10GBASE-T: A new proposal for improving PAM performance with OFDM

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Supporters

- The Tokyo Electric Power Company, Inc.

- POWEREDCOM, Inc.

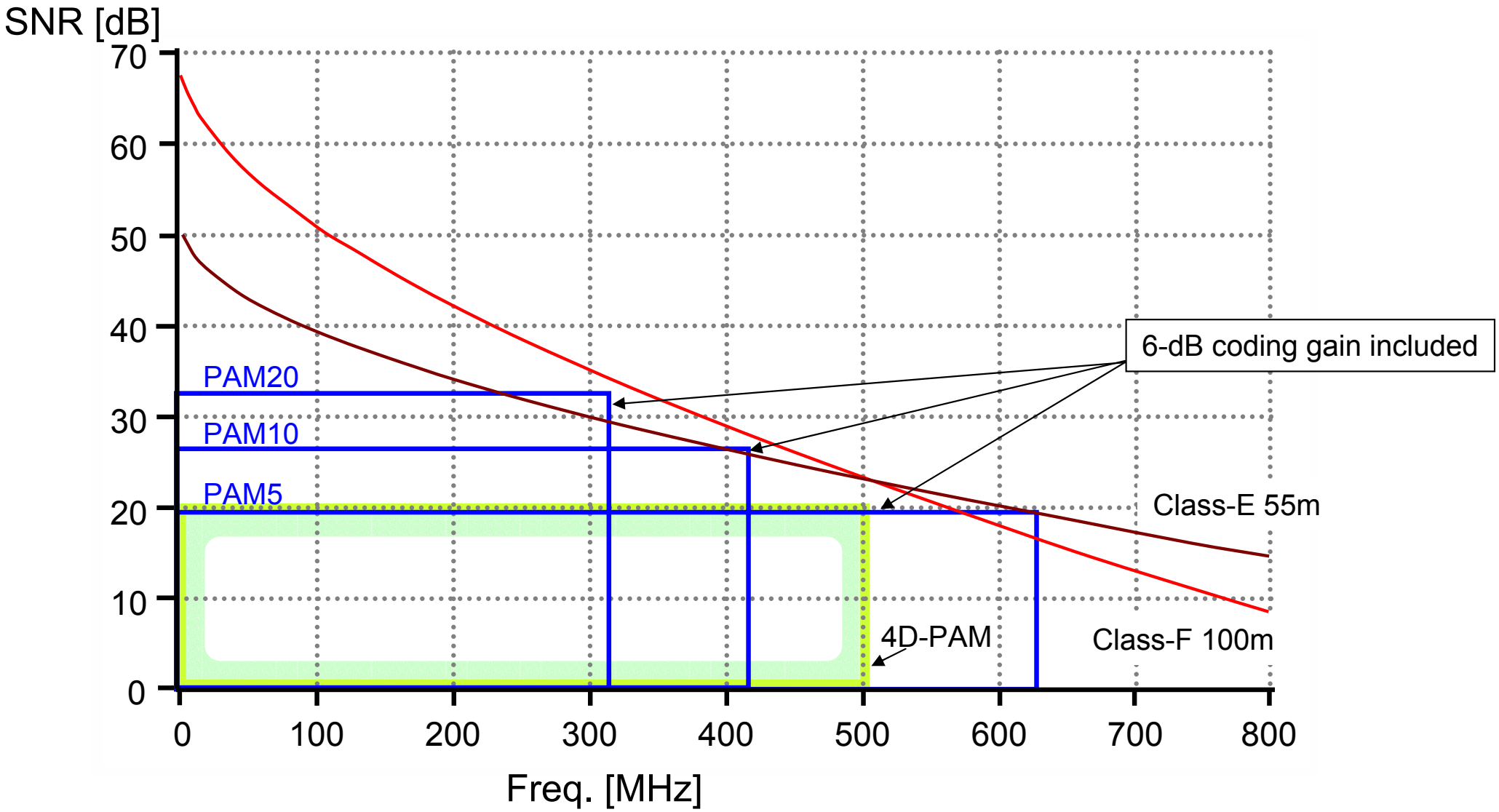
Objectives

- OFDM signal transmission method applied to 10GBASE-T
- PAM-based frequency division multiplexing
  - 10-Gbps data transmission
  - 6.1-dB noise margin
- 100-m signal transmission with CAT-7 cable

1. Current 10GBASE-T proposals

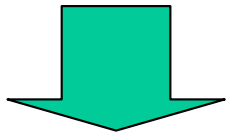
	PAM-20	PAM-10	PAM-5	4D-PAM8
Symbol Rate (Mbps)	625	833	1250	1000
Bandwidth (MHz)	312.5	417	625	500
Launch Voltage (V_{p-p})	-	3	2	-
Required SNR (dB)	33	26	19	20
Noise Margin (dB) with 6 dB coding gain	-4	-1	-3	+3
Latency	< 100 ns	< 100 ns	< 100 ns	0.5-2us

1. Issues with current proposals

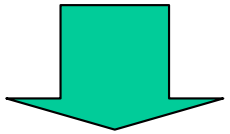


2. OFDM Technique for 10GBASE-T

- Orthogonal Frequency Division Multiplexing (OFDM)
  - Special form of multi-carrier modulation
  - High spectral efficiency
  - Less sensitive to inter-symbol interference



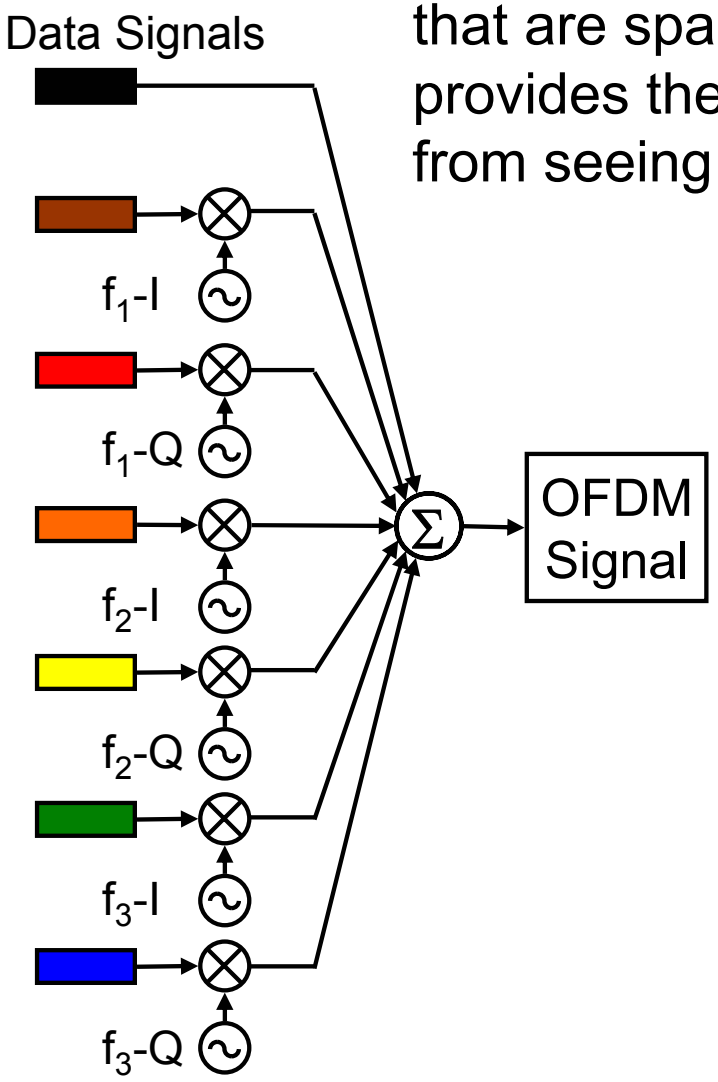
- 7 PAM signals transmitted over 7 frequency-nonselective channels

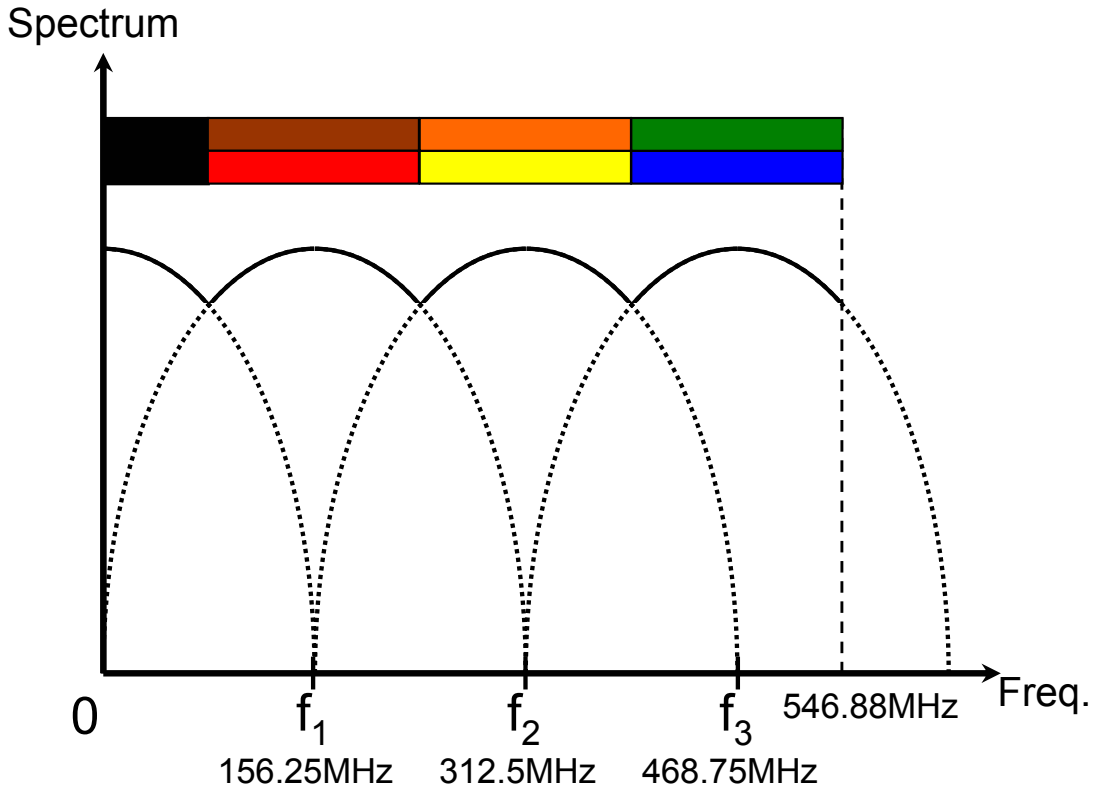


- Required frequency bandwidth: 547 MHz + pilot signal
- Symbol rate: 156.25 MHz (=10GHz/(4chx16bit))
- Low latency: < 100 ns

2. OFDM Technique

OFDM technique distributes the data over a number of carriers that are spaced apart at precise frequencies. This spacing provides the "orthogonality" which prevents the demodulators from seeing frequencies other than their own.

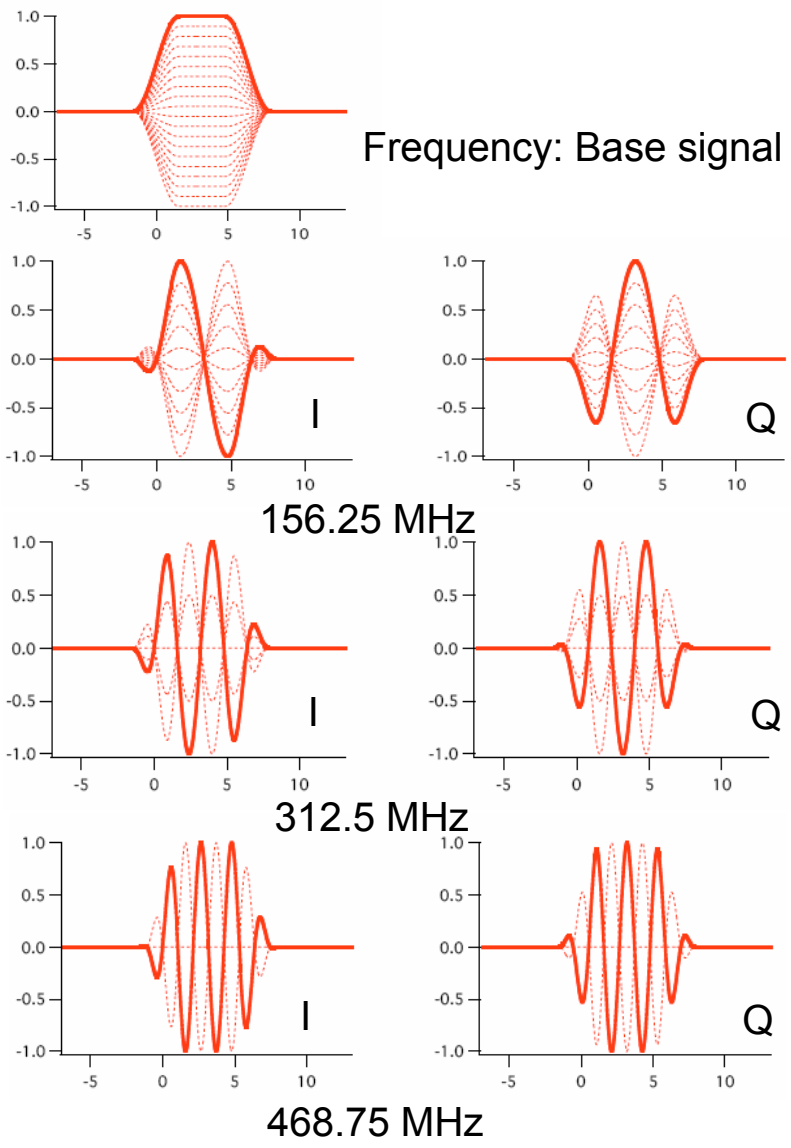




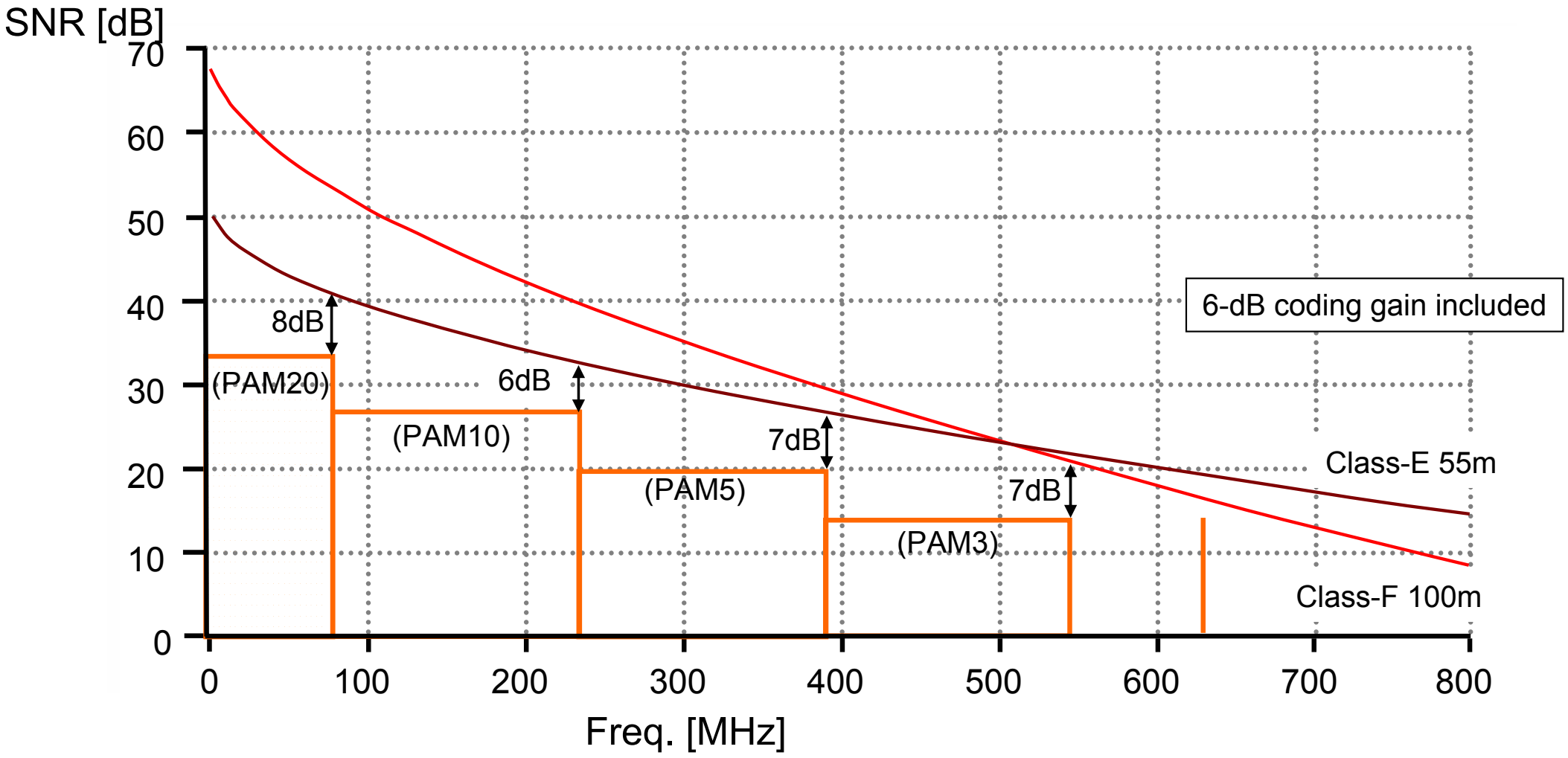
2. Signaling in OFDM

Carrier Frequency	Data bits	PAM Level
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

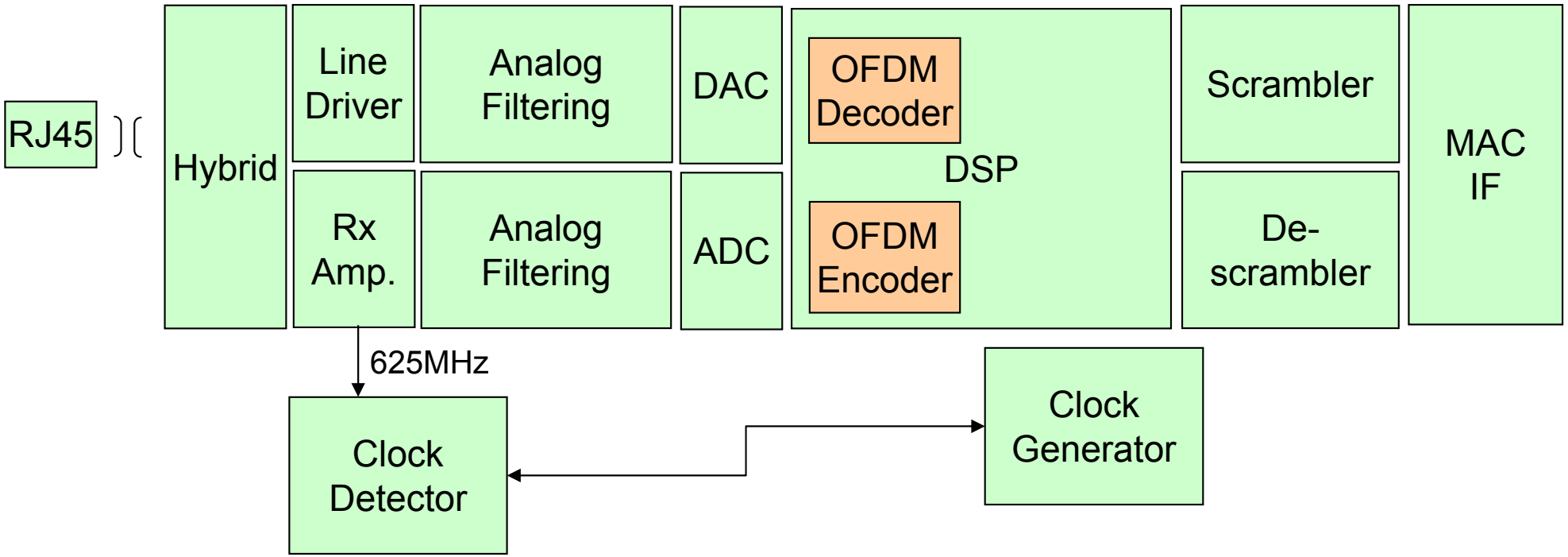
Total 16 bits
I: In-phase, Q: Quadrature-phase



2. SNR Margins

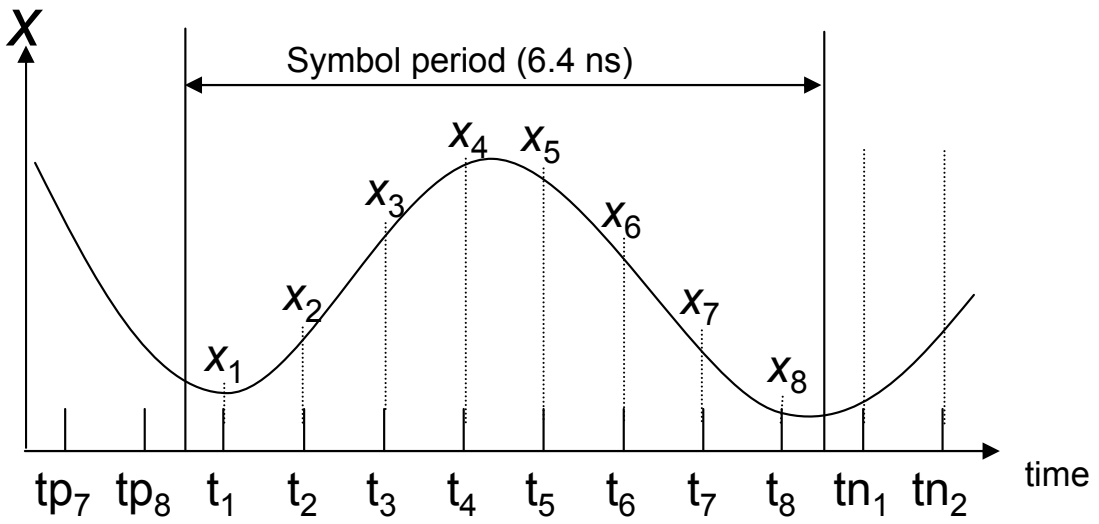


2. Block Diagram



2. OFDM Modulation on DSP

- DSP processing on TX
  - 7 PAM signals (p_i) are converted into 12 OFDM signals (x_i,xp_i,xn_i).
  - One symbol consists of 8 OFDM signals (x_i).



$$\begin{pmatrix} xp_7 \\ xp_8 \\ x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ x_7 \\ x_8 \\ xn_1 \\ xn_2 \end{pmatrix} = \begin{pmatrix} 0.05 & -0.04 & -0.03 & -0.04 & 0.02 & -0.01 & 0.04 \\ 0.31 & -0.09 & -0.29 & -0.17 & -0.23 & -0.20 & -0.15 \\ 0.69 & 0.28 & -0.61 & 0.47 & -0.40 & 0.52 & -0.15 \\ 0.95 & 0.86 & -0.34 & 0.59 & 0.62 & -0.31 & 0.67 \\ 1 & 0.90 & 0.37 & -0.63 & 0.63 & -0.30 & -0.72 \\ 1 & 0.37 & 0.90 & -0.63 & -0.63 & 0.72 & 0.30 \\ 1 & -0.37 & 0.90 & 0.63 & -0.63 & -0.72 & 0.30 \\ 1 & -0.90 & 0.37 & 0.63 & 0.63 & 0.30 & -0.72 \\ 0.95 & -0.86 & -0.34 & -0.59 & 0.62 & 0.31 & 0.67 \\ 0.69 & -0.28 & -0.61 & -0.47 & -0.40 & -0.52 & -0.15 \\ 0.31 & 0.09 & -0.29 & 0.17 & -0.23 & 0.20 & -0.15 \\ 0.05 & 0.04 & -0.03 & 0.04 & 0.02 & 0.01 & 0.04 \end{pmatrix} \begin{pmatrix} p_1 \\ p_2 \\ p_3 \\ p_4 \\ p_5 \\ p_6 \\ p_7 \end{pmatrix}$$

- RX can be handled in reverse fashion of TX.
- Major overhead of OFDM is only 20-ns matrix computation.

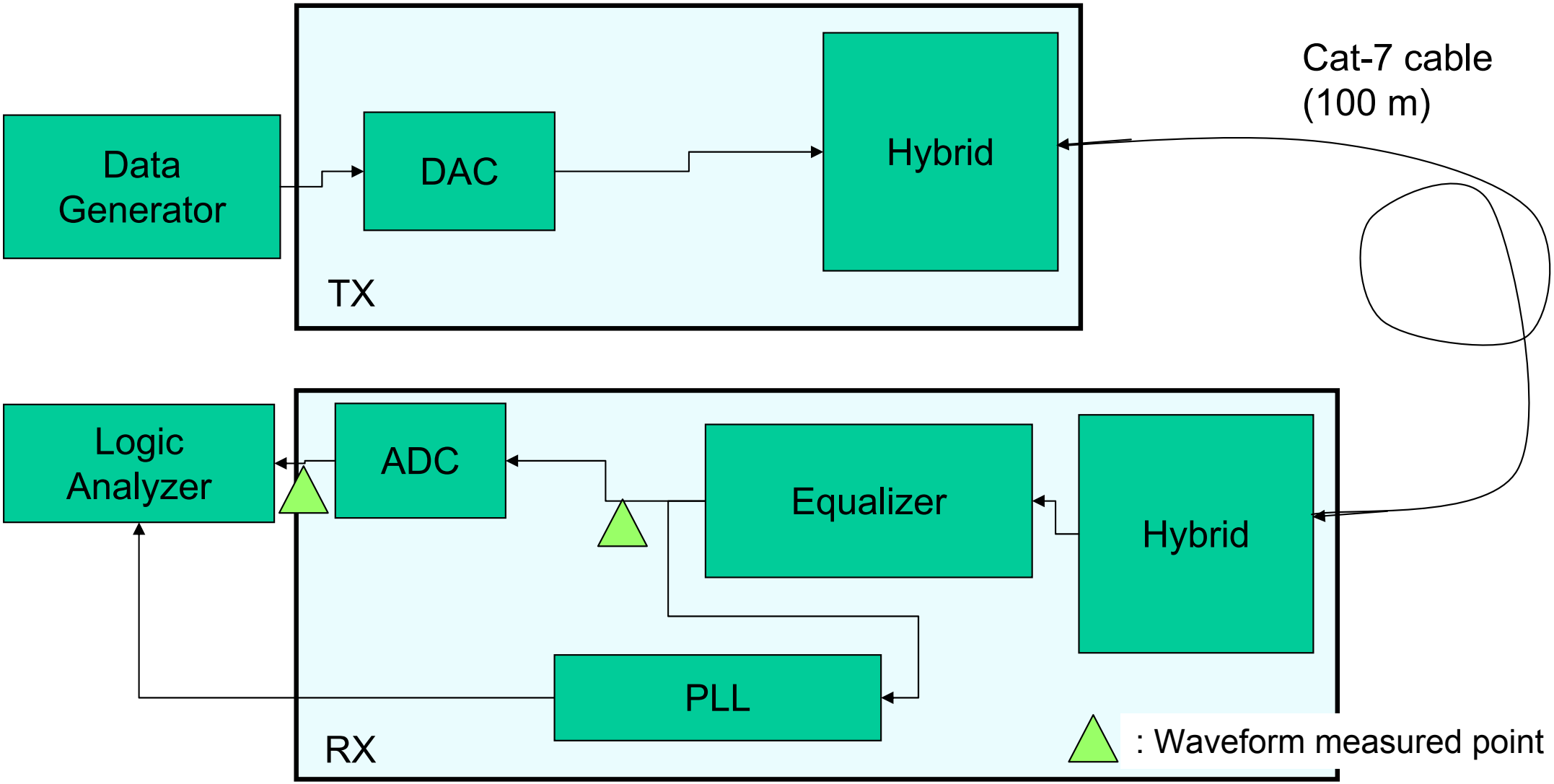
⇒ Low Latency

2. Advantages of OFDM Method

- OFDM achieves high spectral efficiency
  - Required bandwidth is 547 MHz + pilot signal
- Slow symbol rate: 156.25 MHz
  - Inter-symbol interference is small
- Large noise margin: 6.1dB (with 6-dB coding gain)
- Latency: < 100 ns
- Add-on available: PAM-20,10,5, and 4D-PAM8

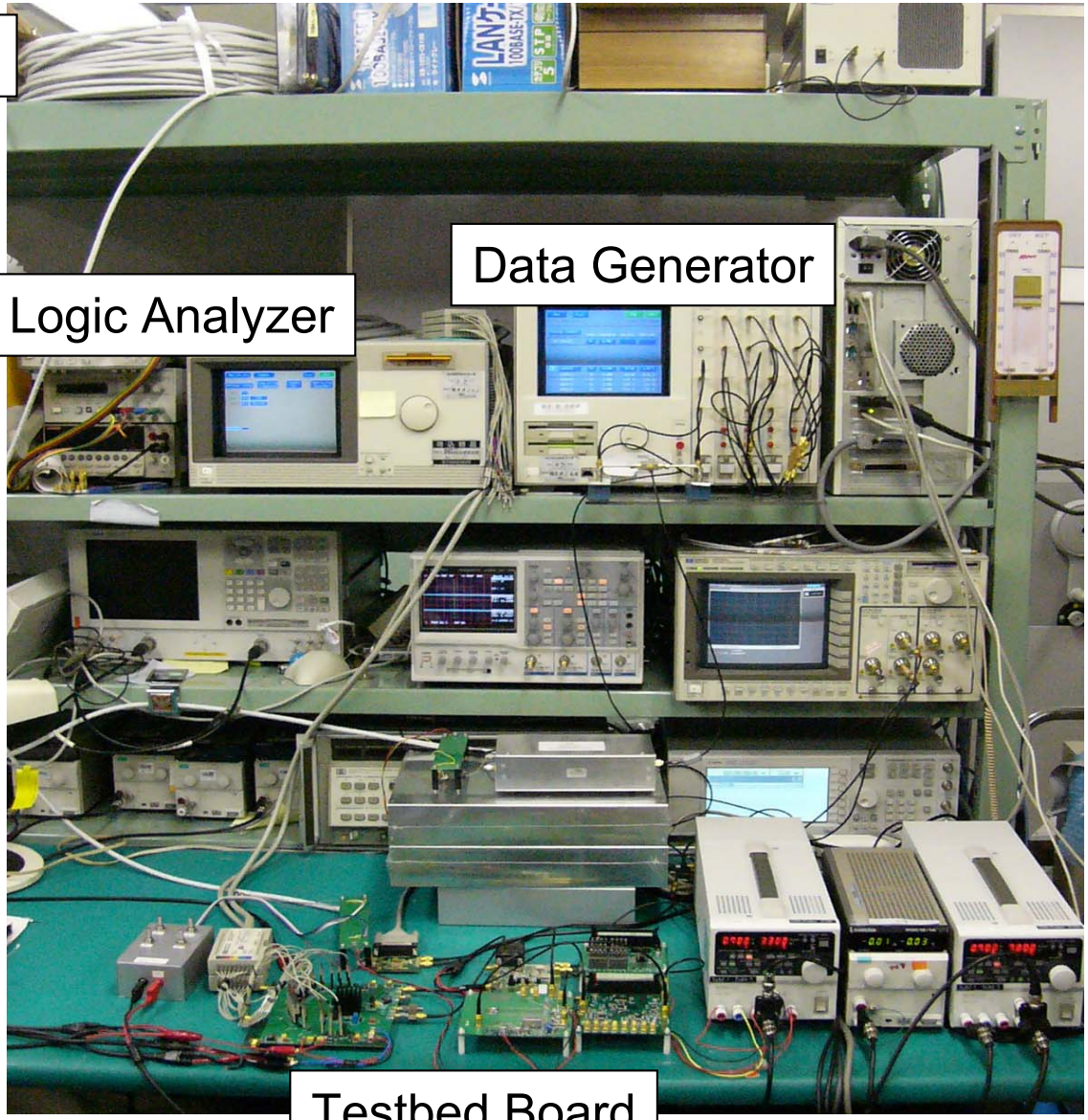
3. Experimental Setup (1)

- 1-symbol and 1-channel data transmission

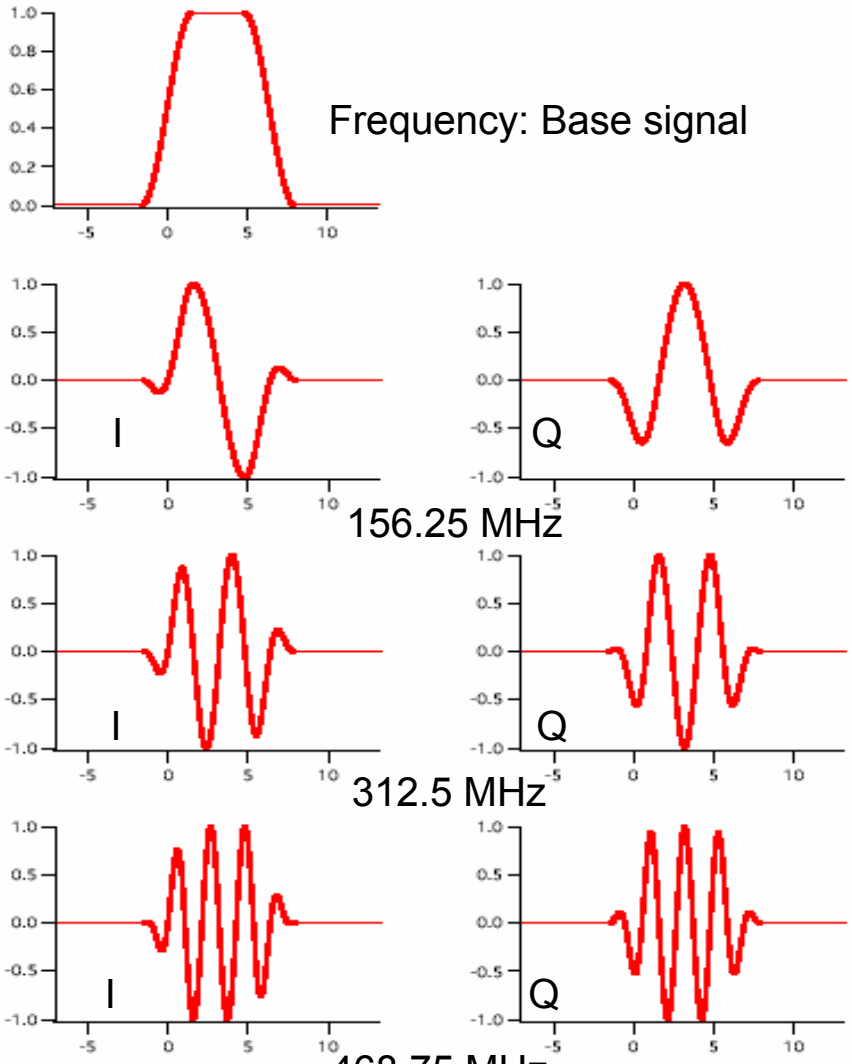


3. Experimental Setup (2)

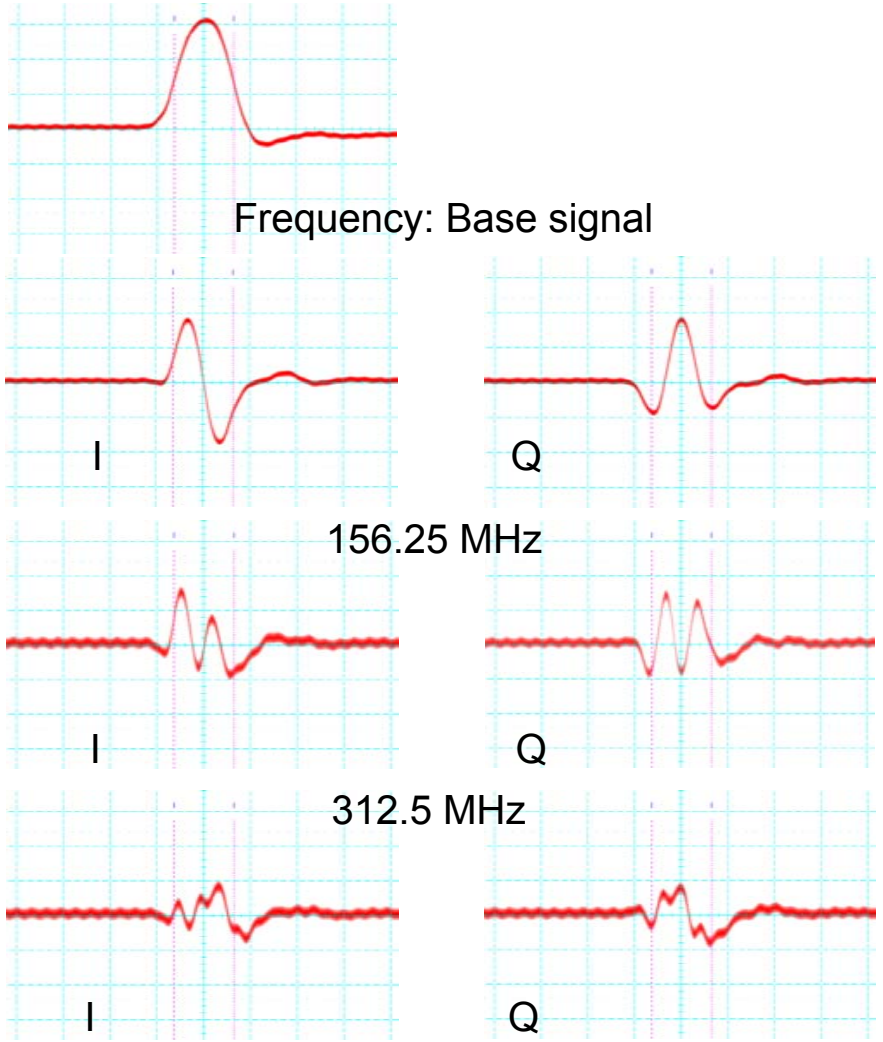
CAT-7 Cable (100 m)



3. Experimental Results (Waveform)



TX side

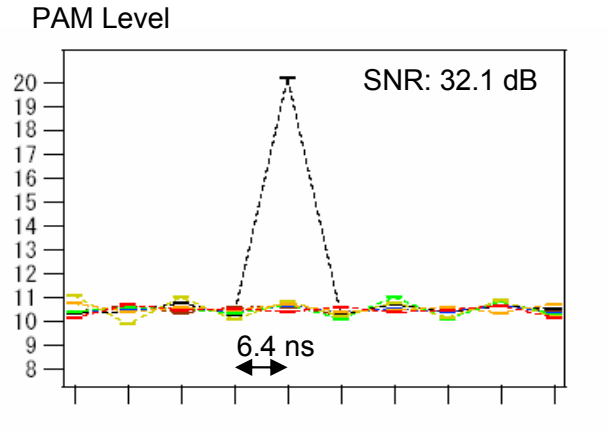


RX side

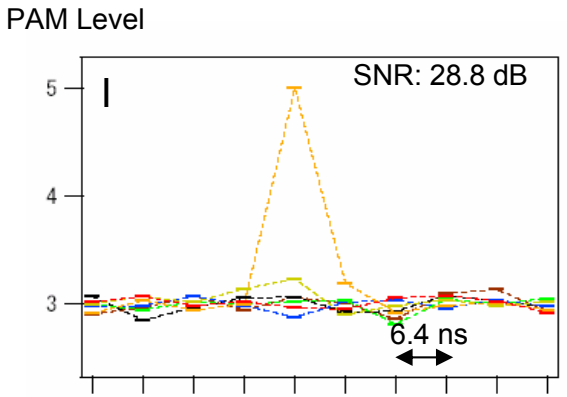
Clock jitter: < 20 ps (RMS)

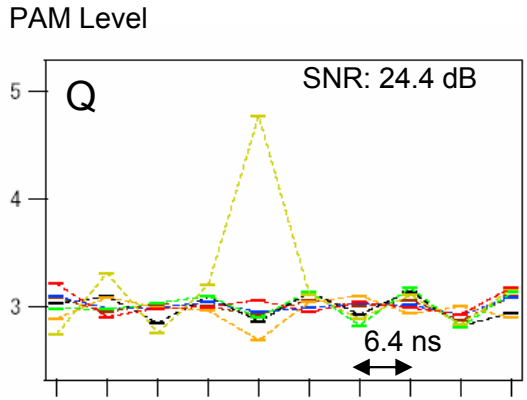
3. Experimental Results (DSP)

- Inter-symbol interference is canceled
- SNR is measured

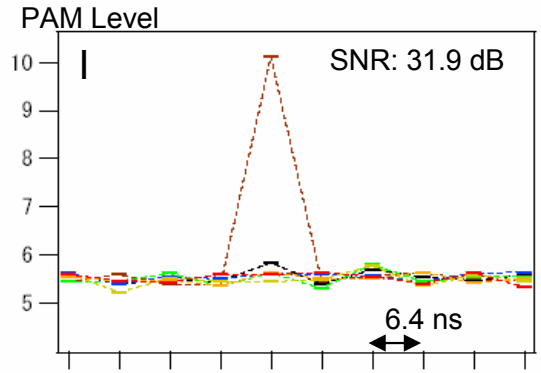


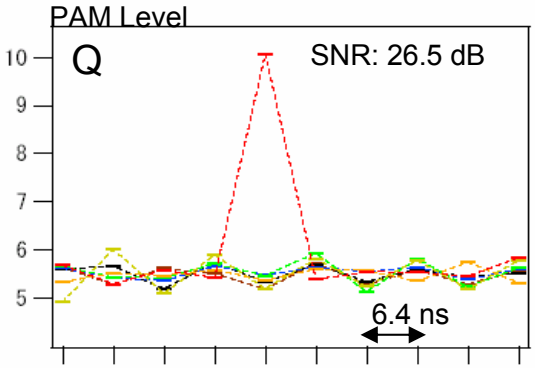
Frequency: Base signal



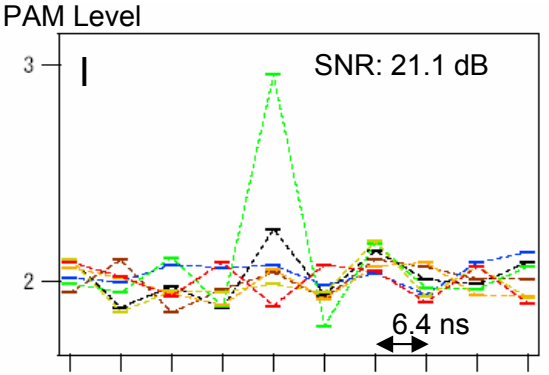


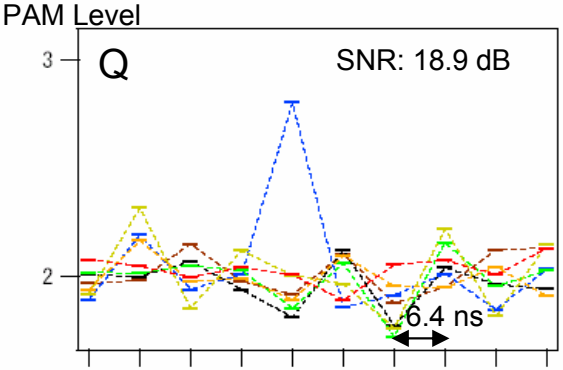
312.5 MHz





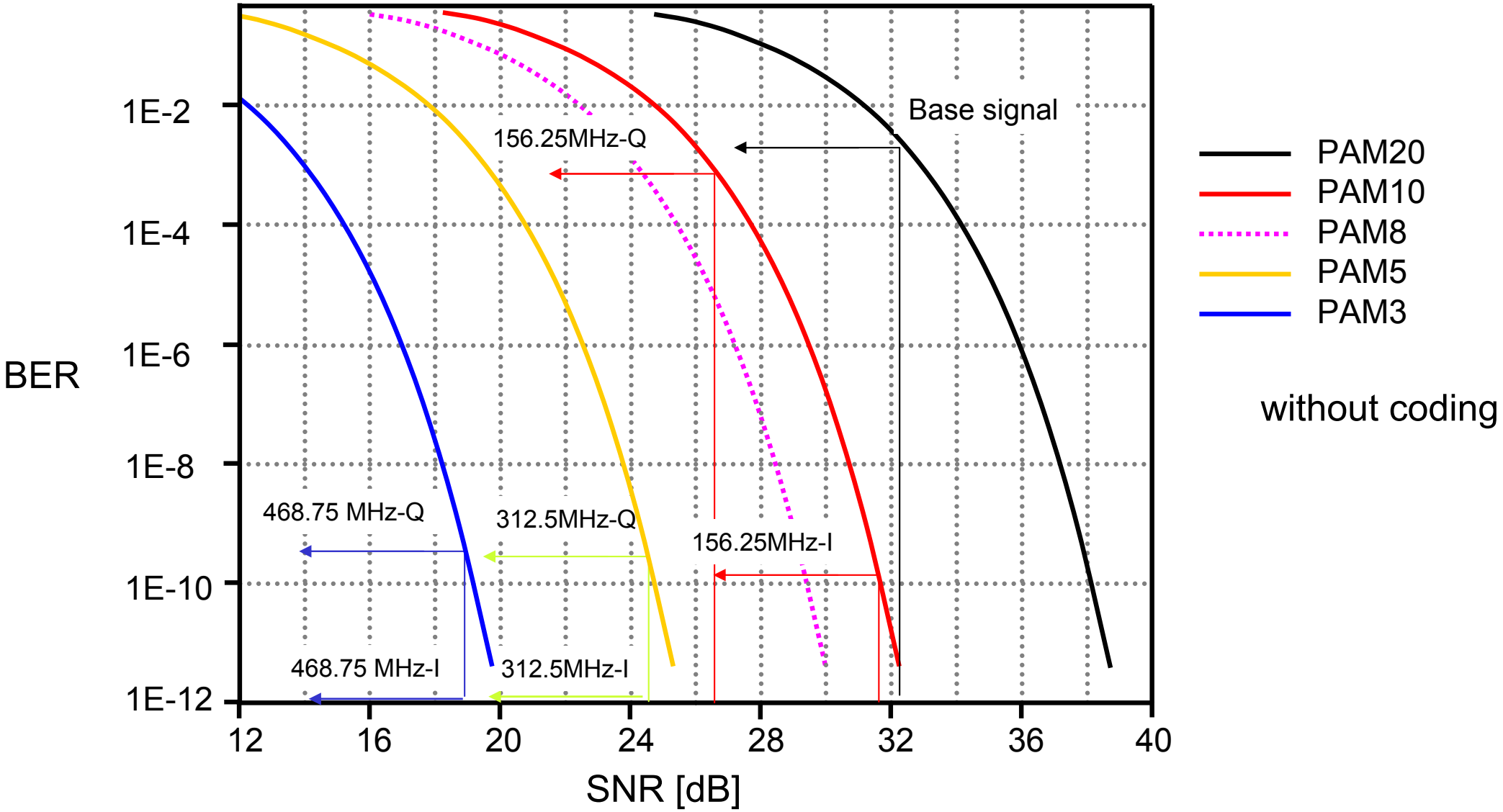
156.25 MHz





468.75 MHz

3. BER Estimation (1)

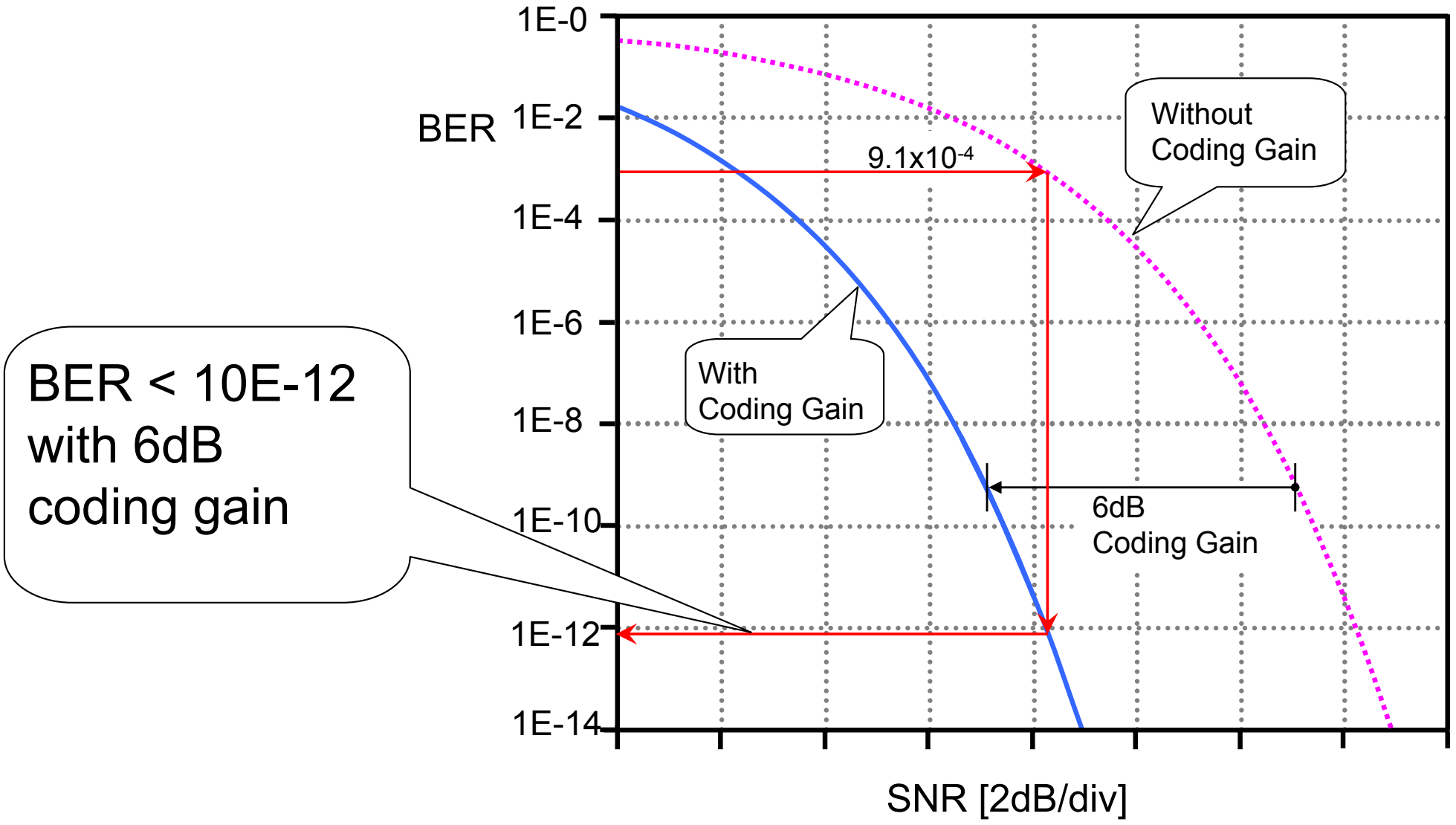


3. BER Estimation (2)

Carrier Frequency (MHz)	Base Signal	156.25 I-phase	156.25 Q-phase	312.5 I-phase	312.5 Q-phase	468.75 I-phase	468.75 Q-phase
PAM Level	20	10	10	5	5	3	3
Assigned Number of bit	4	3	3	2	2	1	1
SNR (dB)	32.09	31.85	26.46	28.81	24.38	21.08	18.89
BER without coding	3.0E-3	2.1E-11	8.5E-4	< 1E-12	2.4E-10	< 1E-12	1.2E-11

Averaged BER without coding: 9.1E-4

3. BER Estimation (3)



Conclusion

- OFDM method applied to 10GBASE-T
  - Required bandwidth: 547 MHz + pilot signal
  - Noise margin: 6.1 dB (with coding gain)
  - Low latency: < 100 ns
- Experimental result
  - 100-m data transmission with BER of < 1E-12