10GBASE-T Signaling

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Line Signaling Requirements

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- Meet 10 Gb/s over a UTP CAT5e/6 channel with BER=10^{-10}
- Backward compatible with 1000BASE-T
  - Launch voltage of 2 V_{pp}
  - Base-band signaling (no modulation)
  - Scrambling used to spread the TX spectrum
- Meet the EMI specification for emitted power (FCC Class A)

PAM signal requirement at BER = 10^{-10}

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M	bits/Baud	Signal bandwidth (MHz)	Baud rate (MS/s)	Detection SNR (dB)
3	1	1250	2500	21.01
5	2	625	1250	25.43
9	3	416	833	30.52
17	4	312.5	625	36.02
33	5	156.25	312.5	41.77

$$\mathbf{SNR = 6\log_2(M) + Gap - Coding\_Gain + Margin}$$

Gap = 11.5dB   Coding_Gain = 6dB   Margin = 6dB

Spectrum of various Line Coding

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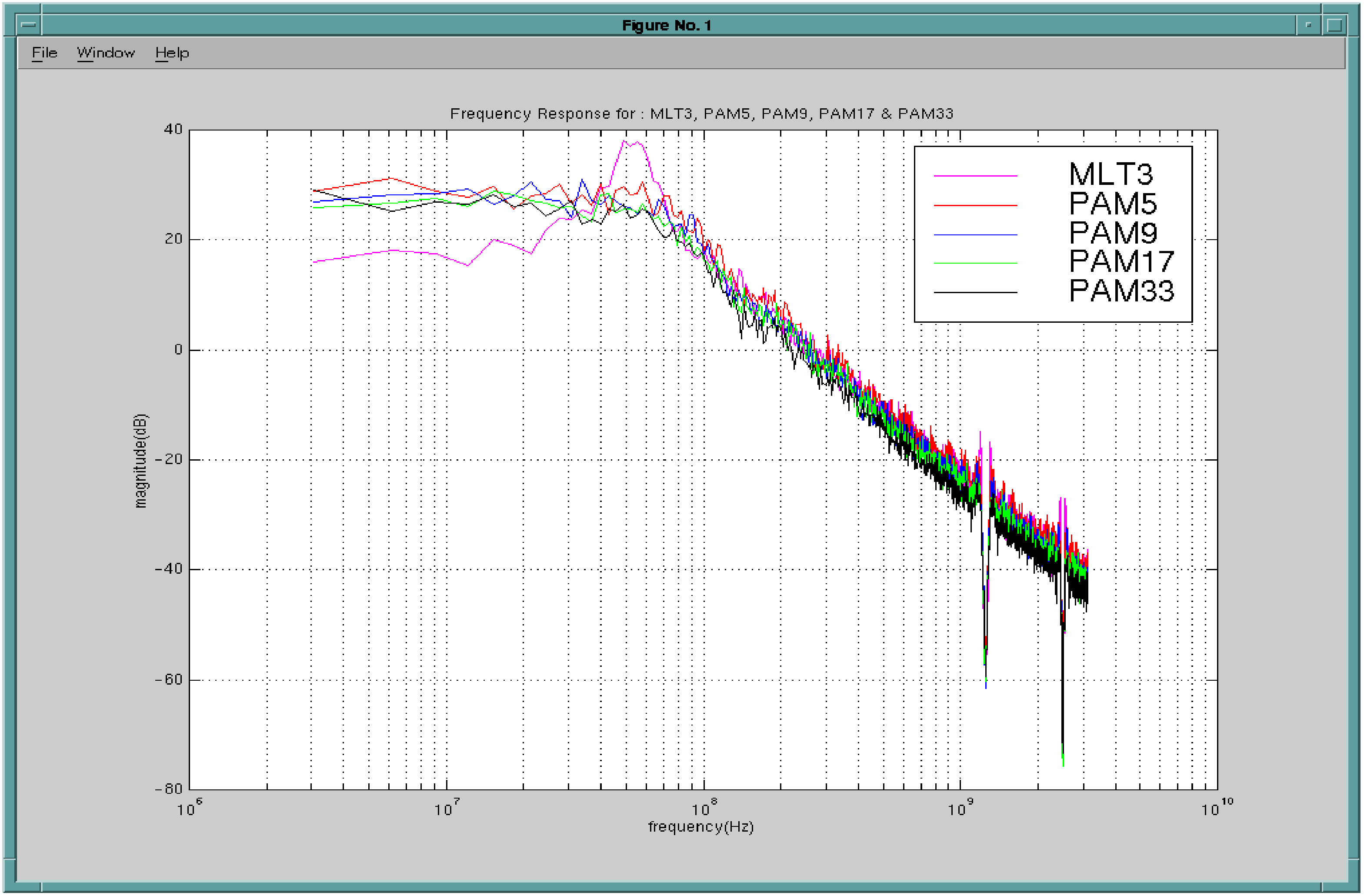

1st Notch Details (f_{notch}= 1.25GHz)

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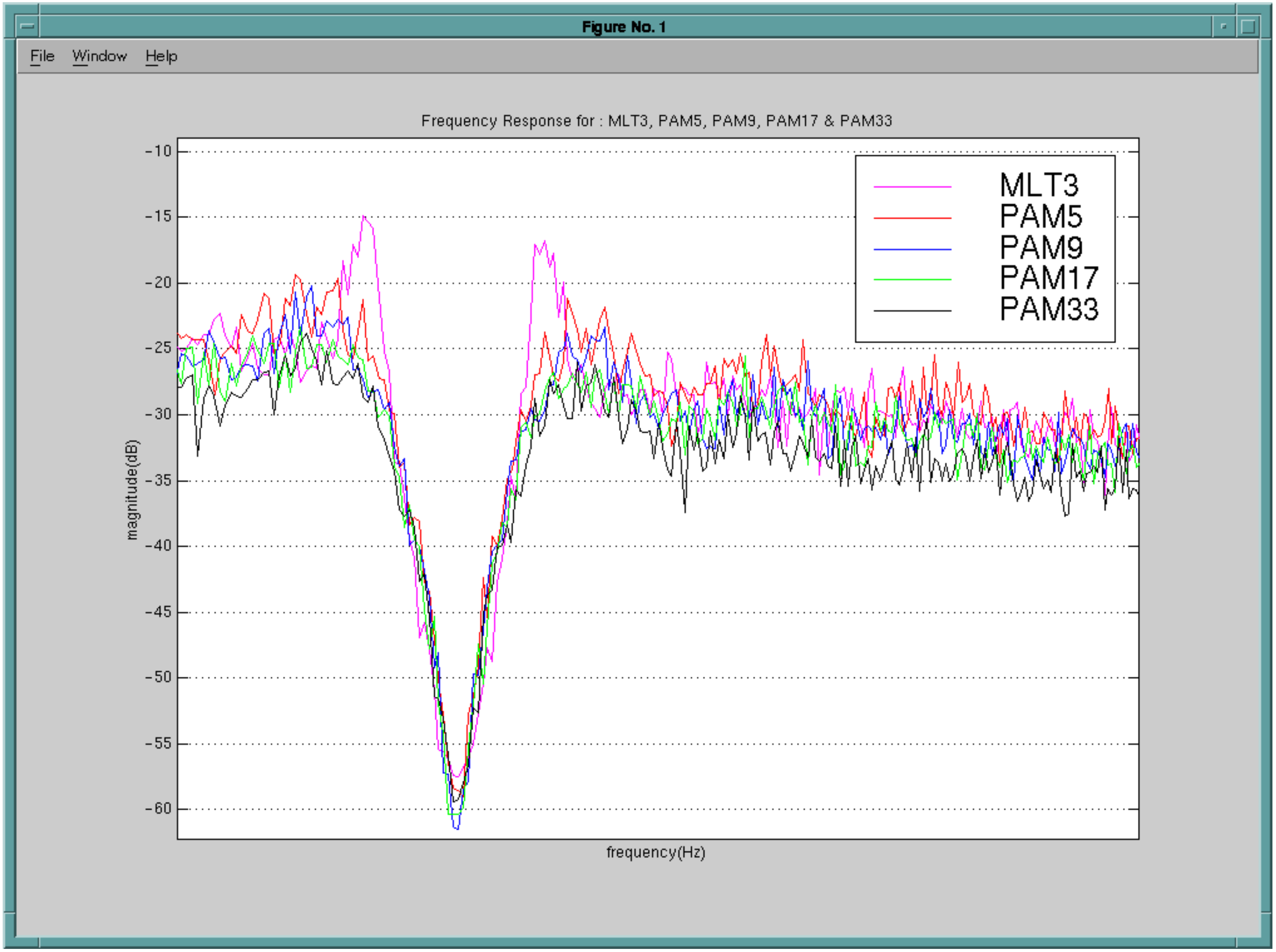

Line Signaling Conclusions

- **MLT3 line-signal (used in 100BASE-T) causes considerable peaking around the pass-band and the notches**
- **PAM5 to PAM33 line-signal frequency spectrums are very similar**
- **PAM5 requires the lowest detection SNR**
- **PAM5 line-signal has been used before (100BASE-T2 & 1000BASE-T)**
- **PAM5 allows line-signal's baud-rate to be a multiple of XGMII's baud-rate (not true of PAM9 & PAM33)**

Channel Impairments (CAT6) (Chris DiMinico)

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- Cable Attenuation (Insertion loss)

$$Attenuation(f) \approx 1.9015\sqrt{f} + 0.0227f + 0.1212 / \sqrt{f} \quad \text{(dB)}$$

- NEXT Loss

$$NEXT(f) \approx 65.0 - 16.7 \log(f / 3.141) \quad \text{(dB)}$$

- FEXT Loss

$$ELFEXT(f) \approx 61.3 - 20\log(f / 1.259) \quad \text{(dB)}$$

- Return Loss

$$RL(f) \approx 19.0 - 10\log(f/20) \quad \text{(dB)}$$

- Noise

$$-140 \quad \text{(dBm/Hz)}$$

Impairments Before Cancellation

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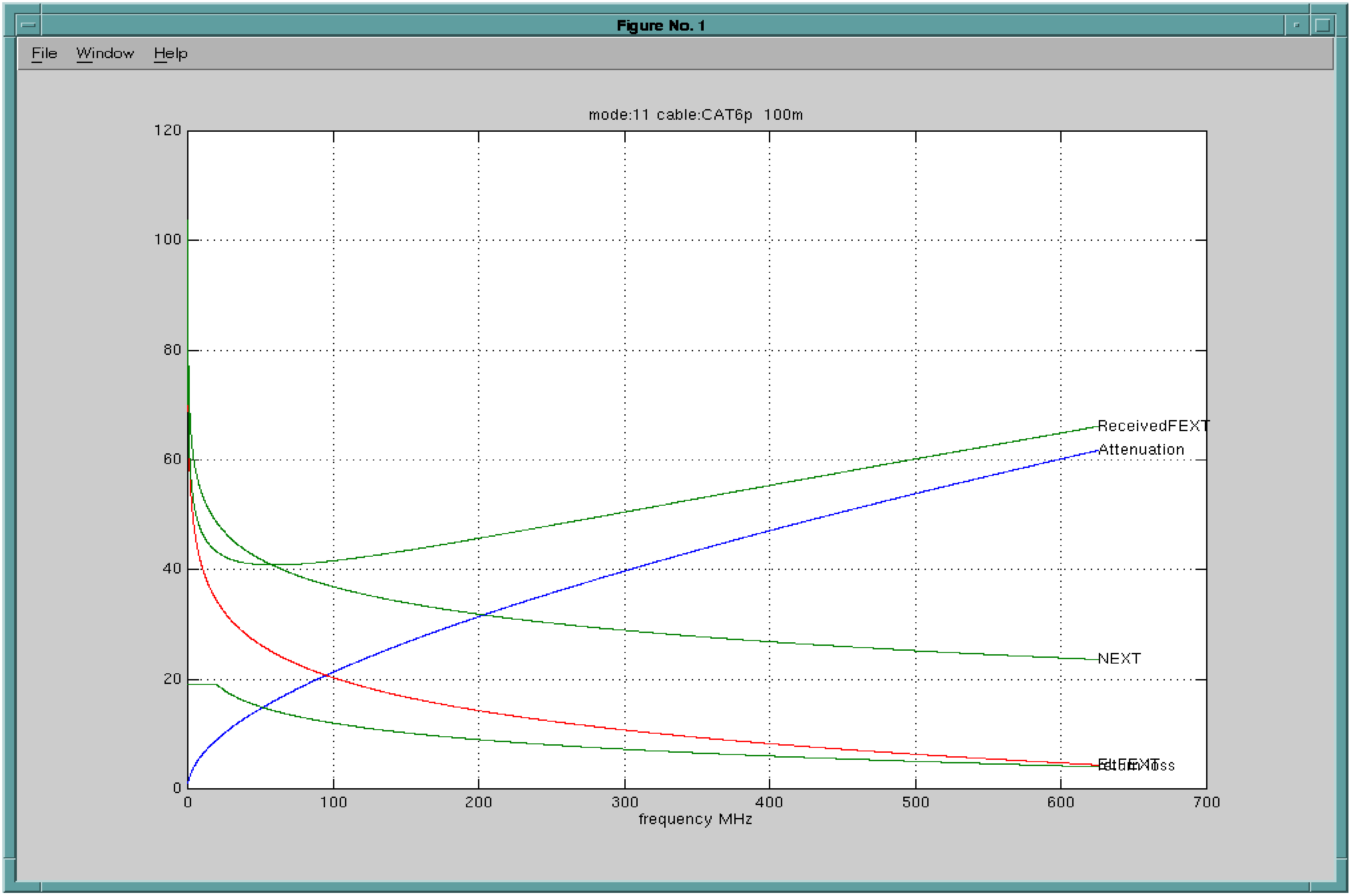

DSP Approach

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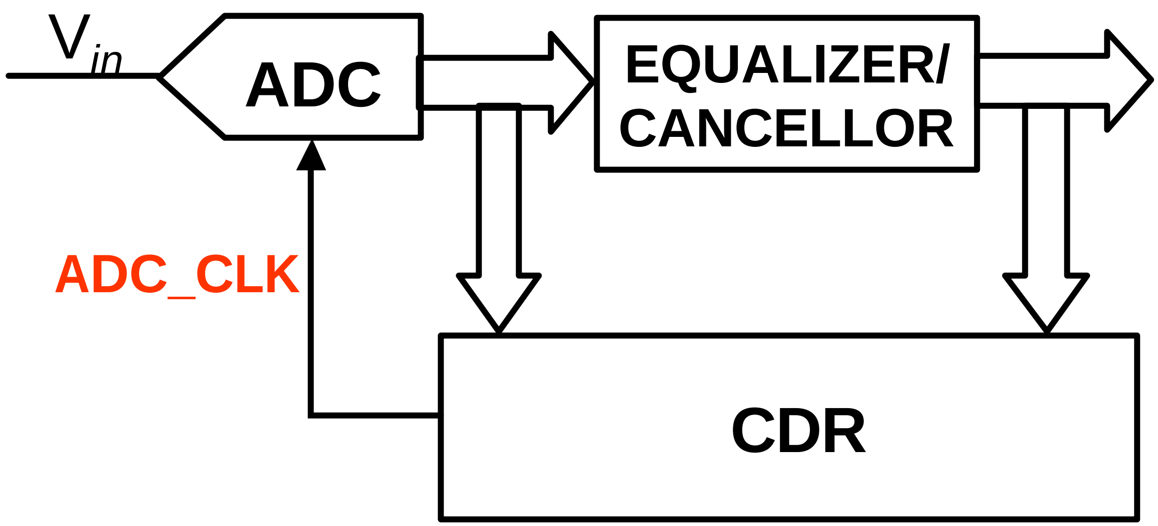

Required Impairment Cancellation (DSP Approach with the lowest ENOB)

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Reach (m)	ECHO Cancellation (dB)	NEXT Cancellation (dB)	FEXT Cancellation (dB)	ADC ENOB (bit)
25	27	16	16	5
50	35	23	20	7
65 (VSR)	44	30	26	7
75	46	30	25	8
100	70	60	50	11

ENOB with ADC_CLK jitter

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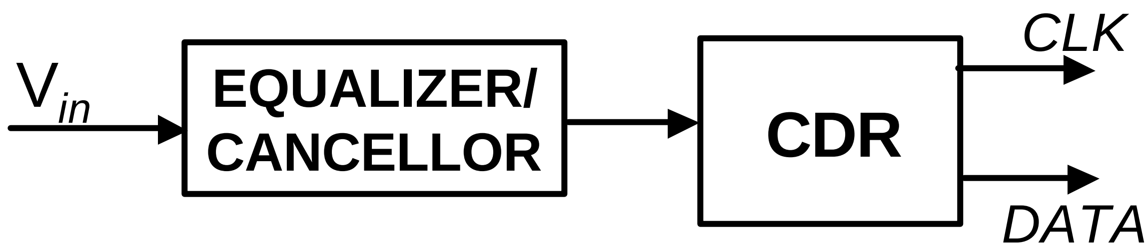
	J_{rms}=0.1ps	J_{rms}=0.3ps	J_{rms}=1ps	J_{rms}=3ps	J_{rms}=10ps
n=5	4.99	4.99	4.96	4.68	3.56
n=6	5.99	5.98	5.84	5.14	3.64
n=7	6.99	6.94	6.50	5.33	3.66
n=8	7.97	7.78	6.83	5.39	3.67
n=9	8.89	8.35	6.95	5.40	3.67
n=10	9.64	8.62	6.98	5.41	3.67
n=11	10.08	8.70	6.99	5.41	3.67
n=12	10.25	8.72	6.99	5.41	3.67

$$J_{rms} < 1 / (4p\ f_{max}\ 2^{ENOB})$$

Analog Approach



Required Impairment Cancellation

Reach (m)	ECHO Cancellation (dB)	NEXT Cancellation (dB)	FEXT Cancellation (dB)
25	25	13	13
50	34	20	20
65 (VSR)	40	23	21
75	44	26	23
100	65	50	50

Industry Offerings

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- National Semi. (ADC10D040)
  - 10 Bit, 40 MSPS, Nyquist, ENOB = 9.4 Bit, jitter < 10 ps (rms)
- National Semi. (ADC08200)
  - 8 Bit, 200 MSPS, Input BW = 50 MHz, ENOB = 7.3 Bit, jitter < 2 ps (rms)
- ADI (AD9071)
  - 10 Bit, 100 MSPS, Nyquist, ENOB = 8.7 Bit, jitter < 3 ps (rms)

Impairments After Cancellation

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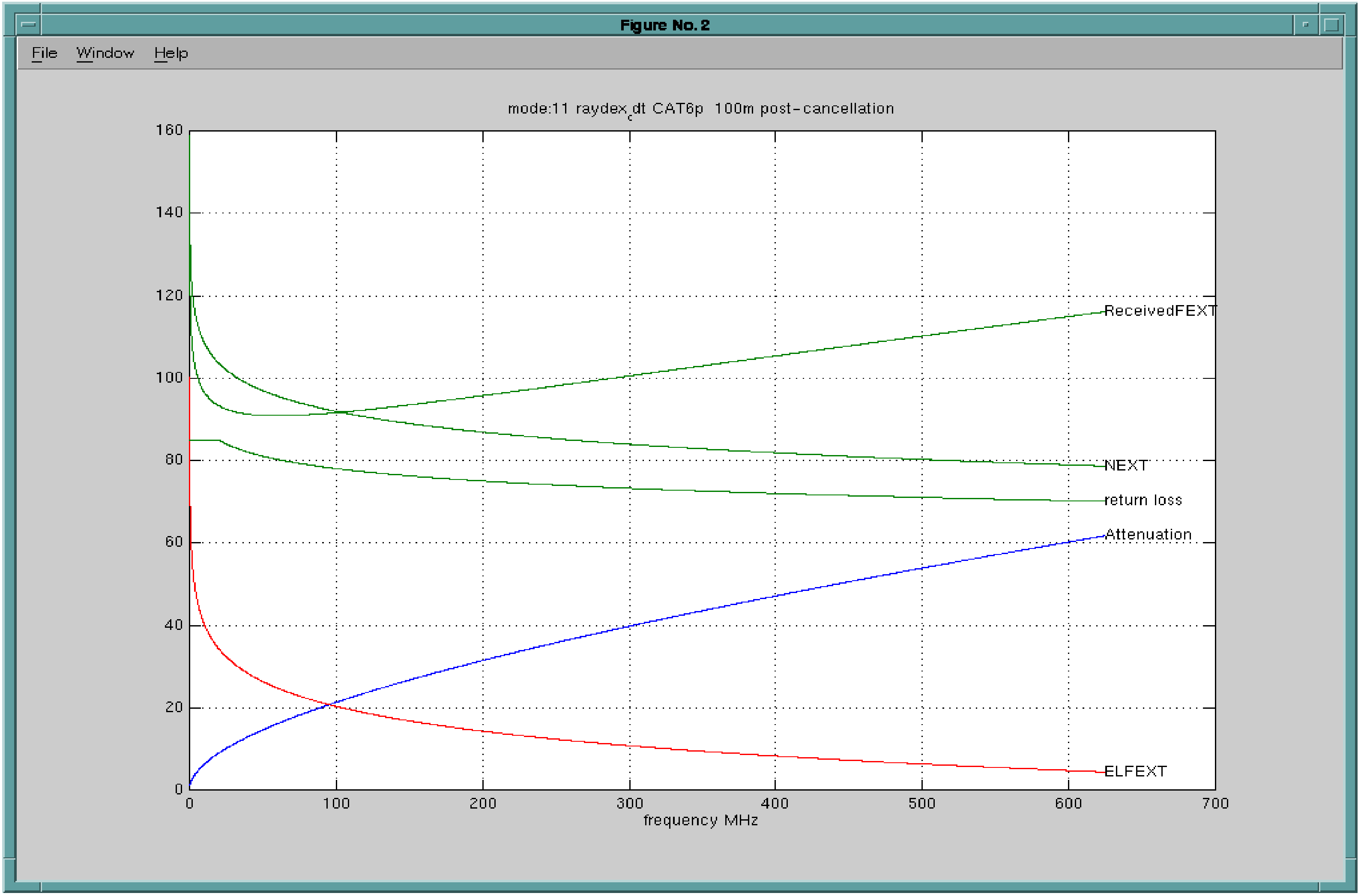

PMA Architecture

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- DFE-based implementation
- Utilize analog FIR adaptive filters to solve the ADC bottleneck
- Master/Slave training for all the cancellers
- Separate cancellers for each impairment
- Architecture similar to 1000BASE-T plus FEXT canceller running at 10X

10GBASE-T Possible Architecture

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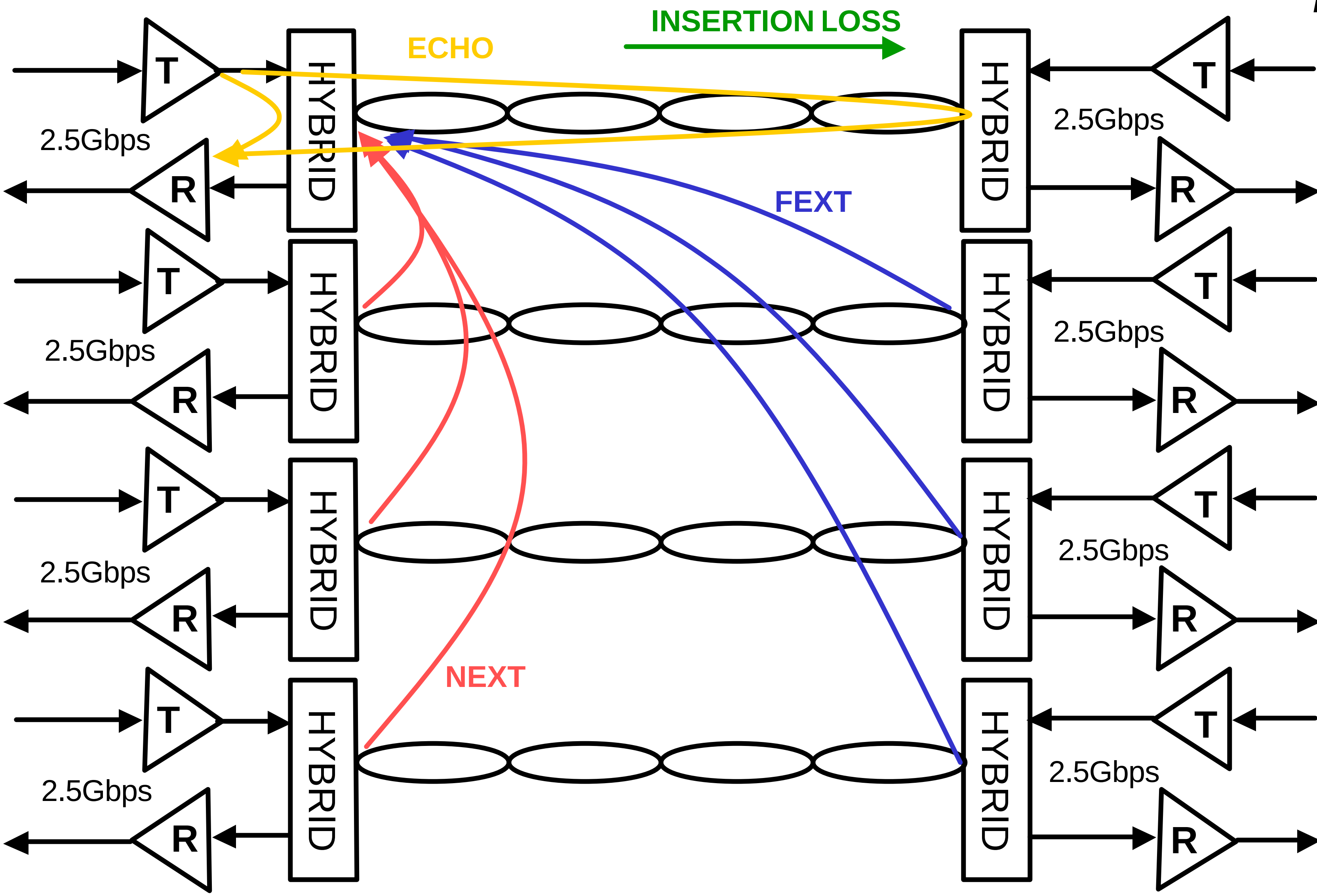

Prior Art High Speed Analog Signal Processing

- **Prior art analog signal processing achieves more than 40dB of high frequency signal restoration/cancellation [1]-[3]**

1. MAX 3802 MAXIM's 3.2 Gbps Quad Adaptive Cable Equalizer with Cable Driver
2. M.H. Shakiba, "A 2.5 Gb/s adaptive cable equalizer", *IEEE ISSCC* pg. 396-397, Feb. 1999
3. A. Baker, "An adaptive cable equalizer for serial digital video rates to 400Mb/s", *IEEE ISSCC* pg. 174-175, Feb. 1996