4. MEASUREMENT RESULTS

The purpose of this section is to describe the tabular and graphical compilation of the measurements results and, in turn, to summarize. Conclusions are provided in the subsequent section.

4.1 Description of Compiled Measurement Results

The powers of the desired signals at MAPL (P_{REF}) for Receiver A (P25 mode), Receiver B (P25 mode), and Receiver B (analog mode) are −121 dBm, −117 dBm, and −119 dBm respectively. Table 4.1 shows the in-band interference rejection for receiver A (P25 mode) and receiver B (P25 and analog modes) when subjected to the various UWB signals, Gaussian noise, and CW signals – all powers measured in a 1-MHz bandwidth. Figure 4.1 shows the same data in a graphical form. Lower interference rejection values indicate that the interference source is less harmful. Thus, these data show that, when using the 1-MBPD method of measurement, Gaussian noise at a -12 dB rejection value is more benign than a CW signal which has a 6 or 7 dB rejection value. While the labels show signals with spectral lines to be “aligned” or “offset” (as described in Section 3.1.2), this only applies to the receivers in P25 mode and does not apply to the analog case. As mentioned in Section 3.1.2, three additional measurements were added to Receiver B as the measurements were in progress, and therefore are not included in the results for Receiver A; this is denoted by dashed lines in Table 4.1.

Table 4.1. In-band Interference Rejection (P_{REF} - P_I) in dB

Signal Type	Receiver		
	Receiver A - P25 Mode	Receiver B - P25 Mode	Receiver B - Analog Mode
Gaussian Noise	-12	-13	-15
CW, Aligned	7	6	3
CW, Offset	6	7	N/A
UWB, 100-kHz PRF, UPS, Non-gated, Aligned	-3	-5	-6
UWB, 100-kHz PRF, UPS, Non-gated, Offset	-4	-5	N/A
UWB, 100-kHz PRF, UPS, Gated, Aligned	-----	-10	-10
UWB, 100-kHz PRF, UPS, Gated, Offset	-----	-11	N/A
UWB, 100-kHz PRF, OOK, Non-gated, Aligned	-5	-5	-7
UWB, 100-kHz PRF, OOK, Non-gated, Offset	-6	-4	N/A
UWB, 100-kHz PRF, ARD, Non-gated	-11	-12	-14
UWB, 100-kHz PRF, ARD, Gated	-----	-21	-20

Con’t Table 4.1. In-band Interference Rejection (P_{REF} - P_I) in dB

Signal Type	Receiver		
	Receiver A - P25 Mode	Receiver B - P25 Mode	Receiver B - Analog Mode
UWB, 100-kHz PRF, RRD, Non-gated	-10	-11	-14
UWB, 20-MHz PRF, UPS, Non-gated, Aligned	8	6	4
UWB, 20-MHz PRF, UPS, Non-gated, Offset	4	5	N/A
UWB, 20-MHz PRF, UPS, Gated, Aligned	0	-1	0
UWB, 20-MHz PRF, UPS, Gated, Offset	-1	-1	N/A
UWB, 20-MHz PRF, OOK, Non-gated, Aligned	8	6	3
UWB, 20-MHz PRF, OOK, Non-gated, Offset	6	5	N/A
UWB, 20-MHz PRF, RRD, Non-gated	-11	-13	-17
UWB, 20-MHz PRF, RRD, Gated	-20	-20	-24

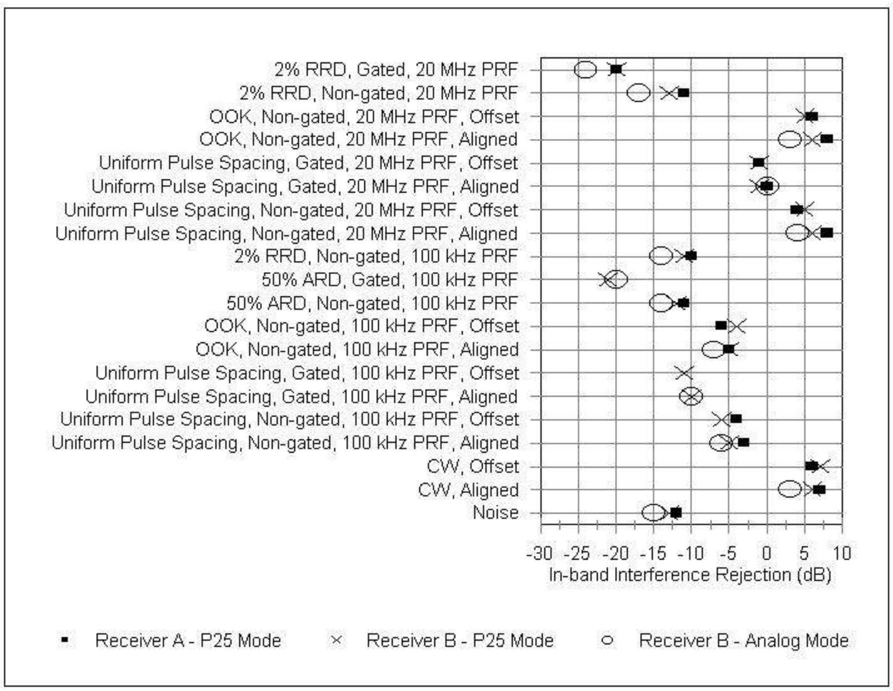

Figure 4.1. In-band interference rejection ($P_{REF} - P_I$).

Figures 4.2, 4.3, 4.6, and 4.7 show P25 radio receiver performance versus variable interference 1-MBPD in the presence of a static desired signal power (described in Section 3.2.1). Figures 4.10 and 4.11 show the same type of plots for Receiver B in analog mode. The thick horizontal line in all of these graphs represents the receiver performance when the LMR signal is held 3 dB above reference sensitivity and no interfering signal is being injected; therefore each of the plots should asymptotically approach this line as the interfering signal power becomes small enough that the primary source of noise is due to the receiver system noise. Signal-to-interference power ratio measured in a 1-MHz bandwidth can be determined by adding 3 dB to P_{REF} for the corresponding receiver and dividing by the values on the abscissa.

Figures 4.4, 4.5, 4.8, and 4.9 show P25 radio receiver performance versus variable desired signal power in the presence of a static interference 1-MBPD (described in Section 3.2.2). Figures UWB 4.12 and 4.13 show the same type of plots for Receiver B in analog mode.

Some of the measurements shown in Figures 4.4 through 4.13 would seem to indicate that CW signals and higher-PRF, non-dithered UWB signals are particularly interfering to LMR receivers. This conclusion is largely an artifact of the way the tests were initially conducted. In particular, the power of the UWB interfering signal was measured in a 1-MHz bandwidth and the average UWB power per MHz was plotted on the graphs. However, some UWB signals (especially high PRF UPS signals) have an average power that varies greatly as a function of frequency. The tests were performed so that the frequencies of highest power were made to coincide with the receiver test frequencies. Therefore, although all UWB test signals may have had equal amplitudes when averaged across a wide bandwidth, they may have represented greatly different amplitudes actually appearing within the 12.5-kHz receiver passband.

Figures 4.14 through 4.19 replot the measurements shown in Figures 4.4 through 4.13. In this case, however, the plots show performance versus signal-to-interference ratio (S/I) in the presence of a static desired signal power, but the interference power is expressed in terms of the mean power passed through a 12.5-kHz filter centered at 138 MHz, the same as the receiver bandwidth. For purposes of brevity this power will be referred to as the Receiver Bandwidth Mean Power Density (RxBMPD). Obtaining the RxBMPD is accomplished by adding, in dB, a bandwidth correction factor for each of the interfering signal powers expressed as a 1-MBPD. The power of any Gaussian noise-like signals (including 50%-ARD and 2%-RRD) is simply corrected by using the following equation:

$$P_{12.5\ \mathrm{kHz}} = \mathit{1\text{-}MBPD} + 10\ \mathrm{Log}_{10}\ (12.5\mathrm{e}3 / 1\mathrm{e}6),$$

where $P_{12.5\ \mathrm{kHz}}$ represents the power in dBm passed through the 12.5-kHz filter.

The power of interfering signals with spectral lines, such as CW and UPS signals, is corrected by determining the ratio of the number of spectral lines in a 1-MHz bandwidth compared to the number of spectral lines passing through the receiver filters; therefore,

$$P_{12.5\ \mathrm{kHz}} = \mathit{1\text{-}MBPD} + 10\ \mathrm{Log}_{10}\ (N_{12.5\ \mathrm{kHz}} / N_{1\ \mathrm{MHz}}),$$

where $N_{12.5\ \mathrm{kHz}}$ and $N_{1\ \mathrm{MHz}}$ represent the number of spectral lines in 12.5 kHz and 1 MHz respectively for the corresponding interfering signal types.

As reported in Appendix D of [3], the total OOK signal power passed through a filter of bandwidth B is

$$\frac{|P(f_c)|^2}{4T^2}[N + TB],$$

where $|P(fc)|^2$ is the power density at f_c for a single pulse, T is the pulse repetition period (i.e. 1/PRF), and N is the nominal number of lines in the filter bandwidth. It follows that, for the same center frequency (f_c), the power ratio for OOK signals passed through two different bandwidths can be expressed as

$$\frac{W_1}{W_2} = \frac{[N_1 + TB_1]}{[N_2 + TB_2]},$$

where W_1 is the power passed through the filter with bandwidth B_1, and N_1 is the number of spectral lines passed through the same filter. The same subscript notation applies to the denominator, where W_2 is the power passed through the filter of bandwidth B_2. The power of OOK signals is therefore corrected using the following equation:

$$P_{12.5\ \mathrm{kHz}} = \mathit{1\text{-}MBPD} + 10\ \mathrm{Log}_{10}\ ([N_{12.5\ \mathrm{kHz}} + T \cdot 12.5\mathrm{e}3]\ /\ [N_{1\ \mathrm{MHz}} + T \cdot 1\mathrm{e}6]).$$

As shown in the following equation, power expressed as a mean power for the gated signals will be 7 dB less than the power measured only during the gated-on time:

$$P_M = P_G + 10\ \log_{10}\ (\textit{gating duty cycle}),$$

where P_M is the mean power in dBm, P_G is the power in dBm during the gated-on time, and the *gating duty cycle* is the fractional time the signal is gated-on (20% gated-on for these measurements).

Table 4.2 shows these bandwidth correction factors in dB applied to the 1-MBPD[†] of each of the signal types in order to obtain the mean power passed through a 12.5-kHz filter centered at 138 MHz.

[†]1-MBPD of all gated signals is expressed in terms of the power during the gated-on time.

Table 4.2. Power Correction Factors (dB)

Signal Type	Correction Factor (dB)
noise	-19.0
CW, offset	0.0
CW, aligned	0.0
100 kHz, 50%-ARD	-19.0
100 kHz, 2%-RRD	-19.0
100 kHz, UPS, offset	-10.0
100 kHz, UPS, aligned	-10.0
100 kHz, OOK, offset	-12.5
100 kHz, OOK, aligned	-12.5
20 MHz, 2%-RRD	-19.0
20 MHz, UPS, offset	0.0
20 MHz, UPS, aligned	0.0
20 MHz, OOK, offset	-0.2
20 MHz, OOK, aligned	-0.2
20 MHz, UPS, gated, offset, mean power	-7.0
20 MHz, UPS, gated, aligned, mean power	-7.0
20 MHz, 2%-RRD, gated, mean power	-26.0

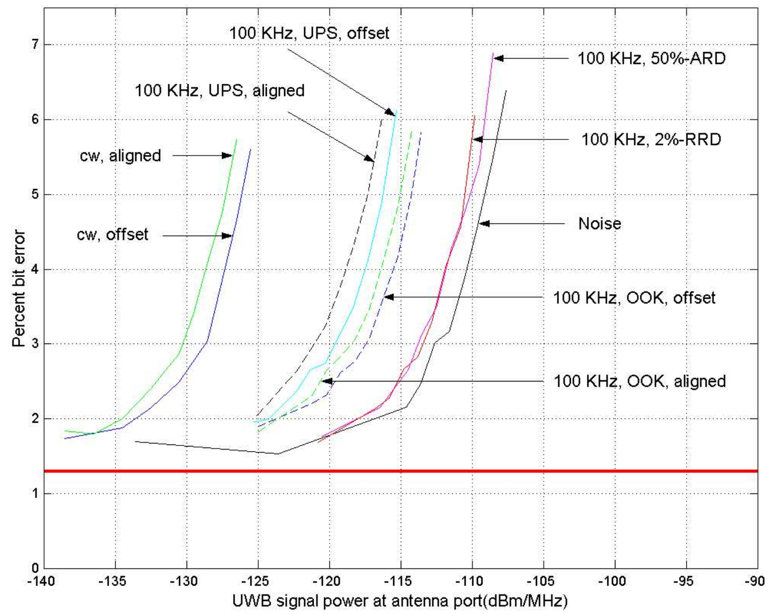

Figure 4.2. Percent bit-error versus variable interference power density for Receiver A in P25 mode – 100-kHz PRF UWB interference.

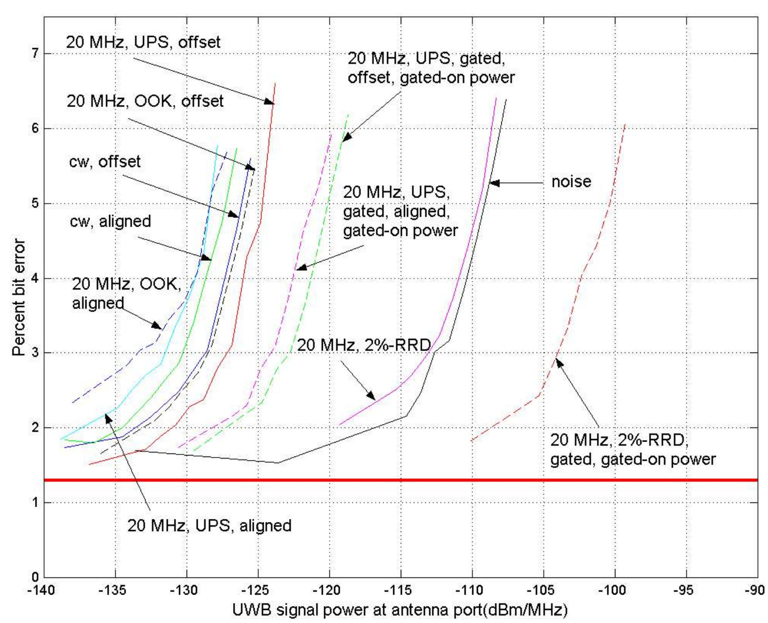

Figure 4.3. Percent bit-error versus variable interference power density for Receiver A in P25 mode – 20-MHz PRF UWB interference.

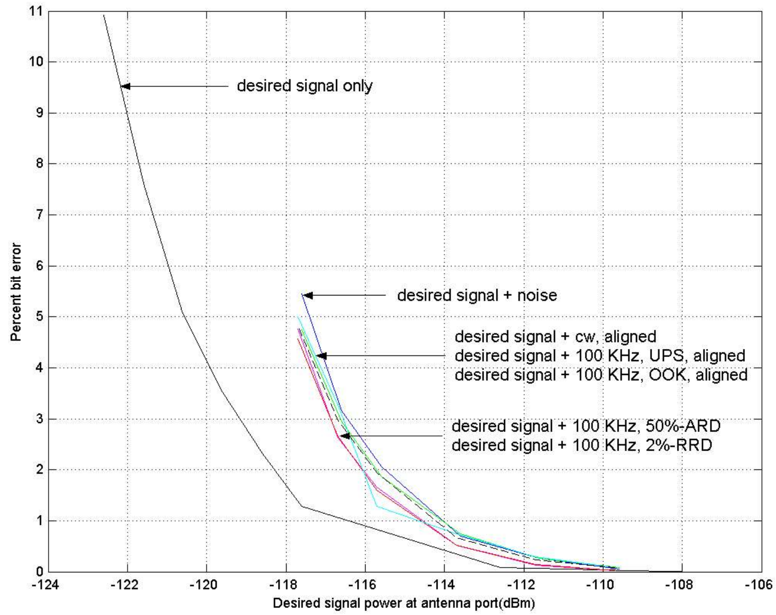

Figure 4.4. Percent bit-error versus variable LMR power for Receiver A in P25 mode – 100-kHz PRF UWB interference.

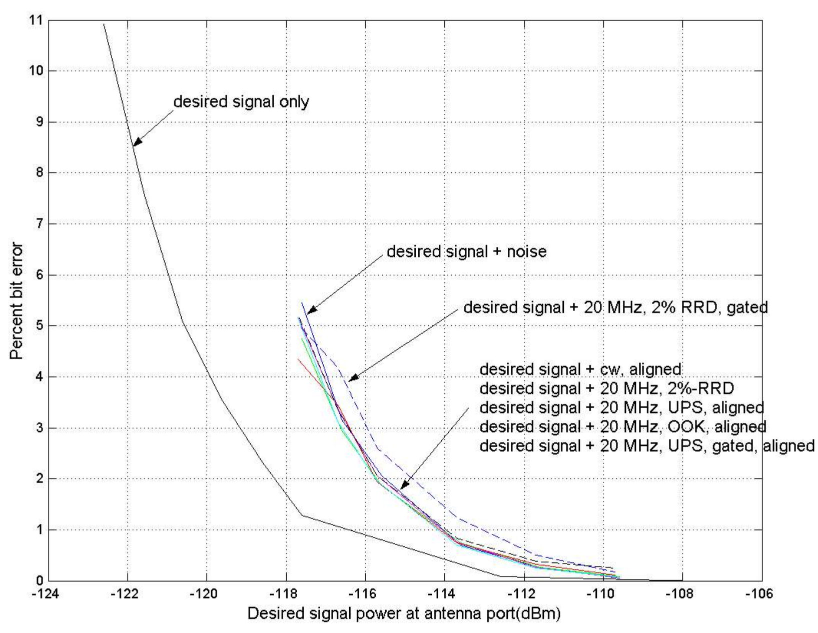

Figure 4.5. Percent bit-error versus variable LMR power for Receiver A in P25 mode – 20-MHz PRF UWB interference.

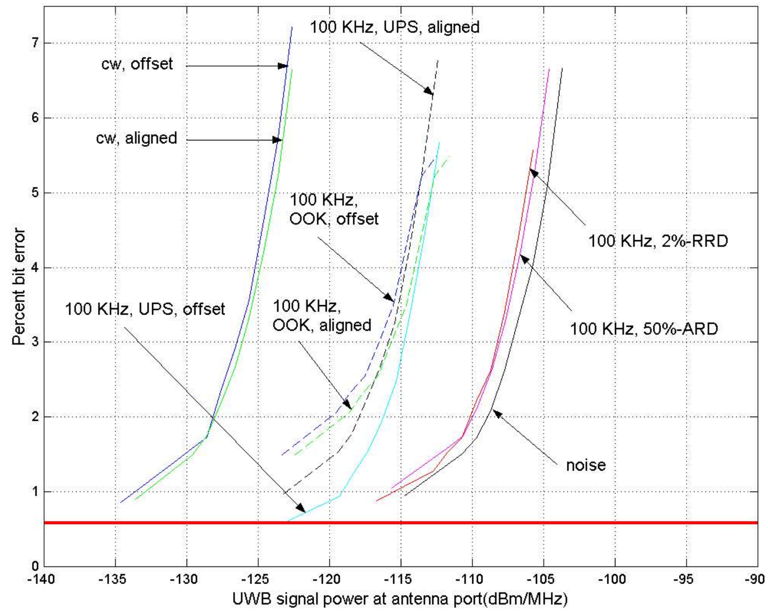

Figure 4.6. Percent bit-error versus variable interference power density for Receiver B in P25 mode – 100-kHz PRF UWB interference.

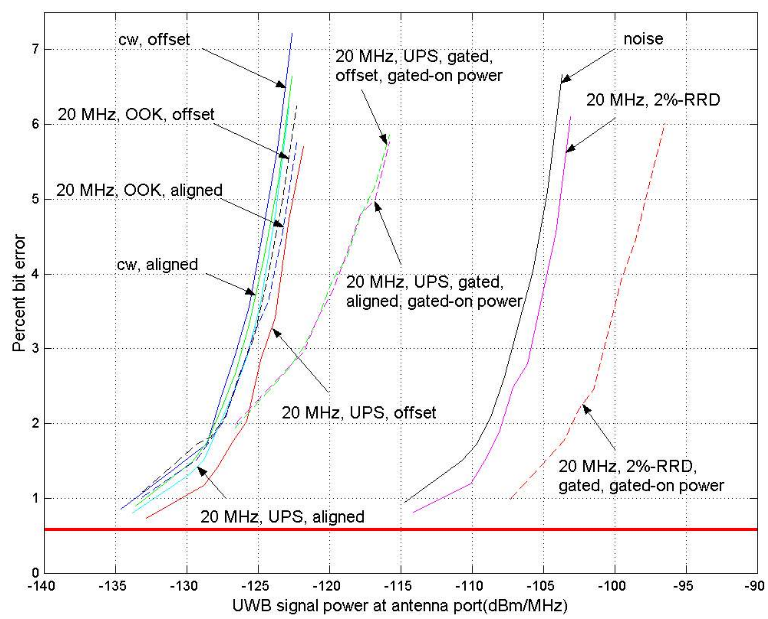

Figure 4.7. Percent bit-error versus variable interference power density for Receiver A in P25 mode – 20-MHz PRF UWB interference.

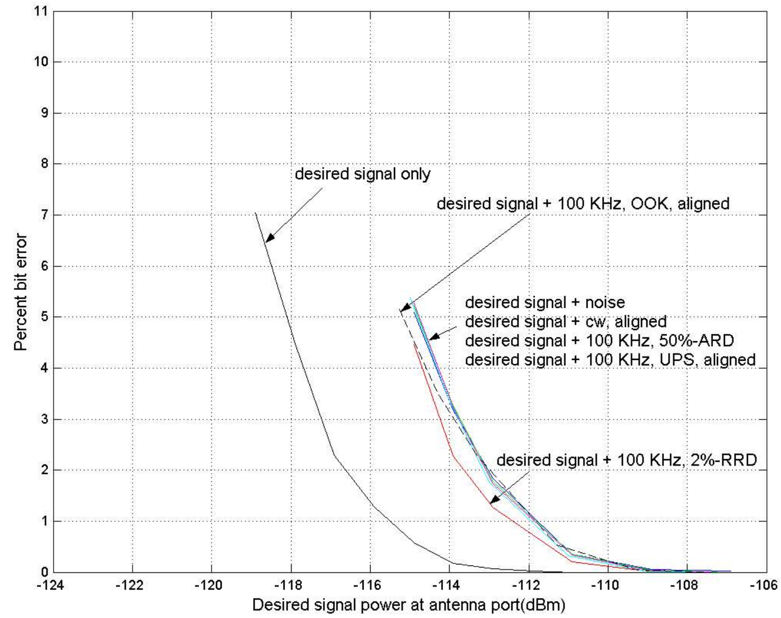

Figure 4.8. Percent bit-error versus variable LMR power for Receiver B in P25 mode – 100-kHz PRF UWB interference.

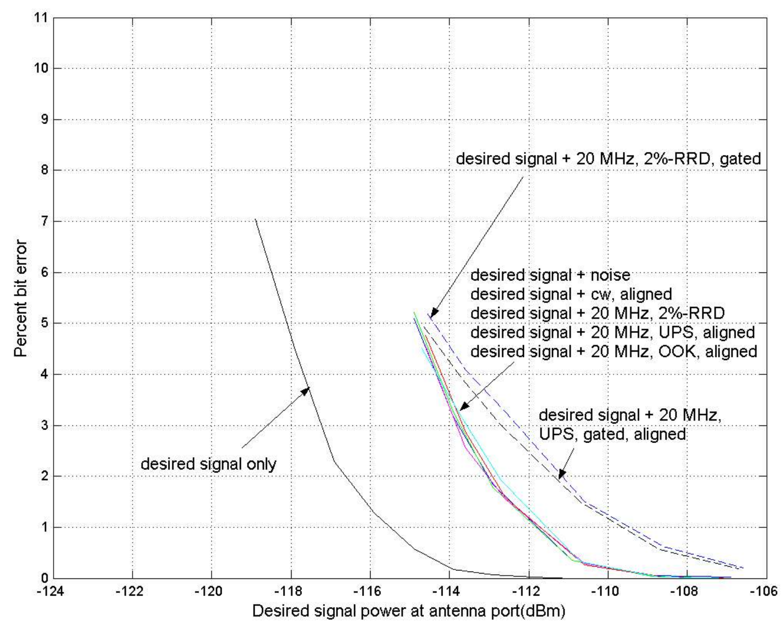

Figure 4.9. Percent bit-error versus variable LMR power for Receiver B in P25 mode – 20-MHz PRF UWB interference.

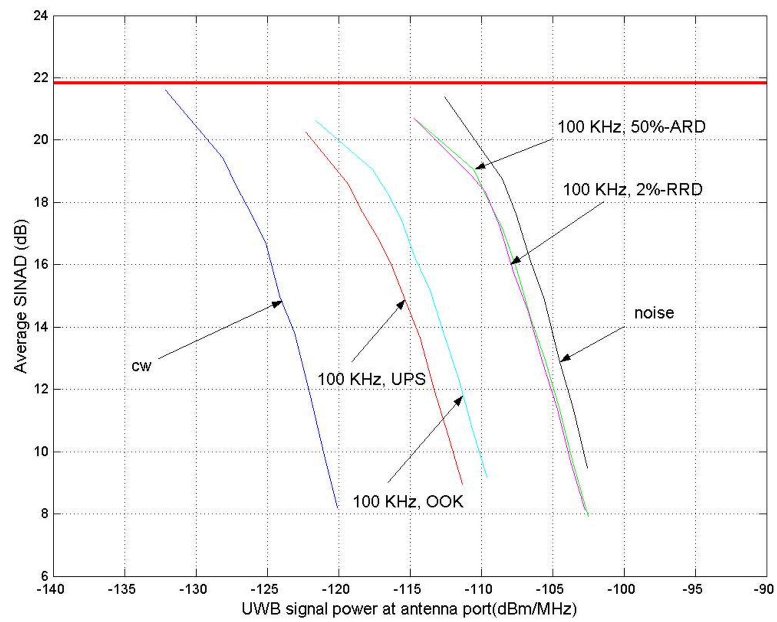

Figure 4.10. Average SINAD versus variable interference power density for Receiver B in analog mode – 100-kHz PRF UWB interference.

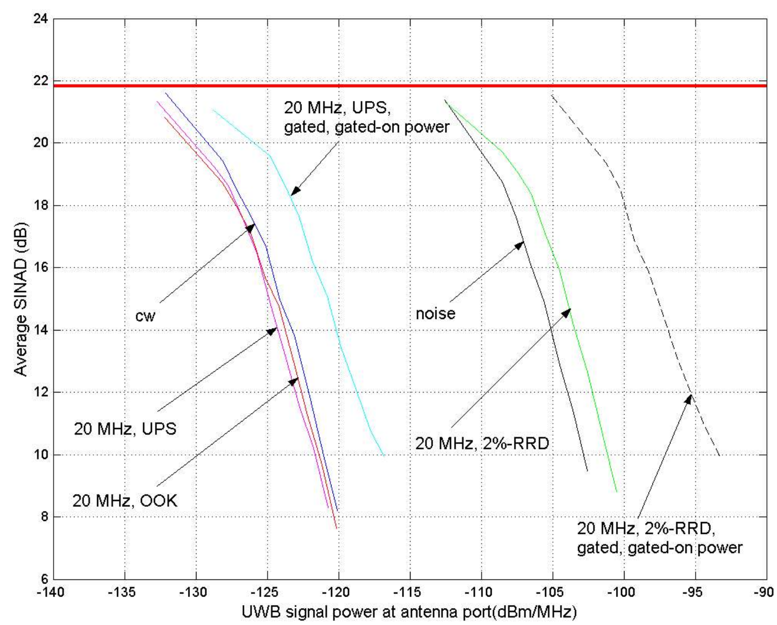

Figure 4.11. Average SINAD versus variable interference power density for Receiver B in analog mode – 20-MHz PRF UWB interference.

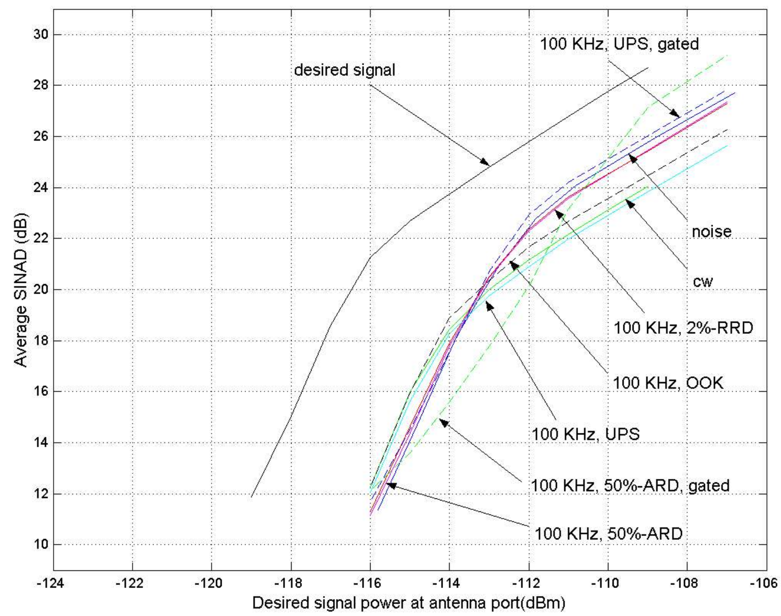

Figure 4.12. Average SINAD versus variable LMR power for Receiver B in analog mode – 100-kHz PRF UWB interference.

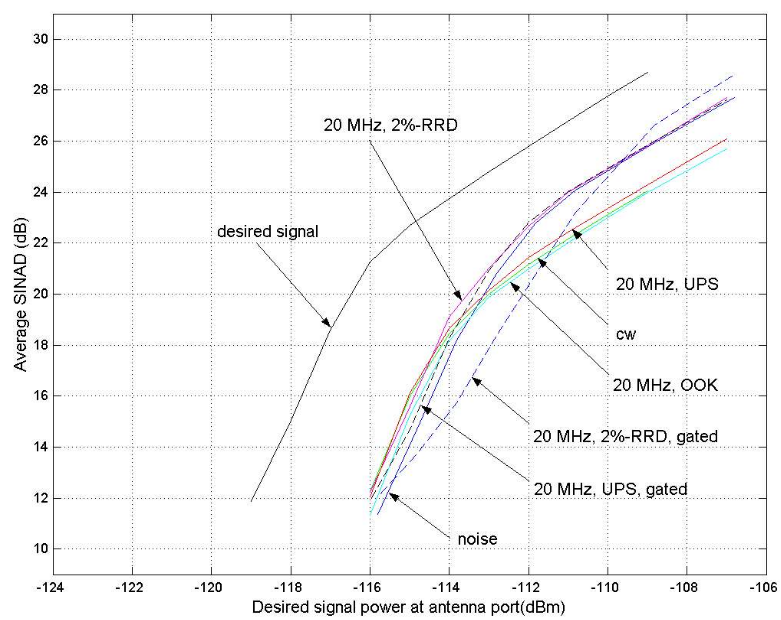

Figure 4.13. Average SINAD versus variable LMR power for Receiver B in analog mode – 20-MHz PRF UWB interference.

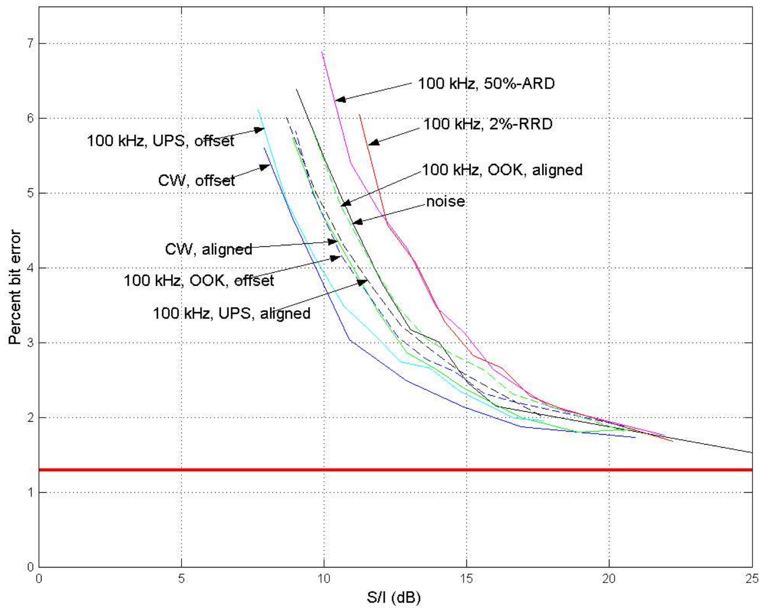

Figure 4.14. Percent bit-error versus S/I for Receiver A in P25 mode – 100-kHz PRF UWB interference.

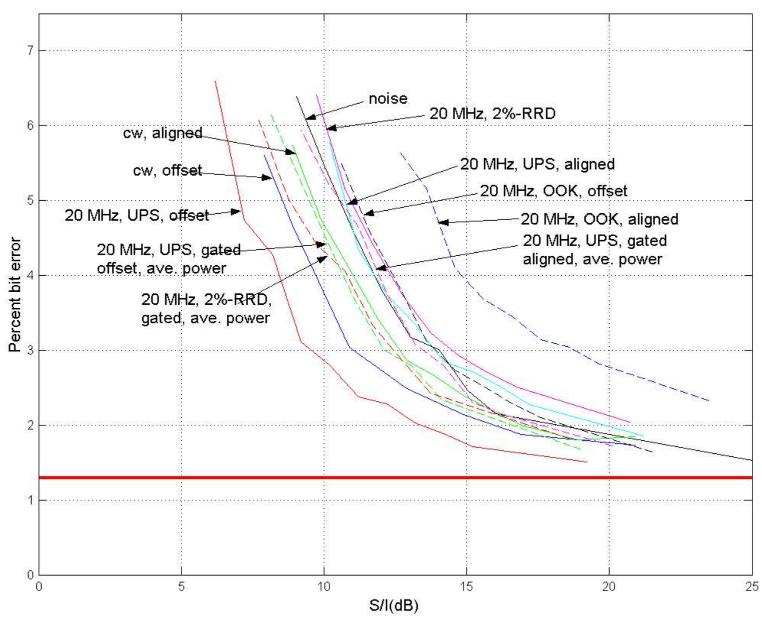

Figure 4.15. Percent bit-error versus S/I for Receiver A in P25 mode – 20-MHz PRF UWB interference.

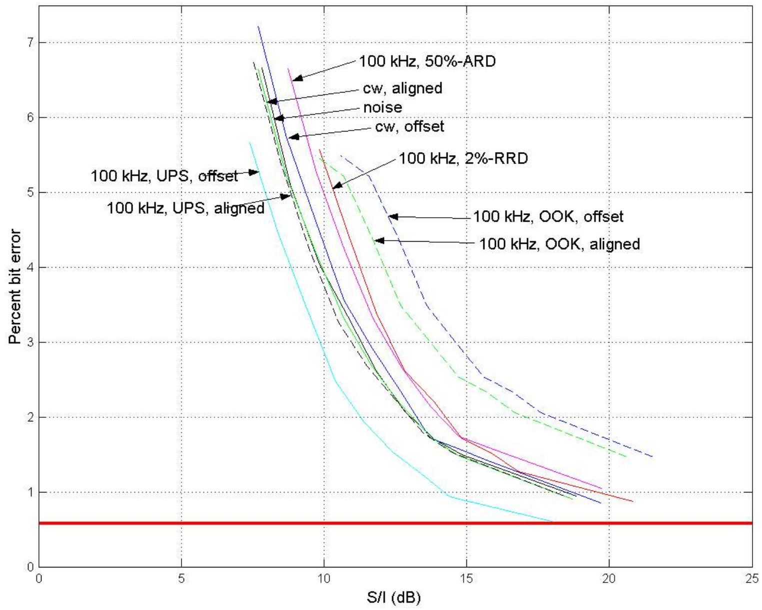

Figure 4.16. Percent bit-error versus S/I for Receiver B in P25 mode – 100-kHz PRF UWB interference.

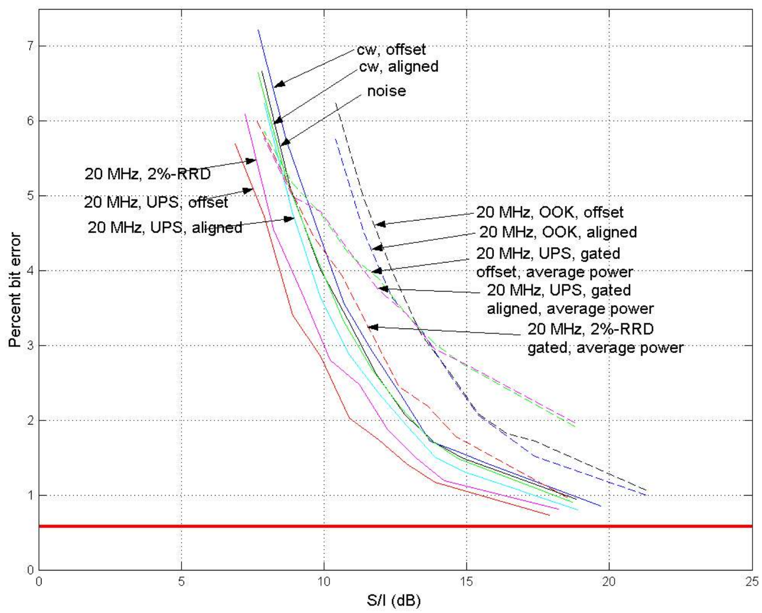

Figure 4.17. Percent bit-error versus S/I for Receiver B in P25 mode – 20-MHz PRF UWB interference.

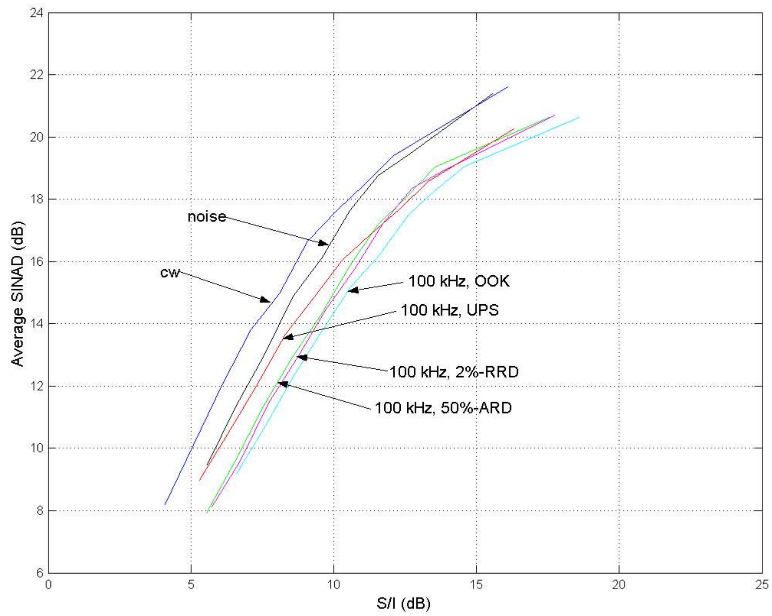

Figure 4.18. Average SINAD versus S/I for Receiver B in analog mode – 100-kHz PRF UWB interference.

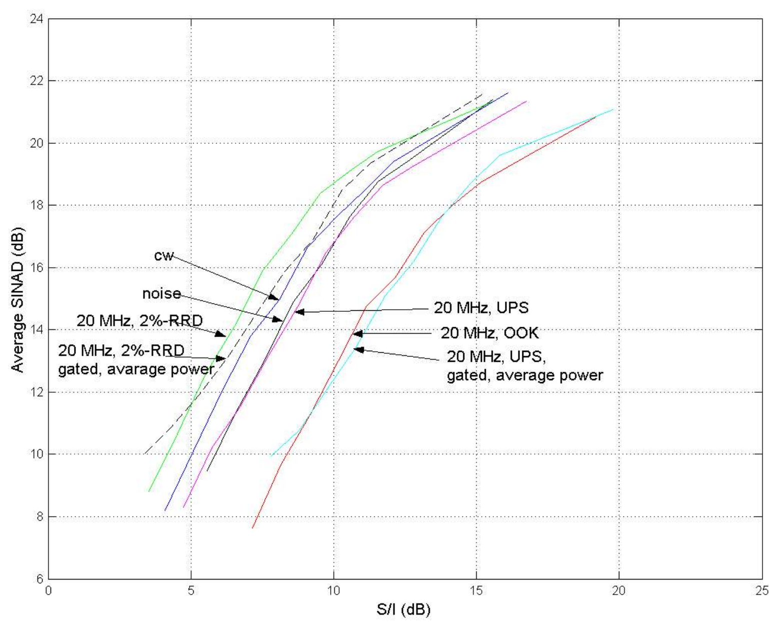

Figure 4.19. Average SINAD versus S/I for Receiver B in analog mode – 20-MHz PRF UWB interference.

4.2 Summary of Measurement Results

There are several trends in receiver response related to the various UWB characteristics such as pulse spacing, PRF, and gating. Figure 4.1 shows these trends (described below) to be remarkably similar among receivers, both in the digital and analog modes.

Because the PRF to receiver-bandwidth ratio for these measurements is always greater than 1, there is an overlapping of adjacent pulses after passing through the 12.5-MHz receiver passband; therefore, dithered signals, both RRD and ARD, have a Gaussian noise-like behavior in both the temporal and spectral domains when passed through the receiver passband transfer function. This is corroborated by Figure 4.1, which shows the in-band interference rejection ratios to be closely similar for noise, 50%-ARD, and 2%-RRD. The same trends can be noted in Figures 4.2, 4.3, 4.6, 4.7, 4.10, and 4.11.

Both the UPS and OOK signals have strong spectral lines. As such, it can be expected that UPS and OOK signals will, for the same 1-MBPD, have a more detrimental effect than dithered signals. For OOK signals used in these measurements, half the signal power is contained in a noise-like component. Therefore, for an equal 1-MBPD, OOK signals are not as likely to degrade receiver performance as the UPS signals. This is corroborated in both Figure 4.1 and Figures 4.2, 4.3, 4.6, 4.7, 4.10, and 4.11, which show UPS signals to be slightly more invasive than their OOK counterparts. Both are seen to be more invasive than dithered signals. For the 100-kHz case, there are 10 spectral lines within the 1-MHz band of power measurement, but only one of those spectral lines passes through the receiver filters. On the other hand, for CW signals and 20-MHz signals, there is only one spectral line within the 1-MHz band of power measurement, and all of the power in that spectral line passes through the receiver filters. Therefore, it is expected that, for signals with strong spectral lines to cause the same level of interference, there should be a 10-dB difference ($10 \log_{10}$[10-spectral-lines/1-spectral-line]) in the 1-MBPD between the 100-kHz signals and the 20-MHz (or CW) signals. This is validated by the same figures mentioned above.

Because the power of the gated signals is stated in terms of the gated-on time, it is expected that, for 20% gating, 7 dB more power is required of the gated signals to degrade the receivers to the same level as the non-gated counterparts. This is also validated for each case as evidenced by Figures 4.1, 4.2, 4.3, 4.6, 4.7, 4.10, and 4.11.

Figures 4.14 through 4.19 show that, when interference power is expressed in terms of RxBMPD, there is difference of only a few dB between signal types for the same level of performance. For the same RxBMPD, gated signals show slightly more performance degradation. When expressed in terms of signal-to-RxBMPD ratio (designated as S/I on the abscissa), reference sensitivity occurs at approximately 10 dB, with a variation of 2 to 5 dB on either side, depending upon the receiver and signal type.