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Performance of GBT-9 with FEC in Multipath, AWGN, CCI, and ACI

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Abstract

This document provides data on GBT-9 performance, for the criteria listed in IEEE-97/157r1, and for the TGb Proposal Comparison Matrix, IEEE 802.11-98/78.

This document, IEE 802.11-98/92 is a more complete description of GBT-9 performance. It provides detailed description of data. A companion document, IEEE 802.11-98/102, is a concise Template style response for the Proposal Comparison Matrix of IEEE 802.11-98/78.

Introduction

This document provides results of simulations of the performance of the Advanced Multirate Barker Codes, AMBC, as used in GBT-9. This data is provided to meet the criteria raised in IEEE 802.11-97/157r1. For clarity, the issues are addressed in the same order as in 97/157r1.

v

Implementation Section

Receiver Structure

GBT-9 requires a linear receiver structure from the first RF stage to the ADC. While this imposes some cost and power constraints on the transmitter PA, this should not impose any constraints on the receiver RF and IF chain. GBT-9 prototypes are using a 6 bit ADC. This is more bits than would be needed with an ideal ADC. However, for now, overspecifying to 6 bits is an easy way to get enough Spurious Free Dynamic Range, or SFDR.

The proposed Advanced Multirate Barker Codes has exceptionally wide flexibility for a range of receiver architecture and complexity. In order of descending cost and performance, the options are :

RAKE receiver with MRC, Maximal Ratio Combining

RAKE with fewer fingers [a]

Matched Filter and no RAKE [b]

[a] Here, the designer need not compromise. The number of fingers needed depends on the number of Advanced Barker Codes in use. Fewer Codes (lower data rate) translates into fewer fingers needed. Because RF channels with large Trms can only support a lower data rate and fewer simultaneous Advanced Barker Codes, these receivers can achieve near-optimal performance with fewer fingers.

[b] For RF channels with low Trms, the RAKE receiver may not be needed.

RAKE			T rms	(nsec)		
Fingers	**50**	**100**	**150**	**200**	**300**	**500**
1	0.377	0.760	0.910	0.966	0.994	1.000
2	0.336	0.720	0.880	0.958	0.993	0.999
3	0.310	0.670	0.840	0.920	0.988	0.998
4	0.310	0.650	0.815	0.890	0.975	0.997
5	0.310	0.620	0.800	0.880	0.967	0.995
6	0.310	0.620	0.790	0.870	0.959	0.991
7	0.310	0.620	0.790	0.865	0.944	0.989
8	0.310	0.620	0.790	0.850	0.930	0.975
9	0.310	0.620	0.790	0.850	0.930	0.954
10	0.310	0.620	0.790	0.850	0.930	0.950
14	0.310	0.620	0.790	0.850	0.930	0.950
16	0.310	0.620	0.790	0.850	0.930	0.950

Table 1., PER *vs.* the Number of RAKE Fingers, when using 4 AMBC Codes, for 64 byte packets, no FEC in use

The simulations assumed a RAKE receiver with MRC.

GBT has experience with MRC RAKE implementations, and estimates a gate count of 35,000 in 0.35 micron silicon. These are asynchronous circuits, and will have less than half the DC power consumption of designs which use DSP's or similar synchronous circuits.

Diversity Implementation

GBT-9 has no Equalizer to train, so GBT-9 can acquire signal in 48 µs, including worst-case Antenna Diversity. This is short, compared with 128 µs for the Low Speed preamble. A Short Header can be implemented with Antenna Diversity; details are shown in Fig. 1, Preamble Lock-Up Time Line.

Optional FEC as an issue for Receiver Structure

Discussion of an FEC is included with Receiver Implementation because the FEC has implications for receiver complexity more than for the transmitter.

GBT's simulations show that the coding gain from use of an FEC adds robustness against multipath. That is, data throughput is greater at all ranges.

GBT-9 has a unique advantage with its high data rate. Even after using half the MPDU bits for the FEC, it can have improved throughput.

The FEC is optional in three ways:

(1) OEM's can choose to implement an FEC or not, depending on the application.

(2) The FEC can be activated on a packet-by-packet basis.

(3) The proposal allows two FEC's. This allows less costly implementation, or the best possible FEC.

A few of the reserved values in the SERVICE field in the PLCP header would indicate the use of an FEC. The FEC only covers the MPDU, not the PLCP header. This makes the implementation straightforward; the receiver has 32 μs to begin the FEC.

When the channel Trms is below about 45 ns, throughput is better without an FEC.

Choice of FEC:

Convolutional codes are known to be somewhat more effective than Block codes, but require considerably more gates. Therefore, it seems sensible to provide for both an inexpensive FEC, and also a stronger FEC.

GBT is continuing to investigate FEC's. The goal is to obtain two FEC's.

In simulations

comparing half rate Block FEC's, BCH(63, 36, 5) and BCH(127, 64, 10) were more effective than others, as shown below:

Trms Ns	BCH (63, 51,2)	BCH (63, 45, 3)	BCH (63, 36, 5)	BCH (127, 64, 10)	UNCODED (inf. SNR)	UNCODED 20 dB SNR
10	17.8	15.7	12.57	11.08	22.0	21.0
20	15.5	14.2	11.5	10.2	19.0	17.8
40	8.0	8.2	8.0	8.0	7.5	7.0
60	4.5	5.0	5.50	6.1	4.4	4.0
80	3.8	4.25	4.45	5.3	3.5	3.2
100	3.6	4.0	4.2	4.8	3.2	3.1
150	3.1	3.5	3.65	4.3	3.0	2.85
200	3.0	3.25	3.45	3.8	2.9	2.75
300	2.75	3.0	3.3	3.4	2.55	2.45
500	2.5	2.6	3.0	3.1	2.0	2.0

Table 2., Higher Throughput with an FEC, Comparing No Code and some BCH Codes at SNR = 20 dB, for 64 Byte Packets.

NOTES: For each T_{rms} the optimum number of Advanced Barker Codes was selected.
For this table, throughput is defined in a simplistic way, and does not consider the fixed delays added by Slot Times, Preambles and Headers, etc. However, the overhead bits, required by each FEC, have been taken into account.

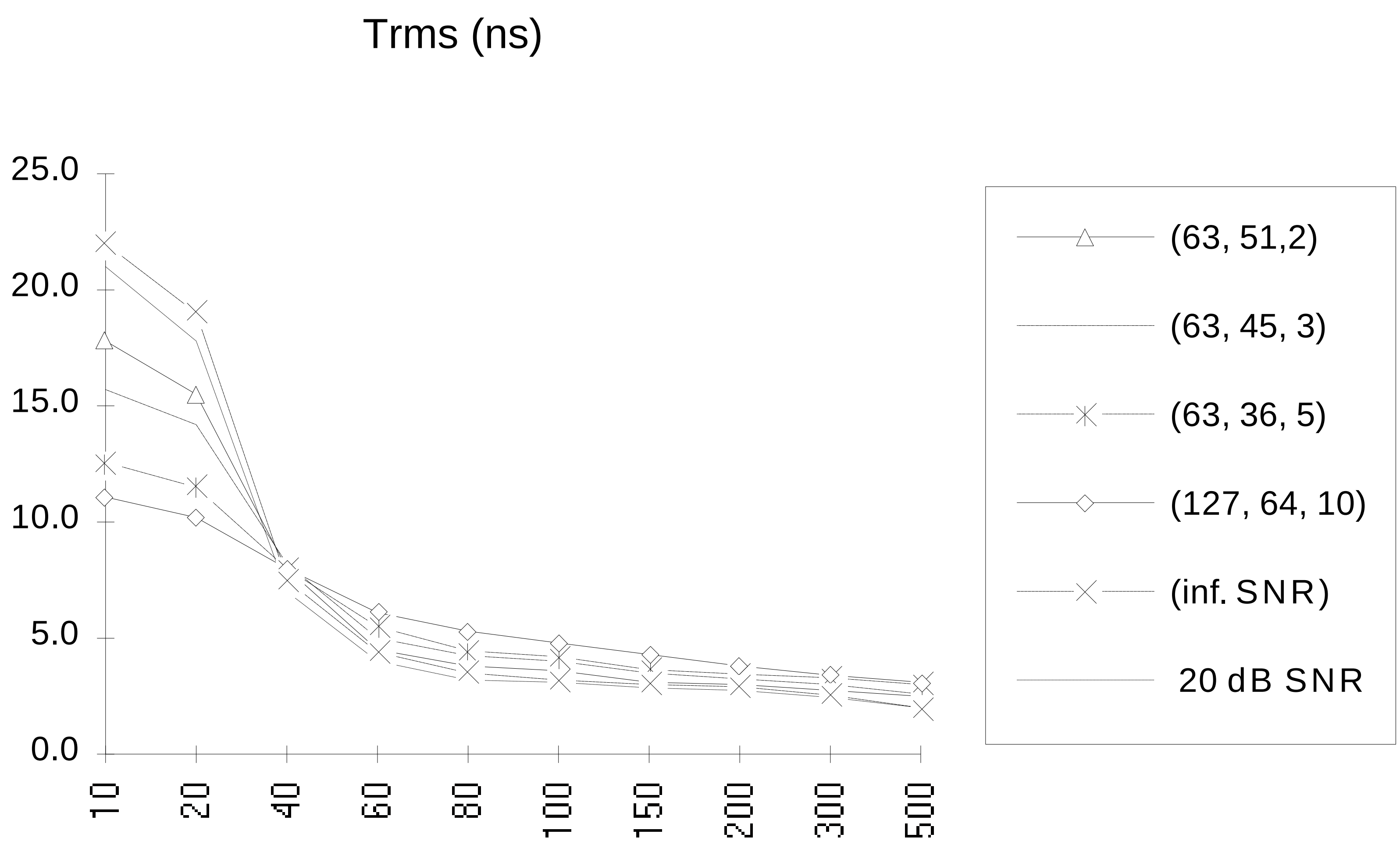

Fig. 1, Throughput in Mb/s, Comparing No Code and Various BCH Codes at SNR = 20 dB, for 64 Byte Packets

The vertical scale is Mb/s, computed simply, without fixed overhead delays.

Immunity to Multipath and Noise Section

Multipath Without Noise

Compared to no FEC, BCH (127, 64, 10) shows major improvement in data throughput.

Trms	Number of Advanced Barker Codes in use						
Ns	12	10	8	6	5	4	3
20	0.06	0.041	0.029	0.0044	0.001	0.001	0.001
30	0.22	0.16	0.10	0.020	0.0055	0.001	0.001
40	0.36	0.27	0.165	0.055	0.0165	0.001	0.001
50	0.48	0.36	0.235	0.097	0.043	0.001	0.001
60	0.55	0.45	0.28	0.14	0.075	0.001	0.001
80	0.72	0.60	0.40	0.22	0.12	0.001	0.001
100	0.82	0.72	0.50	0.30	0.18	0.054	0.001
120	0.87	0.80	0.62	0.34	0.22	0.095	0.001
150	0.94	0.86	0.70	0.40	0.28	0.13	0.001
200	0.96	0.92	0.76	0.51	0.36	0.16	0.001
250	0.98	0.95	0.82	0.58	0.40	0.185	0.001
300	1.00	0.98	0.86	0.68	0.46	0.21	0.04
400	1.00	1.00	0.91	0.83	0.53	0.28	0.09
500	1.00	1.00	0.97	0.92	0.66	0.36	0.12
600	1.00	1.00	0.99	0.97	0.77	0.47	0.14

Table 3., 1000 Byte PER *vs.* T_{rms} for 3 to 12 Advanced Barker Codes,
SNR = 30 dB, with BCH(127,64,10)

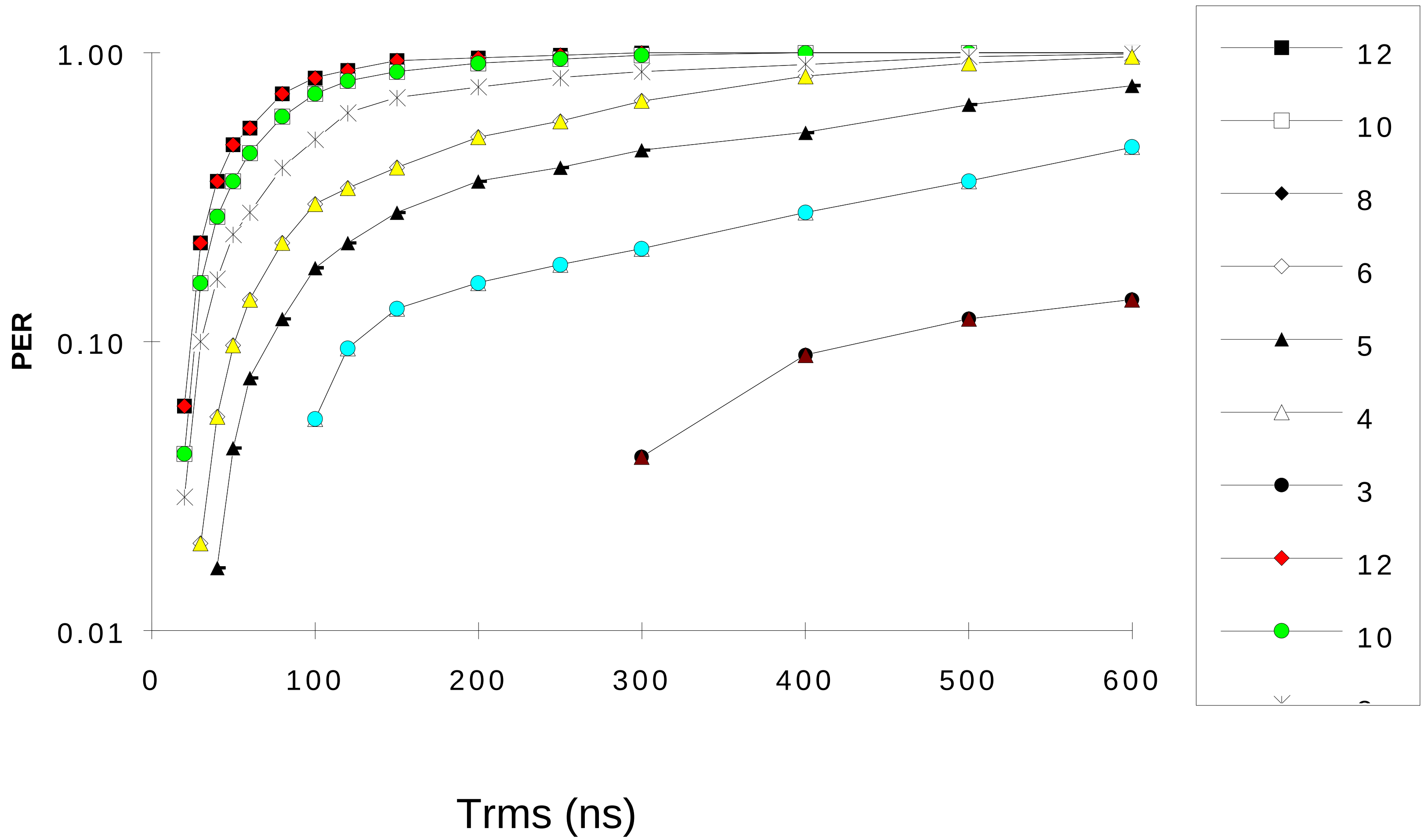

Fig. 2., PER for 1000 Byte Packets, for 3 to 12 Advanced Barker Codes, SNR = 30 dB, with BCH(127,64,10)

Trms Ns	Number of Advanced Barker Codes in use 12	10	8	6	5	4
20	0.04	0.018	0.005	0.001	0.001	0.001
30	0.16	0.10	0.04	0.005	0.001	0.001
40	0.26	0.18	0.088	0.02	0.003	0.001
60	0.40	0.28	0.15	0.06	0.014	0.006
80	0.54	0.42	0.23	0.11	0.034	0.014
100	0.68	0.56	0.32	0.16	0.07	0.022
120	0.76	0.63	0.38	0.19	0.095	0.029
150	0.84	0.71	0.45	0.23	0.12	0.036
200	0.91	0.82	0.58	0.29	0.16	0.05
250	0.94	0.86	0.66	0.34	0.19	0.065
300	0.96	0.90	0.73	0.40	0.23	0.08
400	0.99	0.94	0.80	0.48	0.29	0.11
500	0.995	0.988	0.90	0.56	0.34	0.138
600	1.00	0.99	0.96	0.65	0.41	0.17

Table 4., PER *vs.* T_{rms} for 64 Byte Packets, using 4 to 12 Advanced Barker Codes, SNR = 30 dB in a noiseless channel, using BCH(127,64,10)

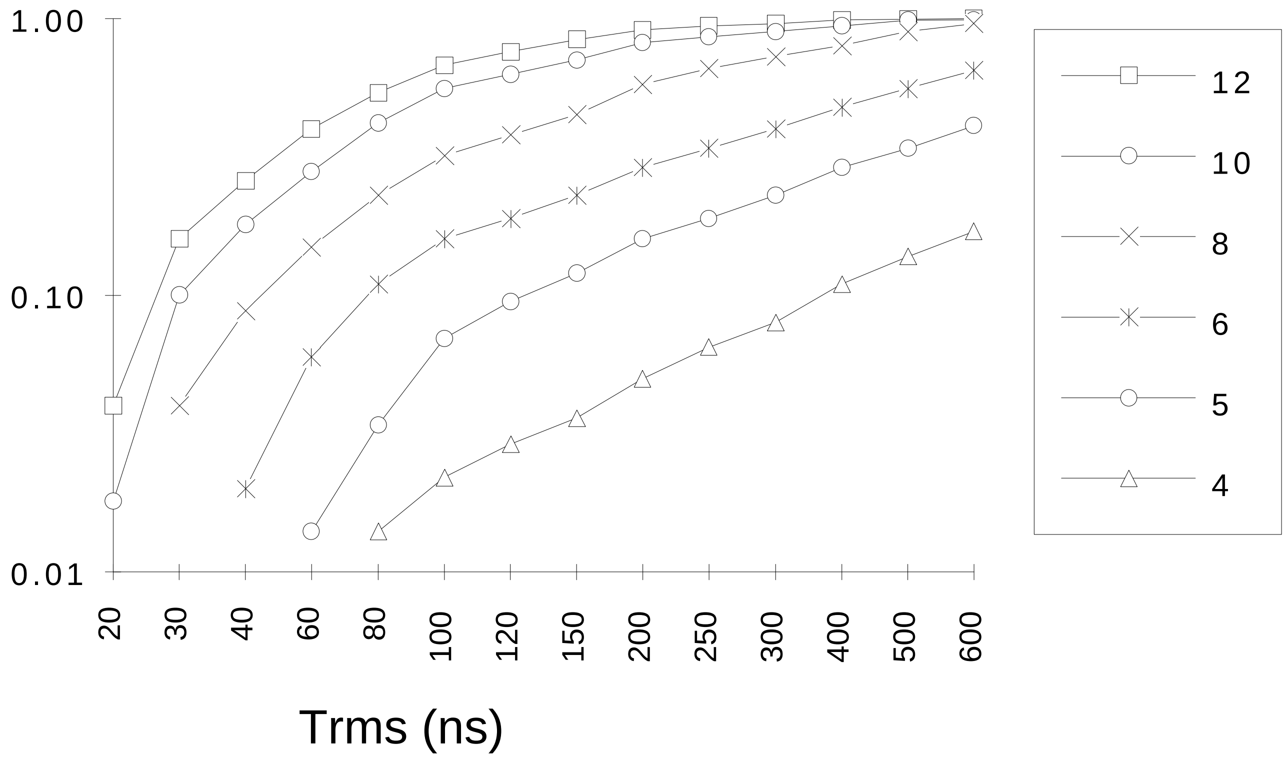

Figure 3., PER *vs.* T_{rms} for 64 Byte Packets, using 4 to 12 Advanced Barker Codes, SNR = 30 dB in a noiseless channel, using BCH(127,64,10)

Even for a Trms of 1500 μs, GBT-9 is able to receive over 40% of the packets at 5.5 Mb/s, with the protection of BCH(63,36,5).

Trms	Number of Codes								
(nsec)	1	2	3	4	5	6	8	10	12
18	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.022	0.036
20	0.001	0.001	0.001	0.001	0.001	0.001	0.150	0.026	0.060
25	0.001	0.001	0.001	0.001	0.001	0.005	0.460	0.090	0.100
30	0.001	0.001	0.001	0.001	0.008	0.030	0.070	0.150	0.180
35	0.001	0.001	0.001	0.001	0.0164	0.055	0.110	0.220	0.290
40	0.001	0.001	0.001	0.001	0.024	0.070	0.150	0.270	0.340
50	0.001	0.001	0.001	0.012	0.050	0.110	0.220	0.380	0.450
60	0.001	0.001	0.001	0.023	0.085	0.170	0.300	0.500	0.580
80	0.001	0.001	0.009	0.042	0.150	0.230	0.430	0.640	0.720
100	0.001	0.001	0.015	0.051	0.180	0.310	0.500	0.720	0.790
120	0.001	0.001	0.018	0.096	0.220	0.400	0.560	0.780	0.860
140	0.001	0.001	0.023	0.105	0.260	0.430	0.630	0.840	0.910
160	0.001	0.001	0.026	0.116	0.290	0.470	0.680	0.870	0.925
180	0.001	0.001	0.030	0.125	0.315	0.490	0.720	0.910	0.946
200	0.001	0.001	0.032	0.135	0.340	0.550	0.740	0.930	0.960
250	0.001	0.001	0.046	0.170	0.420	0.610	0.840	0.960	0.980
300	0.001	0.001	0.051	0.190	0.450	0.670	0.870	0.980	0.990
400	0.001	0.001	0.061	0.270	0.610	0.810	0.930	0.990	1.000
500	0.001	0.050	0.085	0.310	0.740	0.900	0.960	1.000	1.000
1000	0.001	0.200	0.260	0.820	0.890	0.990	1.000	1.000	1.000
1500	0.001	0.370	0.590	0.930	0.940	1.000	1.000	1.000	1.000
2000	0.001	0.570	0.640	0.940	1.000	1.000	1.000	1.000	1.000
3000	0.001	0.860	----	----	----	----	----	----	----
4000	0.075	0.950	----	----	----	----	----	----	----
5000	0.360	1.000	----	----	----	----	----	----	----

Table 5., PER *vs.* T_{rms} for 64 Byte Packets, using BCH(63, 36, 5) in a noiseless channel.

Trms	Number of Codes								
(nsec)	1	2	3	4	5	6	8	10	12
18	0.001	0.001	0.001	0.001	0.001	0.007	0.025	0.039	0.046
20	0.001	0.001	0.001	0.001	0.004	0.019	0.040	0.060	0.072
25	0.001	0.001	0.001	0.001	0.009	0.044	0.090	0.137	0.160
30	0.001	0.001	0.001	0.001	0.032	0.083	0.160	0.240	0.270
35	0.001	0.001	0.001	0.009	0.055	0.130	0.230	0.310	0.360
40	0.001	0.001	0.001	0.020	0.080	0.170	0.290	0.380	0.450
50	0.001	0.001	0.001	0.040	0.131	0.240	0.390	0.540	0.590
60	0.001	0.001	0.001	0.065	0.200	0.300	0.490	0.630	0.680
80	0.001	0.001	0.010	0.110	0.300	0.430	0.630	0.790	0.840
100	0.001	0.001	0.032	0.160	0.380	0.516	0.710	0.860	0.920
120	0.001	0.001	0.058	0.220	0.470	0.610	0.770	0.920	0.940
140	0.001	0.001	0.080	0.270	0.520	0.670	0.840	0.950	0.970
160	0.001	0.001	0.098	0.310	0.560	0.740	0.880	0.980	0.990
180	0.001	0.001	0.120	0.340	0.600	0.780	0.920	1.000	1.000
200	0.001	0.001	0.140	0.360	0.630	0.800	0.940	1.000	1.000
250	0.001	0.001	0.170	0.390	0.700	0.850	0.960	1.000	1.000
300	0.001	0.001	0.190	0.420	0.770	0.900	0.980	1.000	1.000
400	0.001	0.001	0.220	0.500	0.880	0.970	0.990	1.000	1.000
500	0.001	0.082	0.260	0.600	0.930	0.980	1.000	1.000	1.000
1000	0.001	0.300	----	----	----	----	----	----	----
1500	0.010	0.550	----	----	----	----	----	----	----
2000	0.050	0.750	----	----	----	----	----	----	----
3000	0.150	0.920	----	----	----	----	----	----	----
4000	0.340	0.990	----	----	----	----	----	----	----
5000	0.500	1.000	----	----	----	----	----	----	----

Table 6., PER *vs.* T_{rms} for 1000 Byte Packets, using BCH(63, 36, 5) in a noiseless channel.

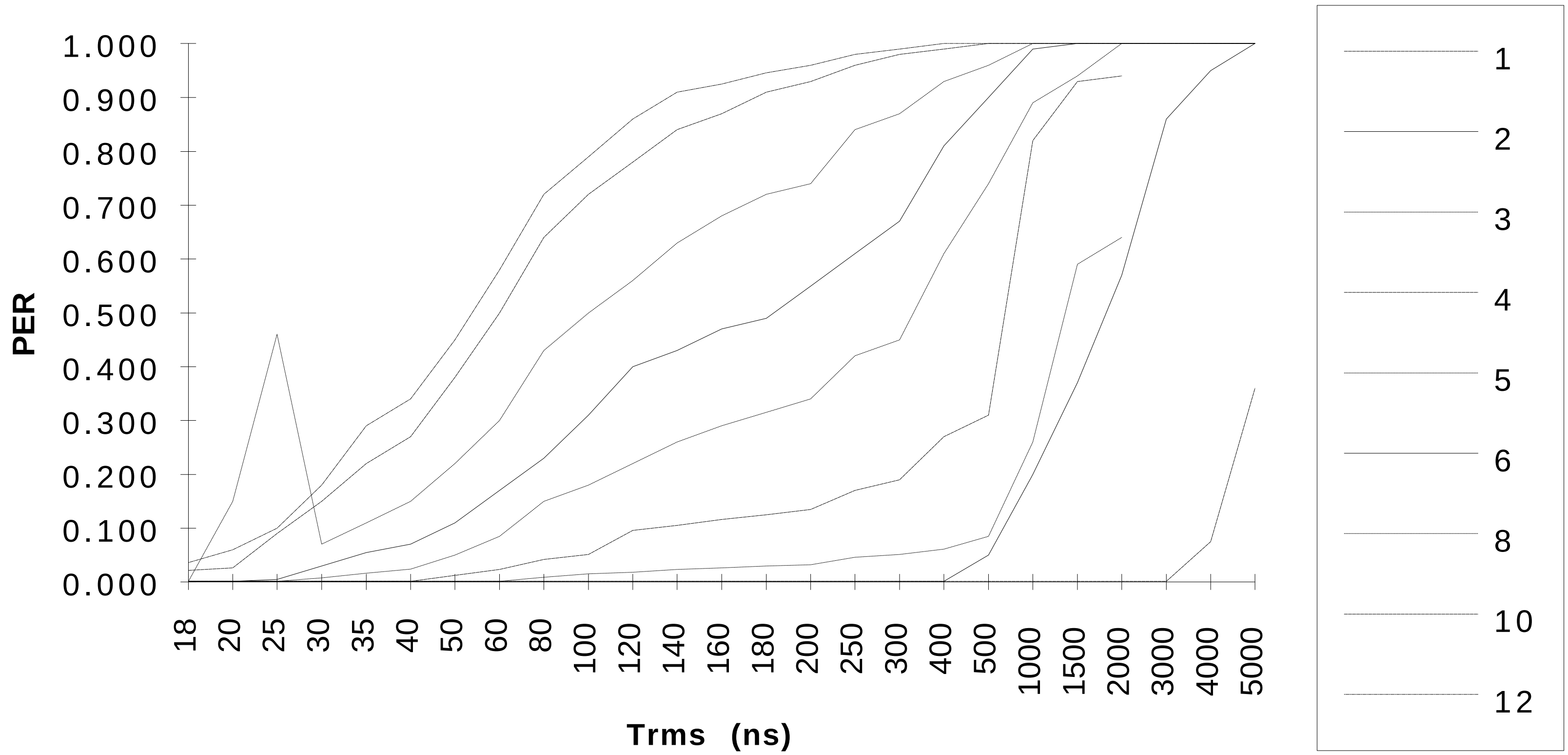

Figure 4., PER *vs.* T_{rms} for 1 to 12 Advanced Barker Codes, using BCH(63, 36, 5) in a noiseless channel. Packet Length = 64 Bytes

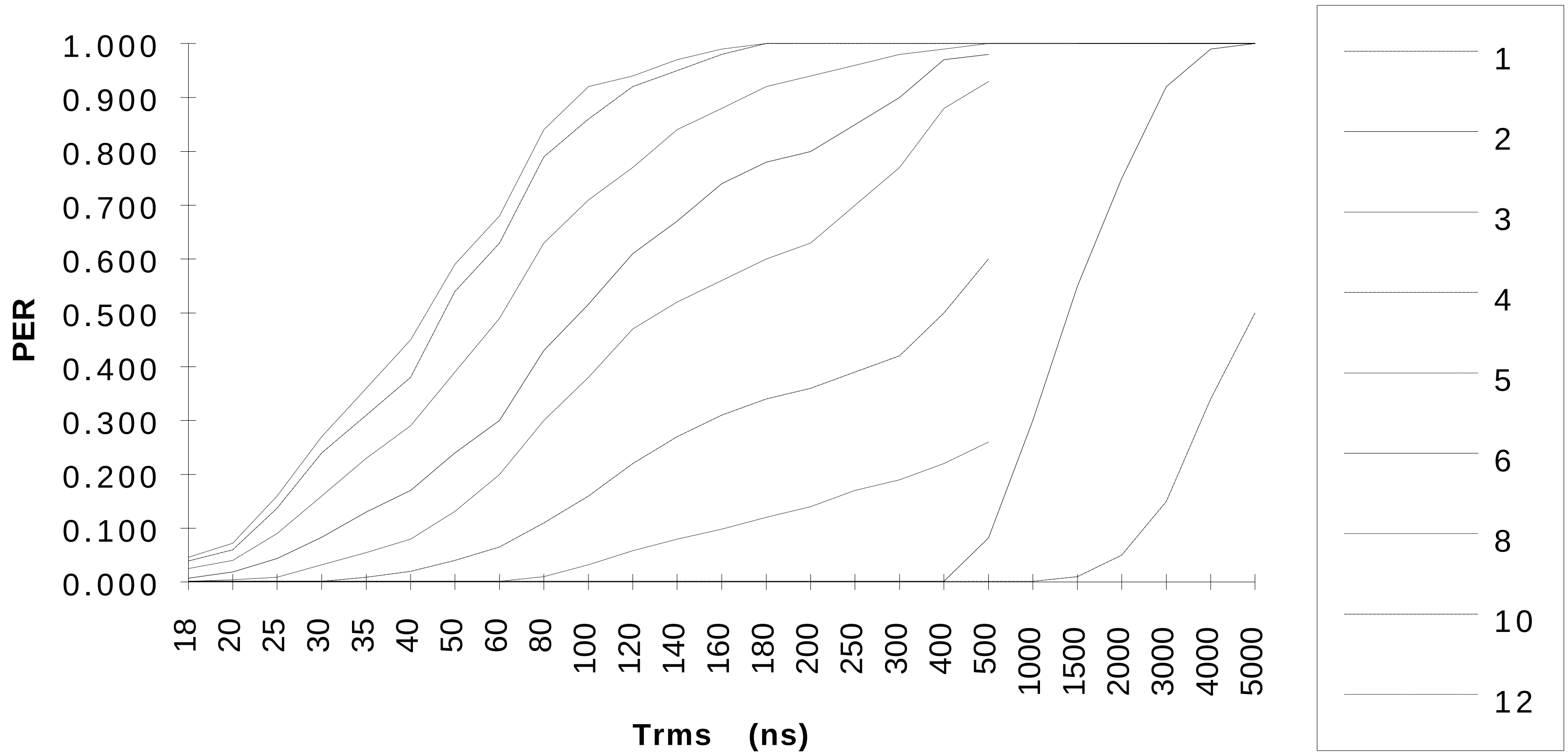

Figure 5., PER *vs.* T_{rms} for 1 to 12 Advanced Barker Codes, using BCH(63, 36, 5) in a noiseless channel. Packet Length = 1000 Bytes

PER is on the vertical axis.

Immunity to Multipath and Noise

1

As requested in 157r1, the following table describes the Eb/No at which the PER goes from [10% due to Trms] up to a PER of 20% due to the combined effects of Eb/No and multipath.

# of	No FEC 64 Byte		No FEC 1000 Byte		1 BCH(63,36,5) 64 Byte		BCH(63,36,5) 1000 Byte	
AMBC codes	Eb /No DB	SNR dB	Eb /No DB	SNR DB	Eb /No dB	SNR dB	Eb /No dB	SNR dB
1	16.0	19.0	18.5	21.5	15.8	16.0	16.2	16.4
2	17.0	23.0	20.0	26.0	15.4	18.6	15.8	19.0
3	17.8	25.6	20.0	27.8	15.0	20.0	15.8	19.8
4	17.5	26.5	19.5	28.5	14.0	20.2	18.0	24.2
5	---	---	---	---	16.4	23.6	17.8	25.0
6	17.0	27.8	19.0	29.8	16.4	24.4	18.1	26.1
8	17.0	29.0	18.3	30.3	16.3	25.5	16.3	25.5
10	16.0	29.0	18.0	31.0	16.3	26.5	15.0	25.2
12	14.0	27.8	17.0	30.8	16.2	27.2	18.3	29.3

Table 7., Eb/No Required to Raise PER from 10% (due to Trms), up to 20%.
GBT-9 without FEC and with BCH(63, 36, 5) FEC

Immunity to Noise

The parameters required for this section of IEEE802-97/157r1 are as follows:

At 8 dB = Eb/No , the PER is 10% for 64 byte packets.

At 9.5 dB = Eb/No , the PER is 10% for 1000 byte packets.

The SNR required for a PER of 10% is a different way to state noise immunity, as shown below. This does not include the effect of an FEC.

	Minimum SNR for 10% PER	
Data Rate Mb/s	64 Byte Packets	1000 Byte Bytes
1.83	11.0	12.5
3.67	14.0	15.5
5.50	15.8	17.3
7.33	17.0	18.5
9.17	18.0	19.5
11.00	18.8	20.3
12.83	19.5	21.0
14.67	20.0	21.5
16.50	20.6	22.1
18.33	21.0	22.5
20.17	21.4	22.9
22.00	21.8	23.3

Table 8., Minimum SNR Required For PER To Not Exceed 10%

It is interesting to note how the PER varies with the SNR, for 64 and 1000 byte packets.

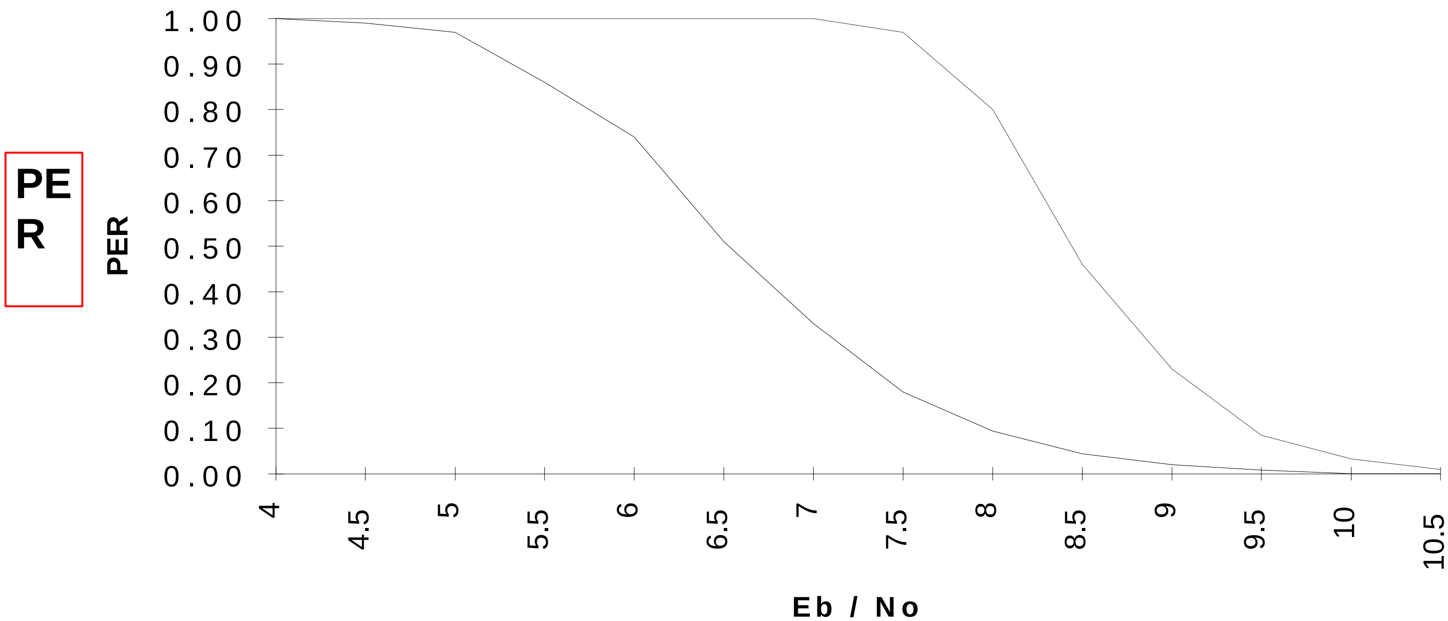

Figure 6., PER vs. Eb/No for packets of length 64 and 1000

GBT has proposed a mandatory sensitivity of -77 dBm at 9.167 Mb/s. This can be achieved with an overall Noise Figure of 15 dB. This is permissive, and allow for economical high volume applications.

The table, below, shows sensitivity for an overall Noise Figure of 8.5 dB, and a BER of only 10^{-5}, without FEC. If the BER is allowed to rise to 2 x 10^{-4}, then an additional 8 dB of sensitivity could be gained. These are textbook values.

Modulation	Data Rate	Sensitivity
BPSK	1 Mb/s	-92.9 dBm
1 Code (QPSK)	2 Mb/s	-90.3 dBm
2 Codes	1.83 Mb/s	-87.3 dBm
3 Codes	3.67 Mb/s	-85.5 dBm
4 Codes	5.5 Mb/s	-84.3 dBm
5 Codes	9.17 Mb/s	-83.3 dBm
6 Codes	11 Mb/s	-82.5 dBm
7 Codes	12.83 Mb/s	-81.8 dBm
8 Codes	14.67 Mb/s	-81.3 dBm
9 Codes	16.5 Mb/s	-80.8 dBm
10 Codes	18.3 Mb/s	-80.3 dBm
11 Codes	20.17 Mb/s	-79.9 dBm
12 Codes	22 Mb/s	-79.5 dBm

Table 9., GBT-9 Receiver Sensitivity at BER = 10E-5

Sensitivity to Clock Accuracy

As presented in IEEE-97/110, pg. 21, the 25 ppm clock tolerances of the Low Speed standard are sufficient for GBT-9. This is true for both the RF Carrier Frequency and the Chip Clock.

GBT-9 includes a Phase Lock Loop which acquires the phase of the incoming signal early in the Preamble. Differential detection is used during this period. Implementation may contain a Costas Loop.

Overhead

Preamble Length:

GBT-9 uses the BPSK of the Low Speed header to acquire phase information, and can easily inter-operate with existing Low Speed WLAN's. If a Short Preamble will be included in the High Speed standard, to obtain the benefit of significantly greater throughput, despite the problematic coexistence with Low Speed devices, then GBT-9 will not have any problem. Neither the RAKE receiver nor the simpler implementations do not require any training sequence, as do all the equalizer-based systems.

As shown below, a total of 48 μs allows for acquisition with antenna diversity.

Figure 7., Preamble Lock-Up Time Line

Slot Size:

GBT-9 has no reason to require longer times than those provided for the Low Speed standard.

GBT has a patented AGC switch, which allows the RX to transition from BPSK in the PLCP header to Advanced Multirate Barker Code for the MPDU, in well under 1 µs.

The CCA mechanism is not changed from the Low Speed standard. Moreover, the spectral mask of GBT-9 is identical to that of Low Speed 802.11 devices.

TX and RX Turnaround Times:

All TX and RX Turnaround Times should remain the same as in the Low Speed standard. The TX has no significant latency. Even changing the number of AMBC codes in use is accomplished with simple multiplexers, and have essentially no latency. The proposed receiver structures do not require an Equalizer, and hence do not require a training period.

SIFS Time:

GBT-9 uses the same SIFS time as provided in the Low Speed standard. For reasons discussed above, there is no change in how easily implementations can operate within the SIFS period.

Spectral Efficiency:

GBT-9 has the same spectral envelope, and approximately the same Adjacent Channel Interference, or ACI, as dose the Low Speed standard. This document presents data on Co-Channel Interference, CCI, to show robustness. In addition, Adjacent Channel Interference, ACI, is excellent. So the CCI and ACI allow Cell Planning to be the same as for the Low Speed standard. In short, the Extension to a High Speed standard does not need to degrade Spectral Efficiency. IEEE 802.11-98/101 will give reasons why a 6 dB Backoff can, in some circumstances, allow greater system capacity, although only 4.5 dB of Backoff is needed for the Spectral Mask.

Cell Planning

Cell Planning is identical to the existing Low Speed system. The only difference is that some applications, employing an FEC, can have a significantly larger radius of operation.

This means that systems integrators and installers would be pleasantly surprised to learn that their old knowledge is not made obsolete by the High Speed Extension to 802.11. RF planning is unchanged from the Low Speed system.

Range:

At the worst case of 15 dB NF for an inexpensive RX, or -87.3 dBm for 3.667 Mb/s, and +30dBm TX output, the Link Budget is approximately 117 dB. There is nothing in this standard to prevent the production of compliant receivers with a NF of 4 dB, still keeping the 2.5 dB implementation factor. That gives a 2 Code sensitivity of - 98 dBm. This permits a Link Budget of -128 dB, for BER = 10E-5 which is substantial. At BER = 2*x*10E-4, the Link Budget could go up to 136 dB.

Clearly, Multipath and interference are more significant than thermal noise. The range is surprisingly wide, when using a RAKE receiver and a modest Block FEC.

Adjacent Channel Interference

GBT-9 can meet the 35 dB ACI of the Low Speed standard without special care. This is based on:

1.) The Matched Filter has low sensitivity to signals which are far off the center frequency.
Such signals are not well correlated, and tend to not get through the Matched Filter. For smaller frequency differences than the 22 MHz of an adjacent channel, the curve, below, Protection Offered by Matched Filter to CW Jamming, shows part of this effect.

2.) Additional rejection is obtained with ordinary IF filters.

Co-Channel Interference

GBT-9 can tolerate CCI where the interferer is stronger than the victim. When the interferer is another GBT-9 system, robustness depends on the data rates being used by the interferer and the victim. Two cases are presented. One case is where the victim and the interferer are using the same data rates, or from 1 to 12 AMBC codes. The other case is where the victim is using one AMBC code, and the interferer is using from 2 to 12 AMBC codes. This depends on the data rates used by the interferer and the victim. Details are given below for packets of 64 and 100 byte length.

# codes in use	Pj / Ps in dB						
	0	1	2	3	4	5	6
2	0.000	0.150	0.430	0.745	0.980	1.000	1.000
3	0.000	0.097	0.360	0.690	0.960	1.000	1.000
4	0.000	0.082	0.290	0.540	0.890	0.990	1.000
5	0.000	0.060	0.260	0.540	0.890	0.990	1.000
6	0.000	0.048	0.235	0.520	0.850	0.980	1.000
7	0.000	0.043	0.225	0.500	0.830	0.980	1.000
8	0.000	0.040	0.200	0.470	0.795	0.970	1.000
10	0.000	0.030	0.175	0.405	0.730	0.960	1.000
12	0.000	0.027	0.130	0.345	0.660	0.940	1.000

Table 10, PER vs. Co-Channel Interference to Signal Power Ratio, when the Operating Link uses one Code, and the Interferer Transmits from 2 to 12 Codes.
1000 Byte Packets SNR = 60 dB

Pj / Ps	Number of AMBC Codes in use									
dB	1	2	3	4	5	6	7	8	10	12
-12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.025
-10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.029	0.160
-9	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.035	0.220	0.450
-8	0.000	0.000	0.000	0.000	0.000	0.012	0.090	0.190	0.520	0.820
-7	0.000	0.000	0.000	0.000	0.025	0.144	0.310	0.550	0.880	1.000
-6	0.000	0.000	0.000	0.024	0.180	0.420	0.680	0.920	1.000	1.000
-5	0.000	0.000	0.015	0.220	0.516	0.830	0.970	1.000	1.000	1.000
-4	0.000	0.000	0.160	0.550	0.885	0.977	1.000	1.000	1.000	1.000
-3	0.000	0.051	0.470	0.890	0.980	1.000	1.000	1.000	1.000	1.000
-2	0.000	0.200	0.820	0.995	1.000	1.000	1.000	1.000	1.000	1.000
-1	0.030	0.530	0.995	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0	0.090	0.940	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1	0.310	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0.640	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3	0.970	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
4	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 11., PER vs. Co-Channel Interference to Signal Power Ratio, when the Operating Link uses one Code, and the Interferer Transmits from 2 to 12 Codes
1000 Byte Packets, SNR = 60 dB, no FEC in use

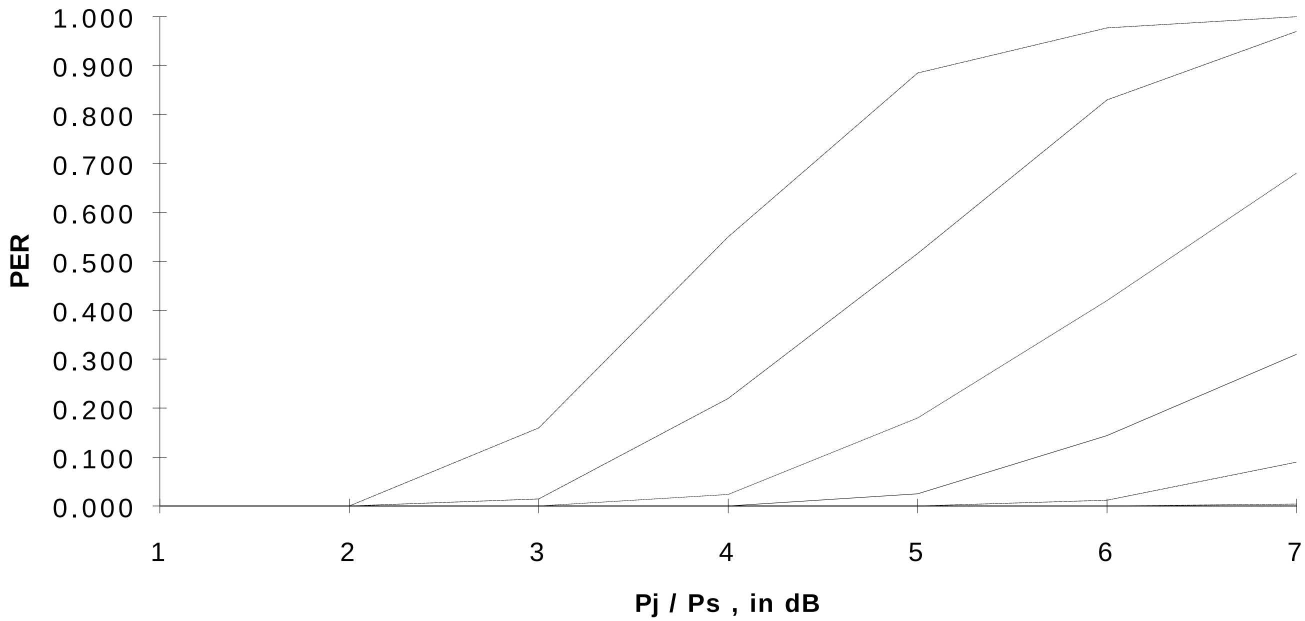

Fig. 8., PER *vs.* Co-Channel Interference to Signal Power Ratio, when the Operating Link uses One Code and the Interferer uses 2 to 8 Codes 1000 Byte Packets, SNR = 60 dB

The vertical scale is PER.

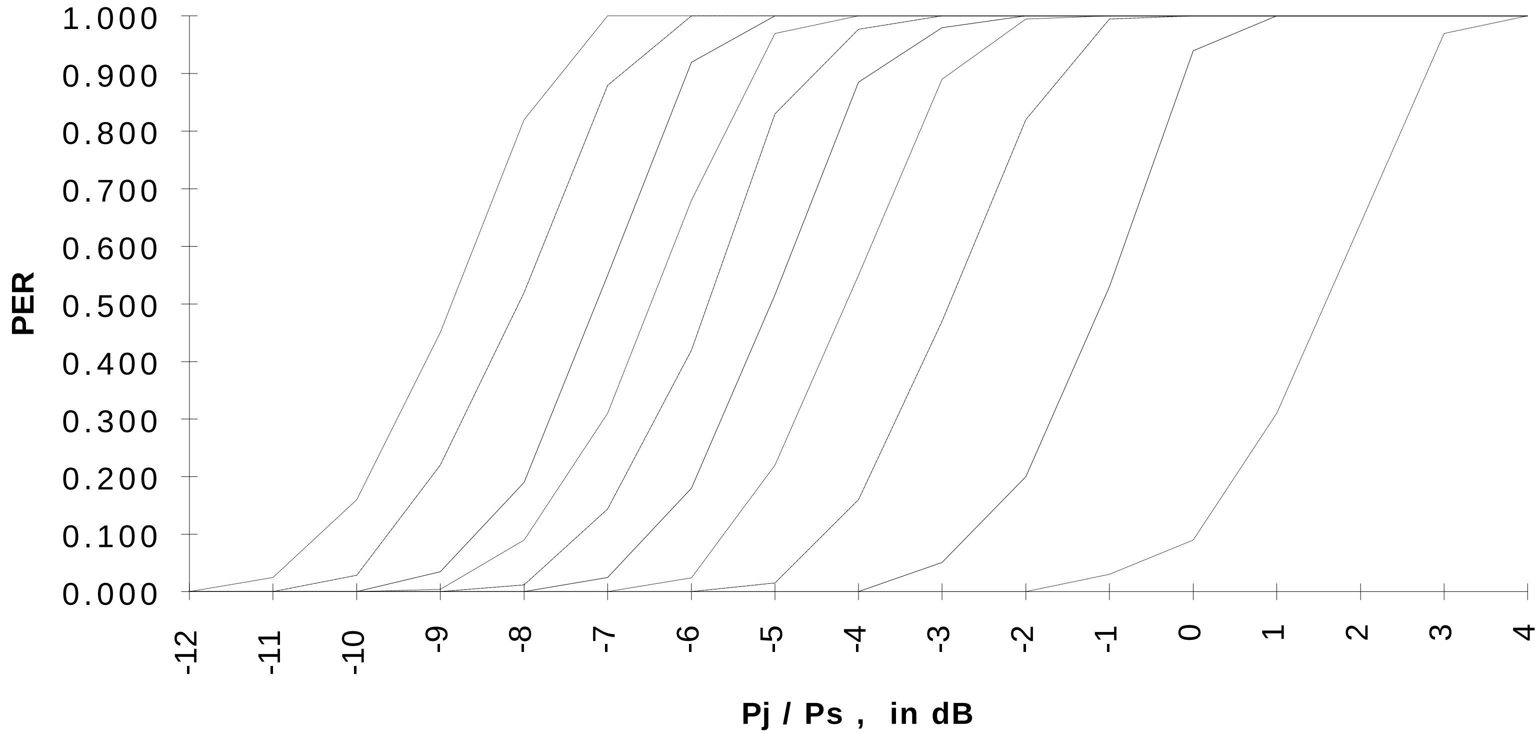

Fig. 9., PER *vs.* Co-Channel Interference to Signal Power Ratio, where the Operating Link and the Interferer both use the same number of AMBC Codes 1000 Byte Packets, SNR = 30 dB

The vertical scale is PER.

CW Jammer Immunity

Table 12. and Fig. 10., below, shows that GBT-9 derives significant protection when the jammer is even a few MHz offset from the carrier frequency.

F offset MHz	J / S dB
-7.5	10
-7.0	8.8
-6.5	7.8
-6.0	6.8
-5.5	5.7
-5.0	5.3
-4.5	4.7
-4.0	4.2
-3.5	3.5
-3.0	3.2
-2.5	2.8
-2.0	2.6
-1.5	2.4
-1.0	2.2
-0.5	2.15
0.0	2.1

F offset MHz	J / S dB
0.5	2.15
1.0	2.2
1.5	2.4
2.0	2.6
2.5	2.8
3.0	3.2
3.5	3.5
4.0	4.2
4.5	4.7
5.0	5.3
5.5	5.7
6.0	6.8
6.5	7.8
7.0	8.8
7.5	10

Table 12., Protection Offered by Matched Filter to CW Jamming

NOTE: This simulation is based upon the FCC CW Processing Gain Test.

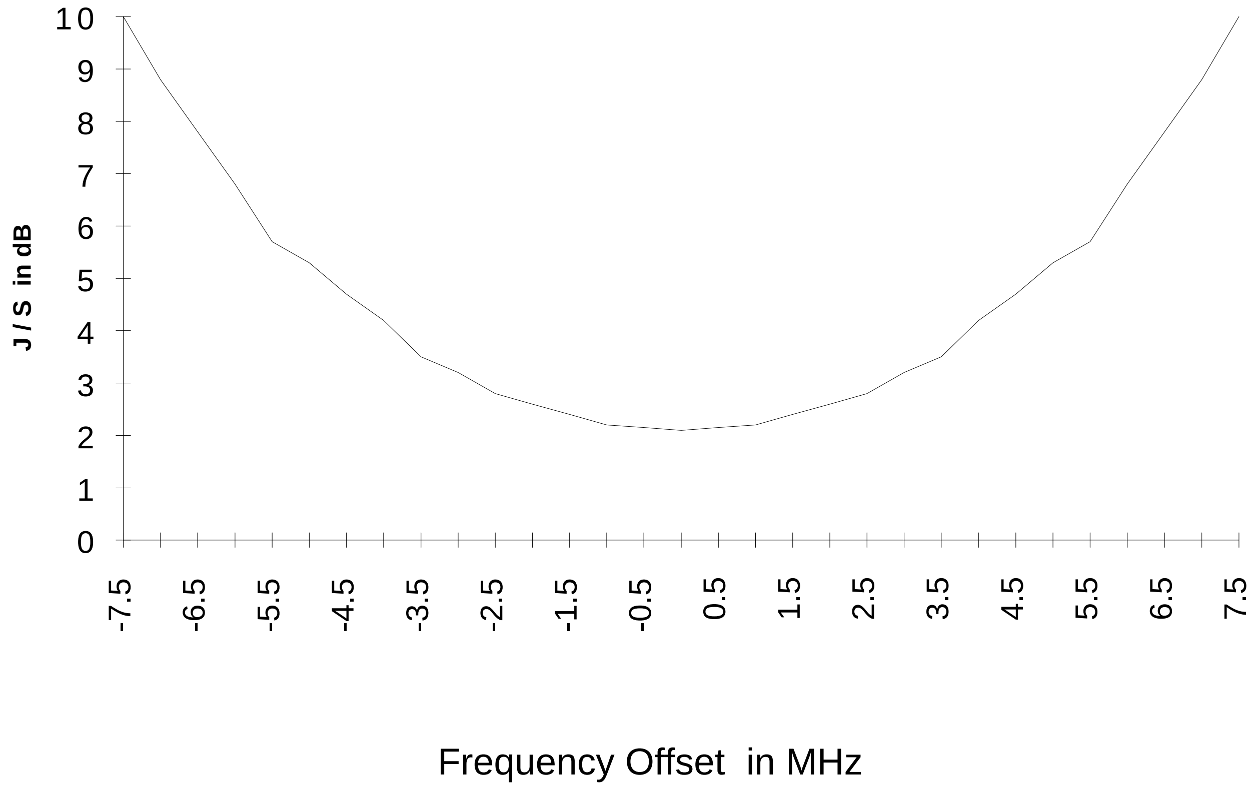

Fig. 10., Protection Offered by Matched Filter to CW Jamming

NOTE: This simulation is based upon the FCC CW Processing Gain Test.

Critical Points

Sensitivity to Phase Noise:

Each of the Advanced Barker codes is QPSK coming out of the de-spreader. Therefore, GBT-9 has no special sensitivity.

DC Power Consumption:

With about 35,000 gates, and based on experience with completed ASIC designs of MRC RAKE receivers, GBT can be confident that DC power consumption is low for baseband IC's.

The TX PA requires 4.5 dB of Backoff to achieve the required Spectral Mask. This is similar to other proposals, and has the same effect on power efficiency.

Antenna Diversity:

Diversity is easily implemented. GBT-9 acquires signals so quickly that, if there were to not be a Short Preamble, GBT-9 has enough time for 4-way diversity. This could be useful in an Access Point. This feature does not require coordination with other devices or protocols.

As with any RAKE receiver, GBT-9 can take advantage of multipath diversity.

Intellectual Property

IEEE 802.11-98/90 aligns GBT's IP policy with IEEE patent policy. GBT is strictly in the business of developing spread-spectrum IP for OEM's, and is not seeking to compete in the OEM market.

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Interoperability / Coexistence

GBT-9 can coexist based on common use of the Low Speed header. The proposal uses the SERVICE field to ensure that Low Speed devices recognize High Speed packets. Low Speed devices should consider any non-zero value in the SERVICE field as an instruction that this packet is not from a compliant device, and the Low Speed device should defer.

If 802.11 TGb decides that, on balance, a Short Header or Preamble is desired, GBT-9 can take full advantage of the potential increase in data throughput. As discussed earlier, GBT-9 normally uses only 48 µs of the Preamble.

With higher data rate, GBT-9 has less channel occupancy for the same traffic load. This means GBT-9 can gets its packets through the RF channel more quickly. This should reduce interference between High and Low Speed systems, with particularly better immunity to / from Frequency Hoppers.

- *end* -