SECTION 3
INTERFERENCE COUPLING MECHANISMS AND MITIGATION OPTIONS

3.1 INTRODUCTION

This section describes how energy radiated from radar stations may cause degradation to earth station receiver performance (interference coupling mechanisms) and methods to enhance compatibility between radar stations and earth stations (interference mitigation options).

Investigations of several interference cases have identified two interference coupling mechanisms that have occurred between radar stations in the 2700-to 3700-MHz portion of the spectrum and 4-GHz fixed-satellite service earth stations. These interference coupling mechanisms are earth station receiver front-end overload and receiver in-band interference due to radar transmitter spurious emissions.

Separation distances at which interference from radar stations to earth stations may occur for each of the interference coupling mechanisms are discussed in Section 4. Measurement procedures to identify the interference coupling mechanisms are described in Section 5.

3.2 RECEIVER FRONT-END OVERLOAD

Receiver front-end overload coupling occurs when energy from the fundamental frequency of an undesired signal saturates the receiver front-end (e.g., low-noise amplifier, or LNA), resulting in gain compression (reduction in output signal level) of the desired signal sufficient to degrade performance. Receiver front-end overload generally occurs from high-power signals in adjacent bands.

The input threshold at which receiver front-end overload occurs is a function of the 1-dB output gain compression level (saturation level) and the gain of the front-end low-noise amplifier:

$$T = C - G \tag{4}$$

Where:
- T = input threshold at which receiver front-end overload occurs, dBm
- C = 1-dB gain compression level of the low-noise amplifier, dBm
- G = low-noise amplifier gain at the radar fundamental frequency, dB.

A typical 1 -dB output gain compression level for a low-noise amplifier is +10 dBm. Earth station receiver systems typically use low-noise amplifiers with 50 to 65 dB gain in the 4-GHz band, and varying (and sometimes even higher) gain outside that band. The input threshold at which receiver front-end overload may be expected to occur is approximately in the range of -55 to -40 dBm.

LNA/LNB/LNC Response

An earth station receiver system typically employs a low-noise, high-gain preamplifier at the antenna feed. The preamplifier may produce output at the same frequencies as are received in the 4-GHz band, in which case it is designated an LNA. Or, the preamplifier may incorporate a mixer which downconverts the signal to a lower frequency band near 1000 MHz (e.g., 950-1450 MHz), in which case it is designated an LNB. A third preamplifier type, designated LNC, downconverts frequencies from the 4-GHz band to a few hundred MHz (e.g., 270-770 MHz) output.

The purpose of a front-end preamplifier is to provide sensitivity to a weak input signal (which requires that the noise figure of the preamplifier be low) and to produce an output with enough gain to compensate for both the line loss between the antenna and the receiver and the noise figure of the receiver. To achieve this functionality, 4-GHz front-end preamplifiers are typically designed to operate with noise figures of about 0.4-0.7 dB (noise temperatures of about 30-50 K) and gain values of about 50-65 dB.

Ideally, the frequency response range of such a preamplifier would be the same as the assigned operational band of the receiver (i.e., 3700- to 4200-MHz). If the frequency response of an amplifier is wider than the allocated band of the receiver, then the likelihood of overloading an earth station preamplifier by emissions from transmitters outside the receiver band is increased.

As part of the effort to resolve occurrences of interference involving fixed 4-GHz satellite earth station receiver systems, the NTIA study sought to quantify the frequency response (gain and sensitivity) of LNAs and LNBs that are representative of devices currently in use at 4-GHz earth stations. For this purpose, one LNA model (designated LNA in this report) and two LNB models (designated LNB #1 and LNB #2 in this report), all of which are commercially available and are in use at earth stations, were purchased by NTIA from retail suppliers. LNB #2 was specified by the manufacturer as incorporating bandpass filtering in its design; the other two devices did not incorporate any built-in bandpass filtering in their designs. All three devices were tested at the NTIA/ITS laboratory in Boulder, CO.

Gain Response and Noise Figure

The gain and noise figure of the LNA and LNB devices were measured using a +18 dB excess noise ratio (ENR) noise diode. Standard Y-factor calibrations were performed to determine gain and sensitivity as a function of frequency.[3] Gain and noise figure curves for

[3] Y-factor calibrations are performed by connecting a calibrated excess noise source to the input of the device under test, and comparing the output power levels when the noise source is turned on and off. The gain and noise figure that are measured are those of the entire system, which in this case consists of the preamplifier under test and a spectrum analyzer used to perform the power measurements. However, if the preamplifier sufficiently overdrives the spectrum analyzer noise figure (as these devices

these units are shown in Figures 2 through 4. The in-band gain of the devices was approximately 50-65 dB, and the in-band noise figures were typically found to be less than or equal to 1 dB. (The noise figures shown in Figures 2 through 4 are about 2 dB, due to the fact that the amplifiers were overdriving a 26-dB spectrum analyzer noise figure.) The LNA exhibited slightly more gain below the operational band than it did in its nominal operational band. LNB #2, which incorporates some bandpass filtering in its design, exhibits this feature as a somewhat sharper cut-off characteristic at about 3500 MHz.

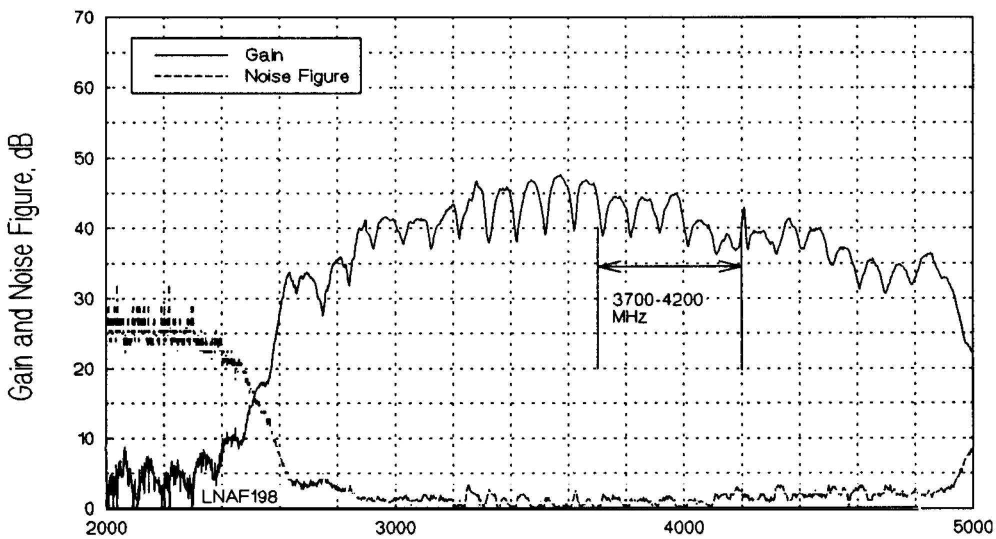

Figure 2. Gain and noise figure of a 4-GHz LNA. Same LNA model has been used in an earth station experiencing RF interference. Y-factor calibration performed with + 18 dB ENR noise diode.

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did), then the characteristics measured are very nearly those of the amplifier alone. For these tests, the noise diode generated +18 dB of noise in excess of the thermal background level, kTB. The quantity kTB is called thermal noise, where k = Boltzmann's constant ($1.38 \cdot 10^{-20}$ mW·s/K), T = system temperature (290 K for these tests), and B = measurement IF bandwidth, Hz, which was $1 \cdot 10^6$ Hz for these tests. kTB was thus -114 dBm for these tests. The complete equation for the system was:

$$G = 10 \log[(10^{P_{on}/10}) - (10^{P_{off}/10})] - ENR_d - kTB$$

where G = amplifier gain in decibels, P_{on} and P_{off} = output power in decibels measured with noise diode on and off, respectively, and ENR_d = excess noise ratio in decibels of the noise diode. The equation for noise figure was:

$$NF = ENR_d - 10 \log[10^{Y/10} - 1]$$

where NF = noise figure of the system in decibels and Y = (P_{on} - P_{off}), in decibels.

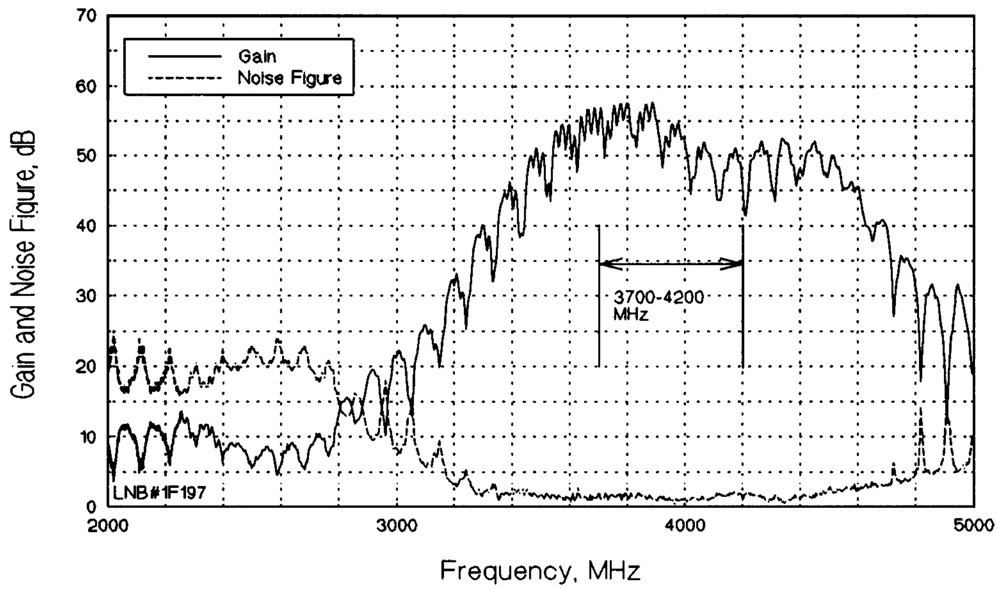

Figure 3. Gain and noise figure of a 4-GHz LNB. Output converted graphically (f_{graph} = 5150 MHz - f_{output}) to show frequency response. Calibration with + 18 dB ENR noise diode.

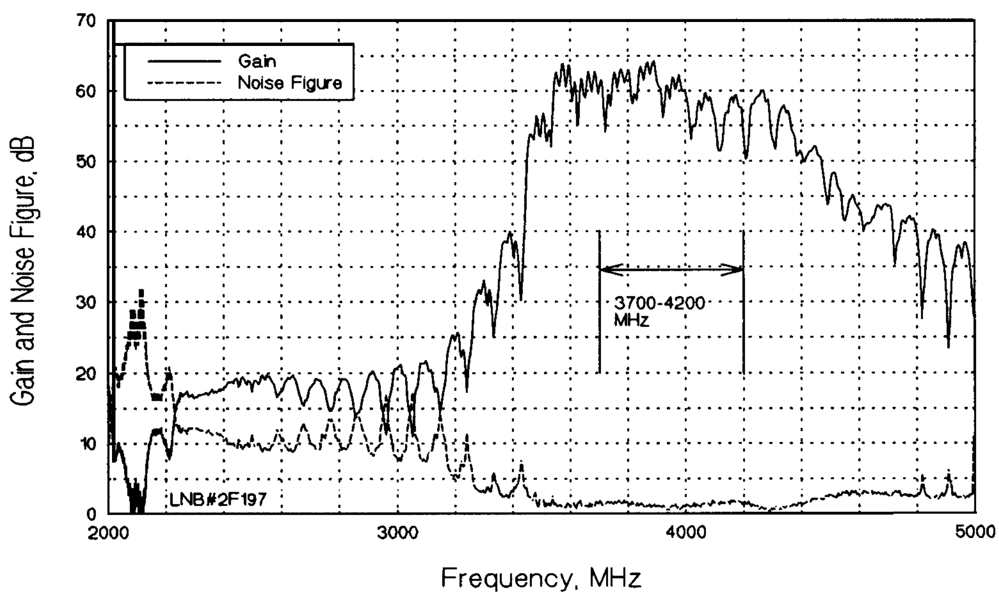

Figure 4. Gain and noise figure of a second 4-GHz LNB, specified by manufacturer as incorporating bandpass filtering. Y-factor calibration performed with + 18 dB ENR noise diode.

The LNA showed the widest frequency response range. This device's response band exhibited less than 10 dB noise figure and more than 35 dB gain between 2800 and 4800 MHz. This response range represents 40 percent of the spectrum below 5 GHz. The response ranges of all three devices include part or all of every radiolocation band between 2700 and 3700 MHz, as well as the 4200- to 4400-MHz aeronautical radionavigation band. This broadband frequency response of low-noise amplifiers used in 4-GHz earth stations makes these systems vulnerable to front-end overload by radars operating outside the 4-GHz band.

Gain Compression

If the input signal level at the amplifier does not exceed the threshold value (see Equation 4), then the output gain of the front-end preamplifier will remain at its nominal design value. However, if the input signal level to the device exceeds a critical threshold, then the gain characteristic of the amplifier will be reduced. A significant feature of this degradation is that gain will be reduced across the entire frequency response range of the amplifier (e.g., 2800-4800 MHz), even if the overload occurs at a single frequency (e.g., 3300 MHz). Figures 5 through 7 show measured gain characteristics of the previously characterized LNA and two LNBs in overload conditions.

One of the requirements of the NTIA tests on the LNA and LNB units was to determine input thresholds at which gain compression begins, and the rate at which gain compression increases with increasing overload. Tests were performed with both continuous wave (CW) overload inputs and with simulated radar inputs. Overload values were measured both with and without the presence of simulated in-band (desired) signals. The tests in which an out-of-band radar signal overloaded the LNA or LNB while a low-power signal was received in-band represented the closest simulation of actual operational conditions; those test results are presented in Figures 5 through 7. Radar signals were simulated with 1-μs pulses at a rate of 1000 pulses per second. The measured overload characteristics were not found to vary as a function of modulation (CW vs. radar-like input) or as a function of the presence or absence of low-amplitude in-band (desired) signals, and the results of those tests duplicated the results shown in Figures 5 through 7.

Figures 5 through 7 show gain responses for each amplifier as measured with a spectrum analyzer. Each amplifier was tested for overload characteristics at three input power levels of a simulated radar signal. To achieve graphical clarity, the input frequencies at the three power levels were adjusted successively to 3300, 3400, and 3500 MHz. The in-band (desired) signals were similarly adjusted to 3900, 4000, and 4100 MHz. The desired input level in each figure is that of the desired signal at 3900 MHz; the decrease in desired signal levels at 4000 MHz and 4100 MHz is due to gain compression.

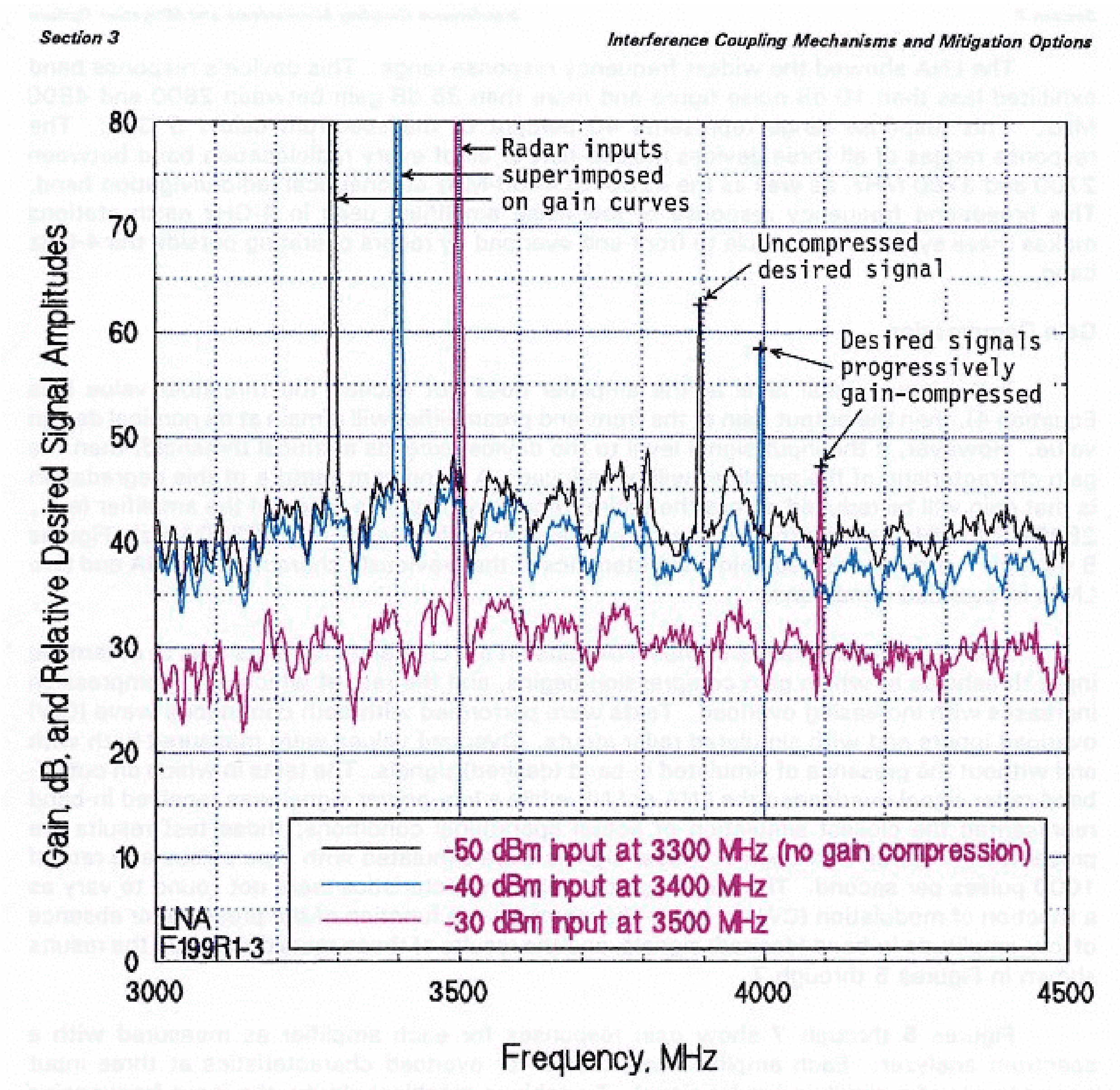

Figure 5. **LNA response as a function of simulated radar inputs. Radar parameters: 1 μs pulses, 1000/sec, at 3300, 3400, 3500 MHz. Desired (in-band) signals are marked at 3900, 4000, 4100 MHz.**

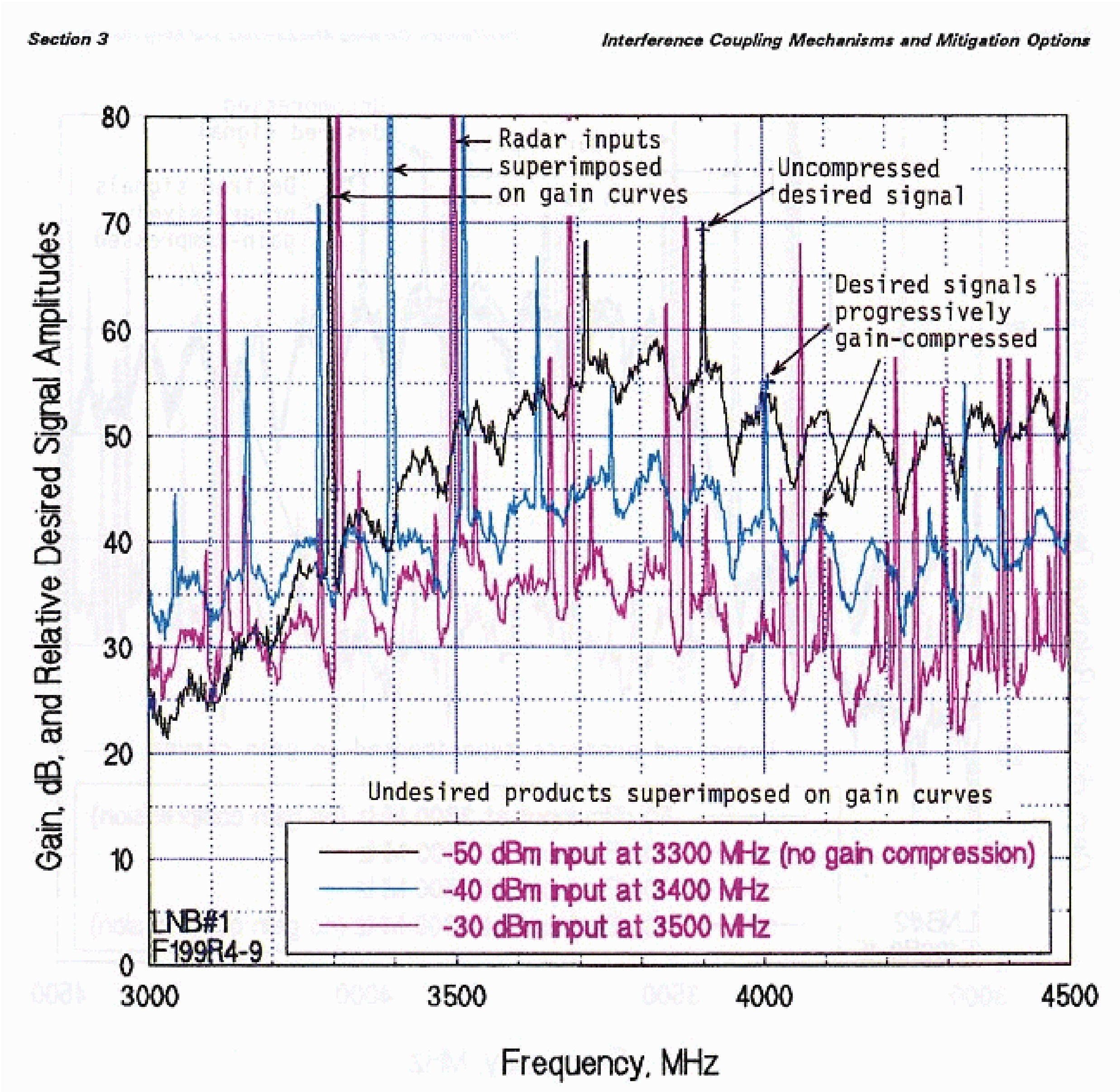

Figure 6. LNB #1 response as a function of simulated radar inputs. Radar inputs identical to Figure 4. Note products at -30 dBm and -40 dBm input amplitudes. Desired signals at 3900, 4000, 4100 MHz.

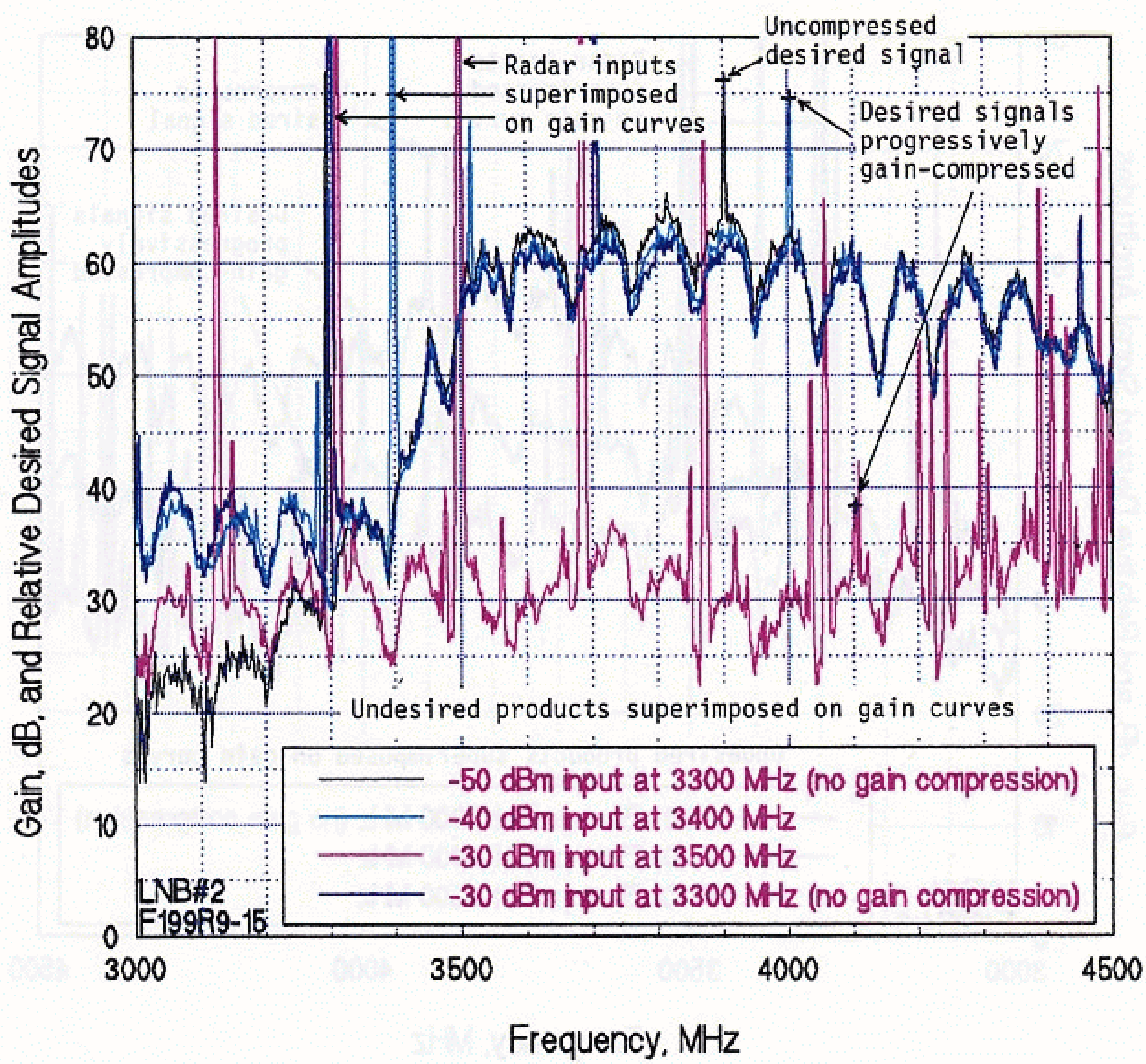

Figure 7. LNB #2 response as a function of simulated radar input. Radar inputs identical to Figures 5-6. Built-in bandpass has decreased susceptibility to overload at input frequencies below 3500 MHz.

At the lowest radar input level (-50 dBm peak power) in each of Figures 5 through 7, the amplifiers are not overloaded and the amplifier gain and the power level of the in-band (desired) signals are normal. We discovered during the tests that the gain of the LNA and of LNB #2 decreased by 1 dB (1 -dB compression point occurred) at a peak power input of about -40 dBm. LNB #1 gain was compressed by about 10 dB at that input level. When the input power of the out-of-band simulated radar signal at 3500 MHz was increased by another 10 dB, to -30 dBm peak, the gain was severely compressed in all three devices. In summary, the gain compression of the LNA/LNB is dependent upon the gain of the device at the frequency of the simulated radar signal.

Note that, although LNB #2 showed an overload response to a simulated radar signal at -30 dBm peak input and a frequency of 3500 MHz, the same device showed essentially no compression when the frequency of the input was shifted down to 3300 MHz. This finding is consistent with the earlier measurement of the 3500-MHz bandpass cutoff built into this device. This response makes this device more resistant to the phenomenon of front-end overload, but does not eliminate the problem for radars tuned above 3500 MHz.

Other Overload Responses

Gain compression may not be the only result of front-end overload; mixing products to the input signal can be generated as part of the device output. Such products are especially likely to occur if the device incorporates a mixing stage (downconversion), as is the case for an LNB or an LNC. A device lacking such stages, such as an LNA, would be expected to be less susceptible to this phenomenon.

During the NTIA tests, such mixing products were not observed for the LNA, but were observed for both LNB devices. In Figures 5 through 7, the only signals that should be seen are the simulated radar inputs at 3300, 3400, and 3500 MHz, and the simulated desired signals at 3900, 4000, and 4100 MHz. However, the LNB responses shown in Figures 6 and 7 exhibit a number of additional responses. Mixing products were produced at peak input power levels of -40 dBm and -30 dBm. For LNB #2, which incorporated bandpass filtering with a 3400-MHz cutoff, a peak input power level of -30 dBm at 3500 MHz (within the bandpass) resulted in generation of undesired products, but the same input power level at 3300 MHz (below the bandpass cutoff) did not produce such responses.

It is critical to note that some of the undesired products in the LNB devices occurred at frequencies within the 4-GHz band. Such responses could result in interference in a receiver system if they were to coincide with the frequencies of desired in-band signals. Also, such responses may easily be misinterpreted by measurement personnel as spurious signals generated by the radar, rather than being correctly identified as a response generated within the earth station’s own RF front-end. (See Section 5 for methods of determining the difference.)

Gain Compression Interval

The interval of overload gain compression of an amplifier is finite. The length of the compression interval is one of the factors which determines the amount of data that a receiver system may lose as a result of overload. NTIA tests were conducted on the three devices previously described to determine their overload compression intervals. For each device, the overload signal was applied at four different peak power levels, which were adjusted to produce gain compressions of 10, 20, 30 and 40 dB in a simulated in-band (desired) signal at 4000 MHz. The input overload signal was pulsed to simulate an out-of-band radar, as had been done during the earlier gain compression tests, with a pulse width of 1 μs, pulse repetition rate of 1000/s, and radar fundamental frequency of 3500 MHz. The output power of the amplifier at the frequency of the simulated desired signal was recorded as a function of elapsed time on a digital oscilloscope, documenting the process of gain compression and the interval of that compression. The results of these tests are shown in Figures 8 through 10. The compression intervals are presented in Table 2.

The compression intervals for the LNA were found to be on the order of several hundred microseconds, whereas the compression intervals for the LNB devices were about two orders of magnitude shorter, on the order of a few microseconds. For the LNA, the interval resulting from a compression of 40 dB was 900 μs, which approached the 1000-μs interval between simulated radar pulses. For LNB #1, the 1-μs gain compression interval from 10-dB compression which is indicated in Figure 9 is probably longer than the device's inherent compression interval; the input pulse was itself 1 μs long. The reason for the difference in gain compression intervals between the LNA and the two LNB devices is not known, and was not pursued as part of this study.

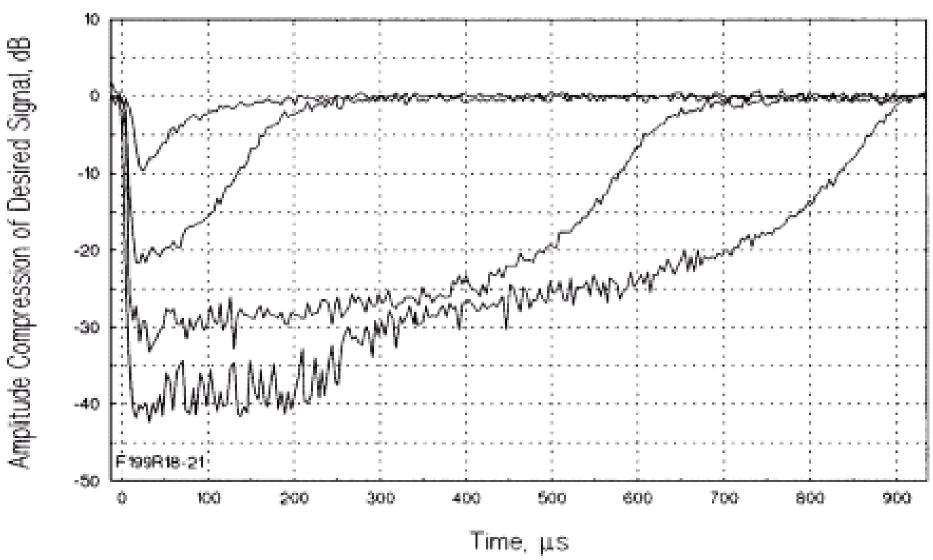

Figure 8. Time domain behavior of LNA at gaiin compression of 10, 20, 30 and 40 dB in desired signal at 4000 MHz. Compression created by out-of-band pulses (1-μs pulse width) at 3500 MHz.

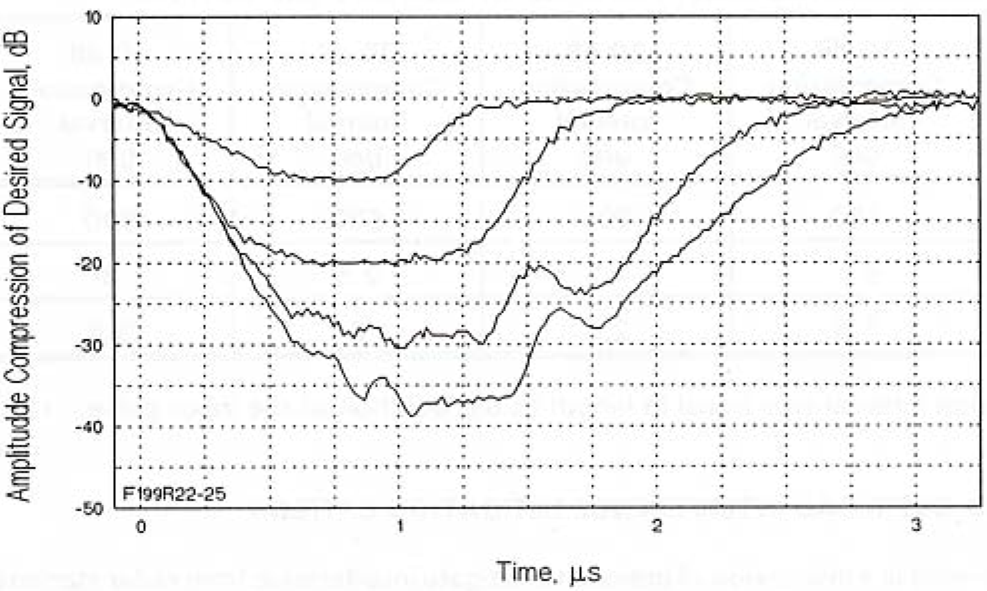

Figure 9. **Time domain behavior of LNB #1 at gain compressions of 10, 20, 30 and 40 dB in desired signal at 4000 MHz. Compression created by out-of-band pulses (1-*µs* pulse width) at 3500 MHz.**

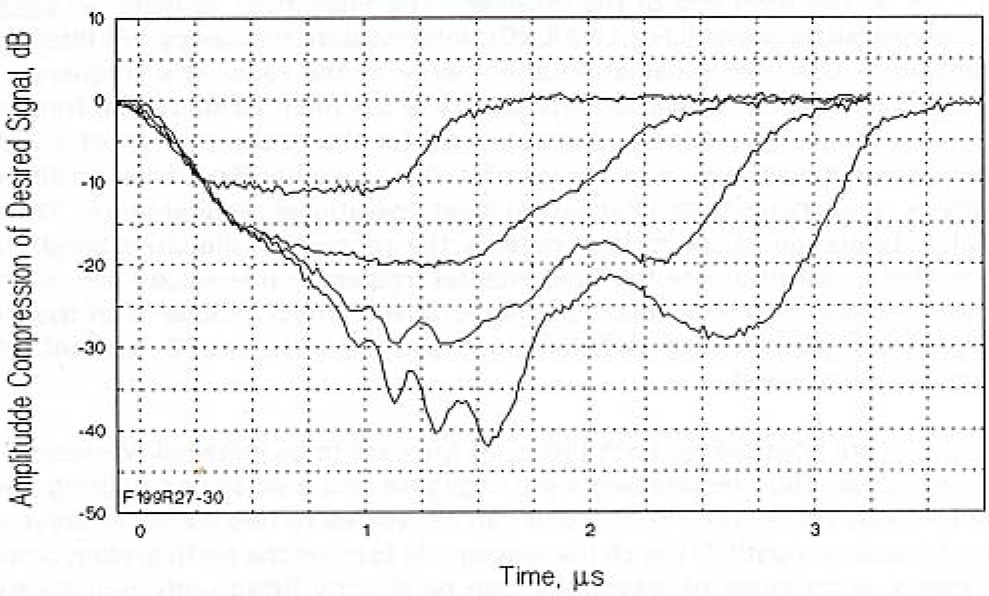

Figure 10. **Time domain behavior of LNB #2 at gain compressions of 10, 20, 30 and 40 dB in desired signal at 4000 MHz. Compression created by out-of-band pulses (1-*µs* pulse width) at 3500 MHz.**

TABLE 2.
GAIN COMPRESSION INTERVALS OF LNA AND LNB DEVICES

	10 dB Compression Interval (μs)	20 dB Compression Interval (μs)	30 dB Compression Interval (μs)	40 dB Compression Interval (μs)
LNA	150	200	650	900
LNB #1	≤1*	1.5	2.5	3
LNB #2	1.5	2.5	3	3.5

* The compression interval was equal in length to the duration of the input pulse: 1 μs.

3.3 FRONT-END OVERLOAD INTERFERENCE MITIGATION OPTIONS

The following is a discussion of options to mitigate interference from radar stations due to emissions at the fundamental frequency (necessary emissions) of the radar causing front-end overload.

RF Filtering

A solution that mitigates interference caused by receiver front-end overload is installation of a filter on the front-end of the receiver. The filter must be installed **ahead** of the earth station low-noise amplifier (LNA/LNB/LNC); intermediate frequency (IF) filtering will **not** solve the problem. The filter must attenuate energy at the receiver's frequency to a minimal extent, but must substantially attenuate energy at the radar fundamental frequency. Ideally, the filter would have a bandpass characteristic for the entire portion of spectrum allocated for use by the receiver (e.g., a bandpass of 3700- to 4200-MHz), so as to allow the receiver frequency or frequencies to be changed to meet operational requirements. The filter must have a high attenuation characteristic outside the receiver's allocated band. At a minimum, such a filter must attenuate the fundamental frequency (necessary emissions) of the interfering radar. Ideally, the filter rejection characteristic would include all of the 2700- to 3700-MHz spectrum allocated to radiolocation, and also the 4200- to 4400-MHz aeronautical radionavigation band.

Several designs are possible for such filters. If they are to be installed on receive-only systems, then power dissipation requirements are negligible and a small box utilizing several tuning stubs can be easily fabricated. Such a unit can be welded to two pieces of waveguide to provide for mechanical compatibility with the waveguide feed on the earth station antenna. Alternatively, a single, short piece of waveguide can be directly fitted with in-guide tuning stubs to provide the same capability. Several companies in the United States and Canada supply both of these types of filters. The frequency response curve of one such filter is shown in Figure 11.

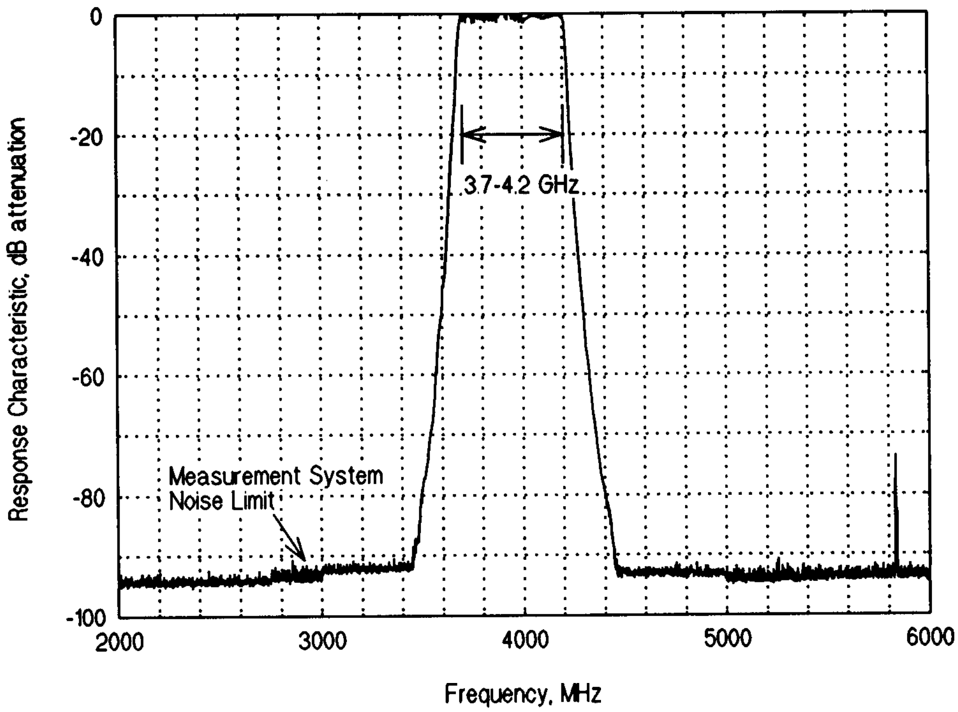

Figure 11. Frequency response curve of a commercially procured 3700-to 4200-MHz bandpass filter of same type as were used to mitigate out-of-band interference to 4-GHz TVRO receivers in south Florida.

The frequency response curve shown in Figure 11 was measured at the NTIA/ITS laboratory in Boulder, CO. The same filter type was used to mitigate interference from the south Florida airborne radar discussed in Section 3.4. The in-band (3700- to 4200-MHz) insertion loss ranges between O and 1 dB, and is typically about 0.5 dB. Out-of-band attenuation is approximately 25 dB within 50 MHz of the band edges, and is in excess of 45 dB within 100 MHz of the band edges. Suppression exceeds 90 dB within 300 MHz of the band edges. In cases in which a radar fundamental is so close to the band edge that the roll-off of the filter is not sufficient to prevent front-end overload, the filter can be re-tuned to shift the bandpass roll-off point to higher or lower frequencies.

3.4 FRONT-END OVERLOAD INTERFERENCE CASES

A case of interference to a 4-GHz earth station from a radar was jointly investigated by NTIA and the U.S. Naval Electronics Engineering Activity (NAVELEX), Charleston, SC, in

1992[4]. The earth station was a television receive only (TVRO) site on a hilltop overlooking the ocean in the San Diego, CA area. The interference coupling mechanism was identified as receiver front-end overload, and the problem was mitigated by installation of a front-end bandpass filter on the TVRO.

In response to complaints of interference to many 4-GHz earth stations in southern Florida from an airborne source, the NTIA Radio Spectrum Measurement System[5] (RSMS) was positioned at two earth station sites during the period of April through June 1993. In April 1993, NTIA identified the source of interference as an airborne radar belonging to the Federal Government. The interfering platform was identified by using the RSMS to obtain the radar characteristics (center frequency, antenna rotation rate, pulse repetition rate, pulse width, and antenna pattern); the Federal Aviation Administration confirmed the identification of the platform. NTIA identified the interference coupling mechanism as receiver front-end overload[6].

NTIA has also assisted in the resolution of other complaints of interference associated with this type of airborne radar platform. In all cases, the interference coupling mechanism has been identified as receiver front-end overload, and the insertion of an RF bandpass filter ahead of the LNA/LNB/LNC has mitigated the interference.[7,8]

It is also known that non-Government marine surface search radars operating at 3050 MHz cause front-end overload in 4-GHz receive systems that are near marine waterways. Characteristics of such activity were documented by NTIA RSMS measurements at Norfolk, VA.[9] Some manufacturers of 3700- to 4200-MHz bandpass filters primarily advertise these devices as being useful for elimination of this interference.

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[4] J.A. Lucas and B.J. Ramsey, "Daniel's CableVision Satellite Receiver Earth Station Interference Study," July 1990, E3 Task Number E90135-C093.

[5] See Section 5, Identification of the Radar, and Appendix A.

[6] F.H. Sanders and R.L. Hinkle, "Interference Resolution Report on Station WGUF Naples, Florida," letter report for NTIA, dated April 7, 1993, and F.H. Sanders and R.L. Hinkle, "Interference Resolution Report on Colony Cablevision of Florida," letter report for NTIA, dated July 6, 1993.

[7] R.L. Hinkle and G. Hurt, "Interference Resolution Report on Time Warner Cable," letter report for NTIA, dated June 22, 1993.

[8] Memo from William D. Gamble to Arlan K. van Doom, "South Florida Radar Interference," dated October 5, 1993.

[9] J.D. Smilley and F.H. Sanders, data and summary of RSMS "Norfolk, VA February 1988 Measurements Notebook. "

3.5 SUMMARY REMARKS ON RECEIVER FRONT-END OVERLOAD

Front-end overload is a phenomenon which occurs when a low-noise, high-gain preamplifier is located at the front-end of a radio receiver system and is subjected to a strong signal from an external source, as given by Equation 4. In this condition, the amplifier will not only gain-compress at the frequency of the overloading signal, but also at all other frequencies in the amplifier's gain response band. Thus, desired signals will be lost at frequencies which may be hundreds or even thousands of megahertz away from the frequency of the signal which is causing overload to occur. The majority of cases of interference to 4-GHz satellite earth stations that have been investigated by NTIA have been found to be due to the phenomenon of front-end overload.

It is important to note three aspects of receiver front-end overload interference which are not always appreciated. First, the filtering provided in a receiver IF stage is irrelevant to the problem of receiver front-end overload. The overload and loss of desired signal occur before the IF stage is reached.

Second, earth station front-end amplifiers may have a significantly wider frequency response range than is indicated by the manufacturer's specifications. Although an amplifier is specified for a given band by the information on its package case (e.g., "3.7-4.2 GHz"), this does not mean that it does not respond to (or filters out) signals outside that range. Quite to the contrary, it is highly likely, especially with current gallium-arsenide field-effect transistor (GaAsFET) technology, that the actual frequency response range of such amplifiers will typically be several gigahertz wide (e.g., 2800-4800 MHz). The actual response of an amplifier can be assessed by connecting the amplifier output to the input of a spectrum analyzer, and observing the frequency range over which the amplifier compensates for the spectrum analyzer noise (that is, the frequency range over which the amplifier excess noise is observed above the analyzer noise floor).

Third, in the presence of an overloading signal outside the 4-GHz band, undesired products may be generated in front-end amplifiers which incorporate mixer/downconverter stage(s) (i.e., LNB/LNC devices); such products may occur anywhere in the frequency response range of the amplifier, including the 3700- to 4200-MHz spectral range used by 4-GHz earth stations. If such products happen to occur at the same frequency or frequencies as desired signals, then interference with earth station operations could result. Also, if a spectrum analyzer is used to observe the spectrum through the earth station receiver, the products which occur in the 4-GHz band may easily be mistakenly identified as spurious radar emissions in this band. Thus, the observed presence of apparent interfering signals in the 3700- to 4200-MHz band does not necessarily mean that such signals are originating from an external source, such as a radar. (See Section 5 for methods of determining the difference between radar spurious emissions in the 4-GHz band and mixing products generated by the front-end LNB/LNC in that band.)

3.6 INTERFERENCE DUE TO RADAR SPURIOUS EMISSIONS IN THE 4-GHz BAND

Radar spurious emission coupling occurs when energy from the radar transmitter spurious emissions in the 3700- to 4200-MHz band causes degradation in the earth station receiver system performance. The predominant factor that governs the level of spurious emissions from radars is the transmitter output device[10] (also referred to as an output tube).

It is important to know the inherent spurious emission levels and variances for the different types of transmitter output tubes in order to assess the potential for interference from radars utilizing these tubes. This information is important in identifying microwave radar tube types that promote efficient use of the spectrum and as a parameter in interference resolution prediction.

Microwave radar tubes inherently generate spurious emission noise that generally dominates spectral emissions at frequency separations greater than 50 MHz from the radar fundamental frequency. (Such emissions are often referred to as "transmitter noise.") Thus, at frequency separations of greater than 50 MHz, the radar emission spectrum is independent of radar system characteristics such as the pulse modulation parameters (e.g., pulse width, pulse modulation, and pulse rise/fall times). Based on measurements contained in studies conducted by NTIA[11] and a review of tube characteristics with major microwave radar tube manufacturers, the inherent spurious emission level for the various types of microwave tubes used in radars are shown in Table 3.

Additional attenuation of spurious emission levels can be achieved through the use of RF bandpass filters inserted in the radar after the output device. With the use of RF bandpass filters, the spurious emission levels of crossed-field amplifiers (CFAS), magnetrons, and coaxial magnetrons can be reduced below -100 dBc. Examples of such output filtering and the effect on a radar's emission spectrum are shown in Figures 12-13. However, in cases where radars use phased array antennas, RF waveguide filters cannot be installed.

Measurements conducted by NTIA (see footnotes 10 and 11) have shown that radars using magnetrons, coaxial magnetrons, and klystrons comply with the spurious emission limits imposed by the RSEC (see Section 2). Although it is not possible to make the power levels of spurious emissions in the 4-GHz band arbitrarily low, some limits, such as those defined by the RSEC, can reasonably be achieved. Measurable emissions may still occur in the 4-GHz band even when a radar meets the RSEC. These emissions may interfere with 4-GHz satellite earth stations by decreasing the carrier-to-interference (C/I) ratio to an unacceptably low level if the radar main beam aims at the earth station. Some examples of radar spurious emissions in the 4-GHz band are shown in Figures 13 through 15.

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10 R.J. Matheson, J.D. Smilley, G.D. Falcon and V.S. Lawrence, "Output Tube Emission Characteristics of Operational Radars," NTIA Report 82-92, January 1982.

11 R.L. Hinkle, "Background Study on Efficient Use of the 2700-2900 MHz Band," NTIA Report 83-117, August 1983, NTIS # PB83-214288.

TABLE 3.
RADAR OUTPUT DEVICE INHERENT SPURIOUS EMISSION LEVELS*

TUBE TYPE	SPURIOUS EMISSION LEVEL RELATIVE TO THE CARRIER MEASURED IN A 1 MHz REFERENCE BANDWIDTH (dBc)
CROSSED-FIELD DEVICES:	
Crossed-Field Amplifiers (CFAs)	-40 to -70
Magnetrons (unlocked)	-65 to -80
Magnetrons (locked)	-75 to -90
Coaxial Magnetrons	-60 to -75
LINEAR-BEAM DEVICES:	
Coupled-Cavity TWTs	-105 to -115
Klystrons	-110 to -120

“ As contained in Radiocommunications Bureau Report 914-2, “Efficient Use of the Radio Spectrum by Radar Stations in the Radiodetermination Service, ” International Radio Consultative Committee (CCIR) XVllth Plenary Assembly, Dusseldorf, 1990.

3.7 RADAR SPURIOUS EMISSIONS INTERFERENCE MITIGATION OPTIONS

The following is a discussion of options to mitigate interference from radar stations due to radar transmitter spurious emissions in the 3700- to 4200-MHz band.

Radar Station RF Filtering

RF waveguide filters can be used in some radars stations to reduce interference to earth stations to acceptable levels. Measurements have shown (see Figures 12 and 13) that RF waveguide filters will suppress radar spurious emissions in the 4-GHz band by at least 40 to 50 dB. In Figure 12, note that the filter is characterized by attenuation in excess of 80 dB at frequencies immediately above the upper cutoff at 3700 MHz, but that this attenuation decreases to as little as 15 dB at frequencies above 4300 MHz. This demonstrates that, while filter installation on a radar station may reduce the potential for interference in one band, it may not provide a solution for other bands even farther removed in the spectrum.

When radar interference to 4-GHz earth stations is caused by spurious emissions from the radar transmitter, the installation of an RF filter for the appropriate band at the radar transmitter is considered a practicable solution provided that it is technically and/or economic-

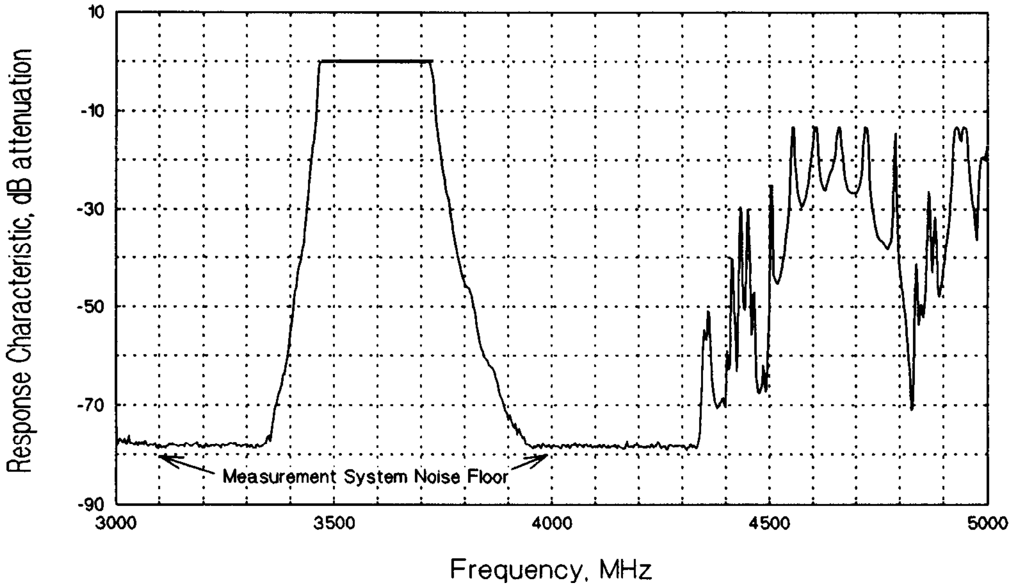

Figure 12. **Measured frequency response curve of a bandpass filter installed on naval radar (Figure 13) to suppress spurious emissions and enhance electromagnetic compatibility with 4-GHz receivers.**

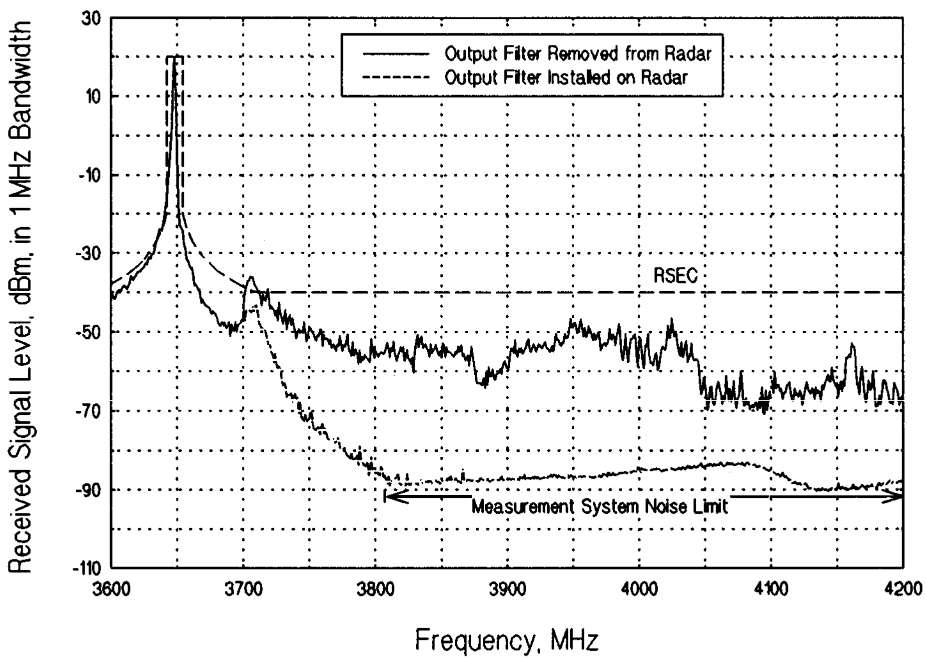

Figure 13. **Spectrum of a naval radar showing effect on spectrum when bandpass filter is installed on radar output. Filtered radar output caused front-end overload interference to a TVRO at San Diego, CA.**

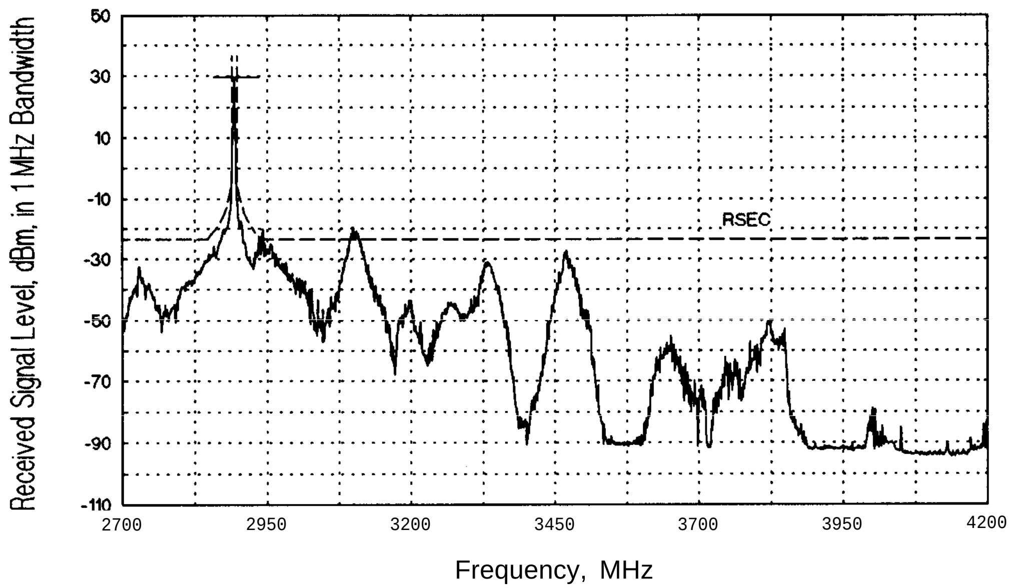

Figure 14. **Spectrum of a WSR-74S weather radar, showing spurious emissions in the 3700- to 4200-MHz range. The spurious emissions from this radar caused interference to a 4-GHz terrestrial radio link.**

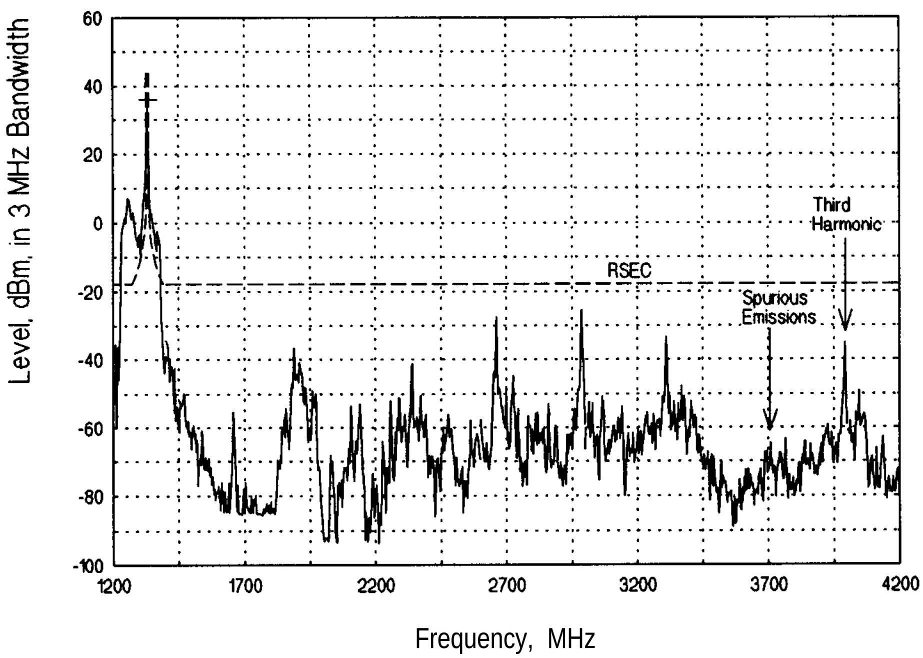

Figure 15. **Emission spectrum of a long-range air search radar. Both spurious emissions and third harmonic occur in the 4-GHz band. Third harmonic produced interference to a terrestrial 4-GHz link.**

ally possible. The policy and responsibility for dealing with the purchase and installation of an RF filter for a specific radar transmitter are discussed in Section 2 of this report.

3.8 EARTH STATION MITIGATION OPTIONS

Antenna Selection

Antenna discrimination, the response of an antenna to signals arriving from various azimuths, varies widely among antenna types. 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. Currently, the vast majority of earth stations use standard parabolic antennas with prime focus feeds. Other types of antennas used which have lower sidelobe levels include those incorporating cassegrain reflectors, offset-fed reflectors and horn reflectors. Antenna manufacturers have stated that shrouded parabolic antennas used for radio-relay systems can also be used in 4-GHz earth stations. Each type has a different response to off-axis signals; typical patterns for these general types of antennas are shown in Figure 16. At off-axis angles in excess of 10 degrees, shrouded parabolic and conical horn reflector antennas can provide 10 to 20 dB of additional suppression of an interfering signal and 20 to 50 dB of suppression for off-axis angles greater than 50 degrees.

Site Selection

Site selection can be used during the design phase of new earth stations to avoid potential interference exposures to operational radar stations. There are many factors that determine the site selection of earth stations. When possible, one of the factors should be the electromagnetic environment. For site selection 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 on site selection may significantly impact the economics of the earth station construction. The key to mitigation of radar interference in selection of a site is electromagnetic shielding by surrounding terrain.

3.9 SPURIOUS EMISSION INTERFERENCE CASES

NTIA has not investigated any cases in which a 4-GHz satellite earth station has experienced interference due to radar transmitter spurious emissions in the 4-GHz band. Some such cases have been documented by NAVELEX Charleston, however. In one case, spurious emissions from a shore-based, long-range naval search radar located on Crown Mountain, St. Thomas, USVI, caused interference to two 4-GHz commercial earth stations on that island.[12] One was an analog TVRO, and the other was a digital telephone satellite earth station. In another set of cases, spurious emissions from high-power radars on ships have caused interference at earth stations located at sites that overlook the ocean.

12 J.A. Lucas, "Radar Interference Due to Receive System Susceptibility and Spurious Emissions," presentation to the Federal Communications Commission, Naval Electronic Systems Engineering Center (NAVELEX), Code 222, Charleston, SC, July 14, 1992.

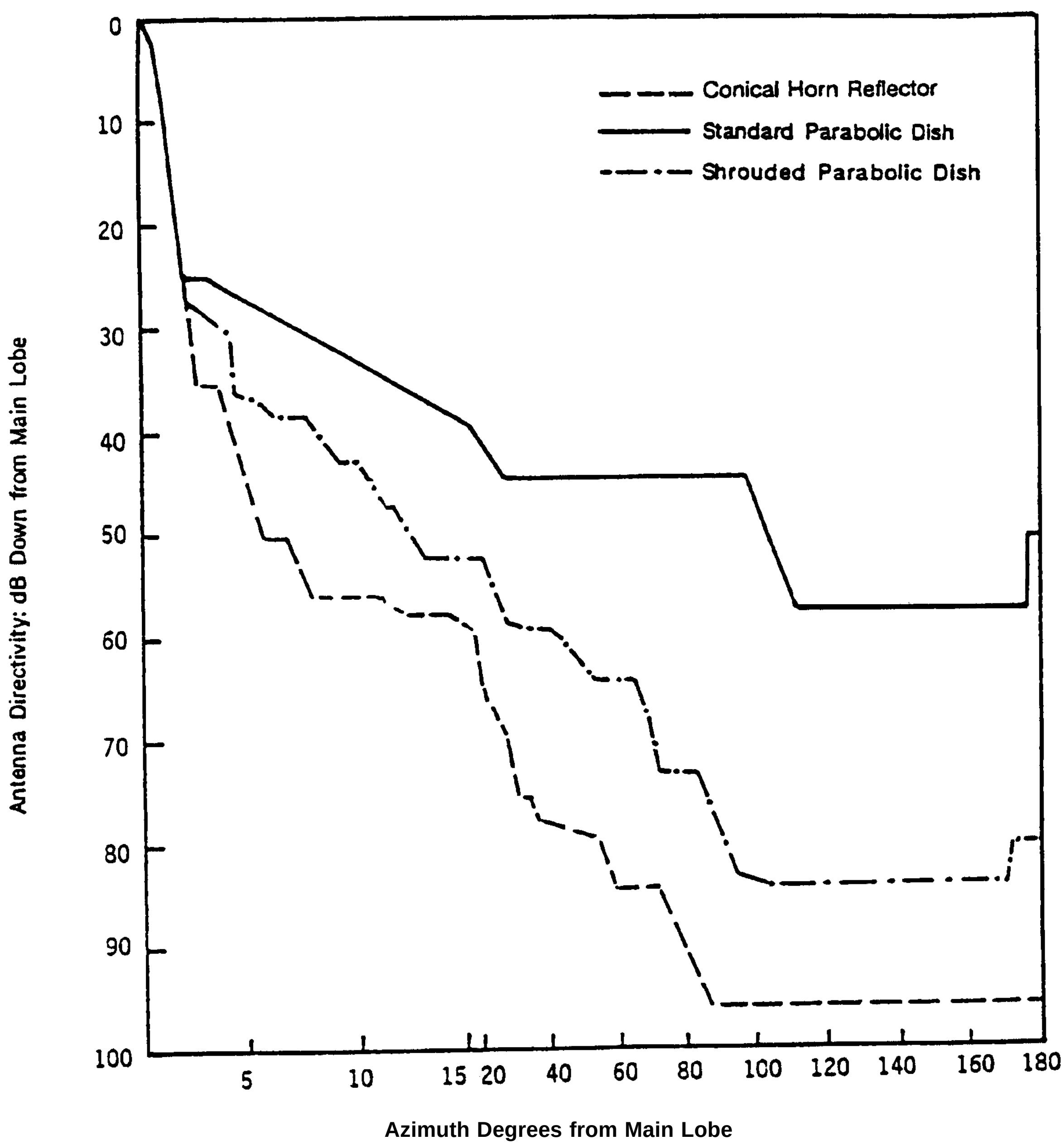

Figure 16. **Comparison of directivities for three high-gain antenna types. Shrouded parabolas and conical horns can exhibit higher directivities than ordinary parabolic. Note scale change at 15 degrees.**

There have been no substantiated cases of airborne radars causing interference due to spurious emissions in the 3700- to 4200-MHz band. All high-power airborne radars in the 2700- to 3700-MHz band use linear beam output devices which have spurious emissions down at least 100 dB from the fundamental.