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ME465 - Sound and Space

02/07/2020

HW1: Introduction to Digital Signal Processing

Question 1

The purpose of question 1 was to implement a function that could perform both a Fast Fourier Transform (FFT) and inverse Fast Fourier Transform (IFFT) of a time domain signal. A 10 second 1 HZ sinusoidal wave was used for testing; To confirm the two functions were computing correctly, Parsevel's theorem was computed after every transform to ensure it held true. See methods 'my_fft' and 'my_ifft' in the appendix code for implementation details. Furthermore, the results were analyzed graphically in Figures 1 and 2. Figure 2, which plots the magnitude of the complex numbers of the frequency spectrum, shows a symmetric response at -1 and 1 Hz as expected.

Figure 1: Time Domain Signals

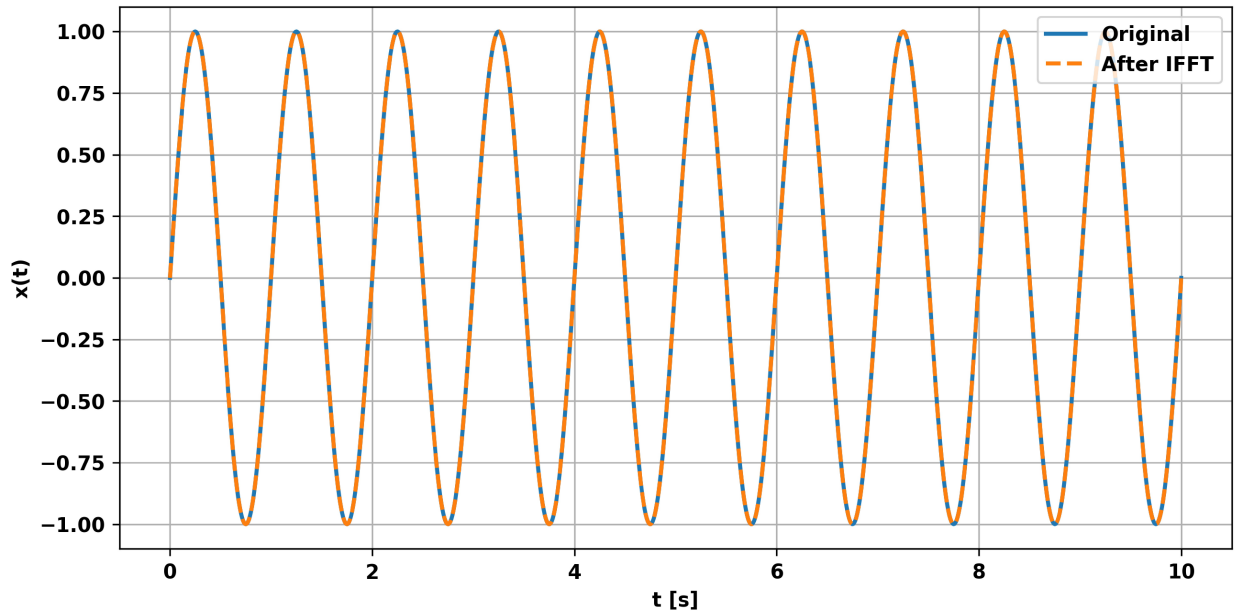
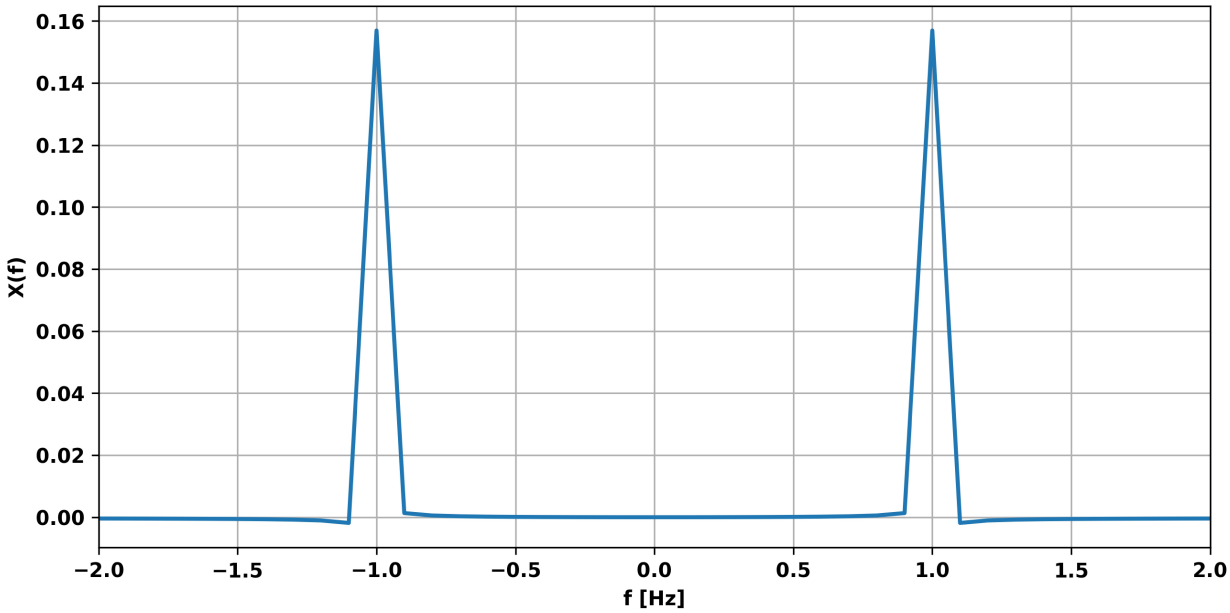


Figure 2: Frequency Domain Signal



Question 2

Question 2 asked to analyze a signal of my own creation: I decided to analyze construction noise in the hopes that I can later design a signal to destructively interfere this kind of noise. Figure 3 shows the time domain signal, Figure 4 shows the frequency domain, and Figure 5 shows a snapshot of the phase as a function of frequency. Figure 4 shows that there are a wide range of frequencies present - the most prominent of which is at +/- 800 Hz.

Figure 3: Construction Noise Time Series

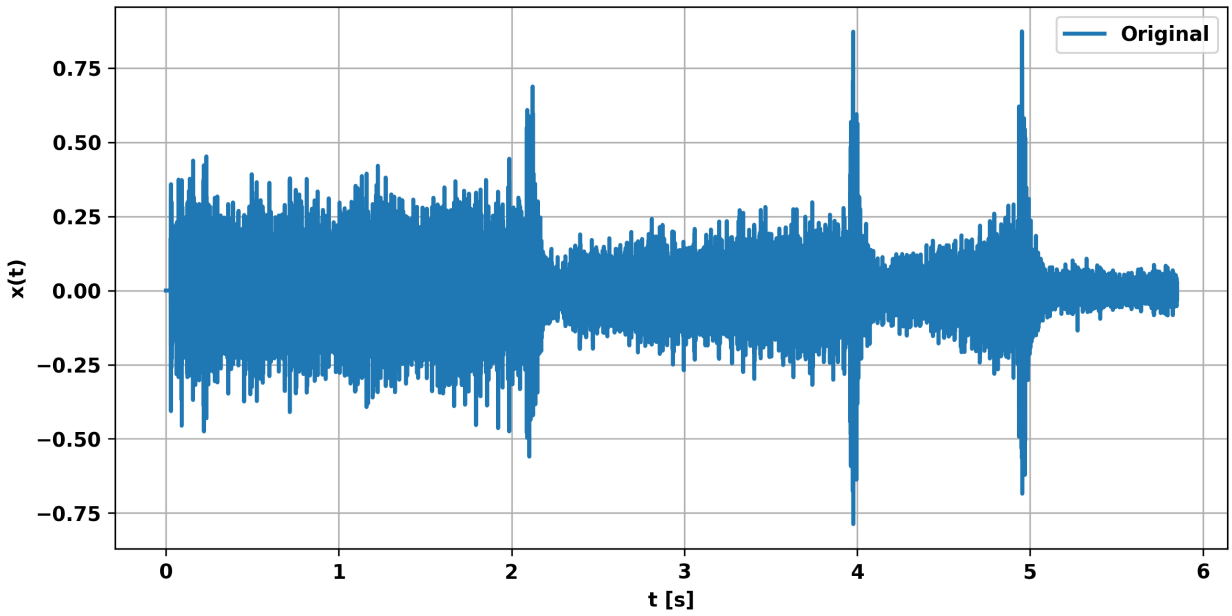


Figure 4: Construction Noise Frequency Domain

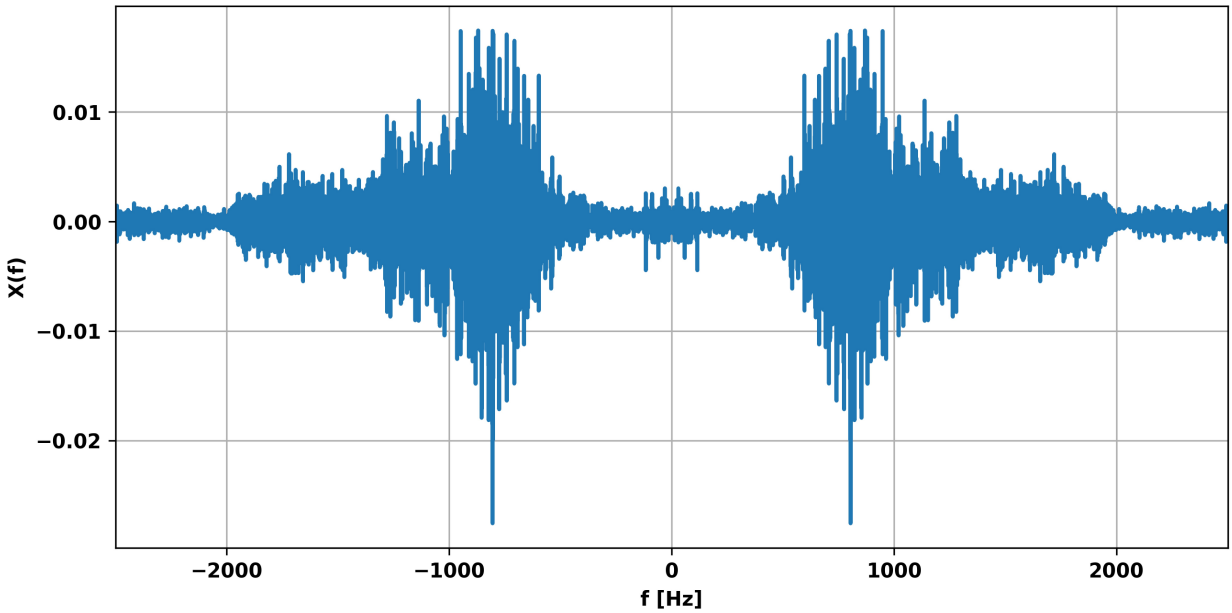
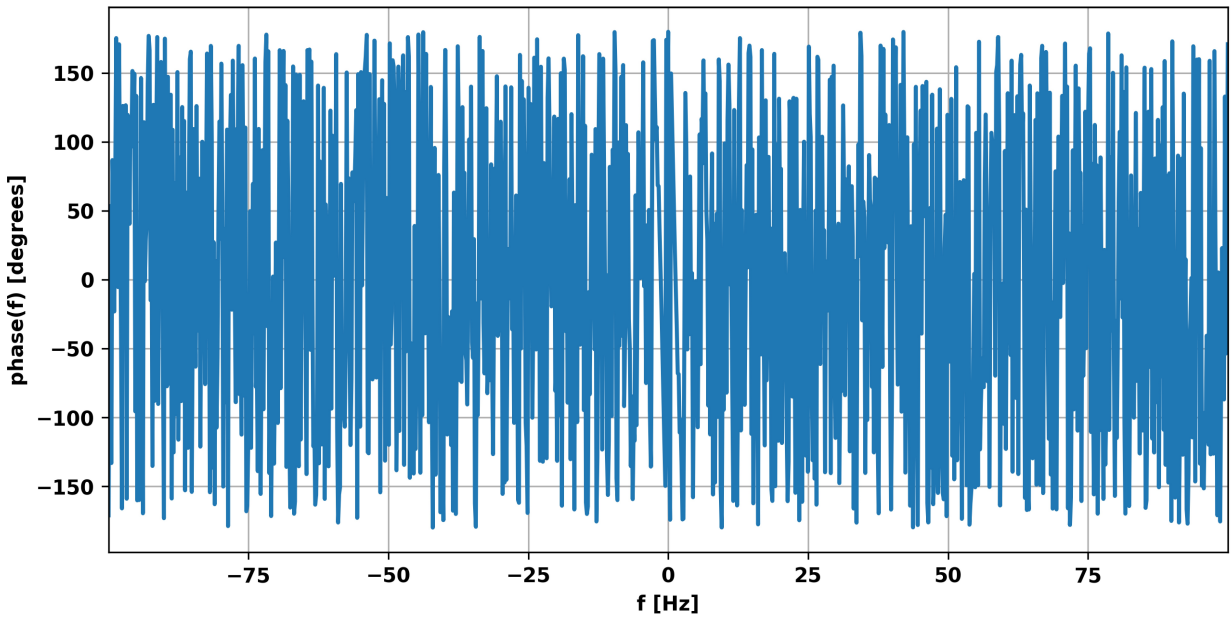


Figure 5: Construction Noise Phase



Question 3

b.) Question 3 instructed to analyze a recorder (musical instrument) melody provided in a .wav file. The seven second time domain signal is plotted in Figure 6 and its frequency response in Figure 7. Nine notes were played in the recording but it was difficult to determine if they were all unique by ear (associated with a different frequency). The frequency response shows 6 large peaks in the positive domain, with several smaller ones (probably harmonics of the first peaks) after 1000 Hz.

Figure 6: Time Domain Signal

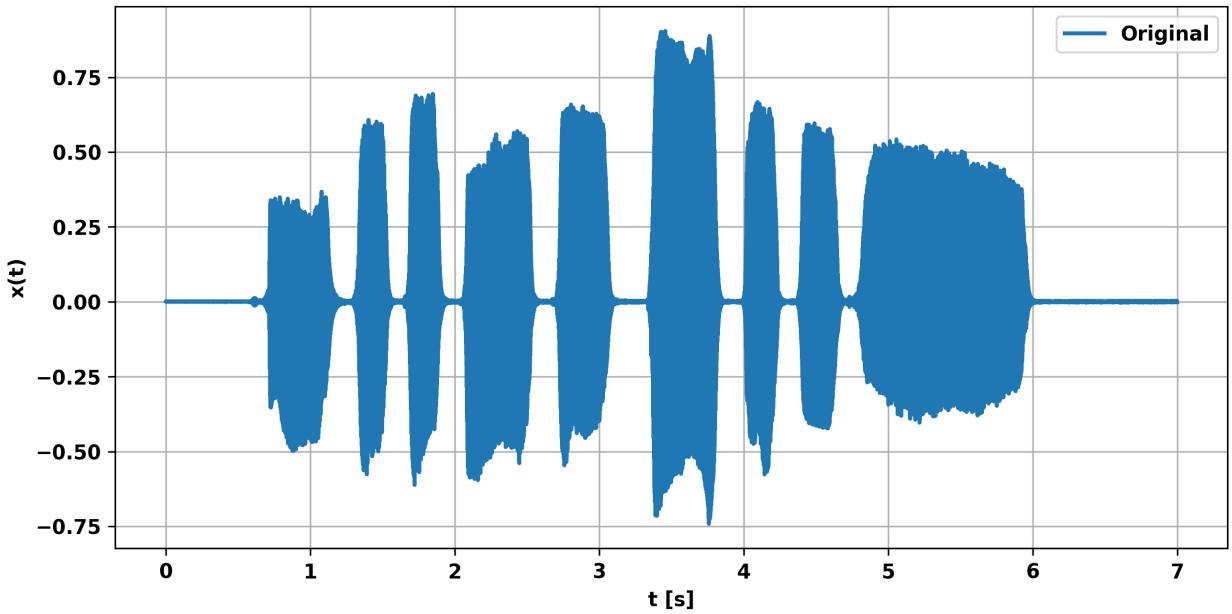
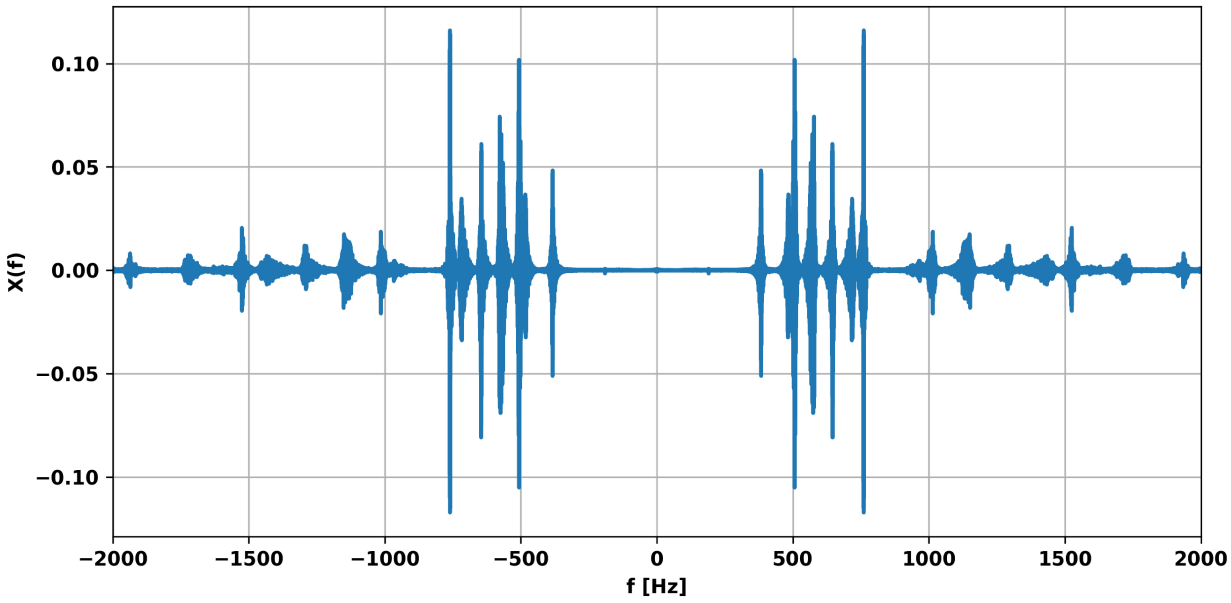
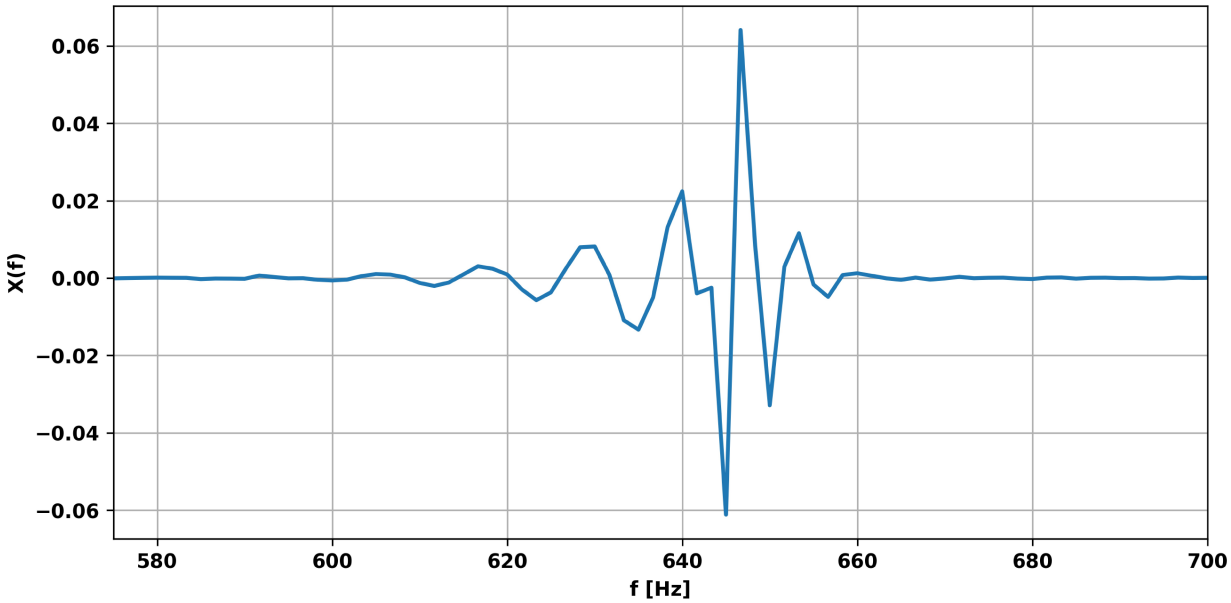


Figure 7: Frequency Domain Signal



c.) Focusing our analysis on just a portion of the sound file during t=[2, 2.6], we see that there is a dominate frequency (largest amplitude) of 647 Hz (Figure 8). Note that the symmetric side of the spectrum isn't depicted in order to provide a closer look at the area of interest.

Figure 8: Snapshot of Positive Frequency Domain of Input Signal during t=[2, 2.6]



Concluding Remarks

For this homework I created a basic toolbox for analyzing digital signals. I created an FFT and IFFT functions which effectively transform signals between the time and frequency domains. The FFT function returns a symmetric frequency response, which indicates that the function performs frequency accounting correctly. The IFFT function returns precisely the original signal in Question 1, which indicates it too is likely working correctly. Furthermore, we saw that some signals we considered have fundamental frequencies with large amplitudes, and harmonics of those frequencies often occur with smaller amplitudes.

tzavelis_hw1

February 6, 2020

[136]:
```
import numpy as np
import pandas as pd
import soundfile as sf
import simpleaudio as sa
import sounddevice as sd
from scipy.io import wavfile
import matplotlib.pyplot as plt
%matplotlib inline
plt.rcParams['font.weight'] = 'bold'
plt.rcParams['axes.labelweight'] = 'bold'
plt.rcParams['lines.linewidth'] = 2
plt.rcParams['axes.titleweight'] = 'bold'
```

[72]:
```
class SignalTB:
    """
        My signal toolbox (SignalTB)!
    """

    def __init__(self, x, fs):
        """
        Arguments:
            x: Time Series
            fs: Sample Frequency
        """
        self.fs = fs; # [hz
        self.x = x    # time domain series
        self.X = None # frequency domain series
        self.signals = None #useful container

        self.N = self.x.shape[0]    # number of samples
        self.L = self.x.index[-1] - self.x.index[0]    # total time of signal [s]
        self.dt = self.L/self.N  # [s]
        self.df = self.fs/self.N

    def my_fft(self):
        """
        Description:
```

```
            This method calculates the fft of a time domain signal using␣
↪numpy's fft function and
        adjusting it appropriately to multiplies it by dt.

        Returns:
            Series of frequency domain signal
        """
        freq = np.arange(-np.ceil(self.N/2)+1,
                         np.floor(self.N/2)+1) * self.df
        X = np.fft.fft(a=self.x.values, n=None, axis=-1, norm=None) * self.dt
        X = np.concatenate((X[self.N//2+1:],
                            X[0:self.N//2+1])) # rearrange the frequencies from␣
↪standard form to sequential. Remember that 1:self.N//2 does not grab that␣
↪second index value
        self.parseval_thrm(self.x,X)  #check Parsevals thrm
        X = pd.Series(data=X,
                      index=freq,
                      name='frequency domain signal')
        self.X = X
        self.signals = [self.x, self.X]
        return X

    def my_ifft(self):
        """
        Description:
            This method calculates the ifft of a time domain signal using␣
↪numpy's ifft function and
        adjusting it appropriately to multiplies it by dt.

        Returns:
            Series of frequency domain signal
        """
        t = np.linspace(start=self.x.index[0], stop=self.x.index[-1], num=self.
↪N, endpoint=True)
        X = self.X.values # these are in sequential, non standard form
        X = np.concatenate((X[int(np.ceil(self.N/2))-1:],
                            X[0:int(np.ceil(self.N/2))-1])) #put the fft values␣
↪in standard form so ifft can accept it
        x = np.fft.ifft(a=X, n=None, axis=-1, norm=None) / self.dt
        #display(x)
        self.parseval_thrm(x,self.X)  #check Parsevals thrm
        self.parseval_thrm(x,X)  #check Parsevals thrm
        x = pd.Series(data=x,
                      index=t,
                      name='time domain signal')
        self.signals = [self.x, self.X, x]
        return x
```

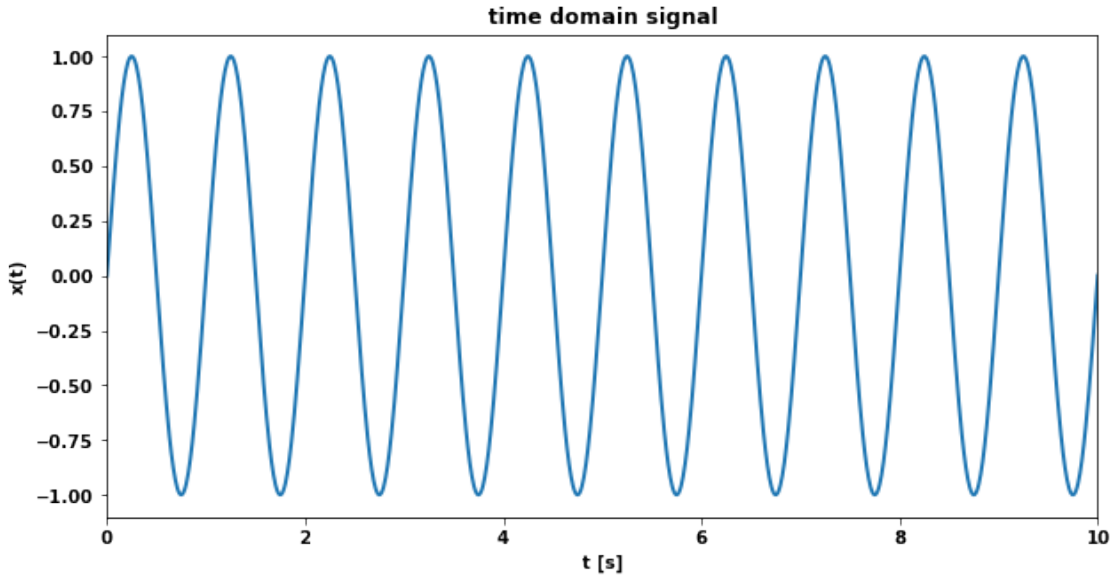
```
    def parseval_thrm(self, x, X):
        """
        Description:
             Checks to make sure Parseval's Theorem holds between a time domain
↪and FFT holds true

        Arguments:
            x: time domain signal
            X: frequency domain signal
        """
        td = round((x**2).sum() * self.dt, 1)
        fd = round((np.absolute(X)**2).sum() * self.df, 1)
        assert td == fd , "Parseval Theorem not satisfied: {} != {}, DFFT is
↪incorrect".format(td,fd)

    def plot_signals(self):
        """
        Description:
            Plots all of the signals in the self.signals container

        Returns:
            Nothing
        """
        figs = []
        for i, sig in enumerate(self.signals):
            fig = plt.figure(figsize=(10,5))
            if sig.name == 'time domain signal': plt.title(sig.name); plt.
↪ylabel('x(t)'); plt.xlabel('t [s]');plt.grid()
            elif sig.name == 'frequency domain signal':
                plt.title(sig.name); plt.ylabel('X(f)'); plt.xlabel('f [Hz]');
↪plt.grid()
                sig = np.absolute(sig) # compute the magnitude of the complex
↪number to plot its magnitude
            sig.plot(); figs.append(fig)
        return figs

    #Useful functions to generate signals
    @staticmethod
    def sin(A,f,L,N):
        """
        Arguments:
            A: Amplitude
            f: Frequency of signal [hz]
            L: Total length of time [s]
            N: Number of points
```

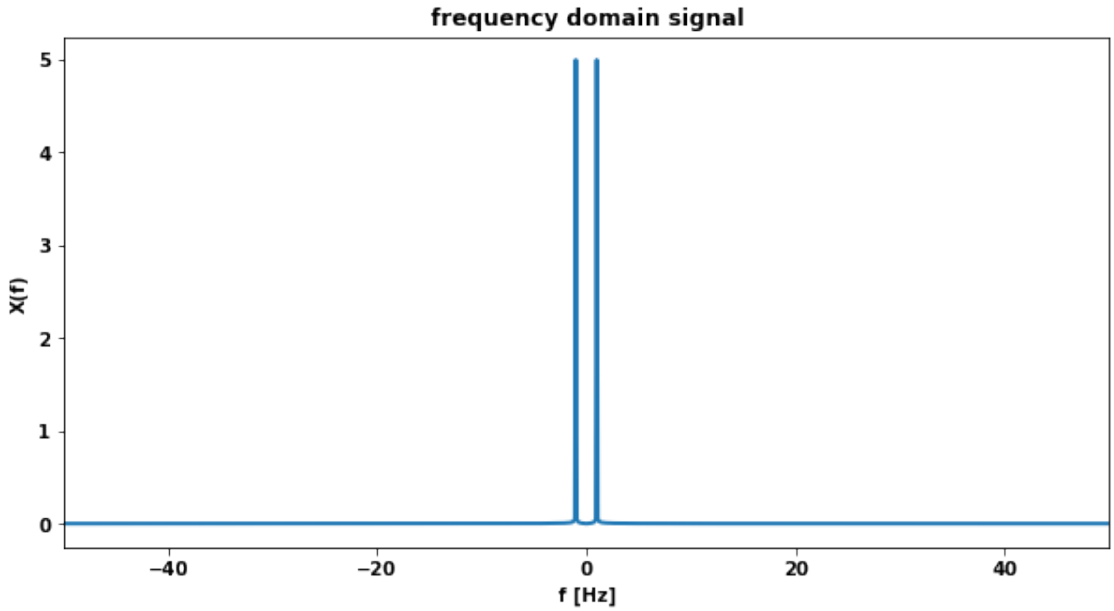
```
        Returns:
            Series
        """
        t = np.linspace(start=0, stop=L, num=N, endpoint=True,dtype=float)
        return pd.Series(data=A*np.sin(2*np.pi*f*t),
                         index=t,
                         name='time domain signal')

    @staticmethod
    def randn_sig(L,N):
        """
        Arguments:
            L : Total length of time [s]
            N : Number of points

        Returns:
            Series
        """
        return pd.Series(data=np.random.randn(N,),
                         index=np.linspace(start=0, stop=L, num=N,␣
↪endpoint=True),
                         name='time domain signal')
```

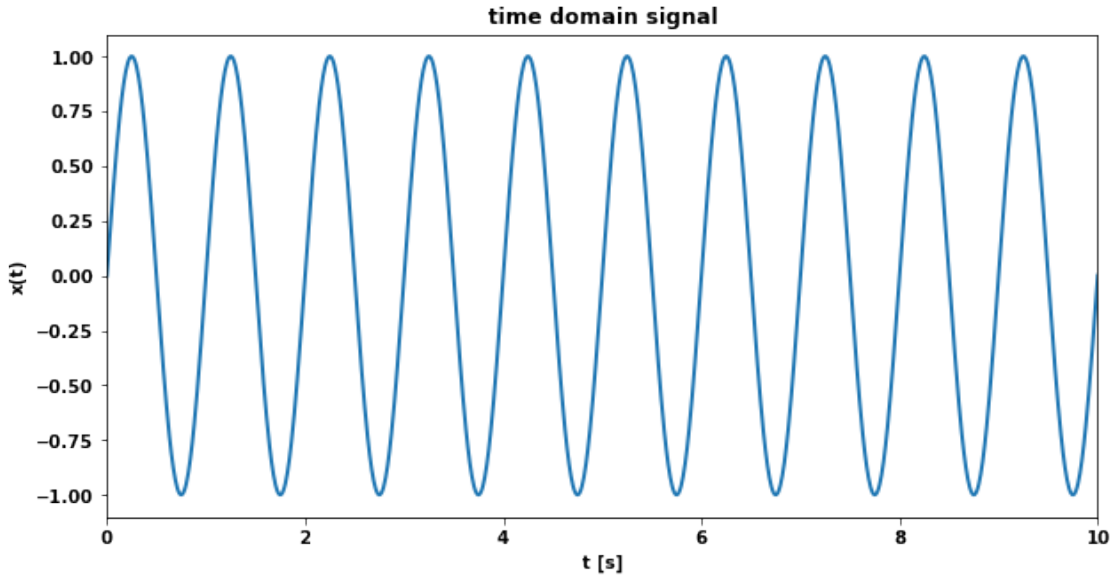
1 Question 1

[238]:
```
N = 1000
L = 10 # [s]
x = SignalTB.sin(A = 1, f = 1, N = N, L = L)
s = SignalTB(x=x,fs=N/L)
fd = s.my_fft();
x2 = s.my_ifft()
s.plot_signals();
```

```
/home/m4rz910/anaconda3/lib/python3.7/site-packages/numpy/core/_asarray.py:85:
ComplexWarning: Casting complex values to real discards the imaginary part
  return array(a, dtype, copy=False, order=order)
```

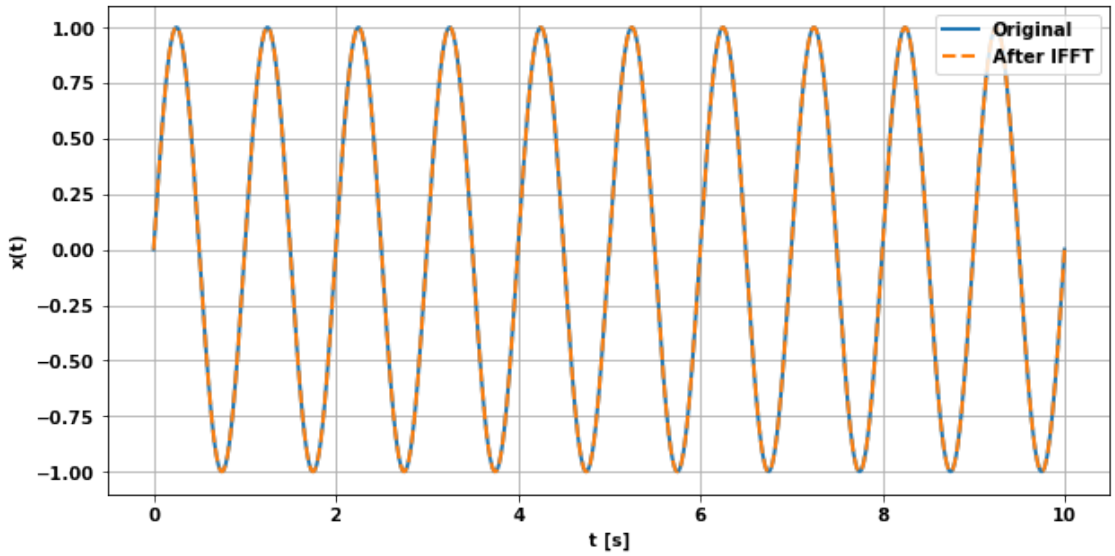

time domain signal
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
x(t)
0
2
4
6
8
10
t [s]

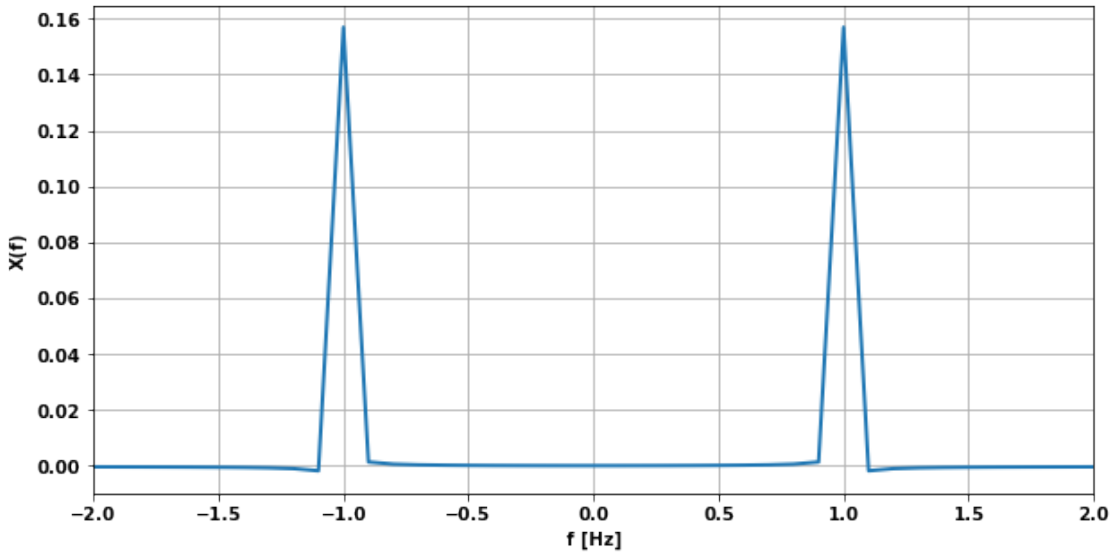

frequency domain signal
5
4
3
2
1
0
X(f)
−40
−20
0
20
40
f [Hz]



[239]:
```
fig = plt.figure(figsize=(10,5))
plt.plot(x)
plt.plot(x2, '--')
plt.ylabel('x(t)'); plt.xlabel('t [s]'); plt.grid(); plt.legend(['Original',␣
↪'After IFFT'], loc = 'upper right')
fig.savefig('./plots/time.png', dpi=300, bbox_inches='tight');

fig= plt.figure(figsize=(10,5))
fd.loc[-2:2].plot(); plt.ylabel('X(f)'); plt.xlabel('f [Hz]'); plt.grid()
fig.savefig('./plots/freq.png', dpi=300, bbox_inches='tight');
```

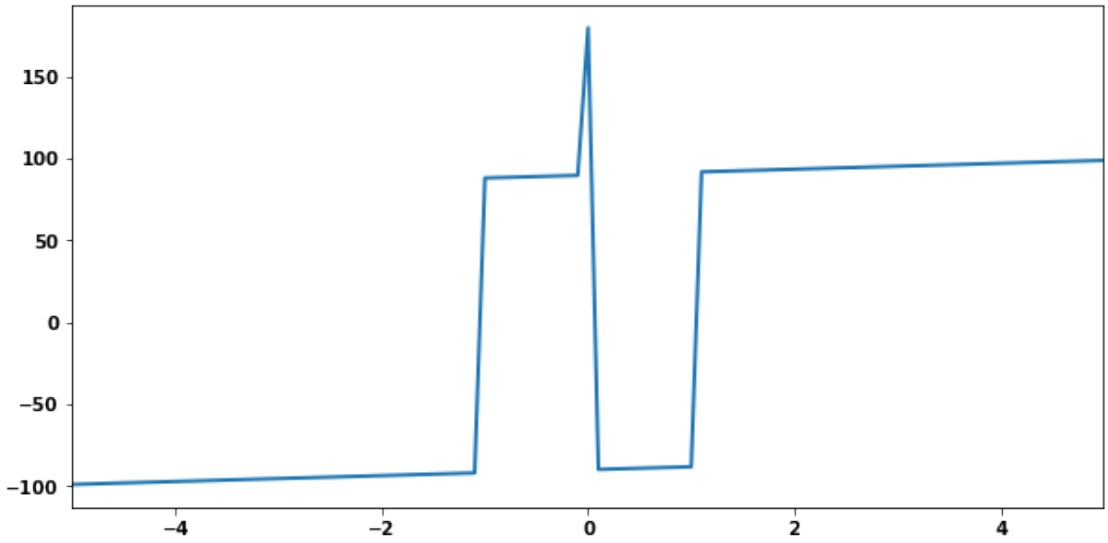
```
/home/m4rz910/anaconda3/lib/python3.7/site-packages/numpy/core/_asarray.py:85:
ComplexWarning: Casting complex values to real discards the imaginary part
  return array(a, dtype, copy=False, order=order)
```





[242]:
```
phase = pd.Series(data=pd.np.angle(fd, deg=True),
                  index=fd.index)
phase[-5:5].plot(figsize=(10,5))
```

[242]: <matplotlib.axes._subplots.AxesSubplot at 0x7f249e3b0a58>



2 Question 2

[187]:
```
# fs = 48000
# duration = 5  # seconds
# myrecording = sd.rec(int(duration * fs), samplerate=fs, channels=1)
# sd.wait()
```

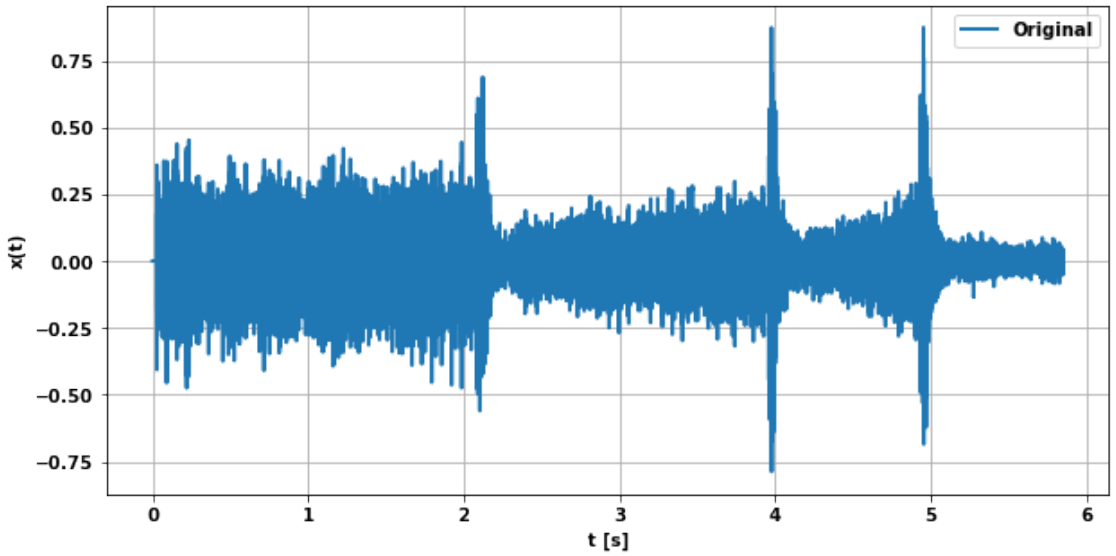
[217]:
```
# sd.play(myrecording)
# wavfile.write('guitar.wav', fs, myrecording.ravel()) # saves it as an␣
 ↪uncompressed wave file
```

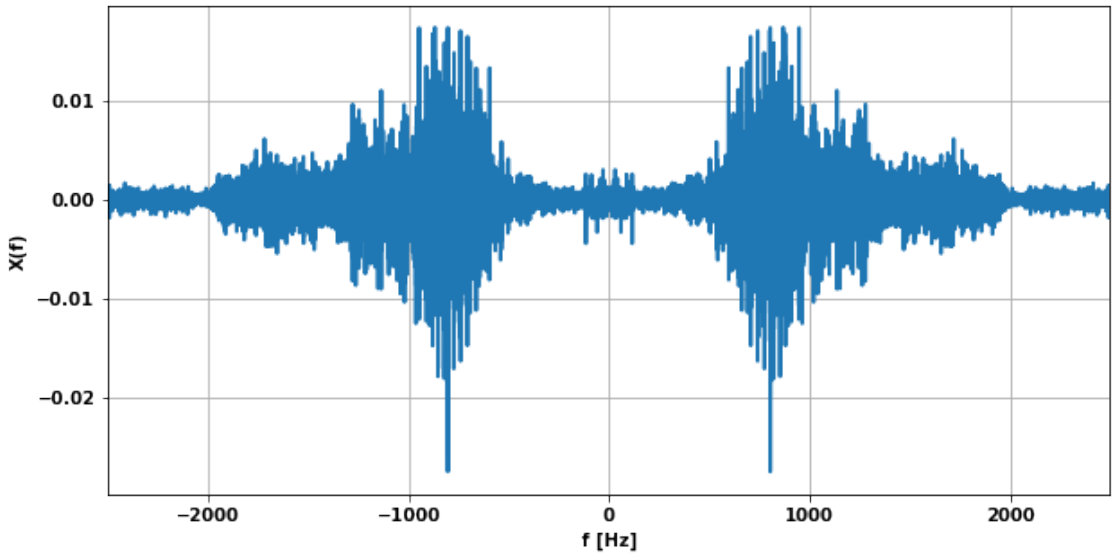
[220]:
```
filename = './construction.wav'
wave_obj = sa.WaveObject.from_wave_file(filename)
play_obj = wave_obj.play()
play_obj.wait_done()
```

[250]:
```
data, fs = sf.read('./construction.wav')
N = len(data)
L = N/fs
x = pd.Series(data=data,
              index=np.linspace(start=0, stop=L, num=N, endpoint=True),
              name='time domain signal')
#x = x.loc[2:2.6] #g
s = SignalTB(x=x,fs=fs)
fd = s.my_fft();
x2 = s.my_ifft()
```

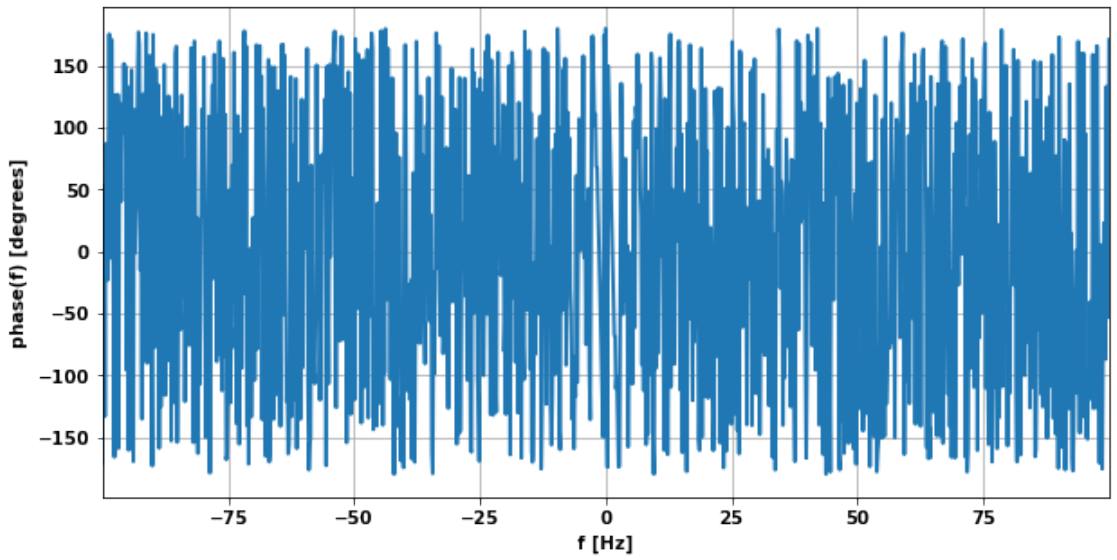
```
fig = plt.figure(figsize=(10,5))
plt.plot(x)
#plt.plot(x2, '--')
plt.ylabel('x(t)'); plt.xlabel('t [s]'); plt.grid(); plt.legend(['Original',␣
 ↪'After IFFT'], loc = 'upper right')
fig.savefig('./plots/2_time.png', dpi=300, bbox_inches='tight');

fig= plt.figure(figsize=(10,5))
fd.loc[-2500:2500].plot(); plt.ylabel('X(f)'); plt.xlabel('f [Hz]'); plt.grid()
fig.savefig('./plots/2_freq.png', dpi=300, bbox_inches='tight');
```

```
/home/m4rz910/anaconda3/lib/python3.7/site-packages/numpy/core/_asarray.py:85:
ComplexWarning: Casting complex values to real discards the imaginary part
  return array(a, dtype, copy=False, order=order)
```





[248]:
```
phase = pd.Series(data=pd.np.angle(fd, deg=True),
                  index=fd.index)
fig= plt.figure(figsize=(10,5))
phase.loc[-100:100].plot(); plt.ylabel('phase(f) [degrees]'); plt.xlabel('f␣
↪[Hz]'); plt.grid()
fig.savefig('./plots/2_phase.png', dpi=300, bbox_inches='tight');
```

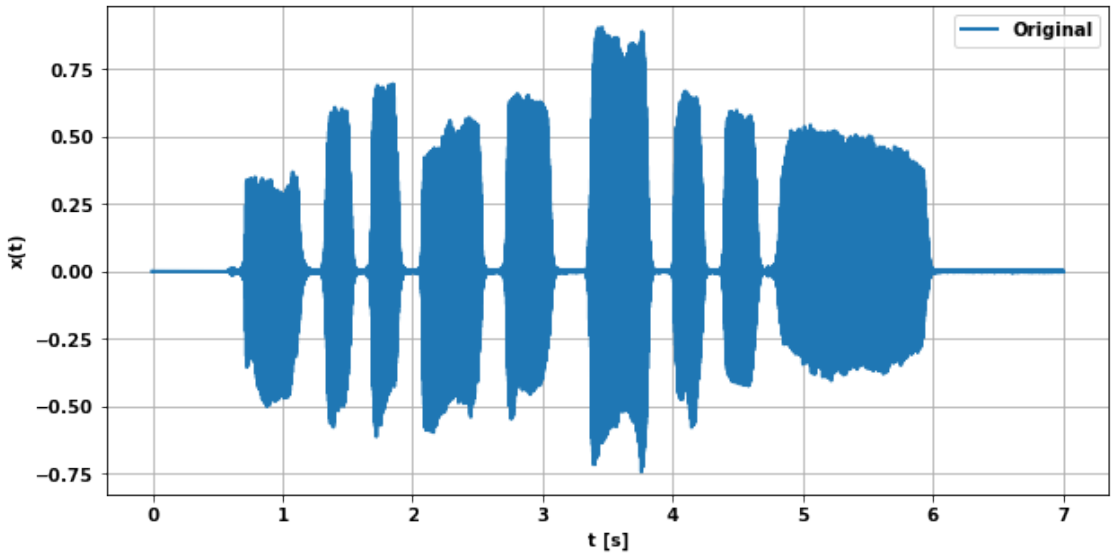


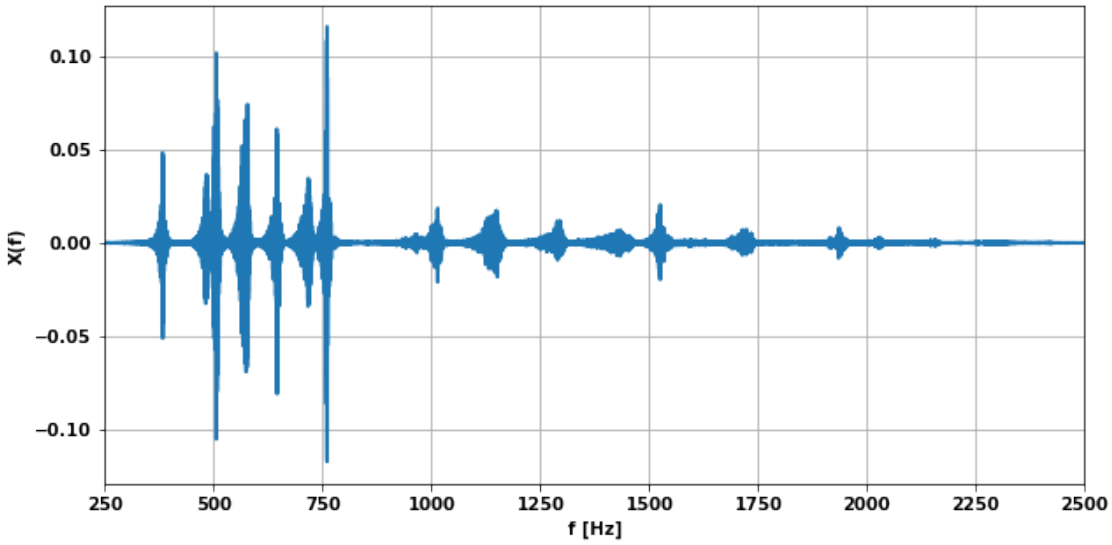
3 Question 3

[179]:
```
filename = './EID 465 - HW 1 - EFP.wav'
wave_obj = sa.WaveObject.from_wave_file(filename)
play_obj = wave_obj.play()
play_obj.wait_done()
#recorder melody
```

[234]:
```
data, fs = sf.read('./EID 465 - HW 1 - EFP.wav')
N = len(data)
L = N/fs
x = pd.Series(data=data,
              index=np.linspace(start=0, stop=L, num=N, endpoint=True),
              name='time domain signal')
#x = x.loc[2:2.6] #g
s = SignalTB(x=x,fs=fs)
fd = s.my_fft();
x2 = s.my_ifft()

fig = plt.figure(figsize=(10,5))
plt.plot(x)
#plt.plot(x2, '--')
plt.ylabel('x(t)'); plt.xlabel('t [s]'); plt.grid(); plt.legend(['Original',␣
 ↪'After IFFT'], loc = 'upper right')
fig.savefig('./plots/3_time.png', dpi=300, bbox_inches='tight');

fig= plt.figure(figsize=(10,5))
fd.loc[250:2500].plot(); plt.ylabel('X(f)'); plt.xlabel('f [Hz]'); plt.grid()
fig.savefig('./plots/3_freq.png', dpi=300, bbox_inches='tight');
```

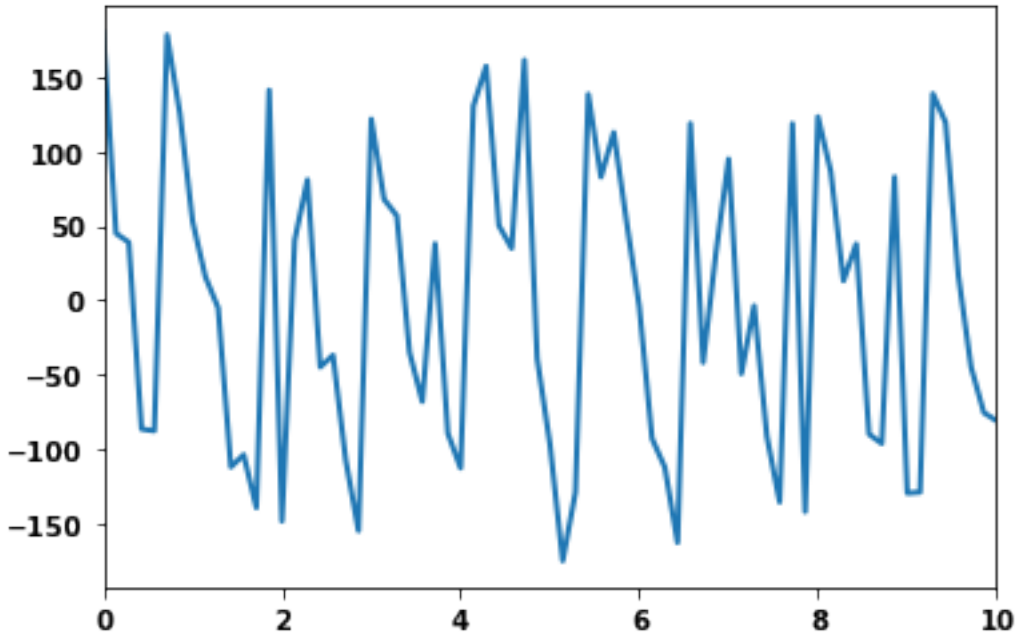
```
/home/m4rz910/anaconda3/lib/python3.7/site-packages/numpy/core/_asarray.py:85:
ComplexWarning: Casting complex values to real discards the imaginary part
  return array(a, dtype, copy=False, order=order)
```





[237]:
```
phase = pd.Series(data=pd.np.angle(fd, deg=True),
                  index=fd.index)
phase.loc[0:10].plot()
```

[237]: <matplotlib.axes._subplots.AxesSubplot at 0x7f249e1c6da0>


150
100
50
0
−50
−100
−150
0
2
4
6
8
10