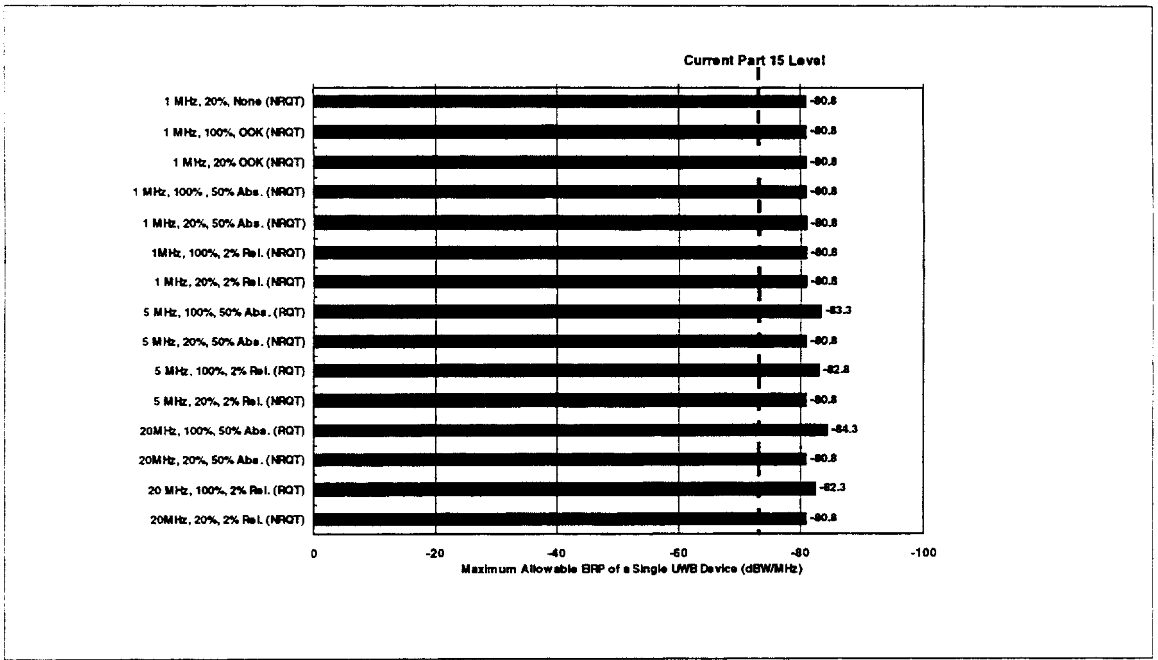

Figure 3-35. Analysis Results for Aviation (Non-Precision Approach Landing) Operational Scenario: C/A-code Receiver and Multiple UWB Devices (Noise-Like UWB Signals)

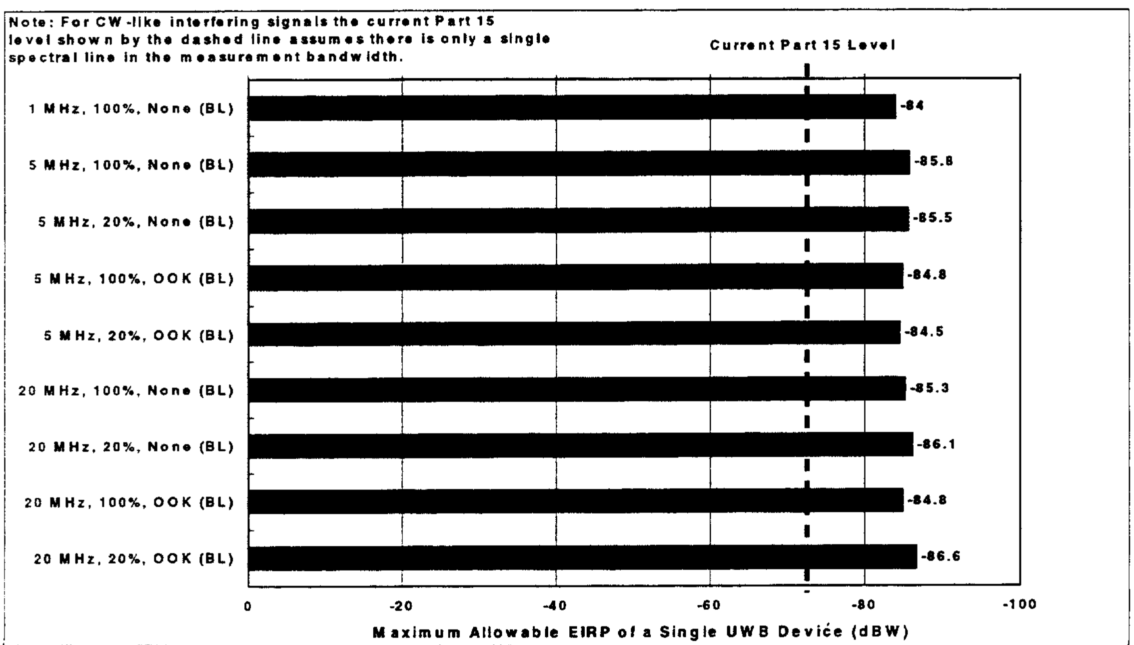

Figure 3-36. Analysis Results for Aviation (Non-Precision Approach Landing) Operational Scenario: C/A-code Receiver and Multiple UWB Devices (CW-Like UWB Signals)

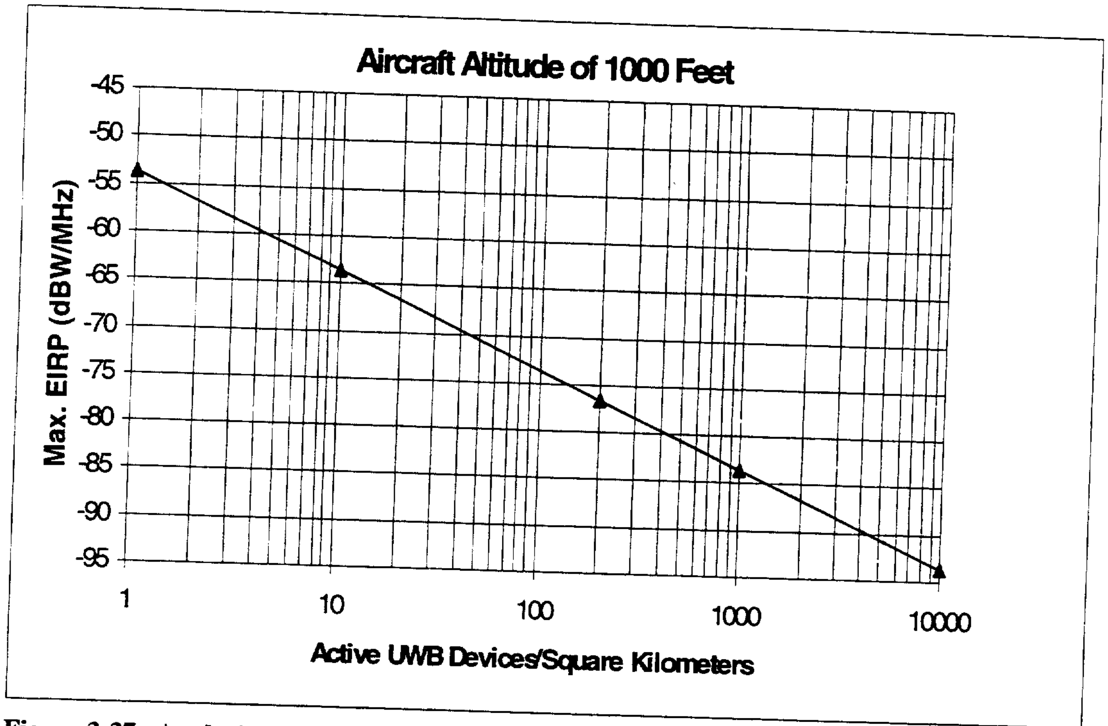

Figure 3-37. Analysis Results for Aviation (En-Route Navigation) Operational Scenario: C/A-code Receiver and Multiple UWB Devices - Outdoor Operation

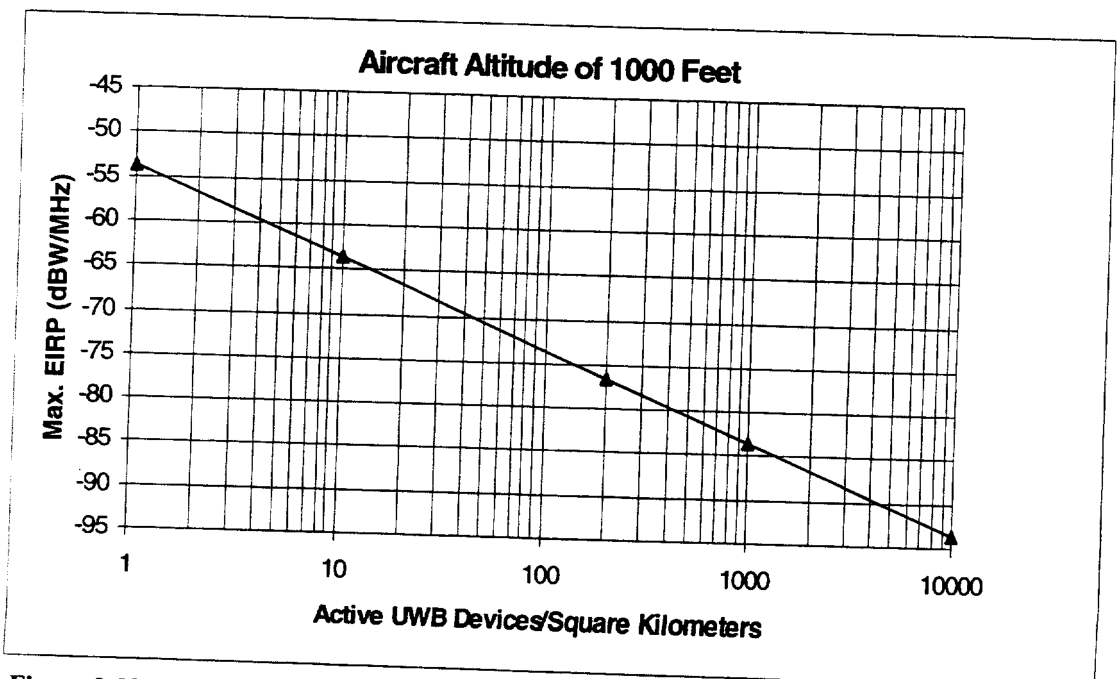

Figure 3-38. Analysis Results for Aviation (En-Route Navigation) Operational Scenario: C/A-code Receiver and Multiple UWB Devices - Indoor Operation

SECTION 4.0
SUMMARY/CONCLUSIONS

4.1 SUMMARY OF MEASUREMENT FINDINGS

In the measurement component of this assessment, 32 UWB signal permutations were identified for examination with respect to the interference potential to GPS receivers. For each of four pulse repetition frequencies (PRFs);100 kHz, 1 MHz, 5 MHz, and 20 MHz, eight distinct UWB waveforms were generated by combining four modulation types (constant PRF, On-Off Keying (OOK), 2% relative dither, and 50% absolute dither) and two states of gating (100% and 20%). Each of these UWB parameters are described in the paragraphs below.

The PRF defines the number of pulses transmitted per unit time (seconds). The PRF governs both the magnitude and spacing of the spectral lines. For example, a 5 MHz PRF signal produces spectral lines that are spaced every 5 MHz in the frequency domain. As the PRF is increased, the spectral lines become spaced further apart, but the energy contained in a each spectral line is increased. Within the context of this report, "constant PRF" refers to an unmodulated UWB signal.

Gating refers to the process of distributing pulses in bursts by employing a programmed set of periods where the UWB transmitter is turned on or off for a period of pulses. For the measurements performed in this study, the gated UWB signal utilized a scheme where a burst of data lasting 4 ms was followed by a 16 ms period when no pulses were transmitted. This is referred to as 20% gating, because the UWB pulses are transmitted 20% of the time. The signal permutations depicted within this report as 100% gating, define a signal where pulses are transmitted 100% of the time.

OOK refers to the process of selectively turning off or eliminating individual pulses to represent data bits. With OOK modulation, the energy in the spectrum is equally divided between the spectral line components and the noise continuum component.

Dithering refers to the random or pseudo-random spacing of the pulses. Two forms of dithered UWB signals were considered in this effort. These are an absolute referenced dither, where the pulse period is varied in relation to the absolute clock, and a relative referenced dither, where the pulse spacing is varied relative to the previous pulse. The PRF of a relative dithered pulse train is equal to the reciprocal of the mean pulse period. Dithering of the pulses in the time domain spreads the spectral line content of a UWB signal in the frequency domain making the signal appear more noise-like.

For illustration, Figure 4-1 shows the spectral content for a 1 MHz PRF UWB signal as measured in a 24 MHz bandpass filter when: unmodulated, OOK modulated, 50% absolute reference dithered, and 2% relative referenced dithered.

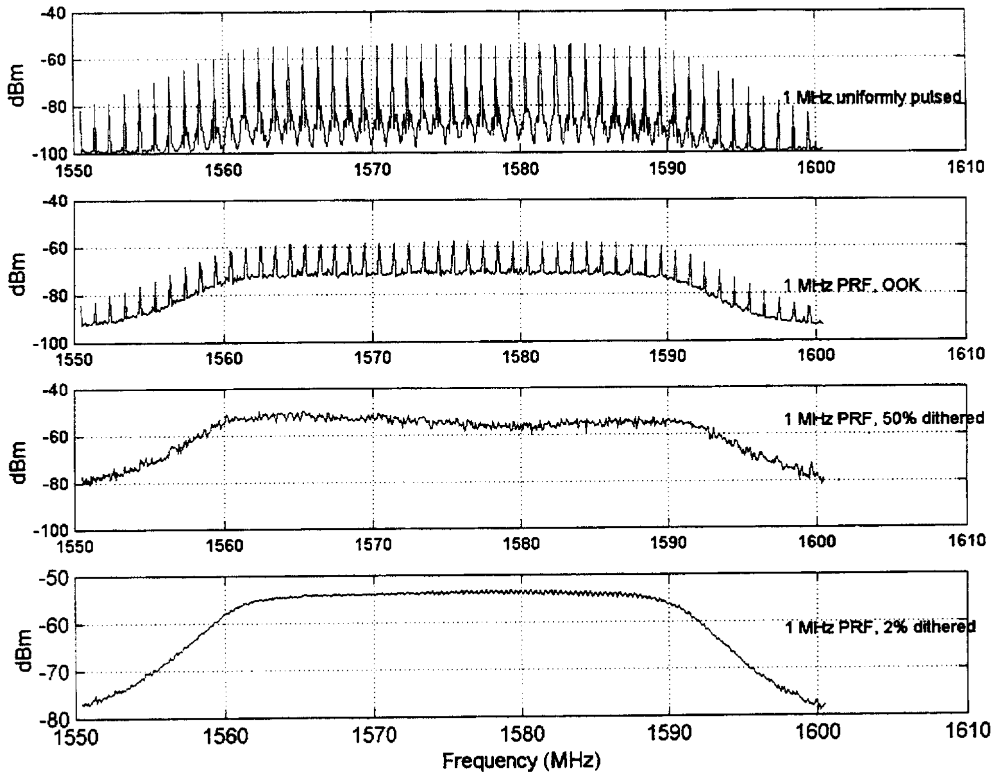

Figure 4-1. Illustration of Modulation Effects on a UWB Signal as Measured in a 24 MHz Bandpass Filter

The results of this measurement effort were found to be UWB signal-dependent and are strongly related to the PRF examined. Thus, in this section, the summary of the measurement results, and the conclusions drawn from them, will be grouped by UWB signal PRF for each of the GPS receivers measured.

4.1.1 C/A-code GPS Receiver

Previous work in quantifying interference to GPS receivers has been performed in RTCA and ITU-R technical working groups comprised of GPS experts. Much of this work has focused on the effect of different interference types to C/A-code GPS receivers, since these represent the most predominant GPS architecture currently present in the civilian marketplace. This work has determined that GPS C/A-code receivers are most susceptible to CW-like interference. This is due to the potential for interfering spectral lines to become aligned with the 1 kHz spaced spectral lines of the GPS C/A-code, produced as a result of the relatively short, periodic nature of the Gold codes used to generate the pseudorandom sequences necessary for code division multiple access (CDMA) operation. RTCA and ITU-R have documented an interference protection level of -150.5 dBW, at the input of the GPS receiver, as necessary to protect GPS receivers from this type of interfering signal.[71] GPS C/A-code receivers are also susceptible to broadband noise-like interference where the documented protection level, at the input of the GPS C/A-code receiver, is -140.5 dBW/MHz.[72]

RTCA has also determined that GPS C/A-code receivers are less sensitive to low duty cycle pulse-like interfering signals. The interference protection level documented for this type of interference is +20 dBm (peak pulse power), at the input to the receiver, for duty cycles less than 10%.[73]

The results of the measurements performed as a part of this assessment agree with the RTCA and the ITU-R protection limits. In the analysis of the measurement results, NTIA found that the interference effects on the GPS C/A-code receiver from each of the UWB signals considered in this assessment could be classified as one of the three conventional interference types; CW-like, noise-like, or pulse-like interference. The APD measurements performed for each of the UWB signal permutations provide some insight into the classification of the waveforms into these three categories.[74] Once the UWB signal was determined to be characteristic of CW-like, noise-like, or low duty cycle pulse-like, a comparison of the measured interference thresholds with the documented interference protection limits are consistent after adjustments are made to account for the difference in GPS signal level assumed at the input to the receiver. The development of the interference protection limits within the RTCA and ITU-R assumed an aviation scenario in which GPS satellites located at or near the horizon are typically unobstructed with respect to a GPS receiver antenna at altitude, and thus can be used in the navigation solution. Within this aviation scenario, the minimum guaranteed GPS signal is assumed to be received through a sidelobe of the GPS antenna, with an antenna gain of -4.5 dBic. In establishing the GPS signal power to use in this measurement effort, a terrestrial scenario was assumed in which those satellites on the horizon are typically obstructed with respect to a GPS antenna. Thus, the minimum guaranteed GPS signal was assumed to be received by the GPS antenna with a gain of 0 dBic. Any applicable scenario-dependent adjustment to the GPS antenna gain is then accounted for in the analysis. For this reason, the measured interference thresholds presented in the following tables must be adjusted by -4.5 dB to account for differences in the antenna gain in order to compare with the interference protection limits defined within the literature.

Tables 4-1 through 4-4 list the measured interference thresholds for the GPS C/A-code receiver. Depending on the UWB signal permutation under consideration, adjustments had to be made to: 1) convert from a 20 MHz bandwidth to a 1 MHz bandwidth, 2) convert from dBm to

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[71] RTCA 229B at C-2; ITU-R M.1477 at Table 1.

[72] Id.

[73] RTCA 229B at C-5.

[74] ITS Report at 55.

dBW, 3) determine the power contained in a spectral line for CW-like signals, 4) account for the division of power between the spectral lines and the noise continuum for OOK modulated signals, and 5) to adjust for gate on-time relative to total time for the gated signals. These adjustments are discussed in detail in section 2.2.2.1 and in Table 3-11 of this document. The adjusted interference threshold level is presented in the last column of these tables. It is this interference threshold level, that when adjusted by -4.5 dB (see discussion above), compares favorably with the published interference protection limits (see Table 2-7).

The results from the aggregate measurements indicate the following with respect to the UWB waveforms examined: 1) for those waveforms associated with a PRF greater than 100 kHz, that were classified as pulse-like, a transition to a noise-like effect occurs when three or more UWB transmitters are assumed to be operating with equivalent power levels at the input to the GPS receiver, 2) when UWB waveforms characteristic of noise-like interference are considered in the aggregate, the effective signal at the output of the GPS receiver IF is determined by adding the average power of each interference signal, and 3) when those UWB signal permutations classified as CW-like are aggregated, the interference mechanism remains that of the individual CW-like signal, i.e., a spectral line alignment between a UWB spectral line and a dominant GPS code line, where the amplitude in the UWB spectral line exceeds that of the GPS code line. As such, the CW-like UWB signals do not add; however, an increase in the number of spectral lines present in the GPS passband, due to an aggregation of UWB devices, is expected to increase the probability of the occurrence of spectral line coincidence. This result is based on the results of the aggregate measurements performed as a part of this study, which was limited by the number of available UWB signal sources.

In Table 4-1, the measured interference thresholds are shown for all eight UWB signal permutations operating at a PRF of 100 kHz. For these waveforms, with the exception of the unmodulated case, the UWB signal generator could not produce enough power to cause the receiver to break-lock with the satellite of interest. This is likely due to the lesser susceptibility of GPS C/A-code receivers to low duty cycle pulsed interference. In these cases, the highest attainable UWB generator power level was recorded and used as the interference threshold in the subsequent analyses. The results shown in the table are those obtained from the single-entry (one UWB transmitter-to-GPS receiver) interaction measurements. The 100 kHz UWB signal permutations were not considered in the aggregate measurements for two reasons. First, a computer simulation was performed to provide an insight into the likely number of 100 kHz PRF UWB signals that would have to be present to produce an equivalent received power at the GPS receiver for an aggregate effect to be observed. The results of the simulation indicated that it would take considerably more than the six UWB generators available to this effort to produce an aggregate effect to the GPS receiver under test for a 100 kHz PRF UWB signal. Second, it is likely that the most probable UWB applications for a 100 kHz PRF signal are for radar or imaging such as ground penetration and through the wall imaging. These types of applications are not expected to result in an extremely large proliferation of UWB devices in the same geographic area, and thus, an aggregate of a large number of these types of devices was deemed unlikely.

TABLE 4-1. UWB Interference Thresholds for C/A-Code Receiver (100 kHz PRF)

UWB Signal Permutation	Signal Description	Category of Interfering Signal	I_{meas} (dBm/20 MHz)	I_T (see Table 3-11)
No Mod; 100%gate	Constant PRF; 100% on-time	pulse-like	-70.0	-112.6 dBW/MHz
No Mod; 20% gate	Constant PRF; 20% on-time	pulse-like	-57.0 [a]	-106.5 dBW/MHz [b]
OOK; 100% gate	On Off Keying Modulated; 100% on-time	pulse-like	-60.0 [a]	-102.6 dBW/MHz [b]
OOK; 20% gate	On-Off Keying Modulated; 20% on-time	pulse-like	-59.5 [a]	-109.4 dBW/MHz [b]
50%abs; 100% gate	50% Absolute Dithered; 100% on-time	pulse-like	-57.0 [a]	-100.0 dBW/MHz [b]
50%abs; 20% gate	50% Absolute Dithered; 20% on-time	pulse-like	-56.5 [a]	-107.0 dBW/MHz [b]
2% rel; 100% gate	2% Relative Dithered; 100% on-time	pulse-like	-57.0 [a]	-100.0 dBW/MHz [b]
2% rel; 20% gate	2% Relative Dithered; 20% on-time	pulse-like	-57.0 [a]	-107.0 dBW/MHz [b]

Notes:
[a] Interference threshold not reached at maximum available UWB generator power.
[b] I_T computed from maximum UWB generator power reading.

Table 4-2 lists the measured interference thresholds for the eight UWB signal permutations utilizing a PRF of 1 MHz. At the 1 MHz PRF, CW-like degradation effects are first observed to the GPS receiver at levels commensurate with the published interference protection limits. This occurs for the case of the unmodulated UWB signal shown in the table. For the remaining seven UWB signal permutations, the interference effects are classified as either pulse-like or noise-like, when considered in the single-entry measurements. However, based on the results of the aggregate measurements, for those 1 MHz PRF UWB waveforms that were characterized as having a pulse-like interference effect to the GPS C/A-code receiver, a transition to noise-like interference effects occurs when as few as three signals are considered.

TABLE 4-2. UWB Interference Thresholds for C/A-Code Receiver (1 MHz PRF)

UWB Signal Permutation	Signal Description	Category of Interfering Signal	I_{meas} (dBm/20 MHz)	I_T (see Table 3-11)
No Mod; 100%gate	Constant PRF; 100% on-time	CW-like	-100.5	-143.7 dBW
No Mod; 20% gate	Constant PRF; 20% on-time	pulse-like [a]	-47.5 [b]	-97.6 dBW/MHz [c]
		noise-like [d]	-91.5	-134.5 dBW/MHz
OOK; 100% gate	On Off Keying Modulated; 100% on-time	pulse-like [a]	-78.0	-121.2 dBW/MHz
		noise like [d]	-91.5	-134.5 dBW/MHz
OOK; 20% gate	On-Off Keying Modulated; 20% on-time	pulse-like [a]	-51.0 [b]	-101.1 dBW/MHz [c]
		noise-like [d]	-91.5	-134.5 dBW/MHz
50%abs; 100% gate	50% Absolute Dithered; 100% on-time	pulse-like [a]	-70.0	-113.0 dBW/MHz
		noise-like [d]	-91.5	-134.5 dBW/MHz
50%abs; 20% gate	50% Absolute Dithering; 20% on-time	pulse-like [a]	-47.5 [b]	-97.5 dBW/MHz [c]
		noise-like [d]	-91.5	-134.5 dBW/MHz
2% rel; 100% gate	2% Relative Dithering; 100% on-time	pulse-like [a]	-88.0	-131.0 dBW/MHz
		noise-like [d]	-91.5	-134.5 dBW/MHz
2% rel; 20% gate	2% Relative Dithering; 20% on-time	pulse-like [a]	-47.0	-97.0 dBW/MHz
		noise-like [d]	-91.5	-134.5 dBW/MHz

Notes:
[a] Single-entry (one UWB transmitter-to-GPS receiver) interaction.
[b] Interference threshold not reached at maximum available UWB generator power.
[c] I_T computed from maximum available UWB generator power reading.
[d] Aggregate (multiple (≥3) UWB transmitters-to-GPS receiver) interaction, based on broad-band noise measurement.

Table 4-3 lists the measured interference thresholds for the eight UWB signal permutations considered that utilized a PRF of 5 MHz. As can be seen from this table, the CW-like impact to the GPS C/A-code receiver becomes more prevalent at the higher PRF. At this PRF, four of these eight UWB waveforms were classified as CW-like with respect to their impact to the GPS C/A-code receiver under test. The results presented in this table also indicate that the dithering techniques considered in this effort can be effective in improving the interference impact to the GPS C/A-code receiver. This is likely due to the spreading of the spectral lines from dithering the signal in the time domain, making it appear more noise-like in the frequency domain. For the two UWB waveforms examined that employed a combination of dithering and gating, the impact observed to the GPS C/A-code receiver in the single-entry case was characteristic of low-duty cycle pulsed interference. However, based on the results of the aggregate measurements, when a multiple of these UWB signals are considered with PRFs greater than 100 kHz, the duty cycle of the effective aggregate signal at the output of the GPS C/A-code receiver IF begins to transition to a noise-like effect, for which the C/A-code receiver shows a greater susceptibility.

TABLE 4-3. UWB Interference Thresholds for C/A-Code Receiver (5 MHz PRF)

UWB Signal Permutation	Signal Description	Category of Interfering Signal	I_{meas} (dBm/20 MHz)	I_T (see Table 3-11)
No Mod; 100%gate	Constant PRF; 100% on-time	CW-like	-108.5	-145.5 dBW
No Mod; 20% gate	Constant PRF; 20% on-time	CW-like	-94.5	-145.2 dBW
OOK; 100% gate	On-Off Keying Modulated; 100% on-time	CW-like	-104.5	-144.5 dBW
OOK; 20% gate	On-Off Keying Modulated; 20% on-time	CW-like	-90.5	-144.2 dBW
50%abs; 100% gate	50% Absolute Dithered; 100% on-time	noise-like	-94.0	-137.0 dBW/MHz
50%abs; 20% gate	50% Absolute Dithered; 20% on-time	pulse-like [a]	-55.0 [b]	-105.0 dBW/MHz [c]
		noise-like [d]	-91.5	-134.5 dBW/MHz
2% rel; 100% gate	2% Relative Dithered; 100% on-time	noise-like	-93.5	-136.5 dBW/MHz
2% rel; 20% gate	2% Relative Dithered; 20% on-time	pulse-like [a]	-39.0 [b]	-89.0 dBW/MHz [c]
		noise-like [d]	-91.5	-134.5 dBW/MHz

Notes:
[a] Single-entry (one UWB transmitter-to-GPS receiver) interaction.
[b] Interference threshold not reached at maximum available UWB generator power.
[c] I_T computed from maximum available UWB generator power reading.
[d] Aggregate (multiple (≥3) UWB transmitters-to-GPS receiver) interaction, based on broad-band noise measurement.

Table 4-4 lists the measured interference thresholds for the eight UWB waveforms using a PRF of 20 MHz. The results are similar to those of the 5 MHz PRF UWB signals. Four of the eight UWB waveforms examined cause a CW-like interference effect to the GPS C/A-code receiver. Dithering of the signal using the techniques considered in this assessment appears to continue to be effective in spreading the spectral lines and thus causing an effect to the GPS C/A-code receiver more characteristic of pulse-like interference when employed in combination with gating (in the single-entry interaction), or noise-like when gating is not used. For those UWB waveforms that were classified as pulse-like, the aggregate measurement results suggest that when three or more of these UWB signals are considered, the effective pulse duty cycle increases to a point where the interference effect to the GPS receiver transitions to that of noise-like interference.

TABLE 4-4. UWB Interference Thresholds for C/A-Code Receiver (20 MHz PRF)

UWB Signal Permutation	Signal Description	Category of Interfering Signal	I_{meas} (dBm/20 MHz)	I_T (see Table 3-11)
No Mod; 100%gate	Constant PRF; 100% on-time	CW-like	-115.0	-145.0 dBW
No Mod; 20% gate	Constant PRF; 20% on-time	CW-like	-102.0	-145.8 dBW
OOK; 100% gate	On Off Keying Modulated; 100% on-time	CW-like	-111.5	-144.5 dBW
OOK; 20% gate	On-Off Keying Modulated; 20% on-time	CW-like	-99.5	-146.3 dBW
50%abs; 100% gate	50% Absolute Dithered; 100% on-time	noise-like	-95.0	-138.0 dBW/MHz
50%abs; 20% gate	50% Absolute Dithered; 20% on-time	pulse-like [a]	-85.0	-135.0 dBW/MHz [c]
		noise-like [d]	-91.5	-134.5 dBW/MHz
2% rel; 100% gate	2% Relative Dithered; 100% on-time	noise-like	-93.0	-136.0 dBW/MHz
2% rel; 20% gate	2% Relative Dithered; 20% on-time	pulse-like [a]	-83.0	-133 dBW/MHz [c]
		noise-like [d]	-91.5	-134.5 dBW/MHz

Notes: [a] Single-entry (one UWB transmitter-to-GPS receiver) interaction.
[b] Interference threshold not reached at maximum available UWB generator power.
[c] I_T computed from maximum available UWB generator power reading.
[d] Aggregate (multiple (≥ 3) UWB transmitters-to-GPS receiver) interaction, based on broad-band noise measurement.

4.1.2 Semi-Codeless GPS Receiver

In this section, the results from the measurement of the susceptibility of a GPS semi-codeless receiver to the set of UWB signal permutations are presented and discussed.

A semi-codeless GPS receiver processes the transmitted GPS P-code signals at the L1 (1575.42 MHz) and L2 (1227.60 MHz) frequencies to provide an accurate measure of the ionospheric delay of the signal received from the satellite. The GPS P-code signal employs a longer pseudorandom code as compared with the Gold code used with the GPS C/A signal. As a result of the use of this longer code, the P-code signal has essentially no spectral line content within its power spectral envelope. Thus, it was anticipated that the CW-like interference mechanism to which the GPS C/A-code tracking receiver is most susceptible, would not be an interference mechanism of concern to the semi-codeless GPS receiver. This premise was borne out in the measurement results for this receiver when an unmodulated 20 MHz PRF and an OOK modulated UWB signal (known from the APDs to be CW-like) were introduced. Therefore, having verified through measurement that spectral line content in the UWB signal is not of particular concern to this GPS receiver architecture, and in an effort to expedite the measurement effort, NTIA reduced the number of signal permutations examined, by eliminating those UWB signal permutations known to produce CW-like signals for the 1 MHz and 5 MHz PRFs. The full complement of UWB signal permutations was retained for the 100 kHz and the 20 MHz PRFs.

Tables 4-5 through 4-8 list the measured semi-codeless receiver interference thresholds for each of the eight UWB waveforms produced, grouped according to PRF.

The results presented in Table 4-5 indicate that the semi-codeless receiver shows a tolerance to low duty cycle pulsed interference, similar to that of the C/A-code tracking receiver. In four of the eight 100 kHz PRF UWB waveforms, the interference threshold was not reached at the maximum output power available from the UWB generator. For the remaining four 100 kHz PRF UWB waveforms, the interference threshold was realized, but at relatively high UWB power levels.

The results presented in Tables 4-6 through 4-8 list the measured interference thresholds at the input to the semi-codeless GPS receiver when subjected to the UWB signal permutations at PRFs of 1, 5, and 20 MHz. These results indicate that the UWB waveforms examined with a PRF greater than 100 kHz, impact the GPS semi-codeless receiver similar to broadband noise-like interference. The results presented in the table also support the observation that this receiver architecture is more sensitive to broadband noise-like interference than the C/A-code tracking GPS receiver. This increased sensitivity to noise-like interference was attributed to the following two factors. The GPS signal level provided to this receiver was 3 dB lower than what was provided in the measurement of the C/A-code receiver, in order to represent the lower signal power of the L1 and L2 P-code signals. Also, semi-codeless processing is inherently noisy and thus is likely more sensitive to an increase in additive noise. It should also be noted that these receiver architectures are not completely independent from C/A-code operation. Not only do they rely on the C/A-code for initial acquisition, they also typically default to C/A-code operations if the P-code signals become unavailable.

TABLE 4-5. UWB Interference Thresholds for Semi-Codeless Receiver (100 kHz PRF)

UWB Signal Permutation	Signal Description	Category of Interfering Signal	I_{meas} (dBm/20 MHz)	I_T (dBW/MHz)
No Mod; 100%gate	Constant PRF; 100% on-time	pulse-like	-75.0	-118.0
No Mod; 20% gate	Constant PRF; 20% on-time	pulse-like	-66.0 [a]	-116.5
OOK; 100% gate	On Off Keying Modulated; 100% on-time	pulse-like	-68.0 [a]	-112.0
OOK; 20% gate	On-Off Keying Modulated; 20% on-time	pulse-like	-68.0 [a]	-118.5
50%abs; 100% gate	50% Absolute Dithered; 100% on-time	pulse-like	-78.0	-121.0
50%abs; 20% gate	50% Absolute Dithered; 20% on-time	pulse-like	-66.0[a]	-116.0
2% rel; 100% gate	2% Relative Dithered; 100% on-time	pulse-like	-76.0	-119.0
2% rel; 20% gate	2% Relative Dithered; 20% on-time	noise-like	-88.0	-138.0

Notes: [a] Interference threshold not reached at maximum available UWB generator power.

TABLE 4-6. UWB Interference Thresholds for Semi-Codeless Receiver (1 MHz PRF)

UWB Signal Permutation	Signal Description	Category of Interfering Signal	I_{meas} (dBm/20 MHz)	I_T (dBW/MHz)
50%abs; 100% gate	50% Absolute Dithered; 100% on-time	noise-like	-108.0	-151.0
50%abs; 20% gate	50% Absolute Dithering; 20% on-time	noise-like	-82.0	-132.0
2% rel; 100% gate	2% Relative Dithering; 100% on-time	noise-like	-106.0	-149.0
2% rel; 20% gate	2% Relative Dithering; 20% on-time	noise-like	-84.0	-134.0

TABLE 4-7. UWB Interference Thresholds for Semi-Codeless Receiver (5 MHz PRF)

UWB Signal Permutation	Signal Description	Category of Interfering Signal	I_{meas} (dBm/20 MHz)	I_T (dBW/MHz)
50%abs; 100% gate	50% Absolute Dithered; 100% on-time	noise-like	-108.0	-151.0
50%abs; 20% gate	50% Absolute Dithered; 20% on-time	noise-like	-101.0	-151.0
2% rel; 100% gate	2% Relative Dithered; 100% on-time	noise-like	-106.0	-149.0
2% rel; 20% gate	2% Relative Dithered; 20% on-time	noise-like	-92.5	-142.5

TABLE 4-8. UWB Interference Thresholds for Semi-Codeless Receiver (20 MHz PRF)

UWB Signal Permutation	Signal Description	Category of Interfering Signal	I_{meas} (dBm/20 MHz)	I_T (dBW/MHz)
No Mod; 100%gate	Constant PRF; 100% on-time	noise-like	-102.0	-145.0
No Mod; 20% gate	Constant PRF; 20% on-time	noise-like	-98.0	-148.0
OOK; 100% gate	On Off Keying Modulated; 100% on-time	noise-like	-94.0	-137.0
OOK; 20 % gate	On-Off Keying Modulated; 20% on-time	noise-like	-96.0	-146.0
50%abs; 100% gate	50% Absolute Dithered; 100% on-time	noise-like	-106.5	-149.5
50%abs; 20% gate	50% Absolute Dithered; Gated (20% on-time)	noise-like	-98.0	-148.0
2% rel; 100% gate	2% Relative Dithered; 100% on-time	noise-like	-106.5	-149.5
2% rel; 20% gate	2% Relative Dithered; 20% on-time	noise-like	-93.5	-143.5

4.1.3 Measurement Conclusions

The measurements indicate that both the C/A-code tracking GPS receiver and the semi-codeless GPS receiver demonstrate a tolerance to all of the UWB signal permutations examined with a PRF of 100 kHz. For the scenarios considered in this assessment, aggregate effects were deemed not to be a concern with respect to those UWB waveforms with a PRF of 100 kHz. When the PRF was increased to 1 MHz, the C/A-code receiver began to show CW-like interference susceptibility to the unmodulated UWB signal permutations at low power levels. When the PRF was increased to 5 MHz and then to 20 MHz, CW-like interference effects to the C/A-code receiver became more prevalent.

These measurements also show that dithering of the UWB pulses in the time domain, using the techniques considered in this assessment, can be effective in spreading the spectral lines in the frequency domain, making the effective signal appear more noise-like. The GPS C/A-code receiver showed approximately 10 dB less sensitivity to these noise-like UWB signals. For PRFs above 100 kHz, a few of the UWB waveforms caused an effect similar to low duty cycle pulsed interference, to which the GPS C/A-code receiver is relatively tolerant. However, the multiple-entry (aggregate) measurements indicate that this advantage is lost when a multiple of as few as three of these UWB signals are considered in aggregation. The aggregate measurements also tend to verify that when multiple noise-like UWB signals are considered, the effective aggregate signal level in the GPS receiver IF is determined by adding the average power of each of the interfering signals.

The semi-codeless receiver measured in this assessment showed a susceptibility similar to what would be expected from broadband noise-like interference for all of the UWB signal permutations employing PRFs of greater than 100 kHz. The semi-codeless GPS receiver was also observed to be more susceptible than the C/A-code receiver to noise-like interference.

The results of the radiated measurements verified that only the GPS antenna gain in the direction of the UWB transmitting device need be considered in the calculating the EIRP from the measured interference thresholds. These results demonstrate that the UWB signals provided to the GPS receivers via a conducted path were consistent with what the GPS receiver would see when the signals were received by a GPS antenna and preamplifier via a radiated path as will be the case in actual operational conditions.

The measurements performed for this assessment assumed GPS operation in the tracking mode of operation (i.e., the GPS receiver was allowed to acquire the satellites necessary to obtain a navigation solution before UWB interference was introduced). The initial (cold-start) acquisition mode of GPS receiver operation is known to be more sensitive to interference than the tracking mode. However, measurements of GPS receiver susceptibility to interference when operating in the cold-start acquisition mode are difficult to perform. Within the RTCA and ITU-R working groups, mentioned previously in this report, the initial acquisition mode of operation is accounted for by reducing the tracking mode interference protection levels by 6 dB.

Additionally, for some of the UWB signal permutations considered in this assessment, a statistically meaningful measurement of the preferred reacquisition interference threshold could not be made. The reacquisition threshold is the UWB power level that results in an abrupt increase in reacquisition time. For these cases, it was necessary to utilize the UWB power level resulting in break-lock as a threshold. A break-lock condition occurs when a GPS receiver can no longer adequately determine the pseudorange for a given satellite because of interference. This was particularly true for those UWB signals that caused a CW-like interference effect in the C/A-code GPS receiver. This does not constitute an endorsement of the use of break-lock as the preferred interference threshold on which to establish final rules for UWB operation.

4.2 SUMMARY OF ANALYSIS FINDINGS

There are literally hundreds of applications of GPS, with additional applications being defined on a seemingly daily basis. To attempt to define a unique operational scenario for each of these applications would be a massive, if not impossible undertaking. Therefore, within the context of this assessment, an effort was made to define a set of operational scenarios, in conjunction with the GPS user and UWB communities, that could be used to bound the possible GPS applications.

The two main parameters needed to perform the analyses, which are defined by the operational scenarios, are the likely separation distance between a GPS receiver and UWB transmitter, and the likely orientation of the antennas with respect to one another. The likely separation distance is used to assess the propagation path loss, to formulate an assumption as to the likelihood of multiple UWB devices in view of the GPS receiver, and to determine the interference allotment for UWB devices within the constraints defined by the application. The likely antenna orientation is used to estimate the antenna gain realized by the GPS antenna in the direction of the UWB devices.

In the public meetings that were held, a set of operational scenarios were defined that NTIA accepts as bounding the parameters of interest. For example, the terrestrial scenarios involving the public safety use of GPS, define a minimum separation distance of 2 meters. The en-route aviation operational scenario defines a minimum separation distance of 1000 feet (approximately 300 meters). These two cases bound the distance separation of the remaining operational scenarios. Furthermore, it appears reasonable that these two scenarios will also bound operational scenarios not specifically considered within this effort, with respect to distance separation. Additionally, it is reasonable to assume that there will be a limited number of UWB devices operating at a distance of 2 meters from a GPS receiver, as defined by the terrestrial operational scenario discussed in Section 3. However, when the en-route aviation scenario is considered, a larger number of UWB devices can be in view from an aircraft at an altitude of 1000 feet. Therefore, it is believed that the operational scenarios considered also bound the GPS application space with respect to the potential aggregation of UWB devices.

In this analysis, NTIA determined the maximum allowable EIRP for the different UWB signal permutations, using the operational scenarios proposed in the public meetings. The results of the analysis are summarized in Tables 4-9 through 4-12. Each table corresponds to a UWB PRF examined in the analysis. The tables provide a description of the: operational scenario; UWB signal characteristics; GPS receiver architecture; interfering signal classification; interference threshold; and the computed values of maximum allowable EIRP. The values of maximum allowable EIRP shown in the Tables 4-9 through 4-12 are for a single UWB device, and represent the highest EIRP at which UWB devices can operate and still provide protection to the GPS receiver architecture under consideration for the conditions specified in the operational scenarios.

Tables 4-9 through 4-12 also include a comparison of the computed values of maximum allowable EIRP with the current Part 15 level of -71.3 dBW/MHz. When the interference effects are classified as pulse-like or noise-like, the values of maximum allowable EIRP can be directly compared to the current Part 15 level. When the interference effect is classified as being CW-like, the maximum allowable EIRP can be compared to the Part 15 level, if it is assumed that there is only a single spectral line in the measurement bandwidth. If the difference between the current Part 15 level and the computed maximum allowable EIRP is negative, no additional attenuation below the current Part 15 level is necessary to protect the GPS receiver architecture under consideration. If the difference is positive, this value specifies the additional attenuation below the current Part 15 level that is necessary to protect the GPS receiver architecture under consideration.

Table 4-9 summarizes the analysis results for UWB devices that operate with a PRF of 100 kHz. For the C/A-code receiver architecture, when the operational scenario includes either a single UWB device or a small number of UWB devices operating with a PRF of 100 kHz, the interference effect was categorized as being pulse-like. The computed values of maximum allowable EIRP range from -73.2 to -40.5 dBW/MHz depending upon the operational scenario under consideration. In the aviation (en-route navigation) operational scenarios, it is assumed that there is a large number of UWB devices present such that, independent of the individual UWB signal parameters, the interference effect can be classified as noise-like (i.e., central limit theorem). The computed values of maximum allowable EIRP are -76.6 dBW/MHz when all of the UWB devices were operating inside of a building and -85.6 dBW/MHz when all of the UWB devices were operating outside of a building.

In the surveying operational scenarios the semi-codeless receiver architecture was considered. As a result of the correlation process that uses the longer P-code signals, the interference effect was classified as noise-like. As shown in Table 4-9, the values of computed maximum allowable EIRP are -81.1 dBW/MHz and -81.2 dBW/MHz for single and multiple (as defined by the operational scenario) UWB device interactions respectively.

Table 4-10 summarizes the analysis results for UWB devices that operate with a PRF of 1 MHz. For the C/A-code receiver architecture, when the operational scenario includes either a single UWB device or a small number of UWB devices operating with a PRF of 1 MHz, the interference effect was classified as CW-like, pulse-like, or noise-like. This classification depends on the modulation and gating percentage employed. When the operational scenario considered a single UWB device employing 100% gating and no modulation, the interference effect was classified as CW-like. For all other signal permutations, the single entry UWB device interaction interference effect was classified as pulse-like. For the single UWB device operational scenario, the interference effect was classified as pulse-like, the maximum allowable EIRP is -91.6 dBW/MHz. When the interference effect was classified as CW-like, the computed values of maximum allowable EIRP range from -104.3 to -71.6 dBW, depending on the operational scenario under consideration. In the operational scenarios where multiple UWB device interactions were considered, the interference effect for 1 MHz, 100% gating, was still CW-like. However, for all other 1 MHz UWB signal permutations, the interference effect was classified as noise-like. When the multiple UWB device interaction interference effect was classified as noise-like, the computed values of maximum allowable EIRP range from -90.2 to -68.4 dBW/MHz, depending upon the operational scenario under consideration. In the aviation (en-route navigation) operational scenarios, there were a large number of UWB devices assumed to be present, therefore the interfering signal was classified as noise-like. The computed values of maximum allowable EIRP are -76.6 dBW/MHz when all of the UWB devices were operating inside of a building and -85.6 dBW/MHz when all of the UWB devices were operating outside of a building.

In the surveying operational scenarios, where the semi-codeless receiver architecture was analyzed, the interference effect was classified as noise-like. As shown in Table 4-10, the values of computed maximum allowable EIRP were -94.1 dBW/MHz and -94.2 dBW/MHz for single and multiple (as defined by the operational scenario) UWB device interactions respectively.

Table 4-11 summarizes the analysis results for UWB devices that operate with a PRF of 5 MHz. In the terrestrial operational scenario where a single UWB device is operating with a PRF of 5 MHz, the interference effect was classified as CW-like, pulse-like, or noise-like. This classification depends on the type of modulation and gating percentage that was employed. The computed values of maximum allowable EIRP for the different interfering signal classifications were: -106.1 dBW (CW-like), -65.6 dBW/MHz (pulse-like), and -97.6 dBW/MHz (noise-like). In the operational scenarios where a small number of UWB devices with a PRF of 5 MHz were operating, the interference effect was classified as either CW-like or noise-like. This classification depends on the type of modulation and gating percentage that was employed. When the interference effect was classified as being CW-like, the values of maximum allowable EIRP range from -95.2 to -73.4 dBW, depending on the operational scenario under consideration. When the interference effect was classified as noise-like, the values of maximum allowable EIRP range from -92.7 dBW/MHz to -70.9 dBW/MHz, depending on the operational scenario under consideration. In the aviation (en-route navigation) operational scenarios, there were a large number of UWB devices assumed to be present, therefore the interfering signal was classified as noise-like. The computed values of maximum allowable EIRP are -76.6 dBW/MHz when all of the UWB devices were operating inside of a building and -85.6 dBW/MHz when all of the UWB devices were operating outside of a building.

In the surveying operational scenarios, where the semi-codeless receiver architecture was considered, the interference effect was classified as being noise-like. As shown in Table 4-11, the values of computed maximum allowable EIRP were -94.1 dBW/MHz and -94.2 dBW/MHz for single and multiple (as defined by the operational scenario) UWB device interactions respectively.

Table 4-12 summarizes the analysis results for UWB devices that operate with a PRF of 20 MHz. In the terrestrial operational scenario where a single UWB device is operating with a PRF of 20 MHz, the interference effect was classified as CW-like, pulse-like, or noise-like. This classification depends on the type of modulation and gating percentage that was employed. The computed values of maximum allowable EIRP for the different interfering signal classifications were: -106.9 dBW (CW-like), -95.6 dBW/MHz (pulse-like), and -98.6 dBW/MHz (noise-like). In the operational scenarios where a small number of UWB devices with a PRF of 20 MHz are operating, the interference effect was classified as being either CW-like or noise-like. This classification depends on the type of modulation and gating percentage that was employed. When the interference effect was classified as CW-like, the values of maximum allowable EIRP range from -96 dBW to –74.2 dBW, depending on the operational scenario under consideration. When the interference effect was classified as being noise-like, the values of maximum allowable EIRP range from -93.7 to -71.9 dBW/MHz, depending on the operational scenario under consideration. In the aviation (en-route navigation) operational scenarios, there were a large number of UWB devices assumed to be present, and the interference effect was classified as being noise-like. The computed values of maximum allowable EIRP are -76.6 dBW/MHz when all of the UWB devices were operating inside of a building and -85.6 dBW/MHz when all of the UWB devices were operating outside of a building.

In the surveying operational scenarios, where the semi-codeless receiver architecture was considered, the interference effect was classified as being noise-like. As shown in Table 4-12, the values of computed maximum allowable EIRP were -92.6 dBW/MHz and -92.7 dBW/MHz for single and multiple (as defined by the operational scenario) UWB device interactions respectively.

Table 4-9. Summary of Analysis Results (PRF = 100 kHz)

Operational Scenario Description					UWB Signal Characteristics			GPS Receiver Architecture	Classification of Interfering Signal	Maximum Interference Threshold (dBW/MHz)	Maximum Allowable EIRP (dBW/MHz)	Comparison with the Current Part 15 Level (dB)
Application	UWB Single	UWB Multiple	UWB Indoor	UWB Outdoor	PRF (MHz)	Gating %	Mod.					
Terrestrial	X			X	0.1	100	None	C/A-code	Pulse-Like	-112.6	-73.2	1.9
Terrestrial		X	X		0.1	100	None	C/A-code	Pulse-Like	-112.6	-57.6	-13.7
Terrestrial		X		X	0.1	100	None	C/A-code	Pulse-Like	-112.6	-62.3	-9
Maritime		X	X		0.1	100	None	C/A-code	Pulse-Like	-112.6	-41.7	-29.6
Maritime		X		X	0.1	100	None	C/A-code	Pulse-Like	-112.6	-48.1	-23.2
Railway		X	X		0.1	100	None	C/A-code	Pulse-Like	-112.6	-56.3	-15
Railway		X		X	0.1	100	None	C/A-code	Pulse-Like	-112.6	-57.8	-13.5
Surveying	X			X	0.1	20	2% Rel.	Semi-Codeless	Noise-Like	-138	-81.1	9.8
Surveying		X		X	0.1	20	2% Rel.	Semi-Codeless	Noise-Like	-138	-81.2	9.9
Aviation-NPA		X		X	0.1	100	None	C/A-code	Pulse-Like	-112.6	-52.9	-18.4
Aviation-ER		X	X		Note 1	Note 1	Note 1	C/A-code	Noise-Like	-134.8	-76.6[2]	5.3
Aviation-ER		X		X	Note 1	Note 1	Note 1	C/A-code	Noise-Like	-134.8	-85.6[2]	14.3

Notes: En-Route Navigation (ER), Non-Precision Approach (NPA)
1. In this operational scenario, it is assumed that there is a large enough number of UWB devices such that independent of the individual UWB signal parameters, the aggregate effect causes noise-like interference.
2. This maximum allowable EIRP is based on a density of 200 UWB devices per square kilometer transmitting simultaneously.

Table 4-10. Summary of Analysis Results (PRF = 1 MHz)

Operational Scenario Description					UWB Signal Characteristics			GPS Receiver Architecture	Classification of Interfering Signal	Maximum Interference Threshold[1]	Maximum Allowable EIRP[1]	Comparison with the Current Part 15 Level (dB)
Application	UWB Single	UWB Multiple	UWB Indoor	UWB Outdoor	PRF (MHz)	Gating %	Mod.					
Terrestrial	X			X	1	100	None	C/A-code	CW-Like	-143.7	-104.3	33
Terrestrial	X			X	1	100	2% Rel.	C/A-code	Pulse-Like	-131	-91.6	20.3
Terrestrial		X	X		1	100	None	C/A-code	CW-Like	-143.7	-88.7	17.4
Terrestrial		X	X		1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-85.5	14.2
Terrestrial		X		X	1	100	None	C/A-code	CW-Like	-143.7	-93.4	22.1
Terrestrial		X		X	1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-90.2	18.9
Maritime		X	X		1	100	None	C/A-code	CW-Like	-143.7	-72.8	1.5
Maritime		X	X		1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-69.6	-1.7
Maritime		X		X	1	100	None	C/A-code	CW-Like	-143.7	-79.2	7.9
Maritime		X		X	1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-76	4.7
Railway		X	X		1	100	None	C/A-code	CW-Like	-143.7	-87.4	16.1
Railway		X	X		1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-83	11.7
Railway		X		X	1	100	None	C/A-code	CW-Like	-143.7	-88.9	17.6
Railway		X		X	1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-84.5	13.2
Surveying	X			X	1	100	50% Abs.	Semi-Codeless	Noise-Like	-151	-94.1	22.8
Surveying		X		X	1	100	50% Abs.	Semi-Codeless	Noise-Like	-151	-94.2	22.9
Aviation-NPA		X		X	1	100	None	C/A-code	CW-Like	-143.7	-84	12.7
Aviation-NPA		X		X	1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-80.8	9.5
Aviation-ER		X	X		Note 2	Note 2	Note 2	C/A-code	Noise-Like	-134.8	-76.6[3]	5.3
Aviation-ER		X		X	Note 2	Note 2	Note 2	C/A-code	Noise-Like	-134.8	-85.6[3]	14.3

Notes: En-Route Navigation (ER), Non-Precision Approach (NPA)
1. When the interference effect has been classified as pulse-like or noise-like, the value is expressed in units of dBW/MHz. The value is expressed in units of dBW when the interference effect has been classified as being CW-like.
2. In this operational scenario, it is assumed that there is a large enough number of UWB devices, such that independent of the individual UWB signal parameters the aggregate effect causes noise-like interference.
3. This maximum allowable EIRP is based on a density of 200 UWB devices per square kilometer transmitting simultaneously.

Table 4-11. Summary of Analysis Results (PRF = 5 MHz)

Operational Scenario Description					UWB Signal Characteristics			GPS Receiver Architecture	Classification of Interfering Signal	Maximum Interference Threshold[1]	Maximum Allowable EIRP[1]	Comparison with the Current Part 15 Level (dB)
Application	UWB Single	UWB Multiple	UWB Indoor	UWB Outdoor	PRF (MHz)	Gating %	Mod.					
Terrestrial	X			X	5	100	None	C/A-code	CW-Like	-145.5	-106.1	34.8
Terrestrial	X			X	5	20	50% Abs.	C/A-code	Pulse-Like	-105	-65.6	-5.7
Terrestrial	X			X	5	100	50% Abs.	C/A-code	Noise-Like	-137	-97.6	26.3
Terrestrial		X	X		5	100	None	C/A-code	CW-Like	-145.5	-90.5	19.2
Terrestrial		X	X		5	100	50% Abs.	C/A-code	Noise-Like	-137	-88	16.7
Terrestrial		X		X	5	100	None	C/A-code	CW-Like	-145.5	-95.2	23.9
Terrestrial		X		X	5	100	50% Abs.	C/A-code	Noise-Like	-137	-92.7	21.4
Maritime		X	X		5	100	None	C/A-code	CW-Like	-145.5	-74.6	3.3
Maritime		X	X		5	100	50% Abs.	C/A-code	Noise-Like	-137	-72.1	0.8
Maritime		X		X	5	100	None	C/A-code	CW-Like	-145.5	-81	9.7
Maritime		X		X	5	100	50% Abs.	C/A-code	Noise-Like	-137	-78.5	7.2
Railway		X	X		5	100	None	C/A-code	CW-Like	-145.5	-89.2	17.9
Railway		X	X		5	100	50% Abs.	C/A-code	Noise-Like	-137	-85.5	14.2
Railway		X		X	5	100	None	C/A-code	CW-Like	-145.5	-90.7	19.4
Railway		X		X	5	100	50% Abs.	C/A-code	Noise-Like	-137	-87	15.7
Surveying	X			X	5	20 & 100	50% Abs.	Semi-Codeless	Noise-Like	-151	-94.1	22.8
Surveying		X		X	5	20 & 100	50% Abs.	Semi-Codeless	Noise-Like	-151	-94.2	22.9
Aviation-NPA		X		X	5	100	None	C/A-code	CW-Like	-145.5	-85.8	14.5
Aviation-NPA		X		X	5	100	50% Abs.	C/A-code	Noise-Like	-137	-83.3	12
Aviation-ER		X	X		Note 2	Note 2	Note 2	C/A-code	Noise-Like	-134.8	-76.6[3]	5.3
Aviation-ER		X		X	Note 2	Note 2	Note 2	C/A-code	Noise-Like	-134.8	-85.6[3]	14.3

Notes: En-Route Navigation (ER), Non-Precision Approach (NPA)

1. When the interference effect has been classified as pulse-like or noise-like, the value is expressed in units of dBW/MHz. The value is expressed in units of dBW when the interference effect has been classified as CW-like.
2. In this operational scenario, it is assumed that there is a large enough number of UWB devices, such that independent of the individual UWB signal parameters the aggregate effect causes noise-like interference.
3. This maximum allowable EIRP is based on a density of 200 UWB devices per square kilometer transmitting simultaneously.

Table 4-12. Summary of Analysis Results (PRF = 20 MHz)

Operational Scenario Description					UWB Signal Characteristics			GPS Receiver Architecture	Classification of Interfering Signal	Maximum Interference Threshold[1]	Maximum Allowable EIRP[1]	Comparison with the Current Part 15 Level (dB)
Application	UWB Single	UWB Multiple	UWB Indoor	UWB Outdoor	PRF (MHz)	Gating %	Mod.					
Terrestrial	X			X	20	20	OOK	C/A-code	CW-Like	-146.3	-106.9	35.6
Terrestrial	X			X	20	20	50% Abs.	C/A-code	Pulse-Like	-135	-95.6	24.3
Terrestrial	X			X	20	100	50% Abs.	C/A-code	Noise-Like	-138	-98.6	27.3
Terrestrial		X	X		20	20	OOK	C/A-code	CW-Like	-146.3	-91.3	20
Terrestrial		X	X		20	100	50% Abs.	C/A-code	Noise-Like	-138	-89	17.7
Terrestrial		X		X	20	20	OOK	C/A-code	CW-Like	-146.3	-96	24.7
Terrestrial		X		X	20	100	50% Abs.	C/A-code	Noise-Like	-138	-93.7	22.4
Maritime		X	X		20	20	OOK	C/A-code	CW-Like	-145	-75.4	4.1
Maritime		X	X		5	100	50% Abs.	C/A-code	Noise-Like	-138	-73.1	1.8
Maritime		X		X	20	20	OOK	C/A-code	CW-Like	-145	-81.8	10.5
Maritime		X		X	20	100	50% Abs.	C/A-code	Noise-Like	-138	-79.5	8.2
Railway		X	X		20	20	OOK	C/A-code	CW-Like	-145	-90	18.7
Railway		X	X		20	100	50% Abs.	C/A-code	Noise-Like	-138	-86.5	15.2
Railway		X		X	20	20	OOK	C/A-code	CW-Like	-145	-91.5	20.2
Railway		X		X	20	100	50% Abs.	C/A-code	Noise-Like	-138	-88	16.7
Surveying	X			X	20	100	50% Abs. & 2% Rel.	Semi-Codeless	Noise-Like	-149.5	-92.6	21.3
Surveying		X		X	20	100	50% Abs. & 2% Rel.	Semi-Codeless	Noise-Like	-149.5	-92.7	21.4
Aviation-NPA		X		X	20	20	OOK	C/A-code	CW-Like	-145	-86.6	15.3
Aviation-NPA		X		X	20	100	50% Abs.	C/A-code	Noise-Like	-138	-84.3	13
Aviation-ER		X	X		Note 2	Note 2	Note 2	C/A-code	Noise-Like	-134.8	-76.6[3]	5.3
Aviation-ER		X		X	Note 2	Note 2	Note 2	C/A-code	Noise-Like	-134.8	-85.6[3]	14.3

Notes: En-Route Navigation (ER), Non-Precision Approach (NPA)

1. When the interference effect has been classified as pulse-like or noise-like, the value is expressed in units of dBW/MHz. The value is expressed in units of dBW when the interference effect has been classified as being CW-like.
2. In this operational scenario, it is assumed that there is a large enough number of UWB devices, such that independent of the individual UWB signal parameters the aggregate effect causes noise-like interference.
3. This maximum allowable EIRP is based on a density of 200 UWB devices per square kilometer transmitting simultaneously.

Certain observations were made based on a review of the last column in Tables 4-9 through 4-12. This column lists the difference between the current Part 15 level of -71.3 dBW/MHz (considered as an average power limit) and the computed maximum allowable EIRP values. A positive number in the last column indicates that the computed allowable EIRP is less than the current Part 15 level.

An examination of Table 4-9 (PRF = 100 kHz) shows the effect of the C/A-code signal process being fairly robust to low-duty cycle pulsed interference. The worse-case comparison to the current Part 15 level for the C/A-code architecture is the aviation en-route navigation operational scenario with UWB devices operating outdoors (14.3 dB below the Part 15 level). This is based on a density of active UWB devices of 200/km^2. If one considers the use of 100 kHz PRF could be of interest in only UWB device applications such as ground penetrating radars and through-the-wall imaging radars, the projected density of UWB devices may not be high, as the use of such devices could be limited. If, for example, the density of UWB devices operating at 100 kHz is 20/km^2, the maximum allowable EIRP would increase by 10 dB. That is the comparison to the Part 15 level would be 4.3 dB for the aviation en-route navigation operational scenario with UWB devices operating outdoors and a limit of 10 dB below the current Part 15 level could be appropriate for all C/A-code uses at 100 kHz.

The 100 kHz PRF also shows the effect of the use of semi-codeless receiver architecture in the surveying operational scenario. It should be noted that surveyors are not the only users of GPS receiver employing semi-codeless techniques. The result of the use of semi-codeless receivers is extremely beneficial in applications for GPS reference stations, high accuracy distance and location measurements (i.e., low dynamic applications). However, the semi-codeless process is inherently more susceptible to interference that is classified as pulsed-like or noise-like, than the C/A-code process (the signal processing is not usually as effective and the P-code signals are not as strong as the C/A-code signal). The results of the analysis for the surveying operational scenario shows the UWB signals would need to be 10 dB below the current Part 15 level to protect the semi-codeless receiver architecture.

Tables 2 through 4 (UWB waveforms with PRFs of 1, 5, and 20 MHz) show that the maximum allowable EIRP level necessary to satisfy the measured GPS performance criteria must be less than the current Part 15 level for most of the operational scenarios considered. Those interactions that involve operational scenario/UWB signal parameter combinations that require an attenuation of 20 dB or more below the Part 15 level were selected for closer inspection. This examination indicates that in most of these cases, the interactions involve: 1) UWB waveforms that were deemed CW-like in their interference effect to the GPS C/A-code receiver architecture, for which the measurements indicate a greater interference susceptibility; 2) applications using semi-codeless receivers, which were determined from the measurements to be more susceptible to UWB waveforms classified as noise-like or pulse-like interference; or 3) operational scenarios in which the UWB transmitter is considered to be operating at a close distance (within several meters) relative to the GPS receiver. This data suggests that if the spectral line content of the UWB waveforms could be removed from consideration, perhaps through regulation, there still remains a number of interactions involving noise-like UWB waveforms at these PRFs for which the EIRP levels would have to be attenuated to levels up to 27 dB below the current Part 15 level.

As shown in Tables 4-9 through 4-12, the results of the analysis indicate that the values of maximum allowable EIRP that are necessary to preclude interference to GPS receivers is highly dependent on the parameters of the UWB signal. This is consistent with the findings from the measurement effort where the performance of the GPS receiver in the presence of a UWB signal was also found to be highly dependent on the UWB signal structure. Figures 4-2 through 4-5 display computed maximum allowable EIRP levels for those UWB signal permutations that were classified within this study as pulse-like, noise-like, and CW-like with respect to their interference effects on the GPS C/A-code receiver. The values reported in these charts represent the maximum allowable EIRP level determined from an analysis of each UWB signal permutation in potential interactions with the GPS C/A-code receiver that were defined by all of the operational scenarios considered in the study

For the operational scenarios that considered multiple UWB devices, Figure 4-2 displays the range maximum allowable EIRP for the UWB signal structures that were classified within this study as pulse-like. Figure 4-4 presents the range of maximum allowable EIRP levels for those UWB waveforms that were classified as noise-like when considered in the analysis based on the operational scenarios. Figure 4-5 presents the range of maximum allowable EIRP levels for those UWB signals that were classified as CW-like in their effects on the GPS C/A-code receiver examined in this study. The labels on the y-axis in Figures 4-2 through 4-5 identify the various UWB signal structures in terms of PRF, percent gating, and type of modulation. For example, a UWB signal structure with a PRF of 100 kHz, 100% gating, and no modulation will have a y-axis label of: 100 kHz, 100%, None.

Figure 4-3 shows those pulse-like interference cases for which a range of EIRP values was not determined in the analysis. These cases involve UWB parameters that cause pulse-like interference in the operational scenario that considered a single UWB device, but result in noise-like interference in the operational scenarios that considered multiple UWB devices. For the C/A code receiver architecture, there was only one scenario considered in the analysis (Single UWB Device Terrestrial Operational Scenario) that involved a single UWB device. Thus only a single EIRP value is shown in Figure 4-3.

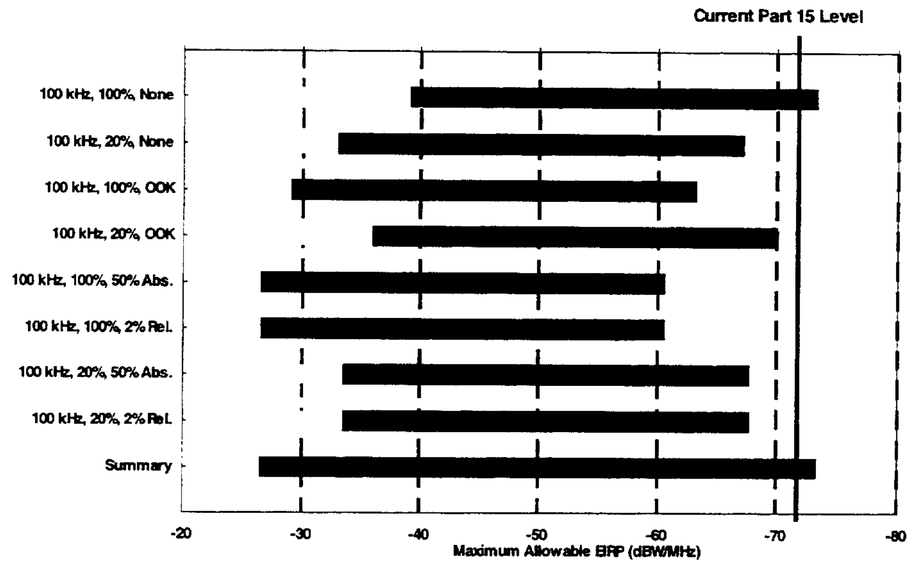

Figure 4-2. Range of Maximum Allowable EIRP for Pulse-Like UWB Signal Structures for the C/A-code Receiver Architecture (Multiple UWB Device Operational Scenarios)

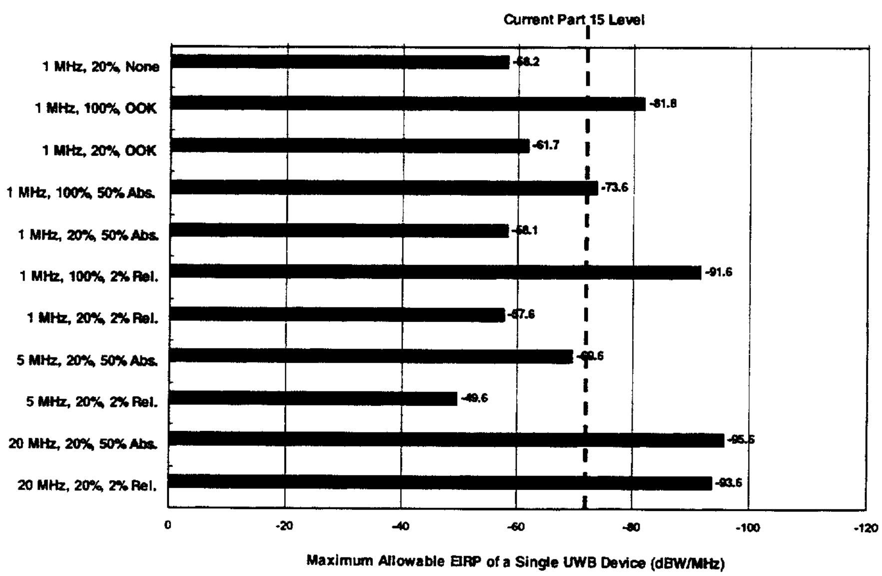

Figure 4-3. Maximum Allowable EIRP for Pulse-Like UWB Signal Structures for the C/A-code Receiver Architecture (Single UWB Device Operational Scenario)

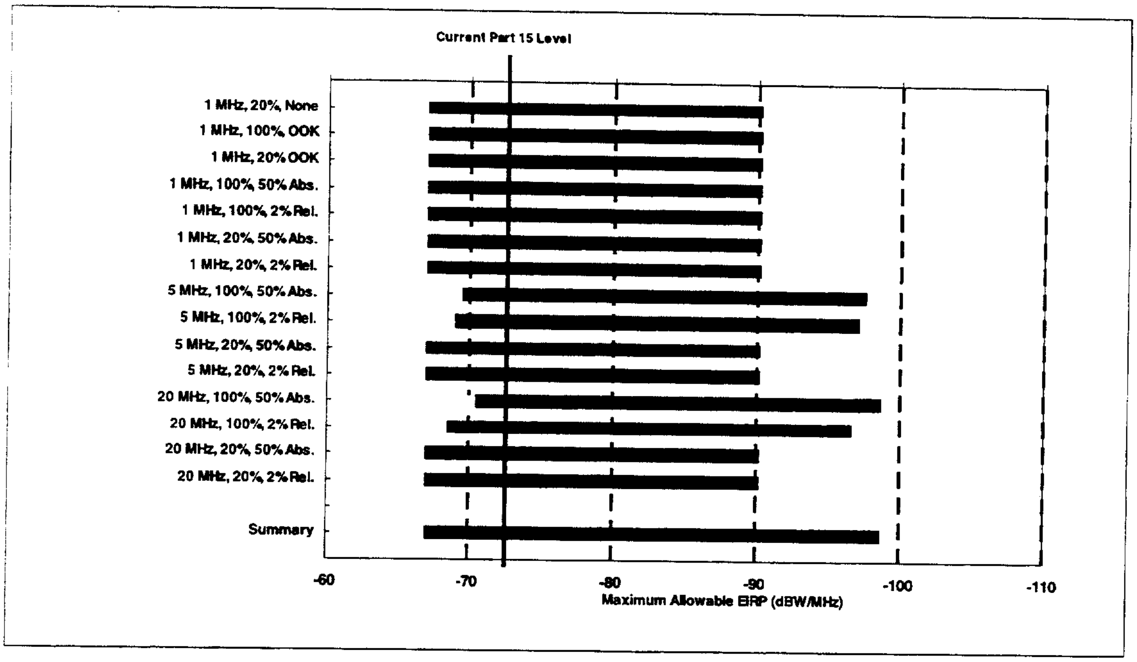

Figure 4-4. Range of Maximum Allowable EIRP for Noise-Like UWB Signal Structures for the C/A-code Receiver Architecture (Multiple UWB Device Operational Scenarios)

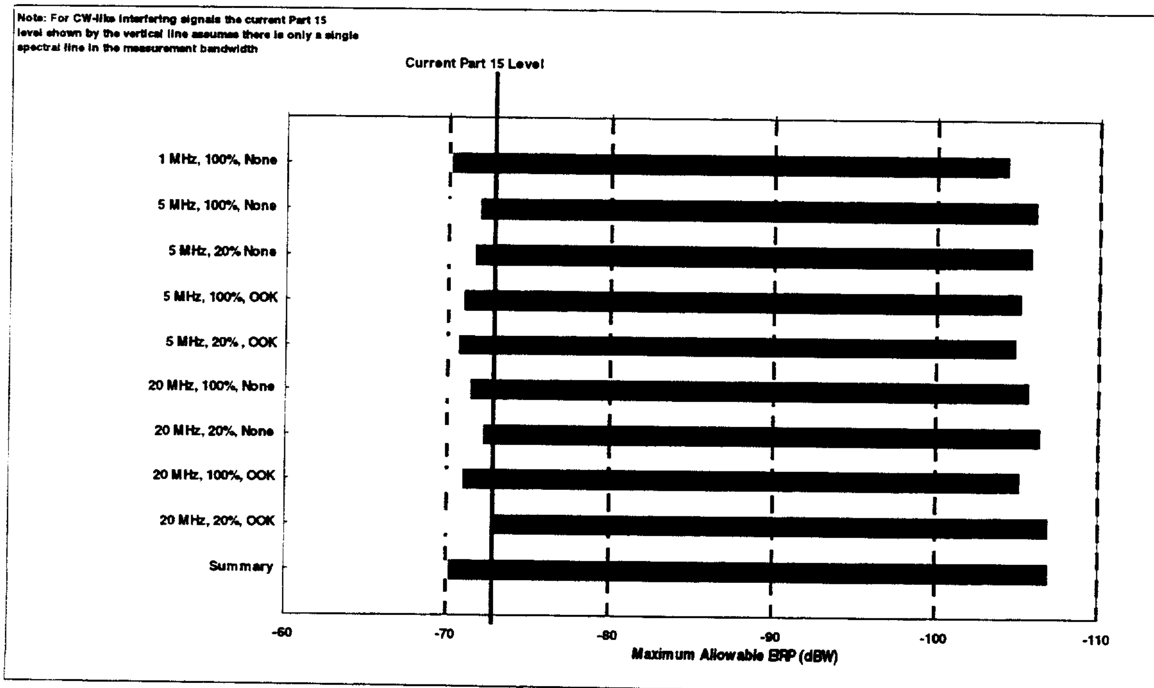

Figure 4-5. Range of Maximum Allowable EIRP for CW-Like UWB Signal Structures for the C/A-code Receiver Architecture (Multiple UWB Device Operational Scenarios)