

CENG 384 - Signals and Systems for Computer Engineers  
Spring 2023  
Homework 4

Geçit, Emre  
e2521581@ceng.metu.edu.tr

Yancı, Baran  
e2449015@ceng.metu.edu.tr

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1. (a)

$$\begin{aligned}H(j\omega) &= \frac{j\omega - 1}{j\omega + 1} \\ \frac{Y(j\omega)}{X(j\omega)} &= \frac{j\omega - 1}{j\omega + 1} \\ Y(j\omega)(j\omega + 1) &= X(j\omega)(j\omega - 1) \\ y'(t) + y(t) &= x'(t) - x(t)\end{aligned}$$

(b)

$$\begin{aligned}H(j\omega) &= \frac{j\omega - 1}{j\omega + 1} \\ h(t) &= \mathcal{F}^{-1}\{H(j\omega)\} \\ &= \mathcal{F}^{-1}\left\{\frac{j\omega - 1}{j\omega + 1}\right\} \\ &= \mathcal{F}^{-1}\left\{\frac{j\omega + 1 - 2}{j\omega + 1}\right\} \\ &= \mathcal{F}^{-1}\left\{\frac{j\omega + 1}{j\omega + 1}\right\} - \mathcal{F}^{-1}\left\{\frac{2}{j\omega + 1}\right\} \\ &= \mathcal{F}^{-1}\{1\} - 2\mathcal{F}^{-1}\left\{\frac{1}{j\omega + 1}\right\} \\ &= \delta(t) - 2e^{-t}u(t)\end{aligned}$$

(c)

$$\begin{aligned}
 y'(t) + y(t) &= x'(t) - x(t) \\
 y'(t) + y(t) &= -2e^{-2t}u(t) - e^{-2t}u(t) \\
 y'(t) + y(t) &= -3e^{-2t}u(t) \\
 y_p(t) &= Ae^{-2t} \\
 y_p'(t) &= -2Ae^{-2t} \\
 -2Ae^{-2t} + Ae^{-2t} &= -3e^{-2t}u(t) \\
 A &= 3 \\
 y_p(t) &= 3e^{-2t} \\
 y_h(t) &= c_1e^{-t}u(t) \\
 y(t) &= y_p(t) + y_h(t) \\
 &= 3e^{-2t} + c_1e^{-t}u(t) \\
 y(0) &= 0 \\
 0 &= 3e^{-2(0)} + c_1e^{-0}u(0) \\
 0 &= 3 + c_1 \\
 c_1 &= -3 \\
 y(t) &= 3e^{-2t} - 3e^{-t}u(t)
 \end{aligned}$$

(d) Block diagram of the system:

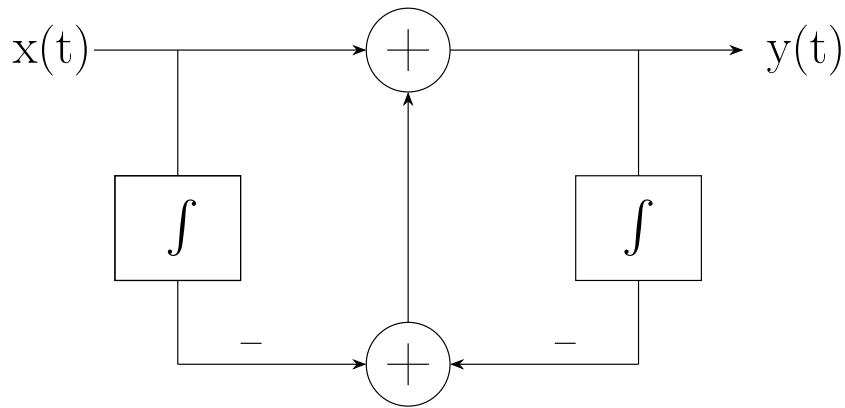


Figure 1: Block Diagram of the System

2. (a)

$$\begin{aligned}
 y[n+1] - \frac{1}{2}y[n] &= x[n+1] \\
 e^{j\omega}Y(e^{j\omega}) - \frac{1}{2}Y(e^{j\omega}) &= e^{j\omega}X(e^{j\omega}) \\
 H(e^{j\omega}) &= \frac{Y(e^{j\omega})}{X(e^{j\omega})} \\
 H(e^{j\omega}) &= \frac{e^{j\omega}}{e^{j\omega} - \frac{1}{2}}
 \end{aligned}$$

(b)

$$\begin{aligned}
H(e^{j\omega}) &= \frac{e^{j\omega}}{e^{j\omega} - \frac{1}{2}} \\
h[n] &= \mathcal{F}^{-1}\{H(e^{j\omega})\} \\
&= \mathcal{F}^{-1}\left\{\frac{e^{j\omega}}{e^{j\omega} - \frac{1}{2}}\right\} \\
&= \mathcal{F}^{-1}\left\{\frac{e^{j\omega} - \frac{1}{2} + \frac{1}{2}}{e^{j\omega} - \frac{1}{2}}\right\} \\
&= \mathcal{F}^{-1}\left\{\frac{e^{j\omega} - \frac{1}{2}}{e^{j\omega} - \frac{1}{2}} + \frac{\frac{1}{2}}{e^{j\omega} - \frac{1}{2}}\right\} \\
&= \mathcal{F}^{-1}\left\{1 + \frac{\frac{1}{2}}{e^{j\omega} - \frac{1}{2}}\right\} \\
&= \mathcal{F}^{-1}\{1\} + \mathcal{F}^{-1}\left\{\frac{\frac{1}{2}}{e^{j\omega} - \frac{1}{2}}\right\} \\
&= \delta[n] + \frac{1}{2}\mathcal{F}^{-1}\left\{\frac{1}{e^{j\omega} - \frac{1}{2}}\right\} \\
&= \delta[n] + \frac{1}{2}e^{\frac{1}{2}n}u[n]
\end{aligned}$$

(c) The initial condition is  $y[a] = 0, a \leq -1$ .

$$\begin{aligned}
y[n+1] - \frac{1}{2}y[n] &= x[n+1] \\
y[n+1] &= \frac{1}{2}y[n] + x[n+1] \\
y[0] &= \frac{1}{2}y[-1] + x[0] \\
&= 0 + 1 \\
&= 1 \\
y[1] &= \frac{1}{2}y[0] + x[1] \\
&= \frac{1}{2} + \frac{3}{4} \\
&= \frac{5}{4} \\
y[2] &= \frac{1}{2}y[1] + x[2] \\
&= \frac{5}{8} + \frac{9}{16} \\
&= \frac{19}{16} \\
y[3] &= \frac{1}{2}y[2] + x[3] \\
&= \frac{19}{32} + \frac{27}{64} \\
&= \frac{65}{64} \\
y[4] &= \frac{1}{2}y[3] + x[4] \\
&= \frac{65}{128} + \frac{81}{256} \\
&= \frac{211}{256} \\
&\dots \\
y[n] &= 2^{-n} \left( 1 + 3 \left( \left( \frac{3}{2} \right)^n - 1 \right) \right)
\end{aligned}$$

3. (a)

$$\begin{aligned}
 H(j\omega) &= H_1(j\omega)H_2(j\omega) \\
 &= \frac{1}{j\omega + 1} \frac{1}{j\omega + 2} \\
 &= \frac{Y(j\omega)}{X(j\omega)} \\
 Y(j\omega)(j\omega + 1)(j\omega + 2) &= X(j\omega) \\
 Y(j\omega)(j^2\omega^2 + 3j\omega + 2) &= X(j\omega) \\
 y''(t) + 3y'(t) + 2y(t) &= x(t)
 \end{aligned}$$

(b)

$$\begin{aligned}
 H(j\omega) &= H_1(j\omega)H_2(j\omega) \\
 H_1(j\omega) &= \frac{1}{j\omega + 1} \\
 H_2(j\omega) &= \frac{1}{j\omega + 2} \\
 H(j\omega) &= \frac{1}{j\omega + 1} \frac{1}{j\omega + 2} \\
 h_1(t) &= \mathcal{F}^{-1}\{H(j\omega)\} \\
 &= \mathcal{F}^{-1}\left\{\frac{1}{j\omega + 1} \frac{1}{j\omega + 2}\right\} \\
 &= \mathcal{F}^{-1}\left\{\frac{1}{j\omega + 1}\right\} * \mathcal{F}^{-1}\left\{\frac{1}{j\omega + 2}\right\} \\
 &= e^{-t}u(t) * e^{-2t}u(t) \\
 &= \int_{-\infty}^{\infty} e^{-(t-\tau)}u(t-\tau)e^{-2\tau}u(\tau)d\tau \\
 &= \int_0^t e^{-(t-\tau)}e^{-2\tau}d\tau \\
 &= \int_0^t e^{-t+\tau}e^{-2\tau}d\tau \\
 &= \int_0^t e^{-t}e^{\tau}e^{-2\tau}d\tau \\
 &= e^{-t} \int_0^t e^{-\tau}d\tau \\
 &= e^{-t} [-e^{-\tau}]_0^t \\
 &= e^{-t} [-e^{-t} + 1] \\
 &= e^{-t} - e^{-2t}
 \end{aligned}$$

(c)

$$\begin{aligned}
 X(j\omega) &= j\omega \\
 Y(j\omega) &= H(j\omega)X(j\omega) \\
 &= \frac{1}{j\omega + 1} \frac{1}{j\omega + 2} j\omega \\
 y(t) &= \mathcal{F}^{-1}\{Y(j\omega)\} \\
 &= \mathcal{F}^{-1}\left\{\frac{j\omega}{(j\omega + 1)(j\omega + 2)}\right\} \\
 &= \mathcal{F}^{-1}\left\{\frac{-1}{j\omega + 1} + \frac{2}{j\omega + 2}\right\} \\
 &= \mathcal{F}^{-1}\left\{\frac{-1}{j\omega + 1}\right\} + \mathcal{F}^{-1}\left\{\frac{2}{j\omega + 2}\right\} \\
 &= -e^{-t}u(t) + 2e^{-2t}u(t)
 \end{aligned}$$

4. (a)

$$H(e^{j\omega}) = \frac{Y(e^{j\omega})}{X(e^{j\omega})} = \frac{5e^{-j\omega} + 12}{e^{-2j\omega} + 5e^{-j\omega} + 6}$$

Found in part 4b

$$Y(e^{j\omega})(e^{-2j\omega} + 5e^{-j\omega} + 6) = X(e^{j\omega})(5e^{-j\omega} + 12)$$

$$y[n - 2] + 5y[n - 1] + 6y[n] = 5x[n - 1] + 12x[n]$$

(b)

$$\begin{aligned} H(e^{j\omega}) &= H_1(e^{j\omega}) + H_2(e^{j\omega}) \\ &= \frac{3}{3 + e^{-j\omega}} + \frac{2}{2 + e^{-j\omega}} \\ &= \frac{5e^{-j\omega} + 12}{e^{-2j\omega} + 5e^{-j\omega} + 6} \end{aligned}$$

(c)

$$\begin{aligned} h[n] &= \mathcal{F}^{-1}\{H_1(j\omega) + H_2(j\omega)\} \\ &= \mathcal{F}^{-1}\left\{\frac{3}{3 + e^{-j\omega}} + \frac{2}{2 + e^{-j\omega}}\right\} \\ &= \mathcal{F}^{-1}\left\{\frac{3}{3 + e^{-j\omega}}\right\} + \mathcal{F}^{-1}\left\{\frac{2}{2 + e^{-j\omega}}\right\} \\ &= \frac{-1}{3}u[n] + \frac{1}{2}u[n] \end{aligned}$$

5. After decoding **encoded.wav** according to the recipe given, a wav file **decoded.wav** is obtained. When played by a media player, the decoded file says "I have a dream".

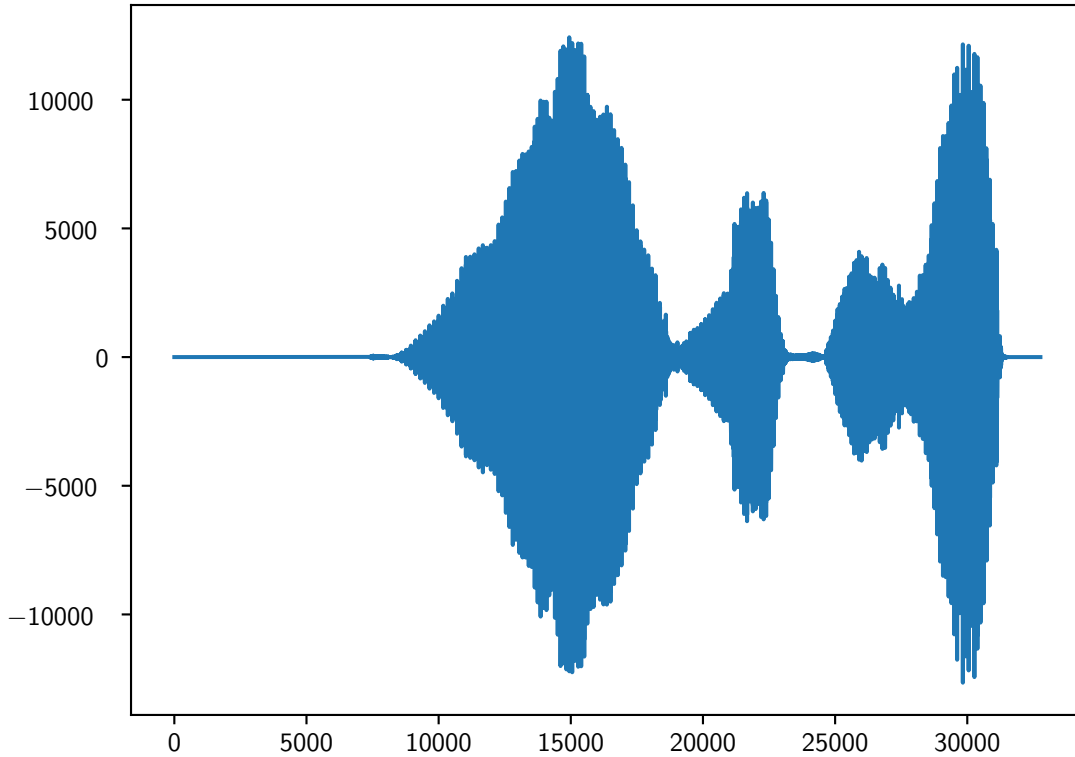


Figure 2: Time Domain Representation of The Encoded Signal

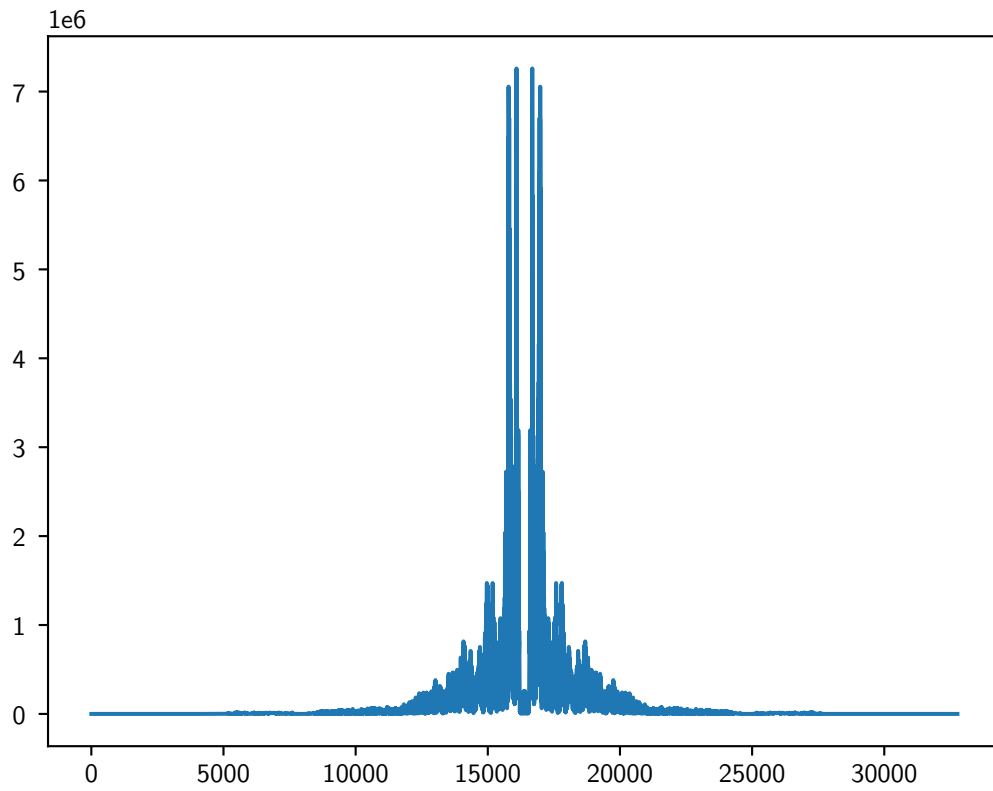


Figure 3: Frequency Domain Representation of The Encoded Signal

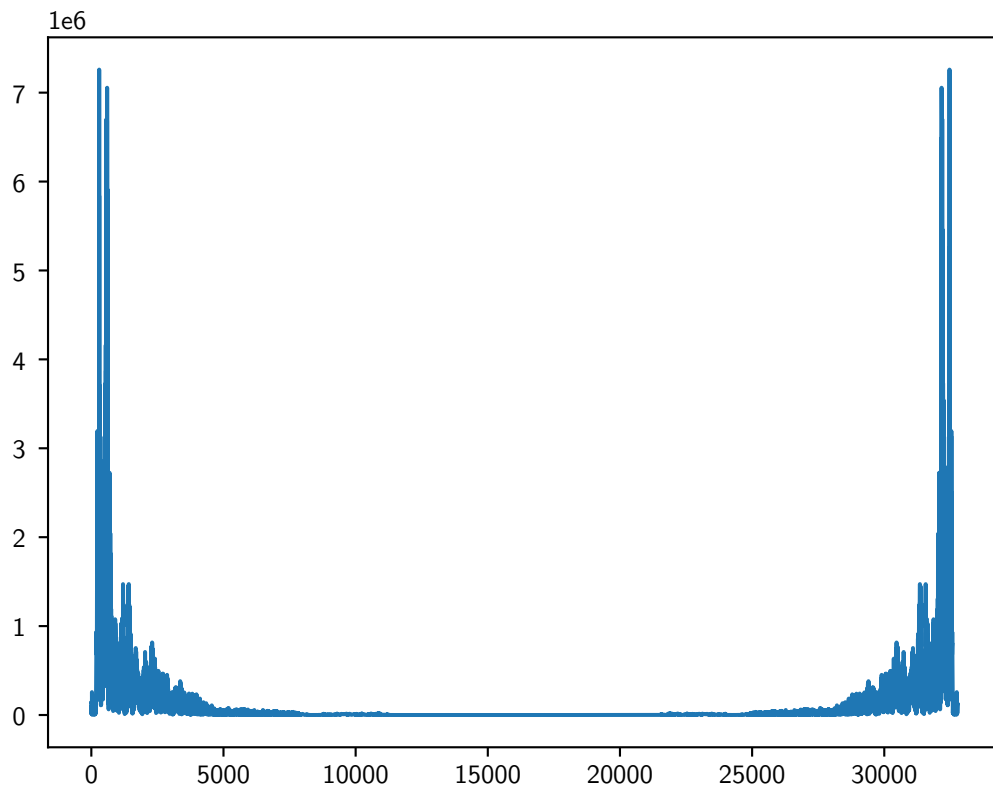


Figure 4: Frequency Domain Representation of The Decoded Signal

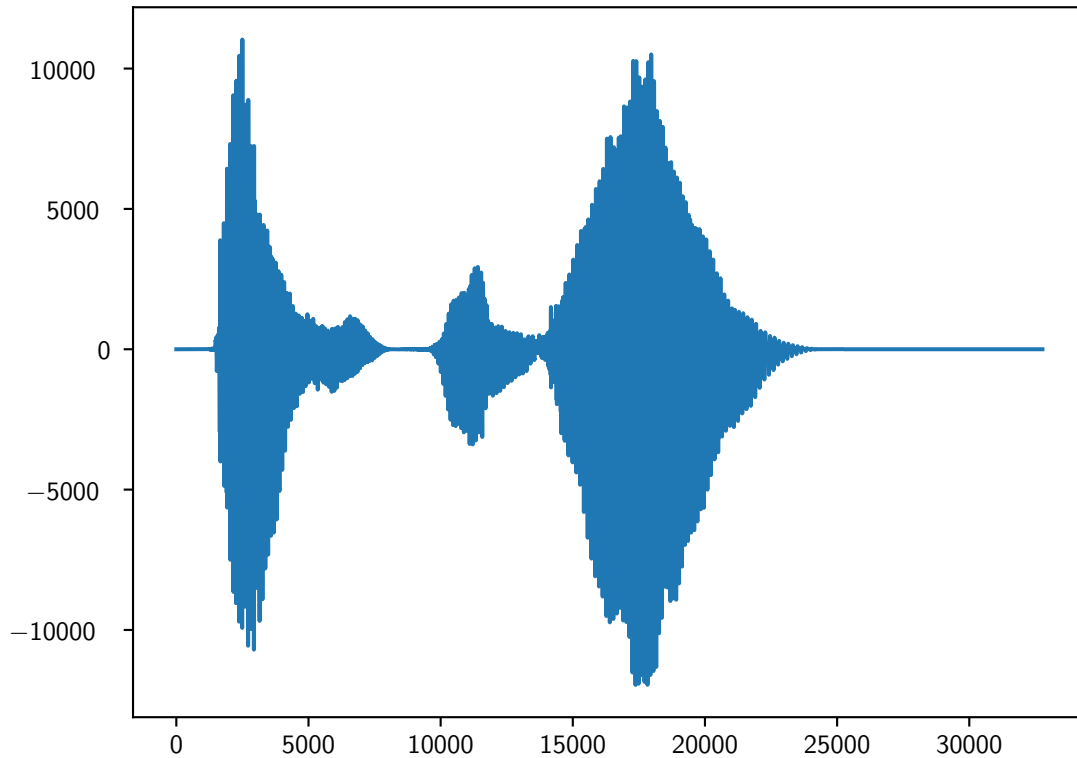


Figure 5: Time Domain Representation of The Decoded Signal

The code for the decoding process is given below.

```
import numpy
from scipy.io import wavfile
from tester import test # This is to verify the implementation, uses numpy.fft
import matplotlib
from matplotlib import pyplot

matplotlib.use("pgf")

def fft(x: numpy.ndarray) -> numpy.ndarray:
    N = len(x)
    if N <= 1:
        return x

    even = fft(x[::2])
    odd = fft(x[1::2]) * numpy.exp(-2j * numpy.pi * numpy.arange(N // 2) / N)
    return numpy.concatenate([even + odd,
                              even - odd])

def ifft(X: numpy.ndarray) -> numpy.ndarray:
    return numpy.flip(fft(X)) / len(X)

def plot(signal, name):
    pyplot.plot(signal)
    pyplot.savefig("figures/" + name + ".pgf")
    pyplot.clf()

rate, encoded = wavfile.read("encoded.wav")
plot(encoded, "encoded")
N = len(encoded)
dft_encoded = fft(encoded)
plot(numpy.abs(dft_encoded), "dft_encoded")
flipped = numpy.flip(dft_encoded)
```

```
dft_decoded = numpy.concatenate([flipped[N//2:], flipped[:N//2]])
plot(numpy.abs(dft_decoded), "dft_decoded")
decoded = ifft(dft_decoded)
plot(decoded.real, "decoded")
assert test(encoded, decoded)
wavfile.write("decoded.wav", rate, decoded.real.astype(numpy.int16))
```