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BER Vs SNR Performance Comparison of DSSS-CDMA FPGA Based Hardware with AWGN, Spreading Codes & Code Modulation Techniques

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Abstract

The Code Division Multiple Access (CDMA) is a multiple-access scheme based on Spread Spectrum (SS) communication techniques. It spreads the message signal to a relatively wide bandwidth by using a unique code that reduces interference, enhances system processing, and differentiates users.

Basically in **CDMA** the **DS-SS technique** is given more importance. The Direct Sequence Spread Spectrum (DS-SS) is a type of modulation that spreads data transmission across available frequency band, in excess of minimum bandwidth available. Because of its advantages, it is used in code division multiple access systems to assign unique code to every user. The research work includes real time processing of signal, BPSK & QPSK modulation and multiplication with pseudo random code to generate spread spectrum, transmitting it over a common frequency band and reproduced the signal using the same pseudo-random code at the receiver.

With the increased popularity of DS-SS CDMA technology, it is obvious that there is need for more comprehensive investigations of analysis and design of this techniques with spreading codes and code modulation techniques.

The hardware consist FPGA Transmitter, Receiver & BER module for typical BER measurement for the transmission of different number of bits. Again for the same performance check the GOLD, MLS and BARKER codes are generated by typical mathematical analysis and calculations of register values given for BER FPGA based module and then vigorous performance is carried out for the BPSK and QPSK code modulation techniques.

The BER values are obtained under different code selection and its transmission with either BPSK or QPSK modulation techniques. The main stresses given on number of bits which are transmitted are changed for better

BER vs SNR performance measurement with different signal value and AWGN values.

Key Words: Code Division Multiple Access (CDMA), Direct Sequence Spread Spectrum (DS-SS), Maximum Length Sequence(MLS), Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), PN Sequence Generator, Additive White Gaussian Noise (AWGN), BER (Bit Error Rate), SNR (Signal to Noise Ratio).

Introduction

The wireless mobile communication systems provide access to the capabilities of the global network at any time, irrespective of the location or mobility of the user. The direct sequence spread spectrum (DS-SS) technique, incorporated into CDMA can accommodate large number of users in one radio channel depending on the voice activity level [1][2]. This feature also provides immunity to jamming signals and enables resolution of multi-path components in a time dispersive radio propagation channel [3].

Spread spectrum is a type of modulation that spreads data transmission across available frequency band, in excess of minimum bandwidth required to send the information. Spreading makes signal resistive to noise and other interference. Spread spectrum is commonly used with personal communication devices such as cell phones and LAN's [1]. Spread spectrum has many unique properties that cannot be found in other techniques like the ability to eliminate or alleviate multi-path interference, communication privacy due to unknown random codes, multi user handling capacity over a single frequency, low power spectral density since signal is spread over a large frequency band [2]. There are two techniques to achieve spread spectrum. The most common methods are:

(1) Direct Sequence Spread Spectrum (DS-SS)

(2) Frequency Hopping Spread Spectrum (FH-SS)

In case of DS-SS, the transmitter converts an incoming data (bit) stream into a symbol stream. Using a digital modulation technique like BPSK or QPSK, a transmitter multiplies symbols with a pseudo random noise code. This multiplication operation artificially increases used bandwidth based on length of chip sequence. A CDMA system is implemented via these coding. Each user over a CDMA system is assigned a unique PN code sequence. Hence, more than one signal can be transmitted on same frequency.

DS-SS Technique

The following are the important states of DS-CDMA system used for transmission and reception of audio signals.

Spread Spectrum

The main principle of spread spectrum communication is that the bandwidth occupancy is much higher than usual. Because of this much larger bandwidth the power spectral density is lower, in the channel the signal just looks like noise [4]. The spreading is done by combining the data signal with a code (code division multiple access) which is independent of the transmitted data message [2]. The advantages of the method are:

- As the signal is spread over a large frequency band, the power spectral density is getting very small, so other communications systems do not suffer from this kind of communications. However, the Gaussian noise level is increasing.
- Random access can be dealt with as a large number of codes can be generated and as a result large number of users can be permitted.
- In this technique without knowing the spreading code, it is (nearly) impossible to recover the transmitted data. Hence security is more.

There are couples of spread spectrum techniques which can be used. The most famous one is Direct Sequence (DS) [7].

Direct Sequence Spread Spectrum (DS-SS)

In a DS-SS system, each user is assigned a unique code sequence that allows the user to spread the information signal across the assigned frequency band [3]. Signals from the various users are separated at the receiver by cross correlation of the received signal with each of the possible user code sequences. Possible narrow band interference is also suppressed in this process. By designing these code sequences to have relatively small cross-correlation, the cross-talk inherent in the demodulation of the signals received from multiple transmitters is minimized [7]. This multiple access method is CDMA, which is a form of a DS-SS system. This modulation transforms an information bearing signal into a transmission signal with a much larger bandwidth. This transformation is achieved by encoding the information signal with a code signal that is independent of the data and has much larger spectral width than the data signal. This spreads the original signal power over a much broader bandwidth, resulting in a lower power density [6].

The ratio of transmitted bandwidth to information bandwidth is called the processing gain Gp of the DS-SS system:

$$Gp = \frac{B_t}{B_i} \tag{1}$$

Where, B_t is the transmission bandwidth and B_i is the bandwidth of the information bearing signal.

DS-SS CDMA Transceiver

Pseudo Noise Signals

Pseudo Noise (PN) signals are very important factor in DS-SS systems. A DS-SS system spreads the base band data by directly multiplying the base band data pulse with a pseudo-noise sequence that is produced by a pseudo-noise code generator [1].

A single pulse or a symbol of the PN waveform is called a chip. They are also considered pseudo random because the sequences are deterministic and known to both the transmitter and the receiver. There are three basic properties that can be applied to a periodic binary sequence as a test of the appearance of randomness; they are balance, run, and correlation property [2]:

1. Balance Property: Good balance requires that in each period of the sequence, the number of binary ones differs from the number of binary zeros by at most one digit.

2. Run Property: A run is defined as sequence of a single type of binary digits. The appearance of the alternate digit in a sequence starts a new run. The length of the run is the number of digits in the run. Among the runs of ones and zeros in each period, it is desirable that about one half the runs of each type are of length 1, about one fourth of length 2, one eighth are of length 3, and so on.

3. Correlation Property: If a period of the sequence is compared term by term with any cyclic shift of it self, it is best if the number of agreements differs from the number of disagreements by not more than one count. In Fig.1, the original signal *m(t)* with a bit period of *Ts*, and the PN signal *p(t)* with bit duration of *Tc* are shown. Taking a closer look at the PN signal *p(t)* illustrates the properties, we just mentioned. A closer verification of its properties is included below. The bit duration of a PN sequence (also called the chip duration) is much less than the base band duration, this will cause the spectrum to spread in the frequency domain [2].

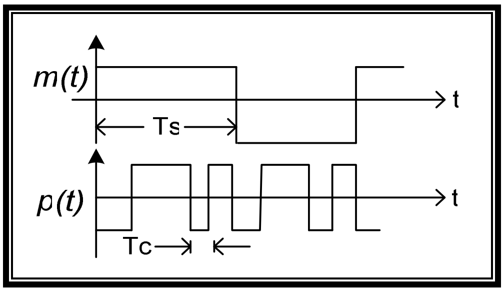

Figure 1: MLS PN Generator.

One of the well known and easy to generate PN sequences are the Maximum Length Sequences (MLS). MLS has all three PN properties. An MLS is generated by the use of shift registers and some logic circuitry in its feedback path. A feedback shift register is said to be linear if its feedback logic circuit consists entirely of Modulo-2 Adders (XOR Gates) [5]. The period of an MLS is given by:

$$N = 2^{m}-1 \tag{2}$$

Where, m is the length of the shift register.

DS-SS Hardware Transmitter

In DS-SS the base-band waveform is multiplied by the PN sequence as shown in Fig. 2. The PN sequence is produced using a PN generator. This generator consists of a shift register, and a logic circuit that determines the PN signal. After spreading, the signal is modulated and transmitted. The most widely used modulation scheme in this technique is BPSK (Binary Phase Shift Keying) [2]. Here, equation (3) represents the DS-SS signal.

$$S_{ss}(t) = \sqrt{2P}m(t)p(t)\cos(\omega_c t+\theta) \quad (3)$$

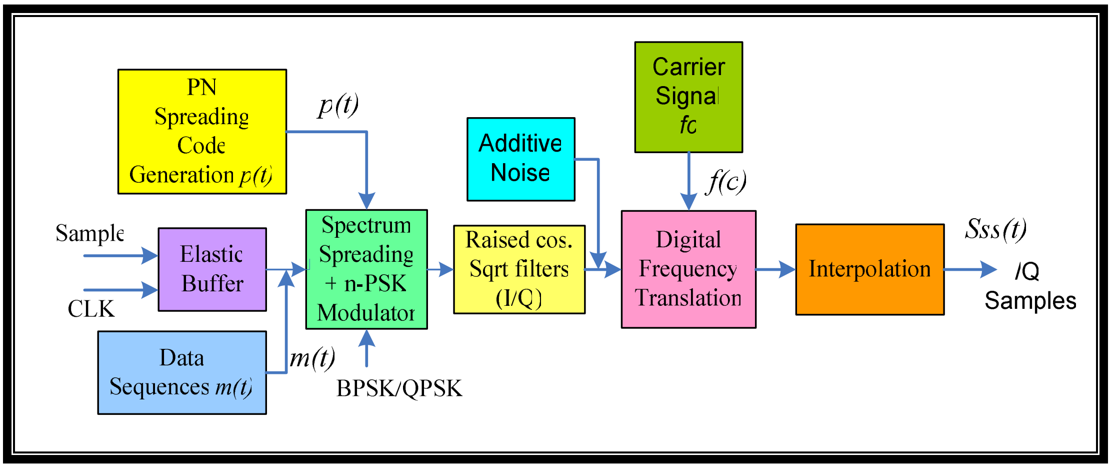

Figure 2: Block Diagram of DS-SS Transmitter.

Where, *m(t)* is the data sequence, *p(t)* is the PN spreading sequence, f_c is the carrier frequency, and *P* is power. Each symbol in *m(t)* represents a data symbol and has duration of *Ts*. Each pulse in *p(t)* represents a chip, and has duration of *Tc*. The transitions of the data symbols and chips coincide such that the ratio *Ts* to *Tc* is an integer [3].

The digital sequence which consists of zeros and ones, represent the data sequence that we are willing to transmit. The zero-one levels are then applied to a Non Return to Zero Encoder (NRZ) that will pull the signal level for the zero bit to –1. The resulting data signal m(t) will consist of (-1, 1) levels. This is important to cause the phase transitions in the carrier frequency. The resulting spread signal is then modulated using the BPSK scheme. The carrier frequency f_c should have a frequency at least 4 times the chip frequency p(t), although to satisfy the Nyquist criteria we need only twice, in most practical applications, at least 4 times the bit frequency is used [2].

A BPSK modulator consists of a multiplier circuit that directly multiplies the incoming signal with the carrier frequency.

DS-SS Hardware Receiver

In the demodulator section, we simply reverse the process. The simplified block diagram of DS-SS receiver is shown in Fig. 3. We, demodulate the BPSK signal first, low pass filter the signal, and then despread the filtered signal, to obtain the original message. The process is described by the following equations:

$$m'(t) = S_{ss}(t)\times\cos(\omega_c t+\theta) \quad (4)$$

$$m_{ss}(t) = \sqrt{2P}m(t)p(t)\frac{1}{2}[\cos(2\omega_c t+\theta)] \quad (5)$$

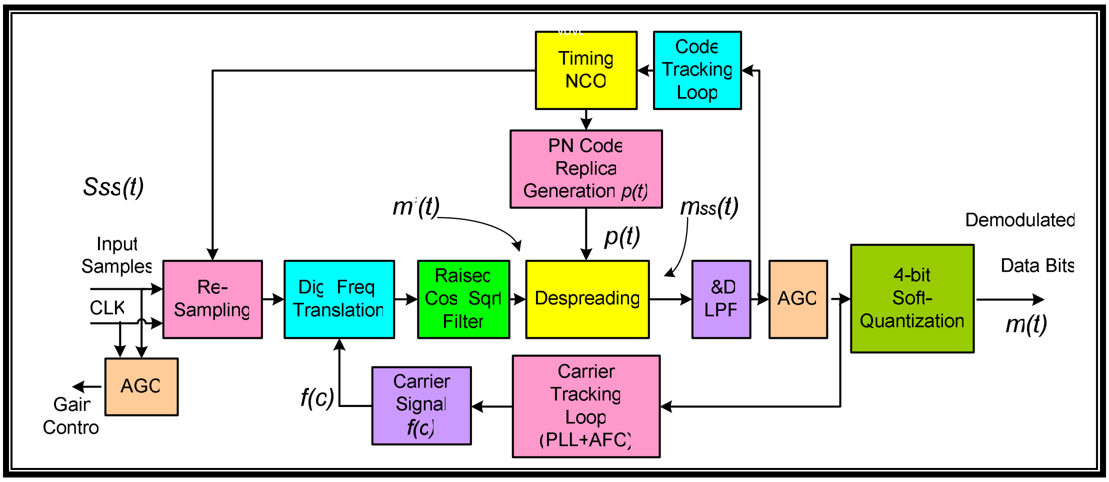

Figure 3: Block Diagram of DS-SS Receiver.

As mentioned in Eq.(4) and Eq.(5), when we, multiply two cosine signals together, we will obtain two expressions, one of which has twice the frequency of the original message and this part can be removed by a low pass filter. The receiver carrier frequency should be synchronized with the transmitter one for data detection, as mentioned earlier [2].

$$m_{ss}(t) = \sqrt{2P}\,\frac{m(t)p(t)}{2} \quad (6)$$

Now, for the PN sequence in the receiver, it was mentioned that it should be an exact replica of the one used in the transmitter. Once, the incoming PN code is correlated with the locally generated one, we can despread the signal [7]. After the signal gets multiplied with the PN sequence, the signal despreads. We, obtain the original bit signal *m(t)* by signal shaping and leveling. This simple description gives idea of the DS-SS Transmitter/Receiver systems used in general.

BER VS SNR Process

In any phase modulation scheme the information is expressed in terms of phase of the carrier. Phase of the carrier signal is shifted according to the input binary data. Two-state phase shift keying (PSK) is called BPSK where the phase of the radio carrier is set to 0 or π according to the value of the incoming bit. Each bit of the digital signal produces a transmit symbol with duration Ts, which is equal to the bit duration Tb. Four-state or quadriphase PSK is called QPSK, in which two bits are combined and the radio carrier is phase-modulated according to the four possible patterns of two bits. Transmitting a symbol takes twice as long as a bit ($T_s = 2 \cdot T_b$) which means that the bandwidth efficiency of QPSK is twice that of BPSK [4][10].

Bit error rate (BER) of a communication system is defined as the ratio of number of error bits and total number of bits transmitted during a specific period. It is the likelihood that a single error bit will occur within received bits, independent of rate of transmission. There are many ways of reducing BER. Here, we focus on spreading code & modulation techniques.

In our case, we have considered the most commonly used channel : the Additive White Gaussian Noise (AWGN) channel where the noise gets spread over the whole spectrum of frequencies.

BER has been measured by comparing the transmitted signal with the received signal and computing the error count over the total number of bits. For any given modulation, the BER is normally expressed in terms of signal to noise ratio (SNR).

BER VS SNR Design & Results

Here, in order to have proper BER vs SNR performance measurement the different pseudo codes like GOLD, MLS and Barker are used with two prominent code modulation techniques e.g. BPSK & QPSK for CDMA mobile communication.

The FPGA BER module different register values are vigorously calculated and feed into the microcontroller for the specific performance. Register 16 favours Signal value and Register 17 favours AWGN (Noise values). These values are fed in Hex and the Decimal values are converted from it for the further calculation and BER measurement. Similar exercise is done with change of transmitted bits from 1,000 bits, 1,00,000 bits, 1,00,00,000 bits and 1,00,00,00,000 bits. The sophisticated analysis is done and tabulated for the better comparison of BER vs SNR performance. The graphs are plotted for different calculation and transmitted bits and comparison is made between BPSK & QPSK modulation techniques for different pseudo codes GOLD, MLS and Barker.

Ber Module Settings for Pseudo Code & Code Modulation

Transmitted Bits: 1,000 Bits (00 (HEX) setting)
Code Used : GOLD CODE
Code Modulation Technique : QPSK

TABLE: 1
Register 16 = 10 (HEX) Signal Value
Register 17 = 10 to FF (HEX) AWGN Noise Value

Sr. No.	Reg 16 (DEC)	Reg 17 (HEX)	Reg 17 (DEC)	SNR	SNR (dB)	No. of Error Bits (HEX)	No. of Error Bits (DEC)	BER = No. of Error Bits / No. of Transmitted Bits
1	16	10	16	1	0	000	0	0
2	16	20	32	0.500	-6.0206	036	54	0.054
3	16	24	36	0.444	-7.0437	083	131	0.131
4	16	28	40	0.400	-7.9588	0BA	186	0.186
5	16	2A	42	0.381	-8.3826	0DA	218	0.218
6	16	30	48	0.333	-9.5424	116	278	0.278
7	16	38	56	0.286	-10.881	14E	334	0.334
8	16	40	64	0.250	-12.041	17E	382	0.382
9	16	45	69	0.232	-12.695	191	401	0.401
10	16	48	72	0.222	-13.064	1A2	418	0.418
11	16	50	80	0.200	-13.979	1BB	443	0.443
12	16	55	85	0.188	-14.506	1C5	453	0.453
13	16	5A	90	0.178	-15.002	1CE	462	0.462
14	16	60	96	0.167	-15.563	1DC	476	0.476
15	16	65	101	0.158	-16.004	1E1	481	0.481
16	16	70	112	0.143	-16.902	1FB	507	0.507
17	16	75	117	0.137	-17.281	200	512	0.512
18	16	80	128	0.125	-18.062	20E	526	0.526
19	16	85	133	0.120	-18.395	213	531	0.531
20	16	90	144	0.111	-19.085	21B	539	0.539
21	16	95	149	0.107	-19.381	21F	543	0.543
22	16	99	153	0.105	-19.611	224	548	0.548
23	16	9F	159	0.101	-19.946	227	551	0.551
24	16	A5	165	0.097	-20.267	229	553	0.553
25	16	AF	175	0.091	-20.778	22D	557	0.557
26	16	B5	181	0.088	-21.071	22F	559	0.559
27	16	BC	188	0.085	-21.401	231	561	0.561
28	16	C5	197	0.081	-21.807	232	562	0.562
29	16	CC	204	0.078	-22.110	234	564	0.564
30	16	D5	213	0.075	-22.485	235	565	0.565
31	16	DC	220	0.073	-22.766	237	567	0.567
32	16	E9	233	0.069	-23.265	23B	571	0.571
33	16	EC	236	0.068	-23.376	23D	573	0.573
34	16	EF	239	0.067	-23.486	23F	575	0.575
35	16	F5	245	0.065	-23.701	240	576	0.576
36	16	FF	255	0.063	-24.048	241	577	0.577

Ber Module Settings For Pseudo Code & Code Modulation

Transmitted Bits : 1,000 Bits (00 (HEX) setting)
Code Used : GOLD, MLS & BARKER CODE
Code Modulation Technique : QPSK & BPSK

TABLE : 2
Register 16 = 10 (HEX) Signal Value
Register 17 = 10 to FF (HEX) AWGN Noise Value

Sr. No.	SNR (dB)	BER OF GOLD QPSK	BER OF GOLD BPSK	BER OF MLS QPSK	BER OF MLS BPSK	BER OF BARKER QPSK	BER OF BARKER BPSK
1	0	0	0	0	0	0	0
2	-6.0206	0.054	0	0	0	0	0
3	-7.0437	0.131	0.084	0.046	0	0	0
4	-7.9588	0.186	0.138	0.096	0.068	0	0
5	-8.3826	0.218	0.178	0.136	0.097	0.043	0
6	-9.5424	0.278	0.246	0.212	0.178	0.136	0.096
7	-10.881	0.334	0.302	0.287	0.267	0.247	0.198
8	-12.041	0.382	0.364	0.363	0.346	0.327	0.298
9	-12.695	0.401	0.394	0.383	0.368	0.349	0.325
10	-13.064	0.418	0.407	0.397	0.386	0.364	0.343
11	-13.979	0.443	0.436	0.424	0.407	0.387	0.368
12	-14.506	0.453	0.442	0.433	0.418	0.407	0.384
13	-15.002	0.462	0.451	0.446	0.432	0.421	0.398
14	-15.563	0.476	0.464	0.451	0.437	0.429	0.409
15	-16.004	0.481	0.477	0.467	0.451	0.441	0.418
16	-16.902	0.507	0.501	0.484	0.467	0.454	0.433
17	-17.281	0.512	0.504	0.492	0.478	0.463	0.442
18	-18.062	0.526	0.518	0.502	0.488	0.476	0.457
19	-18.395	0.531	0.523	0.509	0.493	0.486	0.468
20	-19.085	0.539	0.529	0.515	0.502	0.496	0.478
21	-19.381	0.543	0.537	0.521	0.509	0.501	0.479
22	-19.611	0.548	0.541	0.529	0.515	0.502	0.480
23	-19.946	0.551	0.543	0.536	0.526	0.505	0.481
24	-20.267	0.553	0.548	0.541	0.527	0.507	0.483
25	-20.778	0.557	0.551	0.546	0.528	0.509	0.486
26	-21.071	0.559	0.552	0.547	0.529	0.510	0.488
27	-21.401	0.561	0.555	0.548	0.530	0.512	0.490
28	-21.807	0.562	0.556	0.549	0.531	0.514	0.491
29	-22.110	0.564	0.557	0.551	0.531	0.515	0.493
30	-22.485	0.565	0.558	0.552	0.532	0.515	0.495
31	-22.766	0.567	0.559	0.553	0.533	0.516	0.498
32	-23.265	0.571	0.561	0.554	0.534	0.518	0.500
33	-23.376	0.573	0.563	0.555	0.535	0.519	0.502
34	-23.486	0.575	0.565	0.556	0.536	0.519	0.504
35	-23.701	0.576	0.567	0.558	0.537	0.520	0.505
36	-24.048	0.577	0.569	0.559	0.537	0.521	0.506

Ber Module Settings for Pseudo Code & Code Modulation

Transmitted Bits : 1,00,00,00,000 Bits (0C (HEX) setting)
Code Used : GOLD, MLS & BARKER CODE
Code Modulation Technique : QPSK & BPSK

TABLE : 3

Register 16 = 10 (HEX) Signal Value
Register 17 = 10 to FF (HEX) AWGN Noise Value

Sr. No.	SNR (dB)	BER OF GOLD QPSK	BER OF GOLD BPSK	BER OF MLS QPSK	BER OF MLS BPSK	BER OF BARKER QPSK	BER OF BARKER BPSK
1	0	0	0	0	0	0	0
2	-6.0206	0	0	0	0	0	0
3	-7.0437	0	0	0	0	0	0
4	-7.9588	0	0	0	0	0	0
5	-8.3826	0	0	0	0	0	0
6	-9.5424	0	0	0	0	0	0
7	-10.881	0	0	0	0	0	0
8	-12.041	0	0	0	0	0	0
9	-12.695	0.000088562	0	0	0	0	0
10	-13.064	0.000122389	0.000071983	0	0	0	0
11	-13.979	0.000204646	0.000152762	0.000096348	0	0	0
12	-14.506	0.000282306	0.000241348	0.000175372	0.000112837	0.000065476	0
13	-15.002	0.000325861	0.000298388	0.000242198	0.000197222	0.000147821	0.000086771
14	-15.563	0.000350578	0.000322933	0.000268932	0.000233719	0.000193287	0.000144291
15	-16.004	0.000361256	0.000338618	0.000279912	0.000246712	0.000212652	0.000167332
16	-16.902	0.000387623	0.000361239	0.000319054	0.000287453	0.000256873	0.000228713
17	-17.281	0.000400088	0.000375973	0.000338762	0.000308732	0.000279803	0.000253321
18	-18.062	0.000411399	0.000387439	0.000352581	0.000323811	0.000294882	0.000276382
19	-18.395	0.000425861	0.000398317	0.000370142	0.000341927	0.000316344	0.000294335
20	-19.085	0.000434119	0.000413198	0.000384239	0.000360983	0.000337212	0.000312737
21	-19.381	0.000447586	0.000422823	0.000397706	0.000378812	0.000358229	0.000338665
22	-19.611	0.000449821	0.000427239	0.000409532	0.000389823	0.000371381	0.000347769
23	-19.946	0.000457972	0.000436798	0.000417433	0.000398721	0.000386662	0.000366995
24	-20.267	0.000458226	0.000442832	0.000423392	0.000404392	0.000392023	0.000374923
25	-20.778	0.000462498	0.000446921	0.000430371	0.000412926	0.000402228	0.000385725
26	-21.071	0.000464876	0.000447281	0.000433113	0.000418332	0.000407739	0.000388434
27	-21.401	0.000467956	0.000449431	0.000436732	0.000421443	0.000411638	0.000392752
28	-21.807	0.000468872	0.000456901	0.000441382	0.000427231	0.000414339	0.000396881
29	-22.110	0.000469808	0.000459321	0.000446294	0.000431323	0.000417455	0.000402244
30	-22.485	0.000473455	0.000462893	0.000449654	0.000437581	0.000422632	0.000407504
31	-22.766	0.000475876	0.000464215	0.000452802	0.000440673	0.000424561	0.000409332
32	-23.265	0.000477964	0.000468432	0.000456831	0.000442709	0.000427676	0.000410873
33	-23.376	0.000479391	0.000469326	0.000457323	0.000443149	0.000429881	0.000412834
34	-23.486	0.000481883	0.000469692	0.000458443	0.000444821	0.000431557	0.000413754
35	-23.701	0.000482602	0.000469982	0.000458609	0.000446308	0.000432872	0.000415376
36	-24.048	0.000484203	0.000471002	0.000458933	0.000447243	0.000433119	0.000416702

Ber Vs Snr Results with Awgn
Qpsk, Bpsk Modulation with Gold, Mls & Barker Code
All Comparison With Signal 10 (Hex) & Awgn From 10 To Ff(Hex)

Transmitted Bits : 1,000 bits & 1,00,000 bits

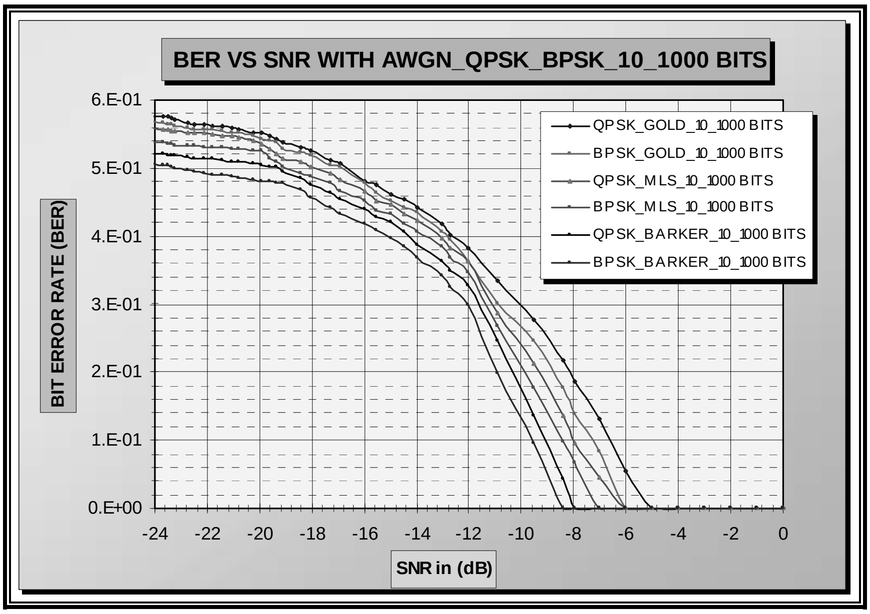

Figure 4: Comparison BER vs SNR for QPSK_BPSK_10_1,000 bits.

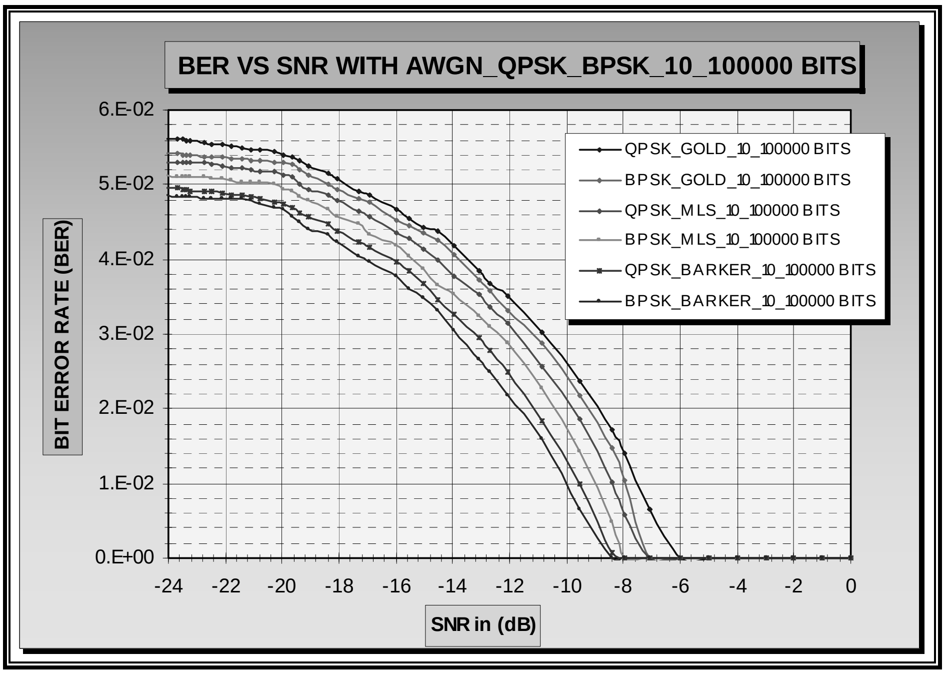

Figure 5: Comparison BER vs SNR for QPSK_BPSK_10_1,00,000 bits.

Ber Vs Snr Results with Awgn
Qpsk, Bpsk Modulation with Gold, Mls & Barker Code
All Comparison With Signal 10 (Hex) & Awgn From 10 To Ff(Hex)

Transmitted Bits : 1,00,00,000 bits & 1,00,00,00,000 bits

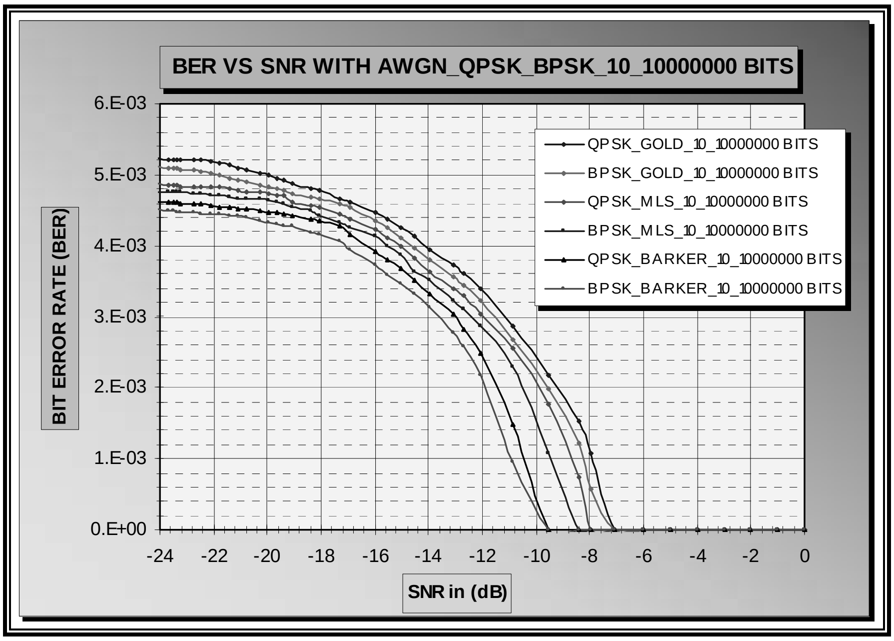

Figure 6: Comparison BER vs SNR for QPSK_BPSK_10_1,00,00,000 bits.

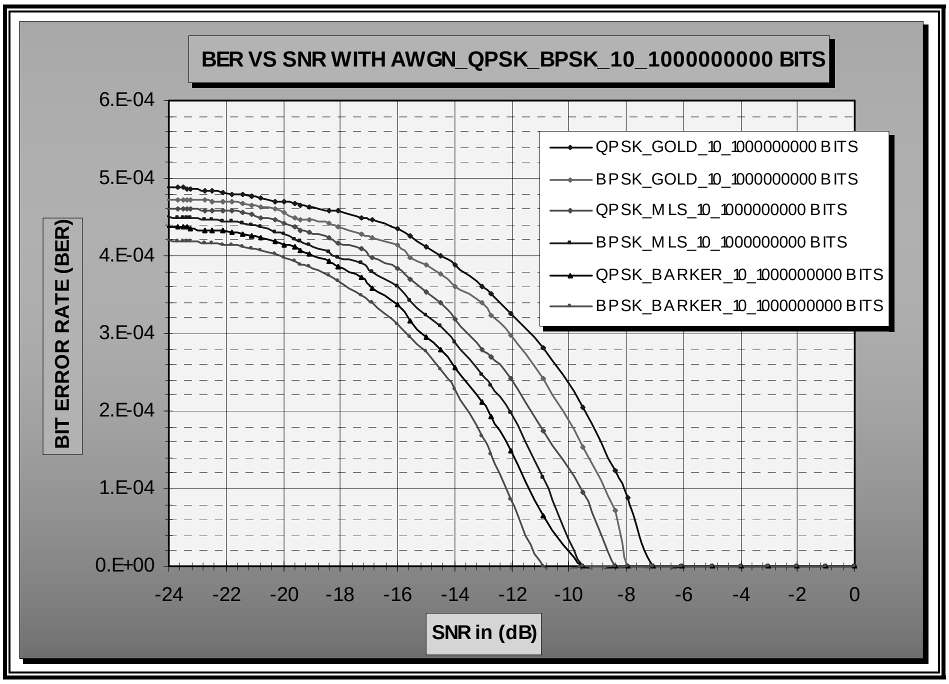

Figure 7: Comparison BER vs SNR for QPSK_BPSK_10_1,00,00,00,000 bits.

Conclusion

The critical exercise is done to evaluate the performance of PSK modulated systems (i.e. BPSK & QPSK) with pseudo codes (GOLD, MLS & Barker) in the presence of a noisy (AWGN) channel along with the ways to reduce the BER. From the above results, it is evident that BPSK modulation is preferred in cases where we need to consider small amounts of transmitting energy. The main reason is that the BPSK offers acceptable BER while transmitting signals of relatively low energy.

Above graph shows the BER vs SNR performance to AWGN channel, where BPSK and QPSK systems performances are compared with the application of different pseudo code like GOLD, MLS & Barker with the increase in transmitting bits. The Transmitting bits are increased from 1000 bits to 1,00,00,00,000 bits and for those different bits the BER vs SNR performance is observed, recorded and evaluated.

The BPSK and QPSK offer almost same BER vs SNR performance under different conditions. Where, it is evident from the results that as the transmitting bits are increased from 1,000 to 1,00,00,00,000 bits the bit error rate is improved from 10^{-1} to 10^{-4} with the almost need of -24 dB of SNR for the hardware module. Now in this case the signal applied is 10(Hex) value and under that condition the BER vs SNR performance is evaluated.

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