Effect of pulse-shaping and channel noise on digital transmission of an image

Girish Chandar, Ganesan
Department of Electrical Engineering
Indian Institute of Technology Gandhinagar
Gandhinagar, India
girish.chandar@iitgn.ac.in

***Abstract*—The project aims to simulate the effects of pulse-shaping and channel noise on digital communication system by designing a communication system in MATLAB. The roll-off factor and channel signal-to-noise ratio(SNR) are varied for pulse-shaping and channel respectively to observe the behaviour of the system. An image is chosen as the source of information and is transmitted through the designed system and the image quality of the received image is measured by appropriate metrics to quantify the effects of pulse-shaping and channel noise in a communication system. Additionally, eye-diagrams are plotted to observe the effect of roll-off factor in Inter-Symbol Interference(ISI).**

***Index Terms*—pulse-shaping, eye-diagram, roll-off factor, ISI, channel noise, image quality**

I. Introduction

Digital Communication System plays an important role in today's world and this project sheds light on the shortcomings of digital transmission. By taking an example of an image the project demonstrates the effect of pulse-shaping and channel noise in digital transmission. Pulse-shaping is done by Raised Cosine Filter and the roll-factor of the filter is varied to study the its effects on image quality. Similarly the SNR of the channel noise is varied to study the effects on image quality.

The motive behind taking an image as the source information is two-fold, namely, 1. It is easy to visualize the effects of the digital transmission as distortion in the image, 2. Sampling and quantization is implicitly done while capturing the image by the sensor in the camera.

II. Theory

A. Pulse-shaping

Dispersion of pulse due to spectral distortion is called Inter-Symbol interference(ISI). To eliminate ISI, Nyquist proposed a criterion [2]. For a pulse $p(t)$ used for pulse shaping it has to satisfy the following condition:

$$p(t) = \begin{cases} 1 & t = 0 \\ 0 & t = \pm nT_b \\ (T_b = \frac{1}{R_b}) & \end{cases}$$

where R_b is bit-rate of the signal. One such realizable pulse is the raised cosine function which has following PSD.

$$P(f) = \begin{cases} 1 & |f| < \frac{R_b}{2} - f_x \\ \frac{1}{2}[1 - \sin\pi(\frac{f - R_b/2}{2f_x})] & |f - \frac{R_b}{2}| < f_x \\ 0 & |f| > \frac{R_b}{2} - f_x \end{cases}$$

$f_x = \frac{rR_b}{2}$, where r is the roll-off factor and $r \in [0, 1]$

Eye-diagrams are an important practical tool to visualize the extent of ISI. Fig. 1

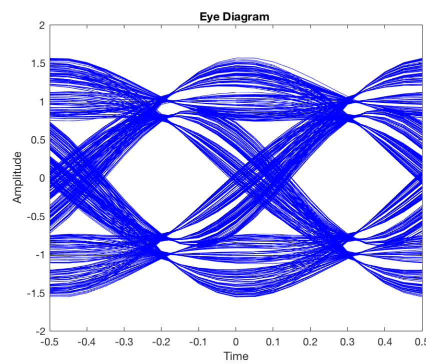


Fig. 1. Eye-Diagram

B. Channel Noise

The transmission channel invariably introduces noise to the transmitted signal. These noises are random and cannot be accurately accounted for at the receiver to cancel it out. But most of noises such as thermal noises can be modeled by White Gaussian Noise(WGN). The channel noise simulated in the project is Additive White Gaussian Noise($AWGN$).

C. Image Quality Metrics

The received image quality is estimated using the three image quality metrics, namely: 1.Mean Square Error(MSE) 2. Peak Signal-to-Noise Ratio($PSNR$) and 3. Structural Similarity Index Metric ($SSIM$). The formula to compute each of the metrics is defined below.

$$MSE(I_1, I_2) = \frac{\sum_{M,N}[I_1(m,n) - I_2(m,n)]^2}{M * N}$$

$$PSNR(I_1, I_2) = 10\log_{10}(\frac{R^2}{MSE(I_1, I_2)})$$

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)}$$

where

- $\mu_x, \mu_y, \sigma_x^2, \sigma_y^2$ are average and variation of x and y respectively. σ_{xy} is the covariance of x and y
- $c_1 = (0.01L)^2$ and $c_2 = (0.03L)^2$ are used to stabilize the division with weak denominator
- L is the dynamic range of pixel values

III. Approach

The simulation is done based on the general pipeline of a digital communication system. This section explains the processes that constitute a digital communication system.

A. Sampling and Quantization

Images are discrete signals and the intensity levels of the pixels are quantized and encoded by 8-bits, i.e., $L = 2^n$ where $n = 8$. Moreover, color have three channel, namely, R,G,B channels. Thus intensity of each pixel of each of the three channels are quantized between 0-255.

Addititionally the image is converted from its matrix form to a 1-Dimensional vector. Thus an image of size $[H, W, D]$, after vectorization, quantization and bit-encoded becomes a 1-D vector of size $[1, H*W*D*8]$.

B. Pulse-Shaping

The bit-encoded signal is converted from $[0, 1]$ to $[-1, 1]$ for ease of detection. This signal is then modulated with pulse $p(t)$ and then transmitted through the channel. The pulse shape should be carefully decided so as to minimize ISI. As mentioned in II-A for $p(t)$ to have zero ISI it must satisfy the Nyquist criterion.

In this project the pulse $p(t)$ is generated by Raised Cosine Filter whose PSD is as defined in II-A.

C. Channel

The simulation models the channel by adding WGN to the transmitted signal. In the simulation it is assumed that the channel is non-dispersive channel and therefore introduces a constant delay

D. Receiver-end Sampling

The noisy signal is then sampled according to a clock. Since all the signals are equally delayed the simulation is able to retrieve the pulses at the sampling instants.

E. Detection

The sampled received signal is then compared against a threshold of zero. If the sampled value is ≤ 0 then it is treated as 1, else it is treated as 0. Detection error occurs when the amplitude of noise is more than the amplitude of signal. This is controlled by the SNR of channel noise.

The percentage of bit-error is calculated in this stage of the simulation.

F. Image Reconstruction

The image is reconstructed from the signal received after detection. The 1-D vector is reshaped into a 3-D matrix.

G. Image Quality Assessment

The image quality of the reconstructed image is calculated by the functions defined in ‘II-C

IV. Simulation

Initially the simulation was to designed in MATLAB-SimuLink but due to sampling time errors the simulation was completely transferred to MATLAB

A. Sampling and Quantization

An 128x128x3 image(Fig. 2)is considered as the source information.

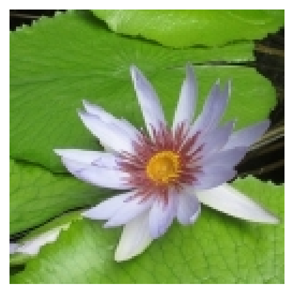


Fig. 2. Input Image

B. Pulse-Shaping

Pulse-shaping is implemented by taking help of the RaisedCosineTransmitFilter [1] function of MATLAB. By specifying samples per symbol, roll-factor and filter-span the filter is generated.

The bit-enoceded signal is passed through this function for pulse-shaping. The filter delay is noted and later used in receiver-end sampling.

The roll-off factor is varied and both image quality and corresponding eye diagrams of the pulse-shaped signals are stored.

C. Channel

The awgn() function of MATLAB is used to model the channel. The fucntion takes the input SNR of Noise and adds WGN to the input signal accordingly.

The SNR of noise is varied and the image quality is measured.

D. Receiver-end Sampling

The filter delay is and samples per symbol defined in pulse-shaping is used to sample the received signal.

E. Detection

The detection is done as explained in III-E and the percentage of bit-error rate stored

F. Image Reconstruction

The image is reconstructed from the signal received after detection back to 128x128x3 and the images for varied SNR of channel noise is stored.

G. Image Quality Assessment

The image quality of the reconstructed image is calculated by the functions defined in 'II-C and the $MSE, PSNR, SSIM$ are stored.

V. Results and Discussion

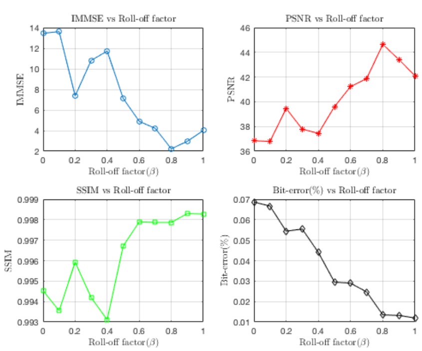


Fig. 3. Effect of Roll-off factor

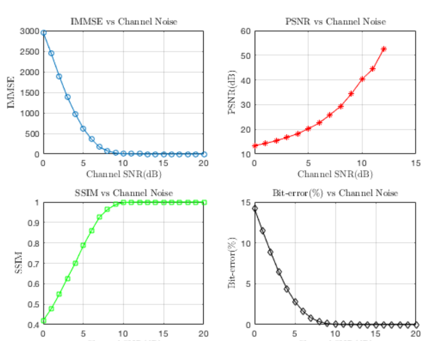
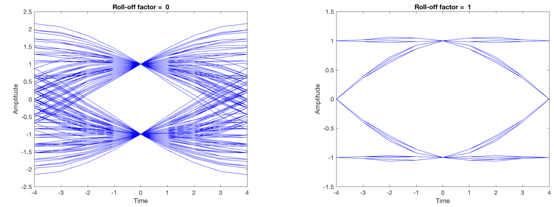


Fig. 4. Effect of Channel-noise



(a) Roll-off factor=0 (b) Roll-off factor=1

Fig. 5. Eye-Diagram

(a) SNR=1 (b) SNR=5 (c) SNR=10

Fig. 6. Eye-Diagram

- It can be observed from Fig 3 and Fig 4 that as the roll-off factor increases the image quality increases
- It can be observed from the eye diagrams Fig 5(a) and Fig 5(b) as roll-off factor increases the ISI decreases.
- Degradation of the image quality can be easily observed in Fig 6

References

[1] https://in.mathworks.com/help/comm/examples/raised-cosine-filtering.html
[2] Modern Digital and Analog Communication System, B.P.Lathi