In response to the issue raised by the Federal Communications Commission concerning PinPoint Corporation's submission OGK30011534001 (731 confirmation number EA94165, correspondence reference 8234), PinPoint provides the following clarification and data. The question concerned the measurement of processing gain under Part 15.247 of the rules. This response will consist of several parts: a statement of the applicable rule, a statement of the results, a description of the system and the measurement process, derivation of the theoretical basis for the measurements and finally the measured data that form the basis for the results.

Applicable Rule

15.247(e): The processing gain of a direct sequence system shall be at least 10 dB. The processing gain represents the improvement to the received signal-to-noise ratio, after filtering to the information bandwidth, from the spreading/despreading function. The processing gain may be determined using one of the following methods:

(1) As measured at the demodulated output of the receiver: the ratio in dB of the signal-to-noise ratio with the system spreading code turned off to the signal-to-noise ratio with the system spreading code turned on.

(2) As measured using the CW jamming margin method: a signal generator is stepped in 50 kHz increments across the passband of the system, recording at each point the generator level required to produce the recommended Bit Error Rate (BER). This level is the jammer level. The output power of the intentional radiator is measured at the same point. The jammer to signal ratio (J/S) is then calculated, discarding the worst 20% of the J/S data points. The lowest remaining J/S ratio is used to calculate the processing gain, as follows: $G_p = (S/N)_o + M_j + L_{sys}$, where G_p = processing gain of the system, $(S/N)_o$ = signal to noise ratio required for the chosen BER, M_j = J/S ratio, and L_{sys} = system losses. Note that total losses in a system, including intentional radiator and receiver, should be assumed to be no more than 2 dB.

Results

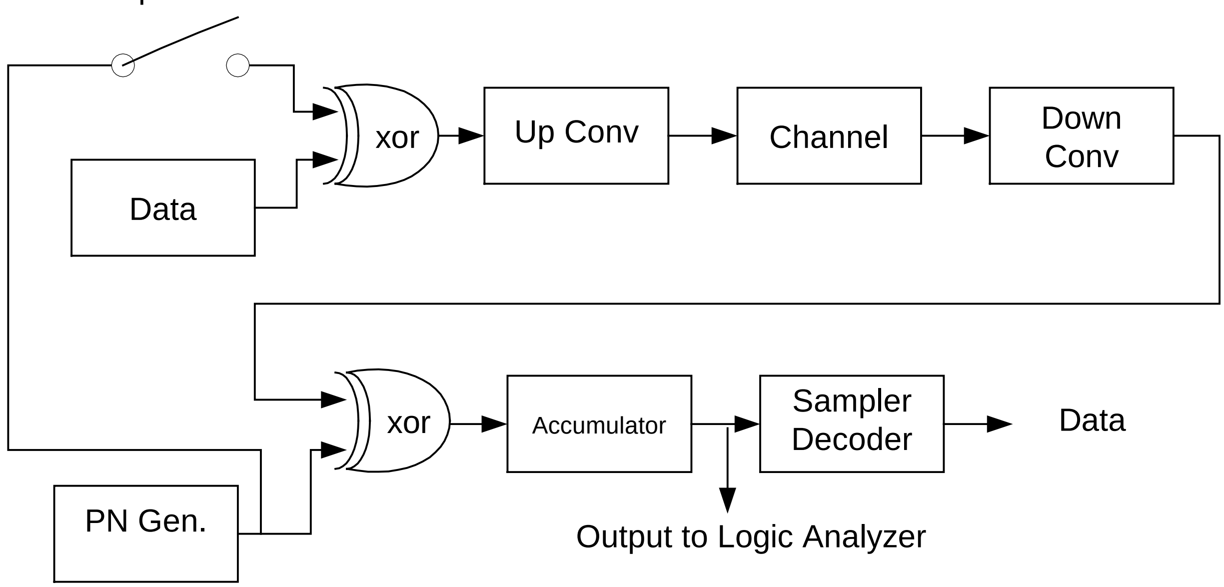
The system firmware was modified to provide test points for conducting bit error rate measurements. In addition, a test mode was introduced that allowed system operation with no spreading. A measurement was made of the baseband signal in the presence of noise with spreading turned off and then repeated with spreading turned on. The ratio of signal-to-noise ratios of system operation with spreading on relative to spreading off was calculated using the data and found to be 19.6dB against a theoretical result of 21.0dB. This was compared to the requirements of Part 15.247(e) and found to be in excess of the requirement for 10dB of processing gain.

Description of the PinPoint 3DiD System and Measurements

PinPoint elects to demonstrate the spreading gain in accordance with 15.247(e) subparagraph (1). Sub Paragraph (2) presents some problems in accurately measuring the system performance because the carrier recovery method utilized by PinPoint for rapid acquisition can lead to erroneous results with a jammer.

The following is a simplified block diagram of the signal processing for the PinPoint 3DiD system. The block diagram emphasizes the spreading and de-spreading aspects of the system.

Switch closed: normal operation
Switch open: test mode



The pseudonoise sequences utilized in both the transmitter and receiver are identical and are synchronous with each other. The system uses codes of length 127 having a chip time of 25 nanoseconds. The receiver subsystem performs 40 correlations simultaneously over a range of expected delays to provide location information of the RF Tag that is part of the complete system. In addition, in the normal spread mode the largest correlation is selected and used for data detection. For the purpose of this submission, firmware was altered to remove this feature since the system bit timing would wander aimlessly when the pseudonoise source is removed at the transmitter. The output from one correlator was used to generate data for this measurement. Also, the baseband data was fixed to a pseudo-random data stream to simplify the determination of bit errors in the demodulated data stream. The baseband data stream was synchronized to the spreading sequence such that the baseband sampler always sampled at the same point in time on the non-spread receive signal as on the spread received signal. In addition, modifications were included to allow for external test points that are normally hidden for product security reasons. All other system functions were left in their normal operating configurations.

These modifications provide the ability to send non-spread data through the entire transmit-receive chain (including the RF elements) in the same manner as spread data. Data demodulation is the same for both spread and non-spread signals. The end result of the demodulation process is a representation of the power of the received signal in digital form, so the tool used to determine the final received baseband signal level is a logic state analyzer. Finally, since the output of the system is digital data, there is no way to directly measure the noise power in the system at baseband, so the noise power was measured at the last intermediate frequency prior to baseband downconversion (at 170MHz).

Theoretical Basis for the Measurement of Processing Gain

Assume the following definitions:

DRx = Received data bit in the normal (spread) configuration
DNRx = Received data bit in the test (non-spread) configuration
DTx= Transmitted data bit in the normal (spread) configuration
DNTx = Transmitted data bit in the test (non-spread) configuration
Dt = Transmitted Data bit
PNi = the i^{th} chip in the Pseudo noise sequence
Ni = The i^{th} noise sample
NRx = The noise in the receiver

The normal (spread) transmitted data stream can be represented as:

$$DTx = Dt \otimes PNi \qquad \text{Equation 1}$$

The test (non-spread) transmitted data stream can be represented as:

$$DNTx = Dt \qquad \text{Equation 2}$$

The received data from the spread transmitted data stream is:

$$DRx = \sum_{i=1}^{127} ((Dt \otimes PNi) \otimes PNi) \otimes Ni \qquad \text{Equation 3}$$

In the system, the transmitted baseband data stream is synchronized with the pseudonoise sequence, so the received data can be represented as:

$$DRx = Dt \otimes \sum_{i=1}^{127} (PNi \otimes PNi \otimes Ni) \qquad \text{Equation 4}$$

In this representation, it is clear that the received baseband data is the transmitted baseband data processed through the correlator (de-spreader) and corrupted by noise from the channel.

When the transmit data is not spread we can represent the output of the receiver as:

$$DNRx = \sum_{i=1}^{127} (Dt \otimes PNi \otimes Ni) \qquad \text{Equation 5}$$

The signal-to-noise ratio of the non-spread received data stream is:

$$SNNRx = \frac{DRx}{NRx} = \frac{\sum_{i=1}^{127} Dt \otimes PNi \otimes Ni}{\sum_{i=1}^{127} Ni}$$ Equation 6

The signal-to-noise ratio of the spread received data stream is:

$$SNRx = \frac{DNRx}{NRx} = \frac{\sum_{i=1}^{127} ((Dt \otimes PNi) \otimes PNi) \otimes Ni}{\sum_{i=1}^{127} Ni}$$ Equation 7

From the definition of the processing gain (ratio of the SNR with spreading to the SNR without spreading), it can be seen that the processing gain is:

Equation 8

$$Gain = 10 * \log \frac{SNRx}{SNNRx} = 10 * \log \frac{\sum_{i=1}^{127} (Dt \otimes PNi \otimes PNi \otimes Ni)}{\sum_{i=1}^{127} (Dt \otimes PNi \otimes Ni)}$$

But since the baseband data is synchronous with the pseudonoise spreading (and despreading) sequences, the processing gain is:

$$Gain = 10 * \log \frac{Dt \otimes \sum_{i=1}^{127} (PNi \otimes PNi \otimes Ni)}{Dt \otimes \sum_{i=1}^{127} (PNi \otimes Ni)}$$ Equation 9

When the data is the same whether spread or not:

$$Gain = 10 * \log \frac{\sum_{i=1}^{127} (PNi \otimes PNi \otimes Ni)}{\sum_{i=1}^{127} (PNi \otimes Ni)}$$

Equation 10

We can reduce the equations further given the properties of pseudonoise sequences. In the absence of noise, the numerator reduces to the 127 since the pseudonoise sequences are identical and synchronous. In the absence of noise, the denominator reduces to 1 since all PN sequences have an equal distribution of ones and zeros except for one chip. As a result the theoretical (noise-free) processing gain is simply:

$$Gain = 10 * \log \frac{127}{1} = 21dB$$

Equation 11

To be valid, the measurements demonstrating processing gain must be conducted with a known noise floor that is identical for the conditions of transmitted data with no spreading and transmitted data with spreading. This formulation also assumes that the baseband data is fully synchronized with the spreading sequence.

Measurements

The PinPoint 3DiD system is designed for use with an external element, the RF Tag. The function of the tag is to shift the frequency of the transmitted signal at 2.442GHz to 5.800GHz, add slow modulation to the shifted signal and radiate back to the system. To demonstrate processing gain, there is no need to complicate the measurements with external modulation, so the tag is replaced with just an external mixer and a signal generator. Finally, an external noise source for control of the signal to noise ratio completes the experimental setup. The experimental configuration is shown below.

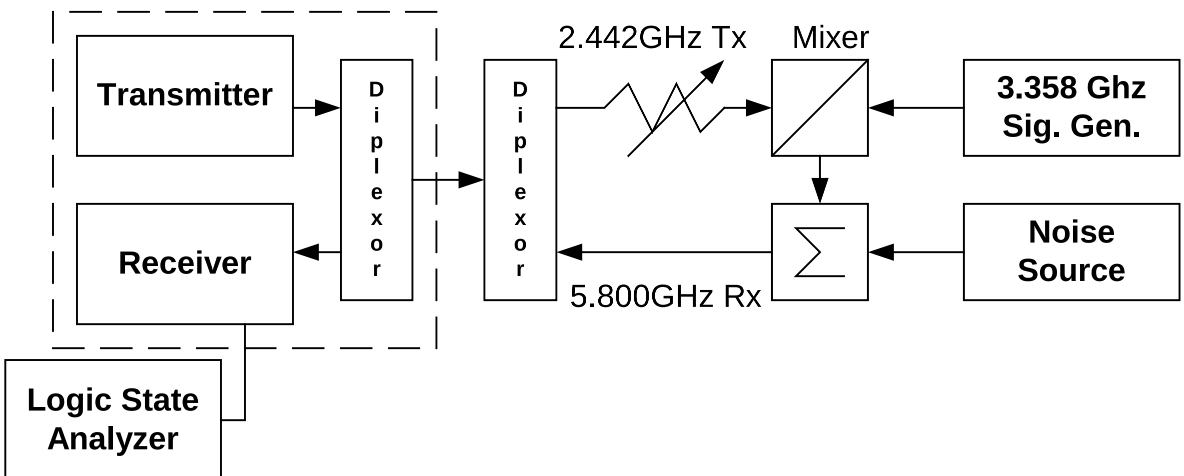


Figure 2 Experimental Setup

The white noise source provided 15.8dB excess noise and is equivalent to –79.2dBm in the 80 MHz system bandwidth. The noise density was held constant through out the tests. The carrier level was adjusted as required. The external mixer and signal generator were used to convert the 2.442GHz transmit signal to 5.8GHz for the receiver. Data was differentially encoded internally within the transmitter and decoded within the receiver. Error pulses and a clock were provided to an external counter.

The firmware provided control to shut off the pseudonoise spreading sequence at the transmitter so that the transmitted data alone modulated the transmit carrier. Figure 3 shows the resulting transmitted spectrum with no spreading applied (that is, with just the baseband data modulating the carrier) and Figure 4 is the transmitter output with spreading. The input to the sampler and decoder was captured on the logic state analyzer. The system was configured to transmit the baseband data without spreading so that the received bit error rate was 0.1 (1 error in 10 bits). The baseband signal-to-noise ratio was 1.5dB.

Table 1 shows the output of the logic state analyzer. It depicts 101 consecutive samples of the demodulated baseband signal while the PN spreading was off. The first column is the sample number, the second column is the magnitude of the baseband signal and the third column is the sign of the signal (0 is positive, 1 is negative). The averaged magnitude of this data set can be found by summing all the magnitudes and dividing by the number of entries, 101. This average magnitude is 1.22. This value represents the level of the baseband signal in the presence of noise with no spreading applied. The theoretical level for perfect demodulation is 1, so this data clearly shows the influence of the noise in the system.

Table 2 presents the same data for the condition that the spreading sequence was enabled. This data is in the same format as Table 1, where the second column of data is the magnitude of the demodulated baseband data. For this data set, the averaged magnitude is 109.2. This value represents the level of the baseband signal in the presence of noise with spreading applied. The theoretical level for perfect correlation is 127.

The averaged magnitude of the baseband signal with spreading on represents the numerator of equation 8 and the averaged magnitude of the baseband signal with spreading off is the denominator, so the result of evaluating that equation is:

Processing Gain = 10 * log(109.2/1.25) = 19.6 dB

To check this measurement, the improvement of the system bit error rate can be examined. The demodulation technique used in this system provides a bit error rate equal to twice the error rate for coherently detected binary phase shift keyed data. For a reference of the bit error rate performance of BPSK, see Lindsey and Simon, Telecommunication Systems Engineering, Dover, 1991, page 195, equation 5-47 and page 234, Figure 5-16.

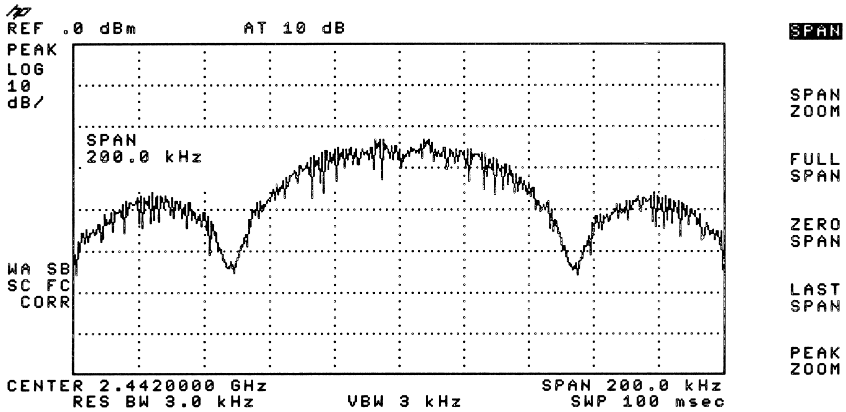
So, for this system,

$$Pe = 2 * 0.5 * erfc(\sqrt{SNR})$$

Evaluating this expression for error probabilities of 0.1 and $1x10^{-7}$ results in signal-to-noise ratios of 1.32dB and 11.52dB, respectively. In other words, the signal-to-noise increase needed to go from a bit error rate of 0.1 to $1x10^{-7}$ is

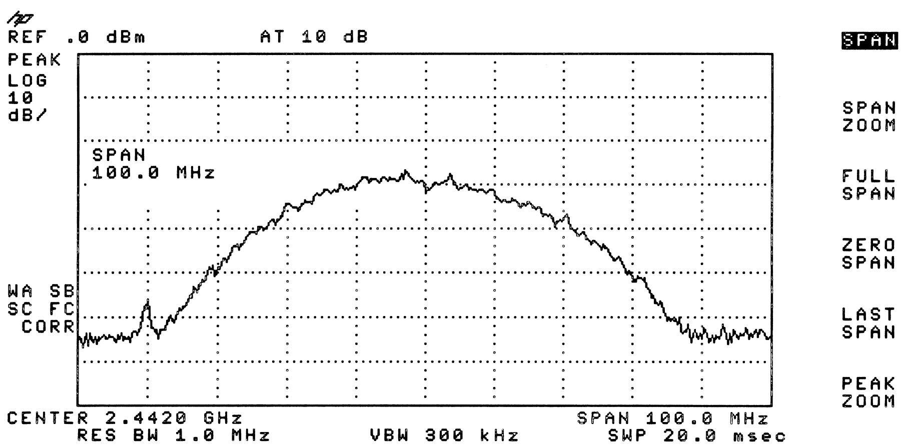
10.2dB. From this we can conclude that the system has at least a 10.2dB increase in processing gain when spreading is turned on. From the other measurement we can conclude that the processing gain is 19.6dB. Both measurements conclusively demonstrate processing gain in excess of 10dB as required by Part 15.247(e)(1).

Figure 3



Non-Spread Transmitted Signal Spectrum

Figure 4



Spread Transmitted Signal Spectrum

Table 1: Sampled Received Baseband Signal Power Level, No Spreading

MACHINE 1 - State Listing

Label > Base >	COR VL Hex	SIGN Hex	Label > Base >	COR VL Hex	SIGN Hex	Label > Base >	COR VL Hex	SIGN Hex
0	01	1	46	01	0	92	01	0
1	01	0	47	01	0	93	01	1
2	01	0	48	01	1	94	01	0
3	01	1	49	01	1	95	01	0
4	01	0	50	01	0	96	01	1
5	01	1	51	01	1	97	01	0
6	01	1	52	01	1	98	05	1
7	01	0	53	01	1	99	01	1
8	01	0	54	01	0	100	01	0
9	03	1	55	01	1			
10	01	1	56	01	0			
11	01	1	57	01	1			
12	01	1	58	03	0			
13	01	1	59	01	0			
14	01	0	60	01	0			
15	03	0	61	01	0			
16	01	0	62	01	1			
17	01	1	63	01	0			
18	01	1	64	01	0			
19	01	0	65	01	1			
20	01	1	66	01	0			
21	03	1	67	03	1			
22	01	1	68	01	1			
23	01	0	69	01	0			
24	01	1	70	01	0			
25	01	0	71	01	1			
26	01	1	72	01	1			
27	01	0	73	01	1			
28	03	0	74	01	1			
29	01	0	75	01	1			
30	01	0	76	01	0			
31	01	1	77	01	0			
32	01	0	78	01	0			
33	01	0	79	01	1			
34	01	1	80	01	1			
35	03	0	81	01	0			
36	01	1	82	01	1			
37	01	1	83	01	1			
38	01	0	84	01	1			
39	01	0	85	03	0			
40	01	1	86	01	1			
41	01	1	87	01	0			
42	01	1	88	01	1			
43	01	1	89	01	0			
44	01	1	90	01	0			
45	03	0	91	01	0			

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Table 2: Sampled Received Baseband Signal Power Level with Spreading

MACHINE 1 - State Listing

Label Base >	COR VL Decima >	SIGN Hex
0	110	0
1	111	1
2	110	0
3	108	1
4	106	0
5	109	1
6	109	1
7	104	1
8	107	1
9	109	0
10	112	1
11	104	1
12	111	0
13	108	1
14	102	0
15	106	0
16	107	1
17	108	1
18	102	0
19	111	0
20	110	0
21	104	0
22	107	0
23	109	1
24	112	1
25	110	1
26	113	0
27	111	0
28	102	1
29	104	0
30	111	0
31	107	0
32	110	1
33	113	0
34	110	1
35	111	0
36	110	1
37	109	1
38	114	1
39	110	1
40	104	0
41	112	1
42	113	1
43	106	0
44	115	1
45	110	0
46	112	0
47	115	1
48	108	1
49	108	0
50	109	0
51	105	0
52	116	0
53	110	0
54	110	1
55	116	1
56	109	1
57	113	0
58	114	0
59	110	1
60	107	0
61	105	0
62	102	0
63	111	1
64	109	0
65	111	1
66	111	0
67	110	1
68	114	1
69	112	1
70	112	1
71	111	0
72	107	1
73	114	1
74	105	0
75	111	1
76	112	0
77	114	0
78	105	1
79	110	1
80	113	0
81	111	0
82	111	0
83	109	0
84	110	0
85	105	1
86	104	1
87	104	1
88	107	0
89	108	0
90	111	1
91	104	0
92	115	0
93	112	0
94	108	1
95	110	0
96	114	1
97	104	0
98	111	1
99	104	1
100	102	1

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