FCC TEST REPORT

PASS TRANSMITTER

SUBJECT: *TRANSMITTER PROCESS GAIN VERIFICATION*

FCC RULE NUMBER: *15.247*

TEST METHODS: *CW JAMMER MARGIN & SPECTRAL DATA*

PASS ID *#4213*

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1.0 OVERVIEW:

This report provides test data for the processing gain verification for the PRISM PASS Transmitter Unit.

2.0 REFERENCES:

Spread Spectrum Systems with Commercial Applications, third edition. Robert C. Dixon

3.0 CONCLUSION:

Three test methods were used to demonstrate that the PRISM PASS Transmitter Unit meets the minimum processing gain requirement of 10 dB.

4.0 TRANSMITTER SPECIFICATIONS:

FREQUENCY:	915 MHz
MODULATION:	BPSK
CHIP RATE:	10 Mcps
MODULATION RATE:	158,730 bps
CODE LENGTH:	63 bits
THEORETICAL PROCESS GAIN:	17.4 dB

5.0 PROCESS GAIN:

Process gain in a direct sequence system is a function of the RF (radio frequency) bandwidth of the signal transmitted, compared with the bit rate of the information. The gain in question is exhibited as a signal-to-noise improvement resulting from the RF-to-information bandwidth tradeoff.

The assumption taken is that the RF bandwidth is that of the main lobe of the [(sinx)/x]2 direct sequence spectrum, which is 0.88 times the bandwidth-spreading code clock rate. Therefore, for a system having 10 Mcps code clock rate and a 158,730 bps information rate the process gain would be $(0.88 \times 10^7)/(158{,}730) = 55.4$ or 17.4 dB.

In reality, the process gain will be less due to modulation inefficiency and bandpass filtering imperfections in the transmitter. The purpose of this report is to show that the processing gain is still greater then 10 dB.

6.0 PASS TRANSMITTER

A PASS transmitter unit (Figure 1) is a device worn on the wrist by prison inmates for the purpose of tracking location in the prison and identification of the individual wearing the unit. It is a self contained single channel spread spectrum transmitter that has its own battery, antenna and housing. It transmits RF in short chirps, once every two seconds.

Figure 1: PASS Transmitter Unit

7.0 BASIC THEORY OF OPERATION

The PASS transmitter operates at 915 MHz using direct sequence Bi-Phase Shift Keying (BPSK). The modulation data rate is 158,730 bps with a chipping rate of 10 Mcps (a 63 bit code). The transmitter operates in chirp mode, normally chirping once for 176 micro seconds every 2 seconds. The chirp transmission data length is 28 bits. The first three bits are defined as preamble, the next 15 bits for identification (ID) code, and the 10 remaining bits for status and CRC checking. The most important bits for valid reception are the three preamble bits (these are the correlator output pulses used for measuring waveforms and amplitudes during testing). The receiver demodulates the spread spectrum RF energy using a surface acoustic wave (SAW) correlator. Figure 6 shows a typical correlator output pulse generated by the transmitter. Figure 5 shows the relationship between bandwidth used and correlator pulse shapes. These pulses are further processed to obtain digital bits (ones and zeros) for computer processing. Valid data is a successful transmission of the 28 bits of a specified ID code.

SUMMARY:

FREQUENCY:	915 MHz
MODULATION:	BPSK
CHIP RATE:	10 Mcps
MODULATION RATE:	158,730 bps
CODE LENGTH:	63 bits
THEORETICAL PROCESS GAIN:	17.4 dB

8.0 PROCESSING GAIN TESTS & METHODS

Three methods will be used to verify the transmit processing gain. The methods are by measuring the transmit spectra with a spectrum analyzer, by observing the correlated pulses, and by using an interferor jamming signal summed with the desired signal. The transmitter can be switched from spread spectrum transmission to CW mode for test purposes. This allows the peak power to be measured easily and compared to the spread spectrum power spectra and interferor jamming signal.

8.1 Spectra Method

The first method used to show process gain is the transmit spectra as shown in Figure 3. The transmit CW (continuous wave) peak power is also shown in Figure 3. This is the quickest and most informative data to demonstrate the spread spectrum bandwidth used. The limits in Figure 3 show compliance of >20 dB to the side lobe emission limits. Figure 2 shows a proper bi-phase modulated signal with a power distribution of $[(\sin x)/x]^2$.

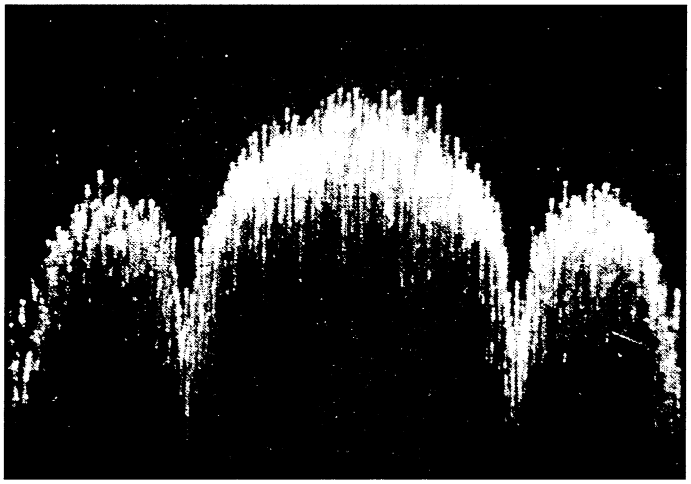

Figure 2: Proper Bi-Phase Modulated Spectra

Figure 4 shows that 90% of the total power is contained in a bandwidth equal to twice the chip rate, thus, for the PASS unit the bandwidth is 20 MHz. Note also that for a bandwidth of 0.7 (X2) of the chip rate (14 MHz), the total power is still 80%, or a loss of 1 dB and at 0.44 (X2) of the chip rate (8.8 MHz) its 63% or a loss of 2 dB. It is therefore important that the bandwidth filtering in the transmitter be wider then 8.8 MHz to have a high processing gain. As shown in Figure 2, the PASS spectra has a power distribution greater then 10 MHz. Figure 3 also shows that the side lobes beyond ±10 MHz are a minimum of 20 dB down.

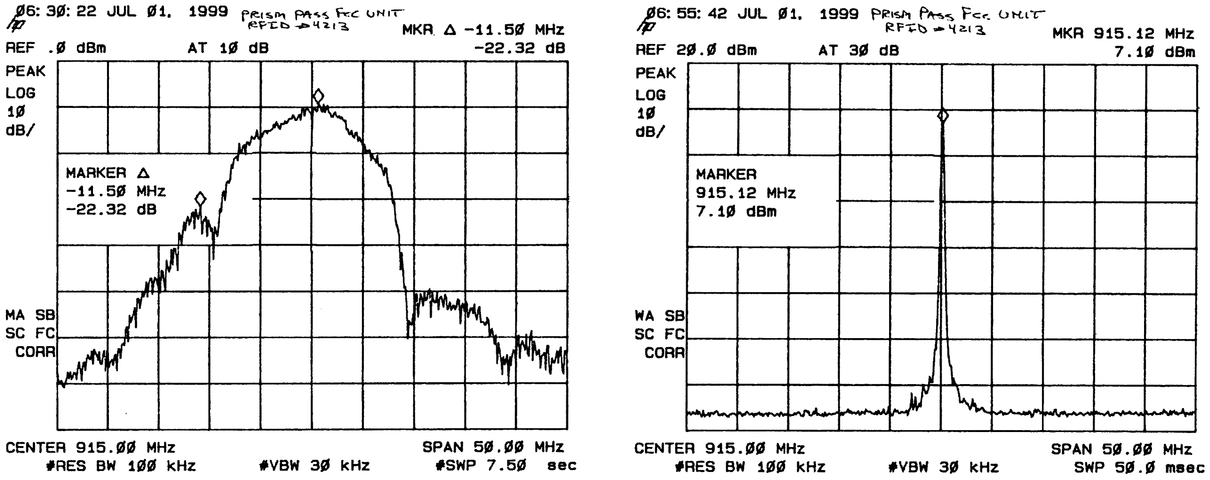

Figure 3: PASS Modulation Spectra & Peak Power Output

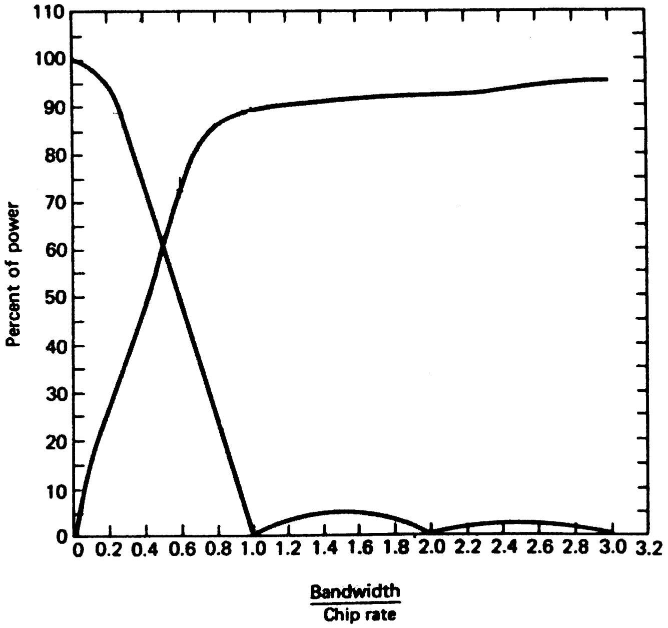

Figure 4: Power Distribution in $[(\sin x)/x]^2$ Spectrum

Spectra Method Conclusion

The bandwidth requirements required for the theoretical processing gain is 8.8 MHz. The spectrum analysis plot shows that the bandwidth is greater then 8.8 MHz, and that the spectra is relatively close to the curve presented in Figure 2 over an 8.8 MHz bandwidth. This implies that the PASS transmitter processing gain is greater than 10 dB.

8.2 Correlated Pulse Wave Shape Method

Signal power loss is not only the effect of bandwidth restriction, however. The side lobes contain much of the harmonic power of the modulation. Thus restriction to a narrow RF bandwidth is the equivalent of restricting the rise and fall times of the modulating code. Therefore, the sharply peaked triangular correlation of a coded signal is rounded by a bandwidth restriction. Figure 5 shows the effect of band restriction on the correlation function of a direct sequence signal. Figure 6 shows the correlated pulse out from a receiver as transmitted from the PASS transmitter.

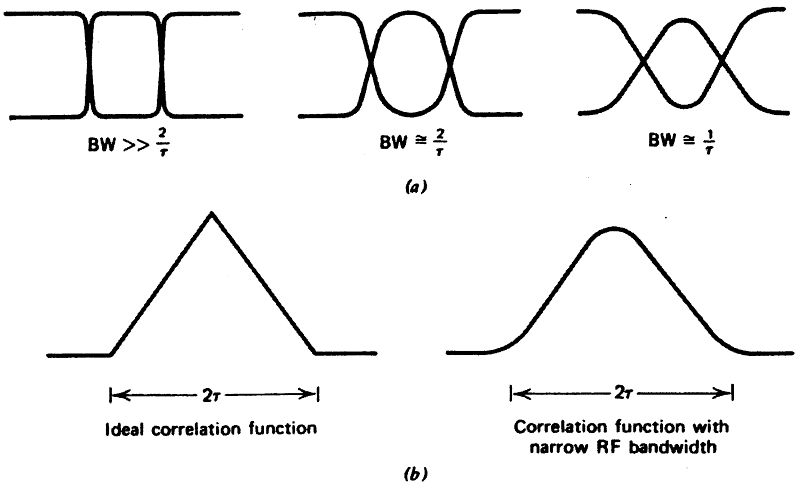

Figure 5: RF bandwidth restriction and its effect on typical direct sequence signals: (a) RF envelope of direct sequence signal for various RF bandwidths; (b) effect of bandwidth restriction on correlation function.

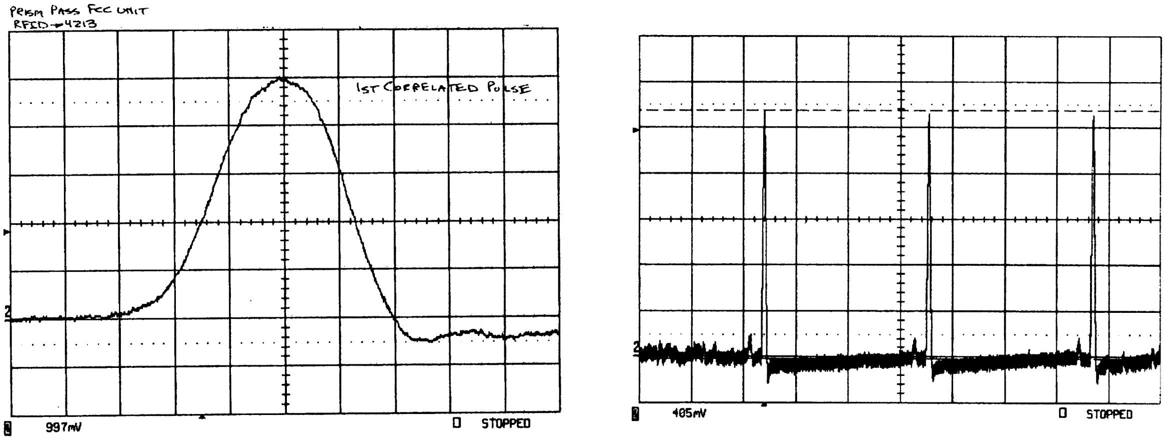

Figure 6: Correlation Pulses from PASS Transmitter

Correlation Pulse Wave Shape Method Conclusion

The correlation pulse shows that the combined transmitter and receiver bandwidth allows a correlation pulse with a bandwidth of greater then 8.8 MHz.

8.3 Jamming Method

The third method used to determine the process gain is by using a Receiver with an interference jammer signal (J) summed with the desired signal (S) and measuring the ratio between the two to give J/S. See Figure 7 for setup details. Note that now we have receiver losses L_{sys} that enter into the gain calculation.

Process gain (Gp) is calculated using:

$$Gp = J/S + L_{sys} + (S/N)_{in}$$

where: L_{sys} = receiver processing losses, taken as 2 dB

$(S/N)_{in}$ = Input Signal to noise, determined by interferor measurements for these tests

A continuous sweeping RF CW (jammer) interferor or a discrete stepped RF CW interferor may be used. In this case the stepped CW RF interferor was chosen. The jammer is stepped over the receiver bandwidth in 50 kHz steps from 908.5 to 921.5 MHz.

To set up the jamming tests, the input sensitivity was first established. The transmit spread spectrum signal (with no jammer signal applied) was attenuated to the receiver until the computer display was on the verge of stopping to receive the ID code of that transmitter (the computer data processing eliminates any wrong ID codes being received). This establishes the lowest signal level that the system can operate at and becomes the reference sensitivity level. The transmitter output is now increased by 40 dB and the jamming signal applied. The jamming signal level is increased until the ID code is on the verge of not being received. The ratio between the jamming signal and the desired signal provides the jamming margin J/S.

8.3.1 JAMMING TESTS

8.3.1.1. Connect equipment as shown in Figure 7.

8.3.1.2. Set the Jammer signal generator to off.

8.3.1.3. While observing the ID code on the computer monitor, increase the attenuation on the PASS transmitter power (starting with a minimum of 40 dB) until the ID code stops being displayed. Decrease the attenuation slowly until the code just appears. Keep in mind that the transmitter chirps only once every 2 seconds.

8.3.1.4. Set the PASS transmitter to CW mode (this is equivalent to peak power output in spread spectrum). Using the spectrum analyzer, measure the power level of the signal at the input of the receiver. This will measure the minimum power level that the receiver can operate at.

8.3.1.5. Increase the input signal level to the receiver by switching out 40 dB of attenuation in the PASS transmitter path. Verify the 40 dB attenuation with the spectrum analyzer and record the power level at the input of the receiver. Return the transmitter to spread spectrum mode. Verify with the monitor that the ID code is being displayed.

8.3.1.6. Apply the jammer CW signal starting at a power level of near -70dBm (using the attenuator in the generator). Increase the power level until the ID code stops. Decrease the power level slowly until the ID code just appears. Measure and record the power level at the receiver input.

8.3.1.7. Repeat step 6 every 50 kHz from 908.5 to 921.5 MHz.

8.3.1.8. In the table, record for every 50 kHz, the difference between the transmitter power level and the jammer power level. This is the J/S number.

8.3.1.9. Calculate process gain using:

$Gp = J/S + Lsys + (S/N)_{in}$

Lsys = receiver processing losses, 2 dB

S/Nin = Input Signal to noise, set to 0 dB for these tests

$= J/S + 2 + (S/N)_{in}$

$(S/N)_{in}$ is recorded in Table 2.
J/S is recorded in Table 1 and shown graphically in Figure 8.
Receiver sensitivity = -96 dBm

8.3.2 Jammer Testing Conclusion

J/S ranges from -0.7 dB to over 8.6 dB. Excluding 20% of the lowest points, the level becomes >1.0 dB. The average is closer to 3 dB. Therefore, using 1.0 dB as the worst value, we have:

$Gp = J/S + Lsys + (S/N)_{in}$

$1 + 2 + 8.1$

11.1 dB worst case, and 13.1 dB for average.

The process gain is typically >11 dB, and is therefore greater then the FCC 10 dB requirement.

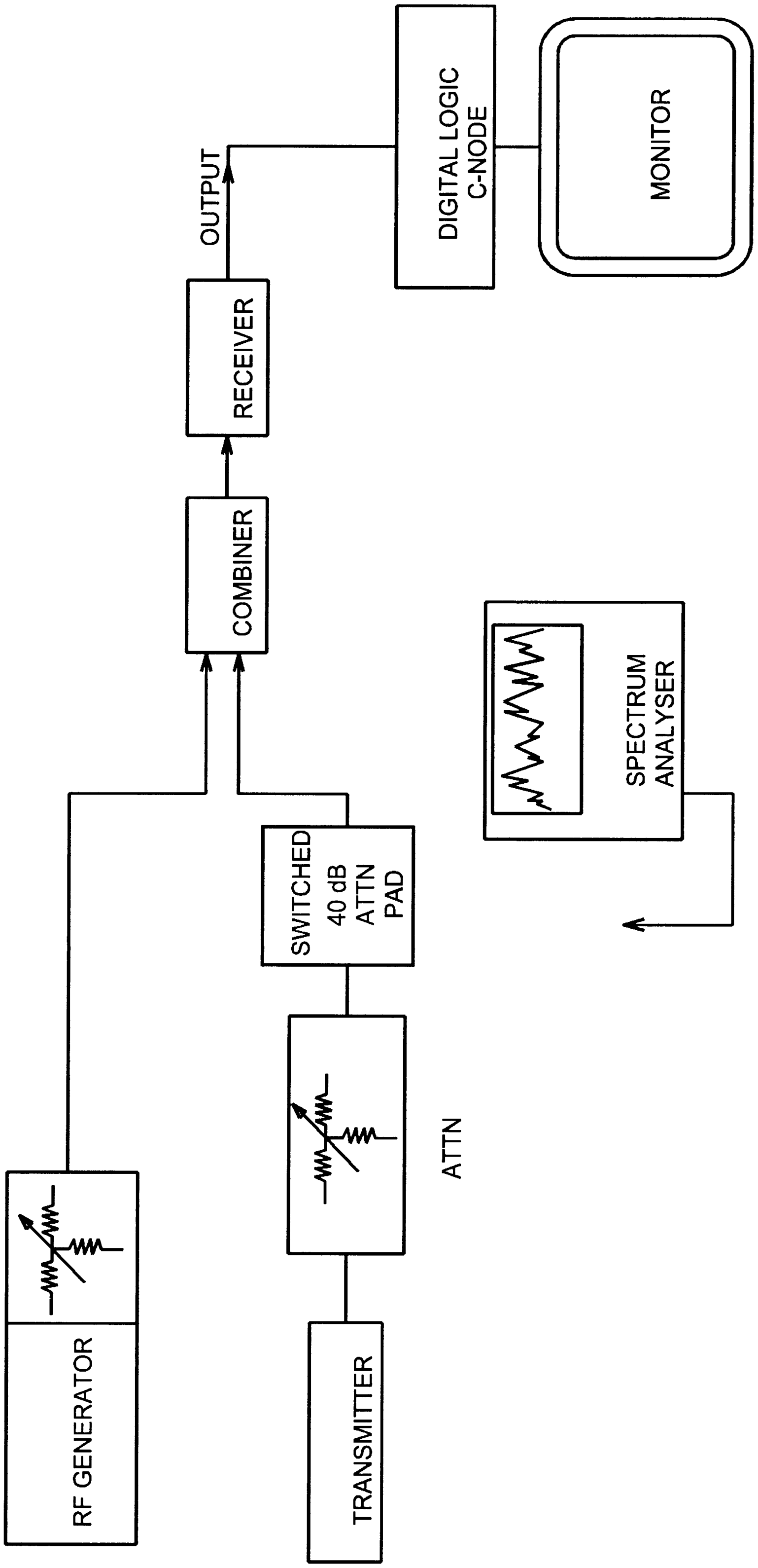

Figure 7: System Setup; Jamming Tests

TABLE 1. JAMMER POWER LEVELS (dBm)

Freq.	Power	Freq.	Power	Freq.	Power
908.50	7.60	909.50	4.30	910.50	2.30
908.55	6.00	909.55	4.10	910.55	2.40
908.60	5.80	909.60	4.80	910.60	3.10
908.65	6.50	909.65	4.30	910.65	3.40
908.70	5.10	909.70	4.10	910.70	2.60
908.75	4.60	909.75	5.20	910.75	1.90
908.80	4.80	909.80	4.50	910.80	2.00
908.85	5.10	909.85	5.20	910.85	2.50
908.90	5.40	909.90	4.20	910.90	2.70
908.95	5.30	909.95	3.80	910.95	2.60
909.00	5.50	910.00	3.70	911.00	2.20
909.05	5.60	910.05	3.10	911.05	1.80
909.10	5.40	910.10	2.90	911.10	3.40
909.15	4.80	910.15	4.70	911.15	3.20
909.20	4.70	910.20	4.80	911.20	1.30
909.25	4.30	910.25	3.40	911.25	0.40
909.30	4.10	910.30	2.60	911.30	0.40
909.35	4.20	910.35	3.20	911.35	2.50
909.40	4.40	910.40	3.40	911.40	1.40
909.45	5.00	910.45	2.80	911.45	1.30

Freq.	Power	Freq.	Power	Freq.	Power
911.50	1.40	912.50	-0.10	913.50	1.70
911.55	2.40	912.55	-0.20	913.55	0.40
911.60	3.00	912.60	0.50	913.60	-0.50
911.65	1.50	912.65	0.90	913.65	-0.70
911.70	0.70	912.70	1.10	913.70	0.00
911.75	0.60	912.75	0.70	913.75	0.60
911.80	1.00	912.80	0.40	913.80	3.00
911.85	0.70	912.85	-0.10	913.85	2.00
911.90	0.90	912.90	-0.40	913.90	0.40
911.95	1.30	912.95	-0.10	913.95	-0.20
912.00	0.70	913.00	0.00	914.00	0.00
912.05	0.90	913.05	-0.80	914.05	0.90
912.10	1.80	913.10	0.00	914.10	3.40
912.15	1.70	913.15	3.60	914.15	0.90
912.20	0.70	913.20	1.00	914.20	-0.40
912.25	0.20	913.25	0.70	914.25	-0.50
912.30	0.80	913.30	1.90	914.30	-0.20
912.35	3.00	913.35	2.20	914.35	0.20
912.40	2.00	913.40	0.70	914.40	0.10
912.45	0.30	913.45	0.60	914.45	0.00

TABLE 1. JAMMER POWER LEVELS (dBm) *continued*

Freq.	Power	Freq.	0.40	Freq.	Power
914.50	0.50	915.50	-0.10	916.50	3.20
914.55	2.90	915.55	0.00	916.55	2.20
914.60	3.40	915.60	0.90	916.60	2.40
914.65	0.90	915.65	2.10	916.65	3.20
914.70	1.00	915.70	2.20	916.70	3.20
914.75	1.30	915.75	1.70	916.75	2.70
914.80	0.30	915.80	2.20	916.80	3.70
914.85	-0.10	915.85	3.50	916.85	5.40
914.90	0.30	915.90	3.90	916.90	3.30
914.95	1.00	915.95	1.70	916.95	2.50
915.00	5.60	916.00	0.00	917.00	4.10
915.05	1.50	916.05	-0.10	917.05	4.00
915.10	1.50	916.10	9.00	917.10	2.20
915.15	1.20	916.15	4.10	917.15	2.30
915.20	1.60	916.20	3.40	917.20	2.90
915.25	2.80	916.25	1.90	917.25	2.70
915.30	1.10	916.30	1.80	917.30	2.70
915.35	1.10	916.35	2.20	917.35	2.80
915.40	3.70	916.40	2.50	917.40	3.30
915.45	1.40	916.45	2.90	917.45	3.30

Freq.	Power	Freq.	Power	Freq.	Power
917.50	3.30	918.50	4.70	919.50	6.20
917.55	3.70	918.55	4.20	919.55	6.30
917.60	5.30	918.60	4.20	919.60	6.30
917.65	5.90	918.65	5.50	919.65	5.90
917.70	4.70	918.70	5.00	919.70	5.30
917.75	3.10	918.75	4.60	919.75	6.30
917.80	3.10	918.80	6.00	919.80	6.70
917.85	5.00	918.85	6.50	919.85	7.00
917.90	4.10	918.90	6.00	919.90	6.60
917.95	3.80	918.95	6.10	919.95	6.80
918.00	4.40	919.00	5.60	920.00	7.30
918.05	4.20	919.05	5.20	920.05	7.20
918.10	4.50	919.10	5.30	920.10	7.00
918.15	5.30	919.15	5.50	920.15	7.30
918.20	5.10	919.20	5.20	920.20	7.00
918.25	5.10	919.25	6.00	920.25	6.30
918.30	5.10	919.30	6.30	920.30	5.70
918.35	6.00	919.35	6.60	920.35	6.30
918.40	5.20	919.40	6.60	920.40	6.50
918.45	4.80	919.45	6.90	920.45	6.80

TABLE 1. JAMMER POWER LEVELS (dBm) *continued*

Freq.	Power
920.50	7.10
920.55	7.80
920.60	8.00
920.65	8.00
920.70	8.20
920.75	7.20
920.80	7.10
920.85	7.10
920.90	7.00
920.95	7.00
921.00	4.10
921.05	7.60
921.10	8.00
921.15	8.30
921.20	8.30
921.25	8.30
921.30	8.50
921.35	8.40
921.40	8.50
921.45	8.50
921.50	8.60

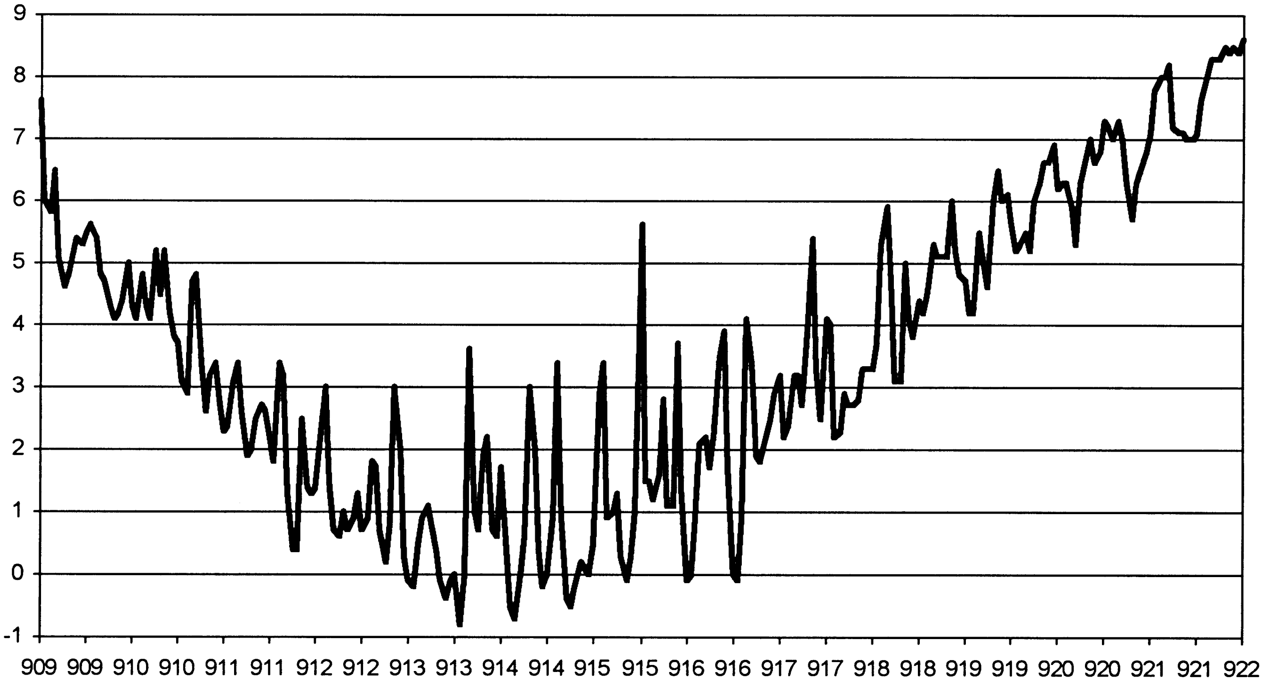

Figure 8: Jamming Margin shown Graphically

9.0 RECEIVER NOISE:

The first step is to establish the signal to noise ratio [(S/N)in] of the receiver. There are several ways of establishing signal to noise, however, the receiver design limits the methods that can be used. One suggested method is to switch between spread spectrum and CW and measure the noise level for each position. The receiver used for these tests has the correlator output available only that resulted in improved noise performance for CW mode, thus not providing the data we required. The other method is to use an interferor CW signal as a noise source. Depending on the receiver design, as the interferor signal is increased, the output noise floor may increase, the output signal may decrease, or both. In our case, the signal decreased with the noise floor being constant. Therefore, the output variation approach is chosen. Here, the output voltage of the receiver correlator was measured prior to the CW interferor being applied. The interferor amplitude was increased in amplitude until the level was equal to the CW output of the PASS unit (this set the spread spectrum power equal to the interferor signal). Again the correlator amplitude was measured and then compared to the normal reference correlator output amplitude. This established indirectly, the signal to noise ratio [(S/N)in].

9.1 Receiver Input Noise Test

9.1.1. Prior to performing the following tests, measure and record the losses through the combiner and cable to the receiver over the test frequency range.

9.1.2. Connect equipment as shown in Figure 11.

9.1.3. Set the Interferor signal generator to off.

9.1.4. While observing the ID code on the computer monitor, increase the attenuation (decreasing the signal power) on the PASS transmitter output (starting with a minimum of 40 dB) until the ID code stops being displayed. Decrease the attenuation slowly until the code just appears. Keep in mind that the transmitter chirps only once every 2 seconds.

9.1.6. Increase the input signal level to the receiver by switching out 40 dB of attenuation in the PASS transmitter path. Verify the 40 dB attenuation with the spectrum analyzer and record the CW PASS power level at the input of the receiver. In spread spectrum mode, measure the correlator output amplitude, voltage V_1. See Figure 9.

9.1.7. Apply the interferor CW signal at 914.5 MHz at the same power level as the PASS unit in CW mode. Repeat at 915.5 MHz. Measure and record both readings for the correlator output amplitude, voltage V_2. See Figure 10.

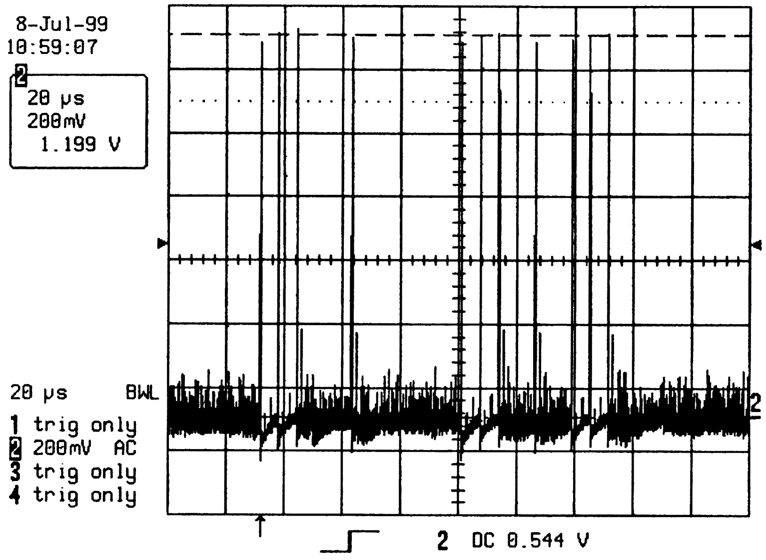

Figure 9: Correlator Output Pulses V_1; Reference Amplitude

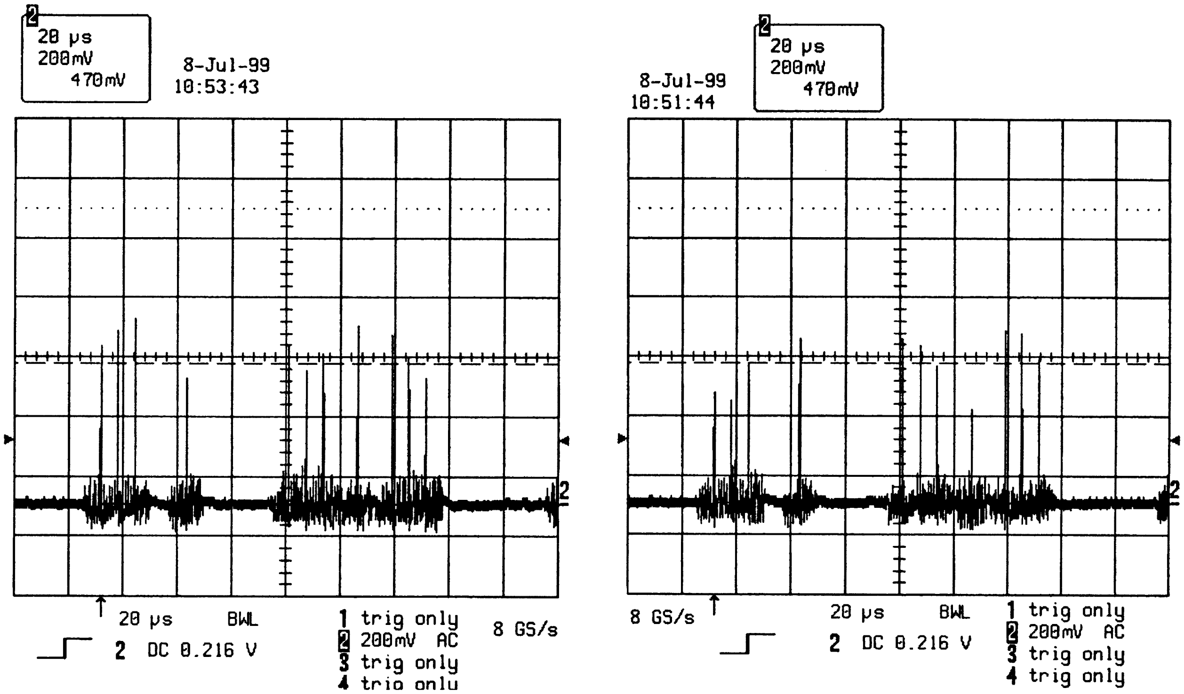

Figure 10: Correlator Output Pulses V_2; Amplitude with CW Interferor Signal

TABLE 2: (S/N)in
20 log V_1 / V_2 20 log 1.199/0.470 **8.1 dB**

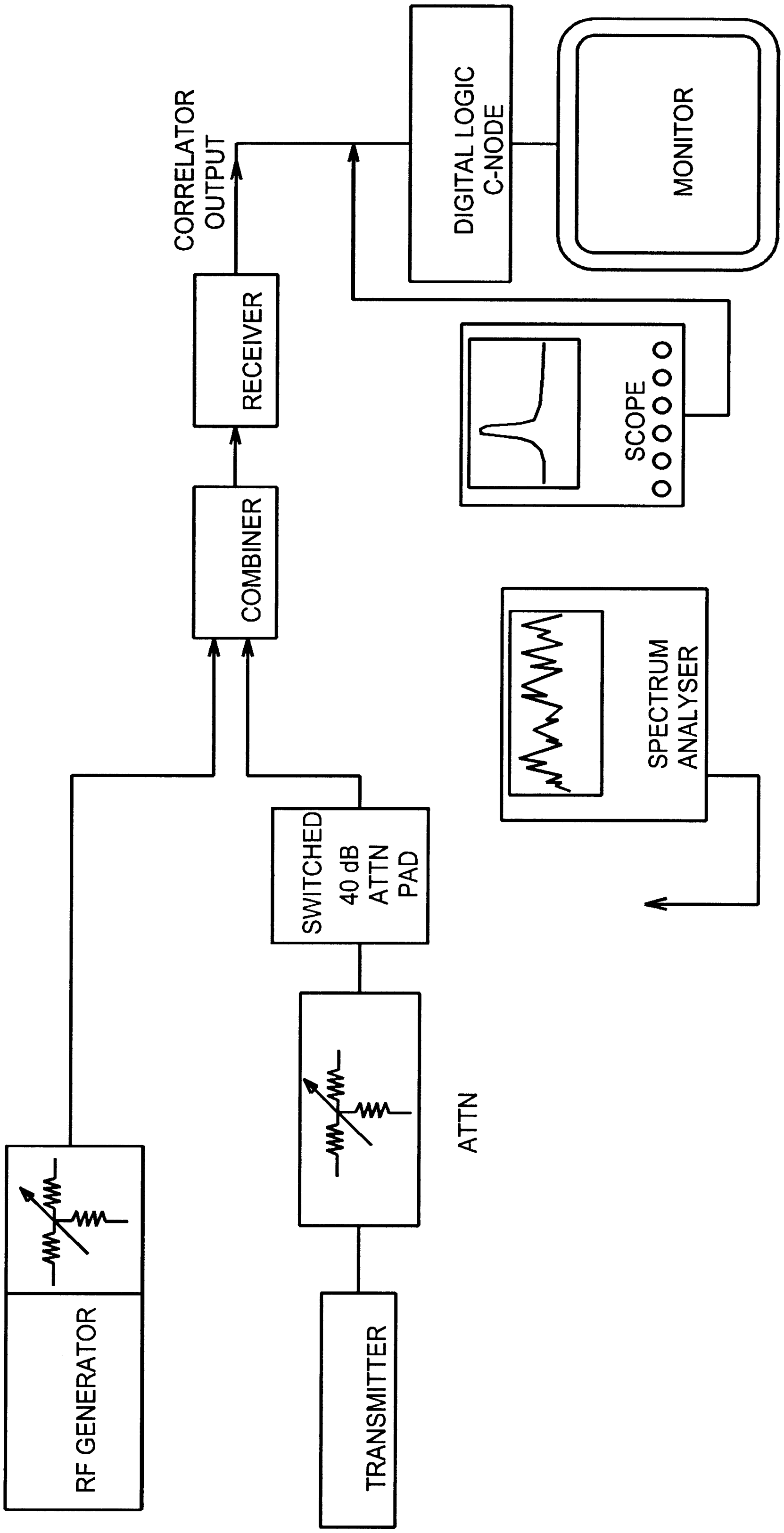

Figure 11: System Setup; Receiver Input Noise Tests

10. EQUIPMENT USED

Scope, Lecroy	LC584AM	
Scope, Tektronix	TDS360	6421-1963
Spectrum Analyzer	HP8595E	6419-2146
Network Analyzer	HP8753D	6424-1902
Attenuator 110 dB	HP8496A	6404-1848
Attenuator 11 dB	HP8494A	6404-1849
Combiner, Mini-Circuits	ZB4PD1-930	
Receiver	PRISM AP	#299
Digital Electronics	PRISM C-Node System	