Gigabit Ethernet UTP-5 PHY

PMC-Sierra, Inc.

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PMC-Sierra, Inc.

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Proposed Gigabit Ethernet PHY

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- **Gigabit Ethernet PHY interface;**
  - ***50 m* short-haul - Full Duplex UTP-5, 4-pair interface**
    - » **one device, roadmap to 100 m**
  - ***100 m* intermediate - Full Duplex UTP-5, 8-pair interface**
    - » **two devices plus GMII mux logic, roadmap to 200 m**
- **Basic Elements:**
  - **Gigabit MII between MAC and PHY (G-MII - 'jimmy')**
  - **Pair division multiplexing**
  - **4 Level Line encoding**
  - **Zero state frame delineation (4LZS)**
  - **Data Scrambling for spectrum management**
  - **Clock and data recovery**
  - **Bit and word synchronization**
- **Continuous time analog, based on existing technology**

4 Pair vs. 8 Pair

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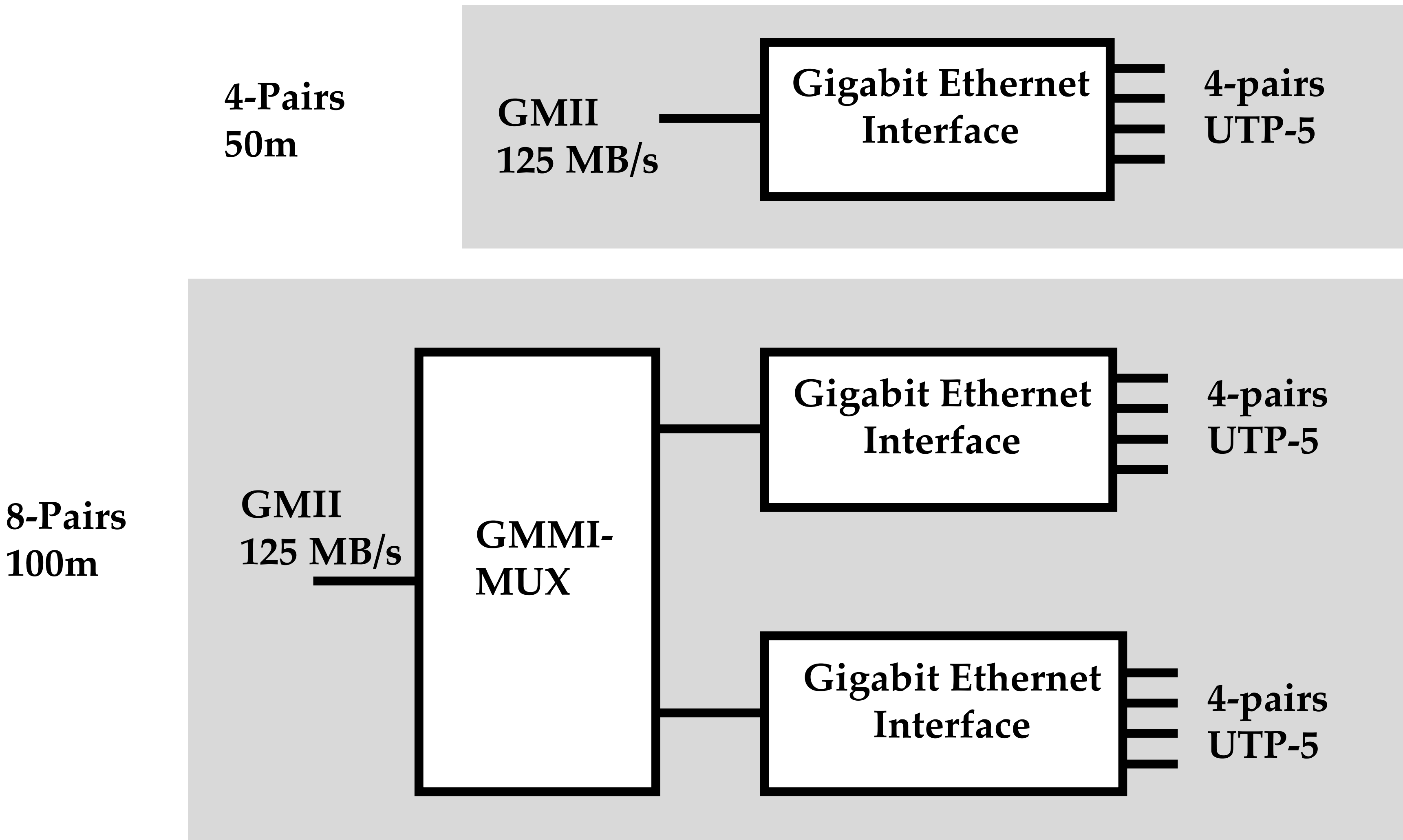

4-Level Code

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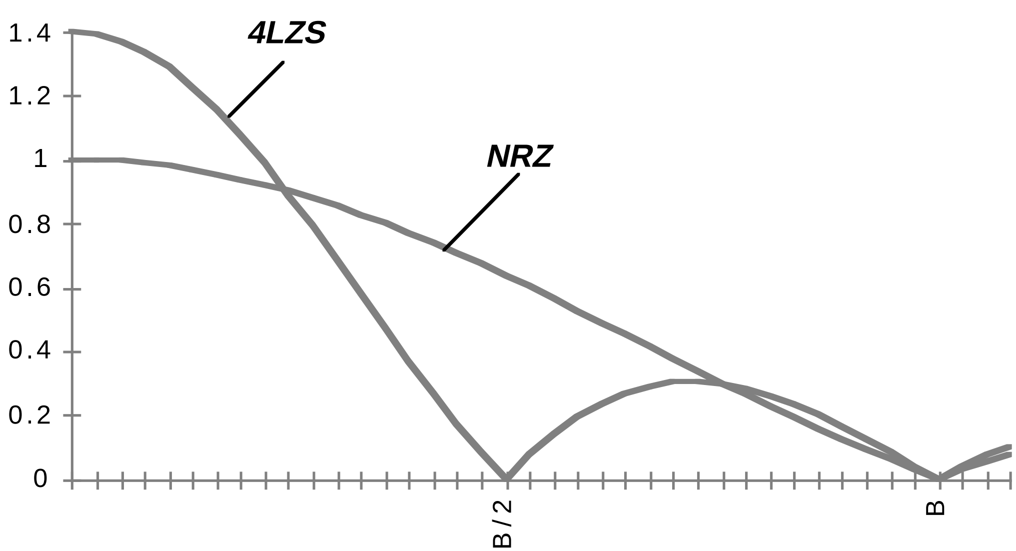
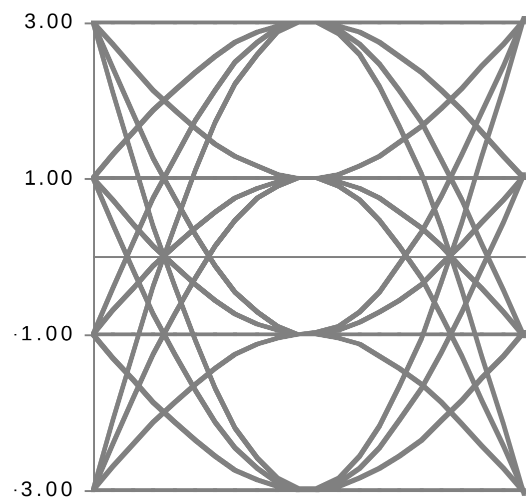
- When coding n bits per pulse, for a bit rate of B, the pulse (symbol) rate is B/n
- 4 Level gives 2 bits per symbol
  - 500 Mbits transmits in 250 Mbaud
- One dimensional code - one degree of complexity

NRZ vs. 4LZS Spectrum at bit rate 'B'



4 Level Eye



Quaternary Slicer SNR

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- **Intrinsic coding power density at slicer is the *symbol variance***
- $\mathbf{SNR = \sigma^2_s / \sigma^2_n \; ; \; \Delta SNR = \sigma^2_{s2B1Q} / \sigma^2_{sNRZ}}$
- $\mathbf{\sigma^2_s = {}^1/_{Lc} \sum_i \langle e_i^2 \rangle}$
- $\mathbf{\sigma^2_{s2B1Q} = {}^1/_4\{(-3)^2+(-1)^2+(1)^2+(3)^2\} = 5}$
- $\mathbf{\sigma^2_{sNRZ} = {}^1/_2\{(-1)^2+(1)^2\} = 1}$
- $\mathbf{\Delta SNR = \sigma^2_{s2B1Q} / \sigma^2_{sNRZ} = 10 \log(5/1) =}$ ***7 dB***

4 levels require 7dB higher SNR than does NRZ for same distance & same symbol rate

Relative Noise Immunity

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- **Flat channel noise power is proportional to the symbol rate [1/T]**
  - $\Delta\sigma_{nflat} = -10 \log [T_{2B1Q}/T_{NRZ}]$
    $= 2$ dB @ 250 Mbaud vs. 155 Mbit NRZ

- **Self-NEXT noise power is proportional to the cubed square root of the symbol rate $[T]^{3/2}$**
  - $\Delta\sigma_{nsnext} = -15 \log [T_{2B1Q}/T_{NRZ}]$
    $= 3$ dB @ 250 Mbaud vs. 155 Mbit NRZ

- **Pair-pair NEXT noise power is frequency and cable geometry dependent**
  - $N(f) = \chi f^{3/2} G(f)$; $\chi = 6.31 \times 10^{-7}$ for Category 5
    $= 3$ dB @ 250 Mbaud 2B1Q vs. 155 Mbit NRZ

PHY Comparisons

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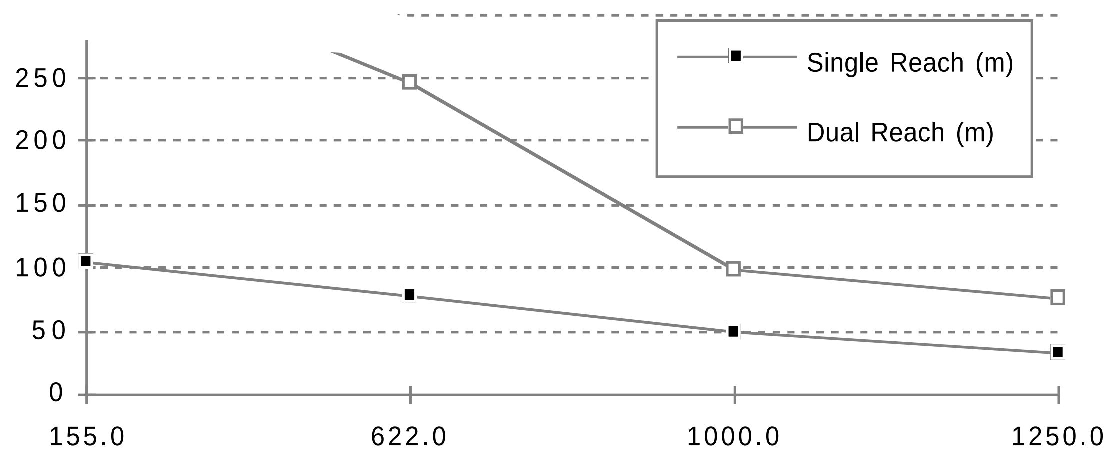
Capacity (Mb/s)	Reach (m)	Reach (m)		Coding Technique
155.0	105		*	NRZ 155 UT
622.0	77	245		4LZS 622 U
1000.0	**50**	**99**		**4LZS 100**
1250.0	33	76		8B10B 100



Reach is more sensitive to symbol period than multi-level code

Modelled Eye Diagram: 20m UTP-5

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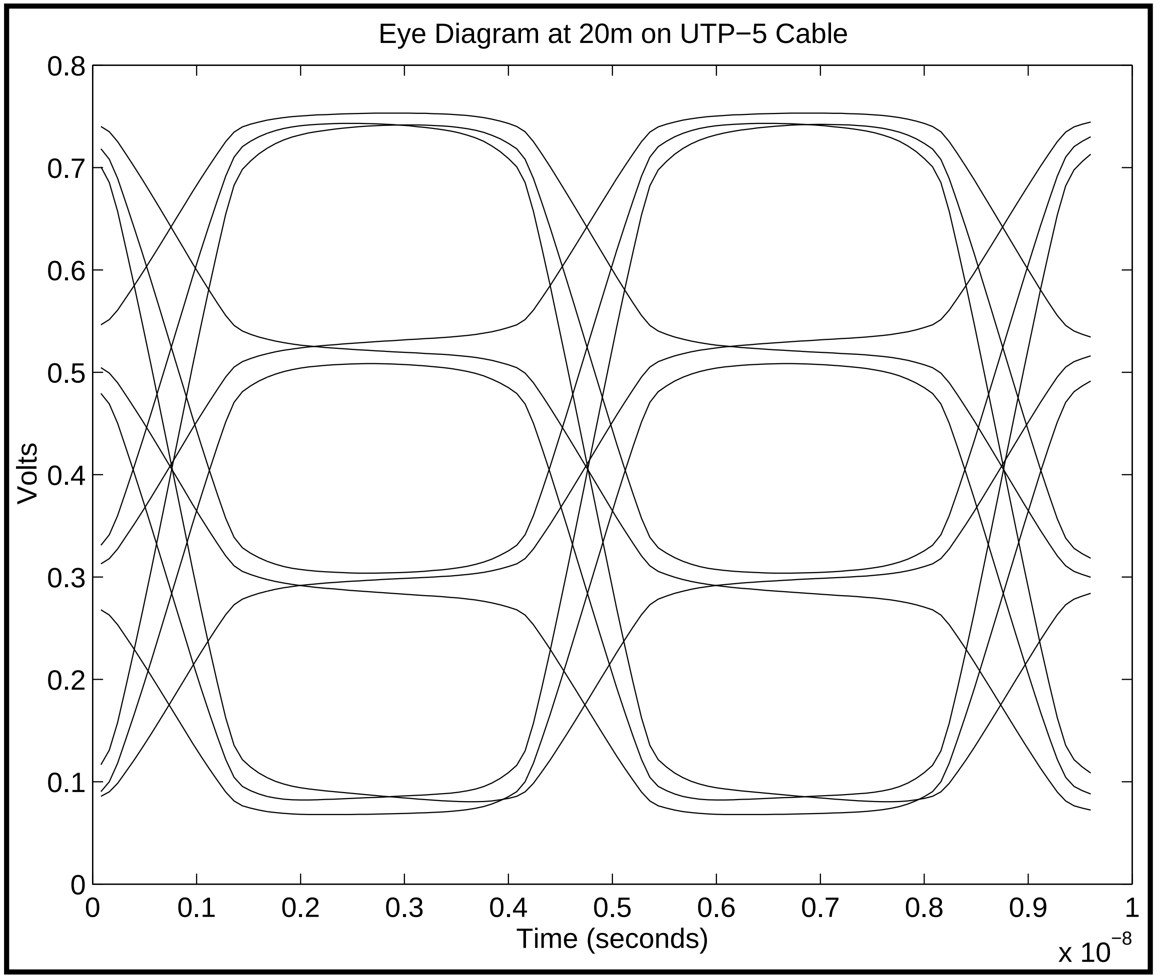
- **Unequalized Eye is open at 20m**
- **Simple equalization will allow operation to 50m**



Modelled Eye Diagram: 20m & Magnetics

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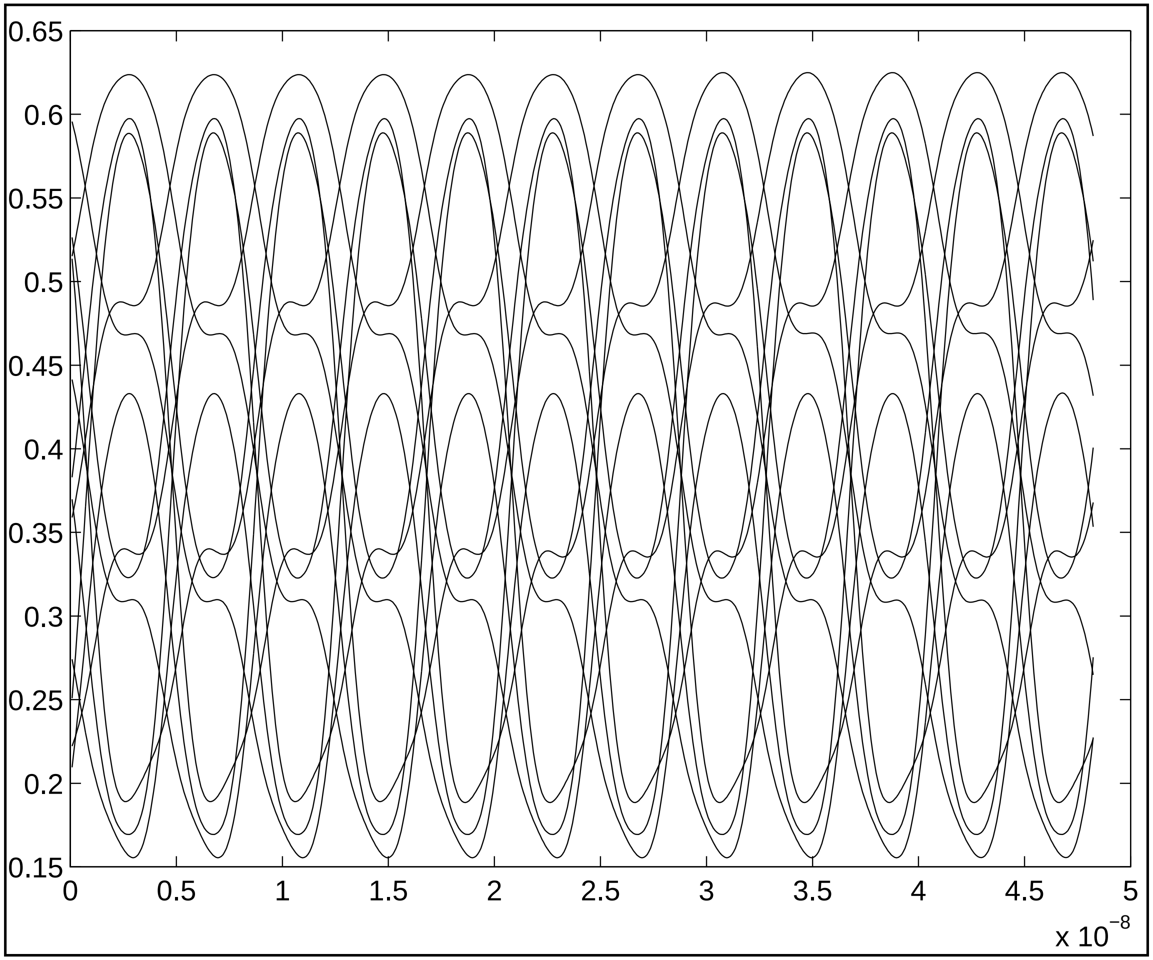
- Significant difference in eye opening
- Modelled with 266 F/C magnetics
- Lab work with Pulse PE65508 shows promise



Experimental Eye Diagram: 20m UTP-5

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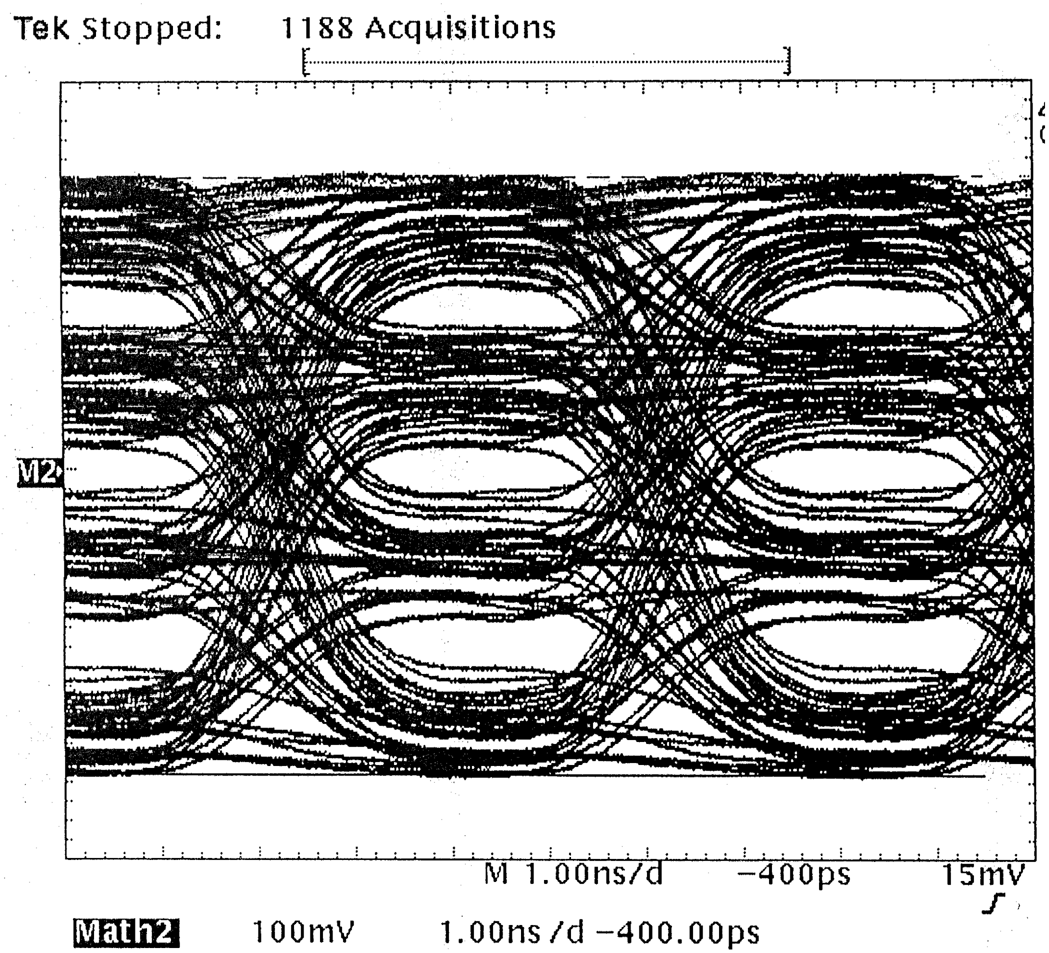
- Unequalized Eye at end of cable
- 20 meters Belden "DataTwist-5" 1583B cable
- 2x3 meter AMP "Netconnect" patch cords
- PRBS 2^{7}-1



Experimental Eye Diagram: 26m UTP-5

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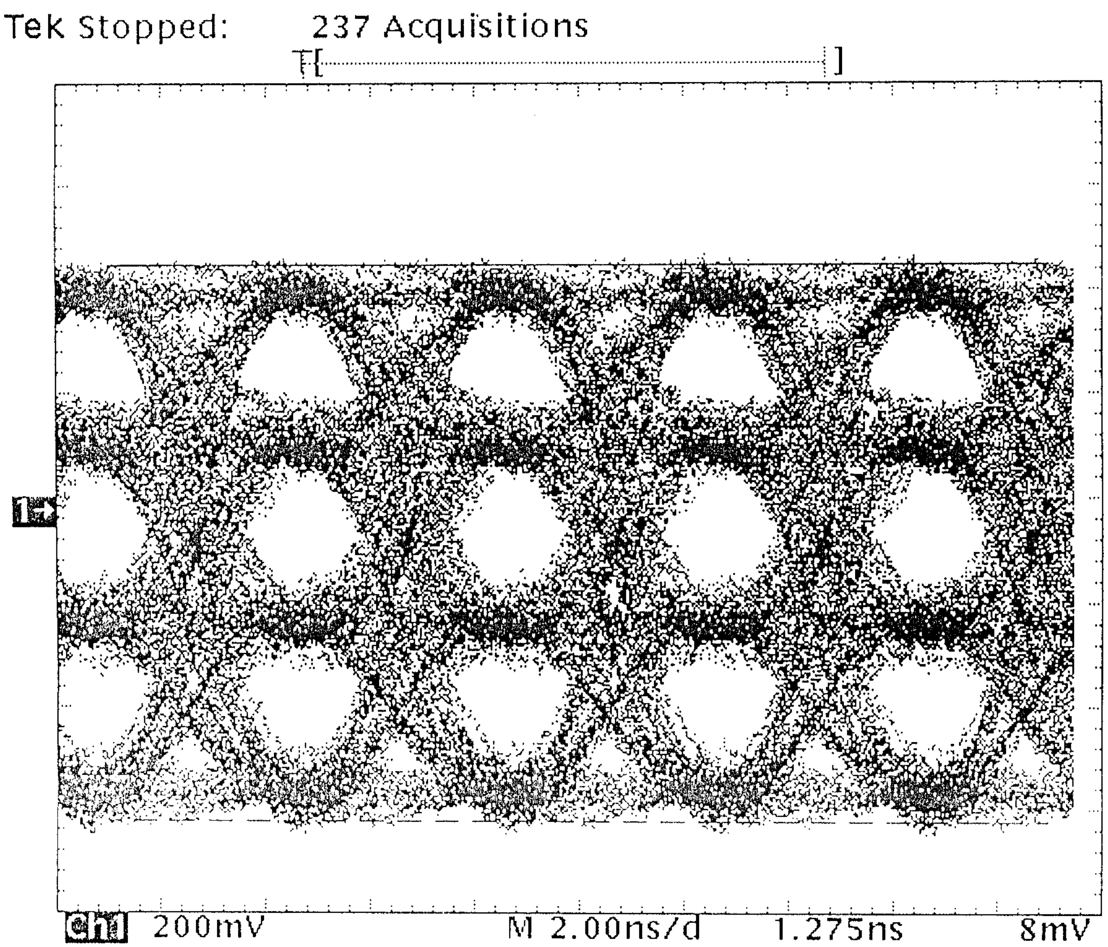
- Unequalized Eye after Rx buffer
- 26 meters AT&T "SystiMax" 1061A cable
- 2x3 meter AMP "Netconnect" patch cords
- PRBS 2^7-1
- Zero Bit Errors on 15 minute intervals (10^{-7})



Spectrum Management

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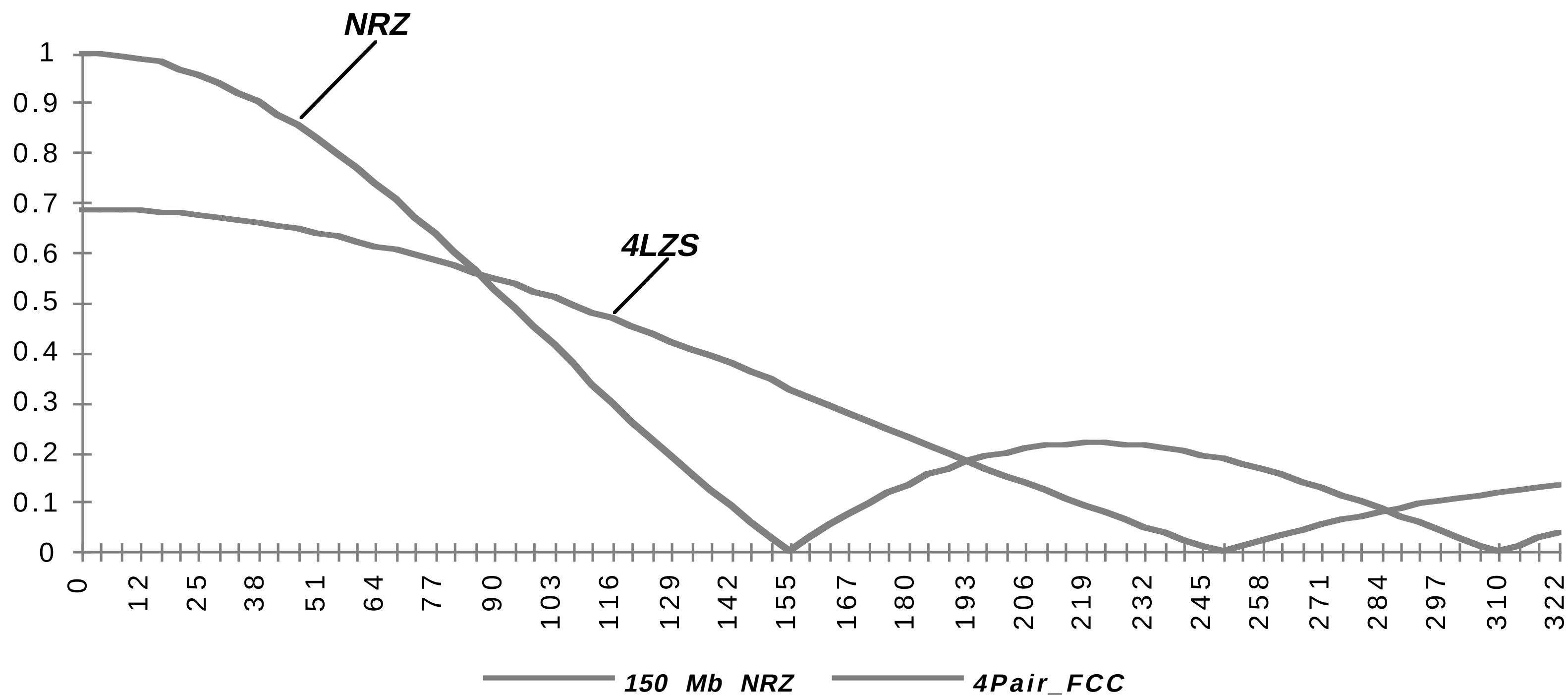
- For a similar launch *level* 4LZS engery is spread over a wider area Hence, lower energy at individual spectral lines
- Use of a scrambler spreads the energy across the spectrum, reducing the energy for radiation at a spectral line.



Frame Handling

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- Bytes from GMII word byte mutliplexed on different pairs
- IDLE pattern maintains bit and word synch
- IDLE to PREAMBLE code delimits start of frame
- Zero State signalling delimits end of frame
  – EOF turns off transmitter for one byte (4 quats)
  – Receiver requires quiescent detection comparators and digital decoding
- IDLE codes could be used to indicate ESCAPE's
  – eg. IDLE defined over 3 quats with 4th used for codes
- IPG used for IDLE codes and Zero State
  – minimum IPG > 96 bits = 12 bytes
  – in 8 pair system - 3 bytes per Tx pair - 1 ZS & 2 IPG Bytes

Gigabit Media Independent Interface (G-MII)

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- Generalize 802.3u MII for Fast Ethernet
- 8-bit wide data, clocked at 125 MHz

– TX_ER	RX_ER	CRS
TX_EN	RX_DV	COL
TX_CLK	RX_CLK	MDC
TXD[7:0]	RXD[7:0]	MDIO

  - 26 pins total
  - 'Flow through timing' - Clocks transmitted with data
- 16 bit data also considered
  - 44 pins total
  - Octet Identification required

G-MII Timing

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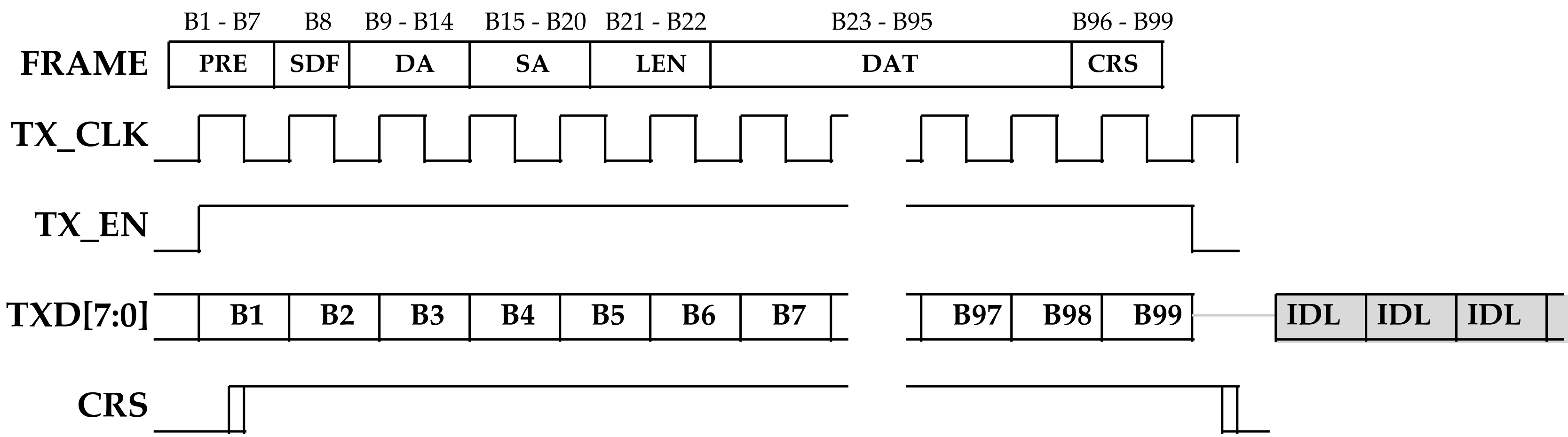
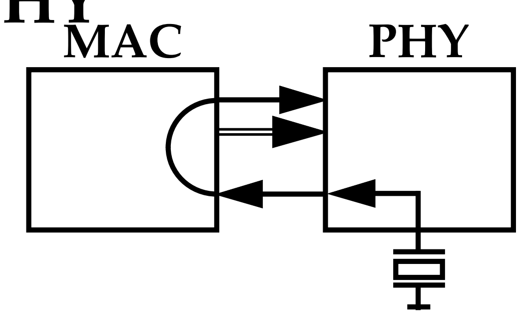
- **8-bit Timing (Odd number of bytes)**



- **PHY transmitter sources clock; clock flows back with data to PHY**



Gigabit PHY Block Diagram

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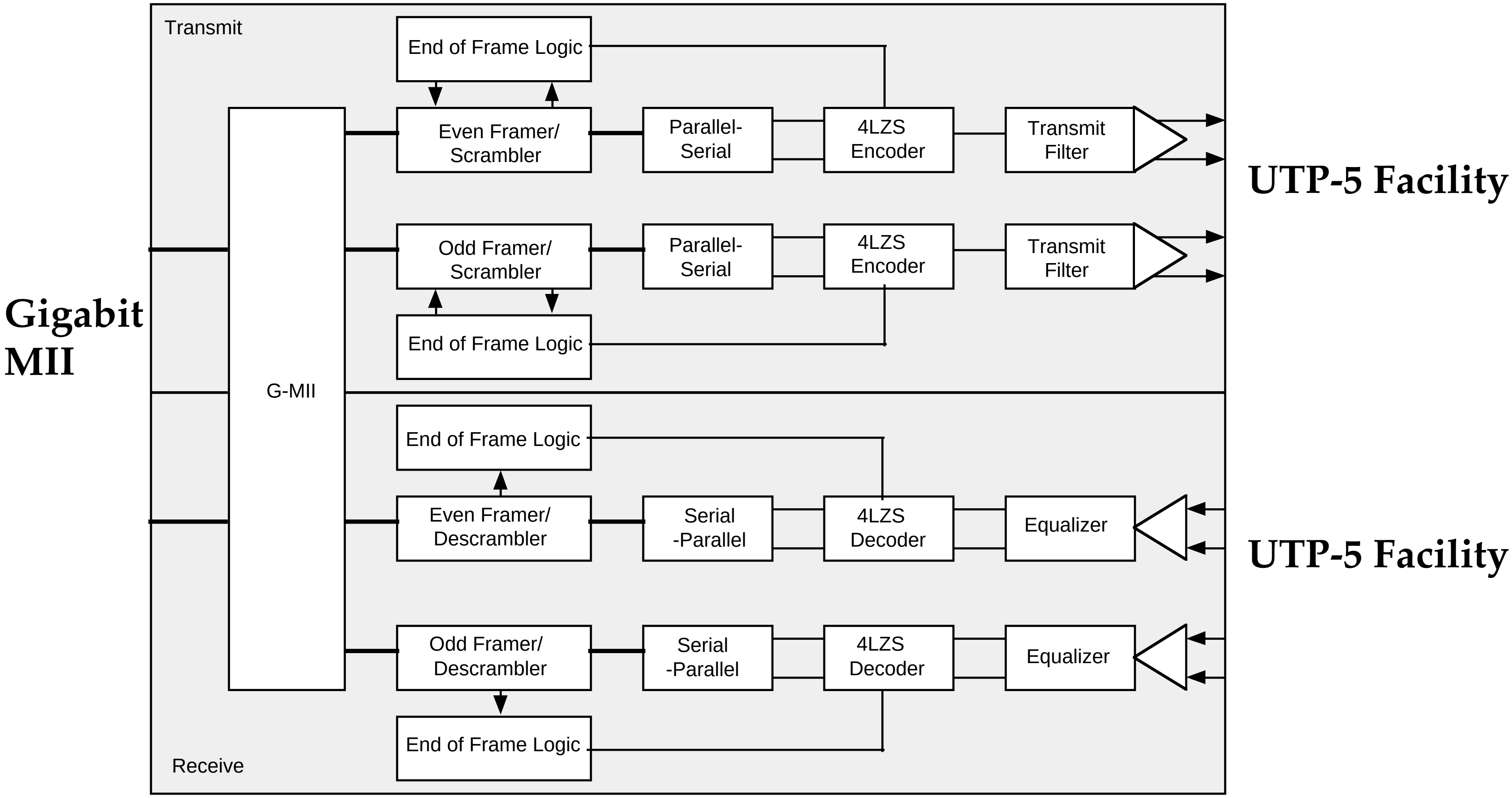

Ongoing Work

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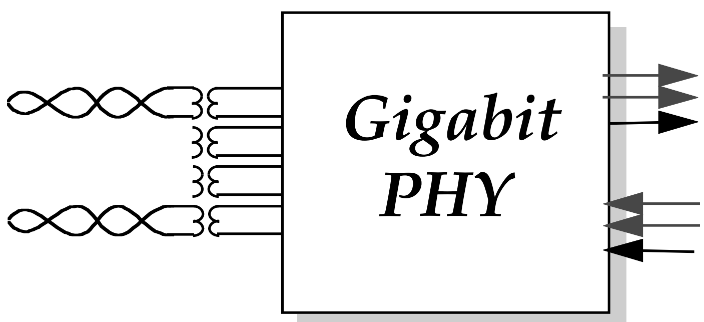
- **BER performance over temperature**
- **Confirm spectral and FCC results**
- **'ESCAPE' words required**
  - **Error conditions, TSC ?**
- **DC balance requirements**
  - **Decision feedback at receiver vs. transmitter RDS correction**
- **Transmit templates and slicing levels**



2x to 3x Fast Ethernet $
based on existing technology

Supplementary Material

RJ-45 Pin Assignment (DTE)

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Proposed 1000BaseT	ATM-UTP	100BaseT
1 - Tx_1	1 - Tx_1	1 - Tx_1
2 - $\overline{Tx_1}$	2 - $\overline{Tx_1}$	2 - $\overline{Tx_1}$
3 - Rx_1	3 -	3 - Rx_1
4 - Rx_2	4 -	4 -
5 - $\overline{Rx_2}$	5 -	5 -
6 - $\overline{Rx_1}$	6 -	6 - $\overline{Rx_1}$
7 - Tx_2	7 - Rx_1	7 -
8 - $\overline{Tx_2}$	8 - $\overline{Rx_1}$	8 -

T568A	T568B
Pair 3	Pair 2
Pair 2	Pair 3
Pair 1	Pair 1
Pair 4	Pair 4

4LZS Code Assignment

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- QPSK & ISDN proven grey code assignment
- Equal Hamming distance between symbols
  - Electrical Levels subject to verification

Code	Bit Pairs	Vnom (mV)	Vmin	Vmax
+3	10	800	700	Vcc+200
+1	11	500	400	600
-1	01	250	200	300
-3	00		Vcc - 200	100

Reach Calculations

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Single Bundle										
		fc		*Attenuation*		*Self-NEXT*		*NEXT Attenuation*	*SNR*	*Reach*
NRZ 155 UTP	155	77.5	0	19.1	0.0	0.0		0.0	19.1	105.0
4LZS 622 UTP	311	77.75	7	19.1	0.0	0.0		0.0	26.2	76.6
4LZS 1000BaseT	500	125	7	24.9	2.1	3.1		3.1	40.2	***49.9***
8B10B 1000BaseT	625	312.5	7	42.0	3.0	4.6		4.6	61.1	32.8

Dual Bundle										
		fc		*Attenuation*		*Self-NEXT*		*NEXT Attenuation*	*∂SNR*	*Reach*
NRZ 155 UTP	77.5	38.75	0	13.1	-3.0	-4.5		-4.5	1.1	1819.4
4LZS 622 UTP	155.5	38.88	7	13.2	-3.0	-4.5		-4.5	8.2	245.2
4LZS 1000BaseT	250	62.5	7	17.0	-0.9	-1.4		-1.4	20.3	***99.0***
8B10B 1000BaseT	312.5	78.13	7	19.2	0.0	0.1		0.1	26.3	76.2

EIA/TIA-568 Specs for UTP

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- Characterized to 100 MHz
- NEXT and Loss limited in length and frequency
- Empirical results show headroom

EIA/TIA-568 Worst-Case Propagation Loss (Lpn) at 20° C				
Cable Type		*dB loss per 100m*		*Frequency range (MHz)*
Category 3	$7.07\sqrt{f} + 0.73\ f$	$2.33\sqrt{f} + .23f$	1.20%	$0.3 \le f \le 16$
Category 4	$6.4\ \sqrt{f} + 0.08f$	$2.10\sqrt{f} + .026f$	0.30%	$0.3 \le f \le 20$
Category 5	$6.4\sqrt{f} + 0.04f$	$1.97\sqrt{f} + 0.023f$	0.30%	$0.3 \le f \le 100$

EIA/TIA-568 Worst-Case NEXT Loss (Lxn)				
Cable Type		*dB pair-pair NEXT loss*	*Connecting HW NEXT loss*	*Frequency range (MHz)*
Category 3	7.94 x 10-5	$41 - 15 \log f$	$58 - 15 \log f$	$f \le 16$
Category 4	2.51 x 10-6	$56 - 15 \log f$	$70 - 15 \log f$	$f \le 20$
Category 5	6.31 x 10-7	$64-15 \log(f/0.77)$	$80 - 15 \log f$	$f \le 100$

Cable Model Match to 568

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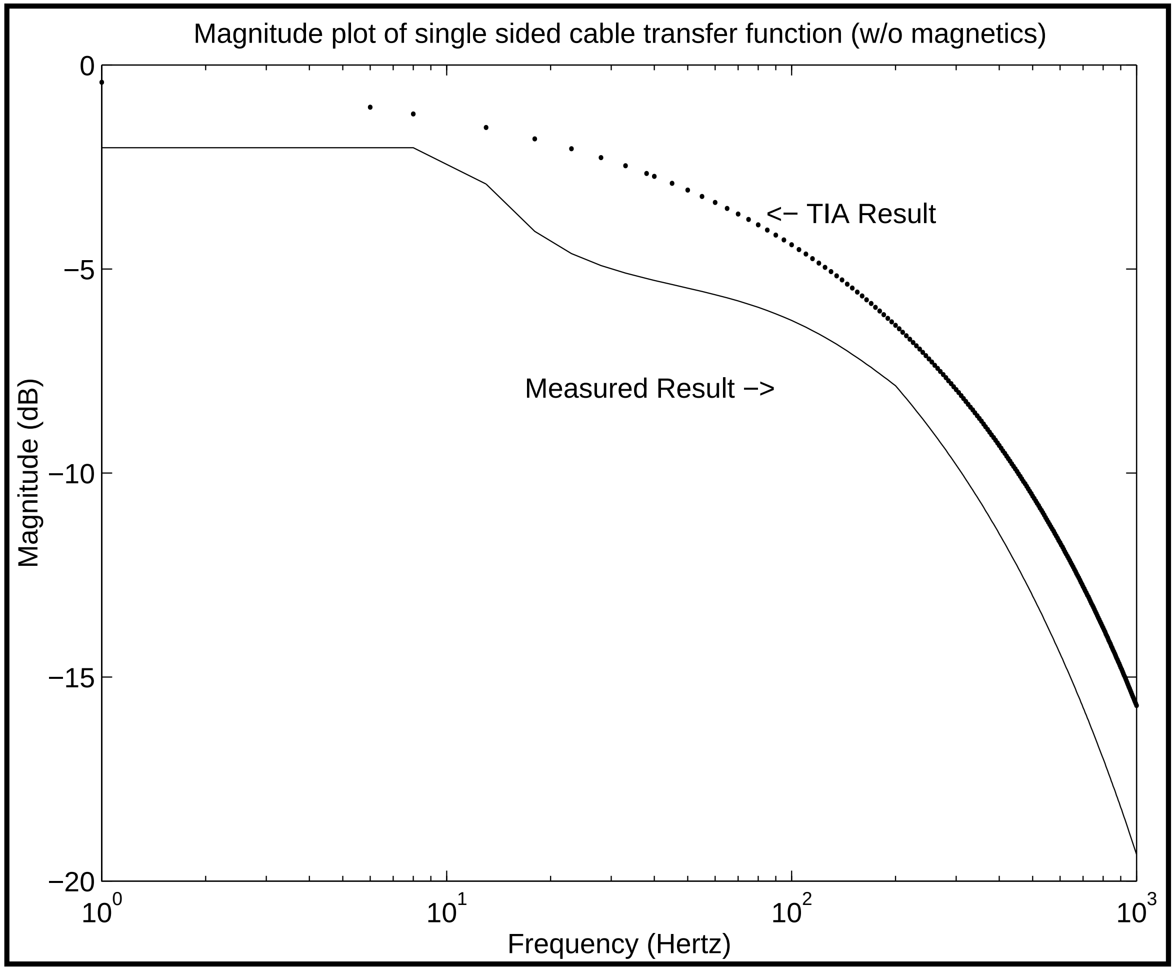

Received Data - 155 Mbit/s

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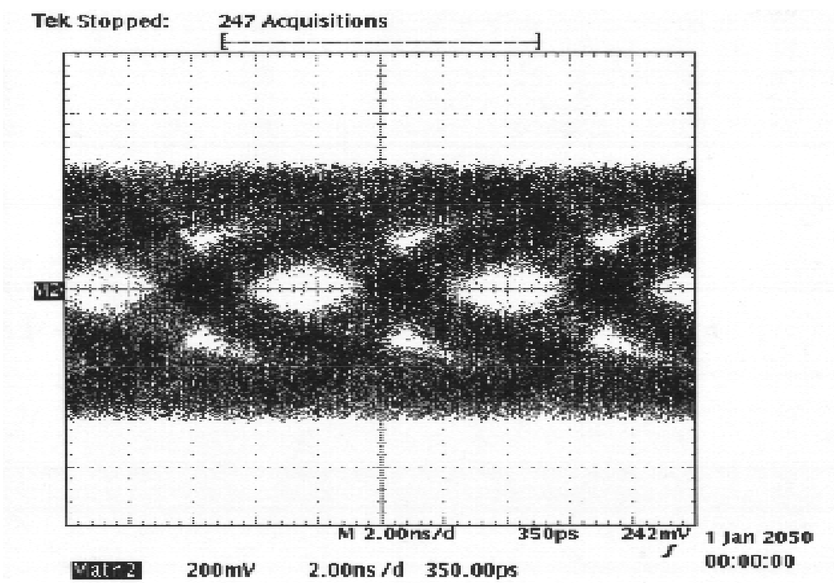
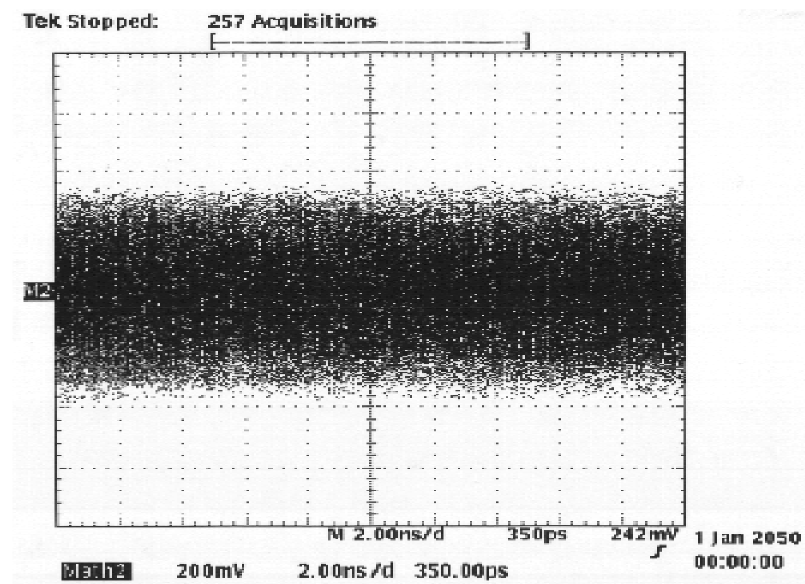


Data eye after 50m of cable



Data eye after 120m of cable

Equalized Receiver - 155 Mbit/s

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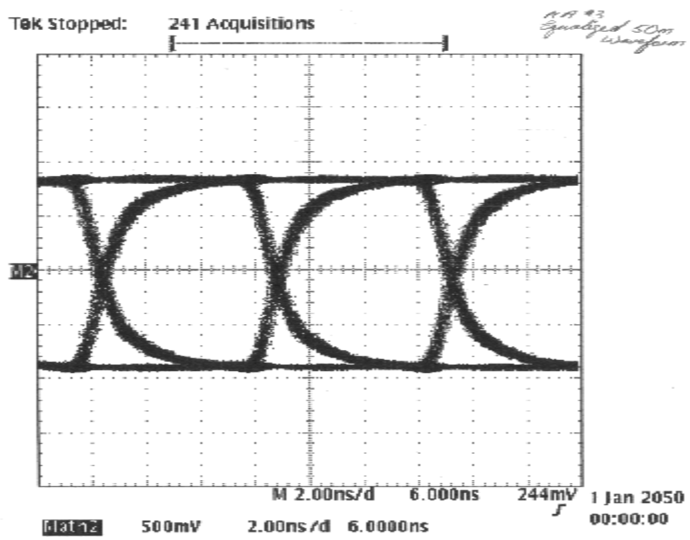
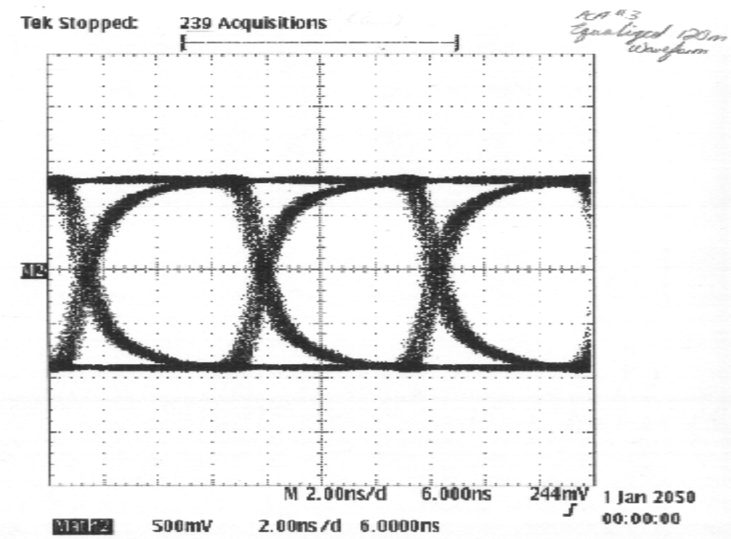


50m cable



120m cable

FCC Radiated Emission Limits

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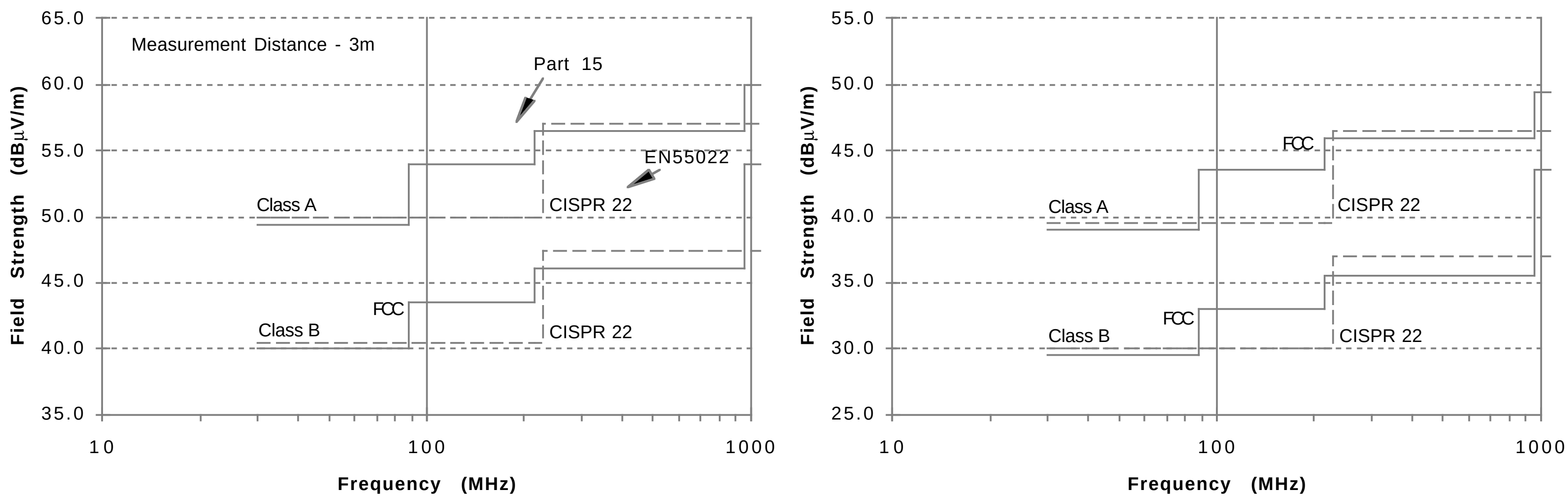
- **Radiated Emission Limits**



CIPSR - Comite **I**nternational **S**pécial des **P**erturbations **R**adio-électriques

FCC Ambient Environment

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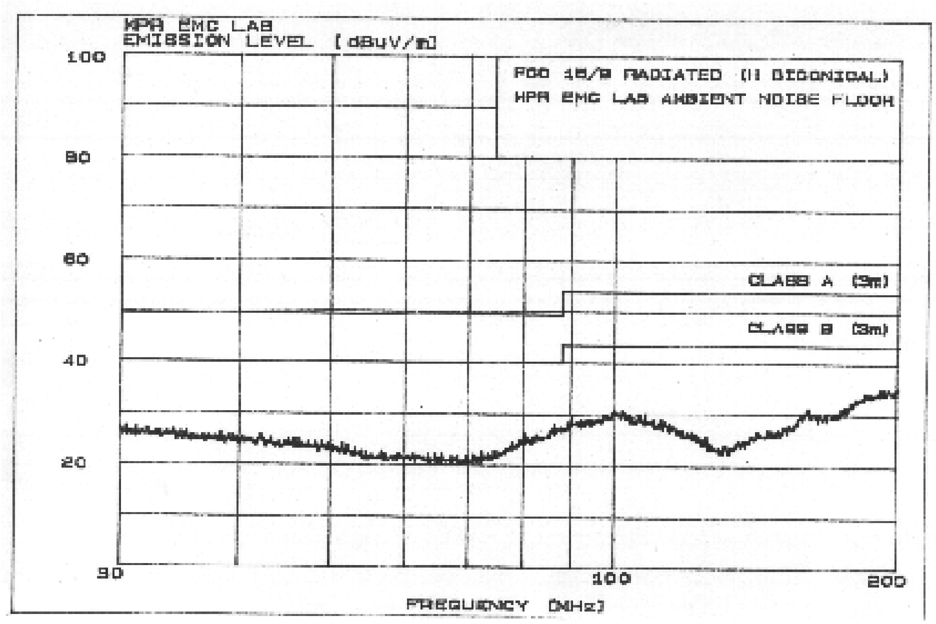
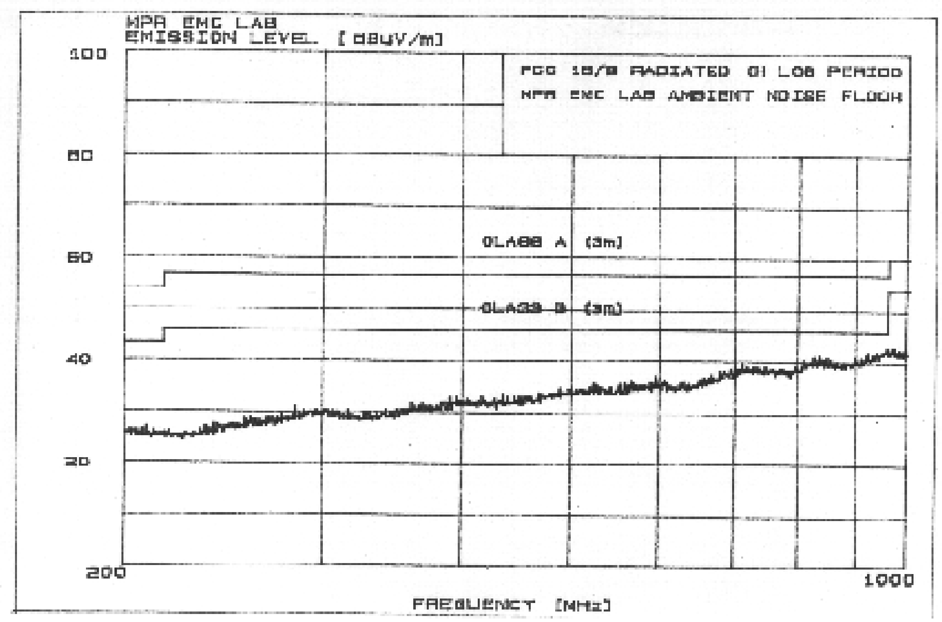
- **Horizontal Antennae**

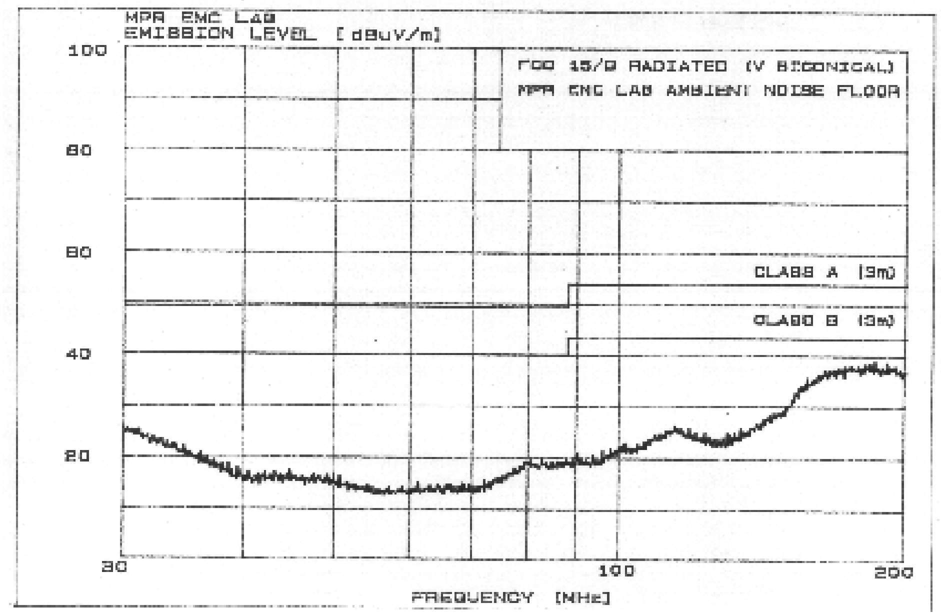


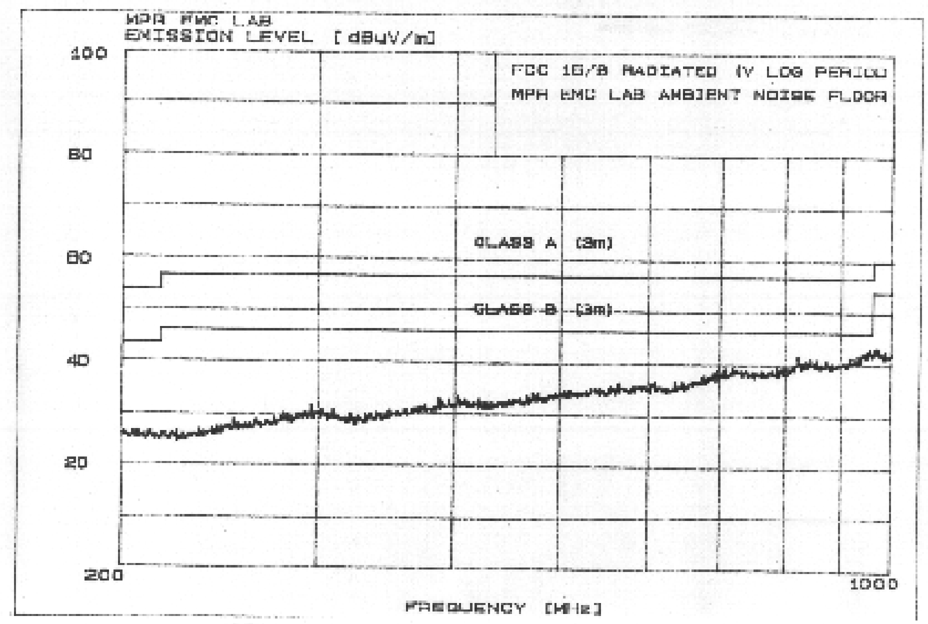


FCC Ambient Environment

PMC-Sierra, Inc.

- **Vertical Antennae**





Workstation Radiated

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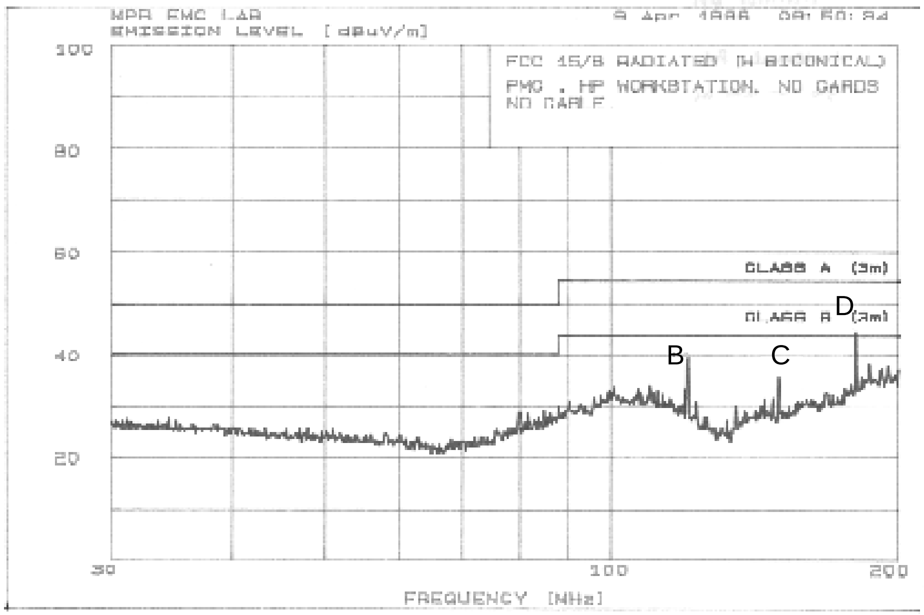
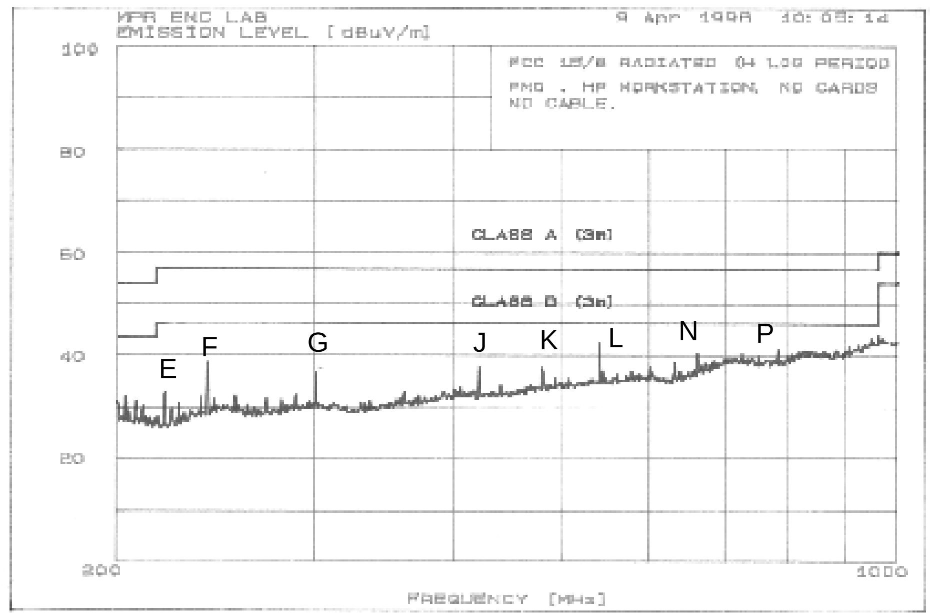
- **Horizontal Antennae**

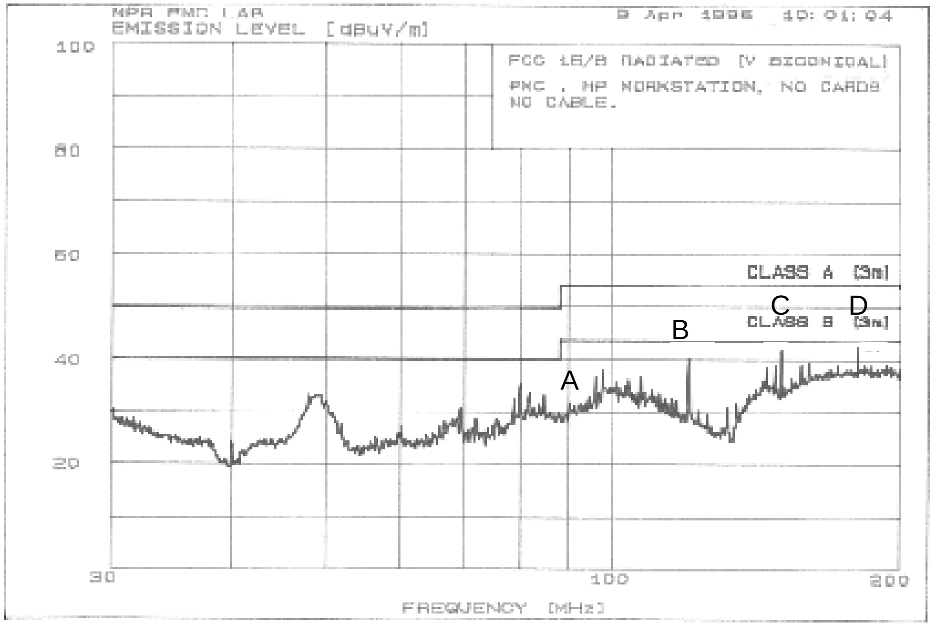


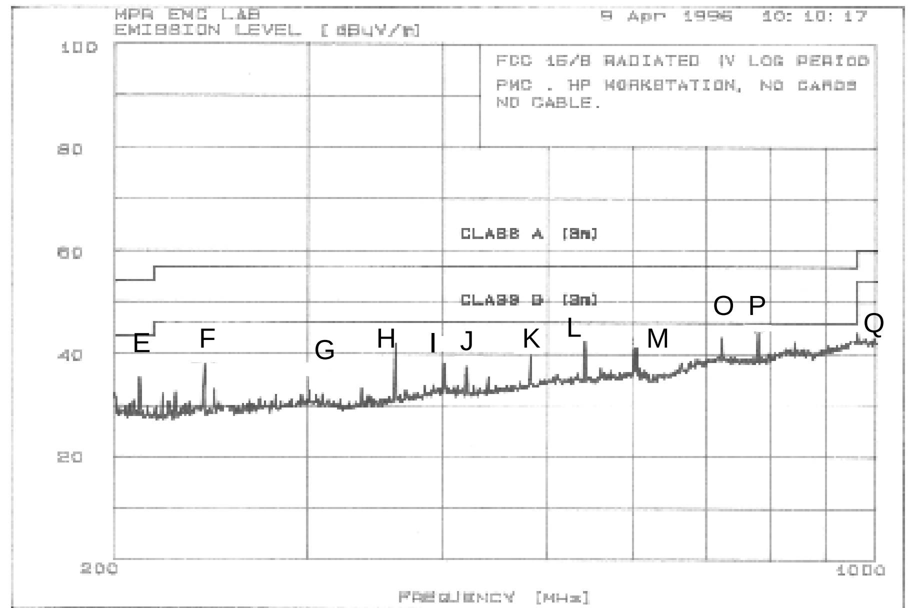


Workstation Radiated

PMC-Sierra, Inc.

- **Vertical Antennae**





155-UTP Radiated

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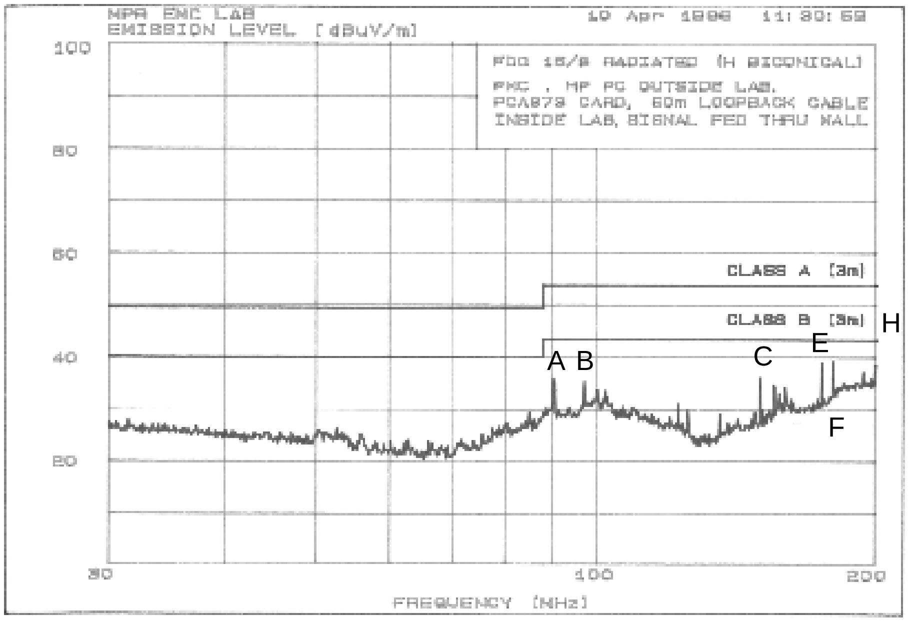
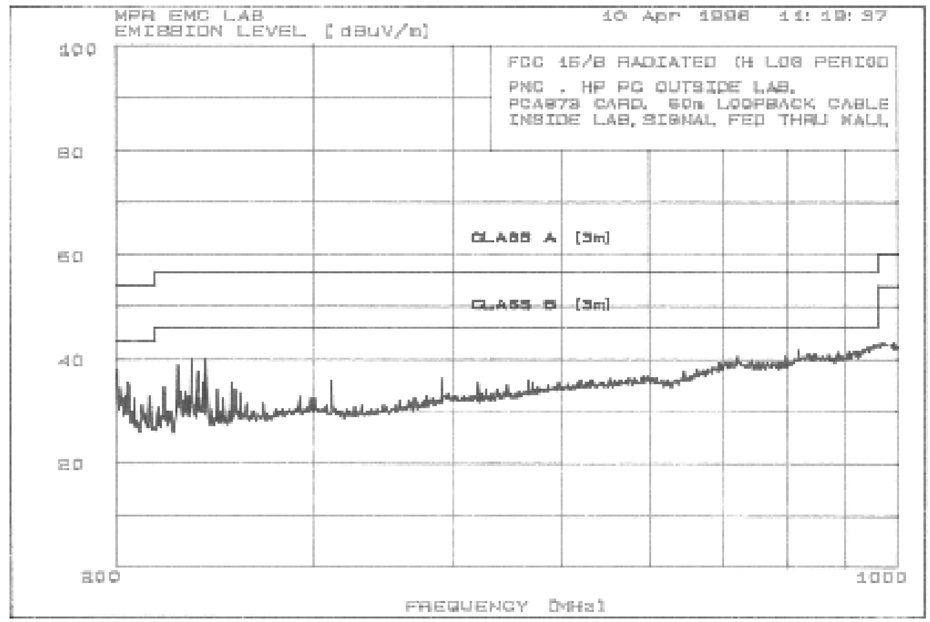
- **Horizontal Antenna**





155-UTP Radiated

PMC-Sierra, Inc.

- **Vertical Antennae**