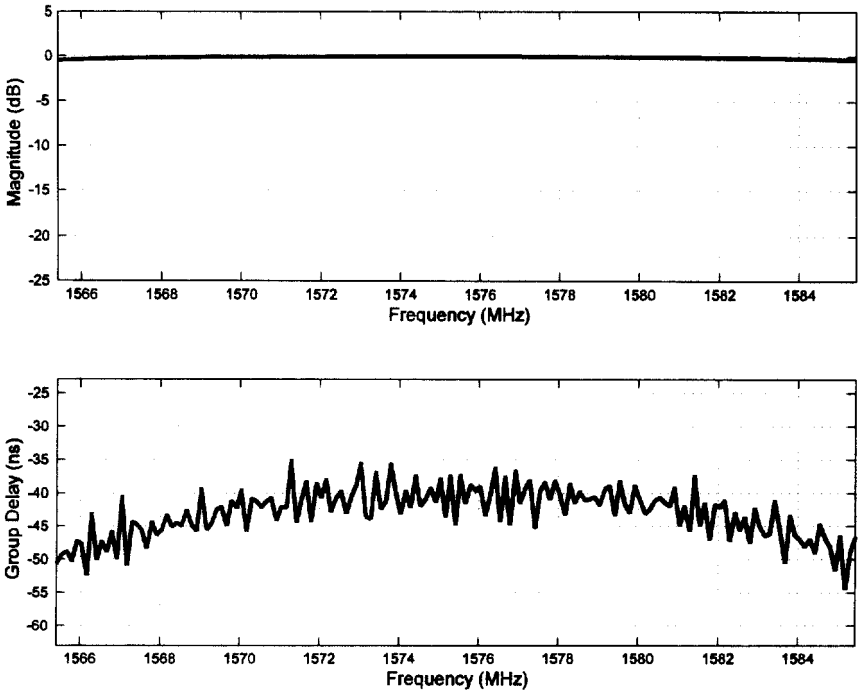

Figure A.2.11. Transfer function magnitude and group delay for filter F4 - 1565 MHz to 1585 MHz.

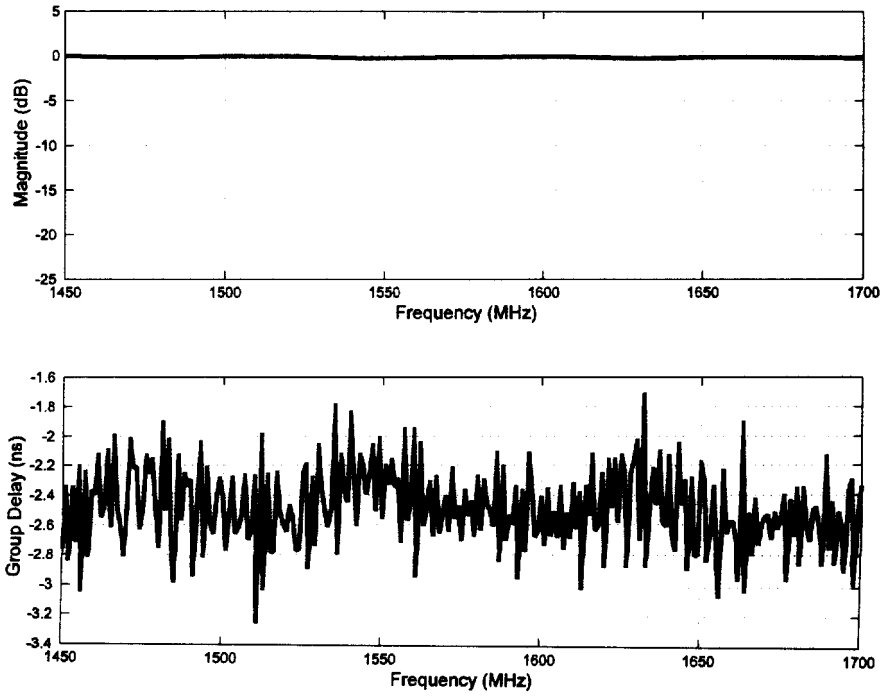

Figure A.2.12. Transfer function magnitude and group delay for filter F2 - 1475 MHz to 1675 MHz.

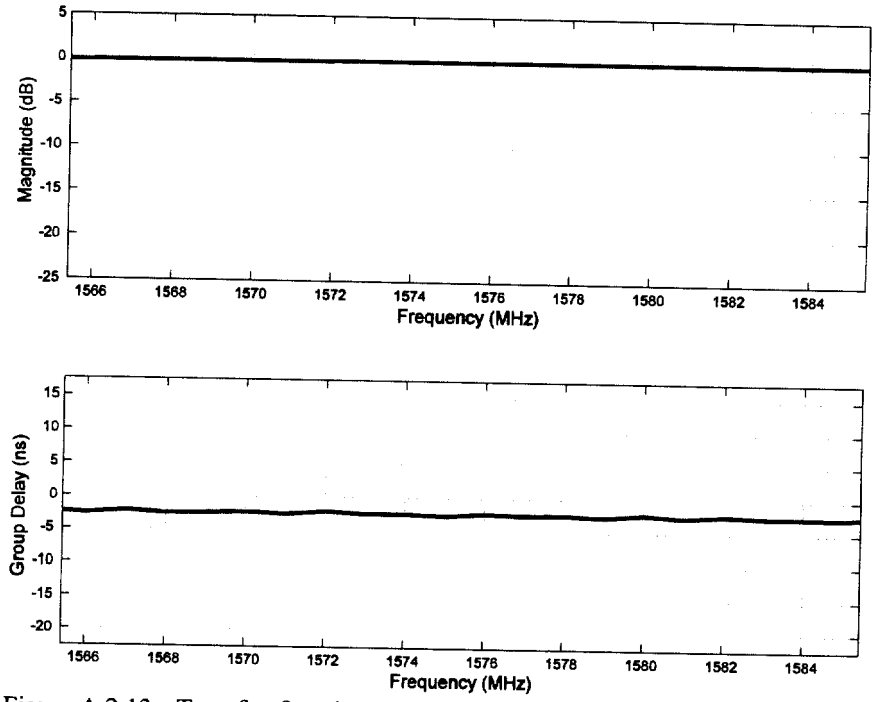

Figure A.2.13. Transfer function magnitude and group delay for filter F2 - 1565 MHz to 1585 MHz.

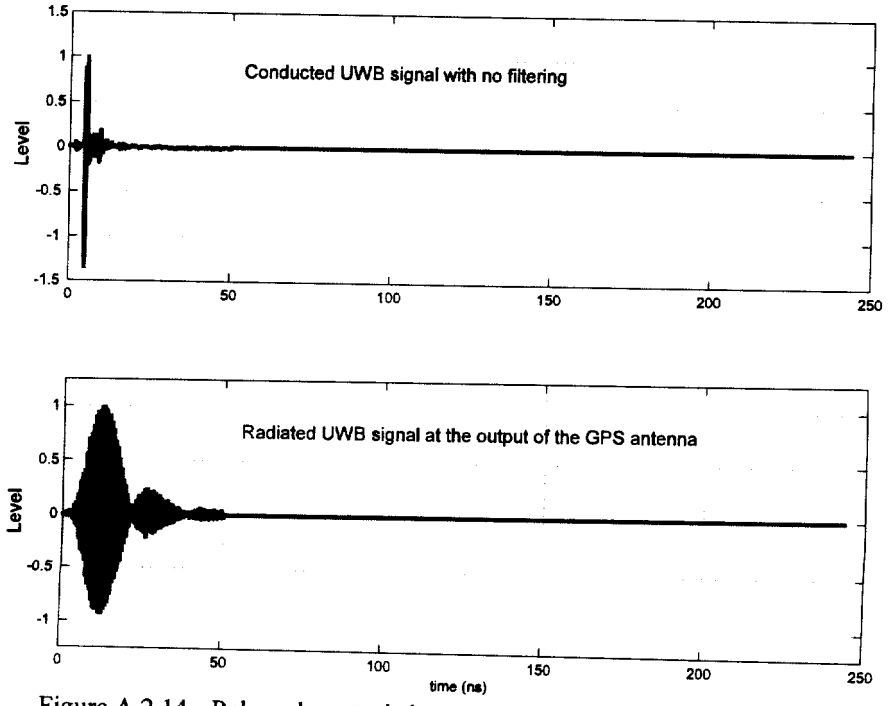

Figure A.2.14. Pulse characteristics - conducted and radiated. (Levels are normalized to peak voltage.)

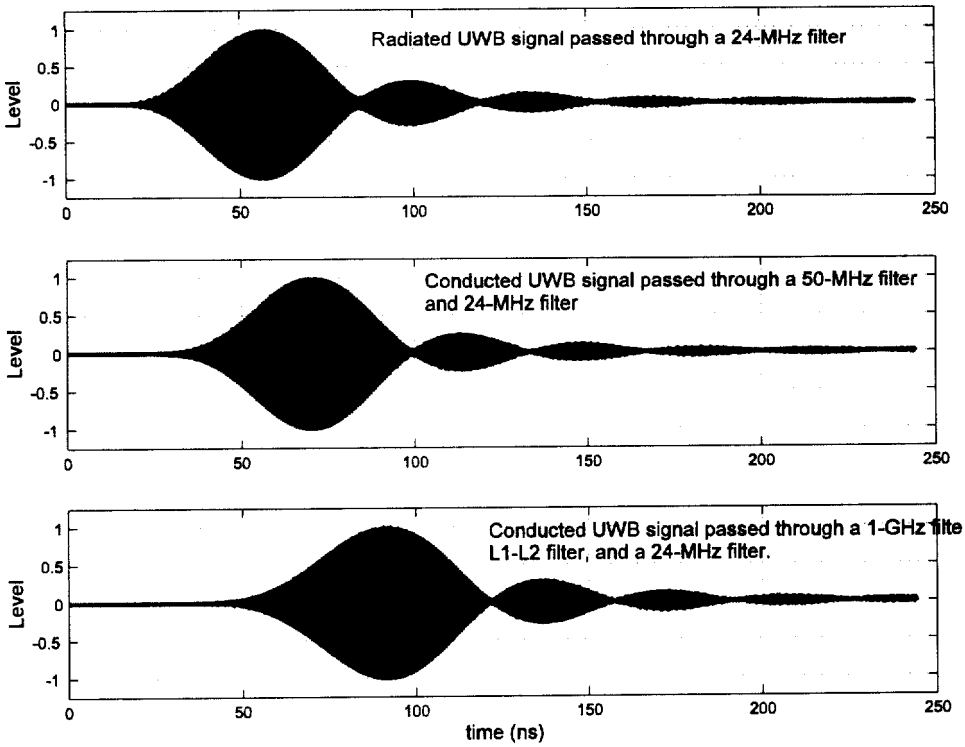

Figure A.2.15. Pulse characteristics through different measurement paths. (Levels are normalized to peak voltage.)

A.3 Multiple Pulse Measurement

Multiple pulse measurements were performed to determine the degree of signal alteration with regard to APDs, when the signal is radiated. While it is possible to have two remarkably different signals with the same amplitude distribution, if a signal, radiated and conducted, has the same amplitude distribution for the two different paths, the time-domain shape is likely to be very similar. For this reason, APD measurements were performed for two different bandwidths (3 MHz and 20 MHz centered at L1) using four different UWB signals. Results of these measurements (see Figures A.3.1 through A.3.8) show very little difference between the radiated and conducted path for the bandwidths of interest.

Data, for both conducted and radiated paths, was acquired and processed using techniques described in NTIA Report 01-383 [1].

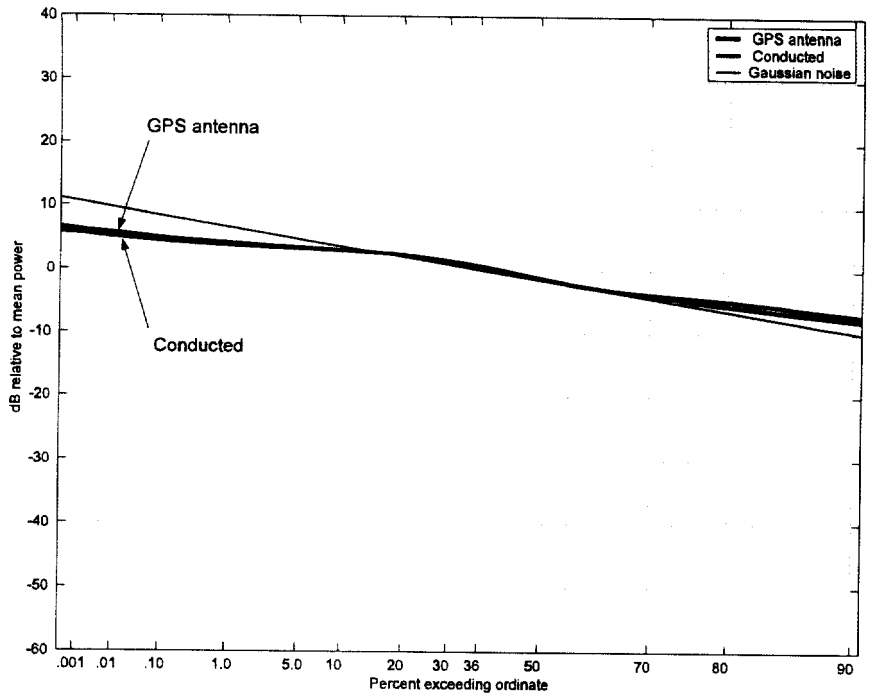

Figure A.3.1. Radiated vs. conducted APDs of 2%-RRD UWB signals (3-MHz PRF, no gating) measured in a 3-MHz bandwidth.

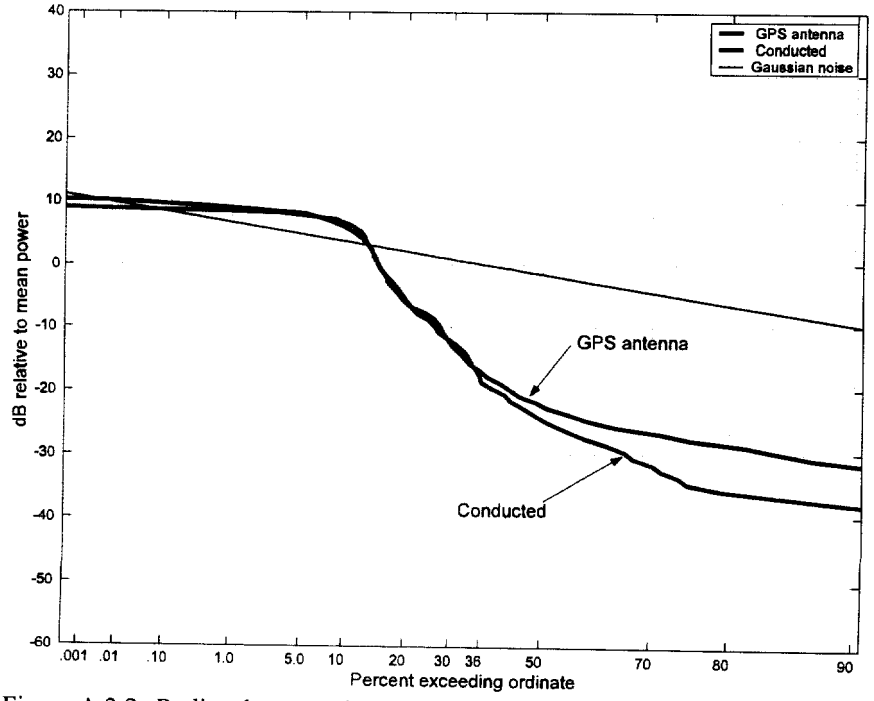

Figure A.3.2. Radiated vs. conducted APDs of 2%-RRD UWB signals (3-MHz PRF, no gating) measured in a 20-MHz bandwidth.

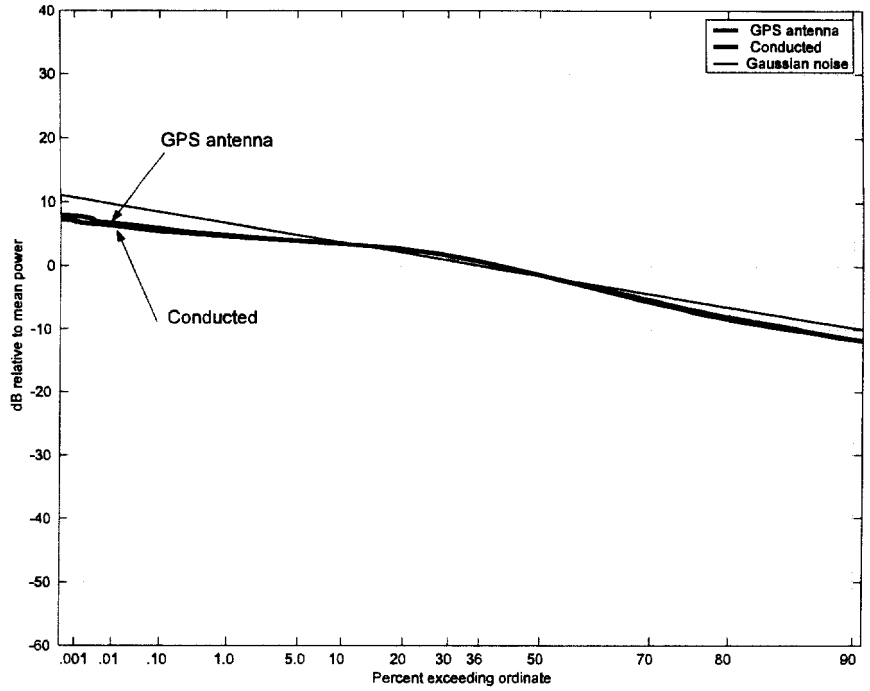

Figure A.3.3. Radiated vs. conducted APDs of 50%-ARD UWB signals (3-MHz PRF, no gating) measured in a 3-MHz bandwidth.

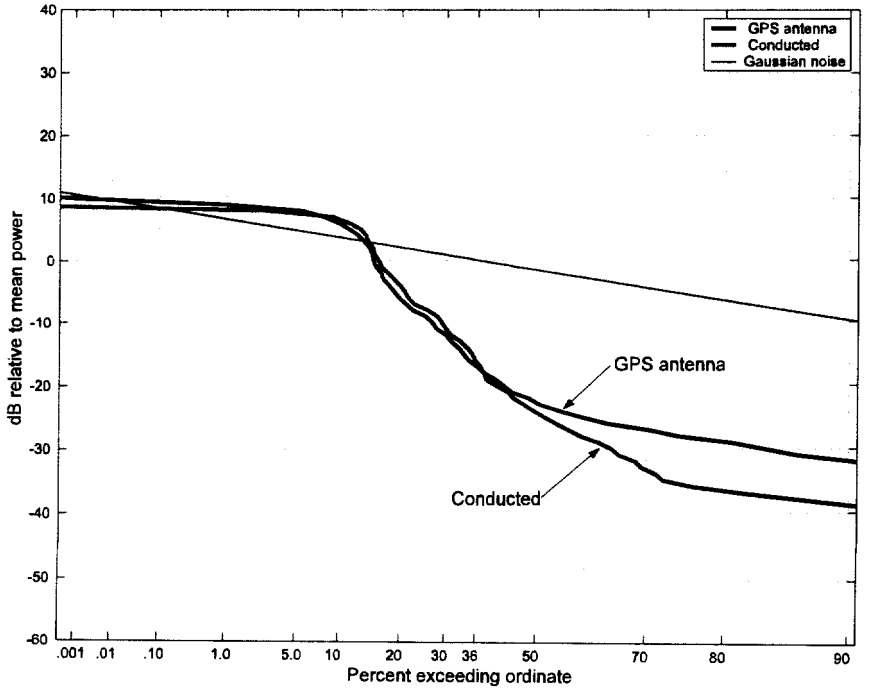

Figure A.3.4. Radiated vs. conducted APDs of 50%-ARD UWB signals (3-MHz PRF, no gating) measured in a 20-MHz bandwidth.

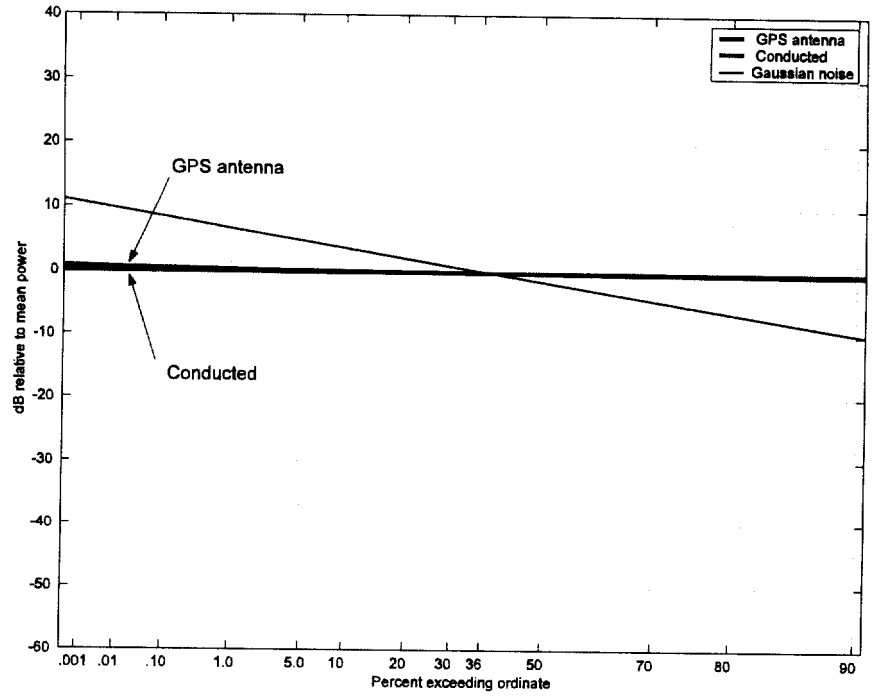

Figure A.3.5. Radiated vs. conducted APDs of UPS UWB signals (10-MHz PRF, no gating) measured in a 3-MHz bandwidth.

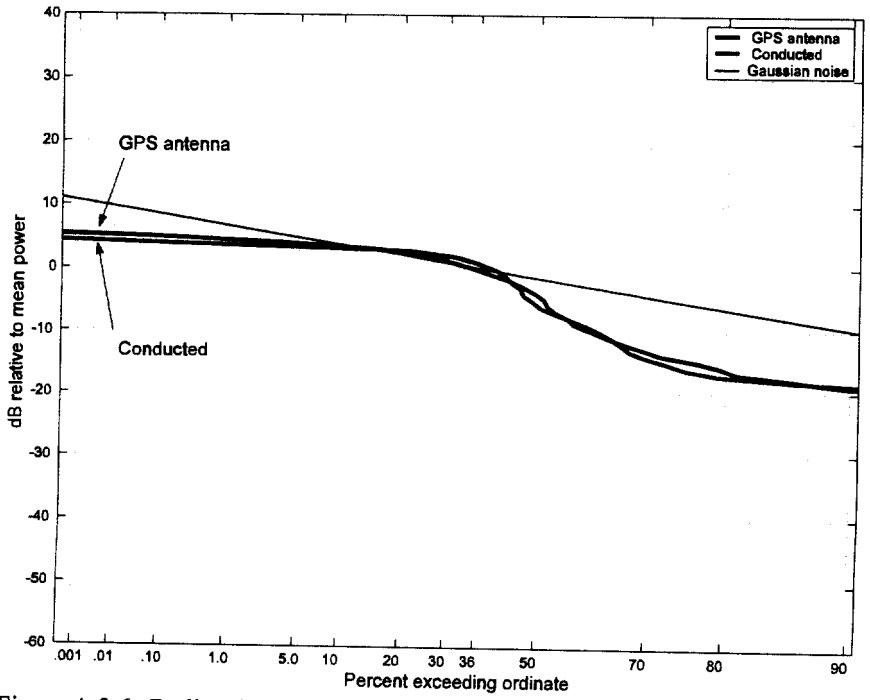

Figure A.3.6. Radiated vs. conducted APDs of UPS UWB signals (10-MHz PRF, no gating) measured in a 20-MHz bandwidth.

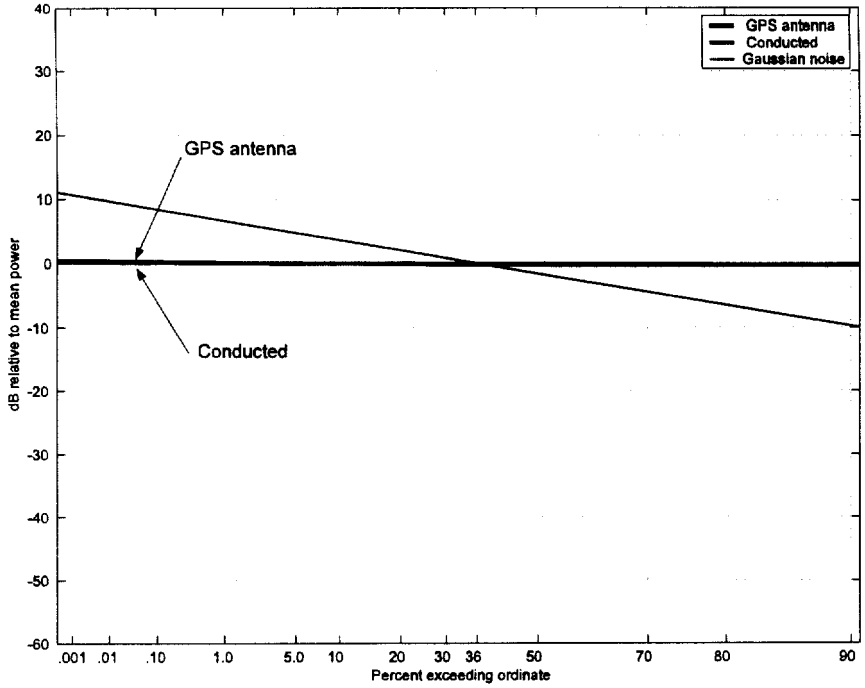

Figure A.3.7. Radiated vs. conducted APDs of UPS UWB signals (20-MHz PRF, no gating) measured in a 3-MHz bandwidth.

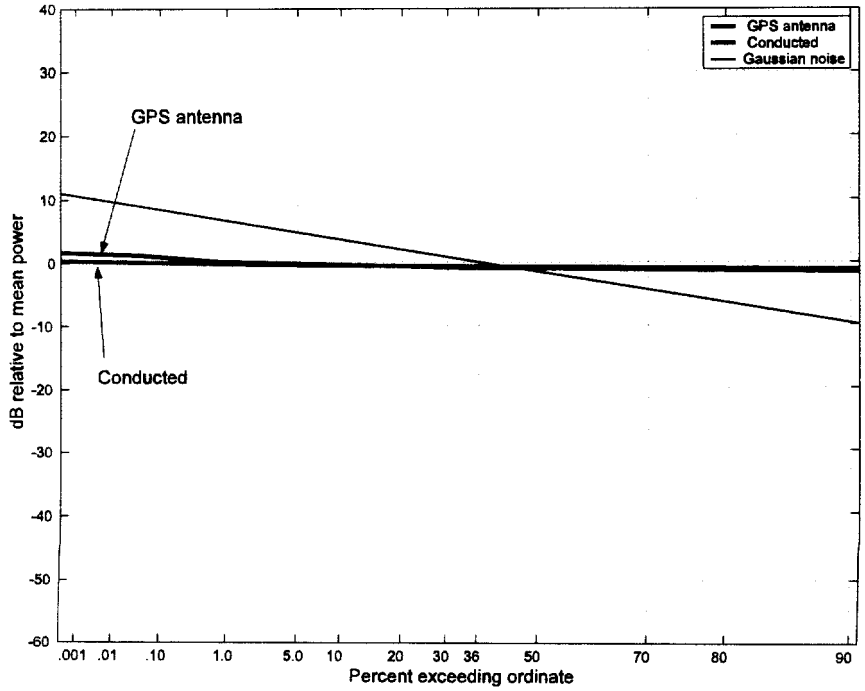

Figure A.3.8. Radiated vs. conducted APDs of UPS UWB signals (20-MHz PRF, no gating) measured in a 20-MHz bandwidth.

A.4 Conclusions

To reiterate what was discussed previously, it is necessary to verify that the conducted and radiated paths have nearly identical affects on the frequency and time-domain characteristics of the signal. Through the measurements described in this Appendix, it was shown that the magnitude and group delay characteristics, as well as the temporal characteristics (as shown through APDs time-domain pulse shapes) were similar whether radiated or conducted through a filtered path. The conclusion is that, while the GPS/UWB interference measurements were performed by transmitting signals through a conducted path, the effects should be no different than those measured during a radiated test (barring channel distortion such as multipath).

References

[1] W.A. Kissick, Ed., "The temporal and spectral characteristics of ultrawideband signals," NTIA Report 01-383, Jan. 2001.

APPENDIX B: HARDWARE SPECIFICATION

B.1 RF Components

A1 - Fixed Coaxial Attenuator
- Manufacturer: Midwest Microwave
- Model: ATT-0444-03-SMA-02
- Frequency range: 0 - 18 GHz
- Attenuation: 3 dB

A2 - Fixed Coaxial Attenuator (3x)
- Manufacturer: Midwest Microwave
- Model: ATT-0444-10-SMA-02
- Frequency range: 0 - 18 GHz
- Attenuation: 10 dB

B - DC Blocking Capacitor
- Manufacturer: Picosecond pulse Labs
- Model: 5502C
- BW(-3dB): 14 GHz
- Rise time: 24 ps
- Delay: 154 ps
- Insertion loss: < 0.5 dB @ 2 GHz

C - 3 way (0 degree) Power Combiner
- Manufacturer: Midwest Microwave
- Model: PWD-5520-03-SMA-79
- Frequency range: 0.5 - 2.0 GHz
- Isolation: 15-dB minimum
- Amplitude Balanced: 0.5 dB
- Phase Balanced: 5 degrees

DC - Directional Coupler
- Manufacturer: Mini-Circuits
- Model: ZFDC-10-5
- Frequency range: 1 - 2000 MHz
- Coupling: 10.8 dB
- Main line loss: 1.8-dB max
- Directivity: 30 dB

F1 - Tunable Bandpass Filter

Manufacturer: K&L Microwave
Model: 5BT-1500/3000-5-N/N
Frequency Range: 1500 - 3000 MHz
3-dB Bandwidth: 100 MHz
Insertion Loss: 1.0-dB max

F2 - Quadruplexer

Manufacturer: Filtronic
Type: SMX142
Passband (J2): 1.050 - 1.900 GHz
Insertion Loss: < 1.0 dB

F3 - Band Pass Filter

Manufacturer: TTE
Type: 315-1575.42M-24M-50-SMA
Center frequency (f_0): 1575.42 MHz
Passband Bandwidth: 0.015 f_0, minimum
Insertion loss at f_0: < -2 dB

F4 - GPS Filter / Amplifier

Manufacturer: Delta Microwave
Model: L5625

	L1 (1575.42 MHz)	L2 (1227.6 MHz)
1-dB Bandwidth:	26.7 MHz	26.9 MHz
Gain:	31.1 dB	32.1 dB
Noise Figure:	1.9 dB	1.8 dB

G1 - Medium Power Amplifier

Manufacturer: Mini-Circuits
Model: ZFL-2000
Frequency range: 10 - 2000 MHz
Gain at 1575.42MHz : 27 dB
Noise Figure: 7 dB
Maximum power: +16dBm

G2 - Low Noise Amplifier

Manufacturer: Mini-Circuits
Model: ZHL-1217HLN
Frequency range: 1200 - 1700 MHz
Gain at 1575.42MHz : 39 dB (measured)
Noise Figure: 1.5 dB
Maximum power: +26 dBm

ND1 - Noise Diode

Manufacturer: Noise / Com, Inc
Model: NC3108A
Serial No. E804
ENR: 27.67 dB @ 1.0 GHz
ENR: 27.09 dB @ 2.0 GHz

ND2 - Noise Diode

Manufacturer: Noise / Com, Inc
Model: NC3108A
Serial No. E574
ENR: 27.02 dB @ 1.0 GHz
ENR: 26.65 dB @ 2.0 GHz

S - 4 way, 0 deg Power Splitter

Manufacturer: Mini-Circuits
Model: ZA4PD-2
Frequency range: 1 - 2 GHz
Isolation: 25 dB
Insertion loss: 6 dB

SW - Coaxial Switch

Manufacturer: Dow-Key Microwave
Model: 401-2308
RF Circuit: SPDT
Frequency range: 0 - 26.5 GHz

T - Termination, SMA, 50 Ohm, 1 Watt

Manufacturer: Inmet
Model: TS180M
Frequency range: 0 - 18 GHz

VA1 - Step Attenuator (Programmable)

Manufacturer: Hewlett Packard
Model: HP8495G
Frequency range: 0 - 4 GHz
Attenuation range: 0 - 70 dB, 10-dB step

VA2 - Step Attenuator (Programmable)

Manufacturer: Hewlett Packard
Model: HP8494H
Frequency range: 0 - 18 GHz
Attenuation range: 0 - 11 dB, 1-dB step

VA3 - Step Attenuator (Programmable)
Manufacturer: Hewlett Packard
Model: HP8496G
Frequency range: 0 - 4 GHz
Attenuation range: 0 - 110 dB, 10-dB step

VA4 - Step Attenuator (Programmable)
Manufacturer: Hewlett Packard
Model: HP8494G
Frequency range: 0 - 4 GHz
Attenuation range: 0 - 11 dB, 1-dB step

VA5 - Step Attenuator (Manual)
Manufacturer: Hewlett Packard
Model: HP8494B
Frequency range: 0 - 18 GHz
Attenuation range: 0 - 11 dB, 1-dB step

VA6 - Step Attenuator (Manual)
Manufacturer: Hewlett Packard
Model: HP8496B
Frequency range: 0 - 18 GHz
Attenuation range: 0 - 110 dB, 10-dB step

VA7 - Step Attenuator (Manual)
Manufacturer: Midwest Microwave
Model: 1044
Frequency range: 0 - 12 GHz
Attenuation range: 0 - 60 dB, 10-dB step and 0 - 10 dB, 1-dB step

B.2 Arbitrary Waveform Generator and Pulse Generator

AWG - Arbitrary Waveform Generator
Manufacturer: Sony / Tektronix
Model: AWG520
Rise Time (10 - 90%): ≤ 2.5 ns (amplitude > 1.0 V)
≤ 1.5 ns (amplitude ≤ 1.0 V)
Fall Time (10 - 90%): ≤ 2.5 ns (amplitude > 1.0 V)
≤ 1.7 ns (amplitude ≤ 1.0 V)
Bandwidth: 500 MHz
Phase Noise: ≤ -90 dBc/Hz (10-kHz offset)
Pulse Width: 10-ns minimum

PG1 - UWB pulse generators

Manufacturer: Time Domain
Model: Pulser PG-2000
Unit Serial Number: NTIA-004
Impulse Amplitude (50-Ω load): 5.8V
Impulse Rise Time (10 - 90%): 200 ps
Impulse Fall Time (90 - 10%): 416 ps
Impulse width (50%): 521 ps
Max. Trigger rate: 40 Mpps

PG2 - Pulse Generator

Manufacturer: MSSI
Model: TFP-1000
Serial Number: 001
Measured @ 10 Mpps
Rise Time: 269 ps
Fall Time: 127 ps
Width (rms): 245 ps
Peak-to-Peak output: 5.39 V
Max. PRF: > 50 Mpps

B.3 GPS Receivers

Rx 1 -

Operating Dimension = Automatic (default)
DGPS Mode = Off
Dynamics Code = Land
Solution Mode = Weighted Over determined Fix (default)
Elevation Mask = 0°
SNR Mask = Minimum
PDOP Mask = 99
PDOP Switch = 99
Measurement Rate = 5 Hz (default)
Position Fix Rate = 1 Hz (default)
Raw Codephase Measurements (i.e., no filtering)
Dynamic filter disabled
Static filter disabled
Altitude Filter Disabled

Rx 2 - DGPS Mode = Off (default)
Elevation Mask = 0°
PDOP Mask = 255
Fastest Measurement Rate = 0.5 seconds

APPENDIX C: CHARACTERISTICS OF GENERATED UWB SIGNALS

The following sections describe details of UWB signal generation and provide APDs for each of the signal permutations used in these measurements.

C.1 Signal Description

Each of the UWB signals used in these measurements was generated using a UWB pulser triggered by either an AWG or custom designed 2%-RRD trigger circuit. Two different pulsers were utilized, each described in Appendix B.2. All single source measurements were performed using the Time Domain Corporation PG-2000 unit, and all aggregate measurements were performed using three Time Domain Corporation PG-2000 units and three MSSI TFP-1000 units. All of the 2%-RRD UWB signals with a PRF of 3 MHz or greater were generated using a custom built dithering trigger circuit.

Table C.1.1 lists parameters for each of the 39 UWB signals used for these measurements. The first 32 UWB signals in the table were used for single source conducted measurements; the remaining 7 signals were used for radiated and/or aggregate measurements.

Table C.1.1.Characteristics of Generated UWB Signals

PRF (MHz)	Pulse Spacing Mode	Duty Cycle (%)	PRL[1] Spacing (kHz)	Spectral Line Placement [2] (MHz)	LSNB [3] (Hz)	LSS [4] (Hz)	Nearest SN to L1 [5] (MHz)
0.1	UPS	100, 20	N/A	1575.570571	N/A, 500	N/A, 50	N/A
1	UPS	100, 20	N/A	1575.570571	N/A, 500	N/A, 50	N/A
3	UPS	100	N/A	1575.570571	N/A	N/A	N/A
5	UPS	100, 20	N/A	1575.570571	N/A, 500	N/A, 50	N/A
10	UPS	100	N/A	1575.570571	N/A	N/A	N/A
20	UPS	100, 20	N/A	1575.570571	N/A, 500	N/A, 50	N/A
0.1	OOK	100, 20	0.059	1575.570571	N/A, 500	N/A, 50	N/A
1	OOK	100, 20	0.017	1575.570571	N/A, 500	N/A, 50	N/A
5	OOK	100, 20	0.089	1575.570571	N/A, 500	N/A, 50	N/A
20	OOK	100, 20	0.357	1575.570571	N/A, 500	N/A, 50	N/A
0.1	50%-ARD	100, 20	0.098	N/A	N/A, 500	N/A, 50	1560
1	50%-ARD	100, 20	0.997	N/A	N/A, 500	N/A, 50	1600
3	50%-ARD	100	N/A	N/A	N/A	N/A	1650
5	50%-ARD	100, 20	4.88	N/A	N/A, 500	N/A, 50	1500
20	50%-ARD	100, 20	19.5	N/A	N/A, 500	N/A, 50	2000
0.1	2%-RRD	100, 20	0.25	N/A	N/A, 500	N/A, 50	1615
1	2%-RRD	100, 20	1.25	N/A	N/A, 500	N/A, 50	1900
3	2%-RRD	100, 20	N/A	N/A	N/A	N/A	N/A
5	2%-RRD	100, 20	N/A	N/A	N/A	N/A	N/A
10	2%-RRD	100, 20	N/A	N/A	N/A	N/A	N/A
20	2%-RRD	100, 20	N/A	N/A	N/A	N/A	N/A

[1] Pattern Repetition Lines (PRL) refer to spectral lines generated due to a repetition of the pulse pattern. (See Section C.2 for a complete discussion.)

[2] Lines due to the pulse repetition period are spaced at intervals equal to the reciprocal of PRF, but for each UWB with these spectral lines, the PRF is adjusted slightly so that one of the lines occurs at 1575.570571 MHz.

[3] Line Spreading Null-to-null Bandwidth (LSNB) refers to the null spacing of the convolving $sinc^2$ function as a result of gating, where the null-to-null bandwidth is equal to 2 times the reciprocal of the gated-on time. (See Section 4.1.2 for a complete discussion.)

[4] Line Spread Spacing (LSS) refers to the spacing between lines of the convolving $sinc^2$ function as a result of gating, where the distance between lines is equal to the reciprocal of the gating period. (See Section 4.1.2 for a complete discussion.)

[5] Spectral Node (SN) refers to a spectral feature due to the placement of the position of pulses within discrete bins. (See Section C.2 for a complete discussion.)

C.2 Residual Spectral Effects due to Signal Generation

Because the pattern of pulse spacing, whether it be OOK or dithering, is stored in the memory of an AWG and because that memory has limits with regard to size, the same pattern has to be repeated at periodic intervals. This pattern repetition results in signal power being gathered up into spectral lines with a spacing equal to the reciprocal of the period of the pattern. For those UWB cases where we would expect real world signals to have no pattern repetition, the pattern is made as long as possible so that the spectral lines are spaced very close together, and therefore, have negligible impact on the receiver. For purposes of brevity, we call these spectral lines Pattern Repetition Lines (PRL).

Also because of the limitations of memory size and sample rates of the AWG, the location of pulses (within the context of dithering) has to be confined to a limited number of discrete time bins. This is illustrated in Figure C.2.1 for the case of 50% clock-referenced dithering, in which the pulse position can be assigned to any of 19 possible discrete positions within the first 50% of the interval between reference clock periods (t is the size of the bins, in units of time). As opposed to a continuum of possible pulse positions, this discrete binning results in some additional spectral features worth noting. Figure C.2.2 demonstrates what we have described as a spectral node (SN), in which there is a depression in the spectral noise and the emergence of spectral lines. The spacing of these spectral nodes is directly related to the bin size t, where the distance between spectral nodes is $1/t$. This phenomenon is described in greater detail in Appendix D (Theoretical Analysis of UWB Signals Using Binary Pulse-modulation and Fixed Time-base Dither). For these measurements, efforts were specifically made to place these spectral nodes in a location other than the L1 and L2 bands.

The custom built 2%-RRD circuit is analog, and therefore signals generated using this circuit do not have PRLs or SNs characteristic of signals generated digitally with an AWG.

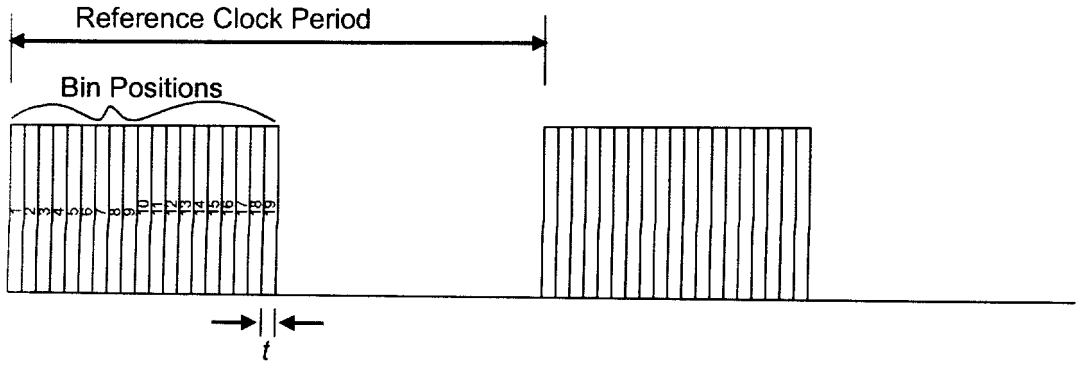

Figure C.2.1. Discrete binning of pulse position for clock referenced dithering.

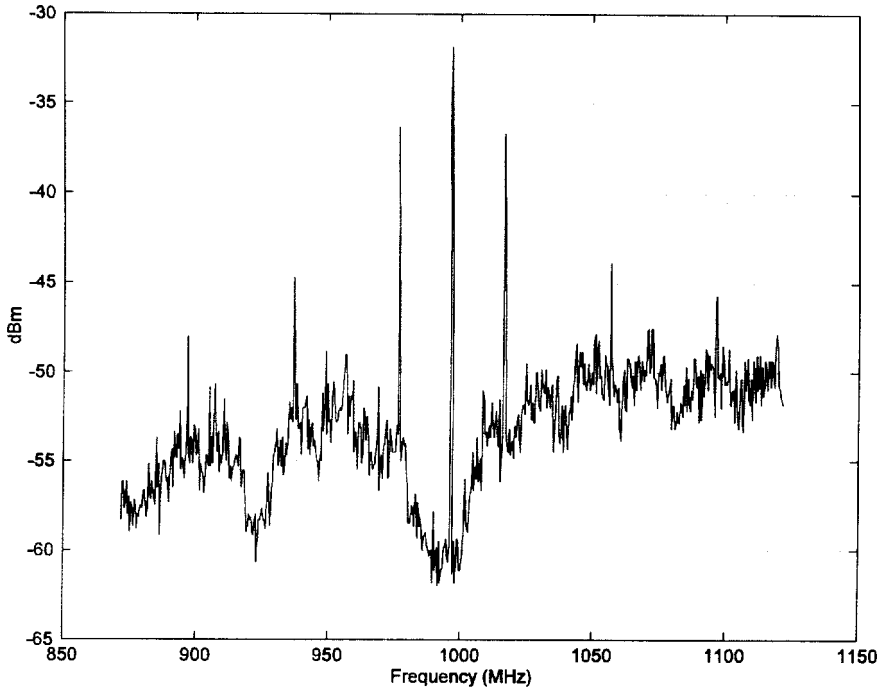

Figure C.2.2. Spectral lines due to discrete binning of pulse position.

C.3 APDs Characteristics of UWB signals

Figures C.3.1 through C.3.29 and Figures C.3.30 through C.3.31 show APDs for each of the 32 different single source UWB permutations and the 9 different aggregate signal scenarios respectively. Two different measurement bandwidths were used – 3 MHz and 20 MHz – representing a bracketing of a wide range of bandwidths. For the single source permutations, several different groupings for composite plots are shown. The four different UWB signals, each representing a different PRF, are plotted as a composite of all the different permutations of pulse spacing modes and gating. Along the other dimension, each of the pulse spacing modes (including gated and non-gated) are plotted as a composite of each of the 4 different PRFs.

For each APD, the mean power is normalized to 0 dBm/20 MHz. Note that mean power for gated signals includes both the gated on and off time. This is in contrast to the power representation of gated signals for operational and observational metrics in Section 6.

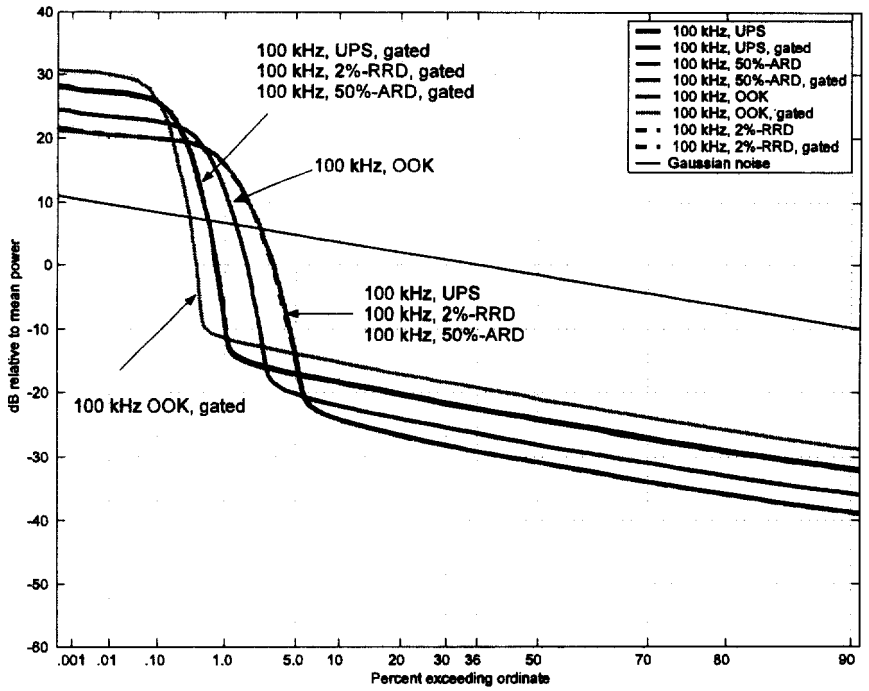

Figure C.3.1. APDs of 100-kHz PRF UWB signals measured in a 3-MHz bandwidth.

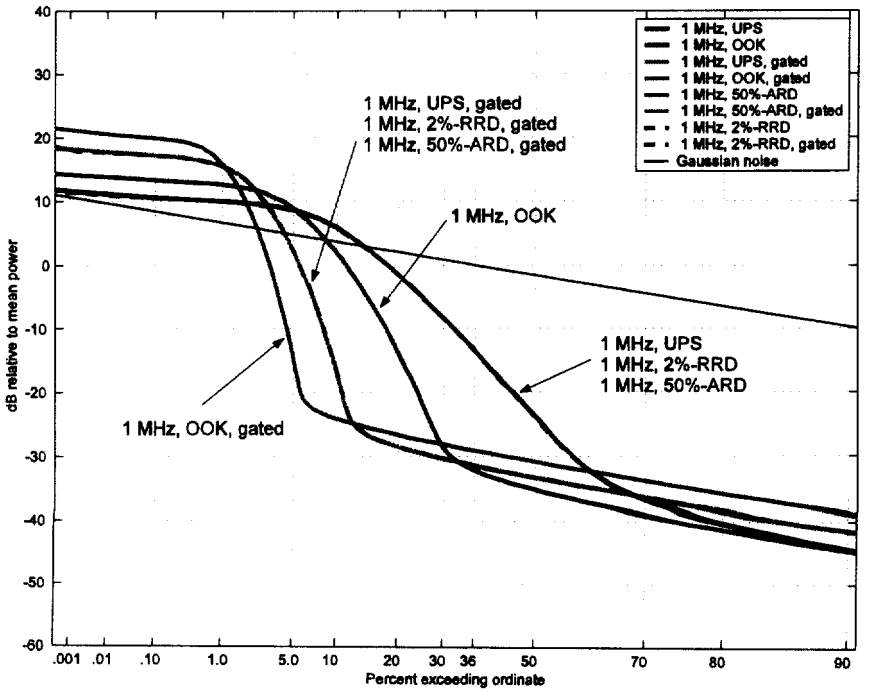

Figure C.3.2. APDs of 1-MHz UWB signals measured in a 3-MHz bandwidth.

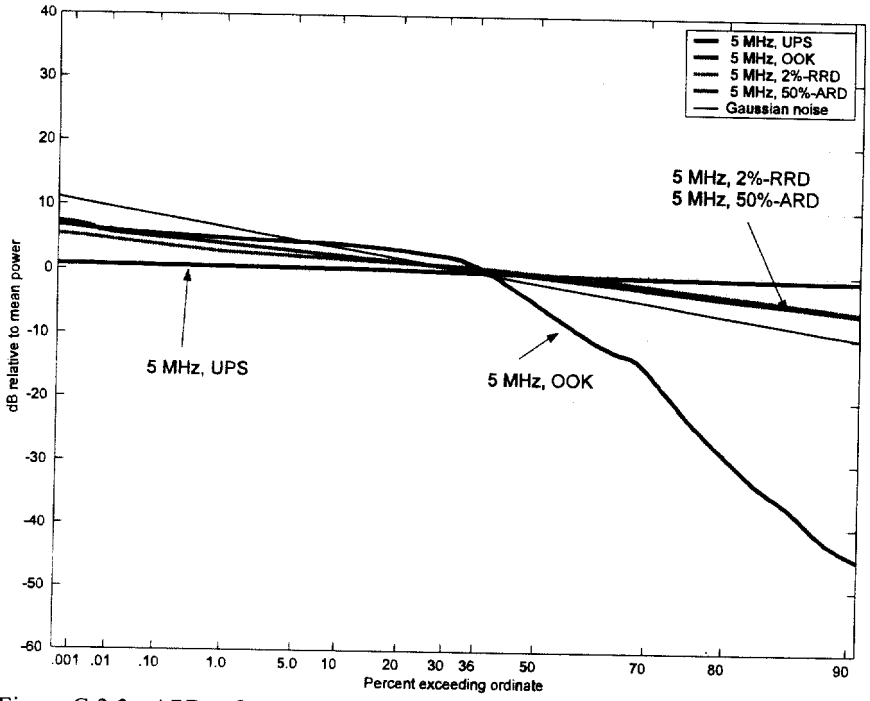

Figure C.3.3. APDs of 5-MHz PRF, non-gated UWB signals measured in a 3-MHz bandwidth.

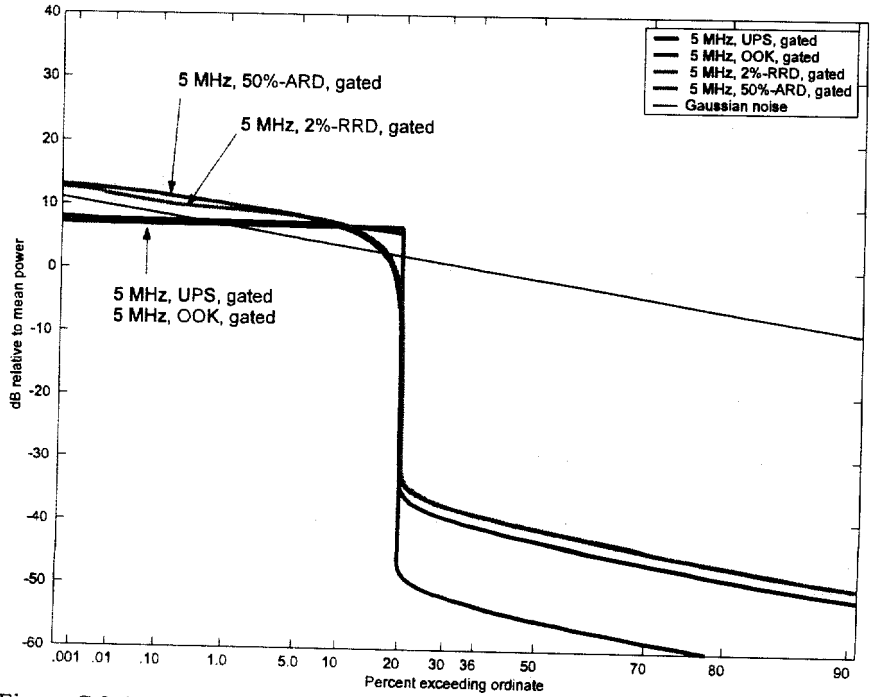

Figure C.3.4. APDs of 5-MHz PRF, gated UWB signals measured in a 3-MHz bandwidth.

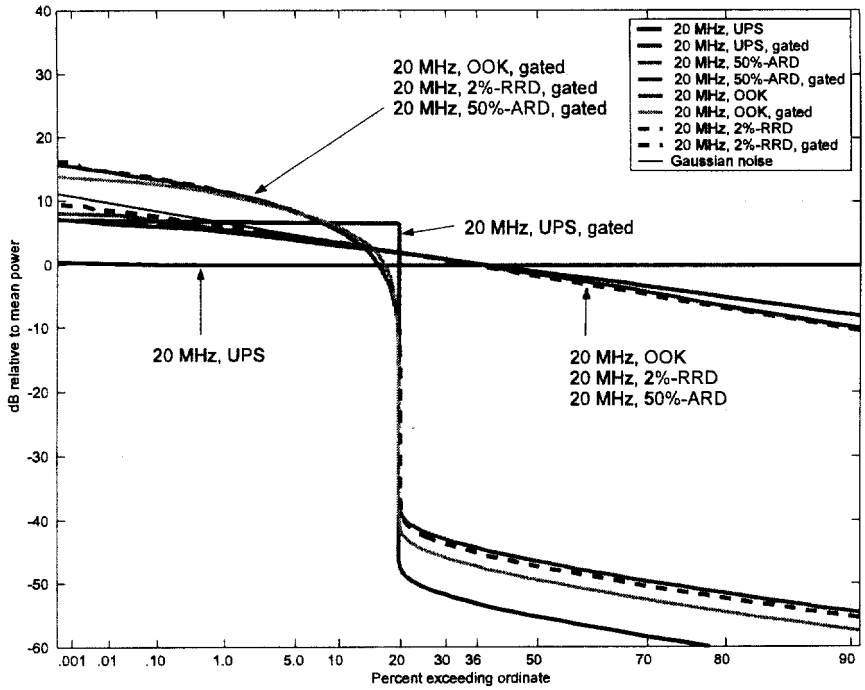

Figure C.3.5. APDs 20-MHz PRF UWB signals measured in a 3-MHz bandwidth.

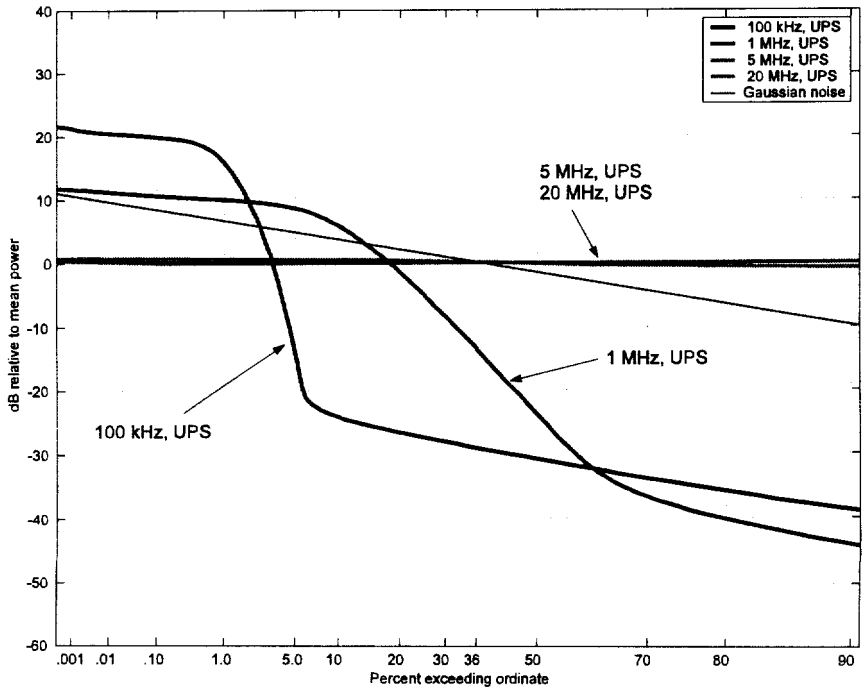

Figure C.3.6. APDs of UPS, non-gated UWB signals measured in a 3-MHz bandwidth.

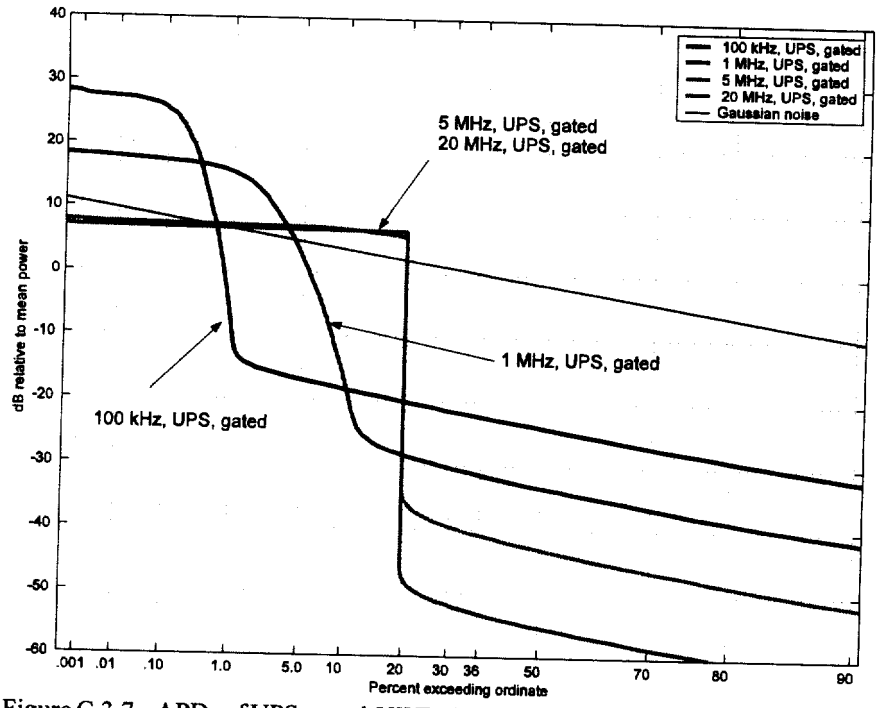

Figure C.3.7. APDs of UPS, gated UWB signals measured in a 3-MHz bandwidth.

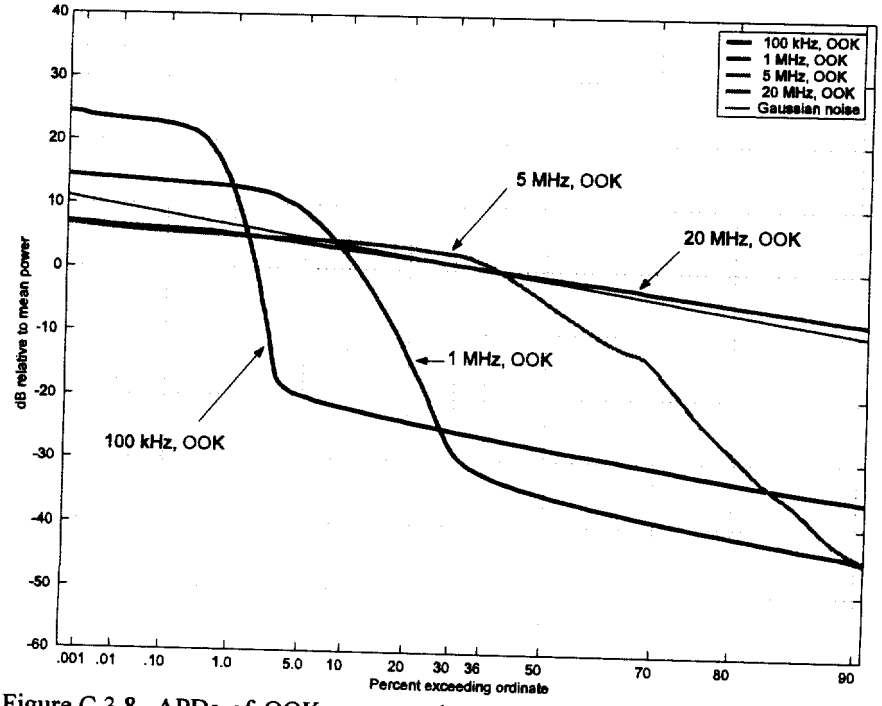

Figure C.3.8. APDs of OOK, non-gated UWB signals measured in a 3-MHz bandwidth.

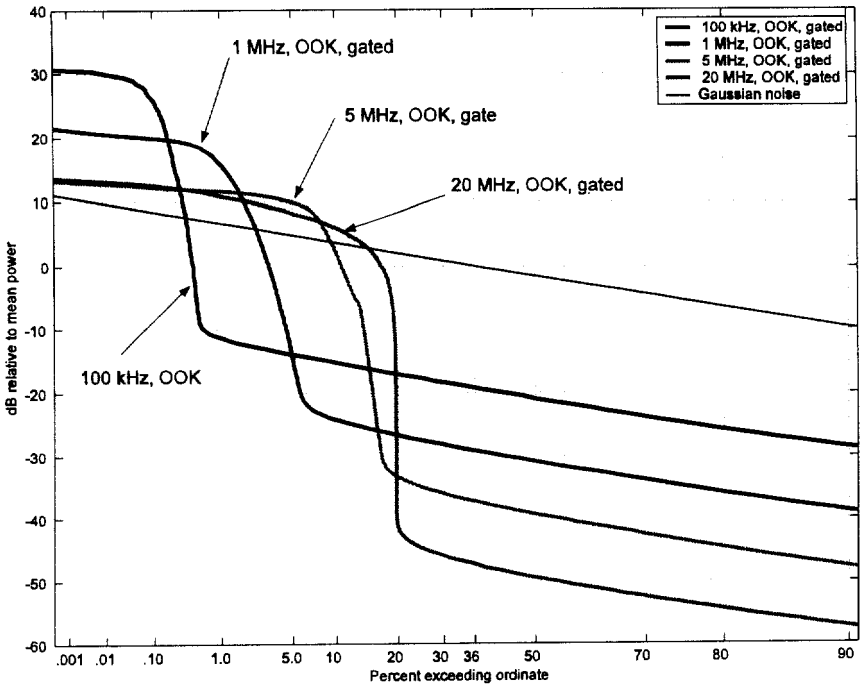

Figure C.3.9. APDs of OOK, gated UWB signals measured in a 3-MHz bandwidth.

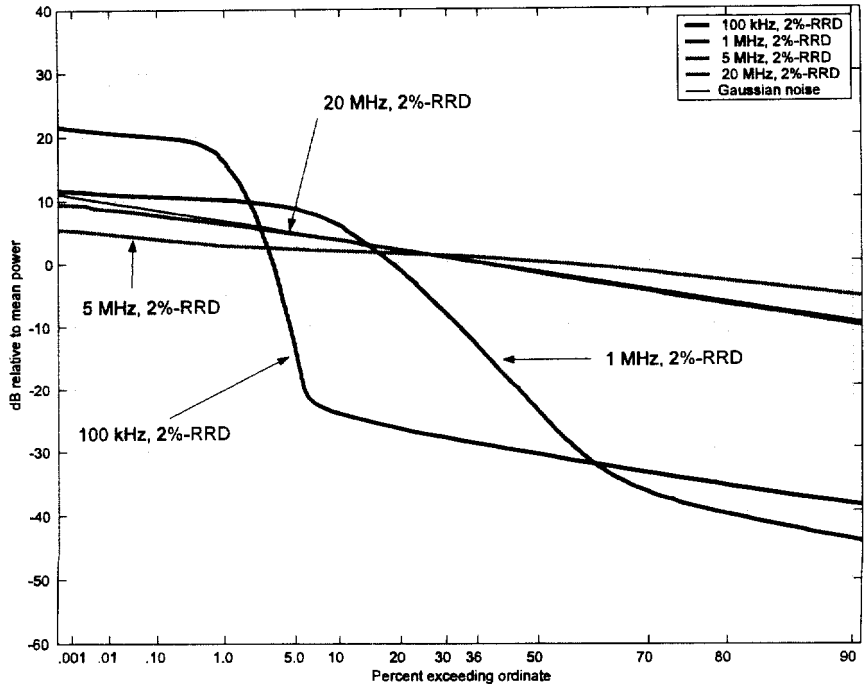

Figure C.3.10. APDs of 2%-RRD, non-gated UWB signals measured in a 3-MHz bandwidth.

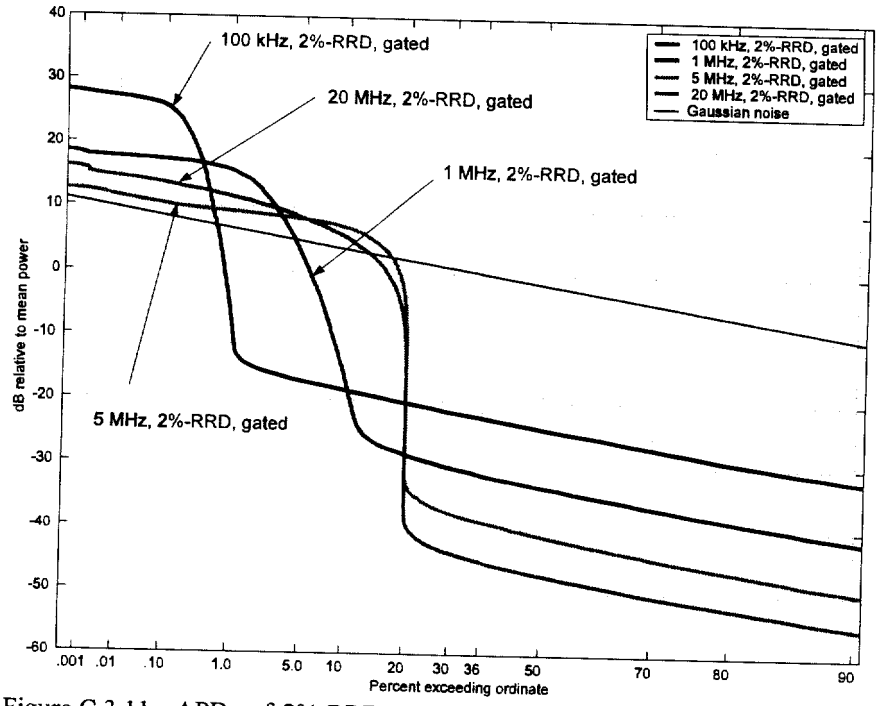

Figure C.3.11. APDs of 2%-RRD, gated UWB signals measured in a 3-MHz bandwidth.

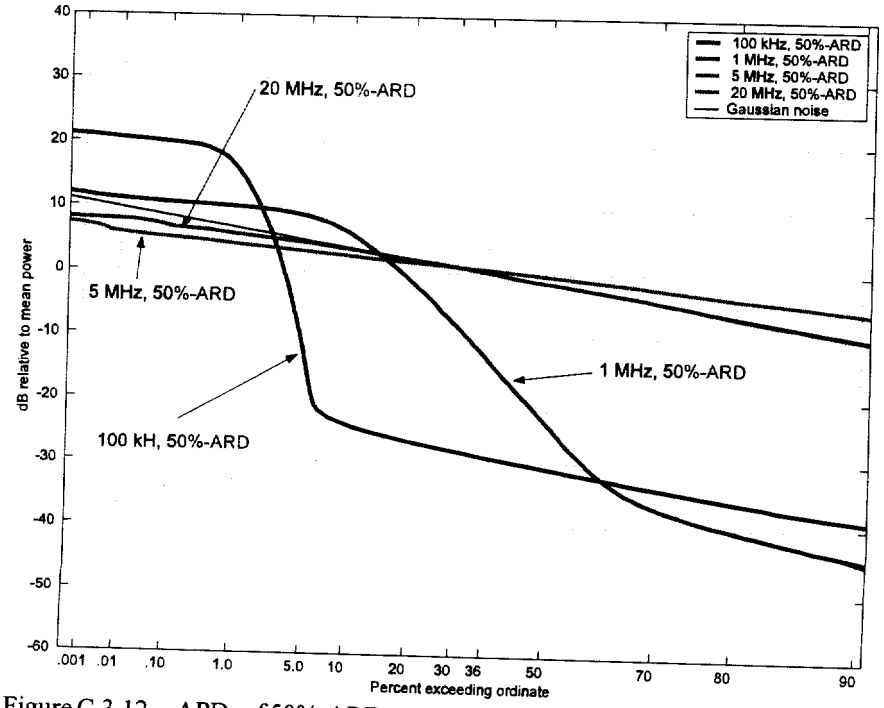

Figure C.3.12. APDs of 50%-ARD, non-gated UWB signals measured in a 3-MHz bandwidth.

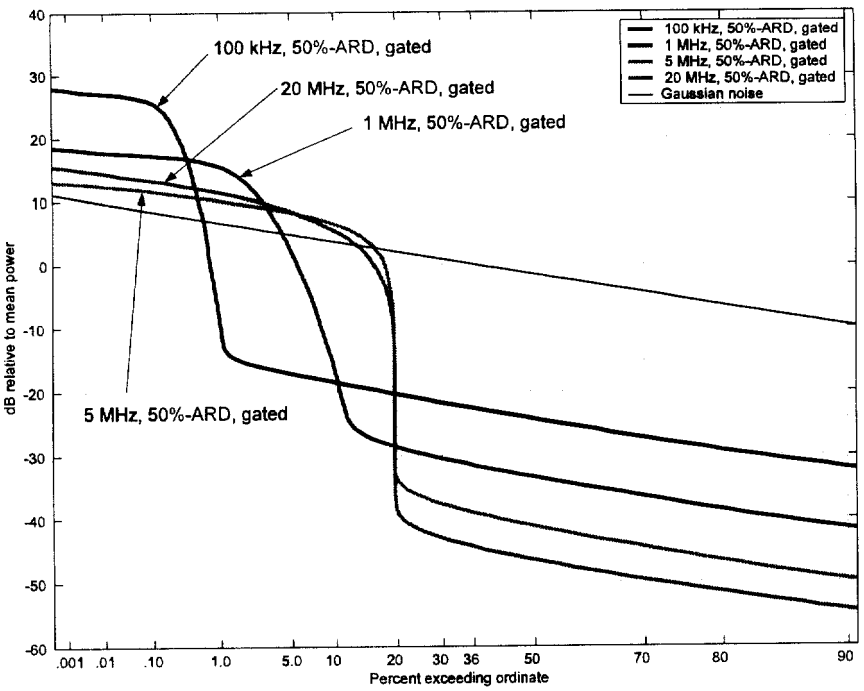

Figure C.3.13. APDs of 50%-ARD, gated UWB signals measured in a 3-MHz bandwidth.

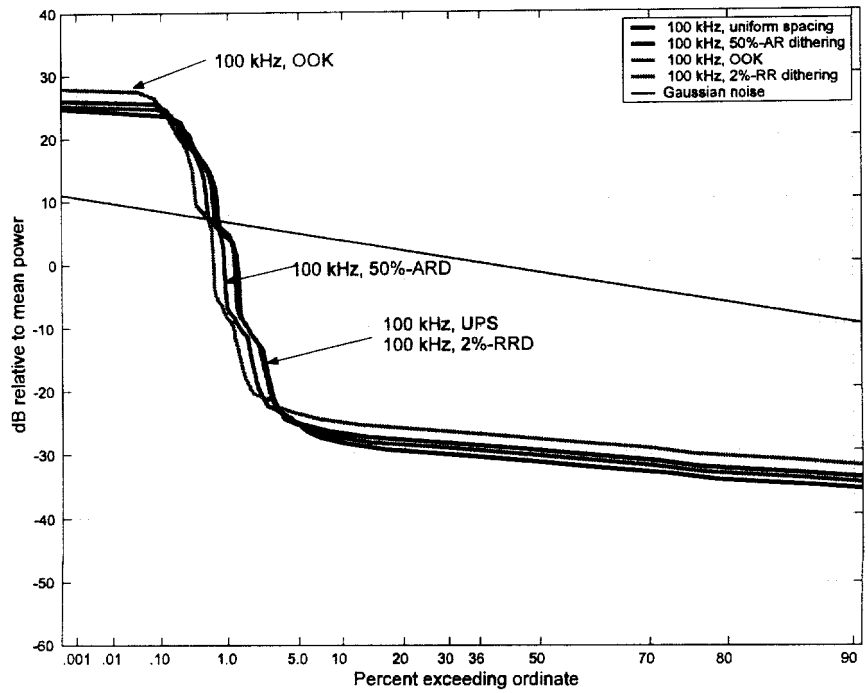

Figure C.3.14. APDs of 100-kHz PRF, non-gated UWB signals measured in a 20-MHz bandwidth.

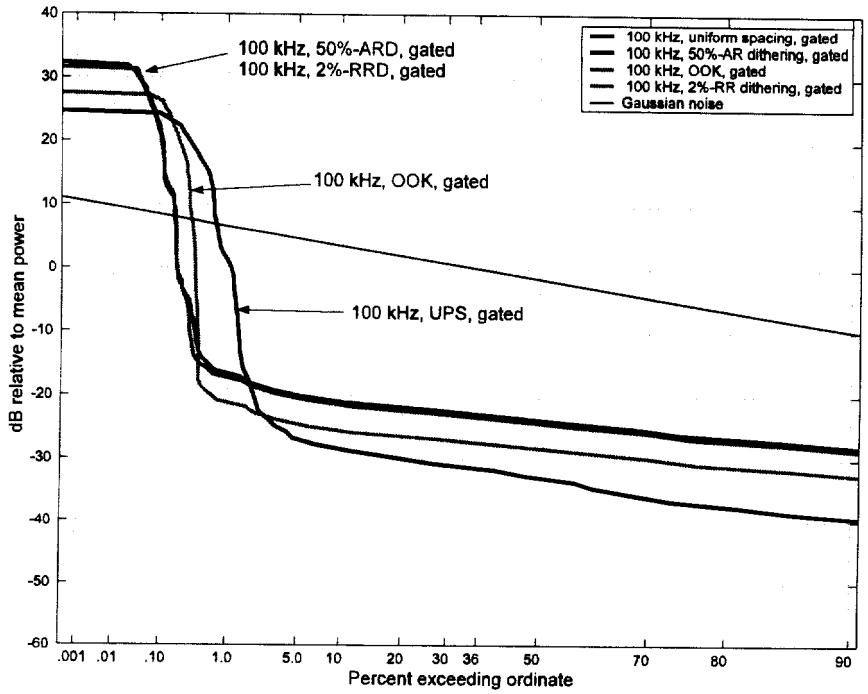

Figure C.3.15. APDs of 100-kHz PRF, gated UWB signals measured in a 20-MHz bandwidth.

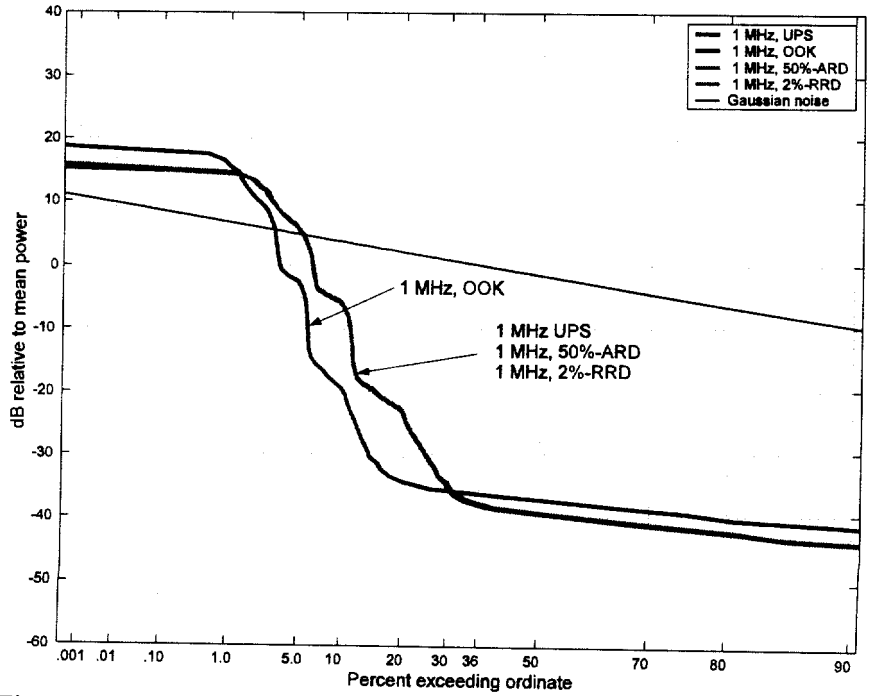

Figure C.3.16. APDs of 1-MHz PRF, non-gated UWB signals measured in a 20 MHz bandwidth.