# Line Coding Proposal for Gigabit Copper PHY

Sreen Raghavan
ComCore Semiconductor, Inc.

# Outline

- Introduction
- Review of existing proposals
- ComCore PHY Proposal
- Comparison of line coding methods

# Introduction

- Goals of copper PHY development
  - 1 Gbit/sec data rate across a 100 meters of CAT5 4 pair wire
  - Meet FCC emission requirements
  - Sufficient SNR margin under worst case conditions
  - Reasonable implementation complexity

# Review of Existing Proposals

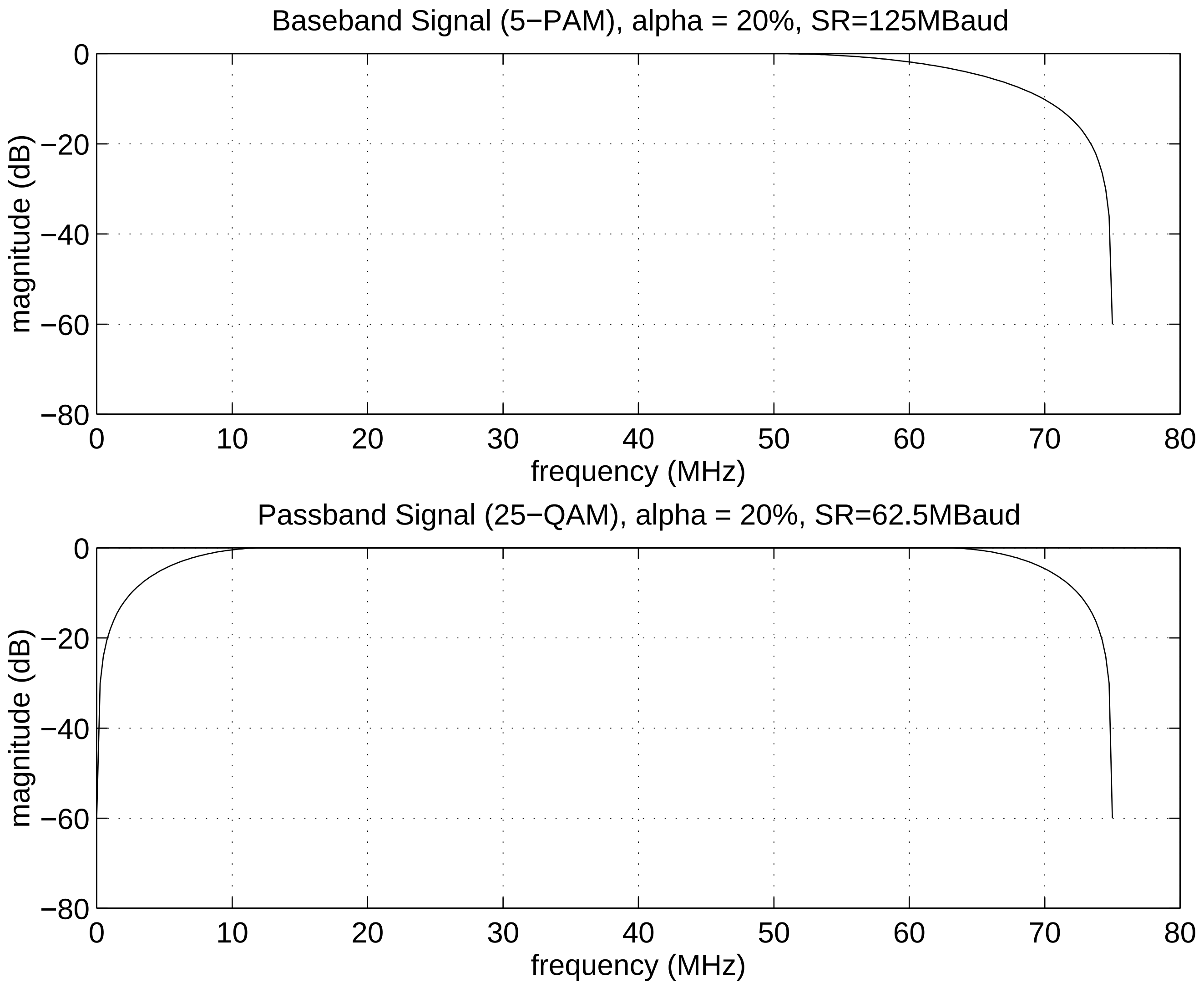
- Baseband line coding
  - 5-level NRZ
- Passband line coding
  - m-QAM (CAP)

# Baseband Vs. Passband

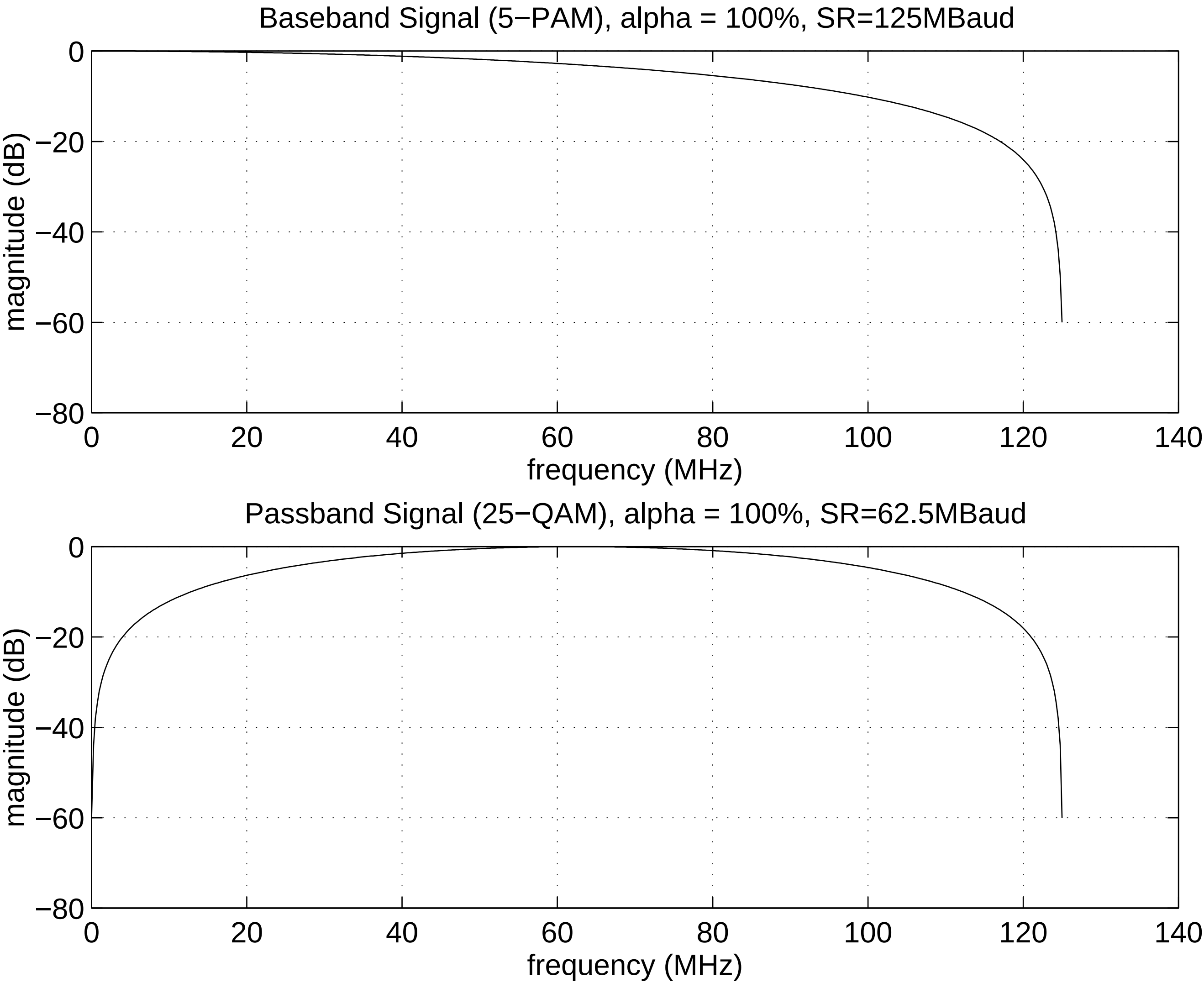
- Bandwidth efficiency for a given roll-off factor is the same for both
- Baseband method (w/o error correction coding) has higher SNR for a given emitted power beyond 30 MHz
- Baseband method suffers from baseline wander, and passband method does not

# Comparison of Baseband Vs. Passband

| **Item** | **5-NRZ,** | **25-QAM,** |
|---|---|---|
| Relative SNR | +1.7 dB | 0 dB |
| Baseline wander | Yes | No |
| ADC Speed (optimal) | 250 Mhz | 250 Mhz |
| ADC Speed (sub-optimal) | 125 Mhz (1 dB SNR penalty) | 250 Mhz (if IF is performed digitally) |
| ADC precision | 6 bits | 6 bits |
| RX DSP complexity | same | same |



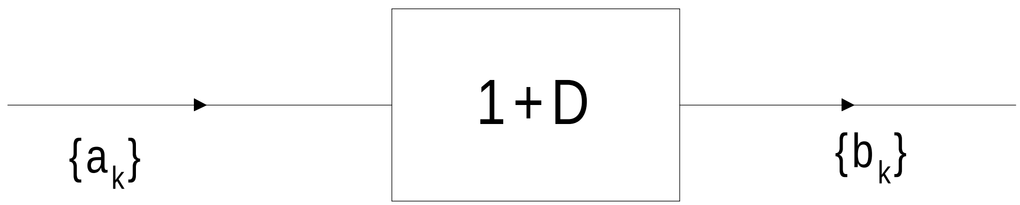
Baseband Signal (5−PAM), alpha = 20%, SR=125MBaud
magnitude (dB)
0
−20
−40
−60
−80
0
10
20
30
40
50
60
70
80
frequency (MHz)
Passband Signal (25−QAM), alpha = 20%, SR=62.5MBaud
magnitude (dB)
0
−20
−40
−60
−80
0
10
20
30
40
50
60
70
80
frequency (MHz)


Baseband Signal (5−PAM), alpha = 100%, SR=125MBaud
magnitude (dB)
0
−20
−40
−60
−80
0
20
40
60
80
100
120
140
frequency (MHz)
Passband Signal (25−QAM), alpha = 100%, SR=62.5MBaud
magnitude (dB)
0
−20
−40
−60
−80
0
20
40
60
80
100
120
140
frequency (MHz)

# ComCore PHY Proposal

- Shape the transmit signal by introducing "controlled ISI" at TX
- Specifically use 9-level (1+D) partial response signaling method
  - gives equivalent data throughput of 5-level NRZ by utilizing only 62.5 MHz bandwidth

# 1+D Partial Response Signalling



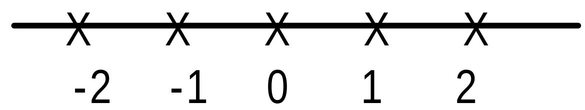

$b_k = a_k + a_{k-1}$

$a_k \rightarrow$ {-2, -1, 0, 1, 2} 5 level NRZ data

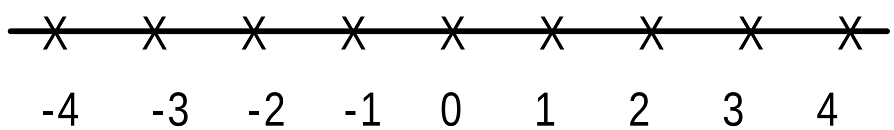
$b_k \rightarrow$ {-4, -3, -2, -1, 0, 1, 2, 3, 4}

# 5 level NRZ and 9 level (1+D)

5 Level NRZ




9 Level (1+D)



# Why use ComCore PHY method?

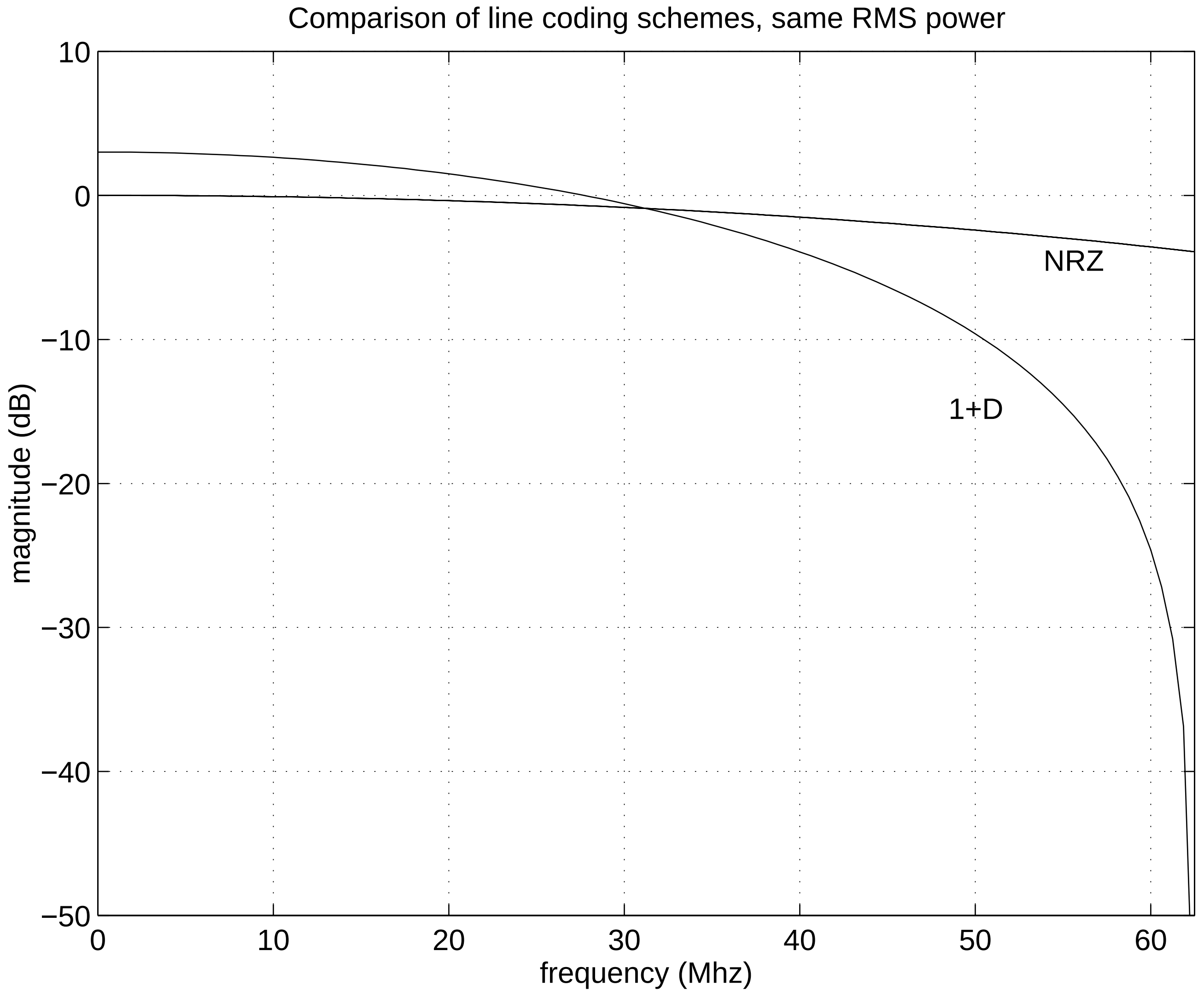
- Advantages
  - better bandwidth utilization than 5-level NRZ (or equivalent QAM)
  - 4.0 dB better SNR than NRZ for the same emitted TX power beyond 30 MHz
  - “optimal” receiver using only 125 MHz ADC (since signal is strictly band-limited to 62.5 MHz)

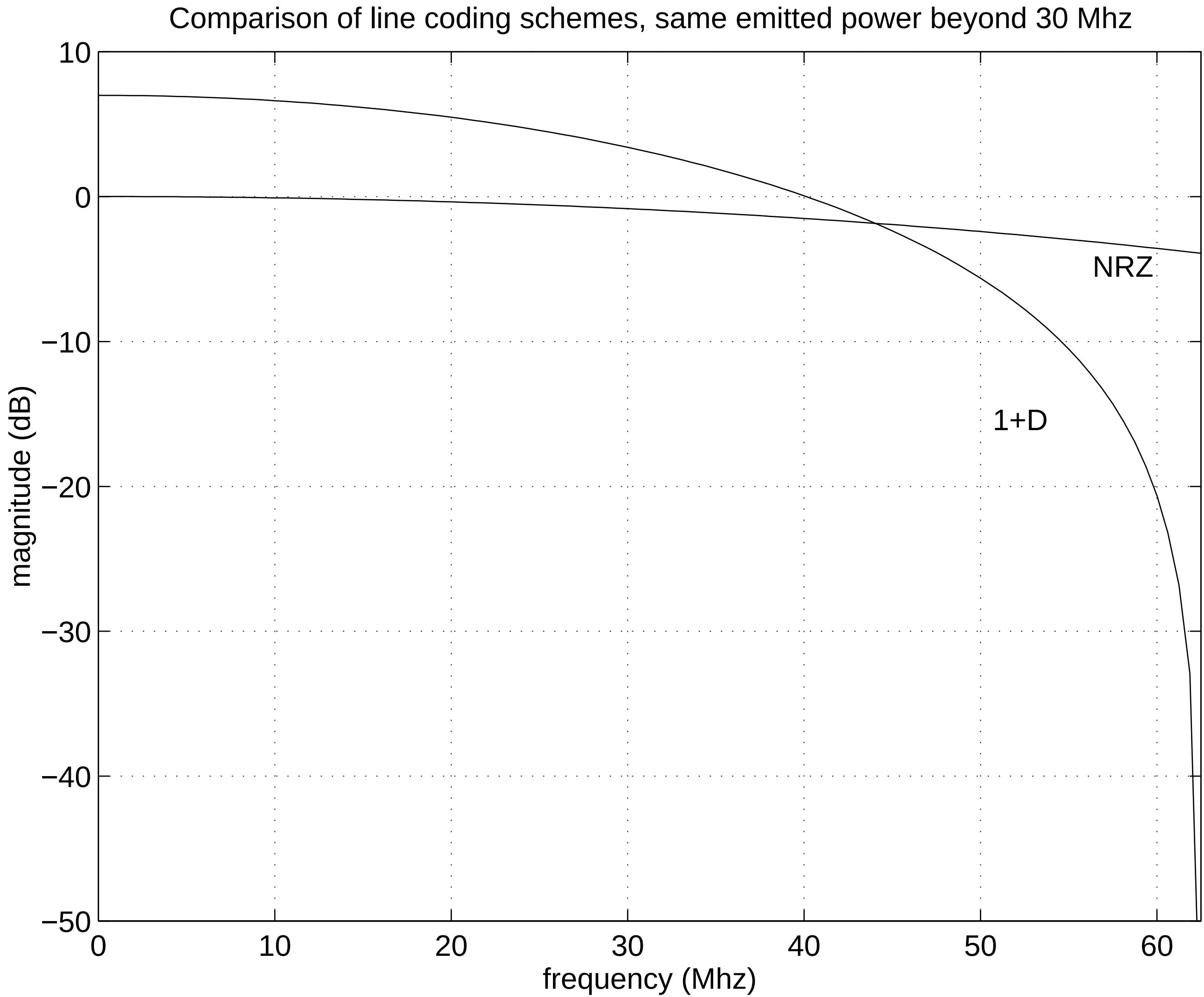
# Why use ComCore PHY method? (contd.)

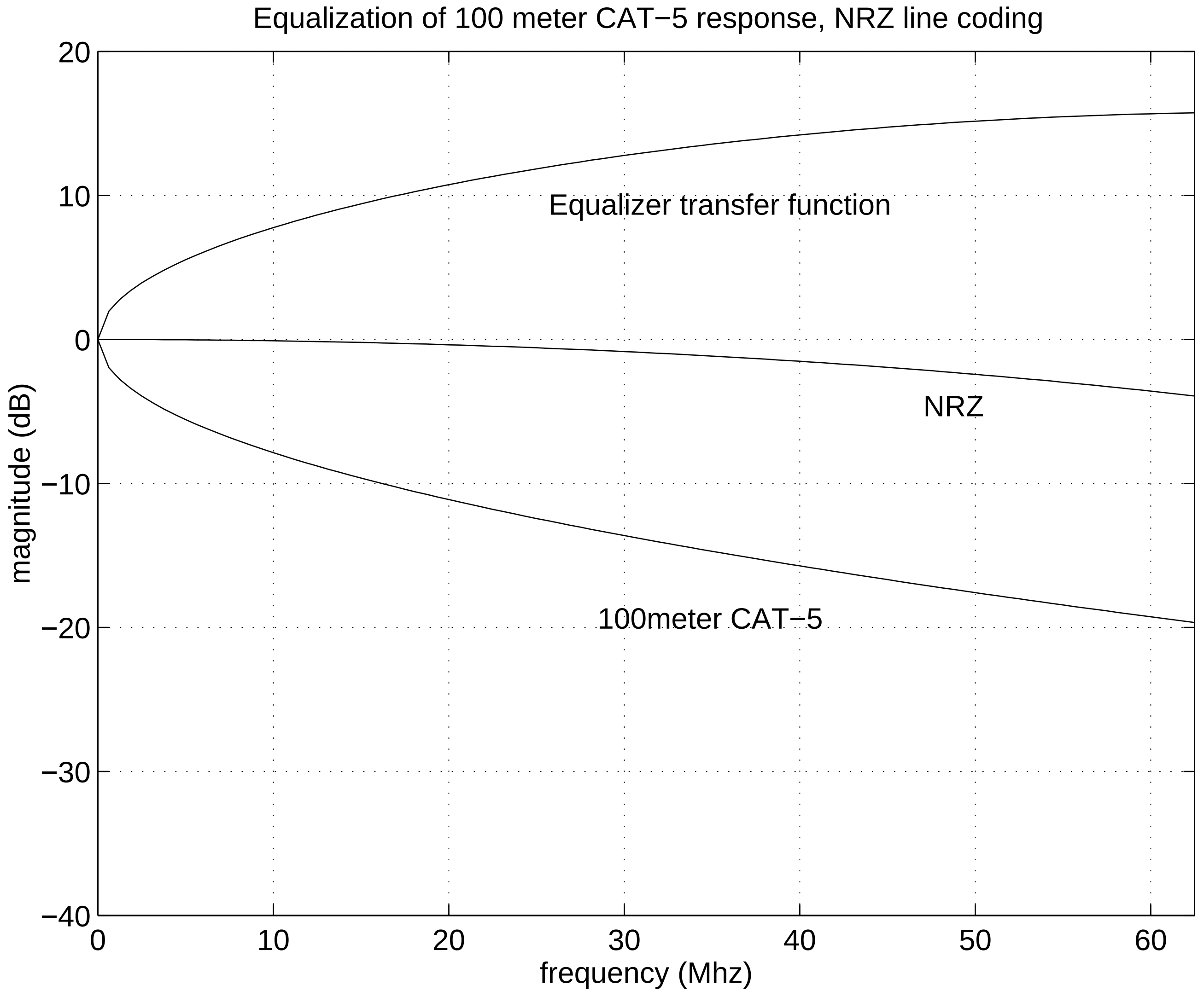
- Equalization can be done using fractionally spaced equalization => equalizer performance is independent of sampling phase !
- same receiver complexity as 5-level NRZ (or, an equivalent QAM)
- Lower equalization noise enhancement at high frequencies (>30 MHz)

# Comparison of 9-level (1+D) with other line codes

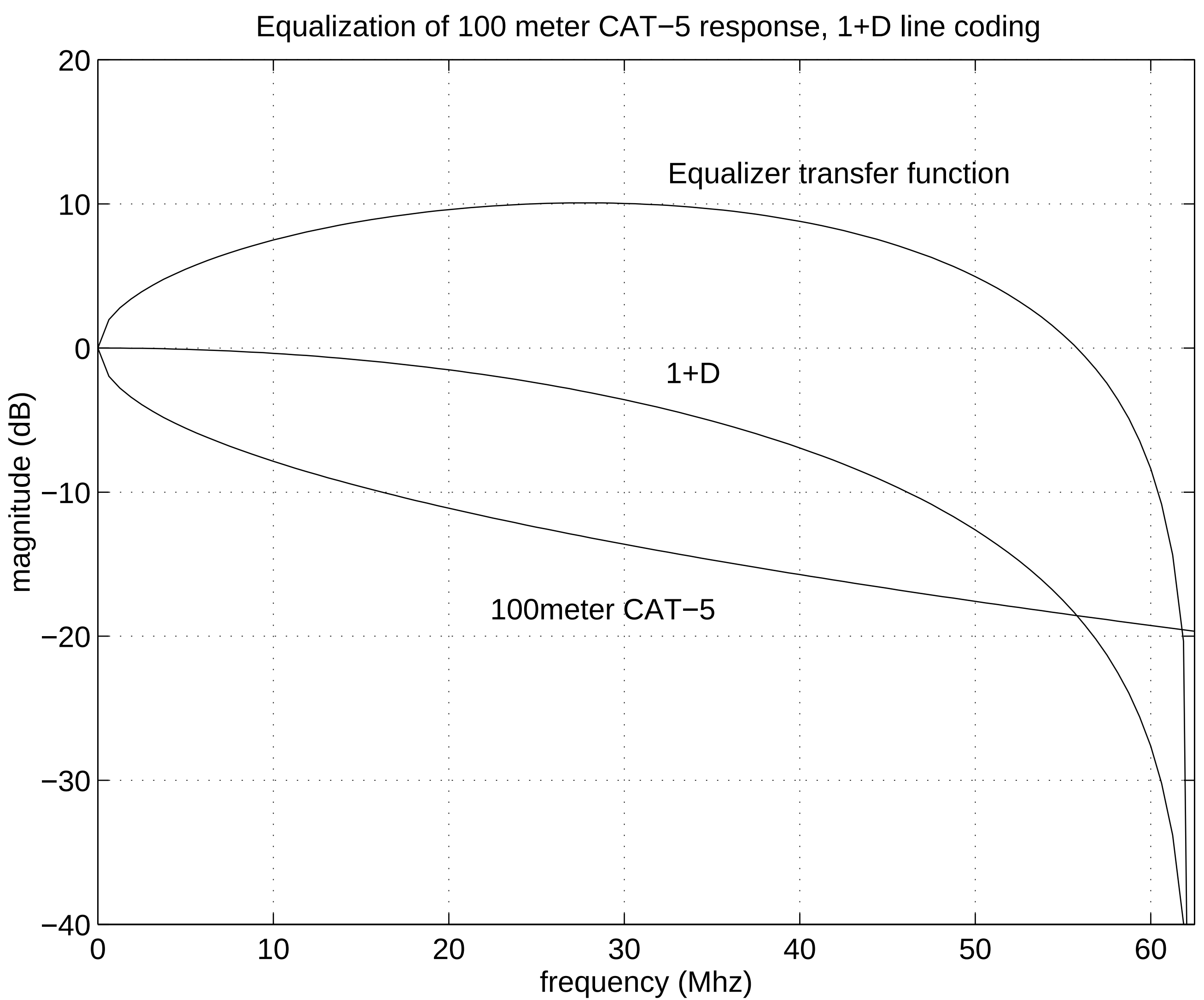
| Item | 9-level (1+D) | 5-level NRZ | 25-QAM, alpha=1.0 |
|---|---|---|---|
| Relative SNR | 0 dB | -4.0 dB | -5.7 dB |
| Baseline wander correction | Yes | Yes | No |
| ADC Complexity | 6.5 bits | 6 bits | 6 bits |
| ADC Speed (optimal) | 125 Mhz | 250 Mhz | 250 Mhz |
| RX DSP | 1.0 | 1.0 | 1.0 |


Comparison of line coding schemes, same RMS power
10
0
−10
−20
−30
−40
−50
magnitude (dB)
0
10
20
30
40
50
60
frequency (Mhz)
NRZ
1+D


Comparison of line coding schemes, same emitted power beyond 30 Mhz
10
0
−10
−20
−30
−40
−50
magnitude (dB)
0
10
20
30
40
50
60
frequency (Mhz)
NRZ
1+D



Equalization of 100 meter CAT−5 response, NRZ line coding
Equalizer transfer function
NRZ
100meter CAT−5
magnitude (dB)
frequency (Mhz)
20
10
0
−10
−20
−30
−40
0
10
20
30
40
50
60


Equalization of 100 meter CAT−5 response, 1+D line coding
Equalizer transfer function
1+D
100meter CAT−5
magnitude (dB)
frequency (Mhz)
20
10
0
−10
−20
−30
−40
0
10
20
30
40
50
60

# Summary

- 9-level (1+D) partial response is an ideal line coding method for Gbit PHY
  - “optimal” receiver signal processing can be done with just 125 MHz ADC
  - 4.0 dB SNR improvement over 5-level NRZ
  - lower equalization noise enhancement
  - receiver DSP is insensitive to sampling phase