Q1

HW 1 EMC Comp.

$$\cancel{\text{Ant AF} = \frac{E}{V} = \frac{1\,V/m}{1.5\,V} = \frac{2}{3}\,m^{-1}}$$

Q1

a)

$$P_{dBm,\,V_{ant}} = -93.5\,dBm + P_{dBm,\,cable}$$

$$= \quad + \left(200\,ft \cdot 8\,\frac{dB}{100\,ft}\right)$$

$$= \quad + \left(\frac{200\,ft}{100\,ft} \cdot 8\,dB\right)$$

$$= \quad + (2 \cdot 8\,dB)$$

$$= -93.5\,dBm + 16\,dB$$

$$P_{dBm,\,V_{ant}} = -77.5\,dBm$$

$$P_W = 10^{(P_{dBm}/10)} \cdot 10^{-3}\,W$$

$$= 10^{(-77.5/10)} \cdot 10^{-3}\,W$$

$$= 10^{-7.75} \cdot 10^{-3}\,W$$

$$P_{W,ant} = 10^{-10.75}\,W$$

$$V_{ant} = \cancel{\sqrt{\frac{P_{ant}}{R_{Rx}}}} = \sqrt{P_{ant} \cdot R_X}$$

$$= \sqrt{10^{-10.75} \cdot 50}$$

$$= \sqrt{10^{-10.75} \cdot 5 \cdot 10^{1}}$$

$$= \sqrt{5 \cdot 10^{-9.75}}$$

$$\approx .0000298$$

$$\approx \cancel{2.98}\ 29.8\,\mu V$$

$$V_{\substack{RX,\\ base}}, dBmV = 20 \log \left(\frac{29.8\,\mu V}{10^{-3}} \right)$$

$$= 20 \log \left([29.8 \cdot 10^{-6}] / 10^{-3} \right)$$

$$= 20 \log \left(29.8 \cdot 10^{-3} \right)$$

$$\cancel{20 \log (29.8}$$

$$= 20 \log \left(2.98 \cdot 10^{-2} \right)$$

$$= 20 \left(\log (2.98) + (-2) \right)$$

$$= 20 (-1.53)$$

$$\boxed{V_{\substack{RX,\\ base}}, dB_{m}V = -30.51\ dB_{m}V}$$

b) Convert to volts to find Electric Field strength

~~$V_{a,\mu V} =$~~ $V_a = 29.8\,\mu V$

$AF^{-1} = \frac{1.5\,V'}{1\,V/m}$ $\qquad AF = \frac{E}{V}$

$E = (AF^{-1})\,V$

~~$E = (1.5\,m^{-1})(29.8\,\mu V)$~~

$E = V/AF$

$E = 29.8\,\mu V / 1.5$

$E = 17.8\overline{66}\ \mu V/m$

$E_{dB\mu V} =$ ~~$= 34.04$~~ $=$

~~$20\log_{10}\left(\frac{17.866}{10^{-3}}\right)$~~

~~$20(\log_{10}(19.866 \cdot 10^{-3})$~~

~~$20\log_{10}(1.7866 \cdot 10^{-2})$~~

~~$20(.298 - 2)$~~

~~-34.94~~

$E_{dB\mu V} = 25.96\ dB\mu V/m$ $\qquad 20\log_{10}(19.866)$

Moving Class B from 3m to 20m

$20\log_{10}(3/20) \approx -16.5\,dB$

Class B @ 220 MHz @ 3m

$46\ dB\mu V/m$

Becomes @ 220 MHz @ 20m

29.5 ~~30~~ $dB\mu V/m$

Passes FCC limits

$\boxed{\begin{array}{l} 25.76\ dB\mu V/m < 29.5\ dB\mu V/m \\ \text{Complies by} \sim 3.5\ dB\mu V/m \end{array}}$

CISPR Class B @ 10m

30-230 MHz → ~~dBμV/m~~ 30 dBμV/m

Scale to 20 m

$$20 \log_{10}\left(\frac{10}{20}\right) = -6.02\ dB$$

CISPR 32 Class B @ 20 m

$$30\ dB\mu V/m - 6.02\ dB = 24\ dB\mu V/m$$

Fails CISPR 32 limits

$\boxed{25.96\ dB\mu V/m > 24\ dB\mu V/m}$

$\boxed{\cancel{\text{Complie}}\ \text{Fails by} \sim 2\ dB\mu V/m}$

Q2

HW1 EMC Comp.

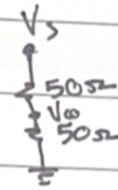
Q2 ALL @ 100 MHz

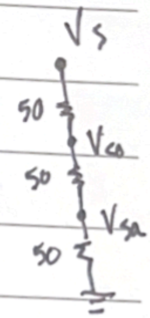
a) $V_{SA} = 56.5\ dB\mu V$

b) $V_{60} = \cancel{53.}\ 56.5\ dB\mu V + \left(200/100\ ft \cdot 4.5\ dB\right)$

$= 56.5\ dB\mu V + 9\ dB$

$V_{60,dB} = \cancel{V_{60}} = 65.5\ dB\mu V$





~~$V_{60} = 20 \log_{10}(65.5$~~

~~$V_{dB} = 20 \log_{10}\left(\frac{V_m}{10^3}\right)$~~

~~$\frac{V_{dB}}{20} = \log_{10}\left(\frac{\mu V}{1000}\right)$~~ $= \log(\mu V)$ ~~$- \log(1000)$~~

~~$10^{(V_{dB}/20)} = \frac{\mu V}{10^3}$~~

~~$10^3\left(10^{(V_{dB}/20)}\right)$~~ $= \mu V$

$V_{60} = 1.93\ mV$

~~$V_S = 2V_{60}$~~ V_S to GND is a voltage divider,

$V_S = 2V_0$

$V_S = 2(1.73\ mV)$

$V_S = 3.86\ mV$ $\qquad 20 \log_{10}(3.86)$

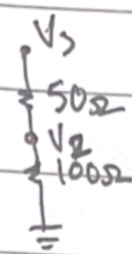
~~$V_{S,dB} = 11.7316\ dBmV$~~

~~$V_{S,dB} = 43\ \ 48.27\ dB\mu V$~~

$V_{S,dB\mu V} = 20 \log_{10}\left(\frac{3.86E{-3}}{1E{-6}}\right)$

$V_{S,dB\mu V} = 71.73\ dB\mu V$

$V_s = 3.86\,\cancel{\mu V}\ mV$



$\cancel{V_2 = \frac{100}{150}}$

$V_2 = \left(\frac{100}{100+50}\right) V_s$

$V_2 = \left(\frac{2}{3}\right) V_s$

$V_2 = 2.57\overline{3}\ mV$

$V_{2,dB} = 20 \log_{10}\left(\frac{2.573 \cdot 10^{-3}}{10^{-6}}\right)$

$\cancel{= 68\ dB\mu V}$

$\boxed{V_{2,dB} = 68.2\ dB\mu V}$

$\cancel{2-b)}$

b) $P = V^2/R$

$\cancel{P = (3.86\ mV)^2/150}$

$\cancel{P = 99.3\ nW}$

$\cancel{P_{dBm} = 10 \log_{10}\left(\frac{99.3 \cdot 10^{-9}}{10^{-3}}\right)}$

$\cancel{P_{dBm} = -40.03\ dBm}$

$P = (2.573\ mV)^2 / 100\,\Omega$

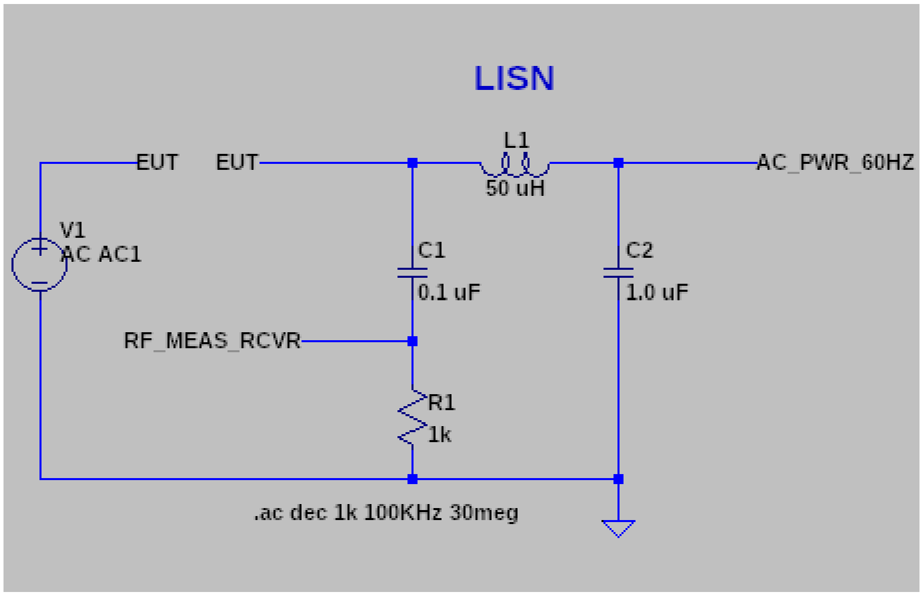
$P = 66.2\ nW$

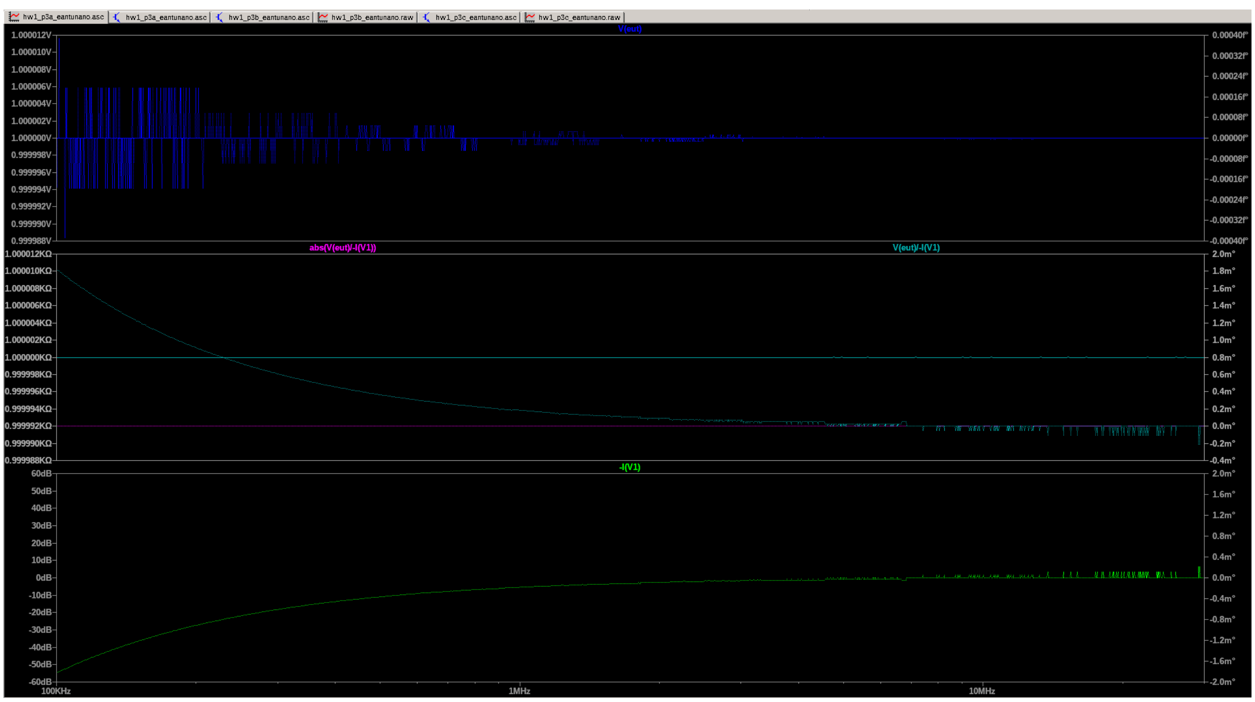
$P_{dBm} = 10 \log_{10}\left(\frac{66.2 \cdot 10^{-9}}{10^{-3}}\right)$

$\boxed{P_{dBm} = -41.79\ dBm}$

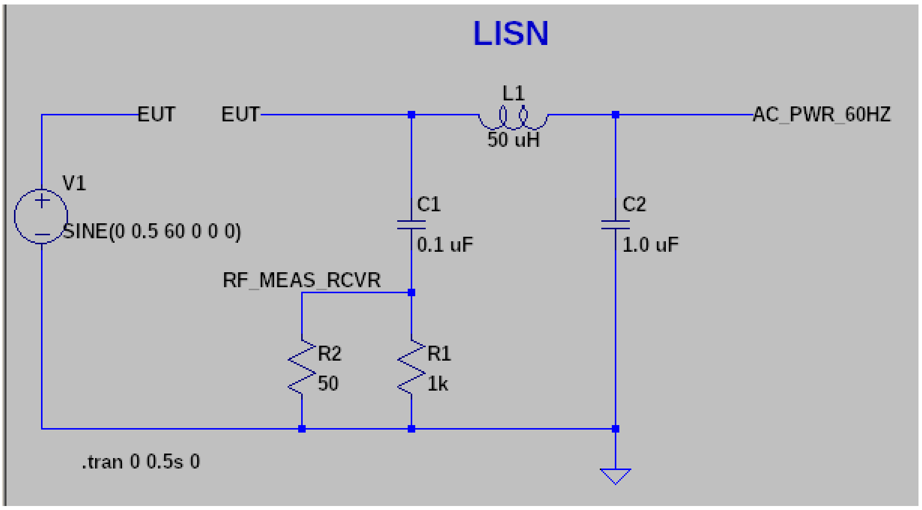
Q3

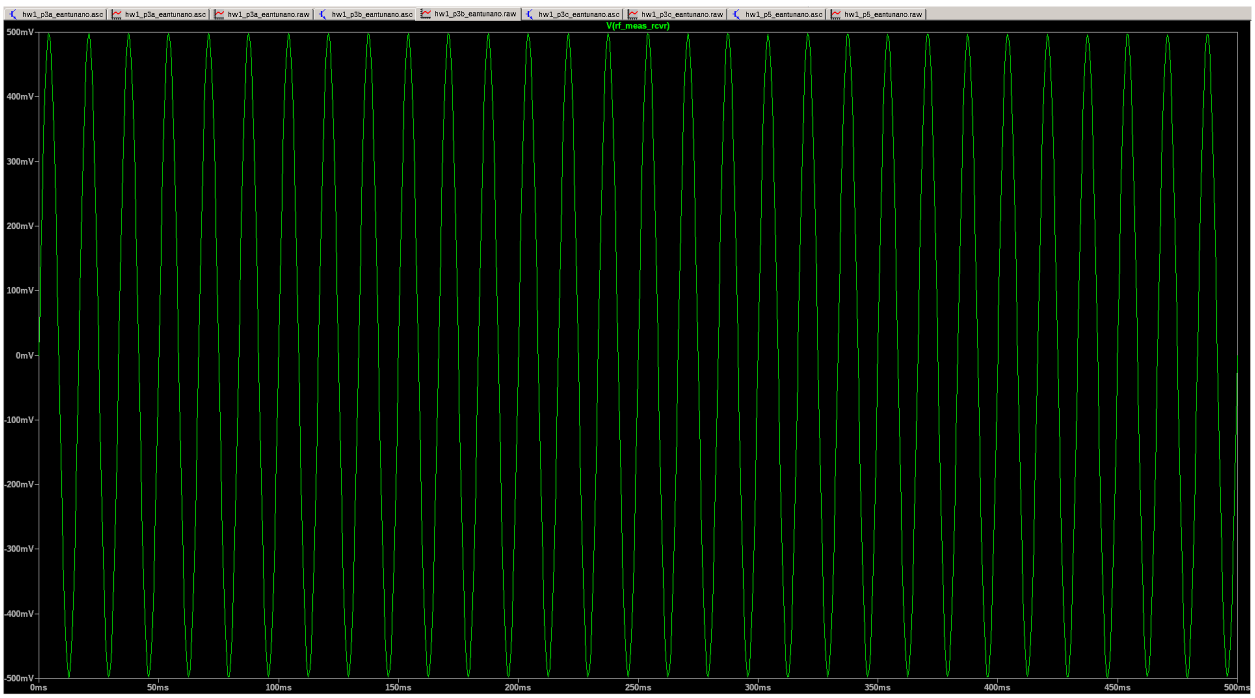
Q3, part a:



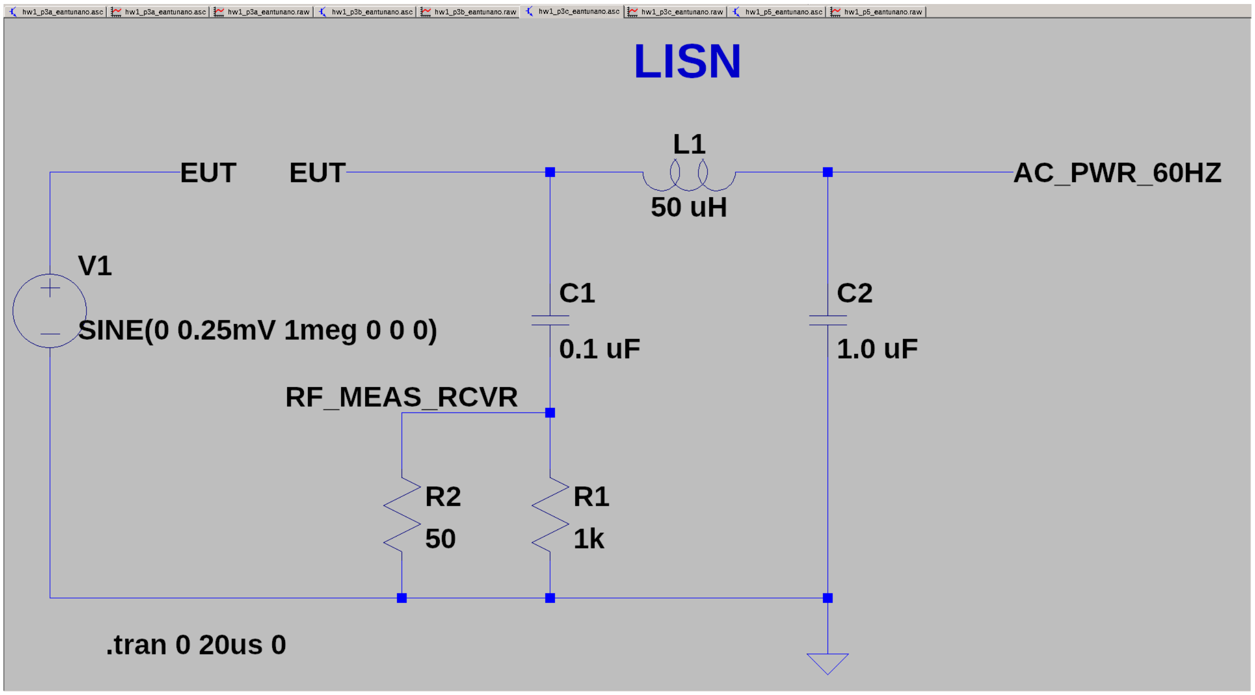


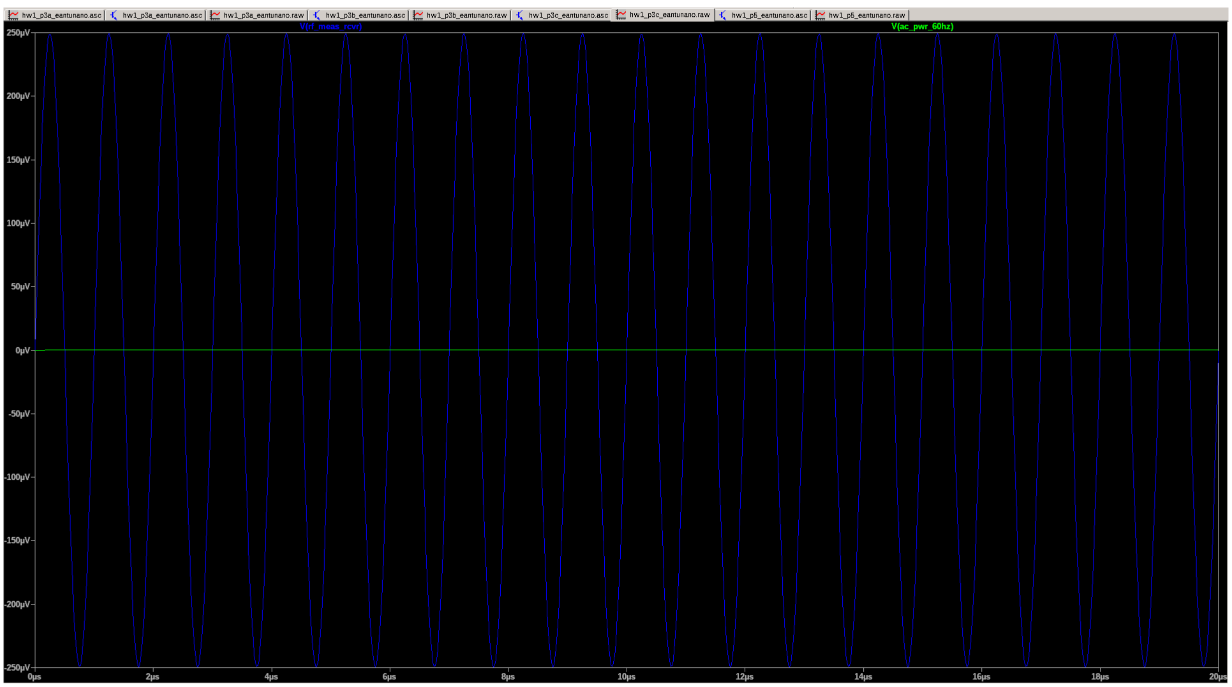
Q3, part b


LISN
EUT
EUT
L1
50 uH
AC_PWR_60HZ
V1
SINE(0 0.5 60 0 0 0)
C1
0.1 uF
C2
1.0 uF
RF_MEAS_RCVR
R2
50
R1
1k
.tran 0 0.5s 0


V(rf_meas_rcvr)
500mV
400mV
300mV
200mV
100mV
0mV
-100mV
-200mV
-300mV
-400mV
-500mV
0ms
50ms
100ms
150ms
200ms
250ms
300ms
350ms
400ms
450ms
500ms

Q3, part c


LISN
EUT
EUT
L1
50 uH
AC_PWR_60HZ
V1
SINE(0 0.25mV 1meg 0 0 0)
C1
0.1 uF
C2
1.0 uF
RF_MEAS_RCVR
R2
50
R1
1k
.tran 0 20us 0


V(ac_pwr_60hz)
250µV
200µV
150µV
100µV
50µV
0µV
-50µV
-100µV
-150µV
-200µV
-250µV
0µs
2µs
4µs
6µs
8µs
10µs
12µs
14µs
16µs
18µs
20µs

Q4

Analytical Solution

First solve for line equation f(x),

$$\frac{x - x_1}{x_2 - x_1} = \frac{y - y_1}{y_2 - y_1}$$

$$\frac{x - 0}{0.5 - 0} = \frac{y - 1}{0 - 1}$$

$$\frac{x}{0.5} = \frac{y - 1}{-1}$$

$$2x = -y + 1$$

$$-y = 2x - 1$$

$$y = -2x + 1$$

$$f(x) = \begin{cases} -2x + 1 & 0 < t \leq \frac{T}{2} \\ 0 & \frac{T}{2} \leq t < T \end{cases}$$

Solve for a_0,

$$a_0 = \frac{1}{T} \int_0^L f(x)\,dx$$

$$= \frac{1}{1} \int_0^{2\tau} f(x)\,dx$$

$$= \int_0^1 f(x)\,dx$$

$$a_0 = \int_0^{0.5} f(x)\,dx$$

$$a_0 = \int_0^{0.5} -2x+1 \; dx \Big]$$

$$a_0 = -\int_0^{0.5} 2x + \int_0^{0.5} 1 \; dx$$

$$= -x^2\Big|_0^{0.5} + x\Big|_0^{0.5}$$

$$= -(0.5^2 - 0^2) + (0.5 - 0)$$

$$= -(0.25) + 0.5$$

$$a_0 = 0.25$$

Solve for a_n,

$$a_n = \frac{2}{1} \int_0^{0.5} f(x)\cos(n\omega_0 x)\,dx \; ; \; \omega_0 = \frac{2\pi}{T} = 2\pi$$

$$= 2 \int_0^{0.5} (-2x+1)\cos(2\pi n x)$$

integration by parts,

$$\int u v\,dx \rightarrow u\int v\,dx - \int u'\left(\int v\,dx\right)dx$$

$$= 2\left[(-2x+1)\left(\frac{\sin(2\pi n x)}{2\pi n}\right)\Big|_0^{0.5} - \left(\left(\int_0^{0.5} -2\,dx\right)\left(\frac{\sin(2\pi n x)}{2\pi n}\,dx\right)\right)\right]$$

$$= 2\left[\left((\cancel{-2(0.5)+1})^{0}(\quad) - (1)\left(\cancel{\frac{\sin(0)}{2\pi n}}^{0}\right)\right) - \left(-\frac{1}{\pi n}\int_0^{0.5} \sin(2\pi n x)\,dx\right)\right]$$

$$= 2\left[\frac{1}{\pi n} \; \frac{-\cos(2\pi n x)}{2\pi n}\Big|_0^{0.5}\right]$$

$$a_n = -\frac{1}{\pi^2 n^2} \; \cos(\pi n) - \cos(0) \rightarrow \text{either } -2\,(n\text{-odd}) \text{ or } 0\,(n\text{-even})$$

$$a_n = \begin{cases} 0, & n \text{ is even} \\ \frac{2}{\pi^2 n^2}, & n \text{ is odd} \end{cases}$$

Solve for b_n,

$$b_n = \frac{2}{1}\int_0^{0.5} f(x)\sin(n\omega_0 x) \; ; \omega_0 = \frac{2\pi}{T} = 2\pi$$

$$b_n = 2\int_0^{0.5} (-2x+1)\sin(2\pi n x)\,dx$$

integration by parts ...

$$b_n = 2\left[\left((-2x+1)\left(-\frac{\cos(2\pi n x)}{2\pi n}dx\right)\Big|_0^{0.5}\right) - \left(\left(\int_0^{0.5} -2\,dx\right)\left(-\frac{\cos(2\pi n x)}{2\pi n}dx\right)\right)\right]$$

$$b_n = 2\left[\cancel{(-2(0.5)+1)}^{0}\frac{\cos(2\pi(0.5)n)}{2\pi n} - (1)\left(-\frac{\cos(0)}{2\pi n}\right)\right] - \left(\frac{1}{\pi n}\int_0^{0.5}\cos(2\pi n x)\,dx\right)\Big]$$

$$b_n = 2\left[\left(\frac{1}{2\pi n}\right) - \frac{1}{\pi n}\left(\frac{\sin(2\pi n x)}{2\pi n}\Big|_0^{0.5}\right)\right]$$

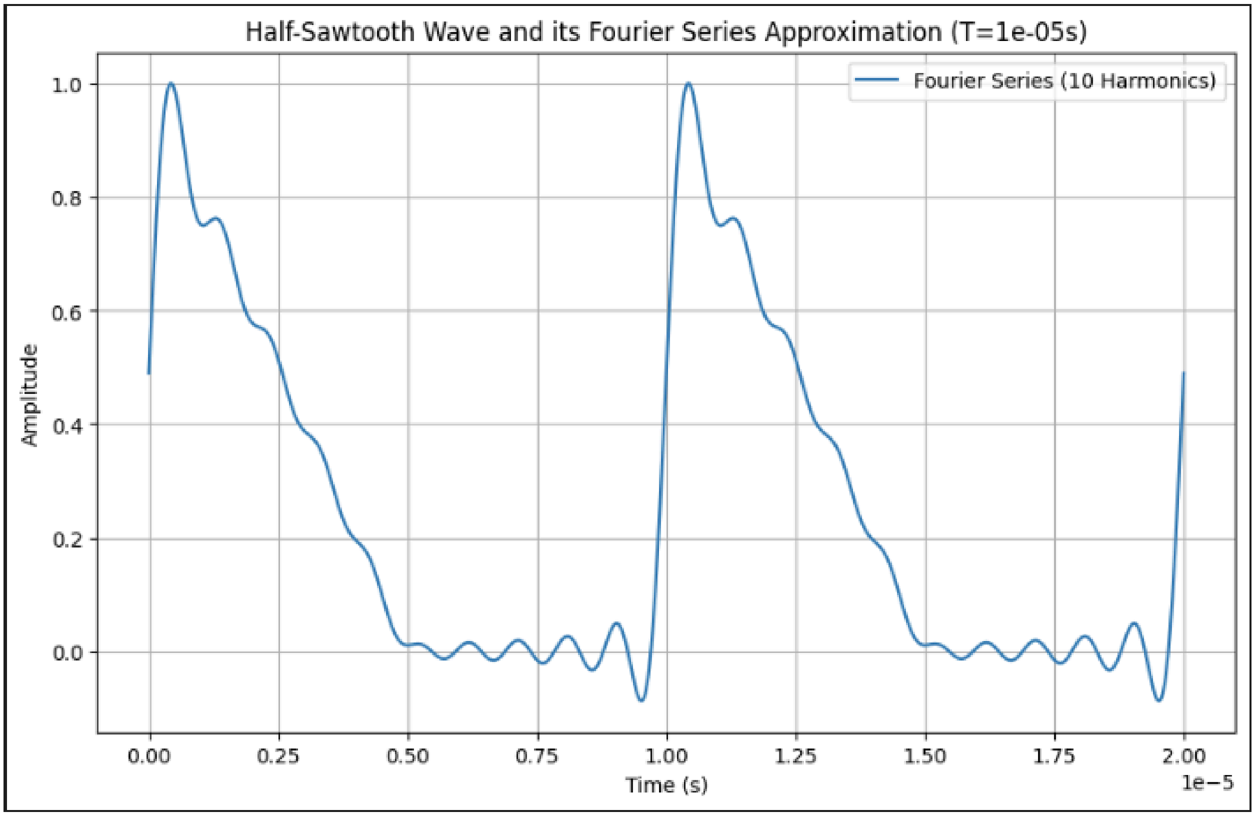
$$b_n = \frac{1}{\pi n} - \left(\frac{1}{\pi^2 n^2}\left(\cancel{\sin(\pi n)}^{0} - \cancel{\sin(0)}^{0}\right)\right)$$

$$b_n = \frac{1}{\pi n}$$

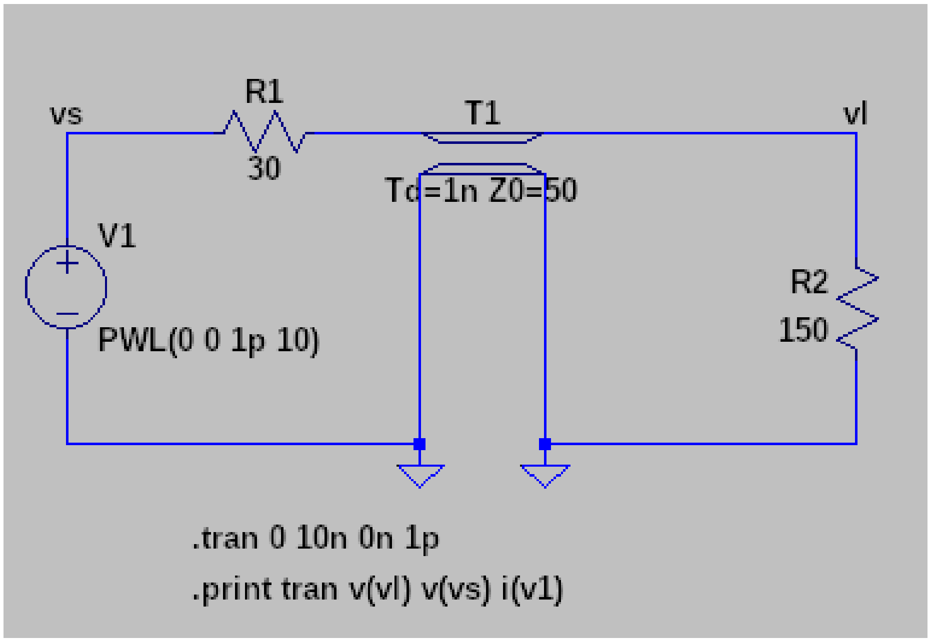
Put all terms together for fourier series expansion,

$$\boxed{f(x) = 0.25 + \sum_{n=1}^{10} a_n + \sum_{n=1}^{10}\frac{1}{\pi n} \quad ; \quad a_n = \begin{cases} 0, & n \text{ is even} \\ \frac{2}{\pi^2 n^2}, & n \text{ is odd}\end{cases}}$$

Github Page:
https://github.com/enriquea02/uw/blob/main/eep579_electromagnetic_compatibility/Assignments/hw1/hw1.ipynb


Half-Sawtooth Wave and its Fourier Series Approximation (T=1e-05s)
Fourier Series (10 Harmonics)
Amplitude
Time (s)
1e−5
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
0.0
0.2
0.4
0.6
0.8
1.0

Q5



Voltage Supply, Load voltage, Current

Solve the time zero voltage and current and reflection coefficient values,

$$V(0,t) = \frac{Z_c}{R_s+Z_c} V_s(t) = \frac{50}{30+50}(10) = 6.25\,V$$

$$I(0,t) = \frac{V_s(t)}{R_s+Z_c} = \frac{10}{80} = 125\,mA$$

Source Reflection Coefficient $\Gamma_S = \frac{30-50}{30+50} = \frac{-20}{80} = -0.25$

Load Reflection Coefficient $\Gamma_L = \frac{150-50}{150+50} = \frac{100}{200} = 0.5$

$$v = 3\times10^8\,m/s \rightarrow v = \frac{3\times10^{8}\,\cancel{m}}{\cancel{s}} \cdot \left(\frac{\cancel{s}}{10^9\,ns}\right)\left(\frac{10^2\,cm}{\cancel{m}}\right) = 3\times10^1\,cm/ns = 30\,cm/ns$$

Voltage reflection values

@ 1ns, $V_{L1} = 6.25 \cdot 6.25\,\Gamma_L = 6.25 + 3.125 = 7.375\,V$

$V_{r1} = 3.125\,V$

@ 2ns, $V_{S1} = 6.25 + V_{r1} + (V_{r1} \cdot \Gamma_s) = 9.375 - 0.78125 = 8.59375\,V$

@ 3ns, $V_{r2} = (V_{r1})(\Gamma_s)(\Gamma_L) = -390\,mV$

$V_{L2} = V_{S1} + V_{r2} = 8.203125\,V$

@ 4ns, $V_{S2} = V_{L2} + (V_{r2} \cdot \Gamma_s) = 8.3\,V$

@ 5ns, $V_{r3} = (V_{r2})(\Gamma_s)(\Gamma_L) = 48.75\,mV$

$V_{L3} = V_{S2} + V_{r3} = 8.34875\,V$

@ 6ns, $V_{S3} = V_{L3} + (V_{r3} \cdot \Gamma_s) = 8.3365625\,V$

@ 7ns, $V_{r4} = (V_{r3})(\Gamma_s)(\Gamma_L) = -6\,mV$

$V_{L4} = V_{S3} + V_{r4} = 8.3305\,V$

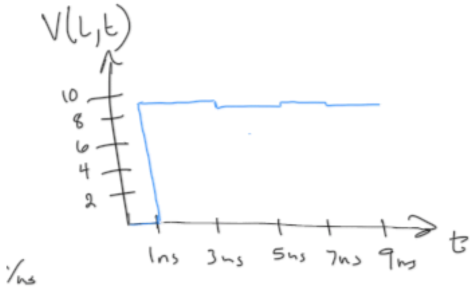
@ 8ns, $V_{S4} = V_{S3} + (V_{r4} \cdot \Gamma_s) = 8.338\,V$

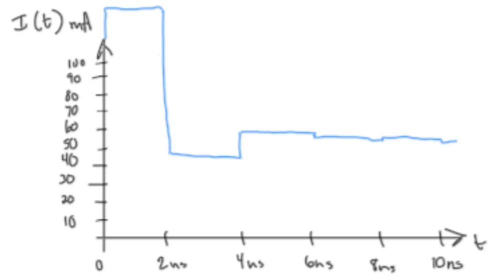
@ 9ns, $V_{r5} = (V_{r4})(\Gamma_s)(\Gamma_L) \approx .75\,mV$

$V_{L5} = V_{S4} + V_{r5} = 8.339\,V$

@ 10ns, $V_{S5} = V_{S4} + (V_{r5}\,\Gamma_s) = 8.3378\,V$

Current reflection values and graphed voltage/current,





@ 0ns, $I_{s1} = \frac{10\,V}{30\Omega + 50\Omega} = 125\,mA$

@ 2ns, $I_{s2} = \frac{V_s - V_{s1}}{R_s} = \frac{10 - 8.59375}{30} = \frac{1.40625}{30} = 46.875\,m$

@ 4ns, $\frac{V_s - V_{s2}}{R_s} = \frac{10 - 8.3}{30} = 56.67\,mA$

@ 6ns, $\frac{V_s - V_{s3}}{R_s} = \frac{10 - 8.3369625}{30} = 55.45\,mA$

@ 8ns, $\frac{V_s - V_{s4}}{R_s} = \frac{10 - 8.338}{30} = 55.40\,mA$

@ 10ns, $\frac{V_s - V_{s5}}{R_s} = \frac{10 - 8.3378}{30} = 55.41\,mA$