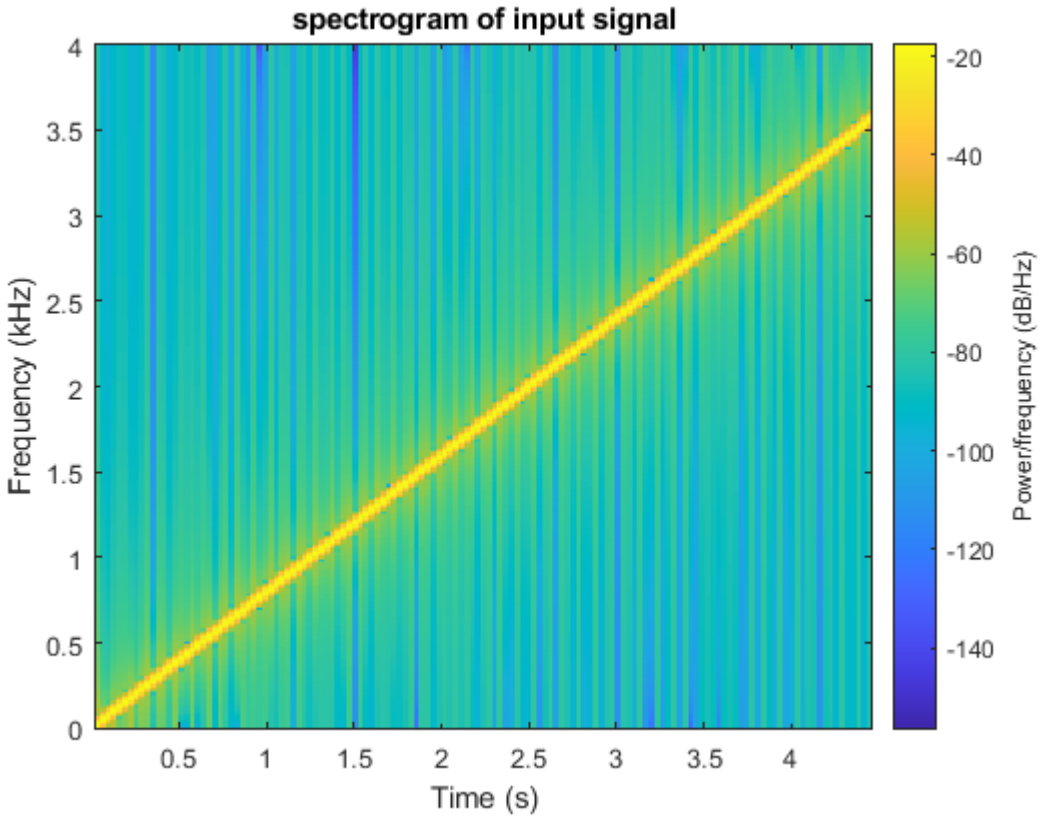
Lab 8

Exercise 8.1

Part A

```
fs = 8000;
tt = 0:1/fs:4.5;
x = cos(2*pi/20*fs*tt.^2);
spectrogram(x, 512, 256, 512, fs, 'yaxis');
title("spectrogram of input signal");
```




```
%soundsc(x,fs);
```

A linearly scaling sound that starts quiet and finishes loud. This is clearly shown on the spectogram.

Part B

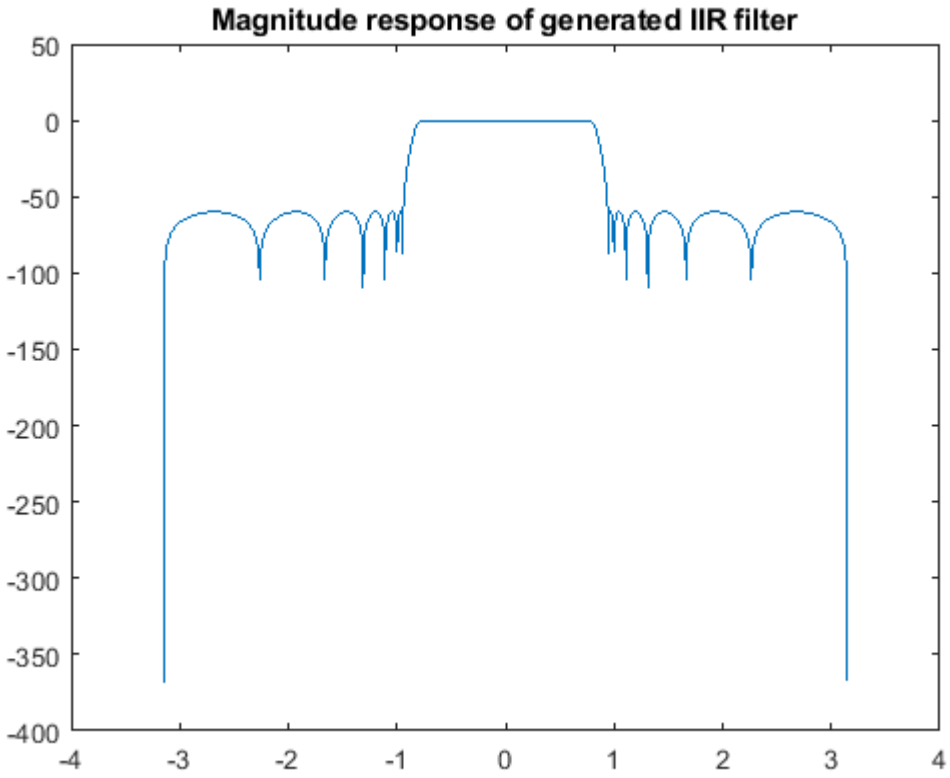
```
%Variables a_iir and b_iir imported from FilterDesigner
disp("Transfer function of IIR filter");display(tf(b_iir,a_iir));
```

```
Transfer function of IIR filter

ans =


  0.004386 s^13 - 0.005247 s^12 + 0.01573 s^11 - 0.007578 s^10

          + 0.01859 s^9 + 0.001705 s^8 + 0.01188 s^7
```

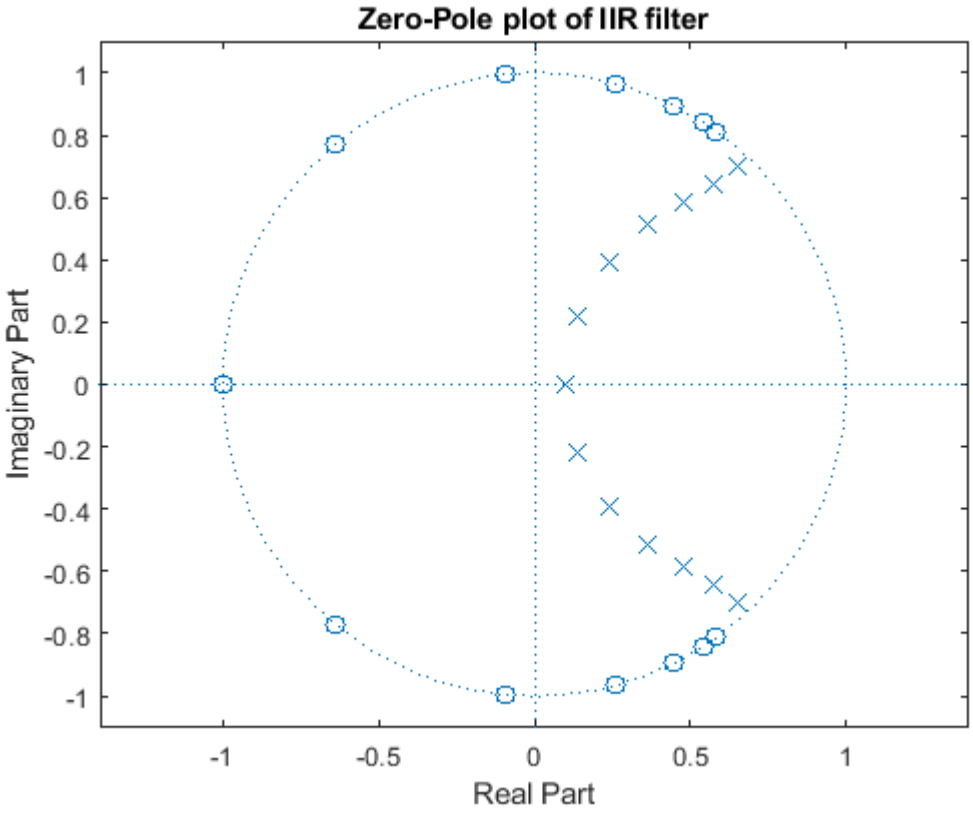
```
          + 0.01188 s^6 + 0.001705 s^5 + 0.01859 s^4
          - 0.007578 s^3 + 0.01573 s^2 - 0.005247 s
                                                 + 0.004386
  ------------------------------------------------------------
   s^13 - 4.976 s^12 + 12.9 s^11 - 21.83 s^10 + 26.6 s^9
           - 24.33 s^8 + 17.1 s^7 - 9.289 s^6 + 3.894 s^5
           - 1.237 s^4 + 0.29 s^3 - 0.04699 s^2 + 0.004828 s
                                                   - 0.000208
```

Continuous-time transfer function.

```
w = -pi:pi/1000:pi;
H_iir = freqz(b_iir,a_iir,w);
mag_iir=mag2db(abs(H_iir));
plot(w,mag_iir);
title('Magnitude response of generated IIR filter');
```

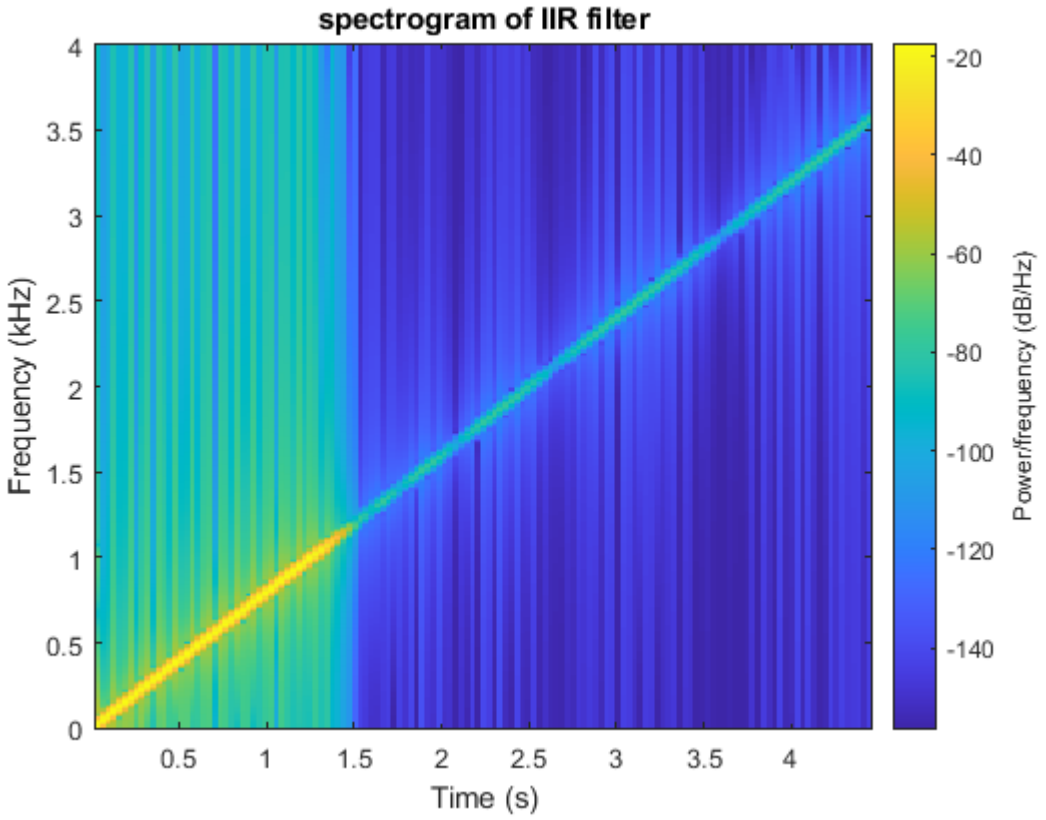



```
zplane(b_iir,a_iir);
title("Zero-Pole plot of IIR filter");
```



Part C

```
x_iir = filter(b_iir,a_iir,x);
spectrogram(x_iir, 512, 256, 512, fs, 'yaxis');
title("spectrogram of IIR filter");
```




```
%soundsc(x_iir,fs);
```

The filtered chirp increased in pitch until it reached 1.5 seconds, or around 1kHz, when it got much quieter, or less intense. It aligns with the magnitude response where the higher intensities are assicociated with the frequencies between -1 and 1 kHz

Part D

```
%b_fir imported from FilterDesigner
disp("Transfer function of FIR filter");display(tf(b_fir));
```

```
Transfer function of FIR filter

ans =

  From input 1 to output:
  -0.001854

  From input 2 to output:
  -0.003831

  From input 3 to output:
  -0.005862

  From input 4 to output:
  -0.006473

  From input 5 to output:
  -0.004585

  From input 6 to output:
```

-0.0002091

From input 7 to output:
0.005172

From input 8 to output:
0.009102

From input 9 to output:
0.009458

From input 10 to output:
0.005854

From input 11 to output:
0.0002124

From input 12 to output:
-0.004088

From input 13 to output:
-0.004186

From input 14 to output:
0.0003015

From input 15 to output:
0.006685

From input 16 to output:
0.01062

From input 17 to output:
0.008859

From input 18 to output:
0.001718

From input 19 to output:
-0.006649

From input 20 to output:
-0.01057

From input 21 to output:
-0.006612

From input 22 to output:
0.003594

From input 23 to output:
0.01372

From input 24 to output:
0.01642

From input 25 to output:
0.008387

From input 26 to output:
-0.006591

From input 27 to output:
-0.01906

From input 28 to output:
-0.01954

From input 29 to output:
-0.005214

From input 30 to output:
0.0167

From input 31 to output:
0.03191

From input 32 to output:
0.0275

From input 33 to output:
0.001145

From input 34 to output:
-0.0345

From input 35 to output:
-0.05607

From input 36 to output:
-0.04118

From input 37 to output:
0.01847

From input 38 to output:
0.1099

From input 39 to output:
0.2022

From input 40 to output:
0.26

From input 41 to output:
0.26

From input 42 to output:
0.2022

From input 43 to output:
0.1099

From input 44 to output:
0.01847

From input 45 to output:
-0.04118

From input 46 to output:
-0.05607

From input 47 to output:
-0.0345

From input 48 to output:
0.001145

From input 49 to output:
0.0275

From input 50 to output:
0.03191

From input 51 to output:
0.0167

From input 52 to output:
-0.005214

From input 53 to output:
-0.01954

From input 54 to output:
-0.01906

From input 55 to output:
-0.006591

From input 56 to output:
0.008387

From input 57 to output:
0.01642

From input 58 to output:
0.01372

From input 59 to output:
0.003594

From input 60 to output:
-0.006612

From input 61 to output:
-0.01057

From input 62 to output:
-0.006649

From input 63 to output:
0.001718

From input 64 to output:
0.008859

From input 65 to output:
0.01062

From input 66 to output:
0.006685

From input 67 to output:
0.0003015

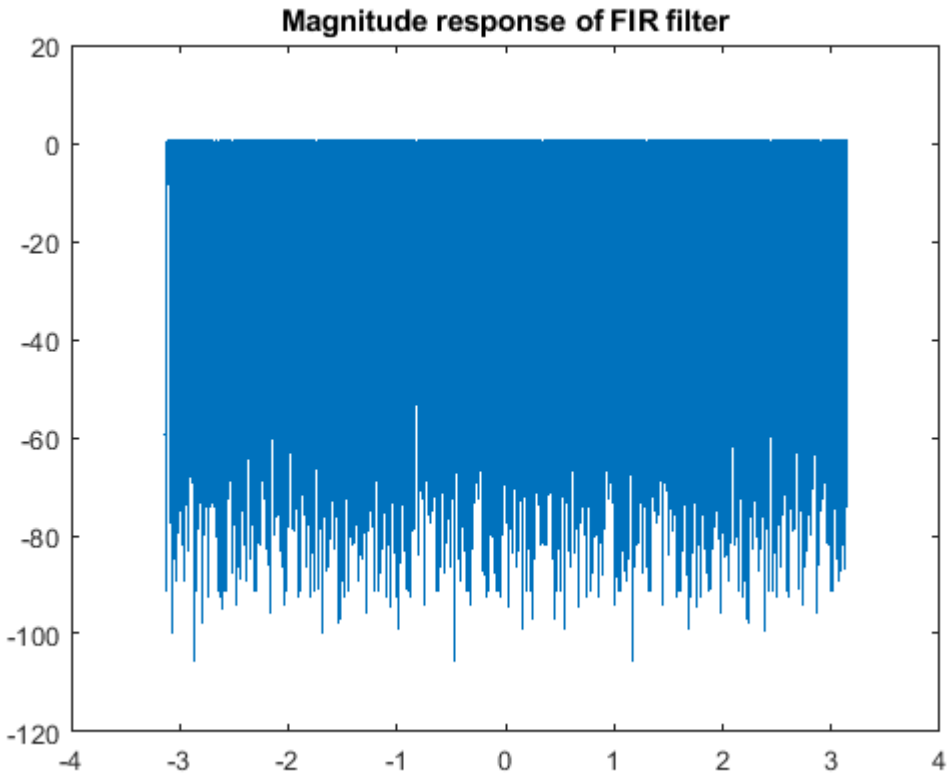
From input 68 to output:
-0.004186

From input 69 to output:
-0.004088

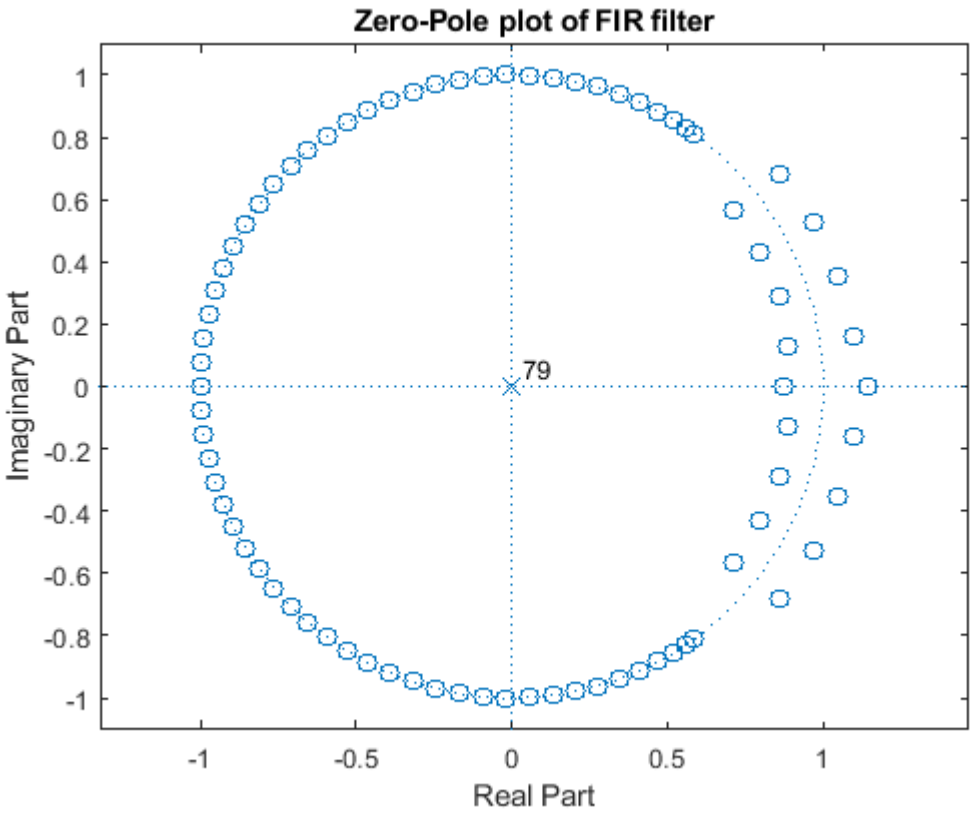
From input 70 to output:

```
  0.0002124

  From input 71 to output:
  0.005854

  From input 72 to output:
  0.009458

  From input 73 to output:
  0.009102

  From input 74 to output:
  0.005172

  From input 75 to output:
  -0.0002091

  From input 76 to output:
  -0.004585

  From input 77 to output:
  -0.006473

  From input 78 to output:
  -0.005862

  From input 79 to output:
  -0.003831

  From input 80 to output:
  -0.001854

Static gain.
```

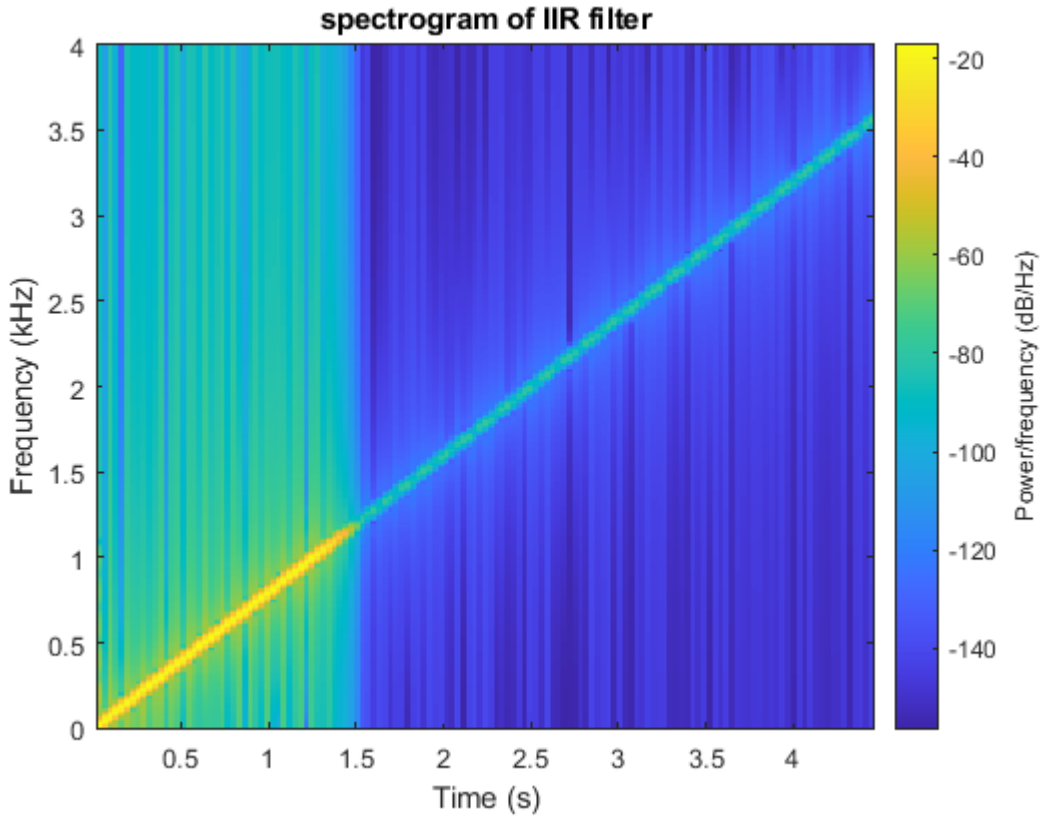
```
w=-pi:pi/18000:pi;
H_fir = freqz(b_fir,1,x);
mag_fir=mag2db(abs(H_fir));
plot(w,mag_fir);
title("Magnitude response of FIR filter");
```




```
zplane(b_fir,1);
title("Zero-Pole plot of FIR filter");
```



```
x_fir = filter(b_fir,1,x);
spectrogram(x_fir, 512, 256, 512, fs, 'yaxis');
title("spectrogram of IIR filter");
```




```
%soundsc(x_fir,fs);
```

The order of the IIR filter is much shorter than the FIR filter, therefore it is computationally much simpler to implement the IIR filter. The audio quality sounded the same for both filters, but it was scratchy as I am running MatLab through UF Apps on my MacBook.

Exercise 8.2

```
[s, s_fs] = audioread('noisy_drum_flute.wav');
%b_s and a_s are imported from filter designer (drum filter)
s_filtered = filter(b_s,a_s,s);
%soundsc(s_filtered,s_fs);
```

•What type of filter did you design: low-pass, high-pass, band-pass, band-stop, all-pass? Why?

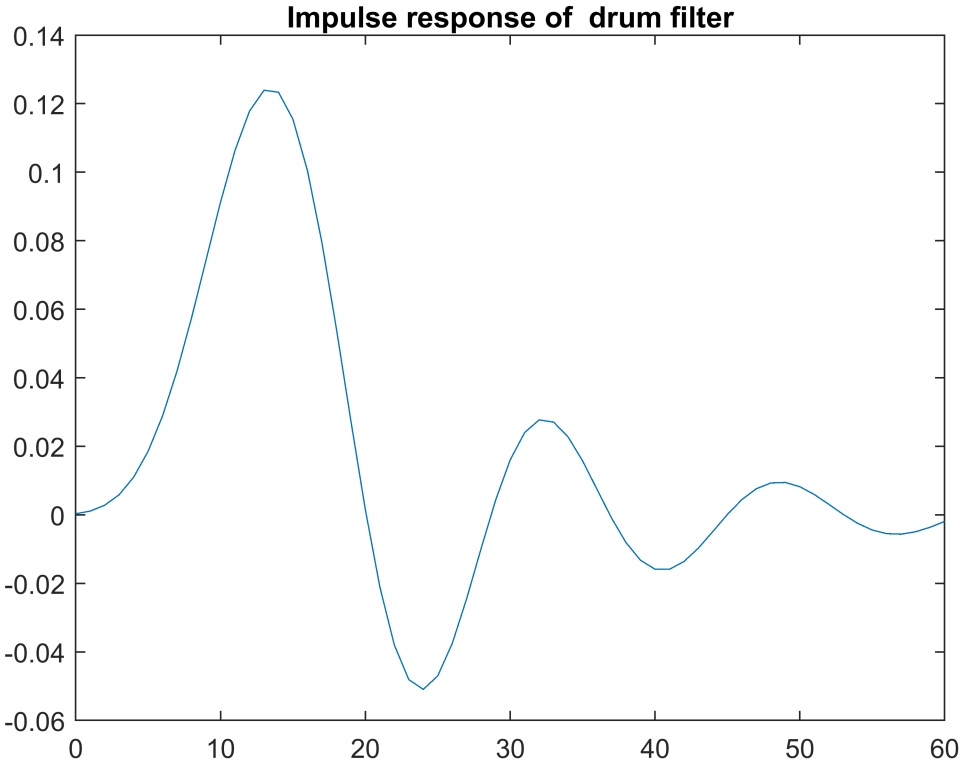
I designed a low-pass filter. I noted the hint at the bottom of the exercise that the drum contained mostly low frequencies and acted on it.

•Did you create an FIR or IIR filter? Why?

I created a IIR filter as the order is much lower than an equivalent FIR filter

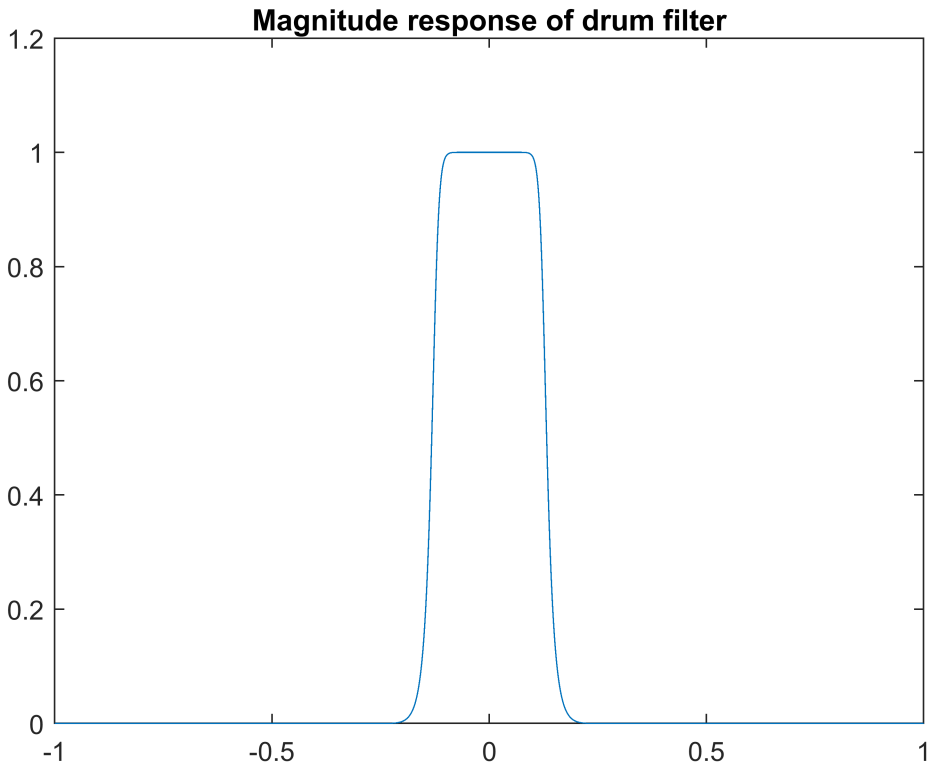
•Plot the filter's impulse response.

```
n = 0:1:60;
impulse=n==0;
impulse_response = filter(b_s,a_s,impulse);
plot(n, impulse_response);
title('Impulse response of  drum filter');
```

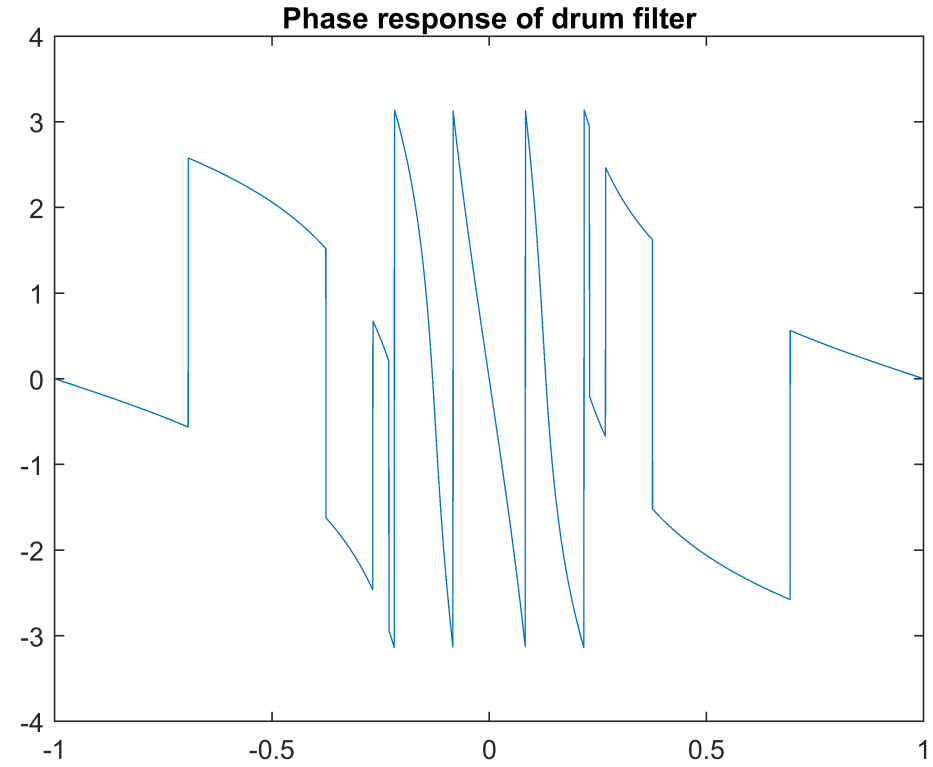


•Plot the magnitude and phase responses of your filter. The horizontal (frequency) axis must be plotted in the unit of Hz. Hint: Use the formula of converting normalized radian frequency to cyclic frequency in the unit of Hz.

```
w = -pi:pi/2000:pi;
H_s = freqz(b_s,a_s,w);
mag_s=abs(H_s);
plot(w/pi,mag_s);
title('Magnitude response of drum filter');
```




```
plot(w/pi,angle(H_s));
title('Phase response of drum filter');
```

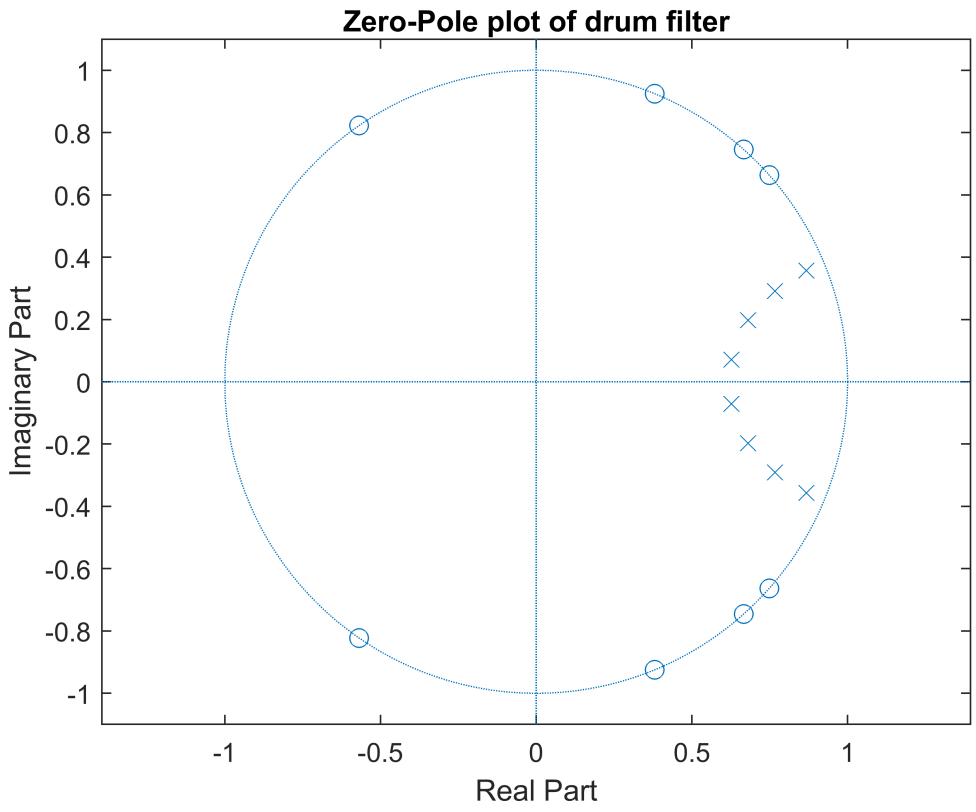


•Write down the transfer function of your filter. Draw its pole-zero plot.

```
disp("Transfer function of drum filter");display(tf(b_s, a_s));
```

```
Transfer function of drum filter

ans =

  0.0003163 s^8 - 0.0007761 s^7 + 0.001286 s^6 - 0.001316 s^5 + 0.001392 s^4
                              - 0.001316 s^3 + 0.001286 s^2 - 0.0007761 s + 0.0003163
  ------------------------------------------------------------------------------------
  s^8 - 5.88 s^7 + 15.35 s^6 - 23.18 s^5 + 22.13 s^4 - 13.65 s^3 + 5.311 s^2
                                                                  - 1.191 s + 0.1176

Continuous-time transfer function.
```

```
zplane(b_s,a_s);
title("Zero-Pole plot of drum filter");
```

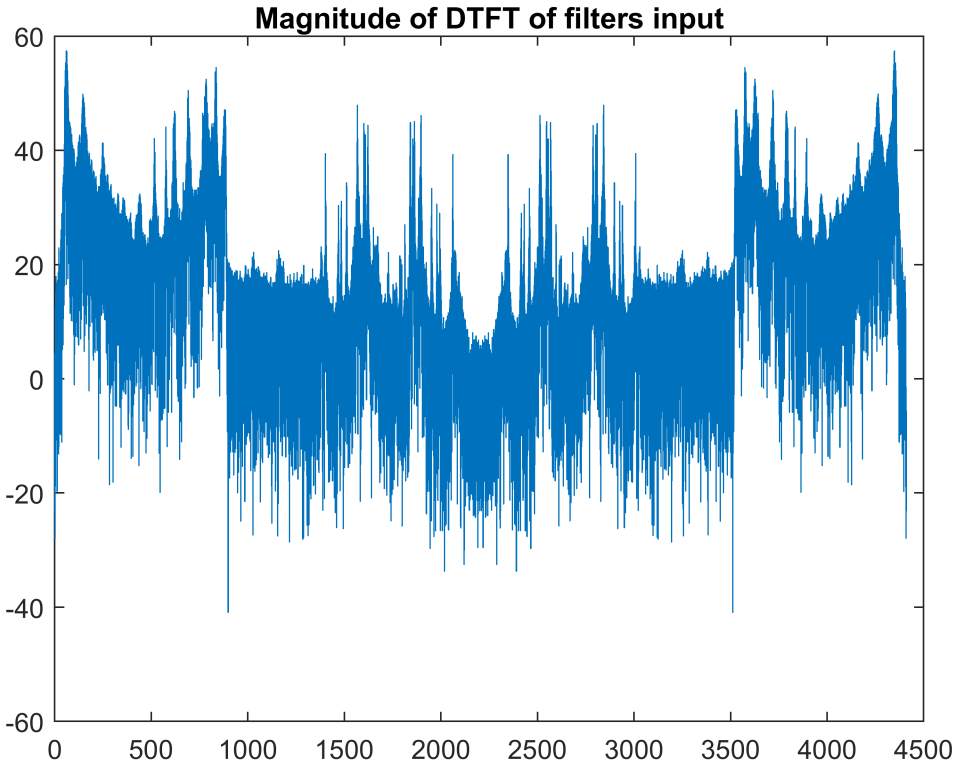


•Correlate the locations of the poles and zeros to the filter's magnitude response.

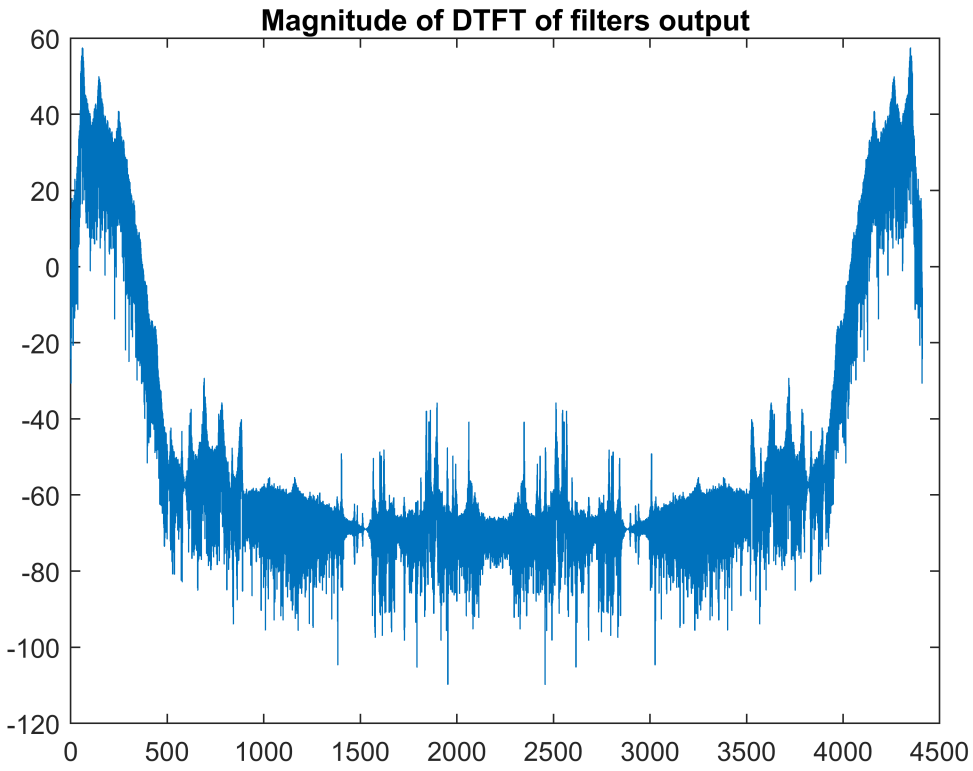
The poles of the filter are all between -0.2 and 0.2 normalized radian frequency, which is shown by the high magnitude between this range. Elsewhere are zeros, which is shown by the lack of any magnitude outside the aforementioned range.

•Plot the magnitudes of the DTFTs of your filter's input and output signals. Again, the horizontal (frequency) axis must be plotted in the unit of Hz.

```
w = 4410*linspace(0,pi,140000);
H_input = fft(s);
plot(w/pi,mag2db(abs(H_input)));
title("Magnitude of DTFT of filters input");
```




```
w = 4410*linspace(0,pi,140000);
H_output = fft(s_filtered);
plot(w/pi,mag2db(abs(H_output)));
title("Magnitude of DTFT of filters output");
```



•Explain the differences between the input and output DTFTs based on your filter's characteristics.

The difference in the DTFTs is due to the filters behavior of filtereing out the higher frequencies. The fact that it does not filter out frequencies above 4000 is strange, but it does not affect the output. This is likely due to the fact that there are no sounds with that frequency in the signal.

•Save the output audio signal to the WAV file drum.wav. Submit the WAV file.

```
audiowrite("drum.wav",s_filtered,s_fs);
```

Exercise 8.3

```
f_filtered = filter(b_f,1,s);
soundsc(f_filtered,s_fs);
```

•What type of filter did you design: low-pass, high-pass, band-pass, band-stop, all-pass? Why?

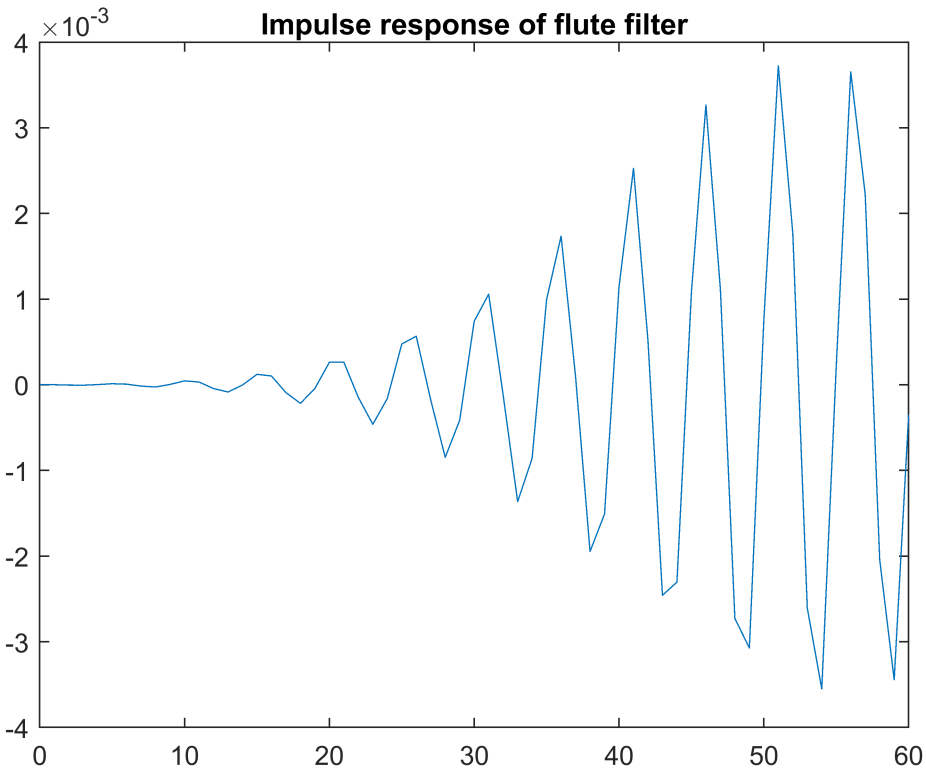
I designed a band-pass filter. Since the flute was at a frequency between the drums and the interference, I had to pull that out without getting any of the other sound, so a band-pass filter did the job. There was a little straggler sound coming in from the surrounding frequencies, but I did the best I could.

•Did you create an FIR or IIR filter? Why?

I created an FIR filter for this one. Working with less coefficients and commands made it easier to iterate on the design.

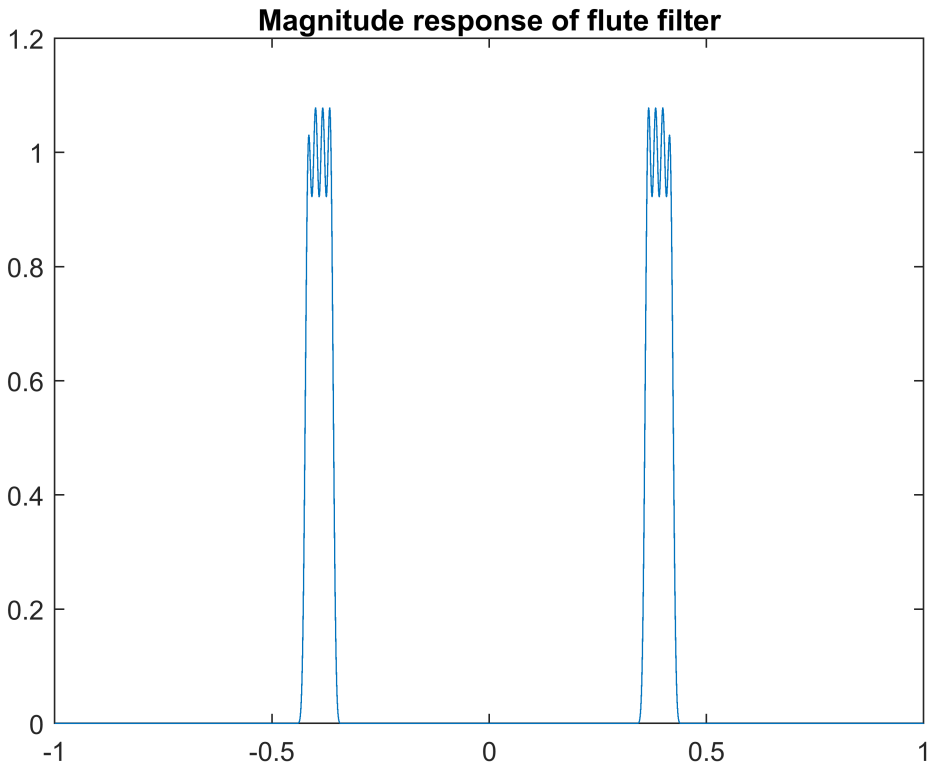
•Plot the filter's impulse response.

```
n = 0:1:60;
impulse=n==0;
impulse_response_f = filter(b_f,1,impulse);
plot(n, impulse_response_f);
title('Impulse response of flute filter');
```

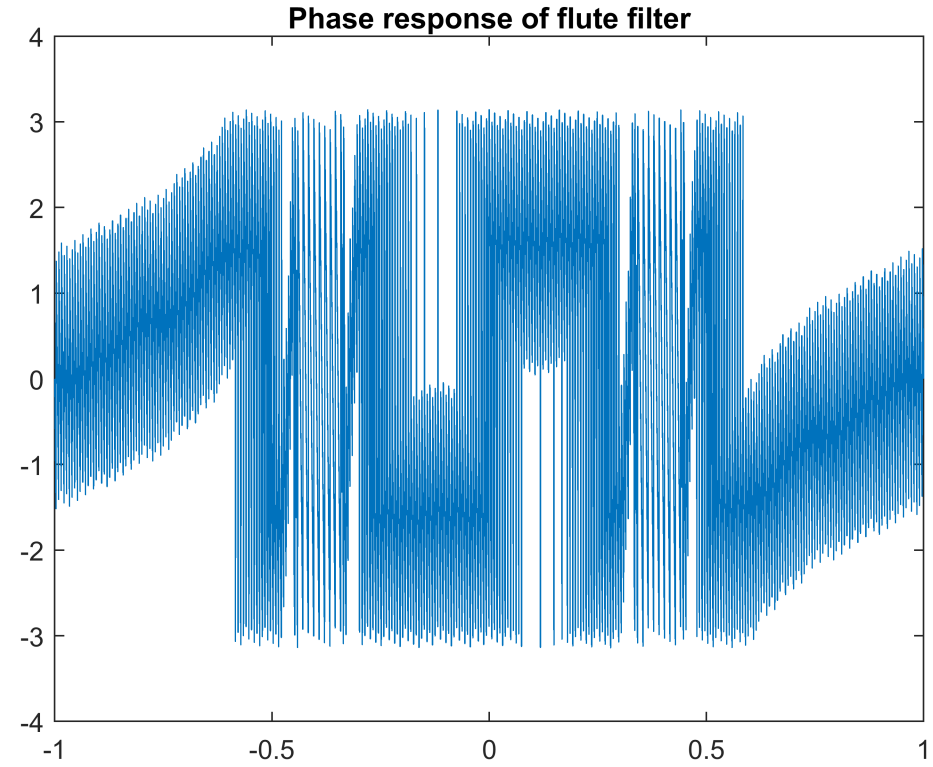


•Plot the magnitude and phase responses of your filter. The horizontal (frequency) axis must be plotted in the unit of Hz. Hint: Use the formula of converting normalized radian frequency to cyclic frequency in the unit of Hz.

```
w = -pi:pi/2000:pi;
H_f = freqz(b_f,1,w);
mag_f=abs(H_f);
plot(w/pi,mag_f);
title('Magnitude response of flute filter');
```




```
plot(w/pi,angle(H_f));
title('Phase response of flute filter');
```



•Write down the transfer function of your filter. Draw its pole-zero plot.

```
disp("Transfer function of flute filter");display(tf(b_f));
```

```
Transfer function of flute filter

ans =

  From input 1 to output:
  1.746e-06

  From input 2 to output:
  6.837e-07

  From input 3 to output:
  -3.515e-06

  From input 4 to output:
  -5.324e-06

  From input 5 to output:
  2.057e-06

  From input 6 to output:
  1.216e-05

  From input 7 to output:
  6.984e-06

  From input 8 to output:
  -1.57e-05

  From input 9 to output:
  -2.586e-05

  From input 10 to output:
  3.945e-06

  From input 11 to output:
  4.536e-05

  From input 12 to output:
  3.177e-05

  From input 13 to output:
  -4.411e-05

  From input 14 to output:
  -8.471e-05

  From input 15 to output:
  -3.24e-06

  From input 16 to output:
  0.0001218

  From input 17 to output:
  0.0001025

  From input 18 to output:
  -9.172e-05

  From input 19 to output:
```

```
-0.0002166

From input 20 to output:
-4.343e-05

From input 21 to output:
0.0002625

From input 22 to output:
0.000263

From input 23 to output:
-0.0001476

From input 24 to output:
-0.0004616

From input 25 to output:
-0.0001603

From input 26 to output:
0.000476

From input 27 to output:
0.0005669

From input 28 to output:
-0.0001772

From input 29 to output:
-0.0008474

From input 30 to output:
-0.0004131

From input 31 to output:
0.0007411

From input 32 to output:
0.001057

From input 33 to output:
-0.0001205

From input 34 to output:
-0.001365

From input 35 to output:
-0.000857

From input 36 to output:
0.0009958

From input 37 to output:
0.001735

From input 38 to output:
9.345e-05

From input 39 to output:
-0.001946

From input 40 to output:
-0.001508
```

```
From input 41 to output:
0.001143

From input 42 to output:
0.002527

From input 43 to output:
0.0005126

From input 44 to output:
-0.002458

From input 45 to output:
-0.002304

From input 46 to output:
0.00108

From input 47 to output:
0.003268

From input 48 to output:
0.001114

From input 49 to output:
-0.002728

From input 50 to output:
-0.003073

From input 51 to output:
0.0007535

From input 52 to output:
0.003723

From input 53 to output:
0.001766

From input 54 to output:
-0.002606

From input 55 to output:
-0.003551

From input 56 to output:
0.0002157

From input 57 to output:
0.003654

From input 58 to output:
0.002222

From input 59 to output:
-0.002042

From input 60 to output:
-0.003445

From input 61 to output:
-0.0003483
```

From input 62 to output:
0.002915

From input 63 to output:
0.002178

From input 64 to output:
-0.001145

From input 65 to output:
-0.002546

From input 66 to output:
-0.0006503

From input 67 to output:
0.001553

From input 68 to output:
0.001388

From input 69 to output:
-0.0001906

From input 70 to output:
-0.0008576

From input 71 to output:
-0.0004015

From input 72 to output:
-0.0001493

From input 73 to output:
-0.0001953

From input 74 to output:
0.0004599

From input 75 to output:
0.001326

From input 76 to output:
0.000535

From input 77 to output:
-0.001725

From input 78 to output:
-0.002302

From input 79 to output:
0.0005121

From input 80 to output:
0.00344

From input 81 to output:
0.002002

From input 82 to output:
-0.002677

From input 83 to output:

```
-0.004341

From input 84 to output:
-8.536e-05

From input 85 to output:
0.004801

From input 86 to output:
0.003496

From input 87 to output:
-0.002691

From input 88 to output:
-0.005529

From input 89 to output:
-0.001028

From input 90 to output:
0.004853

From input 91 to output:
0.004263

From input 92 to output:
-0.001821

From input 93 to output:
-0.005165

From input 94 to output:
-0.00169

From input 95 to output:
0.003432

From input 96 to output:
0.003558

From input 97 to output:
-0.0005414

From input 98 to output:
-0.002944

From input 99 to output:
-0.001335

From input 100 to output:
0.0009122

From input 101 to output:
0.0009946

From input 102 to output:
0.0003894

From input 103 to output:
0.000804

From input 104 to output:
0.0005316
```

```
From input 105 to output:
-0.001853

From input 106 to output:
-0.003153

From input 107 to output:
0.0002615

From input 108 to output:
0.005091

From input 109 to output:
0.003809

From input 110 to output:
-0.003824

From input 111 to output:
-0.007841

From input 112 to output:
-0.001184

From input 113 to output:
0.008523

From input 114 to output:
0.0076

From input 115 to output:
-0.004224

From input 116 to output:
-0.01145

From input 117 to output:
-0.003448

From input 118 to output:
0.009783

From input 119 to output:
0.01031

From input 120 to output:
-0.002972

From input 121 to output:
-0.01226

From input 122 to output:
-0.005231

From input 123 to output:
0.008182

From input 124 to output:
0.01006

From input 125 to output:
-0.0008947
```

```
From input 126 to output:
-0.009098

From input 127 to output:
-0.004745

From input 128 to output:
0.004051

From input 129 to output:
0.005395

From input 130 to output:
0.0004153

From input 131 to output:
-0.001884

From input 132 to output:
-0.0003292

From input 133 to output:
-0.00121

From input 134 to output:
-0.004137

From input 135 to output:
-0.0008848

From input 136 to output:
0.008151

From input 137 to output:
0.008844

From input 138 to output:
-0.005518

From input 139 to output:
-0.01753

From input 140 to output:
-0.006166

From input 141 to output:
0.01869

From input 142 to output:
0.02223

From input 143 to output:
-0.006813

From input 144 to output:
-0.03243

From input 145 to output:
-0.01566

From input 146 to output:
0.027

From input 147 to output:
```

0.03782

From input 148 to output:
-0.003847

From input 149 to output:
-0.04568

From input 150 to output:
-0.02813

From input 151 to output:
0.0308

From input 152 to output:
0.05252

From input 153 to output:
0.00325

From input 154 to output:
-0.05428

From input 155 to output:
-0.04107

From input 156 to output:
0.02908

From input 157 to output:
0.06304

From input 158 to output:
0.01288

From input 159 to output:
-0.05627

From input 160 to output:
-0.05137

From input 161 to output:
0.02242

From input 162 to output:
0.06686

From input 163 to output:
0.02242

From input 164 to output:
-0.05137

From input 165 to output:
-0.05627

From input 166 to output:
0.01288

From input 167 to output:
0.06304

From input 168 to output:
0.02908

From input 169 to output:
-0.04107

From input 170 to output:
-0.05428

From input 171 to output:
0.00325

From input 172 to output:
0.05252

From input 173 to output:
0.0308

From input 174 to output:
-0.02813

From input 175 to output:
-0.04568

From input 176 to output:
-0.003847

From input 177 to output:
0.03782

From input 178 to output:
0.027

From input 179 to output:
-0.01566

From input 180 to output:
-0.03243

From input 181 to output:
-0.006813

From input 182 to output:
0.02223

From input 183 to output:
0.01869

From input 184 to output:
-0.006166

From input 185 to output:
-0.01753

From input 186 to output:
-0.005518

From input 187 to output:
0.008844

From input 188 to output:
0.008151

From input 189 to output:
-0.0008848

From input 190 to output:
-0.004137

From input 191 to output:
-0.00121

From input 192 to output:
-0.0003292

From input 193 to output:
-0.001884

From input 194 to output:
0.0004153

From input 195 to output:
0.005395

From input 196 to output:
0.004051

From input 197 to output:
-0.004745

From input 198 to output:
-0.009098

From input 199 to output:
-0.0008947

From input 200 to output:
0.01006

From input 201 to output:
0.008182

From input 202 to output:
-0.005231

From input 203 to output:
-0.01226

From input 204 to output:
-0.002972

From input 205 to output:
0.01031

From input 206 to output:
0.009783

From input 207 to output:
-0.003448

From input 208 to output:
-0.01145

From input 209 to output:
-0.004224

From input 210 to output:
0.0076

From input 211 to output:

```
0.008523

From input 212 to output:
-0.001184

From input 213 to output:
-0.007841

From input 214 to output:
-0.003824

From input 215 to output:
0.003809

From input 216 to output:
0.005091

From input 217 to output:
0.0002615

From input 218 to output:
-0.003153

From input 219 to output:
-0.001853

From input 220 to output:
0.0005316

From input 221 to output:
0.000804

From input 222 to output:
0.0003894

From input 223 to output:
0.0009946

From input 224 to output:
0.0009122

From input 225 to output:
-0.001335

From input 226 to output:
-0.002944

From input 227 to output:
-0.0005414

From input 228 to output:
0.003558

From input 229 to output:
0.003432

From input 230 to output:
-0.00169

From input 231 to output:
-0.005165

From input 232 to output:
-0.001821
```

```
From input 233 to output:
0.004263

From input 234 to output:
0.004853

From input 235 to output:
-0.001028

From input 236 to output:
-0.005529

From input 237 to output:
-0.002691

From input 238 to output:
0.003496

From input 239 to output:
0.004801

From input 240 to output:
-8.536e-05

From input 241 to output:
-0.004341

From input 242 to output:
-0.002677

From input 243 to output:
0.002002

From input 244 to output:
0.00344

From input 245 to output:
0.0005121

From input 246 to output:
-0.002302

From input 247 to output:
-0.001725

From input 248 to output:
0.000535

From input 249 to output:
0.001326

From input 250 to output:
0.0004599

From input 251 to output:
-0.0001953

From input 252 to output:
-0.0001493

From input 253 to output:
-0.0004015
```

From input 254 to output:
-0.0008576

From input 255 to output:
-0.0001906

From input 256 to output:
0.001388

From input 257 to output:
0.001553

From input 258 to output:
-0.0006503

From input 259 to output:
-0.002546

From input 260 to output:
-0.001145

From input 261 to output:
0.002178

From input 262 to output:
0.002915

From input 263 to output:
-0.0003483

From input 264 to output:
-0.003445

From input 265 to output:
-0.002042

From input 266 to output:
0.002222

From input 267 to output:
0.003654

From input 268 to output:
0.0002157

From input 269 to output:
-0.003551

From input 270 to output:
-0.002606

From input 271 to output:
0.001766

From input 272 to output:
0.003723

From input 273 to output:
0.0007535

From input 274 to output:
-0.003073

From input 275 to output:

-0.002728

From input 276 to output:
0.001114

From input 277 to output:
0.003268

From input 278 to output:
0.00108

From input 279 to output:
-0.002304

From input 280 to output:
-0.002458

From input 281 to output:
0.0005126

From input 282 to output:
0.002527

From input 283 to output:
0.001143

From input 284 to output:
-0.001508

From input 285 to output:
-0.001946

From input 286 to output:
9.345e-05

From input 287 to output:
0.001735

From input 288 to output:
0.0009958

From input 289 to output:
-0.000857

From input 290 to output:
-0.001365

From input 291 to output:
-0.0001205

From input 292 to output:
0.001057

From input 293 to output:
0.0007411

From input 294 to output:
-0.0004131

From input 295 to output:
-0.0008474

From input 296 to output:
-0.0001772

From input 297 to output:
0.0005669

From input 298 to output:
0.000476

From input 299 to output:
-0.0001603

From input 300 to output:
-0.0004616

From input 301 to output:
-0.0001476

From input 302 to output:
0.000263

From input 303 to output:
0.0002625

From input 304 to output:
-4.343e-05

From input 305 to output:
-0.0002166

From input 306 to output:
-9.172e-05

From input 307 to output:
0.0001025

From input 308 to output:
0.0001218

From input 309 to output:
-3.24e-06

From input 310 to output:
-8.471e-05

From input 311 to output:
-4.411e-05

From input 312 to output:
3.177e-05

From input 313 to output:
4.536e-05

From input 314 to output:
3.945e-06

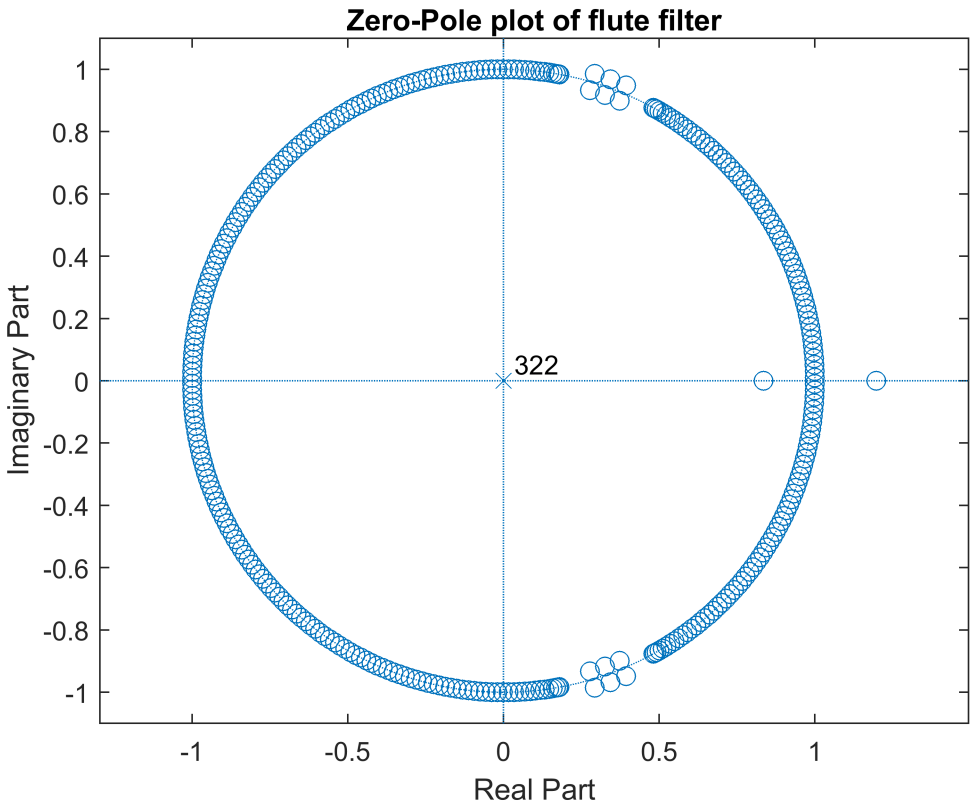
From input 315 to output:
-2.586e-05

From input 316 to output:
-1.57e-05

From input 317 to output:
6.984e-06

```
From input 318 to output:
1.216e-05

From input 319 to output:
2.057e-06

From input 320 to output:
-5.324e-06

From input 321 to output:
-3.515e-06

From input 322 to output:
6.837e-07

From input 323 to output:
1.746e-06

Static gain.
```

```
zplane(b_f,1);
title("Zero-Pole plot of flute filter");
```

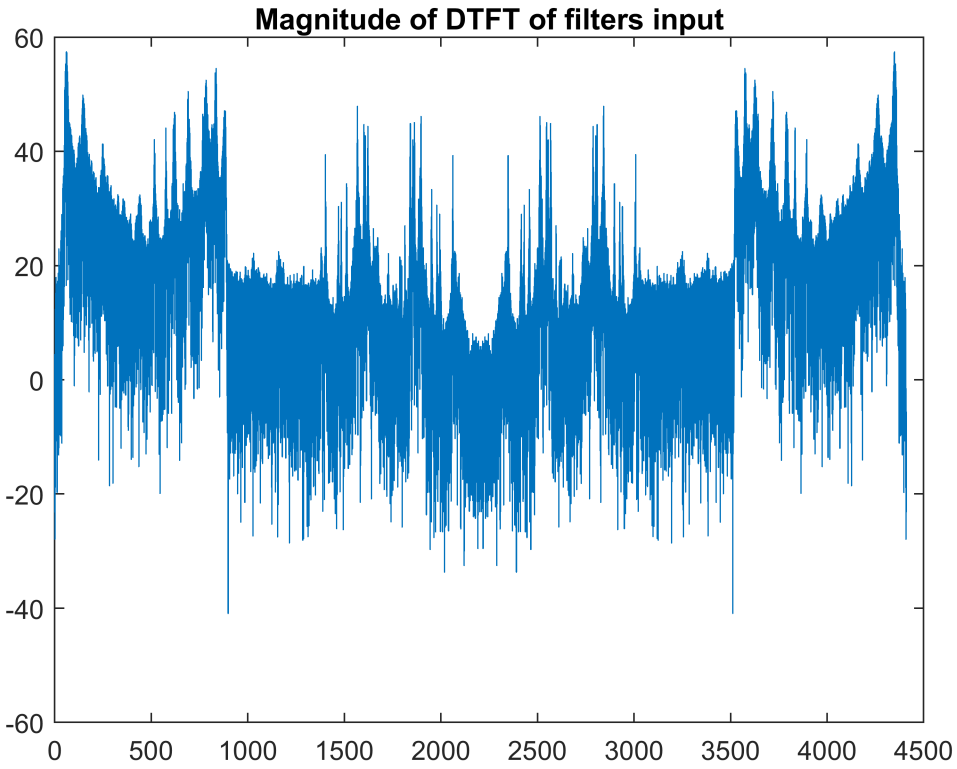


•Correlate the locations of the poles and zeros to the filter's magnitude response.

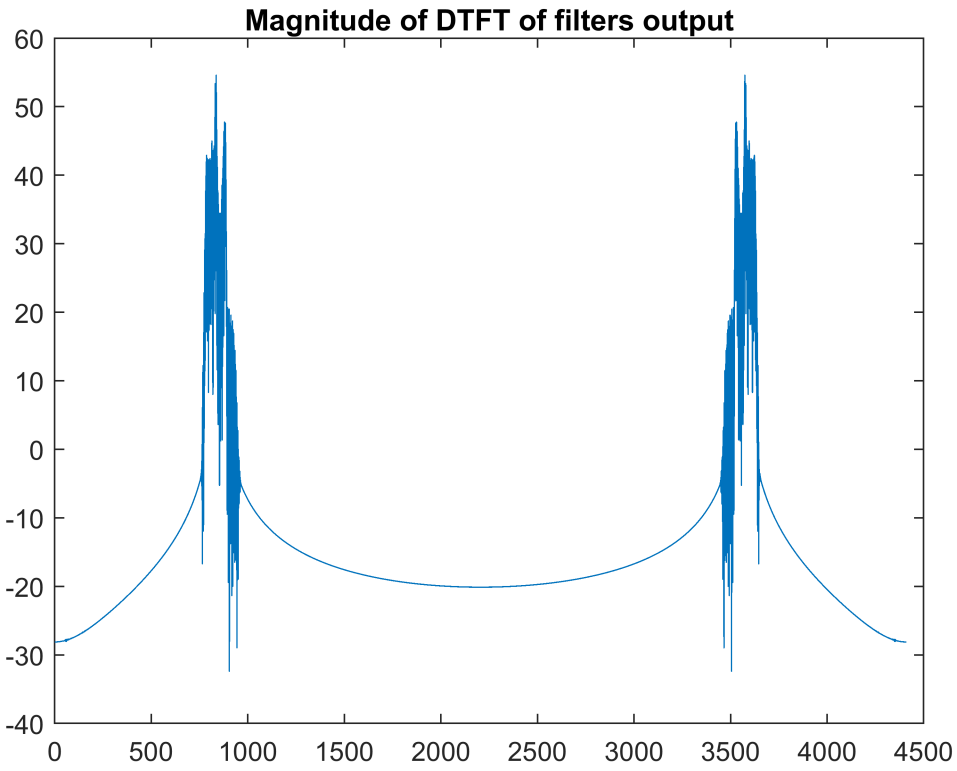
The zeros of the filter are surrounding the unit circle, but there are small gaps right before pi/2. This corresponds with the magnitude response where only a certain "band" of frequency is allowed to pass through. The zeros are concentrated in the middle, as the filter is an FIR.

•Plot the magnitudes of the DTFTs of your filter's input and output signals. Again, the horizontal (frequency) axis must be plotted in the unit of Hz.

```
w = 4410*linspace(0,pi,140000);
H_input = fft(s);
plot(w/pi,mag2db(abs(H_input)));
title("Magnitude of DTFT of filters input");
```




```
w = 4410*linspace(0,pi,140000);
H_output_f = fft(f_filtered);
plot(w/pi,mag2db(abs(H_output_f)));
title("Magnitude of DTFT of filters output");
```



•Explain the differences between the input and output DTFTs based on your filter's characteristics.

The difference in the DTFTs is apparent here. In the input signal, almost all the frequencies can pass. However in the output signal. it is clear that only a small band of frequency is allowed to pass. These bands are where the flute is located.

•Save the output audio signal to the WAV file drum.wav. Submit the WAV file.

```
audiowrite("flute.wav",s_filtered,s_fs);
```