# IEEE 802.11
## Wireless Access Method and Physical Layer Specifications

# DS-SS : BPSK Compatible FBPSK, 2.4 GHz measurements demonstrate 400% advantage, 24 dBm output power instead of 18 dBm

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## Abstract

*FBPSK, a new modulation technique which leads to nonlinear amplified BPSK modems is presented. This BPSK compatible modulation takes advantage of the nonlinear processor pulse shaper FQPSK(1-4). Nonlinearly amplified FBPSK have been shown to meet the IEEE 802.11 specifications for wireless LAN for Direct Sequence Spread Spectrum (DSSS). Experimental data using the latest in microwave technology has shown that FBPSK provides 6.5 dB power advantage over conventional BPSK modems with about 0.3 to 1.1 dB depending on the chosen filters in both transmit and receive side.. FBPSK modulator can deliver 1 Watt output compared to 150 mWatt for BPSK, and can be demodulated using conventional BPSK demodulator. BER performance of FBPSK in both AWGN and Rayleigh fading channels has been evaluated and compared with conventional BPSK modems in both linear and nonlinear channels.*

**Intellectual property** disclosure statements were submitted to IEEE802.11, JTC-TIA and other standardization committee by Dr. Feher Associates during 1993-1994(4). To request technology transfer and licensing package information, contact : Dr. Feher and Associates, Digcom, Inc. 44685 Country Club Drive, El-Macero CA 95618. U.S.A, Tel (916)753-0738; Fax(916)753-1788 or Kamilo Feher at (916)752-8127.

## Introduction

In 1994, the Institute of Electrical and Electronics Engineers IEEE have adopted BPSK as the standard modulation in the IEEE 802.11 Direct sequence spread spectrum (DSSS) for wireless Local area networks(WLAN). BPSK modulated systems has to operate in a linear amplified channel in order to meet the FCC mask at the -30 dB for Bandwidth of +/- 11 MHz bandwidth where the bit rate is 1 Mbits/s with spreading sequence of 11 chips.

Linear amplifiers do not provide good power efficiency in portable and mobile communication systems. In BPSK, nonlinear amplifiers can not be used due to spectral regeneration of spectra outside the legal FCC mask. Studies of spectral spreading and power efficiency of PSK modulated systems have been extensive (10-13) . Unfortunately, there has been no solution to reduce spectral spreading for BPSK modulated systems when subjected to nonlinear amplification.

In this paper, we present FBSPK which is BPSK compatible with constant envelope characteristics. The power spectral density (PSD) FBPSK and BPSK and their power efficiency are compared . It is shown that FBPSK has over 6.5 dB power gain advantage over BPSK, this translates into longer battery life and reduced radiation compared to linear modulated techniques (12). Experimental evaluations of FBPSK/BPSK and their BER performance are also presented.

## FBPSK modem

FBPSK , a constant envelope digital modulation technique is based on quadrature type of modulator structure . FBPSK is also based on FQPSK processor which is a patented technology (1-4). A block diagram of a FBPSK modulator is shown in figure 1.0. A new quadrature component Q is added to the In-phase channel I. Q channel has the same data information as the I channel which is unlike QPSK modulated systems where data are serial to parallel converted. The Q channel is later offset by one half bit Tb/2, this done in order to take advantage of the offset properties and avoid passing through the zero amplitude point during state transitions (12). FQPSK processors are inserted in both I and Q channels to smoothen the baseband pulse shape and to improve the power spectrum under nonlinearly amplification. In our experimental measurements, bit rates of 500 Kb/s and 1Mb/s were evaluated and showed similar spectral and error performance results.

To further improve the spectrum of FBSPK system, correlation between the I and Q channels based on a technique invented and patented by Kato/Feher(2) is introduced. The correlation is controlled by the correlation factor "*a*" which effects the pulse shape in baseband and yields to higher spectral efficiency at the expense of small performance degradation. A correlation factor "*a*" of unity value leads to FBSPK modulated with no correlation between the I and Q channels.

## FQPSK processor

FQPSK baseband processors belong to a family of Intersymbol interference and jitter free Quadrature-Phase shift keying which was introduced to achieve high power and spectral efficiency for satellite communications. The FQPSK pulse shaper has an impulse response *p(t)* which is defined as :

$$p(t) = \begin{cases} 0.5*\{1+\cos(\pi t/Ts)\} & \text{for } |t| \leq Ts \\ 0 & \text{otherwise} \end{cases}$$

where *Ts* is the symbol duration.

FBPSK processor have been designed using VLSI implementation (6-7) or the latest in FPGA technologies ( 8-9). In our laboratory work, we have designed FBPSK modems based on both discrete components and field gate programmable array (FPGA). A top level schematic of a FBPSK baseband processor based Xilinx " FPGA 4005PC-84-6 is shown in figure 2. FBPSK pulse shaped baseband signals with different correlation factor {a} are shown in figure 3 and 4 . Their associated signal state diagrams are shown in figure 5 and 6, note the circle state diagram for a correlation factor of 0.707. The eye diagram of FBPSK with correlation factor of 1.0 is shown in figure 7 Additional studies on the advantage of FQPSK pulse shaping for GFSK and GMSK modulated systems have been conducted and showed simpler circuit implementation than conventional techniques (14-15).

## PSD and Power efficiency

The power spectral density have been evaluated experimentally at UC Davis's Wireless and Communications Research Laboratory. The measured spectrum of both BPSK, and FBPSK (a=0.707) are shown in figure 8, note the spectral regeneration of BPSK under nonlinear amplification. To analyze the power efficiency of the above modems, the input power to the amplifier is reduced until the power spectral density (PSD) meets the FCC mask requirement at the -30 dB point.

FBPSK and FQPSK were also evaluated on several recently released products such as MRFIC 2403 of Motorola, and TAE 1010Aof Teledyne, **and VRAXX** of Minicircuit. Measurements at 900 MHz and 2.4 GHz at the vendors facility confirmed that FQPSK and FBPSK can achieve output power of 24 dBm compared to conventional DQPSK and DBPSK of only 18 dBm ( typical gain of 400% ) under the FCC mask requirements of -30 dB (10-12).

## Demodulation and Compatibility

When demodulating FBPSK modulated signals, only the data in the I channel are required to retrieve all the information because both I and Q have the same data. FBPSK modulated signals can and have been demodulated using conventional BPSK receivers, this makes FBPSK , BPSK compatible. In our measurements, conventional BPSK coherent receiver was used to demodulate both BPSK and FBPSK signals.

## System Performance

The performance of BPSK/FBPSK have been measured and simulated in both linear and nonlinear channels. The BER performance of FBPSK with correlation factor {a} of 0.707 is shown in figure 9 and 10 . FBPSK system suffer some degradation compared to BPSK, additional performance degradation is due to mismatch of cables, test components ,equipment in our lab, and the imperfection of quadrature at both transmitter and receiver .

## Conclusion

A new BPSK compatible, power and spectrally efficient modulation has been presented. This modulation named FBPSK which is based on FQPSK processor can be nonlinearly amplified and have shown over 6.5 dB power advantage compared to BPSK . FBPSK nonlinearly amplified systems meet the FCC mask of -30 dB for DS-SS for wireless LAN. BER performance of FBSPK have been evaluated in linear and nonlinear AWGN channels and exhibits between 0.3 to 1.1 in performance degradation compared to BPSK modulated systems.

## References

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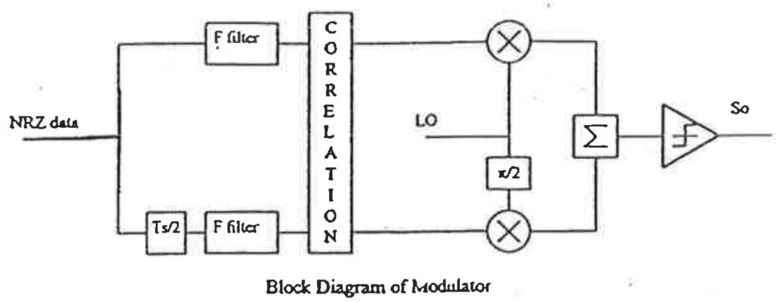



Figure 1, FBPSK modulator with crosscorrelator

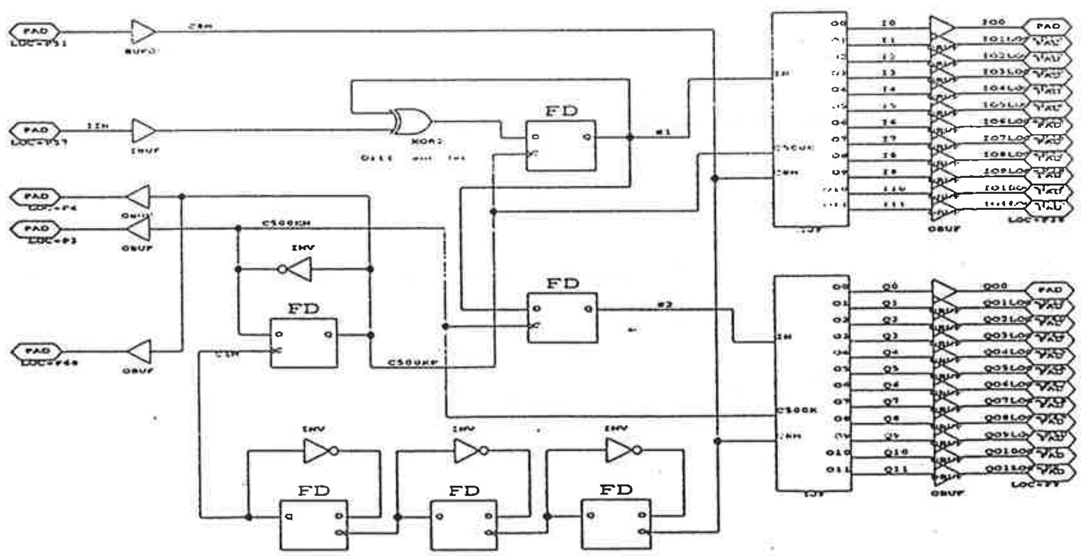



Figure 2.0, FPGA implementation of a FBPSK baseband processor

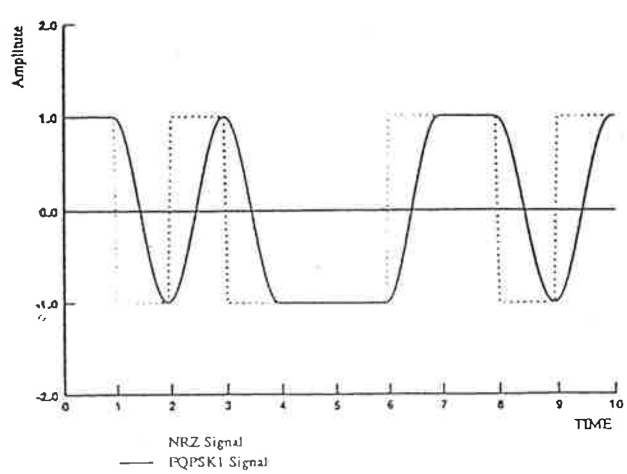



Figure 3.0, Baseband signal of FBPSK

with correlation factor a=1

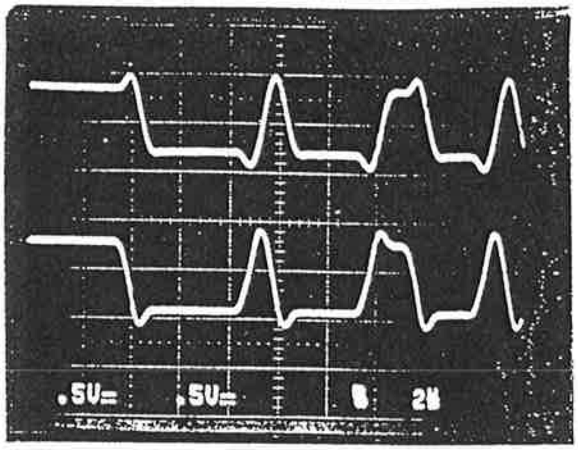



Figure 4.0, Baseband signal of FBPSK with correlation factor a=0.707

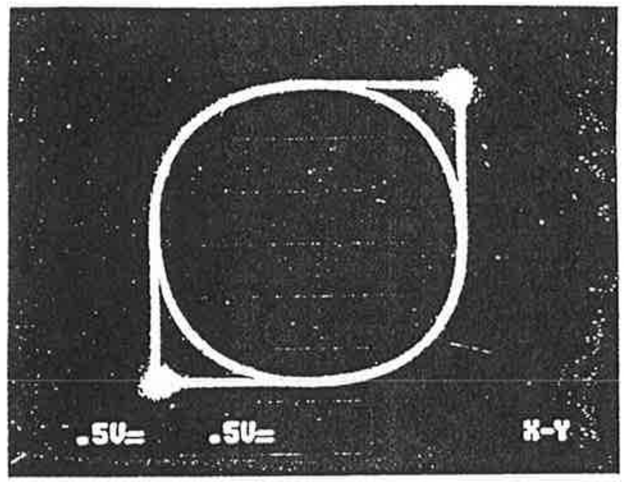



Figure 5.0, Signal state diagram of FBPSK with correlation factor a=1

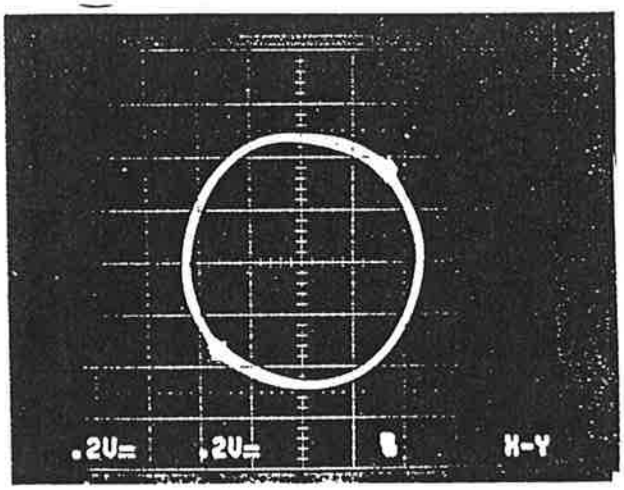



Figure 6.0, Signal state diagram of FBPSK with correlation factor a=0.707

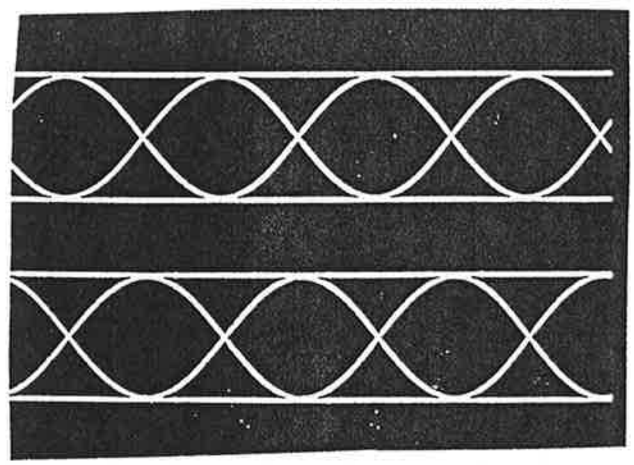
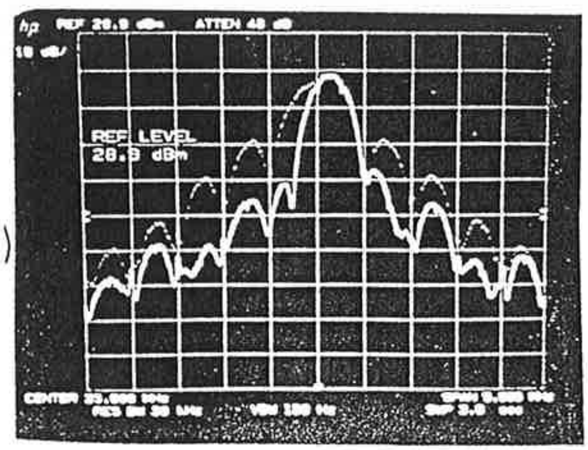


Figure 7.0, Eye diagram of FBPSK with correlation factor a=1

Figure 8.0, Power spectral density of FBPSK and BPSK in nonlinear channel,



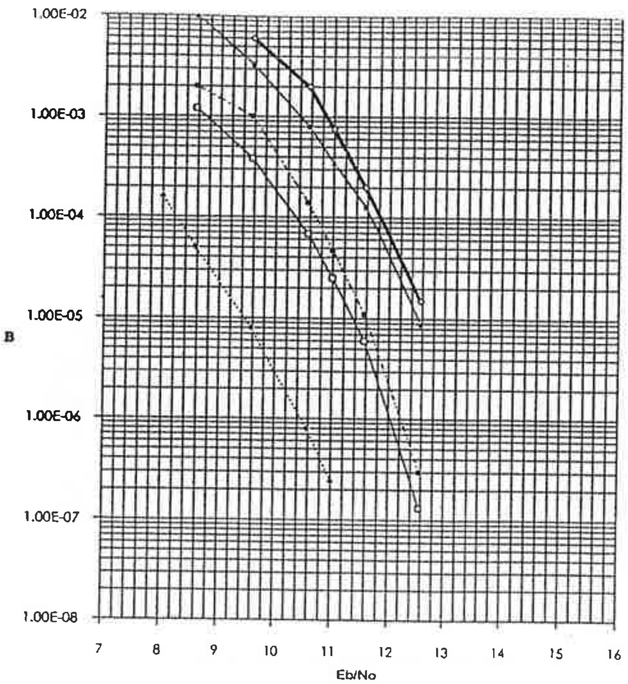



Figure 9.0, Preliminary data of BER measurement in nonlinear channels, System was not optimized ( leakage and impedance mismatch degraded performance).

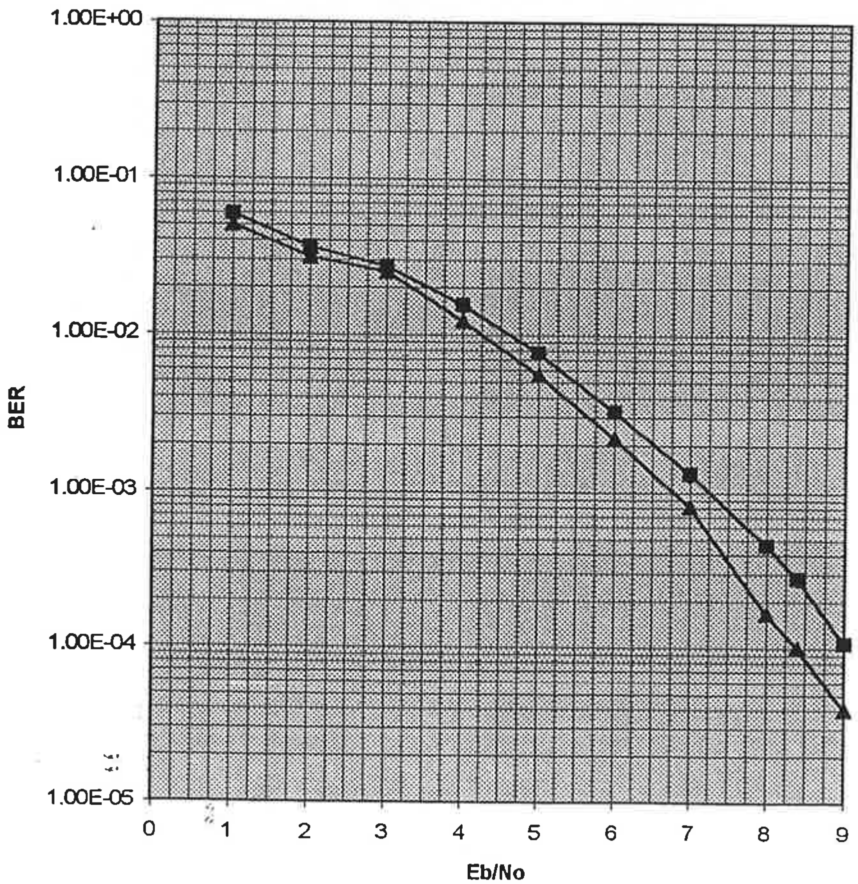
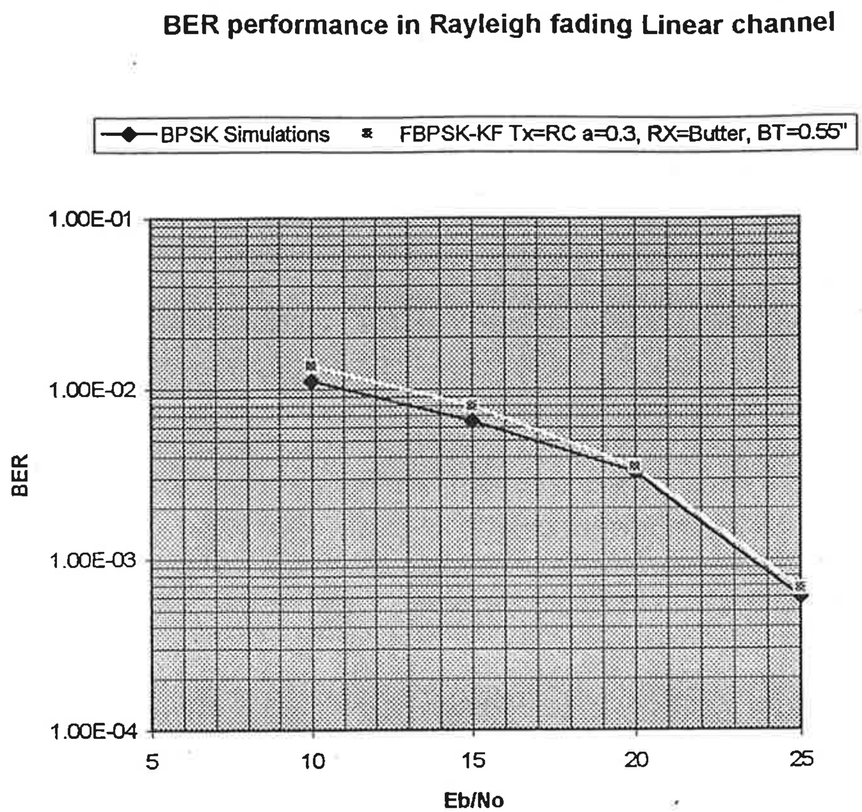
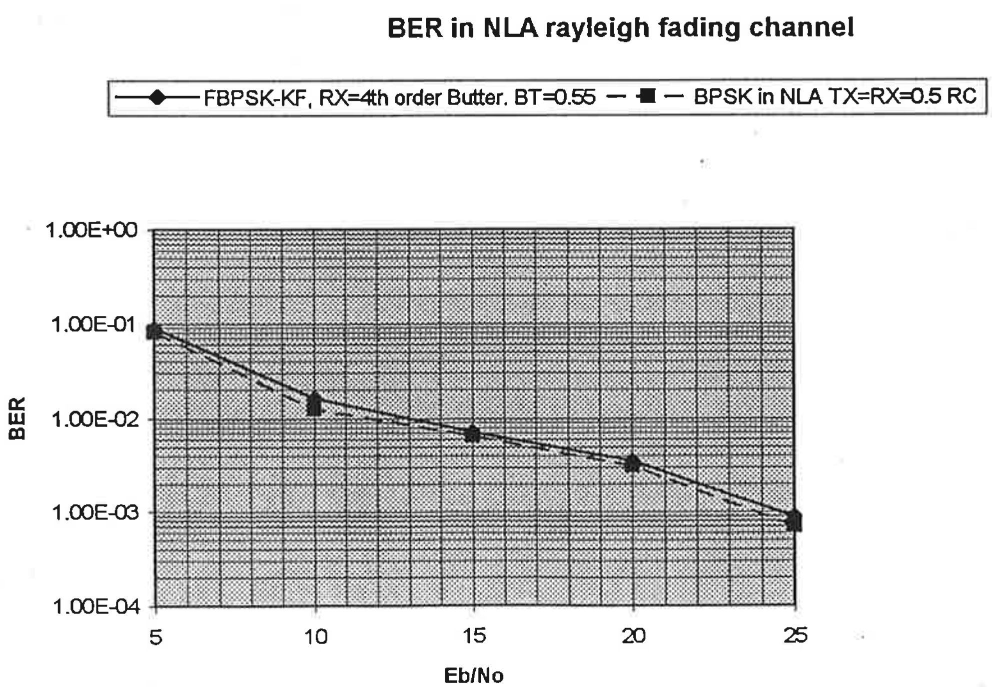



Figure 10.0, Simulated performance of FBPSK/BPSK in linear and nonlinear channels.


BER performance in Rayleigh fading Linear channel
BPSK Simulations
FBPSK-KF Tx=RC a=0.3, RX=Butter, BT=0.55"
1.00E-01
1.00E-02
1.00E-03
1.00E-04
BER
5
10
15
20
25
Eb/No


BER in NLA rayleigh fading channel
FBPSK-KF, RX=4th order Butter. BT=0.55
BPSK in NLA TX=RX=0.5 RC
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
BER
5
10
15
20
25
Eb/No