RXA-100	**RDA-100**
RXA-1000	**RDA-500**
RXA-300	**RDA-300**

SPREAD - SPECTRUM RADIOS

DETAILED TECHNICAL DESCRIPTION

(VERSION 1.2)

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CONFIDENTIAL

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1. INTRODUCTION

The RXA/RDA series radios are a family of spread spectrum transceivers which operate in the 902 to 928 MHz band . The radios are designed to operate at data rates of 121Kbps over the RF link. Several models are available: the RXA-100,RXA-300, RXA-1000, RDA-100, RDA-300 and RDA-500. All four models are essentially identical with the exception of their output power capability and their data interface (refer to the respective reference manuals for details on the interface).The RXA models have a synchronous serial interface while the RDA models have an 8-bit parallel interface. The output power capability is 100 mW for the RXA-100 and RDA-100, 300 mW for the RXA/RDA-300, 500 mW for the RDA-500 and 1W for the RXA-1000.

This manual contains a detailed technical description of the proprietary elements of these Proxim radios. The information contained here is confidential and is not found in the general RXA or RDA Series Reference Manual. The RXA or RDA Series Reference Manual should be consulted when addressing other issues pertaining to the specification, installation or operation of the RXA/RDA radio models.

The reader of this manual is expected to posses a basic knowledge of spread-spectrum systems.

2. OVERVIEW

The RXA/RDA Family of radios use a direct sequencing approach to spread-spectrum. There are several modulation techniques applicable to spreading a carrier with a pre-described code. Among the most common ones are BPSK, QAM, MSK etc. The RXA/RDA radios use a variation of the MSK approach in which the modulation index is increased from the MSK value of 1/2 to a value of 1. By doing so the shape of the transmitted spectrum results in a flat distribution of power, minimizing the power density (mW/Hz) across the modulation bandwidth. In contrast, the MSK resultant $SIN^2(x)/x^2$ spectrum tends to concentrate the power about the carrier frequency resulting in greater power density over this region. Proxim's radios benefit from most attributes found in MSK systems. The benefits which most impact the Proxim system are:

1.- MSK has no AM component to it and therefore can be passed through non-linear (Class C) amplifiers without causing distortions which, among other things, could result in spectral regeneration.

2.- MSK spectrum sidelobes can be reduced greatly, to insignificant levels, by appropriate filtering of the chipping sequence before applying it to the carrier. Having no sidelobes reduces the potential of interference to other users in or outside the frequency band in use.

3.- MSK can be demodulated in one of several ways (IQ Demodulator, PLL Demodulator , FM Discriminator etc) providing flexibility in the design of the receiver.

Following are some of the key specifications of Proxim's spread-spectrum implementation:

Output Power..................................	100 mW , 300 MW , 500mW or 1W
Data Rate:	121 Kbs
Spreading Factor:	11
RF Bandwidth.................................	1.4 MHz
Chipping Sequence Length............	11
# Codes Available...........................	1
Scrambling Sequence Length..........	31
Processing Gain	11 dB
Jamming Margin..............................	-1 dB

3. BLOCK DIAGRAM

Chipping Sequence :

Fundamental to the design of the radio is the choice of a chipping sequence. To meet the processing gain requirements of 10 dB imposed by the FCC, the chipping sequence rate must be at least ten times the data rate of the information (spreading factor >10). Proxim chose an 11 bit Barker code sequence as the basic signalling waveform. An information bit with a value of "1" is transmitted as the Barker code (10110111000) whereas an Information bit with a value of "0" is transmitted as the inverse of the Barker code (01001000111).

The Barker code was chosen for its low DC component as well as for its unique self and cross correlation properties (cross correlation with its own inverse). In fact, it was found that its correlation function's main lobe to side lobe ratio was superior to those of longer sequences (such as a 15 bit maximal length sequence). The net result is greater achievable processing gain and better synchronizing capabilities.

As will be discussed later in more detail, Proxim's system employs a combination of an 11 bit Barker code and a scrambler to meet the randomization requirements imposed by the FCC. This approach enables the use of a "matched filter" type of receiver which results in a self synchronizing system (i.e. synchronization is achieved with every bit of transmitted information). A self synchronizing system is more robust and has the advantage of not requiring lengthy synchronization pre-ambles on every packet transmitted.

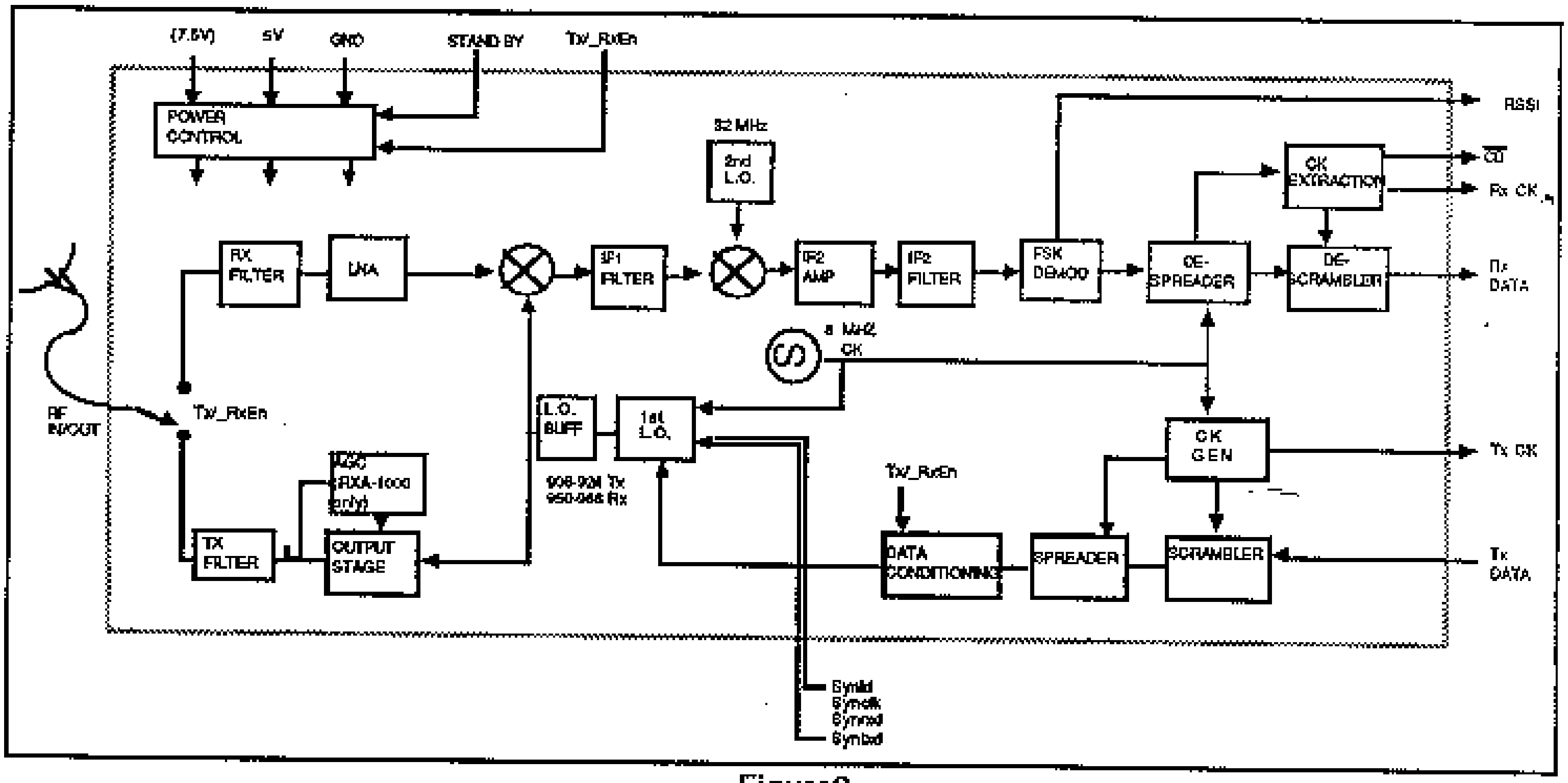

Figure3
OVERALL BLOCK DIAGRAM

Transmitter

The general signal flow through the transmitter section of the radio goes as follows. Data to be transmitted is clocked into the TXDATA input at a positive transition of the TXCLK output. The TXCLK output runs at a 121 Kbs rate. The data is then passed through a scrambler and coded with the chipping sequence on the spreader. Before modulation, the output of the spreader goes to a signal conditioning block which prepares it for driving the FSK modulator. The FSK modulator superimposes the modulation onto a carrier in the 902-928 MHz band. The output of the modulator is amplified, filtered and sent to the antenna connector for transmission. The following sections describe each of these blocks in more detail.

a.. Scrambler:

The RF spectrum of a data stream of all zeroes or all ones chipped with the 11 bit Barker code sequence consists of a series of spectral lines spaced 1/11 of the chipping sequence rate. In our case these spectral lines would be spaced 121 KHz apart resulting in a concentration of the transmitted power at these frequencies. In order to avoid this and distribute the power more evenly throughout the spectrum (under the likely case of an all zero or all one data stream) the RXA/RDA radios scramble the data before it is chipped.

The scrambler used is a self synchronizing 5 stage scrambler with anti-lockup circuitry. Anti-lockup circuitry is commonly used to ensure that certain periodic sequences not send the scrambler into a lock-up condition. The scrambled output is ensured not to repeat in at least 31 bits of the input sequence. The figure 3a shows in detail the major components of the scrambler.

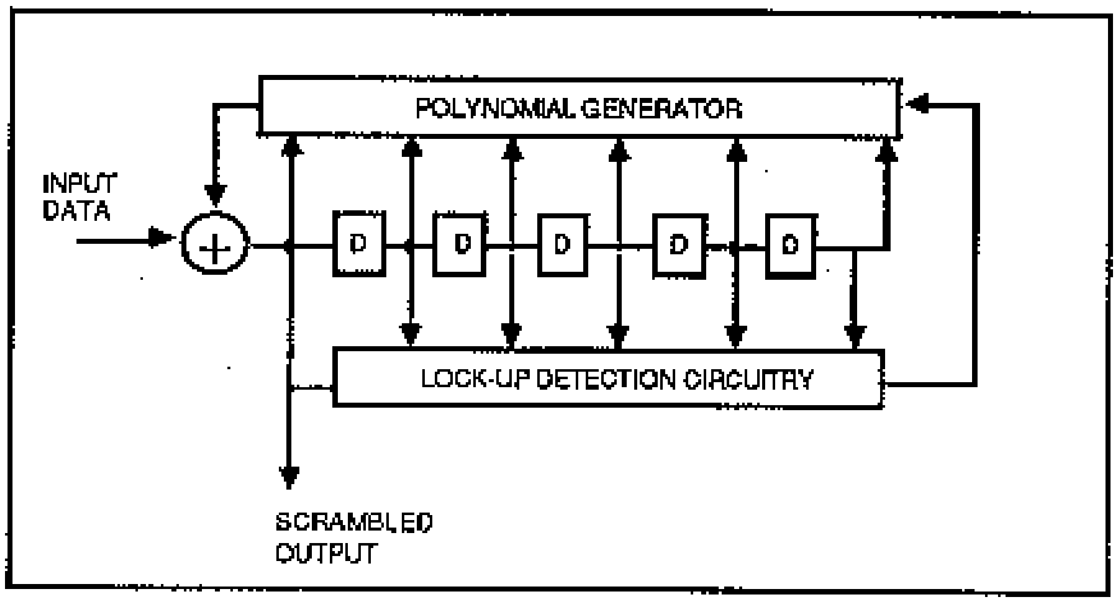

Figure 3a
SCRAMBLER

b.. Spreader:

Once the data has been scrambled, it is fed to the spreader block. The spreader block simply takes the scrambled data and superimposes the 11 bit Barker code sequence onto it. If the scrambled data has a value of 1, the output of the spreader will be the chipping sequence. If the scrambled data has a value of 0, the output of the spreader will be the inverse of the chipping sequence. Figure 3b-1 shows a block diagram of the Spreader depicting its major components.

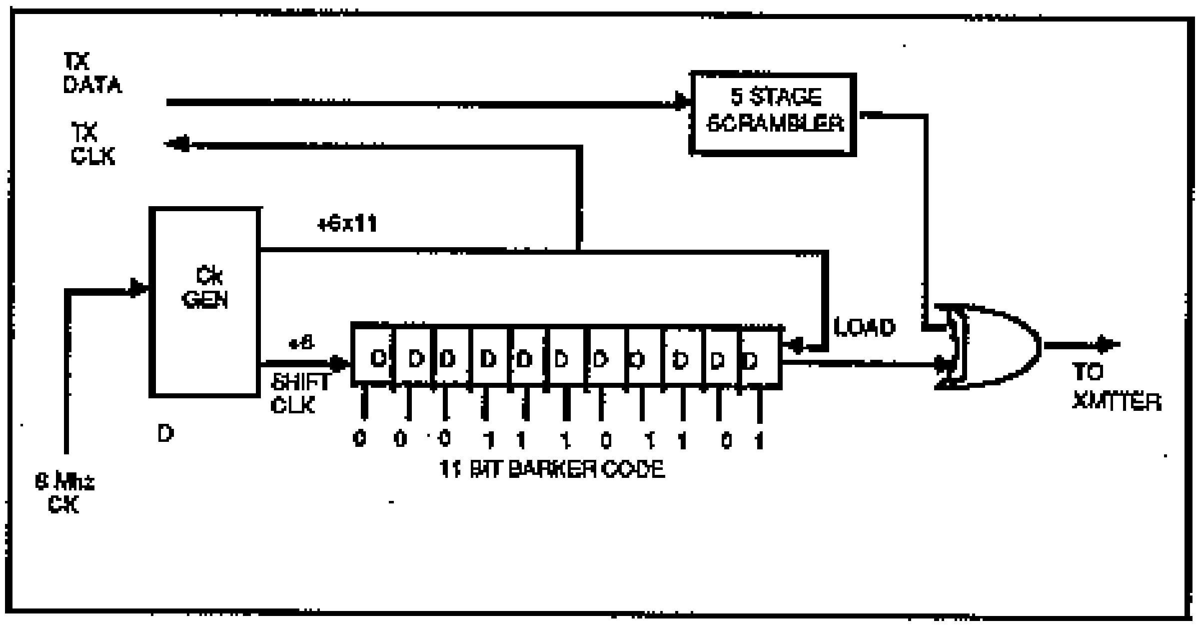

Figure b.1
SPREADER

The 11 bit shift register is loaded with the Barker code at the data rate of 121 kbs (8MHz ÷ 11x6). The bits are then shifted out at the chipping rate of 1.33 MHz (8MHz ÷ 6). The 11 bit chipping sequence in combination with the 5 stage scrambler gives an equivalent sequence length 341 bits long. The resulting power spectra will have components spaced 1/341 x chipping rate (3.9 KHz) apart. In most cases, there will be some additional degree of randomness in the input data itself making the spacing smaller. (See Appendix A for results of the comparison between Proxim's 11 bit sequence/scrambler combination versus a 127 Bit chipping sequence only approaches)

c. Data Conditioning:

Prior to modulating the carrier, the chipped data goes through the data conditioning block. Two functions are served in this block. The first one is to provide the appropriate signal levels into the L.O.'s FM input. This is important to ensure that a deviation index of 1 is achieved resulting in an optimally flat spectral shape. The second function is to filter the signal into the L.O.s FM input with a Gaussian response. This reduces the level of the spectral sidelobes markedly, suppressing any out of channel emissions below the allowable levels needed to meet desired adjacent channel rejection goals (55 dBc).

Figure 3c-1
Output Power Spectra

The out of band suppression achieved is significantly better than that required by the FCC (20 dB of suppression). Once the modulation has been conditioned appropriately, it is applied to the FM input of the Local Oscillator. The net result is a modulated RF carrier with a flat spectral shape and rapidly decreasing sidebands (see figure 3c-1).

d. Modulator:

The Local Oscillator is phase locked to the 8 Mhz master clock with a fairly narrow loop bandwidth. This enables the modulation to be applied to the L.O. outside the loop bandwidth without distortions. The low DC content of the chipping sequence discussed earlier ensures that very little of the energy from the modulation will fall within the bandwidth of the loop.

e. High Power Amplifier (HPA):

The HPA takes the output of the Local Oscillator and amplifies it to the desired output level. The HPA final stages are Class C and use power much more efficiently than linear type of amplifiers. Harmonic content from the HPA is suppressed within the limits allowed by the FCC by a low pass filter at the output.

The RXA-100, RDA-100 and the RDA-500's output amplifier designs are practically identical. The RXA/RDA-100's design is optimized for 5v operation and minimum current draw (essential for battery operation) with an output power capability of 100 mW. The RDA-500's output stage is intended to be operated from a 9v supply and is capable of a maximum of 500 mW of output power. The RXA-1000 output amplifier has an additional stage and it is designed to operate from a nominal 7.5v supply. An ALC loop ensures the output does not exceed 1W under any condition.

RECEIVER

The general signal flow through the receiver section of the radio goes as follows. The signal received by the antenna is fed though the Tx/Rx switch and the bandpass input filter to the low noise amplifier. After amplification, the signal is mixed down to the first IF where it is further amplified and filtered. Then, it is mixed down once again to the second IF where it is filtered and amplified. The output of the second IF is demodulated and then de-spread (or de-chipped). The output of the de-spreader is used by the clock and data recovery circuit to recover the data and the clock. Both of these signals are finally fed to the RXDATA and RXCLK outputs of the radio.

f. Front End:

The receiver front end consists of a Tx/Rx switch, an RF filter to reject image frequencies as well as other spurious inputs, a low noise amplifier and a two stage down-converter. The first down-conversion stage translates the RF to a first IF frequency of 44 MHz where it its amplified and filtered. The second stage further translates the first IF to the second and final IF frequency of 12 MHz. Once again, the resulting signal is amplified and filtered. The 2nd IF output is fed to the demodulator.

g. Demodulator:

The demodulation process consists of two steps. The first step converts the IF signal into a baseband signal. This is accomplished with an FSK type of demodulator. The output of the FSK demodulator, on a noiseless channel, would correspond to the transmitter's modulation input. The next step in the demodulation process is to remove the chipping sequence from the data. This is accomplished by the de-spreader, data extraction and clock extraction blocks. These blocks in essence perform a digital matched filter function necessary to correlate the incoming signal with the receiver's copy of the chipping sequence.

h. De-spreader

The de-spreader consists of an A/D converter and a digital matched filter which is matched to the 11 bit Barker code. The A/D converts the output of the FSK demodulator to its digital representation. This value is then shifted into a 66 element shift register at the system's clock rate. The shift register is divided into 11 buckets of 6 elements each. Each bucket corresponds to <u>one chip</u> of the spreading sequence (in figure 3h-1 a bucket is represented by a block labelled "6*D"). Each element of every bucket is multiplied by a +1 or a -1 according to the chipping sequence value associated with that bucket.

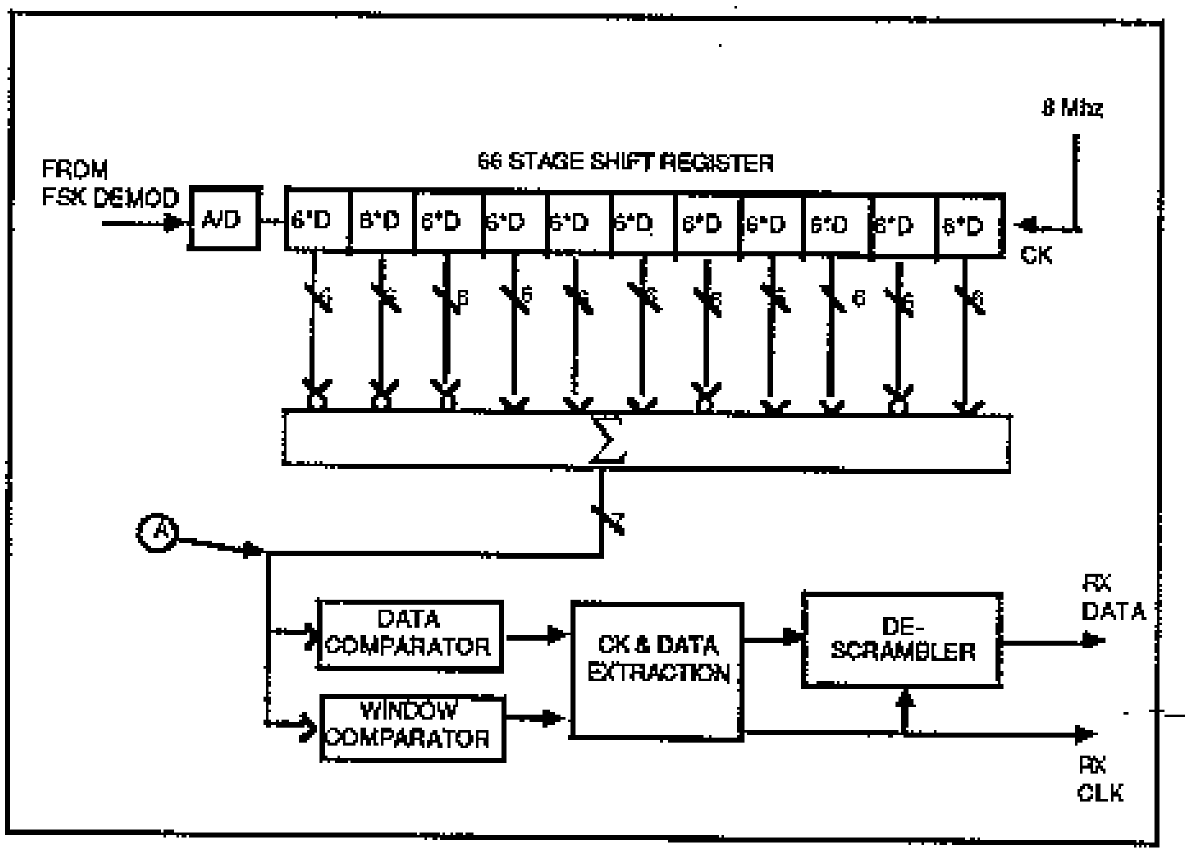

Figure 3h-1
DE-SPREADER, CLOCK & DATA RECOVERY CIRCUITS

The outputs of all 66 multipliers are then summed together to complete the matched filter's <u>correlation</u> operation. The factor of 6 oversampling used in the correlator gives the resolution necessary for proper synchronization. During every cycle of the system clock the correlator repeats the full correlation operation to calculate a new value. Once on every data bit, the sampled output of FSK demodulator, as it is shifted through the shift register, lines up with the chipping sequence (as defined by the multiplier's weights). The correlator's output will peak at this point and drop down to a background noise level, also referred to as sidelobe level, every where else (see figure 3h-1).

The polarity of the peaks will depend on whether the transmitted data was a "1" or a "0". The relative value of the peak-to-sidelobe ratio is dependent on the correlation properties of the chipping sequence as well as the length of it. It also affects the ability to detect the peaks in the presence of noise. A higher peak-to-sidelobe ratio will reduce the likelihood of noise or interference causing invalid threshold crossings (thresholds are discussed in the following section) which could result on errors. Proxim's code is optimal for its length as the level of its correlation sidelobes are the smallest achievable.

Figure 3h-2 is a photograph of the output of the correlator (node labelled "A" in figure 3h-1) as seen through a D/A converter. It should be noted that this node is not generally available for monitoring by radio users as it exists only inside Proxim's spread-spectrum ASIC. This photograph was taken by assembling special hardware that allows the output of the correlator (node "A") to be monitored outside the ASIC. The correlator output was fed to a fast 8 bit D/A converter to yield the waveform shown.

Figure 3h-2
Correlator Output

Figure 3h-3
Correlator Output in the presence of
Noise/Interference

In the presence of noise/interference main lobe-to-side lobe ratio begins to decrease. Figure 3h-3 depicts a condition of heavy noise. It can be noted that timing information is clearly discernable in the correlator output. The clock extraction circuitry will use the time when the correlator output peaks (+ or -) as the sampling instant. The separation between the positive and negative peaks, at the sampling instant, then determines the error rate.

i. Processing Gain:

Processing gain has been defined in a number of different ways in the literature mostly depending on the application. For receivers using correlation detection techniques, as in this case, processing gain is given by the main-lobe to side-lobe ratio out of the correlator. This figure can be calculated by taking the difference between the positive and negative correlation peaks and dividing this number by the difference between the minimum and maximum side-lobe levels.

The 11 bit Barker code sequence used in this design has the special property that the main-lobe to side-lobe ratio is 11 (or 11 dB) as can be seen in figure 3h-2. This processing gain enables the correlation peaks to be clearly discernable even under severe interference/noise conditions (fig 3h-3). The clock and data recovery blocks can then process the output of the correlator to cleanly extract the data from the signal.

j. Data and Clock Extraction:

The correlator's output contains the information needed to determine the transmitted data. To arrive at this determination this signal is processed by the clock and data extraction circuitry. The correlator's output is compared with pre-determined thresholds. A window comparator generates the clock needed to sample the output of the data comparator at the correct instant (the center of the correlation peak).

In addition to generating clock pulses in response to correlation peaks, the clock extraction circuitry will estimate the location of peaks in cases where noise or interference cause the correlation peaks to drop below the threshold levels. This allows the radio to take full advantage of the correlation properties of the Barker code and continue to operate correctly in a heavy noise or interference environment

k. De-scrambler:

Following the de-spreader, the data output from the data recovery circuit is de-scrambled. The function performed by the de-scrambler is inverse of the one performed by the scrambler. The circuitry used is very similar to that of the scrambler.

The output of the de-scrambler is gated prior to feeding the RXDATA line. Controlling the gate is the Carrier Detect signal (_CD). The _CD signal is derived from the output of the correlator and, when active, it indicates that a Proxim compatible RF signal is detected at the input of the radio. When inactive, the data output from the radio is gated off.

4. APPENDIX A

a.- 11 Bit Sequence / 31 bit Scrambler vs 127 Bit Sequence:

The Federal Communications Commission requires manufacturers of spread-spectrum products covered under part 15.247 of the Code to provide proof that the degree randomness achieved from the radio under consideration be equivalent (or better) than what would be achieved if the chipping sequence used were 127 bits in length.

For the purpose of this comparison, Proxim has conducted the following experiment: an RXA-1000 radio was modified to take a 127 bit long output from a pseudo random sequence (PRBS) generator (instead of its internally generated 11 bit Barker code) as the radio's chipping sequence. An RXA-1000 was arbitrarily chosen for this experiment. The results presented below, however, extend to the full family of RDA/RXA radios (since their spread spectrum architecture is identical).

The PRBS generator is of the maximal length kind and was based on the standard polynomial $1 + X^3 + X^7$ using a 7 stage shift register with feedback from the 1st,4th and 7th stages, for its implementation . The resulting pseudo-random sequence then replaced the SPREADER output as the input to the radio's Data Conditioning Block (refer to block diagram). The PRBS used is shown in figure A-2 and can be contrasted with the 11 bit Barker code normally used in Proxim radios and shown in figure A-1.

Figure A-1.- 11 Bit Barker Code Sequence

Figure A-2.- 127 Bit Maximal Length Sequence

The output of the radio, operating in this mode, was monitored with a Tektronix spectrum analyzer model 492P. The following six figures are photographs comparing the output of this modified radio with that of an off-the-shelf RXA-1000. The column on the left depict results from the off-the-shelf radio tests while the column on the right depict results from the modified radio tests. In both cases the data input to the radio was constant stream of "1".

RXA-1000
NORMAL OPERATION

RXA-1000
127 BIT CHIPPING SEQUENCE

Figure A-3.- Measured power spectra of of the off-the-shelf RXA-1000

Figure A-4.- Measured power spectra of the the modified RXA-1000

Figure A-5.- Zoomed-in look at figure A-3. Note resolution bandwidth is now 1 KHz.

Figure A-6.- Zoomed-in look at figure A-4. Note resolution bandwidth is now 1KHz.

RXA-1000
NORMAL OPERATION

RXA-1000
127 BIT CHIPPING SEQUENCE

Figure A-7.- Individual spectral components can be found every ~3.9 KHz. This is the the result of the 1.33MHz chipping rate divided by 341 (the effective length of the 11 bit Barker code/scrambler combination).

Figure A-8.- Individual spectral components can be found every ~10.5 KHz as expected from a 1.33 MHz chipping rate and a 127 bit sequence.

In summary, spectral lines on the off-the-shelf RXA-1000 output power spectra were spaced closer together than those on the RXA-1000 modified with the 127 bit chipping sequence. The level of randomization achieved with the 11 Bit Barker code when used in conjunction with the 5 stage scrambler is approximately 3 times better than what would be achieved with a 127 bit long chipping sequence.

5. APPENDIX B:

In the *Report and Order* adopted by the Federal Communications Commission on June 14, 1990 (Docket No. 89-354), the Commission amended section 15.247 governing spread-spectrum use of the ISM band. One of the rule changes was to require manufacturers of spread spectrum radios to have a processing gain (Gp) equal to or greater than 10 dB. In addition, the Report and Order describes the methodology to be used to measure processing gain. The measurement described is based on the ratio of the system's SNR with the spreading function turned on and off. Unfortunately, manufacturers opting for topologies in which the spreading/de-spreading functions are done inside Custom Application Specific Integrated Circuits (ASICS) may not have access to the nodes where the SNR is to be measured according to the procedure outlined by the Commission. Proxim's architecture falls into this category . For applicants such as Proxim, It is therefore necessary to use an alternative method to show that their system meets the processing gain requirement . Proxim proposes the method described below.

a.- Processing Gain (Gp)

The biggest motivation for using the spread-spectrum techniques covered by section 15.247 of the FCC Rules is to increase the efficiency of utilization of the frequency spectrum. By spreading the transmitted power, the power density is reduced decreasing the potential for interfering with existing users on the band. Conversely, receivers with processing gain are capable of tolerating higher levels of interference from these same users. Our analysis will show that Proxim's spread-spectrum architecture exceeds the FCC requirements both from a transmit and receive standpoint.

Processing gain has been defined in a number of different ways in the literature depending on the particular application. The most commonly used definition[1,2] expresses processing gain in terms of the information rate and the occupied RF bandwidth:

$$Gp = BW/R \qquad (1)$$

According to this most common definition, Proxim clearly meets the Gp requirement with a processing gain of 11.4 dB. While this definition is a good indicator of the level of interference reduction spread spectrum transmitters will potentially cause it does not address the susceptibility the equivalent spread-spectrum receivers will have to external interferers.

b.- Determining Gp: The Jamming Margin Method

Our proposed approach involves determining processing gain from <u>real jamming margin</u> (i.e. interference rejection) measurements. Interference rejection measurements are easily made injecting a controlled amount of CW interference into the communication channel while the Bit Error Rate (BER) is being monitored. The level of the interference is then decreased until the BER reaches a specified limit (1E-5 in our case). At this point the power levels of the interferer and of the desired carrier are measured. The jamming margin is the maximum interference to carrier ratio (I/C) tolerable at the receiver.

The jamming margin is related to processing gain by[3],

$$\text{jamming margin} = Gp - \left[Lsys + (S/N)_{out} \right] = Mj \qquad (2)$$

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[1] .- Marvin K. Simon, Jim K. Omura, Robert A. Scholtz, Barry K. Levitt, *Spread Spectrum Communications Volume II*, Rockville: 1985, p. 5.

[2] .- Robert C. Dixon, *Spread Spectrum Systems*, New York: Wiley Interscience, 1984, p. 10.

[3] .- Ibid, p. 10.

where $(S/N)_{out}$ is the Signal-to-Noise ratio needed at the data detector to achieve the specified BER of the system and Lsys are system losses resulting from non-ideal implementations of the receiver. Jamming margin depends not only on the processing gain but also on the kind of modulation/demodulation used. For example, a coherent PSK demodulator requires (ideally) an inherent lower $(S/N)_{out}$ than a QPSK demodulator to achieve a given BER. For the same processing gain, the PSK demodulator will (again ideally) have a better jamming margin than the QPSK demodulator. Curves relating BER to SNR for different types of demodulators are readily available in the literature[1,2]. Therefore, knowledge of system losses and actual jamming margins, at a given $(S/N)_{out}$ (or given BER which can be related to $(S/N)_{out}$ by the well known curves) is sufficient to determine processing gain.

Proxim's architecture is based on non-coherent FSK demodulation with discriminator detection. Figure B.1 shows typical BER curves for three types of FSK demodulators: coherent, non-coherent and discriminator detector[3]. These curves depict the performance for ideal implementations of the stated systems (i.e they assume optimum modulation index, noise and modulation bandwidths). Real systems will have somewhat poorer performance than that shown[4]. However, this degradation will become part of the system losses (Lsys) term in equation (2).

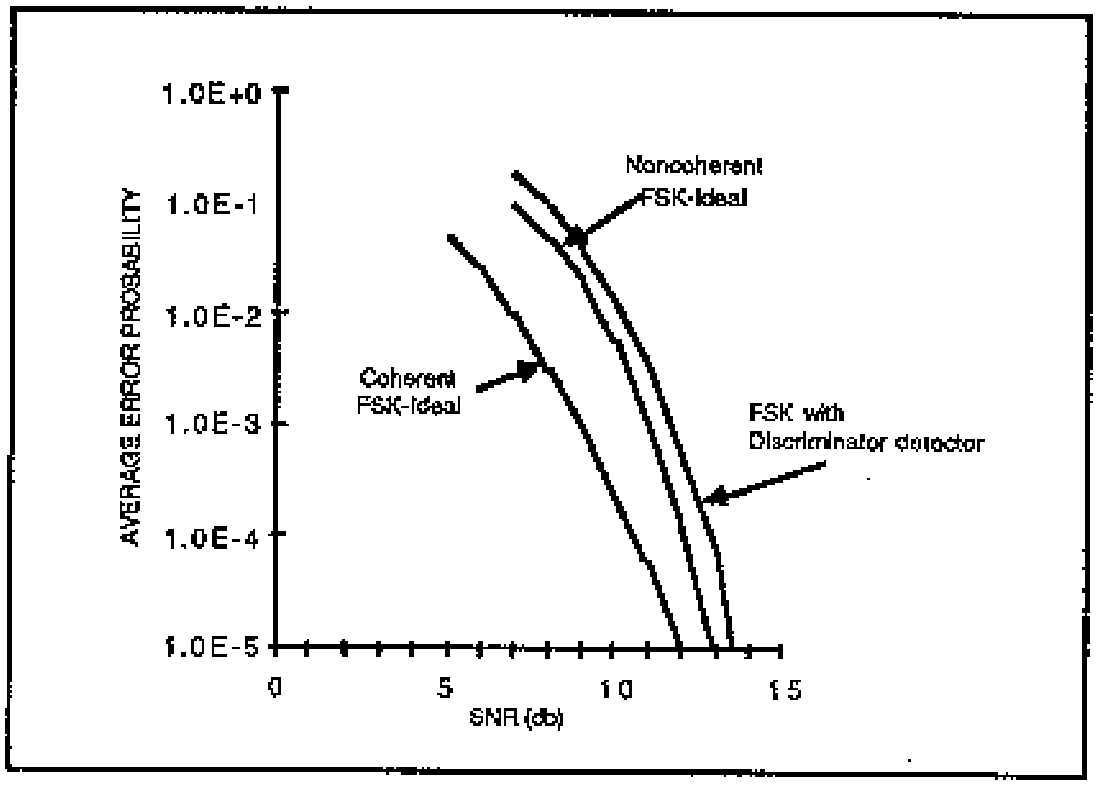

Figure B-1

The measured jamming margin of Proxim's spread-spectrum transceivers is **-1.5 dB**. That is to say that they achieve the specified 1E-5 BER performance with an I/C ratio of -1.5 dB. Procedural details of the test methodology used in measuring jamming margin (including the equipment list) can be found in Proxim's "RXA-1000 and RXA-100 Production Test Manual".

The second term needed for equation (2) is the value of $(S/N)_{out}$ required to achieve the specified BER. Figure B-1 shows that an FSK system with discriminator detector, such as

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[1].- Robert Gagliardi, *Introduction to Communications Engineering,* New York: Wiley Interscience, 1978, Ch 7.

[2].- Kamilo Feher, *Advanced Digital Communications,* New Jersey: Prentice-Hall, 1987, pp. 327-329.

[3].- Gagliardi, *Introduction to Communications Engineering,* p. 309.

[4].- Tjeng T. Tjhung and Paul H. Wittke, "Carrier Transmission of Binary Data in a Restricted Band", *IEEE Transactions on Communications Technology,* pp 295-304, August 1970.

Proxim's, would require a 13.5 dB of $(S/N)_{out}$ for a BER of 1E-5. An ideal noncoherent FSK demodulator would require 12.5 dB for a BER of 1E-4 and 13 dB for a BER of 1E-5[1,2]. For our calculations we will use 13 dB at the specified 1E-5 which is a conservative figure given Proxim's discriminator detector approach.

The final term in equation (2) is Lsys. Since Lsys corresponds to actual physical losses in the system it must be ≥ 0 dB. In calculating Gp, the worst case Lsys occurs when it equals 0 dB. Since Lsys can not be measured without knowledge of Gp we will use this worst case value. With values for jamming margin, $(S/N)_{out}$, and Lsys at hand we can solve equation (2) for processing gain:

$$-1.5\,\mathrm{dB} = Gp - \left[\,0\,\mathrm{dB} + 13\,\mathrm{dB}\,\right]$$

The resulting **Gp Is 11.5 dB**. If we had used the discriminator detector curve with larger required inherent $(S/N)_{out}$ and some more realistic non-zero system loss, the resulting processing gain would be slightly larger.

c.- Conclusions

From the preceding analysis it can be concluded that Proxim's architecture performs at least as well, in the presence of narrow band interferers, as an ideal spread-spectrum system with **12 dB** of processing gain using FSK non-coherent ideal modulation/demodulation. Since the main purpose of the receiver's processing gain is to provide jamming margin, Proxim's systems meets with ample margin the letter and the spirit of the rules in section 15.247 of the FCC Code.

Proxim's use of discriminator detection in conjunction with post detection correlation outperforms systems with similar modulation but using pre-detection correlation (or a front end de-spreader). This is because post detection correlation enhances the capture effect inherent in this kind of FM detection. FM capture effects are lost in the front end de-spreader and make narrow band interfering sources look like noise to the FM detector.

In Proxim's architecture, the maximum processing gain achievable is limited by the FM capture effect of the detector. The jamming margin will not increase linearly if the processing gain of the present system were to be increased. For this reason, Proxim's system does not attempt to spread its signals the full bandwith available as this would result in diminishing returns in terms of processing gain and unnecessary waste of the spectrum. Proxim transceivers, instead , provide several frequency channels, limiting their exposure to interfering signals that might exceed their jamming margin. Had Proxim chosen to spread the full 902-928 band, avoiding these occasional but real interferers (e.g. amateur radio, anti theft device etc.) would have been impossible.

The set of trade-offs incorporated into Proxim's spread spectrum transceivers are in full compliance with the intent and the letter of the FCC rules while providing Proxim's users with a reliable and extremely cost, power and size effective wireless data communication solution.

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[1] .- John D. Oetting, "A Comparison of Modulation Techniques for Digital Radio", *IEEE Transactions on Communications*, Vo. COM-27, No. 12, Dec 1979.

[2] .- Gagliardi, *Introduction to Communications Engineering*, 309.