFR (dB)	DENIED FREQUENCY BAND (MHz)
1	86	27	6.0	169	28	2700-2726
2	88	27	6.0	180*	19	2726-2744
3	90	26.5	8.9	166*	31.6	2768-2782 2838-2842
5	87	27	6.0	167*	31	2736-2767
6	87	27	6.0	163*	35	2700-2711 2849-2861
16	88	24	10.4	161*	30.6	2781-2808
17	84	24	10.4	175	12.6	2777-2783
18	91	26.5	8.9	164	34.6	2748-2762 2818-2832
19	88	24	10.4	154*	37.6	2773-2812
20	86	27	6.0	159*	38	2761-2795
21	90	23	0	177*	26	2866-2875
22	90	23	0	187*	16	2878-2882
23	90	26.5	8.9	173*	24.6	2724-2736 2824-2836
29	96	-13**	0	145	62.2	2821-2849 2773-2805
30	97	-13**	0	155	53.2	2881-2900

*Potential ducting path.
**Height-finding radar backlobe to LSR mainbeam.



☐ Usable Frequency Band 7%.

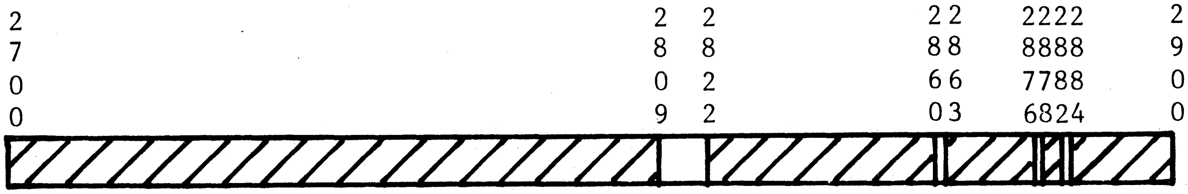
TABLE 5-6

GILLESPIE LSR SITE

RADAR NO.	P_t (dBm)	G_t (dBi)	OTR (dB)	L_p (dB)	REQUIRED OFR (dB)	DENIED FREQUENCY BAND (MHz)
1	86	27	6.0	169	28	2700-2726
3	90	26.5	8.9	165*	32.6	2768-2782 2838-2852
5	87	27	6.0	164*	34	2730-2768
6	87	27	6.0	167*	31	2700-2710 2850-2860
16	88	24	10.4	165*	26.6	2787-2807
18	91	26.5	8.9	186	12.6	2752-2758 2822-2828
19	88	24	10.4	159*	32.6	2779-2809
20	86	27	6.0	173*	24	2779-2790
21	90	23	0	170*	33	2863-2876
22	90	23	0	182*	21	2878-2882
23	90	26.5	8.9	167*	30.6	2723-2737 2823-2837
29	96	39	0	180	45	2830-2844
30	97	-13**	0	161*	47.2	2884-2900

*Potential ducting path.

**Height-finding radar backlobe to LSR mainbeam



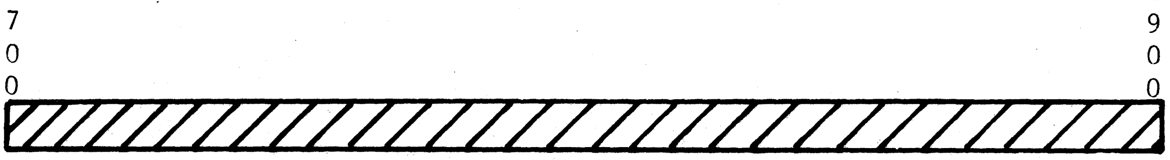
☐ Usable Frequency Band 10%.

TABLE 5-7

EL MONTE LSR SITE

RADAR NO.	P_t (dBm)	G_t (dBi)	OTR (dB)	L_p (dB)	REQUIRED OFR (dB)	DENIED FREQUENCY BAND (MHz)
2	88	27	6.0	178	21.0	2725-2744
3	90	26.5	8.9	148*	49.6	2764-2786 2834-2856
5	87	27	6.0	150*	48.0	2715-2778
6	87	27	6.0	151*	47.0	2700-2716 2844-2866
7	88	27	6.0	160	39.0	2785-2831
8	86	27	6.0	192	5.0	2784-2796
16	88	24	10.4	147*	49.0	2756-2824
19	88	24	10.4	157*	34.6	2775-2811
20	86	27	6.0	160*	37.0	2762-2795
21	90	23	0	164*	39.0	2855-2879
22	90	23	0	180*	23.0	2877-2883
23	90	26.5	8.9	162*	35.6	2723-2737 2823-2837
30	97	-13**	0	148*	60.2	2831-2900

*Potential ducting path
**Height-finding radar backlobe to LSR mainbeam



☐ Usable Frequency Band 0% (See text for possible solution techniques) separation from the height-finding radar denies an LSR deployed at El Monte the use of approximately 35 percent of the 2.7 to 2.9 GHz band.

Using the procedure given in Section 4 for determining the required frequency separation from radars in the environment, there are no available frequency assignments for the El Monte LSR. However, this does not mean that an LSR cannot be deployed at the El Monte airport without performance degradation to the radar system. It may be necessary to use a waveguide filter in one or two of the existing radars, or some type of signal processing technique to suppress interfering signals. (See report by Hinkle, Pratt and Levy (1979) on radar signal processing.) The least expensive way to remedy the frequency assignment problem may be to use a waveguide filter in the Los Angeles ASR-4 radar similar to the waveguide filter used in the AN/GPN-20 radar. With a waveguide filter, the denied frequency band caused by the Los Angeles ASR-4 radar could be reduced from 2715-2778 MHz to 2738-2772 MHz. This would permit the operation of an LSR at El Monte in the 2716 to 2723 MHz band.

Palmdale LSR

The Palmdale LSR site is located North of the San Gabriel Mountain range which isolates the LSR site from the numerous radars in the Los Angeles basin. There are four potential interfering radars in the Los Angeles area which could cause degradation to the performance of an LSR located at Palmdale. TABLE 5-8 lists the potential interfering radars, and the denied frequency band for each of the potential interfering radars. Approximately 22 percent of the band is available for frequency assignment to an LSR located at Palmdale.

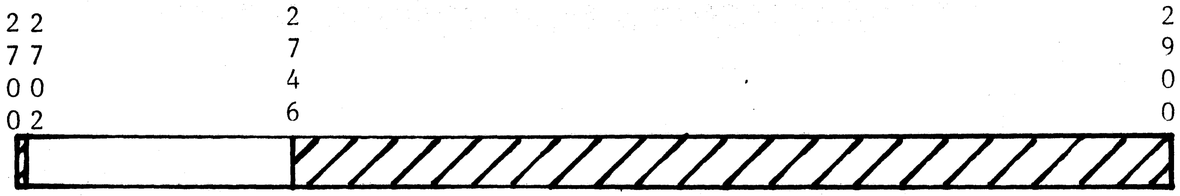
Santa Maria LSR

The Santa Maria LSR site is located between the San Rafael mountain range and the Pacific Ocean in the Santa Maria Valley. The Santa Maria LSR site is isolated from most of the Los Angeles area 2.7 to 2.9 GHz radars. There are only three potential interfering radars which could cause degradation to the performance of an LSR located at Santa Maria (See TABLE 5-9). Approximately 40 percent of the band is available for frequency assignment to an LSR located at Santa Maria.

TABLE 5-8

PALMDALE LSR SITE

RADAR NO.	P_t (dBm)	G_t (dBi)	OTR (dB)	L_p (dB)	REQUIRED OFR (dB)	DENIED FREQUENCY BAND (MHz)
8	86	27	6.0	188	9	2783-2797
9	86	27	6.0	142	55	2822-2900
13	90	26.5	8.9	193	4.6	2700-2702
28	85	30	6.3	141	57.7	2746-2834

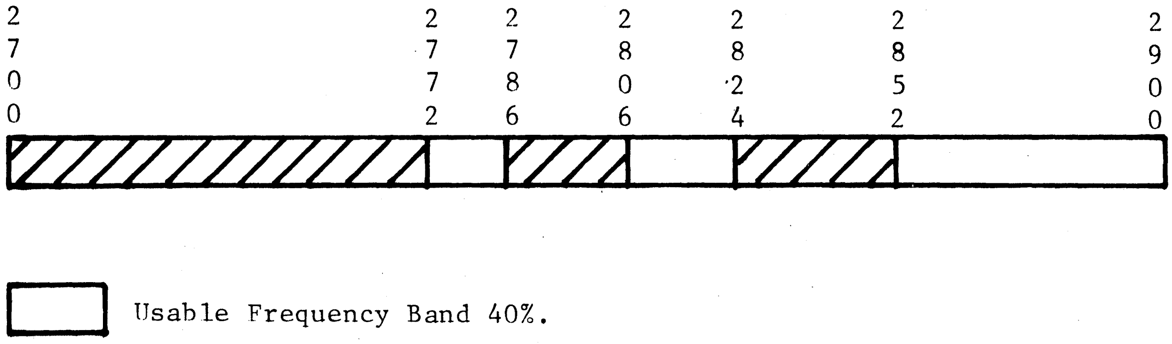


☐ Usable Frequency Band 22%.

TABLE 5-9

SANTA MARIA LSR SITE

RADAR NO.	P_t (dBm)	G_t (dBi)	OTR (dB)	L_p (dB)	REQUIRED OFR (dB)	DENIED FREQUENCY BAND (MHz)
27	88.5	25	7.5	186	10	2798-2802
31	97	39	0	173	53	2786-2806
32	97	39	0	159	67	2700-2772 2824-2852



SECTION 6

SAN FRANCISCO ENVIRONMENT

INTRODUCTION

This section discusses the feasibility of deploying the Limited Surveillance Radar (LSR) at eight proposed sites in the San Francisco area in the 2.7 to 2.9 GHz band. The LSR system characteristics and Interference-to-Noise Ratio (INR) criterion used in the investigation are discussed in Section 3. The procedure used to identify frequencies in the 2.7 to 2.9 GHz band at which the LSR can operate without performance degradation to the radars presently in the environment, or the LSR, is discussed in Section 4.

RADAR ENVIRONMENT OF 2.7 to 2.9 GHz BAND

The present radar environment for the San Francisco area was determined using information obtained from the Western Region FAA Frequency Manager, and the Government Master File. Comparison was made between the two sources, and differences resolved by contacting the FAA and DoD area frequency coordinators. It was determined that there are 23 radars in the San Francisco area operating in the 2.7 to 2.9 GHz band. TABLE 6-1 lists the location, nomenclature, and function of these radars. Figure 6-1 shows the location of these radars on a San Francisco area map. The equipment characteristics of the radars are given in TABLE 6-2.

LSR ENVIRONMENT

Eight potential LSR sites have been identified in the San Francisco area. TABLE 6-3 shows the approximate latitude/longitude locations for the LSR sites, and Figure 6-2 shows the location of the LSR radars in the San Francisco area.

LSR DEPLOYMENT

The following is a discussion of the feasibility of deploying LSRs at the eight proposed sites in the San Francisco area (see TABLE 6-3 and Figure 6-2) without degrading the performance of existing radars in the environment, or the LSR radars.

Merced LSR

The proposed Merced LSR site is located in the San Joaquin Valley. There is only one potential interfering radar to the Merced LSR. The Castle AFB AN/GPN-20 (Radar No. 13) is located approximately 6.7 miles from the proposed Merced LSR site. The Castle AFB radionavigation radar normally operates in the frequency diversity mode at 2715 and 2785 MHz. TABLE 6-4 shows the frequency bands denied by the Castle AFB AN/GPN-20 radar for operation of an LSR at Merced. Approximately 60 percent of the band can be used for operation of the Merced LSR.

TABLE 6-1

LOCATION OF 2.7 - 2.9 GHz RADARS IN SAN FRANCISCO AREA

RADAR No.	CITY/BASE	NOMENCLATURE	LATITUDE			LONGITUDE		
	FAA	Airport Surveillance Radars						
1	Monterey	ASR-8	36	35	16	121	50	09
2	Fresno	ASR-4	36	46	51	119	43	06
3	Mountain View*	ASR-5	37	25	38	122	00	50
4	Oakland	ASR-7	37	42	23	122	13	27
5	Sacramento*	ASR-4	38	39	56	121	24	14
6	Marysville	ASR-5	39	07	49	121	27	35
	FAA/Military	Test Range Surveillance Radars						
7	Panamint Valley	ASR-8	36	02	32	117	17	01
8	Owens Valley	ASR-8	36	37	07	118	01	42
	Navy	Ground Control Approach Radars						
9	Lemoore	ASR-5	36	20	44	119	54	18
10	Alameda	MPN-11	37	47	23	122	19	20
11	Vallejo	MPN-5	38	05	06	122	16	52
	Navy	Tracking Radars						
12	Monterey	APS-20	36	35	52	121	52	25
	Air Force	Ground Control Approach						
13	Castle AFB	GPN-20	37	22	34	120	33	03
14	Hayward ANG	MPN-13	37	40	00	122	07	00
15	Camp Parks	MPN-13	37	42	00	121	54	00
16	Travis AFB	FPN-55	38	16	08	121	54	58
17	Mather AFB	MPN-13	38	33	51	121	17	19
18	Beale AFB	MPN-15	39	08	12	121	26	00
	Air Force	AF Height Finding Radars						
19	Almaden	FPS-90	37	09	38	121	53	47
20	Almaden	MPS-14	37	09	38	121	53	47
21	Mt. Tamalpais	FPS-90	37	55	45	122	35	20
22	Point Arena	FPS-90	38	53	19	123	32	55
	NOAA	Weather Radars						
23	Sacramento	WSR-57	38	35	00	121	29	00

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*Joint FAA/Military

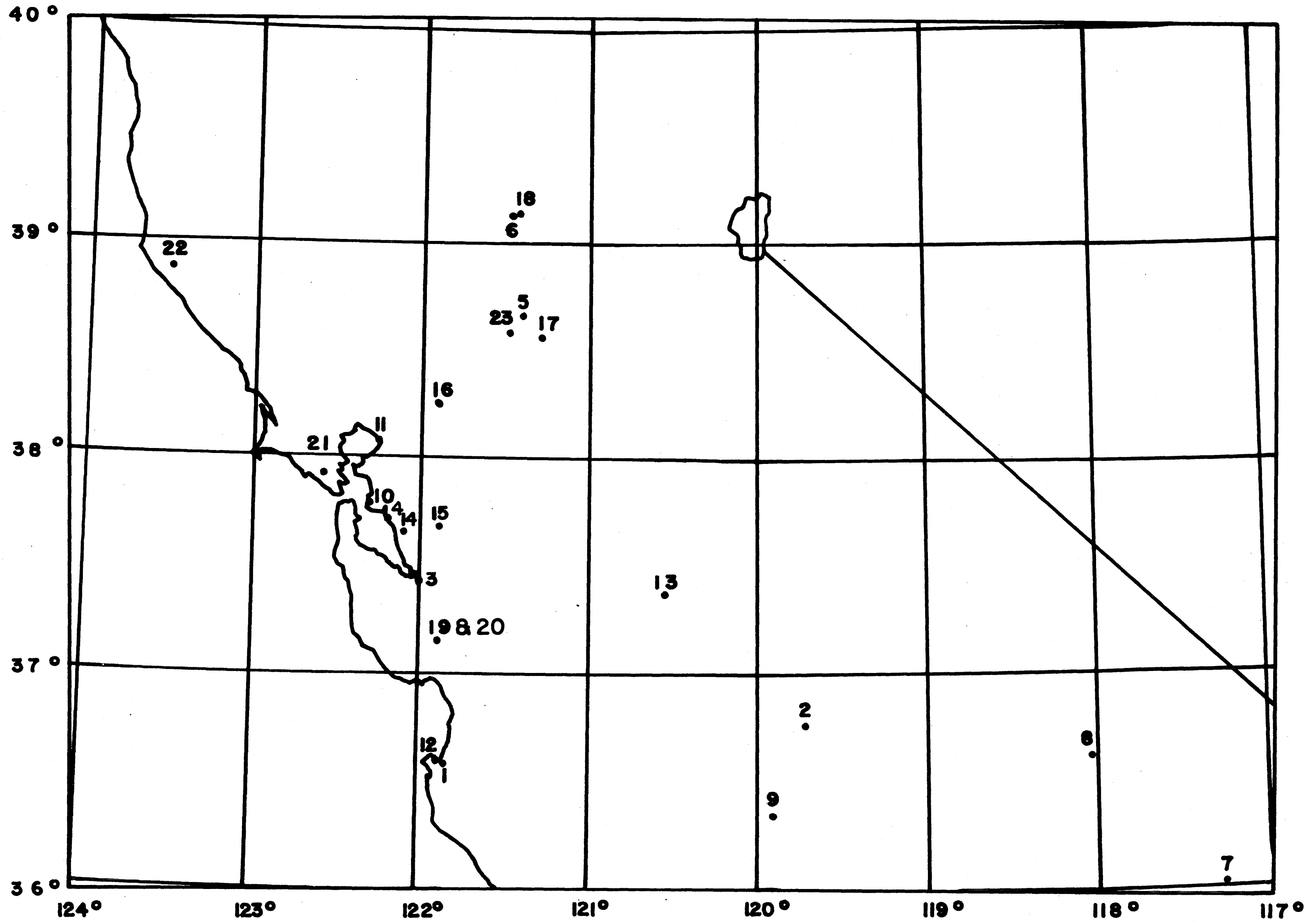


Figure 6-1. Location of Radars in the 2.7-2.9 GHz Band in the San Francisco Area.

TABLE 6-2

CHARACTERISTICS OF 2.7-2.9 GHz RADARS IN SAN FRANCISCO AREA

RADAR NO.	CITY/BASE	EQUIPMENT NOMENCLATURE	ASSIGNED FREQUENCY (MHz)	PEAK POWER (kW)	OUTPUT TUBE TYPE	P.W. (μS)	PRF (PPS)	IF Bw (MHz)	NOISE LEVEL (dBm)	ANTENNA GAIN (dB)	ANTENNA HEIGHT (FT.)	ANTENNA TILT ANGLE (DEGREES)	ANTENNA SCAN RATE (RPM)	SCOPE RANGE (NM)	SIT ELV (FT
1	Monterey	ASR-8	2770 2855	1000	VA-87E	0.6	964	1.1,5*	-110	33.5 32.5	55		12.5	60	253
2	Fresno	ASR-4	2850 - 2860	400	5586+	0.833	840	2.7,5*	-106	34.0	26		13.0	60	332
3	Mountain View	ASR-5	2750 - 2760	500	5586+	0.833	1125	2.7,5*	-106	34.0	26	3.0	13.0	60	9
4	Oakland	ASR-7	2720 - 2730	600	DX276+	0.833	1002	2.7,5	-105	34.0	26	3.0	15.0	60	9
5	Sacramento	ASR-4	2860 - 2870	600	5586+	0.833	810	2.7,5*	-106	34.0	26	3.0	15.0	60	23
6	Marysville	ASR-5	2840 - 2850	600	5586	0.833	830	2.7,5*	-106	34.0	26		13.0	60	113
7	Paramount Valley	ASR-8	2735 2865	1000	VA-87E	0.6	1040	1.1,5*	-110	33.5 32.5	26		12.5	60	1342
8	Owens Valley	ASR-8	2830 2895	1000	VA-87E	0.6	1030	1.1,5*	-110	33.5 32.5	26		12.5	60	3692
9	Lemoore	ASR-5	2800 - 2810	400	VA-87E	0.6	700	1.1,5	-106	33.5 32.5			12.5	60	237
10	Alameda	AN/MPN-11	2800	600	5586	0.5	1500	2.25	-102	33.0	14	3.5	20.0	30	15
11	Vallejo	AN/MPN-5	2800	350		0.8	1200	1.5	-100	33.0	14		15 or 30	50	5
12	Monterey	AN/APS-20	2880	750		2.0	300	1.0	-111	30.0			10	200	46
13	Castle AFB	AN/GPN-20	2715 2785	550	8798	0.833	1040	1.2,5*	-105	33.5 32.5	26		15.0	60	190

* Normal and MTI IF Bw, respectively
\+ FAA ASR radars may use 5586, DX276 or QK1643

TABLE 6-2 CONTINUED

CHARACTERISTICS OF 2.7-2.9 GHz RADARS IN SAN FRANCISCO AREA

RADAR NO.	CITY/BASE	EQUIPMENT NOMENCLATURE	ASSIGNED FREQUENCY (MHz)	PEAK POWER (kW)	OUTPUT TUBE TYPE	P.W. (μS)	PRF (PPS)	IF Bw (MHz)	NOISE LEVEL (dBm)	ANTENNA GAIN (dB)	ANTENNA HEIGHT (FT.)	ANTENNA TILT ANGLE (DEGREES)	ANTENNA SCAN RATE (RPM)	SCOPE RANGE (NM)	SITE ELV. (FT.)
14	Hayward ANG	AN/MPN-13	2800	700	8798	0.7	1100	2.26	-106	32.0	14	3.75	15	30	46
15	Camp Parks	AN/MPN-13	2800	700		0.7	1100	2.26	-106	32.0	14		15	30	
16	Travis AFB	AN/FPN-55	2800	400	8798	0.833	900	2.7,5*	-106	34.0	26	4.25	13	60	68
17	Mather AFB	AN/MPN-13	2800	750	5586	0.7	1100	2.26	-106	32.0	14	5.5	15	30	79
18	Beale AFB	AN/MPN-15	2800	750		0.7	1100	2.26	-106	32.0	14	5.5	15	30	113
19	Almaden	AN/FPS-90	2780	5000	VSM-1143	2.0	278	1.0	-106	39.0	50	N.A	7.5RPM 20-30 CPM	200	3539
20	Almaden	AN/MPS-14	2795	5000	VSM-1143	2.0	278	1.0	-106	39.0	50	N.A	7.5RPM 20-30 CPM	200	3539
21	Mt. Tampalpais	AN/FPS-90	2825	5000	VSM-1143	2.0	356	1.0	-106	39.0	40	N.A	7.5RPM 20-30 CPM	200	2648
22	Point Arena	AN/FPS-90	2795	5000	VSM-1143	2.0	328	1.0	-106	39.0	39	N.A	7.5RPM 20-30 CPM	200	2373
23	Sacramento	WSR-57	2890	500	QK 729	0.5 4.0	545 164	4.5 0.75	-100 -108	36	258	-5to45	0 to 5	250	19

* Normal and MTI IF Bw respectively.

TABLE 6-3

PROPOSED LOCATIONS OF LSRs IN SAN FRANCISCO AREA

RADAR NUMBER	CITY	LATITUDE			LONGITUDE		
24	Merced	37	17	--	120	31	--
25	Modesto	37	38	--	120	57	--
26	Livermore	37	42	--	121	49	--
27	Stockton	37	54	--	121	14	--
28	Concord	37	59	--	122	03	--
29	Napa County	38	13	--	122	17	--
30	Santa Rosa	38	31	--	122	49	--
31	Chico	39	48	--	121	51	--

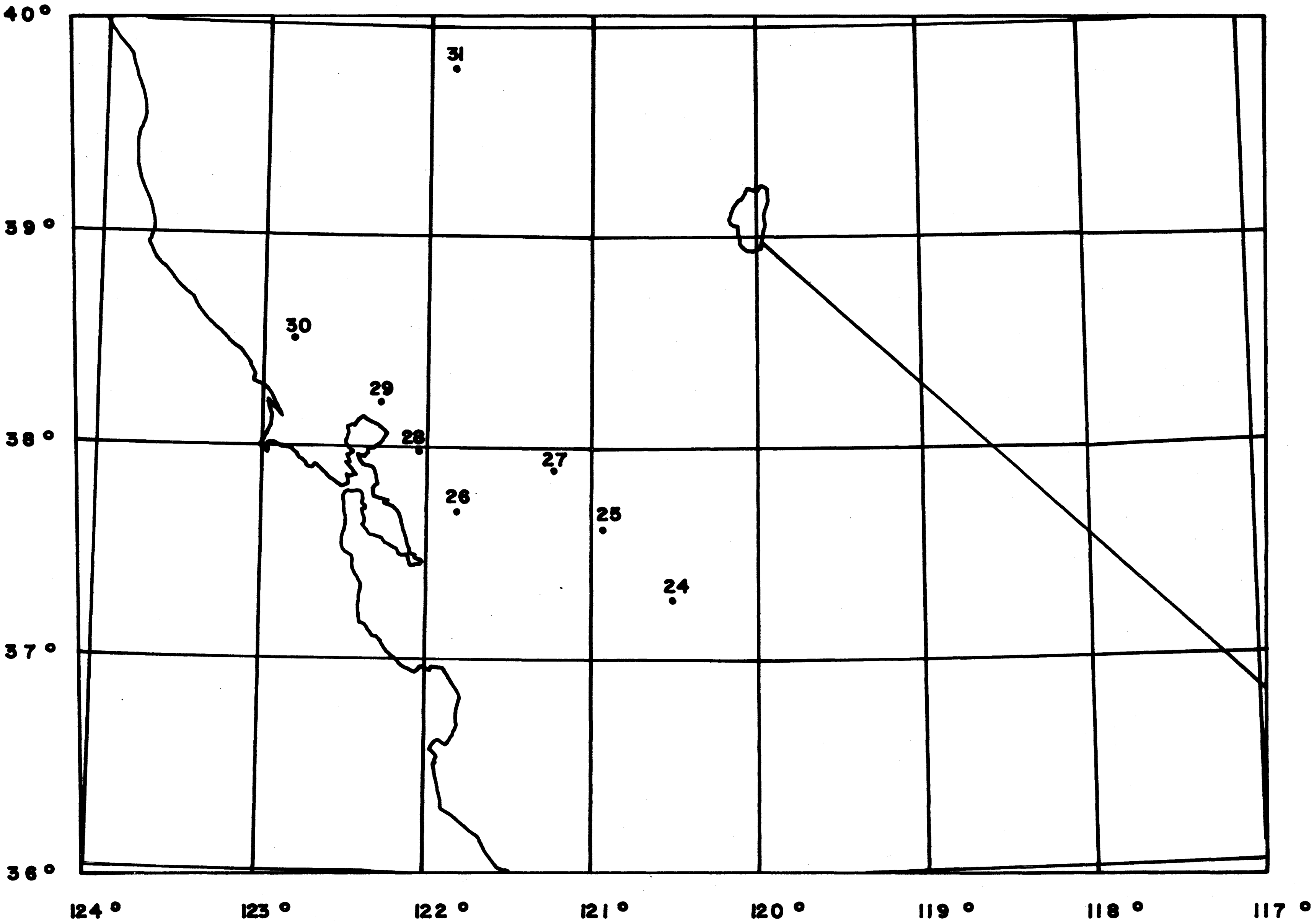
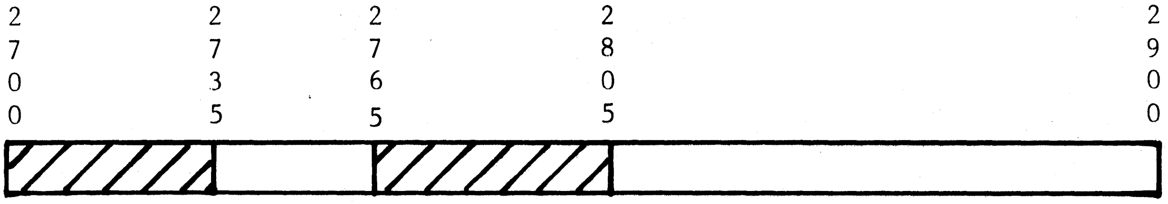


Figure 6-2. Proposed Location of Limited Surveillance Radars (LSRs) in the San Francisco Area.

TABLE 6-4

MERCED LSR SITE

RADAR NO.	P_t (dBm)	G_t (dBi)	OTR (dB)	L_p (dB)	REQUIRED OFR (dB)	DENIED FREQUENCY BAND (MHz)
13	87.4	26.5	6.0	134	63.9	2700-2735 2765-2805



☐ Usable Frequency Band: 60%

Modesto LSR

There are six radars in the San Francisco area which could potentially interfere with an LSR located at Modesto. TABLE 6-5 lists the potential interfering radars, and the denied frequency band of each potential interfering radar. The height-finding radars (Radars Nos. 19 and 20) will only interfere with the LSR when they are nodding at the bearing of the Modesto LSR. TABLE 6-5 shows that approximately 76 percent of the band is available for operation of an LSR at Modesto.

Livermore LSR

The proposed Livermore LSR site is located in the Livermore Valley east of the San Francisco Bay. Livermore Valley has mountain ranges or hills on all four sides. There are eight radars in the San Francisco area which could potentially interfere with an LSR located at Livermore. TABLE 6-6 lists the potential interfering radars, and the denied frequency band for each potential interfering radar. When considering all the potential interfering radars, 26.5 percent of the 2.7 to 2.9 GHz band can be used for operation of an LSR at Livermore.

Stockton LSR

The proposed Stockton LSR is located in the San Joaquin Valley. There are five radars which could potentially interfere with an LSR located at Stockton (see TABLE 6-7). Three of the potential interfering radars are height-finding radars located at Almaden (Radars Nos. 19 and 20) and Mt. Tamalpais (Radar No. 21). The other two potential interfering radars are the Sacramento weather radar (Radar No. 23), and a proposed LSR at Modesto (Radar No. 25). TABLE 6-7 shows the denied frequency band for each of the potential interfering radars. Approximately 81 percent of the band is available for frequency assignment to an LSR located at Stockton.

Concord LSR

Eight radars in the San Francisco area were identified as potential interfering radars if an LSR is located at Concord (see TABLE 6-8). Two of the potential interfering radar propagation paths (Vallejo AN/MPN-5 and Travis AFB AN/FPN-55) were identified as possible ducting paths. Also, the path between the proposed Napa County LSR and the Concord LSR was identified as a possible ducting path. Three height-finding radars (Radar Nos. 19, 20, and 21) could also potentially interfere with an LSR located at Concord. When considering all the potential interfering radars, 40.5 percent of the 2.7 to 2.9 GHz band can be used for operation of an LSR at Concord. TABLE 6-8 shows the available frequencies for operation of an LSR at Concord.

Napa County LSR

The Napa County LSR is located at the North end of the San Francisco/San Pablo Bay. Because the proposed LSR site is located near the North end of the Bay, propagation ducting phenomena, which occurs approximately 50 percent of the time in the Bay area, significantly increases the potential of interference to the proposed Napa County LSR. There are 12 radars in the San Francisco area

TABLE 6-5

MODESTO LSR SITE

RADAR NO.	P_t (dBm)	G_t (dBi)	OTR (dB)	L_p (dB)	REQUIRED OFR (dB)	DENIED FREQUENCY BAND (MHz)
13	87.4	26.5	6.0	159	38.9	2707-2723 2777-2793
19	97	39	0	216	10	2778-2782
20	97	39	0	216	10	2793-2797
21	97	39	0	205	21	2823-2827
24	80	22.5	0	187	5.5	No Assigned Frequency (4MHz)
27	80	22.5	0	186	6.5	No Assigned Frequency (4MHz)

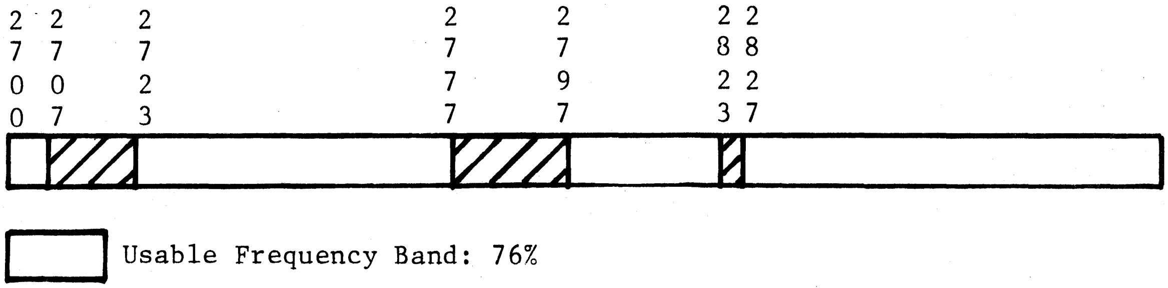


TABLE 6-6

LIVERMORE LSR SITE

RADAR NO.	P_t (dBm)	G_t (dBi)	OTR (dB)	L_p (dB)	REQUIRED OFR (dB)	DENIED FREQUENCY BAND (MHz)
3	87	27	6.0	195	3	2748-2762
4	88	27	6.0	173	26	2712-2735
10	88	26	10.4	171	22.6	2792-2805
14	89	25	7.5	180	16.5	2797-2803
15	89	25	7.5	131	65.5	2723-2859
19	97	39	0	195	31	2776-2782
20	97	39	0	195	31	2791-2797
21	97	39	0	167	59	2807-2833 2761-2786

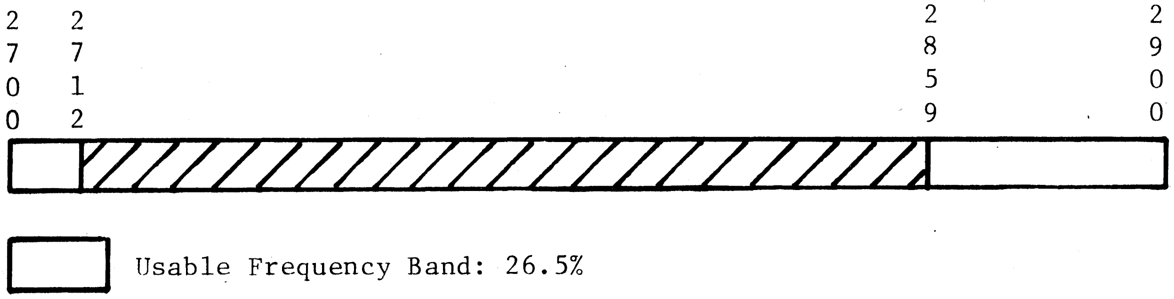
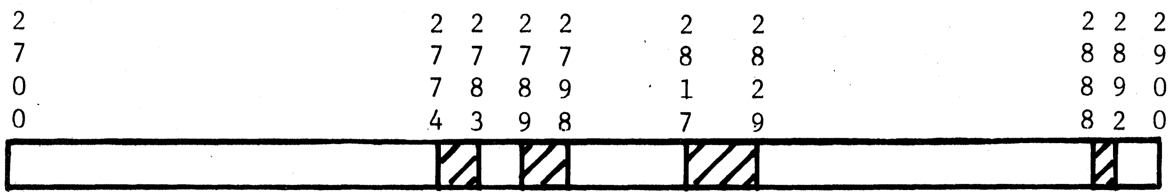


TABLE 6-7

STOCKTON LSR SITE

RADAR NO.	P_t (dBm)	G_t (dBi)	OTR (dB)	L_p (dB)	REQUIRED OFR (dB)	DENIED FREQUENCY BAND (MHz)
19	97	39	0	191	35	2774-2783
20	97	39	0	191	35	2789-2798
21	97	39	0	186	40	2817-2829
23	87	36	0	200	13	2888-2892
25	80	22.5	0	187	5.5	No Assigned Frequency (4 MHz)



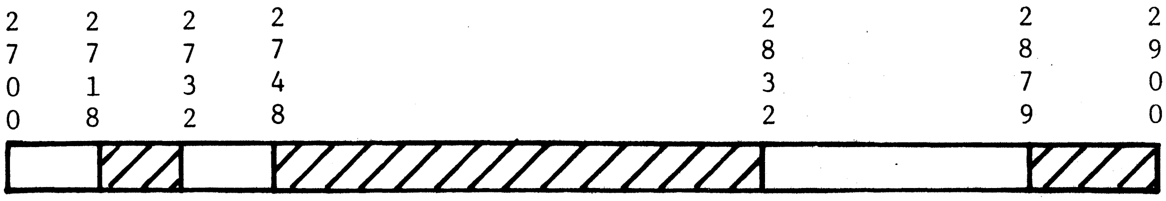
☐ Usable Frequency Band: 31%

TABLE 6-8

CONCORD LSR SITE

RADAR NO.	P_t (dBm)	G_t (dBi)	OTR (dB)	L_p (dB)	REQUIRED OFR (dB)	DENIED FREQUENCY BAND (MHz)
4	88	27	6.0	196	3	2718-2732
11	86	26	6.0	139*	57	2748-2832
16	86	27	6.0	142*	55	2752-2828
19	97	39	0	198	28	2777-2782
20	97	39	0	198	28	2792-2797
21	97	39	0	160	66	2754-2836 2890-2900
23	87	36	0	174	39	2879-2896
29	80	22.5	0	153*	39.5	No Assigned Frequency (12MHz)

*Potential ducting path.



☐ Usable Frequency Band: 40.5%

which could potentially interfere with an LSR located at the Napa County Airport. TABLE 6-9 lists the potential interfering radars, and the denied frequency band for each potential interfering radar. Five of the potential interfering radar propagation paths were identified as potential ducting paths. The Mt. Tamalpais height-finding radar (Radar No. 21) is line-of-sight with the proposed LSR site, and denies the LSR located at Napa County Airport approximately 79.5 percent of the band even for LSR antenna mainbeam coupling to the height-finding radar antenna backlobe.

Using the procedure given in Section 4 for determining the required frequency separation from radars in the environment, there are no available frequency assignments for the Napa County LSR. However, this does not mean that an LSR cannot be deployed at the Napa County Airport without performance degradation to the radar system. A worst case measured height-finding radar emission spectrum (see Appendix A) was used in this analysis. An accurate measurement of the Mt. Tamalpais radar emission spectrum may show that the Mt. Tamalpais radar would not deny deployment of an LSR at the Napa County Airport. Also, if necessary, a waveguide filter could be used in the Mt. Tamalpais radar which would permit deployment of an LSR at the Napa County Airport.

Santa Rosa LSR

There are nine radars in the San Francisco area which could potentially interfere with an LSR located at Santa Rosa. TABLE 6-10 lists the potential interfering radars, and the denied frequency band for each of the potential interfering radars. Six of the potential interfering radar propagation paths were identified as possible ducting paths. Four height-finding radars (Radar Nos. 19 through 22) were identified as posible interfering radars. It is difficult to preclude degradation in the Santa Rosa LSR if the height-finding radars at Almaden and Mt. Tamalpais nod at the bearing of the LSR. When considering all potential interfering radars, 33 percent of the 2.7 to 2.9 GHz band can be used for operation of an LSR at Santa Rosa. TABLE 6-10 shows the available frequencies for operation of an LSR at Santa Rosa.

Chico LSR

There are no radars in the 2.7 to 2.9 GHz band within 50 statute miles of the proposed LSR site at Chico. Therefore, 100 percent of the band is available for frequency assignment of an LSR at Chico.

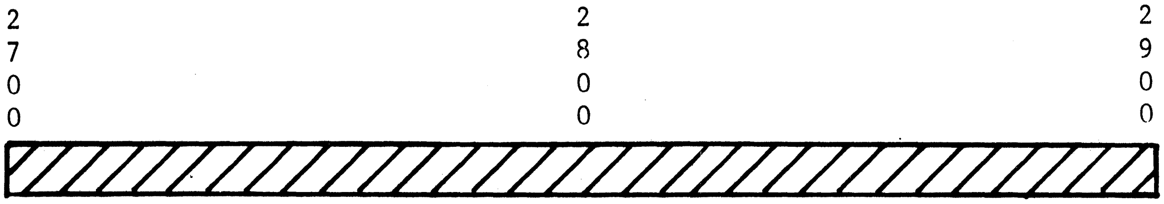
TABLE 6-9

NAPA COUNTY LSR SITE

RADAR NO.	P_t (dBm)	G_t (dBi)	OTR (dB)	L_p (dB)	REQUIRED OFR	DENIED FREQUENCY BAND (MHz)
3	87	27	6.0	162*	36	2728-2769
4	88	27	6.0	146*	53	2700-2754
10	88	26	10.4	145*	48.6	2758-2822
11	86	26	6.0	134*	62	2734-2846
14	89	25	7.5	161*	35.5	2778-2809
15	89	25	7.5	190	6.5	2798-2802
16	86	27	6.0	184	12	2798-2802
19	97	39	0	184	42	2771-2784
20	97	39	0	184	42	2786-2799
21	97	-13**	0	134	74.5	2741-2900
23	87	36	0	208	5	2888-2892
28	80	22.5	0	153	39.5	No Assigned Frequency (12MHz)

*Potential ducting path

**Height-finding radar backlobe to LSR mainbeam



☐ Usable Frequency Band: 0% (See text for possible solution techniques)

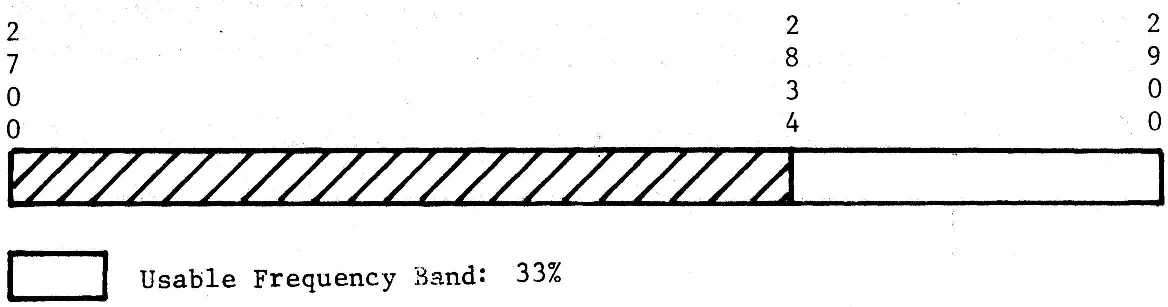
TABLE 6-10

SANTA ROSA LSR SITE

RADAR NO.	P_t (dBm)	G_t (dBi)	OTR (dB)	L_p (dB)	REQUIRED OFR (dB)	DENIED FREQUENCY BAND (MHz)
3	87	27	6.0	157*	41	2724-2772
4	88	27	6.0	152*	47	2700-2747
10	88	26	10.4	152*	41.6	2769-2815
11	86	26	6.0	189	7	2798-2802
14	89	25	7.5	151*	45.5	2769-2815
19	97	-13**	0	151*	57.5	2764-2788
20	97	-13**	0	151*	57.5	2799-2803
21	97	-13**	0	147	61.5	2807-2834 2759-2789
22	97	39	0	200	26	2792-2797

*Potential ducting path.

**Height-finding radar backlobe to LSR mainbeam



APPENDIX A

FREQUENCY-DEPENDENT-REJECTION

INTRODUCTION

The Frequency-Dependent-Rejection (FDR) model accounts for the energy coupling loss of an undesired signal in a victim receiver due to Off-Frequency Rejection (OFR) and On-Tune Rejection (OTR) of the undesired signal, and is therefore a necessary component in predicting radar-to-radar interference levels. The factors which affect the FDR of a victim radar are the victim receiver IF selectivity characteristics, undesired signal emission spectrum, and the frequency separation between the interfering and victim radars. This appendix discusses techniques used to compute the FDR factor. FDR curves used in determining the feasibility of deploying the LSR in the Los Angeles and San Francisco areas are also presented.

IF SELECTIVITY

Since the victim receiver frequency selectivity is the principal means by which the receiver discriminates against undesired signals, it is an important input parameter to the FDR model. Receiver spurious responses must also be considered when determining the FDR of a victim radar to an undesired signal. Spurious responses occur when the undesired signal is at a frequency such that it mixes with the local oscillator to produce an output at the receiver IF frequency. Since most radars have preselector filters, only image responses were investigated. The local oscillator frequency of most radars in the 2.7-2.9 GHz band are tuned to 30 MHz above the receiver RF tuned frequencies in order to obtain an IF frequency of 30 MHz. An RF undesired signal that is 30 MHz above the local oscillator frequency (60 MHz above RF receiver center tuned frequency) will also be down-converted to the 30 MHz IF frequency. Modern radars normally employ an image-rejection mixer or a notch filter at the radar input to suppress image responses. Based on previous radar measurements, the image response of the LSR should be at least 50 dB down. Reduced FDR due to receiver image response was not incorporated in the FDR model, but was considered in an independent FDR calculation.

The selectivity of a receiver is the composite selectivity of all tuned circuitry in the receiver prior to detection; however, in a superheterodyne receiver, the selectivity is determined by the IF stages because the preceding mixer and RF circuits are relatively broader band. This is because the required filter characteristics are more physically realizable and less expensive to build at the lower IF frequency.

LSR IF Selectivity

Since the LSR is in the field evaluation stage, and specifications have not been finalized, the number of IF stages and IF selectivity characteristics are not known. Only the 3 dB IF selectivity bandwidth of the LSR was given on the OT-34 form. The specified 3 dB IF selectivity was 600 kHz. Since most radars in the 2.7-2.9 GHz band have at least five tuned stages, a five-tuned stage IF selectivity model was used with a 600 kHz bandwidth to represent the IF selectivity characteristics of an LSR. Figure A-1 shows the modeled IF selectivity characteristics used in determining the Frequency-Dependent-Rejection (FDR) of an LSR to undesired signals.

EMISSION SPECTRUM

The emission spectrum of a pulse radar is determined by the modulating pulse shape and width, transmitter RF tube, and RF output tube load. The transmission waveguide, rotary couplers, and antennas also affect the emission spectra but to a much less degree. The emission spectrum of radars in the 2.7-2.9 GHz band were categorized according to their pulse width, transmitter RF tube, and whether or not the radar used a waveguide filter. TABLE A-1 shows the categorization of the radars by nomenclature.

The emission spectra of radars in categories 1 through 4 were obtained using a model by Newhouse (1969) which takes into account the frequency shift characteristics of the conventional magnetron. The model was validated by measurements made with the Radio Spectrum Measurement System (RSMS) van. Both modeled and measured emission spectra for the four categories are given in a report by Hinkle, Pratt and Matheson (1976). The modeled emission spectra for categories 1 through 4 are shown in Figures A-2 through A-5 respectively. The emission spectra of radars in categories 5 through 7 were obtained using the RSMS van measurement capability. The measured emission spectra were used in the FDR model for categories 5 through 7. Figures A-6 through A-8 show the measured emission spectra of the radars in categories 5 through 7.

Several emission spectrum measurements of height-finding radars (Category 7) were made using the RSMS van. The height-finding radars (AN/FPS-6, 90) use a coaxial magnetron RF output tube. The undesired mode shown in Figure A-8 on the upper-side of the fundamental frequency was observed on all height-finding radars using a coaxial magnetron. However, the undesired mode shown in figure A-8 on the lower-side was not observed on all the height-finding radar measured emission spectra. These undesirable coaxial magnetron modes are caused by improper rise and fall time of the modulating pulse, and inadequate mode suppression in the coaxial magnetron tube.

Present plans are to use a Traveling-Wave Tube (TWT) RF output tube in the LSRs. A modeled emission spectrum for a trapezoidal pulse shape was used for the LSR. Figure A-9 shows the modeled LSR emission spectrum for a 2.0 μs pulse width and 0.2 μs rise time. The rise time was based on an expected 0.1 pulse width range accuracy (FAA, 1978).

FDR CALCULATIONS

Frequency-Dependent-Rejection (FDR) is the sum of attenuation of the undesired signal due to Off-Frequency-Rejection (OFR) and the On-Tuned-Rejection (OTR) in dB.

$$FDR(dB) = OFR(dB) + OTR(dB)$$

The OTR factor in dB is given by:

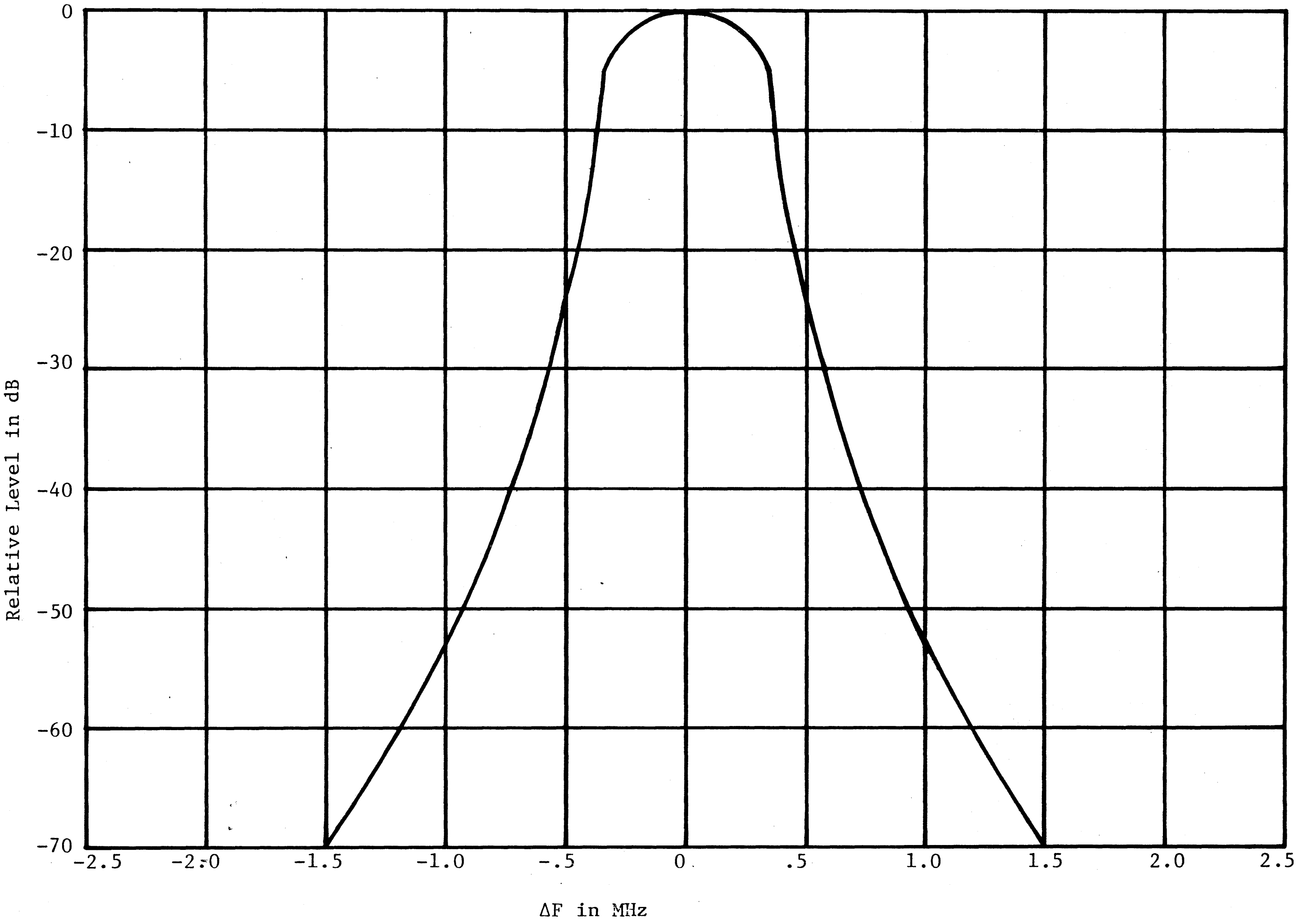


Figure A-1. LSR IF Selectivity

TABLE A-1

Emission Spectrum Categories

Category	Radar Nomenclature	Pulse Width (μs)	Transmitter RF Tube	Waveguide Filter
1	AN/CPN - 4 AN/MPN - 11 AN/FPS - 41* WSR - 54*	.5 .5 .5 .5	Conventional Magnetron	No
2	AN/MPN - 13,14,15 AN/MPN - 5 AN/MPS - 19 AN/FPN - 47,55 AN/GPN - 12 ASR - 4,5,6,7	.7 .8 .8 .833 .833 .833	Conventional Magnetron	No
3	AN/APS - 20 AN/MPS - 14	2.0 2.0	Conventional Magnetron	No
4	AN/FPS - 41* WSR - 57	4.0	Conventional Magnetron	No
5	AN/GPN - 20	.833	Conventional Magnetron	Yes
6	ASR - 8	0.6	Klyston	Yes
7	AN/FPS - 6,90	2.0	Coaxial Magnetron	No

* Weather Radars Which have Two Operational Pulse Widths

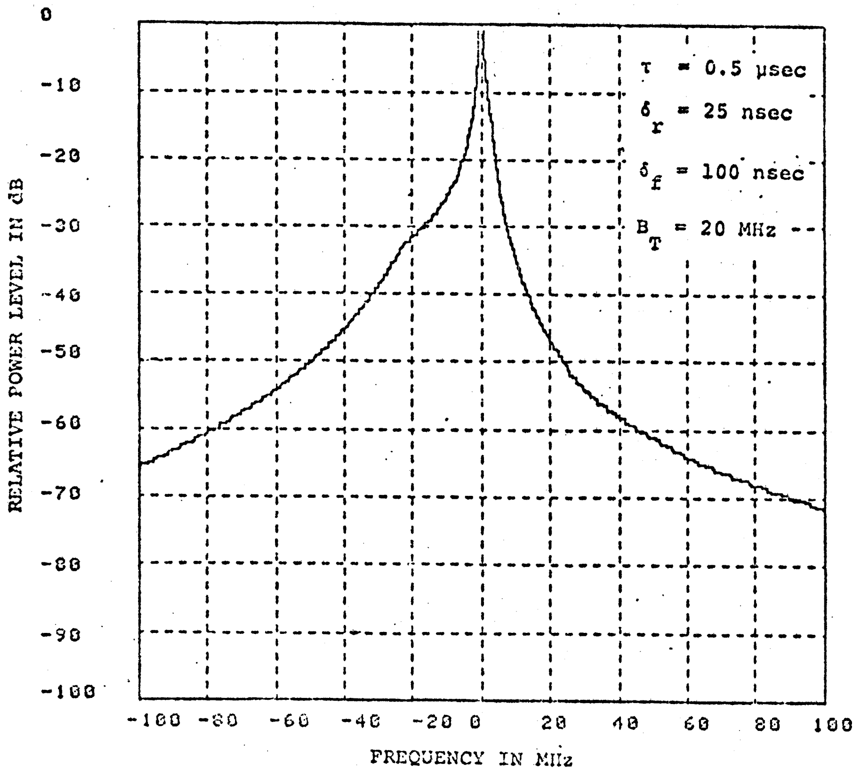


Figure A-2. Modeled Emission Spectrum For Category 1 Radars with Conventional Magnetrons

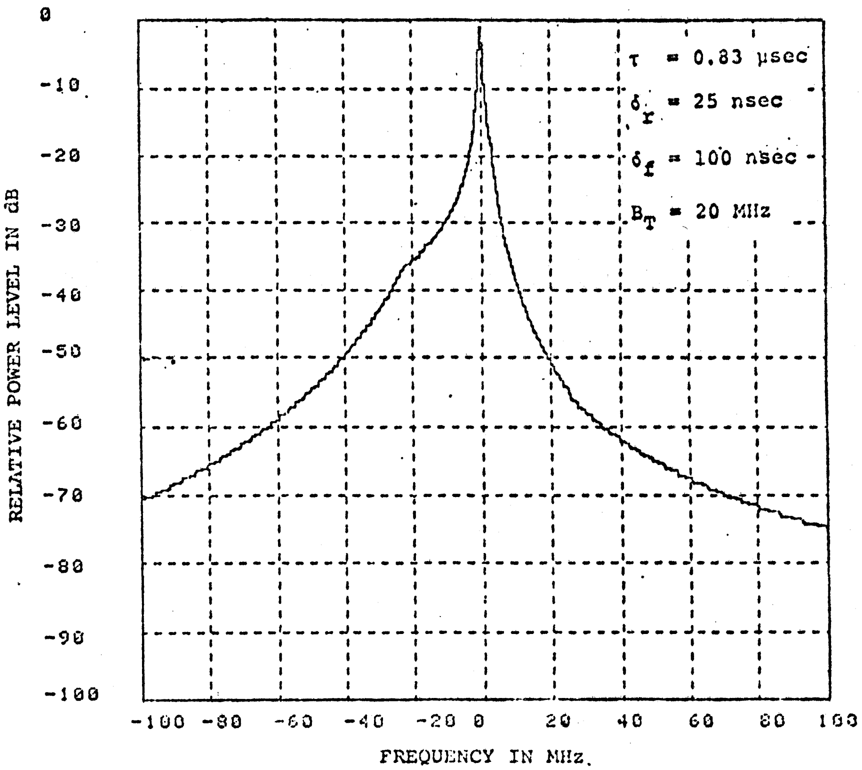


Figure A-3. Modeled Emission Spectrum For Category 2 Radars With Conventional Magnetrons

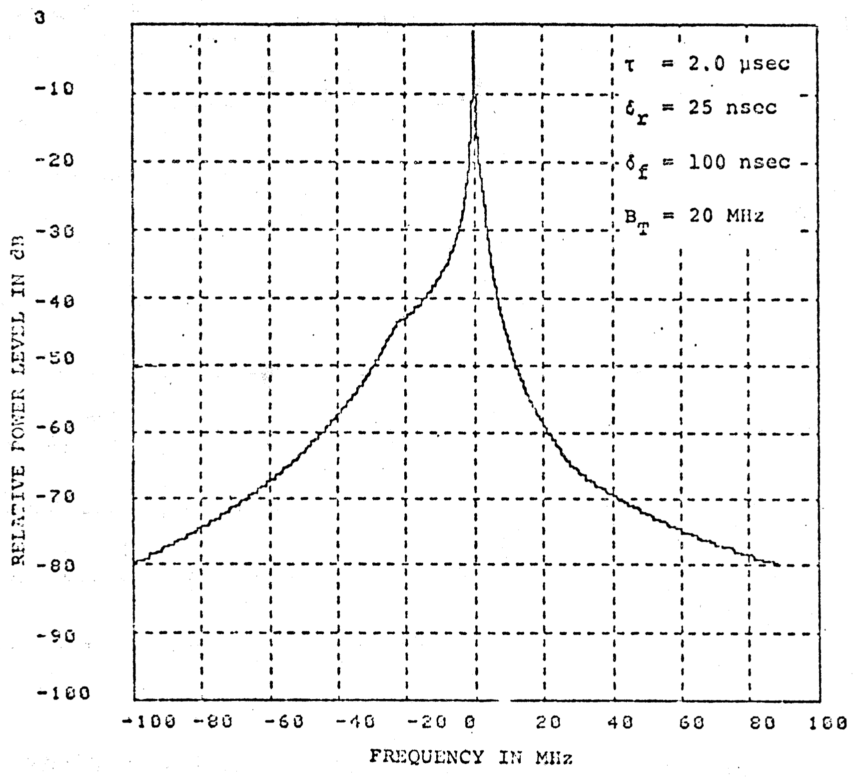


Figure A-4. Modeled Emission Spectrum for Category 3 Radars With Conventional Magnetrons

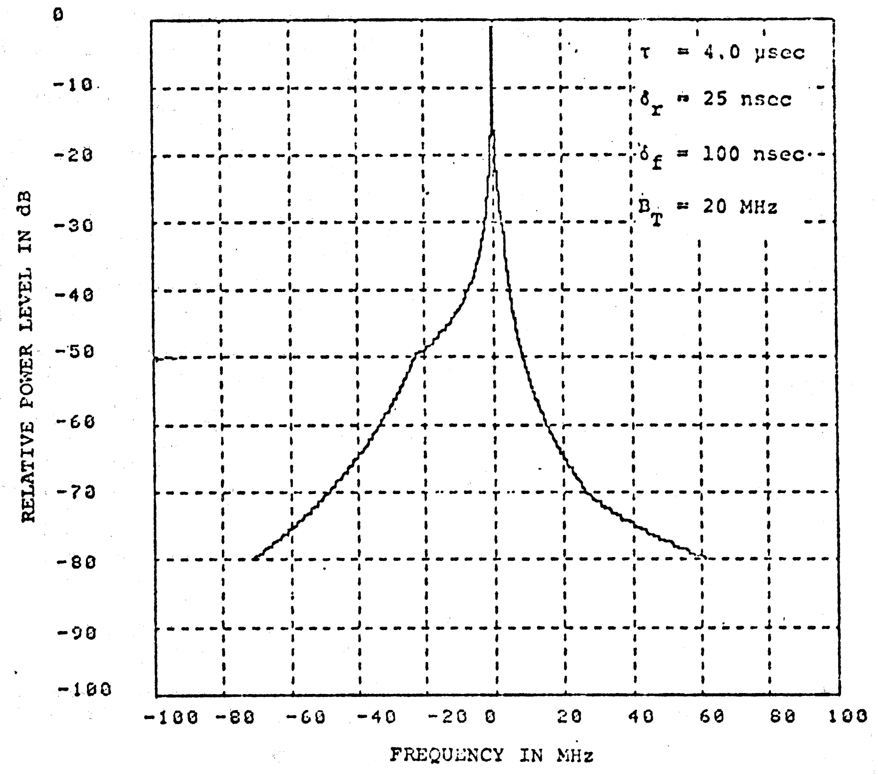


Figure A-5. Modeled Emission Spectrum For Category 4 Radars with Conventional Magnetrons

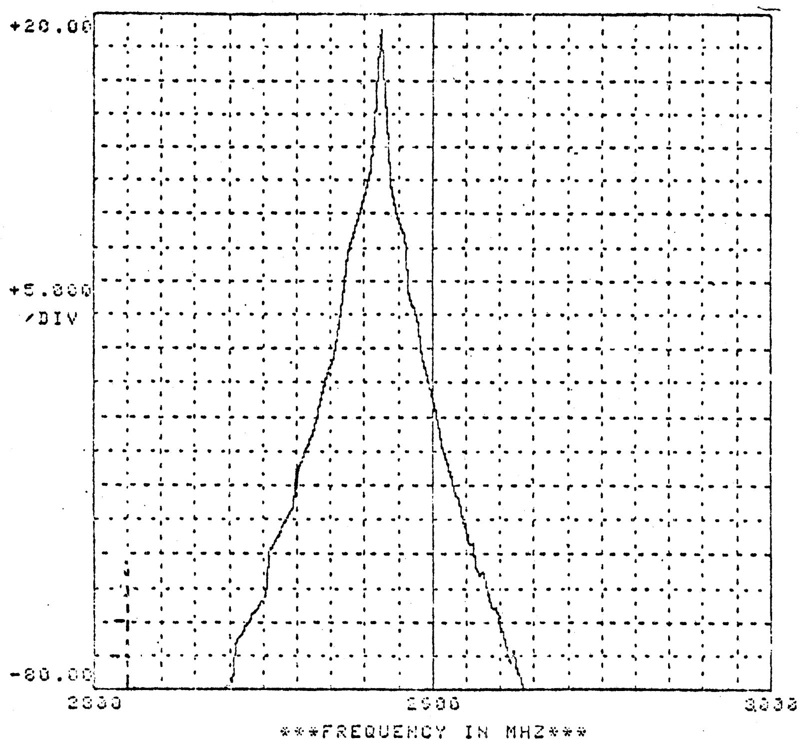


Figure A-6. Measured Emission Spectrum For Category 5 Radars (Conventional Magnetron With Waveguide Filter)

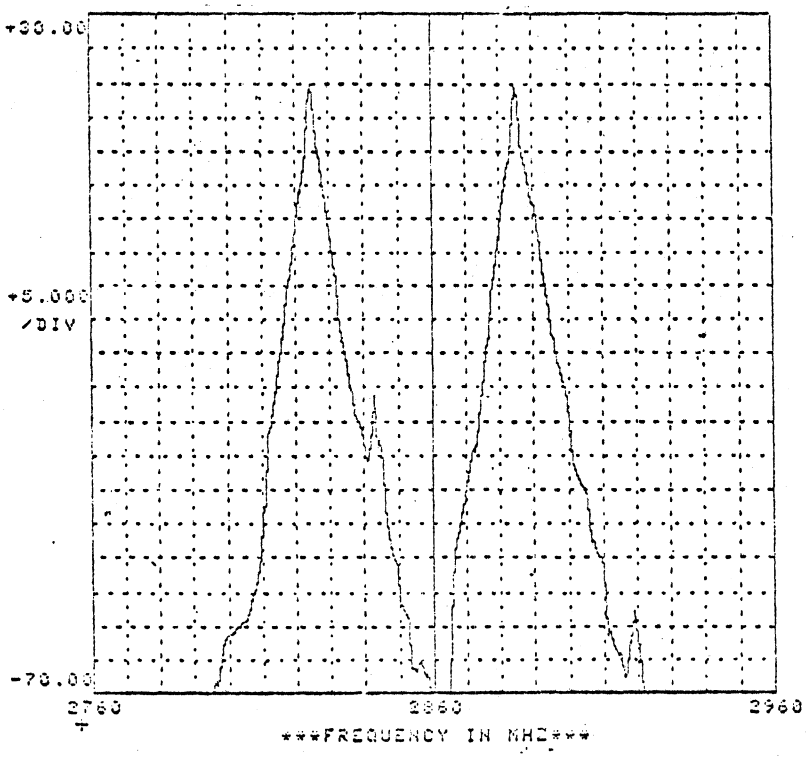


Figure A-7. Measured Emission Spectrum For Category 6 Radars (Klystron)

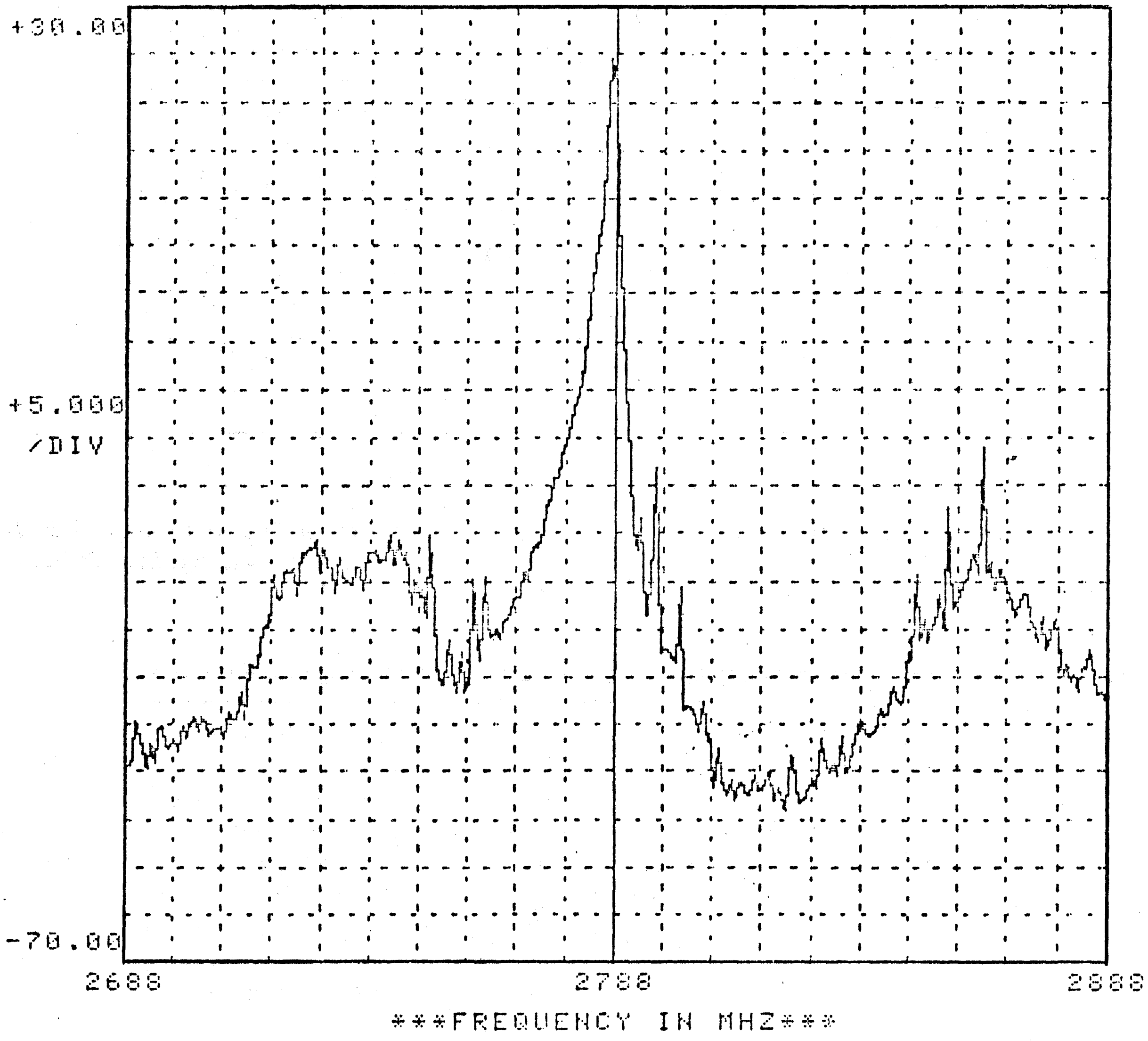


Figure A-8. Measured Emission Spectrum For Category 7 Radars (Coaxial Magnetron)

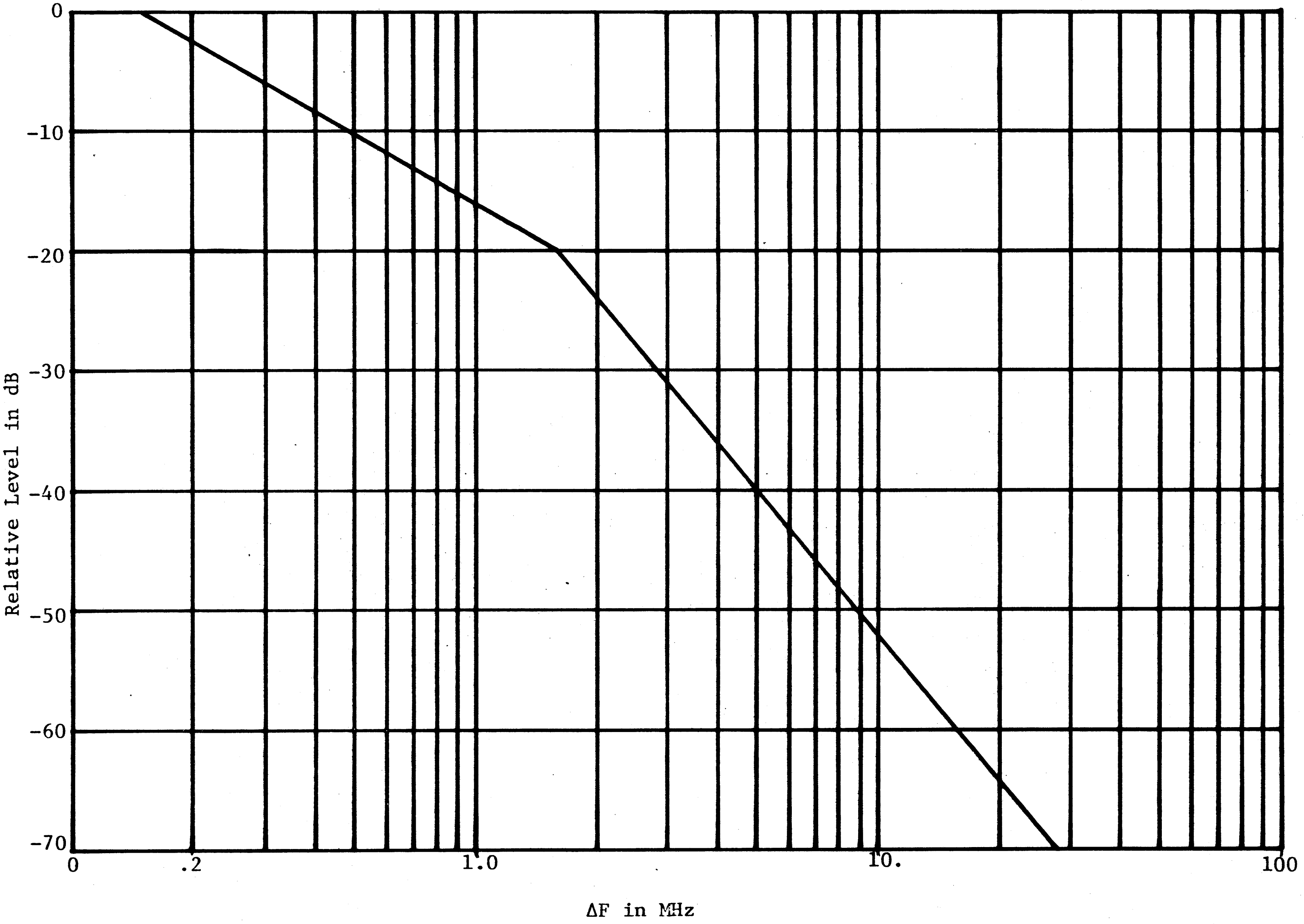


Figure A-9. Modeled LSR Emission Spectrum

$$\mathrm{OTR} = 20 \log_{10} B\tau \qquad \text{for: } B\tau < 1$$

$$= 0 \qquad \text{for: } B\tau > 1$$

where:

B = Receiver 3 dB IF bandwidth, in Hz

τ = Interfering transmitter pulse width, in seconds

A computer program based on CCIR Report 654 was used to obtain the OFR factor. Inputs to the program consisted of amplitude (dB) and frequency data point pairs of the undesired signal emission spectrum and victim receiver IF selectivity curves. The computed OFR curves used for determining the OFR of an LSR to the various categories of radar emission spectrums (See TABLE A-1) are shown in Figures A-10 through A-17.

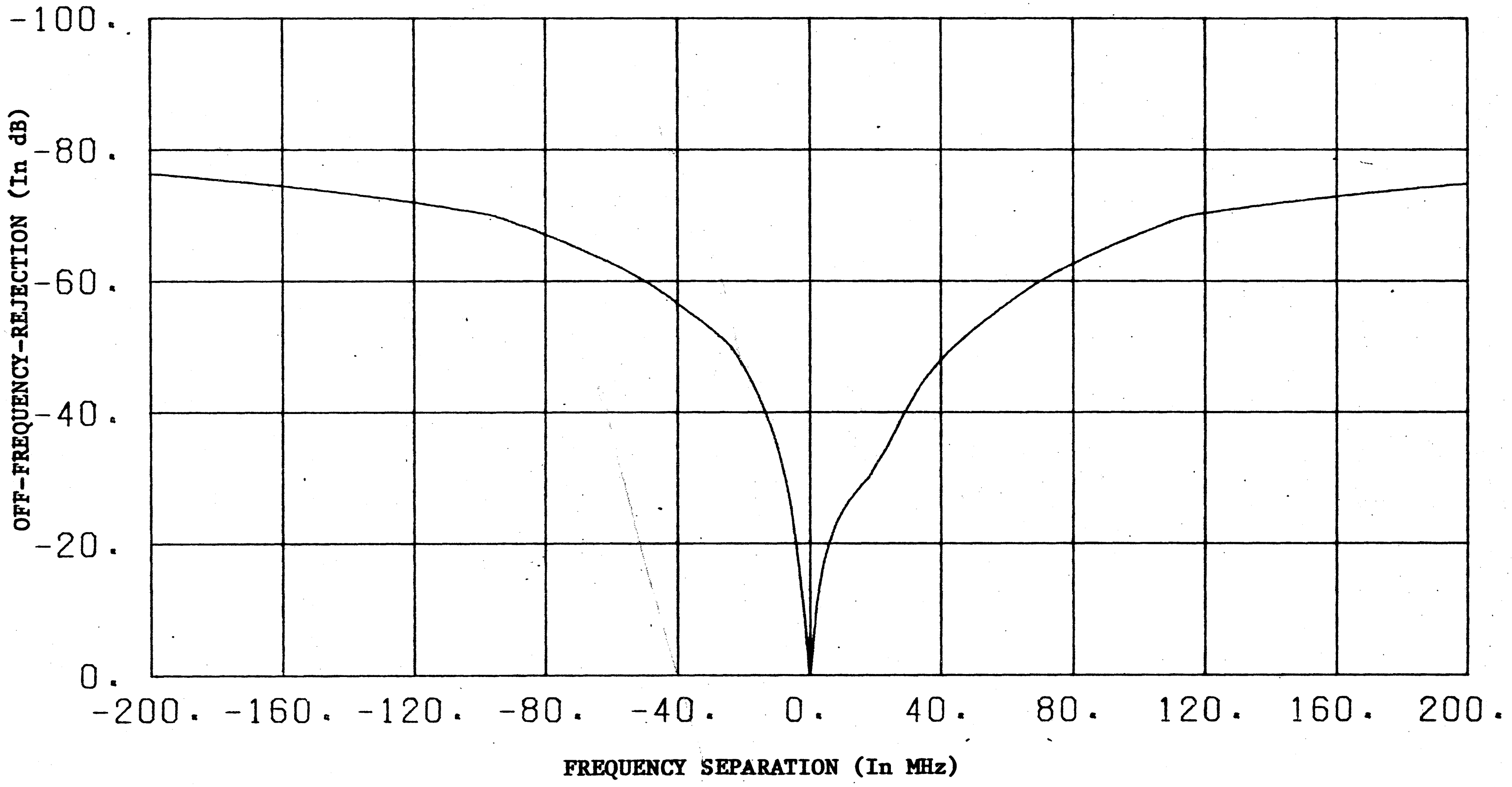


Figure A-10. LSR Off-Frequency-Rejection to Category 1 Radars

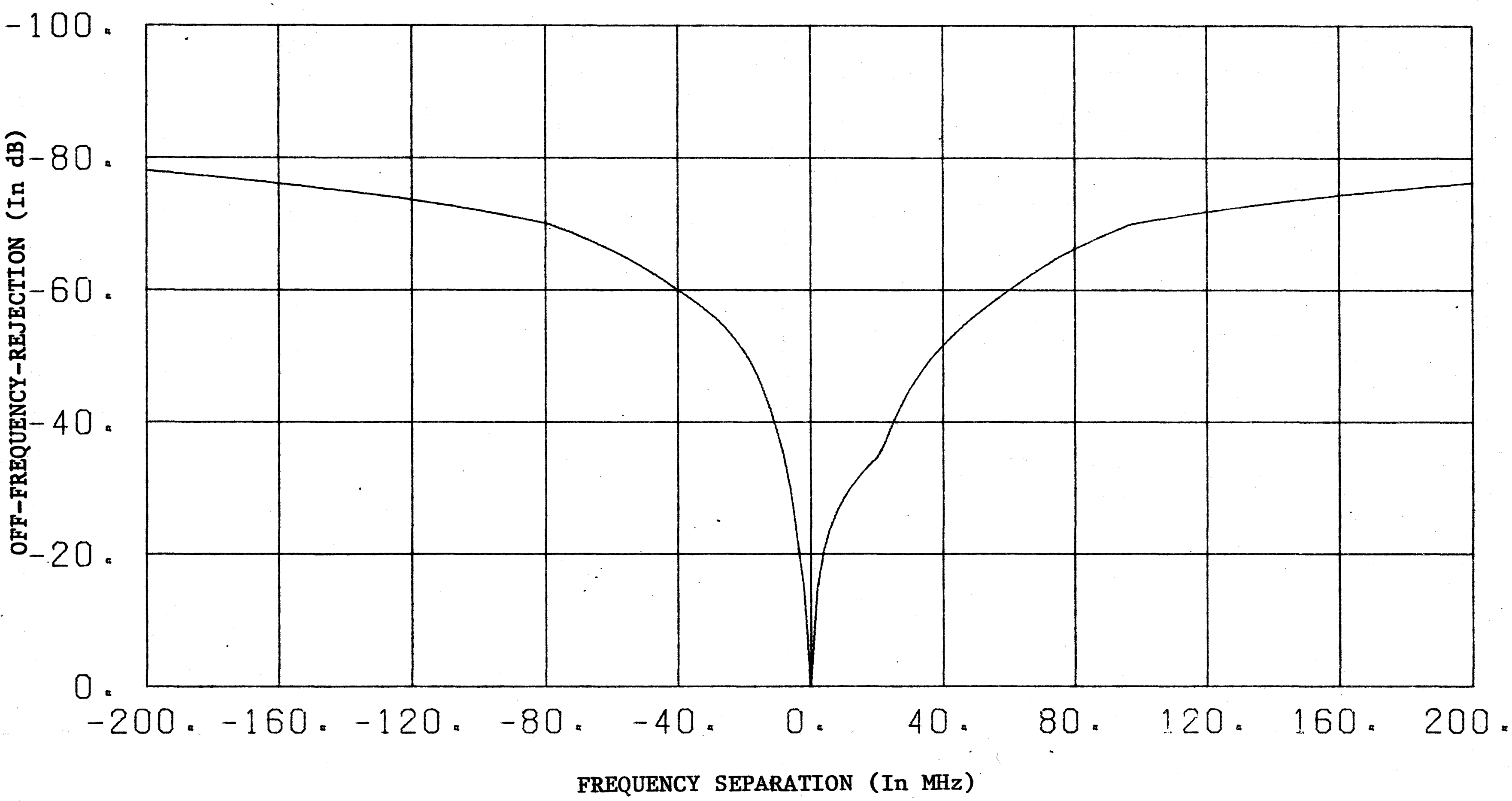


Figure A-11. LSR Off-Frequency-Rejection to Category 2 Radars

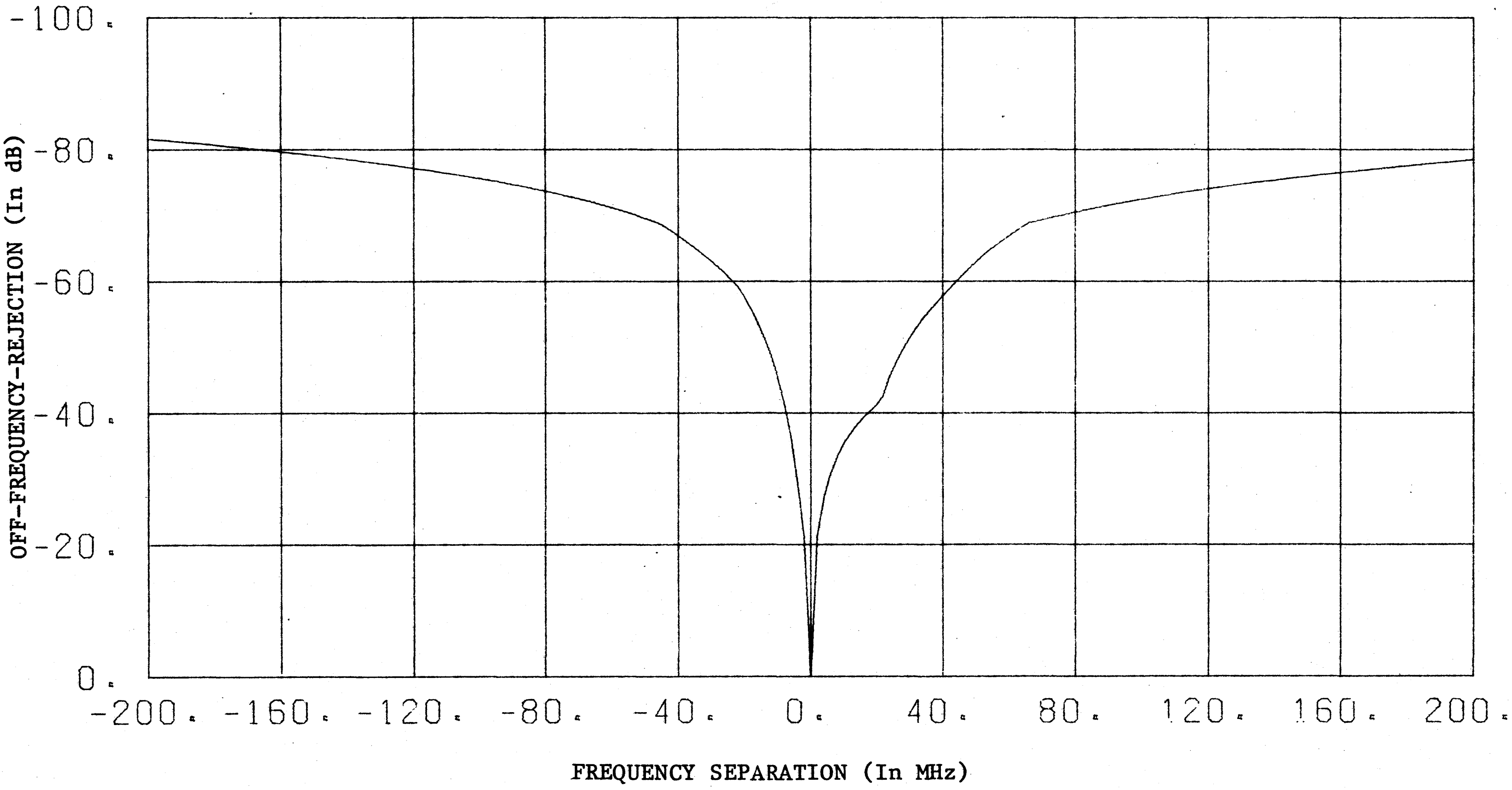


Figure A-12. LSR Off-Frequency-Rejection to Category 3 Radars

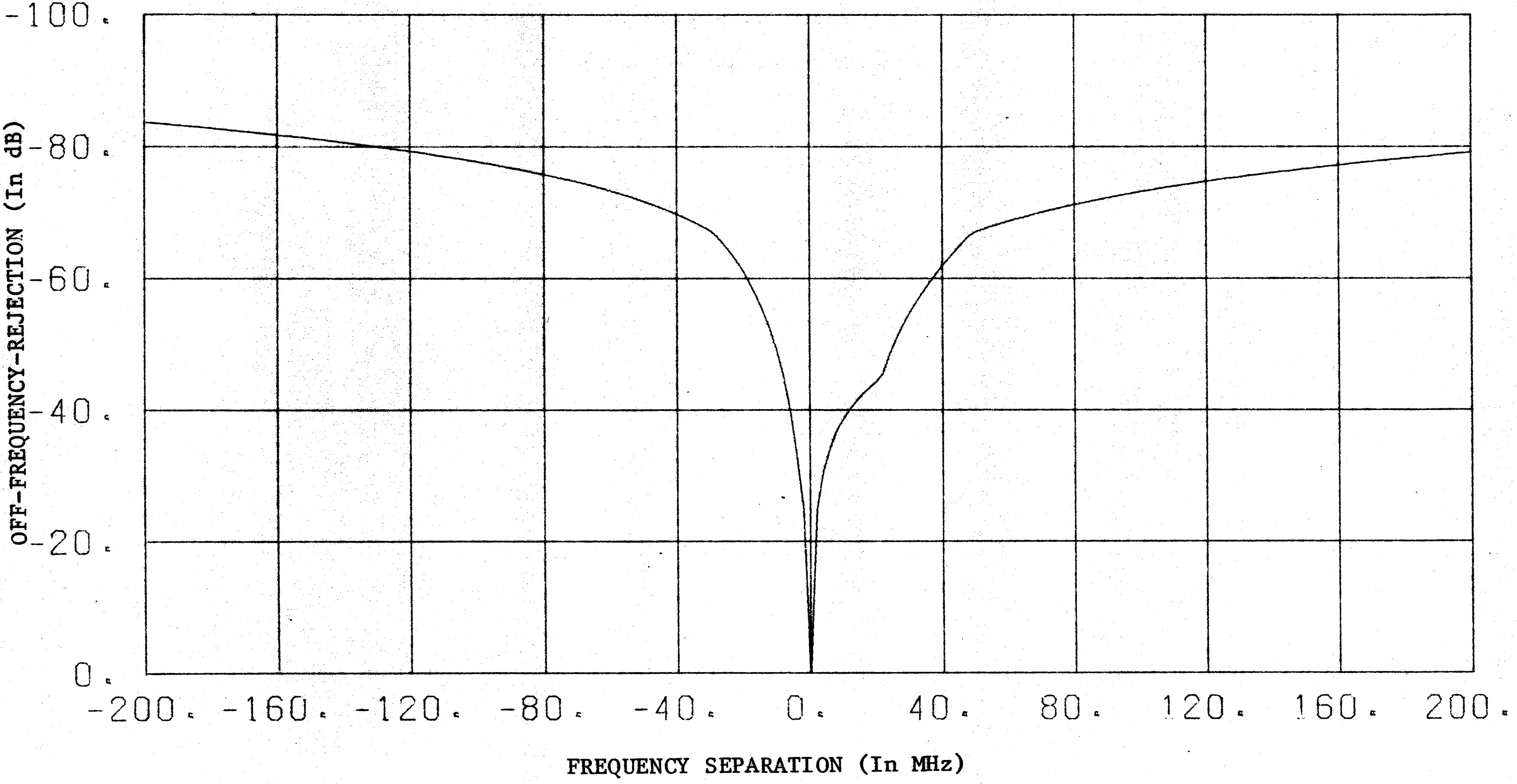


Figure A-13. LSR Off-Frequency-Rejection to Category 4 Radars

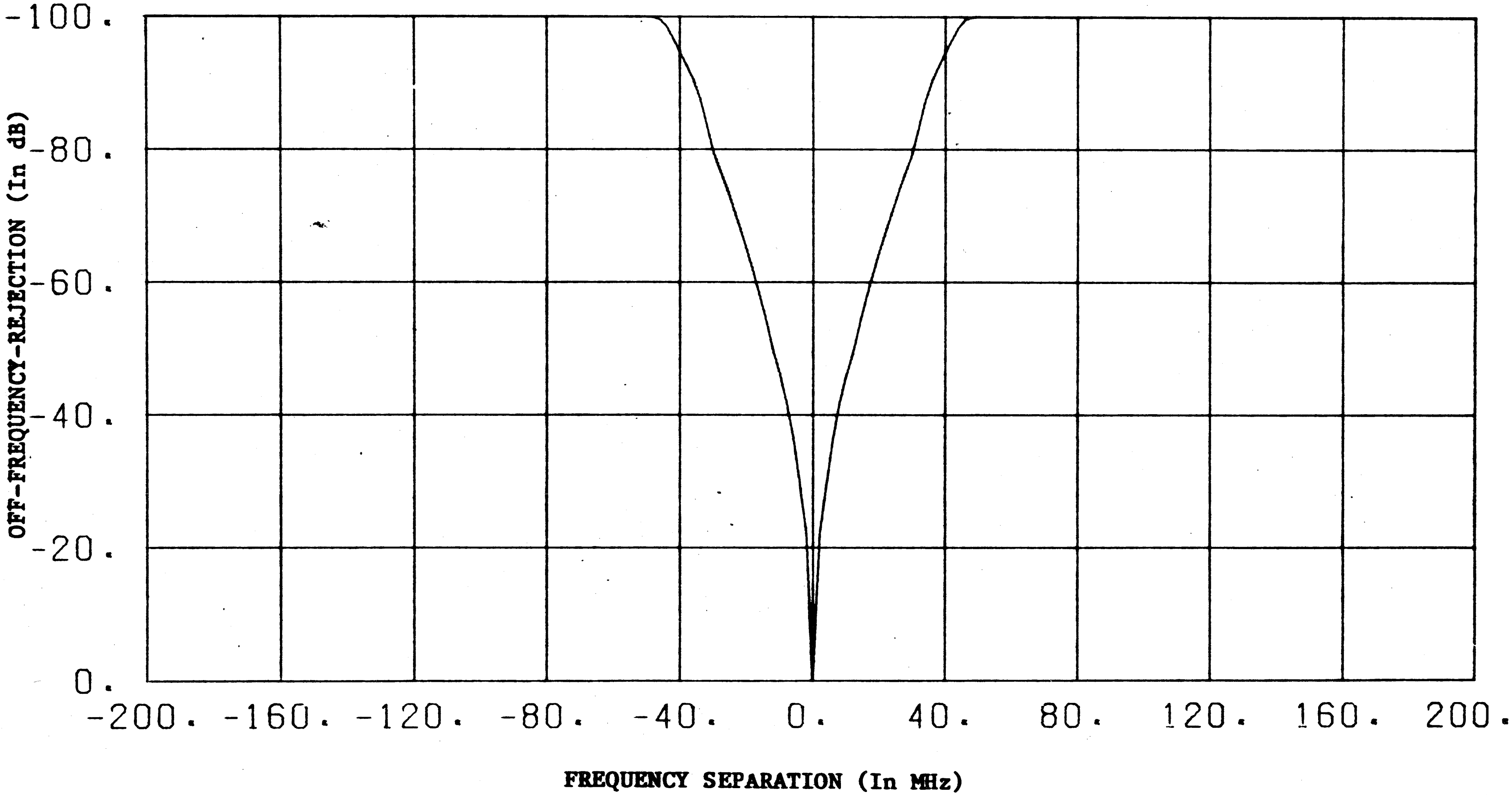


Figure A-14. LSR Off-Frequency-Rejection to Category 5 Radars

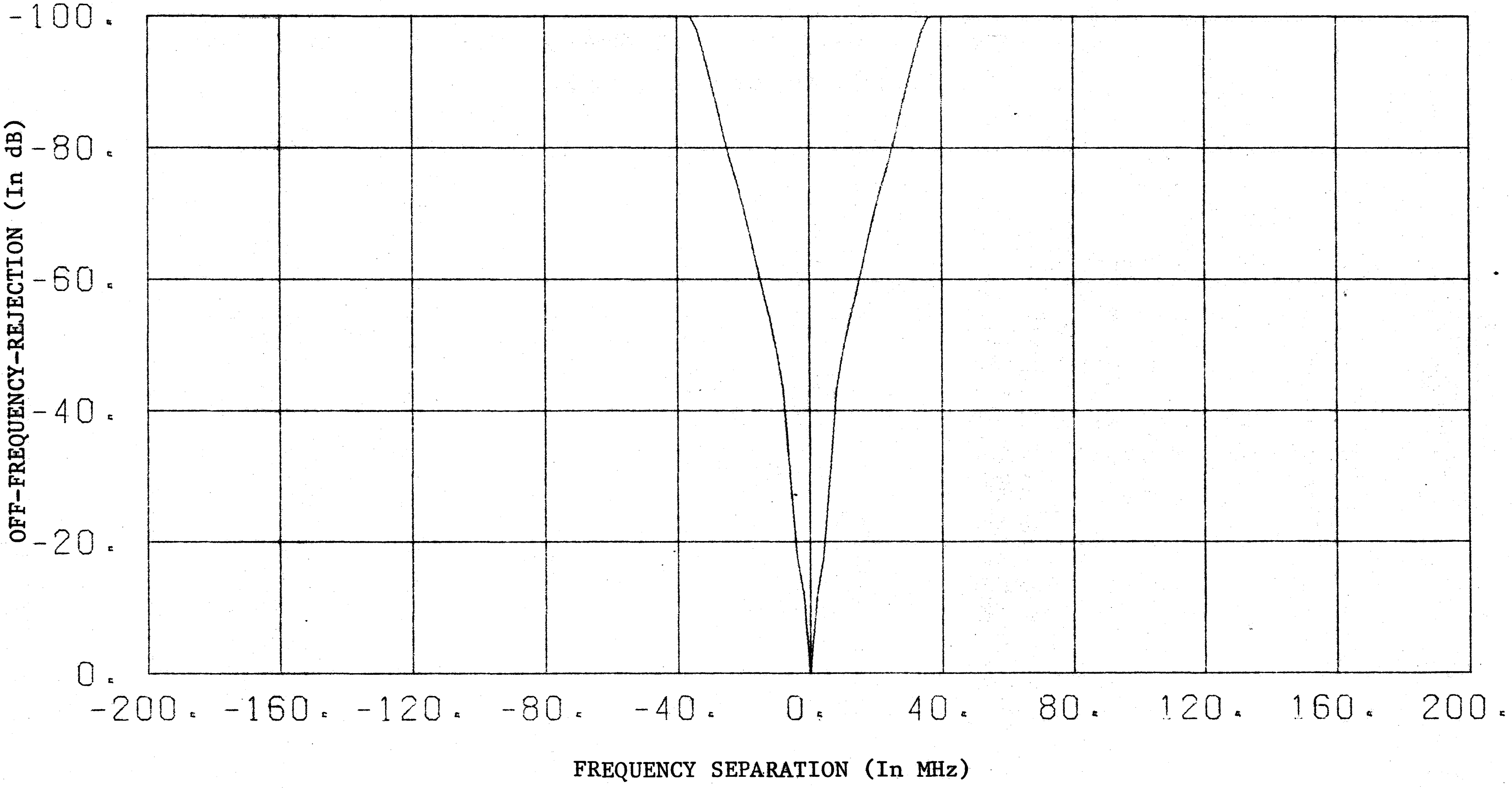


Figure A-15. LSR Off-Frequency-Rejection to Category 6 Radars

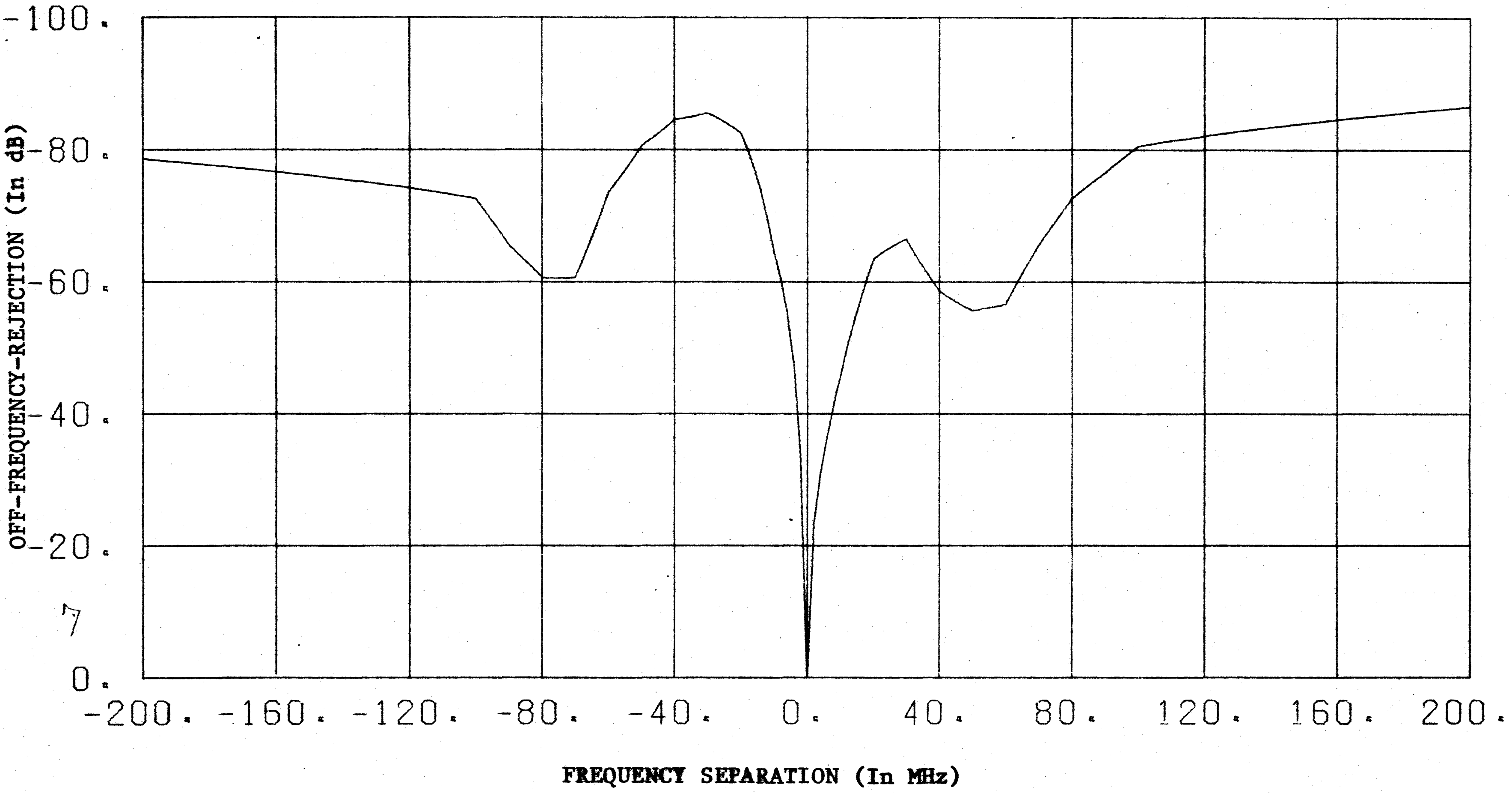


Figure A-16. LSR Off-Frequency-Rejection to Category 7 Radars

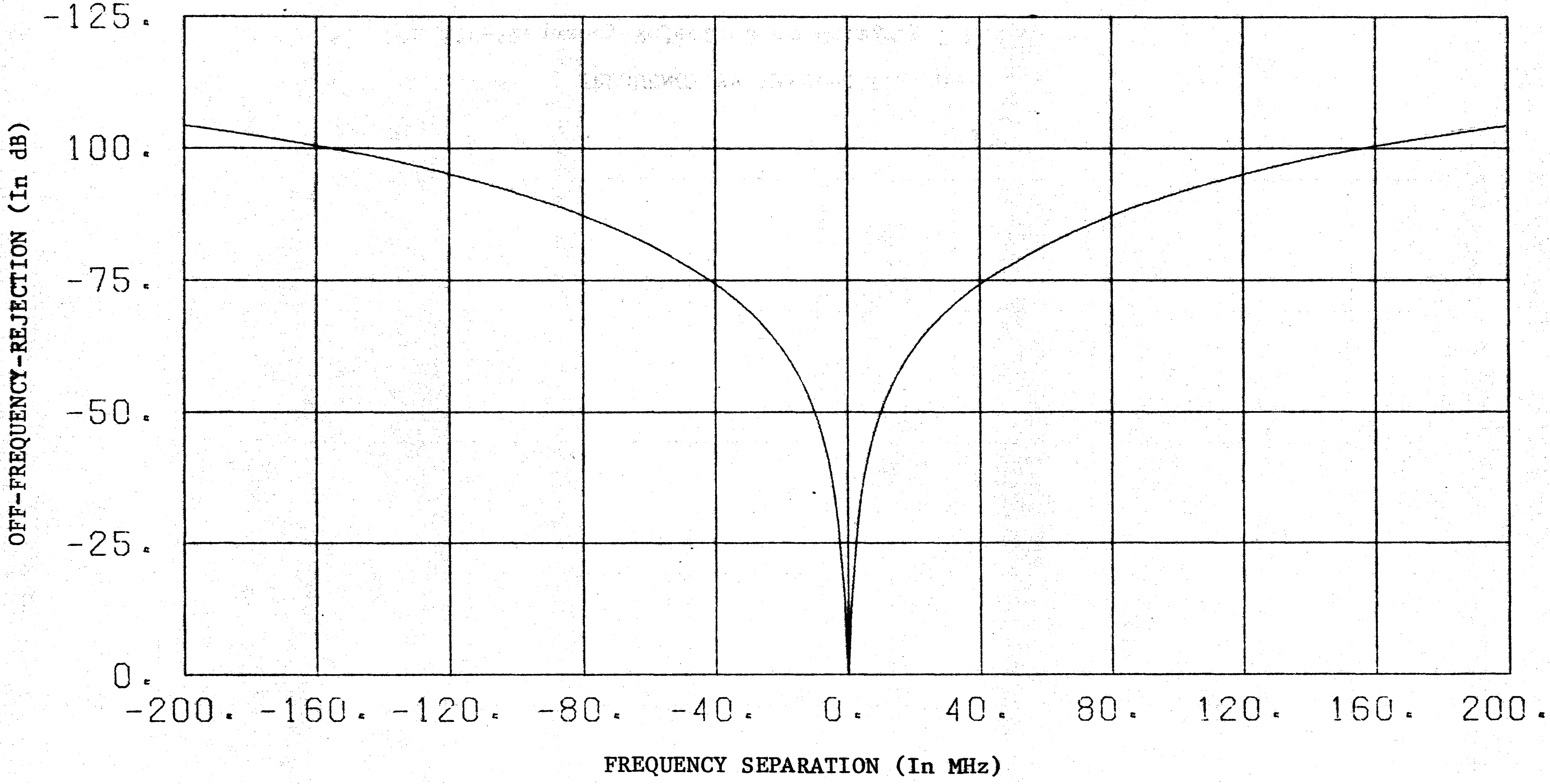


Figure A-17. LSR Off-Frequency-Rejection to LSR Radars

APPENDIX B

LSR PERFORMANCE CRITERION

INTRODUCTION

This appendix contains an analysis of the signal processing of asynchronous pulsed interference through the LSR receiver, and appropriate performance criteria for the LSR in a asynchronous pulsed interference environment. An appropriate peak Interference-to-Noise Ratio (INR) to preclude performance degradation to the LSR is developed. This peak INR criterion was then used to assess the feasibility of deploying LSRs in the 2.7 to 2.9 GHz band in the Los Angeles and San Francisco areas.

PERFORMANCE CRITERIA

In order to assess the feasibility on an electromagnetic capability (EMC) basis of deploying the LSR radars in the Los Angeles and San Francisco area, it is necessary to establish a peak Interference-to-Noise Ratio (INR) which will preclude performance degradation of the LSR System. For this investigation, the criteria used to establish an appropriate peak INR was:

1. The level of interference should not cause false hit reports to be sent to the MTD post-processor which could result in overloading of the post-processor.

2. The level of interference should not cause the MTD threshhold level to be increased by more than 1 dB.

It is shown in a report by Hinkle, Pratt and Levy (1979) that the peak Interference-to-Noise Ratio (INR) gain through a phase detector and a low pass filter when matched to one-half the receiver IF bandwidth and averaged over all phase angles is 0 dB. Therefore, the peak INR at the receiver IF output is equal to the peak INR at the MTD processor input (A/D converters).

To analyze the effects of asynchronous pulsed interference on the MTD processor, both the canceller/transversal filter channel and the Zero Velocity Filter (ZVF) channel signal processing must be considered. The following is a cursory analysis of the signal processing of both channels for noise and asychronous pulsed interference.

Canceller/Transversal Filter Channel

The MTD-II radar at Burlington, Vermont has a two-pulse canceller prior to the seven transversal filters, sometimes called Finite Impulse Response (FIR) filters. Consideration is being given to not using a MTI canceller prior to the FIR filters in the LSR. Because of the uncertainty in whether or not a canceller will be used in the LSR, the transfer properties of the MTD-II with and without a canceller for both noise and asynchronous pulsed interference will be discussed. As previously mentioned, the number of doppler filters proposed for the LSR is 16. However, it may be decided later that only eight doppler filters will be used. Also the type of FIR filters (recursive or nonrecursive), or filter coefficients (weights) to be used in the LSR are not known. Therefore, for this analysis the FIR filter characteristics in the MTD-II will be used to determine a peak INR criterion to be used for the LSR.

Canceller

The following is a discussion of the transfer properties of a two-pulse canceller to noise and asynchronous pulsed interference.

Noise. Since the RMS noise is uncorrelated from epoch to epoch, the RMS noise voltage gain of a canceller can be expressed as:

$$n_{CG} = \sqrt{\sum_{i=0}^{m} a_i^2} \qquad \text{(B-1)}$$

where:

a_i = Binominal weighting factors, $(-1)^i \binom{m}{i}$

m = Canceller filter order, 1 for two-pulse canceller

Therefore, the noise voltage gains for a two-pulse canceller is equal to $\sqrt{2}$.

Interference. Since the binomial weighting factors for a two-pulse canceller are 1 and -1, the peak interference voltage gain through a two-pulse canceller is one. However, the time response of the canceller to asynchronous pulsed interference is important since it has an effect on the gain through the FIR filters which follow. For asynchronous pulsed interference, each interfering pulse at the canceller input will produce several synchronous pulses which will appear at the input of the FIR filter simultaneously. A two-pulse canceller will produce two synchronous pulses at the output of the canceller for each interfering pulse with an amplitude proportional to the binominal weighting factors (1 and -1).

Transversal Filter

The MTD-II has seven doppler filters which are implemented using linear phase nonrecursive transversal filters (FIR filters). Since the filters are linear-phase, the impulse responses or weights of the filters are real. TABLE B-1 shows the filter weights, h (n), for each of the seven transversal filters for both the Inphase (I) and Quadrature (Q) channels in the MTD-II. Figure B-1 shows a block diagram for a nonrecursive transversal filter (FIR filter).

Noise. Neglecting the noise correlation of the canceller, the RMS noise voltage gain of a nonrecursive transversal filter can be expressed as:

$$n_{TFG} = \sqrt{\sum_{n=0}^{N-1} h^2(n)} \qquad \text{(B-2)}$$

where:

N = Number of filter samples, 7
h(n) = Transversal filter weights

TABLE B-1

TRANSVERSAL FILTER WEIGHTS

FILTER WEIGHTS h(n)	FILTER													
	1		2		3		4		5		6		7	
	I	Q	I	Q	I	Q	I	Q	I	Q	I	Q	I	Q
0	-3	-3	2	-3	1	0	1	0	1	0	2	3	-3	3
1	4	-7	8	6	-2	3	-3	0	-2	-3	8	-6	4	7
2	11	5	-12	13	-2	-6	6	0	-2	6	-12	-13	11	-5
3	-2	15	-15	-15	7	3	-7	0	7	-3	-15	15	-2	-15
4	-12	1	15	-12	-6	3	6	0	-6	-3	13	12	-12	-1
5	-2	-8	6	8	1	-4	-3	0	1	4	6	-8	-2	8
6	4	-2	-3	2	1	1	1	0	1	-1	-3	-2	4	2

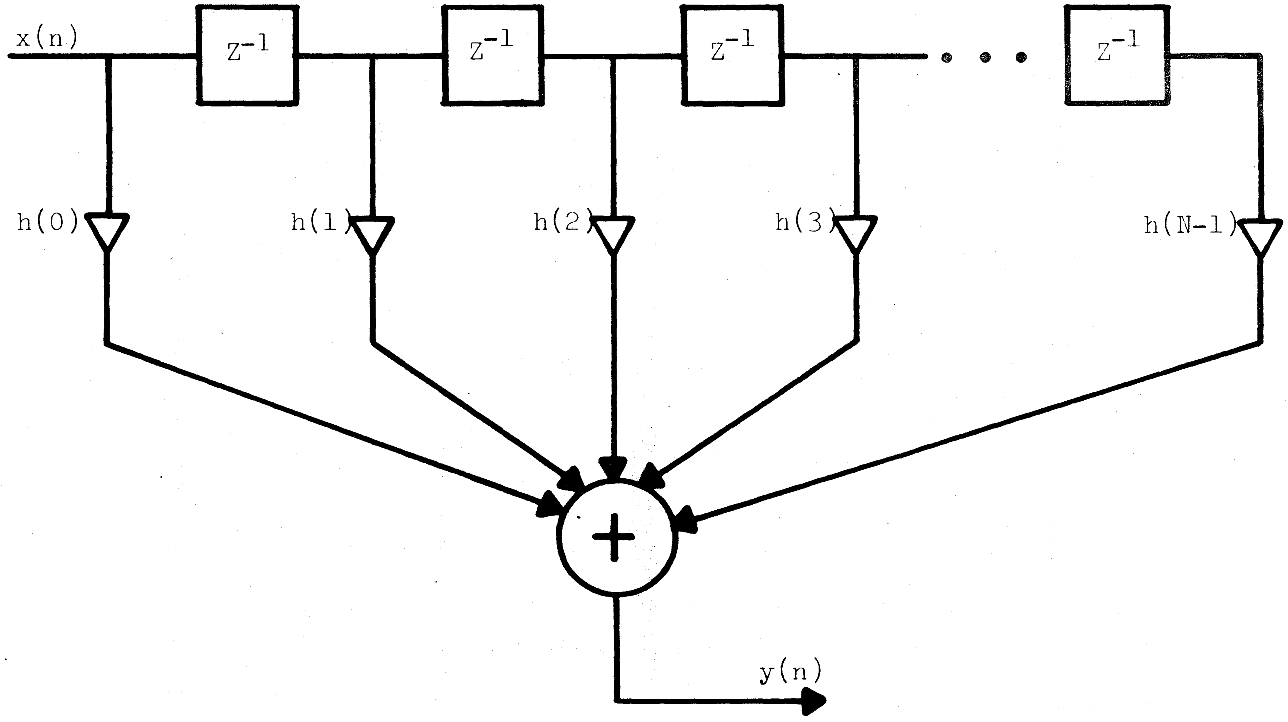


Figure B-1. Direct Form of Finite Impulse Response (FIR) Filter

The noise voltage gain (n_{TFG}) for each filter for the I and Q channels is shown in TABLES B-2 and B-3.

Interference. The gain of the interference through the transversal filter is a function of whether or not a canceller precedes the transversal filters. When a two-pulse canceller precedes the FIR filters, there will be two interfering pulses on two inputs to the FIR filters simultaneously with noise on the other five FIR filter inputs. If a canceller is not used, there most likely will only be one interfering pulse on the inputs to the FIR filters for asynchronous pulsed interference with noise on the other six FIR filter inputs.

When a two-pulse canceller precedes the FIR filters, the peak interference gain of the FIR filters to asynchronous pulsed interference is given by:

$$i_{TFG} = |h(n) - h(n-1)| \qquad \text{(B-3)}$$

For: n = 0 to N

The peak Interference-to-Noise Ratio (INR) voltage gain through the two pulse canceller and FIR filters can be expressed as:

$$INR = \frac{|h(n) - h(n-1)|}{\sqrt{2} \cdot \sqrt{\sum_{n=0}^{N-1} h^2(n)}} \qquad \text{(B-4)}$$

For: n = 0 to N

In order to determine the peak Interference-to-Noise Ratio (INR) at the transversal filter channel output, Equation B-4 must be iterated for both the I and Q channel, and the magnitude algorithm applied. The magnitude of the I and Q channels is obtained by comparing the I and Q signal levels at the FIR filter outputs, and applying the following algorithms.

7/8 LARGER + 1/2 SMALLER (B-5)

This new quantity is compared to LARGER and the greater value transmitted to the output circuit.

The peak INR gain through the two-pulse cancellers and FIR filter was calculated using Equation B-4 for both I and Q channels and applying the magnitude algorithm (Equation B-5). TABLE B-2 shows the maximum peak INR gain through the Transversal filter channel for each filter when a two-pulse canceller is used. The maximum peak INR gain through the transversal filter channel when a canceller is used is -0.5 dB. It should be noted that the peak INR gains shown in TABLE B-2 are the maximum peak INR gain for each filter. The average peak INR gain for each filter would be a few dB lower.

TABLE B-2

PEAK INTERFERENCE-TO-NOISE RATIO GAIN FOR TRANSVERSAL FILTER CHANNEL WITH TWO-PULSE CANCELLER

FILTER NUMBER		CANCELLER NOISE VOLTAGE GAIN	FIR FILTER NOISE VOLTAGE GAIN	FIR FILTER INTERFERENCE VOLTAGE GAIN	FIR FILTER OUTPUT INR VOLTAGE GAIN	FIR FILTER OUTPUT INR GAIN (dB)	MAGNITUDE OUTPUT INR VOLTAGE GAIN	TRANSVERSIAL FILTER CHANNEL GAIN (dB)
1	I	$\sqrt{2}$	17.72	10	0.399	-7.9	0.645	-3.8
	Q	$\sqrt{2}$	19.41	14	0.510	-5.8		
2	I	$\sqrt{2}$	26.58	30	0.798	-2.0	0.739	-2.6
	Q	$\sqrt{2}$	25.51	3	0.083	-21.6		
3	I	$\sqrt{2}$	9.79	9	0.650	-3.7	0.947	-0.5
	Q	$\sqrt{2}$	8.94	9	0.712	-2.9		
4	I	$\sqrt{2}$	11.87	13	0.774	-2.2	0.774	-2.2
	Q	$\sqrt{2}$	0	0	N/A	N/A		
5	I	$\sqrt{2}$	9.79	9	0.650	-3.7	0.947	-0.5
	Q	$\sqrt{2}$	8.94	9	0.712	-2.9		
6	I	$\sqrt{2}$	25.51	3	0.083	-21.6	0.720	-2.8
	Q	$\sqrt{2}$	25.51	28	0.776	-2.2		
7	I	$\sqrt{2}$	17.72	10	0.399	-7.9	0.645	-3.8
	Q	$\sqrt{2}$	19.41	14	0.510	-5.8		

TABLE B-3

PEAK INTERFERENCE-TO-NOISE RATIO GAIN FOR TRANSVERSAL FILTER CHANNEL WITH NO CANCELLER

FILTER NUMBER		FIR FILTER NOISE VOLTAGE GAIN	FIR FILTER INTERFERENCE VOLTAGE GAIN	FIR FILTER OUTPUT INR VOLTAGE GAIN	FIR FILTER OUTPUT INR GAIN (dB)	MAGNITUDE OUTPUT INR VOLTAGE GAIN	TRANSVERSAL FILTER CHANNEL GAIN (dB)
1	I	17.72	2	0.112	-19.0	0.773	-2.2
	Q	19.41	15	0.773	-2.2		
2	I	26.58	15	0.564	-5.0	0.796	-2.0
	Q	25.51	15	0.588	-4.6		
3	I	9.79	7	0.715	-2.9	0.793	-2.0
	Q	8.94	3	0.335	-9.4		
4	I	11.87	7	0.590	-4.6	0.590	-4.6
	Q	0	0	N/A	N/A		
5	I	9.79	7	0.715	-2.9	0.793	-2.0
	Q	8.94	3	0.335	-9.4		
6	I	25.51	15	0.588	-4.6	0.808	-1.8
	Q	25.51	15	0.588	-4.6		
7	I	17.72	2	0.112	-19.0	0.773	-2.2
	Q	19.41	15	0.773	-2.2		

When a canceller is not used prior to the FIR filter the peak interference gain of the FIR filters to asynchronous pulsed interference is given by:

$$i_{TGF} = |h(n)| \tag{B-6}$$

For: n = 0 to N-1

The peak Interference-to-Noise Ratio (INR) voltage gain through the FIR filter can be expressed as:

$$INR = \frac{|h(n)|}{\sqrt{\sum_{n=0}^{N-1} h^2(n)}} \tag{B-7}$$

In order to determine the peak INR at the transversal filter channel output, Equation B-7 was iterated for both the I and Q channel, and the magnitude algorithms applied (Equation B-5). TABLE B-3 shows the maximum peak INR gain through the transversal filter channel for each filter when no canceller is used. The maximum peak INR gain through the Transversal filter channel with no canceller is -1.8 dB. As previously mentioned, it should be noted that the INR gains shown in TABLE B-3 is the maximum peak INR gain for each filter. The average peak INR gain for each filter would be a few dB lower.

Zero Velocity Filter Channel.

Since the two-pulse canceller has a poor low doppler velocity response, a Zero Velocity Filter (ZVF) is employed to see low radial velocity targets. The low pass filter in the MTD-II is implemented using an FIR filter. Since the low pass filter used in the MTD-II is a nonrecursive optimal linear-phase FIR filter, the impulse responses and weights, h (n), of the filter are real. The low pass filter in the MTD-II is an eight sample (N) filter with weights h (n) of -3, -1, 7, 15, 15, 7, 1, 3 for the I channel. The filter weights for the Q channel are all zero. The RMS noise voltage gain of the ZVF is given by:

$$n_{ZVF} = \sqrt{\sum_{n=0}^{N-1} h^2(n)} = 23.83 \tag{B-8}$$

For the case where there is only one interfering pulse present at the input to the ZVF, the maximum peak interfering signal voltage gain through the ZFV is given by:

$$i_{ZVF} = \text{Max } |h(n)| = 15 \tag{B-9}$$

Therefore the maximum peak Interference-to-Noise Ratio (INR) gain in dB through the ZVF is:

$$\mathrm{INR} = 20 \log \left[\frac{\mathrm{Max.}\ |h(n)|}{\sqrt{\sum_{N=0}^{N-1} h^2(n)}} \right] \qquad \text{(B-10)}$$

Using Equation B-10 the maximum peak INR gain through the ZVF is -4.0 dB. Since there is no Q channel output, the maximum peak INR gain out of the magnitude circuit is also -4.0 dB. Thus the maximum peak INR gain for the ZVF channel is -4.0 dB.

MTD Thresholding.

The magnitude of the output signals from the ZVF (doppler filter 0) and the transversal filters (doppler filters 1 through 7) are compared with adaptive background clutter levels and thresholds for report declaration. The adaptive background levels and thresholds are set depending on the clutter phenomenon which are present. The doppler domain is divided into three domains: doppler filter 0 (ZVF channel), doppler filters 2 through 6 and doppler filters 1 and 7.

Doppler Filter 0

The threshold for a report from doppler filter 0 (ZVF channel) is set by a ground clutter recursive filter. Figure B-2 shows a block diagram of the ground clutter recursive filter. A memory and recursive filter is used to implement a scan-to-scan adaptive threshold. On each scan one-eighth of the stored clutter level is subtracted from the stored level. One-eighth of the signal level output from the ZVF is added to the value remaining after subtraction. This new level is then stored in the memory for thresholding on the next scan. The threshold for the ZVF channel is a fixed value between four and eight times the value stored in the memory. Therefore, assuming the adoptive threshold is being set by noise only, the required peak INR at the MTD threshold input must be at least 12 to 18 dB for asynchronous pulsed interference to cause a false report to be sent to the post-procesor. If there is ground clutter in the range bin of interest, the required peak INR for a false report will be greater than 12 to 18 dB. Since the ZVF chanel causes at least a 4 dB loss in the peak INR, the peak INR at the input to the MTD processor (A/D converter) must be at least 16 dB to cause a false report out of the ZVF channel (doppler filter 0).

In order to determine the maximum peak INR that will not cause a one dB increase in the adaptive ground clutter recursive filter threshold, it is necessary to establish the response of the recursive filter to asychronous pulsed interference. For asynchronous pulsed interference, the interference will not add in the recursive filter, and the response at the recursive filter output for the Sth radar scan from the occurrence of an interfering pulse at the filter input can be expressed as:

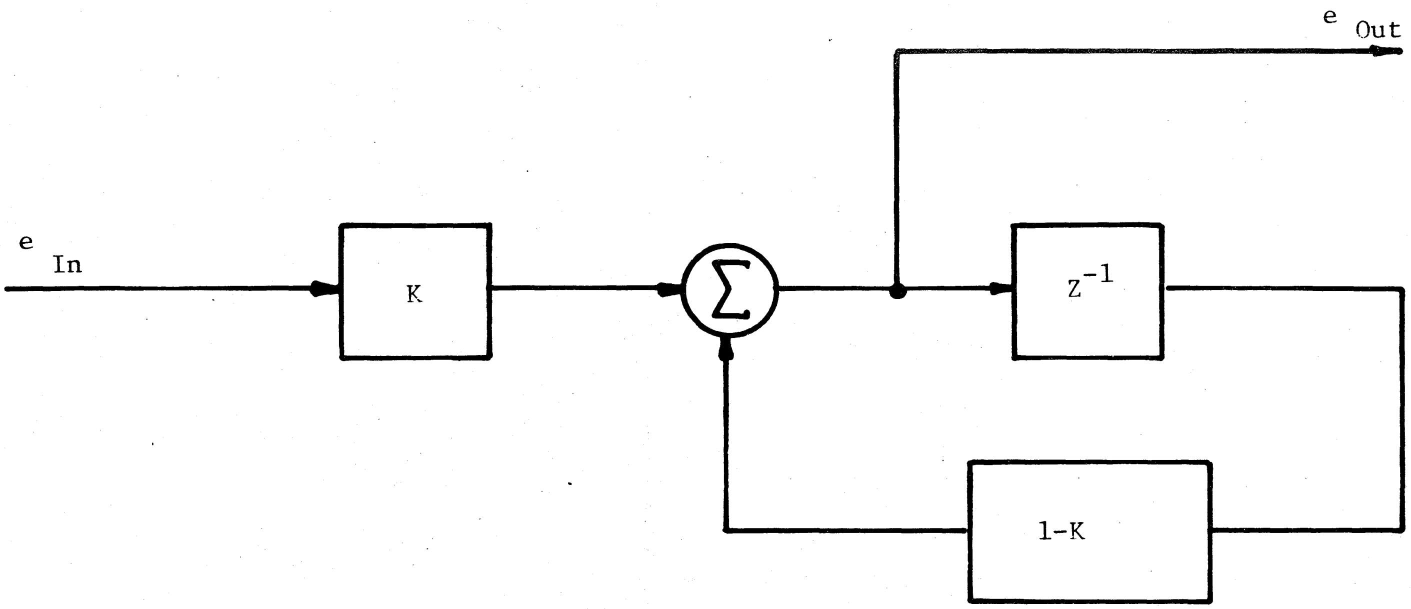


Figure B-2. Block Diagram of Adaptive Threshold Recursive Filter

$$i_o = i_i\, K(1-K)^{S-1} \qquad \text{(B-11)}$$

where:

i_i = Level of interference at the input to the recursive filter, in volts

i_o = Level of interference at the output of the recursive filter, in volts

K = Recursive filter factor, equals 1/8 (.125)

S = Recursive filter epoch, S = 1 is the scan (epoch) at which the interference pulse occurred at the input to the recursive filter

Using Equation B-11, the increase (in dB) caused by asychronous pulsed interference to the recursive filter threshold relative to the threshold level for noise only can be expressed as:

$$T\ (\text{Increase}) = 20 \log \left[\frac{i_i K\ (1-K)^{S-1} + n}{n} \right] \qquad \text{(B-12)}$$

where:

n = average threshold level for noise only, in volts.

Equation B-12, assumes no asychronous interference pulse will occur in the same range-doppler bin for the next "S" radar scans.

TABLE B-4 shows the increase in threshold level caused by asynchronous pulsed interference for peak INRs of 1,3 and 5 dB at the recursive filter input for one to five scans after the interference occurs (S = 1 to 5). If the performance criteria is to not permit the asychronous pulsed interference to increase the recursive filter threshold by more than 1 dB, the peak INR at the recursive filter input should not exceed approximately 1 dB. Since there is approximately a 4 dB peak INR loss through the ZVF channel, the peak INR at the MTD processor input (A/D converter) should not exceed 5.0 dB to preclude a 1 dB increase in the threshold level of the ZVF channel.

Doppler Filters 2 Through 6

The threshold for a report from doppler filters 2 through 6 is set by averaging the received signal over 16 range bins centered on the range bin of interest and excluding the range bin of interest and the adjacent range bins (guard range bins). The threshold for doppler filters 2 through 6 is set at four to eight times the measured average signal level. Therefore the required

TABLE B-4

INCREASE IN RECURSIVE FILTER THRESHOLD LEVEL FOR ASYNCHRONOUS PULSED INTERFERENCE

SCAN (S)	THRESHOLD LEVEL INCREASE (IN dB)			
	INR = 5 dB	INR = 3 dB	INR = 1 dB	INR = 0 dB
1	1.74	1.41	1.14	1.02
2	1.54	1.24	1.00	0.90
3	1.36	1.10	0.88	0.79
4	1.20	0.97	0.78	0.70
5	1.06	0.85	0.68	0.61

peak INR at the threshold input must be at least 12 to 18 dB for asynchronous pulsed interference to cause a false report to be sent to the post-processor. Considering the maximum peak INR gains through the transversal filter channel, the peak INR at the MTD processor input (A/D converter) to preclude asynchronous pulsed interference from causing false reports from doppler filters 2 through 6 should not exceed 12.5 dB if a canceller is used and 13.8 dB if no canceller is used.

The increase in threshold level in dB caused by asychronous pulsed interference relative to the threshold level for noise only in doppler filters 2 through 6 can be expressed as:

$$T\ (\text{Increase}) = 20\ \log \left[\frac{(i/16) + n}{n} \right] \tag{B-13}$$

Using Equation B-13, the maximum peak INR at the doppler filter output which will not result in the threshold being increased by more than 1 dB is a peak INR of approximately 6 dB. Thus, taking into consideration the maximum peak INR gain through the transversal filter channel, the peak INR at the MTD processor input (A/D converter) to preclude asynchronous pulsed interference from causing more than a 1 dB increase in the threshold for doppler filters 2 through 6 should not exceed 6.5 dB if a two-pulse canceller is used, and 7.8 if no canceller used.

Doppler Filters 1 and 7

Doppler filters 1 and 7 can contain clutter due to rain and spillover from the ground backscatter in filter 0. The threshold in these filters is set as the greater of two thresholds: (a) the threshold set for doppler filters 2 through 6, or (b) a fixed binary fraction of the threshold set for doppler filter 0. The maximum peak INR to preclude asynchronous pulsed interference from causing false reports or increasing the thresholds by more than 1 dB for thresholds (a) and (b) above have been previously discussed.

Interference Eliminator Circuit

An interference eliminator circuit has been hard-wired into the MTD-II to eliminate asynchronous pulsed interference. The magnitude of 16 pulses in the same range bin in consecutive azimuth change pulses is taken by adding the absolute values of I and Q at the A/D converter output. The 16 magnitudes are also stored until the average has been computed. Each range bin is then compared with four or five times the average. If any range bin exceeds this number, it is replaced by the average of the 16 range bins. When there is noise only present in 15 of the 16 range bins, asynchronous pulsed interference with a peak INR greater than 12 to 14 dB (depending on the criteria of 4 to 5 times the average) at the MTD procesor input (A/D converter) will be eliminated from further processing in the MTD. Since the peak INR at the MTD processor input for asynchronous pulsed interference to cause a false report must be at least 16 dB for the ZVF channel and 12.5 dB for the Transversal filter channel, the interference eliminator circuit should prevent false reports being sent to the post-processor when noise only is present.

The interference eliminator circuit works when the background is white noise, but it does not work well if the background is clutter (i.e., colored noise). In the latter case the clutter signal level raises the average of the 16 range bins; thus, possibly not eliminating the high level pulse interference. In this case, post-processor algorithms must be utilized to prohibit the false reports caused by the asynchronous pulsed interference from causing false target reports.

Post-Processor

Several algorithms in the MTD-II post-processors are used to preclude initiation of a false track due to false reports caused by asynchronous pulsed interference. False track reports due to asynchronous pulse interference are precluded by:

1. Requiring multiple scan-to-scan reports for track initiation, not single reports which pass the post MTD threshold criteria.
2. Suppression of all reports in a 11.25 degree wedge (for all ranges) when there are more than 10 reports in the wedge. These reports are then not used to initiate tracks in the scan-to-scan correlator and the post-MTD thresholds are not updated for that area.

Summary of Performance Criteria

The interference eliminator circuit in the MTD processor, and algorithms in the post-processor, will preclude asynchronous pulsed interference from causing initiation of false tracks. The performance degradation to the MTD system caused by asynchronous pulsed interference will be of the form of false reports being sent to the MTD post-processor, and an increase in the MTD signal processor adaptive threshold level. TABLE B-5 summarizes the peak Interference-to-Noise Ratio (INR) criteria to preclude the above performance degradation conditions for both MTD channels. From TABLE B-5, it appears that a peak INR criterion that will assure compatible operations in an asynchronous pulsed interference environment is 5 dB or less at the MTD processor input (A/D converter). It is believed that a 5 dB peak INR criterion is conservative since it is based on the maximum peak INR transfer properties of the transversal filter and ZVF channels.

TABLE B-5

PEAK INR PERFORMANCE CRITERIA FOR MTD-II RADAR

CRITERIA / RADAR CHANNEL	FALSE HIT REPORT		1 dB THRESHOLD INCREASE	
	WITH CANCELLER	WITHOUT CANCELLER	WITH CANCELLER	WITHOUT CANCELLER
TRANVERSAL FILTER	INR ≤ 12.5 (dB)	INR ≤ 13.8 (dB)	INR ≤ 6.5 (dB)	INR ≤ 7.8 (dB)
ZERO VELOCITY FILTER	N/A	INR ≤ 16 (dB)	N/A	INR ≤ 5 (dB)

APPENDIX C

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15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The National Telecommunications and Information Administration (NTIA) in the Department of Commerce undertook a detailed program to investigate the feasibility of deploying the Limited Surveillance Radars (LSR) in the 2.7-2.9 GHz band in the Los Angeles and San Francisco areas. The LSR is a Federal Aviation Administration (FAA) air traffic control radar planned for use at general aviation airports with high traffic density that do not qualify for the longer range Airport Surveillance Radars (ASR). This investigation was the third in a series of tasks undertaken by NTIA as part of a spectrum resource assessment of the 2.7-2.9 GHz band. The overall objective of the spectrum resource assessment was to assess the degree of congestion in the band in designated areas in the United States, and to promote more effective utilization of the band.

The investigation showed that the 2.7-2.9 GHz band is congested in both the Los Angeles and San Francisco areas. Major factors contributing to congestion are the Military height-finding radars and the occurance of ducting (superrefraction) propagation conditions. However, the LSR radars can be accommodated in the present environment at the proposed sites in these areas, but it was necessary to conduct a detailed frequency assignment investigation. Due to the high degree of congestion in these areas, it may be necessary, in order to accommodate all the proposed LSR deployments, to retrofit a few existing radars in the envirorment with waveguide filters or receiver signal processing techniques to suppress asynchronous pulsed interference.

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