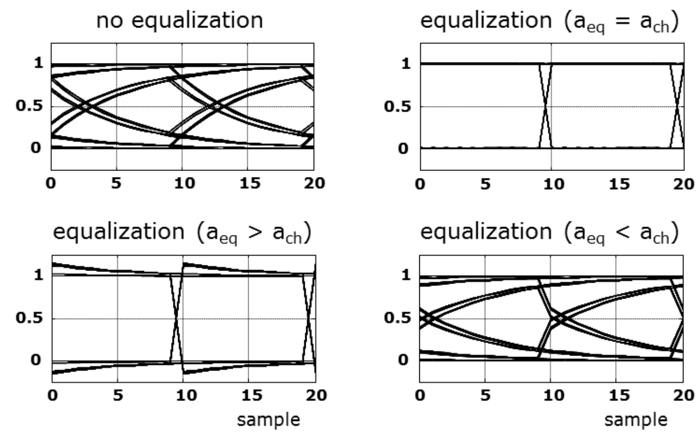
- Pre-course Materials
- Topic 1: Course Overview
- Topic 2: Lossless Source Coding: Hamming Codes
- Topic 3: The Frequency Domain
- Topic 4: Lossy Source Coding
- **Topic 5: Filters and the Frequency Response**
  - **5.1 Channels as Filters**
  - **5.2 Frequency Response** Week 3 Quiz due Nov 16, 2015 at 15:30 UTC
  - **5.3 Filter Examples** Week 3 Quiz due Nov 16, 2015 at 15:30 UTC
  - **5.4 Frequency Response of the IR Channel** Week 3 Quiz due Nov 16, 2015 at 15:30 UTC
  - **5.5 Lab 3 - Frequency Response** Lab due Nov 16, 2015 at 15:30 UTC
- Topic 6: The Discrete Fourier Transform
- MATLAB download and tutorials
- MATLAB Sandbox

## LAB 3 - TASK 3 (1/1 point)

In Part I of this course, we introduced the concept of an equalizer to compensate for the effects of the channel. Because the channel was bandlimited, it introduced intersymbol interference. This caused the eye diagram to close. The equalizer "undid" the effect of the channel, and resulted in a more open eye. Recall that the equalizer depended upon an estimate of the exponential parameter $a$ of the channel. If the estimate is correct, the effects of the channel can be cancelled exactly, resulting in an open and square eye. However, if the estimate is incorrect (too high or too low), then the eye is not exactly square, as shown in the figure below. We implemented the equalizer in Lab 6 of Part I.



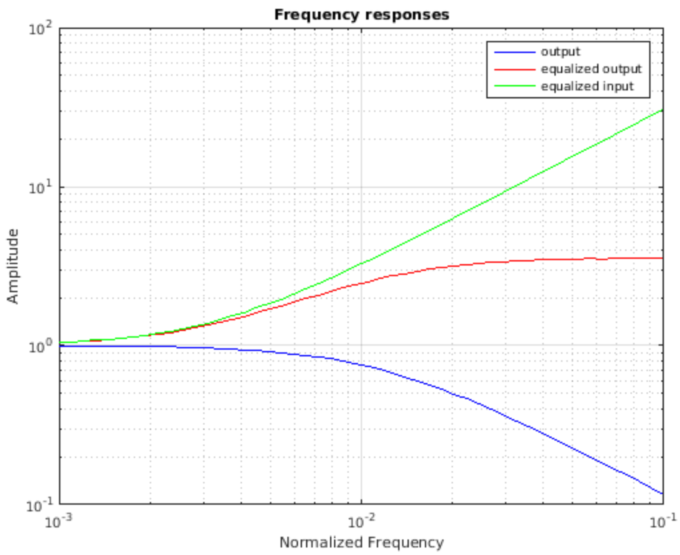

While in the previous part of this course we studied the channel and the equalizer in the time domain, here we study them in the frequency domain. In this lab, we will re-examine the operation of the equalizer. Be reminded that we had to characterize the relationship between the channel input and output and then we designed the equalizer. As a result, we reduced the intersymbol interterfence and showed the results using the eye diagram. In this task, we will study the effect of equalization on the channel using the frequency response. We will compare the amplitudes of the frequency responses of the channel with and without equalization. We will also measure the amplitude of the frequency response of the equalizer itself.

```
% Exponential factor controlling step response of channel
ach = 0.93;
% Exponential factor controlling the equalizer. This is the
% equalizer's estimate of the a of the channel.  Ideally, this
% should equal ach, but in practice, there is often mismatch.
aeq = 0.98;

nsamp = 1200;
n=0:(nsamp-1);

flist = logspace(-3,-1);
h_rx = zeros(1,length(flist));
h_eq_rx = zeros(1,length(flist));
h_eq_tx = zeros(1,length(flist));

for i=1:length(flist)
```

Correct

```
    % normalized frequency of the signal (cycles/sample)
    freq=flist(i);

    % create a sinusoidal function with frequency freq and nsamp samples
    tx_wave = cos(2*pi*freq*n);

    % send the signal through the channel
    rx_wave = txrx(tx_wave,ach,'pureexp');
    eq_rx = equalizer_lab3(rx_wave,aeq);
    eq_tx = equalizer_lab3(tx_wave,aeq);

    % estimate peak to peak amplitudes
    transient =200;
    h_rx(i)= max(rx_wave(transient:end))-min(rx_wave(transient:end));
    h_eq_rx(i)= max(eq_rx(transient:end))-min(eq_rx(transient:end));
    h_eq_tx(i)= max(eq_tx(transient:end))-min(eq_tx(transient:end));
```

Figure 1




eq_rx =

Columns 1 through 17

0.0700 3.3249 3.1620 3.0103 2.8691 2.7376 2.6152 2.5012 2.3950 2.2961 2.2039 2.1181

Columns 18 through 34

1.7122 1.6595 1.6103 1.5644 1.5215 1.4815 1.4440 1.4089 1.3762 1.3454 1.3167 1.2897

Columns 35 through 51

1.1593 1.1418 1.1253 1.1098 1.0951 1.0812 1.0680 1.0555 1.0436 1.0324 1.0216 1.0114

Columns 52 through 68

0.9585 0.9509 0.9435 0.9363 0.9294 0.9227 0.9162 0.9098 0.9036 0.8976 0.8917 0.8859

Columns 69 through 85

0.8532 0.8480 0.8429 0.8378 0.8327 0.8277 0.8228 0.8178 0.8129 0.8080 0.8031 0.7982

Columns 86 through 102

0.7692 0.7643 0.7595 0.7546 0.7498 0.7449 0.7400 0.7351 0.7302 0.7253 0.7204 0.7154

Columns 103 through 119

0.6854 0.6803 0.6752 0.6701 0.6650 0.6598 0.6547 0.6495 0.6443 0.6390 0.6338 0.6285

Columns 120 through 136

0.5964 0.5910 0.5855 0.5801 0.5746 0.5691 0.5635 0.5580 0.5524 0.5468 0.5412 0.5356

Columns 137 through 153

0.5014 0.4956 0.4898 0.4840 0.4782 0.4724 0.4665 0.4606 0.4547 0.4488 0.4429 0.4369

Columns 154 through 170

0.4009 0.3948 0.3887 0.3827 0.3765 0.3704 0.3643 0.3581 0.3520 0.3458 0.3396 0.3334

Columns 171 through 187

0.2959 0.2896 0.2833 0.2770 0.2706 0.2643 0.2580 0.2516 0.2452 0.2389 0.2325 0.2261

Columns 188 through 204

0.1875 0.1811 0.1746 0.1681 0.1617 0.1552 0.1487 0.1422 0.1357 0.1292 0.1227 0.1162

Columns 205 through 221

0.0770 0.0705 0.0639 0.0574 0.0509 0.0443 0.0378 0.0312 0.0247 0.0181 0.0115 0.0050

Columns 222 through 238

-0.0343 -0.0409 -0.0474 -0.0540 -0.0605 -0.0671 -0.0736 -0.0802 -0.0867 -0.0932 -0.0997 -0.1063

Columns 239 through 255

-0.1453 -0.1518 -0.1583 -0.1648 -0.1712 -0.1777 -0.1842 -0.1906 -0.1970 -0.2035 -0.2099 -0.2163

Columns 256 through 272

-0.2546 -0.2610 -0.2673 -0.2737 -0.2800 -0.2863 -0.2926 -0.2989 -0.3052 -0.3114 -0.3177 -0.3239

Columns 273 through 289

-0.3611 -0.3672 -0.3733 -0.3794 -0.3855 -0.3916 -0.3977 -0.4037 -0.4098 -0.4158 -0.4218 -0.4278

Columns 290 through 306

-0.4634 -0.4692 -0.4751 -0.4809 -0.4867 -0.4925 -0.4983 -0.5040 -0.5097 -0.5154 -0.5211 -0.5268

Columns 307 through 323

-0.5604 -0.5659 -0.5714 -0.5769 -0.5823 -0.5877 -0.5931 -0.5985 -0.6039 -0.6092 -0.6145 -0.6198

Columns 324 through 340

-0.6510 -0.6561 -0.6612 -0.6663 -0.6713 -0.6763 -0.6813 -0.6862 -0.6912 -0.6960 -0.7009 -0.7058

Columns 341 through 357

-0.7342 -0.7389 -0.7435 -0.7481 -0.7526 -0.7571 -0.7616 -0.7661 -0.7705 -0.7749 -0.7793 -0.7837

Columns 358 through 374

-0.8091 -0.8132 -0.8173 -0.8213 -0.8254 -0.8294 -0.8333 -0.8372 -0.8411 -0.8450 -0.8488 -0.8526

Columns 375 through 391

-0.8747 -0.8782 -0.8818 -0.8853 -0.8887 -0.8921 -0.8955 -0.8988 -0.9022 -0.9054 -0.9087 -0.9119

Columns 392 through 408

-0.9303 -0.9333 -0.9362 -0.9391 -0.9419 -0.9447 -0.9475 -0.9502 -0.9529 -0.9555 -0.9582 -0.9607

Columns 409 through 425

-0.9754 -0.9777 -0.9800 -0.9822 -0.9844 -0.9865 -0.9887 -0.9907 -0.9928 -0.9948 -0.9967 -0.9986

Columns 426 through 442

-1.0093 -1.0110 -1.0126 -1.0141 -1.0156 -1.0171 -1.0186 -1.0200 -1.0213 -1.0226 -1.0239 -1.0252

Columns 443 through 459

-1.0317 -1.0327 -1.0336 -1.0345 -1.0353 -1.0361 -1.0369 -1.0376 -1.0382 -1.0389 -1.0394 -1.0400

Columns 460 through 476

-1.0424 -1.0427 -1.0429 -1.0431 -1.0432 -1.0433 -1.0433 -1.0433 -1.0433 -1.0432 -1.0431 -1.0430

Columns 477 through 493

-1.0412 -1.0407 -1.0403 -1.0397 -1.0392 -1.0386 -1.0379 -1.0372 -1.0365 -1.0357 -1.0349 -1.0341

Columns 494 through 510

-1.0281 -1.0270 -1.0258 -1.0246 -1.0233 -1.0220 -1.0207 -1.0193 -1.0179 -1.0164 -1.0149 -1.0134

Columns 511 through 527

-1.0033 -1.0015 -0.9996 -0.9977 -0.9958 -0.9938 -0.9918 -0.9897 -0.9876 -0.9855 -0.9833 -0.9811

Columns 528 through 544

-0.9671 -0.9646 -0.9621 -0.9595 -0.9569 -0.9543 -0.9516 -0.9489 -0.9462 -0.9434 -0.9406 -0.9377

Columns 545 through 561

-0.9198 -0.9167 -0.9135 -0.9103 -0.9071 -0.9039 -0.9006 -0.8972 -0.8939 -0.8905 -0.8871 -0.8836

Columns 562 through 578

-0.8620 -0.8583 -0.8546 -0.8508 -0.8470 -0.8432 -0.8393 -0.8354 -0.8314 -0.8274 -0.8234 -0.8194

Columns 579 through 595

-0.7945 -0.7902 -0.7859 -0.7816 -0.7772 -0.7728 -0.7684 -0.7640 -0.7595 -0.7550 -0.7504 -0.7459

Columns 596 through 612

-0.7178 -0.7131 -0.7083 -0.7034 -0.6986 -0.6937 -0.6888 -0.6839 -0.6789 -0.6739 -0.6689 -0.6638

Columns 613 through 629

-0.6330 -0.6278 -0.6226 -0.6173 -0.6120 -0.6067 -0.6013 -0.5960 -0.5906 -0.5851 -0.5797 -0.5742

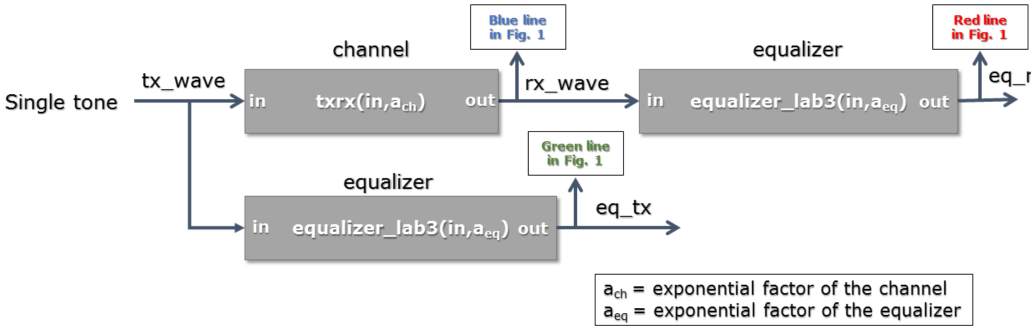
Columns 630 through 646

-0.5410 -0.5354 -0.5298 -0.5241 -0.5184 -0.5127 -0.5070 -0.5013 -0.4955 -0.4897 -0.4839 -0.4781

```
Columns 647 through 663

 -0.4428  -0.4369  -0.4309  -0.4249  -0.4189  -0.4129  -0.4069  -0.4008  -0.3948  -0.3887  -0.3826  -0.3765

Columns 664 through 680

 -0.3396  -0.3334  -0.3271  -0.3209  -0.3147  -0.3084  -0.3021  -0.2959  -0.2896  -0.2833  -0.2770  -0.2706

Columns 681 through 697

 -0.2325  -0.2261  -0.2197  -0.2132  -0.2068  -0.2004  -0.1940  -0.1875  -0.1811  -0.1746  -0.1681  -0.1617

Columns 698 through 714

 -0.1227  -0.1162  -0.1097  -0.1032  -0.0966  -0.0901  -0.0836  -0.0770  -0.0705  -0.0639  -0.0574  -0.0509

Columns 715 through 731

 -0.0115  -0.0050   0.0016   0.0081   0.0147   0.0212   0.0278   0.0343   0.0409   0.0474   0.0540   0.0605

Columns 732 through 748

  0.0997   0.1063   0.1128   0.1193   0.1258   0.1323   0.1388   0.1453   0.1518   0.1583   0.1648   0.1712

Columns 749 through 765

  0.2099   0.2163   0.2227   0.2291   0.2355   0.2419   0.2483   0.2546   0.2610   0.2673   0.2737   0.2800

Columns 766 through 782

  0.3177   0.3239   0.3301   0.3363   0.3425   0.3487   0.3549   0.3611   0.3672   0.3733   0.3794   0.3855

Columns 783 through 799

  0.4218   0.4278   0.4338   0.4397   0.4457   0.4516   0.4575   0.4634   0.4692   0.4751   0.4809   0.4867

Columns 800 through 816

  0.5211   0.5268   0.5325   0.5381   0.5437   0.5493   0.5548   0.5604   0.5659   0.5714   0.5769   0.5823

Columns 817 through 833

  0.6145   0.6198   0.6251   0.6303   0.6355   0.6407   0.6459   0.6510   0.6561   0.6612   0.6663   0.6713

Columns 834 through 850

  0.7009   0.7058   0.7106   0.7154   0.7201   0.7248   0.7295   0.7342   0.7389   0.7435   0.7481   0.7526

Columns 851 through 867

  0.7793   0.7837   0...
```

## INSTRUCTIONS

The MATLAB code above should transmit cosine waves of different frequencies (**tx_wave**) through the channel and record the output both with (**eq_rx**) and without equalization (**rx_wave**). It should also send the input signal **tx_wave** directly through the equalizer so that we can measure its frequency response (**eq_tx**). The connections among these signals are shown in the figure below.




Finally, the code should plot the frequency responses of the channel, the equalized channel and the equalizer on a single graph.

Your first task in this lab is to revise the code in order to obtain the peak to peak response of the above mentioned signals, and store them inside the variables, **h_tx**, **h_rx**, **h_eq_rx**, **h_eq_tx**, respectively. The basic structure of this code is very similar to that you have seen in Task 2. You should make similar modifications, as well as make sure that the signals **eq_rx** and **eq_tx** are computed correctly. The equalizer is implemented using the MATLAB function **out = equalizer_lab3(in,aeq)** where **in** is the input waveform (either the input or output of the channel), **aeq** is the equalizer's estimate of the exponential parameter of the channel (**ach**), and **out** stores the output waveform from the equalizer. The values of **ach** and **aeq** should be the same, but in many practical situations they are different, because the equalizer does not have a perfect model of the channel.

When modifying the code, do not modify the variables **ach**, **aeq**, **nsamp** and **flist**. Remember that when you study the peak to peak response you need to remove the transient response of the signal. For this lab, you can safely assume that the transient response ends before the first 200 samples.

Once you have successfully checked your work, experiment with the code by modifying the parameter **aeq** of the equalizer and use the insight gained to answer the questions below. You have an unlimited number of submissions on this task.

---

## LAB 3 - TASK 3 QUESTION 1 (1 point possible)

Suppose that the aeq < ach. Which of the following is/are true?

- [ ] The equalizer thinks the step response of the channel rises more slowly than it actually does.
- [ ] The equalizer thinks the step response of the channel rises faster than it actually does.
- [ ] High frequencies are amplified by too little after equalization.
- [ ] The equalizer perfectly cancels the effect of the channel.

?

*You have used 0 of 3 submissions*

---

## LAB 3 - TASK 3 QUESTION 2 (1 point possible)

Suppose that the aeq = ach. Which of the following is/are true?

- [ ] The equalizer thinks the step response of the channel rises more slowly than it actually does.
- [ ] The frequency response of the channel after equalization is flat (constant).
- [ ] High frequencies are not amplified enough after equalization.
- [ ] The equalizer perfectly cancels the effect of the channel.

?

*You have used 0 of 3 submissions*

## LAB 3 - TASK 3 QUESTION 3 (1 point possible)

What type of filter is the equalizer?

- ○ Low Pass
- ○ Band Pass
- ○ High Pass

?

*You have used 0 of 1 submissions*