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# Measurements of Pulsed Co-Channel Interference in a 4-GHz Digital Earth Station Receiver

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**ACKNOWLEDGMENT AND DISCLAIMER**

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## FIGURES

# MEASUREMENTS OF PULSED CO-CHANNEL INTERFERENCE IN A 4-GHz DIGITAL EARTH STATION RECEIVER

Frank H. Sanders[1]

Pulsed signals in Earth station receiver spectrum bands have traditionally occurred due to unwanted emissions from adjacent-band transmitters such as radars and altimeters. Analog Earth station receivers sometimes experience interference from such emissions. The trend toward increasing use of digital receivers, coupled with a possible future increase in pulsed signals, have raised the question of the circumstances under which pulsed emissions may cause interference to such receivers. This report documents the results of measurements in which a variety of co-channel pulsed signals were injected into the radio frequency (RF) front-end of an operational, television receive-only (TVRO) digital Earth station. The results identified the susceptibility of the Earth station to pulsed interference as a function of pulse characteristics that included pulse width, pulse repetition rate (both constant and jittered), and peak amplitude. The results indicate that digital Earth station receivers may be vulnerable to interference that creates either a contiguous block of symbol errors or a long series of symbol errors. Interference with lower pulse repetition rates, pulse widths, and duty cycles may also produce effects; in those cases results show the interference amplitude may be increased by as much as 50 dB above the carrier level before significant interference occurs. Quantitative interference thresholds are provided for the performance of electromagnetic compatibility analyses between pulsed interference sources and digital Earth station receivers. Examples of such analyses are provided.

Key words: digital Earth station interference; electromagnetic compatibility analysis; interference analysis; pulsed radio interference; radio interference

## 1. INTRODUCTION

### 1.1 Background

Earth station receivers are allocated to the fixed satellite service (FSS) (Earth) or the broadcast satellite service (BSS) on a primary or co-primary basis in several bands. Examples of such bands (below 19 GHz) include: 3.7-4.2 GHz; 12.2-12.7 GHz; and (future BSS) 17.3-17.8 GHz. Pulsed emissions occur in Earth station receiver bands as a result of adjacent-band operation of radars and other transmitters. The levels of those pulsed emissions have been observed during spectrum surveys [1-4]. They have sometimes adversely affected Earth station operations. Documented interference from adjacent band pulsed radars to Earth station receivers has sometimes resulted

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from spurious emissions on Earth station frequencies. In other cases interference has been caused by dynamic overload of Earth station low-noise amplifiers by strong fundamental-frequency radar emissions in adjacent bands [5] that may be hundreds of megahertz away from operational Earth station receiver frequencies.

Earth stations are increasingly using digital receivers. This raises the question of whether, and under what circumstances, pulsed emissions may cause interference to such receivers. This interference is defined as that which causes perceivable errors in the final system output.

The National Telecommunications and Information Administration (NTIA) has performed a series of measurements to better understand the circumstances under which pulsed emissions may interfere with the operation of digital Earth station receivers. The measurements have been performed at the NTIA Institute for Telecommunication Sciences (ITS) in Boulder, Colorado, in coordination with the NTIA Office of Spectrum Management (OSM) in Washington, DC. The results of those measurements are documented in this report.[2]

## 1.2 Purpose of this Report

This report is designed to provide preliminary, quantitative information to spectrum planners regarding the extent to which digital Earth station receivers may be vulnerable to interference from pulsed emissions. These data are intended to be used to determine the minimum separation distances or frequency separation that may be required between specified Earth station antennas and pulsed emitters.

This report provides only measurements of digital Earth station performance in the presence of co-channel pulsed interference. In the interest of providing timely data to spectrum planners and engineers, the data are presented without extensive analysis of the underlying interference mechanisms.

[2]This measurement effort was limited to co-channel interference. Application to adjacent-band signals would require an understanding of the response of a digital Earth station's receiver to off-frequency pulsed emissions. (Those emissions are a function of radar pulse characteristics and radar output amplifier characteristics.)

# 2. INTERFERENCE INJECTION METHODOLOGY

## 2.1 Radiated Versus Hardline-Coupled Interference

Earth station interference may be expected to normally couple into the receiver via the antenna feed, most likely from somewhere in the antenna pattern sidelobe structure, or with less likelihood in the main beam. For purposes of quantifying interference thresholds, however, radiated coupling presents significant disadvantages and difficulties. Chiefly, the problem is that antenna gain coupling factors in radiated tests with a parabolic antenna are difficult to quantify accurately. This is due to uncertainty in the effective gain of the Earth station antenna in the direction of the interference source, even assuming that the EIRP of the source in the direction of the Earth station antenna is accurately known. Multipath effects may also occur.

Furthermore, radiated coupled measurements would have to be performed outdoors, as the Earth station must receive a desired (satellite) signal during the tests. An outdoor environment further increases the difficulty in ascertaining quantitative data for interference thresholds due to sometimes unpredictable ambient conditions.

Hardline coupling of the interference eliminates problems with quantification of interference thresholds. If the interference signals are injected ahead of the low-noise amplifier (LNA) input at the antenna feed-horn,[3] the levels of injected interference may be assessed relative to the amplitude of the desired signals and of the receiver's noise floor. Those levels may in turn be converted to equivalent absolute incident interference levels by taking into account the nominal gain of the Earth station antenna in any particular direction. Such results have the advantage of being easily scaled to any size antenna with any specified sidelobe and mainbeam gain levels.

## 2.2 Earth Station Receiver Description

The Earth station used for these measurements was a television receive-only (TVRO) type that was procured commercially. The complete antenna assembly is shown in Figure 1. It had a diameter of 3.3 m (10.8 ft). The feed assembly, including the interference hardware coupling, is shown in detail in Figure 2. The complete Earth station system is shown as a block diagram in Figure 3.

The system receives signals in the 3.7-4.2 GHz band from geostationary satellites. The receiver is capable of processing both analog and digital signals. The spectrum of a typical digital signal

[3]Or more commonly, as for the measurements described in this report, ahead of the input of a combined LNA and frequency downconverter, called an LNB.

measured at the LNB output is shown in Figure 4. It is a quadrature phase-shift keyed (QPSK) signal 18.5 MHz wide at the 3-dB points, and nominally 20 MHz wide. Symbol rate is approximately 20 Msps; symbol length is $(20\ \text{MHz})^{-1} = (50\ \text{ns})$. Figure 5 shows the Earth station receiver internal noise level as measured in a 1-MHz IF bandwidth at the LNB output.

RF signals between 3.7-4.2 GHz are downconverted by the front end LNB to 950-1450 MHz.[4] Those signals are routed from the LNB output to the digital receiver input. Within the receiver, the signals are further downconverted, filtered, and processed for quadrature phase information, which is effectively a bit stream. The bit stream is used to construct a television image.

Digital data in the receiver are Viterbi decoded, with Reed-Solomon error correction and interleaving. As depicted in Figure 4, the desired RMS signal level for this Earth station was about -50 dBm in a 1-MHz bandwidth (-37 dBm in 20 MHz), with a 51-dB gain (35 K noise temperature) low noise amplifier (LNA) at the front-end of the receiver. The sum of line loss and coupler loss between the LNB and the receiver input was 7 dB. The signal level at the input to the LNA was thus -81 dBm in a 20-MHz bandwidth.

The signal-to-noise ratio for this signal was about 15 dB. This number was computed in two ways. The first method used previously acquired data graphs to directly compare the signal level to the noise generated by the LNA. Since both the signal and the LNA noise levels scaled as 10 log(bandwidth), the ratio was constant in any bandwidth, and the observed difference of 15 dB was the C/N ratio. The second method was to compute the desired signal level and the noise level separately, and then compute the difference. The peak signal level was -40 dBm in a 1-MHz bandwidth, and thus was -27 dBm in a 20-MHz bandwidth. The RMS noise level in the data was -65 dBm in 1 MHz, or -52 dBm in 20 MHz. The LNA gain was measured 51 dB, and the combined line loss and coupler loss was 7 dB. Summing (-52 dBm - 51 dB +7) gave -96 dBm for the LNA noise in 20 MHz at the signal input. The difference between the -81 dBm of the desired signal and the -96 dBm of the LNA noise level was 15 dB, in agreement with the value read off the earlier referenced graph.

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[4]The receiver used in these measurements has an input frequency range of 950-1450 MHz. The same receiver input frequency range is used by BSS Earth stations operating in the 12.2-12.7 GHz frequency band and the planned BSS band of 17.3-17.7 GHz.

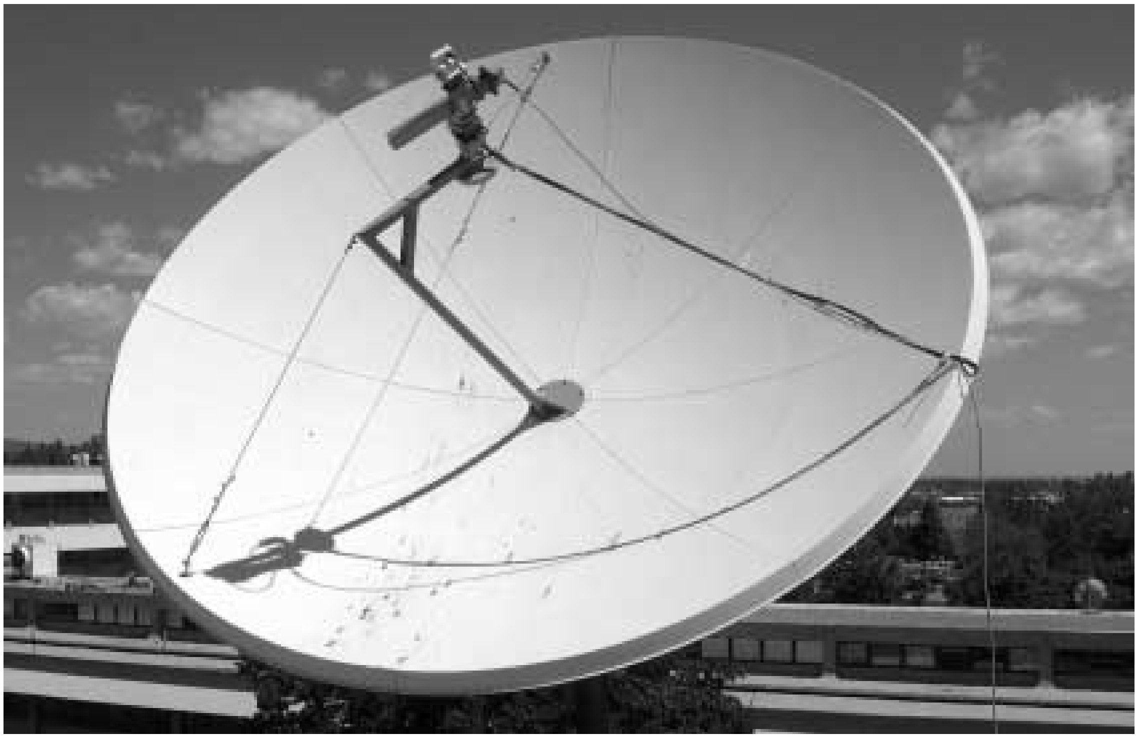

Figure 1. Earth station 3.3-m diameter reflector with RF feed and interference coupler.

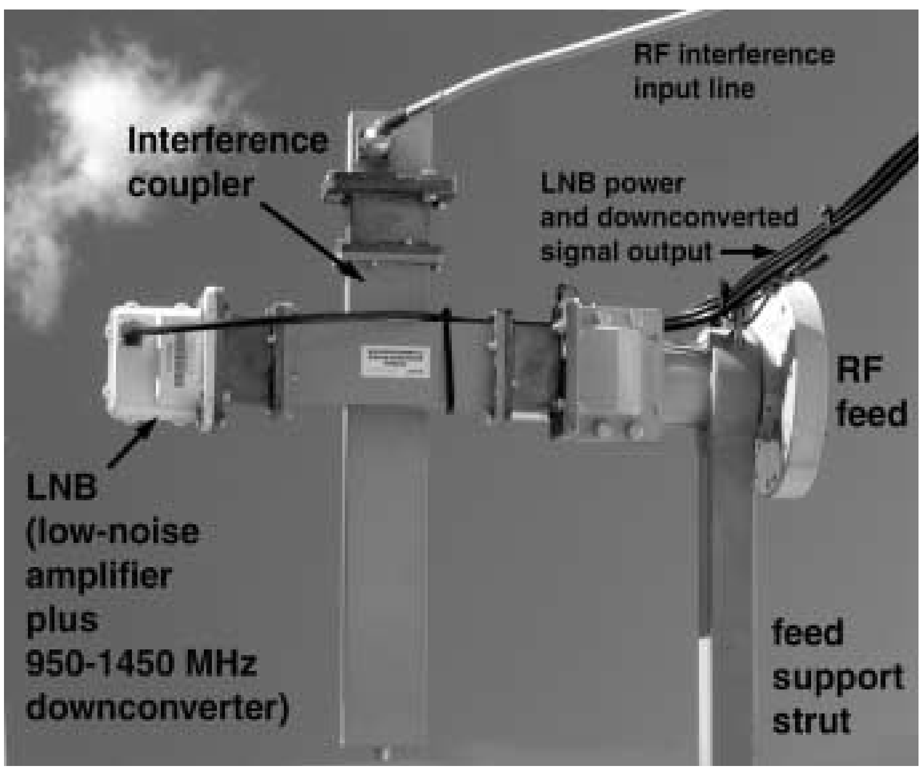


Figure 2. Earth station RF feed and interference coupler (detail view).

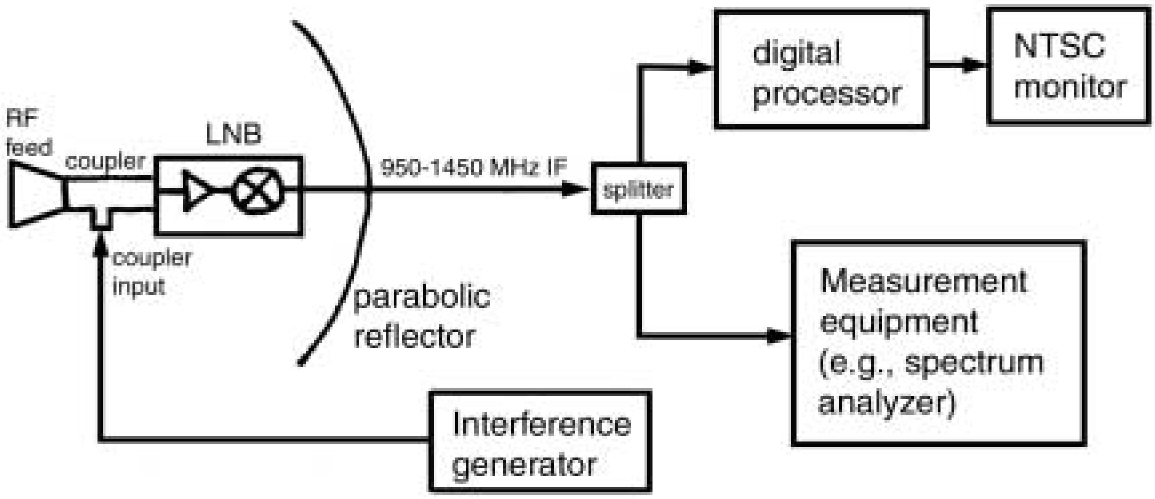


Figure 3. Digital Earth station test and measurement block diagram.

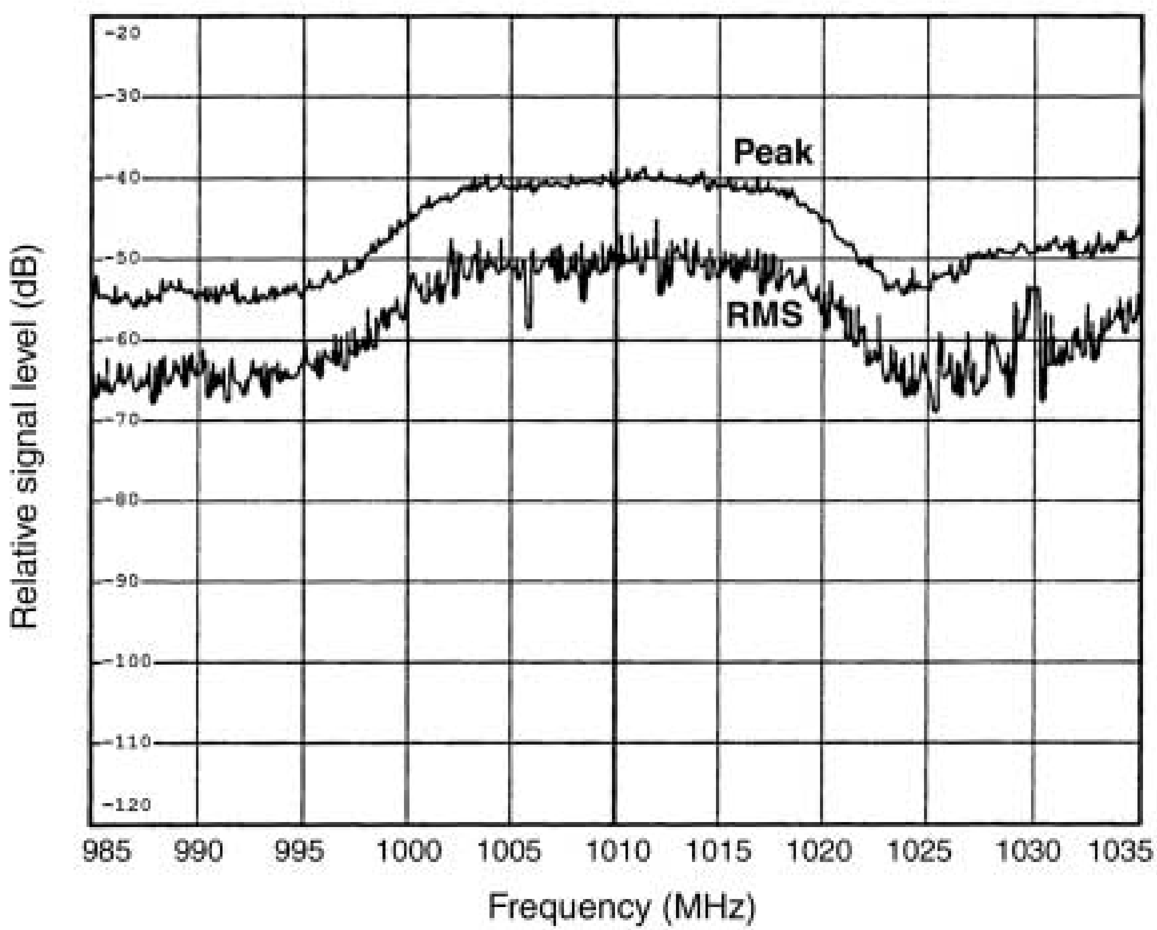


Figure 4. Measured spectrum of desired digital signal in 1-MHz IF bandwidth.

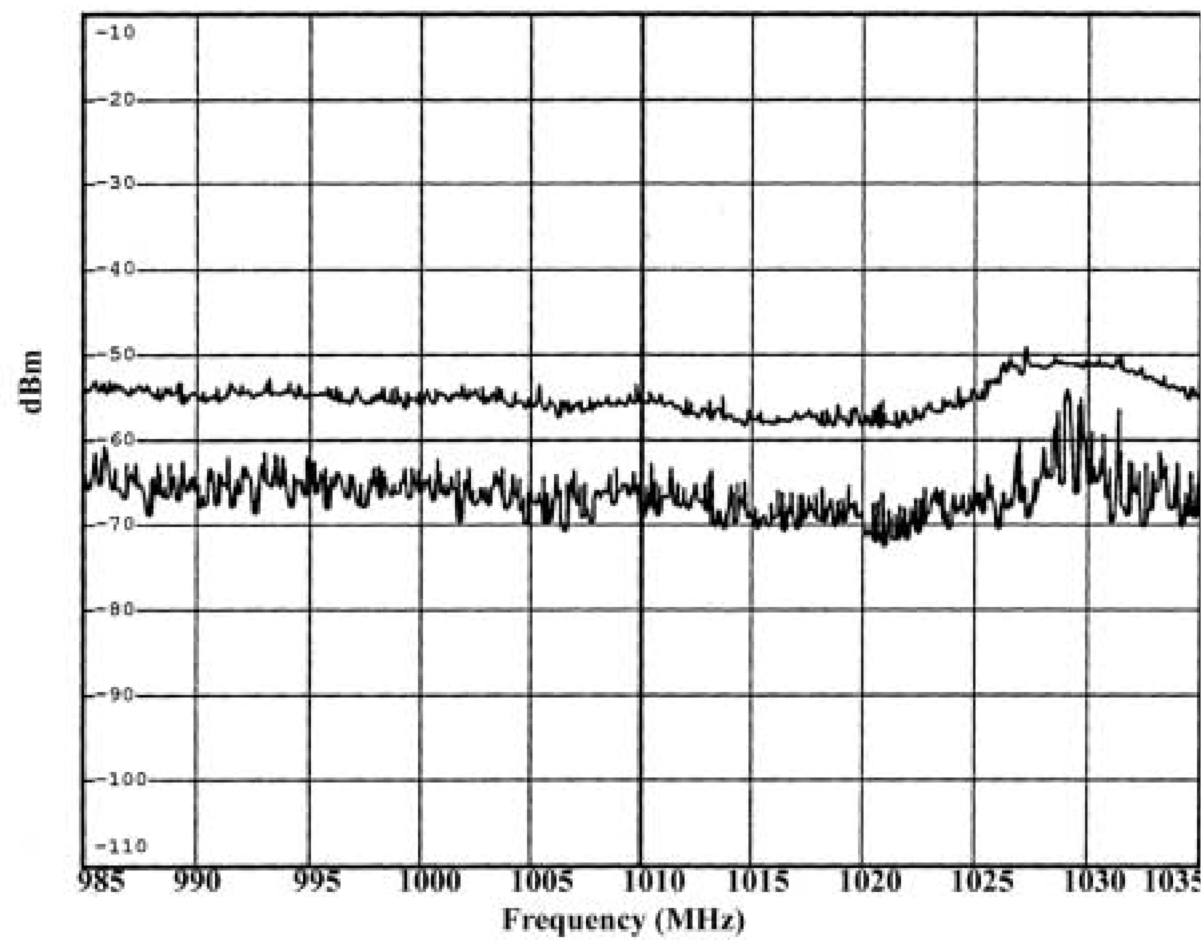


Figure 5. Earth station internal noise (peak and RMS) measured in 1 MHz bandwidth at LNB output.

### 2.3 Interference Signals

Interference signals were generated with a system shown in the block diagram of Figure 6. An arbitrary waveform generator (AWG) was used to trigger a signal generator. Pulse width, repetition rate, and jitter were controlled via the AWG, while RF energy was generated and controlled in amplitude by the signal generator.

The pulse interference parameters that were varied were pulse width, pulse repetition rate (prr), pulse amplitude, and a choice between non-jittered and jittered pulse intervals. Fixed-prr interfering pulsed signals were injected at pulse widths of 50 ns,[5] 100 ns, 500 ns, 1 μs, 5 μs, 10 μs, 50 μs, and 500 μs. Pulse repetition rates for these pulses were 1 kHz, 10 kHz, 100 kHz, 1 MHz, and 6 MHz. When jittering was invoked for the pulsed interference, it was programmed through the AWG. The jittering was based on an absolute time reference, at 50% of the nominal pulse-to-pulse interval. Both jittered and non-jittered pulse sequences were generated with pulse widths of 12.5 ns.

## 2.4 Interference Criteria and Data Collection

The criterion for interference was visible degradation of the television image. Such degradation was observed as tiling, sometimes in conjunction with a freeze-frame effect, as shown in Figure 7. In practice, there was about 1 dB of difference between the non-interference condition and the level at which tiling began to occur. Another 1 dB separated the level at which tiling occurred from the level at which the image was completely lost (ie., dark frame or lost frame condition). That is, about 2 dB separated the baseline level from the level of total breakdown.

Peak interference signal levels were measured relative to the desired signal level of the Earth station receiver. The experimental approach was to first measure the level of the desired signal in the absence of interference. Then the interference signal was injected at an identified peak level that caused tiling. With that signal coupled into the RF input, the feed aperture was blocked with a metal plate to eliminate the desired signal. The peak level of the interference signal at the feed was then measured directly and could be compared to the level of the desired signal as measured previously.

As a control and a reference baseline, continuous-wave (CW) interference was injected into the receiver. With a S/N ratio of 15 dB for the desired signal, the CW signal degraded the Earth station's digital receiver at a carrier-to-interference (C/I)[6] ratio of 8 dB. The absolute desired signal level was -99 dBm, so the absolute threshold for CW interference was -107 dBm. As

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[5]The 50-ns pulse width corresponds to the receiver impulse response (limit) of $[(20\ \mathrm{MHz})^{-1} = 50\ \mathrm{ns}]$. This is the receiver's fastest measured response. 50-ns and shorter pulse widths produce the same (impulse) response in the receiver. Such short impulses may be produced intentionally by interference sources, or may be produced by the leading and trailing edge, double-pulse effect ('rabbit-ears' effect) of adjacent-band radar emissions. The effect is a result of convolving spectrum emission lines that do not include center-frequency emissions.

[6]The term "carrier" is still in common use for these signals, although there is, strictly speaking, no "carrier" for these digital modulations.

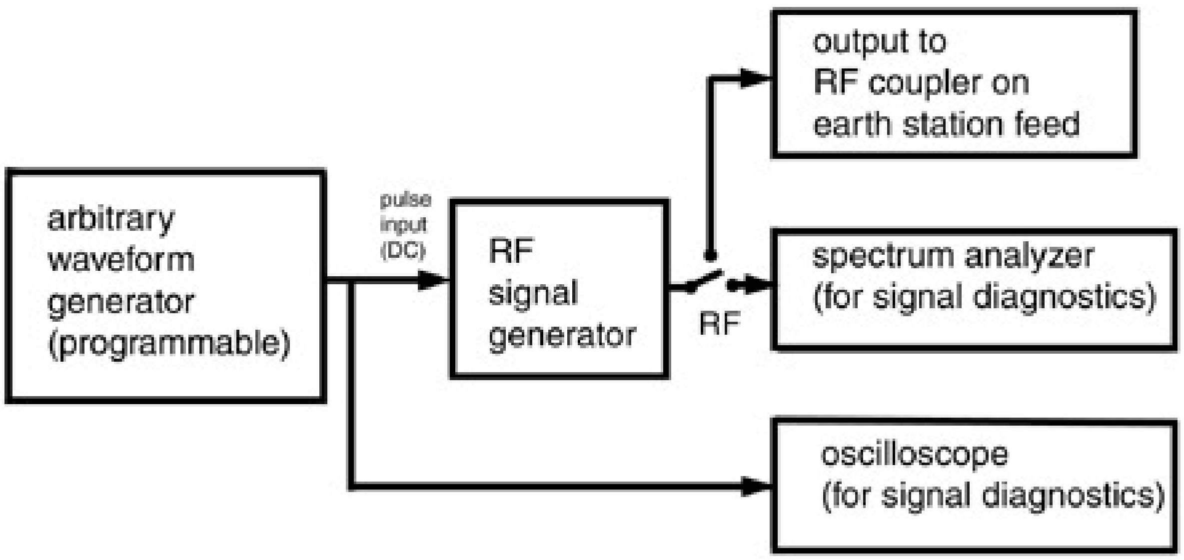


Figure 6. Interference generator block diagram.

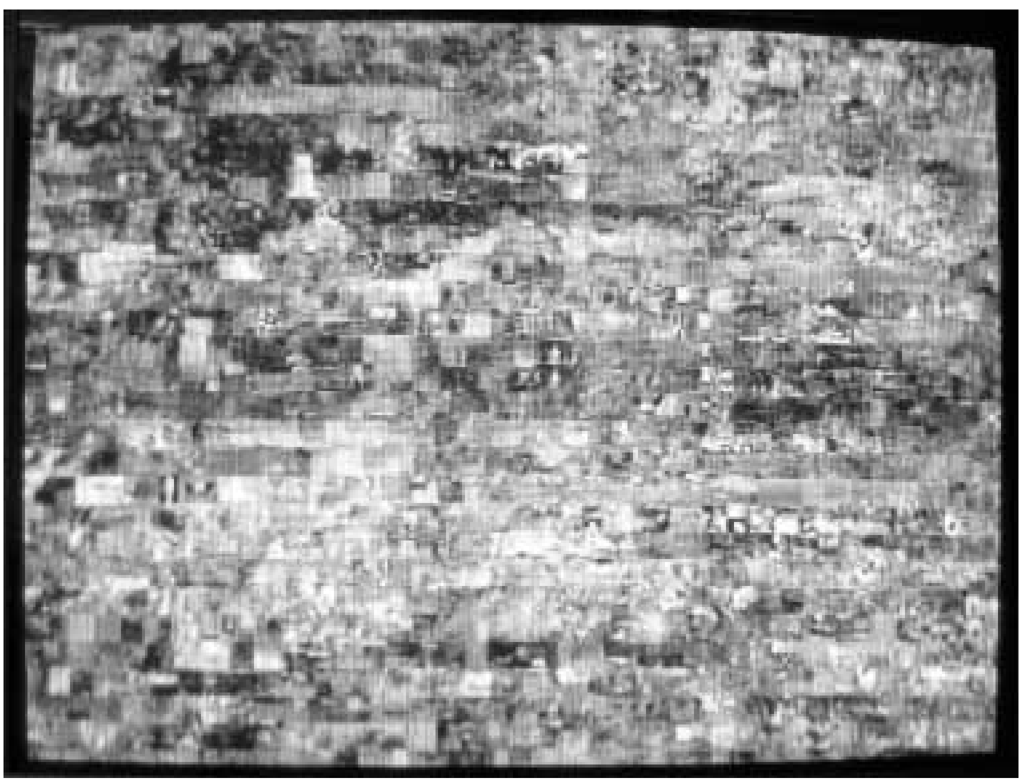

Figure 7. Tiling effect of interference, 1 dB below loss of frame.

discussed in Sections 3 and 4 of this report, these levels should scale as a function of the Earth station antenna aperture, assuming that other factors are held constant.

In the following analysis, note that the power threshold for CW interference is always lower than the interference threshold for similar-power pulsed emissions. Also, in cases where pulse repetition rates are on the order of a megahertz or more and the pulse sequence is unjittered, the pulsed emissions will produce line emissions in the Earth station receiver channels. In that case, the peak power interference thresholds are reduced to those measured earlier for CW interference.

For each combination of pulse width, pulse repetition rate, and jitter, the peak power interference levels were varied as necessary to cause degradation of the TVRO digital signal. For each permutation of pulse parameters, the peak level of the interference was measured relative to that of the desired signal by blocking the RF feed aperture with a metal plate when the interference had been established. This eliminated the desired signal while retaining the interference signal for measurement on a spectrum analyzer (as referenced to Figure 3).

## 3. INTERFERENCE INJECTION RESULTS

This section details the results of the interference injection tests. The testing protocols are described in Section 2. The results are summarized in a set of data graphs.

### 3.1 Interference Data Curves

The results of the interference measurements are shown in Figures 8-14. Of these, Figures 8-12 show the effects of constant-pulse repetition rate (prr) interference on the Earth station. Figures 13-14 show the effects of short-pulse interference on the Earth station. Each data graph shows interference thresholds (carrier to peak interference ratio) as a function of some independent variable, such as interference pulse width, interference pulse repetition rate, or interference pulse duty cycle. Each graph also contains a line showing the threshold where a CW signal caused interference to the Earth station.

In Figure 8, the data are shown as the ratio of interference pulse length to Earth station symbol length. This graph may be used to scale interference effects for any given digital Earth station. Figure 9 is similar to Figure 8, but the interference effects are presented in absolute units. In both of these figures, the interference thresholds are shown as a function of interference pulse width. In Figure 12, interference thresholds are shown as a function of pulse width and pulse repetition rate (prr). At the highest thresholds, the interference levels probably reach overload for the Earth station front-end amplifier.

Review of data in these graphs begs the question, "Why does the degradation of the desired signal depend upon the amplitude of the interfering signal, given that a digital symbol is presumably interfered with at a much lower level, approximating that of the desired signal?" At the highest levels (in excess of about 30 dB above the desired signal level), the interference is probably due to front-end overload of the LNA. At lower levels, the interference pulses may be causing a response in the digital receiver that runs longer than the pulse width of the input interference. The receiver fails when interfering pulses affect a sufficiently large number of consecutive symbols.

In Figure 10, the data are plotted as a function of interference duty cycle. Effectively, the curves of Figures 8 and 9 are held fixed on the vertical axis, but are all moved to the right to converge at a duty cycle of unity, equivalent to a CW signal. (Because duty cycle is pulse width dependent, Figure 10 is an alternative method of displaying the data of Figures 8 and 9.) The data show that, for a duty cycle of about 40% or more, the interference threshold approaches that of CW; that is, high duty cycles have approximately the same effect as CW interference. This also indicates that, for pulsed transmitters that operate with 50-ns or narrower pulses, the resulting performance degradation will be similar to a CW signal for prr's exceeding 8 MHz. Measured data showed this convergence to occur somewhat sooner, at 6.6 MHz.

In Figure 11, interference thresholds are shown as a function of prr and duty cycle. This graph shows the effect of duty cycle as the interference prr is varied. In Figure 12, interference thresholds are shown as a function of prr and pulse width.

Figures 13 and 14 show results for both jittered and non-jittered pulse interference with 12.5-ns pulse width signals. The pulse width of 12.5 ns was one-fourth the symbol length of this Earth station. For comparative purposes, these results are plotted along with 50-ns, fixed-prr interference pulse results. These pulse widths excite the impulse response of the receiver; they are the limiting case for the receiver, as the receiver's shortest response is 50 ns.

### 3.2 Interpretation of Results: Constant PRR Interference

In Figure 8, it is observed that when the pulse repetition interval (pri, equal to 1/(pulse repetition rate)) is 1,000 times the symbol length or longer, and interference pulse widths are approximately equal to the symbol length, the interference must reach levels on the order of 70 dB above the desired signal level to cause degradation. Keeping the interference pulses short and decreasing the pri to 100 times the symbol length, the interference threshold drops to 20 dB relative to the desired signal level. When the pri is 10 times the symbol length, degradation occurs at levels about equal to that of the desired signal. This behavior is inferred to mean that the digital receiver can recover easily from the loss of one symbol out of every few thousand unless the level of the interference signal is extremely high. At a loss of one symbol out of every few hundred, the

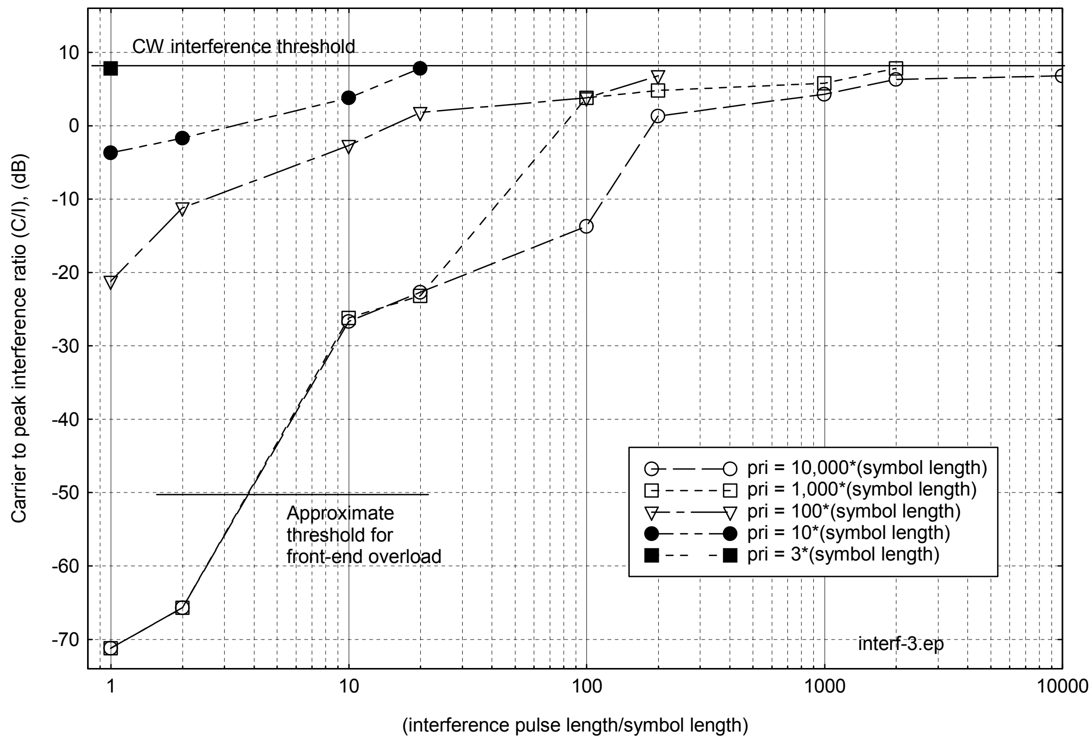


Figure 8. Interference thresholds as a normalized function of pulse repetition interval.

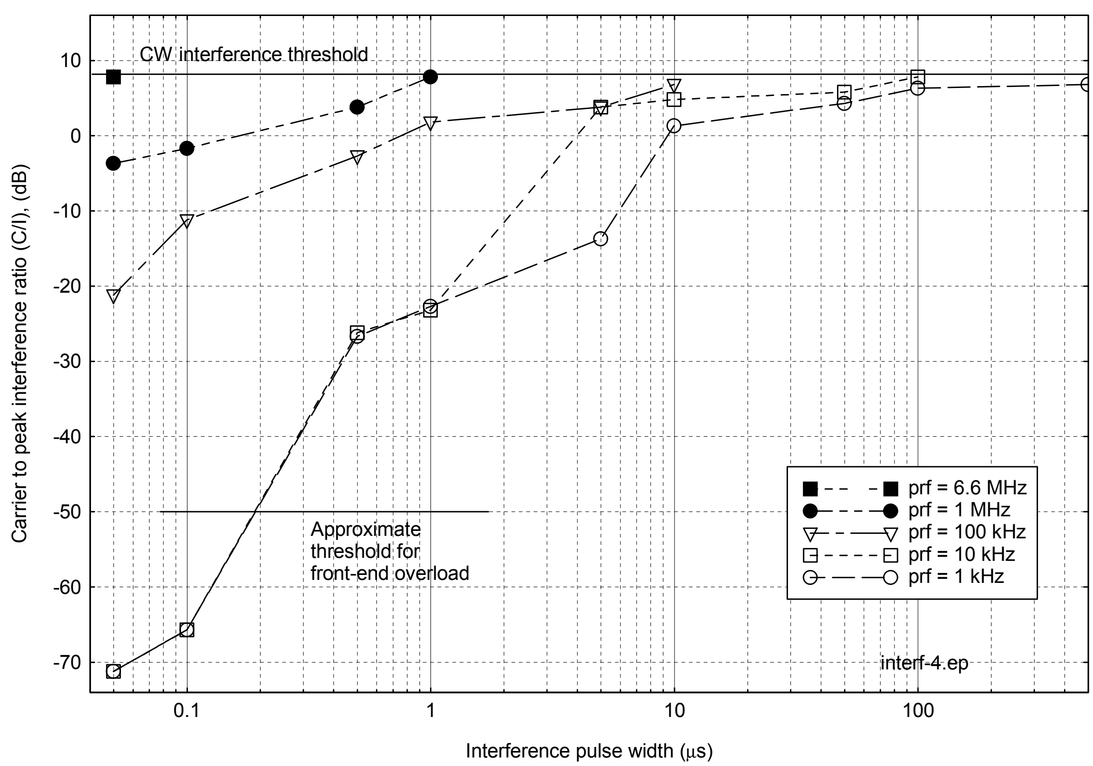


Figure 9. Interference thresholds as a function of pulse repetition frequency.

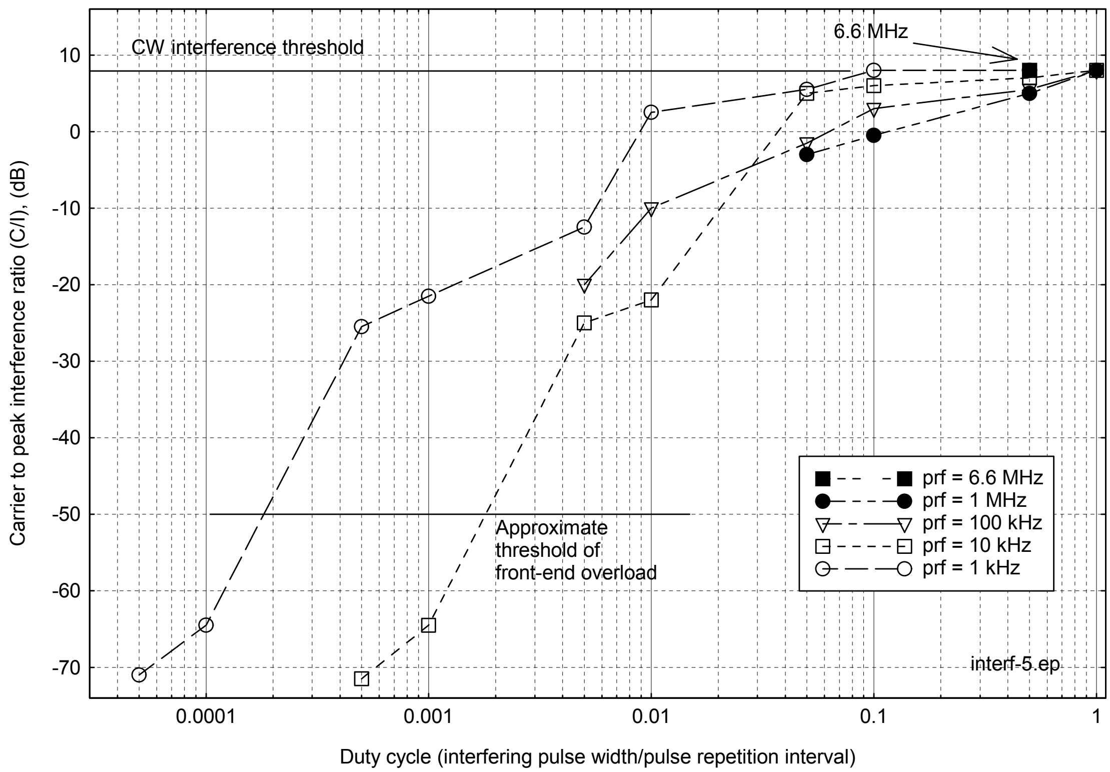


Figure 10. Interference thresholds as a function of duty cycle.

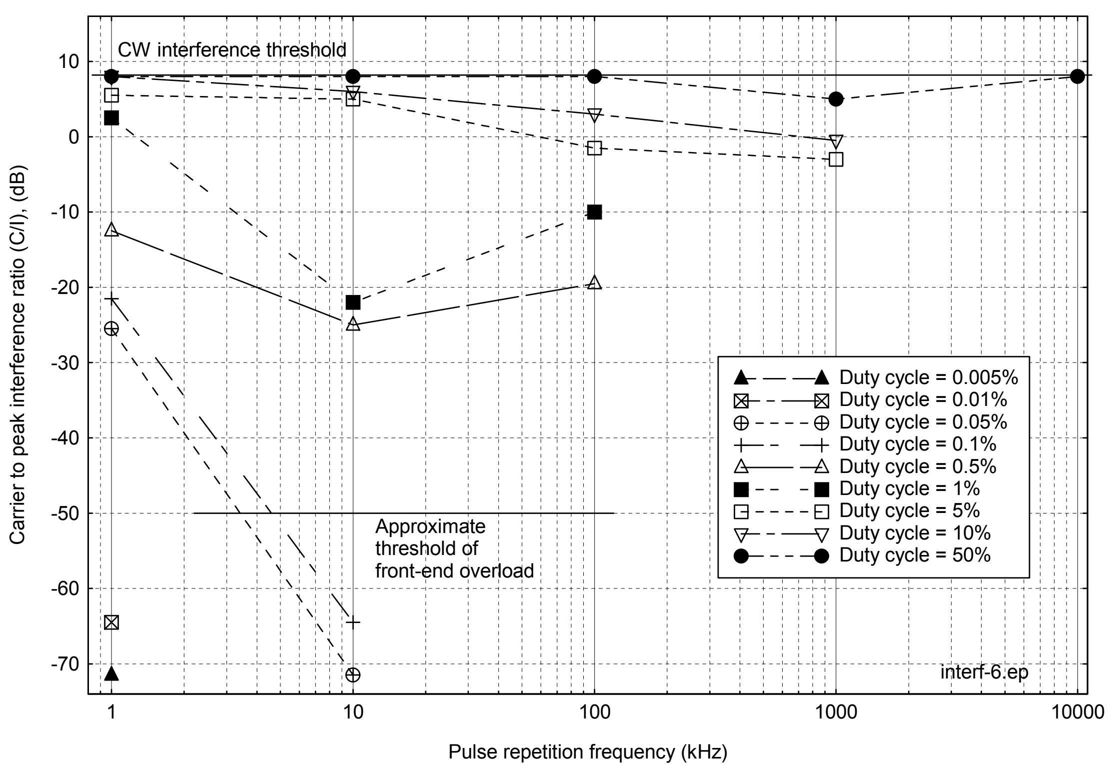


Figure 11. Interference thresholds as a function of pulse repetition rate and duty cycle.

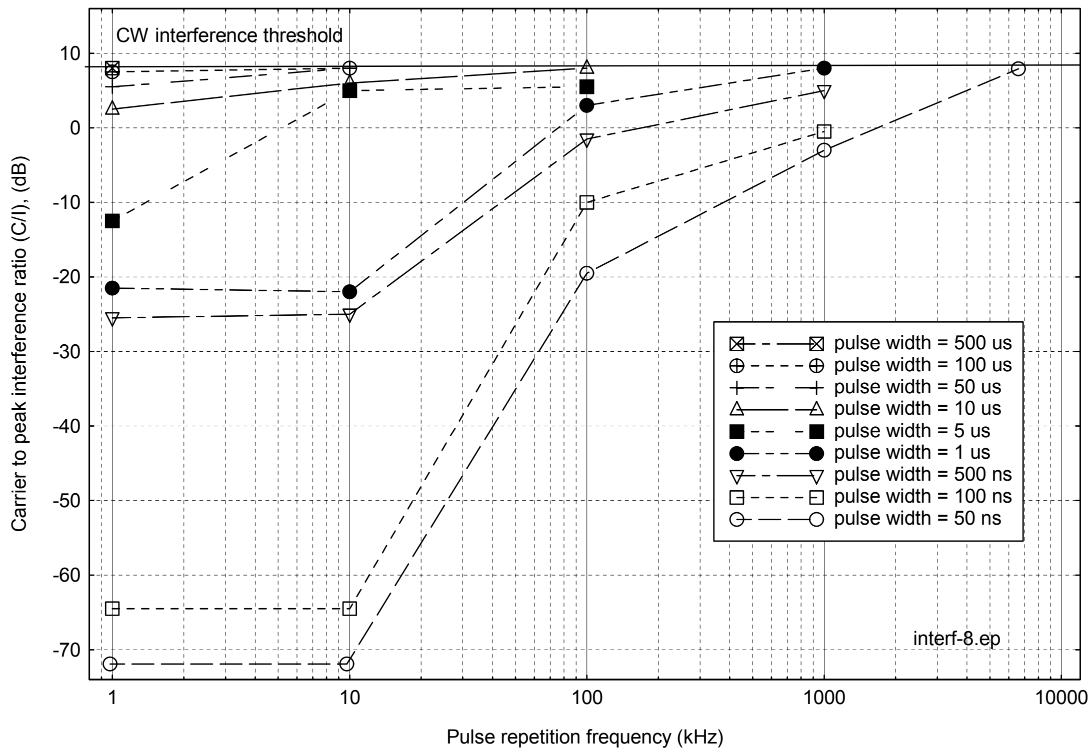


Figure 12. Interference thresholds as a function of interference pulse width and prr.

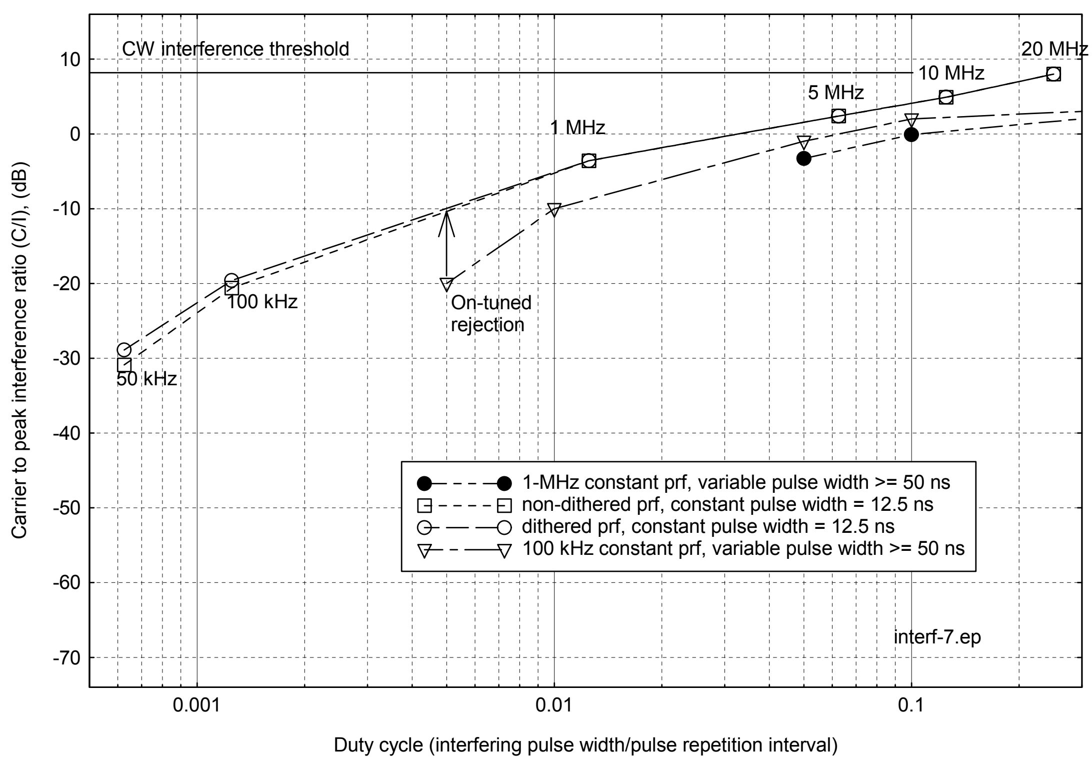


Figure 13. Short-pulse interference thresholds as a function of duty cycle and prr.

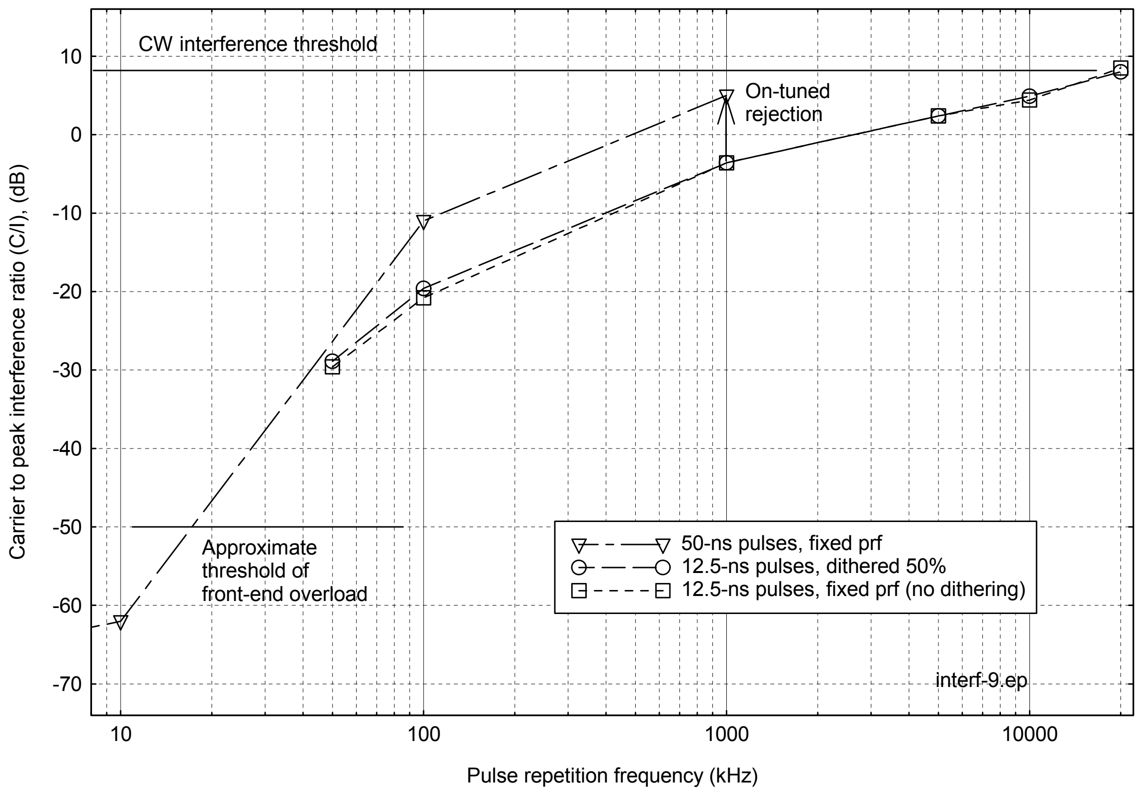


Figure 14. Short-pulse interference thresholds as a function of pulse repetition frequency.

digital receiver is still fairly robust. But when one out of every ten symbols is lost, then the interference need only be about equal to the amplitude of the desired signal to cause receiver degradation.

Moving to longer interference pulse lengths, the levels at which receiver degradation occur gradually decrease. This is apparently due to the fact that, when long-pulse-width interference occurs, many symbols are errored consecutively. The larger the number of consecutively errored symbols, the more sensitive the system becomes to external interference levels.

Finally, as the long pulse lengths occupy an appreciable fraction of the pulse-to-pulse intervals (moving to the far right-hand side of Figures 8 and 9), the situation approaches that of a CW signal, and the interference signal levels converge on the CW interference level.

In Figure 10, the robustness of the digital receiver in the presence of low duty cycle interference is shown. As long as duty cycle is less than 0.005 (a half percent), interference thresholds are at a (C/I) ratio exceeding -10 dB. But the curves converge rapidly to the CW level of 8 dB (C/I) ratio when duty cycle exceeds 1 percent. Results are almost identical for all cases, regardless of absolute pulse repetition rate or pulse width, when duty cycle exceeds 5%.

From this information, it is inferred that, when less than 0.5 percent of symbols are affected, the system's error correction routines work well. The error correction is so effective that system failure, when it occurs, is at levels that are 50-70 dB higher than the desired carrier level. At that level, system failure is probably due to front-end overload of the receiver's low-noise RF amplifier. The front-end overload effect is analyzed at length in another NTIA Report [5]. Loss of receiver synchronization or failure modes unrelated to bit errors may also occur at these extremely high interference levels.

Within a transitional zone where 1-5% of symbols are affected, degradation is easier to inflict but the system is still robust enough to withstand interference levels on the order of 10 to 20 dB above the desired signal level. But when more than 5% of symbols are affected on a continuous basis, the system's error correction capabilities fail to compensate under almost any incident interference signal level exceeding the desired signal level.

In Figure 11, it is observed that interference thresholds are close to that of CW interference for duty cycles of 5% or more, regardless of the interference prr. This is inferred to mean that the Earth station digital data stream processing breaks down when more than 5% of symbols are degraded at C/I ratios of about 8 dB to 0 dB.

In Figure 12, it is seen that the combination of pulse width and prr determines the vulnerability of the Earth station to interference. For prr values less than 100 kHz, the interference thresholds vary over a range of more than 70 dB, depending upon pulse width. For low prr values (below 100 kHz), short pulse widths do not affect the Earth station unless interference levels exceed the desired signal level by tens of decibels.

### 3.3 Interpretation of Results: Jittered-Pulse Interference

In Figures 13 and 14, it is observed that interference thresholds are not affected by jittering vs. fixed-prr characteristics of the 12.5 ns pulses. This is interpreted to mean that the Earth station interference characteristics do not depend upon systematic vs. non-systematic interruption of the data stream. The reason for this non-dependence is probably the interleaving of the bits in the Earth station data stream. Thus, jittering is apparently ineffective as an interference-mitigation approach for Earth stations utilizing this kind of digital data protocol.[7] In these figures, the gap

[7]Note that the amplitude probability distribution (APD) of a signal is unaffected by jittering when the pulse repetition rate is less than the receiver bandwidth. That is, the Earth station receiver is not expected to respond to jittering effects in interference if the pulse repetition rate of the interference is less than the Earth station receiver bandwidth.

between the 100-kHz curve and the other curves is believed to be a result of on-tuned rejection of the 100-kHz pulses.

As for the effect of interference pulse widths that are a fraction of the symbol length of the Earth station data stream, Figures 13 and 14 indicate that this does not change interference thresholds by more than 10 dB relative to interference pulse widths that are about the same as the symbol length. And most of the points on the data curves differ by less than 10 dB for 12.5 ns vs. 50 ns interference pulse lengths. This is interpreted to mean that the Earth station impulse response duration is about the same as the symbol length (50 ns).[8] When interference pulse widths are less than the symbol length, then the receiver simply produces an impulse response with about the same length as a symbol; shortening the impulses does not decrease the length of the receiver's response. Therefore, the receiver responds to such pulses in the same way that it responds to pulses with a width that approximates the symbol length. In effect, pulse lengths shorter than the symbol length do not decrease the interference thresholds of an Earth station appreciably below those of pulses that approximate the station's bit or symbol length.

### 3.4 Determining Electromagnetic Compatibility for Earth Station Installations

The data presented in this report may be used to determine electromagnetic compatibility between Earth stations and sources of pulsed interference.[9] One approach is to define a distance from an Earth station within which no pulsed interference sources may exist. The maximum EIRP of a pulsed source is computed, assuming that the pulse characteristics of the pulsed source can be defined. This approach uses an adaptation of Equation 6 from [5], pg. 40:

$$EIRP = P_r - G_r - 27.5 + 20\log(f) - 20\log(r)$$

where:

EIRP= Maximum effective isotropic radiated power that is to be transmitted by the interference source transmitter (dBm);

$P_r$ = Maximum power to be received as interference by the Earth station (dBm);

$G_r$ = Gain of the Earth station antenna in the direction of the interference source (dBi);

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[8]This impulse response corresponds to the Earth station receiver bandwidth of 20 MHz. It was also confirmed by the result of a two-tone selectivity measurement.

[9]See also reference [5].

f = frequency (MHz);

r = distance between interference source and Earth station (meters);

An example is presented here. This example may be used as a guide for the use of the data presented in this report.

**Example: An Earth station's operators may prevent access by any transmitters out to a radial distance of 100 meters. What is the maximum EIRP allowable at 4 GHz from a pulsed, 1-MHz prf source with a 10 percent duty cycle? Assume that the dish diameter is 3.65 m (12 ft), and that interference couples into a sidelobe that has 25 dB less gain than the antenna's main beam.**

Solution: Referring to the 1-MHz prf curve of Figure 10, the threshold C/I for interference into the receiver is about -0.5 dB. Since the dish diameter used for that graph was 3.3 m, a 3.6-m diameter dish would have 10log((3.65/3.3)^2) more gain, or 0.88 dB. Thus the nominal level of the desired signal would be -81 dBm + 0.88 dB, or -80.1 dBm. The threshold for the interfering signal in the receiver would be 0.5 dB lower, or -79.6 dBm. If the dish main beam gain is +41 dBi, the effective gain of the dish in the specified sidelobe would be (41 dBi - 25 dB) = 16 dBi. Again using the adaptation of Equation (6) from [5],

$$(\text{EIRP, dBm}) = -79.6 - 16 - 27.5 + 20\log(4000) + 20\log(100)$$

which yields limiting peak EIRP = -11 dBm.

Note that the following assumptions have been made in this calculation:

1) diameter of the receiving dish antenna;
2) relative gain of the sidelobe into which interference coupling is expected;
3) pulse characteristics of the interfering signal;
4) distance from the Earth station that interference signals are expected to be reasonably excluded;
5) forward error correction and other error correction mechanisms are similar to those used in the Earth station described in the report.

## 4. CONCLUSIONS AND RECOMMENDATIONS

Based upon the data and analysis presented in Section 3 of this report, some conclusions and recommendations concerning electromagnetic compatibility between Earth station receivers and pulsed interference sources can be made.

### 4.1 Conclusions Regarding Pulsed Interference into Digital Earth Station Receivers

1) Continuous-wave (CW) interference effects occur at the lowest thresholds, approximately 8 dB below that of the desired signal in the bandwidth of the Earth station receiver.

2) Pulsed-interference thresholds for digital Earth station receivers are dependent upon pulse width, pulse repetition rate (prr), and amplitude of the interference. Thresholds increase as pulse widths and prr's decrease. For sufficiently low prr's, interference thresholds may approach the level of front-end overload of the Earth station receiver.

3) When short pulses at low prr's cause interference to an Earth station receiver, the effect is probably due to non-linear effects such as front-end overload of the RF low-noise amplifier.

4) Digital Earth station receivers are relatively robust in the presence of low duty cycle interference. When duty cycle is less than 0.005 (a half percent), interference thresholds exceed 10 dB above the desired signal level. But interference thresholds converge rapidly to the CW level of 8 dB (C/I) ratio when duty cycle exceeds 1 percent. Results are almost identical for all cases, regardless of absolute pulse repetition rate or pulse width, when interference duty cycle exceeds 5 percent. In that case, the interference threshold is nearly that of a CW signal. In effect, the Earth station performance is severely affected if 5 percent or more of symbols are deleted from the data stream.

5) When less than 0.5% of symbols are affected, the system's error correction routines work well. Within a transitional zone of 1-5% of symbols affected, degradation is easier to inflict but the system is still robust enough to withstand peak interference levels on the order of 10 to 20 dB above the desired signal level. But when more than 5% of symbols are affected on a continuous basis, the system's error correction capabilities become inadequate to compensate under almost any incident signal level equalling or exceeding the desired signal level.

6) The combination of pulse width and prr determines the vulnerability of an Earth station to interference. The peak interference threshold is approximately equal to the CW interference threshold for duty cycles $\geq$5%. For prr values less than 100 kHz, the interference thresholds vary over a range of more than 70 dB, depending upon pulse length. For low prr values (below 100 kHz), short pulse widths do not affect the Earth station unless interference levels exceed the desired signal level by tens of decibels.

7) As pulse widths are reduced to less than the symbol length or bit length, the Earth station receiver response time is the duration of the impulse response. This impulse response is nominally about the length of a symbol, but can be longer for high-amplitude interference pulses. Thus, reduction of interference pulse widths to values less than the symbol length is not in itself beneficial in raising the interference threshold of the Earth station. However, if a transmitter peak

power level is held fixed while the pulse widths are shortened, then a benefit will occur due to the reduced emission power within the receiver bandwidth. This effect, sometimes referred to as on-tuned rejection, will reduce the interference level coupled into the Earth station receiver for pulsed interference at a rate of between 10•log to 20•log of the ratio of the receiver bandwidth and the emission bandwidth.

8) Jittering of pulsed interference does not change the interference thresholds of the Earth station. This is because the interleaved nature of the digital data stream makes the system response insensitive to the particular bits that are errored by interference. Whether data bits or symbols are errored on a periodic basis (as for fixed-prr interference sequence) or on a random basis (as for jittered-prr interference sequence) makes no difference, because interleaving effectively randomizes the deleted bits and symbols in both cases.

## 4.2 Recommendations

The data in this report, although preliminary, can be used to compute electromagnetic compatibility (EMC) between digital Earth station receivers and pulsed co-channel interference sources. Although more detailed follow-on studies may be performed to further examine the details of various interference scenarios, the data presented in this report are adequate for approximate determination of EMC parameters between pulsed interference sources and digital Earth station receivers.

# 5. REFERENCES

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