Amplitude, frequency and phase modulation

The purpose of work

It is necessary to modulate raw signals by amplitude, frequency and phase using meander as modulating signal and plot the spectrums of these signals.

Imports of necessary libraries

```
%matplotlib notebook
from numpy import sin, cos, linspace, cumsum, asarray, zeros
from scipy.fft import rfft, rfftfreq, irfft, fft
from scipy.signal import square
from math import *
import matplotlib.pyplot as plt
```

Core functions

```
# Static global variables to work with the signal
TIME_RANGE = 4      # Time range (sec)
FS         = 2048   # Sampling freq (Hz)
SAMPLES    = FS * TIME_RANGE # Count of samples


def t_step(samples=SAMPLES):
    """
    Generates a time steps array
    """
    TIME_STEP = 1 / FS # Sample time interval
    return linspace(0, TIME_RANGE, samples)


def signal(__func__):
    """
    Decorator function for restoring signal from mathematical function
    """
    def wrapper(A, k, w, q):
        t      = t_step()
        f      = [__func__(A, k, w, q, t=ti) for ti in t]
        return (t, f)
    return wrapper


def syntesis(ys):
    """
```

```
     Function recreating a signal from the spectrum
    """
    yf = irfft(ys, norm='ortho')
    xf = t_step(len(yf))
    return (xf, yf)


def spectrum(yf):
    """
    Function realizing spectrum of signal
    """
    freq = rfftfreq(len(yf), 1 / FS)
    ampl = rfft(yf, norm='ortho')
    ampl[0] = 0
    return freq, ampl


def trim(ys, low, high): # BUG THERE
    """
    Method trimming signal by spectrum frequencies
    """
    xs = rfftfreq(SAMPLES, 1 / FS)
    ys[:low]  = 0
    ys[high:] = 0
    return xs, ys


def modulation(harmonic, meander, type):
    """
    Function of modulation harmonic signal by meander.
    It can be modulated by amplitude, frequency and phase

    <type> parameter take values: 'ampl', 'freq', 'phase'
    """
    harms = len(harmonic[0])
    mends = len(meander[0])
    if harms != mends:
        raise ValueError(f'Dimensions and sizes of two signal arrays must be equal! Actual siz

    def freq(harmonic, meander):
        f = []
        i, j = 0, 0
        while j < harms:
            f.append(harmonic[1][j])
            if meander[1][i] == 1:
                j += 2
            else: j += 1
            i += 1

        t = harmonic[0]

        #!!! Fitting the compressed array to its original size
        z = zeros(harms) # Creating zero array of size harms
        z[:len(f)] = f   # Pasting f array at start of zero array
        f = z
        return (t, f)

    modulate = {
        'ampl'  : [harmonic[0], [meander[1][i] * harmonic[1][i] for i in range(harms)]],
        'freq'  : freq(harmonic, meander),
        'phase' : [harmonic[0], [((meander[1][i] if meander[1][i] == 1 else -1) * harmonic[1][
    }
    return asarray(modulate[type])


def restore_decay(x, A, k, a=0):
    """
    Additive fade-restore function
    """
    y = [dump(xi, A, k) + a for xi in x]
    return (y, [-yi for yi in y])


def dump(t, A, k=0):
    """
    Additive function to compute dumping function amplitude
    """
    return A * exp(-k * t)
```

Additive functions for plotting image

```
def ylabel(axes, label):
    """
    Method for setting y label to subplots
    """
    for axis in axes:
        axis.set_ylabel(label)


def xlabel(axes, label):
    """
    Method for setting x label to subplots
    """
    for axis in axes:
        axis.set_xlabel(label)


def grid(axes):
    """
    Method for drawing grid on subplots
    """
    for axis in axes:
        axis.grid()


def xlim(axes, lim):
    """
    Method for setting the x bounds of the displayed function on subplots
    """
    if len(lim) == 1:
        for i, axis in enumerate(axes):
            axis.set_xlim(lim[0])
    else:
        if len(axes) != len(lim):
            raise ValueError(f'Sizes of axes array and limits array must be equal! Actual size
        for i, axis in enumerate(axes):
            axis.set_xlim(lim[i])


def ylim(axes, lim):
    """
    Method for setting the y bounds of the displayed function on subplots
    """
    if len(lim) == 1:
        for i, axis in enumerate(axes):
            axis.set_xlim(lim[0])
    else:
        if len(axes) != len(lim):
            raise ValueError(f'Sizes of axes array and limits array must be equal! Actual size
        for i, axis in enumerate(axes):
            axis.set_xlim(lim[i])


def draw(axes, funcs, ls='-', lw=1, color='tab:blue', fill='out'):
    """
    Mothod for plotting group of subplots
    """
    if len(axes) != len(funcs):
        raise ValueError(f'Sizes of axes array and functions array must be equal! Actual sizes

    if fill == 'out':
        for i in range(len(axes)):
            axes[i].plot(*funcs[i], ls=ls, lw=lw, color=color)
    elif fill == 'in':
        for i in range(len(axes)):
            axes[i].fill_between(*funcs[i], ls=ls, lw=lw, color=color)
```

Describing mathematical functions

```
A = 1.0
k = 0.0


@signal
def harmonic(A, k, w, q, t=None):
    """
    Function-wrapper for mathematical function
    """
    w *= 2*pi
    return dump(t, A, k) * sin(w * t + q)


@signal
def meander(A, k, w, q, t=None):
    """
    Function-wrapper for meander function
    """
    w *= 2 * pi
    sqr = square(w * t)
    return dump(t, A, k) * sqr if sqr >= 0 else 0
```

Computing

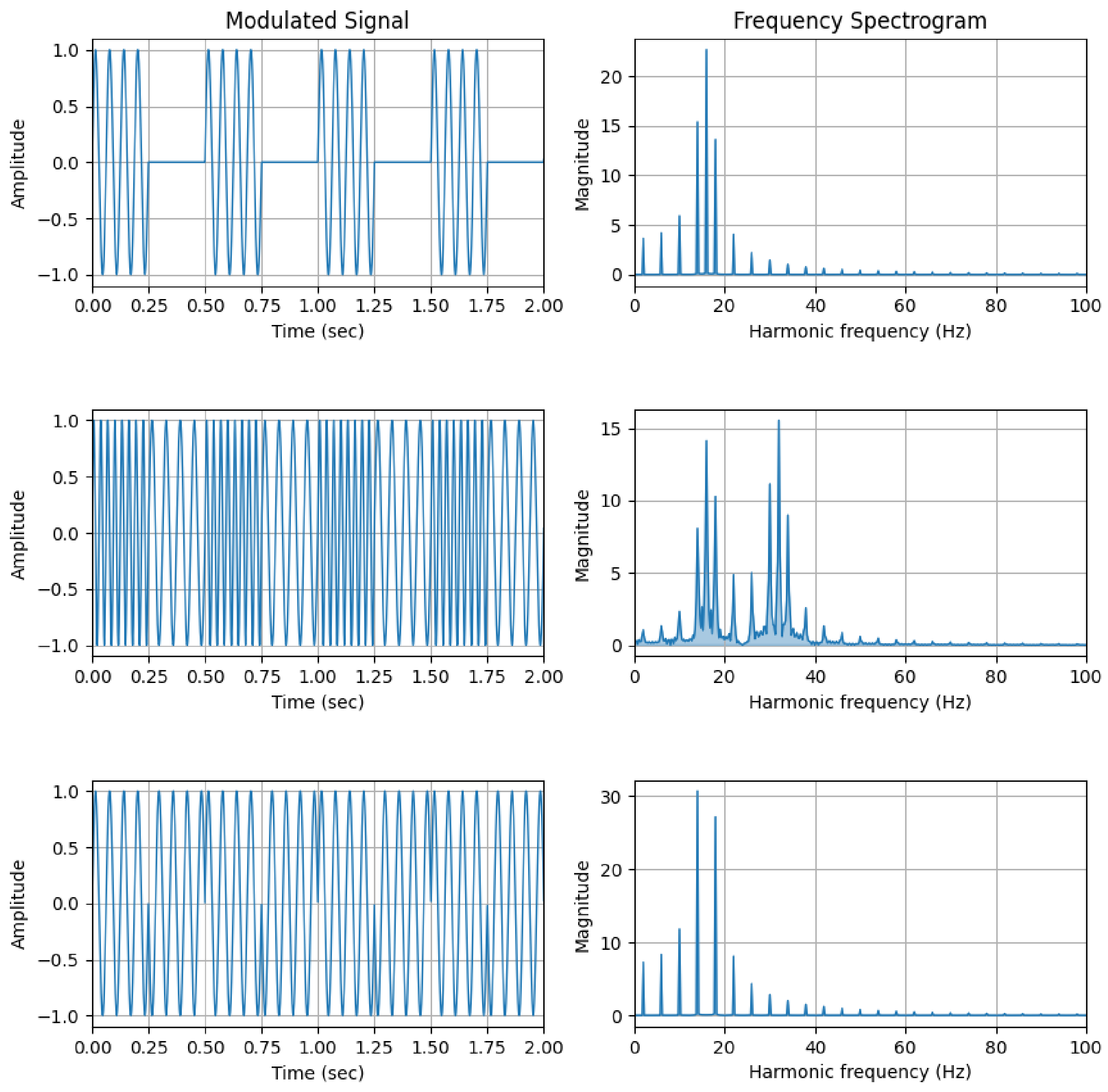
```
# Computing raw signals (harmonic & meander)
xh, yh = harmonic(A, k, 16, 0)
xm, ym = meander(A, k, 2, 0)

# Computing modilated signals
xma, yma = modulation((xh, yh), (xm, ym), 'ampl')
xmf, ymf = modulation((xh, yh), (xm, ym), 'freq')
xmp, ymp = modulation((xh, yh), (xm, ym), 'phase')

# Computing spectrums
xsa, ysa = spectrum(yma)
xsf, ysf = spectrum(ymf)
xsp, ysp = spectrum(ymp)
```

Plotting

```
# Creation of figure and subplots
fig, ((af0, as0), (af2, as2), (af3, as3)) = plt.subplots(figsize=(10, 10), dpi=100, nrows=3, n
fig.subplots_adjust(hspace=0.5)
fig.suptitle('Spectrogram')
signal_axes   = fig.axes[::2]
spectrum_axes = fig.axes[1::2]

# Setting visible intervals
xlim(signal_axes, [(0, 2)])
xlim(spectrum_axes, [(0, 100)])

# Drawing grid
grid(signal_axes)
grid(spectrum_axes)

# Setting y labels
ylabel(signal_axes, 'Amplitude')
ylabel(spectrum_axes, 'Magnitude')

# Setting x labels
xlabel(signal_axes, 'Time (sec)')
xlabel(spectrum_axes, 'Harmonic frequency (Hz)')

# Setting column titles
signal_axes[0].set_title('Modulated Signal')
spectrum_axes[0].set_title('Frequency Spectrogram')

# Plotting
fill_color = (0.121, 0.464, 0.703, 0.39)

draw(signal_axes, [(xma, yma), (xmf, ymf), (xmp, ymp)])
draw(spectrum_axes, [(xsa, abs(ysa)), (xsf, abs(ysf)), (xsp, abs(ysp))], fill='out')
draw(spectrum_axes, [(xsa, abs(ysa)), (xsf, abs(ysf)), (xsp, abs(ysp))], color=fill_color, fil
```

```
<IPython.core.display.Javascript object>
```

Spectrogram


Modulated Signal
Frequency Spectrogram
Amplitude
Time (sec)
Magnitude
Harmonic frequency (Hz)