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 \( 30 \text{m} \) to \( 80 \text{m} \) could be covered by highest speed cost efficient infrared WLAN operated at user selectable bit rates of

- \( 1 \text{Mb/s} \)
- \( 1.4 \text{Mb/s} \)
- \( 2 \text{Mb/s} \)
- \( 2.8 \text{Mb/s} \)
- \( 4.2 \text{Mb/s} \)
- \( 5.6 \text{Mb/s} \)
- \( 8.4 \text{Mb/s} \)
- \( 12.6 \text{Mb/s} \)

The first generation of standardized equipment could operate up to \( 4.2 \text{Mb/s} \). 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 exceed \( 6 \text{ MHz} \), thus accommodates the IEC/CENELEC/DKE standard proposals [42-45]. The baseband spectrum (up to \( 6 \text{MHz} \)) could have up to \( 1 \text{Mb/s} \) data rate with 16PPM [46,47] while the FQPSK modulated data is located between \( 6 \text{MHz} \) and \( 30 \text{MHz} \) in \( 3 \text{MHz} \) spaced channels, thus 8 independent FQPSK modulated systems, initial rate up to \( 8 \times 4.2 \text{Mb/s} = 33.6 \text{Mb/s} \) could be accommodated in the same room. The same electronic hardware architecture enables expansion up to \( 8 \times 12.6 \text{Mb/s} = 100.8 \text{Mb/s} \).

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

Frequency Scheme
(revised Feb. 94)

![EXIRLAN Frequency Scheme Diagram]

**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].
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):

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

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

FQPSK-8*8 =
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

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

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

<table>
<thead>
<tr>
<th>Plus</th>
<th>1Mb/s - 16PPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>8*4.2Mb/s</td>
<td>33.6Mb/s FQPSK</td>
</tr>
<tr>
<td>34.6Mb/s</td>
<td></td>
</tr>
</tbody>
</table>

total 4.2Mb/s per 3MHz modulated bandwidth

assuming 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.

![Figure 2 BER = f(E_b/N_0) performance of FQPSK [1-32]](image)

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 $f(E_b/N_0)$ and MULTIPATH SENSITIVITY

**FQPSK:** Maximal dispersion is $d = 50$ns ($= \tau$) for most practical rooms.

Ref. [A. Moreira et al. [46]

At $f_b = 1$Mb/s rate the impact of $d = 150$ns (3* more than typical room) is negligible on FQPSK. See Fig. 2.

Even at $f_b = 4.2$Mb/s the impact of multipath delay spread of 50ns is negligible.

Illustration: FQPSK at 

- $f_b = 4$Mb/s
- $f_s = 2$MBaud
- $T_s = 500$ns
- $d/T_s = 50$ns/500ns = 0.1

Impact of delay spread (multipath) on FQPSK is negligible.

**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 same bit rate. An illustrative scenario for $f_b = 1$Mb/s

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

* $10\log_{10} 12 = 10.8$dB 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 $E_b/N_0$ is recommended.
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

Submission page 9 K. Feher, UC Davis
### IEEE 802.11

Wireless Access Methods and Physical Layer Specifications

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**Specifications and Template of the IEEE 802.11 Infrared PHY EXIRLAN / FQPSK-based Modulation and Baseband**

Date: March, 1994

Author: Editor IEEE 802.11-IR-Standardization

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<table>
<thead>
<tr>
<th>Topic</th>
<th>Val</th>
<th>Parameter</th>
<th>Specification</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>G</td>
<td>Number of carriered channels</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>N</td>
<td>Frequency range</td>
<td>6...30 MHz</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>N</td>
<td>Bandwidth per carriered channel</td>
<td>3 MHz</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>N1</td>
<td>Modulation</td>
<td>FQPSK</td>
<td></td>
</tr>
</tbody>
</table>
| 5     | N2  | Modulation | multistate FQPSK(4*4)/(4*8) | linearized IR-diodes required for
| 6     | N1  | Data rate/channel | 1, 1.4, 2.5, 4.2 MB/s | selectable (no hopping!), 1st
| 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!), 2nd
| 8     | N   | Eb/No for BER = 10 exp-5 | 10...23 dB | generation |
| 9     | N   | Spectral Suppression (PSD) | -20 dB | at edge of band |
| 10    | N   | IR-wave length | 880 nm | |

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Peter Biomeyer, Editor
REFERENCES


