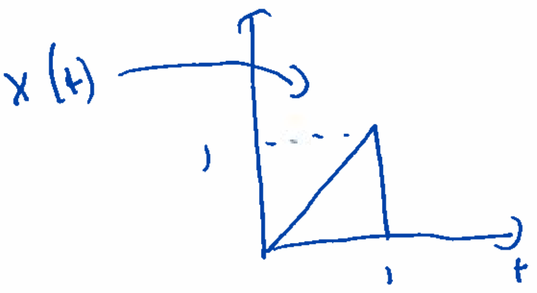
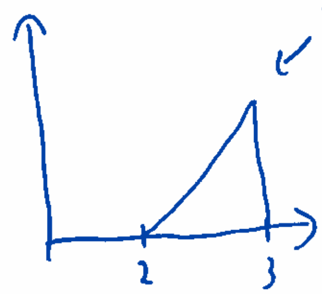
ANSWERS EE2-05 Signals + Linear Systems

QUESTION 1

(a)

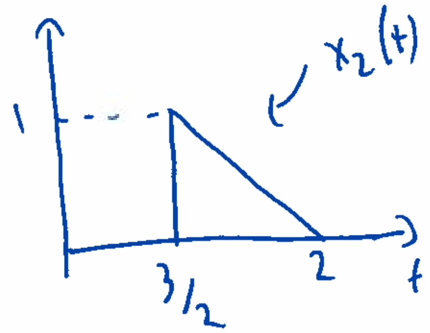


i.



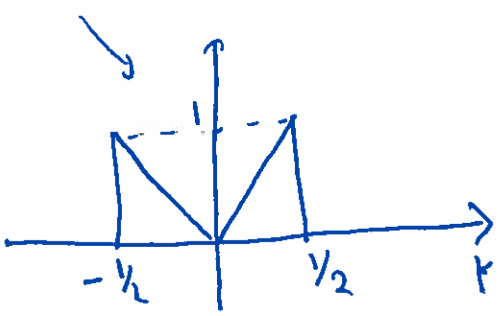
ii.

$x_2(t) = x(-2(t-2))$



iii.

$x_3(t) = x(2t) + x(-2t)$



(b)

i. $y(t) = x(t-2) + x(2-t)$

LET US CHECK LINEARITY

$$x_1(t) \rightarrow y_1(t) = x_1(t-2) + x_1(2-t)$$

$$x_2(t) \rightarrow y_2(t) = x_2(t-2) + x_2(2-t)$$

$$x_3(t) = a x_1(t) + b x_2(t) \rightarrow y_3(t) = a x_1(t-2) + b x_2(t-2) + a x_1(2-t) + b x_2(2-t)$$
$$= a y_1(t) + b y_2(t)$$

HENCE LINEAR

LET US CHECK TIME-INVARIANCE

$$x_1(t) \rightarrow y_1(t) = x_1(t-2) + x_1(2-t)$$

$$x_1(t-t_0) = x_2(t) \rightarrow y_2(t) = x_2(t-2) + x_2(2-t)$$
$$= x_1(t-t_0-2) + x_2(2-t-t_0)$$
$$\neq y_1(t-t_0)$$

NOTE THAT $y_1(t-t_0) = x_1(t-t_0-2) + x_1(2-t+t_0)$

HENCE TIME-VARIANT

ii.

$$y(t) = x(t)\cos 3t$$

THE SYSTEM IS LINEAR

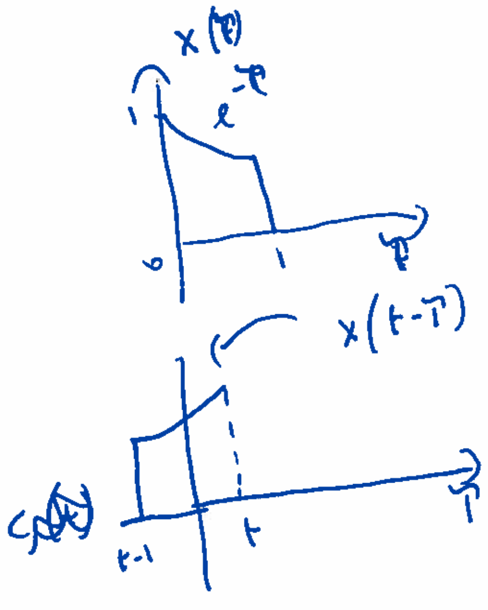
LET US CHECK FOR TIME-INVARIANCE

$$x_1(t) \rightarrow y_1(t) = x_1(t)\cos 3t$$

$$x_2(t) = x_1(t-t_0) \rightarrow y_2(t) = x_1(t-t_0)\cos 3t \neq y_1(t-t_0)$$

HENCE TIME-VARIANT

(c)



HENCE WE HAVE

$$x(t) * x(t) = \begin{cases} 0 & t \leq 0 \\ \int_0^t x(\tau)\,x(t-\tau) & 0 < t \leq 1 \\ \int_{t-1}^1 x(\tau)\,x(t-\tau) & 1 < t \leq 2 \\ 0 & t > 2 \end{cases}$$

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$$\int_0^t x(\tau)\,x(t-\tau)\,d\tau = \int_0^t e^{-\tau}\,e^{-(t-\tau)}\,d\tau = t\,e^{-t} \qquad 0 \le t \le 1$$

$$\int_{t-1}^1 x(\tau)\,x(t-\tau)\,d\tau = \int_{t-1}^1 e^{-\tau}\,e^{-(t-\tau)}\,d\tau = (2-t)\,e^{-t} \qquad 1 < t \le 2$$

HENCE

$$x(t) * x(t) = \begin{cases} 0 & t \le 0 \\ t\,e^{-t} & 0 < t \le 1 \\ (2-t)\,e^{-t} & 1 < t \le 2 \\ 0 & t > 2 \end{cases}$$

(d)

$$y(t) = x(t-1) + x(-(t+1))$$

USING SHIFTING AND SCALING PROPERTY OF THE FT YEALDS:

$$Y(\omega) = X(\omega)\, e^{-jw} + X(-\omega)\, e^{jw}$$

$$= \frac{1}{w^2}\left(1 - jw - e^{-jw} + 1 + jw - e^{jw}\right)$$

$$= \frac{1}{w^2}\left(2 - e^{jw} - e^{-jw}\right) = 4\,\frac{\left(e^{j\frac{w}{2}} - e^{-j\frac{w}{2}}\right)^2}{\left(j\frac{w}{2}\right)^2}$$

$$= \left(\text{SINC}\,\frac{w}{2}\right)^2$$

(e)

i. CHARACTERISTIC POLYNOMIAL

$$s^2 + 4s + 3$$

CHARACTERISTIC ROOTS

$$s_{1,2} = -2 \pm \sqrt{4-3} = \begin{cases} -1 \\ -3 \end{cases}$$

CHARACTERISTIC MODES

$$c_1 e^{-t} + c_2 e^{-3t}$$

ii.

$$y(t) = c_1 e^{-t} + c_2 e^{-3t} \qquad t \geq 0$$

$$y(0) = c_1 + c_2 = 0$$
$$\Rightarrow \quad c_1 = 1$$
$$\dot{y}(0) = -c_1 - 3c_2 = 2 \qquad c_2 = -1$$

HENCE

$$y(t) = \left(e^{-t} - e^{-3t}\right) u(t)$$

iii.

$$(s^2 + 4s + 3) Y(s) = X(s)$$

SINCE $X(s) = \frac{1}{s}$

WE HAVE THAT

$$Y(s) = \frac{1}{s(s+1)(s+3)} = \frac{A}{s} + \frac{B}{s+1} + \frac{C}{s+3}$$

USING COVERING METHOD WE FIND THAT

$$Y(s) = \frac{1}{3s} - \frac{1}{2(s+1)} + \frac{1}{6(s+3)}$$

$$\Updownarrow$$

$$y(t) = \left(\frac{1}{3} - \frac{1}{2} e^{-t} + \frac{1}{6} e^{-3t}\right) u(t)$$

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iv.

BECAUSE OF LINEARITY THE TOTAL ANSWER IS THE SUM OF THE RESPONSES IN PART ii. AND iii. THAT IS

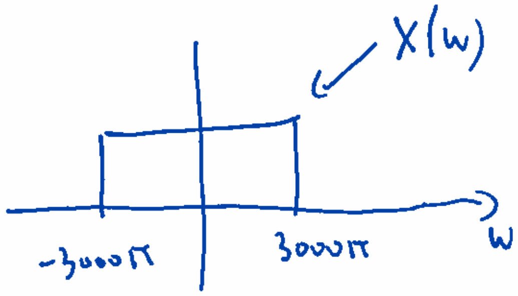
$$y_{TOT}(t) = \left(e^{-t} - e^{-3t}\right)u(t) + \left(\frac{1}{3} - \frac{1}{2}e^{-t} + \frac{1}{6}e^{-3t}\right)u(t)$$

$$= \left(\frac{1}{3} + \frac{1}{2}e^{-t} - \frac{5}{6}e^{-3t}\right)u(t)$$

(8) USING FOURIER TABLES

i.

$$3000\,\mathrm{sinc}(3000\pi t) \iff \mathrm{rect}\left(\frac{w}{6000\pi}\right)$$



ii)

NYQUIST RATE FOR $x(t)$: $f_s = 2 \cdot \frac{3000\pi}{2\pi} = 3\,kHz$

(9)

$$\frac{X(z)}{z} = \frac{z+1}{z^2-5z+4} = \frac{z+1}{(z-4)(z-1)} = \frac{A}{z-4} + \frac{B}{z-1}$$

$$= \frac{5}{3}\frac{1}{z-4} - \frac{2}{3}\frac{1}{z-1}$$

HENCE

$$X(z) = \frac{5}{3}\frac{z}{z-4} - \frac{2}{3}\frac{z}{z-1}$$

USING Z-TRANSFORM TABLE WE GET

$$x[n] = \left(\frac{5}{3}(4)^n - \frac{2}{3}\right)u[n]$$

QUESTION 2

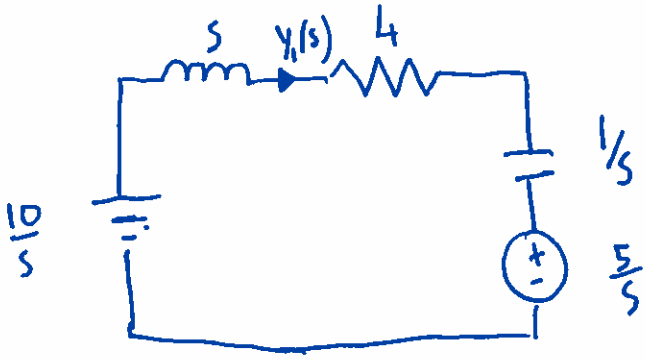
(a)

IN STEADY STATE THE INDUCTOR IS A SHORT CIRCUIT AND THE CAPACITOR IS AN OPEN CIRCUIT THEREFORE

$$y_1(0^-) = 0$$

$$v_c(0^-) = 5V$$

(b) THE EQUIVALENT CIRCUIT IN THE LAPLACE DOMAIN IS:



THUS THE LOOP EQUATION IN THE LAPLACE DOMAIN IS:

$$\frac{10}{s} = sY_1(s) + 4Y_1(s) + \frac{Y_1(s)}{s} + \frac{5}{s} \; ;$$

$$Y_1(s)(s^2+4s+1) = 5 \; ;$$

$$Y_1(s) = \frac{5}{s^2+4s+1}$$

(c) $Y_1(s) = \dfrac{5}{s^2+4s+1} = \dfrac{5}{(s+2-\sqrt{3})(s+2+\sqrt{3})} = \dfrac{5}{2\sqrt{3}}\left(\dfrac{1}{s+2-\sqrt{3}} - \dfrac{1}{s+2+\sqrt{3}}\right)$

USING THE FACT THAT

$$e^{-\lambda t}u(t) \Longleftrightarrow \frac{1}{s+\lambda}$$

WE OBTAIN

$$y_1(t) = \frac{5}{2\sqrt{3}}\left(e^{-(2-\sqrt{3})t} - e^{-(2+\sqrt{3})t}\right)u(t)$$

QUESTION 3

(a)

IF WE DENOTE WITH $F(s)$ THE OUTPUT OF THE FEEDBACK SYSTEM WE HAVE THAT

$$Y(s) = (s+2)\,F(s)$$

$$F(s) = K\left(X(s) - (s+a)^2 F(s)\right)$$

THEREFORE

$$F(s) = \frac{K}{1+K(s+a)^2}\,X(s)$$

AND

$$Y(s) = \frac{K(s+2)}{1+K(s+a)^2}\,X(s)$$

THE TRANSFER FUNCTION IS:

$$H(s) = \frac{Y(s)}{Y(s)} = \frac{K(s+2)}{1+K(s+a)^2}$$

(b) USING FINAL VALUE THEOREM WE HAVE THAT

$$y(\infty) = \lim_{t\to\infty} y(t) = \lim_{s\to 0} sY(s)$$

SINCE $X(s) = 1/s$ AND $K=1$

WE HAVE THAT

$$y(\infty) = \lim_{s \to 0} \frac{s+2}{1+(s+a)^2} = \frac{2}{1+a^2}$$

WE WANT $y(\infty) = \frac{2}{5}$ WITH $a > 0$ $\Rightarrow$ $a = 2$.

(c) i.

$$Y(s) = \frac{s+2}{1+(s+1)^2} \cdot \frac{1}{s}$$

$$= \frac{C}{s} + \frac{As+B}{s^2+2s+2}$$

MULTIPLY BOTH SIDES BY s AND SET $s=0$

$$1 = C$$

THEN MULTIPLY BOTH SIDES BY s AND LET $s \to \infty$

$$0 = 1 + A \Rightarrow A = -1$$

FINALLY SET $s = -1$ TO FIND

$$B = -1$$

WE HAVE

$$Y(s) = \frac{1}{s} - \frac{s+1}{(s+1)^2+1}$$

USING LAPLACE TABLES WE OBTAIN

$$y(t) = u(t) - e^{-t}\cos t \, u(t)$$

ii.

FOR $t \geq 0$

$$y(t) = 1 - e^{-t}\cos t$$

$$\frac{dy}{dt} = e^{-t}\cos t + e^{-t}\sin t = 0$$

$$\Rightarrow e^{-t}(\cos t + \sin t) = 0$$

$$\Rightarrow \cos t = -\sin t \Rightarrow \tan t = -1$$

THIS HAPPENS AT $t = \pi/4 + \pi/2$.

THE OTHER POINT ARE EITHER LOCAL MINIMA OR LOCAL MAXIMA BECAUSE OF THE TERM e^{-t} IN THE EXPRESSION OF $y(t)$.