# EXIRLAN-Infrared FQPSK-Based Proposed Standard

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## Summary

The EXIRLAN (EXpandable Infrared Local Area Network) PHY layer standardization process, initiated by Andromeda of Germany [P. Blomeyer, Ref. 42-45], joined by Siemens, six US and European computer companies allows simultaneous transmission of numerous high speed users in the same room, independently of each other. Distances in the range of **30m to 80m** could be covered by highest speed cost efficient infrared WLAN operated at user selectable bit rates of

**1Mb/s, 1.4Mb/s, 2Mb/s, 2.8Mb/s, 4.2Mb/s, 5.6Mb/s, 8.4Mb/s and 12.6Mb/s**

The first generation of standardized equipment could operate up to 4.2Mb/s. The same electronic FQPSK modulated architecture will enable later, with improved low cost IR transmitting and receiving components i.e., IRLED's photodiodes extension to and above the ETHERNET data rates.

EXIRLAN may coexist with non-compliant IEEE 802.11 baseband transmission IR spectrum provided that it does not exeed 6 MHz, thus accommodates the IEC/CENELEC/DKE standard proposals [42-45]. The baseband spectrum (up to 6MHz) could have up to 1Mb/s data rate with 16PPM [46;47] while the FQPSK modulated data is located between 6MHz and 30MHz in 3MHz spaced channels, thus 8 independent FQPSK modulated systems, initial rate up to 8*4.2Mb/s = 33.6Mb/s could be accommodated in the same room. The same electronic hardware architecture enables expansion up to 8*12.6Mb/s = 100.8Mb/s.

The EXIRLAN high flexible bit rates, extended coverage, robust enhanced performance, large number of flexible users and dramatic cost reduction [42-45] is achieved by FQPSK. FQPSK is the only spectral/power efficient modulation which is a simple, expandable and robust constant envelope suitable for NLA (Nonlinear Amplification) and coherent as well as noncoherent detection. This technique invented by Feher & Associates has been extensively described in the IEEE 802.11 documentation, see Ref. [1-36]. FQPSK is equivalent in structure to MSK and GMSK except it is much more spectrally and power efficient and has simpler baseband processors. Thus FQPSK is at the same time equivalent and compatible with FM modulated digital systems with a modulation index of m=0.5 and is equivalent with OQPSK (Offset QPSK). The simple and powerful baseband processor of the transmit FQPSK leads to the numerous NLA spectral advantages, making it ideally suitable for infrared standardization and multi user applications such as the EXIRLAN proposed standard.

# EXIRLAN

Doc: IEEE P802.11-94/62

Peter Blomeyer, AndroMeDa GmbH

## Frequency Scheme

(revised Feb. 94)

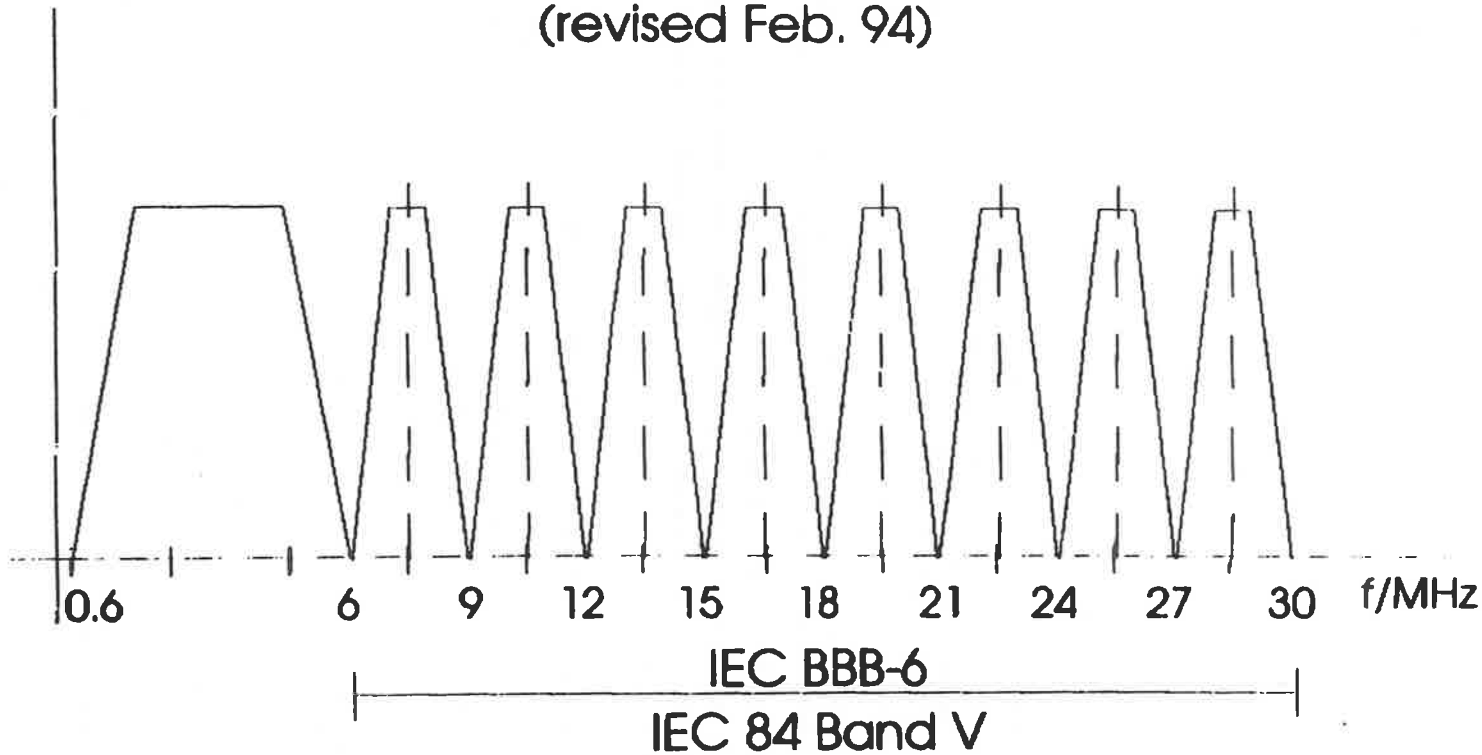


**Fig. 1** EXIRLAN revised baseband and FQPSK modulated multicarrier frequency plan based on [42-45 and 48-49]. In the 6MHz baseband or "coexistence" band of EXIRLAN up to 1Mb/s rate could be transmitted with 16-PPM [46;47]. In the modulated 3MHz wide channels up to 4.2Mb/s per 3MHz could be transmitted in the first generation of constant envelope nonlinearly amplified IR systems. A second generation of standards could accommodate up to 12.6Mb/s per 3MHz [1-32].

Submission page 2 K. Feher, UC Davis
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## IC CHIPS FOR FQPSK*

For FQPSK and compatible quadrature mod/coherent demod OQPSK, GMSK VLSI/ASIC's/ technologies/components for IEEE 802.11 (2.4GHz) and TIA-JTC(1.9GHz) chips in the 300kb/s to 12Mb/s range, numerous companies have solutions and are suggested including (in some cases product or group):

| 300kb/s++ | 1Mb/s to 60Mb/s |
|---|---|
| Siemens | Oki |
| Ericsson/GE | INTEL (iFX740); Ref. [40] FPGA |
| Motorola | TRW MCDD Technology Group |
| Alcatel | UNISYS |
| Northern Telecom | NTT |
| | TELEDYNE (MMIC) TFE 1050 transceiver |
| | Digcom/Dr. Feher Assoc. |
| | HP-CCD |
| | Andromeda |
| | Xilinx XC-4003 (1C-DSP prototypes) |

* Several of these companies (including some of the largest ones) already joined the FQPSK Consortium

## FQPSK REVIEW/DEFINITIONS

The FQPSK family of linearly and nonlinearly amplified (NLA) radio modem techniques have been invented by Feher et al. and described in numerous references. See List of References.

FQPSK-1 = IJF (Intersymbol Interference and Jitter free) simplest baseband processor of OQPSK; Patent No. [1] two-level eye diagrams

FQPSK-kf = FQPSK (xx ... yy) parameters of crosscorrelated and baseband filtered (after correlator) Kato/Feher patented, Ref. [2] method 2-level eye diagram, increased spectral efficiency

FQPSK-4*4 =
FQPSK-8*8 = extended FQPSK to 4 and 8 level baseband signaling states in the I and Q channels

## GEAR SHIFT TO AND FROM 1Mb/s, 1.4Mb/s, 2.8Mb/s or 4.2Mb/s

## PREAMBLE CONTENT: EXACT BIT PATTERNS WITHIN FRAMES TBD LATER

Solution could be very similar to adopted draft standard (IEEE 802.11) DS-SS and of proposed infrared (IR). Reference J. Boer ATT, Editor No. [41].

A : Synchronization field 128 bits of 'ones'

B : Unique word : 16 bits (octal 2717)

16 bits are here assumed instead of 8. Could reduce number of signal bits if required by MAC. See Item 35 in Silberman [39].

### C : 802.11 SIGNAL BITS INFRARED EXAMPLES
### Details TBD by Committee Later

| Bit Patterns* in Frame (HS-FH) | | | | | Bit Rate | Modulation |
|---|---|---|---|---|---|---|
| 10 | 10 | 00 | 00 | 00 | 19.2kb/s | ? PPM baseband |
| 10 | 01 | 00 | 00 | 00 | 115.2kb/s | 16 PPM baseband |
| 00 | 00 | 10 | 00 | 00 | 1Mb/s | 16 PPM baseband |
| 00 | 00 | 01 | 00 | 00 | 1Mb/s | FQPSK (in 3MHz) |
| 00 | 00 | 00 | 10 | 01 | 1.4Mb/s | FQPSK (in 3MHz) |
| | | TBD | | | 2Mb/s | FQPSK (in 3MHz) |
| | | TBD | | | 2.8Mb/s | FQPSK (in 3MHz) |
| | | TBD | | | 4.2Mb/s | FQPSK (in 3MHz) |
| | | TBD | | | 5.6Mb/s | 2nd generation IR |
| | | TBD | | | 8.4Mb/s | 2nd generation IR |
| | | TBD | | | 12.6Mb/s | 2nd generation IR |

**Table 3**

D : Service bits: 8 bits used at vendors discretion; all zeros for 802.11

1. EXIRLAN-System-IR Network Advantages - 1st Generation per Room:

| | | |
|---|---|---|
| Capacity | | 1Mb/s – 16PPM |
| | plus | 8*4.2Mb/s = 33.6Mb/s FQPSK |
| | total | 34.6Mb/s |
| | assuming | max 4.2Mb/s per 3MHz modulated bandwidth |
| | with | NLA constant envelope FQPSK |

2. EXIRLAN 2nd Generation Standard-Capacity per room

| | | |
|---|---|---|
| | | 1Mb/s – 16PPM |
| with multistate FQPSK | 8*12.6Mb/s = | 100.8Mb/s |

Same frequency plan, same architecture as first generation

3. BER Performance of FQPSK-1

The BER = $f(E_b/N_0)$ performance of "FQPSK-1" is the most robust. Even though this is a nonlinearly amplified (NLA) constant envelope system it has the best performance only within 1dB of theoretical optimum linearly amplified QPSK.

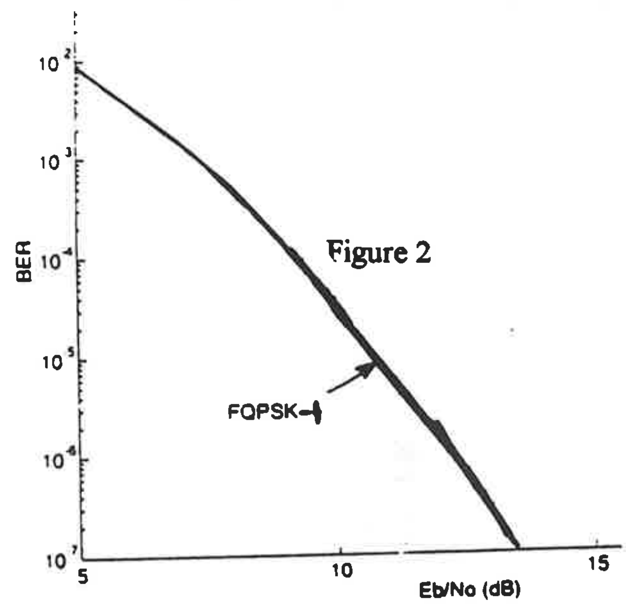


Fig. 2 BER = $f(E_b/N_0)$ performance of FQPSK [1-32]

Due to robust performance FQPSK has been adopted for DS-SS compatible OQPSK standard and is a most serious candidate for the HS-FH IEEE 802.11 standard.

## 4. BER $f(E_b/N_o)$ and MULTIPATH SENSITIVITY

FQPSK: Maximal dispersion is d = 50ns (= tau) for most practical rooms
Ref. [A. Moreira et al. [46]
At $f_b$ = 1Mb/s rate the impact of d = 150ns (3* more than typical room) is negligible on FQPSK. See Fig. 2.
Even at $f_b$ = 4.2Mb/s the impact of multipath delay spread of 50ns is negligible.

Illustration: FQPSK at $f_b$ = 4Mb/s
$f_s$ = 2MBaud
$T_s$ = 500ns
$d/T_s$ = 50ns/500ns = 0.1
Impact of delay spread (multipath) on FQPSK is negligible.

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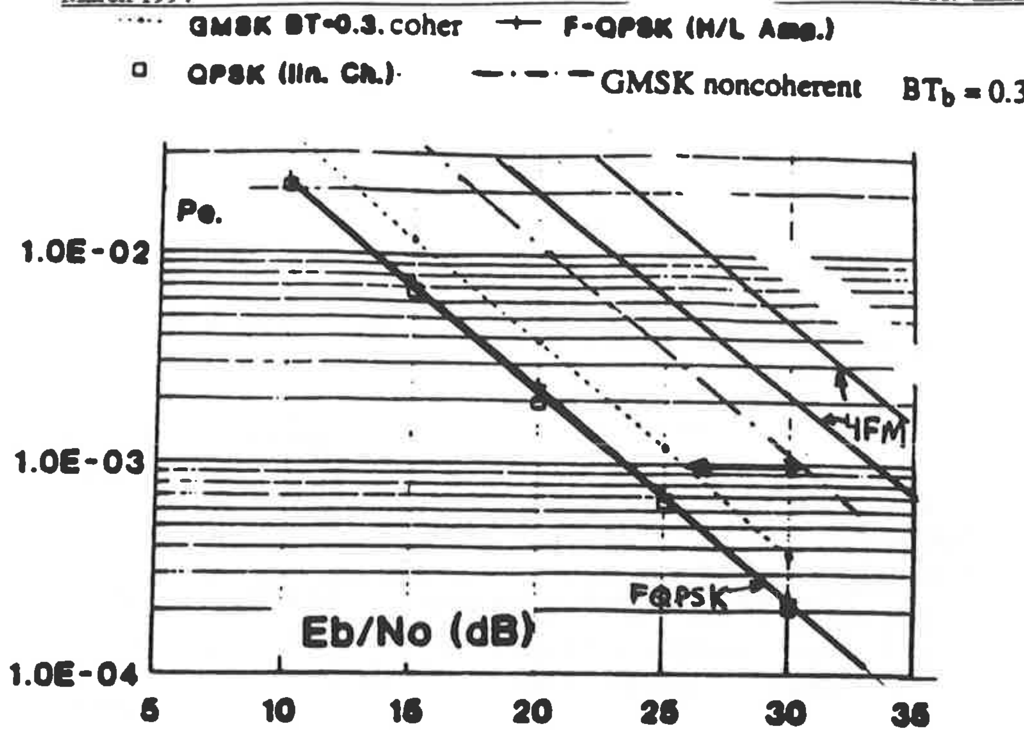
16PPM at 4Mb/s
"... power penalty due to multipath dispersion may have to be considered if no equalization is used ..." from A. Moreira et al. [46]

**Conclusion** FQPSK is much more robust to multipath than same rate 16PPM. adaptive equalization based solution should be avoided due to cost, complexity and synchronization time.



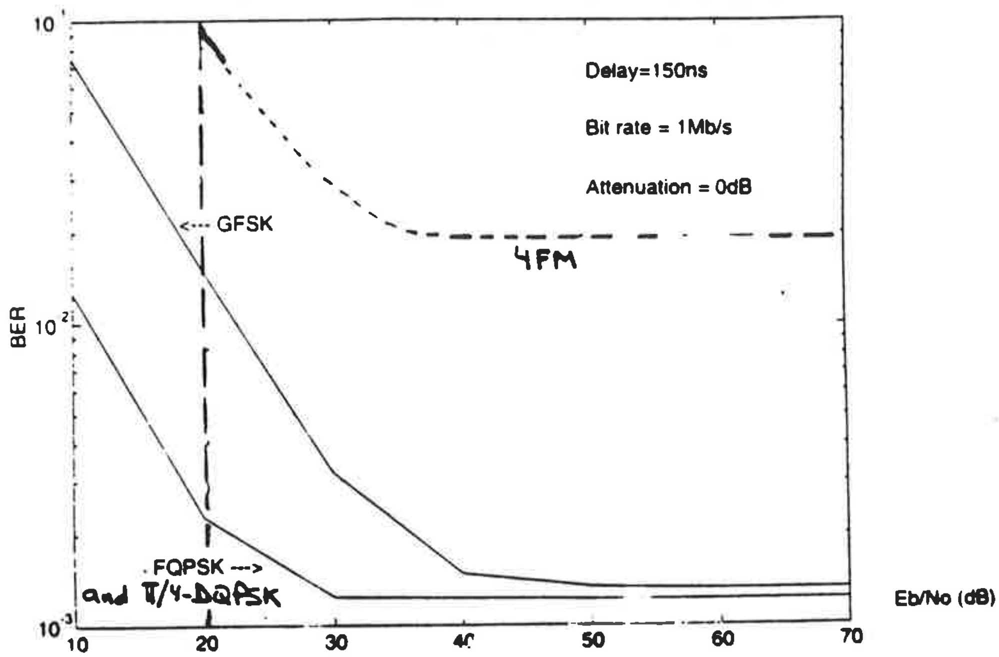




Fig. 3 **BER = f($E_b/N_0$) performance of FQPSK, GMSK and 4-FM constant envelope systems in Rayleigh (top) and Rayleigh/delay spread environment with IEEE 802.11 measured/quoted 150ns delay. 4-FM is estimated. GFSK, GMSK and FQPSK computed/experimentally verified. Note: Based on Dr. P. Leung, Ref. [50] of Australia the delay spread robustness of FQPSK is better than that of coherent QPSK and thus of π/4-DQPSK.** [35]

## S/N comparison of IR range 30m-80m of 16PPM and FQPSK

Based on S/N

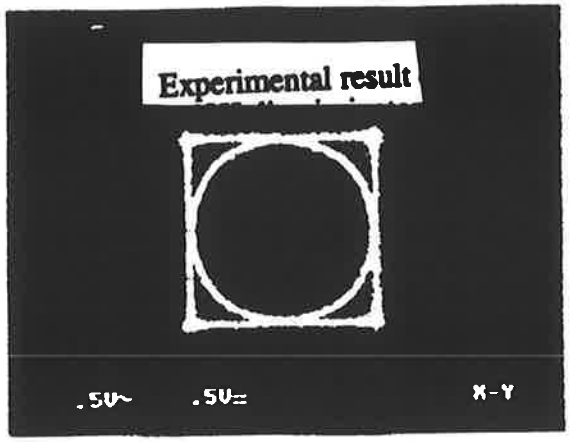
16PPM could require about 8dB less SN than theoretical QPSK or FQPSK due to redundancy in bandwidth.

Let's compare "link budget" based on <u>same</u> bit rate. An illustrative scenario for $f_b$ = 1Mb/s

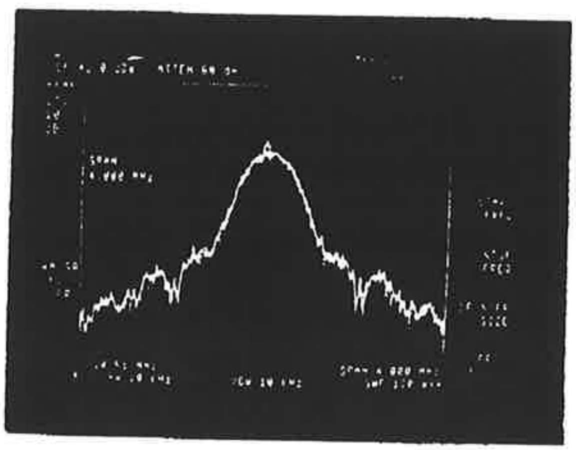
| | 16PPM | FQPSK |
|---|---|---|
| Required S/N for $10^{-5}$ | 4dB | 12dB |
| Required Rx noise bandwidth for 1Mb/s | 6MHz | 0.5MHz |
| Bandwidth noise total | | |
| Penalty of 16PPM over FQPSK (noise BW) | 10.8dB | 0dB |
| Total S/N normalized to 1MHz bandwidth | 14.8dB | 12dB |

* 10log12 = 10.8dB that is FQPSK receiver 6* less noise

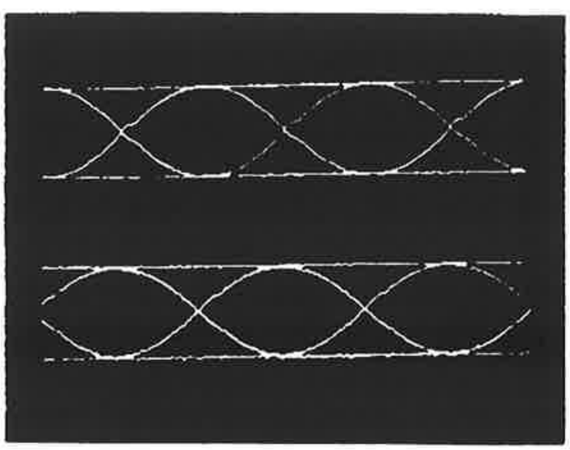
Conclusion: Power link budget of FQPSK is about 2.8dB better, based on the assumptions. Multipath tolerance spectral efficiency/flexibility of FQPSK is at least 6* larger than 16PPM. A thorough link budget study and preparation of specifications based on $E_b/N_o$ is recommended.



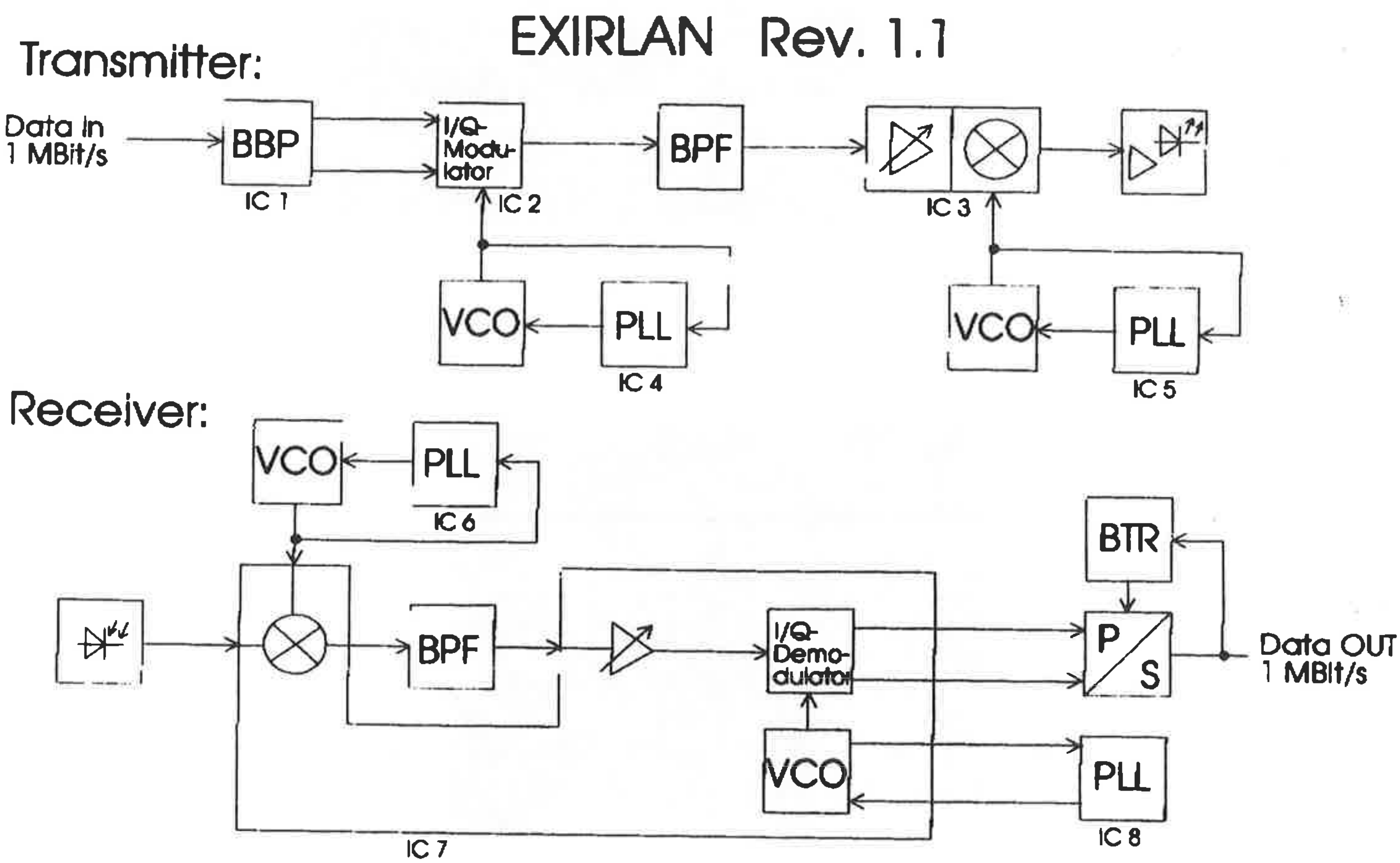

"Constellation Diagram of FQPSK" nonlinear-IR system



Nonlinearly Amplified (NLA) "C-class" or hardlimited spectrum of Constant Envelope "FQPSK-I" at 1 Mb/s rate. Horizontal: 400 kHz/div; vertical: 10 dB/div



In-phase "I" and Quadrature "Q" eye diagrams of DSP-generated 1 Mb/s (500 kBaud per I and Q) FQPSK-EXIRLAN system

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IEEE P802.11
Wireless Access Methods and Physical Layer Specifications

## Specifications and Template of the IEEE802.11 Infrared PHY EXIRLAN / FQSPK-based Modulation and Baseband -

**Date:** March , 1994

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| Topic | Val | Parameter | Specification | Comments |
|---|---|---|---|---|
| 1 | G | Number of carriered channels | 8 | |
| 2 | N | Frequency range | 6...30 MHz | |
| 3 | N | Bandwidth per carriered channel | 3 MHz | |
| 4 | N1 | Modulation | FQPSK | |
| 5 | N2 | Modulation | multistate FQPSK(4*4)/(8*8) | linearized IR-diodes required |
| 6 | N1 | Data rate/channel | 1, 1.4, 2.8, 4.2 Mb/s | selectable (no hopping!) 1s genereration |
| 7 | N2 | Data rate/channel | 1, 1.4, 2, 2.8, 4.2, 5.6, 8.4, 10, 12.6 Mb/s | selectable (no hopping!), 2nc generation |
| 8 | N | Eb/ No for BER = 10 exp-5 | 10...23 dB | |
| 9 | N | Spectral Suppression (PSD) | -20 dB | at edge of band |
| 10 | N | IR-wave length | 880 nm | |

**REFERENCES**


[1] K. Feher: "Filter," U.S. Patent No. 4,339,724. Issued July 13, 1982. Canada No. 1130871, August 31, 1982.

[2] S. Kato, K. Feher: "Correlated Signal Processor," U.S. Patent No. 4,567,602. Issued January 28, 1986. Canada No. 1211-517. Issued September 16, 1986.

[3] K. Feher: "Modem/radio for nonlinearly amplified systems," patent disclosure files in preparation, Digcom, Inc. Confidential and proprietary, Digcom, Inc., 44685 Country Club Dr., El Macero, CA 95618, December 1992.

[4] J. S. Seo, K. Feher: "Superposed Quadrature Modulated Baseband Signal Processor," U.S. Patent No. 4,644,565, issued February 17, 1987. Canadian Patent No. 1-265-851; issued February 13, 1990.

[5] K. Feher: "Notice of Patent Applicability," Document IEEE P.802.11-93/139, Atlanta, September 1993.

[6] K. Feher: "FQPSK: A modulation power efficient RF amplification proposal for increased spectral efficiency and capacity GMSK and π/4-QPSK compatible PHY standard," Document IEEE P.802.11-93/97, Denver, CO, July 13, 1993.

[7] S. Kato, S. Kubota, K. Seki, Ta. Sakata, K. Kobayashi, Y. Matsumoto "Implementation architectures, suggested preambles and VLSI components for FQPSK, offset QPSK and GFSK standard 1 Mb/s rate and for higher bit rate WLAN," a submission by NTT-Japan, Document IEEE P.802.11-93/137.

[8] J. Socci: "GFSK as a modulation scheme for a frequency hopped PHY," A submission by National Semiconductor, Document IEEE P.802.11-93/76, Denver, CO, July 1993.

[9] J. MacDonald: "Discussion of modulation parameters for the 2.4 GHZ FH PHY," a submission by Motorola, Document IEEE P.802.11-93/76, Denver, CO, July 1993.

[10] Leung, P.S.K., K. Feher: "FQPSK – A superior modulation technique for mobile and Personal Communications," IEEE Transactions on Broadcasting, Vol. 39, No. 2, June 1993, pp. 288-294.

[11] Leung, P.S.K., K. Feher: "F-QPSK – A Superior Modulation for Future Generations of High-Capacity Microcellular PCS Systems" Proceedings of the IEEE - VTC-93, May 18-20, 1993, Secaucus, NJ.

[12] K. Feher: "Wireless Digital Communications" manuscript for a forthcoming book Fall 1994 and/or publications. File ©KF, University of California, Davis, September 1992.

[13] Feher, K. , Ed.: "Advanced Digital Communications: Systems and Signal Processing Techniques," Prentice-Hali, Inc., Englewood Cliffs, New Jersey 07632, 1987.

[14] J. McDonald, R. DeGroot, C. LaRosa: "Discussion of 0.39 GMSK modulation for frequency hop spread spectrum," a submision by Motorola. Submission to IEEE 802.11 Wireless Access Methods and Physical Layer Specifications, Document IEEE P.802.11 93-97, May 1993.

[15] N. Silberman: "Proposal for a modulation technique for frequency hopping spread spectrum PHY standard," a submission by California Microwave, Inc., IEEE P.802.11 93/94, May 10, 1993.

[16] Feher, K.: "Modems for Emerging Digital Cellular Mobile Radio Systems," IEEE Transactions on Vehicular Technology, Vol. 40, No. 2, May 1991.

[17] S. Kato, K. Feher: "XPSK: A new cross-correlated phase-shift-keying modulation technique," IEEE Transactions on Communications, May 1983.

[18] J. Boer, P. Stuhsaker: "Establishment of DSSS PHY Parameters," IEEE 802.11-93/145, September 1993.

[19] N. Silberman, J. Boer: "Draft proposal for a frequency hopping and direct sequence spread spectrum PHY standard," IEEE 802.11-93/83r1, July 1993.

[20] K. Feher: "1 Mb/s and higher data rate PHY/MAC: GFSK and FQPSK," IEEE 802.11-93/138, September 1993.

[21] J. Boer: "Proposal for 2 Mb/s DSSS PHY," IEEE 802.11-93/37, March 1993.

[22] EiA/TiA-Qualcomm, Inc.: "Spread spectrum digital cellular system dual-mode mobile station-base station compatibility standard," Proposed EiA/TiA Interim Standard, April 21, 1992; TiA Distribution TR 45.5, April 1992.

[23] S. Kato et al., NTT: "Preamble specifications for the standard 1 Mb/s FH-SS system and for higher speed systems," IEEE P.802.11 93/188, November 1993.

[24] S. Kato et al., NTT: "Performance of OQPSK and equivalent FQPSK-KF for the DS-SS system," IEEE P.802.11 93/189, November 1993.

[25] Z. Wan, K. Feher: "Modulation specifications for 2 Mb/s, DS-SS system," IEEE 802.11-94/02, Wireless Access and Physical Layer Specifications, Jan. 1994.

[26] H. Mehdi, K. Feher: "Compatible power efficient NLA technique (1 Watt) for DS-SS," IEEE 802.11-94/04, Wireless Access and Physical Layer Specifications, Jan. 1994.

[27] Y. Guo, H. Yan, K. Feher: "Proposed modulation and data rate for higher speed frequency hopped spread spectrum (HS-FH-SS) standard," IEEE 802.11-94/03, Wireless Access and Physical Layer Specifications, Jan. 1994.

[28] M. Soderstrand et al. (with Feher): "DS-SS and higher speed FH-SS modem VLSI implementation," IEEE 802.11-94/06, Wireless Access and Physical Layer Specifications, Jan. 1994.

[29] S. Kato (NTT-Japan) et al.: "Implementation architecture and suggested preambles: VLSI implementation of FQPSK and offset QSPK-WLAN," IEEE 802.11-93/137, Wireless Access and Physical Layer Specifications, Jan. 1994.

[30] K. Feher: "FQPSK, GMSK, and QPSK compatible proposed air interface standards for TDMA, FDMA, and CDMA," JTC (AIR)/94.01.19-035, Jan. 1994.

[31] K. Feher: "JTC Modulation Standard Group—FQPSK Consortium: Spectrum utilization with compatible/expandable GMSK, QSPK, and FQPSK," JTC TR 46.3.3/TIPI.4 Telecommunications Industry Association.

[32] K. Feher: "HS-FH and IR FQPSK-based proposed standards for 1.4 Mbit/s to 4.2 Mbit/s," IEEE 802.11-94/51, March, 1994.

[33] E. Creviston (Teledyne), Atienza, Gao, and Guo: "Experimental evaluation of DQPSK and FQPSK for DS-SS, FH-SS and IR applications," IEEE 802.11-94/52.

[34] Golanbari, Fu, Mehdi, and Yan: "CCA (Clear Channel Assessment) proposed solutions for 1 Mbit/s GFSK and higher rate FQPSK systems," IEEE 802.11-94/53.

[35] Golanbari, Dang, Leung, and Mehdi: "Performance study of GFSK and of 4FM, FQPSK, $\pi/4$-DQPSK in a delay spread environment," IEEE 802.11-94/54.

[36] K. Feher: "Infrared EXIRLAN - FQPSK proposed flexible standard," IEEE 802.11-94/55, March, 1994.

[37] J. Edney (Symbionics): "Proposal for a higher data rate frequency hopping modulation scheme," IEEE P.802.11-94/34, Jan. 1994.

[38] J. Grau (Proxim): "High speed frequency hopping PHY proposal," IEEE P.802.11-94/8, January 1994.

[39] N. Silberman (ed.): "Draft proposal for a higher data rate frequency hopping spread spectrum PHY standard," (known as "TEMPLATE" document), IEEE P.802.11-93/210a, January 10, 1994.

[40] C. Brown (Intel): "Wireless communications building blocks: A new approach with programmable logic," Draft of submitted and anticipated publication in EE Times, April 1, 1994.

[41] J. Boer (AT&T, Editor): "Draft proposal for a direct sequence spread spectrum PHY standard," IEEE P.802.11-93/232r1, January 26, 1994.

[42] P. Blomeyer: "Revised version of the combined baseband and multichannel IR-PHY EXIRLAN," IEEE P.802.11-94/62.

[43] P. Blomeyer: "Implementation of EXIRLAN multichannel IR-PHY using existing commodity components," IEEE P.802.11-94/63.

[44] P. Blomeyer: "Compatibility issues between existing IR techniques and present/future requirements," IEEE P.802.11-94/64.

[45] P. Blomeyer: "EXIRLAN Template," IEEE P.802.11-94/65, March 1994.

[46] A. J. C. Moreira, R. T. Valaolas, A. M. de Oliveire Duarte: "Infrared modulation method: 16 pulse position modulation," IEEE P.802.11-93/154, September 1993.

[47] A. J. C. Moreira, R. T. Valaolas, A. M. de Oliveire Duarte: "Modulation-encoding techniques for wireless infrared transmission," IEEE P.802.11-93/79, May 1993.

[48] P. Blomeyer: "EXIRLAN: A multichannel, high speed, medium range IR-local area network," IEEE P.802.11-93/217, November 1993.

[49] P. Blomeyer (Andromeda): "Structural needs for an IR-standard," IEEE P.802.11-94/24, January 1994.

[50] P. Leung: "Performance of FQPSK and coherent QPSK modulation in indoor PCS communications environment with time delay spread," IEEE P.802.11-94/xx, March, Vancouver.