NTIA REPORT 90-260

Ground-Based Weather Radar Compatibility with Digital Radio-Relay Microwave Systems

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MARCH 1990

ACKNOWLEDGMENT

This project could not have been completed without the extraordinary efforts of National Telecommunications and Information Administration (NTIA), Federal Communications Commission (FCC) and National Spectrum Managers Association (NSMA) personnel. NTIA members of the working group included: Robert L. Hinkle (chairman), Philip E. Gawthrop (vice-chairman), Gary Patrick, Dr. David Cohen and Cesar Filippi. Mr. Ray Laforge represented the FCC. The NSMA members who served on the joint working group were: Dick Callahan, AT&T (NSMA Board of Directors); Douglass Hall, Comsearch (NSMA Chairman of "RFI" Working Group); Larrie Sutliff, Bell Communications Research (NSMA Board of Directors); and Richard Slade, AT&T Bell Laboratories. Richard Slade provided technical expertise on digital microwave systems and performed necessary measurements for assessing the effects of pulsed signals in digital microwave systems.

The Institute for Telecommunication Sciences (ITS), Spectrum Use Measurement Group provided data taken with the Radio Spectrum Measurement System (RSMS) and analysis of the measured data. The RSMS measurements were conducted by John Smilley and Frank Sanders. Vince Lawrence and Terryll Nemeth performed the analysis of the RSMS data.

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ABSTRACT

This report examines the potential for ground-based weather radar (meteorological radar) interference to digital microwave systems in the common carrier bands of 3700-4200 MHz and 5925-6425 MHz. Reported cases of interference to microwave common carrier systems from ground-based weather radar systems have increased due to the trend towards digital modulations. Because of this interference, NTIA, the FCC and the National Spectrum Managers Association formed an informal working group to investigate and document the potential problems.

The existing and planned spectrum uses by ground-based weather radars and digital microwave systems are addressed as well as regulations and policy pertaining to their electromagnetic compatibility. Methods to mitigate the interference in both the radar transmitter and microwave receiver are also provided.

KEY WORDS

Weather Radars Systems
Meteorological Aids Service
Digital Microwave Systems
Electromagnetic Compatibility (EMC) Analysis
Radar Spurious Emissions
Interference Mitigation Options

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SECTION 1

INTRODUCTION

BACKGROUND

The National Telecommunications and Information Administration (NTIA) is responsible for managing the Federal Government's use of the radio frequency spectrum. NTIA's responsibilities include establishing policies concerning spectrum assignment, allocation and use, and providing various departments and agencies with guidance to ensure that their conduct of telecommunications activities is consistent with these policies.[1] In discharging these responsibilities, NTIA assesses spectrum utilization, identifying existing and/or potential compatibility problems among the telecommunications systems that belong to various departments and agencies, provides recommendations for resolving any compatibility conflicts that may exist in the use of the radio frequency spectrum, and recommends changes to promote spectrum efficiency and improve spectrum management procedures.

Over the past several years NTIA has noted an increase in the reported cases of interference to microwave radio-relay systems from both Government and non-Government ground-based weather radar systems. Also, the National Spectrum Managers Association (NSMA), an industry group concerned with common carrier frequency coordination and radio interference issues, independently has been investigating reported interference problems associated with radar interference to common carrier microwave systems. The increase in radar interference apparently resulted from the trend toward higher order digital modulations in microwave systems. Such systems are more susceptible to interference than microwave systems using analog modulation.

In December 1988, NTIA and the NSMA met to discuss the reported cases of Government and non-Government ground-based weather radar interference to common carrier microwave systems. Because of the increasing trend towards deploying digital microwave systems, NTIA initiated a study to investigate the reported interference from ground-based weather radars to common carrier microwave systems. To provide related information, a working group was established consisting of NTIA, Federal Communications Commission (FCC) and NSMA members.

The International Radio Consultative Committee (CCIR) also has been cognizant of the reports of radar interference and has initiated a Question[2] and Study Program[3]

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1 NTIA, Manual of Regulations and Procedures for Federal Radio Frequency Management, National Telecommunications and Information Administration, Washington, D.C., Revised September 1989.

2 CCIR Question 28/9, "Maximum Allowable Degradation of the Fixed Service from Services in the Adjacent Bands in the Frequency Range 1 to 20 GHz," XVIth Plenary Assembly, Vol. IX - Part 1, Dubrovnik, 1986.

to examine the maximum allowable degradation of radio-relay systems due to energy spread from services in the adjacent bands. A report[4] modified at the recent CCIR Study Group 9 interim meeting proposes to limit allowable interference from systems such as radars to extremely low levels. This could greatly restrict the acceptable sites for new relay systems unless spurious emissions from radar systems are appropriately controlled or unless sites are chosen more carefully considering the existing electromagnetic environment.

OBJECTIVE

This task provides procedures to assess the potential for interference, and techniques to minimize electromagnetic compatibility (EMC) conflicts, between Government and non-Government ground based weather radars operating in the 2700-2900 and 5350-5650 MHz bands and digital common carrier systems operating in the 3700-4200 and 5925-6425 MHz bands.

APPROACH

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

a) determine the emission characteristics (frequency and time domain) of weather radars using NTIA's Radio Spectrum Measurement System (RSMS) van,

b) determine the degradation criteria and susceptibility of digital microwave receivers to weather radar emissions,

c) identify various methods for both the radar transmitting and the microwave receiving systems to mitigate the incompatibility,

d) determine distance separations to indicate when detailed EMC analysis is required to ensure EMC between weather radars and microwave systems,

e) review existing Government and non-Government policies and regulations to identify coordination procedures and propose changes which will minimize potential conflicts between ground-based weather radars and common carrier systems.

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3 CCIR Study Programme 28A/9, "Maximum Allowable Degradation of Radio-Relay Systems Due to Energy Spread From Services in the Adjacent Bands," Interim Meeting of Study Group 9, Vol. IX - Part 1, Geneva 1988.

4 CCIR Draft Revision of Report AB/9, "Maximum Allowable Performance and Availability Degradations to Radio-Relay Systems Arising From Interference From Emissions and Radiations From Other Sources," (Question 28/9), Final Meeting of Study Group 9, Document 9/421-E, Geneva, October 1989.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

The use of high-speed digital modulation by the radio-relay service in the common carrier bands has grown rapidly in recent years. As the change to digital systems has evolved, there have been several reported cases of interference to common carrier microwave systems from ground-based weather radars (meteorological radars).

This study reports on an investigation of possible causes and solutions to the reported interference problems. Systems studied in the report include weather radars operating in the 2700-2900 MHz and 5350-5650 MHz bands and digital microwave equipment operating in the 3700-4200 MHz and 5925-6425 MHz bands.

The following are conclusions and recommendations based on the findings contained in this report.

MAJOR CONCLUSIONS

1. Microwave radio-relay systems deployed today are more susceptible to interference for several reasons. These include: 1) evolution from analog to digital modulation, 2) evolution of digital technology to higher order modulations (16-QAM to 64-QAM), 3) improved microwave receiver sensitivity levels, and 4) increased use of microwave systems to relay digital data information, that require higher performance criteria (i.e., bit error rate (BER) of 10^{-6} or better as compared to voice BER of 10^{-3}).

2. Thirteen cases of interference to common carrier microwave receivers from both Government and non-Government ground-based weather radars have been reported and documented. In most of these cases, interference has occurred when the microwave system was changed from analog to digital modulation. In all the reported interference cases, the weather radars used a magnetron output tube.

3. For twelve of the thirteen reported interference cases, the ground-based weather radars were produced by one manufacturer.

4. When both the radar and microwave systems meet their applicable standards, appropriate NTIA and FCC interference resolution policies are not clear. Section 2.3.7 of the NTIA Manual (See Ref. 1, page 2-5) relates to the Government's policy.

5. The majority of the new non-Government ground-based weathers radars are expected to use magnetron output tubes. As a result, these types of ground-based weather radars will continue to have the potential to cause interference to common carrier systems.

6. The majority of new Government ground-based weather radars are expected to use klystron output tubes, which have typical spurious emission levels 50 dB lower than existing weather radars using magnetron output tubes. For example, the Government is procuring two new types of radars, the Next Generation Radar

(NEXRAD) [2700-2900 MHz] and the Terminal Doppler Weather Radar (TDWR) [5600-5650 MHz]. The NEXRAD will replace the majority of the existing Government weather radars. Both the NEXRAD and TDWR are expected to be deployed in the 1994-1995 time frame.

7. Microwave system route engineers need access to an accurate assignment and equipment characteristics database of ground-based weather radars for planning specific routes as well as to identify potential interference to common carrier microwave systems.

SPECIFIC CONCLUSIONS

Spectrum Use

The following are conclusions related to present and future use of the spectrum by Government and non-Government ground-based weather (meteorological) radar stations. The spectrum use is based on information obtained from the December 1988 Government Master File (GMF).

1. The 2700-2900 MHz and 5600-5650 MHz bands are allocated on a primary basis to the Meteorological Aids Service. There are 183 assignments for Government ground-based weathers radar stations in these bands. In addition, 82 Government and 158 non-Government ground-based weather radar stations have assignments in the 5350-5600 MHz bands operating on a secondary basis per record note S144 (See Ref. 1, Annex A, page A-7). Typical characteristics of these weather radars are 250-500 kW output power, 40 dBi antenna gain and use of magnetron output tubes (detailed spectrum measurements are available for most ground-based weather radar types).

2. The National Weather Service (NWS) will declare as surplus their existing ground-based weather radars through the General Service Administration (GSA) as the NEXRAD is deployed.

3. Digital radio-relay systems currently being used in the 3700-4200 MHz and 5925-6425 MHz bands typically have a 20 to 30 MHz bandwidth and a 90 or 135 Mb/s data rate, respectively for 64-QAM systems.

Electromagnetic Compatibility

The following are conclusions related to the potential for interference (electromagnetic incompatibility) from ground-based weather (meteorological) radar stations to common carrier radio-relay stations.

4. Performance degradation to common carrier radio-relay systems from ground-based weather radar systems can be caused by two coupling mechanisms:

   a. microwave radio-relay receiver front-end overload due to the radar fundamental frequency and

   b. radar spurious emission reception in the common carrier bands.

5. The effects of radar pulsed emissions on digital microwave systems are a function of the coupling mechanism (radar spurious emissions or front-end overload), radar pulse train characteristics and effects of the environment on the pulsed emissions (e.g., pulse stretching due to multiple coupling paths). In addition, the digital signal format used in the receiving system and the receiver time waveform response as well as special signal processing circuitry influence the effects of the radar emissions.

6. The observed effects of pulsed emissions from ground-based weather radars on digital microwave radio-relay systems generally seem to fall into the following five performance categories given below. Section 5 of this report describes each of these performance categories in detail.

   a. increased background error rate, BER $< 10^{-6}$

   b. error rates momentarily above threshold, BER $> 10^{-6}$

   c. severely errored second events, BER $> 10^{-3}$

   d. out-of-frame events, and

   e. loss-of-service.

Interference Mitigation Options

The following are conclusions related to methods used to mitigate interference from ground-based weather (meteorological) radars to common carrier radio-relay systems.

7. When interference from a radar is observed in a microwave system, one of the first steps in attempting to mitigate the interference is to determine if the coupling mechanism is front-end overload. If it is, an RF filter in the microwave system ahead of the low noise amplifier (LNA) may be used to mitigate the interference.

8. Radar system options used to mitigate interference caused by radar transmitter spurious emissions include: installation of a waveguide RF filter, replacement of the output device or modification of the pulse shaping network.

9. In some interference cases the replacement of the conventional or coaxial magnetron with the same type tube has reduced the spurious emission levels in the common carrier bands. This solution may be a temporary fix because many tubes degrade with age.

10. Microwave system options used to mitigate reception of radar spurious emissions include the use of: alternate bands, alternate RF channels, space/pattern diversity, forward error correction, and path rerouting. An alternative available to mitigate potential interference problems to digital microwave systems is the use of fiber optics; however, factors to be considered in determining whether to use fiber optics over microwave systems are: transmission distance, start-up time, channel capacity and economics (including purchase of right-of-way for the fiber optic cables).

11. Interference between radar and microwave systems can often be mitigated by introducing fixes to either or both systems. However, it should not be assumed that a radar transmitter modification is either technically feasible or economically the best choice to mitigate interference cases. The advantages of using radar transmitter mitigation fixes, when practicable, include: 1) fixes for each affected receiver may be avoided, 2) additional flexibility may be afforded to designers of new microwave routes, and 3) no recurring costs for receiver mitigation fixes for newly deployed microwave systems.

Spectrum Management Issues

Spectrum management issues need to be resolved. Conclusions relating to those issues are below.

12. Many of the ground-based weather radar station assignments in the GMF do not contain information in the latitude and longitude field for seconds (degrees / minutes / seconds). Although this is not required in the GMF, the information is necessary to accurately assess the potential for interference.

13. The non-Government ground-based weather radar station assignments in the GMF and NGMF do not contain information on the nomenclature of the deployed equipment. The identification of the nomenclature of the radar is important in assessing the potential for interference.

14. The FCC Rules and Regulations (Title 47 Code of Federal Regulations, Part 90) require ground-based weather radars to be licensed as radiolocation service assignments (with a station class of RL) and, as such, are difficult to identify in the frequency licensing records of the FCC (no distinguishing station designator such as WXD).

15. A guideline for mitigation procedures should be developed for use when interference occurs from ground-based weather radars to digital microwave systems.

RECOMMENDATIONS

The following are NTIA staff recommendations based on the findings of this report. NTIA management will evaluate these recommendations to determine if they can or should be implemented from a policy, regulatory, or procedural viewpoint. Any action to implement these recommendations will be via separate correspondence modifying established rules, regulations and procedures.

1. Microwave system designers and operators use the methods and information presented in this report (e.g., use of RF filters, microwave network route planning/site selection, alternate bands, etc.) to identify and avoid the potential for interference between ground-based weather radars and new, or modified, digital microwave systems.

2. NTIA and FCC clarify national spectrum policy pertaining to spurious emission interference problems when systems are in compliance with applicable spectrum standards. The current government spurious emissions policy is contained in the NTIA Manual, Chapter 2, Section 2.3.7 (See Ref. 1, page 2-5). This section should indicate, providing appropriate spectrum standards are met, that an existing station is recognized as having priority over new or modified stations and engineering solutions may require the cooperation of all parties.

3. NTIA, in coordination with the FCC, hold discussions with major ground-based weather radar manufacturers to suggest that industry lead the way to reduce spurious emission levels of their ground-based weather radars (e.g., by incorporation of waveguide RF filters by the manufacturer). The insertion of waveguide filters in new ground-based weather radars will lower radar spurious emission levels, and thus, the potential for interference from these radars will be reduced. In addition, the insertion of these filters will assist in promoting the export of U.S. manufactured ground-based weather radars.

4. NTIA request that any Government agency surplusing ground-based weather radars through General Services Administration (GSA) or other agencies include in their disposal documents a statement requiring that if the purchasers wish to redeploy these systems, the redeployed radars shall contain waveguide filters.

5. NTIA, in coordination with the FCC, review and, if necessary, update the appropriate standards associated with ground-based weather radars operating in the shared 5350-5650 MHz band.

6. NTIA submit appropriate findings of this study for publication in international fora, such as the International Radio Consultative Committee (CCIR), to identify the various methods of resolving and avoiding interference between ground-based weather radars and microwave systems. This may help counter international pressures for severe restrictions on radar spurious emission levels.

7. The National Spectrum Managers Association (NSMA) establish a database of ground-based weather radars operating in the 2700-2900 MHz and 5350-5650 MHz bands as an aid in avoiding spectrum conflicts with new or modified microwave systems.

SECTION 3

RULES AND REGULATIONS

INTRODUCTION

In the United States, ground-based meteorological radar stations are authorized to operate on a primary basis in the 2700-2900 MHz and 5600-5650 MHz bands. Also, a large number of these meteorological radar stations operate in the 5350-5600 MHz bands on a secondary basis. This section contains the rules and regulations applicable to these systems. The National Allocations, definitions, and applicable footnotes for the 2700-2900 and 5600-5650 MHz bands are discussed along with the applicable technical standards for Government and non-Government meteorological aid radars. The frequency coordination processes for the ground-based Government and non-Government meteorological radar stations are also included in this section.

In the United States, the bands 3700-4200 and 5925-6425 MHz are exclusively allocated on a primary basis to non-Government use of Fixed and Fixed-Satellite Service (note: 3700-4200 MHz has downlink allocation and 5925-6425 MHz has uplink allocation.) The applicable rules and regulations for the common carrier microwave systems are not discussed in detail in this report and the reader is referred to Title 47 of the Code of Federal Regulation (CFR) Part 21.

NATIONAL ALLOCATION RULES

In the United States, the band 2700-2900 MHz is allocated for exclusive Government services as indicated in TABLE 3-1. The Government allocates this band to the Aeronautical Radionavigation and Meteorological Aids Services on a primary basis, and to the Radiolocation Service on a secondary basis. The radiolocation use is limited to the military services (footnote G2). All military service radiolocation assignments must be fully coordinated with the Meteorological Aids services as well as the Aeronautical Radionavigation services (footnote G15). Non-Government operations are permitted in this band (US18); however, these operations are subject to the conclusions of appropriate arrangements between the FCC and Government agencies concerned.

The band 5600-5650 MHz is allocated on a shared basis for Government and non-Government services as indicated in TABLE 3-2. The band is allocated to the Maritime Radionavigation and Meteorological Aids Services on a co-equal primary basis, and to the Radiolocation Service on a secondary basis. Government radiolocation service, although on a secondary basis, is primarily for the military services; however, limited use is permitted by other Government agencies in support of experimentation and research programs (footnote G56).

The bands 5350-5460, 5460-5470 and 5470-5600 MHz show no allocation for Government or non-Government Meteorological Aids Service; however, through a GMF record note (S144, See Record Note on Tables 4-1 and 4-2), a large number of these stations operate on a secondary basis.

TABLE 3-1

NATIONAL ALLOCATIONS FOR THE BAND 2700-2900 MHz			
BAND (MHz)	PROVISIONS	GOVERNMENT	Non-GOVERNMENT
2700-2900	US18 717 770	AERONAUTICAL RADIONAVIGATION METEOROLOGICAL AIDS Radiolocation G2 G15	

US Footnote:

US18 Navigation aids in the US and possessions in the bands 9-14 kHz, 90-110 kHz, 190-415 kHz, 510-535 kHz, and 2700-2900 MHz are normally operated by the US Government. However, authorizations may be made by the FCC for non-Government operation in these bands subject to the conclusion of appropriate arrangements between the FCC and the Government agencies concerned and upon special showing of need for service which the Government is not yet prepared to render.

Government Footnotes:

G2 In the bands 216-225, 420-450 (except as provided by US217,) 890-902, 928-942, 1300-1400, 2300-2450, 2700-2900, 5650-5925, and 9000-9200 MHz, the Government radiolocation is limited to the military services.

G15 Use of the band 2700-2900 MHz by the military fixed and shipborne air defense radiolocation installations will be fully coordinated with the meteorological aids and aeronautical radionavigation services. The military air defense installations will be moved from the band 2700-2900 MHz at the earliest practicable date. Until such time as military air defense installations can be accommodated satisfactorily elsewhere in the spectrum, such operations will, insofar as practicable, be adjusted to meet the requirements of the aeronautical radionavigation service.

International Footnotes:

717 The use of the bands 1300-1350 MHz, 2700-2900 MHz, and 9000-9200 MHz by the aeronautical radionavigation service is restricted to ground-based radars and to the associated air borne transponders which transmit only on frequencies in these bands and only when actuated by radars operating in the same band.

770 In the band 2700-2900 MHz, ground-based radars used for meteorological purposes are authorized to operate on a basis of equality with stations of the aeronautical radionavigation service.

TABLE 3-2

NATIONAL ALLOCATIONS FOR THE BAND 5600-5650 MHz			
BAND (MHz)	PROVISIONS	GOVERNMENT	Non-GOVERNMENT
5600-5650	US51 US65 772 802	MARITIME RADIONAVIGATION METEOROLOGICAL AIDS Radiolocation G56	MARITIME RADIONAVIGATION METEOROLOGICAL AIDS Radiolocation

US Footnotes:

US51 In the bands 5600-5650 MHz and 9300-9500 MHz, the non-Government radiolocation service shall not cause harmful interference to the Government radiolocation service.

US65 The use of the band 5460-5650 MHz by the maritime radionavigation service is limited to shipborne radars.

Government Footnotes:

G56 Government radiolocation in the bands 1215-1300, 2900-3100, 5350-5650 and 9300-9500 MHz is primarily for military services; however, limited secondary use is permitted by other Government agencies in support of experimentation and research programs. In addition, limited secondary use is permitted for survey operations in the band 2900-3100 MHz.

International Footnotes:

772 In the bands 2900-3100 MHz, 5470-5650 MHz and 9200-9300 MHz, the use of shipborne transponder systems shall be confined to the subbands 2930-2950 MHz, 5470-5480 MHz and 9280-9300 MHz.

802 Between 5600-5650 MHz, ground-based radars used for meteorological purposes are authorized to operate on a basis of equality with stations of the maritime radionavigation service.

TECHNICAL STANDARDS (Government and Non-Government)

The following is a discussion of technical standards pertaining to Government and Non-Government ground-based meteorological radar stations. Only technical standard requirements which affect the electromagnetic compatibility between meteorological radar stations and common carrier systems will be discussed in detail.

GOVERNMENT TECHNICAL STANDARDS

Chapter 5 of the NTIA Manual contains the technical standards, minimum performance requirements and design objectives that are applicable to telecommunication equipment used in the Government radio stations. However, within the Federal Government, any Government agency may promulgate more stringent standards for its own use.

The technical standards for Government meteorological radar stations depend on the date of the development and subsequent procurement contract and the frequency band of operation.

Radar Spectrum Engineering Criteria

The Radar Spectrum Engineering Criteria (RSEC) apply to all Government radar systems. RSEC specifications are contained in Part 5.3 of the NTIA Manual. The RSEC specifies certain equipment characteristics to ensure an acceptable degree of electromagnetic compatibility among radar systems, and between such systems and those of other radio services sharing the frequency spectrum. Since the initial adoption of the RSEC by NTIA there have been several revisions to the RSEC. The RSEC is applicable to Government ground-based meteorological radar stations built after January 1, 1973 and before October 1, 1977 (IRAC Doc. 13898/2). The RSEC Criteria C is applicable to Government ground-based meteorological radar stations effective October 1, 1977 (IRAC Doc. 19866). The RSEC Criteria D is applicable to ground-based meteorological radar stations operating in the 2700-2900 MHz band after October 1, 1982 (IRAC Doc. 22834).

While the specific technical requirements of the RSEC are omitted herein, the following list identifies the radar characteristics that are considered:

(1) Emission Bandwidth
(2) Emission Levels
(3) Antenna Patterns
(4) Frequency Tolerance
(5) Tunability
(6) Image and Spurious Rejection
(7) Local-oscillator Radiation

Since the common carrier systems do not operate in bands adjacent to meteorological radar stations, the requirements pertaining to emission levels and in particular the spurious emissions (emission floor level) are pertinent in determining the electromagnetic compatibility between the systems. The RSEC spurious emission level requirement is specified in dB, X, relative to the peak power level at the fundamental frequency. The procedure for measurement of the radar emission characteristics is documented in an NTIA report.[5]

For all radars developed and subsequent procurement contracts let after 1 January 1973 and before 1 October 1977, the RSEC spurious emission level requirement is:

$$\left.\begin{aligned} X(dB) &= 40 \text{ dB, or} \\ X(dB) &= P_t - 20 \log_{10}F_o + 100 \end{aligned}\right\} \text{ whichever is the larger value.} \qquad (3\text{-}1)$$

where: $P_t = P_p + 20 \log_{10}DC + 10 \log_{10}(1000/PRR)$

and: $X(dB)$ = Spurious emission level relative to the peak power
F_o = Nominal operating frequency, MHz
P_t = Maximum spectrum power density, dBm/kHz
P_p = Peak power, dBm
DC = Duty cycle = $t \times PRR \times 10^{-6}$
PRR = Pulse repetition rate in pulses per second
t = PW = Pulse width, microseconds (us)

For all radars which were developed and subsequent procurement contracts let after 1 October 1977, the RSEC Criteria C spurious emission level requirement is:

$$\left.\begin{aligned} X(dB) &= 60 \text{ dB, or} \\ X(dB) &= P_t + 30 \end{aligned}\right\} \text{ whichever is the larger value.} \qquad (3\text{-}2)$$

where: $P_t = P_p + 20 \log_{10}(Nt) + 10 \log_{10}(PRR) - PG - 90$

and: N = Total number of chips (sub-pulses) contained in the pulse (N = 1, for non-FM and FM pulse radars)
PG = Processing gain (dB)
PG = 0, for non-FM, non-coded pulse radars
PG = $10 \log_{10}(d)$, for FM pulse radars
PG = $10 \log_{10}(N)$, for coded pulse radars
t = PW = Emitted pulse duration in usec at 50% amplitude (voltage) points. For coded pulses, the pulse duration is the interval between 50% amplitude points of one chip (sub-pulse). The 100% amplitude is the normal flat top level of the pulse. (us)

The RSEC Criteria D became effective for all new fixed radars in the 2700-2900 MHz band on October 1, 1982. The RSEC Criteria D spurious emission level, X(dB), is 80 dB below the maximum spectral power density. In addition, all harmonic frequencies shall be at a level that is at least 60 dB below the maximum spectral power density.

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[5] Sell, John, Measurement Procedures for the Radar Spectrum Engineering Criteria, NTIA Report 84 - 157, U.S. Department of Commerce, National Telecommunications and Information Administration, August 1984.

Non-GOVERNMENT TECHNICAL STANDARDS

The standards for the non-Government radiolocation radar stations may be found in Title 47 of the U.S. Code of the Federal Regulations.[6] The FCC licenses weather radars (meteorological radar stations) as radiolocation stations. The characteristics which determine electromagnetic compatibility (EMC) are the transmitter power and authorized bandwidth. All of the technical standards pertaining to radiolocation stations may be found in Title 47 of U.S. Code of Federal Regulations, Part 90.

For Non-Government meteorological radar stations the spurious emission level must be attenuated below the mean output power of the transmitter at least 43 plus 10 $\log_{10}$(mean output power in watts) decibels or 80 decibels, whichever is the lesser attenuation.

$$\left.\begin{aligned} X\,(\mathrm{dB}) &= 43 + 10\log_{10}(P_{ave}), \quad \text{or} \\ X\,(\mathrm{dB}) &= 80\ \mathrm{dB} \end{aligned}\right\} \text{whichever is the lesser attenuation.} \qquad (3\text{-}3)$$

where: P_{ave} = mean output power in watts
P_{ave} = P_p in watts x DC

COMPARISON OF GOVERNMENT AND Non-GOVERNMENT STANDARDS

Figure 3-1 shows a comparison of Government and non-Government spurious emission level standards for meteorological radar stations. The comparison was made using a representative range of equipment characteristics given in Appendix C. Specifically, the duty cycle (DC) values used were 0.0007 (PW = 4.7 us and PRR = 150 PPS) and 0.002 (PW = 1.0 us and PRR = 2000 PPS).

The CFR Title 47 Part 90 limit for radiolocation spurious emission may be more stringent than the Radar Spectrum Engineering Criteria (RSEC) Criteria C. However, the measurement procedures need to be compared in detail (e.g., NTIA measurement procedure specifies peak power whereas the FCC specifies average power).

POLICY REGARDING SPURIOUS EMISSION INTERFERENCE

The Government policy regarding interference due to spurious emissions is contained in the NTIA Manual, Chapter 2, Section 2.3.7 and states, "In principle, spurious emissions from stations of one Radio Service shall not cause harmful interference to stations of the same or another Radio Service within recognized service areas of the latter stations, whether operated in the same or different frequency bands. (See Part 5.1 for considerations that must be taken into account in the application of this policy.)"

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[6] Federal Communications Commission, Title 47 Code of Federal Regulations, Telecommunications, Part 80 to End, Office of the Federal Register, National Archives and Records Administration, Revised as of October 1, 1988.

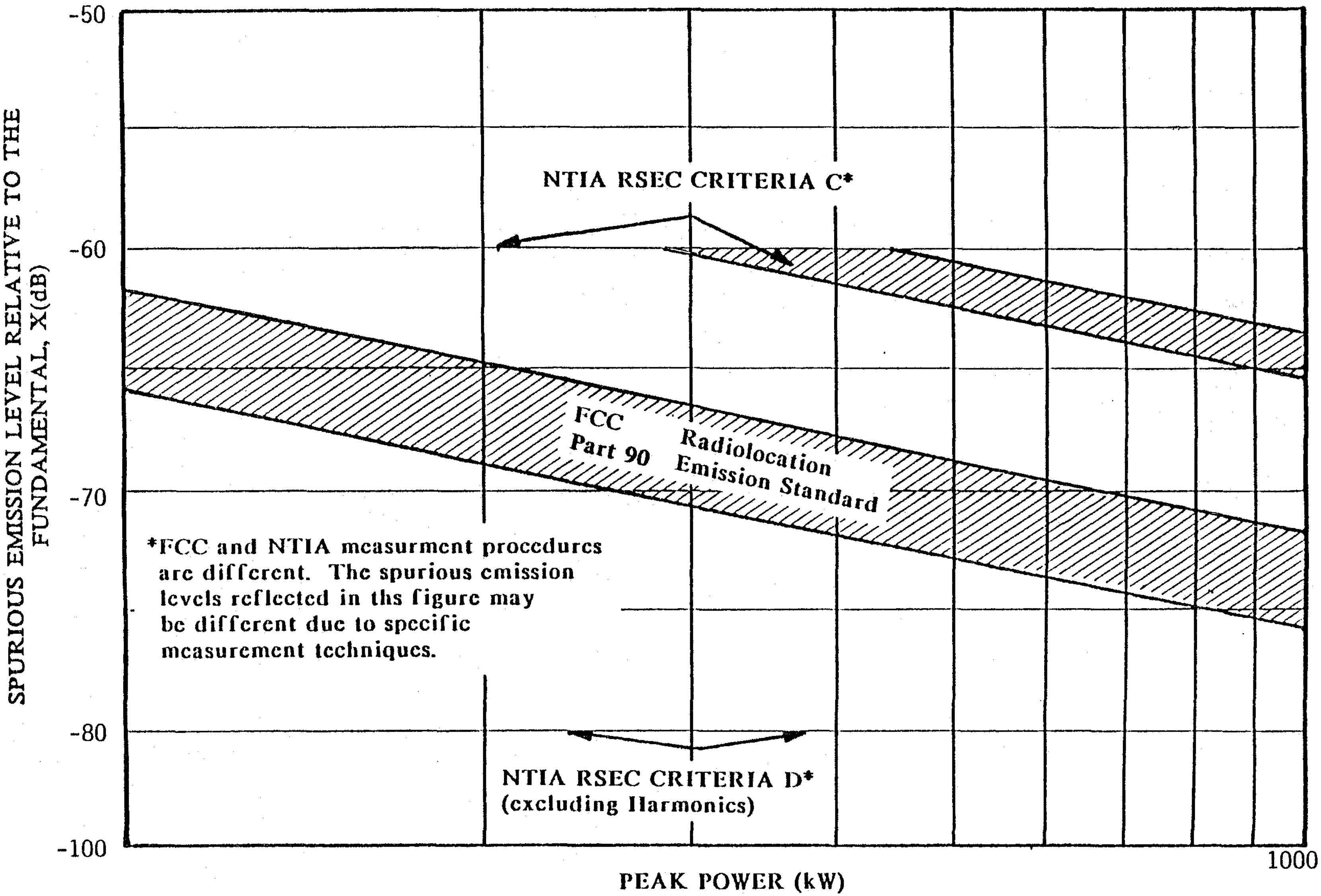

Figure 3-1. Comparison of spurious emission level standards for government and nongovernment meteorological radar stations.

The above policy does not address procedures for establishing the responsibility for mitigating spurious emission interference from stations conforming to applicable spectrum standards.

The Title 47 of the U.S. Code of Federal Regulations does not contain a policy regarding interference due to spurious emissions when systems are conforming to their applicable spectrum standards.

FREQUENCY COORDINATION PROCEDURES

Government Frequency Coordination Procedures:

The procedures and principles for the assignment and coordination of frequencies for Government agencies are contained in the NTIA Manual, Chapter 8. These procedures are as follows.

1. Each agency makes the necessary technical studies, selects potential frequencies, coordinates with other Government agencies involved, and prepares and files an application with the NTIA, Office of Spectrum Management (OSM), Frequency Assignment Branch (FAB), for consideration by the Frequency Assignment Subcommittee (FAS) of the Interdepartment Radio Advisory Committee (IRAC).

2. The FCC FAS Representative submits frequency assignment applications for non-Government use of the spectrum in shared bands and other bands where there might be an impact on, or from, Government operations.

3. The OSM/FAB reviews the applications for accuracy, completeness, and compliance with regulations and procedures. The FAS agendas are distributed on a daily basis to FAS member agencies for study regarding the protection of their existing assignments. For new major systems, agencies may submit requests for spectrum support certification to the Spectrum Planning Subcommittee (SPS) of the IRAC with certification granted by the NTIA.

4. The FAS, under established policy guidelines, considers frequency assignments on a daily basis. When additional policy guidance is necessary, the NTIA (with IRAC coordination) is consulted. Matters that cannot be resolved are referred to the Deputy Associate Administrator, OSM, NTIA who resolves them or refers them to the Administrator NTIA for decision.

5. Matters of considerable importance, such as changes to the National Tables of Allocations, significant Government use of non-Government frequency bands, etc. are recommended to NTIA for consultation with the FCC or other appropriate agencies. The FCC, which represents the public, may object, concur, or give tacit approval to important issues that may arise in the IRAC.

6. The Government Master File (GMF) is the file where frequency authorizations are recorded for exclusive Government frequency bands and shared Government and non-Government frequency bands. The NTIA GMF is updated to reflect those frequency assignment actions agreed to by the FAS member agencies and approved by the Deputy Associate Administrator, OSM, NTIA.

The NTIA Manual, Section 8.3.16 and Annex D, sets forth the procedures for field level selection and coordination of the use of radio frequencies in the 2700-2900 MHz band. The purpose of this procedure is to provide for the local selection of frequencies and to minimize, through effective coordination, the possibility of harmful interference in certain bands and geographical areas. This coordination procedure is applicable to the use of frequencies in the 2700-2900 MHz band by U.S. Government radio stations within the U.S. and Possessions.

Non-Government Frequency Coordination Procedures

Procedure for Obtaining a Radio Station Authorization and for Commencement of Operation:

Persons desiring to install and operate radio transmitting equipment must submit an application for a radio station authorization in accordance with the rules for the particular service. The FCC licenses weather radars as Radiolocation stations. The FCC permits the operation within the 5 GHz range for non-Government weather radar stations in the following bands:

Band	Limitations
5250-5350 MHz	1
5350-5460 MHz	2 & 3
5460-5470 MHz	2 & 4
5470-5600 MHz	2 & 5
5600-5650 MHz	6

(1) This frequency band is shared with and is on a secondary basis to the Government Radiolocation Service.

(2) Speed measuring devices will not be authorized in this band.

(3) This frequency band is shared with and is on a secondary basis to the Aeronautical Radionavigation Stations (Part 87) and to the Government Radiolocation Service.

(4) The Non-Government Radiolocation Service in this band is secondary to the Maritime Radionavigation Stations (Part 80) the Aeronautical Radionavigation Stations (Part 87) and the Government Radiolocation Service.

(5) This frequency band is shared with and is on a secondary basis to the Maritime Radionavigation Service (Part 80) and to the Government Radiolocation Service.

(6) This frequency band is shared with and is on a secondary basis to the Maritime Radionavigation Service (Part 80) and to the Government Meteorological Aids Service.

The procedures for licensing and coordination of non-Government meteorological radar stations are as follows:

1. Once the applicant determines, through manufacturers/applicant dialogue, that an FCC license is required, the applicant completes an appropriate application form and sends this form (along with any monetary fees) to the FCC, Land Mobile Branch at Gettysburg, PA 17326. (For meteorological radar stations, the form is FCC Form 574.)

2. FCC examiners at Gettysburg review the applications for accuracy, completeness (including signature), and compliance with regulations and procedures.

3. If IRAC coordination is required (shared Government/non-Government bands), the FCC examiner sends this transaction (through internal documentation) to the FCC, Office of Engineering and Technology (OET), Spectrum Engineering Division (SED), Frequency Liaison Branch (FLB), Washington, D.C. for that coordination.

4. The FLB Chief (FAS liaison representative) submits frequency assignment applications to the FAS for non-Government use of the spectrum in three cases: in shared Government/non-Government bands, in the Exclusive Government bands and in any band that has a contractor conducting operations on Government frequencies. The IRAC/FAS member agencies (representing the Government) may object, concur, or give tacit approval to important issues that may arise in the IRAC.

5. Once the FAS has approved this action, the assignment goes into the GMF and, in the same time frame, the FLB sends the approved action back to Gettysburg where they issue a license by mail. The newly licensed action is then placed into the non-Government master file (NGMF) database.

SECTION 4

SPECTRUM USAGE

INTRODUCTION

This section contains a description of the present and projected meteorological radar station environment in the 2700-2900 MHz and in the 5350-5650 MHz bands. Spectrum usage of these bands by various Government agencies as well as non-Government licensees is discussed. The equipment characteristics for present and planned meteorological radar stations are contained in Appendix C.

Also contained in this section is a brief discussion on common carrier spectrum use in the 3700-4200 and 5925-6425 MHz bands.

WEATHER RADAR SPECTRUM USAGE

The following is a discussion of the Government and non-Government spectrum usage by meteorological radar stations. The present spectrum usage data was obtained from the Government Master File (GMF), December 1988. The future Government spectrum usage requirement was obtained from various Government agencies and frequency management offices.

Present Environment

2700-2900 MHz band, Government. TABLE 4-1 shows the Government meteorological radar station assignments (Station Class WXD) and the equipment nomenclatures deployed in the 2700-2900 MHz band by agency. There are a total of 72 Government meteorological radar station assignments in this band. The Department of Commerce National Weather Service (NWS) has 97% of meteorological radar station assignments in the band. These NWS radars are used for precipitation detection and severe storm early warning. The equipment types deployed by the NWS are the WSR-57 and WSR-74S. Figure 4-1 shows the locations of Government meteorological radar station assignments in the 2700-2900 MHz band.

5350-5650 MHz band, Government. TABLE 4-2 shows the Government meteorological radar station assignments (Station Class WXD) that operate in the 5350-5650 MHz bands. There are 193 Government meteorological radar station assignments in the GMF of which 185 assignments are on discrete frequencies and 8 assignments operate under band assignments. Of these 193 assignments, 111 assignments are within the primary band allocated to the Meteorological Aids Service (5600-5650 MHz). Of those 111 assignments, 72 are Commerce/NWS, 37 are Air Force, 1 is Navy and 1 is other agency assignment.

The remaining 82 meteorological radar station assignments operate in the 5350-5600 MHz band under a special Record Note, S144 (defined in TABLE 4-1 and 4-2). Of these 82 assignments, 64 are Air Force, 10 are Navy, 2 are National Science Foundation and 6 are other agency assignments.

TABLE 4-1

STATISTICS ON GOVERNMENT METEOROLOGICAL RADAR STATION ASSIGNMENTS IN THE 2700-2900 MHz BAND

Agency	Number of Assignments	Bands (MHz)	Equipment Nomenclatures
Commerce/NWS	44	2700-2900	WSR-57
Commerce/NWS	16	2700-2900	WSR-74S
Commerce/NWS	3	2700-2900	WDS-73
Commerce/NWS	1	2700-2900	AN/FPS-18
Commerce/NWS	1	2700-2900 2900-3000*	Prototype/DOC
Commerce/NWS	1	2700-2900	WR100-5 (Commercial version of 74S)
NSF[a]	1	2700-2900	AN/FPS-18
NASA[b]	1	2700-2900	Prototype/NASA
Totals	68		

a = National Science Foundation
b = National Aeronautics and Space Administration

* **Record Notes:**

S144 This assignment is not in complete conformity with the National Table of Frequency Allocations. Those operations that are conducted under the nonconforming portions of this assignment are on a secondary basis to operations conducted under assignments that are in conformity with the National Table of Frequency Allocations.

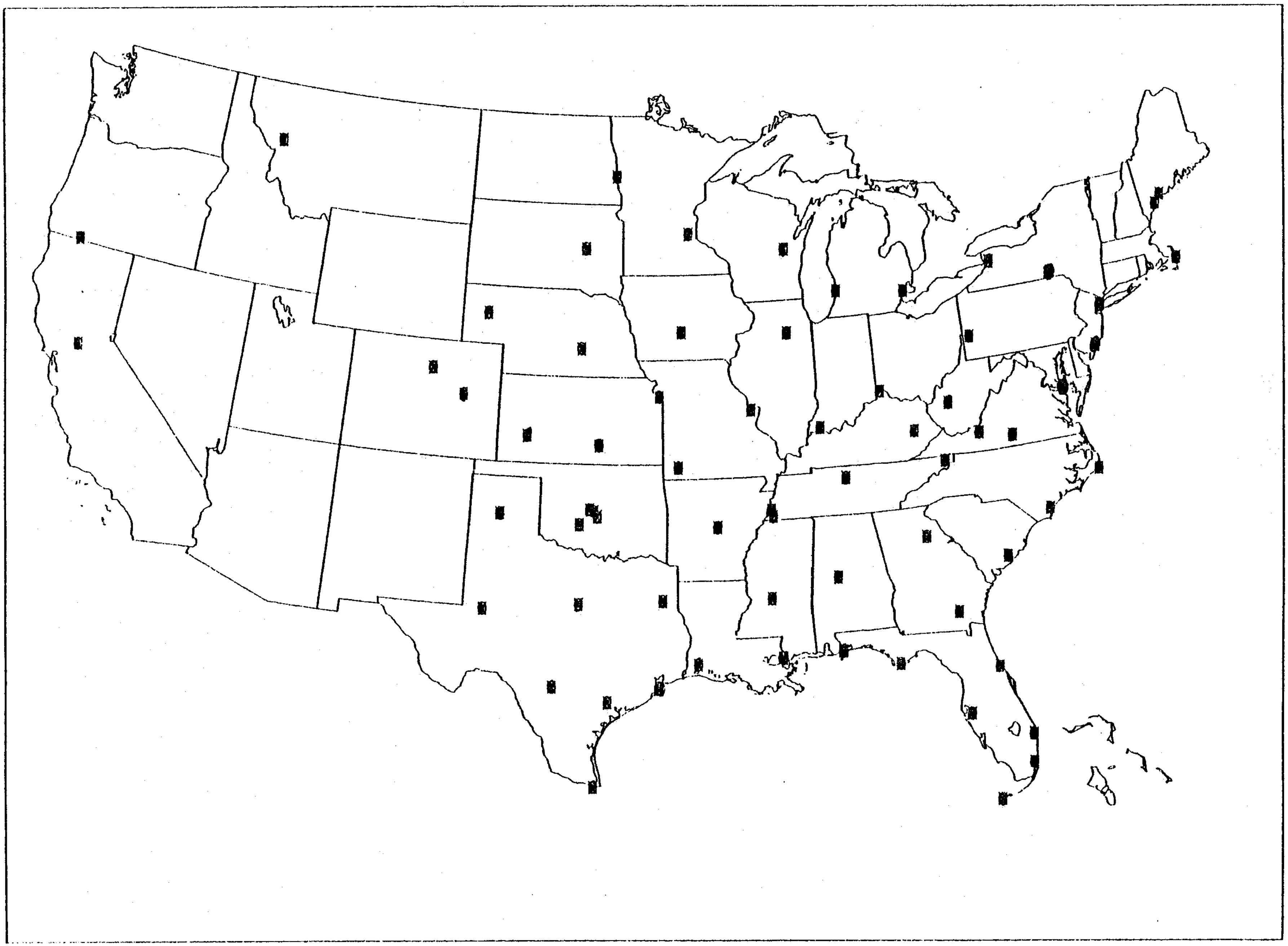

Figure 4-1. Government meteorological radar station locations in the 2700-2900 MHz band.

TABLE 4-2

STATISTICS ON GOVERNMENT METEOROLOGICAL RADAR STATION ASSIGNMENTS IN THE 5350-5650 MHz BANDS

Agency	Number of Assignments	Total per Agency	Bands (MHz)	Equipment Nomenclatures
Air Force	2		5350-5460*	WRT-701C
Air Force	2		5460-5650*	AN/FPS-077
Air Force	57		5460-5600*	AN/FPS-077
Air Force	1		5470-5600*	AN/FPS-106
Air Force	2		5470-5600*	AN/FPQ-21
Air Force	13		5600-5650	AN/FPS-077
Air Force	14		5600-5650	AN/FPQ-21
Air Force	10		5600-5650	AN/TPS-068
		101		
Commerce/NWS	72		5600-5650	WSR-74C
		72		
Navy	3		5460-5650*	AN/FPS-106
Navy	1		5460-5650*	AN/FPS-81
Navy	6		5470-5600*	AN/FPS-106
Navy	1		5600-5650	AN/FPS-106
		11		
NSF[a]	1		5350-5600*	CP-3
NSF[a]	1		5350-5600*	CP-4
		2		
Others	6		5350-5460*	WRT-701C
Other	1		5600-5650	WSR-74C
		7		
Totals	193			

[a] = National Science Foundation

* The Government meteorological radar assignments that do <u>not</u> operate in the primary band allocated to meteorological aids service (5600-5650) are subject to Record Note S144 and E039 (NTIA Manual, Annex A).

Record Notes:

S144 This assignment is not in complete conformity with the National Table of Frequency Allocations. Those operations that are conducted under the nonconforming portions of this assignment are on a secondary basis to operations conducted under assignments that are in conformity with the National Table of Frequency Allocations.

E039 The authorized emission bandwidth shall be so located within the band that it does not extend beyond the upper or lower limits of the authorized band shown in the *FRB entry of the circuit remarks. If a portion(s) of the authorized band is to be excluded (*FBE) the authorized emission bandwidth must not extend into any portion(s) of the excluded band(s).

The major equipment types deployed in the bands are the WSR-74C and AN/FPS-077 with 38% and 37% respectively. Figure 4-2 shows the locations of Government meteorological radar station assignments in 5350-5650 MHz band.

<u>5350-5600 MHz band, Non-Government.</u> The FCC licensees do not utilize the shared meteorological aids band of 5600-5650 MHz. TABLE 4-3 shows 158 non-Government (NG) meteorological radar station assignments that operate in the 5350-5600 MHz bands listed in the Government Master File. Of those 158 assignments, 144 are band assignments (tunable over a frequency range) per Record Note E039 and operate on a non-conformance basis per Record Note S144. Of the 144 assignments, over 60 are radiolocation (ground based doppler weather radar) assignments with transmitter output power of less than 55 dBm. The remaining 14 assignments operate on discrete frequencies and, per Record Note S144. Thus, all non-Government meteorological radar station assignments in the GMF operate on a non-conformance basis. Figure 4-3 shows the locations of non-Government meteorological radar station assignments in bands in the vicinity of 5600-5650 MHz. Information on equipment nomenclatures are not available for these stations.

Future Environment

<u>2700-2900 MHz band, Government.</u> A joint weather radar system developed by the Department of Commerce NWS, the Federal Aviation Administration (FAA) and Department of Defense (DoD) will be deployed in the 2700-2900 MHz band. This system, the Next Generation Radar (NEXRAD) system, will provide both reflectivity processing for precipitation detection and doppler processing for enhanced detection of tornados and microbursts (wind-shear). Current plans are for deployment of the NEXRAD radar systems during the 1990-1994 time frame. Plans are for 113 NWS sites and 25 DoD sites. The 16 FAA sites are for a variant of the NEXRAD system, designated Interim Terminal Weather Radar (ITWR), at 16 high-density airport locations for wind-shear detection and close-in forecasting. Plans are to install these ITWR radars between 1990 and 1992, and to replace them under FAA/NWS agreement, with the Terminal Doppler Weather Radar (TDWR) system. Figure 4-4 shows the planned NWS and DoD locations of the NEXRAD stations.

The IRAC Spectrum Planning Subcommittee (See Ref. 1, Chapter 8, para. 8.3.1 to 8.3.7, pages 8-23 to 8-35) has given spectrum support to the NEXRAD system and the NTIA has granted spectrum certification (IRAC Doc. 25627) for the NEXRAD system. Complete information on spectrum support for the NEXRAD system can be found in SPS IDN 87-52. The NEXRAD system is the first radar built that complies with RSEC Criteria D which has more stringent spurious emission level limits than Criteria C. Also, NTIA approved a U.S. footnote to allow the NEXRAD system to operate above 2900 MHz up to a maximum frequency of 3000 MHz (IRAC Doc. 25612). The NEXRAD radars can use the 2900-3000 MHz band when an assignment cannot be made available within the 2700-2900 MHz range. (Note: Although NTIA, with IRAC concurrence, has approved the US footnote, the FCC must complete its proceeding on this footnote before it becomes applicable).

The current NWS 2700-2900 MHz radars will be removed from service and declared surplus Government property as they are replaced by the WSR-88D (NEXRAD) radar. The 30 year old WSR-57 units will be scrapped after all useful parts have been removed. The first WSR-74S units to be decommissioned will also be used for spare parts. However, later units will be declared surplus on site, when possible, through the General Services Administration (GSA). The Army has contracted for the purchase of two DWSR-88S meteorological radars for operational use in late 1989 for deployment at White Sands Missile Range.

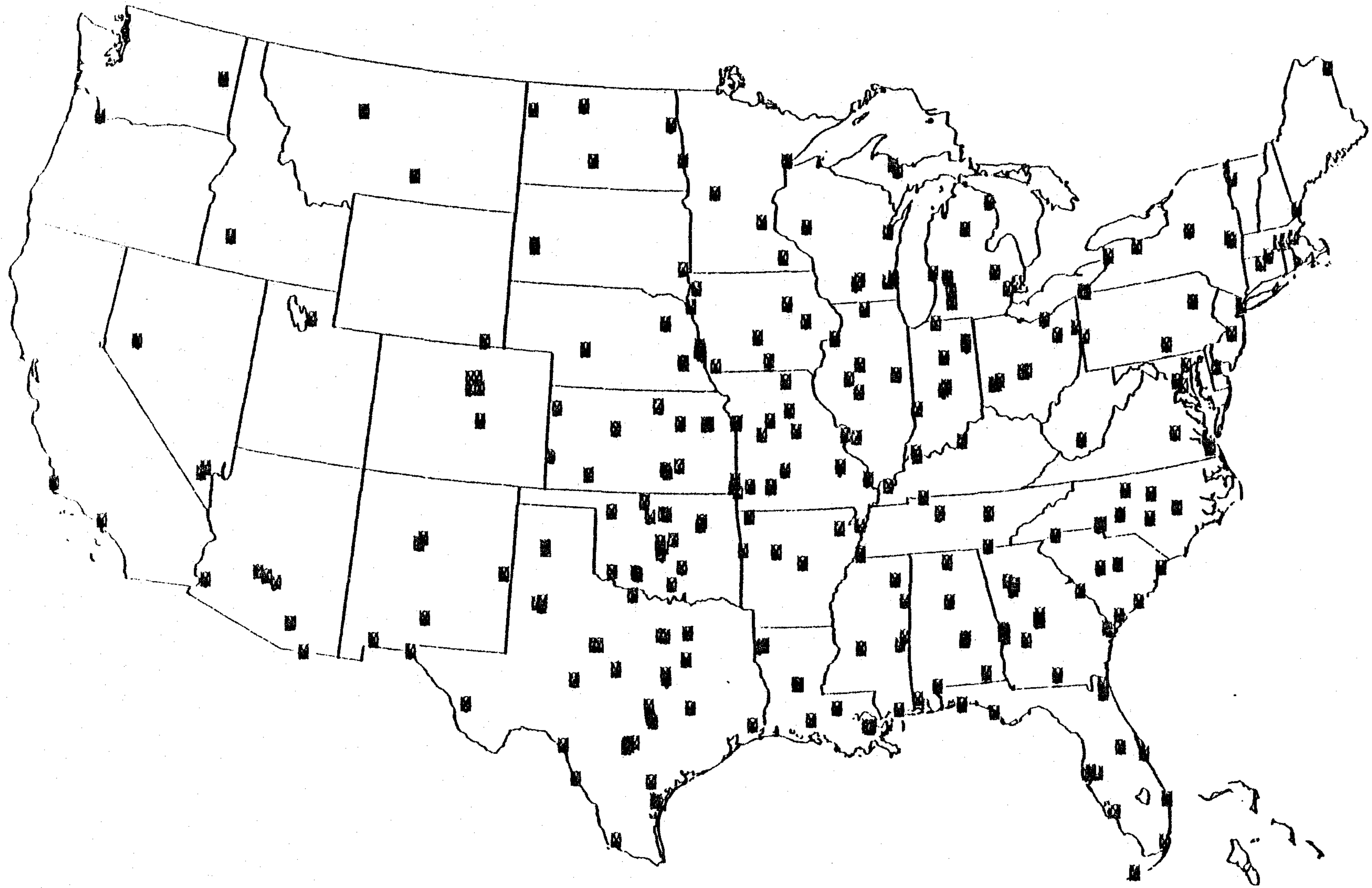

Figure 4-2. Government meteorological radar station locations in the 5600-5650 MHz band and in the vicinity of 5600-5650 MHz.

TABLE 4-3

STATISTICS ON Non-GOVERNMENT METEOROLOGICAL RADAR STATION ASSIGNMENTS IN THE 5350-5600 MHz BANDS

Use	Number of Assignments	Bands (MHz)
Non-Government	100	5350-5460
Non-Government	1	5380-5420
Non-Government	2	5350-5600
Non-Government	1	5460-5470
Non-Government	54	5470-5600
Total # of Assignments	158	

In summary, by 1994, it is estimated that the number of Government meteorological radar stations in the 2700-2900 MHz band will increase approximately 130% (72 to 169) within continental United States (CONUS).

5600-5650 MHz band, Government. The FAA plans to deploy the Terminal Doppler Weather Radar (TDWR) systems for weather forecasting and wind-shear detection within 16 km (10 miles) of airports at 47 sites by 1994. The TDWR system uses technology developed for the NEXRAD system. Figure 4-5 shows the planned locations for the TDWR systems for the 47 sites. The FAA may deploy an additional 55 TDWR systems in 1995 and 1996.

At 16 sites, under FAA/NWS agreement, the FAA plans to utilize the NEXRAD system (ITWR system defined earlier in future use of 2700-2900 MHz) because the NEXRAD system is planned somewhat earlier than the TDWR system. When the TDWR system becomes operational, the FAA will discontinue using the NEXRAD system and utilize the TDWR system for wind-shear detection and close-in weather forecasting. The TDWR system has spectrum certification (IRAC Doc. 25877) and complete information on spectrum support for the TDWR system is found in SPS IDN 87-55.

NWS is currently in the process of formulating a policy for surplusing the existing WSR-74C radars through GSA after the implementation of NEXRAD. DoD plans for the installation of the NEXRAD radars are dependent upon the availability of the necessary funding. If the funding is provided, the plan currently calls for the installation to be finished in 1995. Even if that schedule is met, the currently used AN/FPS-77 and AN/FPQ-21 weather radar systems will not be completely taken out of service until approximately 1997. It is expected to take that long to complete all necessary testing on the NEXRAD systems. Note that even after 1997, the Air Force may used some of the present day systems in back-up roles.

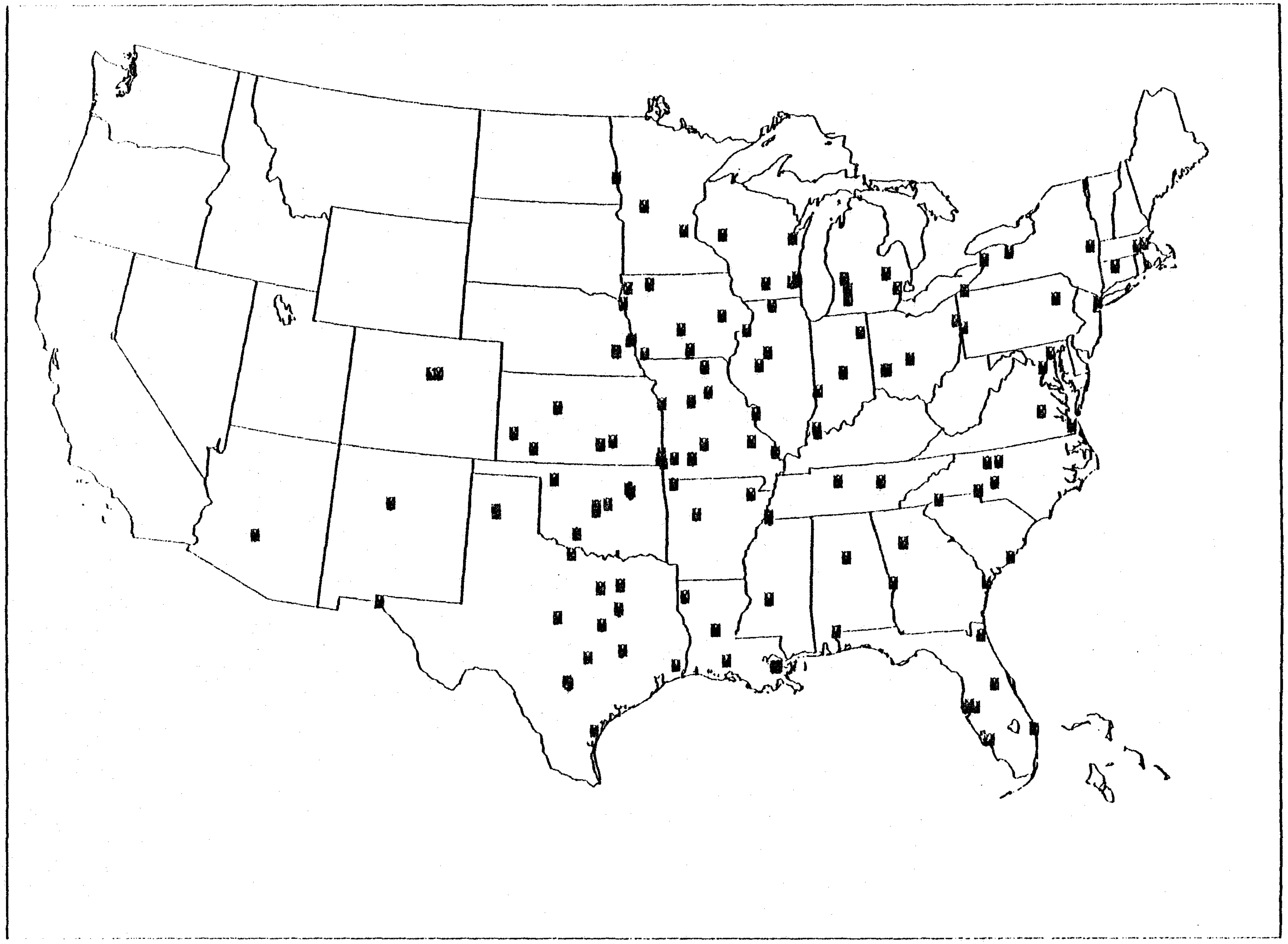

Figure 4-3. Non-Government meteorological radar station locations in bands in the vicinity of 5600-5650 MHz.

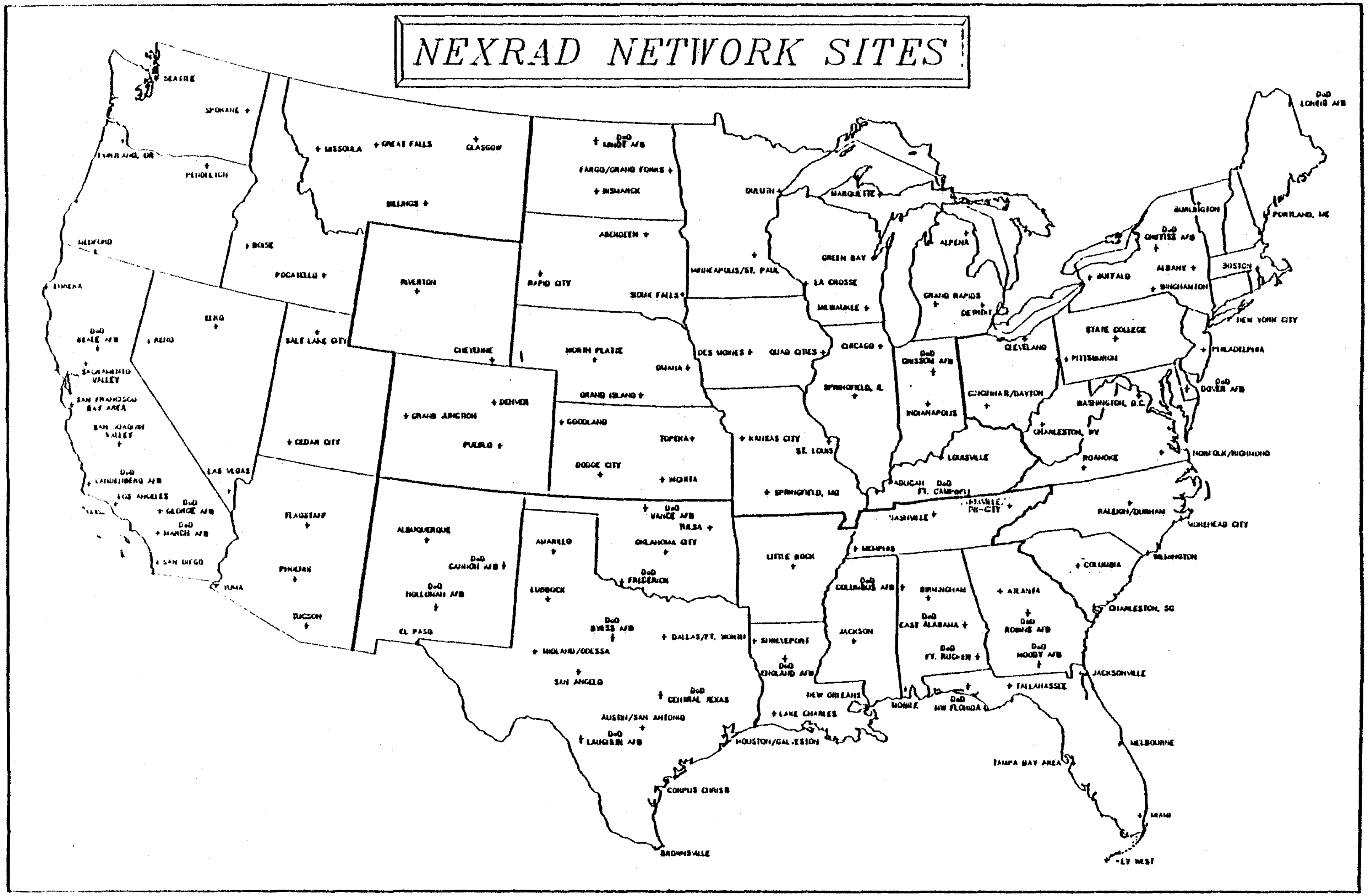

Figure 4-4. Planned U.S. NEXRAD sites utilizated by NWS and DoD by the year 1994.

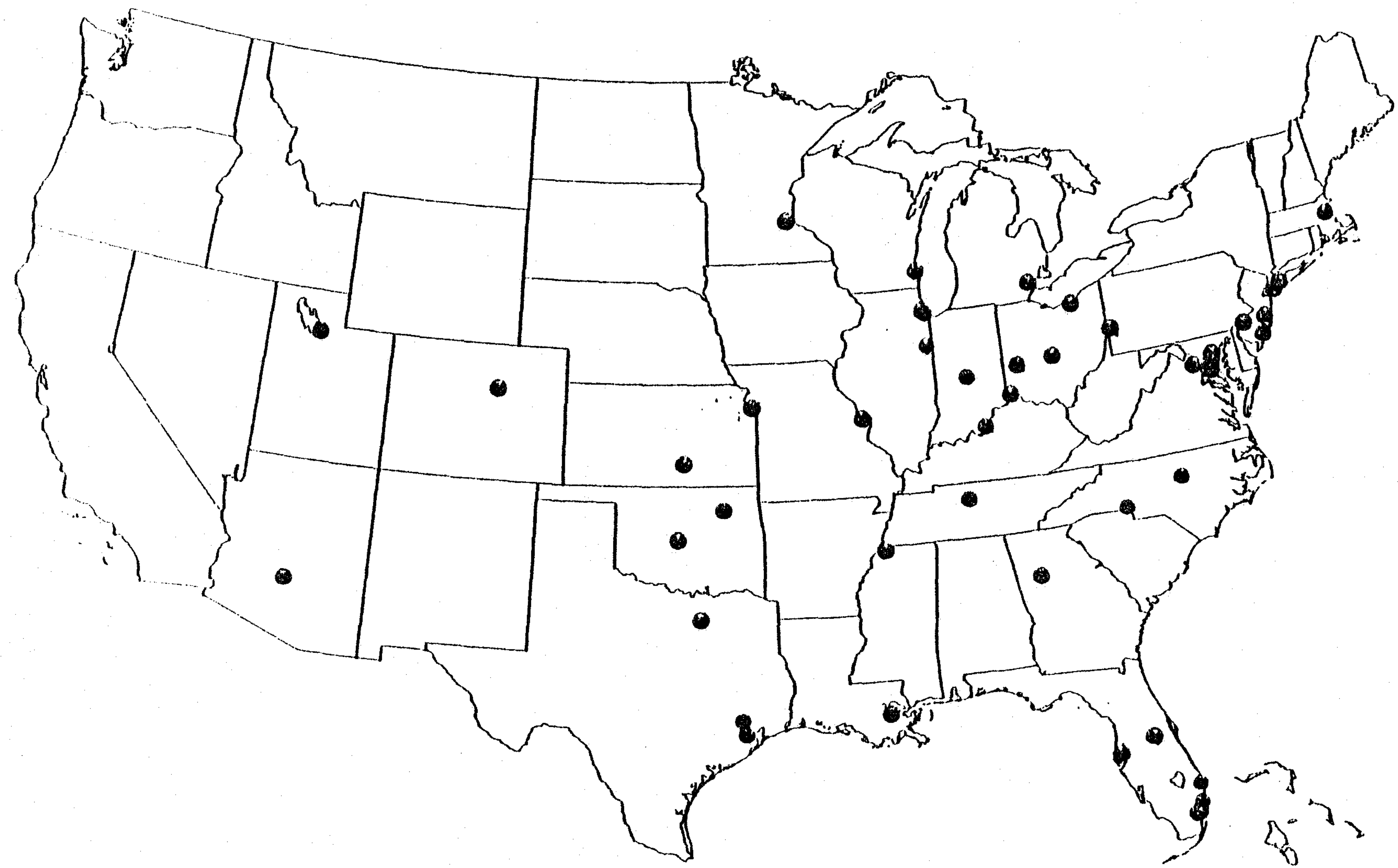

Figure 4-5. Projected FAA TDWR U.S. sites by the year 1994.

Other Government agencies may still use the band(s) 5350-5600 MHz for weather observation, but may decide that the NEXRAD system will suffice for all their weather forecasting needs in the future.

In summary, by 1994-1997 timeframe, it is estimated that the number of Government meteorological radar stations in bands in the vicinity of 5600-5650 MHz will decline approximately 60% (193 to 80) within CONUS.

5350-5600 MHz band, Non-Government. Future use of radars for meteorological purposes by non-Government licensees in the 5350-5600 MHz bands is unknown. However, manufacturers are continuing to produce equipments that operate within these bands with trend towards the new radars using doppler processing.

5600-5650 MHz band, Non-Government. There is no known existing or planned use by non-Government licensees of the shared band 5600-5650 MHz. Future use by the Collins Ground Based Doppler Radar will not utilize the 5600-5650 MHz based on technical considerations unless they change their frequency of operation (see equipment characteristics) in Appendix C. Future use by radar manufacturers apparently will not occur in the 5600-5650 MHz band based on the FCC procedures (see Section 3 under non-Government Frequency Coordination Procedures/Limitation 6).

COMMON CARRIER SPECTRUM USAGE

Common carrier use of the 4 GHz band (3700-4200 MHz) began in the late 1940s and has developed into a network of over 5,000 point-to-point microwave stations in the continental United States. This band is shared with several million earth station receiver facilities, over 11,000 of which are licensed and therefore afforded interference protection. (The remainder are unlicensed "backyard" earth stations.) The band is also used for temporary fixed point-to-point microwave to accommodate emergency restoration, service emergencies and occasional video relays.

Similarly, 6 GHz common carrier band (5925-6425 MHz) usage has grown from its start in 1953 to include over 11,000 point-to-point microwave stations nationwide and over 1500 earth station transmitting facilities.

Typical path lengths in these bands are about 25-30 miles (40-48 km). Scatter charts of the 4 GHz and 6 GHz band point-to-point common carrier installations are shown in Figures 4-6 and 4-7.

Each of the 4 GHz stations is potentially capable of using the 12 pair of 20 MHz bandwidth channels allocated to this service on both vertical and horizontal polarization; currently, systems using 90 Mb digital 64-QAM have the capability of carrying 1344 equivalent voice grade channels or 1800 voice grade circuits using analog technology.

The 6 GHz band is divided into 8 pairs of 30 MHz channels allowing 135 Mb digital 64-QAM which will support 2016 equivalent voice grade channels or 2400 analog circuits using analog FM modulation, or 6000 circuits using AM-SSB modulation.

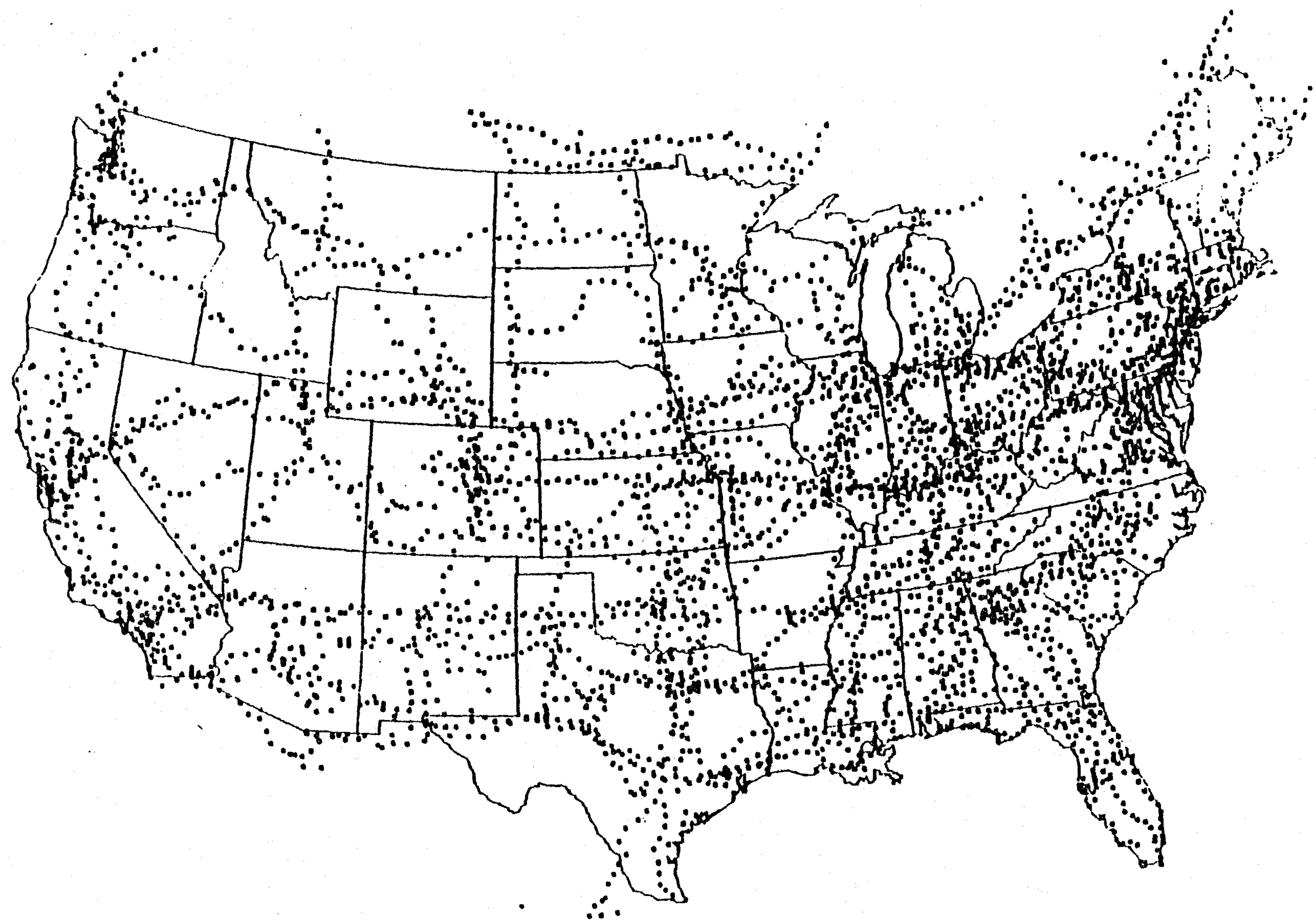

Figure 4-6. 4 GHz point-to-point common carrier stations.

Figure 4-7. 6 GHz point-to-point common carrier stations.

Because of the demands of the marketplace for digital connectivity, common carriers are generally migrating from analog to digital systems as the need or opportunity arises.

The method for accommodation of new or changed facilities into these two bands on a non-interference basis involves a process of prior frequency coordination specified by the FCC in CFR47 Section 21.100 (d) (for terrestrial facilities) and Section 25.203 (for earth stations) which requires that those proposing new facilities first verify that the design of candidate stations is such that they will produce negligible interference to existing (or previously designed and coordinated) facilities and will receive similarly unaffecting levels of RF radiation from all other stations.

Allowable cochannel and adjacent channel interference levels used in this prior coordination process are based on the potential for multiple exposures under varying atmospheric conditions when the desired received signal is faded to the design limit.

Proposed microwave system stations, typically with output powers in the one to five watt range, which would produce interfering signals to licensed and previously coordinated stations of levels in excess of approximately -130 dBW (terrestrial) or -154 dBW per 4 kHz of bandwidth (satellite) at the receiver input would be unlikely to receive the required prior coordination approvals described in the previous paragraph, and therefore may not be authorized. Computation of these levels routinely take into account such factors as transmitter power, transmit and receive antenna discriminations, path loss, transmission loss and network loss.

Currently, industry practice is to verify non-interference with operators of terrestrial stations within 125 to 150 miles (201 to 241 km) of the proposed facility; extension of this distance to over 200 miles (322 km) within the arc of the antenna main lobe, producing a "keyhole" topology for analysis of interference effects, is becoming common practice. Operators of stations within this coordination area study technical details of each proposal. Their acceptance, or lack of objection, is required before the FCC will proceed with the licensing process for the new facility. Prior Coordination Notices (PCNs) reflecting this type of activity are issued in excess of 7,000 times each year, indicating a high level of construction and upgrade activity.

This process has resulted in a dense network of carefully designed facilities which takes advantage of all available techniques to minimize interference among stations. It also encourages the development of more accurate interference prediction methodologies. As the lower microwave bands have become more congested, there has been a trend to use higher bands which are less congested. In the higher bands, however, problems are introduced which relate to propagation losses and rainfall attenuation. Therefore, these bands are not always suitable or cost-effective alternatives. As a result, methods are being developed to even more intensely use the lower bands. For example, the industry is studying, and attempting to more accurately predict, reflection of radiated microwave energy which may produce unexpected interference in another station which has no direct path exposure to the interfering transmitter, but may experience interference via reflected paths. The shielding loss of various types of structures, when in the vicinity of earth station installations, is also being explored to improve interference prediction capabilities.

SECTION 5

EMC ANALYSIS AND INTERFERENCE EFFECTS

INTRODUCTION

This section contains the analysis procedures for establishing the distance around meteorological radar stations for use in determining when detailed EMC analysis may be required. The interference coupling mechanisms, radar pulsed emission effects and protection threshold for microwave radio-relay systems and possible coupling paths are discussed.

COUPLING MECHANISMS

The following is a discussion of how the radiated energy from the meteorological radar stations is coupled into digital common carrier radio-relay microwave systems. Investigation of several interference cases have identified two coupling mechanisms: microwave radio-relay system front-end overload (desensitization) at the radar fundamental frequency and radar spurious emission in the common carrier bands.

Microwave Front-end Overload

Some digital microwave systems use a low-noise preamplifier in the waveguide run ahead of the channel dropping or separating filters. These low-noise preamplifiers enhance the desired signal and preserve the noise figure of the receivers which would otherwise be degraded by the insertion loss of the channel filters. Although the digital radio-relay systems operate in bands not adjacent to the meteorological radar stations, energy from the fundamental frequency of these radars may enter and saturate the low-noise amplifiers. When this occurs, the amplifier may be blocked for considerably more than the pulse duration and severe errored seconds usually occur. Front-end overload may be mitigated by the insertion of an RF filter in the receiving waveguide ahead of the low-noise amplifier or using individual low-noise amplifiers following the channel separating filters.

The coupling mechanism of front-end overload from the 5 GHz meteorological radars has been observed only in digital radio-relay systems operating in the 5925-6425 MHz band. For digital radio-relay systems operating in the 3700-4200 MHz range utilizing a conical horn reflector antenna with a circular waveguide (WC 281) reducing down to a square waveguide (WS-179), the fundamental energy of the 2.7-2.9 GHz meteorological radars is reflected out of the horn antenna due to the waveguide cut-off frequency of 3.26 GHz of the WS-179. However, digital radio-relay systems in the 3700-4200 MHz that use standard parabolic reflector antennas with rectangular waveguide (WR-229), the waveguide cut-off frequency is 2.58 GHz. Thus microwave systems that use WR-229 waveguide may be susceptible to front-end overload. A detailed discussion of the coupling mechanism of front-end overload is given in Appendix B.

Radar Spurious Emissions

Since the common carrier systems do not operate in bands adjacent to meteorological radar systems, the inherent spurious emissions of tubes in the meteorological radar systems determine the level of radar energy radiated in the common carrier bands. The level of the radar spurious emissions are independent of the radar pulse modulation (i.e., pulse width). The predominant factor that governs the level of spurious emissions in the common carrier bands is the radar output device. Types of output devices used in meteorological radar stations are: magnetrons (conventional and coaxial), klystrons and solid state multiplier diodes.

To characterize the spurious emission levels for the various types of output devices used in meteorological radar systems the NTIA Radio Spectrum Measurement System (RSMS) van was used to perform radar measurements. The measurements were made using a 1 MHz reference bandwidth which is a standard measurement bandwidth used for the measurement of spurious emissions.[7] The RSMS receiver noise floor for a 1 MHz bandwidth is -95 dBm.

Magnetrons. Two types of magnetrons are used in meteorological radar stations, conventional and coaxial. The nominal output peak power for these tubes is 84 to 87 dBm (see Appendix C). Figures 5-1 and 5-2 show radiated measurements of a WSR-57 radar which uses a conventional magnetron tube. The measured spurious emission levels from the WSR-57 in the 3700-4200 MHz band were -70 to -96 dBc (dBc is dB relative to the fundamental carrier) and in the 5925-6425 MHz band were -96 to below -122 dBc (see note on TABLE 5-1 for further definition of "below").

The trend, in recent years, has been toward coaxial magnetrons for use in weather radars because of their cleaner emission spectrum around the fundamental operating frequency. The measurements made on the WSR-74S at three locations (Figures 5-3 through 5-7) show the variation of the spurious emission levels in the 3700-4200 MHz band to be -76 to below -135 dBc and in the 5925-6725 MHz band to be -112 to below -124 dBc. Figures 5-8, 5-9 and 5-10 show radiated emission spectrum measurements of WSR-74C and WR100-2 which use a coaxial magnetron. Figure 5-11 shows radiated emission measurements of the DWSR-88CTV which uses a coaxial magnetron for doppler processing. The measured spurious emission levels in the 3700-4200 MHz band were -101 to below -110 dBc and in the 5925-6425 MHz band were -56 to -101 dBc. The variation in the spurious emission levels for the same or similar nomenclatures are attributed to several phenomena: impedance matching of the transmission line and radar output tube, relative age of the coaxial magnetron used and the pulse shaping (filtering) network.[8]

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7 Skolnik, Merrill I., Radar Handbook, McGraw-Hill Book Company, copyright 1970, pp 7-42.

8 Hinkle, Robert L., Pratt, Robert M., Matheson, Robert J., Spectrum Resource Assessment in the 2.7 to 2.9 GHz Band, Phase II: Measurement and Model Validation (Report No. 1), OT Report 76-97, United States Department of Commerce, Office of Telecommunications, Washington, D.C., August 1976, pages 43, 44, 71, 72, 74-76.

Meteorological radar stations which use coaxial magnetrons and have the capability to perform doppler processing, prime or injection lock the coaxial magnetron. Discussions with U.S. manufacturers have indicated that priming/injection locking of magnetron tubes will reduce the spurious emission level by an additional 10 dB.

Klystrons. New Government meteorological radars planned for deployment in the early 1990's (NEXRAD and TDWR) will use klystron output tubes. The nominal output peak power for these tubes is 84 to 89 dBm (see Appendix C). Radiated measurements made with the RSMS van show the klystron tube spurious emission levels to be approximately -110 to -120 dBc measured with a 1 MHz bandwidth.[9] Figure 5-12 shows the radiated RSMS spectra measurements of spurious emission levels for the test and evaluation NEXRAD radar at Norman, OK. The measured spurious emission levels in the 3700-4200 MHz band were below -110 dBc and in the 5925-6425 MHz were below -110 dBc. For the NEXRAD (WSR-88D) radar, no pulses were detected in the 4 and 6 GHz common carrier bands.

Multiplier Diodes. Solid state multiplier diode output devices are used in affordable low power meteorological radars. The nominal output peak power for these tubes is 53 dBm (see Appendix C). These radars use a series of multiplier diodes to produce pulses. Figure 5-13 shows radiated RSMS spectra measurements of the spurious emission levels for the solid state Ground Based Doppler Weather Radar (measured with a 1 MHz bandwidth). The measured spurious emission levels in the 3700-4200 MHz band were -80 to below -90 dBc and in the 5925-6425 MHz were below -90 dBc. For the WRT-701C radar, no pulses were detected in the 4 and 6 GHz common carrier bands.

Summary. The meteorological radars which use conventional or coaxial magnetrons are the only radars that are likely to cause interference to digital radio-relay systems due to high spurious emission levels. TABLE 5-1 is a summary of the spurious emission characteristics for magnetron output tubes that are used in meteorological radar stations in the frequency ranges of 2700-2900 MHz and 5350-5650 MHz.

FREQUENCY-DEPENDENT REJECTION (Peak Power)

The frequency separation between meteorological radar stations in the 2700-2900 MHz band and the nearest affected common carrier radio-relay band at 3700-4200 MHz is 800 to 1500 MHz. The frequency separation between the 5350-5650 MHz meteorological radar stations and the nearest affected common carrier radio-relay band at 5925-6425 MHZ is 275 to 1075 MHz. At frequency separations of this magnitude (approx. 300-1500 MHz) the inherent spurious emissions of the radar governs the level of interference coupled into the microwave radio-relay receiver (as seen early this section under Radar Spurious Emissions). Figure 5-14 thru 5-19 show representative radiated RSMS spectra measurements of the spurious emission levels for conventional and coaxial magnetrons (measured with 30 MHz bandwidth).

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9 Hinkle, Robert L., Background Study On Efficient Use Of The 2700-2900 MHz Band, NTIA Report 83-117, United States Department of Commerce, National Telecommunications and Information Administration, Washington, D.C., April 1983, pages 43, 44, 71, 72, 74-76.

TABLE 5-1

SPURIOUS EMISSION CHARACTERISTICS OF CONVENTIONAL AND COAXIAL MAGNETRONS IN THE COMMON CARRIER BANDS

Nomenclature	Radar Output Devices	Spurious Emission Range Relative To Radar Fundamental Level (dBc) (measured in a 1 MHz bandwidth)	
		3700-4200 MHz	5925-6425 MHz
WSR-57	Conventional Magnetron	- 70 to - 96	- 96 to below - 122
WSR-74S	Coaxial Magnetron	- 76 to below - 135	- 112 to below - 124
WSR-74C (WR100-2/-5)	Coaxial Magnetron	- 101 to below - 110	- 56 to - 101
WSR-88D	Klystron	below -110	below -110
WRT-701C	Multiplier Diode	- 80 to below - 90	- 85 to below - 90

note: "Below" indicates that the noise floor-level of the measurement receiver, - 95 dBm, was reached and the spurious emission level range may be less than indicated.

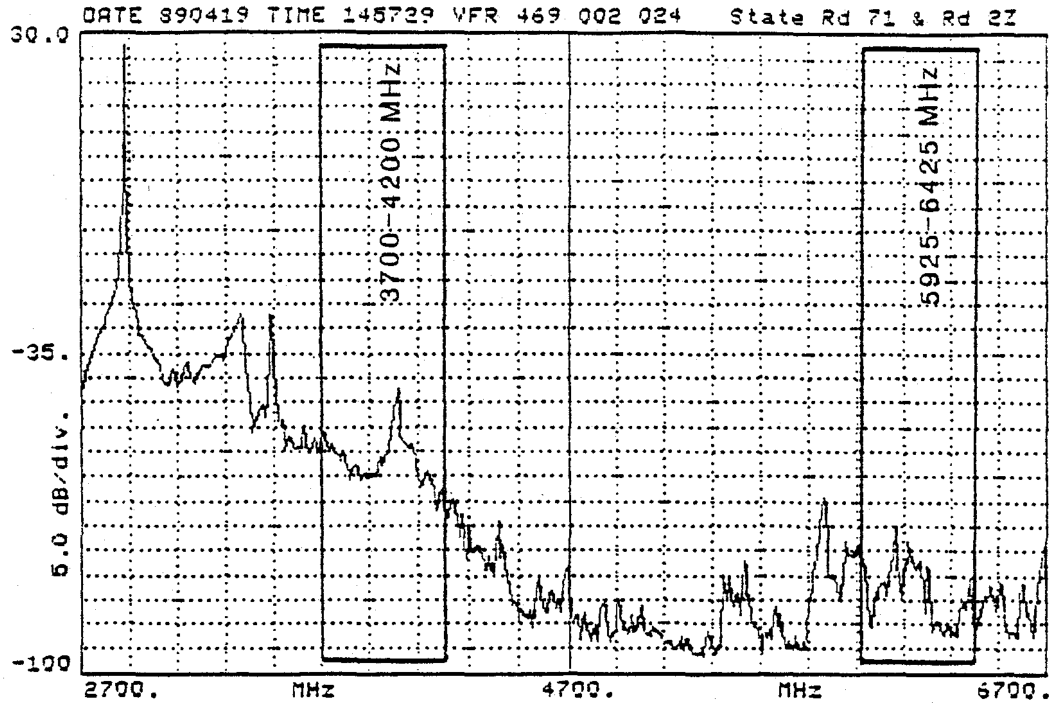

Figure 5-1. Radiated spectrum measurements of the WSR-57 radar at Limon, CO, (pulsewidth = 1 μs).

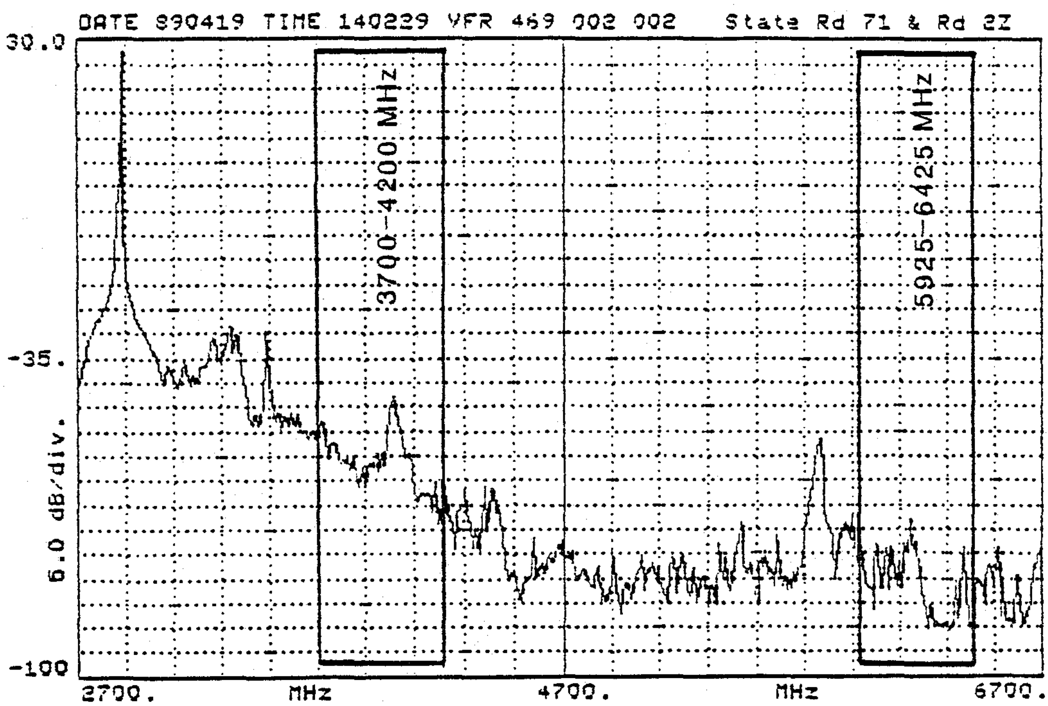

Figure 5-2. Radiated spectrum measurements of the WSR-57 radar at Limon, CO, (pulsewidth = 4 μs).

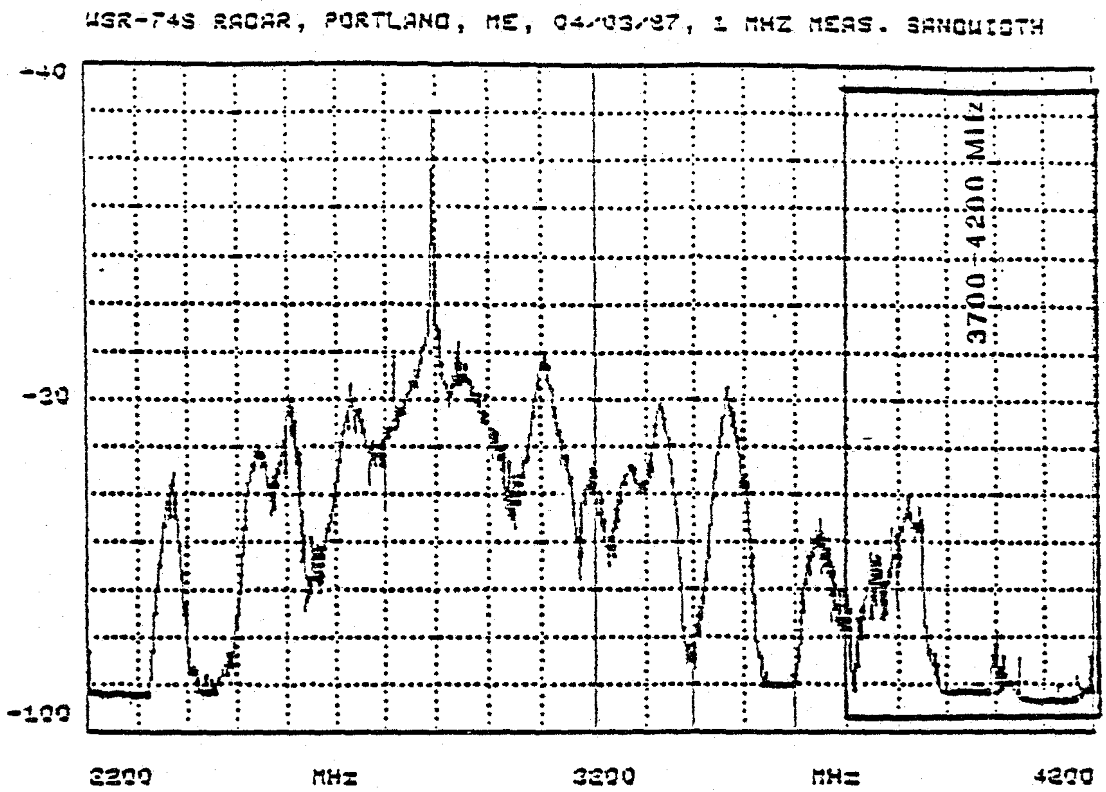

Figure 5-3. Radiated spectrum measurements of the WSR-74S radar at Portland, ME, (pulsewidth = 4 µs).

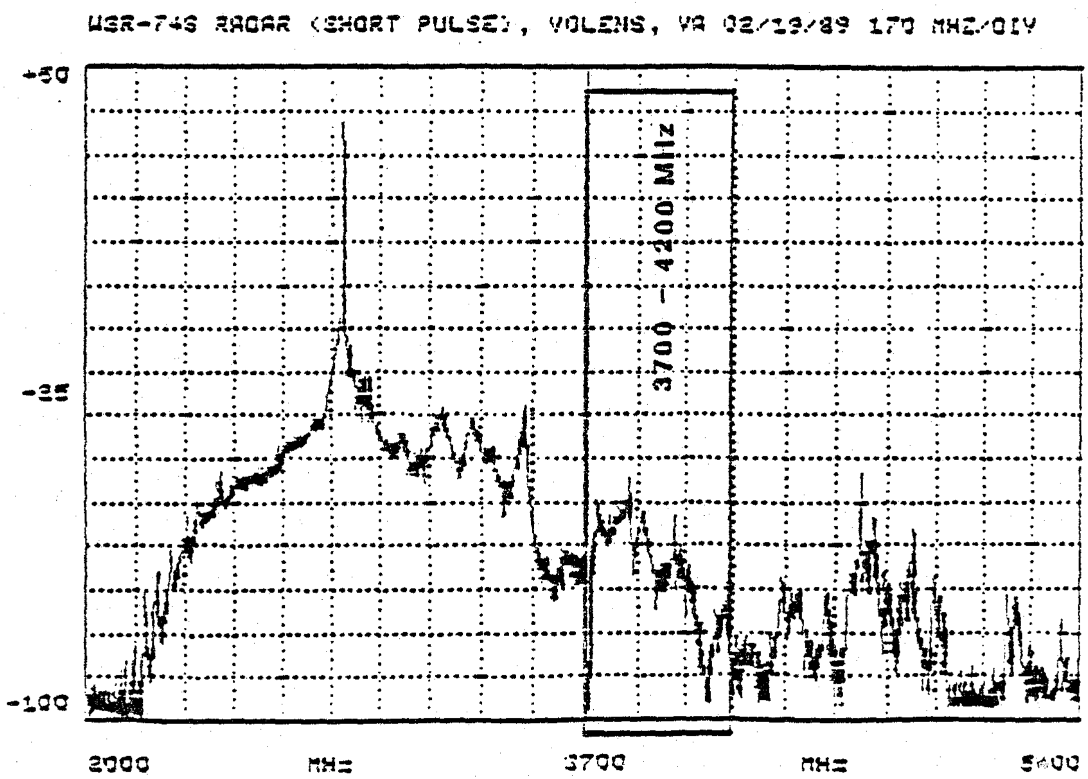

Figure 5-4. Radiated spectrum measurements of the WSR-74S radar at Volens, VA (pulsewidth = 1 µs).

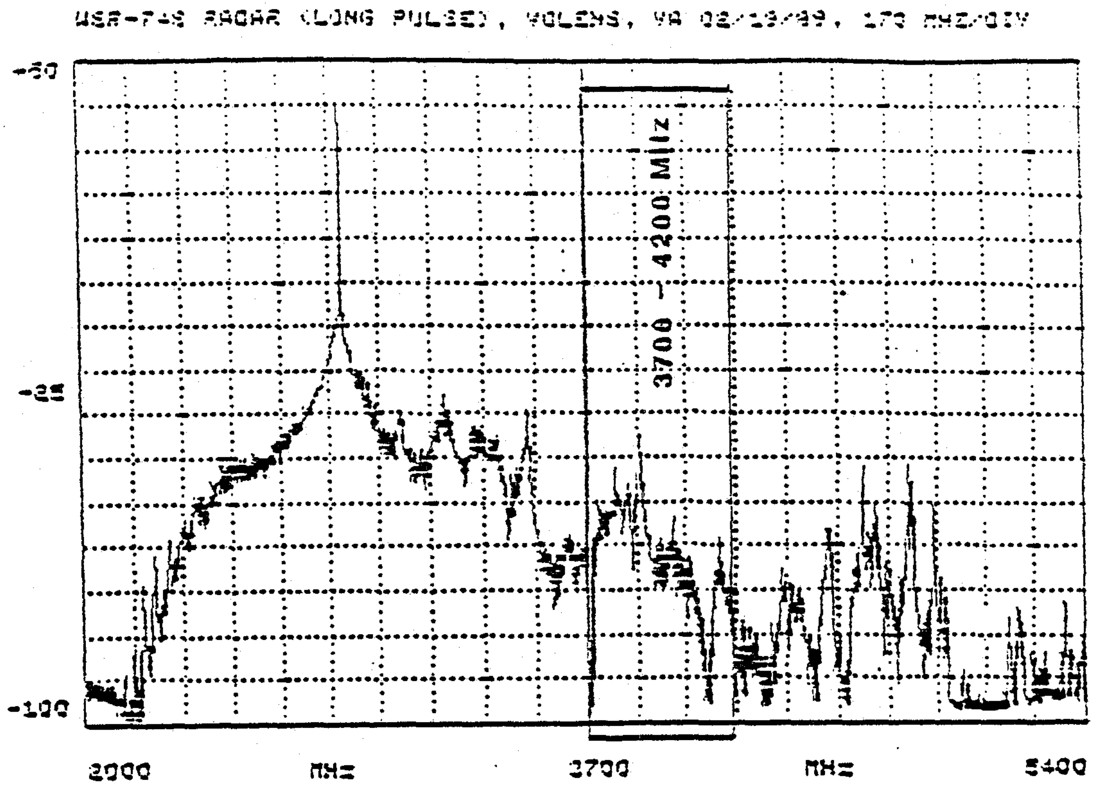

Figure 5-5. Radiated spectrum measurements of the WSR-74S radar at Volens, VA (pulsewidth = 4 µs).

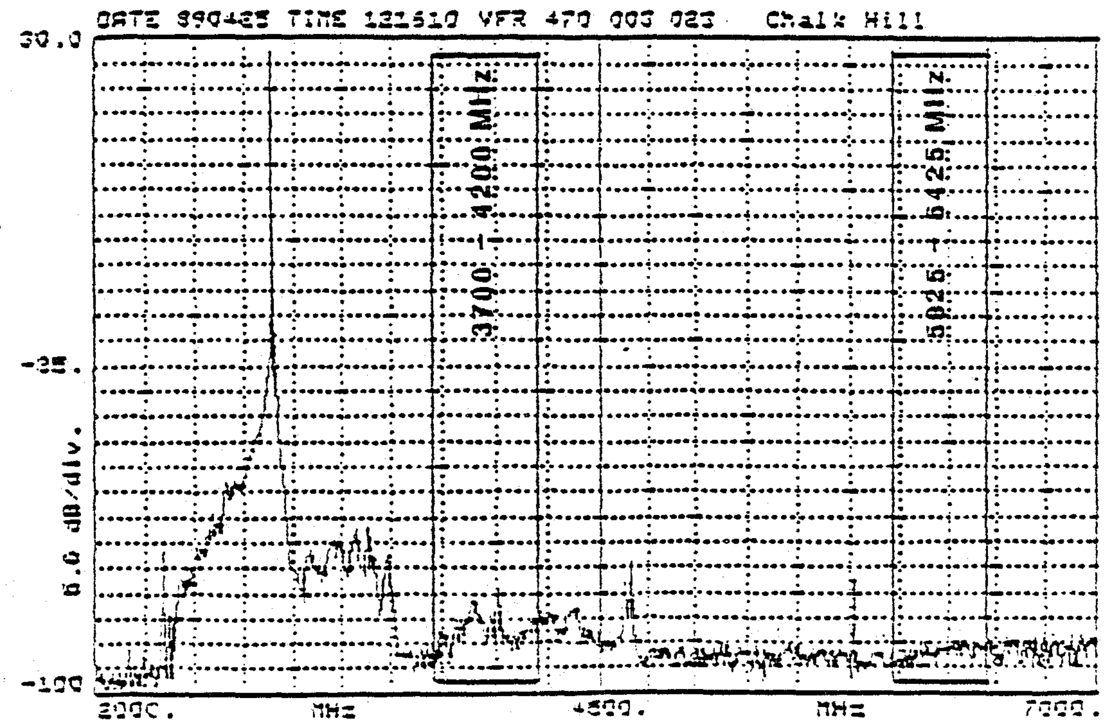

Figure 5-6. Radiated spectrum measurements of the WSR-74S radar at Longview, TX (pulsewidth = 1 µs).

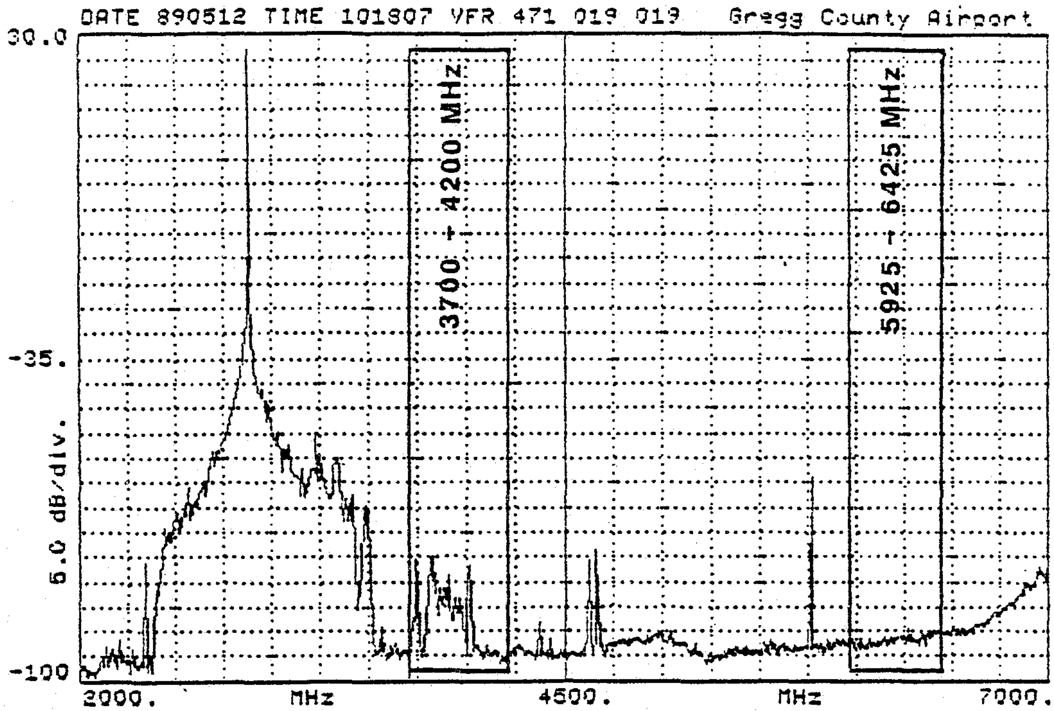

Figure 5-7. Radiated spectrum measurements of the WSR-74S radar at Longview, TX (pulsewidth = 4 μs).

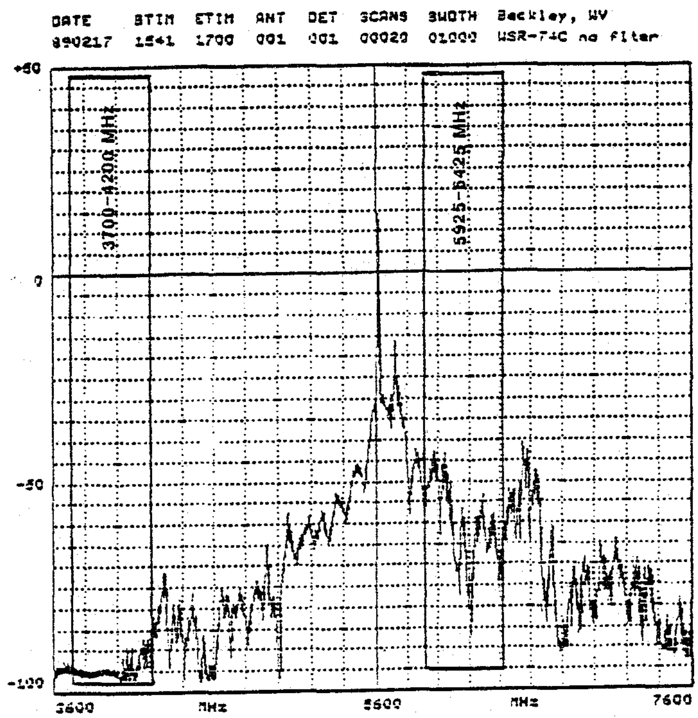

Figure 5-8. Radiated spectrum measurements of the WSR-74C radar at Beckley, WVA (pulsewidth = 3 us).

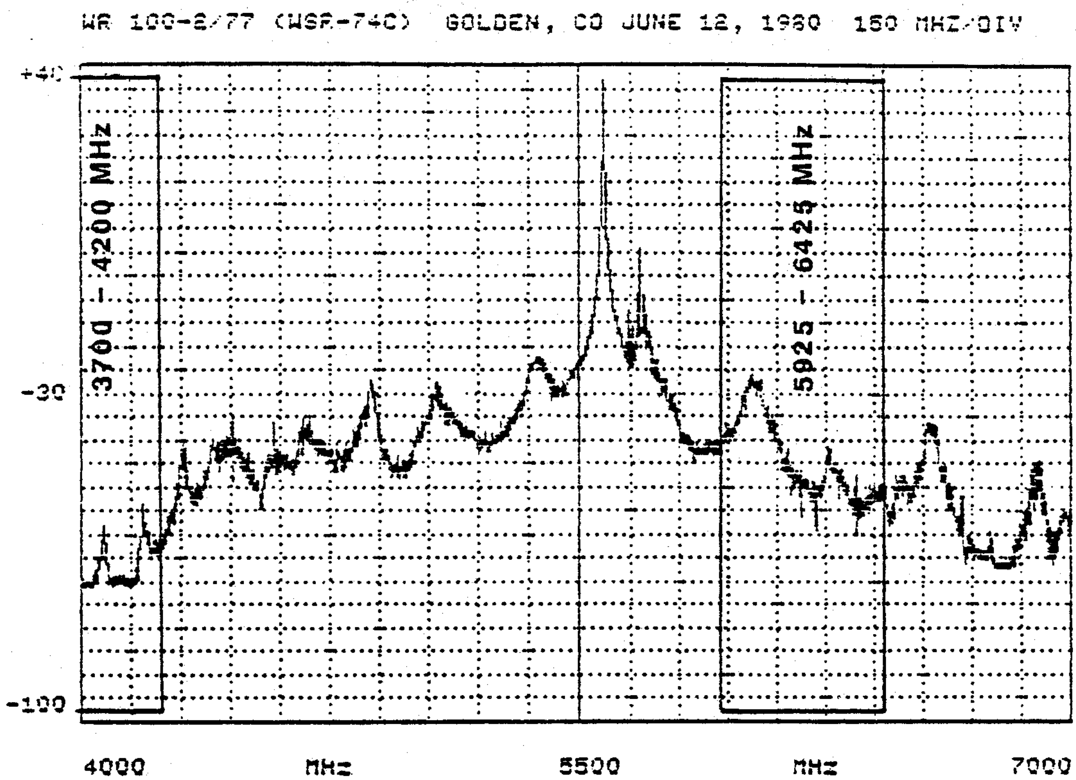

Figure 5-9. Radiated spectrum measurements of the WR100-2 radar at Golden, CO (pulsewidth = 3 μs).

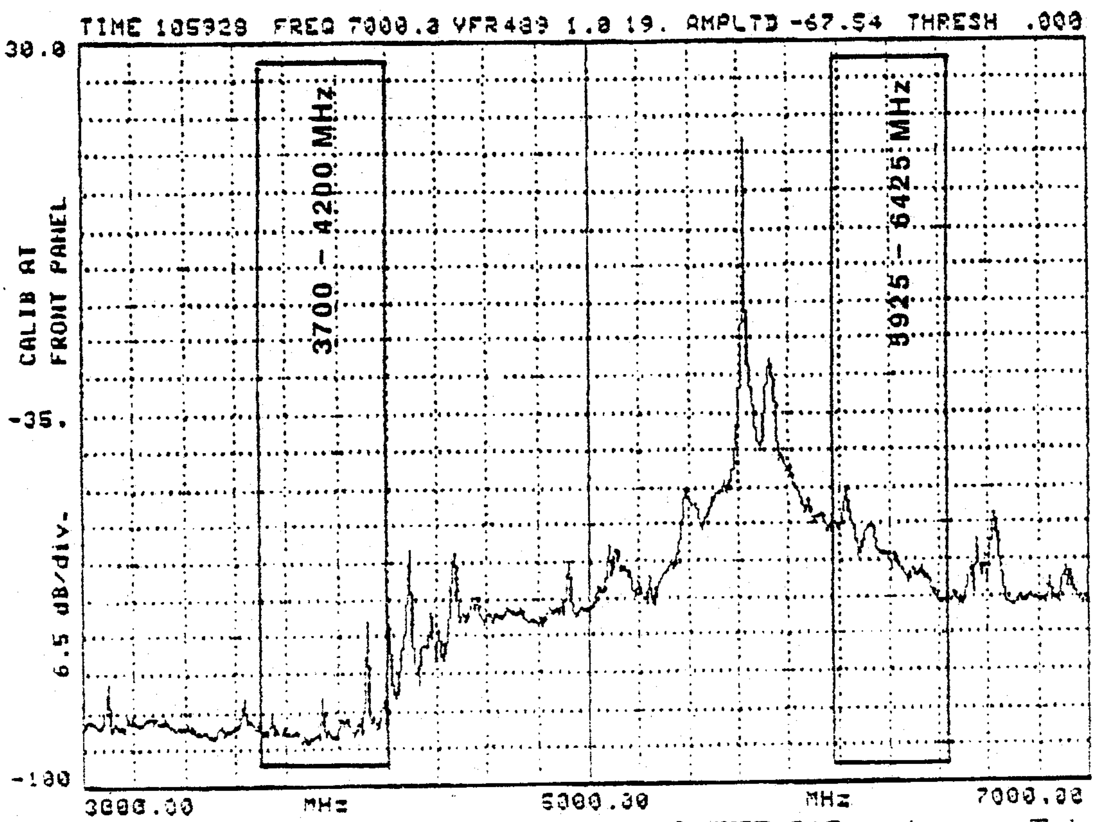

Figure 5-10. Radiated spectrum measurements of WSR-74C radar at Tulsa, OK (pulsewidth = 3.0 μs).

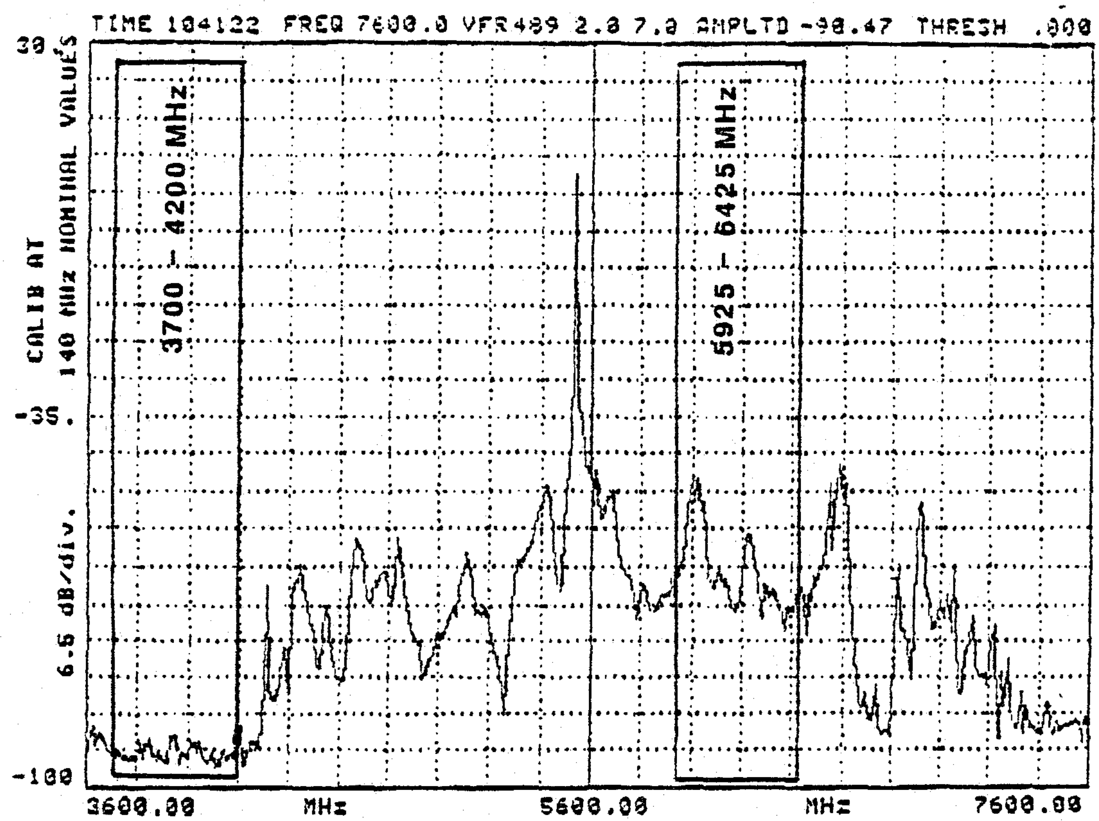

Figure 5-11. Radiated spectrum measurements of the DWSR-88 CTV radar at Tulsa, OK (pulswidth 0.8 μs).

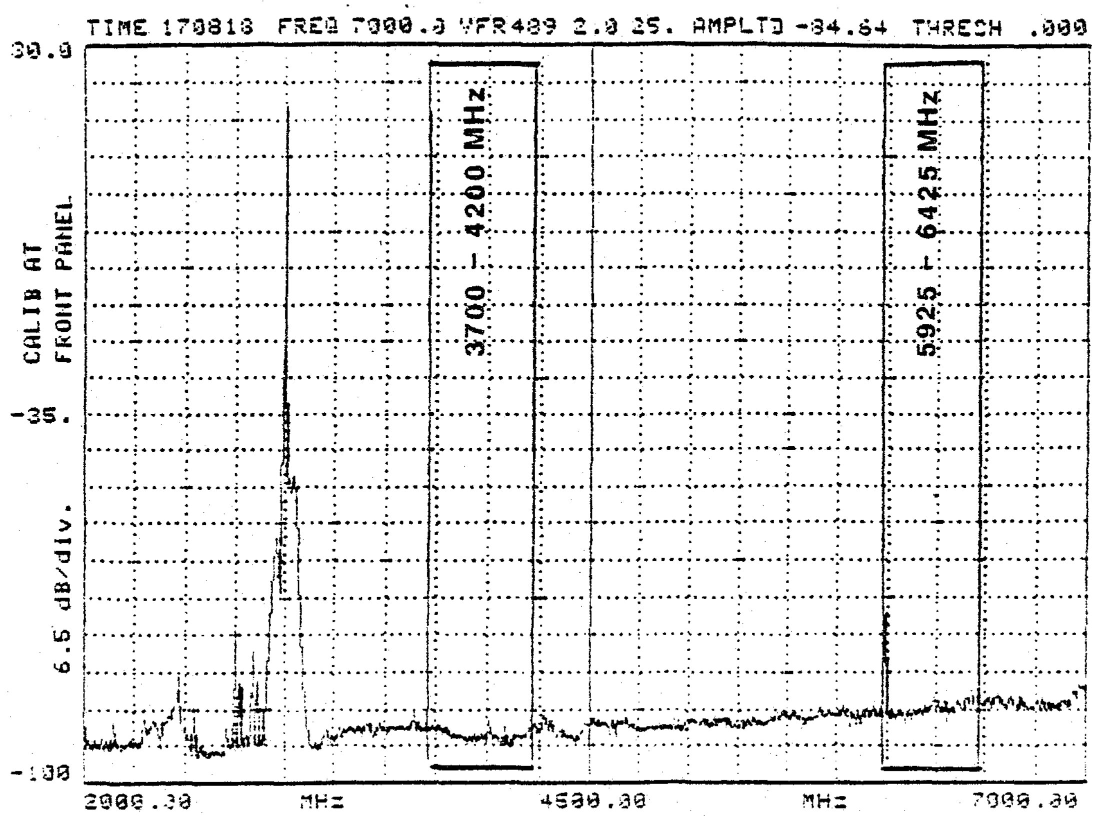

Figure 5-12. Radiated spectrum measurements of the test and evaluation NEXRAD radar at Norman, OK, (pulsewidth = 1.67 us).

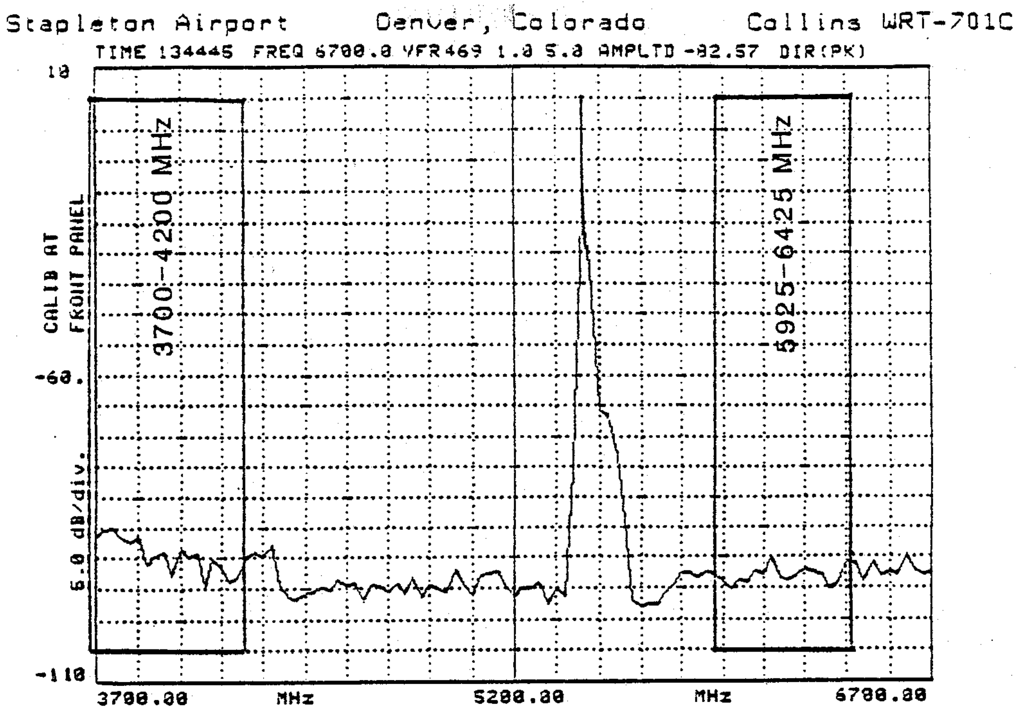

Figure 5-13. Radiated spectrum measurements of the WRT-710C radar at Denver, CO.

The frequency-dependent rejection (FDR) is the rejection provided by a receiver to an input signal as a result of the bandwidth of the receiver and the frequency separation between the receiver and the transmitter. The FDR for radio-relay systems can be obtained from the spurious emission levels measured with a 1 MHz bandwidth given in TABLE 5-1 plus a bandwidth correction factor. The radio-relay systems in the 4 and 6 GHz bands have a receiver IF bandwidth of approximately 17 and 25 MHz respectively. Since the measurements were made with a spectrum analyzer bandwidth of 1 MHz (Standard spectrum analyzer bandwidth), a correction must be applied to the measured spurious emission levels to reflect the peak power received with a 17 or 25 MHz system. This bandwidth correction factor is 20 $\log_{10}$[receiver intermediate frequency (IF) bandwidth in MHz] for receiver IF bandwidths less than the reciprocal of the radar pulse rise/fall times[10] (see Appendix E).

Measurements of rise/fall times of meteorological radars has shown that the rise time of the emitted pulse are significantly shorter than the fall time. Nominal measured rise times for the radars using conventional magnetrons is approximately 25 ns (equivalent response bandwidth = 40 MHz). Nominal measured rise times for the radars that used coaxial magnetrons is dependent on frequency band. The 3 GHz meteorological radar has a nominal value of 150 ns (equivalent response bandwidth = 6.7 MHz), and the 5 GHz meteorological radar has a nominal value of 40 ns (equivalent response bandwidth = 25 MHz). TABLE 5-2 is a summary of the FDR levels for different radar devices as seen in the common carrier bands of 3700-4200 MHz and 5925-6425 MHz.

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10 CCIR Report 972, "Peak Power Responses to Intermittent Interference Signals", XVIth Plenary Assembly, Vol. I - Recommendations and Reports of the CCIR, 1986, Dubrovnik, 1986.

TABLE 5-2

RADAR PEAK FREQUENCY-DEPENDENT REJECTION (FDR) IN COMMON CARRIER BANDS

Nomenclature	Radar Output Tubes	Frequency-Dependent Rejection Range (dBc)	
		3700-4200 MHz (@ 17 MHz IF BW)	5925-6425 MHz (@ 25 MHz IF BW)
WSR-57	Conventional Magnetron	-53 to -79	-79 to below -104
WSR-74S	Coaxial Magnetron	-59 to below -118	-95 to below -107
WSR-74C (WR100-2/-5)	Coaxial Magnetron	-76 to below -85	-28 to -73

note: "Below" indicates (in TABLE 5-1) that the noise floor-level of the measurement receiver, - 95 dBm, was reached and that these FDR levels may be less than (e.g., more negative than) what is indicated.

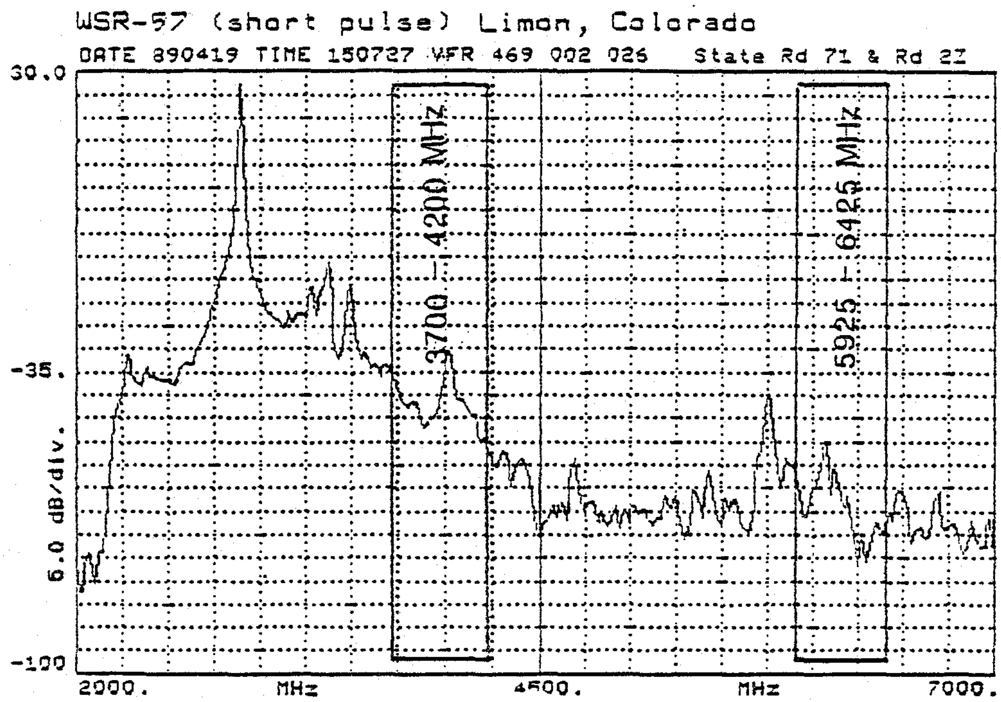

Figure 5-14. Radiated spectrum measurements of spurious emission levels for the WSR-57 conventional magnetron with a short pulse (measured with 30 MHz bandwidth).

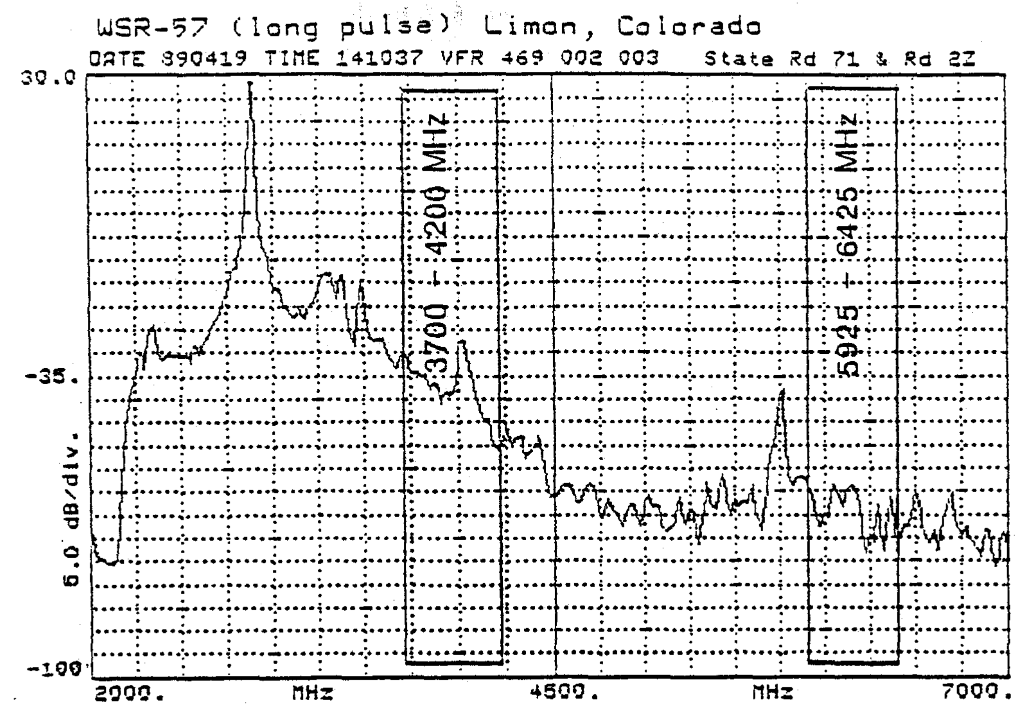

Figure 5-15. Radiated spectrum measurements of spurious emission levels for the WSR-57 conventional magnetron with a long pulse (measured with 30 MHz bandwidth).

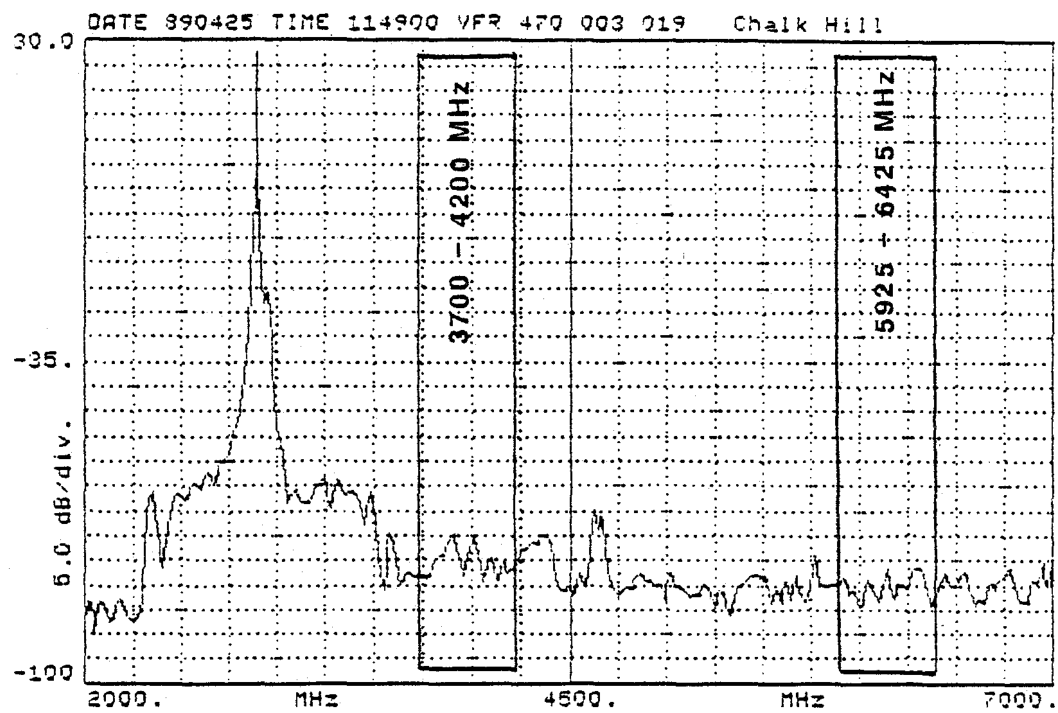

Figure 5-16. Radiated spectrum measurements of spurious emission levels for the WSR-74S coaxial magnetron with a short pulse (measured with 30 MHz bandwidth).

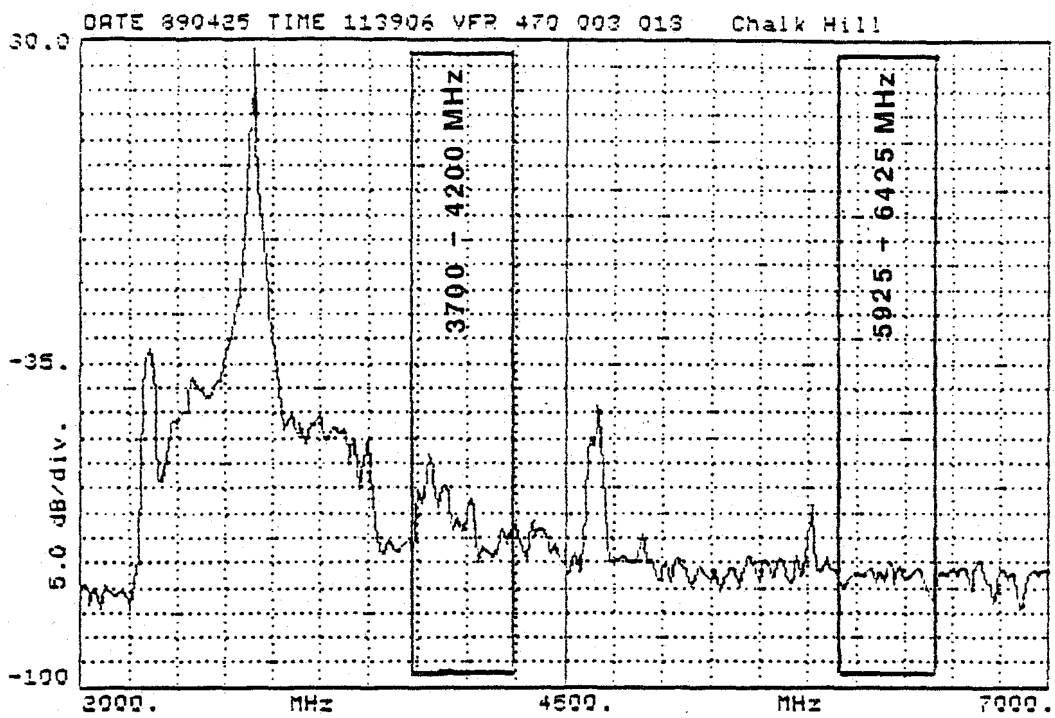

Figure 5-17. Radiated spectrum measurements of spurious emission levels for the WSR-74S coaxial magnetron with a long pulse (measured with 30 MHz bandwidth).

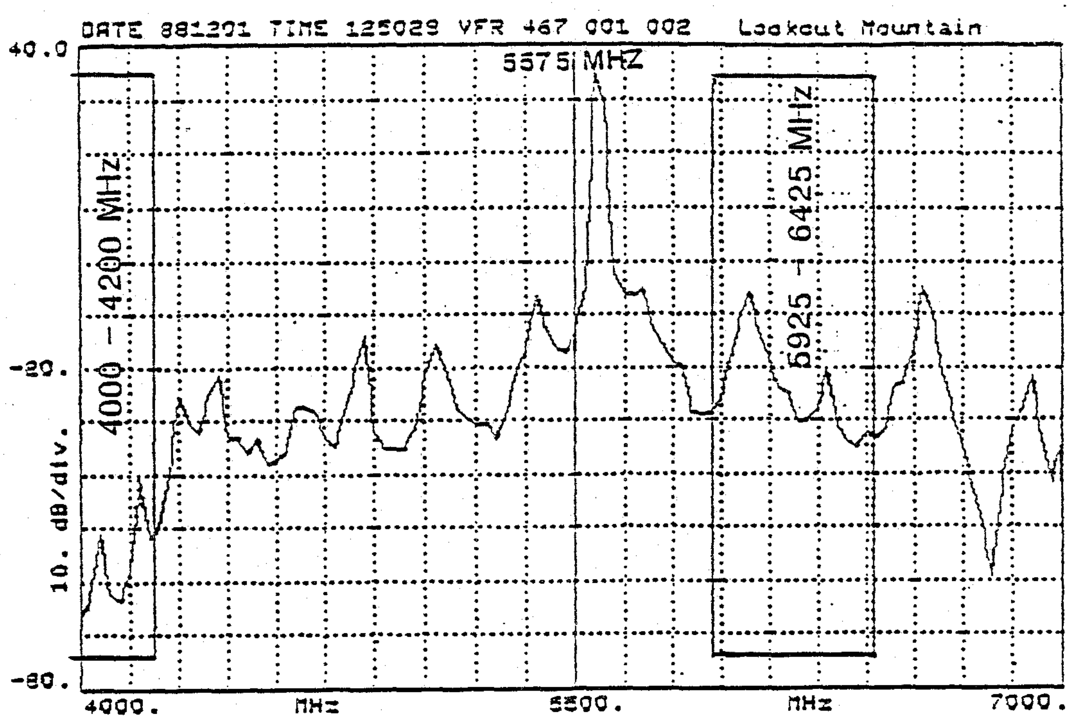

Figure 5-18. Radiated spectrum measurements of spurious emission levels for the WR100-2 coaxial magnetron (measured with 30 MHz bandwidth).

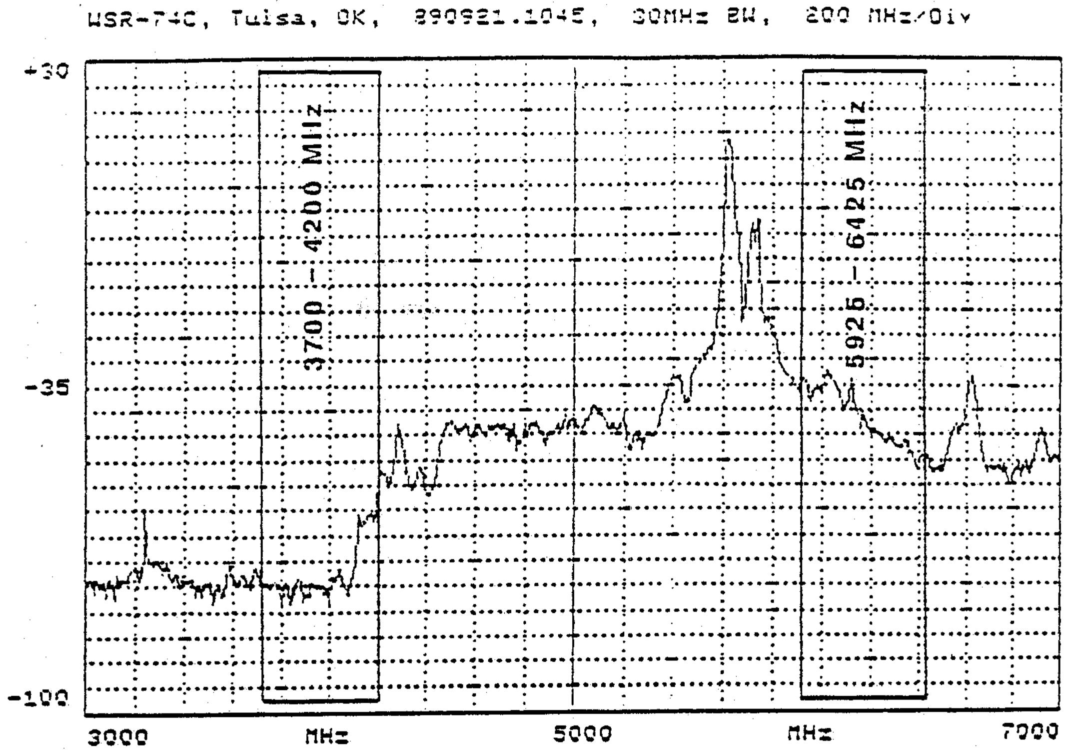

Figure 5-19. Radiated spectrum measurements of spurious emission levels for the WSR-74C coaxial magnetron (measured with 30 MHz bandwidth).

TIME WAVEFORM RESPONSE

In order to determine the effect of spurious emissions from meteorological radar stations on digital radio-relay system performance, it is necessary to characterize the pulse time waveform responses in the receiver IF passband. Figures 5-20 and 5-21 show pulse time waveform measurements at the radar fundamental frequency (reference pulse width) as well as at other frequencies in the common carrier bands. These measurements were made with the RSMS front end (RF preselector through IF output) and a digital oscilloscope. The time waveforms indicate that the radar spurious emissions in the common carrier bands consist of three components: spurious emissions produced from the pulse modulation leading edge, trailing edge, and spurious emissions produced by the output device inherent noise during the pulse interval.

The spurious emissions occurring during the leading and trailing edges of the pulse are broad band in nature thus producing an impulse response in the common carrier receiver IF output. The width of these impulse responses are equal to the reciprocal of the receiver IF bandwidth. That is, the leading and trailing edge impulse response are approximately 50 ηs and 33 ηs for a 4 GHz and 6 GHz common carrier system respectively. Therefore, the leading and trailing edge impulse responses appear as short pulses approximately equal to a baud interval of a digital system. It should be noted that Figures 5-20 and 5-21 show the leading and trailing edge impulse responses are not always of equal amplitude and that some receive pulses may not have a leading or trailing edge impulse response. Also the amplitude of the impulse response is a function of the tuned frequency of the receiver and IF bandwidth. The peak amplitude of the leading and trailing edge impulse responses increase at 20 $\log_{10}$ (Receiver IF bandwidth) for receiver IF bandwidths less than the reciprocal of the radar pulse rise/fall times.

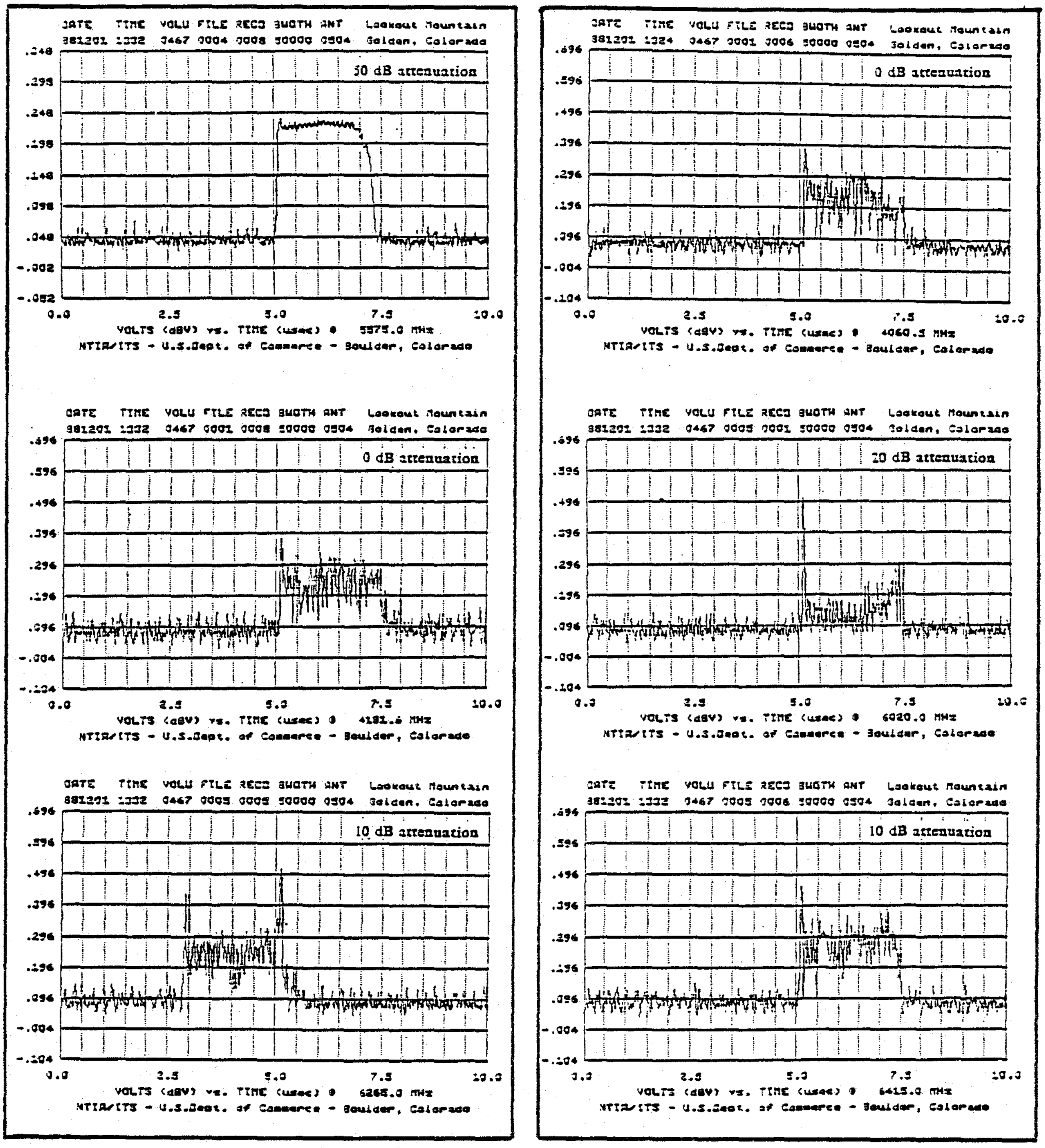

Figure 5-20. Pulse time waveform measurements of a WR100-2 (measured in a 30 MHz bandwidth).

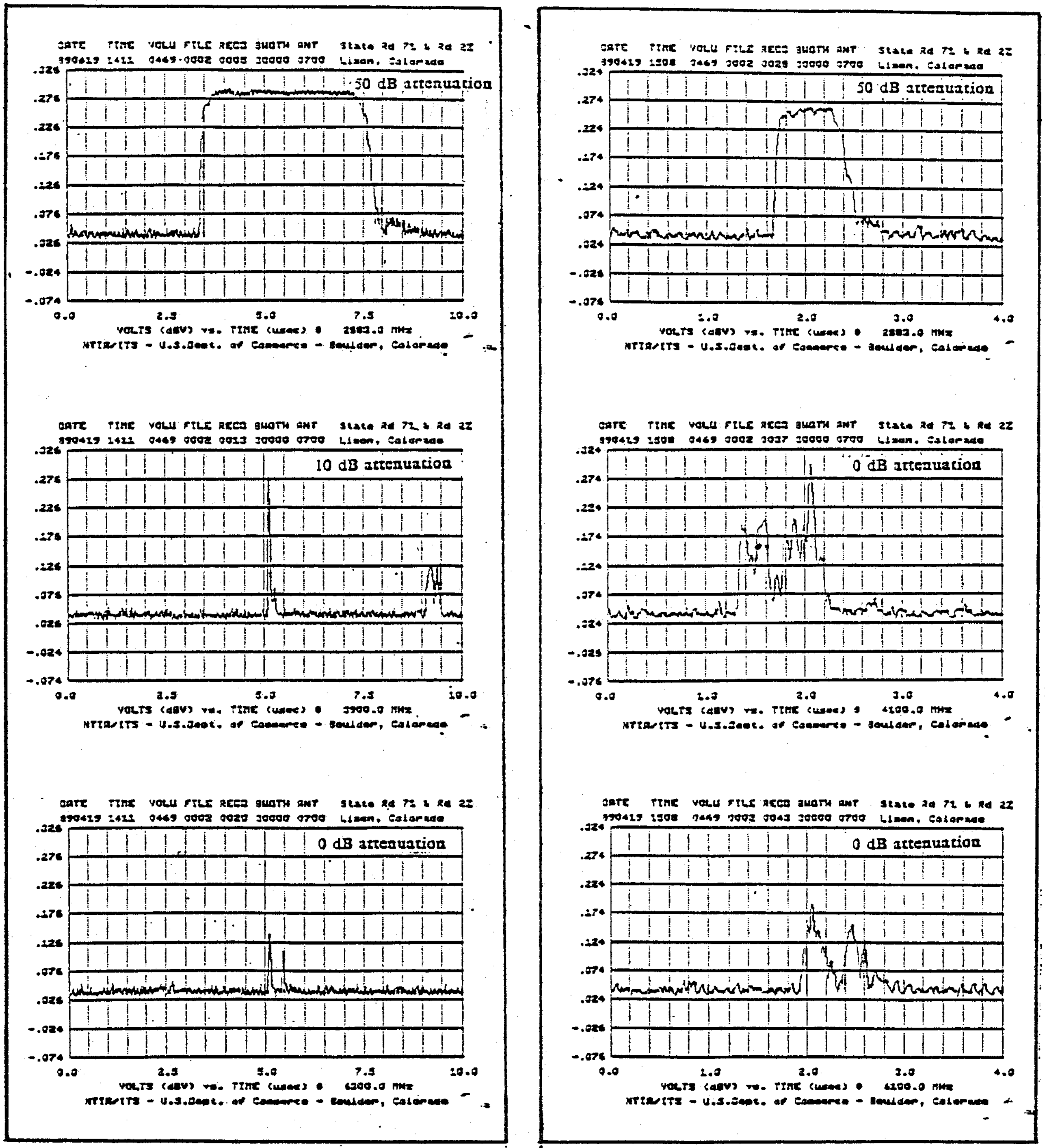

Figure 5-21. Pulse time waveform measurements of a WSR-57, long pulse (4.0 µs) and short pulse (1.0 µs) (measured with 30 MHz bandwidth).

The spurious emissions occurring during the pulse interval are noise like in nature and are produced by the radar output device. The amplitude of these noise like emissions are also a function of the tuned frequency of the receiver and are more predominant at spurious modes of the output device. The amplitude of the non-coherent noise during the pulse interval increases as 10 $\log_{10}$ of the receiver IF bandwidth.

In summary, the radar spurious emissions produce two types of time waveform responses at a microwave receiver IF output: 1) impulse responses (key clicks) due to the radar pulse modulation leading and/or trailing edge and 2) non-coherent noise during the pulse interval. The effects of these time waveform responses on microwave receiver performance are discussed below.

RADAR PULSED EMISSION EFFECTS

The effects of radar pulsed emissions into digital microwave systems are a function of the coupling mechanism (Radar spurious emissions or front-end overload), radar pulse train characteristics (peak amplitude, pulse width and number of pulses) and the effects of the environment on the pulsed emissions (multiple coupling path). In addition, the digital signal format (e.g., modulation type, frame coding), receiver time waveform response and special signal processing circuitry influence the effects of the radar emissions. The time-waveform response of the digital receiver to radar spurious responses were discussed previously in this section. The digital format structure for a DS-3 and the implementation of three DS-3s in a 64-QAM is given in Appendix A.

Observed interference cases have shown that interference from meteorological radars to microwave receivers only occurs from pulses emanating from the mainbeam of the radar. The total number of radar pulses for single path coupling as seen by a microwave receiver emanating from the mainbeam per azimuth scan (continuously turning at 360°) can be estimated using the following equation:

$$N = [(PRF)(BW)] / [(6)(RPM)] \qquad (5\text{-}1)$$

where:

N = Number of pulses observed per pass emanating from the mainbeam of the radar

PRF = Pulse repetition frequency, in pps

BW = Beamwidth of the radar, in degrees

RPM = Antenna rotation rate, in revolutions per minute

Sample calculations;

N for WSR-$57_{\text{at } 0.5\ \mu s}$ = [(545)(2.2)] / [(6)(3)]
= 66 pulses

N for WSR-$74S_{\text{at } 4.0\ \mu s}$ = [(162)(2.0)] / [(6)(3)]
= 18 pulses

Using meteorological radar characteristics for operational radars given in Section 4, the number of pulses per azimuth scan for the 2700-2900 MHz radars range between 18 pulses to 66 pulses and for the 5350-5650 MHz radars range between 11 pulses to 21 pulses. The exposure duration is approximately 0.08 to 0.12 seconds per pass.

The observed effects of pulsed emissions from meteorological radars into digital microwave radio-relay facilities generally have fallen into the following five performance categories: 1) Time-dependent increased background error rate (dribble), 2) Error rates momentarily above threshold: initiating spurious failure reports and channel switching or initiating service failure alarms on multiple channels, 3) Events of severe errored second on one or multiple channels, 4) Out-of-frame events, and 5) Loss of service. The effects of severe errored seconds and loss-of-frame are indistinguishable to the field observer.

Each of these five categories are discussed below. The first three categories are caused by coupling mechanism of spurious responses, the fourth by both front-end overload and spurious emissions and the fifth by the coupling mechanism of front-end overload.

Background or Residual Dribbling Error Rates

Radar spurious emissions that appear as impulse responses (key click) or low level full duration pulses in the digital microwave receiving system can cause background or residual dribbling error rates. As described earlier, receiver impulse responses can be generated by the radar pulse leading and trailing edges. The width of these impulse responses are equal to the reciprocal of the receiver IF bandwidth. For example, for the 4 GHz and 6 GHz common carrier bands, the calculated values of the impulse response are 50 ηs and 33 ηs, respectively. This value is approximately equal to a baud interval of the digital microwave system (~ 45 ηs). For this specific case, the effect of radar leading and trailing edge impulse responses on system performance for a train of pulses emanating from the radar mainbeam is estimated by the following equation:

$$BER = \{(0.5)\,[(P)(N)(M)]\,/\,[(R)(DT)]\} \qquad (5\text{-}2)$$

where:

BER = Bit error rate

P = The number of leading/trailing impulses per radar pulse (# of baud interval per pulse), 0,1,or 2

N = Number of pulses observed per pass emanating from the mainbeam of the radar,

M = Number of bits per baud, (6 for 64-QAM)

R = Rate of signals, (135 Mb/s for 3 DS-3s)

DT = Detection Time, (0.1 second)

Sample calculations;

$$\text{BER for WSR-74S}_{\text{at } 4.0\ \mu s} = \{(0.5)\ [(2)(18)(6)]/[(135\text{x}10^{6})(0.1)]\}$$
$$= 8\text{x}10^{-6} \quad [\text{8 errors per one million bits}]$$

Depending on the amplitude and number of impulse responses during the mainbeam scan the BER may exceed 10^{-6} [one error per million bits]. In addition, for this case of impulse response interference, the digital radio error correction system may be able to rectify errors occurring in a single baud interval. As a result, when error correction is used, the required C/I protection threshold can be reduced by approximately 10 dB (See Appendix A). This 10 dB improvement is only applicable to pulse type interference producing impulse responce like signals in the receiver. Therefore, it is not applicable to continuious wave interference such as another microwave signal.

Error Rates Momentarily Above Threshold

Error rates momentarily above threshold (BER > 10^{-6}) can occur when radar spurious emissions produce a pulse width of full duration above the microwave receiver C/I protection threshold. For this case, the pulse duration of the operational meteorological radar pulses are typically in the order of 1 to 4 microseconds. When the full pulse duration exceeds the required C/I protection threshold, it will defeat the error correction function and result in a block of errors which to occur for each incoming pulse. When this situation occurs, a block of errors will typically range between 100 and 500 bits, depending on the duration of the pulse.

The estimate of the bit error rate occurring from receiving a train of pulses of full pulse width duration is given by:

$$\text{BER} = \{(0.5)\ [(N)(PW/BI)(M)]\ /\ [(R)(DT)]\} \qquad (5\text{-}3)$$

where:

BER	=	Bit error rate
N	=	Number of pulses per mainbeam scan of the radar
PW	=	Radar pulse width, (1 µs, 3 µs or 4 µs)
BI	=	Baud interval, (for 3 DS-3s = 45 ηs)
M	=	Number of bits per baud, (6 for 64-QAM)
R	=	Rate of signals, (135 Mb/s for 3 DS-3s)
DT	=	Detection Time, (0.1 second)

Sample calculation;

$$\text{BER for WSR-74S}_{\text{at } 4.0\ \mu s} = \{(0.5)\ [(18)(4\text{x}10^{-6}/45\text{x}10^{-9})(6)]\ /\ [(135\text{x}10^{6})(0.1)]\}$$
$$= 3.56\text{x}10^{-4} \quad [\text{3.56 errors per ten thousand bits}]$$

For the meteorological radar characteristics given in Appendix C, the BER for a pulse train of pulses of full duration will be less than 10^{-3} [one error per one thousand bits].

Severe Errored Second Events

Severe errored seconds in a digital microwave radio-relay receiver can occur due to front-end overload or radar spurious emissions. For spurious emission coupling, severe errored seconds can only occur as a result of multiple scattering reflections of a radar pulse. These multiple scattering reflections are usually due to reflections caused by terrain (hills and mountains) or buildings. The major effect of multiple scattering is to cause some stretching of the received pulse width, and additional pulses when the difference in distance between the direct and reflected path exceeds the distance that a signal can travel in one pulse width. Thus multiple scattering propagation may add to the severity of the interference caused by pulsed radars. When multipath scattering occurs (pulse stretching) the BER may exceed 10^{-3} [one error per one thousand bits].

Out-of-Frame

If the radar pulse at the receiver IF output exceeds five consecutive framing pulses (approximately 10.2 µs, See Appendix A), system out-of-frame will occur. Out-of-frame will result in the receiving system causing all downstream systems to reframe as well. The reframe interval will last for tens of milliseconds and inevitably cause a severe errored second to all payloads in the channel. Also, error correction provides no advantage when Out-of-frame occurs. Out-of-frame can occur by the coupling mechanisms of front-end overload or spurious responses.

In the case where front-end overload causes out-of-frame, the radar signal level at the receiver input must typically be greater than 2.5 dBm at the fundamental frequency and the pulse duration greater than 4 µs. Due to the recovery time of the low-noise preamplifier, a 4 µs radar pulse is stretched greater than 10.2 µs. Front-end overload has been observed in 6 GHz microwave systems from 5 GHz meteorological radars. Appendix B contains measured data on out-of-frame for front-end overload for a parametric range of radar signal levels and pulse widths.

In the case where radar spurious emissions cause front-end overload, multiple path scattering of a radar pulse must exist to stretch the received pulse to greater than 10.2 µs since the transmitted pulse width of meteorological radars is less than 5 µs.

Loss-of-Service

For loss-of-service to occur in the microwave receiver, the total transmission outage time ranges between 2.5 to 10 seconds. This loss-of-service event occurs when the microwave low-noise preamplifier becomes overloaded by the energy of the radar fundamental frequency or when the radar antenna mainbeam is continuously pointed, for whatever reason, at the microwave station. Typical radar signal levels greater than -2 dBm at the low-noise preamplifier input will cause front-end overload (See Appendix B). When this occurs, the amplifier may be blocked for considerably more than the pulse duration and severe errored seconds usually occur. Prolonged events involving total loss-of-service have only been seen very rarely and these have been corrected by added RF filters in the affected receiver. This effect may be handled by filters in the receiving waveguide ahead of the low-noise amplifier. Alternatively, individual low-noise amplifiers may be used following the separating filters.

Summary

In summary, there are many radar system, microwave system and environmental factors which influence the effects of pulsed radar emissions on the digital microwave receiver system. These effects are very complex to determine analytically. Because of this complexity, all efforts should be made to ensure compatibility by maintaining a sufficient protection threshold (carrier-to-interference ratio).

PROTECTION THRESHOLD

To ensure compatibility between meteorological radars and common carrier microwave receivers a C/I (carrier-to-interference) protection threshold must be established. A review of past technical literature has indicates the appropriate C/I protection threshold for pulsed interference is difficult to determine analytically since the interference is "bursty" in nature. Consequently, laboratory and/or field test measurements have been used as the bases for estimating the C/I protection threshold necessary to preclude interference.

Based on laboratory test measurements[11], it was found that no significant performance degradation to a 64-QAM microwave receiver from pulsed emissions appears until the C/I ratio dropped below 30 dB for a faded desired signal. Therefore, theoretically the C/I ratios would be 24 and 36 dB for 16-QAM and 256-QAM, respectively.

To establish a C/I protection threshold for an unfaded desired signal level, the desired signal fade duration as a function of fade depth for space diversity operations and radar antenna gain probabilities must be considered. Considering these factors, a 25 dB protection fade margin will provide a probability of outage due to radar interference approximately equal to the non-interference outage condition (See Ref. 11). Therefore, the proposed C/I protection threshold ratios are 49, 55, and 61 dB for 16-QAM, 64-QAM, and 256-QAM digital modulations respectively.

Discussed below is an example of establishing appropriate analysis distances using the C/I protection threshold of 55 dB for digital microwave receivers using 64-QAM which represents the majority of digital receivers currently being deployed by the common carrier industry.

EMC DISTANCE CALCULATIONS

The analysis presented herein discusses when a detailed EMC study should be performed. To determine the distance around a meteorological radar in which it may be necessary to perform an analysis, it is necessary to determine the required

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[11] AT&T Memorandum, Richard Callahan, Radio Transmission Engineering Section, AT&T Headquarters, Rt. 202-206, Bedminster, NJ, 01971, SUBJECT: Weather Surveillance Radar Interference to Digital Common Carrier Microwave Systems, DATES: May 17; June 12; June 23; July 7; July 25; August 6, 1989.

be necessary to perform an analysis, it is necessary to determine the required propagation loss which will ensure compatibility. For direct path coupling the required propagation loss is given by:

$$L_p = C/I - C + P_T + G_T + G_R - I_T - I_R + FDR \quad (5\text{-}4)$$

where:

L_p = Median propagation path loss between the transmitting and receiving antennas, in dB.

C/I = Carrier-to-interference ratio necessary to maintain an acceptable performance criteria, for 64-QAM assumed 55 dB.

C = Nominal 64-QAM microwave receiver system (unfaded) carrier level at the receiver input, nominal -33 dBm.

P_T = Peak transmitted power of interfering meteorological radar system (See TABLE 5-3), in dBm.

G_T = Interfering meteorological radar system mainbeam antenna gain (See TABLE 5-3), in dBi.

G_R = Radio-relay common carrier receiver mainbeam antenna gain, nominal 39 dBi and 43 dBi for 4 and 6 GHz bands respectively.

I_T = Insertion loss in the meteorological radar system, in dB (assumed 2 dB).

I_R = Insertion loss in a 64-QAM receiving system, in dB (assumed 3.5 dB).

FDR = Frequency-Dependent Rejection of spurious emissions between the Meteorological radar transmitter and the radio-relay common carrier receiver (See TABLE 5-3), in dBc.

TABLE 5-3

NOMINAL METEOROLOGICAL RADAR SYSTEM CHARACTERISTICS

Nomenclature	Peak Output Power (dBm) P_T	Mainbeam Gain Antenna, (dBi) G_T	Frequency Dependent Rejection, FDR (dB)	
			4 GHz	6 GHz
WSR-57	87	38	- 53	- 79
WSR-74S	87	38	- 59	- 95
WSR-74C	84	40	- 76	- 28

Once the required propagation loss is determined an appropriate propagation model must be applied to determine the analysis distance around a meteorological radar in which it may be necessary to perform a detailed analysis. For this analysis, the Integrated Propagation System (IPS)[12] was used to estimate the distance for the required basic transmission loss. Figure 5-22 shows the basic propagation loss versus distance for the 4 and 6 GHz bands. TABLE 5-4 shows the required propagation loss and analysis distance for the meteorological radars which use a magnetron output device.

TABLE 5-4

ANALYSIS DISTANCE (d) FOR CARRIER-TO-INTERFERENCE RATIO OF 70 dB GIVEN IN STATUTE MILES

Device Type	3700-4200 MHz Band		5925-6425 MHz Band	
	L_P (dB)	d(st.mi.)[km]	L_P(dB)	d(st.mi.)[km]
Conventional Magnetrons in the 2.7-2.9 GHz range	194	65 [105]	172	50 [80]
Coaxial Magnetrons in the 2.7-2.9 GHz range	188	55 [88]	156	45 [72]
Coaxial Magnetrons in the 5 GHz range	132	20 [32]	222	150 [241]

The analysis distances given in TABLE 5-4 are for smooth earth coupling. The table is intended as a cull in determining when a detailed EMC analysis may be required. When performing a detailed analysis, a propagation model which takes into consideration the terrain (TIREM)[13], building attenuation and foliage attenuation between the microwave receiver and the radar should be used. Also, in areas where ducting is prevalent, ducting should be considered in determining the propagation loss.

In addition, when performing a detailed EMC analysis, it is also necessary to perform an analysis for indirect path coupling (multiple path scattering). Multiple path scattering caused by terrain or building reflections can result in significantly less propagation loss than along the direct great circle path and cause an apparent stretching of the radar pulses. Therefore, multiple path scattering may significantly increase the potential degradation to the microwave system.

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[12] Frazier, W.E. and Anderson, D.S., "A propagation Model for Electromagnetic Compatibility," Unclassified Proceedings of the Ninth Tri Services Conference on Electromagnetic Compatibility, IIT Research Institute, Chicago, ILL, October 1963.

[13] Benoit, G., Terrain-Integrated Rough-Earth Model (TIREM) Handbook, ECAC-HDBK-86-076, DoD Electromagnetic Compatibility Analysis Center, Annapolis, MD, September 1986.

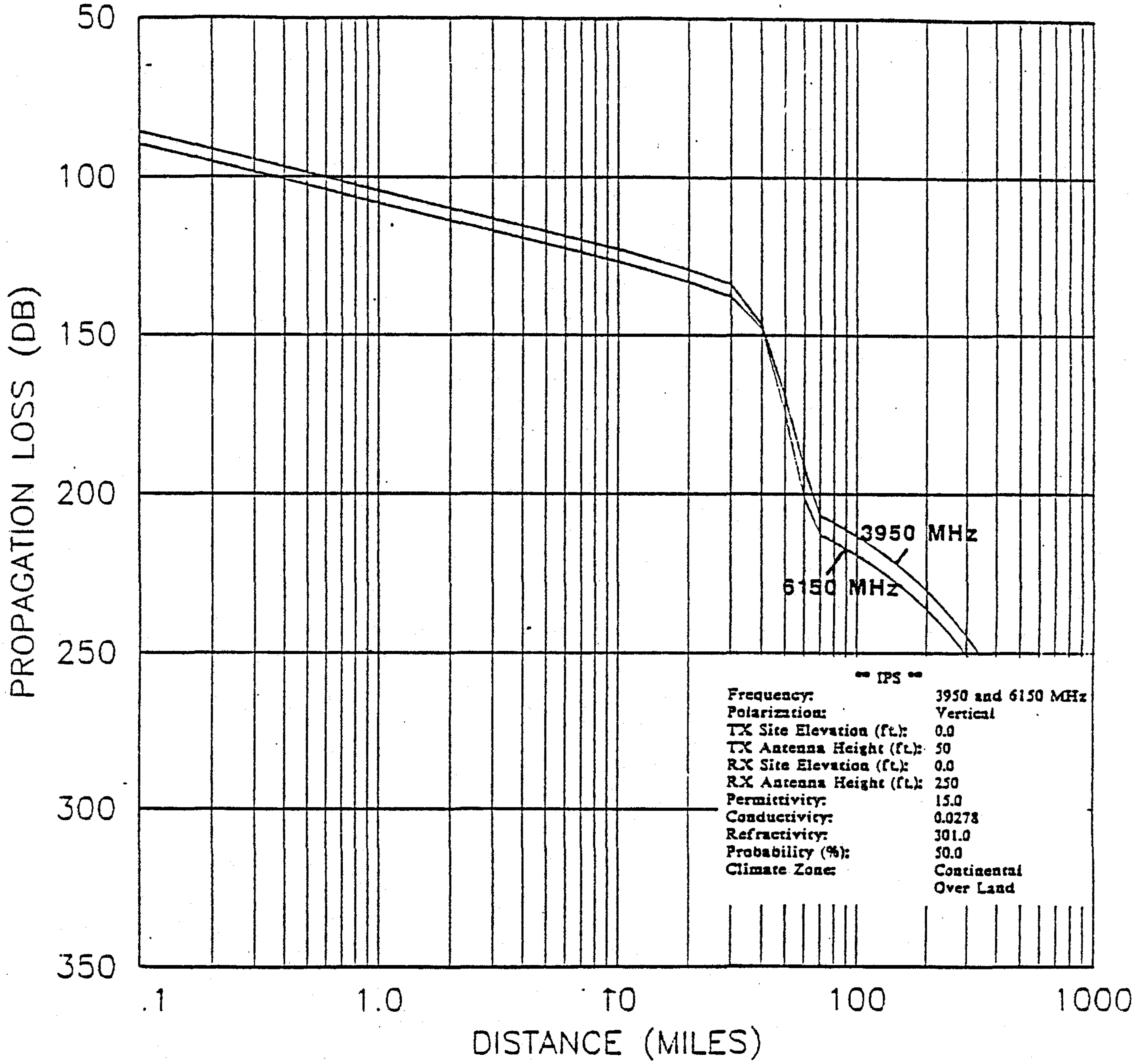

Figure 5-22. Propagation Loss versus Distance Separation curves.

SECTION 6

INTERFERENCE MITIGATION OPTIONS

INTRODUCTION

Methods to enhance the compatibility between radar and microwave systems must be reviewed and action taken so that microwave system performance is not degraded due to inter system interference. The cost associated for each of the various methods to enhance compatibility will vary. The cost as well as the selection of an appropriate mitigation option will not be addressed. Additionally, no interference resolution policy for spurious emission interference is discussed in this section. This section discusses various options which may be effective in reducing interference from meteorological radar systems into digital microwave systems. Both the common carrier microwave system and the meteorological radar system mitigation options are discussed.

Appendix D contains a compendium of reported interference cases and methods used to mitigate the interference. Also discussed in this section is an alternative to radiocommunication, fiber optics, to avoid the interference situation.

MICROWAVE SYSTEM MITIGATION OPTIONS

Many of the techniques employed by the microwave system designers to enhance system performance may be expected to reduce the susceptibility of these systems to interference from meteorological radar transmitters. RF filters which limit the input bandwidth, space/pattern diversity, antenna selection and forward-error correction are all examples of microwave system design features which may tend to lessen the impact of radar emissions on these receiving systems. In many cases, the combinations of these systems design features may not be sufficient to reduce the interference effects to acceptable levels. In some cases, if the desired path is to be usable at all, it may be necessary for the microwave system to use alternate channels, alternate bands or alternate path routing, where available.

Microwave RF Filters

When interference from a radar system is observed in a microwave system, one of the first steps in attempting to reduce the interference is to determine if the coupling mechanism is front-end overload caused by the radar fundamental frequency. If front-end overload of the low-noise preamplifier (LNA) by the meteorological radar signal is the coupling mechanism, an RF blocking filter ahead of the waveguide run may be used to protect the LNA from radar interferencc. Appendix B contains a detailed discussion of the condition of front-end overload and radar signal levels which cause performance degradation due to this phenomenon.

Front-end LNA overload has only been observed in digital systems operating in the 5925-6425 MHz band from the 5 GHz meteorological radars. Receiver RF filters will not be effective against interference from meteorological radars if the interference is due to radar spurious emissions at the digital receiver frequencies. In these cases, other options must be considered.

Space Diversity

The space diversity systems installed in most digital common carrier systems tend to decrease microwave system susceptibility to radar interference, and are effective in cases where the radar causes interference during the time the radio route is involved in a multipath fade condition. This is because space diversity reduces the total fade time by providing a second receive path which is uncorrelated with the primary receive path. If the interfering signal causes system performance degradation all the time (i.e., when the desired signal is unfaded), space diversity is not a viable option.

Space diversity is used in digital radio-relay systems to reduce the amount of time below the desired received level caused by multipath fading. It requires two antennas mounted at different heights and placed so that simultaneous fading does not occur. The received signals from the antennas are then compared at the microwave receiver input and the best signal selected. Thus, maximum system performance is maintained during a faded condition.

Most digital common carrier systems already employ space diversity, therefore, this technique is generally not available as a radar interference reduction technique to further reduce system susceptibility to radar interference. The space diversity improvement factor is a function of the path length, operating frequency, vertical spacing of the antennas and the fade margin.[14] For example, for a nominal 40 dB fade margin, 30 statute mile (~48 km) Hop and 50 feet (~15 m) vertical separation between antennas, this improvement factor is 10 dB for a 6 GHz system. Thus, the implementation of space diversity in this case, would provide an equivalent 10 dB improvement in C/I for multipath fading.

Pattern Diversity

A method which employs a similar technique to space diversity, in that signals from a second, uncorrelated, receive path may be available to the system when the primary signal has faded, employs a single antenna with the capability to provide an output for two separate receive patterns. Separate waveguide ports are provided for each pattern at each polarization. These "pattern diverse" signals are then compared and the best signal is selected, as happens with signals from two different antennas in a space diversity system. Employment of this technique has the potential to reduce the total time that the desired received signal is below the radar interference level, thereby decreasing the impact of the radar interference along with the impact of multipath fading. Pattern diversity is sometimes employed by microwave system designers in lieu of space diversity.

Forward Error Correction

Forward error correction (FEC) coding is a method used in most digital microwave systems to improve the BER performance, particularly when the system is power

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[14] GTE Lenkurt Incorporated, Engineering Considerations for Microwave Communications Systems, Lenkurt Electric Co., Inc., San Carlos, CA, copyright June 1970, 1972, and 1975, pp 21-24, pp 28-31 and pp 55-65.

limited. The utilization of FEC coding techniques permits a limited number of errors to be corrected at the receiving end by means of special coding and software (or hardware) implemented at both ends of the circuit. Measurements (See Ref. 11) have shown that for a double-error correcting code, the threshold for errors breaking through to the payload is improved by approximately 10 dB when the interfering pulse duration is one baud interval (i.e., the interference produces a receiver impulse response, key click).

Alternate Channel Use

The level of radar spurious emissions in common carrier bands varies unpredictably as a function of common carrier channel frequency. Measurements (at 30 MHz IF bandwidth) in Section 5 show a variation of 15-20 dB depending on the channel frequency. Therefore, when interference from a radar system into a digital radio-relay system is encountered, one method to temporarily reduce the interference is to use alternate channels. For example, alternate channel use was a temporary solution in the Portland, Maine interference case (see Appendix D).

Alternate channel use may only be a viable solution when unused channels are available. In any case, alternate channel use should only be considered as a temporary fix since the radar spurious emission levels at various frequencies are a function of matching of the impedance of the radar transmitter line and tube output, age of the radar output tube and the pulse shaping (filtering) network.

Alternate Band Deployment

When designing a new microwave link or modifying an existing microwave link (i.e., conversion from analog to digital), various factors must be considered in selecting an appropriate frequency band. One of the factors should be the electromagnetic environment in the area of deployment (See Ref. 15). If a weather radar is operating in the vicinity, the selection of a band for deployment of the microwave system is likely to affect the potential for radar interference. The selection of an appropriate band is dependent on the type of output device used in a radar which determines the radar spurious emission levels and the radar harmonic levels. The radar FDR characteristics in the 4 and 6 GHz common carrier bands for the various meteorological radar nomenclatures are given in TABLE 5-2 of Section 5. For example, if an WSR-57 radar is operational or planned in the vicinity, approximately a 25 dB improvement in C/I may be achieved if the microwave system is deployed in the 6 GHz band rather than the 4 GHz band. Similarly, if a WSR-74C radar is in the vicinity of the microwave route, approximately a 40 dB improvement in C/I can be achieved if the microwave system is deployed in the 4 GHz band rather than the 6 GHz band.

To date, there has been only one reported case of interference from the 4th harmonic of a 2700-2900 MHz ground-based weather radar into a digital radio-relay system operating in the 11 GHz band. Therefore, the 11 GHz band may also be an alternate band for use if 3 and/or 5 GHz meteorological radars are located in the vicinity. However, it should be noted that a typical 11 GHz hop is approximately 10-15 statute miles (16-24 km), principally as a countermeasure to rain attenuation, versus the 4/6 GHz hops which are typically 25-30 statute miles (40-48 km). Therefore additional microwave repeater installations could be required for these solutions.

For alternate band deployment to be successful as an interference mitigation option, knowledge of the location of these radar stations is vital.

Path Routing

Where possible, path routing selections can be used during the design phase of new routes to avoid potential interference exposures to operational or planned meteorological radar stations. There are many factors that determine the site selection of stations in a radio-relay route. One of the factors should be the electromagnetic environment. For path routing to be successful as an interference mitigation option, knowledge of the location of radar stations is necessary. It should be recognized, however, that additional constraints or site selections may significantly impact the economics of the microwave route construction.

Two methods to aid in the mitigation of radar interference at the radio site are radio-relay system antenna selection discrimination and antenna site shielding (See Ref.14).

<u>Antenna Selection.</u> Antenna discrimination, the response of the antenna to signals arriving from various azimuths, varies widely among antennas. In some situations, it may be possible to take advantage of those characteristics to reduce the response of a system to interference arriving from a particular direction.

Three antenna types commonly used for common carrier radio-relay communications are the Standard Parabolic Dish (STD), the Shrouded Parabolic Dish (SHD) and the Conical Horn Reflector (CHR). Each have different responses to off-axis signal; typical patterns for these general types of antennas are shown in Figure 6-1. To estimate the minimum required off-axis pointing angle for microwave systems, it is necessary to determine the maximum permissible radio-relay receiver antenna gain using the following equation:

$$G_R(\theta) = -C/I + C - P_T - G_T + I_T + I_R + L_p - FDR \qquad (6\text{-}1)$$

Where:

$G_R(\theta)$ = Radio-relay receiver antenna gain in the direction of the interfering radar, in dBi.

C/I = Carrier-to-interference ratio necessary to maintain an acceptable performance criteria, (for 64 QAM: typically 55 dB).

C = Nominal microwave receiver system (unfaded) carrier level at the receiver input, (nominal -33 dBm for 64 QAM system).

P_T = Peak transmitted power of interfering meteorological radar system, in dBm.

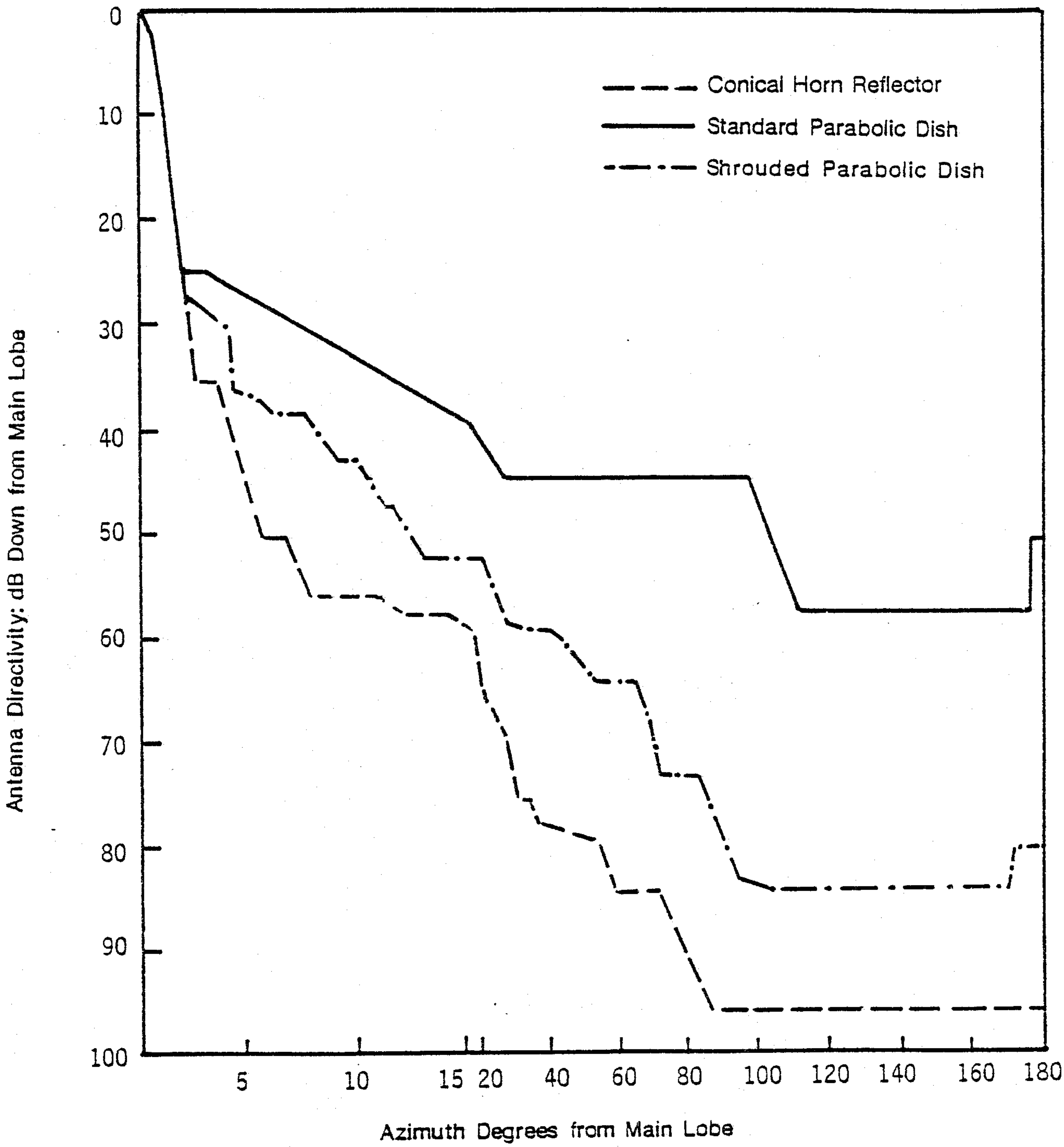

Figure 6-1. Comparison of typical 10 foot (3 m) 4/6 GHz Common Carrier Radio Relay Antennas.

G_T = Interfering meteorological radar system mainbeam antenna gain, in dBi.

I_T = Insertion loss in the meteorological radar system, in dB (assumed to be approximately 2 dB).

I_R = Insertion loss in the microwave receiving system, in dB (assumed to be approximately 3.5 dB)

L_p = Median propagation path loss between the transmitting and receiving antennas, in dB.

FDR = Frequency-Dependent Rejection of spurious emissions between the Meteorological radar transmitter and the radio-relay common carrier receiver, in dBc (dB below the carrier).

Note: The numerical values assumed here may be useful in producing an estimate which will indicate if this technique is viable for a particular path. If so, more precise design parameters should be used.

Once the maximum permissible radio-relay receiver antenna gain, $G_R(\theta)$, is determined, Figure 6-1 can be used to establish the required off-axis angle. The required off-axis angle is a function of the FDR (band dependent, 4 or 6 GHz, and radar nomenclature dependent) and propagation path loss (distance and terrain dependent). A propagation model which considers terrain features should be used to determine the propagation path loss.

Depending on the distance and angular separation between the radio-relay system and the meteorological radar system and the radar nomenclature involved, the required off-axis suppression (pointing angle) may not be achievable.

Antenna Site Shielding. One method to reduce the peak pulsed power of a radar entering the microwave radio-relay system is to shield (or screen) the microwave antenna from the radar transmitted beam, if practicable. Shielding may be available from the topography between the radar and the microwave antennas or it may be man-made.

RADAR SYSTEM MITIGATION OPTIONS

When interference is caused by out-of-band emissions or spurious emissions, the most desirable method of mitigating the interference is to reduce the unwanted emissions at the transmitter. In some cases the only method to mitigate the effects on interference caused by spurious emission is to reduce the spurious emission level at the transmitting source. However, this may not always be technically feasible or economically the must practicalable solution. Advantages of dealing with potential interference at the transmitter is that multiple receiver fixes may be avoided, additional flexibility may be afforded to designer of new microwave routes and non-recurring costs of receiver mitigation fixes for newly deployed microwave systems. Methods to mitigate interference from meteorological radars using transmitter fixes include waveguide RF filters and replacement of transmitting tubes.

Radar RF Filters

Radio Frequency (RF) waveguide filters have been used in several meteorological radars to reduce interference to radio-relay systems to acceptable levels (See Appendix D). To date, RF bandpass filters have only been used in 5 GHz meteorological radars to mitigate interference into the common carrier band 5925-6425 MHz. Measurements have shown (See Figures 6-2) that RF waveguide filters will suppress radar spurious emissions by approximately 40 to 50 dB.

When meteorological radar interference into digital microwave radio-relay systems is caused by spurious emissions from the radars, the installation of RF filter at the radar transmitter is considered a practicable solution provided that it is technically and\or economically possible. The policy and responsibility dealing with the purchase and installation of an RF filter for a specific radar transmitter is not addressed in this report.

Replacement Of Output Device

Variations in meteorological radar spurious emission levels have been observed in radars using coaxial and conventional magnetron tubes. These variations may be attributed to changes in: modulating pulse shaping networks, anode voltage and current and arcing in the tube due to age. The meteorological radar users, on a routine basis, may need to perform periodic checks of the radar transmitter to determine whether these transmitters have, because of age, developed spurious components that were not present when the transmitter was new. In some reported cases, interference problems have been corrected by replacing the output device.[15]

ALTERNATIVE TO RADIOCOMMUNICATIONS

Fiber Optics

Major advances in fiber optics communication technology in the past decade have made it a viable alternative to line-of-sight (LOS) microwave systems. Factors considered in determining whether to use fiber optics over LOS are: transmission distance, start-up time, channel capacity, and economics (including purchase of right-of-way for the fiber optics cables). Generally the decision to use fiber optics is based on these factors; therefore, fiber optics may not be a viable interference avoidance option.

Fiber optic communications rather than by radio frequencies offers the advantages of very wide bandwidth and total electrical isolation. Also, since the fiber waveguide is completely dielectric, it is impervious to electromagnetic interference. Therefore, the use of fiber optic communications may be desirable to link two or more radio-relay stations as an option to avoid interference in some situations.

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[15] H.U. Eichhorn, "Radar Interference Into High Capacity Digital Radio," presented at the 2nd European Conference on Radio-Relay Systems, Abano Terme-Padua, Italy, April 17-21, 1989, pp 187-193.

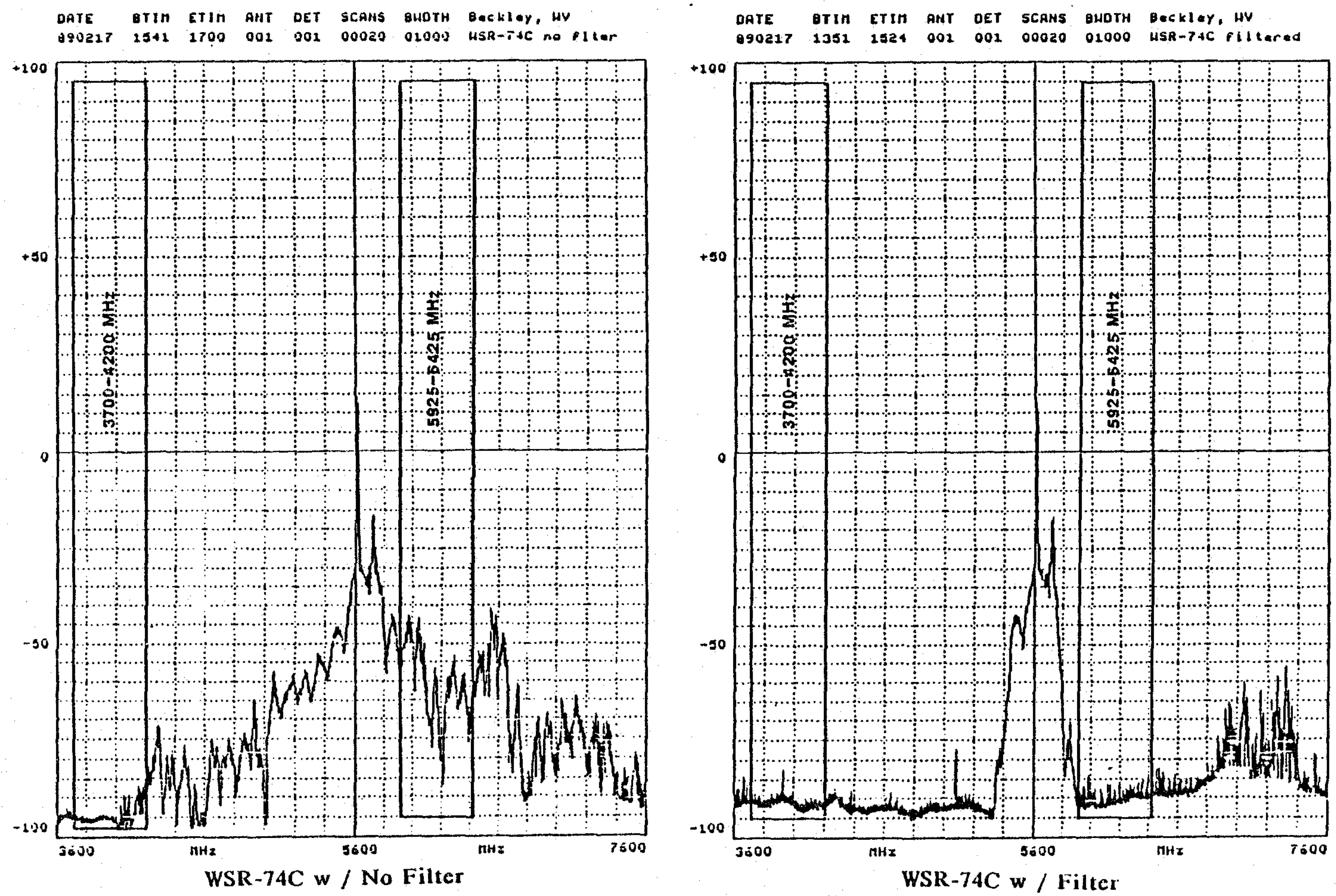


Figure 6-2. **Radiated spectrum measurements of the WSR-74C radar at Beckley, WVA without and with an RF Filter.**

APPENDIX A

STANDARD DS-3 SIGNAL FORMAT

INTRODUCTION

This Appendix contains a partial description of the DS-3 signal which is currently universal to North American high-speed digital common-carrier transmission. It also describes signal formats which can combine several DS-3 signals for digital radio transmission. Both non-error correcting and error correcting radio signal formats are discussed. The information is presented to provide background for determining the effect of pulse type signals on digital systems. The DS-3 signal format may be routed over lightwave, radio, and even coaxial facilities. Its signalling rate is 44.736 megabits per second +/- 20 parts per million and it accommodates 672 voice-grade telephone circuits or their equivalent in data traffic or other digital payloads including video. While the type of underlying payload may vary, the bit rate and frame patterns shown here are standardized and a parity system is included for the purposes of monitoring transport quality along the route of transmission (But not end-to-end). The bit, framing, and parity intervals for the DS-3 signal are indicated in Figure A-1.

NOTES ON DS-3 ERROR RATE MONITORING

The parity check system is used to spot errors accumulated in a single switching section which may cover several hundred miles. By the conventions of DS-3 networking, this parity must be reset to agree with the data before the signal is handed off to the next section. This process aids in fault localization but does not help with end-to-end monitoring. The function of transmission is to carry the load from one digital cross-connect [DSX-3] to the next and to include monitoring for the purposes of protection switching and fault location (see Figure A-2).

In Figure A-2, the F0-F0-F1-F1-F0... F-bit pattern repeats endlessly, appearing at 170-bit intervals, and establishes a high-speed or F-frame. An intermediate pattern, offset by 85 bits from the F-bits repeats over an interval of 28 F-bits and forms the M frame. Thus the payload data bits of one M-frame are carried in 56 blocks of 84 bits each and there are just over 9398 of these M-frames per second. There is one parity check per M-frame which simply indicates if the number of "1s" in the payload in the single frame is odd or even.

Each parity check represents the 4704 payload bits in one M-frame. At low error rates and with the errors randomly distributed, it is unlikely that more than one error will be encountered in an M-frame. For example, at a BER of 10^{-6} [one error per million bits] one count in 212 M-frames can be expected. This rate is also the threshold at which a channel is considered non-acceptable and above which a request for protection switching occurs. For a BER of 10^{-4} [one error per ten thousand bits], approximately one M-frame in two will contain an error. A significant number of frames will contain two errors. The two-error cases will not be reported by simple parity because paired errors do not change the odd-even parity count. For a short continuous block of errors, as in the case of an interfering pulse lasting a 1 to 3 microseconds within an M-frame, only a single parity error can be issued and that is with a 50% probability. Finally, if either a high random error rate [approximately 1

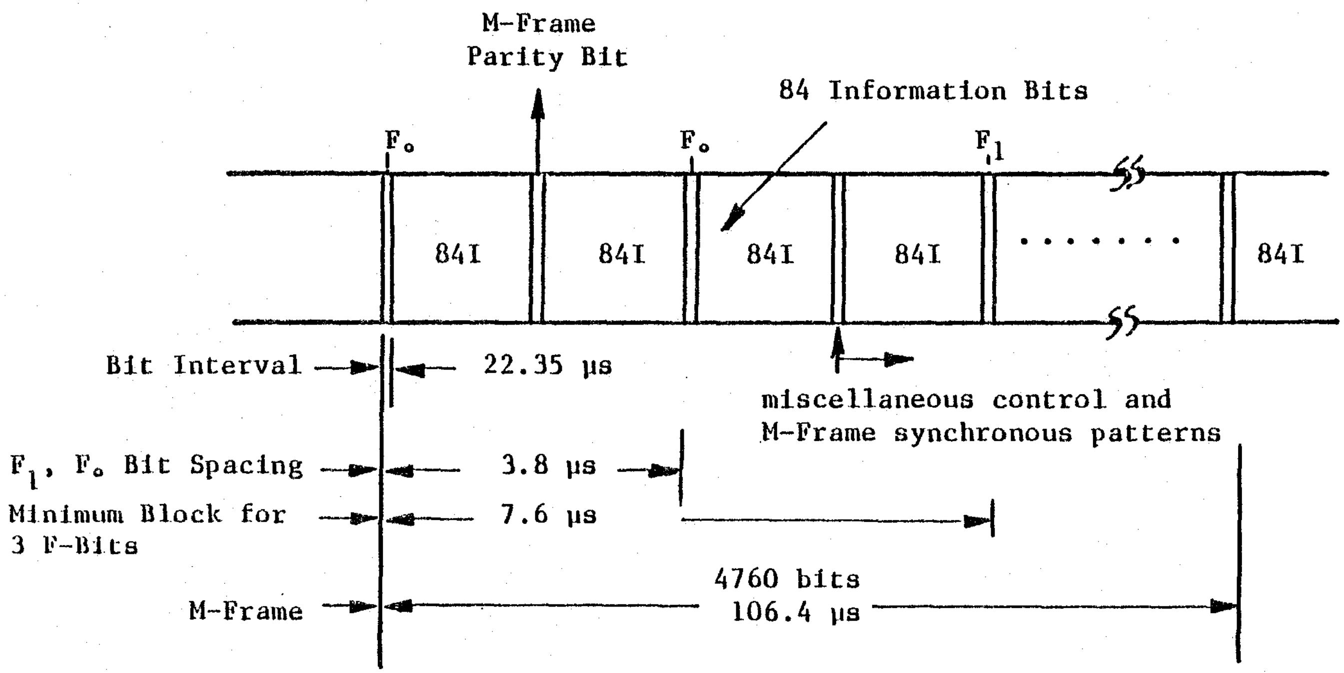


Figure A-1. DS-3 Timing.

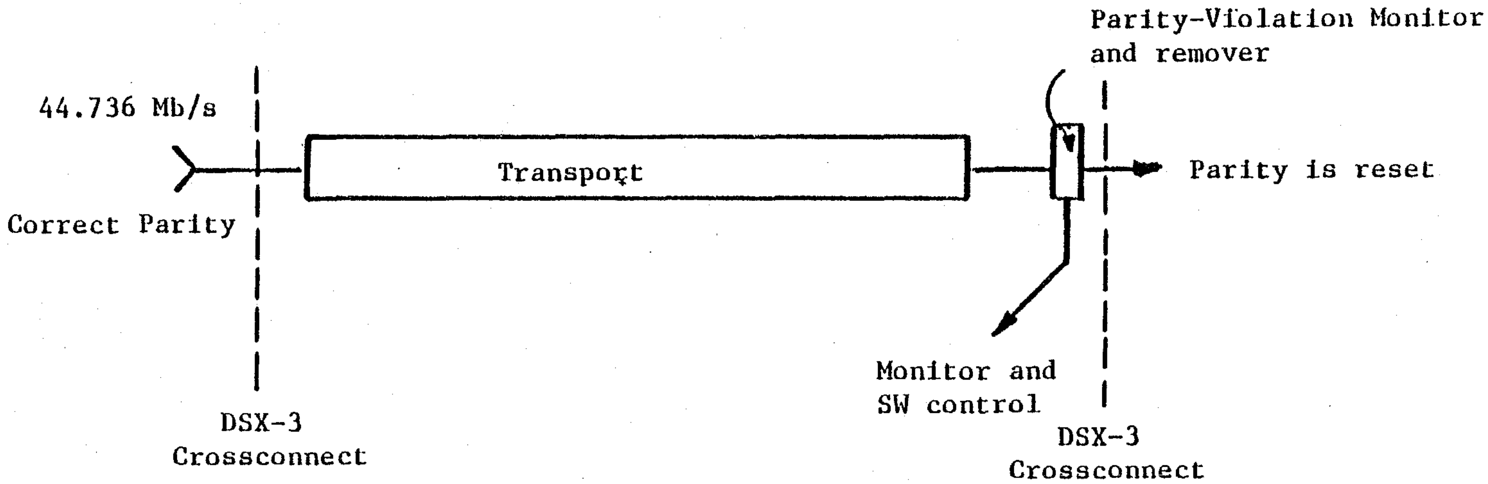


Figure A-2. DS-3 Transport.

error per one thousand, 10^{-3}] or else a solid block of errors causes three F-bits in a running series of 16 to be in error, a reframe will be initiated which will cause all downstream services to reframe. This is a severe-errored-second event even if protection switching can subsequently transfer service to an unaffected channel.

RADIO SYSTEM FRAME FOR 3 DS-3 SIGNALS IN 30 MHz, 64 QAM, NON-ERROR CORRECTING

Figure A-3 shows how, for the purpose of carrying three DS-3 signals simultaneously on a radio channel, a radio frame generator is employed to do the following: 1) Bring the three tributary DS-3 signals up to an identical bit rate through a process known as stuffing, 2) Split the signal into six parallel paths each operating at 1/6 of the total bit rate, 3) Add a fast-frame pattern at every 58th time slot, 4) Calculate and include a Cyclic Redundancy Check [CRC] over successive groups of six fast frame blocks, 5) Provide the necessary overhead for maintenance, signalling, etc. and include them in the fast frame slots in a pattern of 48 F-frames per M-frame. The time dimensions of this signal are included in Figure A-3. Finally, the 6-rail output signal is modulated onto a radio transmitter.

The error sensitivities of this composite signal are similar in many respects to DS-3 which has been described previously. The symbol or "baud" intervals are longer but each one contains six bits of data as a result of 6-parallel-rail transmission. The CRC error checks occur more often: 65,400+ per second rather than 9398, and multiple errors in a single check group will be caught and reported as a single count with near certainty (15/16). However, a block of 1 or 2 microseconds will still be reported as a single count. A BER of 10^{-6} will initiate a protection switch request. For a 135 MB/s system such as this, a sustained BER of 10^{-6} will cause 135 CRC counts per second. To insure timely response in the event of propagation fading, the switch request trigger is set at 14 CRC counts in less than 0.1 second. Thus, CRC counts caused by a pulsed interferer at a rate above 140 pulses per second will trigger a request. The length and strength of the pulses will affect customer services directly, but the seriousness cannot be measured by the parity scheme. However, a block of errors which hits five consecutive F symbols, a period of 10.2 us, will initiate a reframe of downstream services. For interference from a weather radar to cause a reframe, multipath propagation scattering must occur.

RADIO SYSTEM FRAME FOR 3 DS-3 SIGNALS IN 30 MHz PLUS ERROR CORRECTION

Figure A-4 shows the inclusion of an error-correction coding scheme which operates over blocks of 18 payload baud intervals and introduces an additional baud interval of coded information. This allows the finding and correction of up to two bit errors in the block. The timing patterns and keying rates are altered slightly to accommodate the additional information in the signal. For well spaced random errors, the improvement in error rate can be impressive. For a line error rate of 10^{-6} due to thermal noise, the demonstrated payload error rate is 10^{-11}. However, at a line rate of 10^{-3}, there is little gain, if any. For a very short interfering pulse lasting one baud interval (approximately 40.0 ns), this system obtains about 10 dB of advantage in signal to interference ratio at the onset of errors. For a block of errors lasting

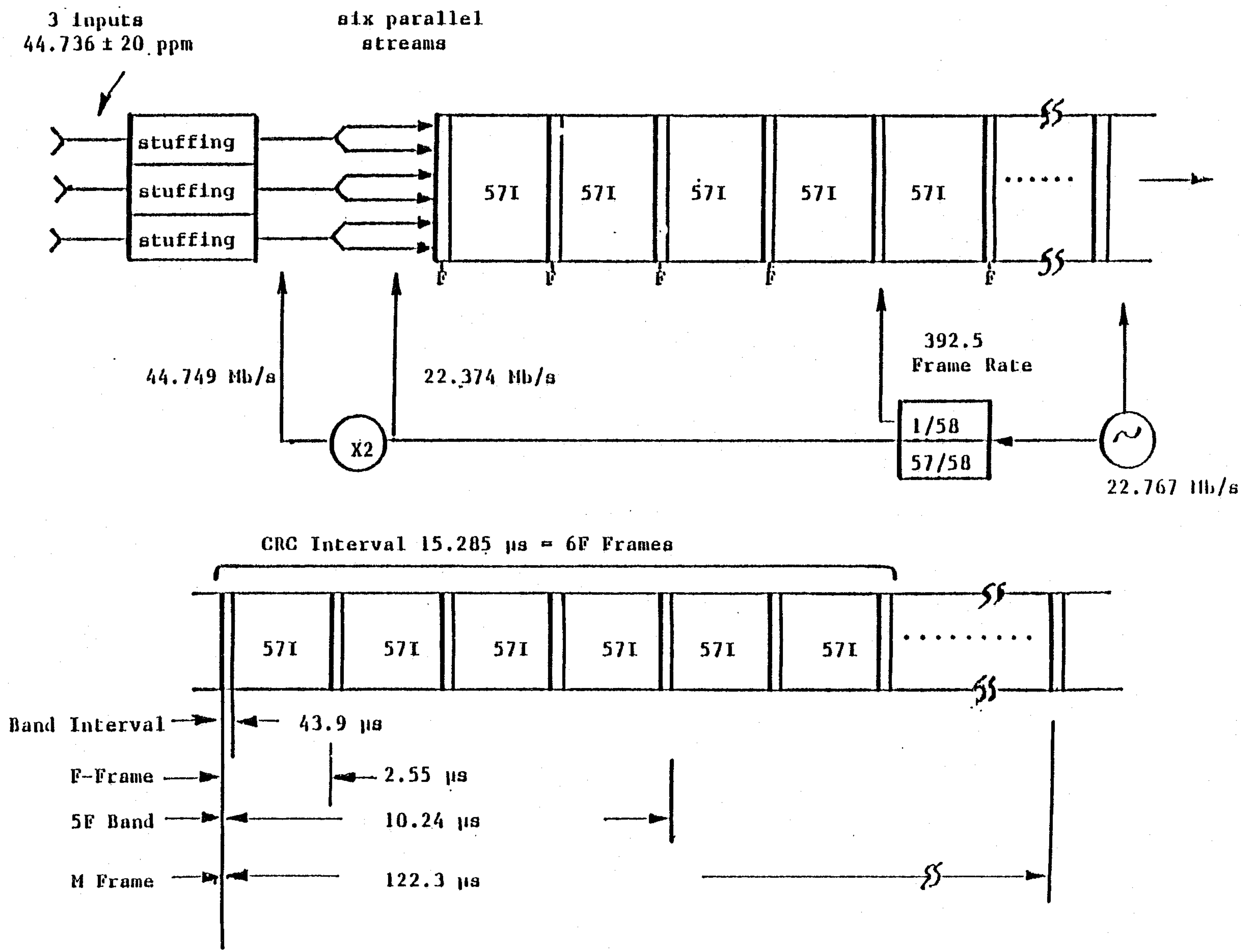


Figure A-3. Three (3) DS-3 Signals in 30 MHz, Non-Error Correcting 64-QAM.

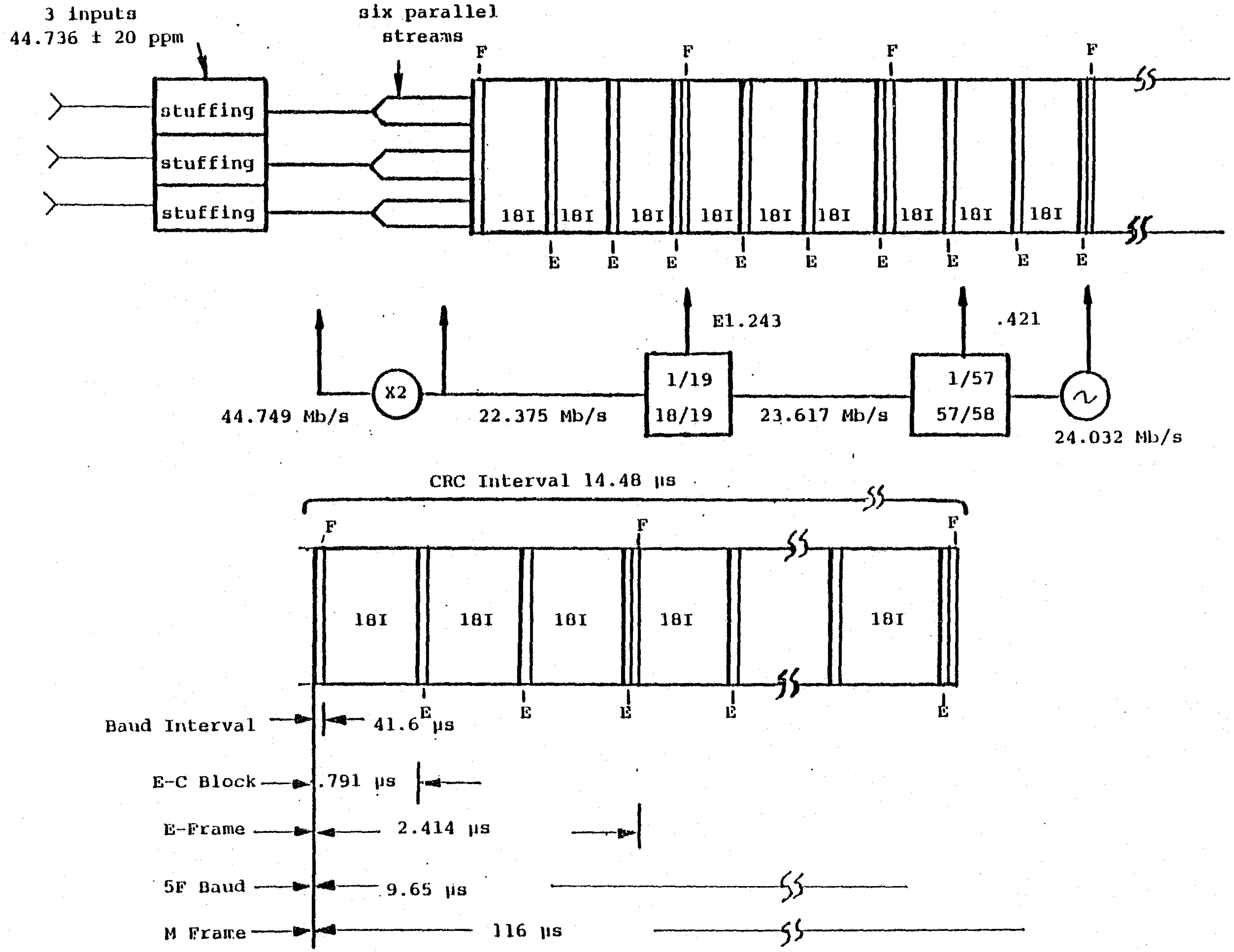


Figure A-4. Three (3) DS-3 Signals in 30 MHz, Error Correcting 64-QAM.

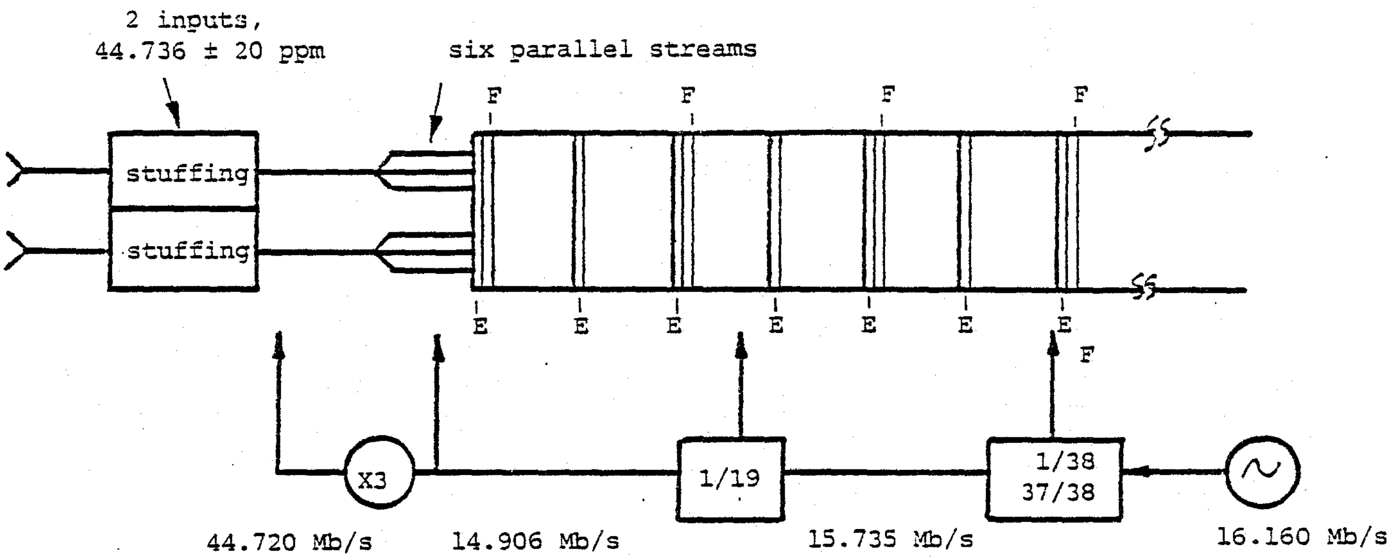
several baud intervals, there is no gain at all. The receiver impulse responses (key clicks) caused by the leading and trailing edges of the pulsed spurious emissions are approximately one baud interval in length.

The protection switch initiation threshold for this system is based on the CRC count rate, not the DS-3 parity rate. In ordinary propagation fading, this means that protection switches can often be affected before errors appear in the DS-3 payload. However, abrupt onset, as in the case of pulsed interference, cannot be anticipated and events which affect two or more channels simultaneously cannot be accommodated by protection switching.

These two nested error-monitoring systems in an error-correcting system can be used to rate the severity of the exposure to pulsed interference, but the results of each are open to further interpretation. In each instance, an investigation is triggered by automated reports which show periods of degraded performance as evidenced by switching and reports of high CRC activity. A further investigation then is made to assess the effect on DS-3 parity and framing [after error correction and protection switching]. Beyond this, on-site measurements of pulse amplitude and duration are coupled with out-of-service test which allow bit-by-bit testing of error patterns that cannot be done by the sampling methods of parity of CRC checks.

RADIO SYSTEM FRAME FOR 2 DS-3 IN 20 MHz, 64 QAM WITH ERROR CORRECTION

Figure A-5 is the lower-rate equivalent of Figure A-4. It is given here for completeness and the discussion of the previous section applies.



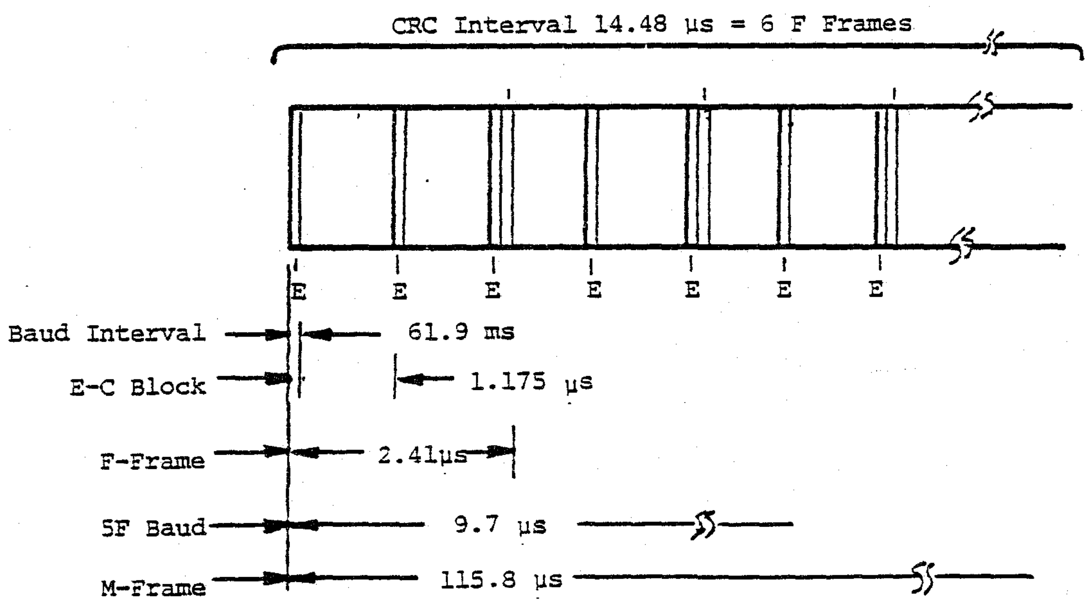


Figure A-5. Two (2) DS-3 IN 20 MHz, Error Correcting 64-QAM.

APPENDIX B

FRONT-END OVERLOAD

INTRODUCTION

This appendix contains a discussion of the measurement results on the front-end overload effects of high power interference into a 6 GHz common carrier receiving system with a low-noise preamplifier (LNA). The test results for continuous wave (CW) signal as well as pulsed (similar to meteorological radar pulses) signal effects into digital point-to-point radio-relay systems for both high gain and low gain LNAs are presented.

These tests concentrate on the overload effects which may result if an unprotected wideband low-noise amplifier encounters high level pulses at the operating frequency of the radar. With radars operating in a range of +85 dBm with 40 dB antennas, the received pulses may be greater than 50 dB above the desired microwave signal level.

A test setup was constructed (see Figure B-1) wherein a standard digital radio channel could be operated with nominal signal level and an independent pulsed signal could be introduced out-of-band to simulate the coupling from a properly operated radar. Measurements of the microwave and interfering signal levels were taken at the input and output of the LNA. The measurements taken at the input of the LNA (test point AA) were representative of high powered interference conditions. Measurements taken at the output of the LNA (test point BB) show the effect of the high powered interference. Care was taken to control sidebands on the interferer to avoid direct coupling at the digital microwave channel frequency. The degradation to the microwave signal is a result of compression (desensitization) of the low-noise amplifiers(s).

TESTS WITH 15 dB LNA

This preamplifier is used on longer than average hops. A nominal (standard practice) digital signal level of -28.5 dBm was used. TABLE B-1 shows the compression of the desired microwave signal at the receiver input (test point CC) as a function of a CW signal levels at the LNA input and output. Compression of the desired microwave signal level commences for an interfering signal level at about 0 dBm.

TABLE B-2 shows the development of Cyclic Redundancy Checks (CRCs), DS-3 payload parity, bit-by-bit direct DS-3 error counts (pseudo-random pattern), BER for DS-3 (45 Mb/s) and DS-3 payload Out-of-Frame (OOF) counts per second as a function pulse signal level using a pulse width of 4 us and a prf of 150 pps. It is shown that the CRC pulse count saturates very quickly (at 370-380 CRC/sec.) at a pulsed signal level of +2.5 dBm which is about the onset of desired signal compression. During the measurements the desired signal envelope was viewed to observe the "recovery" time while the amplifier recovers from the overload caused by the high power pulsed signals. The measurements showed that the "recovery" time increased as the pulsed signal level was increased which is evident by the increase in bit errors (BE) per second. When error correction was used, DS-3 parity pulses showed little improvement because most of the symbols are in error during the pulse. If the interference is left on (C.W.), the

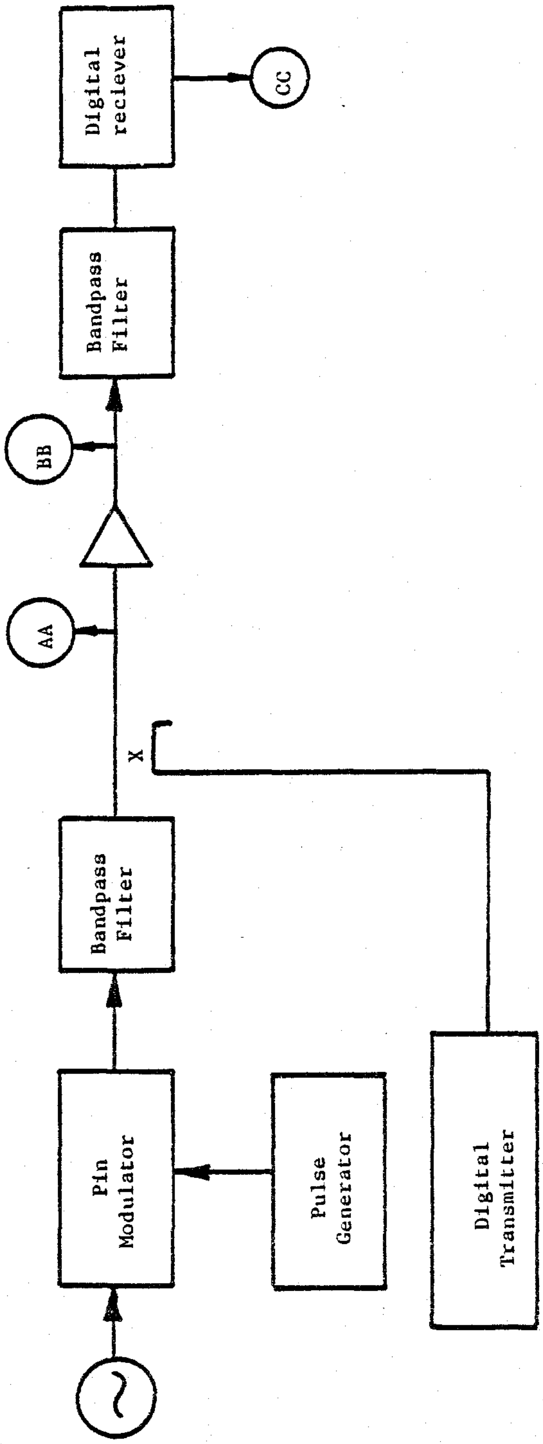


Figure B-1. Standard digital radio-relay channel and an independent pulse generator.

TABLE B-1

THE EFFECT OF CONTINUOUS-WAVE SIGNALS
ON A 15 dB HIGH-GAIN LOW-NOISE PREAMPLIFIER

CW SIGNAL LEVEL (INTERFERENCE)			Digital Microwave Signal Compression (dB)
Test Point AA (dBm)	Test Point BB (dBm)	Gain of LNA (dB)	
- 7.5	+ 7.8	+ 15.3	0.0
- 1.4	+ 13.8	+ 15.3	0.0
+ 2.5	+ 17.0	+ 14.5	0.8
+ 7.5	+ 20.5	+ 13.0	5.0
+ 12.5	+ 21.3	+ 8.8	12.0
+ 16.5	+ 17.0	+ 0.5	17.0

TABLE B-2

THE EFFECT OF A 4 us PULSEWIDTH and PRF 150 pps
ON A 15 dB HIGH-GAIN LOW-NOISE PREAMPLIFIER

Signal Level Test Point AA (dBm)	CRC/sec.	DS-3 Payload parity/sec.	DS-3 bit-by-bit BE/sec.	Calculated DS-3 BER 45 Mb/sec.	DS-3 OOF/sec.
- 7.5	0	0	0	-	0
- 1.4	1-2	0	0	-	0
+ 0.6	90	1-2	1-2	4.4×10^{-8}	0
+ 2.5	370	85	3700	8.2×10^{-5}	0
+ 7.5	380	120	11,700	2.6×10^{-4}	0
+ 12.5	380	130	16,500	3.6×10^{-4}	0
+ 16.5	380	130	20,000	4.4×10^{-4}	0-1

error rates disappear, confirming that momentary amplitude compression and not clipping is the real interfering mechanism.

Measurements were also made to investigate the effect of pulse width in causing DS-3 out-of-frames (OOF). A single out-of-frame causes a severe errored second. For an out-of-frame to occur, the microwave signal must be lost (compressed) for approximately five consecutive framing pulses (10.2 us, See Appendix A). TABLE B-3 shows that at the on-set of desired signal compression (pulse signal level of +2.5 dBm) out-of-frame does not occur unless the pulse width is greater than 10 us. However, as the pulsed signal level is increased the problem grows rapidly even for a 4 us pulse width because the of the microwave signal compression "recovery" time rapidly increases to exceed five consecutive framing pulses (10.2 us).

TESTS WITH 10 dB LNA

Tests were also performed on a lower gain version of LNA used on standard hops. A nominal (standard practice) digital signal level of -23.5 dBm was used. TABLE B-4 shows the compression of the desired microwave signal at the receiver input (test point CC) as a function of a CW signal levels at the LNA input and output. Compression of the desired microwave signal level commences for an CW input signal level at about +3.0 dBm.

TABLE B-5 again shows the development of Cyclic Redundancy Checks (CRCs), DS-3 payload parity, bit-by-bit direct DS-3 error counts (pseudo-random pattern), BER for DS-3 (45 Mb/s) and DS-3 payload Out-of-Frame (OOF) counts per second as a function pulse signal level using a pulse width of 4 us and a prf of 150 pps.

SUMMARY

Because of the potential catastrophic effects of front-end overload on digital system performance, a waveguide highpass filter (HPF) is required when microwave systems encounter pulsed signal levels of greater than 0 dBm when an LNA is used. Figure B-2 below shows the loss characteristic of the waveguide filter commonly used to prevent meteorological radar signals in the 5600-5650 GHz band from blocking an LNA.

TABLE B-3

THE EFFECT OF PULSEWIDTH vs. DS-3 OUT-OF-FRAME/second
ON A 15 dB HIGH-GAIN LOW-NOISE PREAMPLIFIER

Signal Level Test Point AA (dBm)	Pulsewidth 4 μs	Pulsewidth 6 μs	Pulsewidth 8 μs	Pulsewidth 10 μs	Pulsewidth 20 μs
- 2.5	Nil	Nil	Nil	Nil	Nil
+ 2.5	Nil	Nil	Nil	0-1	1-3
+ 7.5	Nil	1-2	3-4	8-12	28-36
+ 16.5	0-1	4-5	8-12	15-18	48-54

TABLE B-4

THE EFFECT OF CONTINUOUS-WAVE SIGNALS
ON A 10 dB LOW-GAIN LOW-NOISE PREAMPLIFIER

CW SIGNAL LEVEL (INTERFERENCE)			Digital Microwave Signal Compression (dB)
Test Point AA (dBm)	Test Point BB (dBm)	Gain of LNA (dB)	
- 7.5	+ 2.7	+ 10.2	0.0
- 2.5	+ 7.6	+ 10.1	0.0
+ 2.5	+ 12.6	+ 10.1	0.0
+ 7.5	+ 16.6	+ 9.1	3.0
+ 12.5	+ 17.5	+ 5.0	11.5
+ 16.5	+ 17.2	+ 0.7	16.0

TABLE B-5

THE EFFECT OF A 4 us PULSEWIDTH and PRF 150 pps ON A 10 dB LOW-GAIN LOW-NOISE PREAMPLIFIER

Signal Level Test Point AA	CRC/sec.	DS-3 Payload parity/sec.	DS-3 bit-by-bit BE/sec.	Calculated DS-3 BER 45 Mb/sec.	DS-3 OOF/sec.
+ 2.5	0	0	0	-	0
+ 3.5	0-1	0	0	-	0
+ 4.5	11	0	0	-	0
+ 5.5	140*	13	25	$5.5x10^{-7}$	0
+ 6.5	320*	110	2000	$4.4x10^{-5}$	0
+ 7.5	340*	125	4100	$9.1x10^{-5}$	0
+ 8.5	340*	125	5300	$1.2x10^{-4}$	0
+ 9.5	340*	125	7300	$1.6x10^{-4}$	0
+ 10.5	340*	125	9200	$2.0x10^{-4}$	0
+ 11.5	340*	125	9800	$2.2x10^{-4}$	0
+ 12.5	340*	125	9900	$2.2x10^{-4}$	0

*switch request was initiated.

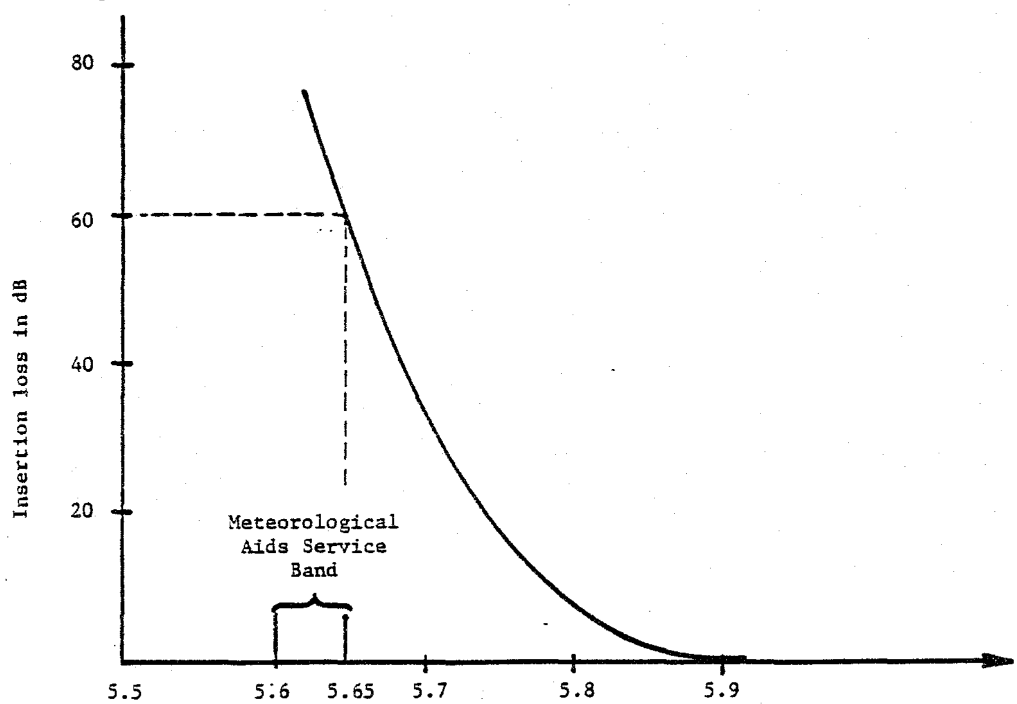


Figure B-2. Insertion loss versus frequency for a waveguide filter used to block meteorological radar.

APPENDIX C

EQUIPMENT CHARACTERISTICS

WEATHER RADAR

INTRODUCTION

The following is a summary of representative equipment characteristics of the meteorological radar stations used in the 2700-2900 MHz, 5600-5650 MHz band and in other bands between 5350-5600 MHz. The radar equipment characteristics of current production models of meteorological radar stations as well as planned meteorological radar stations (NEXRAD and TDWR systems) are provided.

Model		**WSR-57**	
Manufacturer		Raytheon	
Frequency Range		2700-2900 MHz	
Output Tube		Conventional Magnetron	
Peak Power		500 kW (87 dBm)	
Duty Cycle		0.00027@ 0.5 µs	0.000656@ 4.0 µs
Pulse Width		0.5 or 4.0 µs	
Pulse Repetition Rate		545 PPS@ 0.5 µs	164 PPS@ 4.0 µs
RX Noise Figure		unknown	
Min. Discernable Signal		-107 dBm	
Antenna:	Diameter	12 feet, parabolic dish	
	Mainbeam Gain	38 dBi	
	Beamwidth	2.2°	
	Elevation Angle	-5° to +45°	
	Azimuth Scan Time	17 to 20 seconds and manual slewing	

Model		**WSR-74S**
Manufacturer		Enterprise Electronics Corporation
Frequency Range		2700-2900 MHz
Output Tube		Coaxial Magnetron
Peak Power		500 kW (87 dBm)
Duty Cycle		0.000545@ 1.0 μs 0.000648@ 4.0 μs
Pulse Width		1 or 4 μs
Pulse Repetition Rate		539 PPS@ 1.0 μs 162 PPS@ 4.0 μs
RX Noise Figure		9 dB
Min. Discernable Signal		-110 dBm
Antenna:	Diameter	12 feet, parabolic dish
	Mainbeam Gain	38 dBi
	Beamwidth	2.0°
	Elevation Angle	-2° to +60°
	Azimuth Scan Time	17 to 20 seconds

Model		**DWSR-88S "Doppler"**
Manufacturer		Enterprise Electronics Corporation
Frequency Range		2700-2900 MHz
Output Tube		Coaxial Magnetron (locked for coherent processing)
Peak Power		500 kW (87 dBm)
Duty Cycle		0.00085@ 0.8 μs 0.00085@ 2.0 μs
Pulse Width		0.8 or 2.0 μs
Pulse Repetition Rate		1063 PPS@ 0.8 μs 300 PPS@ 2.0 μs
RX Noise Figure		5 dB
Min. Discernable Signal		-109 dBm
Antenna:	Diameter	12, 14, 20 feet, parabolic dish
	Mainbeam Gain	38, 39, 42dBi
	Beamwidth	2.0°, 1.7°, 1.2°
	Elevation Angle	0° to +60°
	Azimuth Scan Time	20 seconds@ 0.8 μs, 60 seconds@ 2.0 μs

Model		NEXRAD
Manufacturer		UNISYS Corp.
Frequency Range		2700-3000 MHz
Output Tube		klystron
Peak Power		750 kW (88.8 dBm,normal), 1MW max.(90 dBm
Duty Cycle		0.0021[16]
Pulse Width		1.6 μs and 4.7 μs
Pulse Repetition Rate		318-1304 PPS@ 1.6 μs 318-452 PPS@ 4.7μs
RX Noise Figure		2.1 dB
Min. Discernable Signal		-115 dBm
Antenna:	Diameter	28 feet, parabolic dish
	Mainbeam Gain	45 dBi
	Beamwidth	0.89° to 0.95°
	Elevation Angle	-1° to +45°[16]
	Azimuth Scan Time	20 seconds

Model		WSR-74C (WR100-2 or -5 prior to 1974) and AN/FPQ-21	
Manufacturer		Enterprise Electronics Corporation	
Frequency Range		5450-5825 MHz	
Output Tube		Coaxial Magnetron	
Peak Power		250 kW (84 dBm)	
Duty Cycle		0.000777	
Pulse Width		3 μs	
Pulse Repetition Rate		259 PPS	
RX Noise Figure		9 dB	
Min. Discernable Signal		-104 dBm	
Antenna:	Diameter	8 feet (WSR-74C)	12 feet (AN/FPQ-21) dish
	Mainbeam Gain	40 dBi	44 dBi
	Beamwidth	1.5°	1.1°
	Elevation Angle	-2° to +60°	
	Azimuth Scan Time	17 to 20 seconds and manual slewing	

16 William H. Heiss, David L. McGrew and Dale Sirmans, "Nexrad: Next Generation Radar (WSR-88D)," Microwave Journal, January 1990, pages 79 - 98.

Model		**WR 100-2/77 (Doppler) (revised in 1977)**
Manufacturer		Enterprise Electronics Corporation
Output Tube		5550-5600 MHz
Frequency Range		Coaxial Magnetron
Peak Power		250 kw(84 dBm)
Duty Cycle		40 dBi
Pulse Width		Short pulse 0.5 μs, long pulse 2.0 μs
Pulse Repetition Rate		704, 880 and 1100 pps
RX Noise Figure		9 dB
Min. Discernable Signal		-104 dBm
Antenna:	Diameter	8 ft
	Mainbeam Gain	40 dBi parabolic dish
	Beamwidth	1.5°
	Elevation Angle	- 2° to + 60°
	Azimuth Scan Time	17 to 20 sec. and manual slewing

Model		**AN/FPS-077**
Manufacturer		Lear Siegler, Inc.
Frequency Range		5450-5650 MHz
Output Tube		Coaxial Magnetron
Peak Power		250-350 kW (84-85 dBm)
Duty Cycle		0.000777
Pulse Width		2 μs
Pulse Repetition Rate		186-324 PPS
RX Noise Figure		9 dB
Min. Discernable Signal		-104 dBm
Antenna:	Diameter	12 feet, parabolic dish
	Mainbeam Gain	44 dBi
	Beamwidth	1.1°
	Elevation Angle	-2° to +60°
	Azimuth Scan Time	17 to 20 seconds

Model	**DWSR-88C, -88CTV and -90CTV "Doppler"**
Manufacturer	Enterprise Electronics Corporation
Frequency Range	5450-5825 MHz
Output Tube	Coaxial Magnetron (locked for coherent processing)
Peak Power	250 kW (84 dBm), max 300 kW (84.7 dBm)
Duty Cycle	0.00085
Pulse Width	0.8 μs
Pulse Repetition Rate	1063 PPS
RX Noise Figure	3.5 dB
Min. Discernable Signal	-106 dBm
Antenna: Diameter	6, 8, 12, 14 feet parabolic dish
Mainbeam Gain	37, 39, 44, 45 dBi
Beamwidth	2.0°, 1.6°, 1.1°, 0.95°
Elevation Angle	0° to +60° (manual operation from 0° to 90°)
Azimuth Scan Time	20 seconds

Model	**WRT-701C, Ground Based Doppler Weather Radar**
Manufacturer	Rockwell International, Collins Division
Output Tube	Solid state multiplier diode technology
Frequency Range	5441.481 MHz (precipitation mode) 5439.998 MHz (turbulence mode)
Peak Power	200 watts (53 dBm)
Duty Cycle	0.0112
Pulse Width	varies from 1 μs to 20 μs
Pulse Repetition Rate	variable from 180 to 1400 PPS
RX Noise Figure	5.0 dB
Min. Discernable Signal	-125 dBm (@ 20 μs)
Antenna: Diameter	slotted array flat plate antenna (roughly circular, 28 inches in diameter)
Mainbeam Gain	30.5 dBi
Beamwidth	5.4°
Elevation Angle	-2° to + 60°
Azimuth Scan Time	8 sec., 16 sec., 32 sec. or manual mode

Model		**Terminal Doppler Weather Radar (TDWR)**
Manufacturer		Raytheon
Output Tube		klystron
Frequency Range		5600-5650 MHz
Peak Power		250 kW (84 dBm)
Duty Cycle		0.0022
Pulse Width		1.1 μs
Pulse Repetition Rate		2000 PPS
RX Noise Figure		1.8 dB
Min. Discernable Signal		109 dBm
Antenna:	Diameter	25 feet, parabolic dish
	Mainbeam Gain	50 dBi
	Beamwidth	0.5°,
	Elevation Angle	-1° to +60°
	Azimuth Scan Time	11 seconds

APPENDIX D

COMPENDIUM OF INTERFERENCE CASES

INTRODUCTION

This appendix contains a discussion of cases where meteorological radars have caused interference to common carrier radio relay systems. As discussed earlier, and shown in several of the interference cases discussed in this section, service provided by digital microwave receivers are more susceptible to pulsed interference than analog frequency modulated (FM) microwave receivers. Therefore, for completeness, radar interference to both digital and analog microwave systems is discussed below.

BACKGROUND

The use of high speed digital modulation in radio relay systems in the common carrier bands has grown rapidly in recent years as a byproduct of the evolving digitization of telephone and data communication networks and also the advent of advanced digital radio modulation techniques permitting per-channel telephone circuit capacities comparable to analog FM systems.

Common carrier microwave radio relay systems are designed to achieve high communications performance as part of the public switched telephone network. This network requires a high degree of service quality and a minimum time objective for outages caused by multipath fading or interference. In general, digital errors associated with these networks fall into the following categories:

A. Time-dependent increased background error rate (Called dribble). [BER less than 10^{-6}]

B. Error Rates Momentarily Above Threshold [BER greater than 10^{-6}] when initiating spurious failure reports and channel switching or initiate service failure alarms on multiple channels.

C. Severe Errored Seconds (Seconds with average error rate exceeding 10^{-3}).

D. Out-of-frame or reframe events.

E. Loss of service.

The annual per-hop outage performance objective for a digital radio relay system depend on the individual application. For long haul service in trunks with 4000 mile (6436 km) objectives, there is an annual outage or unavailability objective of no more than 105 minutes end to end (0.02%) which translates to a net of about 20 seconds per hop per year. This applies to interruptions severe enough to interrupt service. There is also a maximum objective of one severe-errored second per day per hop based on the retransmission effect on digital data services. For short-haul service, the objectives are somewhat less critical as to total annual outage per hop, but the severe errored second objective is the same. In the context of these objectives, therefore, any "burst" type interference, such as caused by radar spurious emissions, in any facility results in a serious degradation of service.

Occasionally, equipment or propagation fading effects will increase the average bit error rate of a channel, causing it to rise above 10^{-6} (the channel switch request point). If an outage occurs smoothly over tens of milliseconds in a working channel and if a protection channel is a part of the system design and is available, a protection channel switch transfer can be made without affecting service. If the outage occurs abruptly, as in the case of equipment failure or burst-like interference, a transfer to the protection channel may take place only after the penalty of a severe errored second. Two or more channels operating simultaneously beyond the switch request point will cause a service failure alarm because these systems are limited to a single protection channel where one is provided.

In many radar interference cases, the digital radio relay system performance is not degraded when the microwave signal is unfaded. However, the level of the interfering signal is such that the fade margin is reduced, thus effectively increasing the outage probability when the desired signal fades. Because of this, the interference is often intermittent making it difficult to determine how much the microwave system performance is being degraded by radar interference.

To date, several cases of radar interference into microwave receivers have been documented. Each of these reported interference cases are unique since the nature and effect of the interference on a particular microwave system is a function of the coupling mechanism (Radar spurious emissions or front-end overload), radar pulse train characteristics (peak amplitude, pulse width and number of pulses) and the effects of the environment on the pulsed emissions (multiple coupling paths). In addition, the microwave signal format (e.g, framing, coding, modulation) as well as special signal processing circuitry, influences the effects of the radar spurious emissions. A detailed discussion of the effect of radar pulsed emissions on microwave systems is given in Section 5.

The following is a discussion of thirteen selected interference cases occurring from meteorological radars to microwave systems (common carrier and private systems). Two interference cases will be discussed in detail to provide an understanding of the complexity in resolving the interfering source, coupling mechanism and the potential interfering signal levels which can occur in the microwave receiving system. Summary information is provided for the other interference cases as well as the two interference cases discussed in detail.

ATLANTA, GA (CASE 1)

In August 1980, field testing on the DR 6-30 digital microwave radio system operating from Atlanta to Palmetto, GA indicated that external interference was degrading system performance. The DR 6-30 at Palmetto, GA was found to contain bursts of error groups at approximately 20 second intervals. The error effect was associated with fading, of less than 10 dB, and was speculated to result from radar interference. Measurements during the period of 25 August through 5 September 1980 identified the interference source as a weather surveillance radar operated by the National Weather Service (NWS) Forecast Offices at 1001 International Boulevard, just north of the airport at Atlanta (see Figure D-1). Verification was obtained via

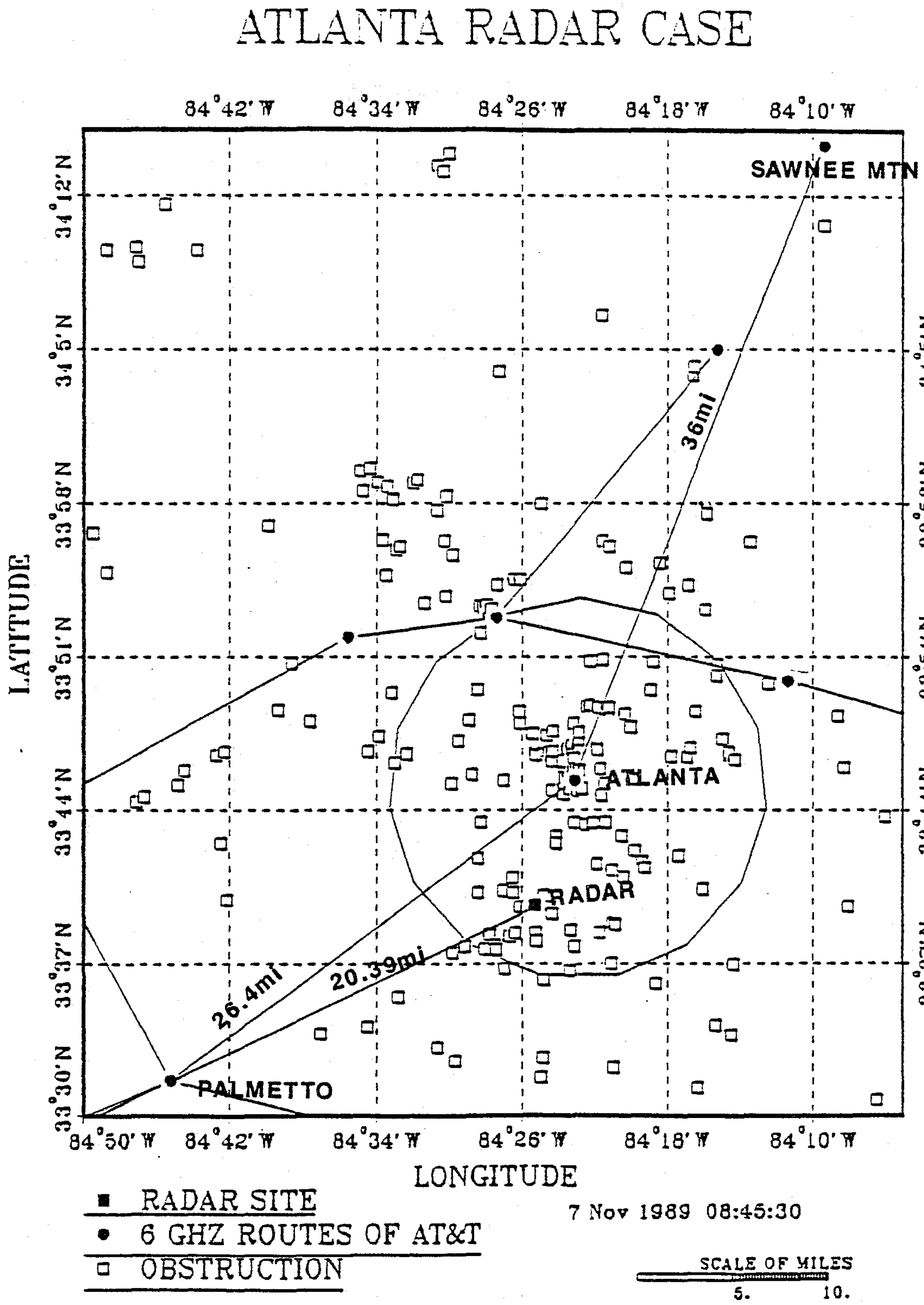


Figure D-1. Atlanta to Palmetto interference case (CASE 1) cooperation with the NWS in turning the radar off and on, and aiming the antenna in the direction of maximum interference.[17]

Once the interfering radar signal was identified, measurements were made to assess the actual radar signal levels and coupling mechanisms. The peak power and time waveform were measured at the radar fundamental operating frequency (5625 MHz) directly before the wideband low-noise receiving preamplifier used in DR 6-30 microwave receiving site at Palmetto.

The measurements showed that the interference resulted in two coupling mechanisms occurring in the digital microwave receiver: front-end overload at the radar fundamental frequency and radar spurious emissions in the common carrier band. The interference from the radar emission entered the microwave receiver located at Palmetto via both direct and indirect paths (See Figure D-1). The received interfering pulse train consisted of approximately 20 pulses on each pass from the radar mainbeam when it was pointed at the Palmetto, GA site (direct path) and at the city of Atlanta (indirect path).

The radar signal level at the fundamental frequency was measured at -4 dBm and was a result of indirect multipath scattering off of tall buildings located within the city of Atlanta, GA via the in-direct microwave path between Atlanta and Palmetto, GA. In addition, radar signals were being received at a level of -19 dBm along the direct path (separation distance 20.39 mi) between the radar and the microwave receiver site at Palmetto. The radar interfering signal level received via the direct path was less than the signal received via the indirect path because the indirect path was line-of-sight due to the reflections off of the tall buildings (See Figure D-1).

The radar signal coupled in by spurious emissions caused impulse responses in the DR-6 channels. The peak amplitude of these impulse responses was found to be approximately equivalent to = -60 dBm in the antenna system with a duration of approximately 50 nanoseconds at a point where the unfaded DR 6-30 signal is -33 dBm. This results in a C/I level of 27 dB. The practical C/I ratio required for error-free reception of an 16 QAM digital signal is approximately 24 dB. Thus, a desired signal fade of greater than 3 dB would cause degradation to the microwave system.

The effects as a result of radar spurious emissions could only be controlled at the radar transmitter. Various discussions with the radar manufacturer were held to obtain a solution to the problem. In view of the amount of reduction desired (upwards of 35 dB in this case and more with a worse exposure) it was decided that installing a band-pass filter was the most desirable approach. Accordingly, arrangements were made with the radar manufacturer to procure one band-pass filter to be placed in the weather radar at Atlanta for the purposes of controlling interference into the 5925-6425 MHz common carrier band. The band-pass filter was installed in the radar in late 1983. Summary information on this interference case (Case 1) is provided below.

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[17] AT&T Laboratories Internal Memorandum from R.P. Slade, AT&T Bell Labs, 1600 Osgood Street, North Andover, MA 01845, SUBJECT: "DR6-30 Radar Interference WR-74C Weather Radar - Case 40395-2," Date: October 7, 1980.

In addition to the interference being received at the microwave receiver site in Palmetto from the NWS radar located in Atlanta, it was determined that the same radar was causing interference to a second microwave receiver site located at Shawnee Mtn, GA via a direct coupling path (Figure D-1). However, as a result of implementing the band-pass filter in the radar located at Atlanta, interference to both microwave receiver sites (Palmetto and Shawnee Mtn) was eliminated. Summary information on this case is provided below (Case 1A).

Summary Information (Case 1): ATLANTA TO PALMETTO

<u>General</u>	
Date of occurrence:	August 1980 Atlanta
Coupling path:	Indirect (Off city buildings)
Mitigation Method:	Band-Pass Filter in radar (in 1983)
Degradation Mechanism:	Spurious emissions
Performance Degradation:	Background errors (Dribble) during modest fading (less than 10 dB
Current Status:	Implementing the band-pass filter in the radar has eliminated the degradation to the microwave receiver.
<u>Radar System</u>	
Operator:	National Weather Service (NWS)
Transmitter Location:	Atlanta, Ga
Nomenclature:	WSR-74C
Frequency Band (MHz):	5600-5650
Peak Output Power (kW):	250
Antenna Gain (dBi):	40 (8 ft. dish)
Pulse Rep. Rate (pps):	259
Pulse width (μsec):	3.3
<u>Microwave System</u>	
Operator:	AT&T
Nomenclature:	DR 6-30 (90 MB/S)
Modulation Type:	16-QAM
Transmitter Location:	Atlanta, GA 33 45 21 N 84 23 10 W
Receiver Location:	Palmetto, GA 33 38 N 84 45 13 W
Frequency Band:	6 GHz

<u>Comments:</u>

Summary Information (Case 1A): ATLANTA TO SHAWNEE MTN

General		
Date of occurrence:	Mid 1983	
Coupling path:	Direct	
Mitigation Method:	Bandpass Filter in radar (same as Case 1)	
Degradation Mechanism:	Spurious emissions	
Performance Degradation:	Receiver overload, Loss of Frame	
Current Status:	Implementing the band-pass filter in the radar (same in (Case 1) has eliminated the degradation to the microwave receiver at Shawnee Mtn, GA.	
Radar System		
Operator:	NWS	
Transmitter Location:	Atlanta, Ga	
Nomenclature:	WSR-74C	
Frequency Band (MHz):	5600-5650	
Peak Output Power (kW):	250	
Antenna Gain (dBi):	40 (8 ft. dish)	
Pulse Rep. Rate (pps):	259	
Pulse width (µsec):	3.3	
Microwave System		
Operator:	AT&T	
Nomenclature:	DR 6-30 (90 MB/S)	
Modulation Type:	16-QAM	
Transmitter Location:	Atlanta, GA	33 45 21 N 84 23 10 W
Receiver Location:	Shawnee Mtn, GA	33 38 N 84 45 13 W
Frequency Band:	6 GHz	

Comments: The interference to the microwave receiver located at Shawnee Mtn, GA was eliminated as a result of implementing the bandpass filter in the NWS weather radar located in Atlanta, GA. This radar is the same radar as given in Case 1.

PORTLAND, ME (CASE 2)

Upon the conversion of the TD-2 Microwave Radio between Portland, Maine and Littleton, Massachusetts from it's original FDM/FM (Analog) application to TD-90 for Digital Service it was observed that there was an external source present that was degrading the digital system.[18]

Initial measurements indicated that from 1 to 10 errors in the total 90 Megabit data payload were going uncorrected. Examination of each of the established channels showed that they all had a problem to some extent, with some being worse than others. Although this particular digital radio system features a very effective technique of Forward Error Correction whatever was causing degradation to the microwave system was breaching the Error Correction Circuitry. Figure D-2 shows the route layout between Portland, Maine and Littleton, Massachusetts.

In early February, 1987 a channel was observed that consistently displayed very brief clusters of errors, on the order of a microsecond in duration. These clusters, each contained between five and twenty five CRC bit errors (Cyclic Redundancy Check) bits. These bursts of CRC errors did not have the randomness characteristic of a typical microwave equipment trouble. The possibility of the problem being in digital circuity of the transmitting Modem responsible for the CRC bits had been eliminated by monitoring the 64 QAM output of the modem before it passed through the first Microwave Radio Transmitter at Portland.

Since the interference was "burst-like" in nature this led to two observations. The first observation was that the bursts of CRC errors were observable at each of the stations on the route between Portland and Littleton once the signal left Portland. These stations included the first repeater Sanford, ME, the second repeater at Chester, NH and the terminal station at Littleton, MA. The second observation was that even though the bursts of CRC errors were not the same size at each station they occurred at exactly the same time at all points. That is a 1 to 5 CRC burst at one station would often appear as a 5 to 10 error burst at another station, but at exactly the same time.

At the receiver end of the first hop (Sanford, ME) a pulse modulated signal was observed to be interfering with the digital radio signal being transmitted from Portland. An important characteristic of the interfering signal was that each string of pulses lasted for approximately a tenth of a second. It was immediately apparent that the interfering signal was from a radar, thus the task turned into one of characterizing and locating the offending radar.

In addition, the level of the interfering signal was seen to vary as much as 20 dB between successive trains of pulses, occasionally reaching a level equal to that of the microwave radio channels affected. Radiation was observed in the vicinity of 3300 MHz, 3500 MHz, and 3800 MHz and the modulation appeared to be in the form of steep sided pulses of about 5 microseconds in duration. It was noted that either a short

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18 AT&T Memorandum Report from Donald Van Dorn, AT&T Eastern Region, 440 Hamilton Avenue, White Plains, NY, 10601, SUBJECT: "RADAR Interference TD-90 4 GHz Digital Radio WSR-74S (S-BAND) Weather Surveillance RADAR", DATE: July 20, 1987.

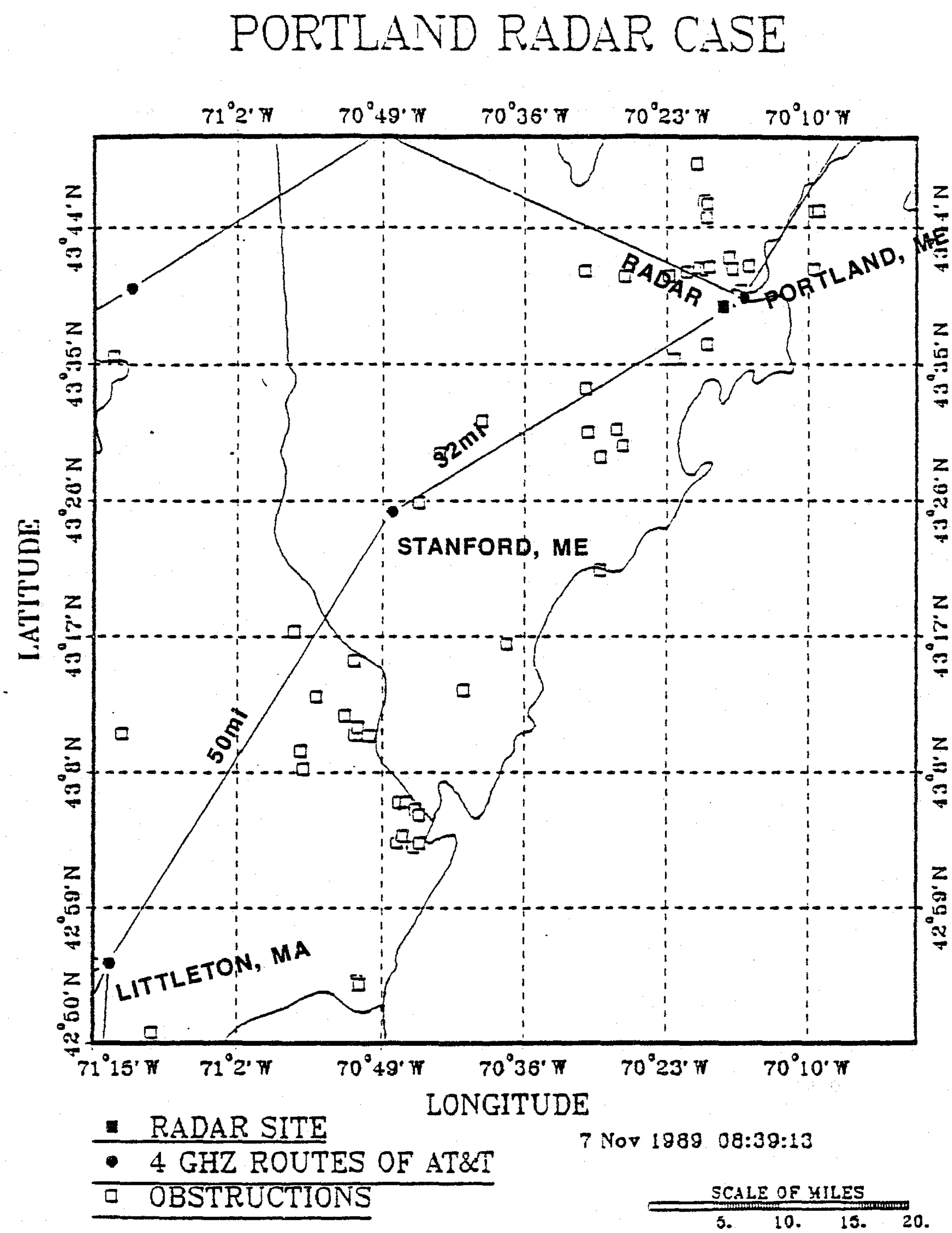

Figure D-2. Portland, Maine to Litteton, Massachusetts Case (CASE 2) burst of pulses was being emitted for about 100 milliseconds every 20 seconds if the radar was one that employed a fixed beam or; if azimuth scanning was occurring when the radar was illuminating the Sanford antennas at 20 second intervals; i.e., 3 revolutions per minute. The fixed beam vs. azimuth scanning question was confirmed by timing measurements showing a sequence of alternating 8 and 12 second intervals between the pulse trains received at Sanford and Portland.

Additional tests were conducted to account for the possibility that the interfering signal might result from Non-Linear elements employed in the Microwave Radio front end reacting adversely to a high level signal not otherwise evident. All indications were that the interference was being emitted in the common carrier band and that it originated from a point north of Sanford since the interference was not visible on the Chester antennas at Sanford.

Measurements taken at the Portland microwave receiver showed that the interfering signal was entering the Sanford antennas at Portland as well as those aimed toward Cornish, ME. (located north of Sanford). Although the interference was not as high in level into the antennas at Portland as it was at Sanford, all of the other characteristics were identical.

A telephone call was made the Portland Forecast Office of the National Weather Service (NWS) who operates the Weather Surveillance radar at the airport in Portland, ME. Testing, with the cooperation of the NWS indicated that their WSR-74S radar located at the airport in Portland was operating at 2896 MHz with a peak power of 410 Kilowatts (86.1 dBm). Subsequent measurements of the spurious emissions from the WSR-74S indicate that it was operating within specifications for its type and vintage. However, the level of spurious emission generated by the radar into the 3.7 to 4.2 GHz Microwave Common Carrier Band is sufficiently high to cause interference for the specific exposure that exists at Sanford, M.E microwave repeater site.

Test measurements were conducted to determine the average level of the interference from the radar relative to the microwave radio receiver normal input signal level for various microwave receiver frequencies at Sanford. The results are given below:

Frequency (MHz)	Carrier/Interference Level (dB)
3770	30
3790	30
3810	10
3830	30
3890	35
3970	25

From this data, a number the various microwave channels would be affected due to emissions from the radar.

Tests were conducted to determine the effect of continuous orientation of the radar toward both the Sanford and Portland towers on data error rate. In the case of the Sanford tower, failure of the Receive Modem on channel 8 (3830 MHz) to reliably recover data was the result. Channel 8 performance in the direction from Portland toward Littleton was degraded to a bit-error-rate (BER) of approximately 10^{-5} while the radar was oriented to illuminated the Sanford tower. As a result of this error rate, channel switching in the microwave receiver occurred. No effect on data performance was observed with the radar fixed on the Portland tower. The significance of testing for this " Constant Exposure" from the radar is that this weather surveillance radar is often used in a "Manual Train" mode while examining cloud formations or storms.

Substantial effort was expended to observe the radar signal at the operating fundamental frequency via the antenna and waveguide in the microwave. It was known that considerable energy was contained in the impulsive signal being radiated and the fear that the Microwave Receiver portion of the Digital Radio might in some way be impeaching the data payload was lingering. Knowledge of the specific frequency of operation of the radar made it possible to reconcile the absence of any trace of the main pulses of the radar transmitter; they were below the antenna cutoff frequency. Therefore, based on this information it was concluded that there was complete protection of the microwave receiver at 4 GHz from the main pulse of the radar (no front-end overload).

Since the spurious radar emissions on the operating frequency of the digital microwave receiver were the mechanism causing degradation problems to the microwave receiving site it was concluded that an immediate solution was not available. In addition, it was determined that it would take longer to fix the interference problem due to radar spurious emissions than the time available before the Digital Radio would be needed for service. To be sure of satisfying the service requirements the interim solution to the problem was to establish a temporary replacement channel 5 (4090 MHz) in the direction from Portland to Sanford. This temporary channel utilizes packaged portable equipment brought in expressly for this temporary application.

The long term solution to the interference problem involved working with the manufacturer of the radar, Enterprise Electronics, with some recommendations from AT&T Bell Laboratories establishing a set of specifications for a spurious suppression Filter was developed. Some of the considerations that went into the design were:

Required Attenuation of the Spurious
Power Output of the RADAR Transmitter
Available Mounting Space
Long Term Reliability of the Filter
Long Term Reliability of the RADAR Transmitter with the added Filter

A filter suitable for this application with the above considerations included into its design was ordered by AT&T for the WSR-74S radar at Portland. Currently, the spurious suppression filter has not been placed in the radar located at Portland and the microwave remains operating on the temporary channel 5 at 4090 MHz.

Summary information on this interference case is provided on the next page.

Summary of Information (CASE 2): PORTLAND, ME

<u>General</u>

Date of occurrence:	February 1987
Coupling path:	Direct
Mitigation:	Change operating frequency of microwave
Degradation Mechanism::	Spurious Emissions
Performance Degradation:	High Bit Error Rate Bursts
Current Status:	No degradation to the microwave receiver as a result of the microwave operating on alternate channel.

<u>Radar System</u>

Operator:	NWS
Transmitter Location:	Portland, ME
Nomenclature:	WSR-74S
Frequency Band (MHz):	2000 MHz
Peak Output Power (kW):	410
Antenna Gain (dBi):	38 (12 ft dish)
Pulse Rep. Rate (pps):	Short 539 Long 162
Pulse width (μsec):	Short 1 Long 4

<u>Microwave System</u>

Operator:	AT&T
Nomenclature:	TD 90
Modulation Type:	64-QAM
Transmitter Location:	Portland, ME 43 39 21 N 70 15 52 W
Receiver Location:	Sanford, ME 43 25 14 N 70 48 12 N
Frequency band:	4 GHz

<u>Comments:</u> Rf waveguide filter for the radar has been ordered but not installed.

ADDITIONAL INTERFERENCE CASES

The following are additional reported interference cases. Given for each interference case is a summary of characteristics.

MOLINE, IL (CASE 3)

Problem: WSR-74C Radar Interference with the 6 GHz common carrier band analog microwave receiver 7/76.

Mitigation: Bandpass Filter installed on radar 9/77.

Summary of Information:

General	
Date of occurrence:	7/76
Coupling path:	Direct
Mitigation Method:	Bandpass Filter
Degradation Mechanism:	Spurious Emissions
Performance Degradation:	Errored Seconds
Current Status:	Implementation of Bandpass Filter has resulted in no degradation to microwave receiver.
Radar System	
Operator:	NWS
Transmitter Location:	Moline, ILL
Nomenclature:	WSR -74C
Frequency Band (MHz):	5600-5650
Peak Output Power (kW):	250
Antenna Gain (dBi):	40
Pulse Rep. Rate (pps):	259
Pulse width (µsec):	3
Microwave System	
Operator:	AT&T
Nomenclature:	DR 6-30
Modulation Type:	16 QAM
Transmitter Location:	Moline: 41 29 01 N 90 31 37 W
Receiver Location:	Alpha: 41 14 20 N 90 20 25 W
Frequency Band:	6 GHz

Comments:

TULSA, OK (CASE 4)

Problem: NWS WSR-74C Radar Interference with the 6 GHz common carrier microwave receiver 7/86.

Mitigation: MITEC filter installed 10/86

Summary of Information:

General

Date of occurrence:	7/86
Coupling path:	Direct
Mitigation Method:	MITEC Bandpass Filter
Degradation Mechanism:	Spurious Emissions
Performance Degradation:	Errored seconds
Current Status:	Implementing the band-pass filter in the radar has eliminated the degradation to the microwave receiver.

Radar System

Operator:	NWS
Transmitter Location:	Tulsa, OK
Nomenclature:	WSR-74C
Frequency Band (MHz):	5600-5650
Peak Output Power (kW):	250
Antenna Gain (dBi):	40
Pulse Rep. Rate (pps):	259
Pulse width (μsec):	3

Microwave System

Operator:	Time-Mirror Microwave Company
Nomenclature:	Rockwell Analog Radio (MARGC)
Modulation Type:	Analog 2400 channel FDM/FM
Transmitter Location:	Tulsa JNT, OK 36 06 56 N 96 01 02 W
Receiver Location:	Verdigris, OK 36 19 18 N 95 42 51 W
Frequency Band:	6 GHz

Comments:

TULSA, OK (CASE 5)

Problem: TV station WR 100-2/77 (Doppler) radar interference with the 6 GHz common carrier microwave receiver 10/28/89.

Mitigation: MITEC filter installed 10/86

Summary of Information

<u>General</u>

Date of occurrence:	10/86
Coupling path:	Direct
Mitigation Method:	MITEC Bandpass Filter
Degradation Mechanism:	Spurious Emissions
Performance Degradation:	Errored Seconds
Current Status:	Implementing the band-pass filter in the radar has eliminated the degradation to the microwave receiver.

<u>Radar System</u>

Operator:	KJRH TV
Transmitter Location:	Tulsa, OK
Nomenclature:	WR-100-2/77
Frequency Band (MHz):	5550-5600
Peak Output Power (kW):	250
Antenna Gain (dBi):	40
Pulse Rep. Rate (pps):	704, 880, 1100
Pulse width (μsec):	0.5 short 2.0 long

<u>Microwave System</u>

Operator:	MCI Telecommunications	
Nomenclature:	KA-1095B (5400 Channel Radio)	
Modulation Type:	SSB	
Transmitter Location:	Broken Arrow, OK	36 04 56 N 95 45 27 W
Receiver Location:	Tanglewood, OK	36 10 17 N 95 13 23 W
Frequency Band:	6 GHz	

<u>Comments:</u>

SHREVEPORT, LA (CASE 6)

Problem: WSR-74C Radar interference with 6 GHz common carrier microwave receiver 3/88.

Mitigation: MITEC filter installed 3/88.

Summary of Information

General

Date of occurrence:	3/88
Coupling path:	
Mitigation Method:	MITEC Bandpass Filter
Degradation Mechanism:	
Performance Degradation:	
Current Status:	

Radar System

Operator:	NWS
Transmitter Location:	Shreveport, LA
Nomenclature:	WSR-74C
Frequency Band (MHz):	5600-5650
Peak Output Power (kW):	250
Antenna Gain (dBi):	40
Pulse Rep. Rate (pps):	259
Pulse width (µsec):	3

Microwave System

Operator:	Netwave Systems
Nomenclature:	
Modulation Type:	
Transmitter Location:	Dixie Grdn, LA 32 27 20N 93 41 18W
Receiver Location:	Shreveport, LA 32 30 34N 93 44 55W
Frequency Band:	6 GHz

Comments:

BECKLEY, WV (CASE 7)

Problem: WSR-74C Radar interference with 6 GHz common carrier microwave receiver 8/88.

Mitigation: MITEC Bandpass filter was installed by NWS November 1989.

Summary of Information

<u>General</u>

Date of occurrence:	8/88
Coupling path:	
Mitigation Method:	MITEC Bandpass filter
Degradation Mechanism:	
Performance Degradation:	
Current Status:	Implementing the Bandpass filter in the radar has eliminated the degradation to the WSWP-TV microwave receiver.

<u>Radar System</u>

Operator:	NWS
Transmitter Location:	Beckley, Va
Nomenclature:	WSR-74C
Frequency Band (MHz):	5600-5650
Peak Output Power (kW):	250
Antenna Gain (dBi):	40
Pulse Rep. Rate (pps):	259
Pulse width (μsec):	3

<u>Microwave System</u>

Operator:	WSWP, TV Station at Beckley, WV Microwave System	
Nomenclature:	Microwave Associates; MA85T06GW - VIDEO	
Modulation Type:	25000F9	
Transmitter Location:	Bolt, WV	37 47 15.0N 81 29 28.5W
Receiver Location:	Beckley, WV	37 47 06.0N 81 06 45.0W
Frequency Band:	6 GHz	

<u>Comments:</u> WSWP-TV purchased the MITEC filter required for the radar (per NWS specs) and NWS installed the MITEC filter in November 1989.

BURLINGTON, VT (CASE 8)

Problem: WSR-74C Radar interference with 6 GHz common carrier microwave receiver 4/89.

Mitigation: MITEC filter installed 5/89.

Summary of Information

<u>General</u>

Date of occurrence:	4/89
Coupling path:	
Mitigation Method:	MITEC Bandpass Filter
Degradation Mechanism:	
Performance Degradation:	
Current Status:	Implementing the band-pass filter in the radar has eliminated the degradation to the microwave receiver.

<u>Radar System</u>

Operator:	NWS
Transmitter Location:	Burlington, VT
Nomenclature:	WSR-74C
Frequency Band (MHz):	5600-5650
Peak Output Power (kW):	250
Antenna Gain (dBi):	40
Pulse Rep. Rate (pps):	259
Pulse width (μsec):	3

<u>Microwave System</u>

Operator:	Eastern Microwave Incorporated	
Nomenclature:		
Modulation Type:		
Transmitter Location:	Mt. Pritchard, VT	44 22 12N 73 06 24W
Receiver Location:	Rouses Point, VT	45 00 35N 73 22 34W
Frequency Band:	6 GHz	

<u>Comments:</u> Eastern Microwave Incorporated paid additional money to get the filter quickly from MITEC and as a result be placed in the radar to eliminate the degradation.

COLUMBIA, SC (CASE 9)

Problem: WSR-74C Radar interference with 6 GHz common carrier microwave receiver 6/89.

Mitigation: AT&T procuring correct MITEC filter. The filter was installed on December 6, 1989.

Summary of Information

<u>General</u>	
Date of occurrence:	6/89
Coupling path:	Direct
Mitigation Method:	MITEC Bandpass Filter
Degradation Mechanism:	Spurious Emissions
Performance Degradation:	Loss of Frame
Current Status:	Implementing the band-pass filter in the radar has eliminated the degradation to the microwave receiver.

<u>Radar System</u>	
Operator:	NWS
Transmitter Location:	Columbia, SC
Nomenclature:	WSR-74C
Frequency Band (MHz):	5600-5650
Peak Output Power (kW):	250
Antenna Gain (dBi):	40
Pulse Rep. Rate (pps):	259
Pulse width (μsec):	3

<u>Microwave System</u>		
Operator:	AT&T	
Nomenclature:	DR 6-30	
Modulation Type:	16-QAM	
Transmitter Location:	Columbia, SC	34 00 29 N 81 01 42 W
Receiver Location:	Beaney, SC	34 10 N 80 47 15 W
Frequency Band:	6 GHz	

<u>Comments:</u> Enterprise Electronic (manufacturer of the radar) provided the MITEC filter free of charge to AT&T after some negotiation.

NORFOLK, VA (CASE 10)

Summary of Information

General	
Date of occurrence:	February 1989 and December 1989; intermittent dates
Coupling path:	unknown
Mitigation:	Tube Change
Degradation Mechanism:	
Performance Degradation:	High Bit Error Rate Bursts
Current Status:	unresolved
Radar System	
Operator:	Knight Ridder*
Transmitter Location:	Norfolk, VA 36 51 18N 76 17 26W
Nomenclature:	
Center Frequency:	
Peak Output Power:	
Antenna Gain:	
Pulse Rep. Rate:	16.8 seconds
Pulse width:	
Microwave System	
Operator:	C&P Telephone Company
Nomenclature:	WECO DR6-30
Modulation Type:	30000A9Y
Transmitter Location:	Norfolk, VA 36 51 11N 76 17 25W
Receiver Location:	Hampton, VA 37 01 35N 76 20 34W
Frequency band:	6 GHz
Comments:	The interference problem has not occured since the December 1989.

* tests were conducted; however, they did not substantiate that the Knight Ridder radar was the interference source.

SACRAMENTO, CA (CASE 11)

Problem: WSR-57 Radar Interference at 5945 & 11545 MHz 6/89.

Mitigation: Trying to obtain RF waveguide filter and determine if filter can physically be placed in radar. (7/89).

Summary of Information

<u>General</u>

Date of occurrence:	6/89
Coupling path:	
Mitigation Method:	Operator has changed frequencies in 11 GHz band.
Degradation Mechanism:	
Performance Degradation:	Spurious emissions at 2nd and 4th harmonic of fundamental.
Current Status:	No degradation as a result of temporary changing frequencies in microwave receiver. No final solution to the problem as of 9/89.

<u>Radar System</u>

Operator:	NWS
Transmitter Location:	Sacramento, CA
Nomenclature:	WSR-57
Frequency Band (MHz):	2700-2900
Peak Output Power (kW):	500
Antenna Gain (dBi):	38
Pulse Rep. Rate (pps):	Short 545 Long 164
Pulse width (μs):	Short 0.5 Long 4.0

<u>Microwave System</u>

Operator:	Western Telecommunications	
Nomenclature:	Northern Telecom Inc., CXP7UJRD11C1	
Modulation Type:	64-QAM	
Transmitter Location:	Sacramento, CA	38 34 44.0N 121 29 47.0W
Receiver Location:	Rio Linda, CA	38 45 56.0N 121 31 25.0W
Frequency Band:	6 GHz 11 GHz	

<u>Comments:</u> The WSR-57 was developed, procured and installed before January 1, 1973 and therefore was granted a waver from the 1973 and later RSEC requirements.

STANFORD, CT (CASE 12)

Problem: WSR-57 Radar interference with 6 GHz common carrier microwave receiver 7/89.

Mitigation: Change WSR-57 magnetron tube.

Summary of Information

<u>General</u>

Date of occurrence:	7/89
Coupling path:	
Mitigation Method:	Change Magnetron Tube
Degradation Mechanism:	
Performance Degradation:	
Current Status:	Implementation of new tube has resulted in no degradation to microwave receiver.

<u>Radar System</u>

Operator:	NWS
Transmitter Location:	Stamford, CT
Nomenclature:	WSR-57
Frequency Band (MHz):	2700-2900
Peak Output Power (kW):	500
Antenna Gain (dBi):	38
Pulse Rep. Rate (pps):	164 short 545 long
Pulse width (μsec):	0.5 short 4.0 long

<u>Microwave System</u>

Operator:	Group W (Division of Westinghouse)
Nomenclature:	
Modulation Type:	
Transmitter Location:	
Receiver Location:	
Frequency Band:	6 GHz

<u>Comments:</u>

BILLINGS, MT (CASE 13)

Problem: WSC-74C Radar interference with the 6 GHz common carrier microwave receiver in July 1989.

Mitigation: LNA removed and adjustment of the microwave output power level.

Summary of Information

General		
Date of occurrence:	7/1/89	
Coupling path:	Direct	
Mitigation Method:	LNA in microwave receiver removed. Adjustment of microwave output power level	
Degradation Mechanism:	Front end overload	
Performance Degradation:	Errored Seconds	
Current Status:	No degradation to microwave receiver	
Radar System		
Operator:	NWS	
Transmitter Location:	Billings, MT	
Nomenclature:	WSR-74C	
Frequency Band (MHz):	5600-5650	
Peak Output Power (kW):	250	
Antenna Gain (dBi):	40	
Pulse Rep. Rate (pps):	259	
Pulse width (μsec):	3	
Microwave System		
Operator:	AT&T	
Nomenclature:	DR 6-135	
Modulation Type:	64-QAM	
Transmitter Location:	Billings, MT	45 46 55 N 108 30 31 W
Receiver Location:	Billings Jnt, MT	45 43 44 N 108 22 43 W
Frequency Band:	6 GHz	

Comments:

SUMMARY

In most radar interference cases, the digital radio relay system performance is not degraded when the microwave signal is unfaded. However, when the level of the interfering signal is such that the fade margin is reduced, the outage probability objective that the microwave system was designed to meet will be exceeded and service affecting outages are likely when the desired signal fades. Because of the coincidence of these service outages with episodes of fading the radar interference is often blamed on natural phenomena making it unapparent that the microwave system performance is being degraded by radar spurious emissions.

This appendix has discussed thirteen selected cases of reported interference from meteorological radars to microwave radio relay systems. Eleven of the interference cases were from government radars and two from non-government radars. Both the Government and non-Government radar operators have cooperated with NTIA and the microwave radio-relay owners to mitigate interference problems, when feasible.

In one of the interference cases a waveguide filter in the microwave was used to mitigate front end overload effects, an RF waveguide filter was put in six weather radars to reduce the spurious emissions, and the transmitter output tube was changed in two radars to mitigate the interference. Furthermore, of the reported interference cases, there were two cases in which the microwave system frequency of operation has been changed, one case where the output power in the microwave transmitter was reduced, and two cases where the interference problem has not been resolved.

Policy and regulation procedures affixing responsibility for mitigating interference from spurious emissions have been discussed in many of the interference cases. Specifically, these discussions have included determining the mitigation burden between users of meteorological radars and microwave systems. However, for the eight reported interference cases when an RF waveguide filter was installed in the radar transmitter to mitigate the interference, the cost was assumed by the microwave common carrier industry. Therefore, guidelines for Government agencies, non-Government users and the microwave industry on mitigation procedures for field personnel pertaining to interference from ground based Meteorological radars to microwave systems would be helpful in expediting the resolution of interference and in assuring that responsibility is assumed by the appropriate party.

The coupling mechanism of front-end overload from meteorological radars has only been observed in digital relay systems operating in the 6 GHz band. In addition, there has been one reported case of interference from a meteorological radar operating near the 3 GHz band to a common carrier microwave receiver operating in both the 6 GHz and 11 GHz bands. Similarly, there have been no reported cases of interference from meteorological radars operating in the 5 GHz band to common carrier receivers operating in the 4 GHz band.

APPENDIX E

PEAK POWER RESPONSE OF A COMMUNICATIONS RECEIVER TO RADAR PULSE TRAINS

This appendix calculates the peak power responses for a receiver considerably off-tuned from the center frequency of the interference responding to the rise and fall time parts of the interference pulse. The interference effects of an intermittent radar pulse train are often dependent upon the peak response rather than an average response. This Appendix calculates the peak response for a rectangular pulse train. Figures E-1 and E-2 shows the condition for analysis in the time domain. Note that the time domain signals in Figure E-2 correspond to the condition $B_r > 1/T$ and a large frequency deviation (Δf) from the tuned frequency.

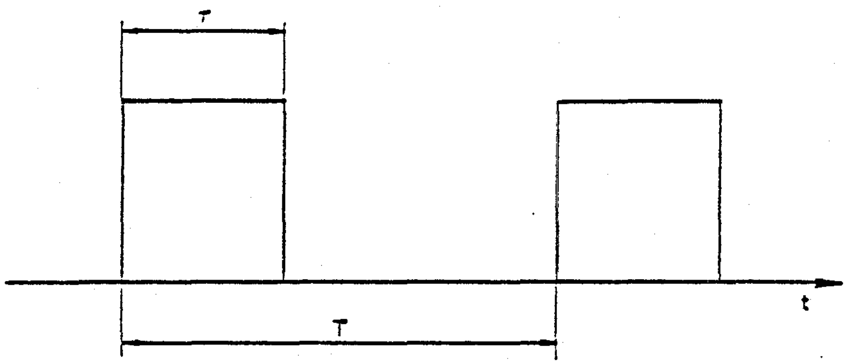

Figure E-1. Input radar pulse time waveform.

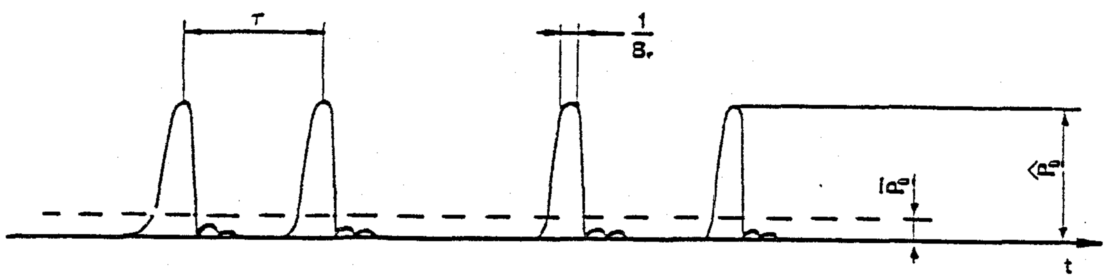

Figure E-2. Output time waveform for condition $B_r > 1/T$ and large frequency deviation (Δf) from the tuned frequency.

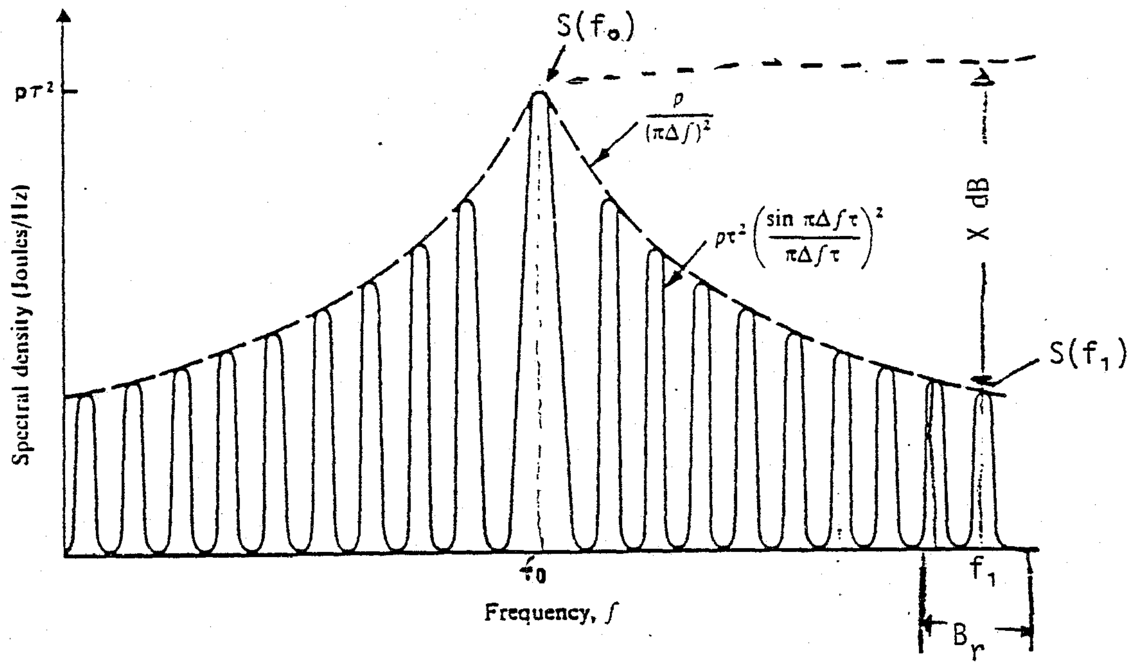

Figure E-3.

Figure E-3 shows the power spectral density (frequency domain) for the input pulse. For the conditions of this report, the receiver can be modeled as a bandpass filter with response

$$-B_r/2 \leq f \leq B_r/2 = H(f) = 1 \qquad \text{(E-1)}$$

$$= 0 \text{ elsewhere}$$

The response to each radar pulse is assumed to be an impulse response at the start of the pulse and an impulse response at the end of each pulse. This response is illustrated in Figure E-4.

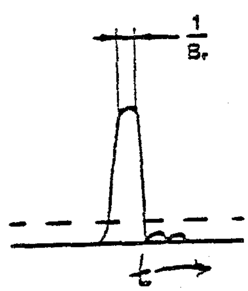

Figure E-4.

The time-waveform of the response from each impulse is from Javid and Brenner (1969), eq. 6-31.

$$v(out) = \frac{S(f_1)^{1/2} B_r \sin[2\pi B_r(t-T_d)]}{2\pi B_r(t-T_d)} \quad \text{(E-2)}$$

where

T_d = arbitrary phase angle

$S(f_1)$ = power spectral density at f_i

$$\text{Let } S(f_1) = \xi S(f_o) \quad \text{(E-3)}$$

where

$S(f_o)$ = maximum value of power spectral density assumed to occur at f_o.

From (3) $10\log_{10}[S(f_o)] - 10\log_{10}[S(f_1)] = 10\log_{10}(1/\xi)$ (E-4)

$$S(f_o)dB - S(f_1)dB = X\ dB \quad \text{(see Figure 2)} \quad \text{(E-5)}$$

The peak value of the receiver response from equation (2) is

$$v_{out}(peak) = [S(f_1)]^{1/2} B_r \quad \text{(E-6)}$$

$$\hat{P}_t(dB) = 20\log_{10} v_{out}(peak) = S(f_o)_{dB} - X_{dB} + 20\log_{10} B_r \quad \text{(E-7)}$$

where

$\hat{P}_t$ = peak power of the receiver response waveform (dB).

The above shows that if we measure an emission level with a 1 MHz bandwidth and then if we utilize a 17 or 25 MHz bandwidth system, we add 20 $\log_{10}(17)$ or 20 ($\log_{10}25$).

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FORM NTIA-29
(4-80)

U.S. DEPARTMENT OF COMMERCE
NAT'L. TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION

BIBLIOGRAPHIC DATA SHEET

	1. PUBLICATION NO.	2. Gov't Accession No.	3. Recipient's Accession No.
	NTIA TR-90-260		

4. TITLE AND SUBTITLE
GROUND-BASED WEATHER RADAR COMPATIBILITY WITH DIGITAL RADIO-RELAY MICROWAVE SYSTEMS

5. Publication Date
March 1990

6. Performing Organization Code

7. AUTHOR(S)
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8. PERFORMING ORGANIZATION NAME AND ADDRESS
National Telecommunications & Information Administration
Annapolis Office
179 Admiral Cochrane Drive
Annapolis, Maryland 21401

9. Project/Task/Work Unit No.

10. Contract/Grant No.

11. Sponsoring Organization Name and Address
U.S. Department of Commerce/NTIA
179 Admiral Cochrane Drive
Annapolis, Maryland 21401

12. Type of Report and Period Covered
Technical Report

13.

14. SUPPLEMENTARY NOTES

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.)*

This report examines the potential for ground-based weather radar (meteorological radar) interference to digital microwave systems in the common carrier bands of 3700-4200 MHz and 5925-6425 MHz. Reported cases of interference to microwave common carrier systems from ground-based weather radar systems have increased due to the trend towards digital modulations. Because of this interference, NTIA, the FCC and the National Spectrum Managers Association formed an informal working group to investigate and document the potential problems.

The existing and planned spectrum uses by ground-based weather radars and digital microwave systems are addressed as well as regulations and policy pertaining to their electromagnetic compatibility. Methods to mitigate the interference in both the radar transmitter and microwave receiver are also provided.

16. Key Words *(Alphabetical order, separated by semicolons)*

Weather Radars Systems
Meteorological Aids Service
Digital Microwave Systems
Electromagnetic Compatibility (EMC) Analysis
Radar Spurious Emissions
Interference Mitigation Options

17. AVAILABILITY STATEMENT	18. Security Class. *(This report)*	20. Number of pages
☒ UNLIMITED.	UNCLASSIFIED	145
☐ FOR OFFICIAL DISTRIBUTION.	19. Security Class. *(This page)* UNCLASSIFIED	21. Price: N/A