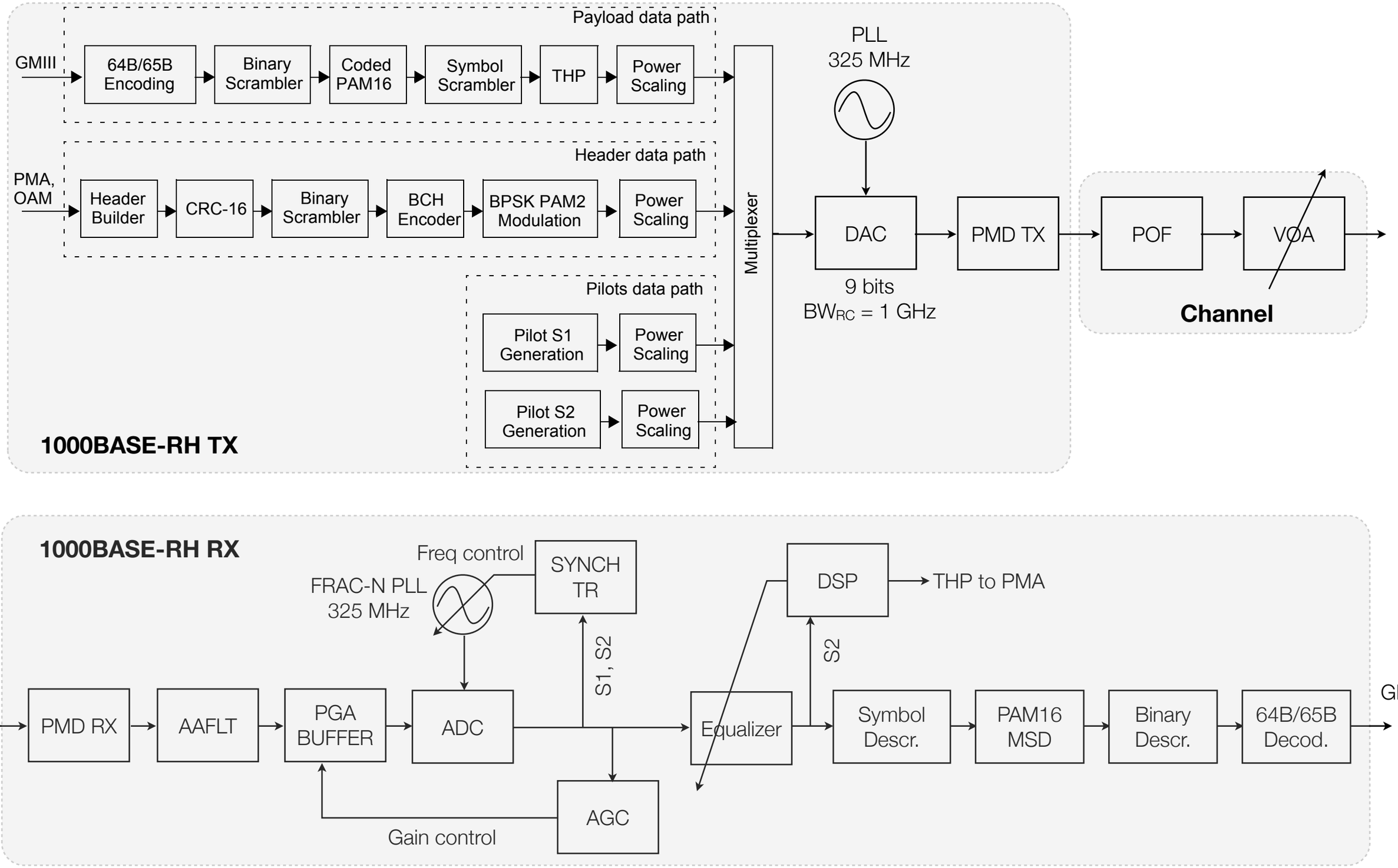
# 1000BASE-RH PHY system simulations

Rubén Pérez-Aranda
(rubenpda@kdpof.com)

**IEEE 802.3bv Task Force - September 2015**

# Simulation scheme

# 1000BASE-RH PHY simulation scheme



# 1000BASE-RH transmit block

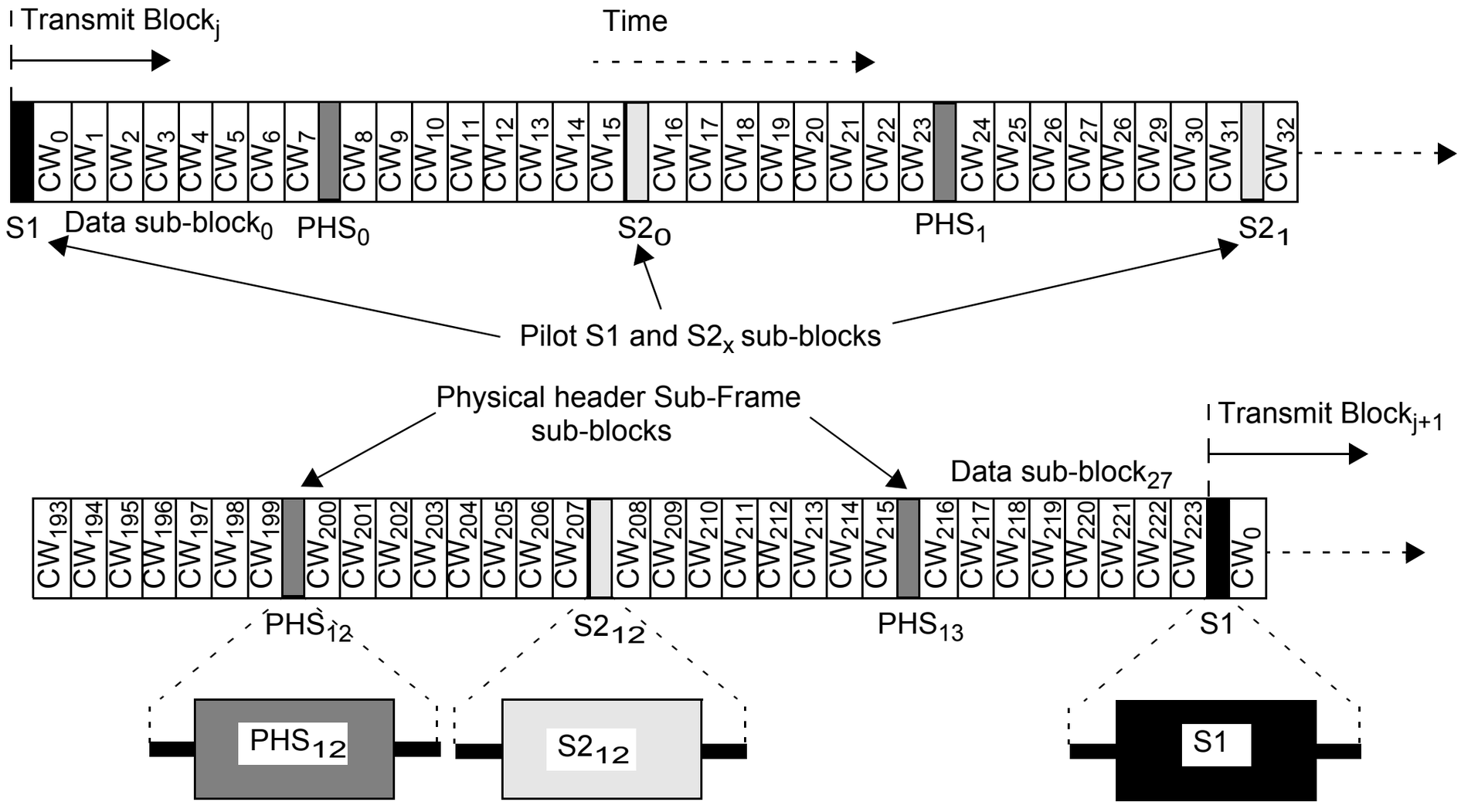
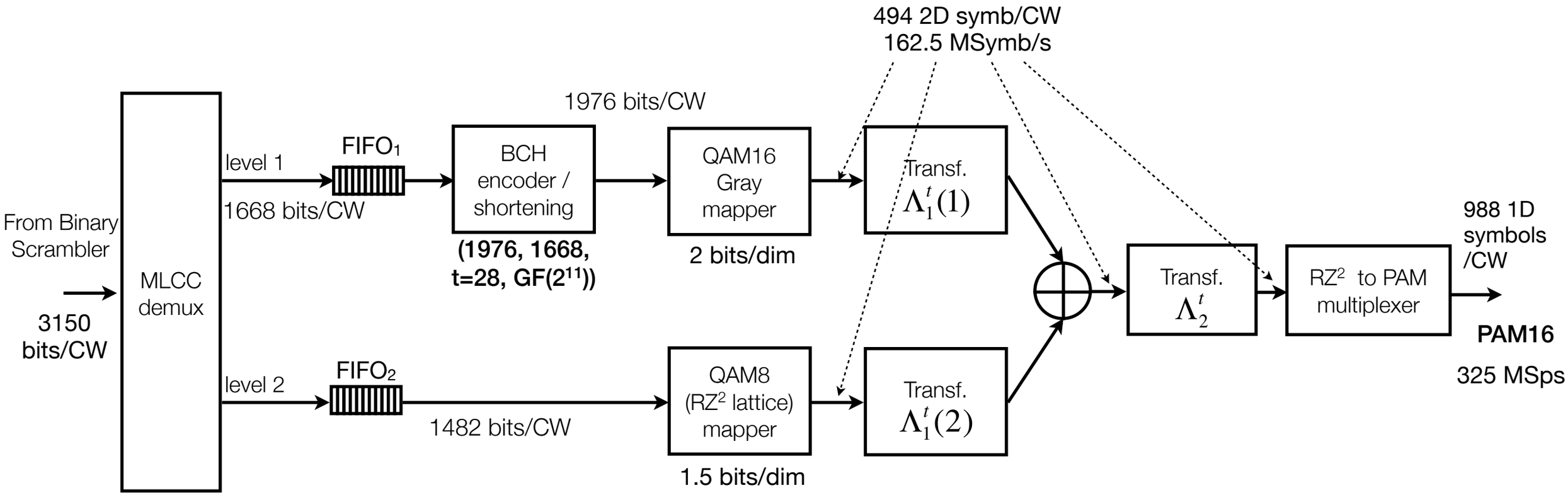


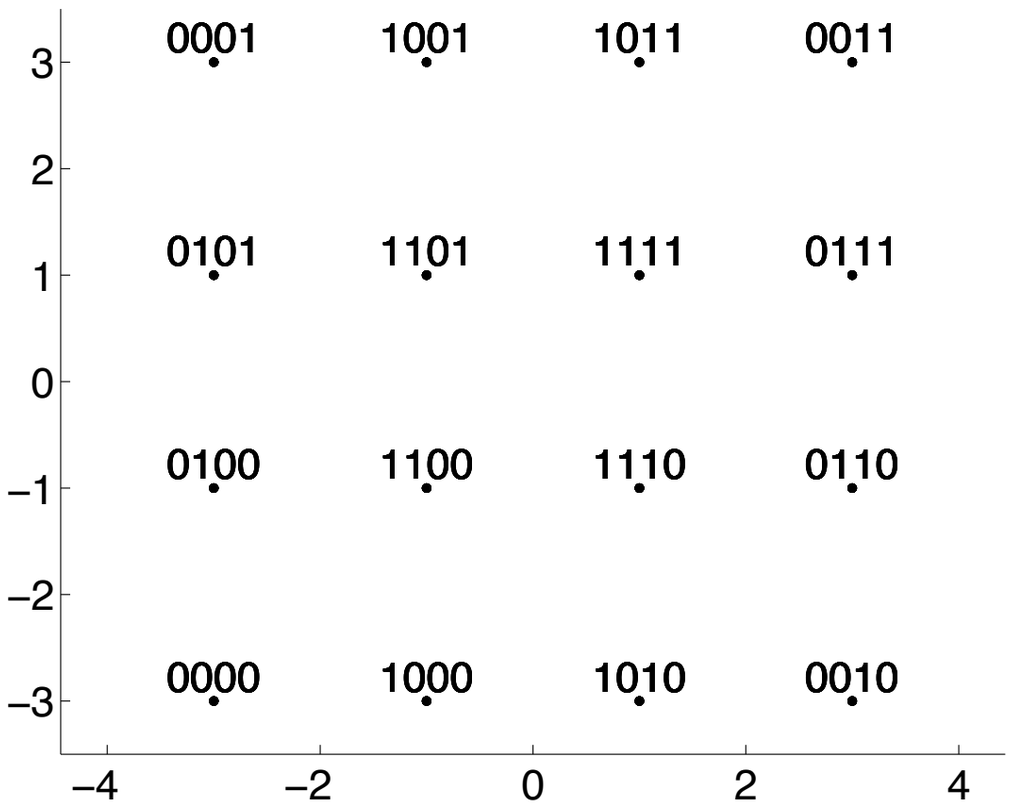

**Figure 114–4—1000BASE-H Transmit Block**

# PAM16 encoder

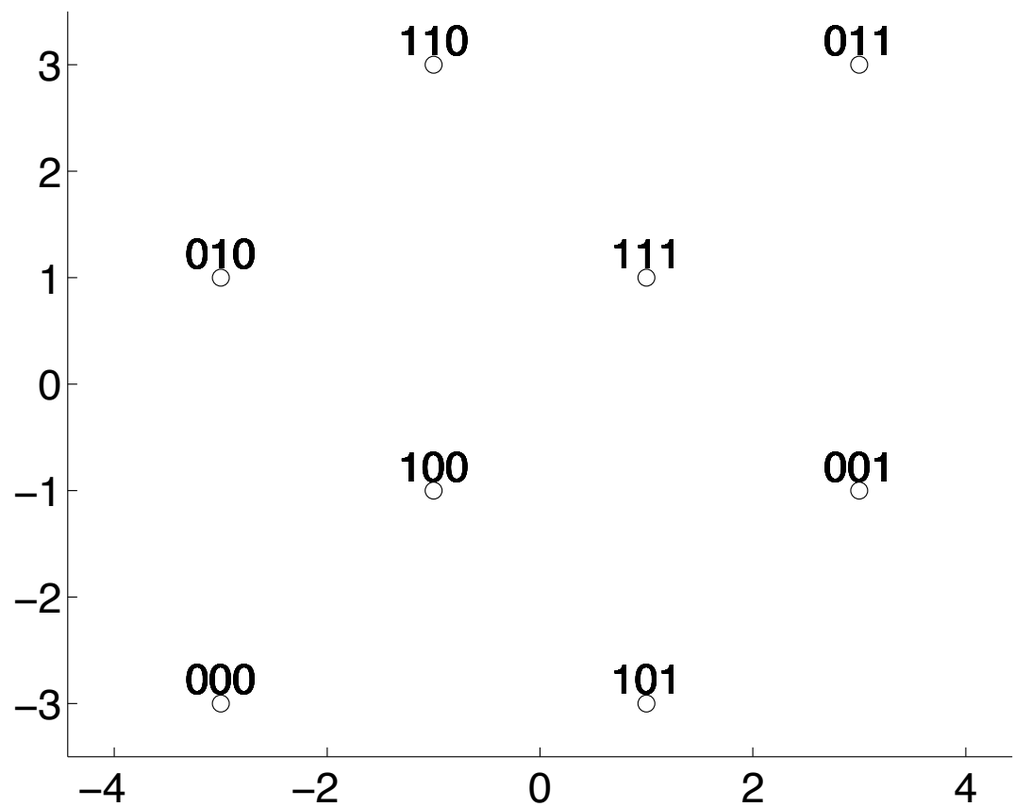


# PAM16 encoder

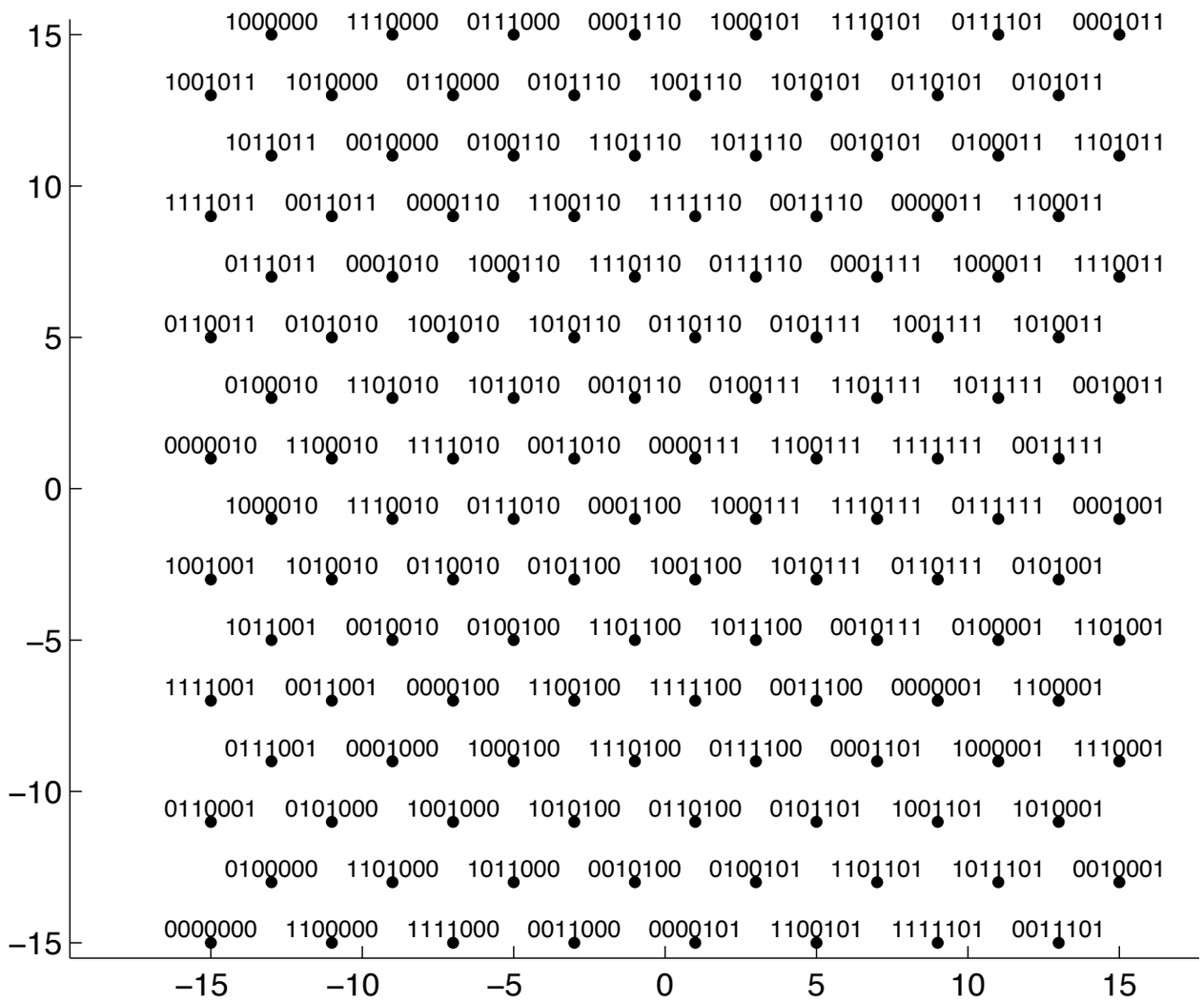
Level 1, QAM16




Level 2, QAM8

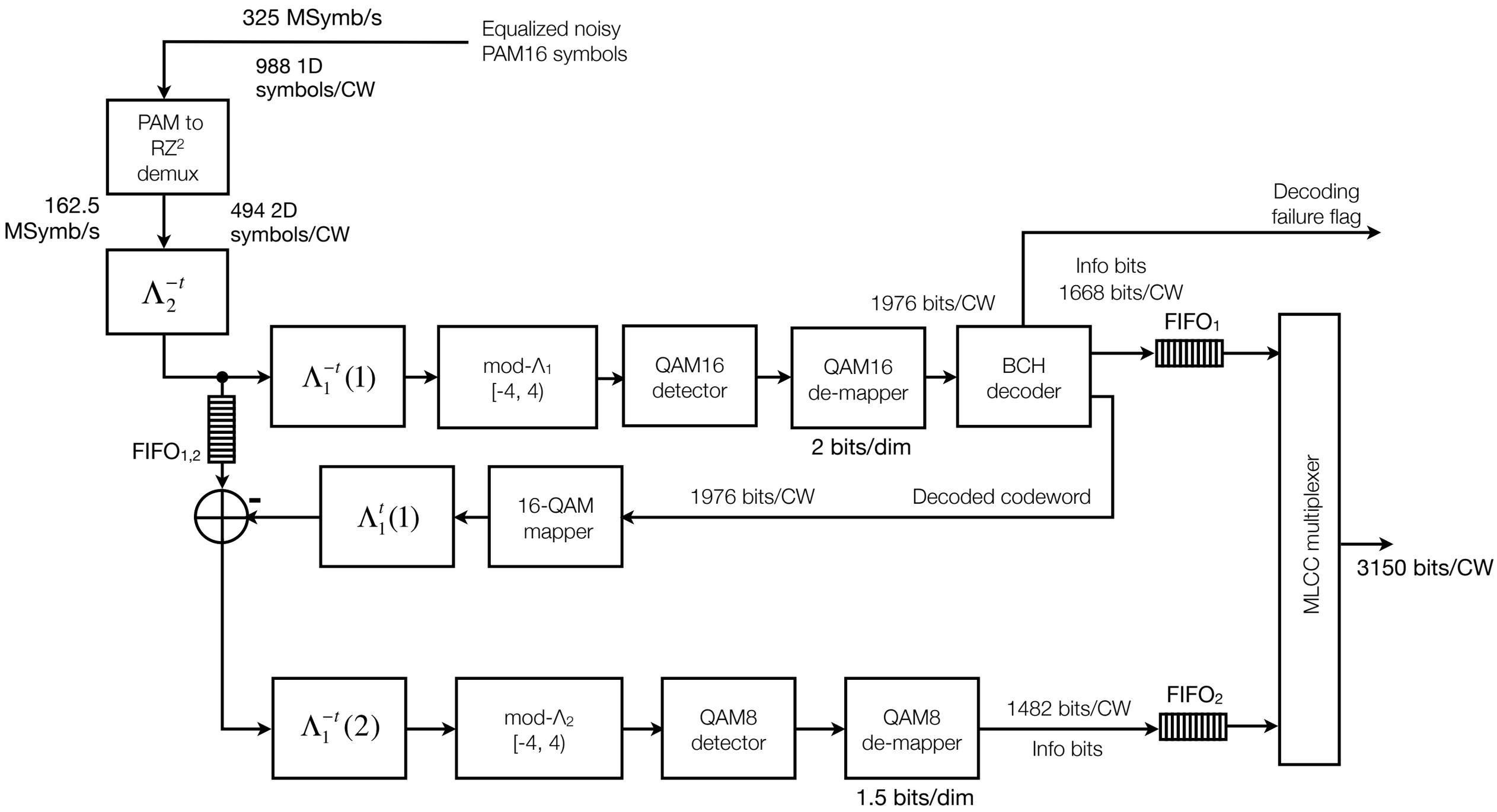


# PAM16 encoder




- Basic numbers of constellation:
  - 128 points in a 2D constellation
  - $\log_2(128) = 7$ bits / 2D symbol
  - 7 bits =
    - 4 bits of 1st MLCC level
    - 3 bits of 2nd MLCC level
  - Each 2D symbol are transmitted at a rate of 162.5 MSymb/s
  - To transmit over 1D (i.e. intensity modulation of LED), the system does time interleaving of both coordinates of 2D constellation at double rate, that is 325 MSymb/s
  - Each 2D point can be represented by 2 coordinates that can take 16 different values each one: {-15, -13, … 13, 15} therefore, 16-PAM
  - This is PAM16, but encoded with 3.5 bits/ 1D symbol (i.e. 7bits/2D) instead of 4 bits
  - 3.1883 bits of 3.5 are information bits, the rest is parity for error correction and detection

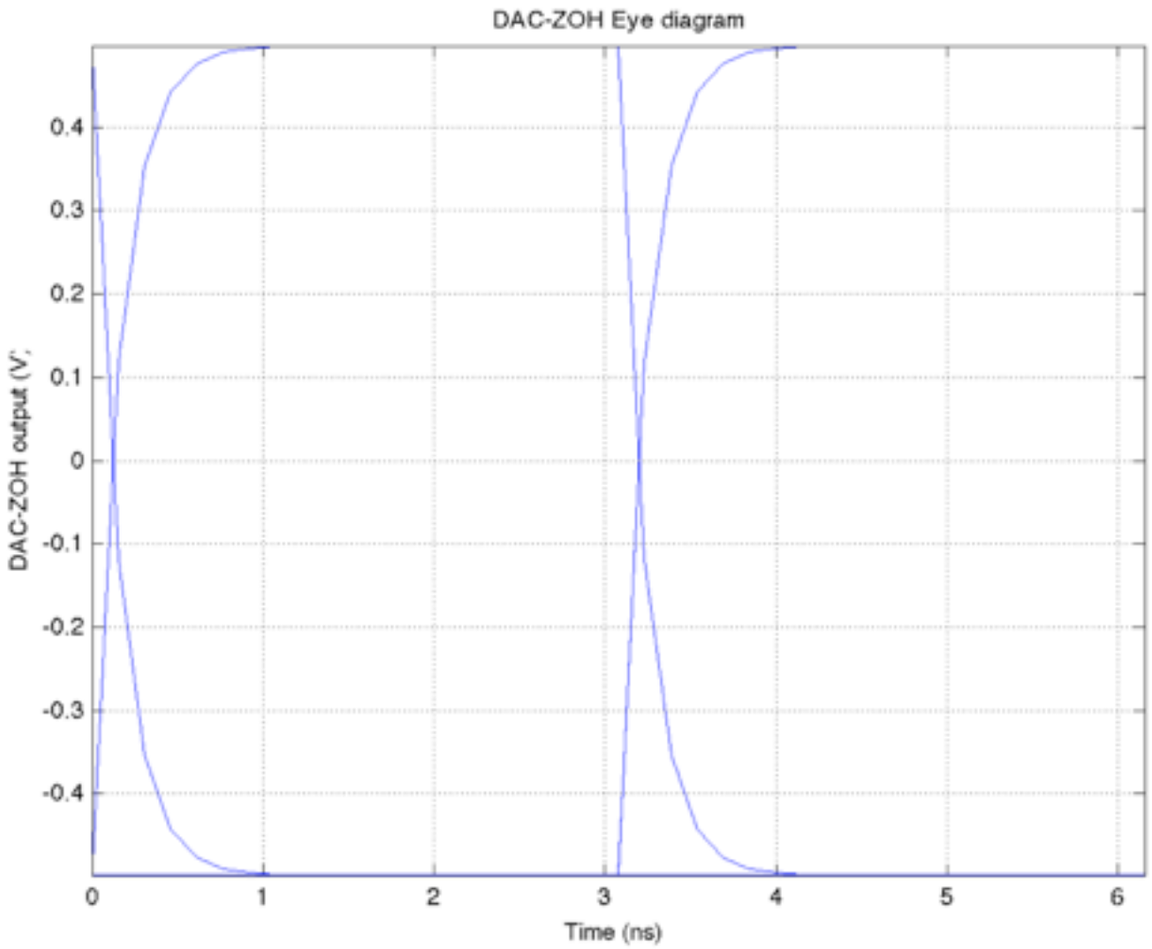
# PAM16 multi-stage decoder



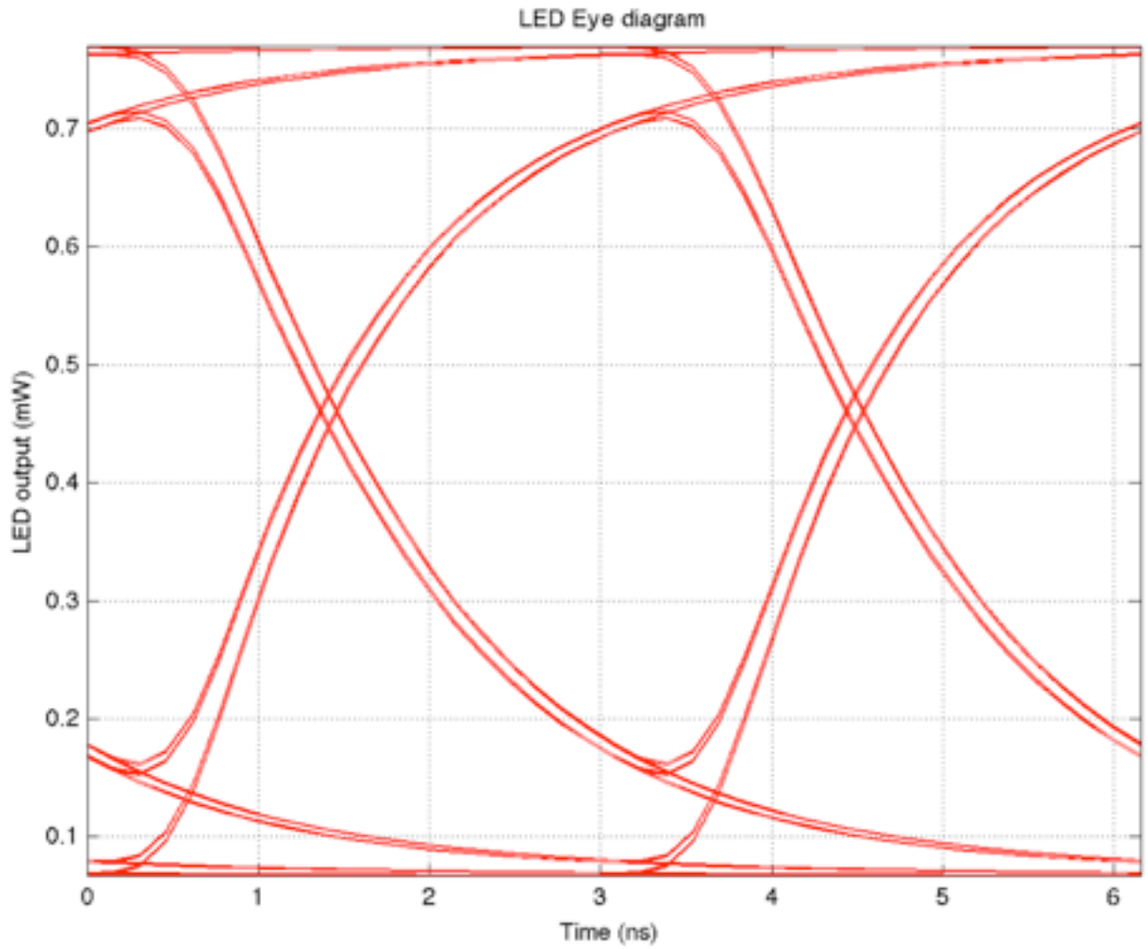
# Eye diagrams

# Eye diagrams for S1, PHS

DAC output

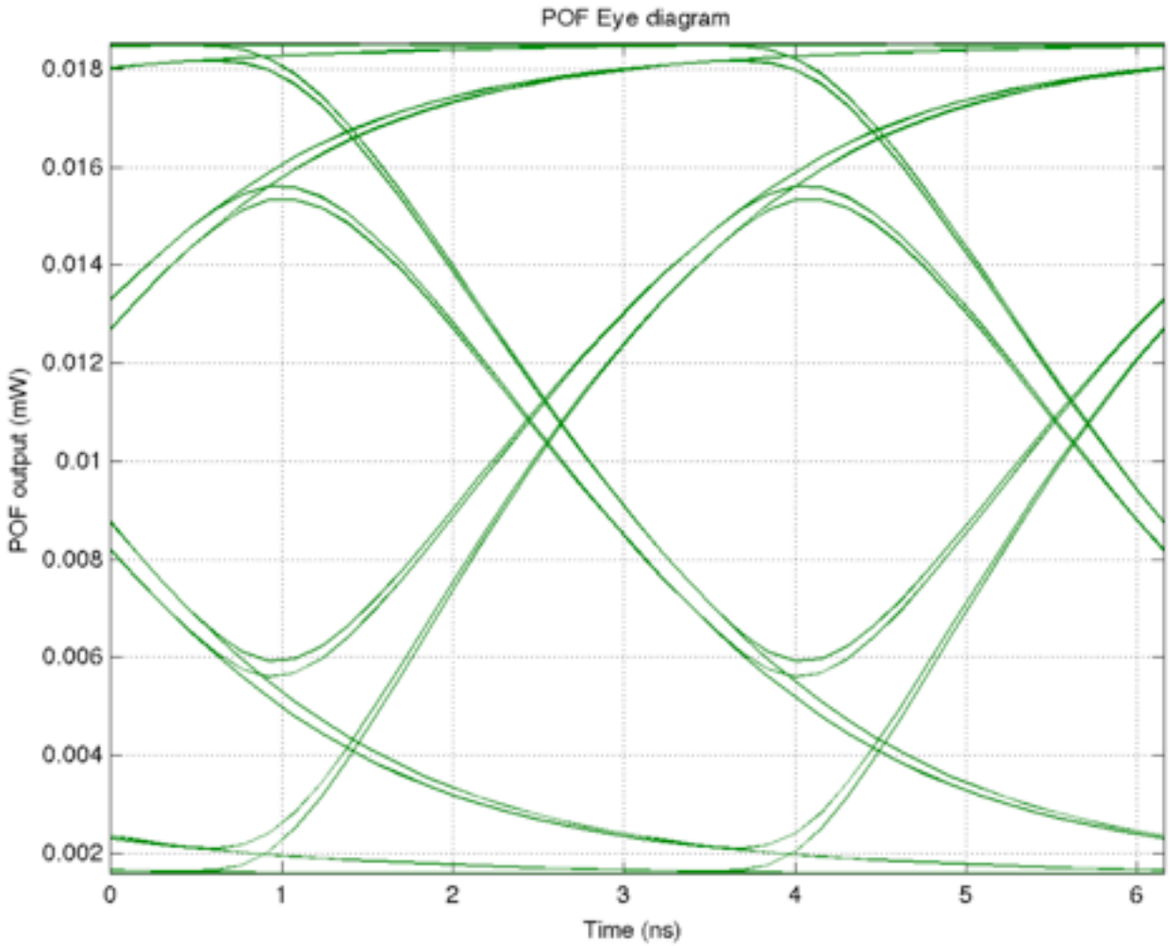



TP2 - Driver+LED output
(worst case response)

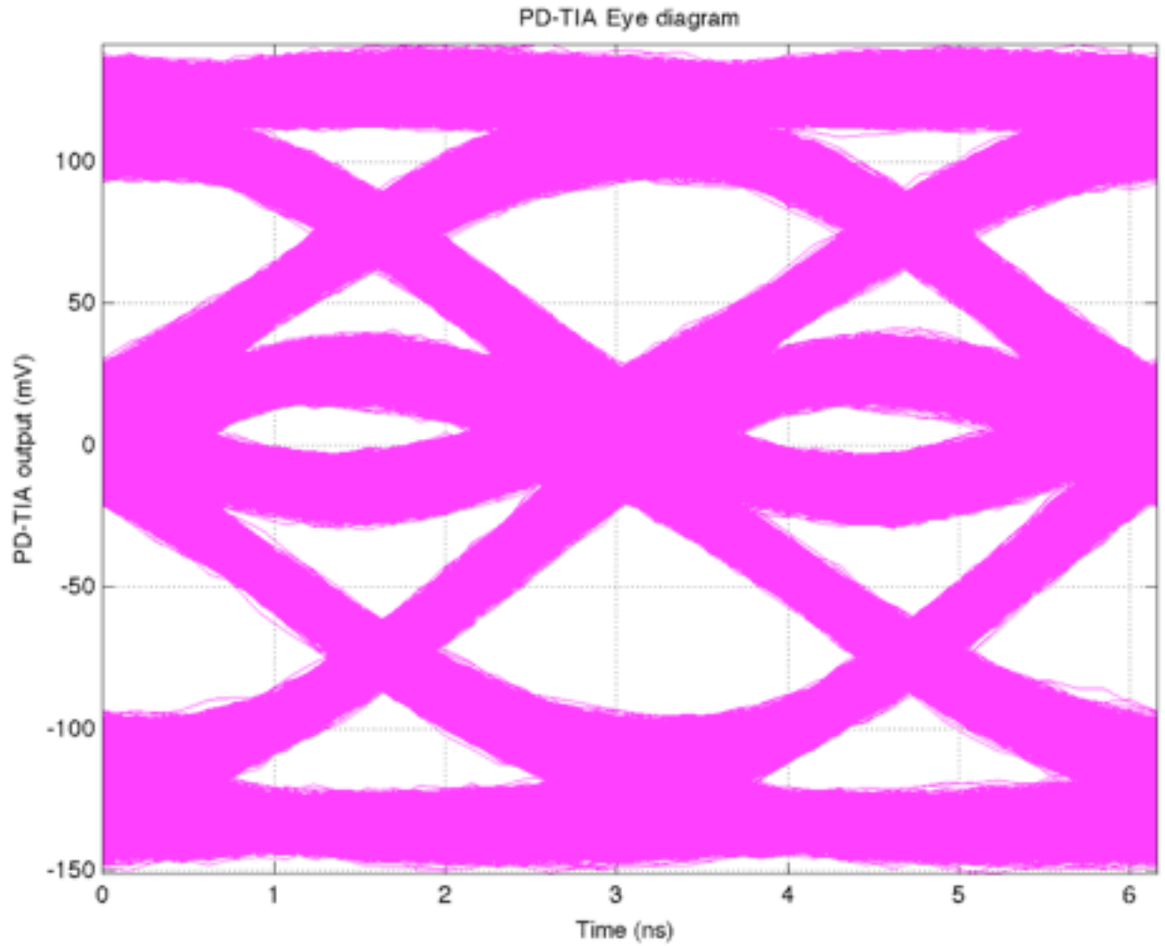


# Eye diagrams for S1, PHS

TP3 - 15m POF + VOA
$AOP_{TP3}$ = -18.5 dBm

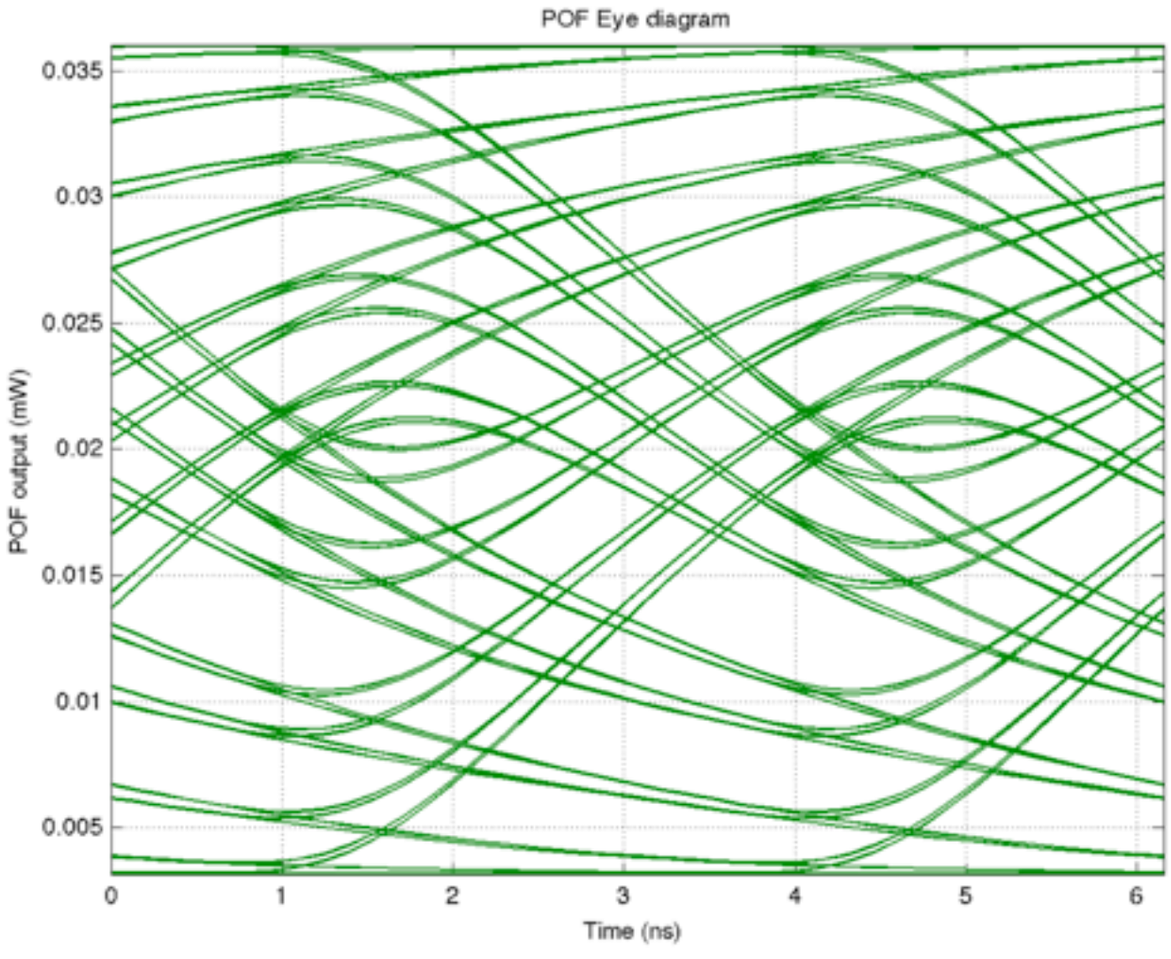



PD-TIA output
(worst case, Tj=125°C)

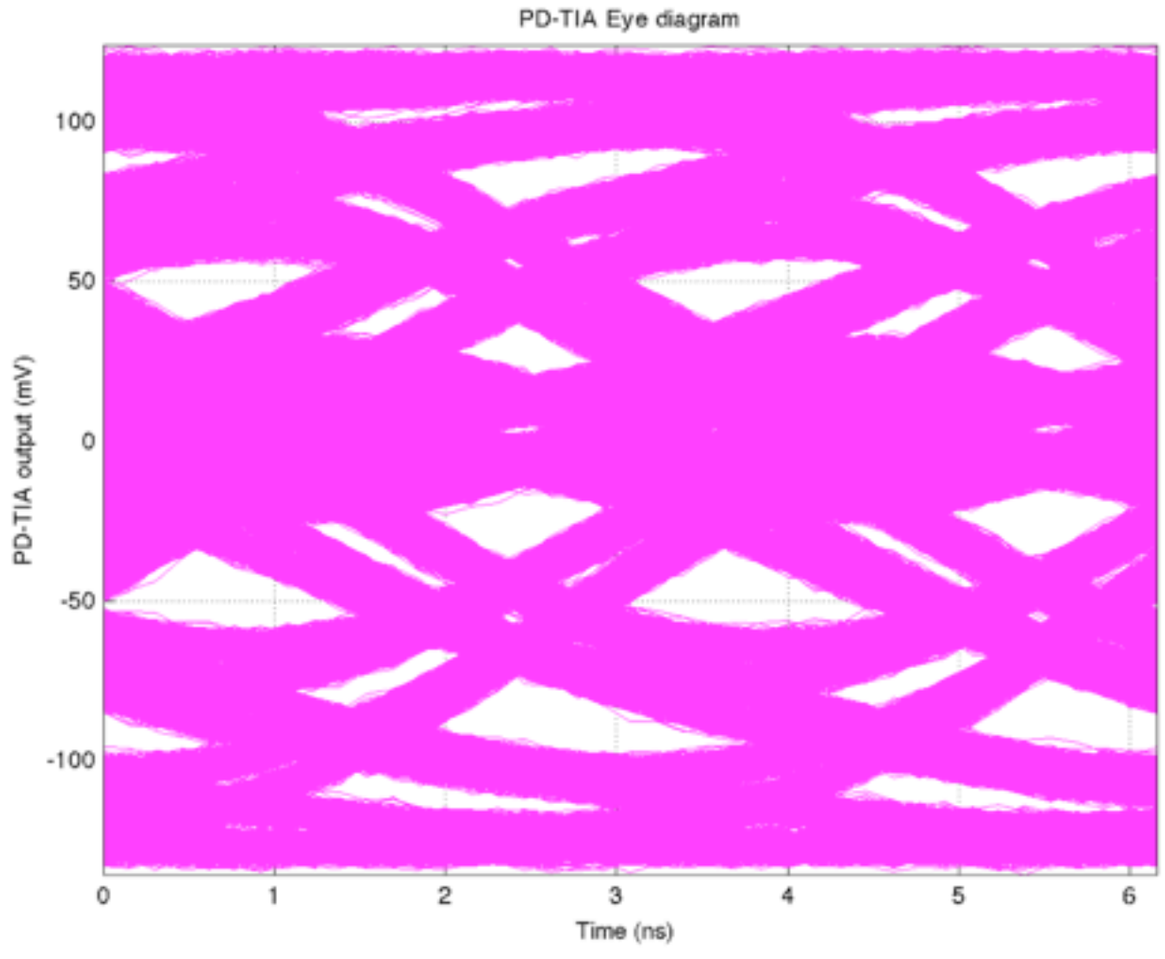


# Eye diagrams for S1, PHS

TP3 - 50m POF + VOA
$AOP_{TP3}$ = -17 dBm

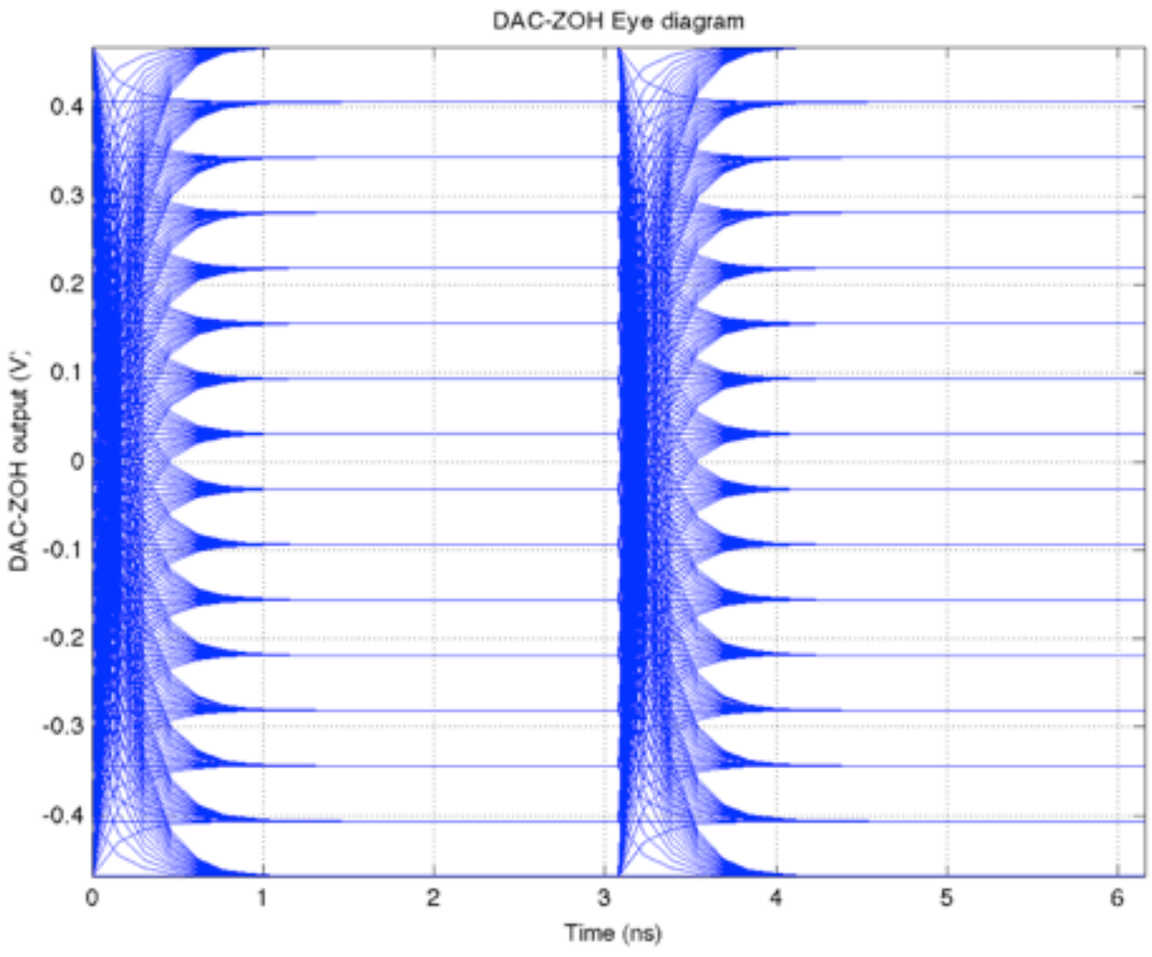



PD-TIA output
(worst case, Tj=125°C)

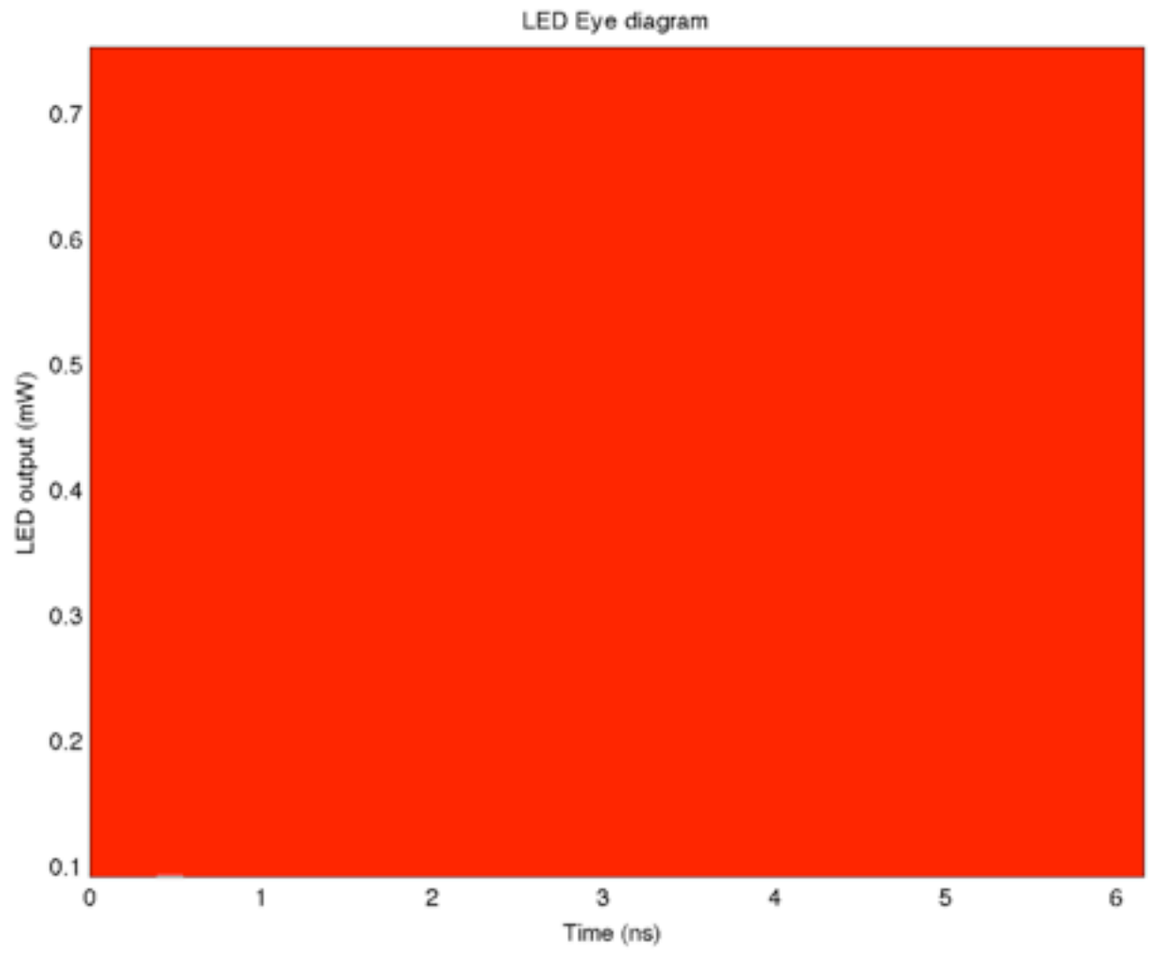


# Eye diagrams for DATA without THP

DAC output

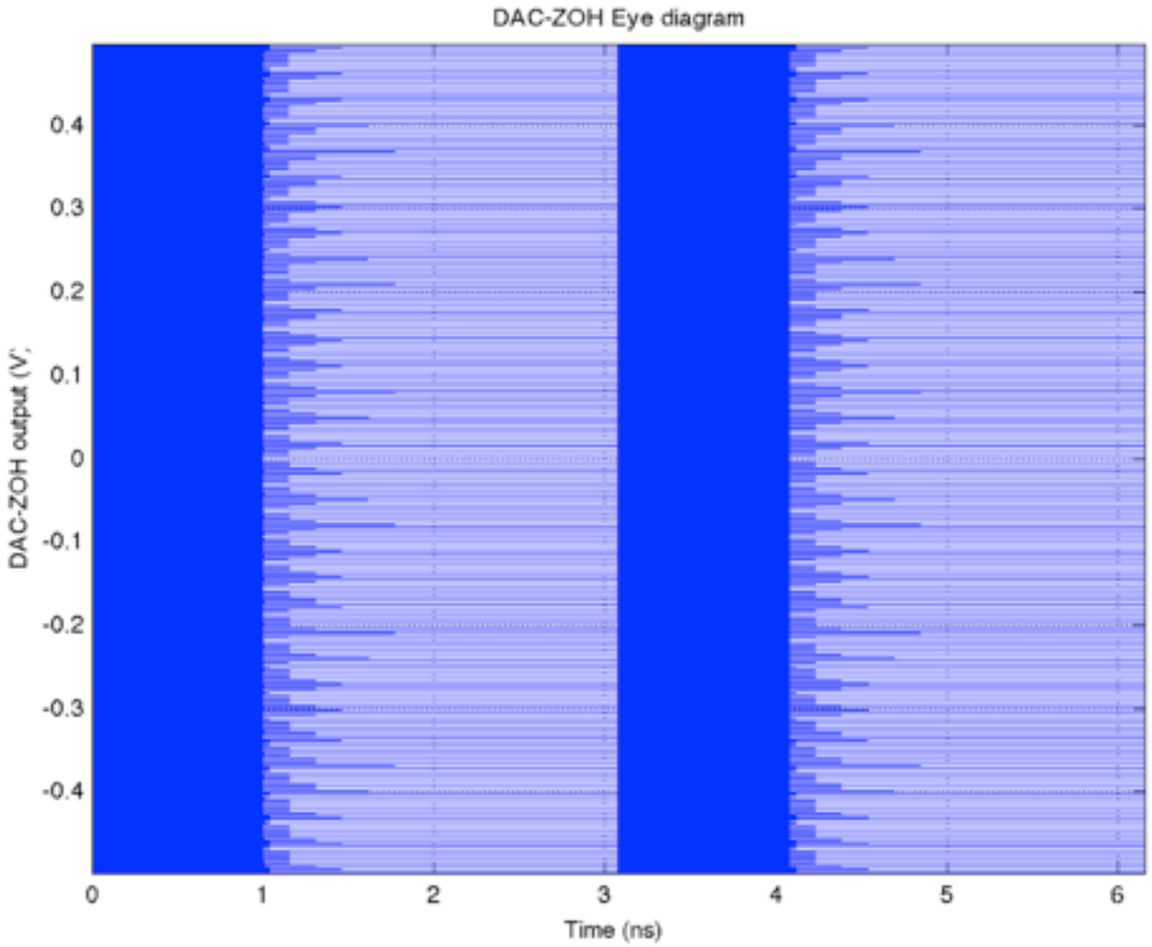



TP2 - Driver+LED output
(worst case response)

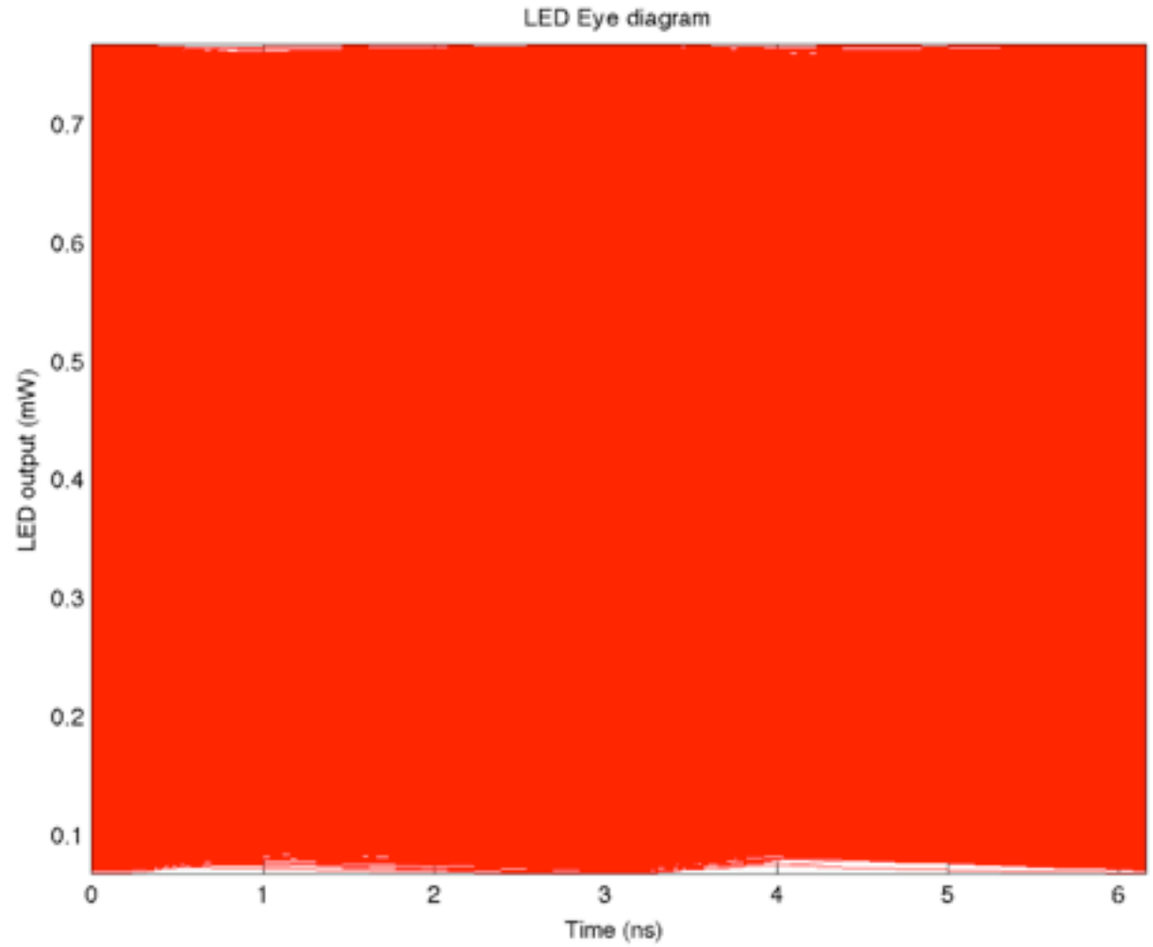


# Eye diagrams for S2

## DAC output

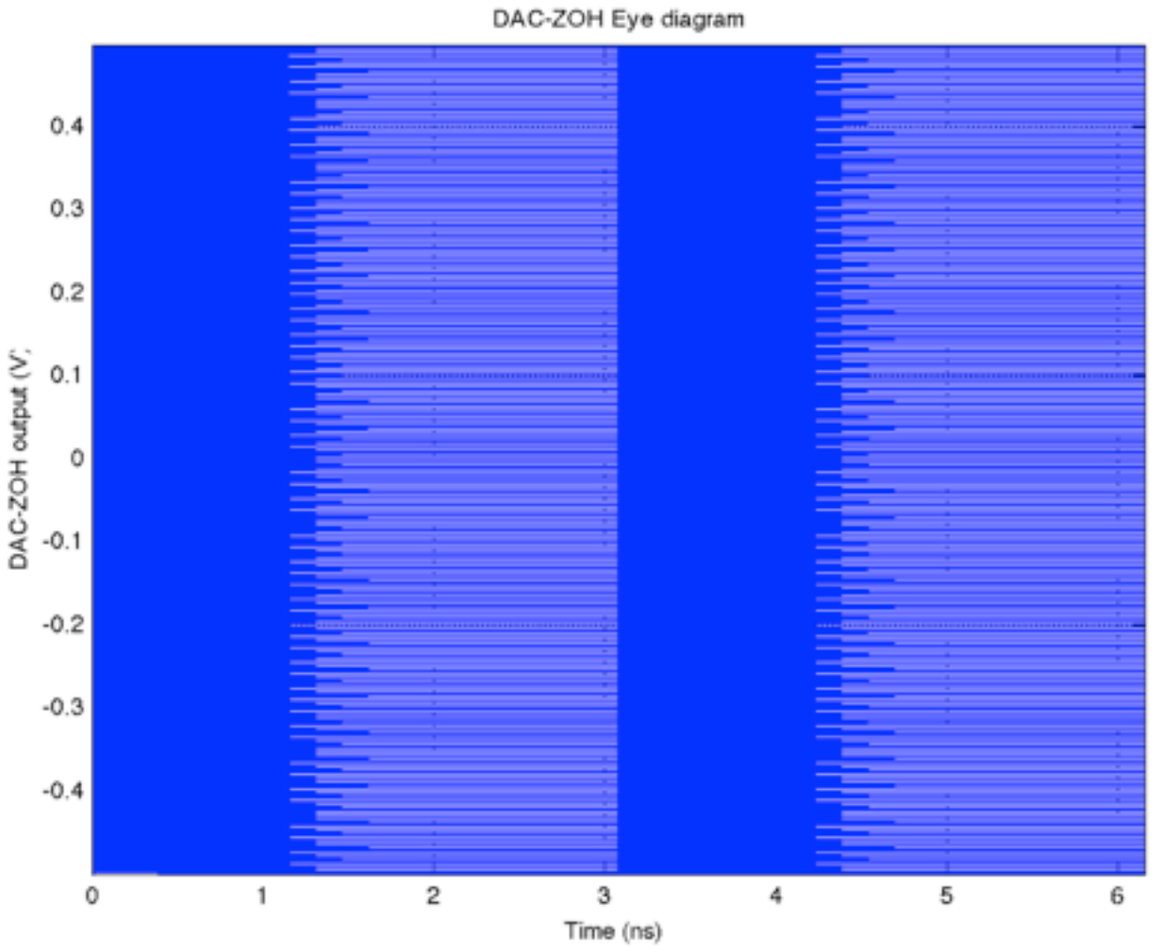



## TP2 - Driver+LED output (worst case response)

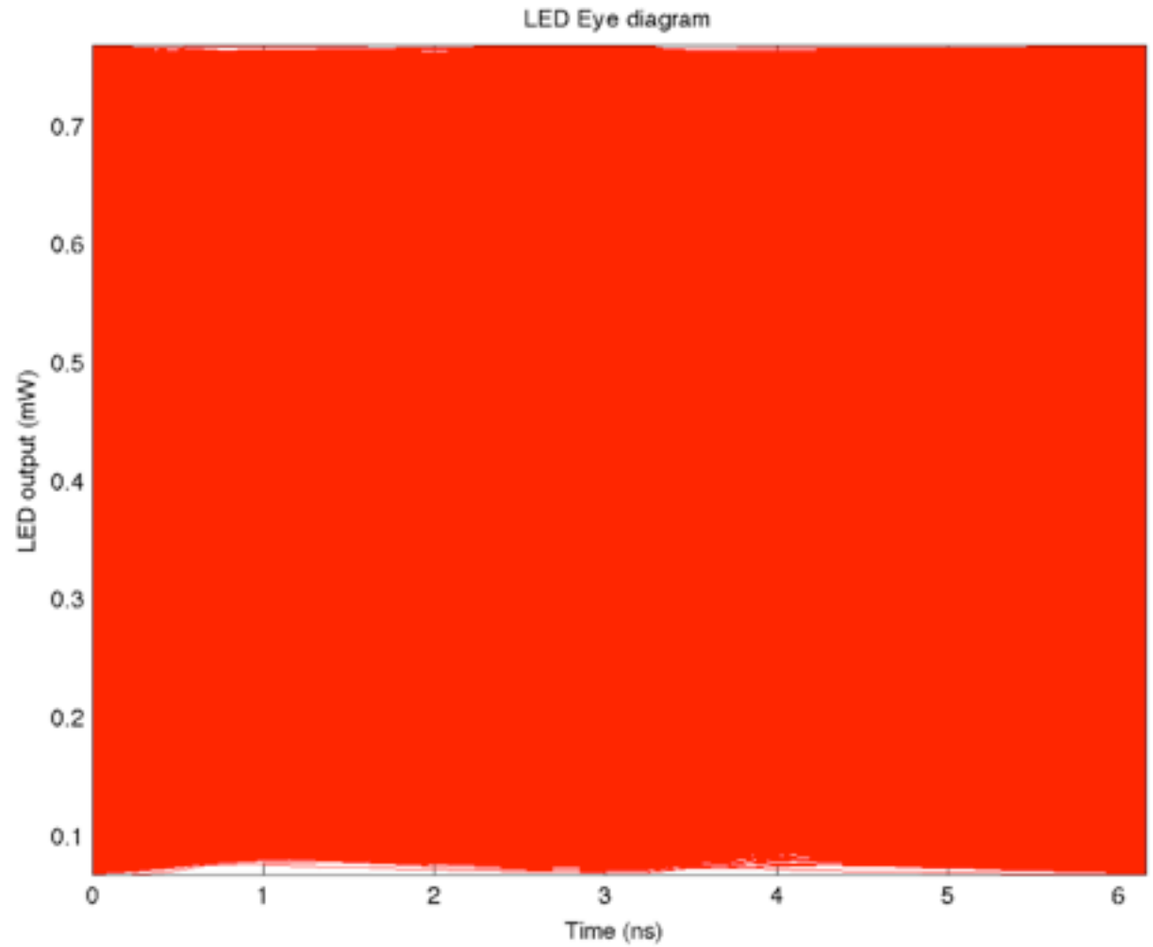


# Eye diagrams for DATA with THP

DAC output

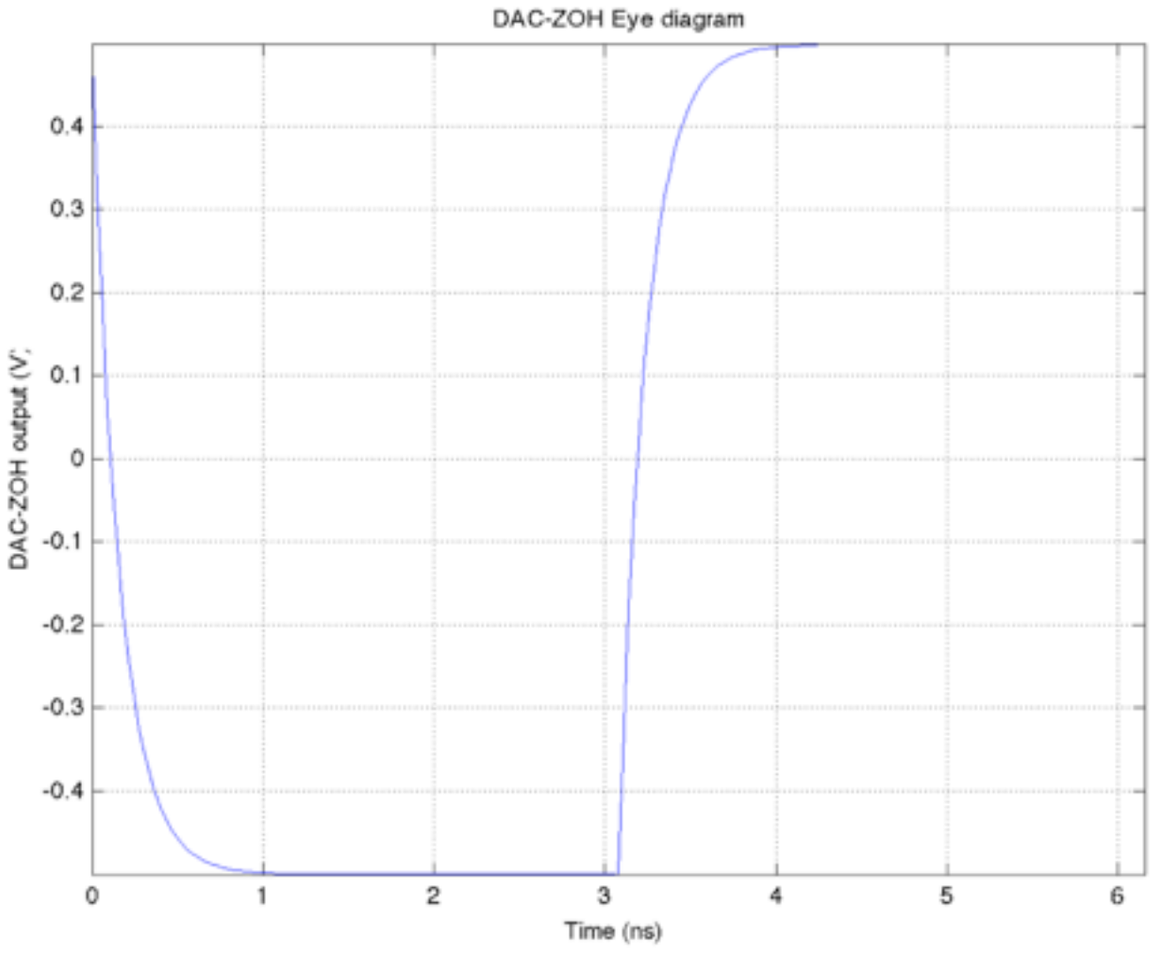



TP2 - Driver+LED output
(worst case response)

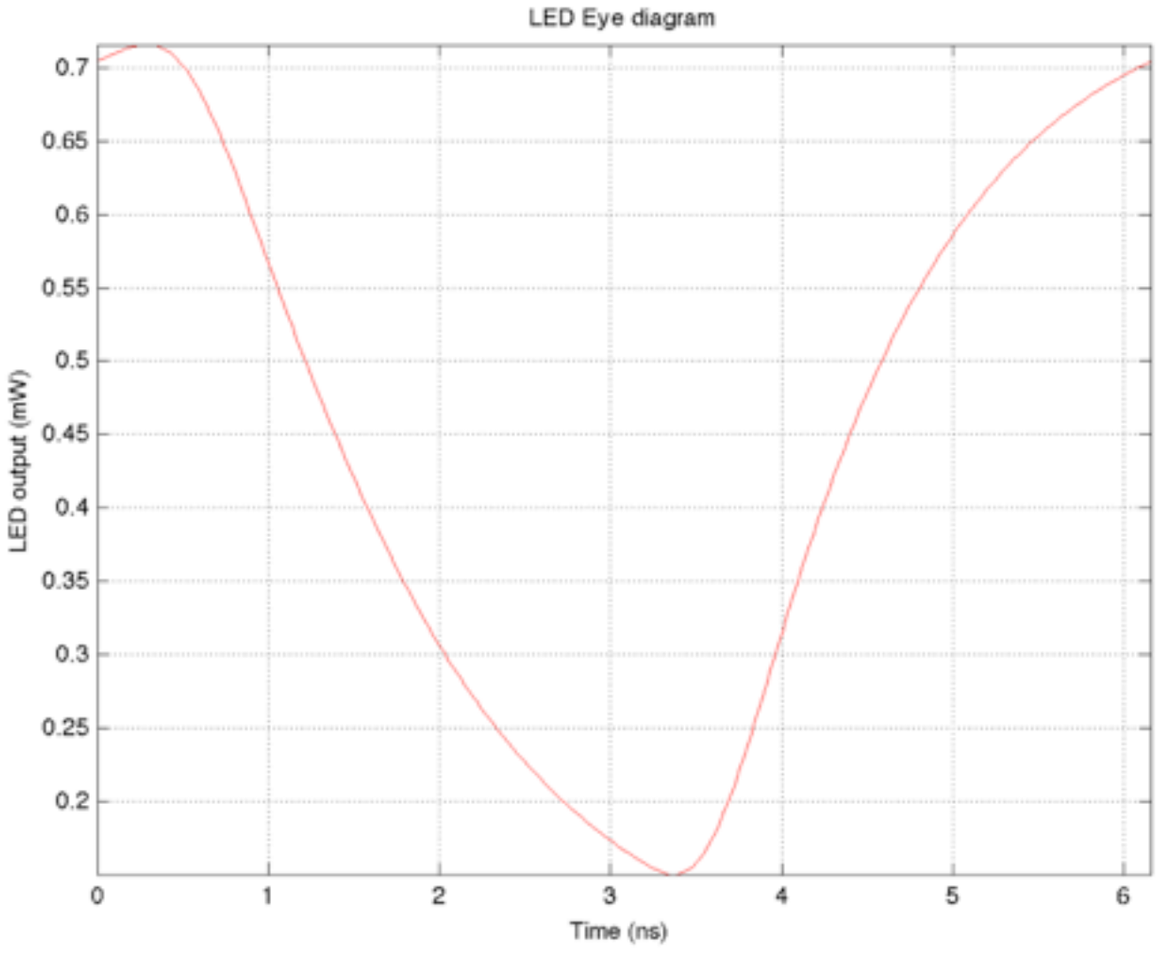


# Eye diagrams for Test mode 2

DAC output

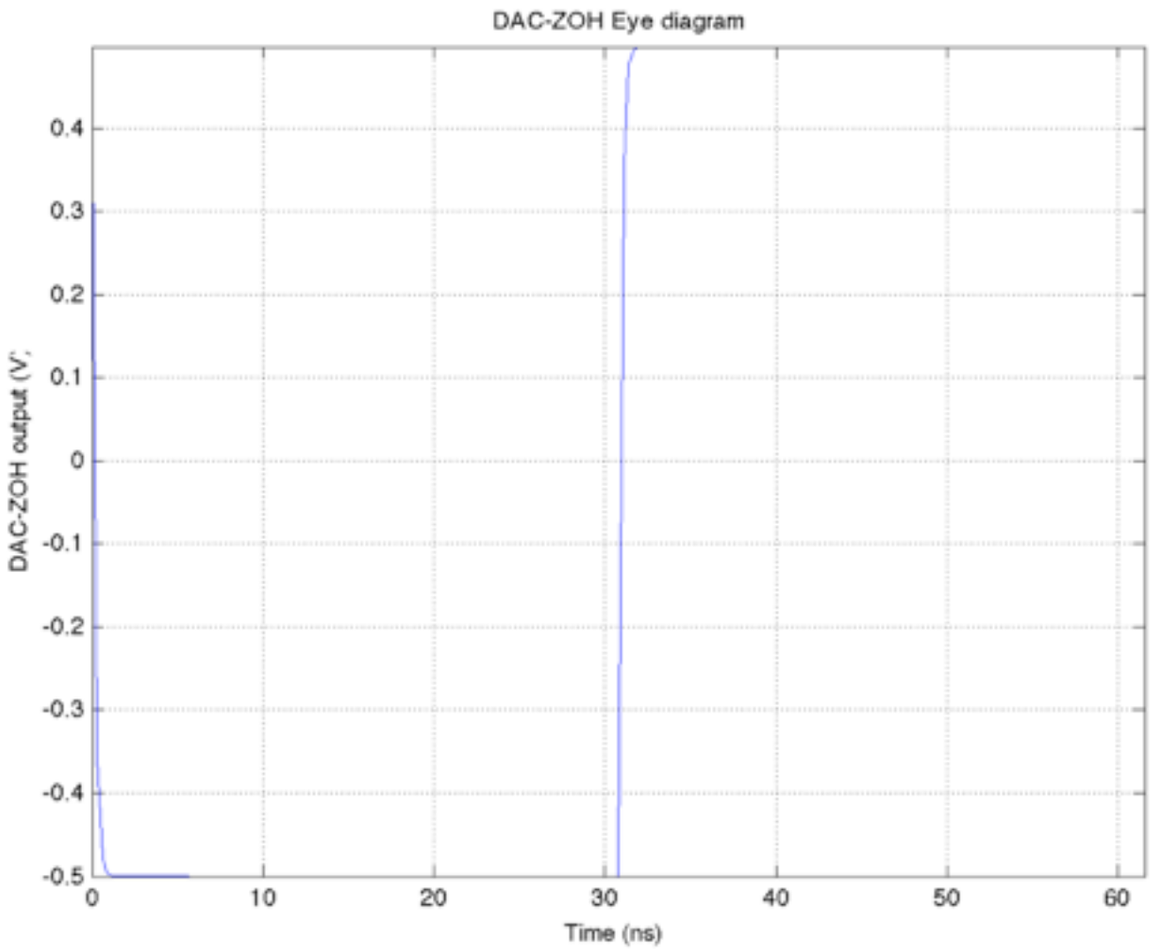



TP2 - Driver+LED output
(worst case response)

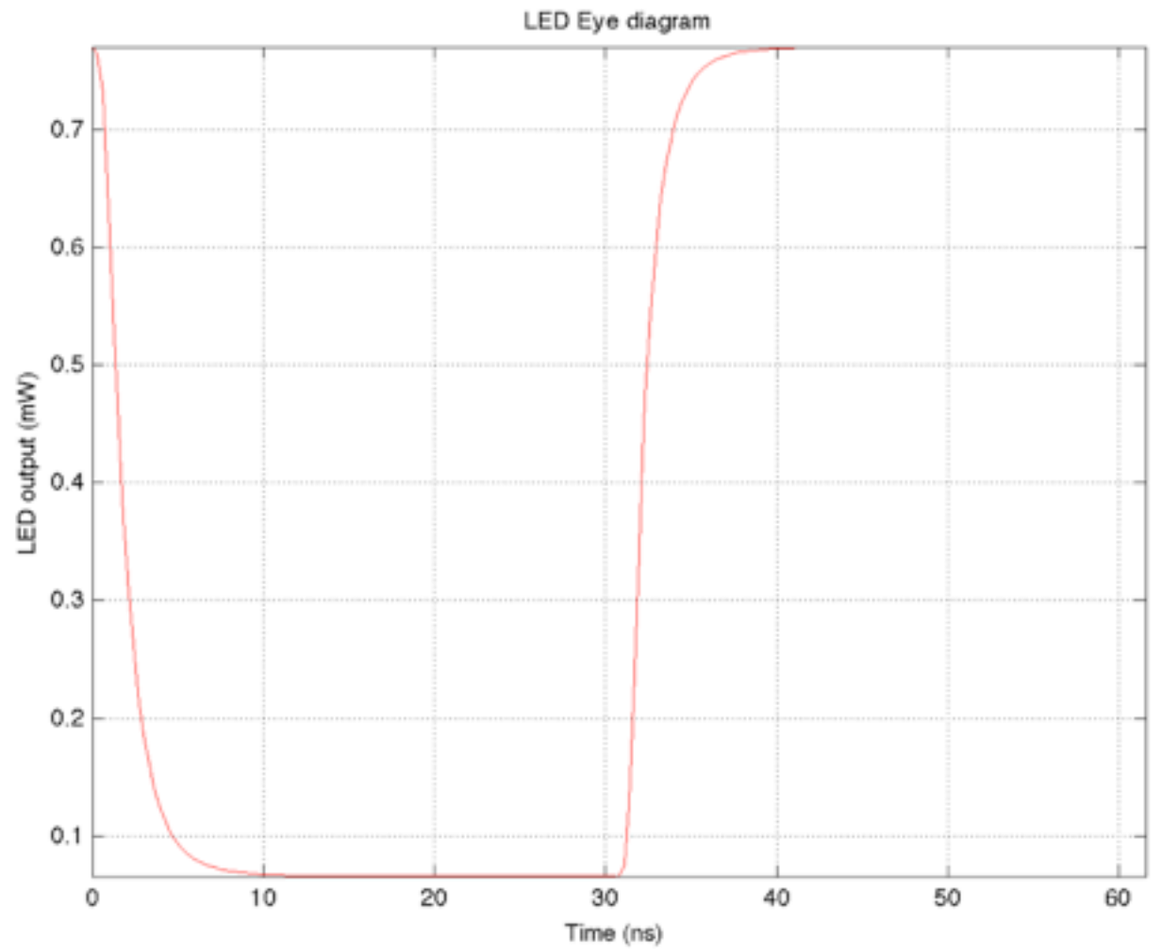


# Eye diagrams for Test mode 3

DAC output



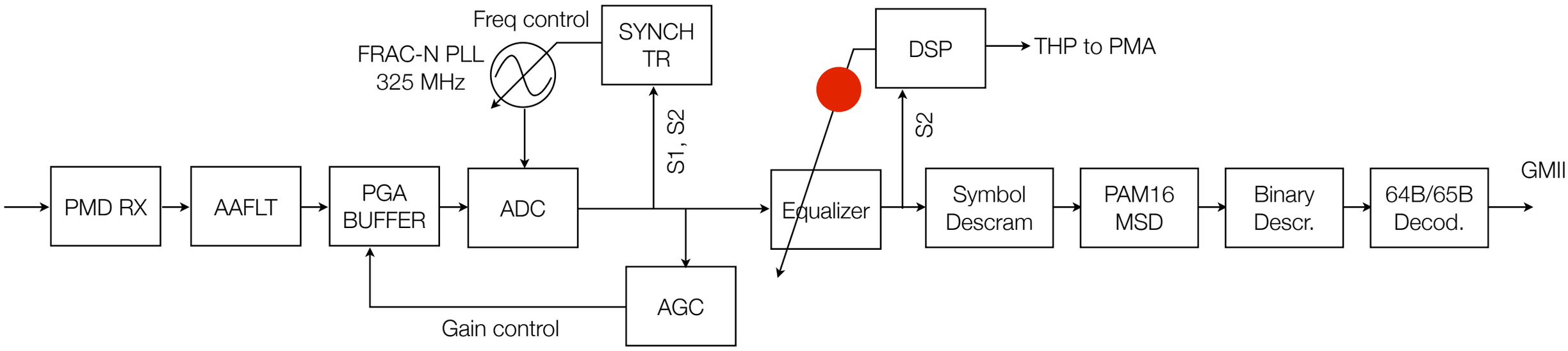

TP2 - Driver+LED output
(worst case response)



# 1000BASE-RH receiver operation

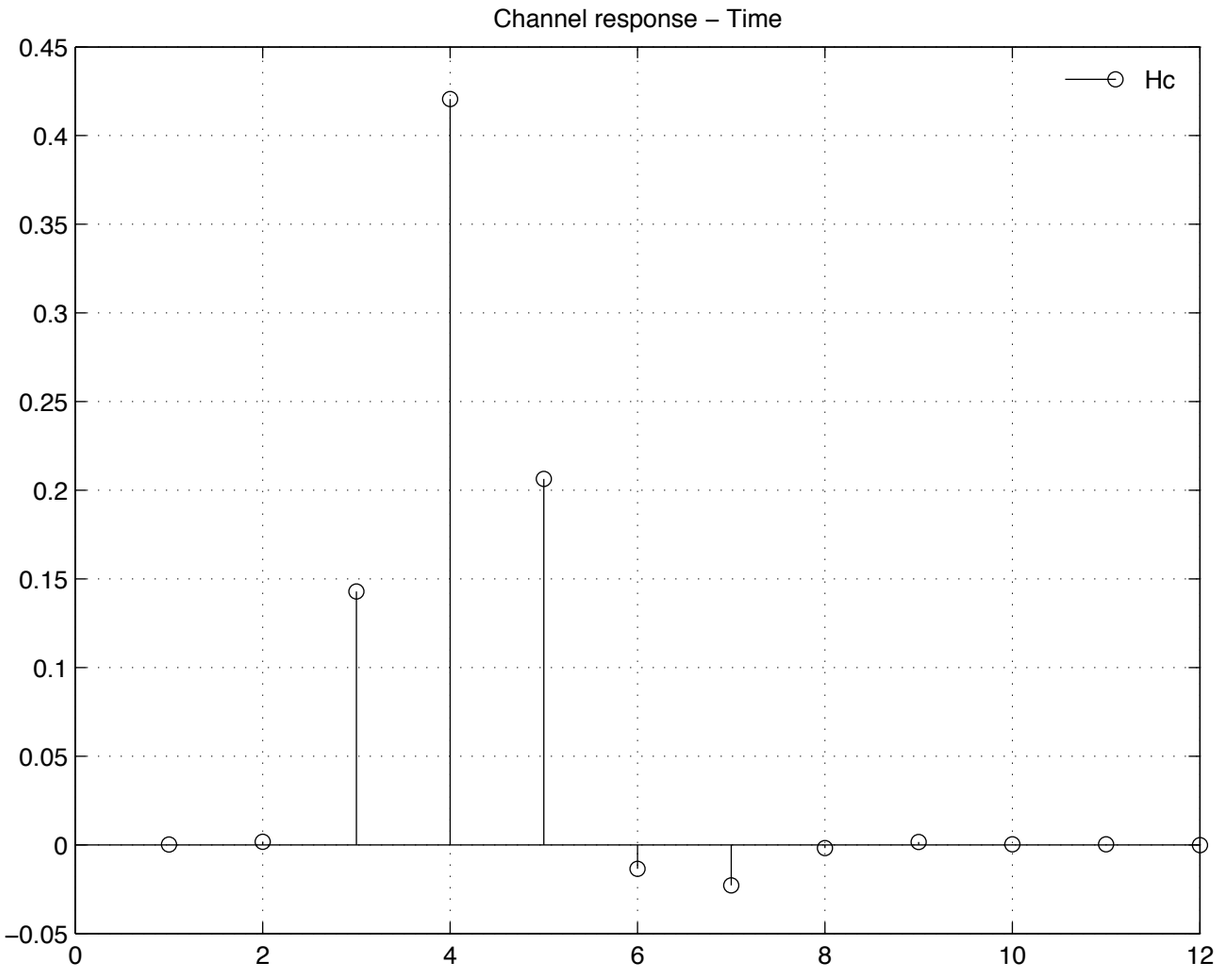
15 m of POF at sensitivity

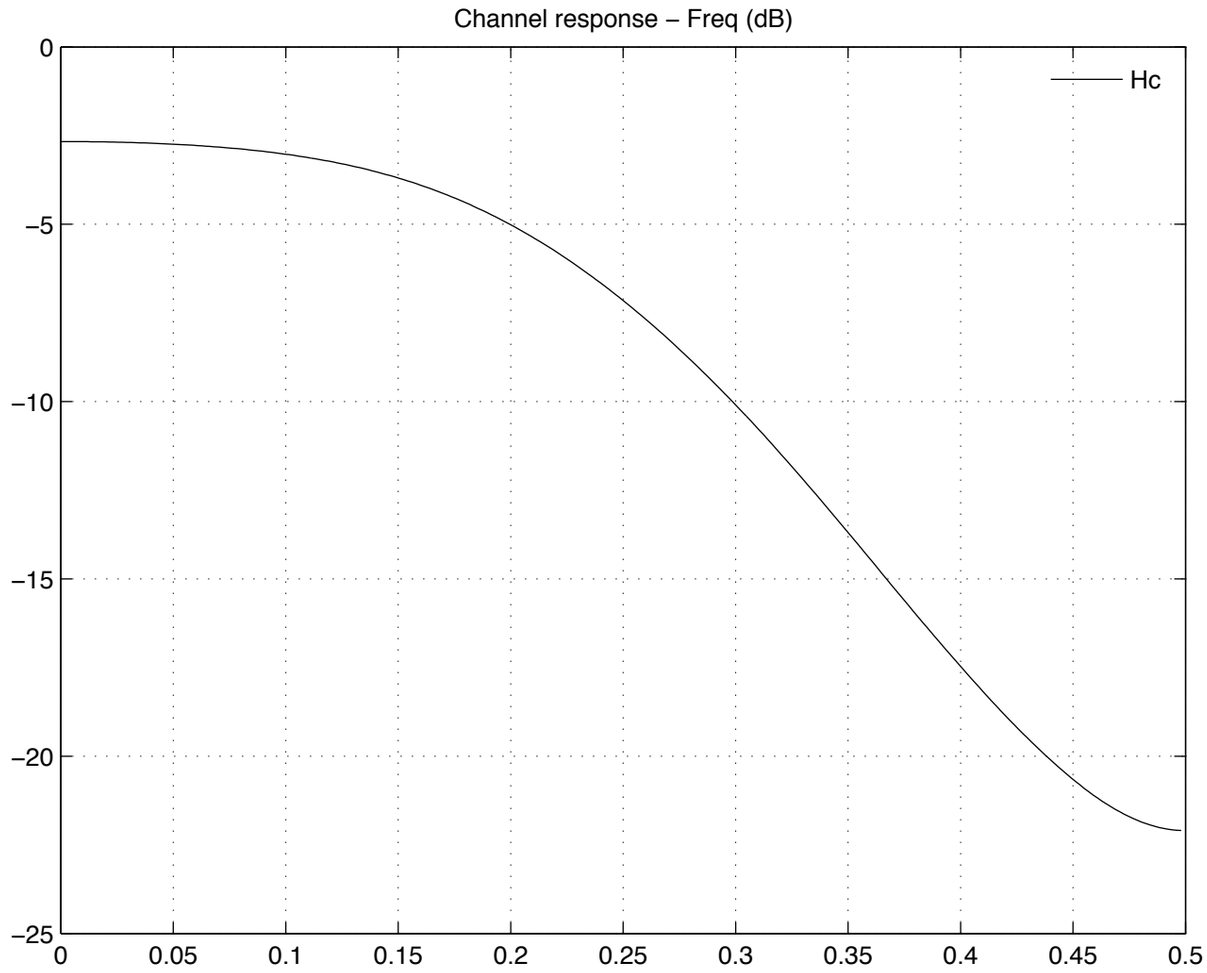
# 1000BASE-RH PHY receiver operation



# 1000BASE-RH PHY estimated channel

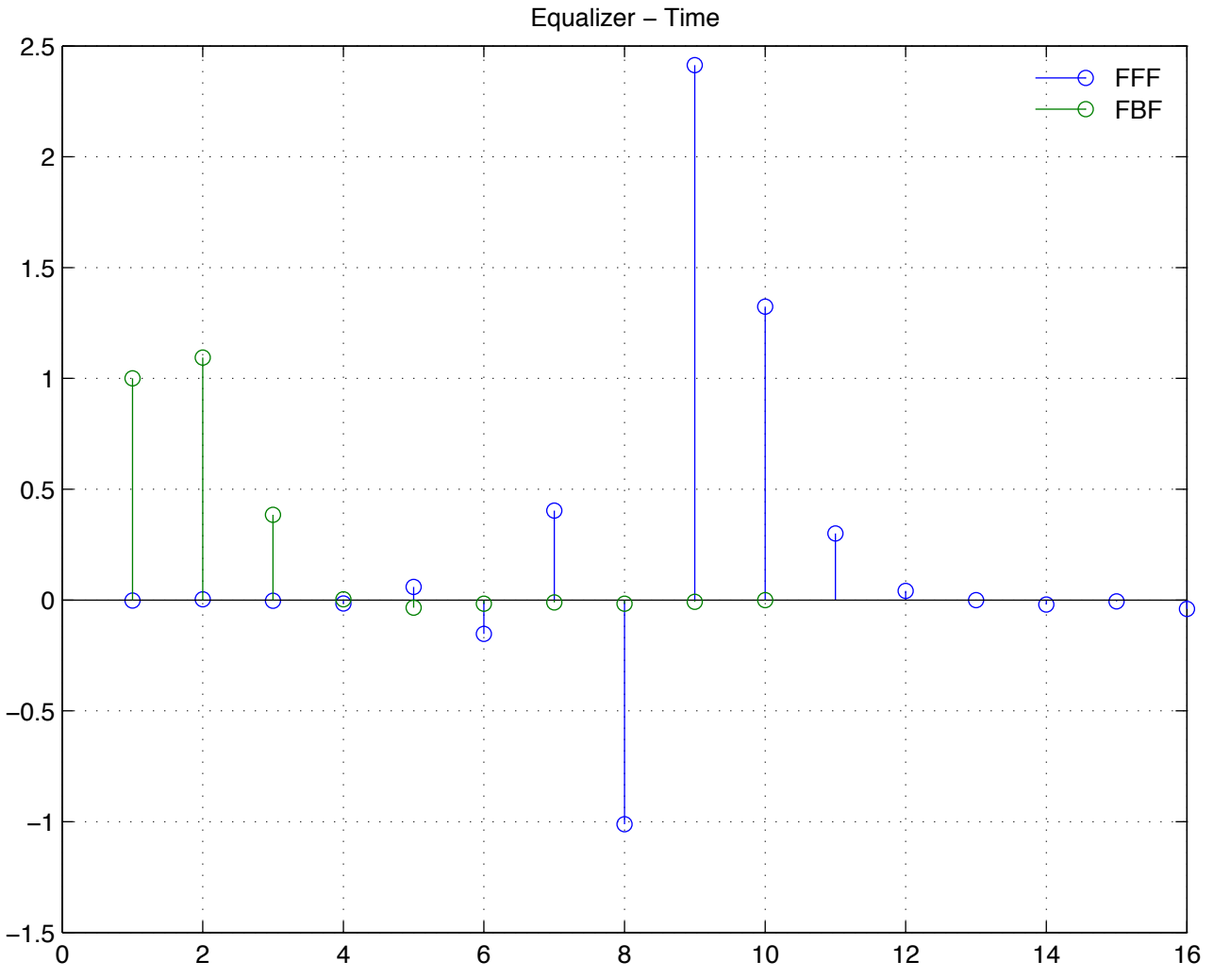
## 15m POF at sensitivity

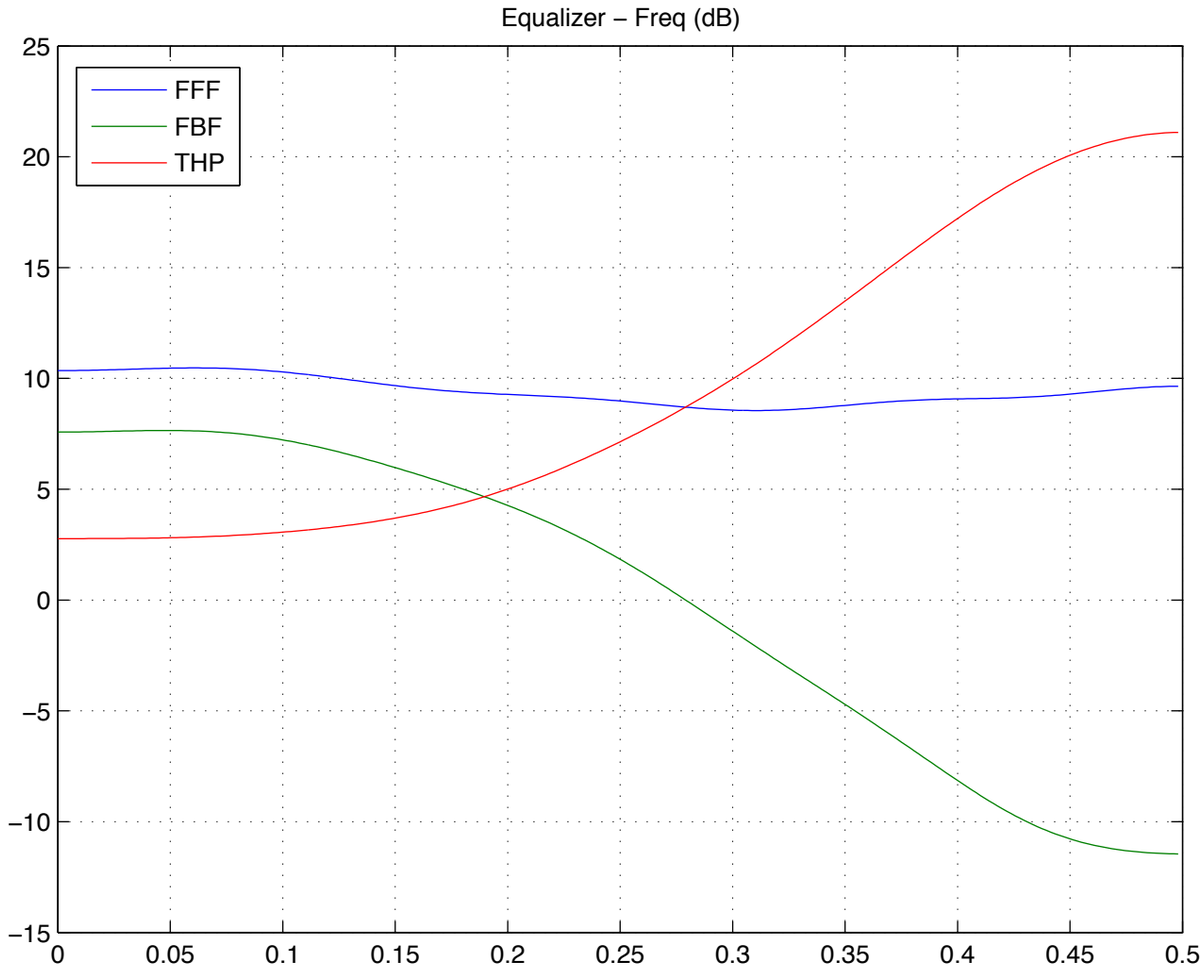


# 1000BASE-RH PHY estimated THP

## 15m POF at sensitivity



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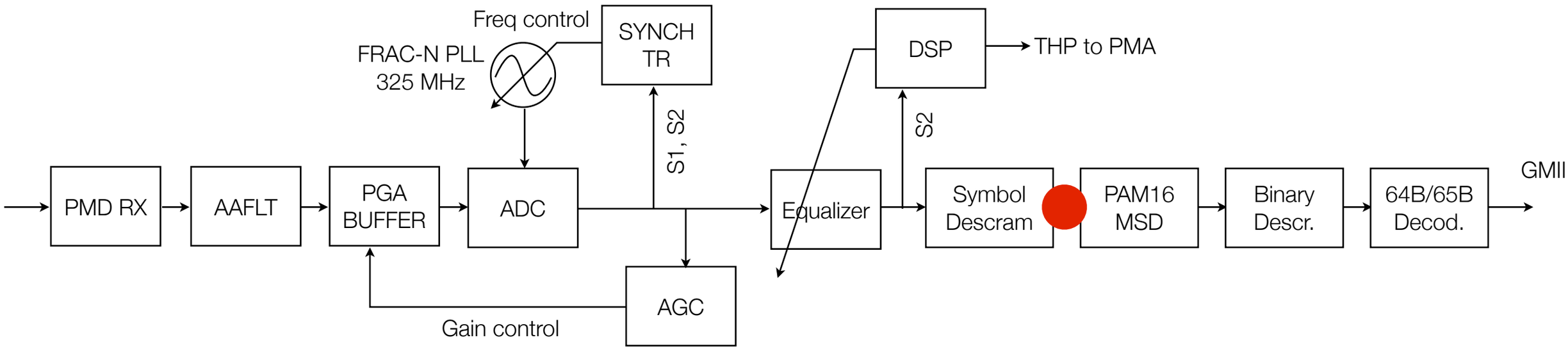
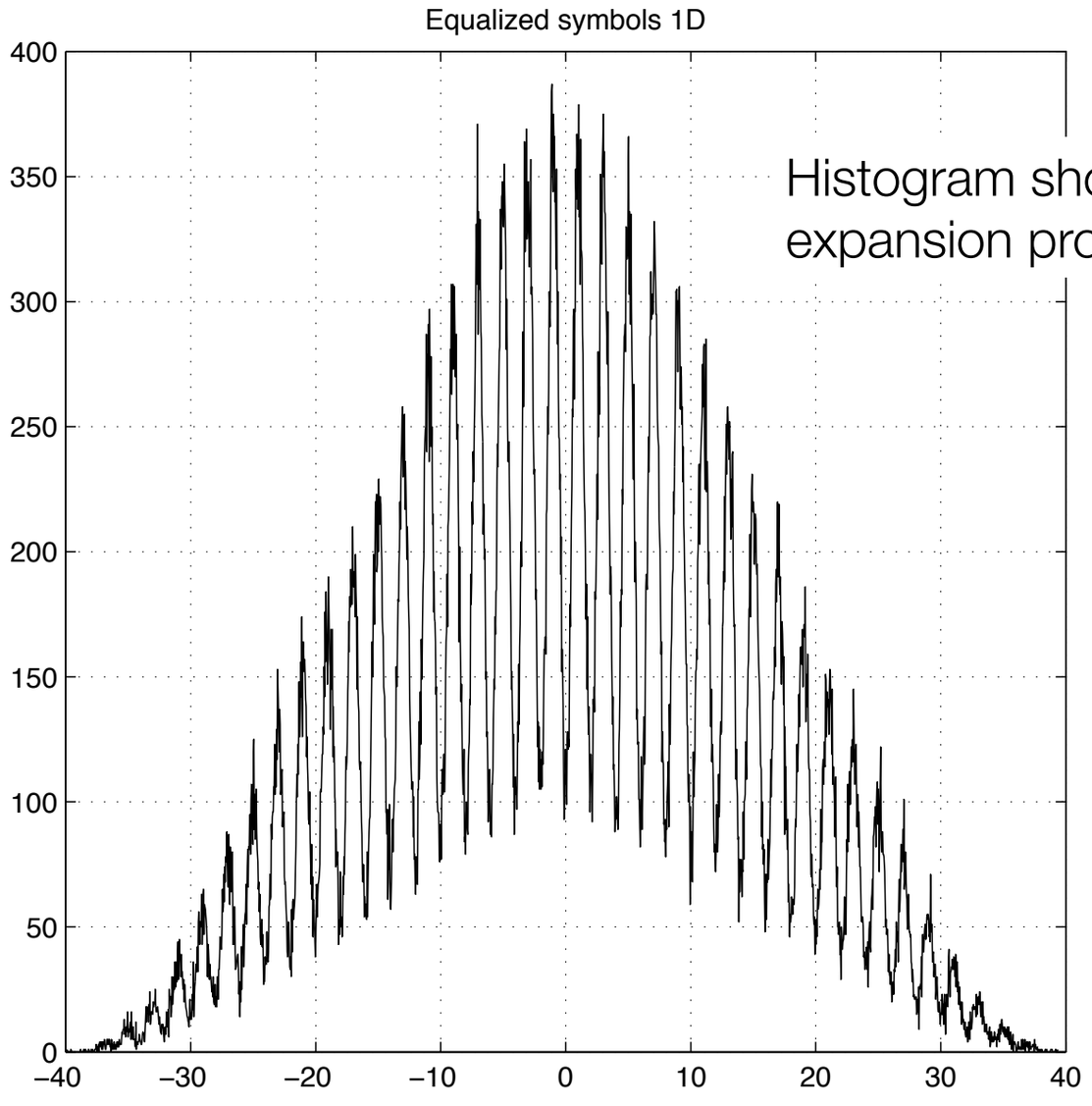


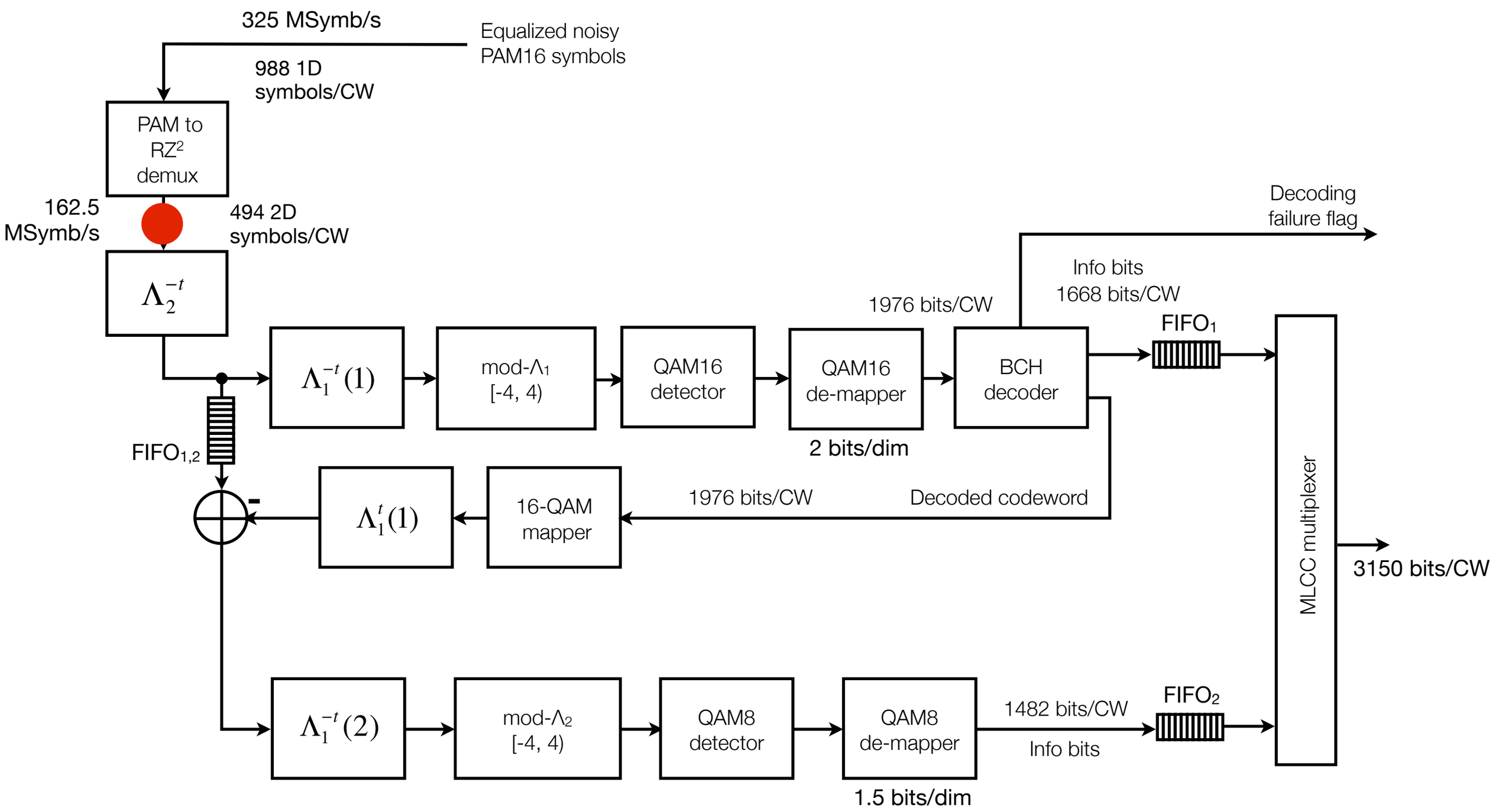
# 1000BASE-RH PHY equalized 1D symbols

## 15m POF at sensitivity



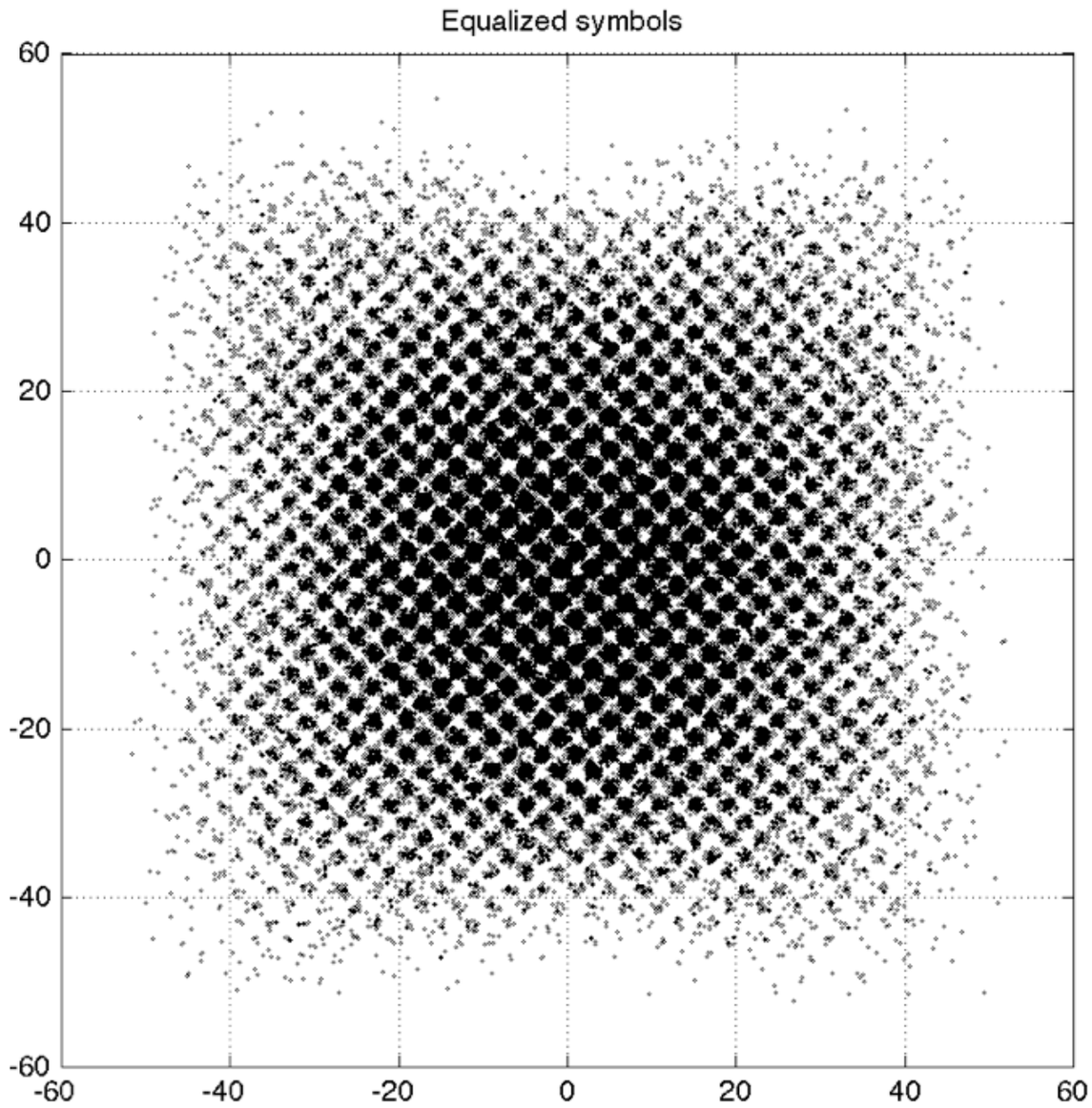

Histogram shows the constellation expansion produced by THP

# PAM16 multi-stage decoder

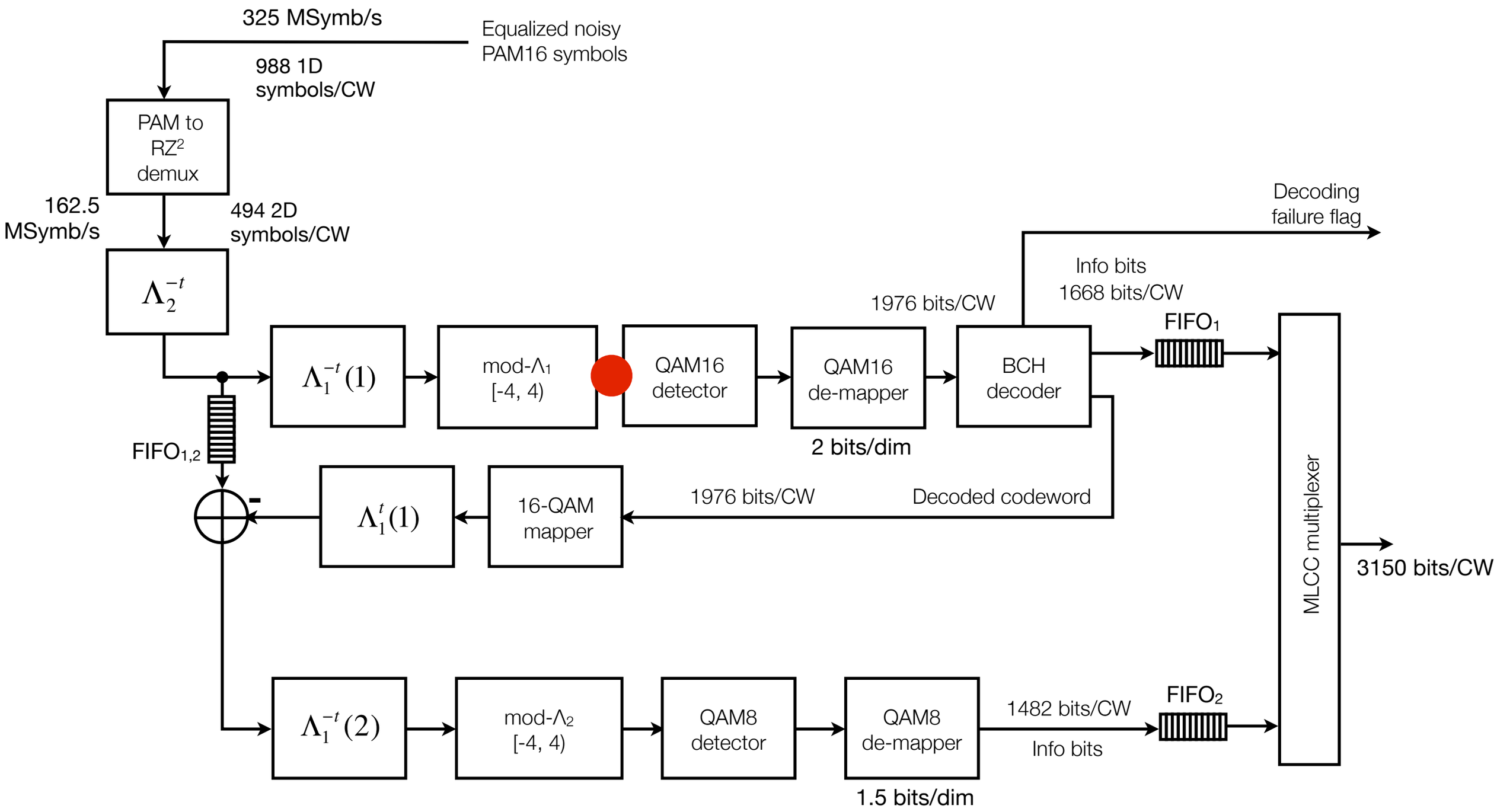


# PAM16 multi-stage decoder - PAM to 2D demux

## 15m POF at sensitivity

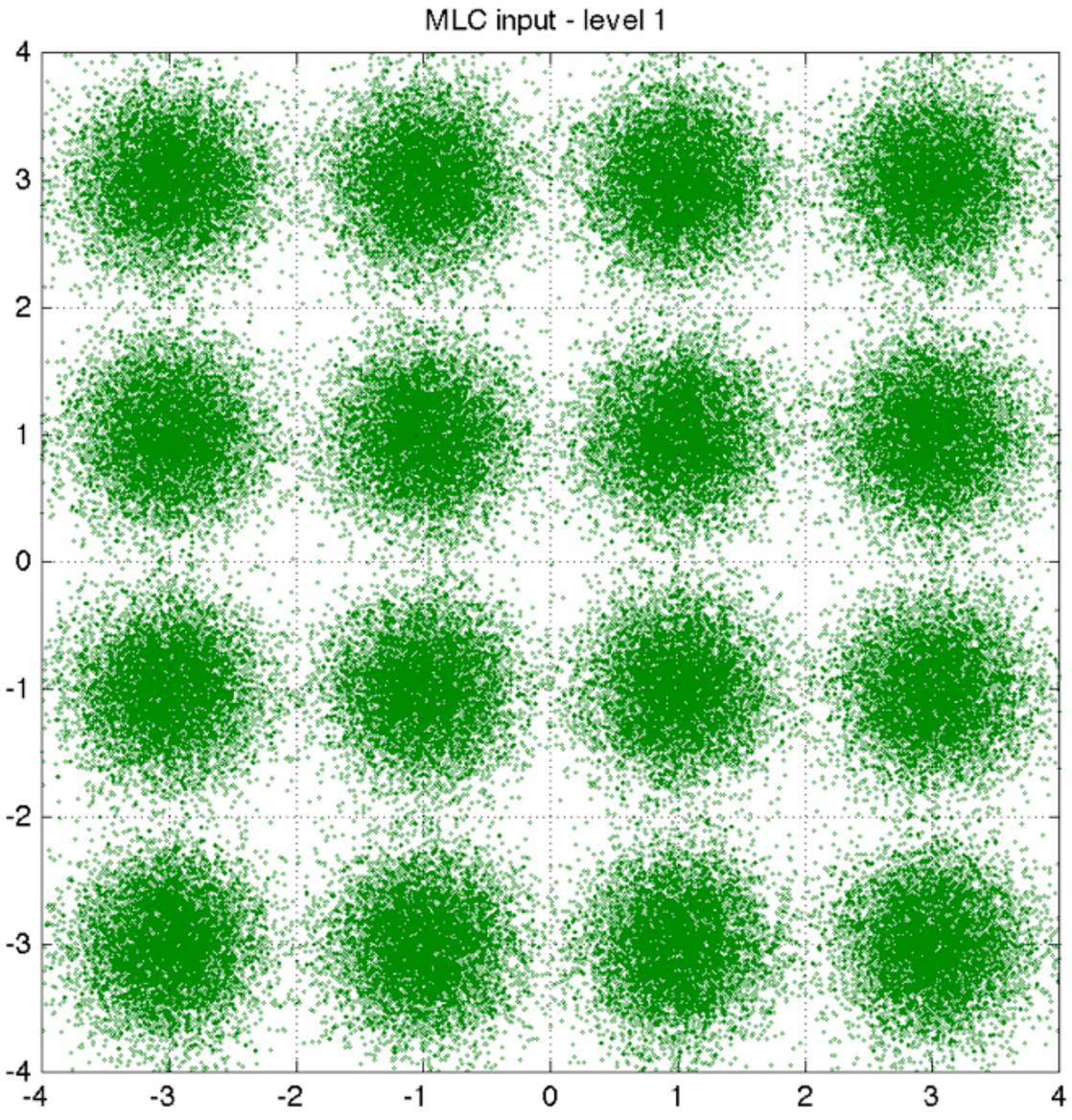


# PAM16 multi-stage decoder

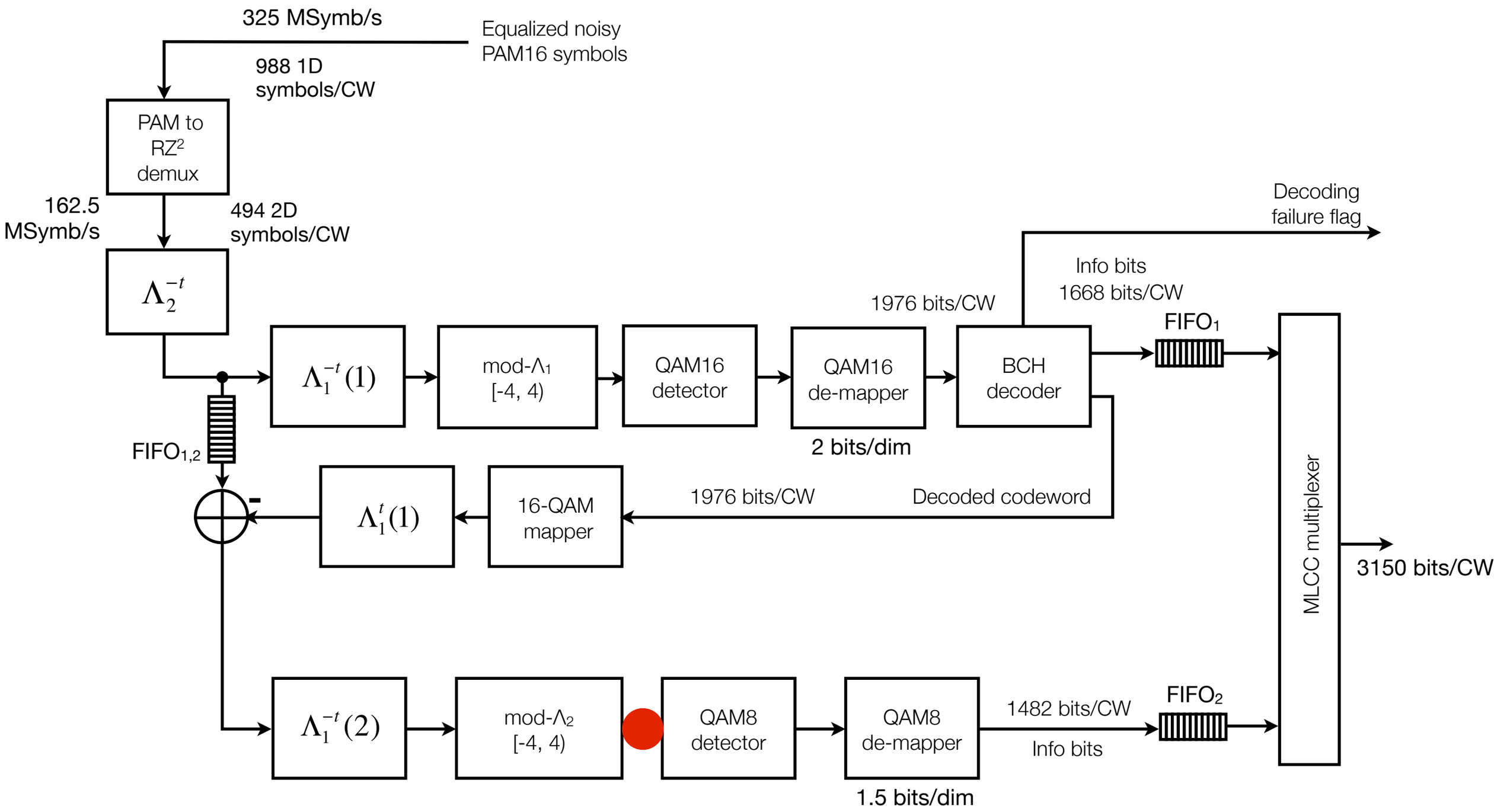


# PAM16 multi-stage decoder - 1st level input

## 15m POF at sensitivity

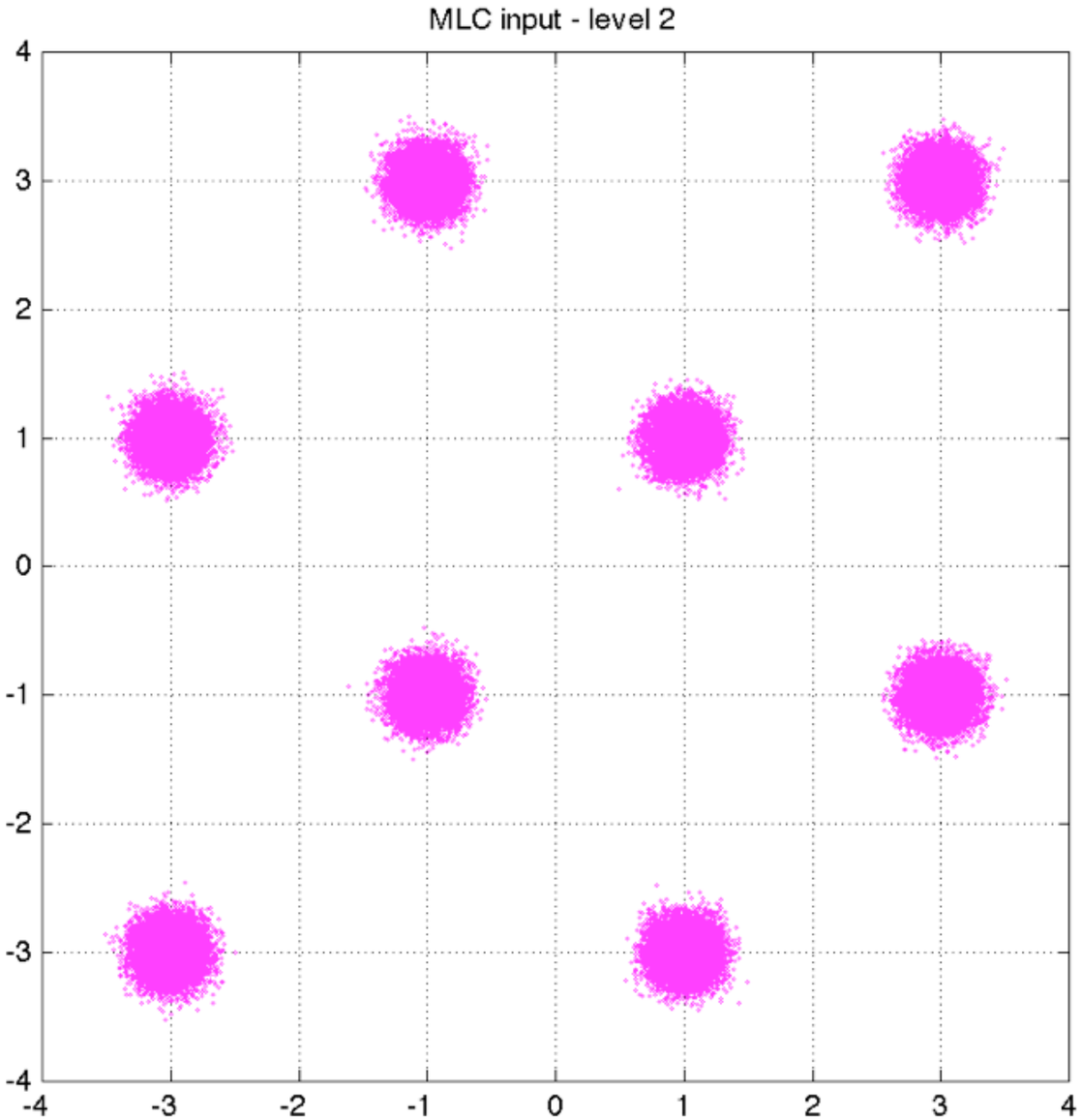


# PAM16 multi-stage decoder



# PAM16 multi-stage decoder - 2nd level input

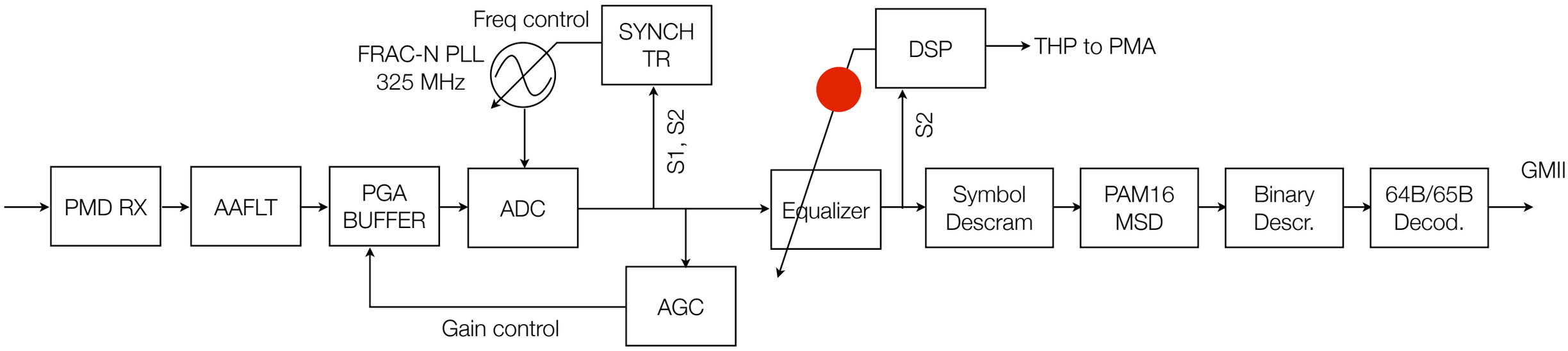
15m POF at sensitivity



# 1000BASE-RH receiver operation

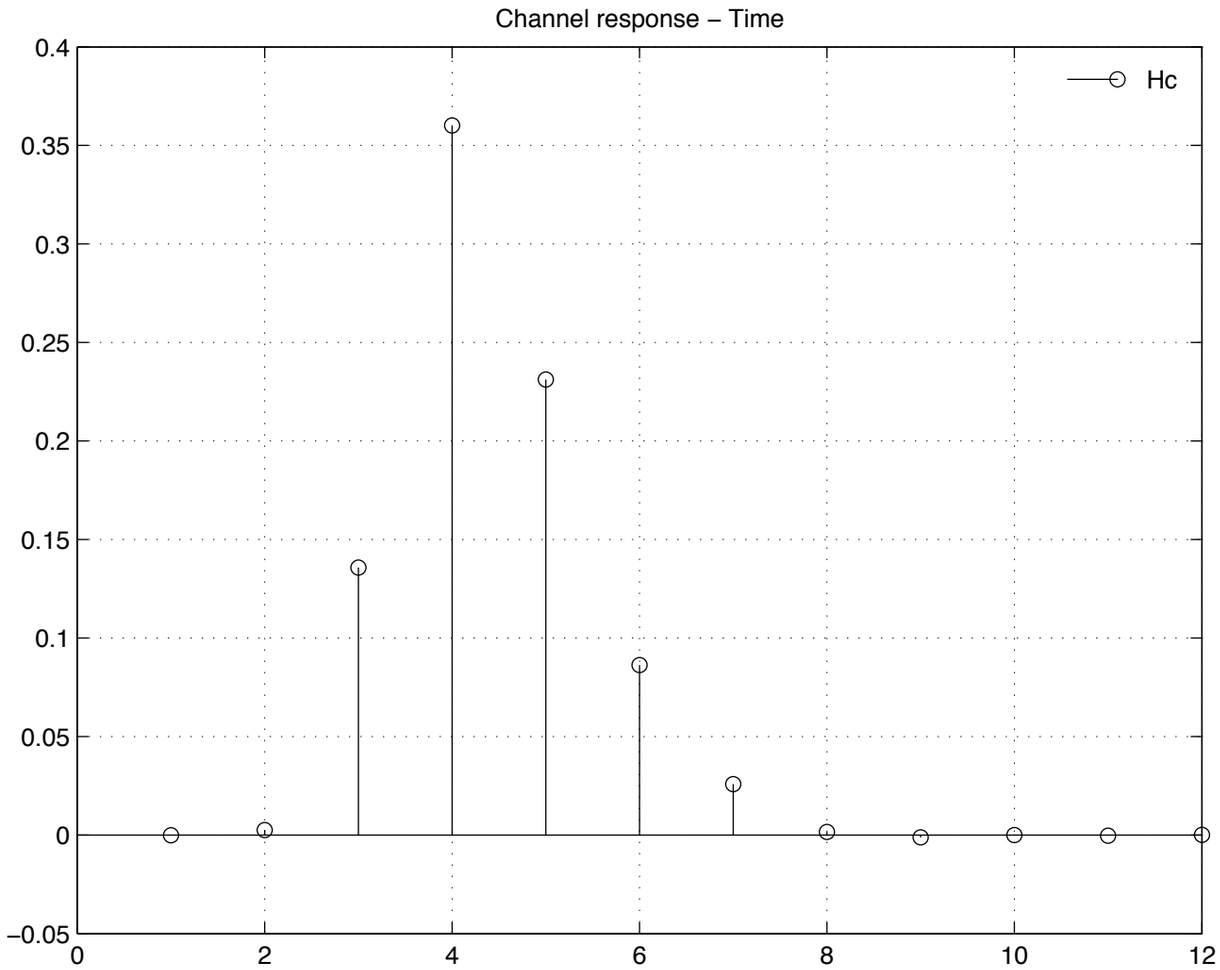
50 m of POF at sensitivity

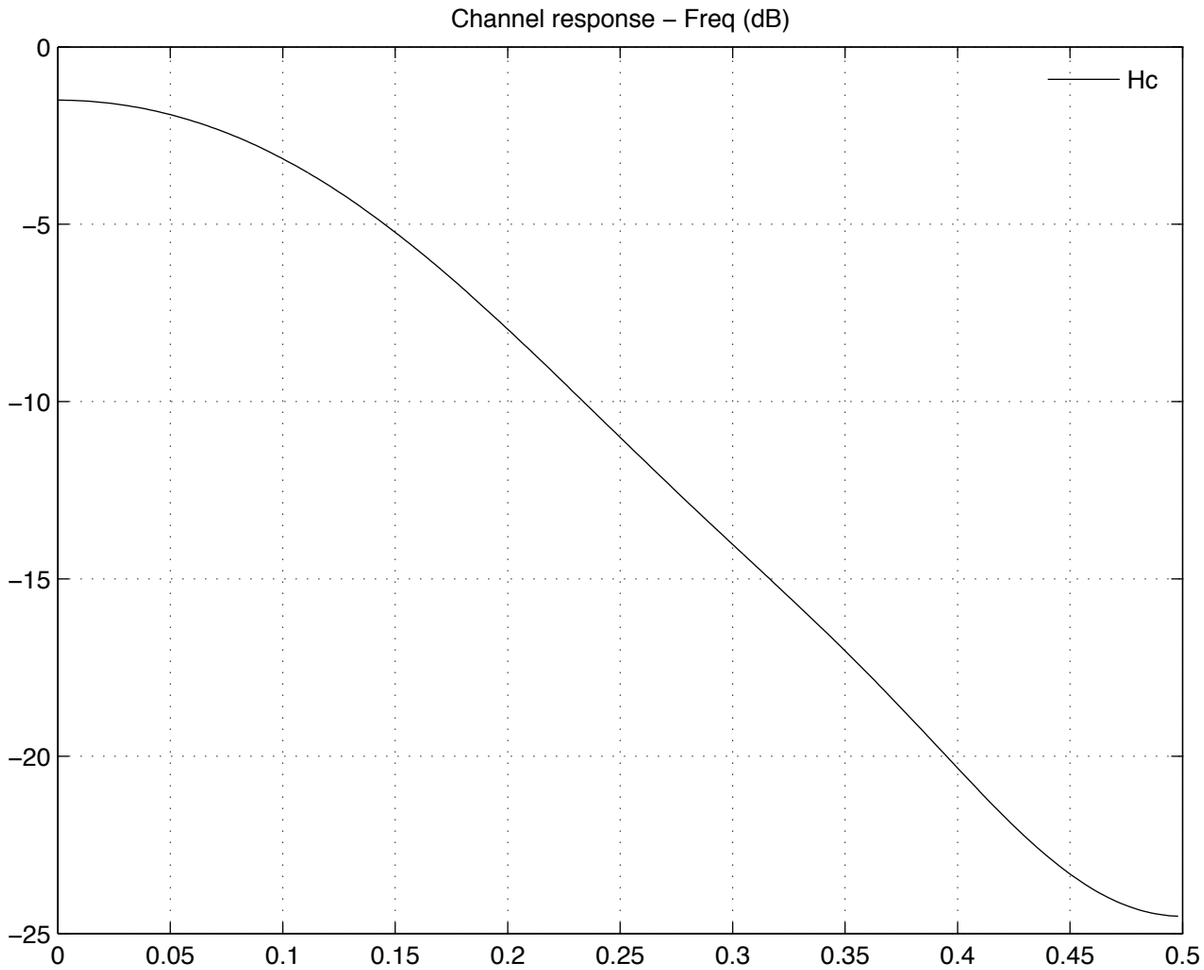
# 1000BASE-RH PHY receiver operation



# 1000BASE-RH PHY estimated channel

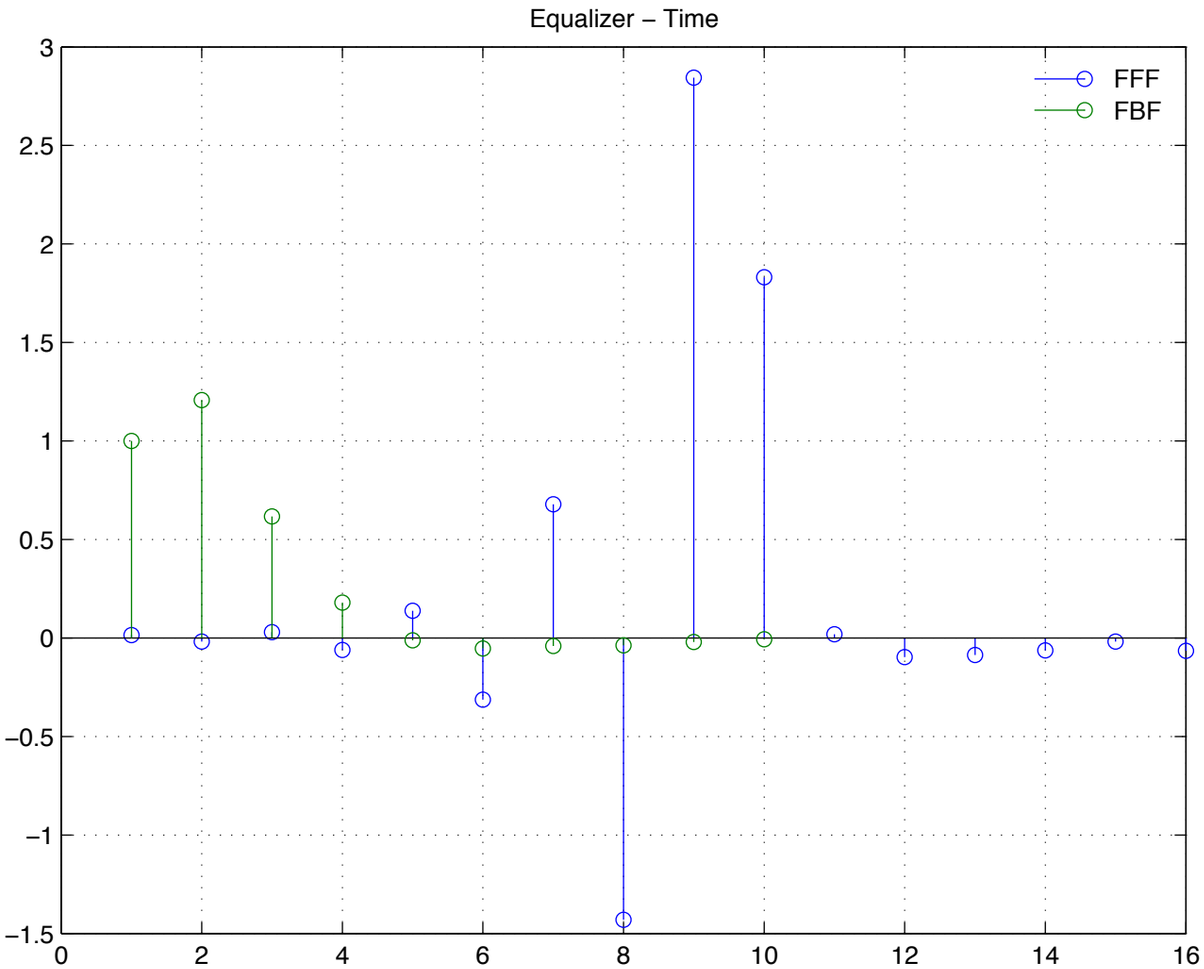
## 50m POF at sensitivity

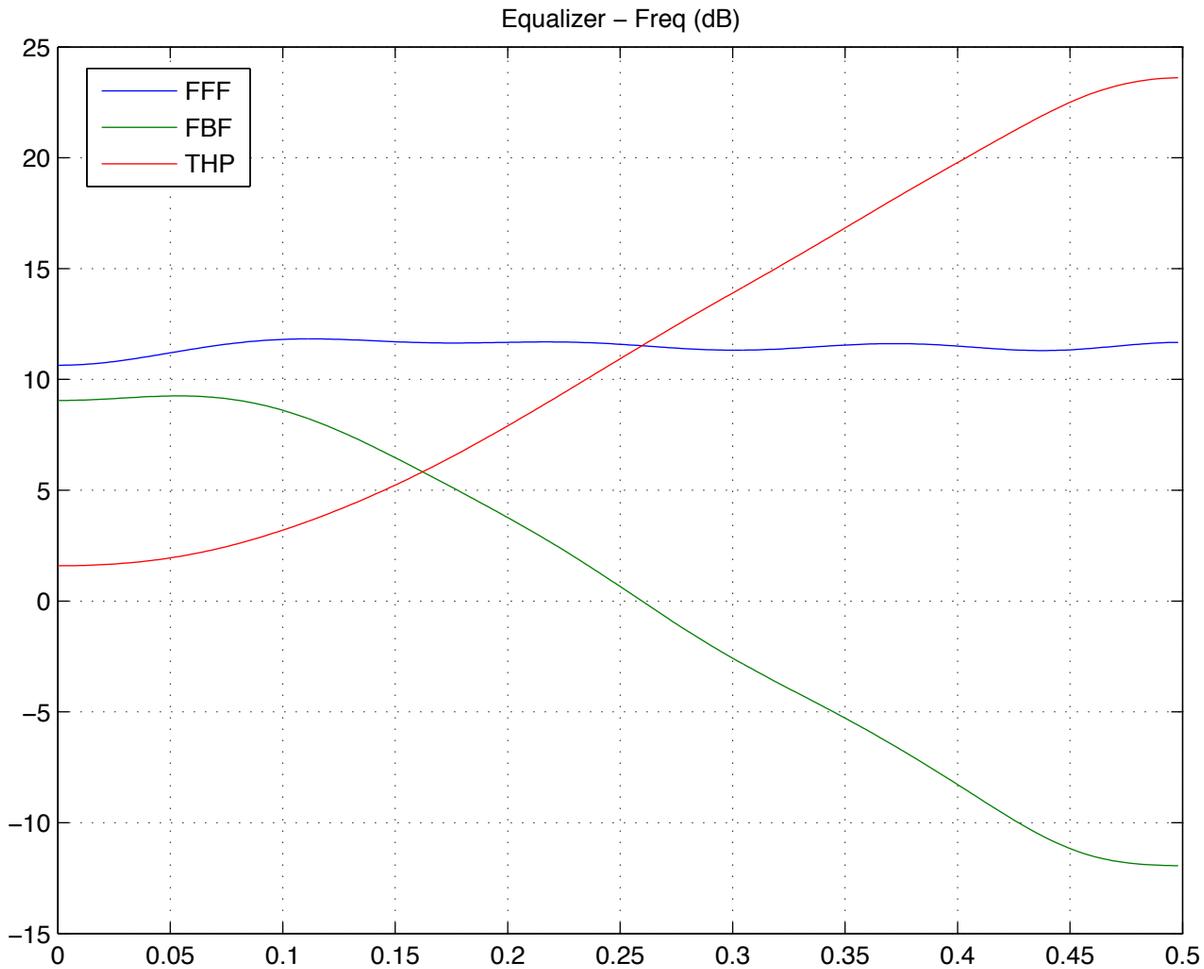


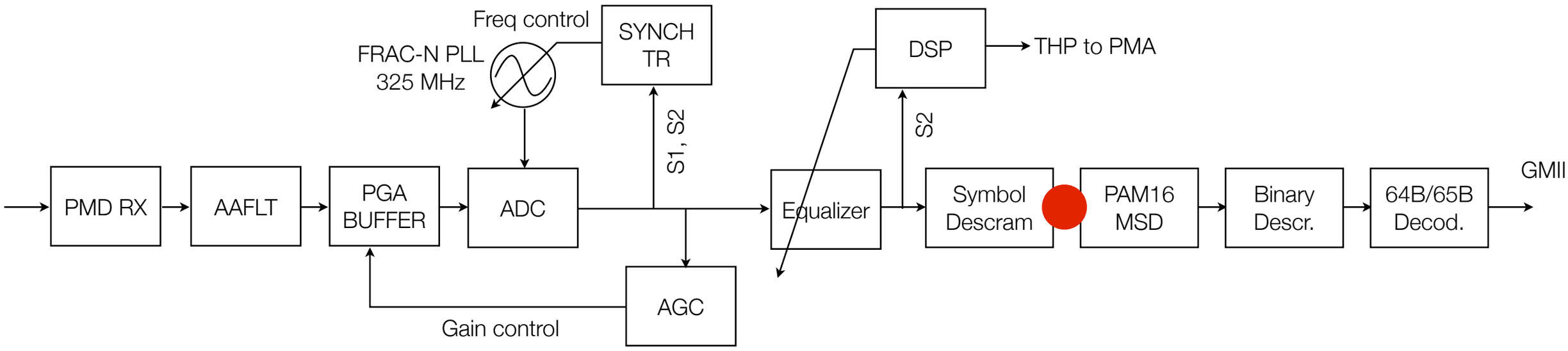
# 1000BASE-RH PHY estimated THP

## 50m POF at sensitivity



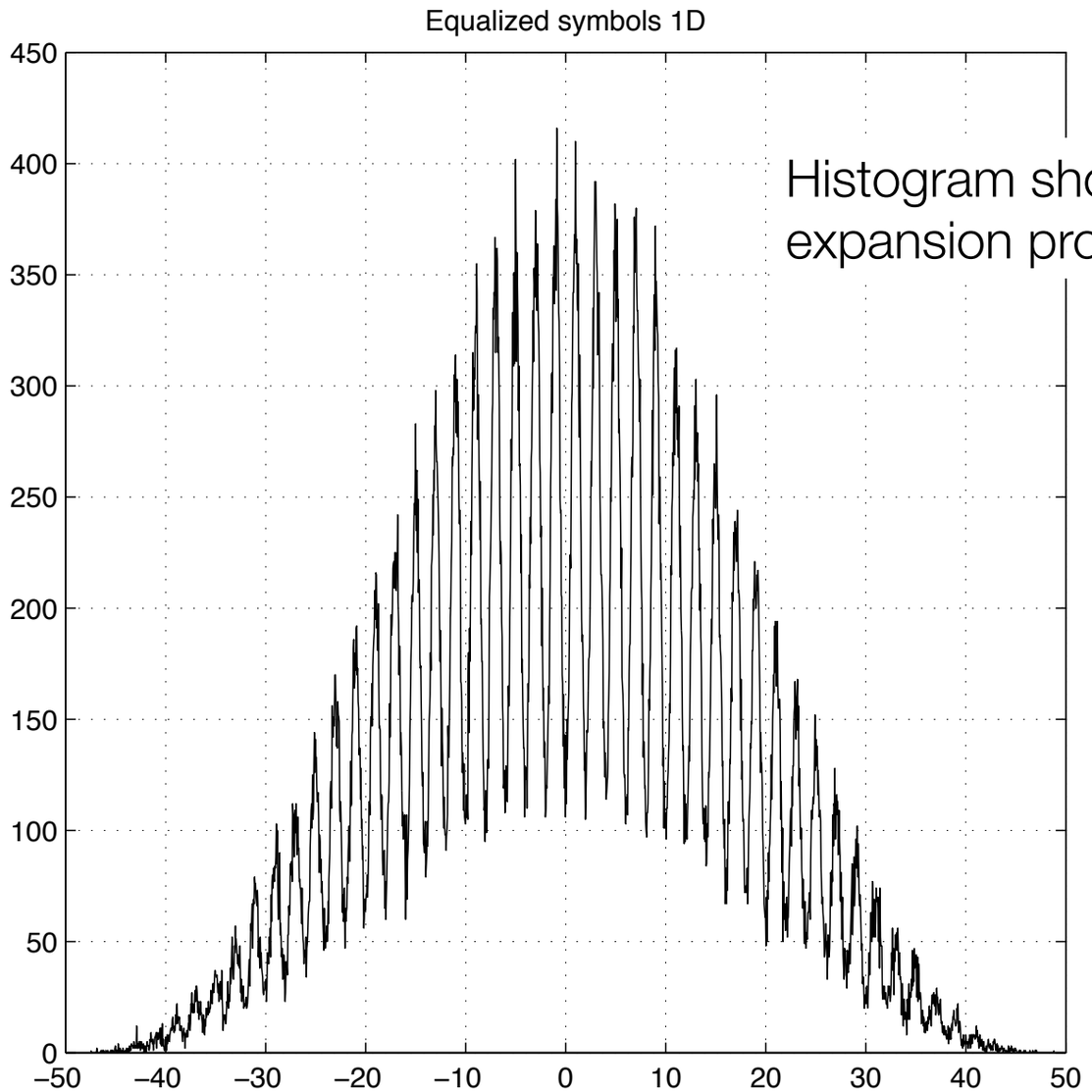



# 1000BASE-RH PHY receiver operation



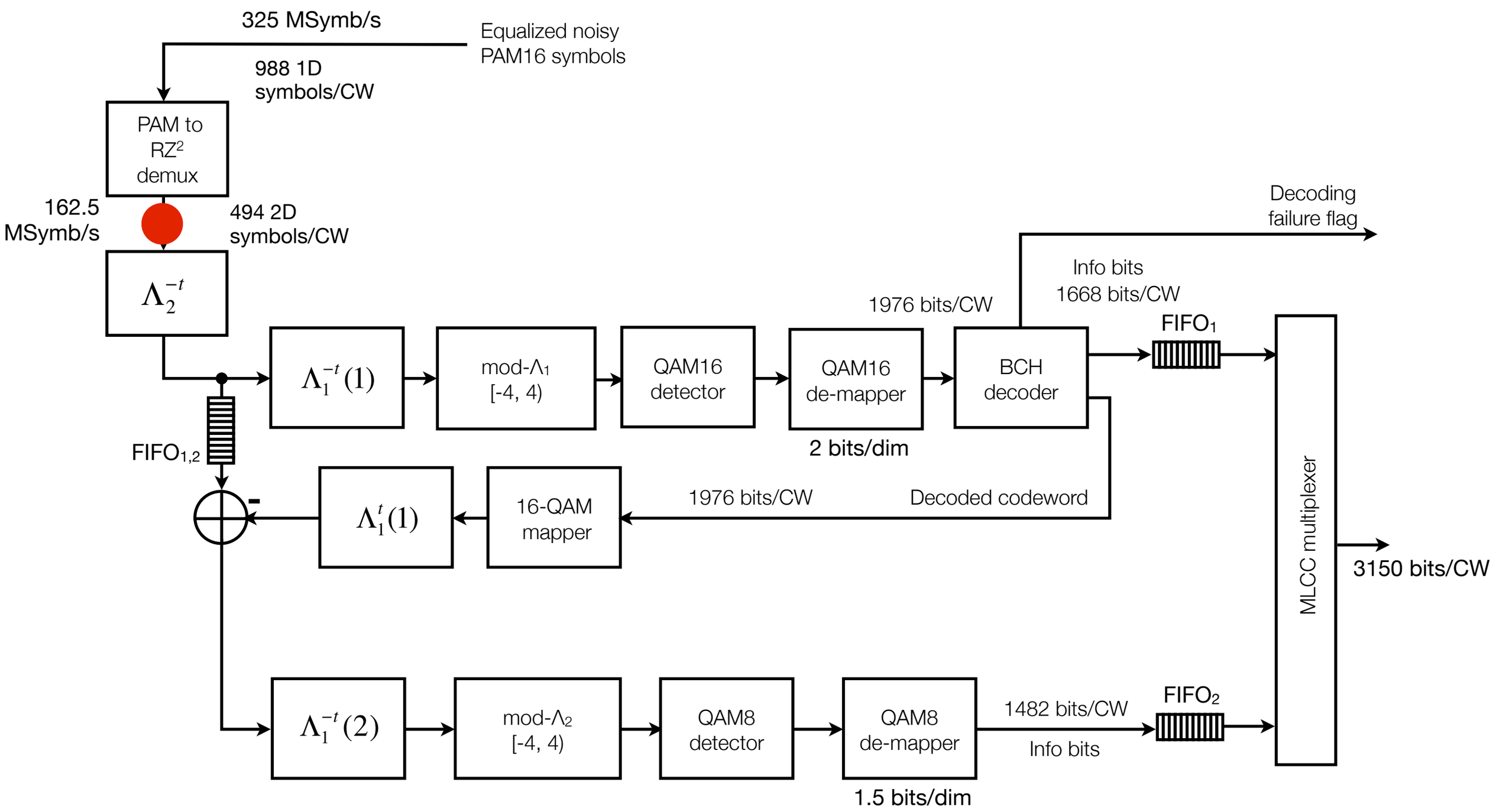
# 1000BASE-RH PHY equalized 1D symbols

## 50m POF at sensitivity



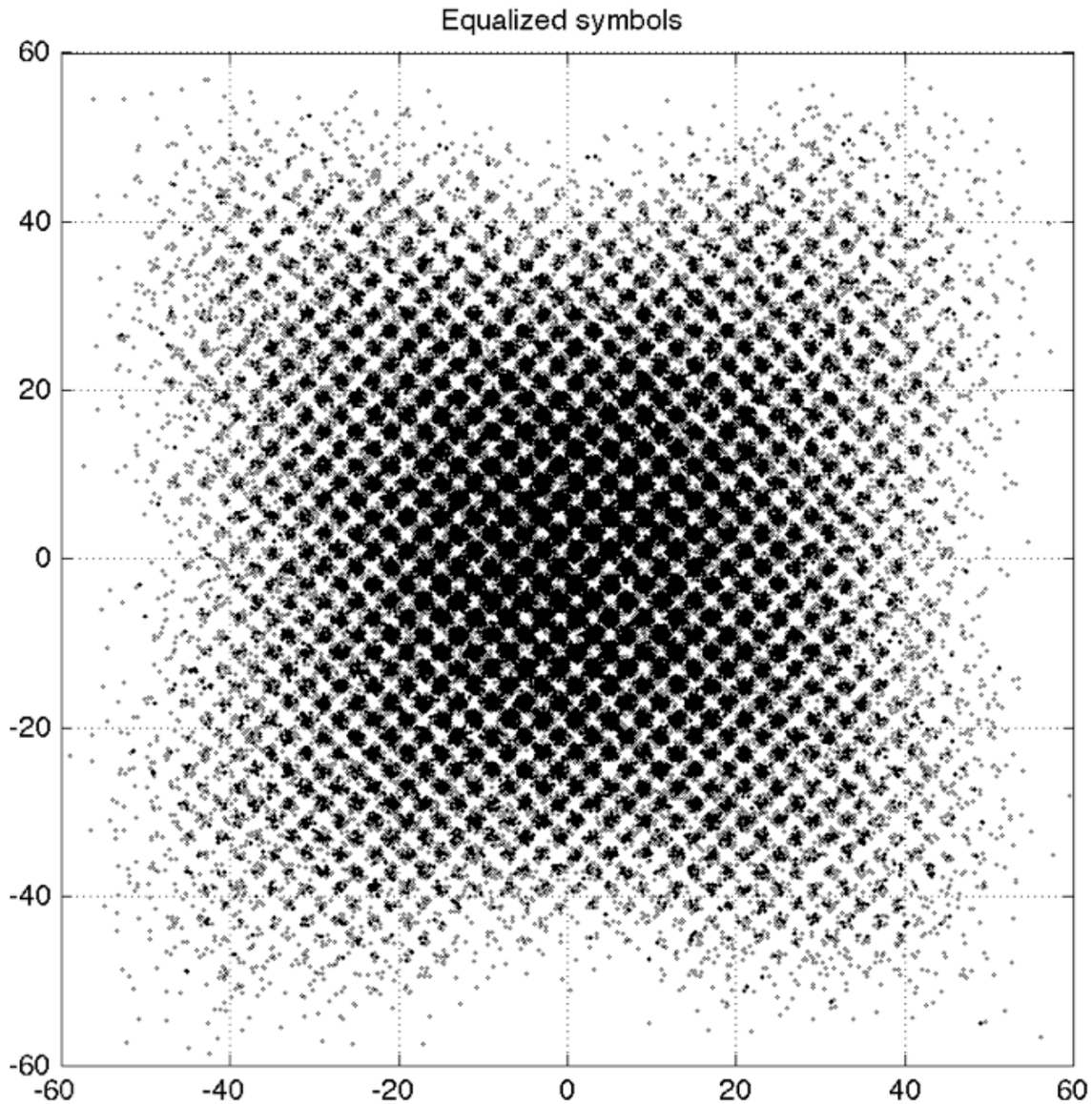

Histogram shows the constellation expansion produced by THP

# PAM16 multi-stage decoder

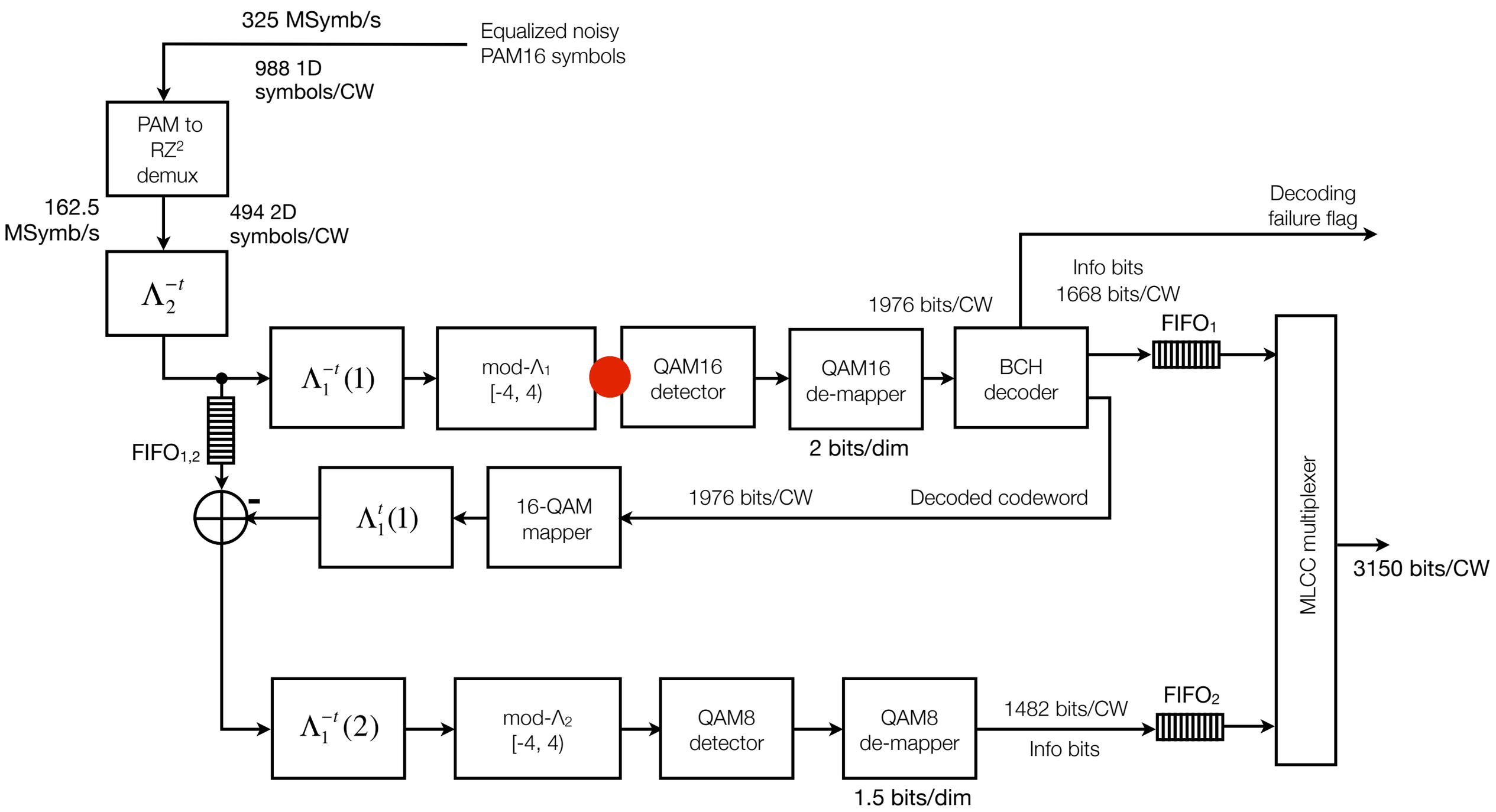


# PAM16 multi-stage decoder - PAM to 2D demux

## 50m POF at sensitivity

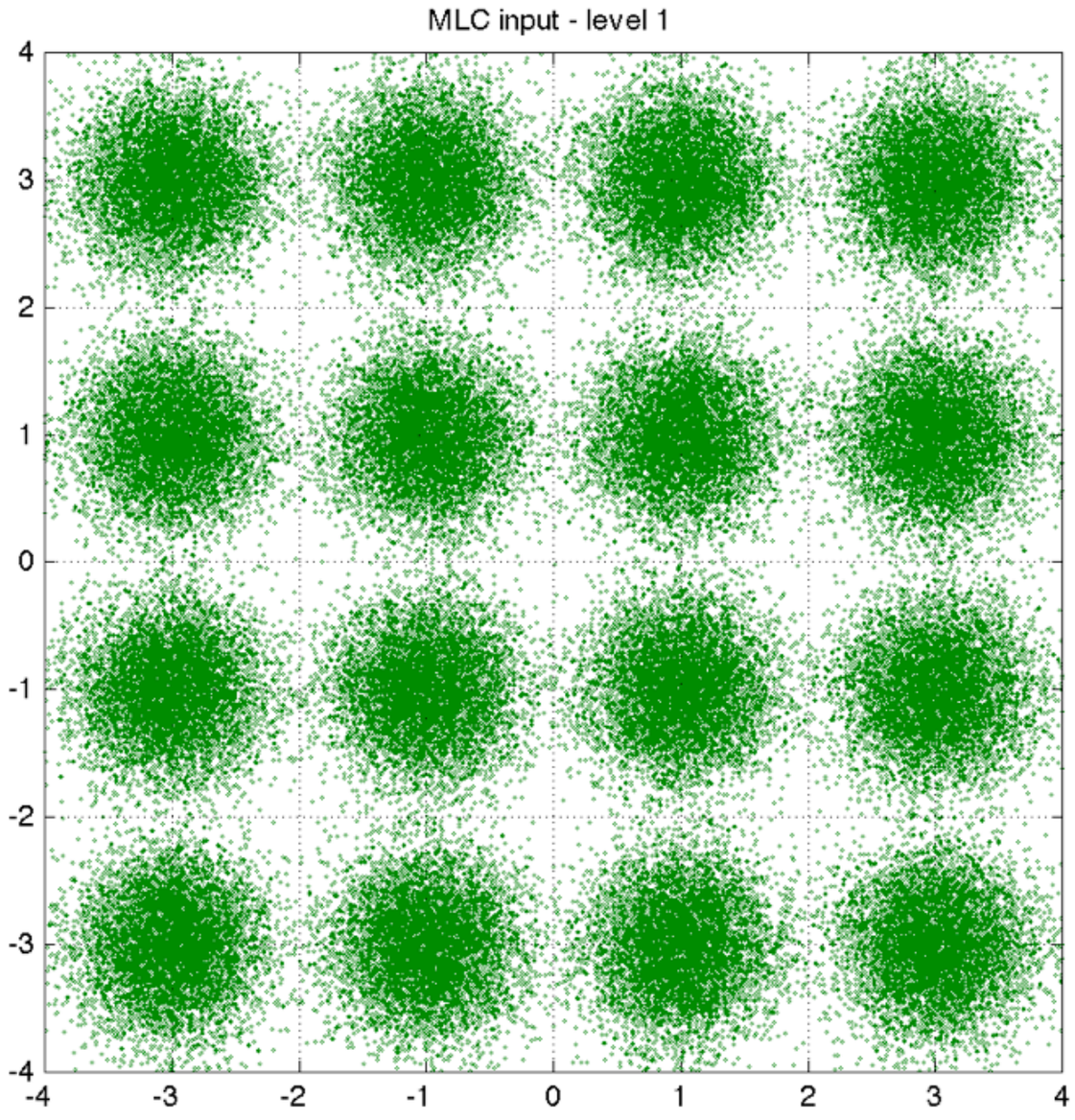


# PAM16 multi-stage decoder

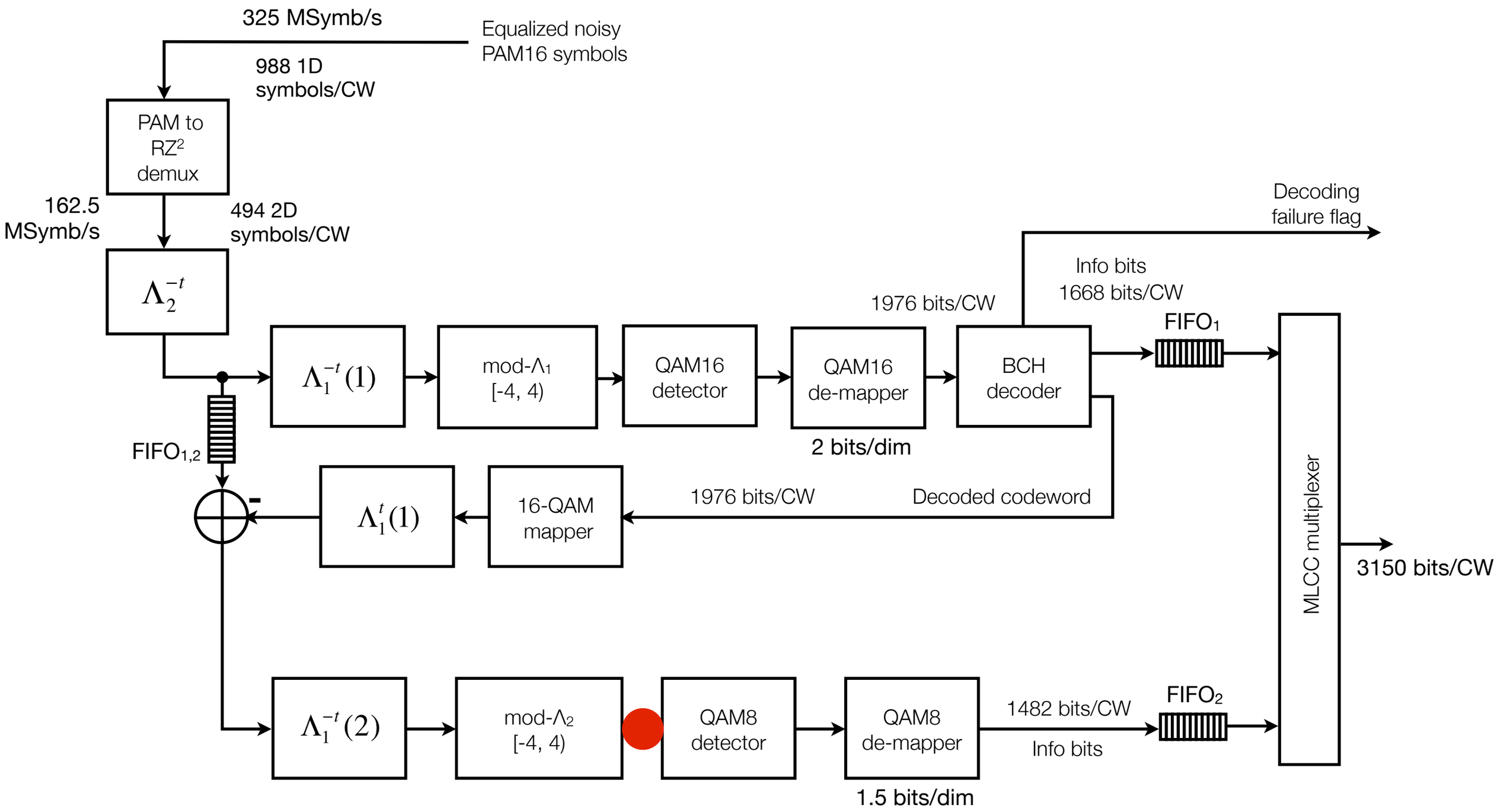


# PAM16 multi-stage decoder - 1st level input

## 50m POF at sensitivity

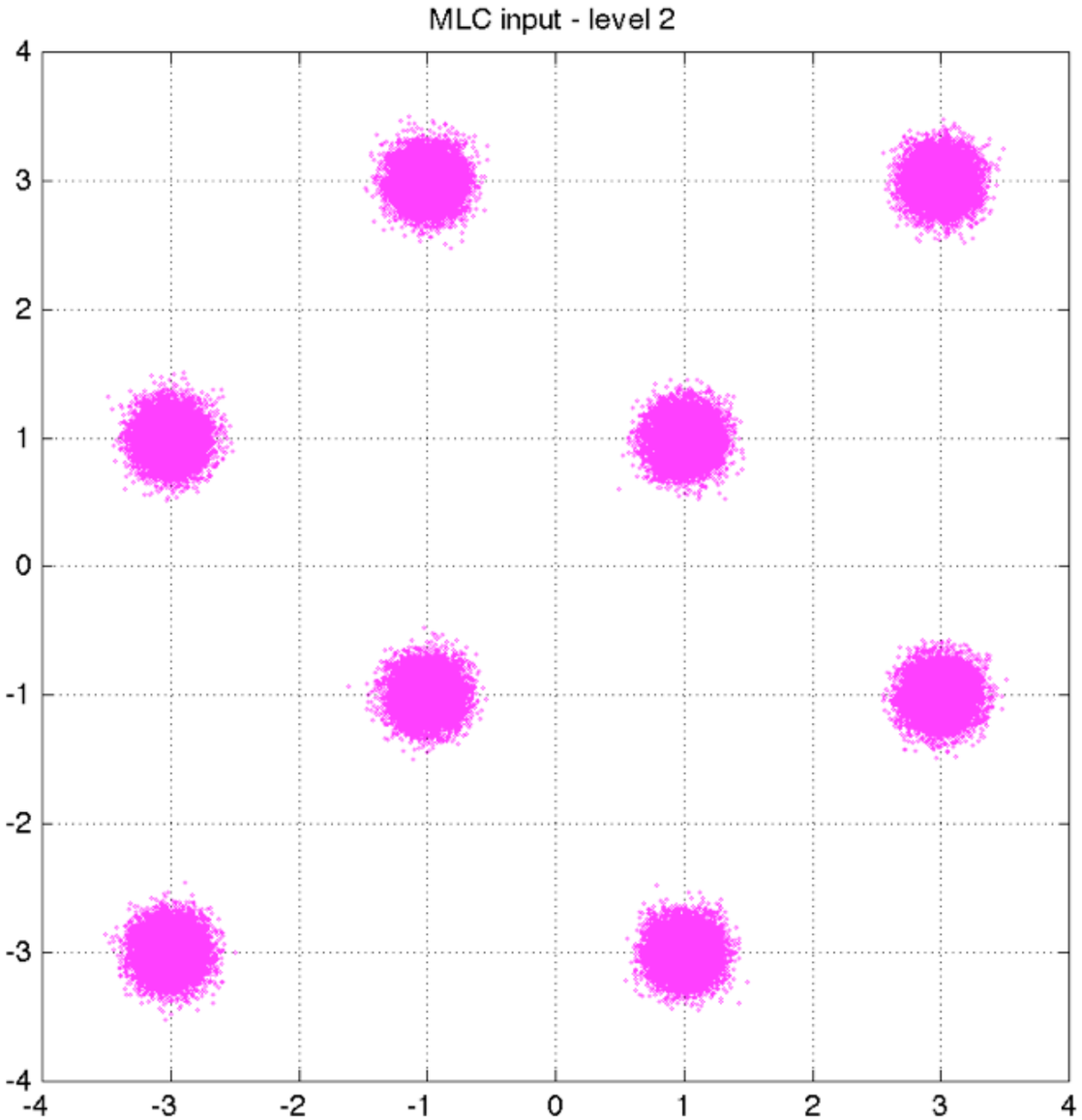


# PAM16 multi-stage decoder



# PAM16 multi-stage decoder - 2nd level input

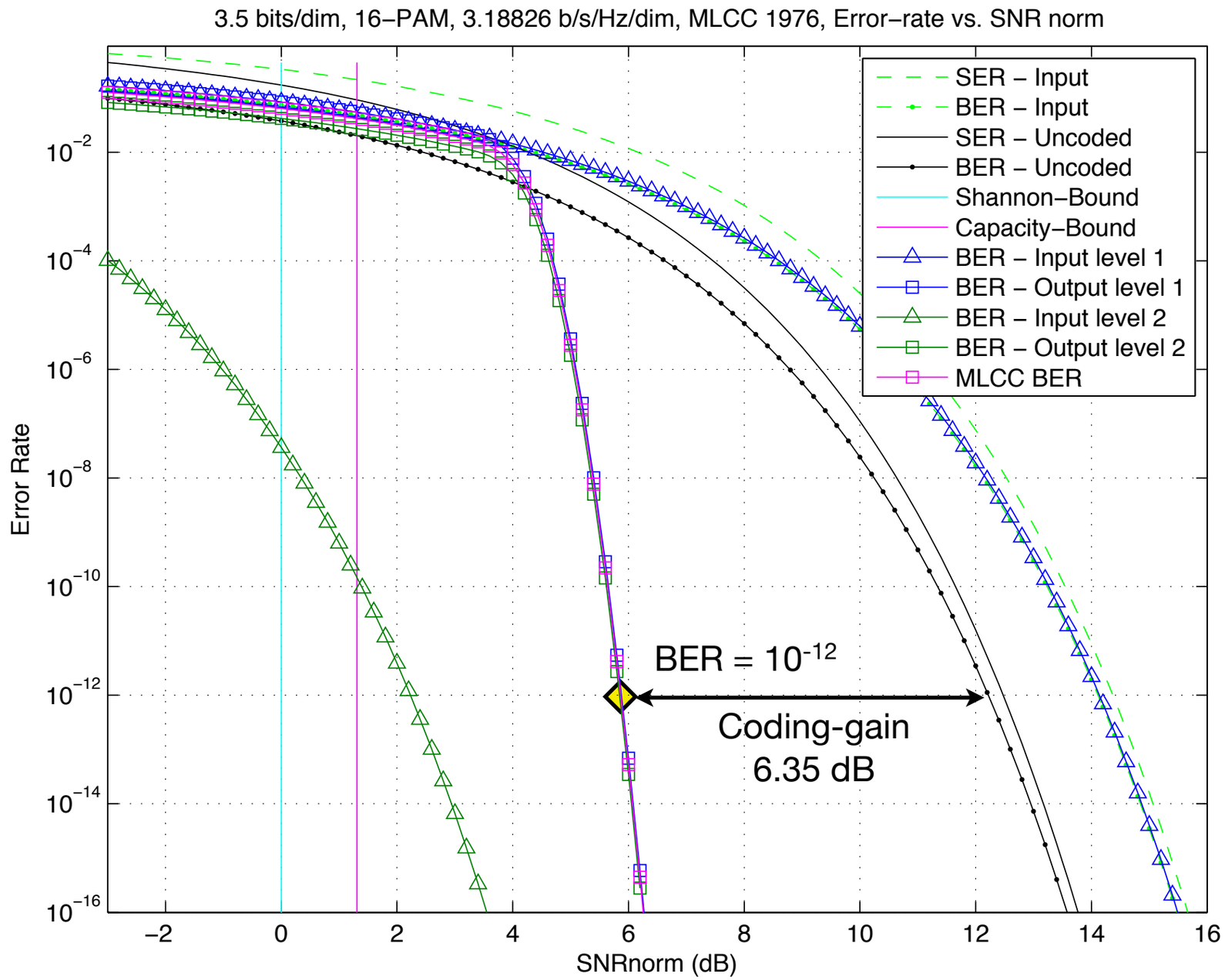
## 50m POF at sensitivity




# Coded PAM16 performance reminder

## Material presented in January 2015

# Coded PAM16 - Performance



# Coded PAM16 - Performance analysis

```
-- BER analysis: --
Channel: THP
Level 1: BCH(1976, 1668, 28) m = 11
Spect. Eff.: 3.18826 b/s/Hz/dim
Shannon gap (BER = 1e-12):                5.87 dB
Capacity bound gap (BER = 1e-12):         4.56 dB
SNR (BER = 1e-12):                        25.01 dB
Uncoded gap (BER = 1e-12):                12.2 dB
Coding gain (BER = 1e-12):                6.35 dB
Input SER (BER = 1e-12):                  0.0132918
Input BER (BER = 1e-12):                  0.00291155
Input BER MLC level 1 (BER = 1e-12):      0.00332296
Input BER MLC level 2 (BER = 1e-12):      2.06509e-27

-- MTTFPA analysis: --
MLC level 1:
   MTBE (BER = 1e-12):                                09 h:31 m:44 s
   MTTFPA with FCS detect (BER = 1e-12):              4.7e+06 y
   MTTFPA with BCH detect (BER = 1e-12):              1.1e+27 y
   MTTFPA with BCH & FCS detect (BER = 1e-12): 4.7e+36 y
MLC level 2:
   MTBE (BER = 1e-12):                                3.3e+10 y
   MTTFPA with FCS detect (BER = 1e-12):              1.4e+20 y

MLC as a whole:
   MTBE (BER = 1e-12):   09 h:31 m:44 s
   MTTFPA -PHY & FCS- (BER = 1e-12): 1.4e+20 y
   MTTFPA -just PHY-  (BER = 1e-12): 3.3e+10 y


-- PER analysis: --
   Eth Frame Size = 64 bytes,   PER = 1.1e-10 (BER = 1e-12)
   Eth Frame Size = 256 bytes,  PER = 1.6e-10 (BER = 1e-12)
   Eth Frame Size = 512 bytes,  PER = 1.9e-10 (BER = 1e-12)
   Eth Frame Size = 1024 bytes, PER = 3.7e-10 (BER = 1e-12)
   Eth Frame Size = 1522 bytes, PER = 5.4e-10 (BER = 1e-12)
```

**High coding gain**. Basically, it is responsible of 6 dBo of link budget, considering that the TIA has to implement an AGC based on trans-impedance control

**High input BER to Level 1**.This is good for an implementation of Link Monitor able to determine the link quality accurately and fast. Bit errors corrected by the BCH decoder per codeword may be a good estimate of the received signal quality.

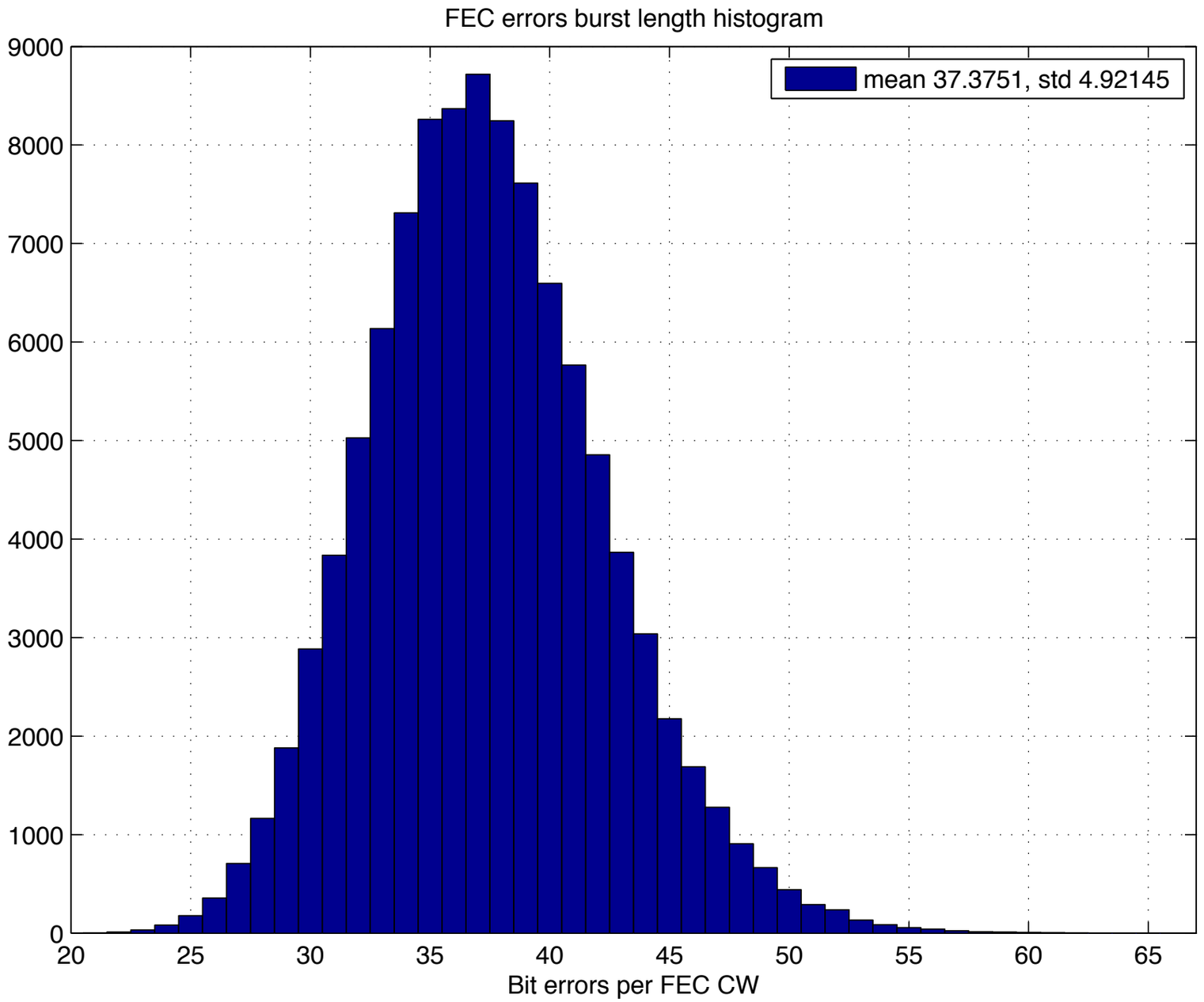
**FCS does not suffice to provide MTTFPA > age of universe.** Error detection capability of BCH is needed. Error detection capability will also avoid error propagation in Ethernet frames encapsulation due to bad frame delimiters detection.

**MAC FCS is not required for MTTFPA.** BCH suffices to detect packet errors, and the MTBE of second level is > age of universe. The MTTFPA is determined by the second level, which is the minimum.

**Low PER**. Because the error arrives in bursts from FEC decoder and BCH error detection capability is used.
**PER < BER*PktSz/10**

# Coded PAM16 - Performance analysis

- Errors burst length statistics for an erroneous code-word event (MC simulation):



# Coded PAM16 - Performance analysis

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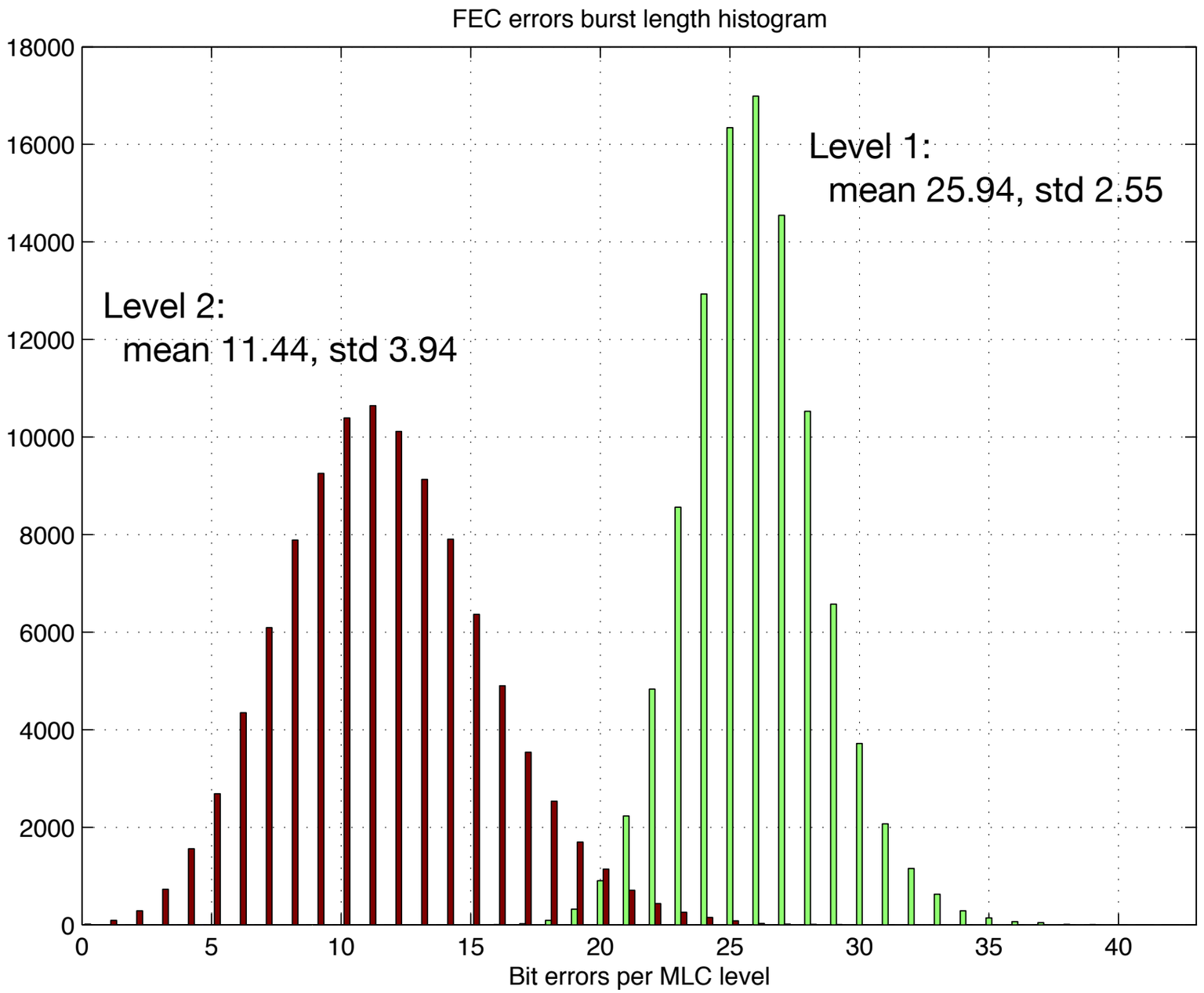

# Coded PAM16 - Performance analysis

- Link budget, MTBE and MTTFPA as a function of BER:

| | **BER ≤ $10^{-10}$** | **BER ≤ $10^{-11}$** | **BER ≤ $10^{-12}$** | **BER ≤ $10^{-13}$** | **BER ≤ $10^{-14}$** |
|---|---|---|---|---|---|
| **MTBE** | 5m:45s | 57m:28s | 9h:32m | 4 days | 39 days |
| **MTTFPA -PHY + FCS- (years)** | $6{,}9 \cdot 10^{18}$ | $3{,}2 \cdot 10^{19}$ | $1{,}4 \cdot 10^{20}$ | $6{,}0 \cdot 10^{20}$ | $2{,}4 \cdot 10^{21}$ |
| **MTTFPA -only PHY- (years)** | $1{,}6 \cdot 10^{9}$ | $7{,}4 \cdot 10^{9}$ | $3{,}3 \cdot 10^{10}$ | $1{,}4 \cdot 10^{10}$ | $5{,}7 \cdot 10^{11}$ |

Age of universe ≃ $13.8 \cdot 10^{9}$ years


# Questions?