PAM8 vs PAM12 Basic Analysis

(Time Domain Behavioral Simulation)

Introduction

Three "finite" system configurations have been constructed, simulated in time domain and analyzed. Study systems include PAM8 according to "rao_1_0704.pdf" with the discrete transmitter (Tx) filter (referred to as PAM8F), basic PAM8 – both @ 1GHz, and an exemplary PAM12 system @ 825 MHz. The later was derived by a simple frequency scaling of respective elements in the basic PAM8.

Class E channel (#3) characteristic was assumed with line transformer at each end (0.5 dB loss, 1st order high-pass and low-pass @ 120 kHz and 600 MHz respectively). Wide band (4.2 GHz) continuous time (CT) noise model was employed to generate system background white noise.

Studied systems key block characteristics are given in Table I below. Tx launch level of 1V peak (chip side) was set in all simulations.

Table I. Studied systems key block characteristics

Component and/or Characteristic	PAM8 (I) Fs =1 GHz	PAM8F (II) Fs =1 GHz	PAM12 (III) Fs =825 MHz
Tx Discrete Filter	none	0.75 + 0.25D	none
Tx LPF CT BW5, Cutoff [MHz]	500 (Fs/2)	500 (Fs/2)	412.5 (Fs/2)
Rx LPF CT BW3, Cutoff [MHz]	500 (Fs/2)	500 (Fs/2)	412.5 (Fs/2)
FFE FIR #Taps	64	64	64
DFE FIR #Taps	64	64	64

Where *Fs* is the system baud rate, *D* is the delay operator, *LPF* – low pass filter, *BW* designates a Butterworth filter type followed by a numeral, indicating the filter order.

System SNR at Slicer

Achievable signal to noise ratio (SNR) at slicer was measured through behavioral time domain simulation. No error control coding was employed. Respective SNR figures and Symbol Error Rates (SER) observed in simulation with system noise floor at −140dBm/Hz are summarized in Table II.

Table II. Studied systems SNR and SER characteristics

System Characteristic	PAM8 Fs = 1 GHz	PAM8F Fs = 1 GHz	PAM12 Fs = 825 MHz
Slicer SNR, [dB]	20.90	19.67	24.07
Req. SNR @ 1e–12	30.1	30.1	33.6
Margin to 1e–12, [dB]	–9.2	–10.43	–9.53
Achieved SER	1/69	1/24.4	1/40

As expected, all systems exhibit considerable negative SNR margin with respect to (w.r.t.) the 1e–12 operating point. The difference between PAM8 and PAM12 is small – about 0.3 dB. Large coding gain on the order of 10 dB or more will be required to reach 10GBASE-T performance objectives. PAM8F shows 1.23 dB lower margin than PAM8 and 0.9 dB lower than PAM12.

EMI Ingress

The receiver immunity to an external interferer could be assessed based on the detector (slicer) sensitivity and gain observed from the receiver input to the detector. This gain is a function of frequency. For a narrow-band interferer at a given center frequency (e.g. AM or FM), the receiver gain would need to be evaluated around that frequency. Alternatively, for a wide-band impulse type disturber an integral metric obtained in the disturber spectral band would be more appropriate. Aliasing effects need to be considered in the analysis.

To produce an error event at the slicer the absolute value of a noise sample should exceed half the decision distance. For a given slicer aperture PAM8 has approximately 3.92 dB larger distance between adjacent levels than PAM12. For example, a +/–1 V slicer would have ~0.2857 V of level separation (min. distance) in PAM8 and ~0.1818 V in PAM12.

Gain vs. frequency characteristic in the receiver is a result of so called minimum mean square error (MMSE) equalizer adaptive optimization. Outcome of such optimization is largely dependent on the channel high frequency attenuation, as well as the spectrum of the receiver input noise. Because “faster” PAM8 signal sees more attenuation and dispersion in the channel, the required receiver gain ends up higher than in “slower” PAM12, whereby reducing the net distance advantage of PAM8 to somewhat below 3.92dB. The degree of loss will depend on the channel frequency response and input noise. Below a brief receiver gain analysis is presented for the three studied systems for the case of –140dBm/Hz noise floor.

For comparison purposes the receiver front end is assumed to be linear, allowing the Rx front-end flat gain to be lumped into the Feed Forward Equalizer (FFE) coefficients. In that case the rest of the receiver chain is assumed to have a nominal gain of 0dB. Resulting FFE frequency response characteristics for PAM8, PAM8F and PAM12 are shown in Fig. 1, with key parameters detailed in Table III.

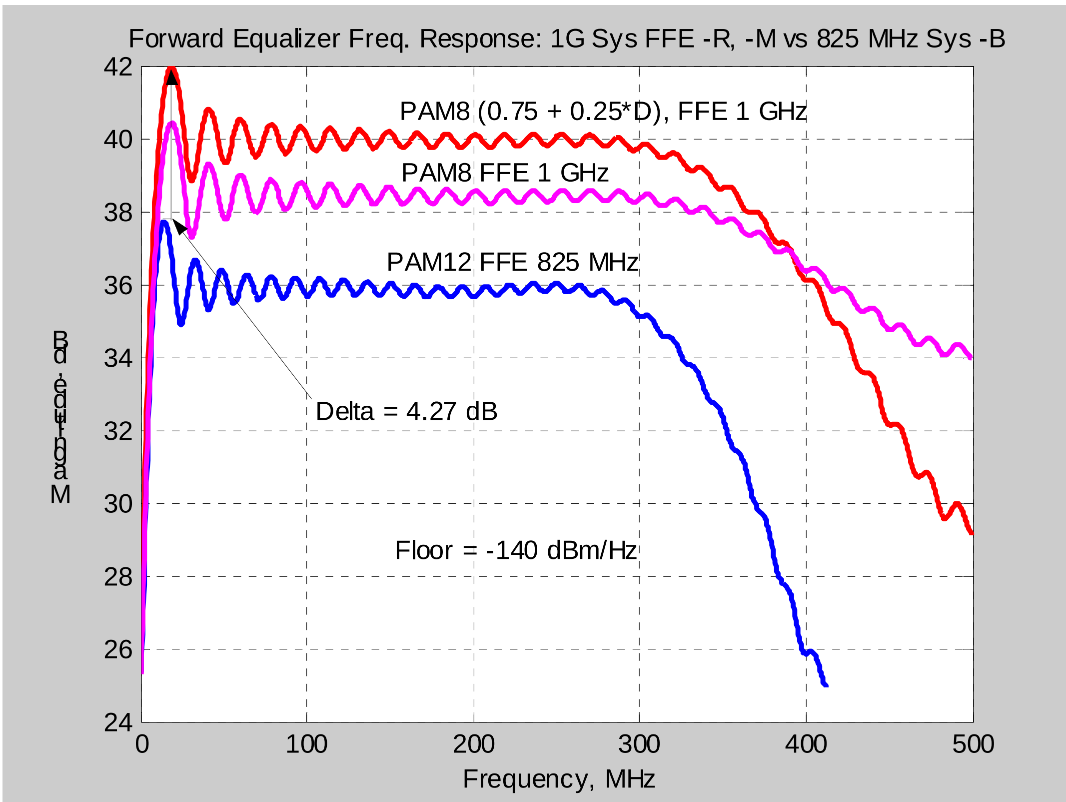

Figure 1. PAM8, PAM8F and PAM12 MMSE FFE Frequency Responses with –140dBm/Hz noise floor

Table III. FFE frequency response characteristic details

Characteristic	PAM8	PAM8F	PAM12
Net FFE gain 10*log(sum(c_i^2)) [dB]	37.8	38.9	35
FFE max. gain [dB] @ [MHz]	40.44 @ 18.6	41.97 @ 18.6	37.7 @ 14.1
Norm. max. FFE gain [dB]	36.51	38	37.7
3-dB cutoff[MHz]	440	390	340

Where c_i is the FFE *i*-th coefficient, $i = 1, 2, \ldots, 64$ and *sum()* designates summation operation over all bracketed elements.

It could be observed from the graphs that PAM8F system exhibits highest gain up to ~390 MHz with a maximum of ~42 dB @ 18.6 MHz. This is due to additional frequency dependent attenuation introduced by the discrete Tx filter (up to 6 dB @ 500 MHz). As a result the FFE peak gain is 1.53 dB higher than in PAM8 and 4.27 dB higher than in PAM12. Normalized with distance difference of 3.92 dB the FFE gain maxima are shown in the fourth row in Table III. PAM8 has the lowest peak gain, whereas PAM12 shows the lowest 3-dB cutoff and exhibits considerable roll off above 300 MHz.

Based on above numerical analysis the predicted immunity to a sine wave interferer at the frequency where the FFE gain maxima are observed should not differ much in all three cases (PAM8F, being slightly worse than the other two.) At the band end frequencies, however, PAM12 having considerably smaller gain, should exhibit better immunity.

Out-of-Nyquist band system immunity (e.g. to a wide band impulse noise) will depend on the receiver composite continuous–discrete time frequency response. Impulse immunity analysis is not captured in the “Crane” test used in 1000BASE–T.

The system sine wave immunity predictions made earlier have been verified in simulations whereby a 5 mV peak sinusoidal disturber was injected at the MDI input. For the lower frequency band the sine wave was applied at 18.6 MHz and 14.1 MHz for PAM8 and PAM12 systems respectively. For the mid and upper band the sine frequency was set to 200 and 400 MHz in all three schemes. To allow the disturber impact to be clearly observed, the receiver adaptive equalizers were frozen and no background noise was employed. System SER figures are presented in Table IV.

Table IV. SER w.r.t a sinusoidal interference.

Disturber Frequency [MHz]	PAM8 SER	PAM8F SER	PAM12 SER
14.1	-	-	1/1.84
18.6	1/1.8	1/1.63	-
200	1/1.43	1/1.42	1/1.4
400	1/1.97	1/2.08	1/132

It could be seen from Table IV that for the low and mid band sine wave interference the immunity is relatively poor across all three schemes, whereas at the band end (400MHz) PAM12 showed considerably better result than the rest (1-Gbaud systems also showed SER improvement around Fs/2 = 500 MHz).

Conclusions

Three finite 10GBASE−T transceiver system configurations have been analyzed w.r.t. noise floor of −140dBm/Hz in the time domain: a generic PAM8, PAM8 with Tx discrete filter and a generic PAM12 system derived from PAM8 by frequency scaling of the major transceiver block parameters. All three studied schemes demonstrated a considerable negative SNR over the 100m Class E link segment characteristic, necessitating large coding gain on the order of 10 dB or higher to approach the 10GBASE−T performance objective. PAM8 and PAM12 systems showed ~1 dB better SNR than Tx filtered PAM8.

Immunity analysis to external sinusoidal interference shows that even relatively small 5mV peak in-band disturber could cause significant performance degradation in PAM8 and PAM12 systems alike. However, inherently lower band PAM12 demonstrated considerably better immunity at high frequencies around 400 MHz. In addition to a narrow band interference test, specification of a wide band impulse test would most likely be required in 10GBASE−T standard.

Introduction of extra in-band loss at 10GBASE−T transmitter, as a potential EMI egress mitigation measure, would likely degrade further the already low SNR margin at the receiver and compromise its EMI ingress immunity.