Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**PERFORMANCE IN GAUSSIAN NOISE OF PROPOSED PN SYNC PREAMBLE FOR IEEE 802.16 OFDM**
Date Submitted	**2001-7-06**
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Re:	Call for Contributions: Comments on 802.16ab-01/01
Abstract	This document presents a preliminary preamble design for OFDM in license/license exempt bands.
Purpose	Adopting proposed design for section 8.3.6.3.3.5 and modification of section 8.3.6.4.2.2
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Release	
Patent Policy and Procedures	

1. OBJECTIVE

This document proposes the structure and simulation results of a preamble design for 802.16 OFDM systems. It is intended to fill in the empty section 8.3.6.3.3.5 and to improve section 8.3.6.4.2.2 of draft standard [1]. Further editorial changes will be conducted if this design is adapted.

2. BACKGROUND

The downlink requirement is for a subscriber unit to be able to synchronize to the base station in time and frequency, and then to do a channel measurement for demodulation of subsequent OFDM symbols. Compared to N_{FFT} =64 of IEEE 802.11a, the larger N_{FFT} sizes of IEEE 802.16 create a conflict between tolerance of multipath delay and tolerance of oscillator frequency error. This document presents a feasible synchronization scheme. The synchronization scheme can be applied to the uplink also, although frequency error is not a problem on the uplink because it has been corrected by the downlink synchronization.

2.1 DESIGN TRADEOFF BETWEEN MULTIPATH PROTECTION AND FREQUENCY AMBIGUITY

A design tradeoff exists between tolerance of delayed multipath and tolerance of frequency error. The requirement of IEEE 802.16 is to be able to use T_g/T_b as large as 0.25 and also accommodate a frequency error of at least 20 ppm in the subscriber unit. The short sync preamble design of IEEE 802.11a with tones spaced by $4/T_b$, as proposed in Wi-LAN s 802.16a Preamble Design and in 8.3.6.4.2.2, Eq(27), of the June 2001 Draft repeats the waveform after $T_b/4$, so would be compatible with the guard interval requirement of IEEE 802.16; however, then the maximum tolerable frequency error would be $2/T_b$ for extracting an unambiguous frequency estimate from the short sync preamble by comparing phase between the waveform repetitions. Taking as an example channel bandwidth = 3.5 MHz and N_{FFT} = 256 at a carrier frequency of 5 GHz, for which T_b = 62.69 μsec, 20 ppm frequency error converts to a carrier frequency error of $6.27/T_b$, which exceeds the maximum tolerable frequency error. If the approach is taken of increasing the tone spacing in the short sync preamble, as in 8.3.6.4.2.2, Eq(27), the period of the short sync preamble would be decreased to less than $T_b/4$, and the tolerable multipath delay would be decreased below the requirement of IEEE 802.16. This design tradeoff becomes more difficult as N_{FFT} increases, or the bandwidth decreases, or as the carrier frequency increases.

3. DOWNLINK PREAMBLE DESIGN

3.1 PROPOSED PN SYNC PREAMBLE

It is proposed to transmit a short PN sync preamble as biphase modulation of the carrier at the start of each downlink frame. The PN chip rate should be low enough and the waveform transitions appropriately shaped to ensure meeting spectral mask requirements. Perhaps the PN chip rate should be at most half the channel bandwidth, which would place spectral nulls of the PN modulation at the band edges. The maximum duration of the PN sync preamble is $2(T_g+T_b)$ but could be less. With 200 tones in the mandatory N_{FFT} = 256 and E/N_o > 3 dB per tone for the QPSK rate-1/2 data modulation, the E/N_o

available for acquisition of the PN sync preamble > 29 dB for the maximum duration. Thus, acquisition of the proposed PN sync premable will be very reliable.

On the downlink, the purpose of the PN sync preamble is to enable the receiver to easily extract from it estimates of the frame timing (e.g., TOA) and the carrier frequency error. A long sync preamble similar to IEEE 802.11a follows for channel measurement.

The PN code was proposed in the previous document [2] with 127 chips, but by adding one extra chip, -1, the length is extended to a more convenient 128 chips without increasing the peak sidelobe of the autocorrelation function of the code. The PN code now proposed is the balanced 128-chip sequence

```
-1-1-1 1-1-1-1 1 1 1-1-1 1 1-1-1 1-1-1-1-1-1 1-1 1-1 1-1-1 1 1 1
-1 1-1-1 1 1 1-1 1-1-1-1 1 1-1 1-1 1-1 1 1 1 1 1-1 1 1-1-1 1 1-1
-1-1 1 1 1-1 1 1 1 1 1-1-1 1 1-1 1-1-1 1-1 1 1-1 1-1-1-1-1-1-1-1
 1 1 1-1 1-1-1-1 1 1 1 1 1 1 1-1 1-1-1 1-1 1 1-1 1-1-1 1 1-1-1-1
```

which has a ratio of peak autocorrelation to maximum sidelobe correlation of 128/7 and no DC content. This PN code applies to the mandatory OFDM mode, $N_{FFT} = 256$. The PN code biphase modulates the transmitted carrier in the time domain. However, to facilitate the reduction of the out-of-band spectral components, the sync code modulation is stored in the frequency domain and transformed into the time domain by the IFFT algorithm already existing in the transmitter for OFDM; thus, the filtering for spectral control is applied in the frequency domain.

3.2 DIGITAL MATCHED FILTER TO DETECT THE EPOCH OF THE SYNC PREAMBLE AND ESTIMATE THE CARRIER FREQUENCY

One possible implementation in the receiver to detect the epoch of the PN sync preamble is a digital matched filter. The tap weights can be quantized to ±1 despite transmitter filtering. Another possible implementation is multiple correlators that search over the time uncertainty (one frame). Yet another possible implementation uses the FFT technique, multiplying the transform of the received samples by the inverse transform of the PN sync code and transforming back to the time domain.

The matched filter will not detect the PN sync preamble of duration T_s if the carrier frequency error is greater than approximately $0.5/T_s$. For the maximum duration, this is approximately $0.25/T_b$. A frequency search over the total frequency uncertainty can be done in the receiver, extending the search over multiple frames, or the matched filter can be provided with multiple summing networks to extend the detectable frequency range.

When PN sync is detected, an accurate carrier frequency estimate can be extracted by breaking the total duration T_s into two separate parts in the matched filter and computing the phase difference between the correlations in the two parts. This extracted frequency estimate is unambiguous over the range $\pm 1/T_s$.

3.3 LONG SYNC PREAMBLE FOR CHANNEL MEASUREMENT

The long sync preamble follows the PN sync preamble and has duration $2(T_g+T_b)$. For $N_{FFT} = 256$, the long sync preamble transmits 200 tones with spacing $1/T_b$. The waveform has two repetitions of duration T_b with a cyclic prefix, as in IEEE 802.11a and as proposed by Wi-LAN. The long sync preamble is used for channel measurement. Two FFT computations are done in accordance with the epoch obtained from the PN sync preamble. Furthermore, by exploiting the periodicity of T_b, a fine carrier frequency estimate can be extracted by the phase difference between the two FFT computations summed over all the tones. The channel measurement for each tone is the complex sum of the two FFT computations.

Each tone of the long sync preamble is biphase modulated by a known modulation for the purpose of reducing the peak/average power ratio in the time waveform produced by the IFFT. An example of such modulation for 200 tones is as follows

```
 1 1 1-1 1 1-1 1 1 1 1-1-1 1 1-1 1-1 1-1 1
-1-1 1-1 1 1-1 1 1-1 1 1 1-1 1 1-1-1-1 1-1
-1 1-1 1 1 1-1 1 1 1 1 1-1-1 1 1 1-1-1 1 1
 1 1 1 1-1-1-1 1-1 1-1-1-1-1-1-1 1 1 1-1-1
-1-1 1-1-1 1 1 1 1-1 1-1-1-1 1-1 0-1 1 1 1
-1 1-1-1-1-1 1 1-1 1 1 1 1-1-1-1 1 1 1 1 1
 1-1 1-1 1 1 1-1-1-1-1-1-1 1 1-1-1-1 1 1-1
-1-1-1-1 1-1-1-1 1-1 1 1-1 1 1 1-1-1 1-1-1
-1 1-1-1 1-1-1 1-1 1 1-1 1-1 1-1 1-1-1 1 1
-1-1-1-1 1-1-1 1-1-1-1-1
```

where the 0 denotes the omitted tone at center frequency.

4. UPLINK SYNC PREAMBLE

The uplink has zero carrier frequency error, but the PN sync preamble still can be utilized to enable ranging. The long sync preamble follows the PN sync preamble and is used for channel estimation of each tone on the uplink.

5. SIMULATION

The purpose of this section is to present simulation results showing that the proposed PN sync preamble has the desired property of enabling the receiver to extract both an accurate TOA estimate and an accurate frequency error estimate at a useful S/N. Also, the ability of the receiver to reject a signal with a large frequency offset is studied to demonstrate the feasibility of performing a search in the frequency domain when the frequency error is large without any problem of a spurious acquisition of a strong signal. The long sync preamble for channel estimation is not simulated.

5.1 SIMULATION MODEL

For this section, postulate the signal bandwidth to be the same as IEEE 802.11a. Thus, the simulation generates the complex waveform at a sampling rate of 40 Msamples/sec for the OFDM signal assumed to have T_b = 12.8 μsec with 200 tones (192 data tones and 8 fixed pilots). The tone spacing of the OFDM symbol is 78.125 KHz. The transmitted signal is filtered by a 4-pole Butterworth filter with 3-dB bandpass = 27 MHz, and the received signal is also filtered by a 4-pole Butterworth filter with 3-dB bandpass = 27 MHz. Prior to receive filtering, independent complex Gaussian noise samples are added to simulate white noise. The PN sync code waveform is preceded by thermal noise and followed by a noise-like signal at the transmit power level to represent the subsequent long sync preamble and OFDM symbols. The OFDM mode N_{FFT} = 256 is implemented with a 512-point IFFT and FFT, so the waveform is generated at the complex sampling rate of 40 Msamples/sec. The receiver takes complex samples of the filtered signal plus noise at 40 Msamples/sec and quantizes the samples by the ADC.

The PN sync preamble has a PN chip rate of 10 Mchips/sec so has a duration of 12.8 μsec, or 512 samples. Conceptually, the carrier is biphase modulated by the PN chips, and the power of the PN sync preamble equals the average power of all 200 tones in the assumed OFDM waveform. (The power of the sync code preamble possibly could be higher, since the peak/average power ratio of the unfiltered sync code waveform is 0 dB.) The proposed chip rate produces spectral nulls at ±10 MHz. The PN sync code is stored in the frequency domain by computing the IFFT of the unfiltered time domain waveform and setting all frequency components outside the range —10 MHz to 10 MHz to zero to be consistent with spectral mask requirements. This means to zero all the bins from 129 to 384 of the 512-point IFFT.

The starting carrier phase and assumed timing in the receiver is random for each simulation run. The receiver processing correlates the received samples with the 128-chip PN code. A complex sum is formed over 128 received samples with a spacing of four samples in time. The sampling rate of the input to and output from the matched filter remains 40 MHz. Alternatively, the sum can be formed over 256 received samples with a spacing of two samples or over 512 received samples, but the performance improvement achieved thereby from the greater processing complexity is found to be negligible. The correlation is the result of by multiplying the sequence of received samples by the replica binary PN code.

The location of the peak correlation specifies the TOA of the PN sync preamble. In the simulation, the global peak is detected by waiting 512 samples after each local peak to test whether a larger peak occurs later. Therefore, with multipath, the largest multipath component will be detected with a resolution of one sample. However, multipath was not actually simulated for this document, which studies performance in Gaussian noise. The estimate of the carrier frequency offset is proportional to the angle of the product of the complex conjugate of the first half of the correlation multiplied by the second half of the correlation, computed at the instant of the peak correlation.

5.2 AGC

AGC is essential to set the signal level for the subsequent OFDM demodulation of data symbols. To control the receiver AGC, a short-term power averaging is done. The simulation sums over 128 received samples, which are presumed to be quantized by an 8-bit ADC, and adjusts the input gain proportional to the ratio of the desired power to the measured power. This gain adjustment is done once every 128 received samples.

5.3 RESULTANT CORRELATION FUNCTION OF PN SYNC CODE

Figures 1 and 2 plot the correlation function of the PN sync code resulting in the receiver with a frequency error of zero. Figure 1 assumes no transmitter filtering except the Butterworth filter. Figure 2 assumes the spectral components are zeroed in the transmitter outside the frequency range —10 MHz to 10 MHz. There is a negligible difference between the two plots; i.e., the spectral control of the PN sync code has a negligible impact.

5.4 RESULTS

The detection threshold is set empirically to eliminate spurious detections. The sync detection performance is quantified as a function of the E/N_o per data tone in an OFDM symbol with $T_g/T_b = 0.25$.

Assuming the frequency components outside the frequency range —10 MHz to 10 MHz are set to zero, Figure 3 plots the probability of sync detection at a frequency error of 0, and Figure 4 plots the required E/N_o per data tone as a function of the carrier frequency error to maintain a detection probability of 0.9. With a frequency error of 60 KHz or more, sync detection never occurs even on a very strong signal.

The estimate of the TOA has a standard deviation of about 0.5 sample, or 12.5 nsec, even at a detection probability of 0.9. The standard deviation of the error of the carrier frequency estimate is roughly 7 KHz at a detection probability of 0.9, but still is roughly 5 KHz with a very strong signal, probably a result of quantization in the computation. The AGC is set with a standard deviation of about 0.5 dB.

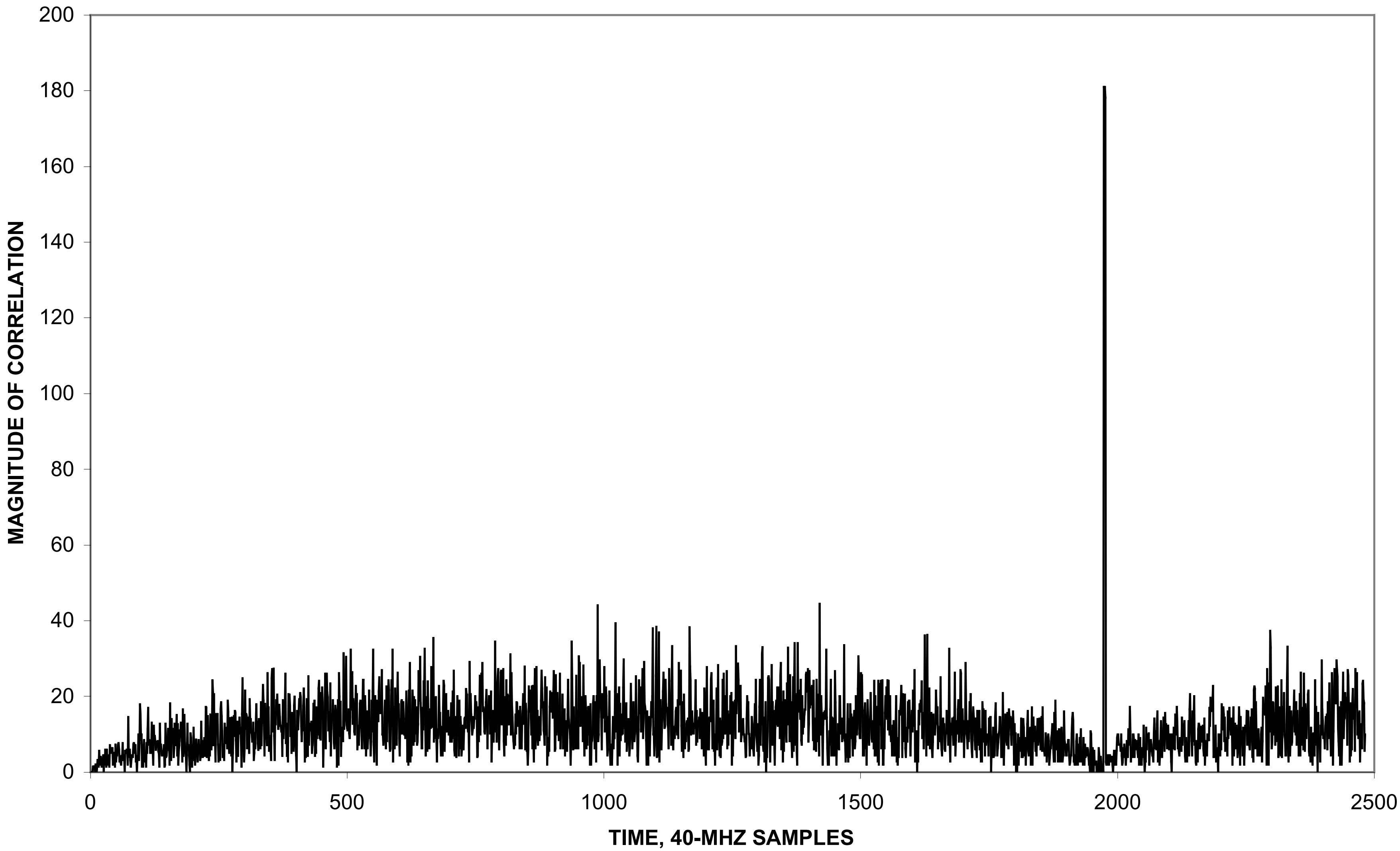
6. CONCLUSIONS

The proposed PN sync preamble appears to meet the performance objectives for the OFDM mode, $N_{FFT} = 256$. The sync detection in Gaussian noise is reliable at a S/N well below the requirement at the minimum data rate. The TOA and frequency estimates are reasonably accurate. The AGC is set accurately. Spectral control of the PN sync code waveform in the frequency domain enables compatibility with the OFDM spectral mask requirement.

7. REFERENCES

[1] Draft standard, IEEE 802.16ab-01/01, June 2001
[2] OFDM Ad-Hoc Intranet, WMUX Input to preamble design , June 2001

FIG 1. CORRELATION FUNCTION OF RECEIVED PN SYNC CODE



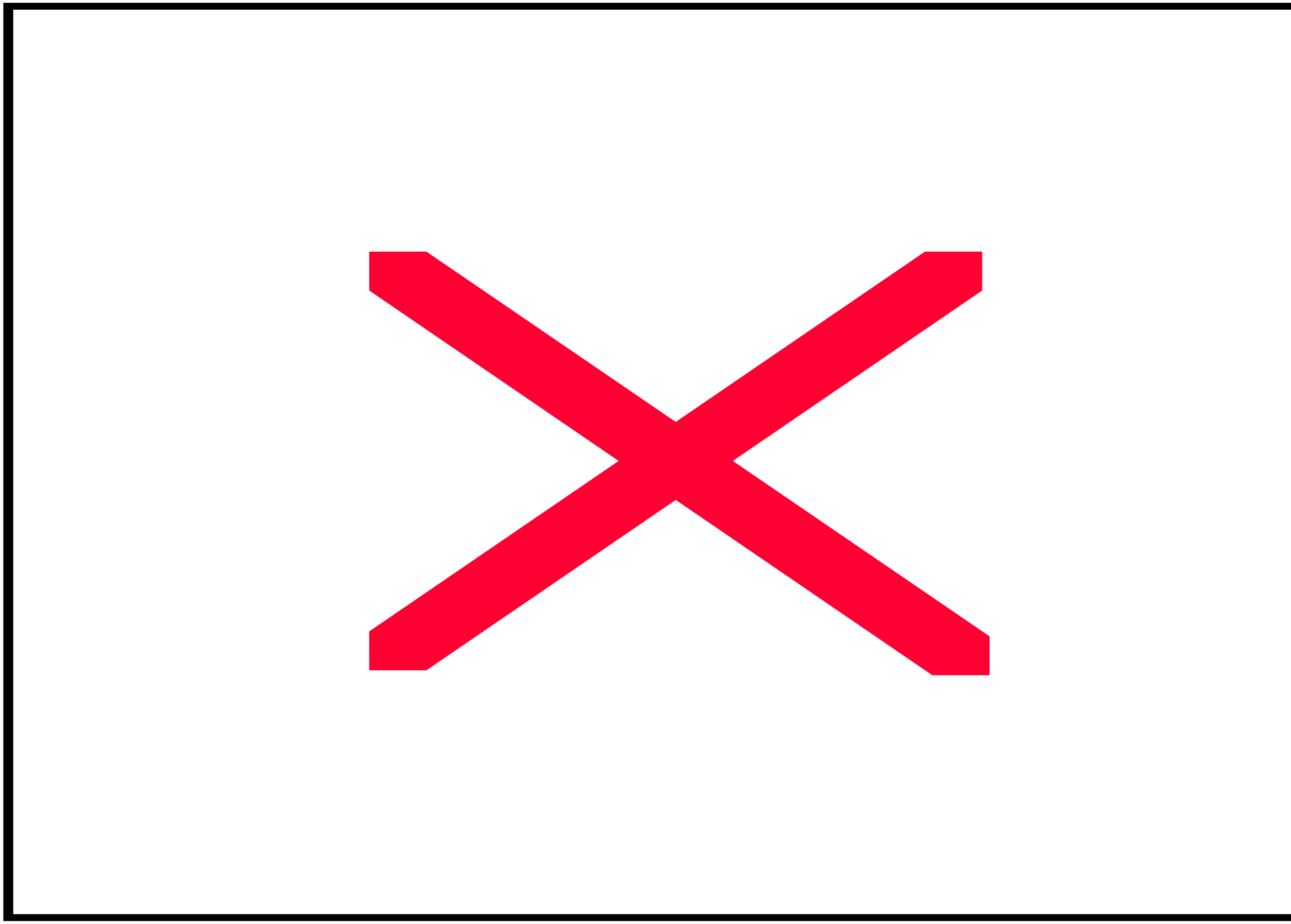


FIG 3. PROBABILITY OF DETECTION OF PN SYNC PREAMBLE

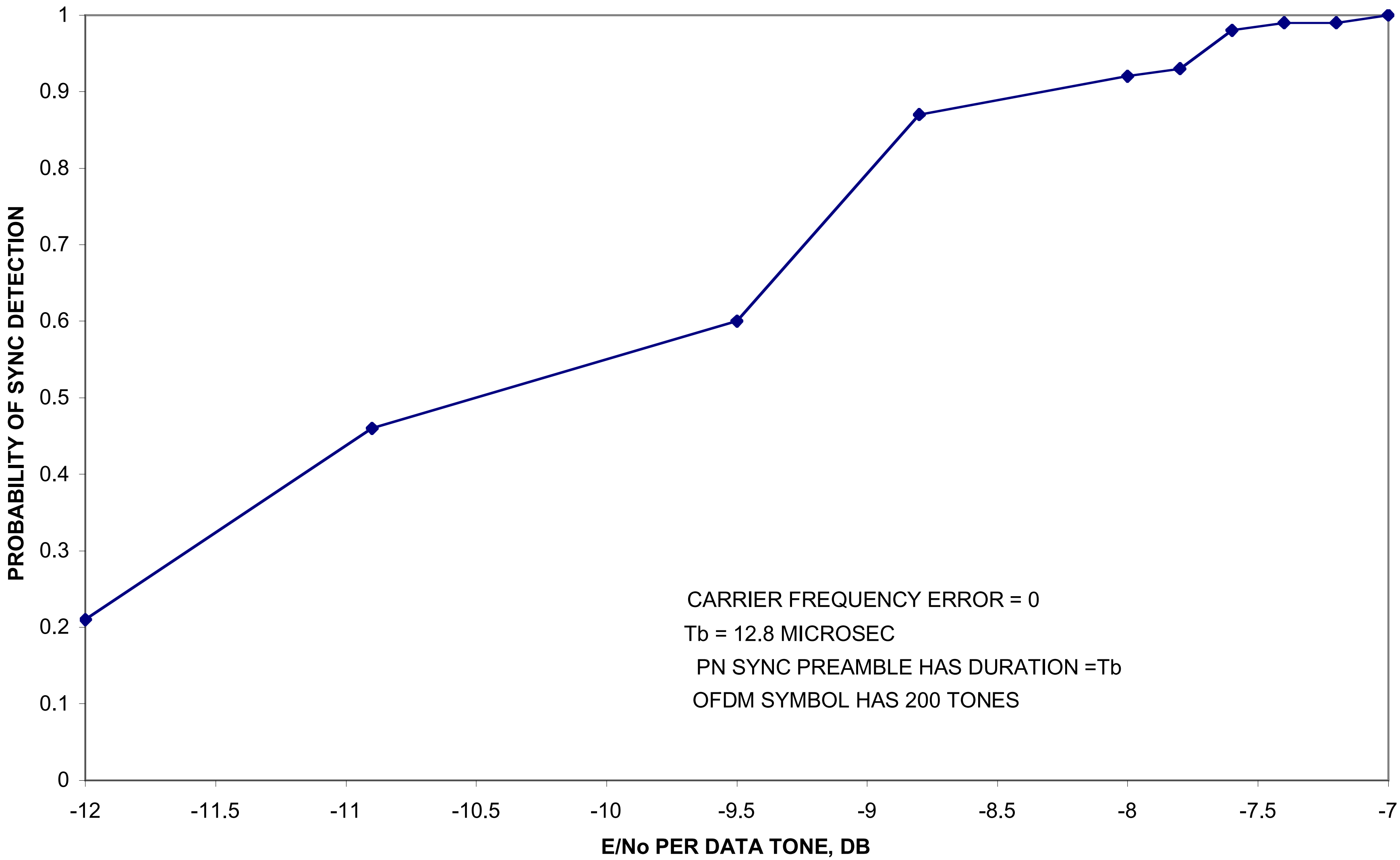


FIG 4. EFFECT OF CARRIER FREQUENCY ERROR ON PN SYNC DETECTION