tzavelis_hw4

February 28, 2020

[272]:

```
import numpy as np
import pandas as pd
from scipy import signal
import soundfile as sf
import simpleaudio as sa
import sounddevice as sd
from scipy.io import wavfile
import matplotlib.pyplot as plt
%matplotlib inline
import seaborn as sns

plt.rcParams['font.weight'] = 'bold'
plt.rcParams['axes.labelweight'] = 'bold'
plt.rcParams['lines.linewidth'] = 1
plt.rcParams['axes.titleweight'] = 'bold'

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.sxx = None
        self.gxx = None
        self.gxx_rms_a = None
        self.gxx_linear_a = None
        self.signals = [self.x] #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 get_signals():
        return filter(lambda x: x is not None, [self.X, self.x, self.sxx, self.
↪gxx])

    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[int(np.floor(self.N/2))+1:],
                            X[0:int(np.floor(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
        X = pd.Series(data=X,
                      index=freq,
                      name='X')
        self.X = X
        self.parseval_thrm(self.x,self.X)  #check Parsevals thrm
        self.signals.append(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
        self.parseval_thrm(x,X)  #check Parsevals thrm
        x = pd.Series(data=x,
                      index=t,
                      name='x2')
        self.signals.append(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: {} != {}".
↪format(td,fd)

    def sd(self):
        """
        Descrition:
            Spectral Density
        """
        sxx = np.abs(self.X)**2 / self.L; sxx.name = 'S_xx'; #display('sxx',sxx)
        # mean squared check
        X_ms = round(1/self.L * np.sum(np.abs(self.X)**2)*self.df,1)
        sxx_ms = round(np.sum(sxx)*self.df,1)
        assert X_ms == sxx_ms, 'Mean Squared Value Error: {} != {}'.
↪format(X_ms,sxx_ms)
        self.sxx = sxx
        self.signals.append(self.sxx)

        #gxx
        freq = np.arange(0, np.floor(self.N/2)+1) * self.df;␣
↪#display('freq',freq)
        i_zero = int(np.ceil(self.N/2)-1); #display('i_zero',i_zero)

        X = self.sxx.values[i_zero:] * 2 #grab from the center value all the␣
↪way to the end and double it
```

```
        X[0] = X[0]/2
        if self.N%2 == 0: X[-1] = X[-1]/2 #even
        gxx = pd.Series(data=X,
                        index=freq,
                        name='G_xx')

        # mean squared check
        gxx_ms = round(np.sum(gxx) * self.df,1)
        assert sxx_ms == gxx_ms, 'Mean Squared Value Error: {} != {}'.
↪format(sxx_ms,gxx_ms)
        self.gxx = gxx # uts of db
        self.signals.append(self.gxx)
        return self.sxx, self.gxx

    def rms_a(self, n_intervals = 16):
        """
            RMS Averaging for Gxx
        """
        frames=[]
        for i in range(1,n_intervals+1):
            x = self.x.iloc[int((i-1)*self.N/n_intervals):int(i*self.N/
↪n_intervals)]
            m = SignalTB(x=x, fs=self.fs)
            m.my_fft(); #calc fft
            m.sd() #calculate sxx and gxx
            frames.append(m.gxx) #save each gxx for averaging
        assert len(frames) == n_intervals, 'Could not perfectly cut the number␣
↪of samples by the n_interval: {}'.format(n_intervals)
        gxx_rms_a = pd.concat(frames,axis='columns').mean(axis='columns') #␣
↪calculates the mean of at each row (frequency)
        gxx_rms_a.name = 'G_xx_rms_a'
        self.gxx_rms_a = gxx_rms_a
        self.signals.append(gxx_rms_a)
        return gxx_rms_a

    def linear_a(self, n_intervals = 16):
        """
            Linear Averaging for X, then calculation of Gxx
        """
        frames=[]
        for i in range(1,n_intervals+1):
            x = self.x.iloc[int((i-1)*self.N/n_intervals):int(i*self.N/
↪n_intervals)]
            m = SignalTB(x=x, fs=self.fs)
            m.my_fft(); #calc fft
            frames.append(m.X) #save the fft
```

```
        assert len(frames) == n_intervals, 'Could not perfectly cut the number of samples by the n_interval: {}'.format(n_intervals)
        X_a = pd.concat(frames,axis='columns').mean(axis='columns') #average all the X's at each frequency

        #generate a temporary object so that you can perform computations
        m = SignalTB(x=self.x.iloc[int((i-1)*self.N/n_intervals):int(i*self.N/n_intervals)], fs=self.fs) # the time signal passed in doesn't mean anything, its just necessary to instatiate object
        m.X = X_a #set the new averaged X_a as the frequency domain signal in the temporary object
        m.sd()
        m.gxx.name = 'G_xx_linear_a'
        self.gxx_linear_a = m.gxx
        self.signals.append(m.gxx)
        return m.gxx

    def time_a(self, n_intervals = 16):
        """
            Time Averaging for x, then calculation of Gxx
        """
        frames=[]
        for i in range(1,n_intervals+1):
            x = self.x.iloc[int((i-1)*self.N/n_intervals):int(i*self.N/n_intervals)]
            x = pd.Series(data=x.values,
                          index=self.x.index[0:int(self.N/n_intervals)]) # make sure that all the objects have the same time index. This is important for taking the average and when we instatiate a new object.
            frames.append(x) #save the fft
        assert len(frames) == n_intervals, 'Could not perfectly cut the number of samples by the n_interval: {}'.format(n_intervals)
        x_a = pd.concat(frames,axis='columns').mean(axis='columns'); #display(x_a);

        m = SignalTB(x=x_a, fs=self.fs) #generate a temporary object
        m.my_fft()
        m.sd()
        m.gxx.name = 'G_xx_time_a'
        self.gxx_time_a = m.gxx
        self.signals.append(m.gxx)
        return m.gxx

    def spectrogram(self, n_intervals = 16, overlap = 0.25):
        """
            Spectrogram!
```

```
        """
        p_size = int(np.floor(self.N/n_intervals));#print('psize: {}'.
↪format(p_size));print('n_intervals*p_size: {}'.format(n_intervals*p_size))
        x = self.x.iloc[0:int(n_intervals*p_size)]

        frames=[]
        for i in range(1,n_intervals+1):
            if i == 1:
                f = 0
                l = p_size
            else:
                f = l - int(np.floor(overlap*p_size))
                l = f + p_size
            sig = x.iloc[f:l]
            m = SignalTB(x=sig, fs=self.fs)
            m.my_fft();
            m.sd()
            r = (int((i-1)*self.N/n_intervals) + int(i*self.N/n_intervals))/2
            m.gxx.name = round(r*m.dt,1)  # name the slice at the middle
            frames.append(m.gxx)
        assert len(frames) == n_intervals, 'Could not perfectly cut the number␣
↪of samples by the n_interval: {}'.format(n_intervals)
        gxx_df = pd.concat(frames,axis='columns').sort_index(ascending=False)
        gxx_df.name = 'Gxx_spectro'

        gxx_df.index = gxx_df.index.values.round(decimals=1)
        self.gxx_df = gxx_df
        self.signals.append(self.gxx_df)

        return gxx_df

    def plot_signals(self, xrange=None):
        """
        Description:
            Plots all of the signals in the self.signals container

        Returns:
            Nothing
        """

        for i, sig in enumerate(self.signals):
            if type(sig) != pd.DataFrame:
                if sig.dtype == complex: sig = np.absolute(sig) # ALWAYS the␣
↪magnitude of this in case its a complex number
            fig = plt.figure(figsize=(10,5))
            plt.title(sig.name)
            if sig.name in ['x','x2','time domain signal']:
```

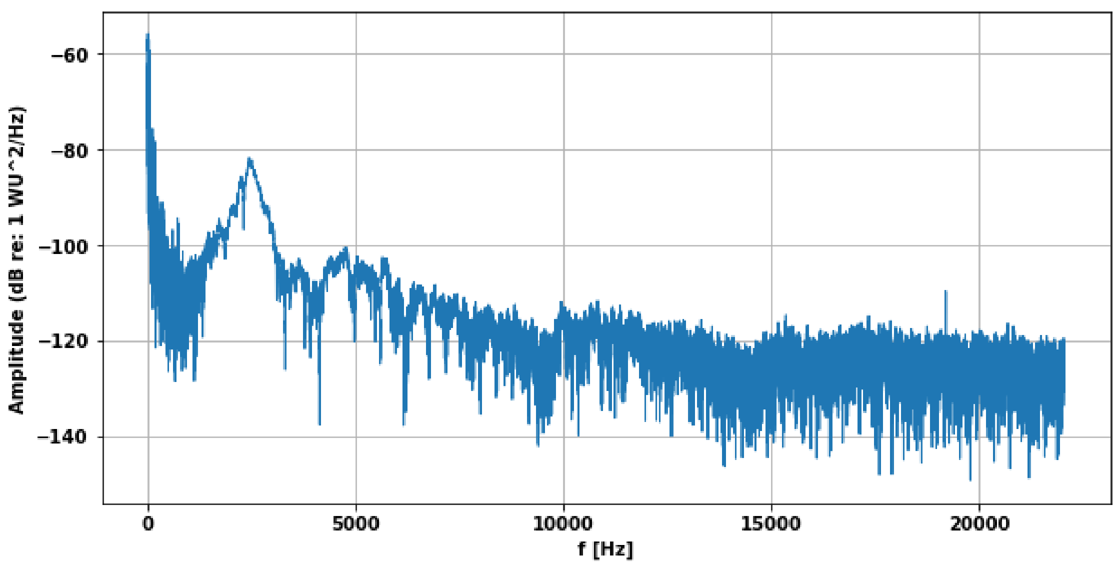
```
            plt.ylabel('x(t)'); plt.xlabel('t [s]')
        elif sig.name in␣
↪['X','S_xx','G_xx','G_xx_rms_a','G_xx_linear_a','G_xx_time_a']:
            sig = 10*np.log10(sig); plt.ylabel('X(f)'); plt.xlabel('f␣
↪[Hz]'); #plt.ylim([-30:])
        elif sig.name in ['Gxx_spectro']:
            sns.heatmap(sig, cmap="jet"); plt.ylabel('f [Hz]'); plt.
↪xlabel('t [s]')
            continue
        if xrange != None:
            sig[xrange[0]:xrange[1]].plot();
        else:
            sig.plot();
        plt.grid()

#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='x')

@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='x')
```

```python
    @staticmethod
    def csd(s0,s1):
        """
        Descrition:
            Cross Spectral Density
        """
        #calculate the fft of the objects
        s0.my_fft(); s1.my_fft()

        #sxy
        sxy = np.conj(s0.X)*s1.X / s0.L; sxy.name = 'S_xy';

        #gxy
        freq = np.arange(0, np.floor(s0.N/2)+1) * s0.df; #display('freq',freq)
        i_zero = int(np.ceil(s0.N/2)-1); #display('i_zero',i_zero)

        X = sxy.values[i_zero:] * 2 #grab from the center value all the way to the end and double it
        X[0] = X[0]/2
        if s0.N%2 == 0: X[-1] = X[-1]/2 #even
        gxy = pd.Series(data=X,
                        index=freq,
                        name='G_xy')
        return sxy, gxy

    def cross_corr(self,s0,s1):
        """
        Description:
            Cross correlation F^-1(Sxy)
        """
        sxy, gxy = SignalTB.csd(s0,s1)
        X = sxy.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
        self.parseval_thrm(x,X)  #check Parsevals thrm
        x = np.concatenate((x[int(np.floor(self.N/2))+1:],
                            x[0:int(np.floor(self.N/2))+1])) #put the fft values in standard form so ifft can accept it
        t = np.arange(-np.ceil(self.N/2)+1,np.floor(self.N/2)+1) * self.dt

        cross_corr = pd.Series(data=x,
                               index=t,
                               name='Cross Correlation')
        return cross_corr, sxy, gxy
```

1 HW 4 - Excercise

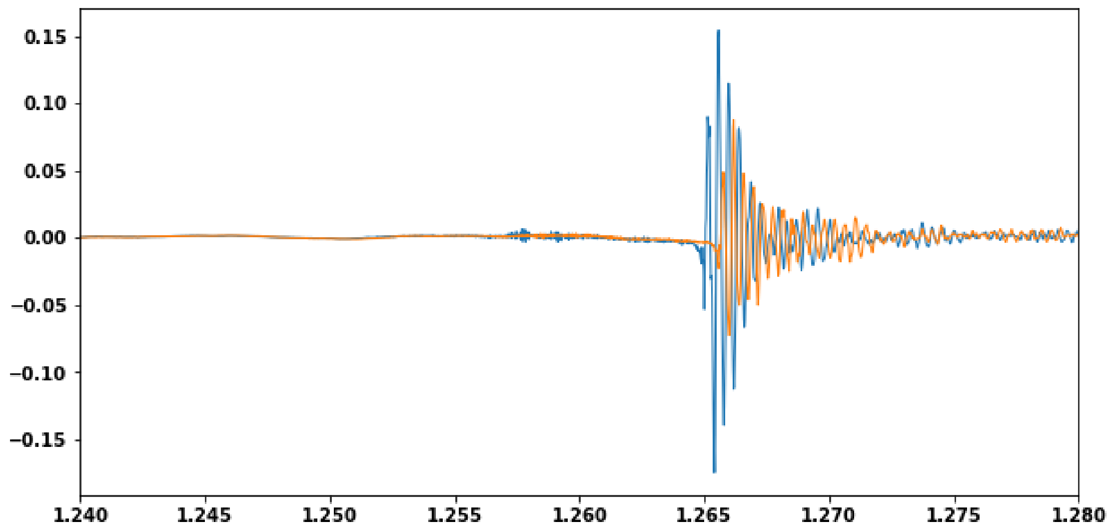
[34]:
```
data, fs = sf.read('./hw4_excercise_files/cross_corr_example.wav');
N = len(data); display(N)
L = N/fs;
df = pd.DataFrame(data=data,
                  index=np.linspace(start=0, stop=L, num=N, endpoint=True))

s0 = SignalTB(x=df[1], fs=fs)
s1 = SignalTB(x=df[0], fs=fs)
cross_corr, sxy, gxy = s0.cross_corr(s0,s1)

fig = plt.figure(figsize=(10,5))
plt.plot(10*np.log10(np.abs(gxy)));
plt.ylabel('Amplitude (dB re: 1 WU^2/Hz)'); plt.xlabel('f [Hz]');#plt.
 ↪xlim([250,260])
plt.grid()
#fig.savefig('./plots/hw3_2_gxx_averages.png', dpi=300, bbox_inches='tight');
```

132300



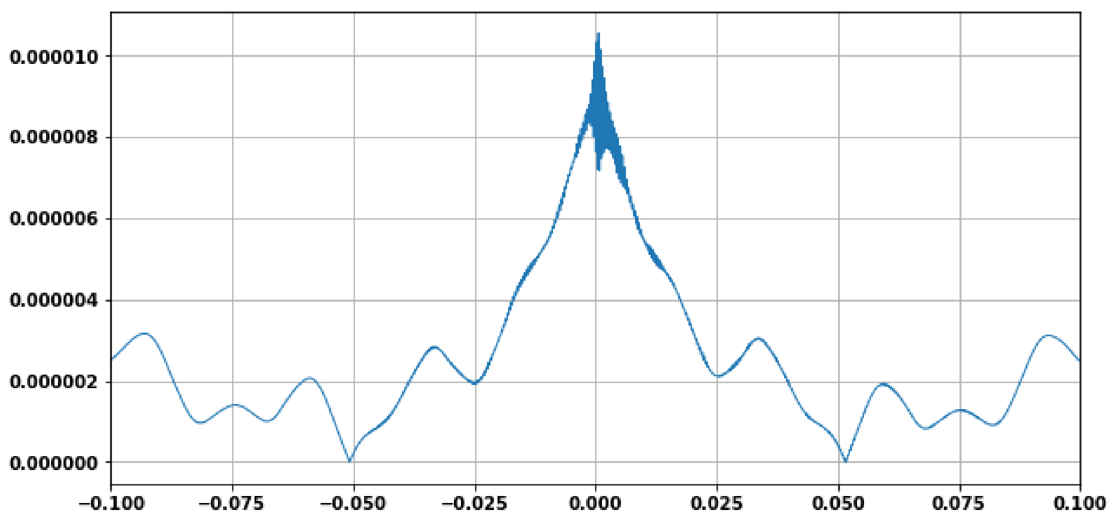
[35]:
```
plt.figure(figsize=(10,5))
s0.x.plot()
s1.x.plot()
plt.xlim((1.24,1.28))
```

[35]: (1.24, 1.28)



[37]:
```
plt.figure(figsize=(10,5))
#plt.plot(10*np.log10(np.abs((s0.cross_corr(sxy)))));plt.grid(); plt.xlim([-.
↪025,.025])
plt.plot(np.abs(cross_corr));plt.grid(); plt.xlim([-.1,.1]);
np.abs(cross_corr).idxmax()
```

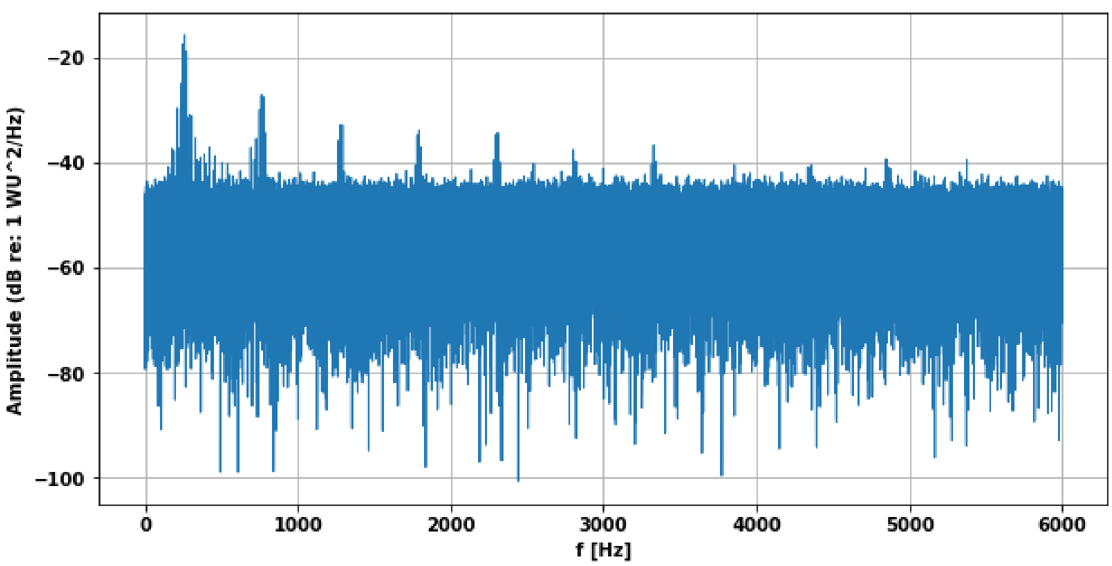
[37]: 0.0005895691609977325



2 HW 4

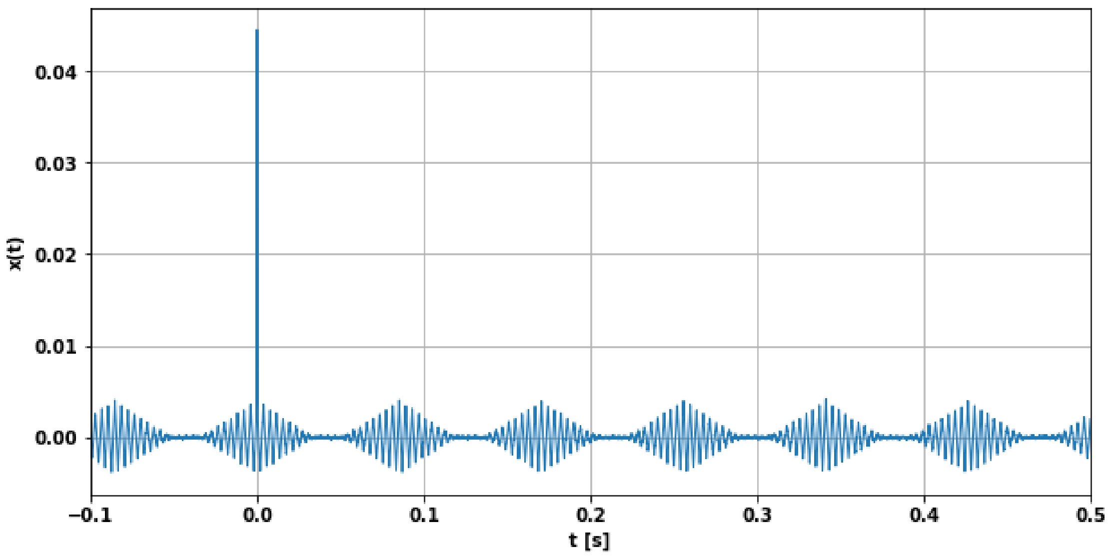
[291]:
```
data, fs = sf.read('./hw3_files/HW2_pulsenoise.wav');
N = len(data); print(N)
L = N/fs;
s = pd.Series(data=data,
              index=np.linspace(start=0, stop=L, num=N, endpoint=True))

s0 = SignalTB(x=s, fs=fs)
s1 = SignalTB(x=s, fs=fs)
cross_corr, sxy, gxy = s0.cross_corr(s0,s1)

fig = plt.figure(figsize=(10,5))
plt.plot(10*np.log10(np.abs(gxy)));
plt.ylabel('Amplitude (dB re: 1 WU^2/Hz)'); plt.xlabel('f [Hz]');#plt.
↪xlim([250,260])
plt.grid()
```

262196



[297]:
```
fig = plt.figure(figsize=(10,5))
plt.plot(cross_corr);plt.grid(); plt.xlim([-0.1,.5]); #plt.ylim([0,0.0037])
plt.ylabel('x(t)'); plt.xlabel('t [s]')
fig.savefig('./plots/hw4_crosscorr.png', dpi=300, bbox_inches='tight');
cross_corr.idxmax()
```

[297]: 0.0



[293]:
```
p_length = 0.12-0.05 #by looking at the plot
n_intervals = len(signal.find_peaks(cross_corr, distance=t_len*s0.fs)[0]) - 1␣
↪#subtract one to not count center one
print('pulse length: {}\nn_intervals: {}'.format(p_length,n_intervals))
```

```
pulse length: 0.06999999999999999
n_intervals: 256
```

[137]:
```
s0.x.iloc[:len(data)]
```

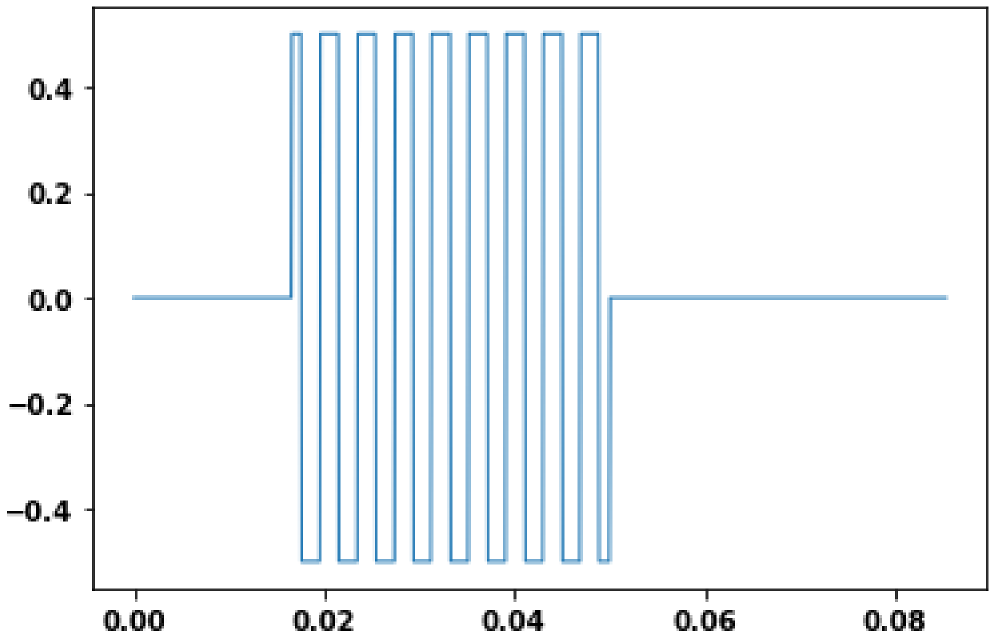
[137]:
```
0.000000      0.116852
0.000083     -0.080841
0.000167      0.509888
0.000250      0.027252
0.000333      0.050537
                ...
21.849333    -0.017609
21.849417     0.222748
21.849500     0.124054
21.849583    -0.018585
21.849667     0.153748
Length: 262196, dtype: float64
```

[298]:
```
data, fs = sf.read('./hw3_files/HW2_pulse.wav');
N = len(data); print(N)
L = N/fs; print(L)
s = pd.Series(data=data,
              index=np.linspace(start=0,stop=L,num=N,endpoint=True))
```

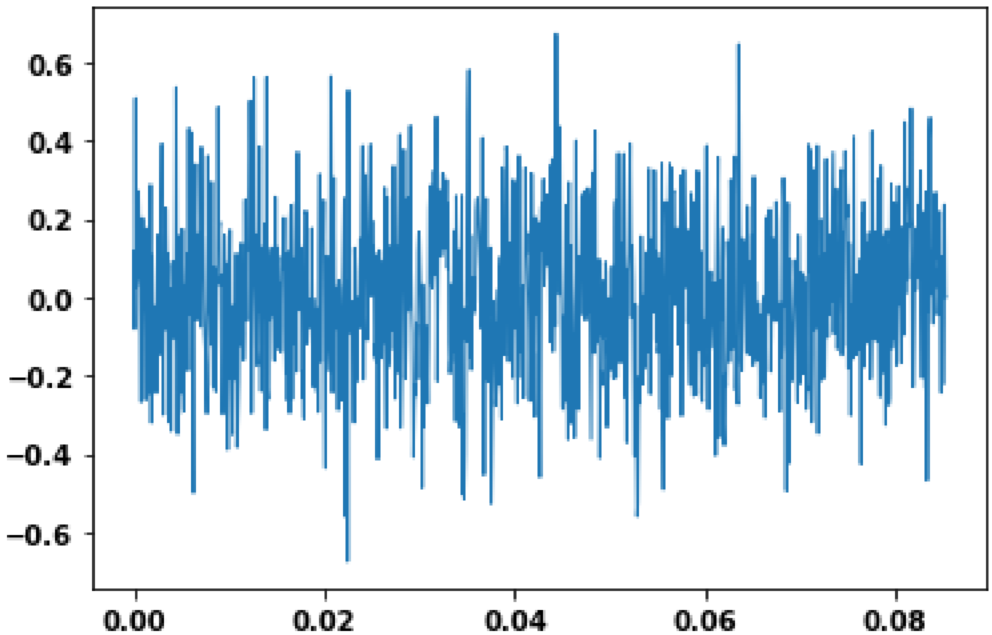
```
s3 = SignalTB(x=s, fs=fs)
plt.plot(s3.x)
```

```
1024
0.08533333333333333
```

[298]: [<matplotlib.lines.Line2D at 0x7f0fd8431400>]



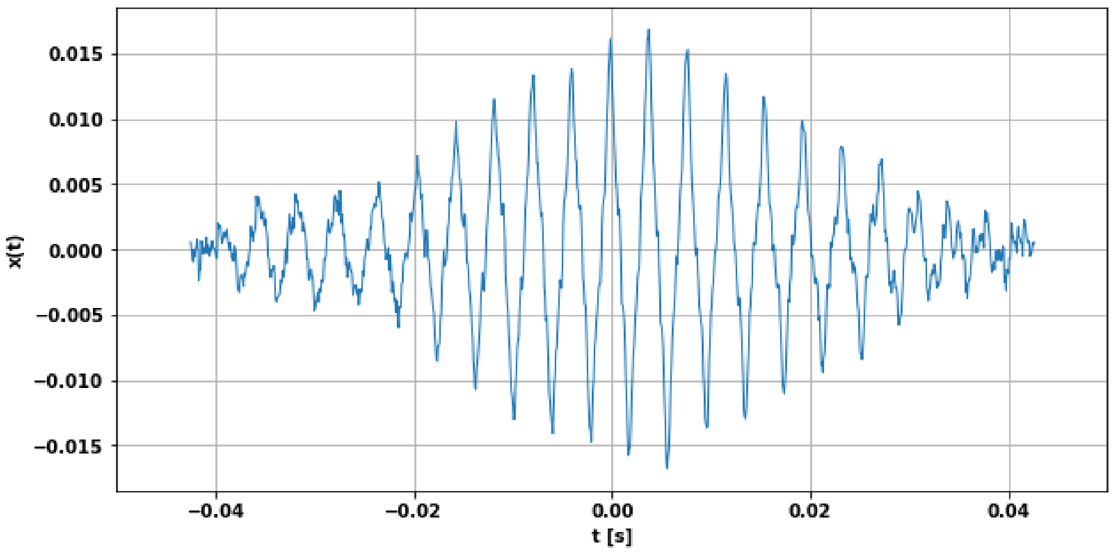
[144]:
```
s0_s = SignalTB(x=s0.x.iloc[0:len(data)], fs=fs)
plt.plot(s0.x.iloc[0:len(data)]);
```



[300]:
```
cross_corr, sxy, gxy = s0_s.cross_corr(s3,s0_s)
```

[303]:
```
fig = plt.figure(figsize=(10,5))
plt.plot(cross_corr);plt.grid(); plt.xlim([-0.05,0.05]); #plt.ylim([0,0.0037])
plt.ylabel('x(t)'); plt.xlabel('t [s]')
fig.savefig('./plots/hw4_crosscorr.png', dpi=300, bbox_inches='tight');

cross_corr.idxmax() * 343
```

[303]: 1.2849987973936088

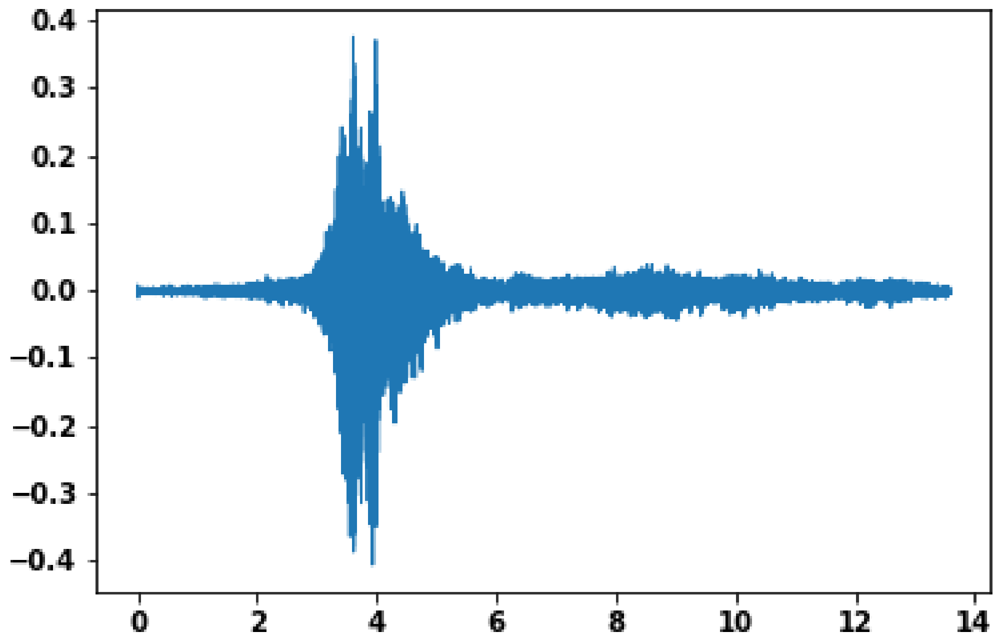


3 spectrogram

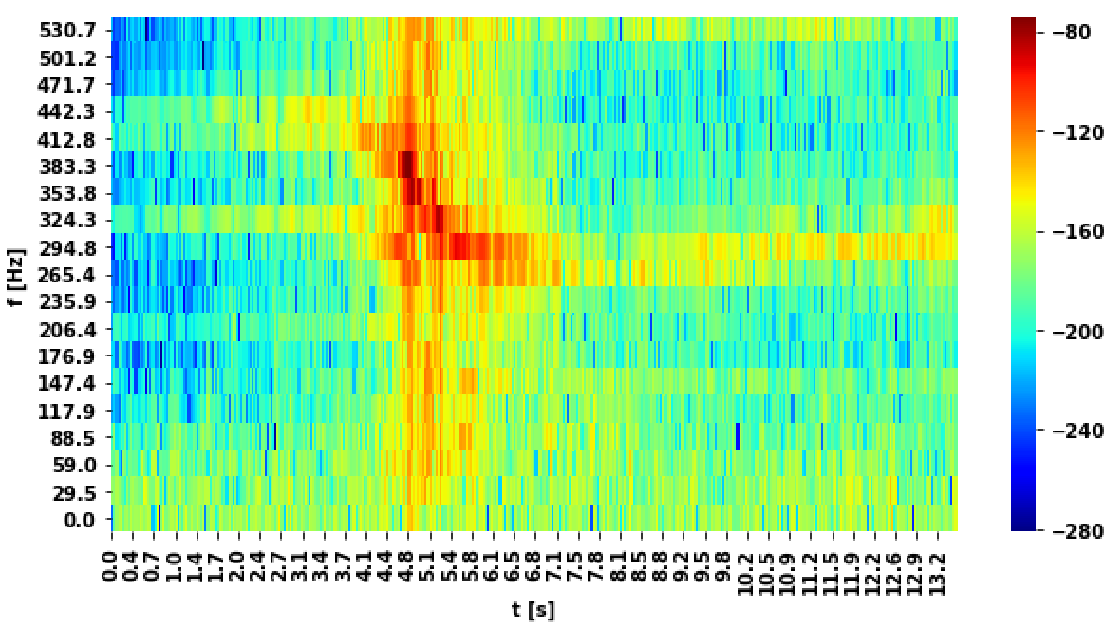
[306]:
```
data, fs = sf.read('./hw4/HW4_spect.wav');
N = len(data); print(N)
L = N/fs; print(L)
s = pd.Series(data=data,
              index=np.linspace(start=0,stop=L,num=N,endpoint=True))
s = SignalTB(x=s, fs=fs)
plt.plot(s.x)
```

```
163011
13.58425
```

[306]:
```
[<matplotlib.lines.Line2D at 0x7f0fd8948710>]
```



[340]:
```
gxx_spectro = s.spectrogram(n_intervals = 400,overlap = 0.25)
fig = plt.figure(figsize=(10,5))
sns.heatmap(10*np.log(gxx_spectro.iloc[185:]),cmap="jet"); plt.ylabel('f [Hz]');
 ↪ plt.xlabel('t [s]');# plt.set_label('Amplitude (dB re: 1 WU^2/Hz)')
fig.savefig('./plots/spectrogram.png', dpi=300, bbox_inches='tight');
```



[341]:
```
c = 353
vl= 294
vh= 442
v = 343 * (vl+vh)/(vh-vl)
v
```

[341]: 1705.7297297297298

[343]:
```
vl= 383
vh= 442
f0 = 295
df = vh-vl
df*c/f0
```

[343]: 70.6