Middle East Technical University

Electrical-Electronics Engineering Department

EE301 Term Project Part - I (2016-2017 Fall Semester)

Group 149

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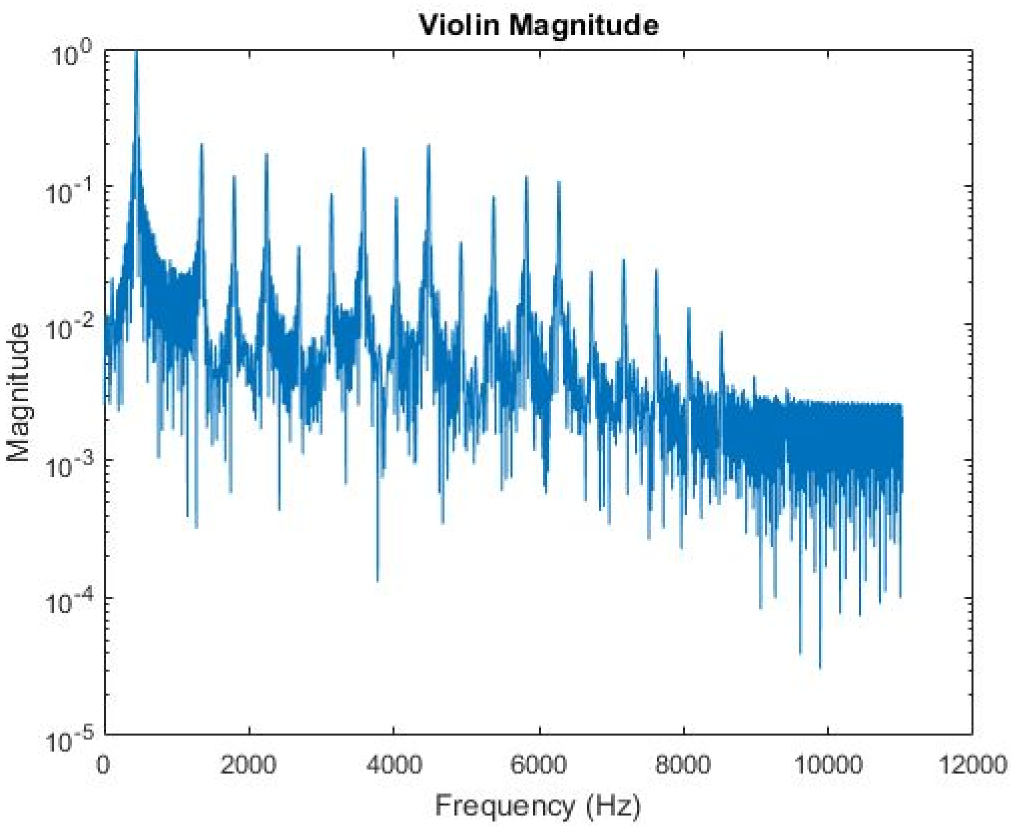
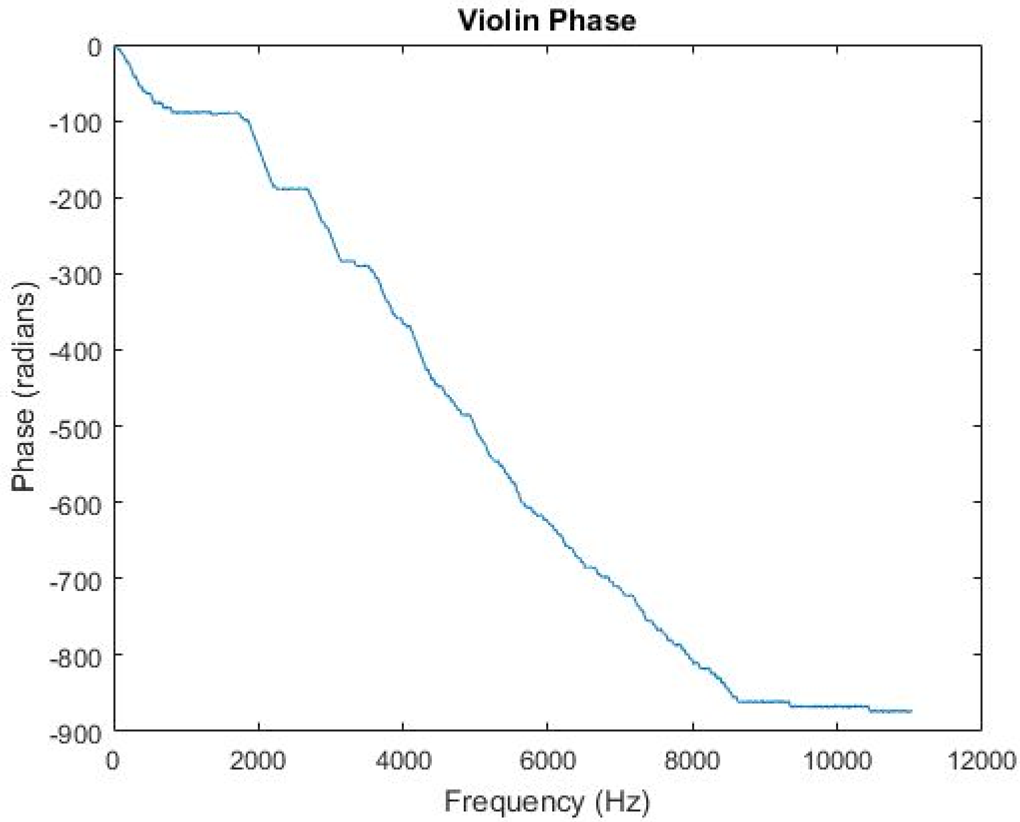
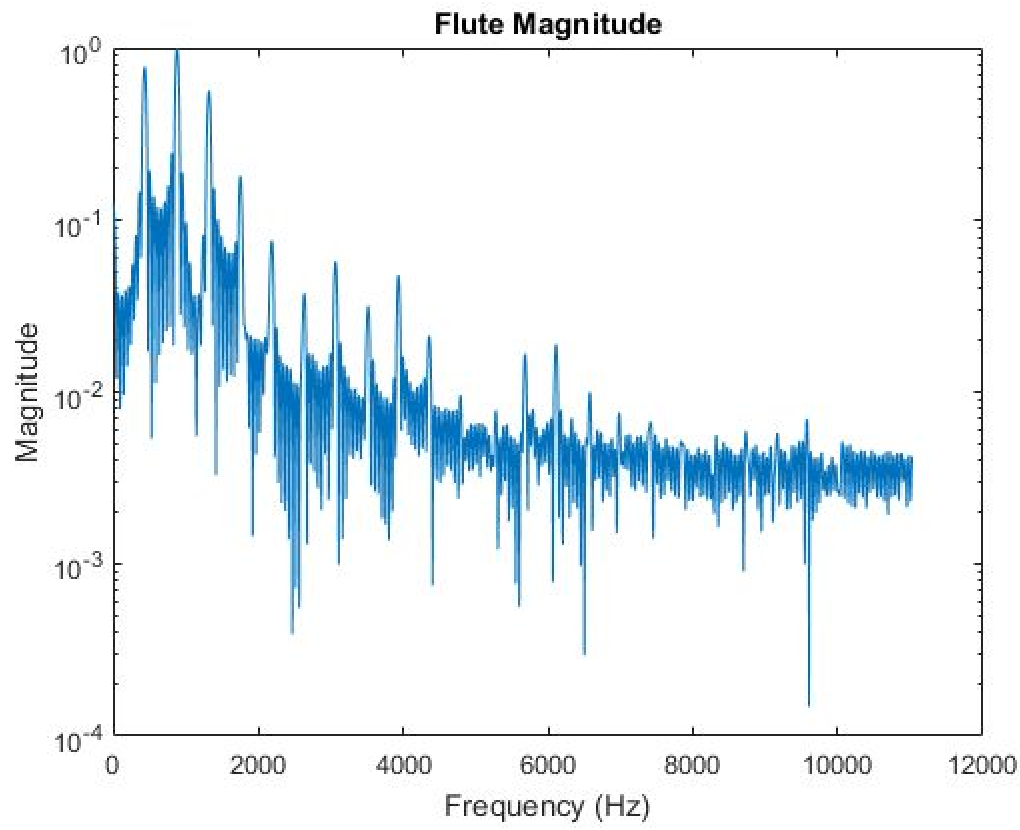
PUBLISHED MATLAB CODE AND RELATED PLOTS

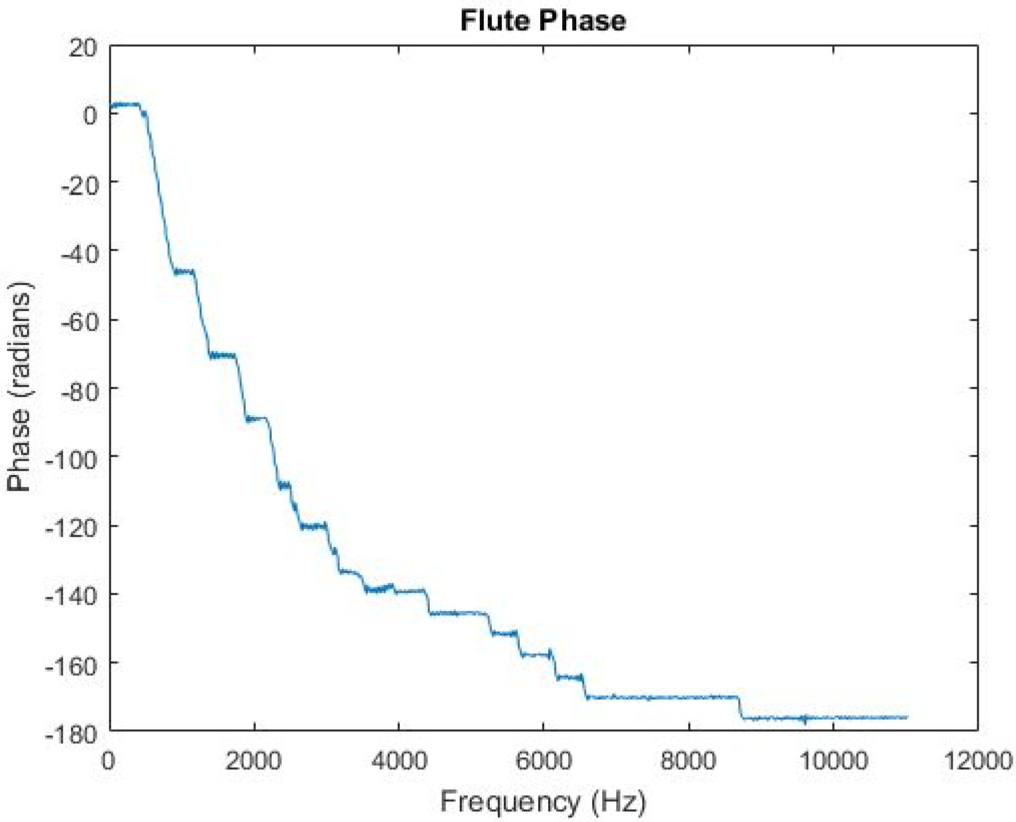
```
[audio_signal, Fs]=audioread('violin_A4.wav');
time_index=audio_signal(39690:40572);

N=2^12;
CTFT_sampled = fft(time_index,N)/N;
CTFT_sampled_abs = abs(CTFT_sampled(2:N/2));
freq = (1:N/2-1)*Fs/N;
CTFT_sampled_abs=CTFT_sampled_abs/max(CTFT_sampled_abs);
figure;
semilogy(freq,CTFT_sampled_abs)
xlabel('Frequency (Hz)');
ylabel('Magnitude');
title('Violin Magnitude');

figure;
plot(freq,phase(CTFT_sampled(2:N/2)));
ylabel('Phase (radians)');
xlabel('Frequency (Hz)');
title('Violin Phase');


[audio_signal, Fs]=audioread('flute_A4.wav');
time_index=audio_signal(2205:2646);

N=2^12;
CTFT_sampled = fft(time_index,N)/N;
CTFT_sampled_abs = abs(CTFT_sampled(2:N/2));
freq = (1:N/2-1)*Fs/N;
CTFT_sampled_abs=CTFT_sampled_abs/max(CTFT_sampled_abs);
figure;
semilogy(freq,CTFT_sampled_abs)
xlabel('Frequency (Hz)');
ylabel('Magnitude');
title('Flute Magnitude');


figure;
plot(freq,phase(CTFT_sampled(2:N/2)));
ylabel('Phase (radians)');
xlabel('Frequency (Hz)');
title('Flute Phase');

[audio_signal, Fs]=audioread('singer_A4.wav');
time_index=audio_signal(1874:2315);
```

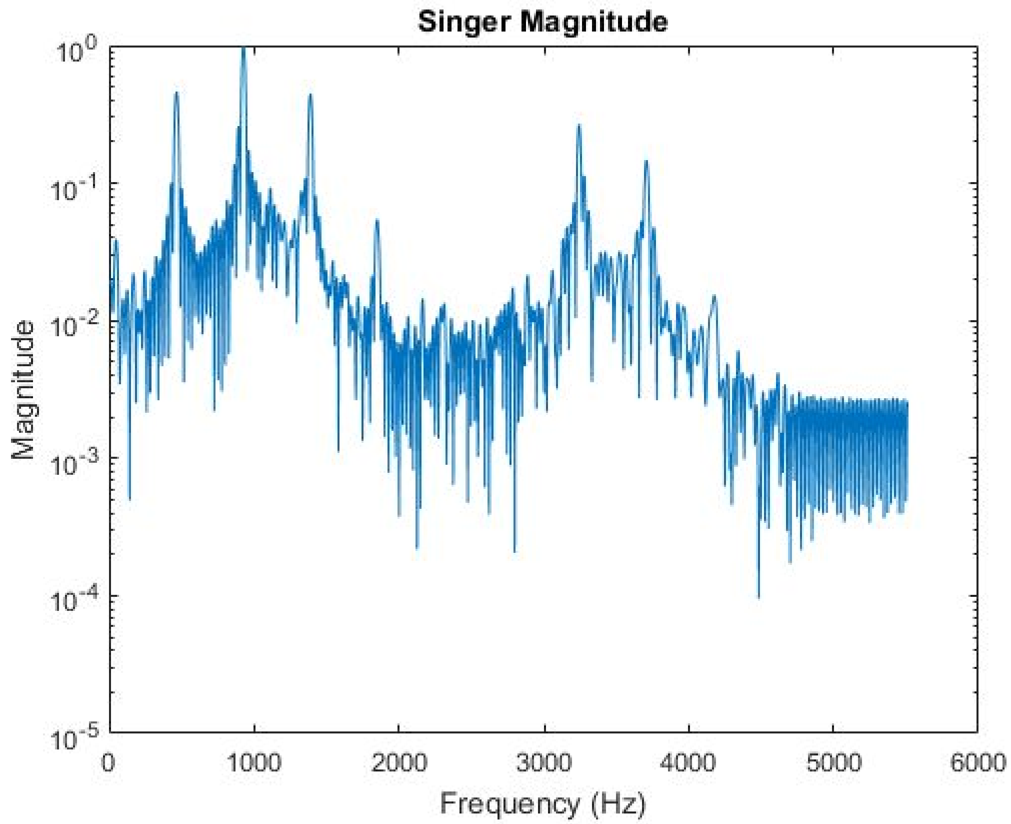
```
N=2^12;
CTFT_sampled = fft(time_index,N)/N;
CTFT_sampled_abs = abs(CTFT_sampled(2:N/2));
freq = (1:N/2-1)*Fs/N;
CTFT_sampled_abs=CTFT_sampled_abs/max(CTFT_sampled_abs);
figure;
semilogy(freq,CTFT_sampled_abs)
xlabel('Frequency (Hz)');
ylabel('Magnitude');
title('Singer Magnitude');


figure;
plot(freq,phase(CTFT_sampled(2:N/2)));
ylabel('Phase (radians)');
xlabel('Frequency (Hz)');
title('Singer Phase');
```

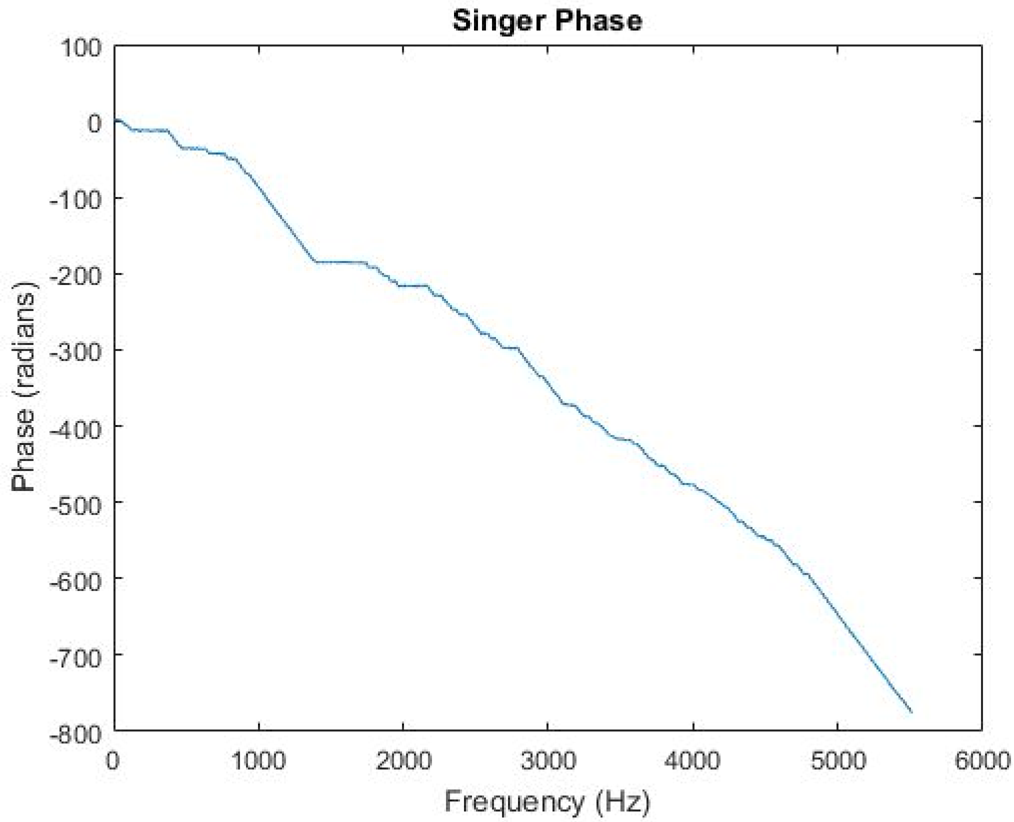



Violin Phase
Phase (radians)
Frequency (Hz)
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
0
2000
4000
6000
8000
10000
12000


Flute Magnitude
Magnitude
Frequency (Hz)
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
2000
4000
6000
8000
10000
12000


Flute Phase
Phase (radians)
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
0
2000
4000
6000
8000
10000
12000
Frequency (Hz)


Singer Magnitude
Magnitude
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
0
1000
2000
3000
4000
5000
6000
Frequency (Hz)



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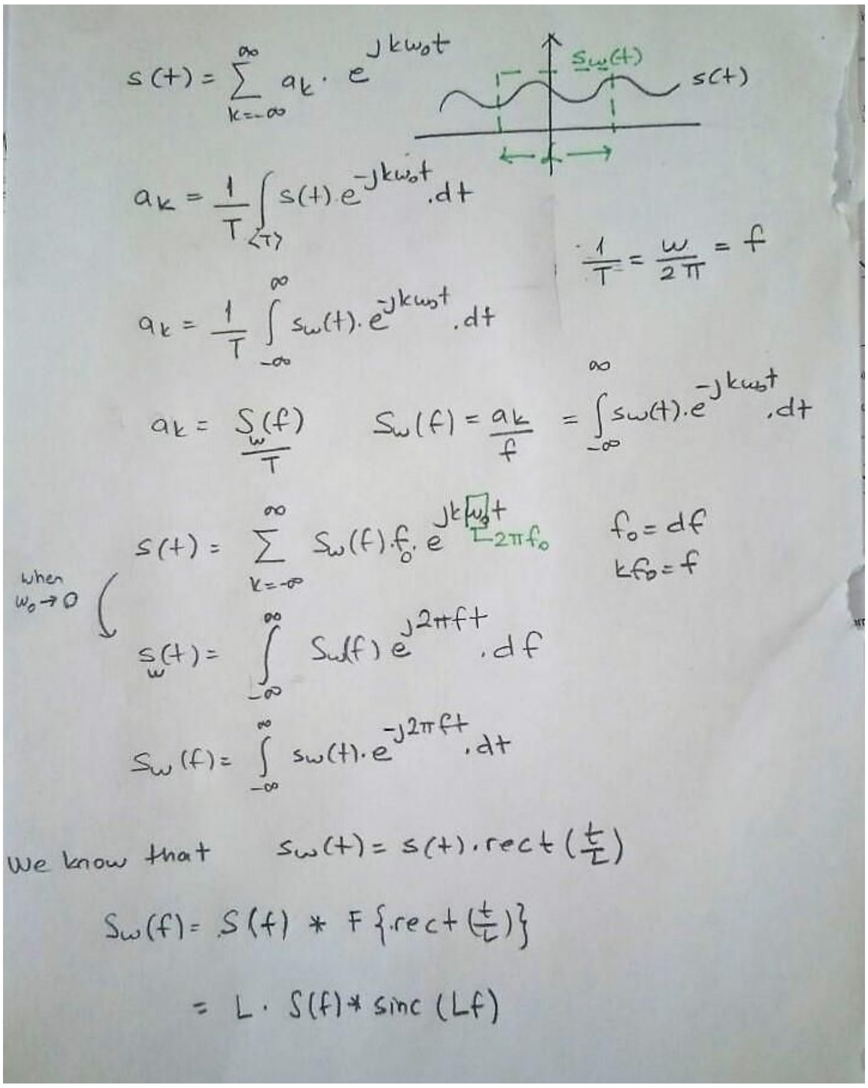
Answers to the Related Questions

Q1) For this question the following steps are shown in the provided Figure 1.



$$s(t) = \sum_{k=-\infty}^{\infty} a_k \cdot e^{jkw_0t}$$

$$a_k = \frac{1}{T}\int_{\langle T\rangle} s(t)\, e^{-jkw_0t}\, dt$$

$$\frac{1}{T} = \frac{w}{2\pi} = f$$

$$a_k = \frac{1}{T}\int_{-\infty}^{\infty} s_w(t) \cdot e^{-jkw_0t}\, dt$$

$$a_k = \frac{S_w(f)}{T} \qquad S_w(f) = \frac{a_k}{f} = \int_{-\infty}^{\infty} s_w(t) \cdot e^{-jkw_0t}\, dt$$

$$s(t) = \sum_{k=-\infty}^{\infty} S_w(f) \cdot f_0 \cdot e^{jk\boxed{w_0}t} \quad (2\pi f_0) \qquad f_0 = df \quad kf_0 = f$$

when $w_0 \to 0$

$$s_w(t) = \int_{-\infty}^{\infty} S_w(f)\, e^{j2\pi ft}\, df$$

$$S_w(f) = \int_{-\infty}^{\infty} s_w(t) \cdot e^{-j2\pi ft}\, dt$$

We know that $s_w(t) = s(t) \cdot rect\left(\frac{t}{L}\right)$

$$S_w(f) = S(f) * F\left\{rect\left(\frac{t}{L}\right)\right\}$$

$$= L \cdot S(f) * sinc(Lf)$$

Figure 1. s(t) to $s_w(t)$ representation

$s_w(t) = s(t) \cdot rect(\frac{t}{L})$ *Eq. (1.1)*

$S_w(\omega) = \frac{1}{2\pi} S(\omega) * F\{rect(\frac{t}{L})\}$ *Eq. (1.2)*

$S_w(\omega) = \frac{1}{2\pi} S(\omega) * L \cdot sinc(\frac{L\omega}{2\pi})$ *Eq. (1.3)*

$$S_w(f) = L \cdot S(f) * sinc(Lf)$$

Eq. (1.4)

Q2) For this question equations 1 &2 are found as :

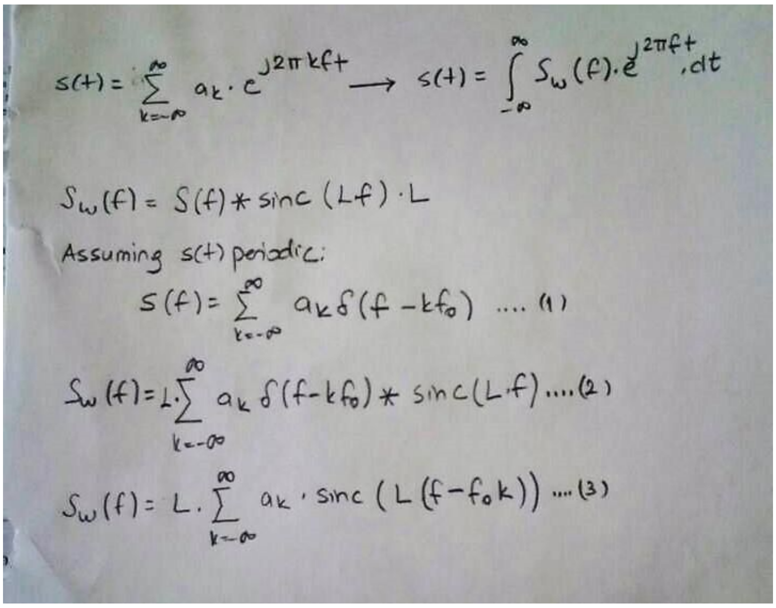
$$S_w(\omega) = \sum_{k=-\infty}^{\infty} a_k \cdot sinc\, \frac{L(\omega - k\omega_0)}{2\pi}$$

Equation (2)

$$S_w(f) = \sum_{k=-\infty}^{\infty} a_k \cdot sinc\, L(f - kf_0)$$

Equation (3)

For the previous steps to obtain the equations 1 & 2, the steps given in Figure 2. are used.


$s(t) = \sum_{k=-\infty}^{\infty} a_k \cdot e^{j2\pi k f t} \longrightarrow s(t) = \int_{-\infty}^{\infty} S_w(f) \cdot e^{j2\pi f t} \, dt$

$S_w(f) = S(f) * \text{sinc}(Lf) \cdot L$

Assuming $s(t)$ periodic:

$S(f) = \sum_{k=-\infty}^{\infty} a_k \delta(f - k f_0)$ .... (1)

$S_w(f) = L \cdot \sum_{k=-\infty}^{\infty} a_k \delta(f - k f_0) * \text{sinc}(L \cdot f)$ .... (2)

$S_w(f) = L \cdot \sum_{k=-\infty}^{\infty} a_k \cdot \text{sinc}(L(f - f_0 k))$ .... (3)

Figure 2. Previous steps

Q3) We can multiply with an impulse train whose period is multiples of ω_0, fundamental frequency. That is using equation (4):

$$\sum_{k=-\infty}^{\infty} (\delta(\omega - k\omega_0))$$

Equation (4)

So that a sinc with ω_0.k has a nonzero value at the center frequency meaning that other sinc's will have zero value where the specific sinc has its peak value.

For this, the frequency interval must be ω_0 .

Q4) When we plotted the time domain signals (Figure 3, 5 and 7.), we saw that while the violin was close to a periodic signal, none of the signals were periodic. This is due to the non-ideality of the player, singer etc. There are frequency contributions other than the harmonics of the fundamental frequency since none of the instruments and the singer can play the "La" note exactly on the same frequency in a time period. Audio files include frequencies around but other than the fundamental frequency. This causes distortions.

Q5) Table 1 shows a list for the coefficients' normalized values with their corresponding frequency and phase angle in degrees. The table is obtained using the values read in Figure 4, 6 and 8. (Also the corresponding phase graphs which can be found in the first part of the document).

Violin a_k ***value/Frequency/Angle°***	***Flute*** a_k ***value/Frequency/Angle°***	***Singer*** a_k ***value/Frequency/Angle°***
0.881/441,4/ -61,85	0.7771/436 / 1,142	0.4596/463 / -34,35
0.2041/1346/ -90,44	0.988/866,7 / -44,33	0.9727/923 / -69,69
0.1208/1793/ -97,58	0.5645/1314 / -62,86	0.4464/1389 / 176,6
0.1746/2239/ 172,4	0.181/1750 / -71,89	0.05455/1849 / 160,4
0.03681/2686/ 169	0.07602/2180 / -89,79	0.01336/2312 / 119,5
0.0885/3138/ 77,6	0.03645/2638 / -120	0.01735/2786 / 62,1
0.1915/3585/ 62,5	0.05771/3063 / -126,8	0.2678/3243/ -26,1
0.08317/4037/ -7,7	0.0316/3515 / -137,5	0.1478/3709/ -83,6
0.201/4484/ -86,7	0.04776/3935 / -138,8	0.01528/4177 /-139,8
0.03837/4926/ -126,3	0.02121/4355 /-139,4	
0.08474/5378/ 166,3		
0.1184/5825/ 105		
0.1093/6277/ 61,5		

0.02414/6724/ 24		
0.0296/7176/ -3,3		
0.02325/7628/ -53,6		
0.01318/8075/ -91		
0.008732/8522/ 128,4		
0.004129/8979/ 141,4		

Table 1. Normalized values of the coefficients with their corresponding frequency and phase angle

Plots of samples which are required to be taken on a specific time period and obtained ak values from the Fourier transform magnitude vs. frequency plots:

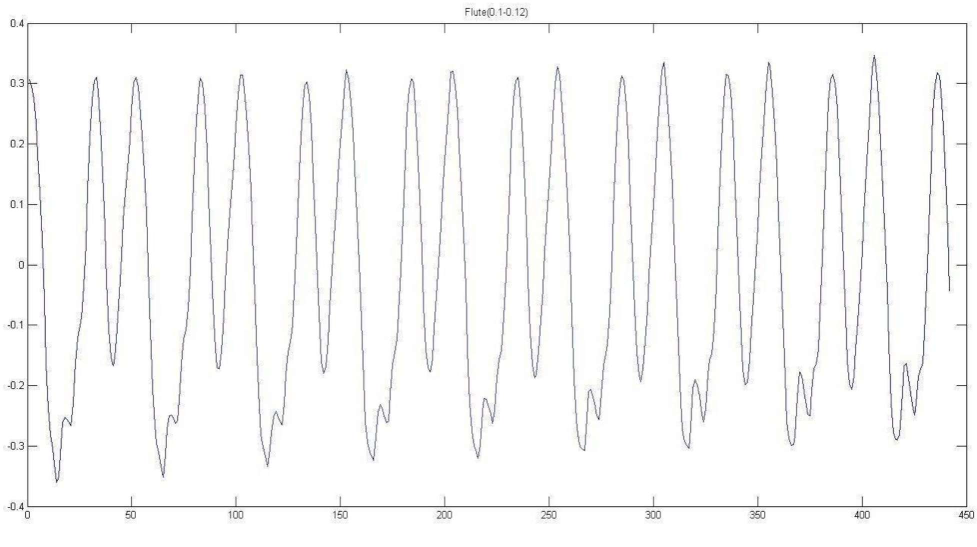


Figure 3. Flute signal for t between 1.0-1.2 sec

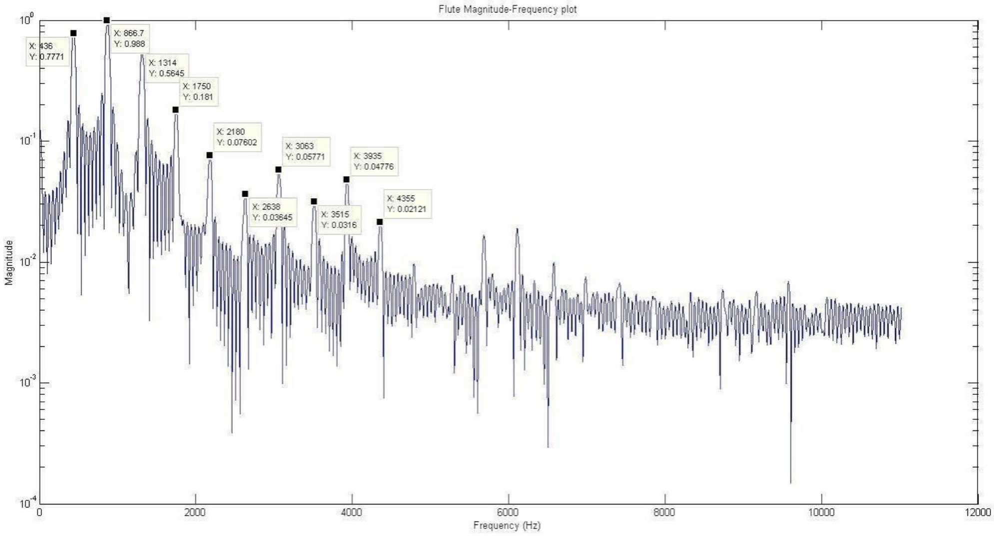


Figure 4. Data values for maximum coefficients of flute

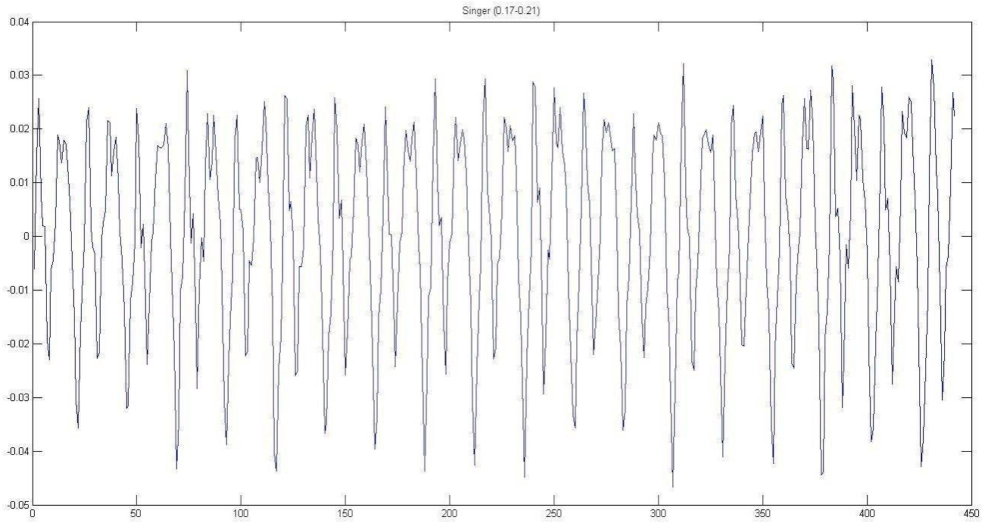


Figure 5. Singer signal for t between 0.17-0.21 sec

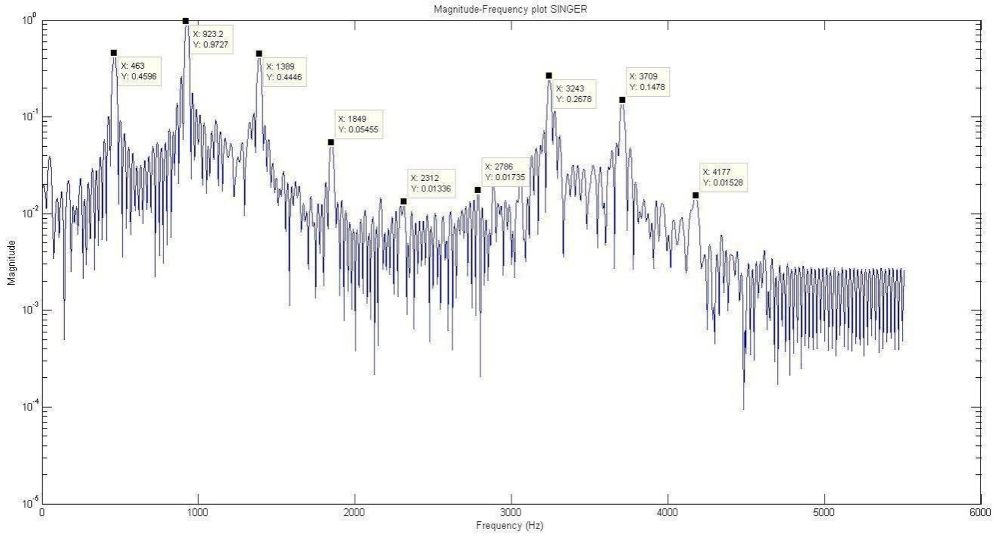


Figure 6. Data values for maximum coefficients of singer

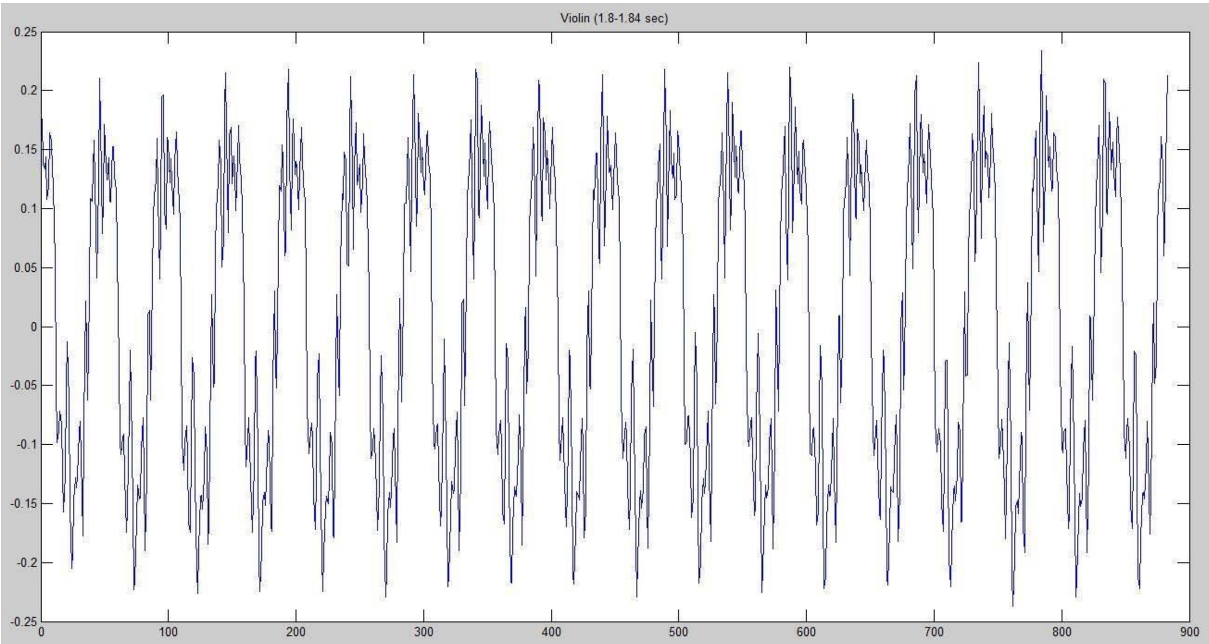


Figure 7. Violin signal for t between 1.8-1.84 sec

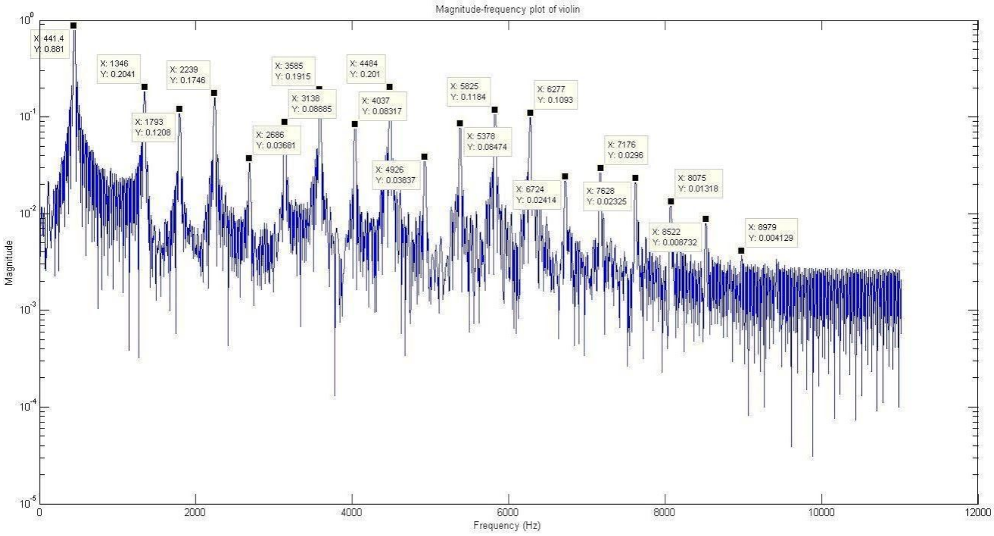


Figure 8. Data values for maximum coefficients of violin