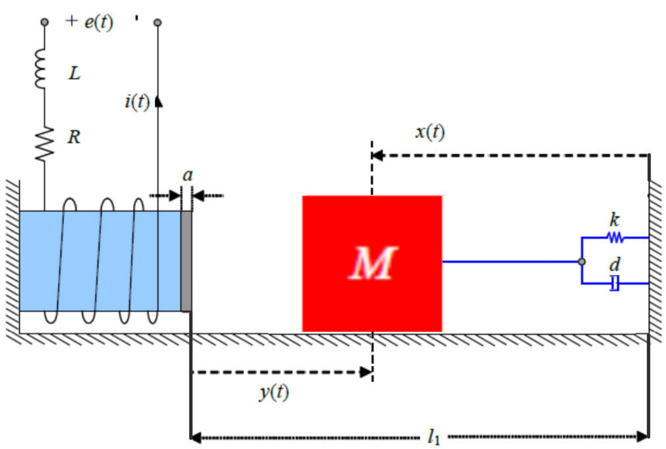
Solución Tarea N°1

```
clear all, close all
format shortG
set(0,'DefaultAxesFontName', 'Times New Roman')
set(0,'DefaultAxesFontSize', 11)
set(0,'DefaultLineLineWidth', 2)
set(0,'DefaultAxesFontWeight', 'bold')
```

Problema 1: Estudiar un sistema electromecánico.



a) Modelo.

$$M\frac{\mathrm{d}^2}{\mathrm{d}t^2}x(t) = F_m(t) - k(x(t)-l_0) - d\frac{\mathrm{d}}{\mathrm{d}t}x(t), \qquad e(t) = L\frac{\mathrm{d}}{\mathrm{d}t}i(t) + Ri(t).$$

$$M\frac{\mathrm{d}^2}{\mathrm{d}t^2}x(t) = \frac{k_i i(t)^2}{y(t)+a} - k(x(t)-l_0) - d\frac{\mathrm{d}}{\mathrm{d}t}x(t), \qquad e(t) = L\frac{\mathrm{d}}{\mathrm{d}t}i(t) + Ri(t).$$

$$M\frac{\mathrm{d}^2}{\mathrm{d}t^2}x(t) = \frac{k_i i(t)^2}{l_1 - x(t)+a} - k(x(t)-l_0) - d\frac{\mathrm{d}}{\mathrm{d}t}x(t), \qquad e(t) = L\frac{\mathrm{d}}{\mathrm{d}t}i(t) + Ri(t).$$

Clasificación de cantidades.

Orden: 3

Parametros: $M,\ k,\ d, k_i, l_0, l_1,\ a,\ R,\ L.$

Entradas: $e(t)$

Perturbaciones: no hay

Salidas: $x(t)$

Variables de estado: $x_1(t) = x(t)\,, \quad x_2(t) = \frac{\mathrm{d}}{\mathrm{d}t}x(t)\,, \quad x_3(t) = i(t)\,.$

Ecuaciones de estado.

$$u(t) = e(t)\,.$$

$$\frac{\mathrm{d}}{\mathrm{d}t}x_1(t) = x_2(t)\,,$$

$$\frac{\mathrm{d}}{\mathrm{d}t}x_2(t) = \frac{1}{M}\frac{k_i x_3(t)^2}{l_1 - x_1(t) + a} - \frac{k}{M}(x_1(t) - l_0) - \frac{d}{M}x_2(t)\,,$$

$$\frac{\mathrm{d}}{\mathrm{d}t}x_3(t) = \frac{1}{L}u(t) - \frac{R}{L}x_3(t)\,.$$

b) Clasificación del sistema.

No lineal

Continuo

Dinámico

Causal

Tiempo invariante

Parametros concentrados

c) Punto de operación.

$$0 = x_{2o},$$

$$0 = \frac{1}{M}\frac{k_i {x_{3o}}^2}{l_1 - x_{1o} + a} - \frac{k}{M}(x_{1o} - l_0) - \frac{d}{M}x_{2o},$$

$$0 = \frac{1}{L}u_o - \frac{R}{L}x_{3o}.$$

```
syms M k d ki l0 l1 a R L
syms x10 x20 x30 u0
% Ecuaciones en el punto de op.
eq1 = 0 == x20;
eq2 = 0 == (1/M)*ki*x30^2/(l1 - x10 + a) - k/M*(x10 - l0) - d/M*x20;
eq3 = 0 == 1/L*u0 - R/L*x30;
% Ultiza ecuación arbitraria para que n° ecuacion = n° incognitas.
eq4 = u0 == 2;
S = solve([eq1 eq2 eq3 eq4],[x10 x20 x30 u0])
```

```
S = struct with fields:
    x10: [2×1 sym]
    x20: [2×1 sym]
    x30: [2×1 sym]
     u0: [2×1 sym]
```

```
S.x10, S.x20, S.x30, S.u0
```

```
ans =
```

$$\begin{pmatrix} \frac{R\,a + R\,l_0 + R\,l_1 + \sigma_1}{2\,R} \\ \frac{R\,a + R\,l_0 + R\,l_1 - \sigma_1}{2\,R} \end{pmatrix}$$

where

$$\sigma_1 = \sqrt{\frac{k\,R^2\,a^2 - 2\,k\,R^2\,a\,l_0 + 2\,k\,R^2\,a\,l_1 + k\,R^2\,{l_0}^2 - 2\,k\,R^2\,l_0\,l_1 + k\,R^2\,{l_1}^2 - 16\,\mathrm{ki}}{k}}$$

```
ans =
```

$$\begin{pmatrix} 0 \\ 0 \end{pmatrix}$$

```
ans =
```

$$\begin{pmatrix} \frac{2}{R} \\ \frac{2}{R} \end{pmatrix}$$

```
ans =
```

$$\begin{pmatrix} 2 \\ 2 \end{pmatrix}$$

Linealización.

```
dx1 = x20;
dx2 = (1/M)*ki*x30^2/(l1 - x10 + a) - k/M*(x10 - l0) - d/M*x20;
dx3 = 1/L*u0 - R/L*x30;
A = [diff(dx1,x10) diff(dx1,x20) diff(dx1,x30);
     diff(dx2,x10) diff(dx2,x20) diff(dx2,x30);
     diff(dx3,x10) diff(dx3,x20) diff(dx3,x30)]
```

```
A =
```

$$\begin{pmatrix} 0 & 1 & 0 \\ \frac{\mathrm{ki}\, {x_{30}}^2}{M\ (a+l_1-x_{10})^2}-\frac{k}{M} & -\frac{d}{M} & \frac{2\,\mathrm{ki}\, x_{30}}{M\ (a+l_1-x_{10})} \\ 0 & 0 & -\frac{R}{L} \end{pmatrix}$$

```
b = [diff(dx1,u0) diff(dx2,u0) diff(dx3,u0)]'
```

b =

$$\begin{pmatrix} 0 \\ 0 \\ \frac{1}{L} \end{pmatrix}$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\Delta\mathbf{x}(t)=\frac{\mathrm{d}}{\mathrm{d}t}\begin{bmatrix} x_1(t)-x_{1o} \\ x_2(t)-x_{2o} \\ x_3(t)-x_{3o} \end{bmatrix}=\begin{bmatrix} 0 & 1 & 0 \\ \frac{k_i x_{3o}^2}{M(a+l_1-x_{1o})}-\frac{k}{M} & -\frac{d}{M} & \frac{2k_i x_{3o}}{M(a+l_1-x_{1o})} \\ 0 & 0 & -\frac{R}{L} \end{bmatrix}\begin{bmatrix} x_1(t)-x_{1o} \\ x_2(t)-x_{2o} \\ x_3(t)-x_{3o} \end{bmatrix}+\begin{bmatrix} 0 \\ 0 \\ \frac{1}{L} \end{bmatrix}(u(t)-u_0)$$

$$\Delta y(t)=y(t)-y_0=[1\quad 0\quad 0]\begin{bmatrix} x_1(t)-x_{1o} \\ x_2(t)-x_{2o} \\ x_3(t)-x_{3o} \end{bmatrix}$$

c) Simulación sistema linealizado

```
% Parametros
R = 0.5;
L = 50e-3;
a = 2e-2;
ki = 3e-3;
l1 = 50e-2;
l0 = 30e-2;
M = 250e-3;
k = 24.5;
d = 1.5;
```

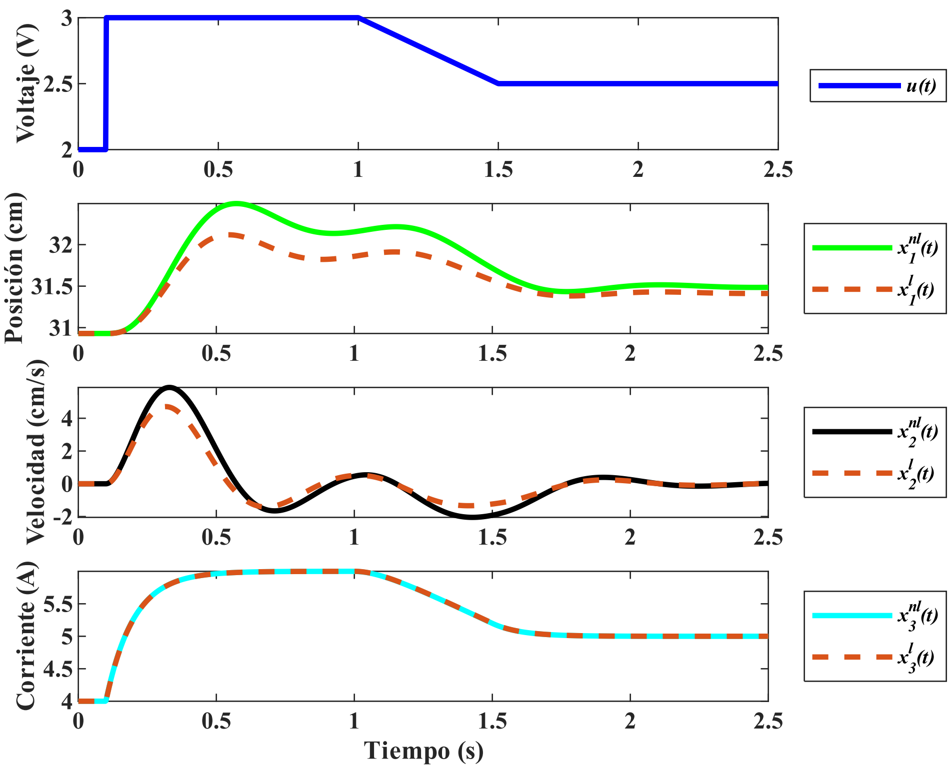
```
% Punto de op.
p_operacion = eval([S.x10 S.x20 S.x30 S.u0])
```

```
p_operacion = 2×4
      0.5107          0          4          2
      0.3093          0          4          2
```

```
% hay 2 puntos.. se escoge uno arbitrario.
x10 = p_operacion(2,1); x20 = p_operacion(2,2); x30 = p_operacion(2,3); u0 = p_operacion(2,4);
A = eval(A), b = eval(b), c = [1 0 0]
```

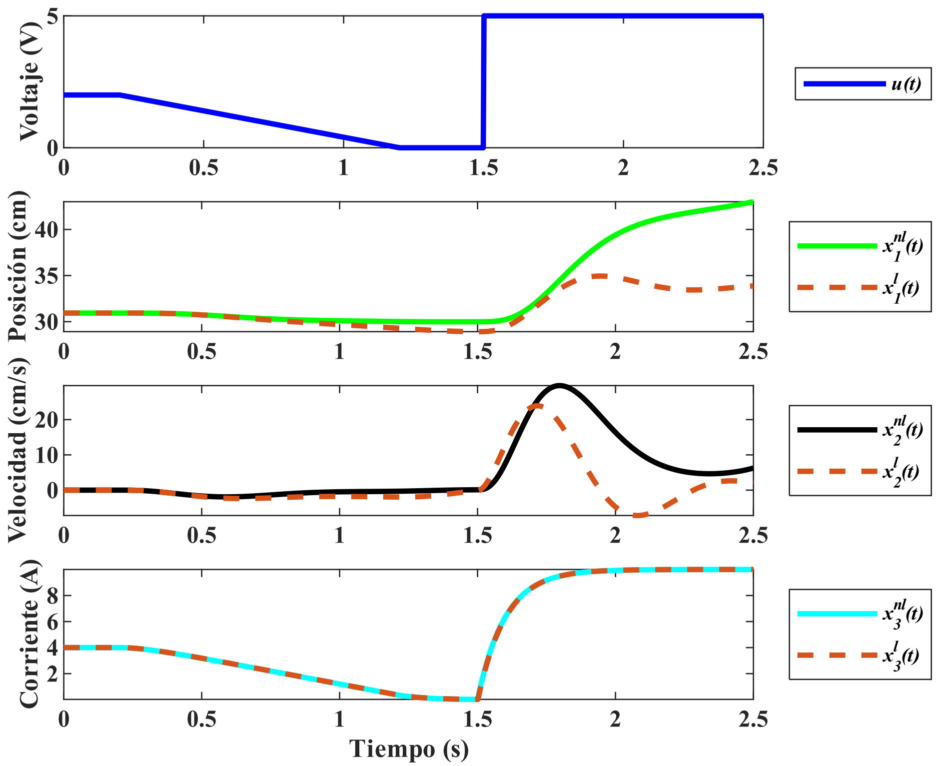
```
A = 3×3
           0          1          0
     -93.675         -6    0.45562
           0          0        -10
b = 3×1
     0
     0
    20
c = 1×3
     1     0     0
```

```
% Definición del sistema linealizado
iman_lineal = ss(A,b,c,0);
% Entrada 1
t = linspace(0,2.5,1000);
u = u0 + 1*esc(t,0.1) - 1*ram(t,1) + 1*ram(t,1.5);
% Simulación 1
[~,~,x_l] = lsim(iman_lineal, u-u0,t,[0 0 0]);
[~,x_nl] = ode45(@iman_no_lineal,t,[x10 x20 x30]);
figure
subplot(411), plot(t,u,'b'), axis tight, ylabel('Voltaje (V)'), legend('\itu(t)','Location','eastoutside')
subplot(412), plot(t,x_nl(:,1)*100,'g',t,(x_l(:,1)+x10)*100,'--'), axis tight, ylabel('Posición (cm)'),
legend('\itx_1^{nl}(t)','\itx_1^{l}(t)','Location','eastoutside')
subplot(413), plot(t,x_nl(:,2)*100,'k',t,(x_l(:,2)+x20)*100,'--'), axis tight, ylabel('Velocidad (cm/s)'),
legend('\itx_2^{nl}(t)','\itx_2^{l}(t)','Location','eastoutside')
subplot(414), plot(t,x_nl(:,3),'c',t,x_l(:,3)+x30,'--'), axis tight, ylabel('Corriente (A)'), legend('\itx_3^{nl}
(t)','\itx_3^{l}(t)','Location','eastoutside'), xlabel('Tiempo (s)')
```



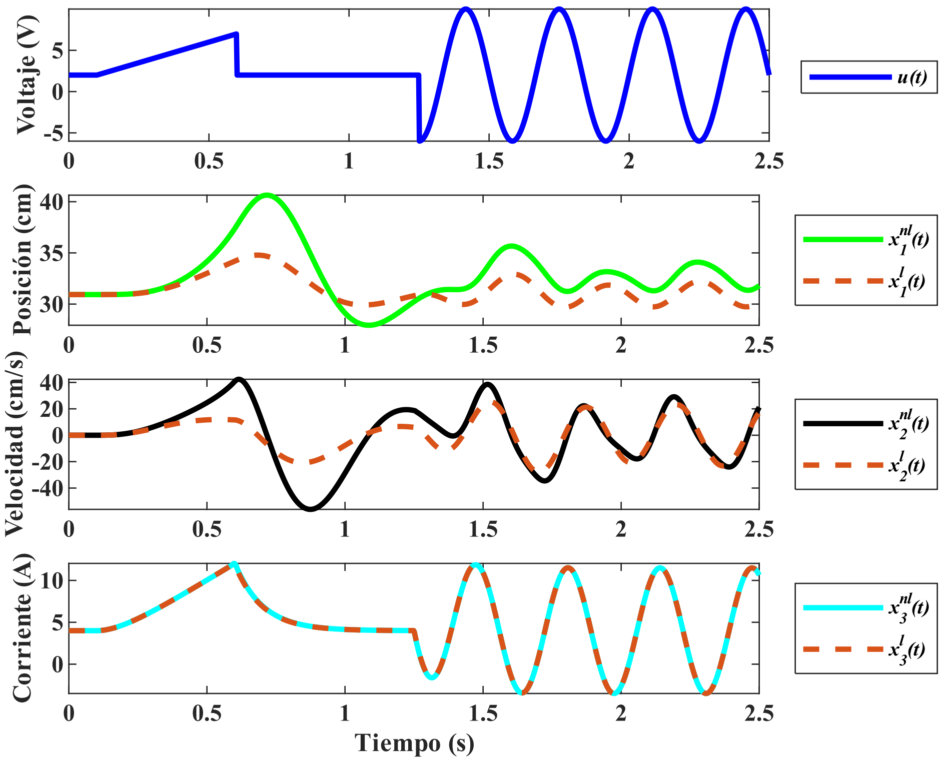

```
% Entrada 2
t = linspace(0,2.5,1000);
u = u0 - 2*ram(t,0.2) + 2*ram(t,1.2) + 5*esc(t,1.5);
% Simulación 2
[~,~,x_l] = lsim(iman_lineal, u-u0,t,[0 0 0]);
[~,x_nl] = ode45(@iman_no_lineal2,t,[x10 x20 x30]);
figure
subplot(411), plot(t,u,'b'), axis tight, ylabel('Voltaje (V)'), legend('\itu(t)','Location','eastoutside')
subplot(412), plot(t,x_nl(:,1)*100,'g',t,(x_l(:,1)+x10)*100,'--'), axis tight, ylabel('Posición (cm)'),
legend('\itx_1^{nl}(t)','\itx_1^{l}(t)','Location','eastoutside')
subplot(413), plot(t,x_nl(:,2)*100,'k',t,(x_l(:,2)+x20)*100,'--'), axis tight, ylabel('Velocidad (cm/s)'),
legend('\itx_2^{nl}(t)','\itx_2^{l}(t)','Location','eastoutside')
```

```
subplot(414), plot(t,x_nl(:,3),'c',t,x_l(:,3)+x30,'--'), axis tight, ylabel('Corriente (A)'), legend('\itx_3^{nl}
(t)','\itx_3^{l}(t)','Location','eastoutside'), xlabel('Tiempo (s)')
```




```
% Entrada 3
t = linspace(0,2.5,1000);
u = u0 + 10*ram(t,0.1) - 10*ram(t,0.6) - 5*esc(t,0.6) + 8*sin(2*pi*3*t).*esc(t,1.25);
% Simulación 3
[~,~,x_l] = lsim(iman_lineal, u-u0,t,[0 0 0]);
[~,x_nl] = ode45(@iman_no_lineal3,t,[x10 x20 x30]);
figure
subplot(411), plot(t,u,'b'), axis tight, ylabel('Voltaje (V)'), legend('\itu(t)','Location','eastoutside')
subplot(412), plot(t,x_nl(:,1)*100,'g',t,(x_l(:,1)+x10)*100,'--'), axis tight, ylabel('Posición (cm)'),
legend('\itx_1^{nl}(t)','\itx_1^{l}(t)','Location','eastoutside')
```

```
subplot(413), plot(t,x_nl(:,2)*100,'k',t,(x_l(:,2)+x20)*100,'--'), axis tight, ylabel('Velocidad (cm/s)'),
legend('\itx_2^{nl}(t)','\itx_2^{l}(t)','Location','eastoutside')
subplot(414), plot(t,x_nl(:,3),'c',t,x_l(:,3)+x30,'--'), axis tight, ylabel('Corriente (A)'), legend('\itx_3^{nl}
(t)','\itx_3^{l}(t)','Location','eastoutside'), xlabel('Tiempo (s)')
```



e) Reducción de orden.

La dinámica de la corriente se asume instantanea. Se reduce en 1 el orden y la cantidad de variables de estado.

$$\frac{\mathrm{d}}{\mathrm{d}t}x_3(t) = \frac{1}{L}u(t) - \frac{R}{L}x_3(t) = 0$$

$$x_3(t) = \frac{1}{R}u(t)$$

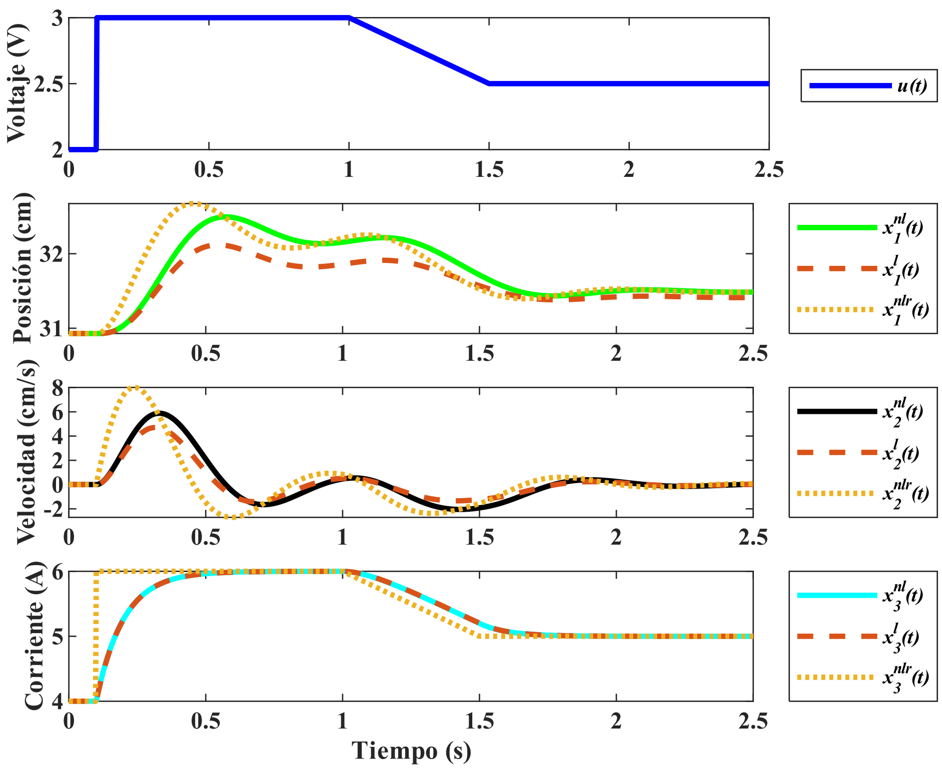
Modelo.

$$\frac{\mathrm{d}}{\mathrm{d}t}x_1(t) = x_2(t),$$

$$\frac{\mathrm{d}}{\mathrm{d}t}x_2(t) = \frac{1}{M}\frac{k_i\left(\frac{1}{R}u(t)\right)^2}{l_1 - x_1(t) + a} - \frac{k}{M}(x_1(t) - l_0) - \frac{d}{M}x_2(t).$$

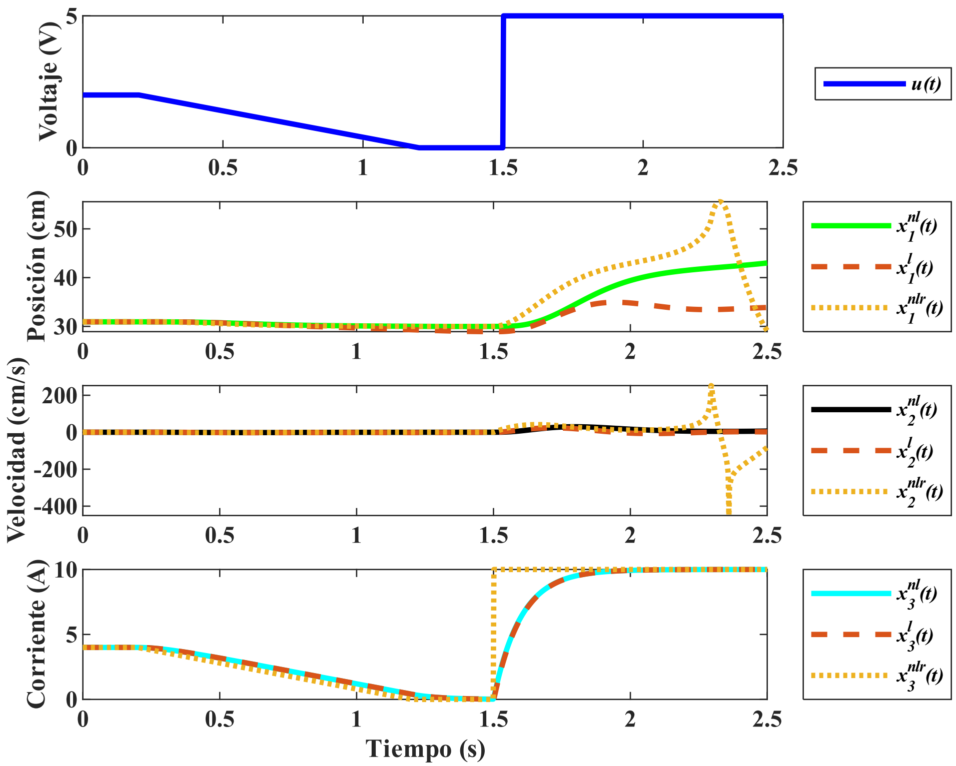
Simulación.

```
% Entrada 1
t = linspace(0,2.5,1000);
u = u0 + 1*esc(t,0.1) - 1*ram(t,1) + 1*ram(t,1.5);
% Simulación 1
[~,~,x_l] = lsim(iman_lineal, u-u0,t,[0 0 0]);
[~,x_nl] = ode45(@iman_no_lineal,t,[x10 x20 x30]);
[~,x_nl_r] = ode45(@iman_no_lineal_reducido,t,[x10 x20]);
figure
subplot(411), plot(t,u,'b'), axis tight, ylabel('Voltaje (V)'), legend('\itu(t)','Location','eastoutside')
subplot(412), plot(t,x_nl(:,1)*100,'g',t,(x_l(:,1)+x10)*100,'--',t,x_nl_r(:,1)*100,':'), axis tight,
ylabel('Posición (cm)'), legend('\itx_1^{nl}(t)','\itx_1^{l}(t)','\itx_1^{nlr}(t)','Location','eastoutside')
subplot(413), plot(t,x_nl(:,2)*100,'k',t,(x_l(:,2)+x20)*100,'--',t,x_nl_r(:,2)*100,':'), axis tight,
ylabel('Velocidad (cm/s)'), legend('\itx_2^{nl}(t)','\itx_2^{l}(t)','\itx_2^{nlr}(t)','Location','eastoutside')
subplot(414), plot(t,x_nl(:,3),'c',t,x_l(:,3)+x30,'--',t,u/R,':'), axis tight, ylabel('Corriente (A)'),
legend('\itx_3^{nl}(t)','\itx_3^{l}(t)','\itx_3^{nlr}(t)','Location','eastoutside'), xlabel('Tiempo (s)')
```



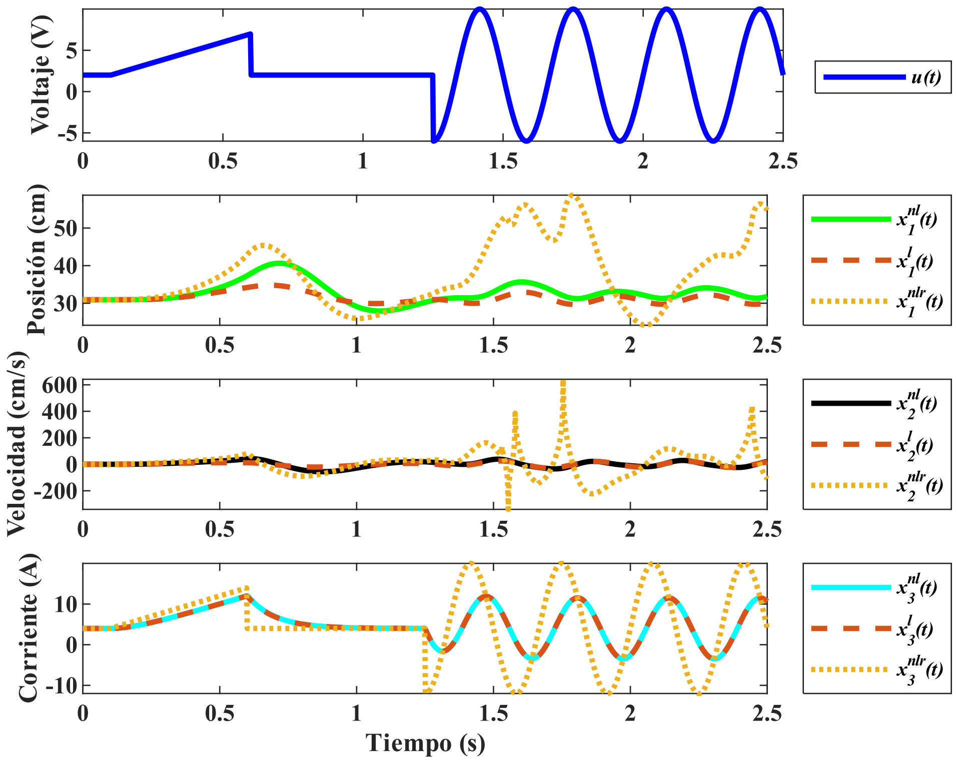

```
% Entrada 2
t = linspace(0,2.5,1000);
u = u0 - 2*ram(t,0.2) + 2*ram(t,1.2) + 5*esc(t,1.5);
% Simulación 2
[~,~,x_l] = lsim(iman_lineal, u-u0,t,[0 0 0]);
[~,x_nl] = ode45(@iman_no_lineal2,t,[x10 x20 x30]);
[~,x_nl_r] = ode45(@iman_no_lineal2_reducido,t,[x10 x20]);
figure
subplot(411), plot(t,u,'b'), axis tight, ylabel('Voltaje (V)'), legend('\itu(t)','Location','eastoutside')
subplot(412), plot(t,x_nl(:,1)*100,'g',t,(x_l(:,1)+x10)*100,'--',t,x_nl_r(:,1)*100,':'), axis tight,
ylabel('Posición (cm)'), legend('\itx_1^{nl}(t)','\itx_1^{l}(t)','\itx_1^{nlr}(t)','Location','eastoutside')
subplot(413), plot(t,x_nl(:,2)*100,'k',t,(x_l(:,2)+x20)*100,'--',t,x_nl_r(:,2)*100,':'), axis tight,
ylabel('Velocidad (cm/s)'), legend('\itx_2^{nl}(t)','\itx_2^{l}(t)','\itx_2^{nlr}(t)','Location','eastoutside')
```

```
subplot(414), plot(t,x_nl(:,3),'c',t,x_l(:,3)+x30,'--',t,u/R,':'), axis tight, ylabel('Corriente (A)'),
legend('\itx_3^{nl}(t)','\itx_3^{l}(t)','\itx_3^{nlr}(t)','Location','eastoutside'), xlabel('Tiempo (s)')
```




```
% Entrada 3
t = linspace(0,2.5,1000);
u = u0 + 10*ram(t,0.1) - 10*ram(t,0.6) - 5*esc(t,0.6) + 8*sin(2*pi*3*t).*esc(t,1.25);
% Simulación 3
[~,~,x_l] = lsim(iman_lineal, u-u0,t,[0 0 0]);
[~,x_nl] = ode45(@iman_no_lineal3,t,[x10 x20 x30]);
[~,x_nl_r] = ode45(@iman_no_lineal3_reducido,t,[x10 x20]);
figure
subplot(411), plot(t,u,'b'), axis tight, ylabel('Voltaje (V)'), legend('\itu(t)','Location','eastoutside')
subplot(412), plot(t,x_nl(:,1)*100,'g',t,(x_l(:,1)+x10)*100,'--',t,x_nl_r(:,1)*100,':'), axis tight,
ylabel('Posición (cm)'), legend('\itx_1^{nl}(t)','\itx_1^{l}(t)','\itx_1^{nlr}(t)','Location','eastoutside')
```

```
subplot(413), plot(t,x_nl(:,2)*100,'k',t,(x_l(:,2)+x20)*100,'--',t,x_nl_r(:,2)*100,':'), axis tight,
ylabel('Velocidad (cm/s)'), legend('\itx_2^{nl}(t)','\itx_2^{l}(t)','\itx_2^{nlr}(t)','Location','eastoutside')
subplot(414), plot(t,x_nl(:,3),'c',t,x_l(:,3)+x30,'--',t,u/R,':'), axis tight, ylabel('Corriente (A)'),
legend('\itx_3^{nl}(t)','\itx_3^{l}(t)','\itx_3^{nlr}(t)','Location','eastoutside'), xlabel('Tiempo (s)')
```



Problema 2: Estudiar circuito RLC discreto.

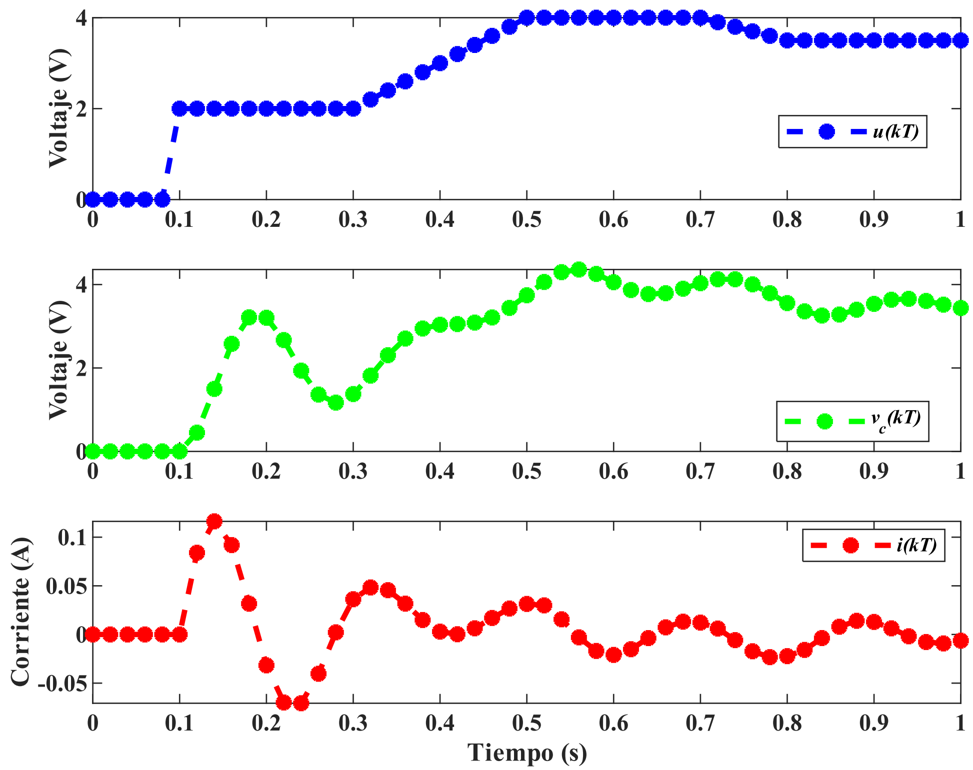
Sistema.

```
A = [0.775 8.327; -0.042 0.609]; B = [0.225 0.042]'; C = [1 0]; D = 0;
T = 0.02;
RLC = ss(A,B,C,D,T)
```

```
RLC =

  A =
            x1      x2
   x1    0.775   8.327
   x2   -0.042   0.609

  B =
           u1
   x1   0.225
   x2   0.042

  C =
        x1  x2
   y1    1   0

  D =
        u1
   y1    0

Sample time: 0.02 seconds
Discrete-time state-space model.
Model Properties
```

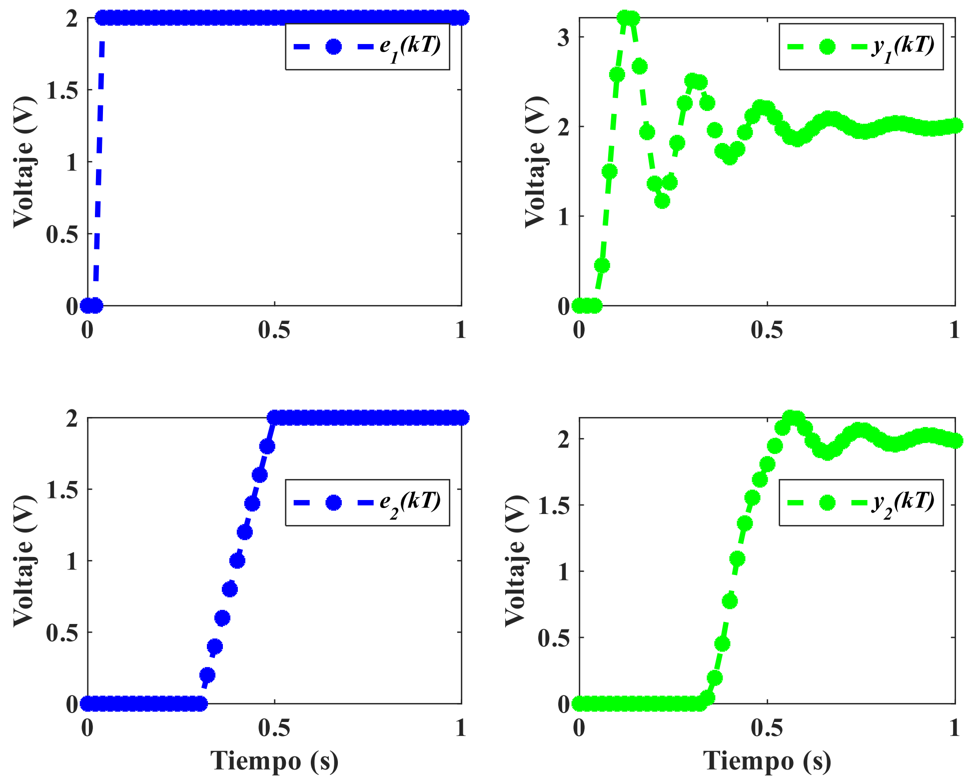
a) Simulación

```
k = 0:50;
kT = k*T;
e = 2*esc(kT,5*T) + 10*ram(kT,15*T) - 10*ram(kT,25*T) - 5*ram(kT,35*T) + 5*ram(kT,40*T);
[~,~,x] = lsim(RLC,e,kT);
figure
subplot(311),plot(kT,e,'b--*'), axis tight, ylabel('Voltaje (V)'), legend('\itu(kT)','Location','best')
subplot(312),plot(kT,x(:,1),'g--*'), axis tight, ylabel('Voltaje (V)'), legend('\itv_c(kT)','Location','best')
subplot(313),plot(kT,x(:,2),'r--*'), axis tight, ylabel('Corriente (A)'), legend('\iti(kT)','Location','best'),
xlabel('Tiempo (s)')
```

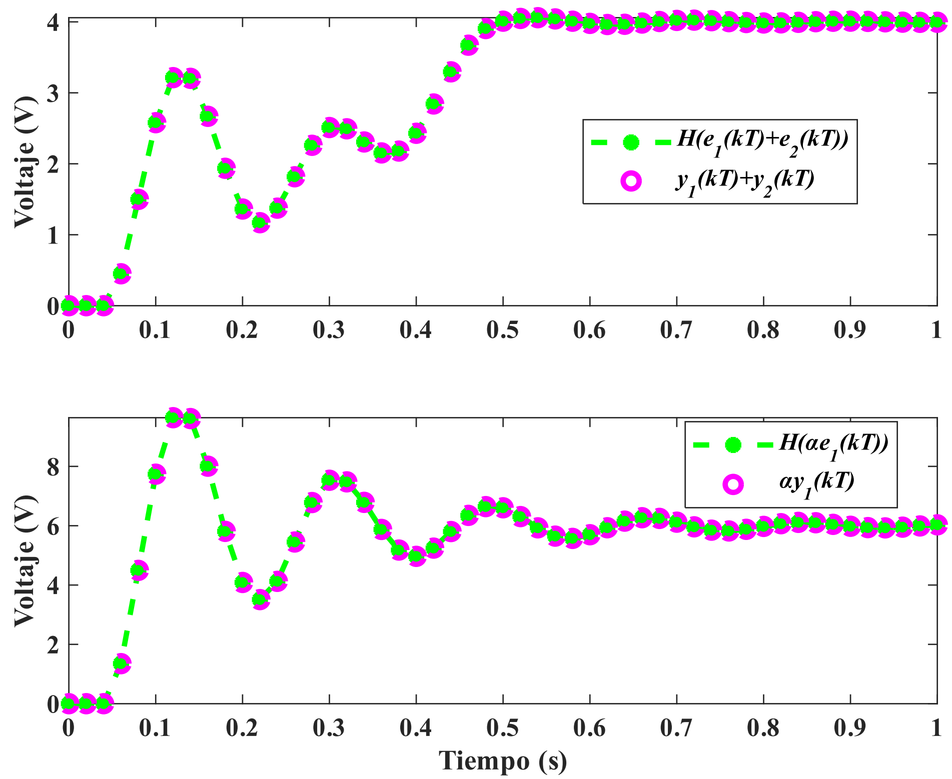


b) Principio de superposición y homogeneidad.

```
e1 = 2*esc(kT,2*T); [y1,~,~] = lsim(RLC,e1,kT);
e2 = 10*ram(kT,15*T) - 10*ram(kT,25*T); [y2,~,~] = lsim(RLC,e2,kT);
figure
subplot(221), plot(kT,e1,'b--*'), axis tight, ylabel('Voltaje (V)'), legend('\ite_1(kT)','Location','best')
subplot(222), plot(kT,y1,'g--*'), axis tight, ylabel('Voltaje (V)'), legend('\ity_1(kT)','Location','best')
subplot(223), plot(kT,e2,'b--*'), axis tight, ylabel('Voltaje (V)'), legend('\ite_2(kT)','Location','best'),
xlabel('Tiempo (s)')
subplot(224), plot(kT,y2,'g--*'), axis tight, ylabel('Voltaje (V)'), legend('\ity_2(kT)','Location','best'),
xlabel('Tiempo (s)')
```

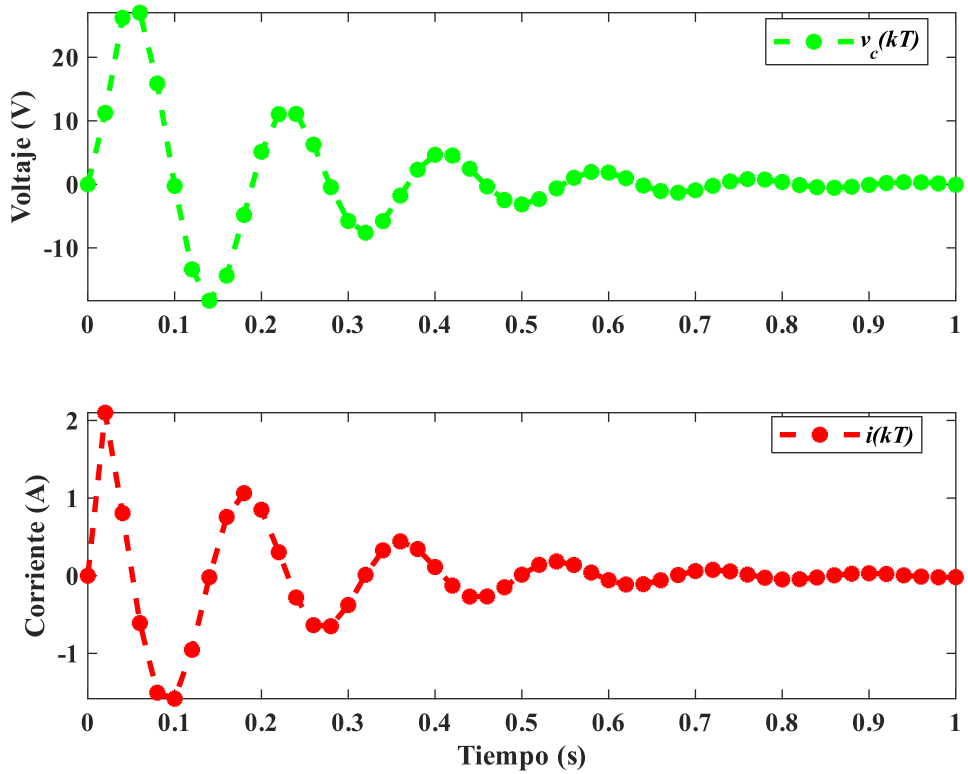



```
[y1_2,~,~] = lsim(RLC,e1+e2,kT);
alpha = 3;
[alpha_y1,~,~] = lsim(RLC,alpha*e1,kT);
figure
subplot(211),plot(kT,y1_2,'g--*',kT,y1+y2,'mo'), axis tight, ylabel('Voltaje (V)'), legend('\itH(e_1(kT)
+e_2(kT))','\ity_1(kT)+y_2(kT)','Location','best')
subplot(212),plot(kT,alpha_y1,'g--*',kT,alpha*y1,'mo'), axis tight, ylabel('Voltaje (V)'),
legend('\itH(αe_1(kT))','\itαy_1(kT)','Location','best'), xlabel('Tiempo (s)')
```



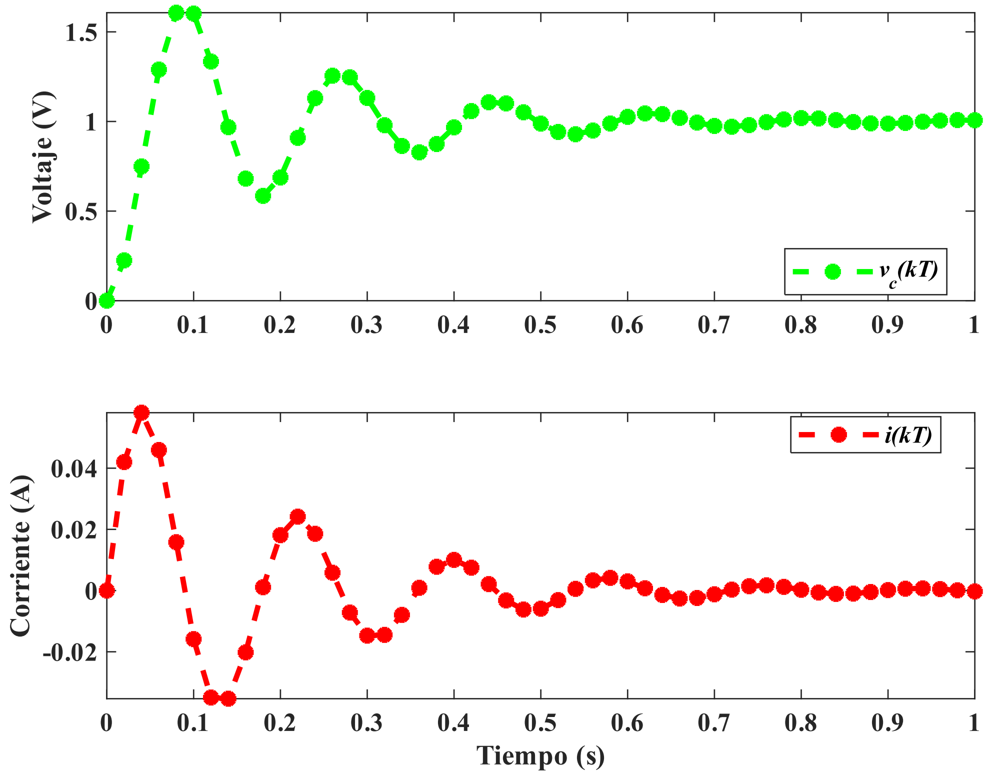
c) Respuesta a entrada discreta impulso.

```
[~,~,x] = impulse(RLC,kT);
figure
subplot(211),plot(kT,x(:,1),'g--*'), axis tight, ylabel('Voltaje (V)'), legend('\itv_c(kT)','Location','best')
subplot(212),plot(kT,x(:,2),'r--*'), axis tight, ylabel('Corriente (A)'), legend('\iti(kT)','Location','best'),
xlabel('Tiempo (s)')
```



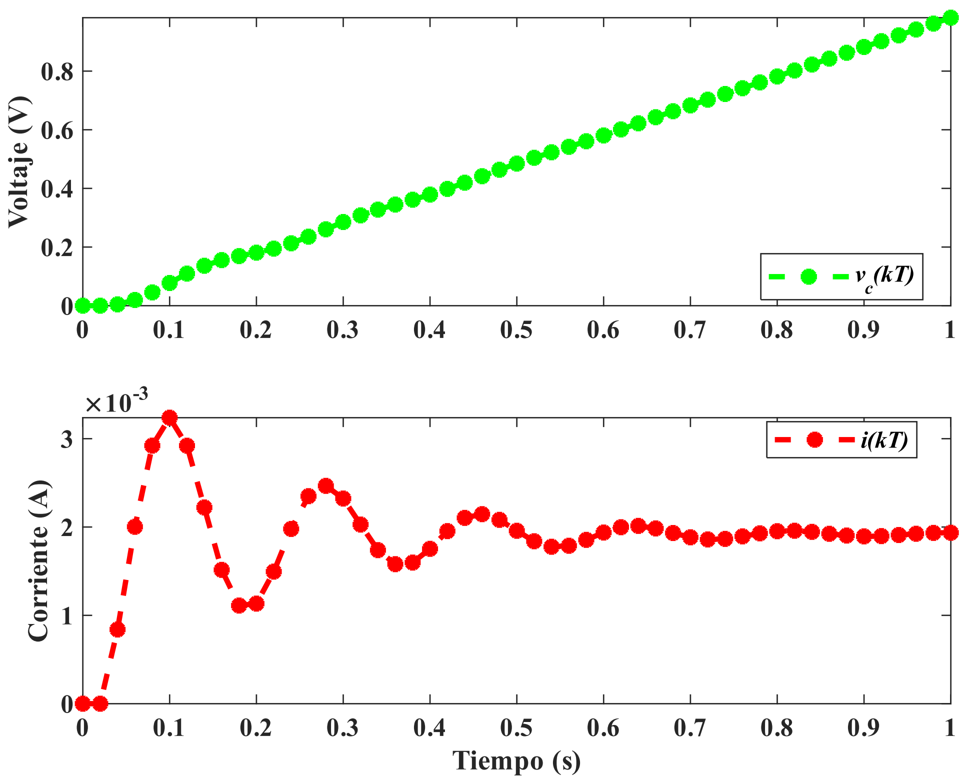
Respuesta a entrada escalón.

```
[~,~,x] = step(RLC,kT);
figure
subplot(211),plot(kT,x(:,1),'g--*'), axis tight, ylabel('Voltaje (V)'), legend('\itv_c(kT)','Location','best')
subplot(212),plot(kT,x(:,2),'r--*'), axis tight, ylabel('Corriente (A)'), legend('\iti(kT)','Location','best'),
xlabel('Tiempo (s)')
```



Respuesta a entrada rampa.

```
u = ram(kT,0);
[~,~,x] = lsim(RLC,u,kT);
figure
subplot(211),plot(kT,x(:,1),'g--*'), axis tight, ylabel('Voltaje (V)'), legend('\itv_c(kT)','Location','best')
subplot(212),plot(kT,x(:,2),'r--*'), axis tight, ylabel('Corriente (A)'), legend('\iti(kT)','Location','best'),
xlabel('Tiempo (s)')
```



Problema 3: Preguntas de desarrollo.

a) Respuesta de un S.L.I. ante entrada arbitraria.

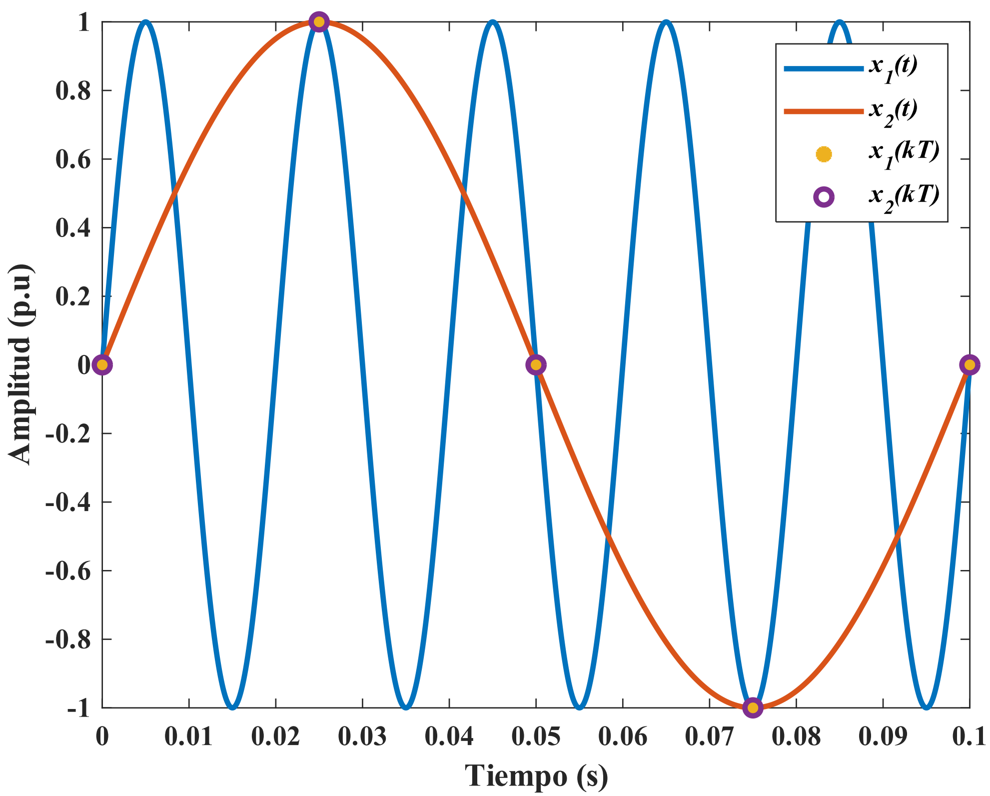
$$h(t) = \frac{\mathrm{d}}{\mathrm{d}t} y_{\text{step}}(t) = e^{-\frac{t}{2}} u(t)$$

$$y(t) = e^{-\frac{t-2}{2}} u(t-2) - 2\left(1 - e^{-\frac{t-4}{2}}\right) u(t-4)$$

b) Aliasing.

Dos señales tiempo continuo son indeferenciables en tiempo discreto debido a un muestreo insuficiente.

```
f1 = 50;
f2 = 10;
ts = 0.025;
Tend = 1/f2;
kT = 0:ts:Tend;
t = linspace(0,Tend,1000);
x1 = sin(2*pi*f1*kT);
x2 = sin(2*pi*f2*kT);
figure()
plot(t,sin(2*pi*f1*t),t,sin(2*pi*f2*t),kT,x1,'*',kT,x2,'o'),
legend('\itx_1(t)','\itx_2(t)','\itx_1(kT)','\itx_2(kT)'), xlabel('Tiempo (s)'), ylabel('Amplitud (p.u)')
```



c) Transformada de Laplace.

```
syms t
f1 = 2/3*(t+3)*heaviside(t+3) - 4/3*t*heaviside(t) + 2/3*(t-3)*heaviside(t-3);
f1_s = laplace(f1)
```

f1_s =

$$\frac{2\ (3\,s+1)}{3\,s^2}+\frac{2\,e^{-3\,s}}{3\,s^2}-\frac{4}{3\,s^2}$$

```
f2 = -heaviside(t+2) + 2*heaviside(t) - heaviside(t-2);
f2_s = laplace(f2)
```

f2_s =

$$\frac{1}{s}-\frac{e^{-2\,s}}{s}$$

```
function dx = iman_no_lineal(t,x) % Definición del imán no lineal para entrada 1.
% Parametros
R = 0.5;
L = 50e-3;
a = 2e-2;
ki = 3e-3;
l1 = 50e-2;
l0 = 30e-2;
M = 250e-3;
k = 24.5;
d = 1.5;
% Entrada
u0 = 2;%3542/765;
u = u0 + 1*esc(t,0.1) - 1*ram(t,1) + 1*ram(t,1.5);
% Ecuaciones diferenciales
dx(1) = x(2);
dx(2) = (1/M)*ki*x(3)*x(3)/(l1 - x(1) + a) - k/M*(x(1) - l0) - d/M*x(2);
dx(3) = 1/L*u - R/L*x(3);
dx = [dx(1); dx(2); dx(3)];
```

```
end
function dx = iman_no_lineal2(t,x) % Definición del imán no lineal para entrada 2.
% Parametros
R = 0.5;
L = 50e-3;
a = 2e-2;
ki = 3e-3;
l1 = 50e-2;
l0 = 30e-2;
M = 250e-3;
k = 24.5;
d = 1.5;
% Entrada
u0 = 2;%3542/765;
u = u0 - 2*ram(t,0.2) + 2*ram(t,1.2) + 5*esc(t,1.5);
% Ecuaciones diferenciales
dx(1) = x(2);
dx(2) = (1/M)*ki*x(3)*x(3)/(l1 - x(1) + a) - k/M*(x(1) - l0) - d/M*x(2);
dx(3) = 1/L*u - R/L*x(3);
dx = [dx(1); dx(2); dx(3)];
end
function dx = iman_no_lineal3(t,x) % Definición del imán no lineal para entrada 3.
% Parametros
R = 0.5;
L = 50e-3;
a = 2e-2;
ki = 3e-3;
l1 = 50e-2;
l0 = 30e-2;
M = 250e-3;
k = 24.5;
d = 1.5;
% Entrada
u0 = 2;%3542/765;
u = u0 + 10*ram(t,0.1) - 10*ram(t,0.6) - 5*esc(t,0.6) + 8*sin(2*pi*3*t).*esc(t,1.25);
% Ecuaciones diferenciales
dx(1) = x(2);
```

```
dx(2) = (1/M)*ki*x(3)*x(3)/(l1 - x(1) + a) - k/M*(x(1) - l0) - d/M*x(2);
dx(3) = 1/L*u - R/L*x(3);
dx = [dx(1); dx(2); dx(3)];
end
function dx = iman_no_lineal_reducido(t,x) % Definición del imán no lineal reducido para entrada 1.
% Parametros
R = 0.5;
L = 50e-3;
a = 2e-2;
ki = 3e-3;
l1 = 50e-2;
l0 = 30e-2;
M = 250e-3;
k = 24.5;
d = 1.5;
% Entrada
u0 = 2;%3542/765;
u = u0 + 1*esc(t,0.1) - 1*ram(t,1) + 1*ram(t,1.5);
% Ecuaciones diferenciales
i = u/R;
dx(1) = x(2);
dx(2) = (1/M)*ki*i^2/(l1 - x(1) + a) - k/M*(x(1) - l0) - d/M*x(2);
dx = [dx(1); dx(2)];
end
function dx = iman_no_lineal2_reducido(t,x) % Definición del imán no lineal reducido para entrada 2.
% Parametros
R = 0.5;
L = 50e-3;
a = 2e-2;
ki = 3e-3;
l1 = 50e-2;
l0 = 30e-2;
M = 250e-3;
k = 24.5;
d = 1.5;
% Entrada
u0 = 2;%3542/765;
```

```
u = u0 - 2*ram(t,0.2) + 2*ram(t,1.2) + 5*esc(t,1.5);
% Ecuaciones diferenciales
i = u/R;
dx(1) = x(2);
dx(2) = (1/M)*ki*i^2/(l1 - x(1) + a) - k/M*(x(1) - l0) - d/M*x(2);
dx = [dx(1); dx(2)];
end
function dx = iman_no_lineal3_reducido(t,x) % Definición del imán no lineal reducido para entrada 3.
% Parametros
R = 0.5;
L = 50e-3;
a = 2e-2;
ki = 3e-3;
l1 = 50e-2;
l0 = 30e-2;
M = 250e-3;
k = 24.5;
d = 1.5;
% Entrada
u0 = 2;%3542/765;
u = u0 + 10*ram(t,0.1) - 10*ram(t,0.6) - 5*esc(t,0.6) + 8*sin(2*pi*3*t).*esc(t,1.25);
% Ecuaciones diferenciales
i = u/R;
dx(1) = x(2);
dx(2) = (1/M)*ki*i^2/(l1 - x(1) + a) - k/M*(x(1) - l0) - d/M*x(2);
dx = [dx(1); dx(2)];
end
function u = esc(t,t0)
    u = t>=t0;
end
function r = ram(t,t0)
    r = (t - t0).*esc(t,t0);
end
```