GYTE
Electronics Engineering

ELEC 331
Electronic Circuits 2

Fall 2014

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HW 11
Questions and Answers

Updated December 26, 2014 - 11:21

Assigned: 20141202

Due: 20141208

Answers Out: 20141209

Late Due: 20141215

Contents

Amplitude Modulation and Envelopes — Sobot 9.1

9.1. For this problem, use these four single-tone signals:
$S_1 = V_1 \sin(\omega_1 t)$, $S_2 = V_2 \sin(\omega_2 t)$, $S_3 = \cos(|\omega_1 - \omega_2|t)$, and $S_4 = \cos((\omega_1 + \omega_2)t)$.
Assuming $f_1 = 1\,\text{MHz}$, $f_2 = 20\,\text{MHz}$, $V_1 = 2$ V, and $V_2 = 3$ V, do the following:

(a) Find an expression for $S = S_1 S_2$. Using graphing software of your choice, plot S, $(V_1 V_2)S_1$, and $-(V_1 V_2)S_1$ in the same window. Observe the relative relationships between these signals.
(b) Plot $S_o = 1/2 \cdot (V_1 V_2) \cdot (S_3 - S_4)$. What can you conclude?

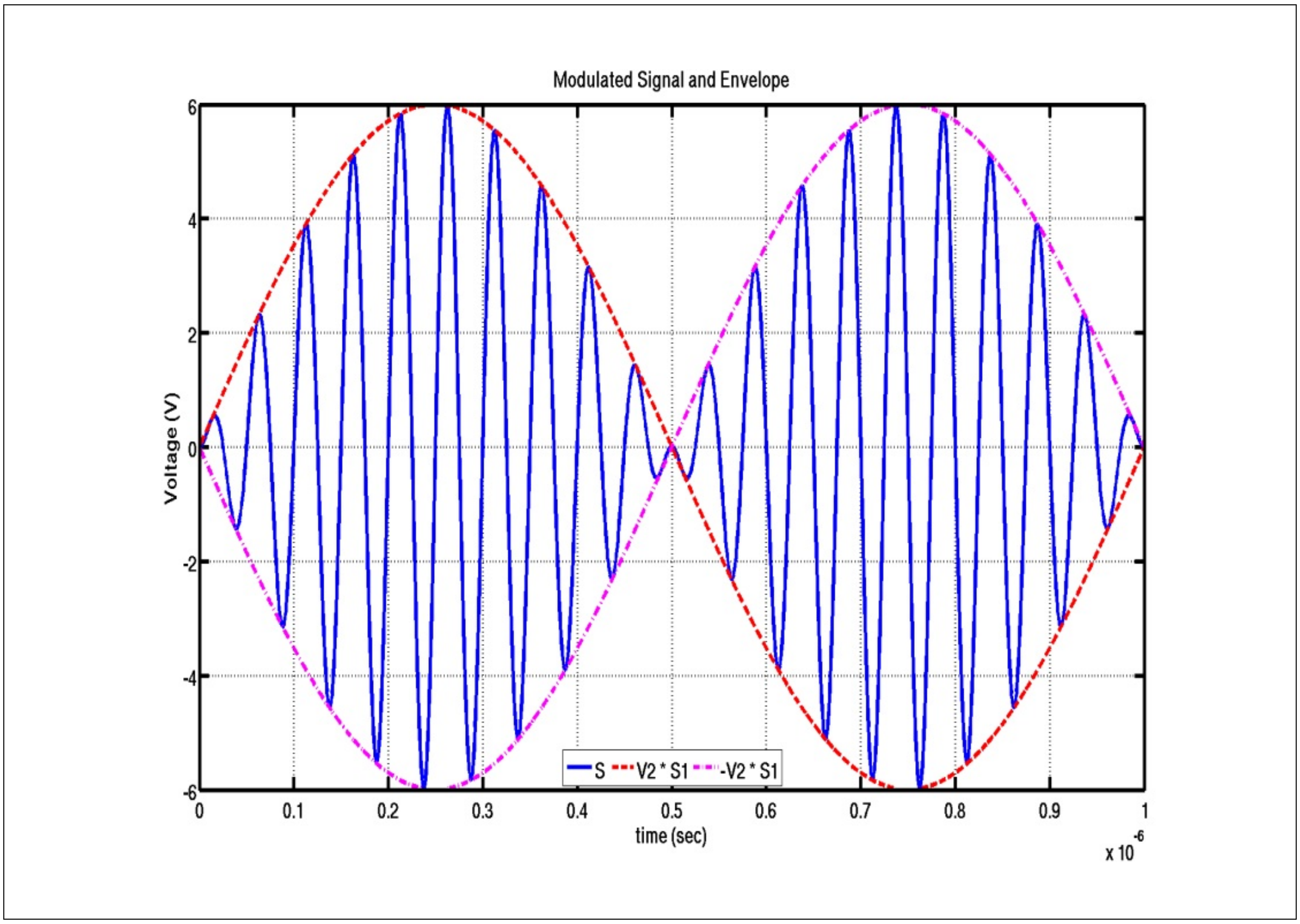
Notes: None.

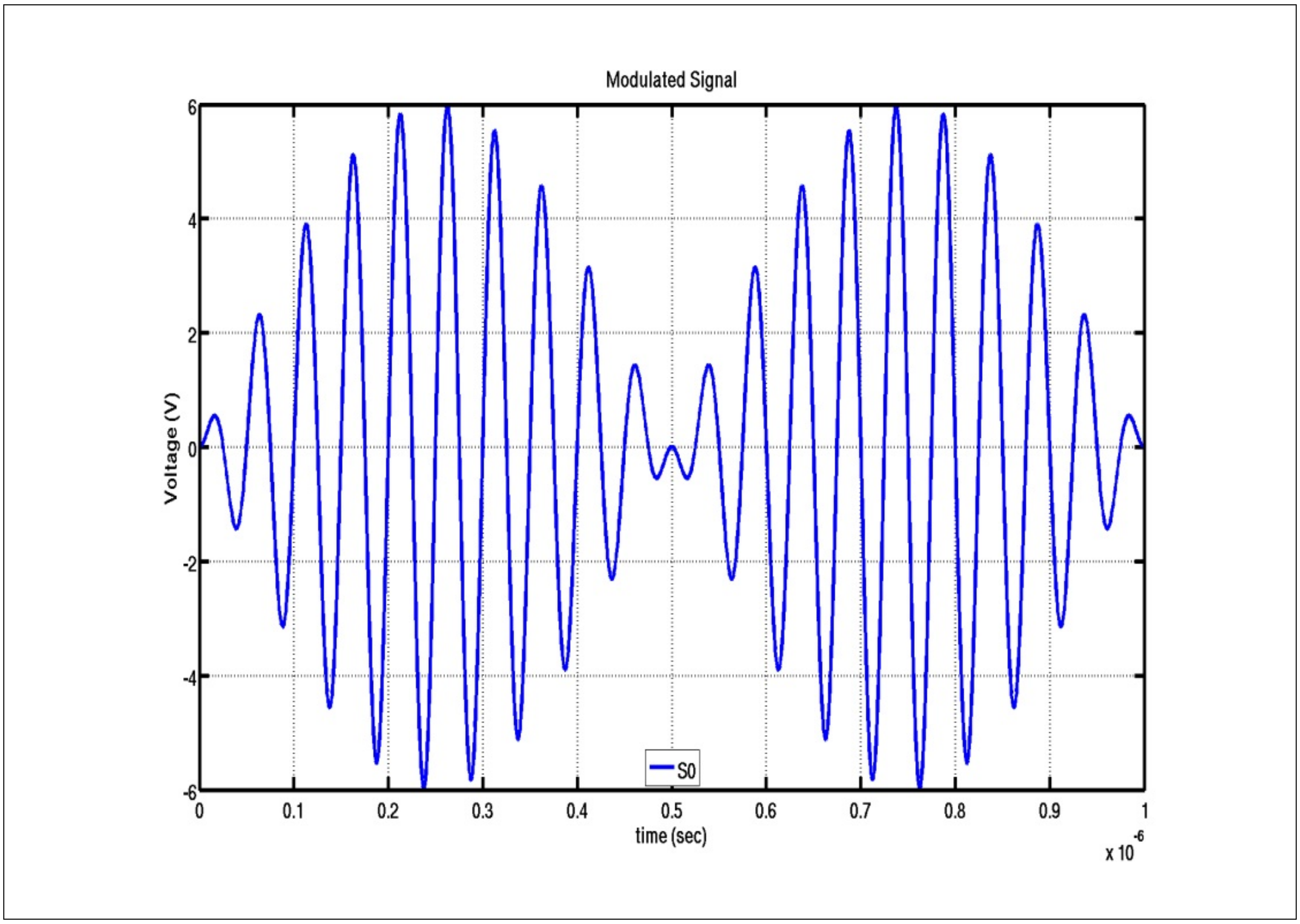
Additional Tasks: There is a mistake in the expressions involved in this question, find it and correct it before solving the question.

Necessary Knowledge and Skills: Amplitude modulation, signal multiplication, ideal mixing operation, time-domain signals, envelopes.

```
!cl .

close all
clear classes
clear all

% parameters
V1 = 2;
V2 = 3;

f1 = 1e6;
f2 = 20e6;

w1 = 2*pi*f1;
w2 = 2*pi*f2;

N = 20*100;
t = [0:N-1] / N * 1 / f1;

% signals
S1 = V1*sin(w1*t);
S2 = V2*sin(w2*t);

S3 = cos( abs(w1-w2) * t );
S4 = cos( (w1+w2) * t );

S = S1.*S2;

S0 = 1/2 * V1 * V2 * ( S3 - S4 );

% plots
myLineWidth = 4;
myFontSize  = 24;

figure(101)
h1 = plot(...
    t , S , ...
    'b' , ...
    'LineWidth' , myLineWidth ...
    );
hold off;

hold on;
h2 = plot(...
    t , V2*S1 , ...
    'r--' , ...
    'LineWidth' , myLineWidth ...
    );
hold off;

hold on;
h3 = plot(...
    t , -V2*S1 , ...
    'm-.' , ...
    'LineWidth' , myLineWidth ...
    );
hold off;

grid on;

set(gca,'units','normalized')
set(gca,'Box','on','FontName','Arial',...
    'FontSize',myFontSize,'FontWeight','bold','LineWidth',4)

xlabel('time (sec)');
ylabel('Voltage (V)');
title('Modulated Signal and Envelope')

legend(...
    [h1 h2 h3] , ...
```

```
    'S' , 'V2 * S1' , '-V2 * S1' , ...
    'Orientation' , 'Horizontal' , ...
    'Location'    , 'South' ...
    );

figure(102)
h4 = plot(...
    t , S0 , ...
    'b', ...
    'LineWidth' , myLineWidth ...
    );
hold off;

grid on;

set(gca,'units','normalized')
set(gca,'Box','on','FontName','Arial',...
    'FontSize',myFontSize,'FontWeight','bold','LineWidth',4)

xlabel('time (sec)');
ylabel('Voltage (V)');
title('Modulated Signal')

legend(...
    h4 , ...
    'S0' , ...
    'Orientation' , 'Horizontal' , ...
    'Location'    , 'South' ...
    );
```


Modulated Signal and Envelope
Voltage (V)
time (sec)
x 10^-6
S
V2 * S1
-V2 * S1
6
4
2
0
-2
-4
-6
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Modulated Signal
Voltage (V)
time (sec)
x 10^-6
S0
6
4
2
0
-2
-4
-6
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

RF, IF, and Image Frequency

Sobot 9.3

9.3. A large number of radio stations transmit their programs at various carrier frequencies. A radio receiver is tuned to receive an AM wave transmitted at a carrier frequency of $f_{RF} = 980\,\text{kHz}$. The LO inside the receiver is set at $f_{LO} = 1{,}435\,\text{kHz}$. Find:

(a) The frequencies coming out of the receiver's mixer.
(b) Which frequency is IF.
(c) The frequency of a radio station which would represent an image frequency to the radio station.
(d) The frequency graph of the frequencies involved.

Notes: None.

Additional Tasks: None.

Necessary Knowledge and Skills: RF, IF, ideal mixing operation, down-conversion, demodulation, image frequency.

Sobot 9.3

a) The mixer outputs two frequencies.

$$f_{RF} + f_{LO} = 980 + 1435$$
$$= 2415 \text{ KHz}$$

$$|f_{RF} - f_{LO}| = 455 \text{ KHz}$$

b) f_{IF} in down-conversion is 455 KHz.

f_{IF} is intermediate frequency

c) The following two frequencies will result in the same f_{IF} when mixer with the signal with f_{LO}:

$$f_{LO} - f_{IF} = 1435 - 455 = 980 \text{ KHz}$$

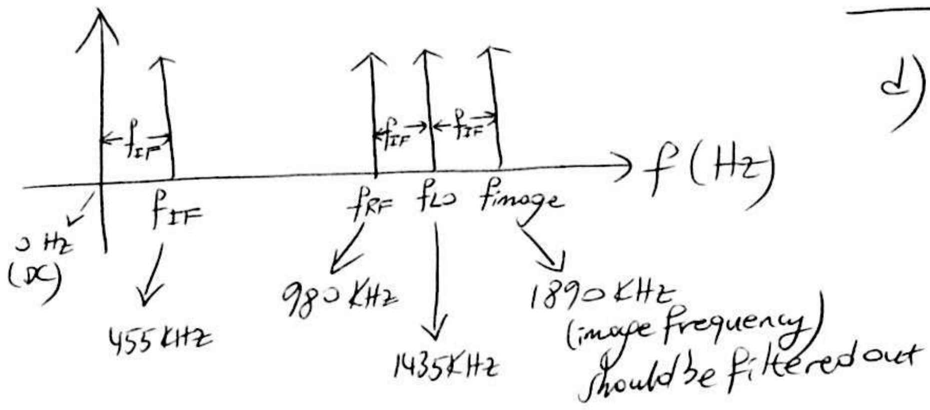
$$\Rightarrow f_{LO} + f_{IF} = 1435 + 455 = 1890 \text{ KHz}$$

this one is the image frequency (should be filtered out before inputting into the mixer.)

① ②

Sol: bot
9.3

d)



(2)
(3)

Q-Factor

Prepare a short report on the Q-factor of LC resonators, on how it relates to bandwidth and signal attenuation.

Notes: None.

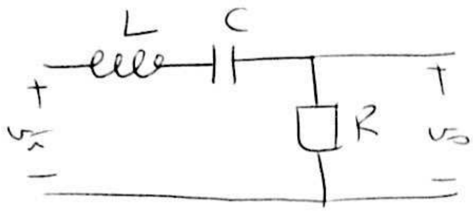
Additional Tasks: None.

Necessary Knowledge and Skills: LC resonators, bandpass filters, bandwidth, attenuation of components at nearby frequencies.

Q-factor of LC resonators

See Rashid Appendix B for a similar discussion

Q-factor of a series LC tank



$$G(s) = \frac{v_o}{v_i} = \frac{R}{R + Ls + \frac{1}{Cs}}$$

$$= \frac{RCs}{LCs^2 + RCs + 1} = \frac{Rs/L}{s^2 + \frac{R}{L}s + \frac{1}{LC}}$$

$$w_o^2 = \frac{1}{LC} \Rightarrow w_o = \frac{1}{\sqrt{LC}}$$

resonant freq

$$G(s) = \frac{2\delta w_o s}{s^2 + 2\delta w_o w + w_o^2}$$

$$2\delta w_o = \frac{R}{L} \Rightarrow 2\delta \frac{1}{\sqrt{LC}} = \frac{R}{L}$$

then $\delta = \frac{R}{2}\sqrt{\frac{C}{L}}$

$$G(jw) = \frac{2\delta w_o \cdot jw}{(w_o^2 - w^2) + 2\delta w_o \cdot jw}$$

 1

Q-factor contin.

$$G(jw)\Big|_{w=w_0} = 1$$

Find the two $-3dB$ frequencies

$$|G(jw)|^2 = \frac{1}{2}$$

$$\frac{(2\delta w_0 w)^2}{(w_0^2 - w^2)^2 + (2\delta w_0 w)^2} = \frac{1}{2}$$

$$(2\delta w_0 w)^2 = (w_0^2 - w^2)^2$$

$$2\delta w_0 w = w_0^2 - w^2$$

$$-2\delta w_0 w = w_0^2 - w^2$$

$$w^2 + 2\delta w_0 w - w_0^2 = 0$$

$$w^2 - 2\delta w_0 w - w_0^2 = 0$$

$$w_L = -\delta w_0 + w_0\sqrt{1+\delta^2}$$

$$w_H = \delta w_0 + w_0\sqrt{1+\delta^2}$$

$$BW = w_H - w_L = 2\delta w_0 = 2\frac{R}{2}\sqrt{\frac{C}{L}}\frac{1}{\sqrt{LC}}$$

$$= \frac{R}{L} \quad (\text{indep of } C)$$

Quality factor $Q = \frac{w_0}{BW} = \frac{1/\sqrt{LC}}{R/L} = \frac{L}{R}\frac{1}{\sqrt{LC}} = \frac{1}{R}\sqrt{\frac{L}{C}}$

(defines how selective the LC resonator is)

2

Attenuation by LC Tank Resonators — Sobot 9.4

9.4. A tuned RF amplifier has an LC tank with $Q = 20$ and it is tuned at RF frequency f_0. Estimate the attenuation of the image signal, if the image frequency is 10% higher than the RF signal.

Notes: None.

Additional Tasks: None.

Necessary Knowledge and Skills: LC tank resonators, Q factor, attenuation of components at nearby frequencies, RF.

Sobot
9.4

Assume that the RLC network is in series.

Else where it was found that

$$G(s) = \frac{Rs/L}{s^2 + \frac{R}{L}s + \frac{1}{LC}}$$

$$w_o = \frac{1}{\sqrt{LC}}$$

$$\left.\begin{aligned} BW &= \frac{R}{L} \\ Q &= \frac{w_o}{BW} \end{aligned}\right\} \quad BW = \frac{R}{L} = \frac{w_o}{Q}$$

Then

$$G(s) = \frac{\frac{w_o}{Q}s}{s^2 + \frac{w_o}{Q}s + w_o^2}$$

$$G(jw) = \frac{jw\frac{w_o}{Q}}{\left(w_o^2 - w^2\right) + jw\frac{w_o}{Q}}$$

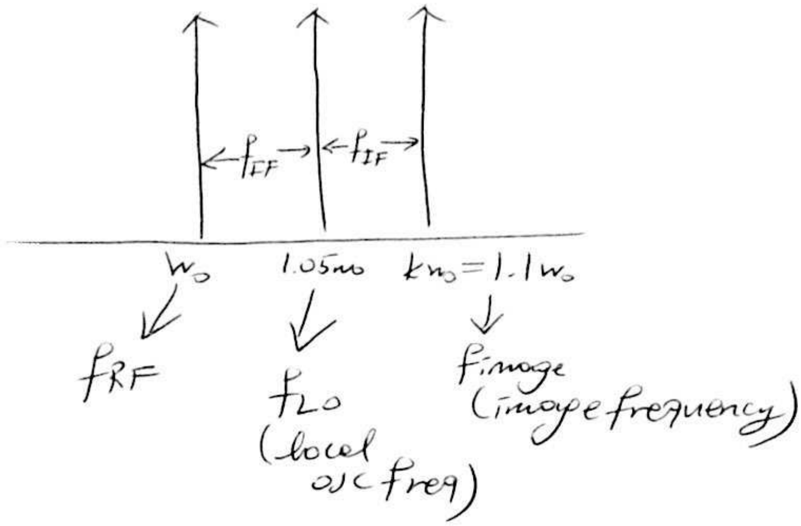
$$\left|G(jw)\right|^2 = \frac{\left(w\frac{w_o}{Q}\right)^2}{\left(w_o^2 - w^2\right)^2 + \left(w\frac{w_o}{Q}\right)^2} = \left(\frac{1}{A}\right)^2$$

where A is the attenuation factor at w
and $w = kw_o$ (a factor k multiplied by w_o)

1

Sbot
9.4
contin-

$$(*)\quad \left|G(jk\omega_0)\right|^2 = \frac{\left(\frac{k}{Q}\right)^2}{(1-k^2)^2+\left(\frac{k}{Q}\right)^2} = \left(\frac{1}{A}\right)^2$$



The LC tank is tuned at w_0.

Before entering the mixer, the image freq component at kw_0 needs to be filtered out with the LC tank of $Q=20$.

in $(*)$ set $k = 1.1$
$Q = 20$

compute A: attenuation factor

then also compute $20\log_{10} A$: attenuation factor in dB

(2)