IEEE 802.11
Wireless Access Method and Physical Specification

Title: **Analysis of OQPSK Modulation On DSSS PHY Acquisition**

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1. INTRODUCTION

The purpose of this paper is to present data and analysis of the impact of using OQPSK modulation with respect to DSSS signal acquisition. The use of a spreading code (PN code) in DSSS systems complicates the signals demodulation process by introducing code acquisition and subsequent signal despreading prior to demodulation.

This paper will examine the following issues:

- •Comparison of passband and baseband carrier recovery
- •Incoherent code acquisition for DQPSK vs OQPSK
- •Limitations in DS PHY protocol flexibility

2. Carrier Recovery: Passband vs Baseband Techniques

Carrier tracking is generally performed after PN code acquisition (code lock) using the recovered PSK baseband signal. Passband techniques (COSTAS loop etc.) are generally avoided for the following reasons:

- •DSSS signal is at or below the noise floor. Carrier recovery requires positive SNR (3 to 7 dB) for acquisition
- •Phase noise of the recovered despread signal has an improvement in phase noise proportional to the PN code gain

Assuming that most designers would like to take advantage of a significant reduction in phase noise, code acquisition is performed as an incoherent process.

There is, however, an additional penalty incurred by using passband carrier recovery techniques: increased current drain in receive mode. The following numerical example based on NTT's submission Document 93/137 remodulation recovery technique and Telxon's baseband decision directed PLL technique will illustrate the point.

Consider the current DS PHY waveform:

- • 2 Mbps /1 Msymbol QPSK baseband signal

•11 chip spreading code resulting in 11 Mhz baseband signal

•22 M sample per second minimum Nyquist sampling required

In Document 93/137, NTT presents a passband remodulation technique for carrier recovery of GMSK/QPSK signals which are not spread with a PN code. Remodulation and its derivative algorithms are generally accepted as the most robust carrier recovery techniques available.

If this technique was to be applied to a DS spread QPSK signal, each chip would treated as a QPSK symbol as if it were a 22 Mbps QPSK waveform. The NTT LSIC for wireless LAN implementation requires 10K gates for QPSK recovery and demodulation. Based on the block diagram provided by NTT and knowledge of ASIC signal processing implementation and complexity, 80% or 8K gates are devoted to the carrier recovery function. (NOTE: the NTT wireless LAN LSIC provides no circuity for code recovery, despreading, or code tracking) Given NTT's estimate of 10 mW at 1.5 Mbps for the entire ASIC and 3.3V operation, we can derive the following:

$$\text{Current} = (10\text{mW}/3.3\text{V})*(8\text{Kgates}/10\text{Kgates})*(22\text{MBps}/1.5\text{MBps})$$
$$= 35.5 \text{ ma}$$

If were to apply the NTT remodulation technique after PN code despreading and baseband signal recovery at 1 Msymbol / 2 Mbps rate, we would get the following current budget:

$$\text{Current} = (10\text{mW}/3.3\text{V})*(8\text{Kgates}/10\text{Kgates})*(2\text{MBps}/1.5\text{MBps})$$
$$= 3.2 \text{ ma}$$

This is a significant reduction in the current budget for a wireless lan receiver. Consider this: 90% of the active operation of a wireless lan is in receive mode.

But we can do better than this, remodulation is a robust and computationally complex carrier recovery technique used for both fast carrier acquisition and low carrier to noise (C/N) recovery. After despreading the signal, we have a reduction in delay spread and 10 dB improvement in C/N. In fact the C/N after despread must exceed 8dB or the BER will result in loss of a packet. At 8 dB C/N, PLL techniques can readily be used to acquire the carrier. The complexity of remodulation is not required.

Telxon uses a decision directed PLL for carrier recovery. The signal phase estimates are derived from the differential demodulator circuity which is used to perform symbol to bit conversion. Telxon's implementation requires 1 K gates operating at the 1 Msymbol/2MBps rate to perform this function. Using the NTT's energy figures, we derive the following current budget:

$$\text{Current} = (10\text{mW}/3.3\text{V})*(1\text{Kgates}/10\text{Kgates})*(2\text{MBps}/1.5\text{MBps})$$
$$= 0.4 \text{ ma}$$

By performing carrier recovery after despreading we greatly decreased both our recovered phase noise and our receive current drain. The logical conclusion is that PN code acquisition should precede carrier recovery in DSSS systems.

In the next section will examine the performance of incoherent DQPSK and OQPSK PN code acquisition.

3.0 Incoherent Recovery of DQPSK and OQPSK DSSS Modulation

The PN code search and acquisition process is based on selecting the PN code time delay at the receiver which results in maximum correlation as compared to all other code delays. Once this is established the receiver uses PN code tracking circuitry (eg. early/late, tau dither, etc.) to maintain and optimize the PN code alignment. This process is made possible due to the following properties of the codes selected for spreading:

- Codes result in cyclostationary correlations of period N = code length
- Codes have a triangular autocorrelation function within +/– 1 chip of code start (t=0) with a normalized maximum of 1
- Codes have a normalized autocorrelation of 1/N for t>1 or t<–1

A quadrature modulation process is used to generate either of the DQPSK or OQPSK waveforms.

DQPSK modulation requires the following steps:

- The input bitstream is parsed into dibits
- The dibits are differentially encoded into symbol state I and Q
- The I and Q channels are modulated with the PN code (code repetition rate = symbol rate)

The OQPSK modulation is based on LANNAIR's proposal derived from Document 93/135. The OQPSK waveform places a 1/2 symbol delay between the I and Q which results in a 5.5 chip offset in the codes. LANNAIR proposed treating each arm as an independent DBPSK. OQPSK modulation requires the following steps:

- The input bitstream is demultiplexed into an I and Q bitstream
- The I and Q arms are DBPSK encoded (1 or –1)
- The I and Q channels are modulated with the PN code
- The Q arm is delayed by 5.5 chips relative to the I arm

Figure 1 illustrates these modulation processes.

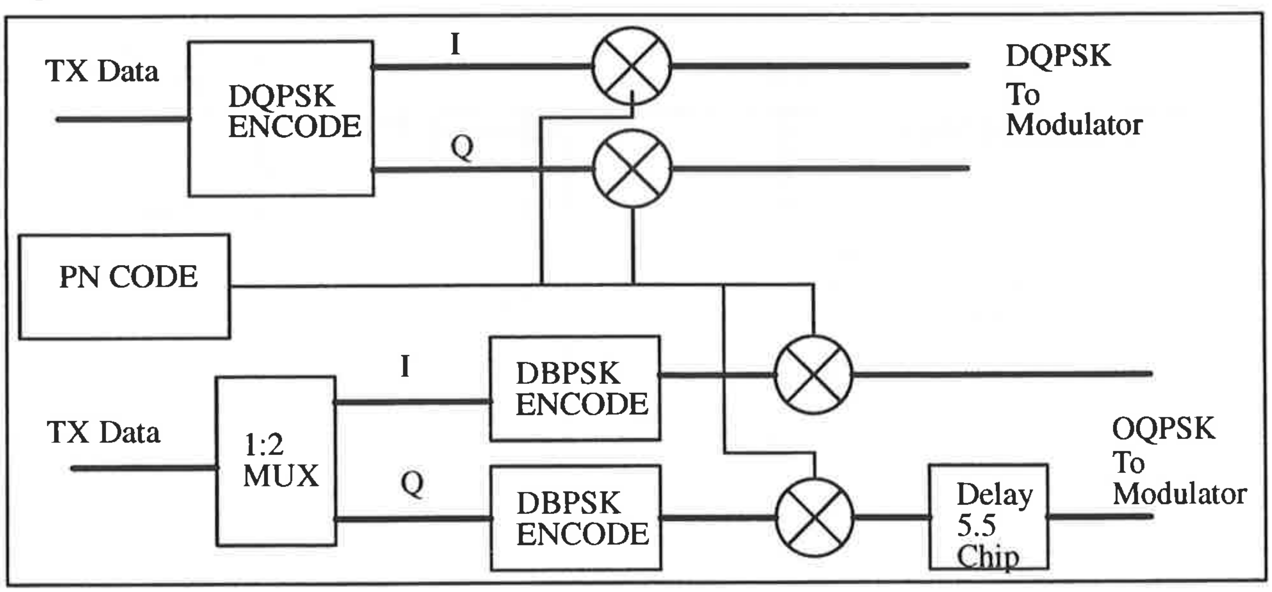

Figure 1 DQPSK and OQPSK DSSS Modulation

The PN code autocorrelation function for the I and Q channels for DQPSK and OQPSK modulation is provided in Figure 2. For DQPSK, the I and Q arms achieve peak correlation simultaneously at code repetition rate. For OQPSK modulation, the I and Q arms each achieve peak correlation at the code repetition rate but are separated by 5.5 chips. When one arm is at a peak normalized autocorrelation of the other arm is at maximum decorrelation of 1/N.

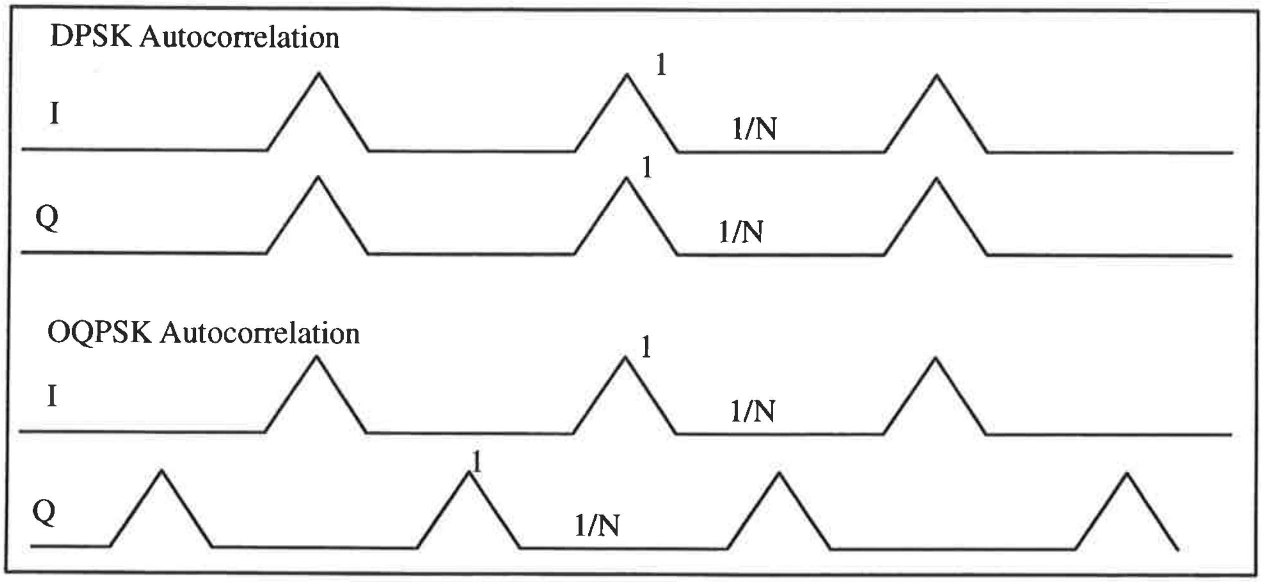

Figure 2 DQPSK and OQPSK Autocorrelation Functions

Incoherent code recovery is based on evaluating the magnitude ($I^2 + Q^2$) of the received correlated signal and selecting the peak. LANNAIR proposed independent recovery of each I and Q arm as a DBPSK signal. However, until carrier recovery is completed and phase corrections are applied to force the transmitted I and Q DBPSK signal into the corresponding I and Q receiving arms, the acquisition must use a joint I and Q estimate. Figure 3 illustrates a matched filter decorrelation and demodulation for both DQPSK and OQPSK based on LANNAIR's OQPSK proposal.

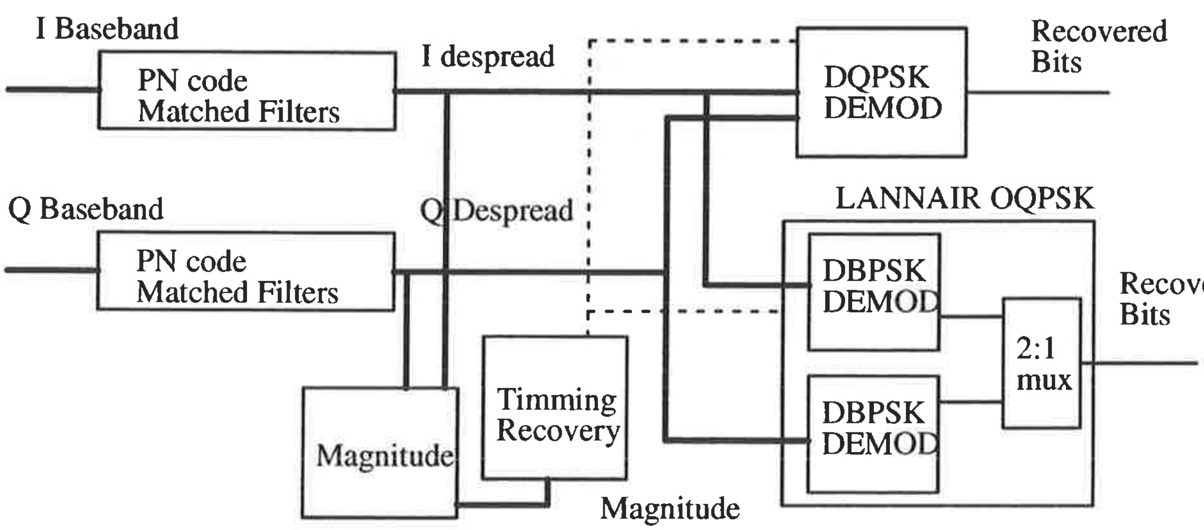

Figure 3 DQPSK and OQPSK Recovery and Demodulation Diagram

There are significant differences between the recovered magnitudes for DQPSK and OQPSK. Table 1 lists these magnitude properties. Figure 4 illustrates the autocorrelation magnitudes. Based on the LANNAIR detection architecture, OQPSK suffers from a **3 dB loss** of correlation power during acquisition. This is a significant loss considering that the 802.11 DS PHY 11 chip code provides only 10.4 dB of processing gain.

Modulation	Magnitude (N chip code)	Peak Repetition
DQPSK	power $=(I^2+Q^2) = (N^2+N^2)$ mag = sqrt(2)*N	1x Code repetition repetition rate
OQPSK	power $=(I^2+Q^2) = (N^2+ 1)$ mag = sqrt(N^2+ 1) (approx = N)	2x Code repetition rate

Table 1 Comparison of DQPSK and OQPSK Correlation Magnitude

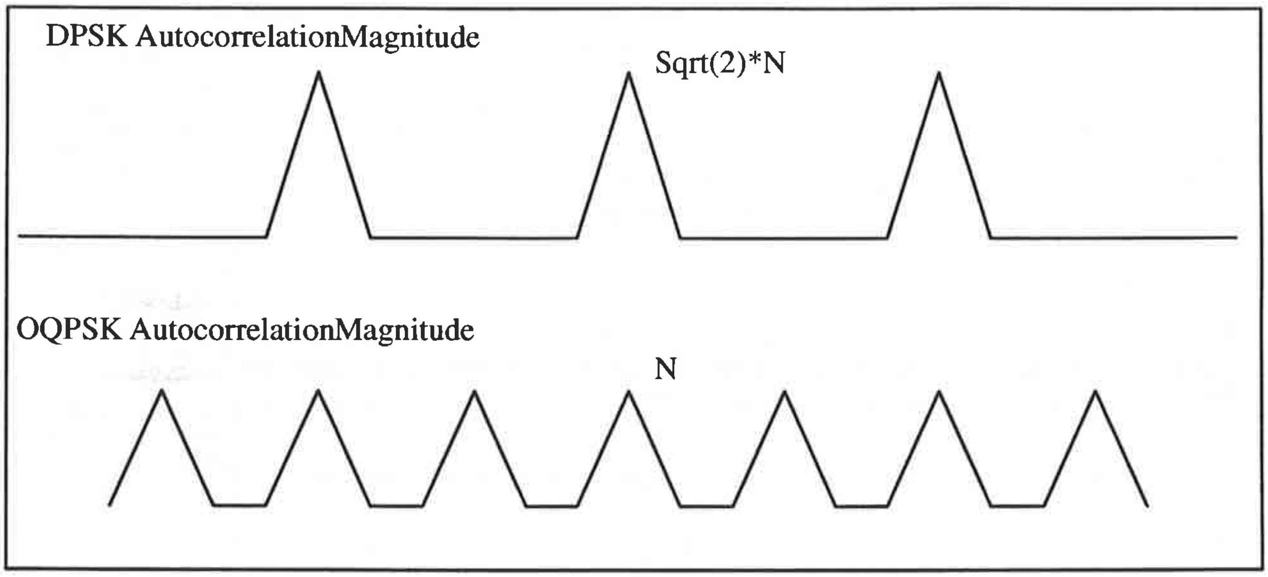

Figure 4 DQPSK and OQPSK Correlation Magnitudes

To confirm this analysis, a simulation of the DQPSK and OQPSK modulations was performed using COMDISCO's SPW simulation package. The simulations were based on the following:

•11 chip 802.11 PN code

•Maximum 802.11 received frequency offset of 50 ppm (+25 ppm TX, –25 ppm RX)

•5dB SNR received spread signal

•Sample rate = 2 samples per chip

•22 register matched filter I and Q channel correlators (as proposed by LANNAIR)

Based on the correlation of 22 samples per 11 chip PN code we would expect to see correlation peak magnitudes as follows:

•DBPSK magnitude = sqrt(I^2+Q^2) = sqrt(22^2+22^2) = 31

•OQPSK magniture =sqrt(I^2+Q^2) = sqrt(22^2+1^2) = 22

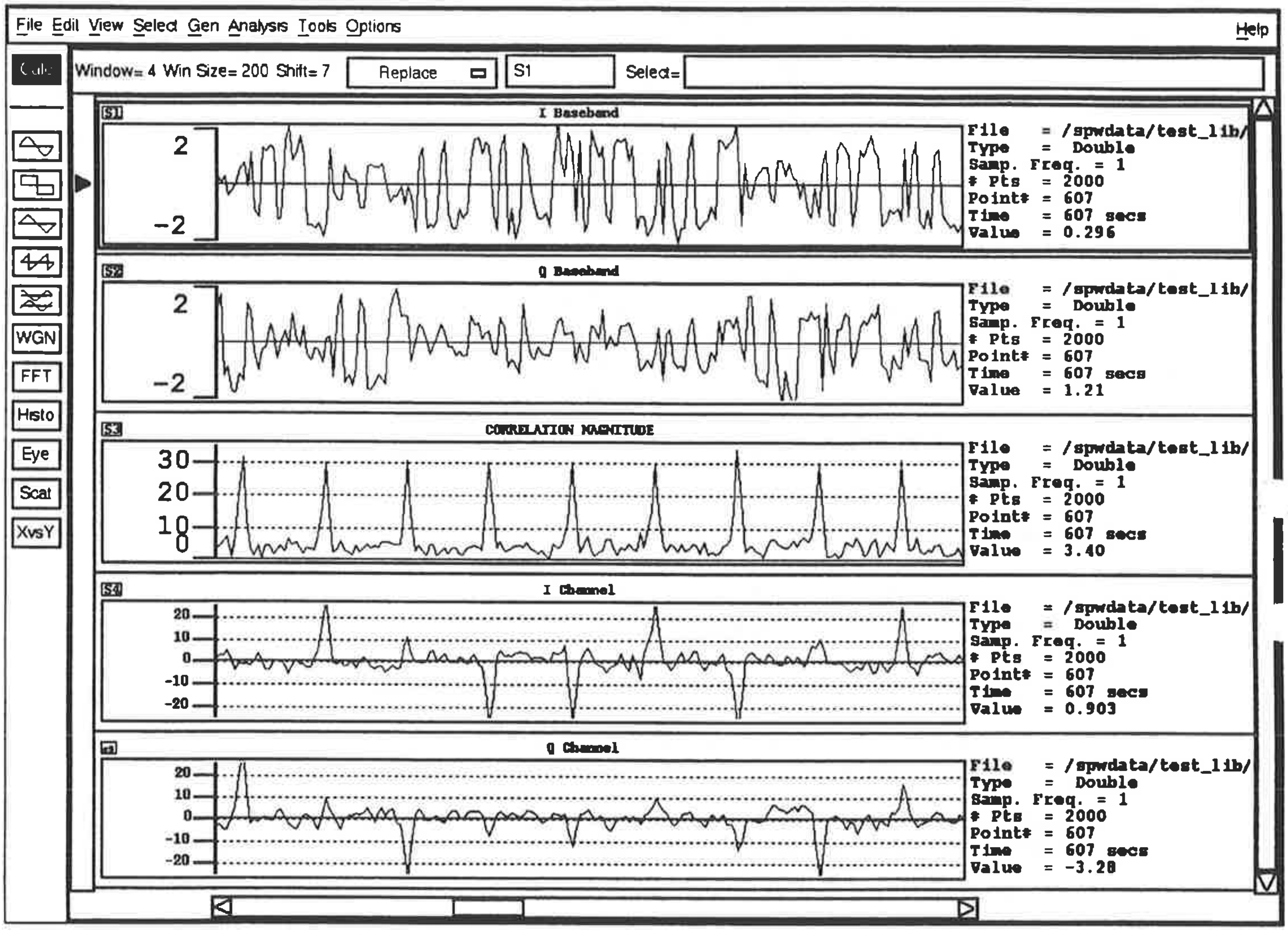

Figure 5 DQPSK 2000 Simulation Samples

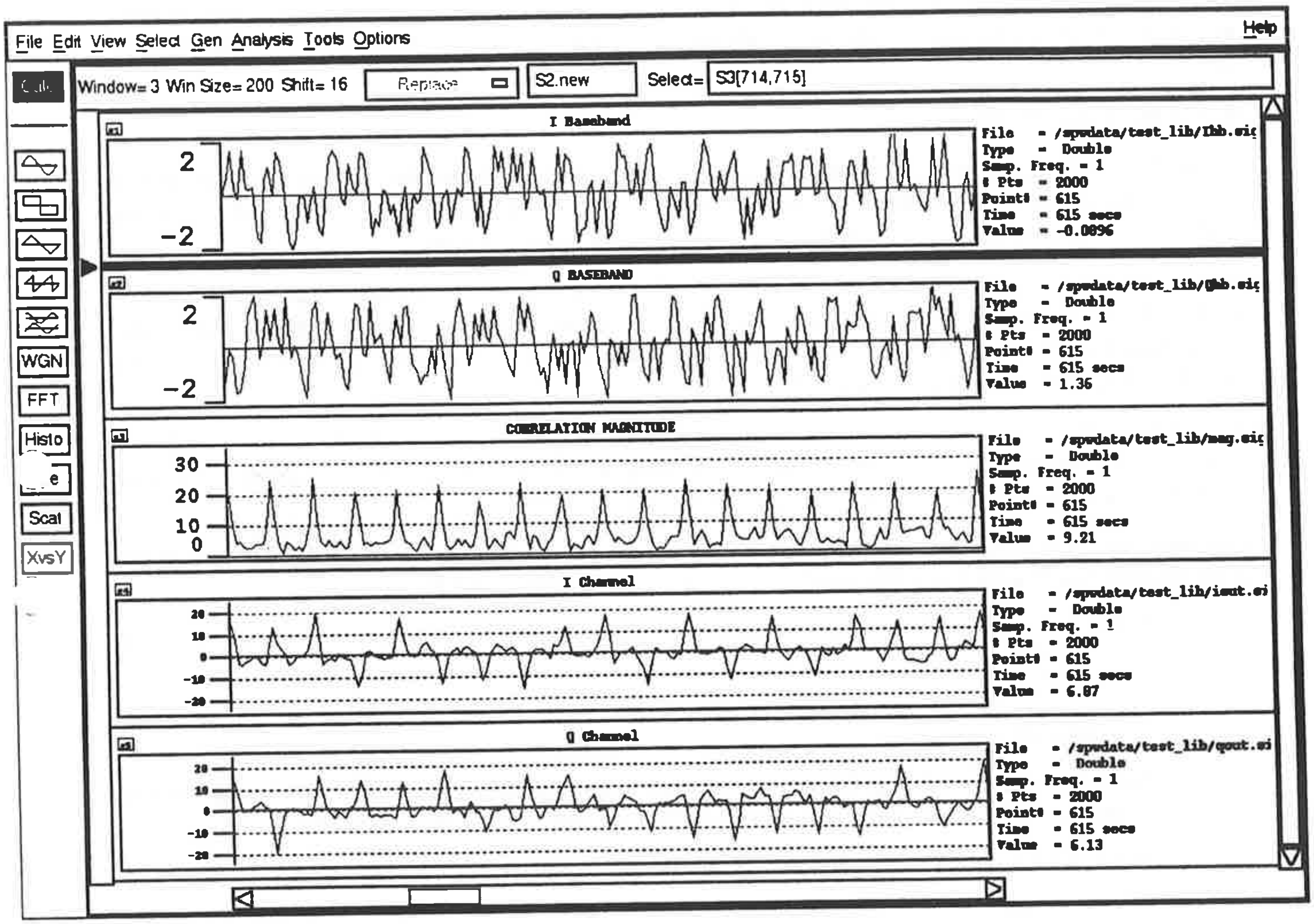

Figure 6 OQPSK 2000 Simulation Samples

Figures 5 and 6 confirm the analysis results. OQPSK suffers a 3 dB correlation loss relative to DQPSK (or DBPSK) for incoherent code recovery. Further, it is not possible to treat the recovered OQPSK I and Q arms as independent DBPSK signals until the following conditions are meet:

- •Carrier lock is achieved (need a stable phase reference)
- •The association of I Tx with I RX and Q TX with Q RX must be established to properly interleave the two independent bitstreams into a single bitstream to present to the MAC.

Another concern arises the use of OQPSK, 2 differential demodulation cycles must be performed per symbol. I assume that the differential demodulator hardware would be shared between each demodulation arm. This results in a doubling of the clocking rate for the receive circuitry and (assuming a CMOS digital implementation) a doubling of the RX current drain for differential demodulation.

4.0 Other Considerations

In creating a standard, our responsibility is to not only arrive at a baseline specification for the DS PHY, we must also provide the flexibility for future growth. Document 93/145 proposed signalling and vendor bits to extend the the 802.11 DS PHY for this exact reason.

At 2.4 GHz, FCC and ETSI rules would allow 11 chip DS PHY systems operating at up to 8 MBPS. In the 5 GHz ISM band, 16 MBPS could be achieved. Granted, mobile users may not be able to use these rates due to fading and delay spread, however, stationary users and fixed point to point services could readily make use of this capability.

As vendors begin delivery of enhanced data rate 802.11 DS PHY systems, interoperation with current 1 MBPS BPSK / 2 MBPS QPSK can be maintained. The signalling bit proposal in Document 93/145 would allow rates to be set on a packet by packet basis.

Consider the following transactions between an AP (access point) with 2 MBPS capability and a STA (remote user) with 4 MBPS capability using CSMA with an ACK:

- •The roaming STA (STA1) enters a new service area and must register for services with the access point.
- •The STA1 sends its registration packet at 1 MBPS BPSK (all 802.11 DS PHY systems support 1 MBPS BPSK)
- •The AP returns an ACK at 1 MBPS BPSK (for simplicity this confirms the STA is registered to the AP, the AP user table indicates that STA1 modulation = 1 MBPS BPSK)
- •The next STA packet is sent at 2 MBPS QPSK
- •The AP returns an ACK at 2 MBPS QPSK (the AP user table is updated: STA1 modulation = 2 MBPS)
- •The next STA packet is sent at 4 MBPS QPSK
- •At the AP, the packet CRC fails, no ACK is sent, and no updates to the STA1 modulation table are made
- •After an ACK timeout period, STA1 retransmits the packet at 4 MBPS and the AP does not respond. This cycle is repeated for N packets where N is a threshold for DS rate negotiation.
- •After N failures at 4 MBPS STA1 falls back to 2 MBPS QPSK, AP to STA1 and STA1 to AP transactions will continue at 2 MBPS QPSK

This was a simple example of upward negotiation of the DS PHY rate. Consider the following additional capabilities:

- At any point during these transactions, an AP to STA1 transaction could have occurred at the highest successful rate in the AP user table.
- At any point in time an AP broadcast packet can be sent to all users in the service area using 1 MBPS BPSK (all 802.11 will provide 1 MBPS BPSK services)
- If link conditions deteriorate, a downward negotiation transfer rate can be initiated by the STA based on the ACK threshold N

NOTE: The previous example may seem familiar to the reader. It is based on elements of rate negotiation used in GROUP 3 fax, multi drop modem networks, and the JTIDS military spread spectrum packet network.

This type of dynamic rate change/negotiation is possible because the proposed DS PHY header in Document 93/145 is ALWAYS 1 MBPS BPSK. The shift to the increased data rate occurs on the 1st mac packet symbol after the header. NO modulator retraining is required. Reinitilization of the 7 tap randomizer is not required.

For a DQPSK DS PHY system, a complete shift in symbol and chip rates occurs at a single point in time at the transmitter and at the receiver. The rate shift can be easily easily coordinated in the TX and RX hardware.

The OQPSK system suffers from a 5.5 chip separation in the I and Q arms. When the doubling of the I arm chip rate occurs, 5.5 chip chips at the old rate remain for the Q arm. In fact, a complete symbol at the higher rate will be transmitted in the I arm before the Q arm is switched to the higher rate. At this point all the OQPSK timing is off. Alternately, the 5.5 chips remaining in the Q arm could be dropped. This results in a 3 dB loss for the first symbol in the MAC packet. For a user at the far edge of a cell, this could create a bit error and loss of a packet.

The point here is simple. The DS PHY is part of a system. If we concentrate on optimizing a single item in a system (in this case use of OQPSK for simple class C RF amplification), we do so at the expense of other system capabilities. There are alternatives to pure class C amplifier operation which can meet the 802.11 spectrum mask while providing amplification efficiencies close to class C operation. (note: these techniques were developed in the 1950's and 1960's by RF engineers working on high power RADAR systems ... they are applicable to DSSS systems. In fact the 802.11 11 chip code is a BARKER sequence developed for Pulse Doppler RADAR)

Looking at the larger picture, many 802.11 users will be in the industrial and commercial sectors which is currently the largest user of wireless LAN services. BPSK modulation will be required to support industrial and commercial (warehouse, large store, etc.) environments. For DS PHY systems DBPSK provides the greatest level of multipath protection for a given transmission power and PN code length (processing gain). DBPSK is not a constant modulus signal. Pure class C amplification cannot used with DBPSK modulation if the modulator is to avoid sidelobe regeneration and meet the 802.11 spectrum mask.