

IEEE 802.16.3 PHY Utilizing Turbo Product Codes

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Dave Williams

AHA

Pullman 2365

NW Hopkins Court, WA

Voice: 509.334.1000 x 165

Fax: 509.334.9000

E-mail: davew@aha.com

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IEEE 802.16.3 PHY Utilizing Turbo Product Codes

Dave Williams
Sean Sonander
Neil McSparron
Garik Markarian
Keith Pickavance

Advanced Hardware Architectures

2365 NE Hopkins Court
Pullman WA 99163-5601

Structure of Presentation

- ¥ Turbo Product Codes
- ¥ Encoding TPC s
- ¥ TPC s Under Single Carrier System
- ¥ TPC s Under Multicarrier System
- ¥ Conclusion

Properties of TPCs

- Turbo Product Codes (TPCs) are very flexible
- Can support any data block size, resolution 1 bit
- TPCs can support a very wide range of code rates with a single, unified encoder/decoder strategy
- From below rate $1/3$ to as high as rate 0.98
- Multiple vendor support exists
- Product Codes were described in 1948 by Elias

cont

Properties of TPCs (cont)

- Codes described here are the same type that are included in the 802.16.1 specification
- Data rates are lower, hence decoder is potentially less complex/lower cost than 802.16.1 codes
- Depending on codes chosen, the decoder can be implemented with < 150 Kgates (includes memory)

TPC — Encoding Operation

$$(n, k) = (n_x - s_x, k_x - s_x) \times (n_y - s_y, k_y - s_y)$$

⌘ Choose Code Parameter (n, k)

⌘ Choose Component Codes (n_x, k_x)

⌘ Shorten Component Codes as Required $(s_x,$

Note on Component Codes

¥ Component Codes based on extended Hamming Codes (Hamming Code+1 bit parity)

Extended Hamming Code	Hamming Code	Gen Poly
(8,4)	(7,4)	$x^3 + x + 1$
(16,11)	(15,11)	$x^4 + x + 1$
(32,26)	(31,26)	$x^5 + x^2 + 1$
(64,57)	(63,57)	$x^6 + x + 1$
(128,120)	(127,120)	$x^7 + x^3 + 1$
(256,247)	(255,247)	$x^8 + x + 1$

2D TPC Coding Example

TPC Code Required: **(2304,1681)**

- ¥ Choose Component Codes (use $\div n$)
- ¥ Extended Hamming Code **(64,57)**
- ¥ Shorten Code by 16, to make **(48,41)** code

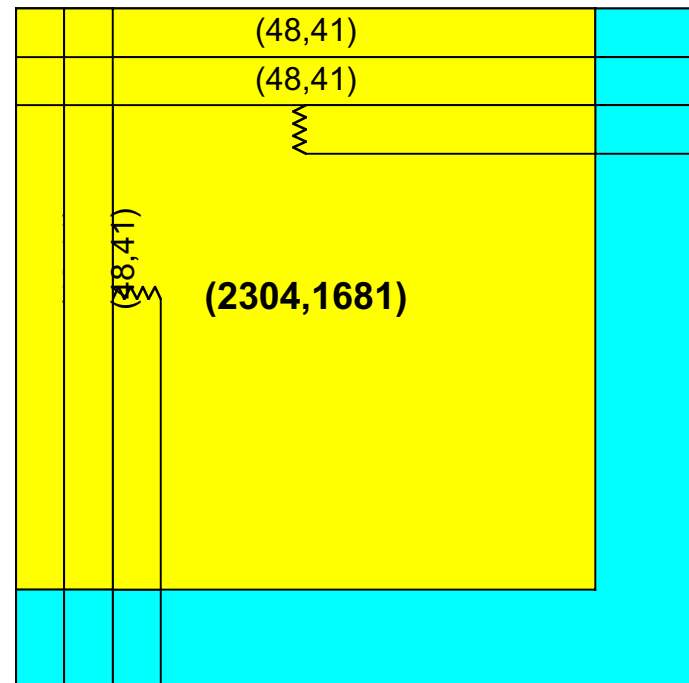
$$(48,41) \times (48,41) = (2304,1681)$$

2D Visualization

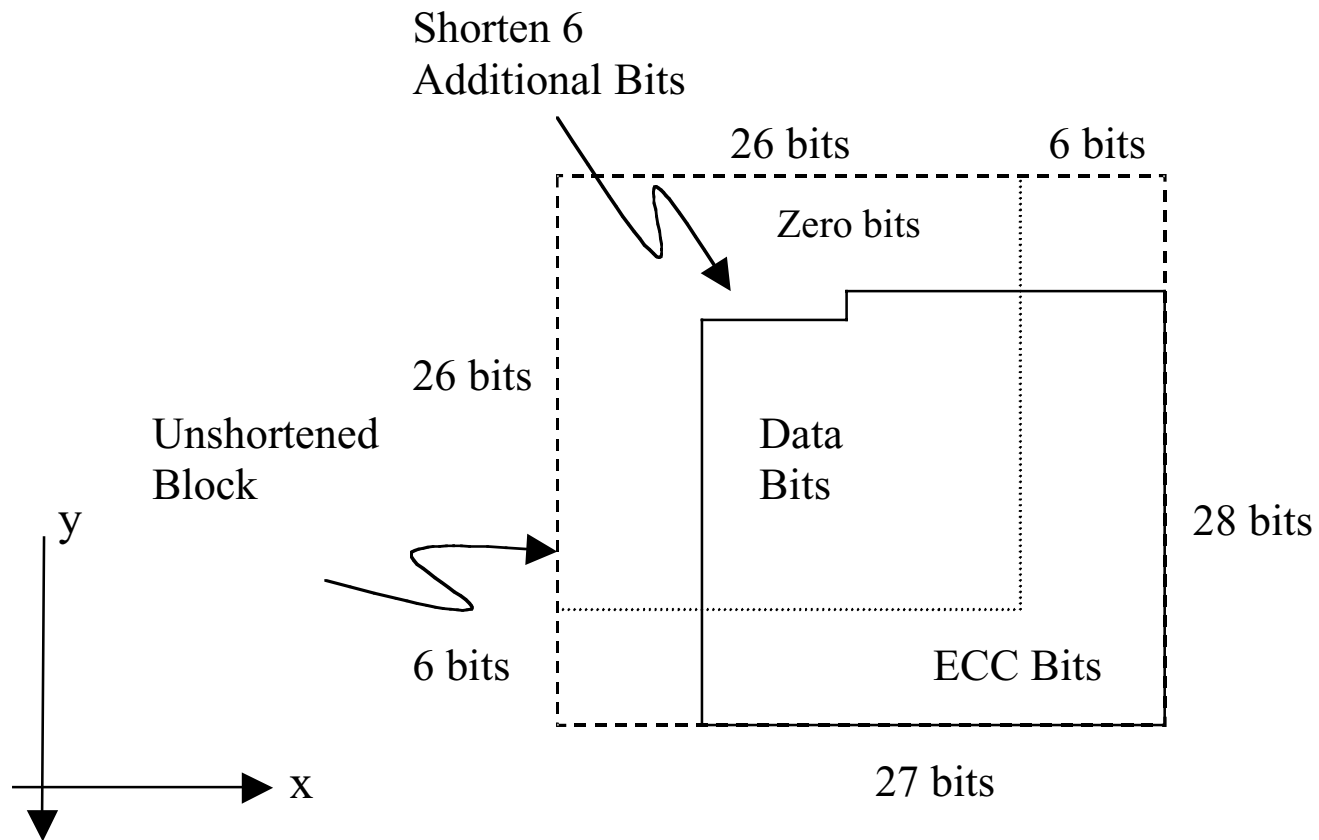
Resultant code is:

$$(48, 41) \times (48, 41) =$$

$$(2304, 1681)$$



Encoding a 2-D TPC

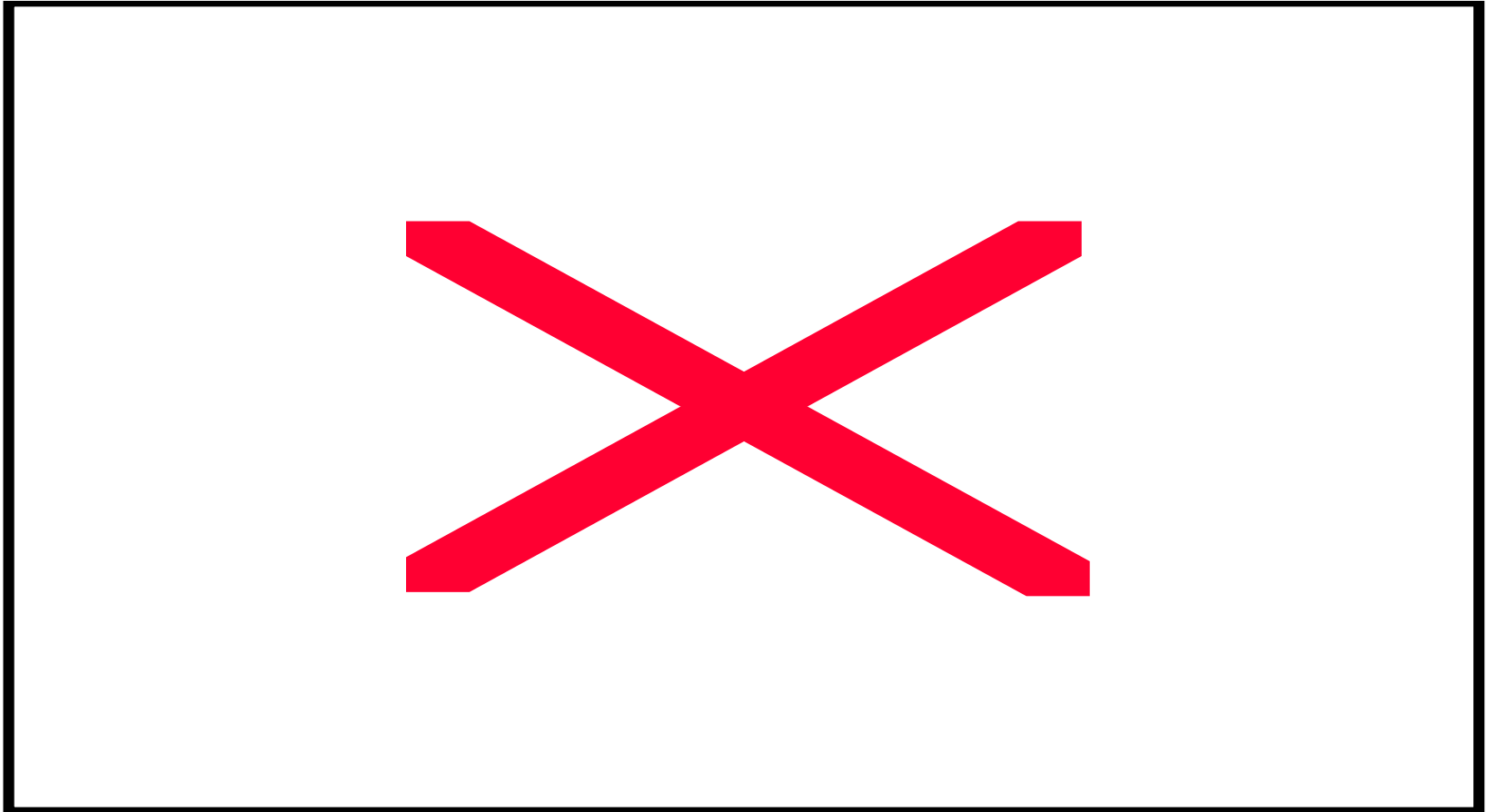


TPC s Under Single Carrier System

- ¥ Typical Single Carrier Framework
- ¥ Integrating TPC s into Single Carrier Systems
- ¥ Performance Enhancements with TPC s

Single Carrier PHY

¥ Comprises of:



Representative TPC s for Single Carrier

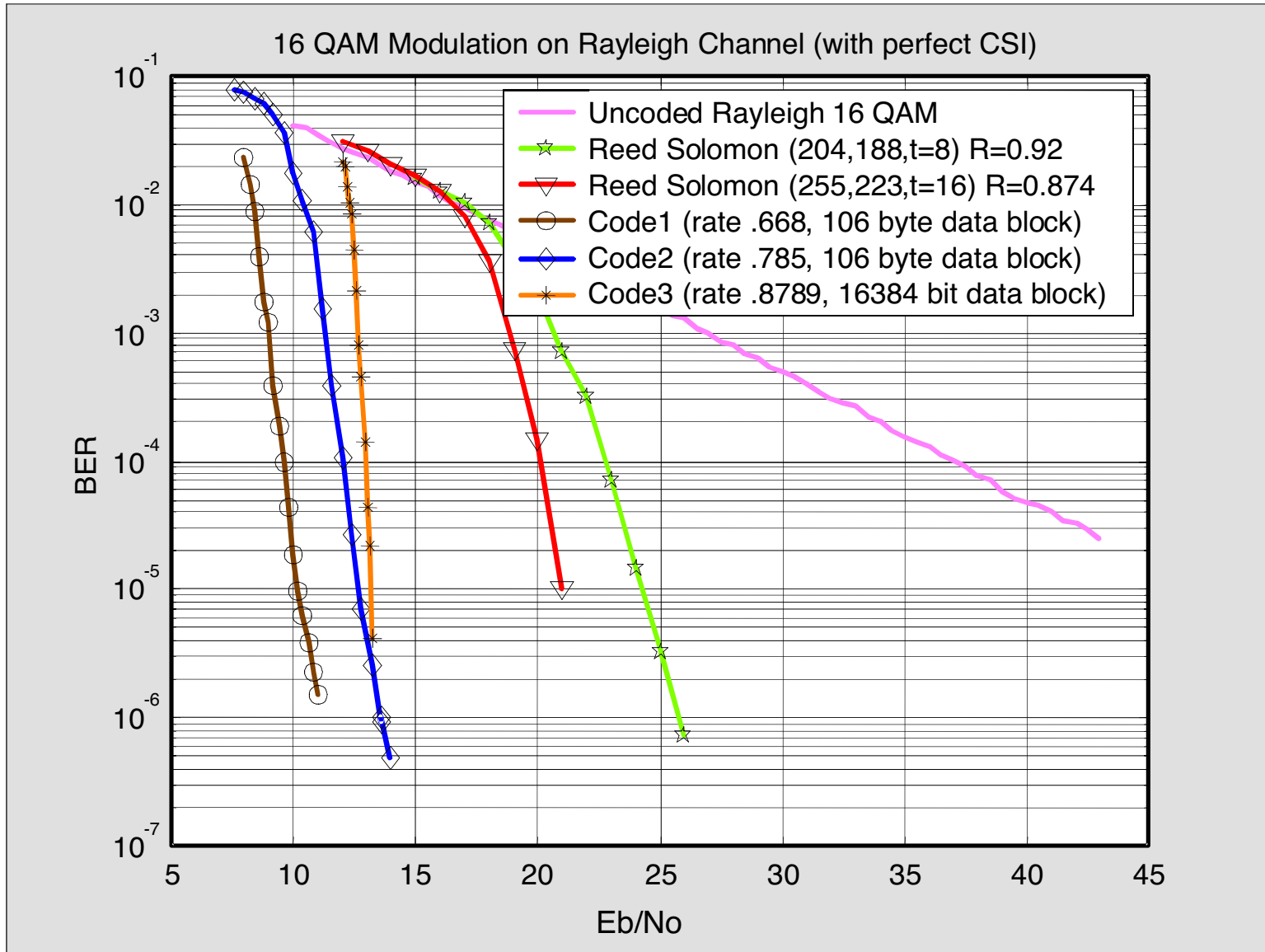
Larger TPCs

Code	$(32,26)^2 \times (16,11)$, QPSK	$(32,26)^2 \times (16,11)$, 16 QAM
Code Rate	0.454	0.454
E_b/N_o @BER= 10^{-6}	1.5	4.7
E_b/N_o @BER= 10^{-9}	1.8	5.1

Shorter TPCs, from TG1 (burst or continuous)

Code	$(39,32) \times (39,32)$ s1=s2=25	$(46,39) \times (46,39)$ s1=s2=18 s=17
Code Rate	0.673	0.717
E_b/N_o @BER= 10^{-6} (4/16/64 QAM)	3.5/6.5/10.7	3.6/6.6/10.5
E_b/N_o @BER= 10^{-9} (4/16/64 QAM)	4.3/7.5/11.7	4.3/7.8/11.5

16 QAM Performance in a Rayleigh Channel

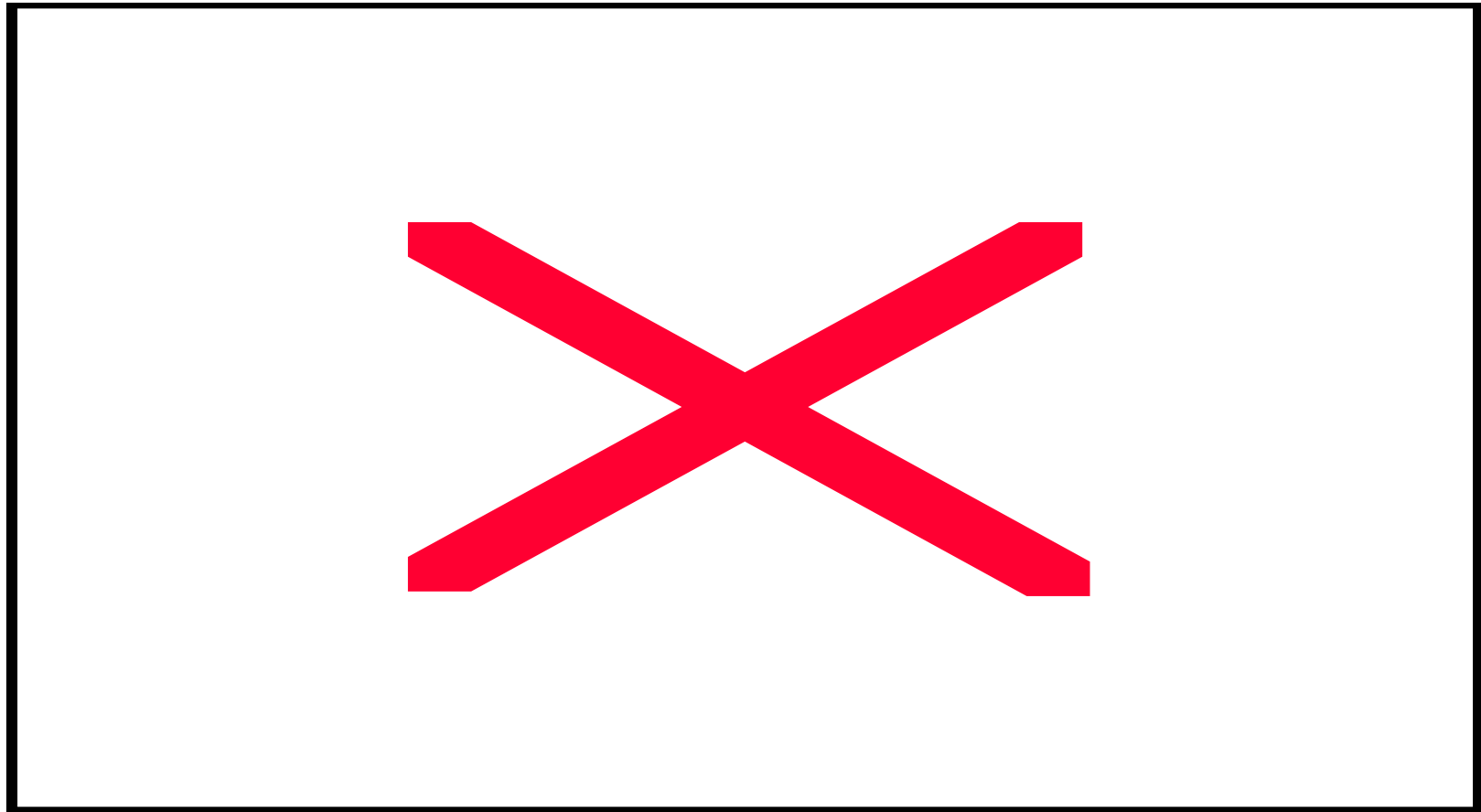


TPC s Under Multicarrier System

- ¥ Typical Multicarrier Framework
- ¥ Integrating TPC s into Multicarrier Systems
- ¥ Performance Enhancements with TPC s

Multicarrier 64 Point FFT PHY

¥ Comprises of:



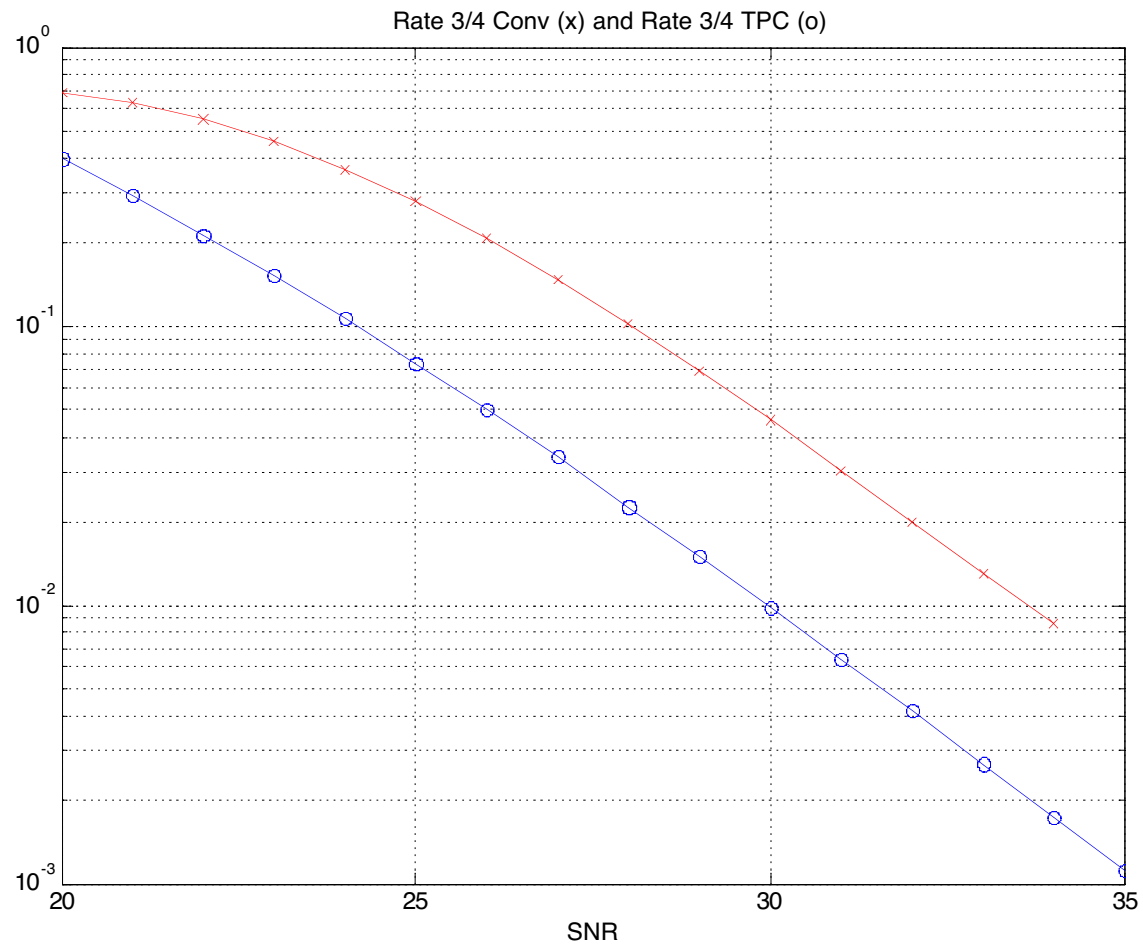
64 Point FFT Structure

¥ Code lengths multiple of 48 bits

¥ Minimum number of TPCs Required

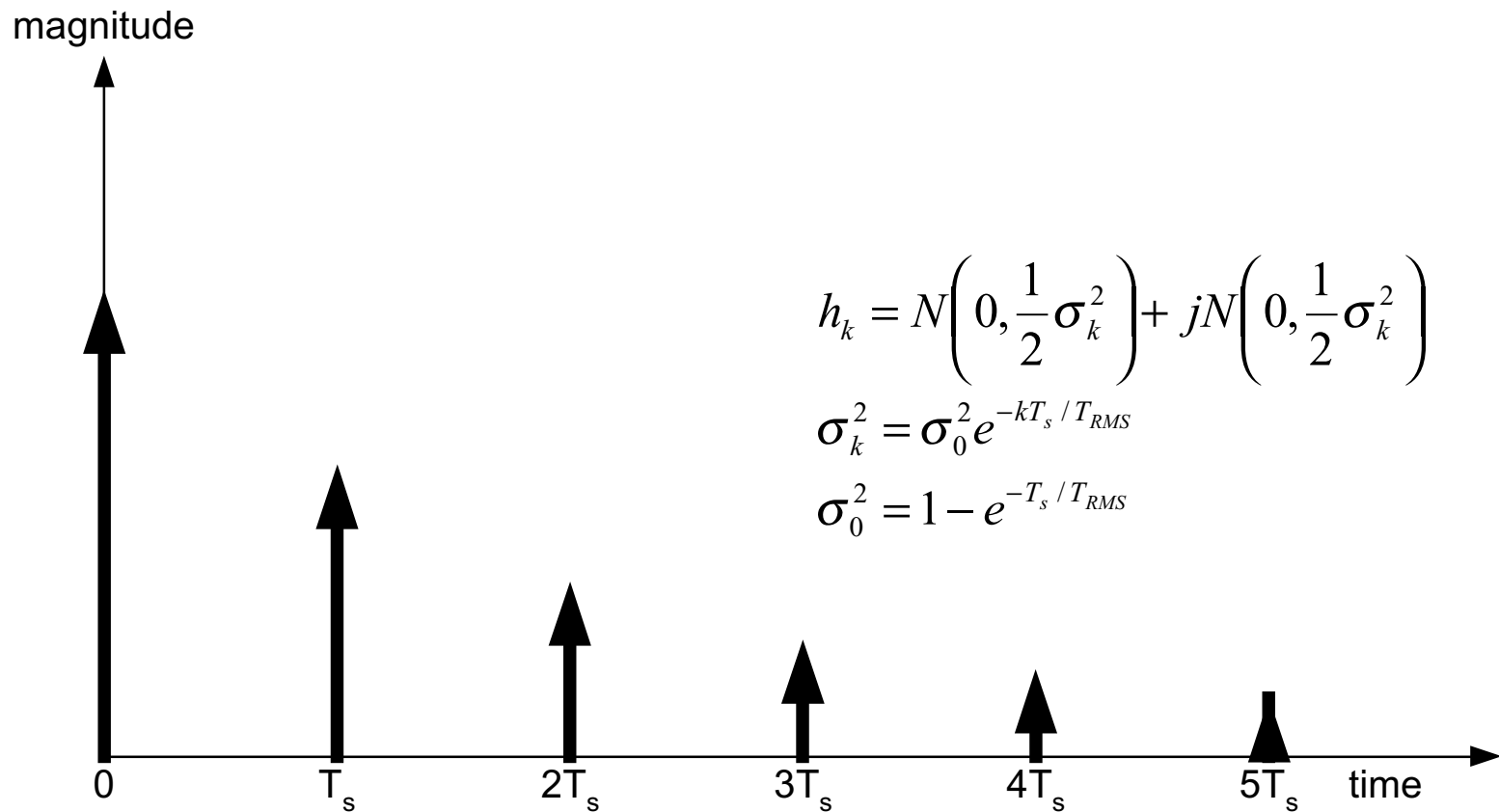
Subcarrier Modulation	Coding Rate	Data Rate /Mbit/s	Coded Bits per OFDM symbol	Data bits per OFDM symbol
BPSK	1/2	1.33	48	24
BPSK	3/4	2	48	36
QPSK	1/2	2.66	96	48
QPSK	3/4	4	96	72
16 QAM	1/2	5.33	192	96
16 QAM	3/4	8	192	144
64 QAM	2/3	10.67	288	192
64 QAM	3/4	12	288	216

Multicarrier Performance Under Fading Conditions



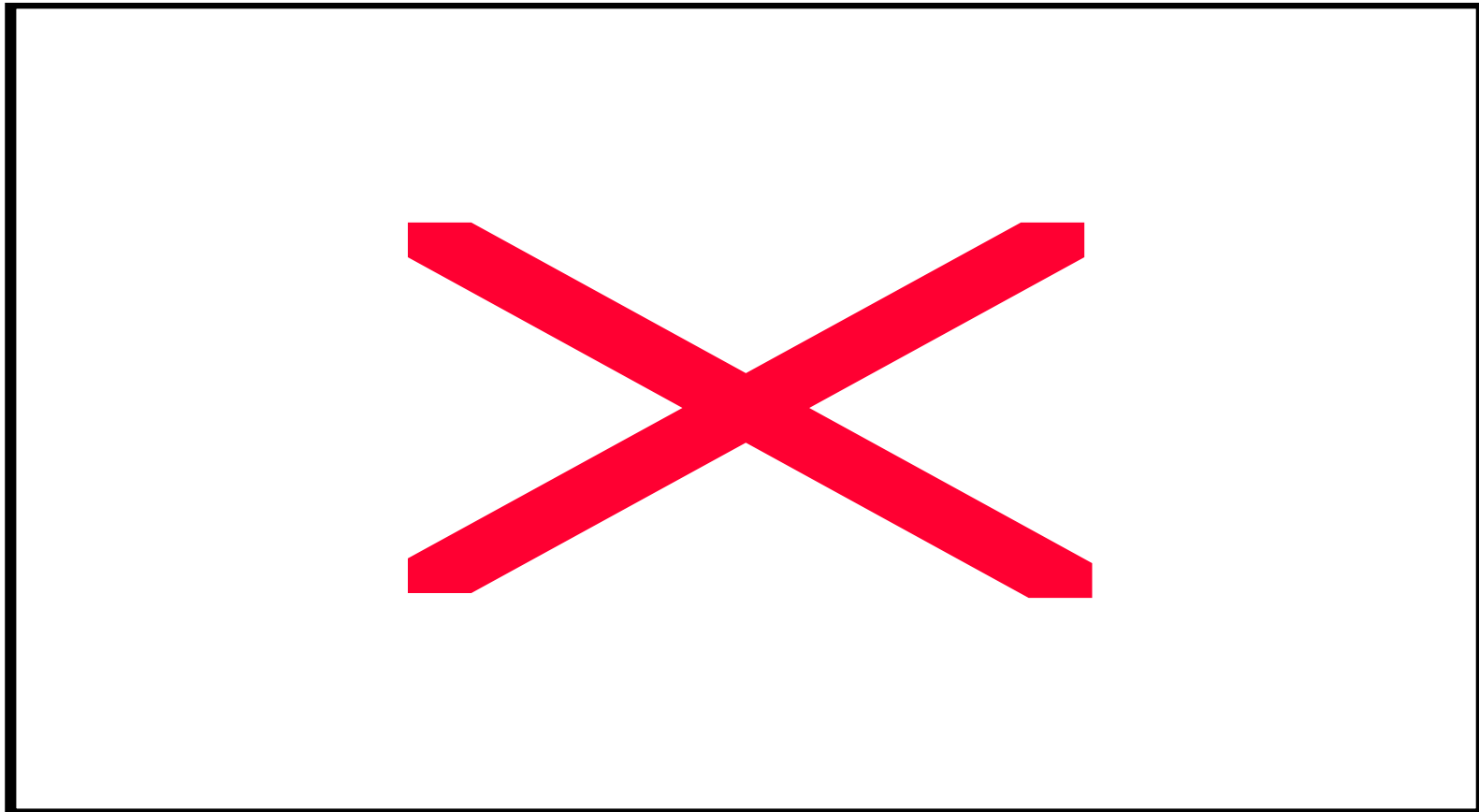
Fading Model

Independent fade across packets



Enhanced Multicarrier Format

¥ Comprises of:



256 Point FFT Structure

¥ Code lengths multiple of 96 bits

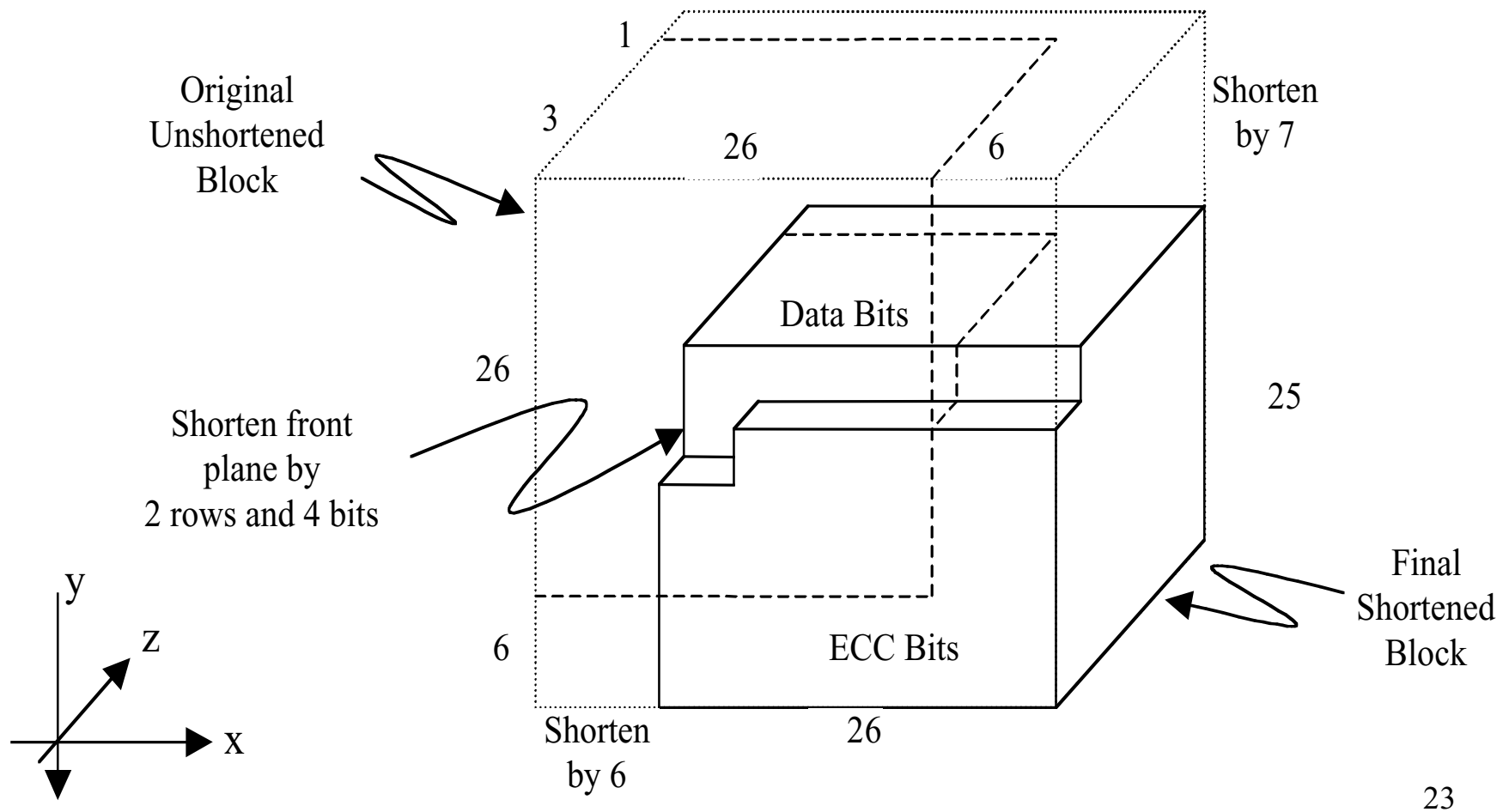
¥ Minimum number of TPCs Required

Subcarrier Modulation	Coding Rate	Data Rate /Mbit/s	Code Bits per OFDM symbol	Data bits per OFDM symbol
BPSK	1/2	1.33	192	96
BPSK	3/4	2	192	144
QPSK	1/2	2.66	384	192
QPSK	3/4	4	384	288
16 QAM	1/2	5.33	768	376
16 QAM	3/4	8	768	576
64 QAM	2/3	10.67	1152	768
64 QAM	3/4	12	1152	864

Conclusion

- ¥ TPCs are readily integrated into single carrier or multicarrier frameworks
- ¥ TPCs Provide high performance combined with high spectral efficiency
- ¥ TPCs may be implemented IP free
- ¥ TPCs have been selected TG1
- ¥ Off the shelf chips and cores available
- ¥ TPC technology is consistent with both SS and BS target costs

Example of 3-D TPC



Error Floor vs. Flare

¥ For TPCs, there is minimal error flare because of high D_{\min} (typ 16 or greater)

¥ Depending on the TPC code used:

—Minor flaring starting @ about 10^{-6} to 10^{-12}

—Flare is predictable

¥ Block size

¥ d_{\min}