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PPM

A modulation technique for high speed wireless systems
by Jan Boer, Lucent Technologies

Lucent Technologies
Bell Labs Innovations

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Goals for higher speed in ISM band

- Raw bitrate 8-10 Mbit/s
- Comply to FCC rules
  - 10 dB processing gain (in case of Direct Sequence)

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Performance criteria

- Coverage
  - Not more than 10 dB sensitivity drop compared to 802.11
- Delay spread
  - office 50 ns
  - retail up to 200 ns
  - industrial > 200 ns

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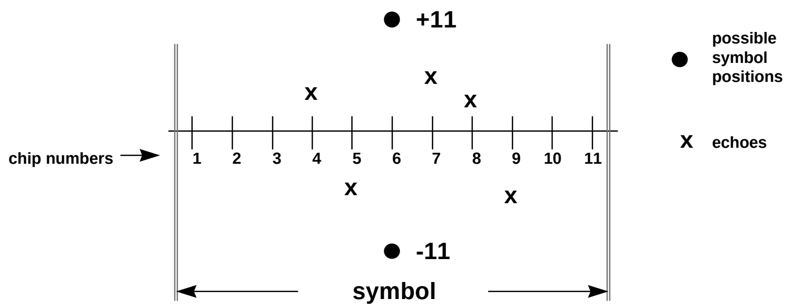
Compatibility goals

- interoperable / coexistence with current 802.11

What is PPM

- PPM is Puls Position Modulation based on the current Direct Sequence technology using the 11-chip Barker Sequence.
- Occupying same bandwidth PPM makes high speed possible:
  - 5, 8, 10 or 11 Mbit/s
- Developed at Bell Labs

Current 802.11 2 Mbit/s system



Information Rate = 1 bit/symbol/quadrature component = 2 bits/symbol
Chips: 11 (essentially) orthogonal positions due to Barker code

Note: only a single position (out of the 11) is used

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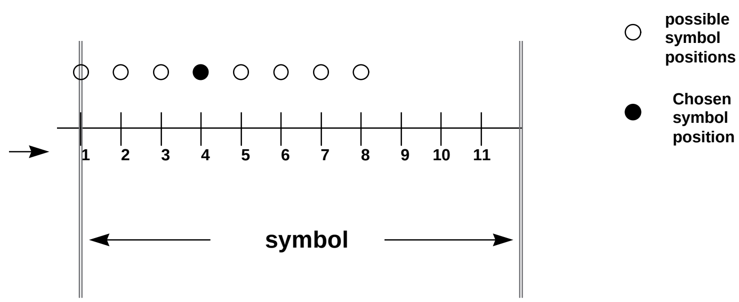
Use 8 out of 11 positions



Example: Number of positions, M = 8
$K = \log_2 M = 3$ bits/symbol

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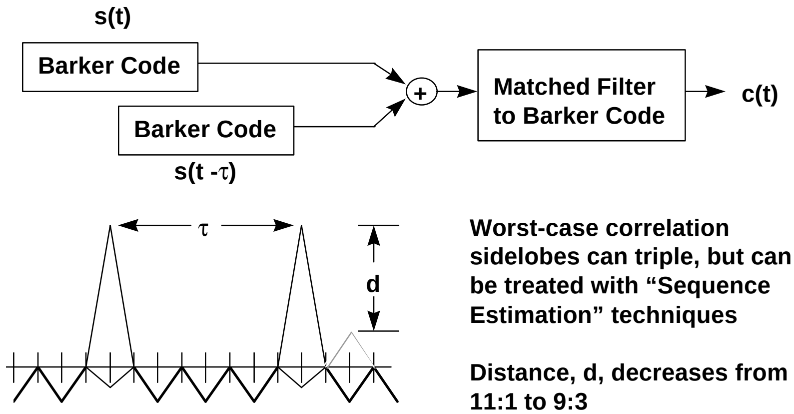
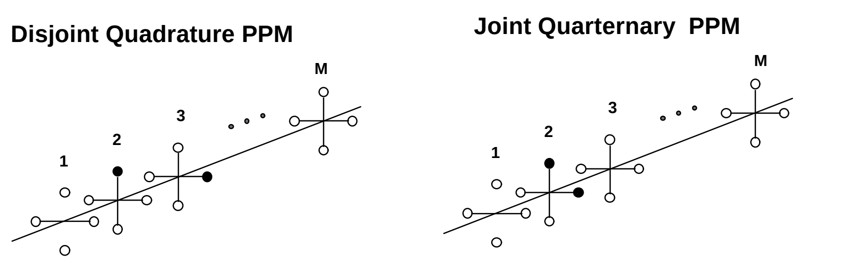
Barker Code Pulse Position Modulation



Worst-case correlation sidelobes can triple, but can be treated with "Sequence Estimation" techniques

Distance, d, decreases from 11:1 to 9:3

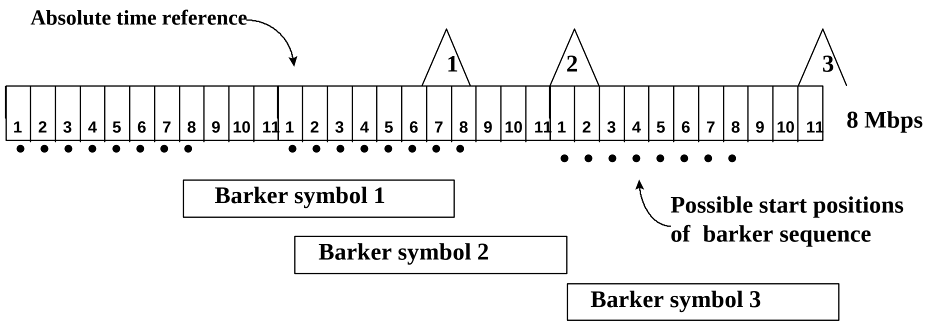
PPM Principals



M ways to choose each (I&Q)channel
P polarities per channel choice
Number of possible configurations:
N= M*M*P*P
M = 8, P=2 N=256; 8 bits/symbol

M ways to choose both I&Q channels
4 polarities.
N= M *4 = 8*4 = 32 -->5 bits/symbol

How to increase datarate



* 3 positions not used by ppm

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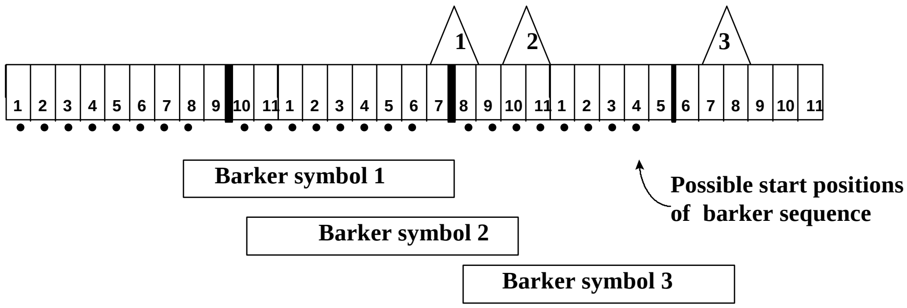
10 Mbit/s



.818 micro second
symbol time

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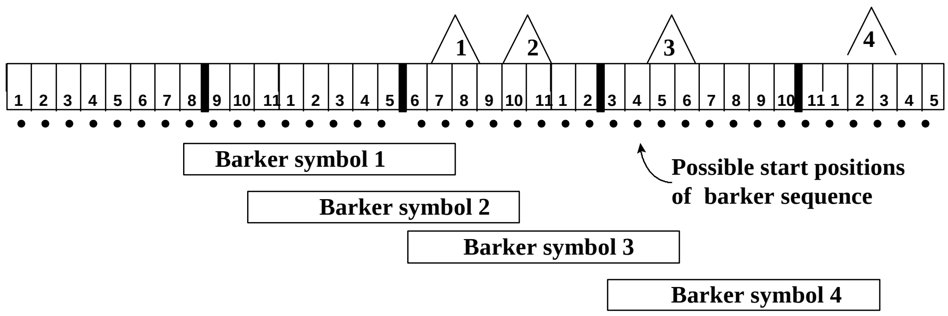
11 Mbit/s



symbol time
.727 micro second

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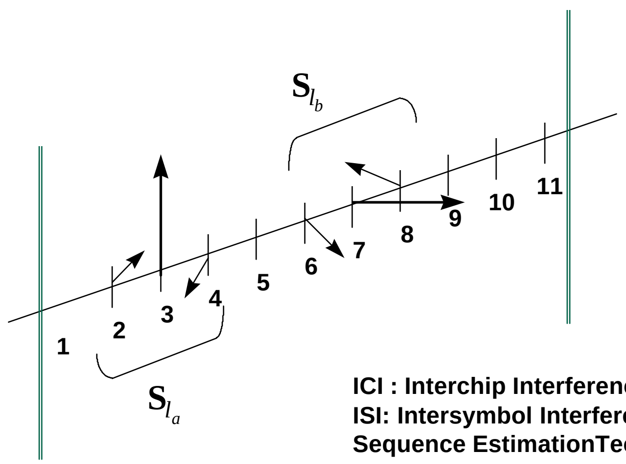
Problem with dispersive channel



$$\mathbf{r} = a\mathbf{S}_{l_a} + jb\mathbf{S}_{l_b} + \mathbf{n}$$
$$a,b \in \pm 1$$
$$l_a, l_b \in (1,\ldots,8)$$
$$i = (a,b,l_a,l_b)$$

ICI : Interchip Interference (cross rail)
ISI: Intersymbol Interference
Sequence EstimationTechniques still appropriate

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Optimum MLSE Reciever

- Derivation of Optimum Receiver in
  - Barker Code Position Modulation for High-Rate Communication in the ISM Band

    Israel Bar David and Rajeev Krishnamoorty

    Bell Labs Technical Journal, Autumn 1996
- Function to compensate Cross Rail Interference, Side Lobes, ISI
- PPM makes reduction of complexity possible at moderate costs

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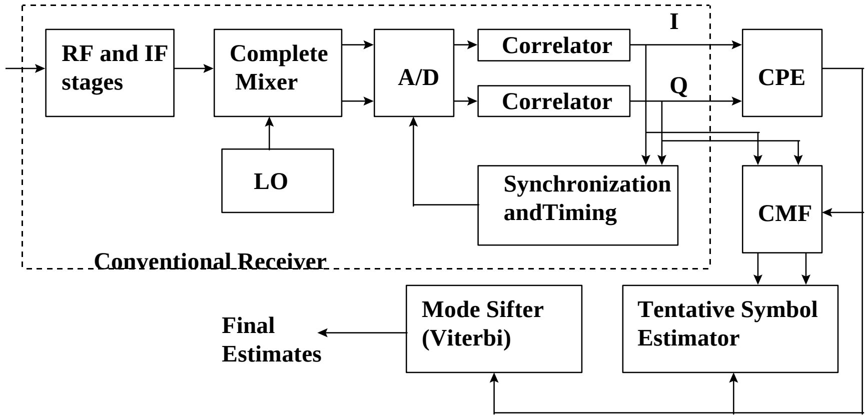
Receiver complexity



CPE channel parameter estimator
CMF channel matched filter

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Receiver Functions: Channel Matched Filter

- Concentrate all energy
- Gives optimal sample timing
- Estimation of the channel parameters needed
  - many well-known methods
  - can be achieved during training
    - on preamble

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Receiver Functions: Tentative Symbol Estimator

- With knowledge of channel TSE removes cross rail interference for all possible symbols (actually 256, in essense 64 because polarity is not contributing to complexity)
- Due to autocorrelation properties of Barker sidelobes can initially be ignored (mode sifter can take care)
- Estimates N most likely symbols (N=4)

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Receiver Functions: Mode Sifter

- Reduced state trellis structure sifting the tentatively retained modes (maxima of TSE)
- Calculates path metric taking ISI and sidelobs into account
- Trellis path determines final estimate
  - – path depth of 4 is sufficient

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Reduced complexity receiver

- Implementation specific
- Manufactorer choice
- At the cost of some performance
- Gatecount in order of 2-3 times current 802.11

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Performance

- Parameters
  - Packet error rate
    - 100 bytes packets
  - SNR
  - Time delay spread
    - 0, 50, 100, 200 ns

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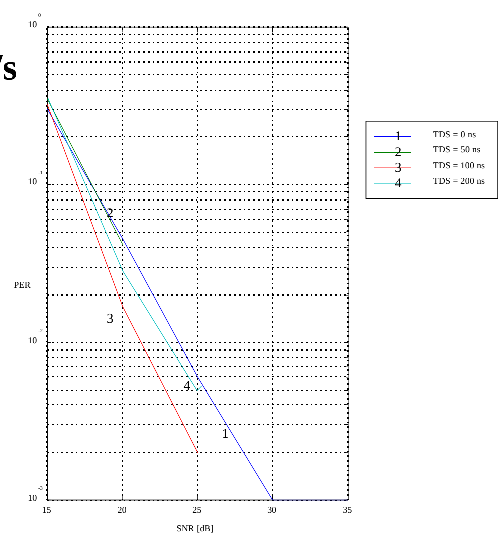
Performance of 8 Mbit/s

Moderate complexity receiver: CMF, TSE and MS



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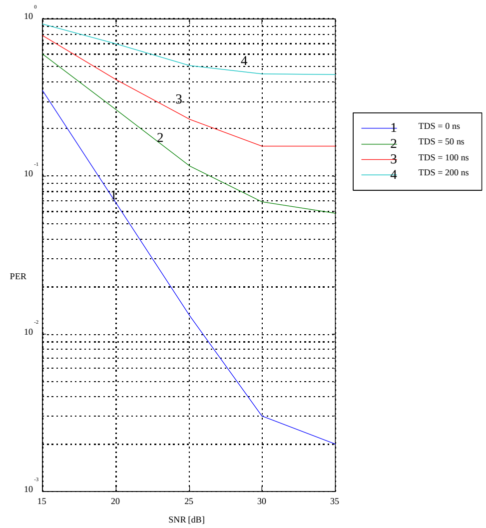
Performance of 8 Mbit/s

Low complexity receiver (CMF only)



PPM Performance

Bitrate	FER | TDS >	0 ns	50 ns	100 ns	200 ns
5 TSE+MS	10-2 10-1	22 16	20 16	20 16	19 15
5 CMF only	10-2 10-1	22 17	20 16	17 15	25 16
8 TSE+MS	10-2 10-1	24 13	24 13	21 13	23 13
8 CMF only	10-2 10-1	26 19	x 22	x x	x x
10 TSE+MS	10-2 10-1	22 18	24 18	30 18	x x
11 TSE+MS	10-2 10-1	24 18	29 19	x 23	x x

SNR

Performance Highlights

- For 5 and 8 Mbit/s a delayspread of 200ns is no problem for a reduced complexity Rx
- 8 Mbit/s with simple Rx (CMF only) will tolerate 50-70 ns (at FER 10-1)
- 5 Mbit/s with simple RX can handle at least 100ns
- 10 and 11Mbit/s can handle 100 ns (at FER 10-1)

Sensitivity

- 5 Mbit/s PPM looses compared to 2 Mbit/s 802.11 only 0.5dB
- 8 Mbit/s PPM 3.5dB
- 10, 11 Mbit/s in same order as 8 Mbit/s

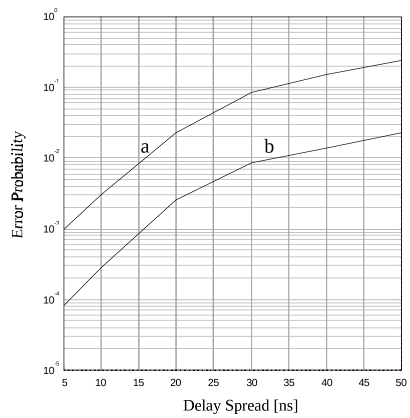
PPM and FCC

- 8 Mbit/s approved by FCC
- 10/11 there is a risk (increasing symbol rate)
- Higher rate in PPM is also possible using QAM (16 QAM gives 10 Mbit/s)
- QAM is certainly acceptable by the FCC (performance penalty)

Comparison to Walsh Code Modulation

- Performed same simulation with Harris Walsh code proposal
- BER and FER was simulated for framelength 100 bytes
- Low complexity receiver, perfect timing and phase sync assumed.

Performance of Walsh code (Harris proposal)



a) Irreducible packet error ratio versus delay spread for a packet size of 100 symbols or 800 bits,
b) irreducible bit error ratio, both for exponentially decaying Rayleigh fading channels.

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Can Walsh be made more robust?

- Delayspread above 30 ns (10% FER) is problem
- Equalizer---> very complex, less performance (noise enhancement)
- maximum likelyhood sequence estimation techniques simular to ppm?
  - can not split MLSE into 2 components (TSE and Mode sifter) due to large cross correlations of all Walsh codes
  - Walsh sidelobs are high, can not be ignored in TSE to get moderate complexity

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Finally Walsh has compliance issue with FCC

- Meets jammer test
- Does not meet the ‘required’ spreading code of 10 chips

Preamble

- PPM is Barker sequence based and can train on 802.11 DS preamble (192 microseconds)
- Shorter preamble is possible.
  - 24 microseconds for Rx training (synchronization, channel matched filter)
  - + time for energy detection and possibly antenna diversity
  - + time to send over header info at higer rate
  - total preamble time needed in the order of 50 microseconds

Coexistence and interoperability issues

- With long 802.11 header PPM is fully coexistence and interoperable (can fall back to 1 and 2 Mbit/s)
- If 20 micros slottime is maintained also with a short header coexistence and/or interoperability is possible

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Possible coexistence scenario

- mix 1/2 Mbit/s with long preamble and PPM with short preamble
  - 1/2 Mbit detects short preamble (carrier)
    - waits for SFD; not found
    - defers until energy or carrier drop
  - PPM can detect long preamble
- long/short can be made to defer for eachother

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Possible interoperability scenario

- PPM with both short and long header
  - receiver has to detect short or long (short header different from scrambled ones)
- In high speed network run short header
- falls back to long header if appropriate

Conclusion

- PPM the way to go for higher speed in ISM band
- 5,8,10,11 Mbit/s
- high performance with moderate complexity receiver
- receiver complexity implementers choice
- FCC approved

Conclusion con't

- Works fine with IEEE802.11 preamble
  - standardization effort minimal, just adds an annex
- PPM is not dependent on current IEEE preamble
  - througput increase by defining short preamble
  - interoperability and coexistence possible