Refinement of OFDM signaling method for 10GBASE-T

May 2004

Yuji Kasai, Eiichi Takahashi, Tetsuya Higuchi
(National Institute of Advanced Industrial Science and Technology)

Masahiro Murakawa
(Evolvable Systems Research Institute)

Shinji Nishimura
(Hitachi, Ltd.)

Supporters

- The Tokyo Electric Power Company, Inc.

- POWEREDCOM, Inc.

Objectives

- **Proposal of new method of OFDM signal transmission**
  - **Optimized for new cable model**
  - **5 carriers (vs. 7 for Mar., 2004 version)**
  - **Using RS-LDPC (2048,1723)**
  - **Required bandwidth: 391 MHz**

- **Simple structure and large noise margin**
  - **+7.9 noise margin with model #2**
  - **Reliable and simple clock recovery with pilot signal**
    - **Lower pilot-signal frequency(469 MHz vs. 625 MHz in Mar. 2004)**
  - **Low symbol rate of 156 MHz (cf. PAM: 833 MHz to 1 GHz)**
  - **Estimated jitter tolerance: 35 ps**

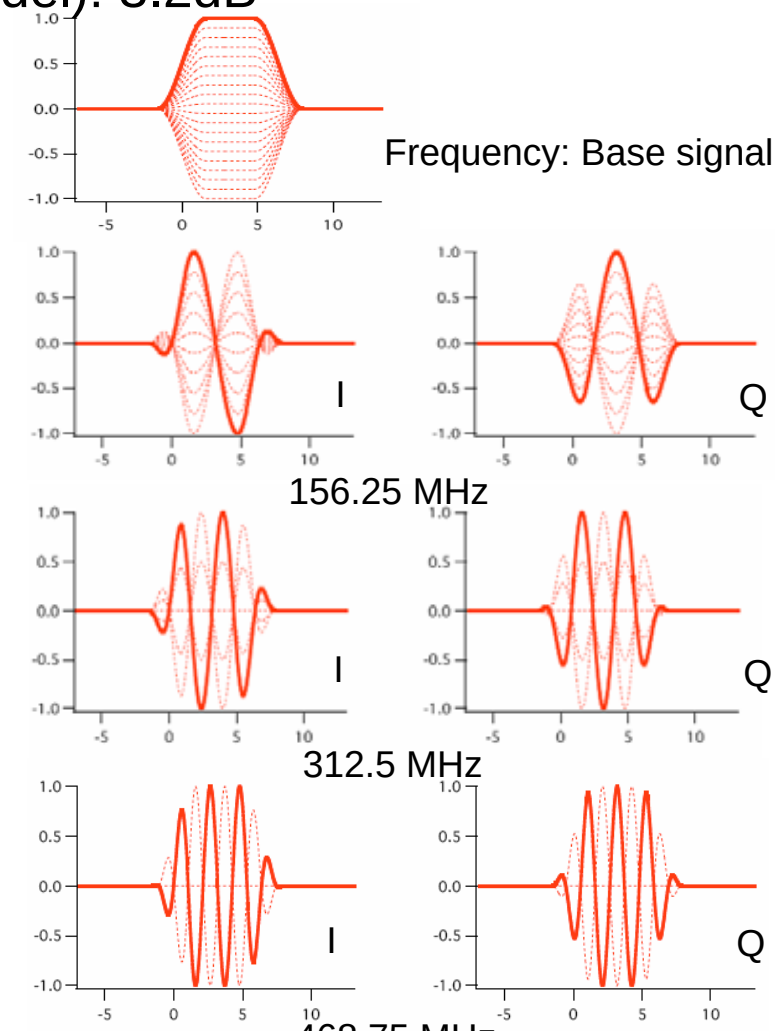
Previous OFDM method (March)

- Demonstrated data transmission over 100 m on Cat-7 cable
- Noise margin (100-m Cat-7, new cabling model): 3.2dB

Carrier frequency	Data (bits)	PAM levels
Base signal	4	20
156.25 MHz (I,Q)	3+3	10
312.5 MHz (I,Q)	2+2	5
468.75 MHz (I,Q)	1+1	3
625 MHz pilot signal	0	0

Total: 16 bits

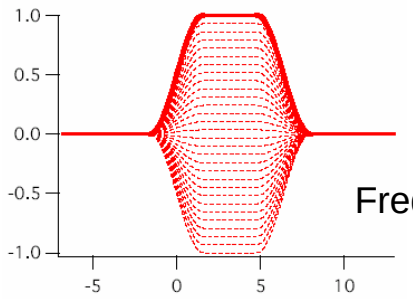
I: In-phase, Q: Quadrature-phase



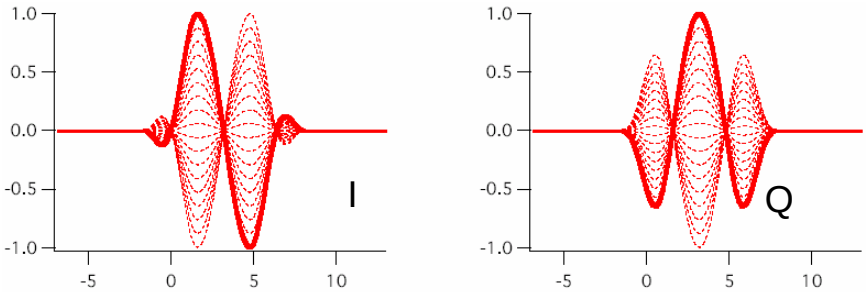
New proposal for OFDM signaling

Carrier frequency	Data (bits)	PAM levels
Base signal	4.9	30
156.25 MHz (I,Q)	4.2+4.2	18
312.5 MHz (I,Q)	3+3	8
469 MHz pilot signal	0	0

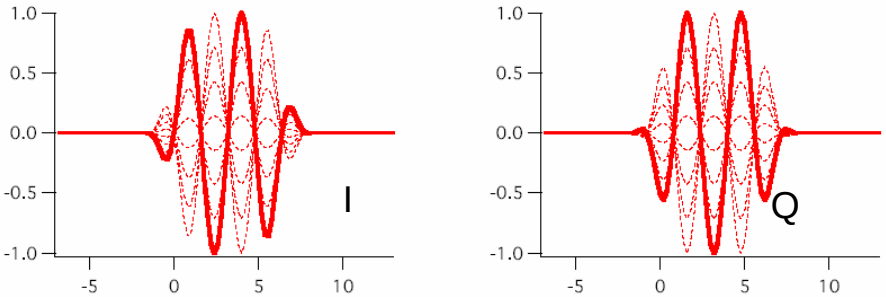
Total: 19.3 bits
I: In-phase, Q: Quadrature-phase



Frequency: Base signal



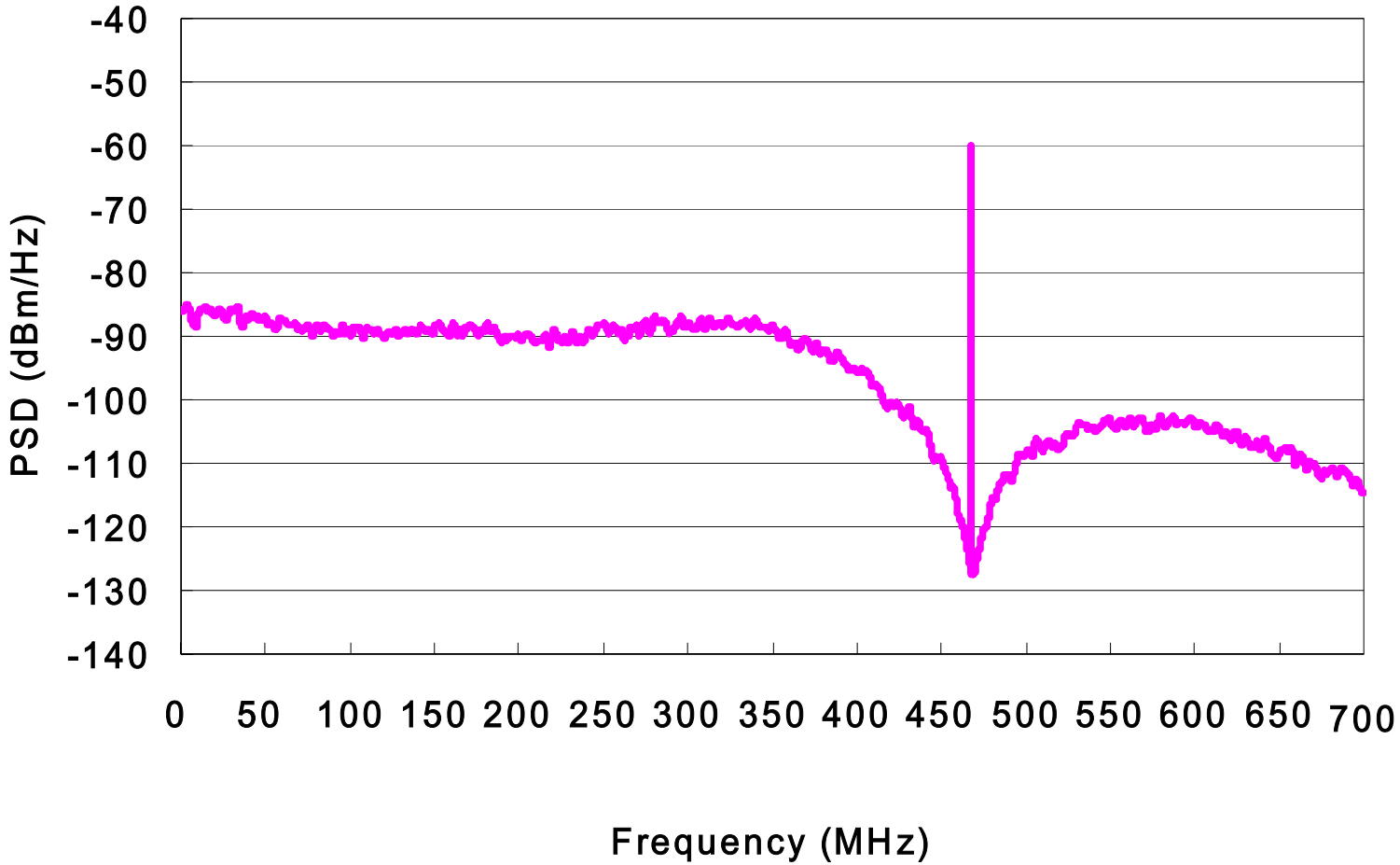
156.25 MHz



312.5 MHz

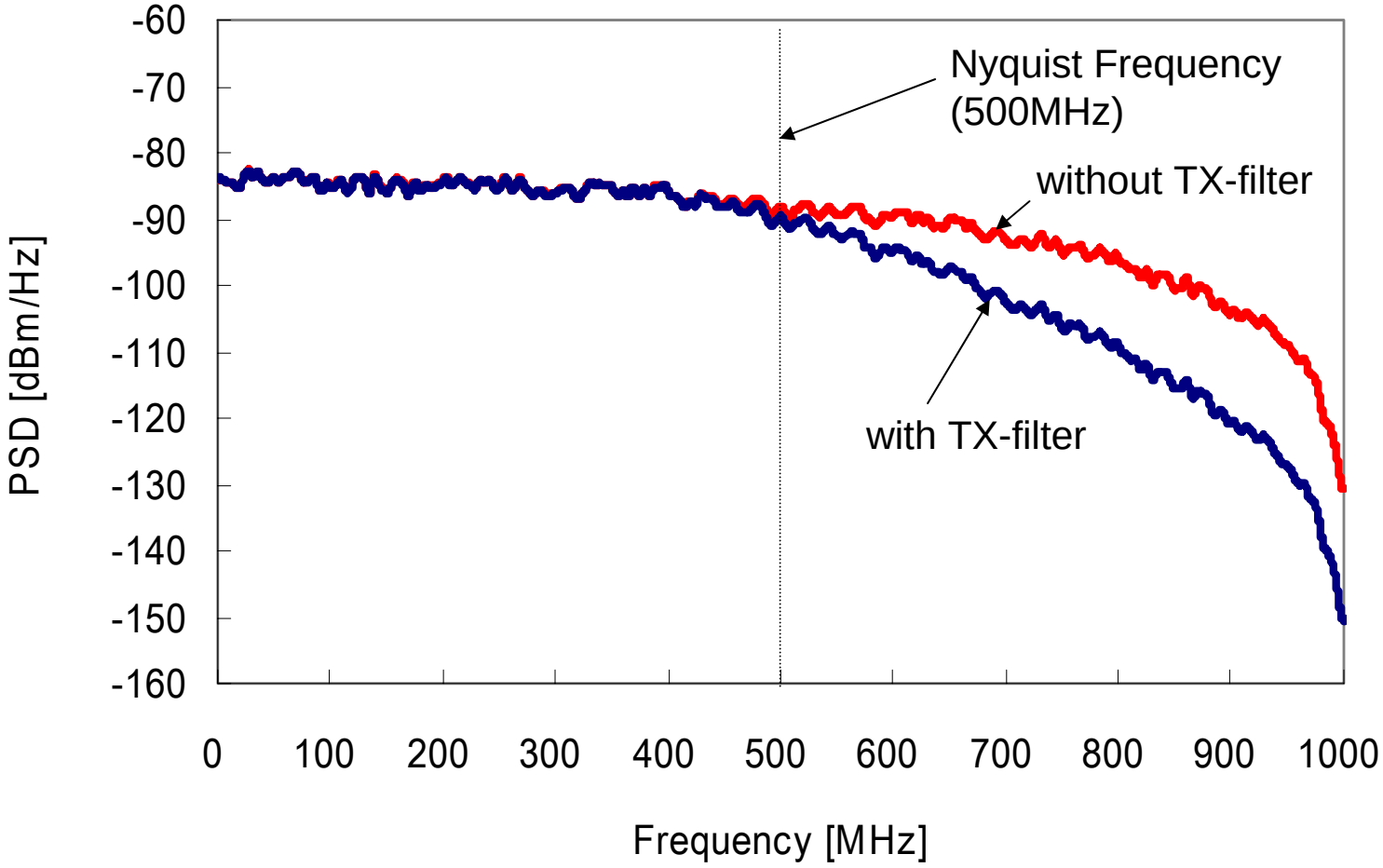
Transmitted signal (OFDM)

- TX filter: -18 dB/octave, fc=391 MHz



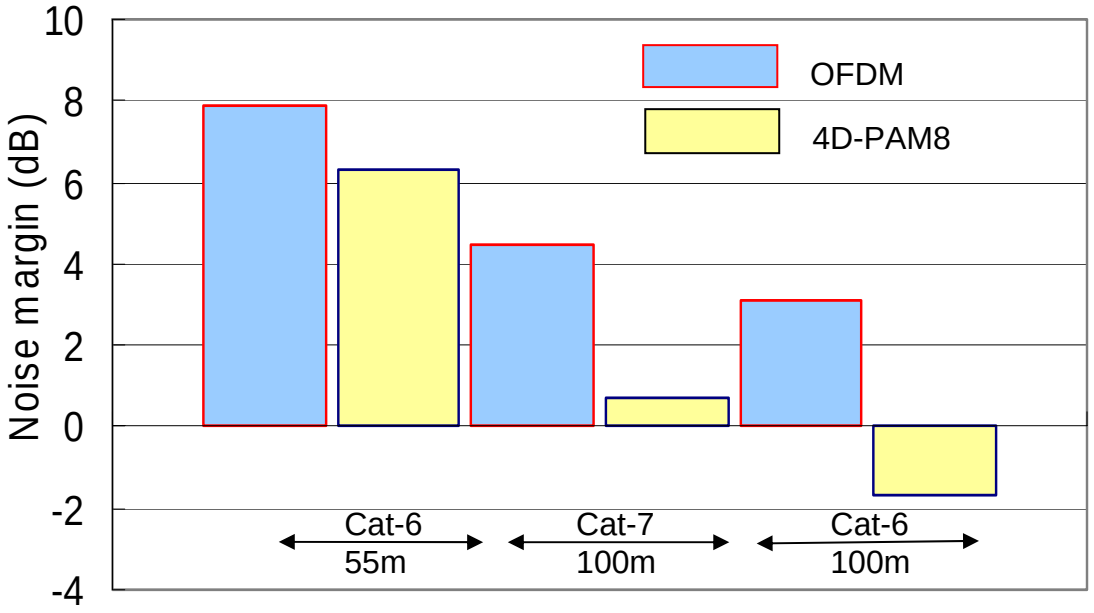
Transmitted signal (4D-PAM8)

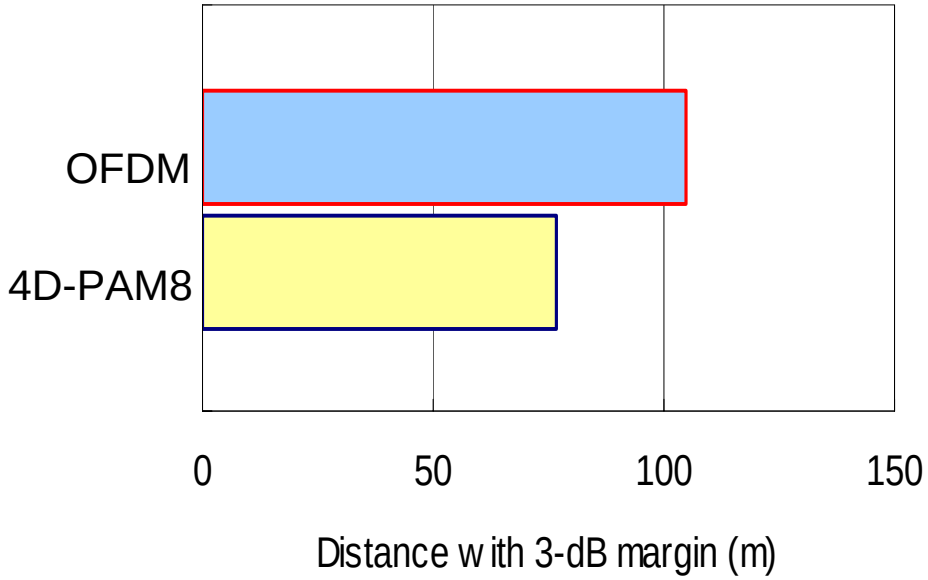
- TX filter: -18 dB/octave, fc=500 MHz



Evaluation (noise margin)

- Using RS-LDPC (2048,1723) based on rao_1_1103.pdf
- Based on practical equalizers and low-pass filters
  - ANEXT spectrum existing out of the signal band (391MHz for OFDM,500MHz for 4D-PAM8) is taken into account.





Advantages of OFDM Method

(1) High spectral efficiency
- Required bandwidth is 391 MHz + pilot signal (469 MHz)

(2) Low symbol rate: 156 MHz
- Inter-symbol interference is small

(3) Strong jitter tolerance: 35 ps

(4) Noise margin: 7.9 dB (with RS-LDPC coding)

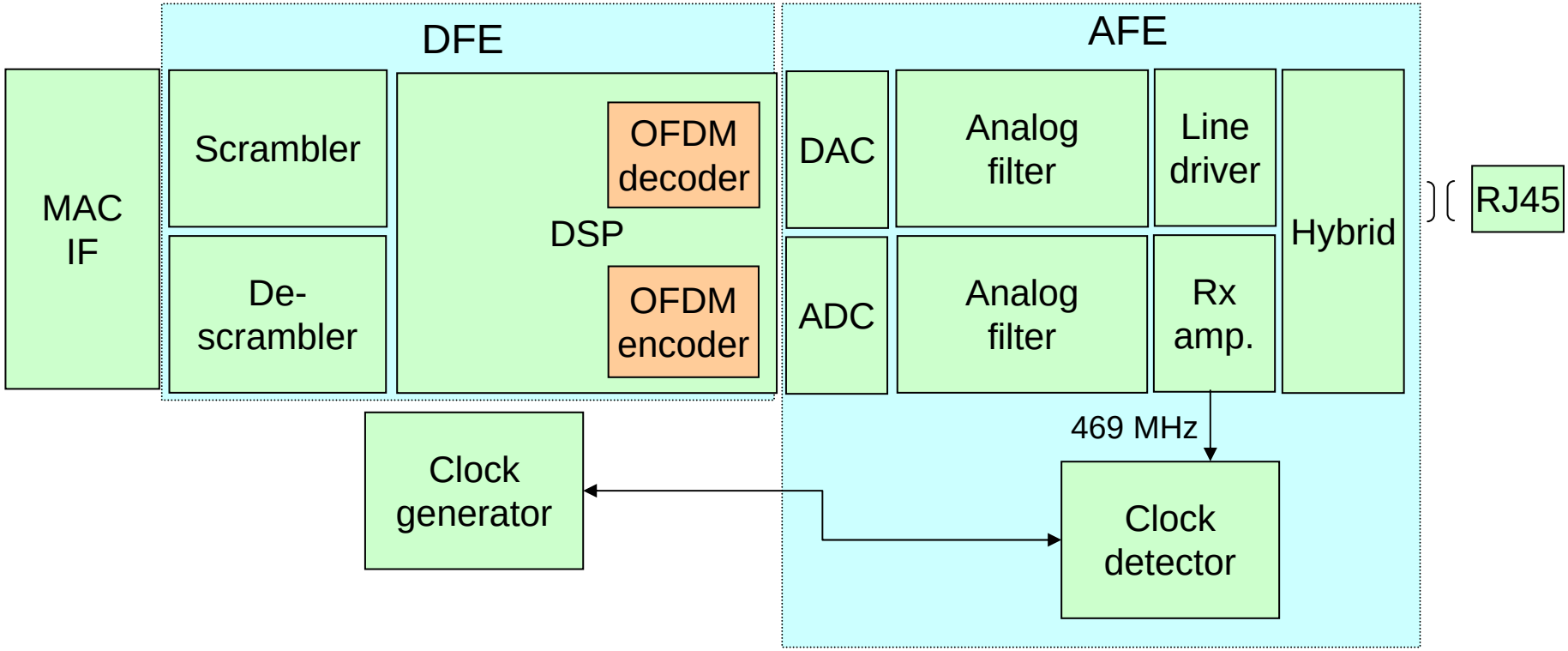
(5) Latency: 1.5-2 us (analog front end: <20 ns)

(6) Pilot signal provides ease of clock recovery

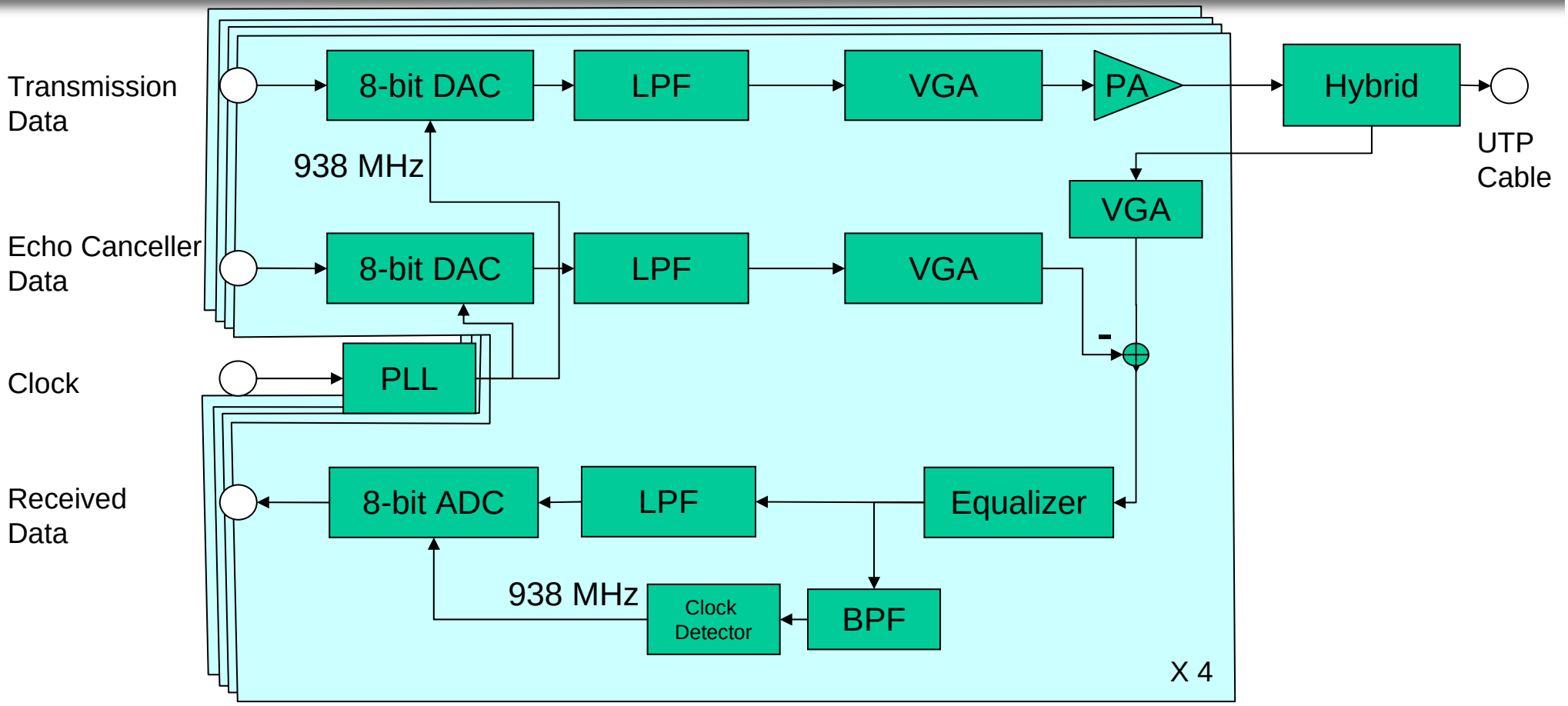
Comparison with other methods

		PAM-10 without coding	4D-PAM8	OFDM
Symbol rate (MHz)		833	1000	156
Bandwidth (MHz)		417	500	391
Launch voltage (V_{p-p})		3	-	1.5
Noise margin (dB)	Model #1	-9.7	0.7	4.5
	Model #2	-5.7	6.3	7.9
Latency (without cable)		< 100 ns	0.5-2 us	1.5-2 us
Jitter tolerance (ps)		3	-	35

Block diagram of the LSI

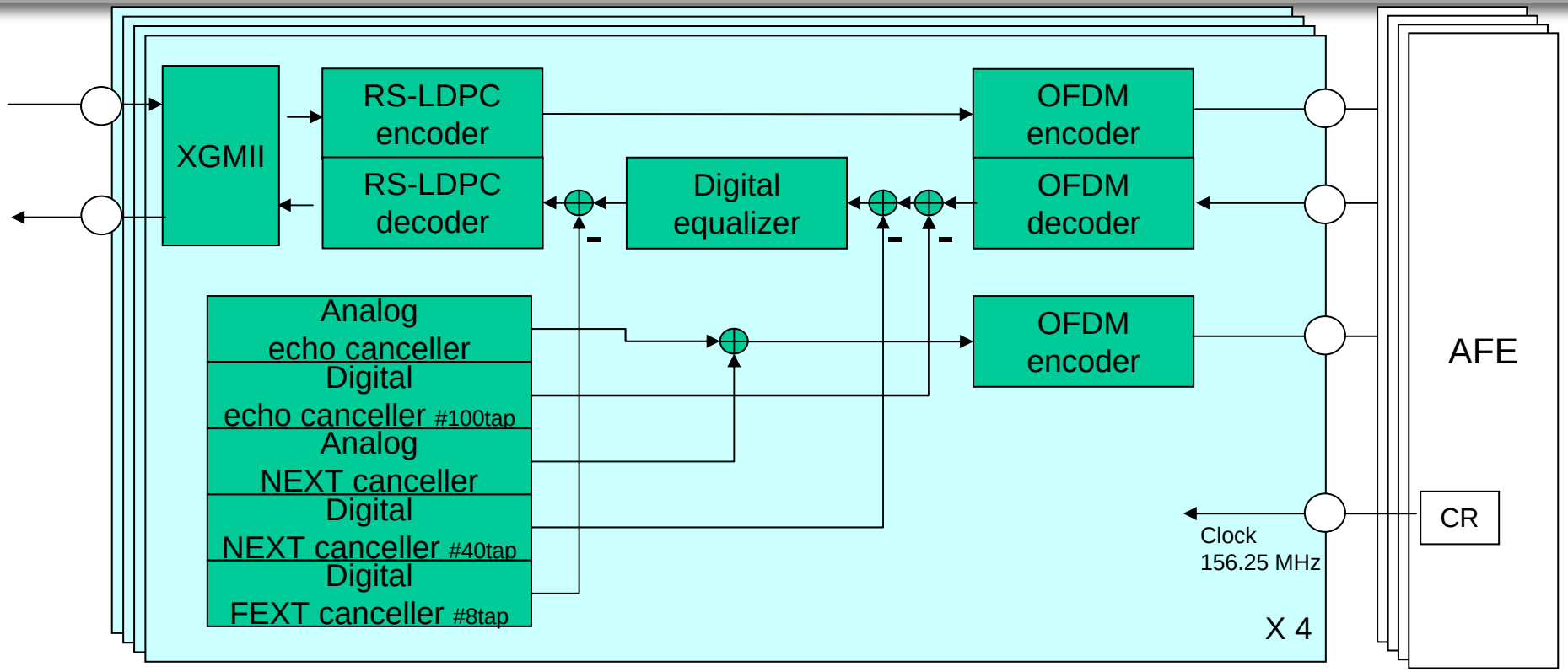


Structure of AFE



- Latency: <20 ns
- Power consumption (0.13um-CMOS): 5.0 W (I/O: 1.7W)

Structure of DFE



	Latency (ns)	Scale (Mgates)	Power consumption (W) 0.13um-CMOS
OFDM encoder/decoder	**100**	**0.1**	**0.2**
RS-LDPC encoder/decoder	**1000-1500**	**2.0**	**4.2**
Others	**400**	**0.6**	**1.2**
Total	**1500-2000**	**2.7**	**5.6**

Conclusion

- Improved OFDM method for 10GBASE-T
  - Only 5 carriers
  - Low symbol rate: 156 MHz
  - Required bandwidth: 391 MHz + pilot signal
- Simulation results
  - Noise margin: 7.9 dB (with RS-LDPC coding)
  - Easy clock recovery
  - Large jitter tolerance: 35 ps

Jitter (experimental result)

- Measured jitter of recovered clock (1250 MHz): 8.6 ps (RMS)