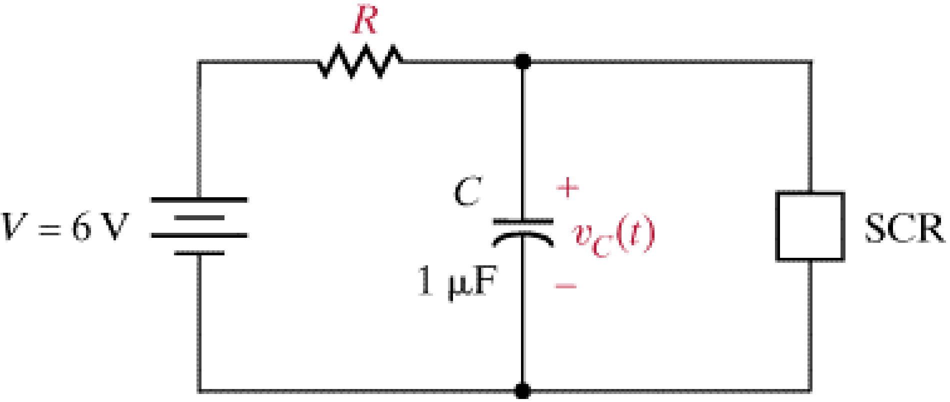
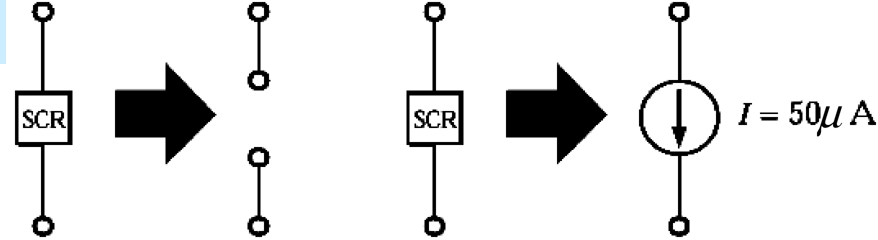
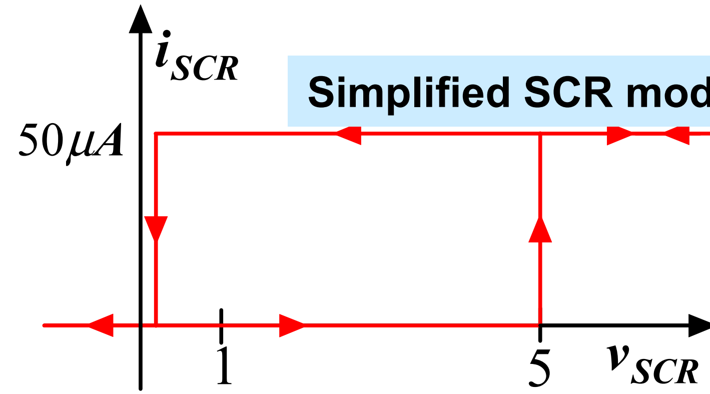
LEARNING APPLICATION | **HEART PACEMAKER**





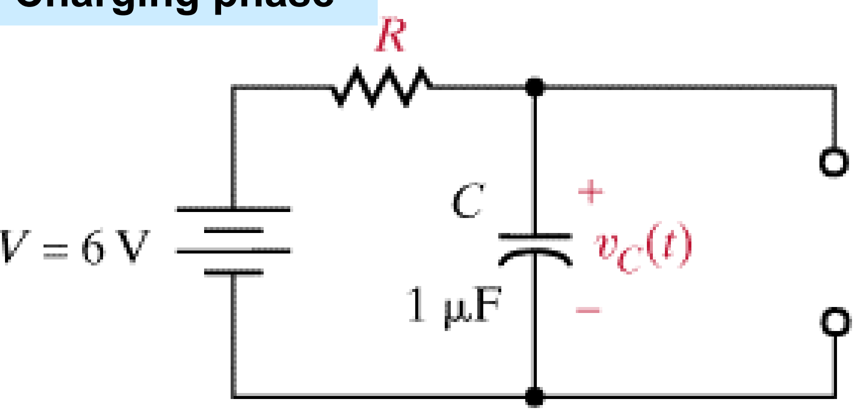


Simplified SCR model

SCR "fires"

Find R so that the SCR is ready to fire after one second of capacitor charging

Charging phase



$$v_C(t) = K_1 + K_2 e^{-\frac{t}{\tau}}, t > 0$$

$$\tau = RC = 10^{-6} R$$

$$v_C(\infty) = 6V = K_1$$

$$v_C(0) = 0.2V = K_1 + K_2$$

$$K_1 = 6$$

$$K_2 = 5.8$$

$$v_C(t) = 6 - 5.8 e^{-\frac{t}{RC}}, \ t > 0$$

$$\text{Required:} \ v_C(1) = 5V = 6 - 5.8 e^{-\frac{1}{RC}}$$

$$e^{\frac{1}{RC}} = 5.8 \Rightarrow \frac{1}{RC} = 1.758 \Rightarrow R = 569 k\Omega$$

$$\tau = RC = .569$$

As soon as the SCR switches off the capacitor starts charging. Hence, assume

$$v_C(0) = 0.2$$

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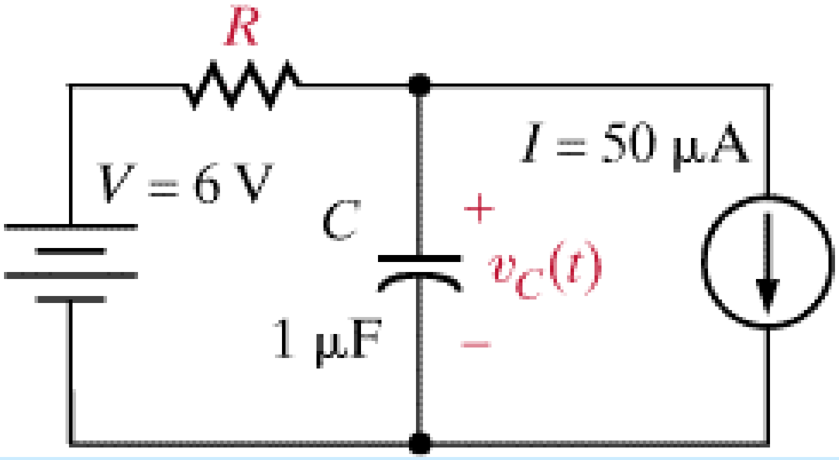
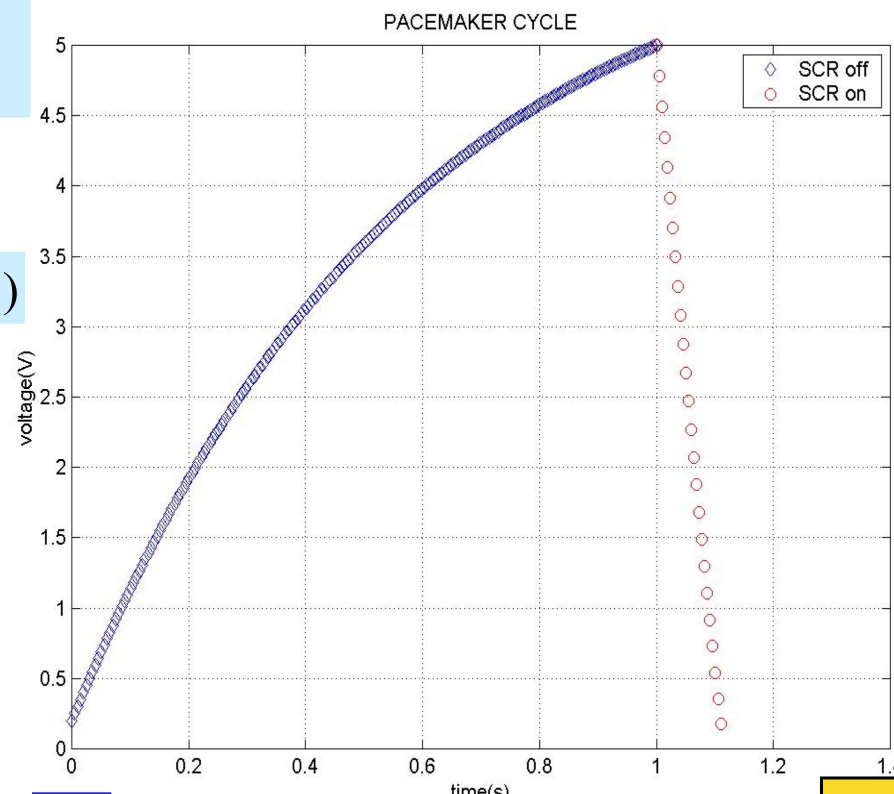
THE DISCHARGE STAGE




```
%example6p12
%visualizes one cycle of pacemaker
%charge cycle
tau=0.569;
tc=linspace(0,1,200);
vc=6-5.8*exp(-tc/tau);
%discharge cycle. SCR on
td=linspace(1,1.11,25);
vcd=-22.45+27.45*exp(-(td-1)/tau);
plot(tc,vc,'bd',td,vcd,'ro'),grid,
title('PACEMAKER CYCLE')
xlabel('time(s)'), ylabel('voltage(V)')
legend('SCR off', 'SCR on')
```



With the chosen resistor discharge starts after one second and the capacitor voltage is 5V

$$v_C(t) = K_1 + K_2 e^{-\frac{(t-1)}{\tau}}, \; t > 1$$

$$\tau = 0.569s$$

$$v_C(1) = 5V$$

$$v_C(\infty) = 6 - RI = 6 - 0.569 \times 10^6 (\Omega) \times 50 \times 10^{-6} (A)$$

$$K_1 = -22.45$$

$$K_1 + K_2 = 5 \Rightarrow K_2 = 27.45$$

$$v_C(t) = -22.45 + 27.45 e^{-\frac{(t-1)}{0.569}} \quad t > 1$$

For SCR turn off

$$v_C(1 + T_{off}) = 0.2$$

$$e^{\frac{T_{off}}{0.569}} = \frac{27.45}{22.65} \Rightarrow T_{off} = 0.11s$$

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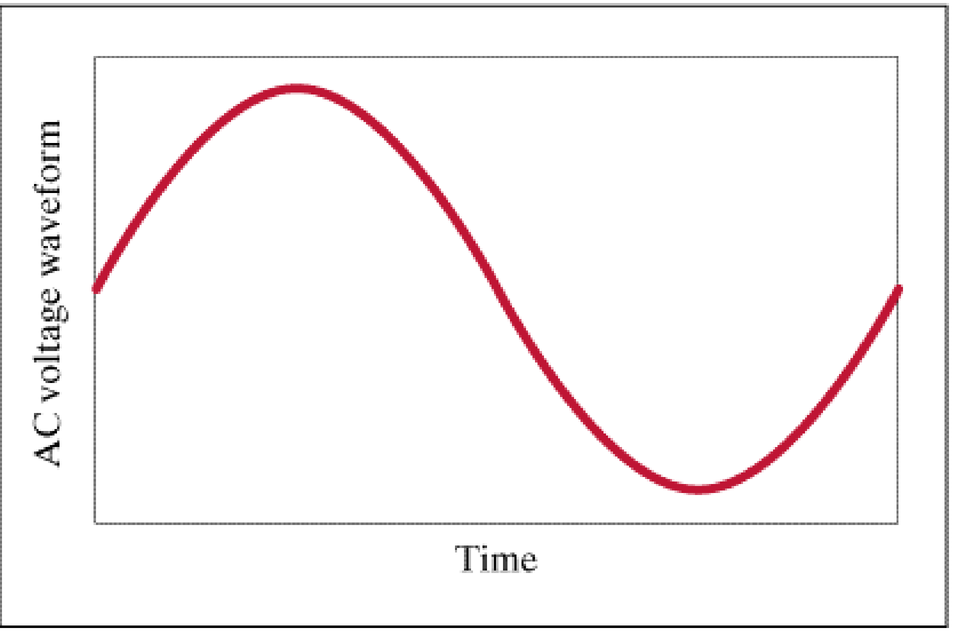
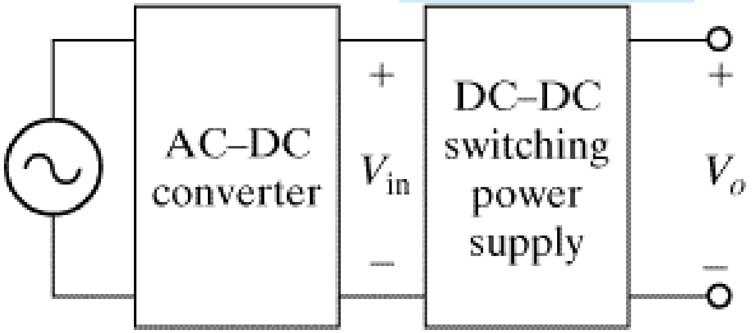
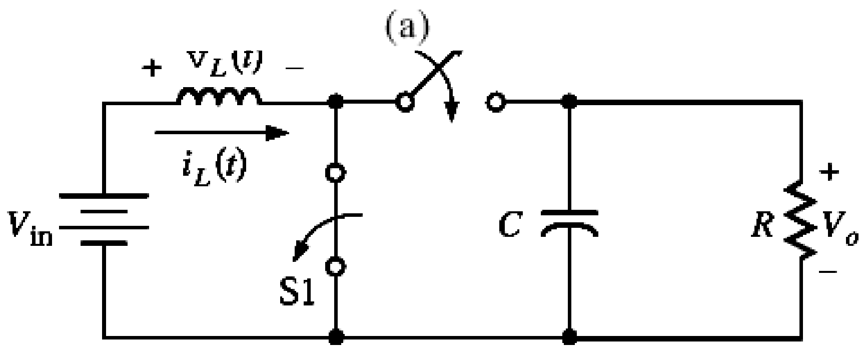
LEARNING EXAMPLE **BOOSTER CONVERTER**

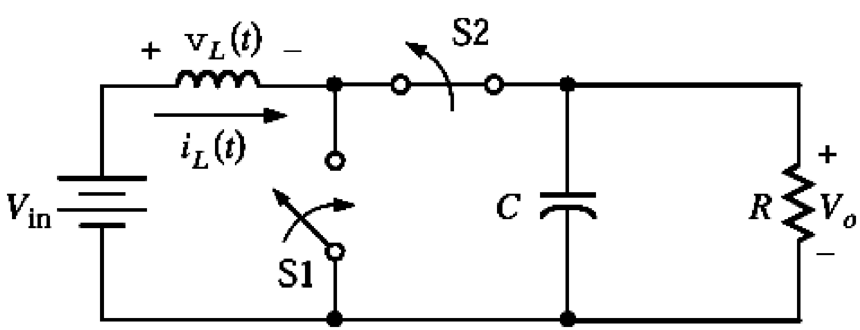


e.g. booster



STANDARD DC POWER SUPPLY



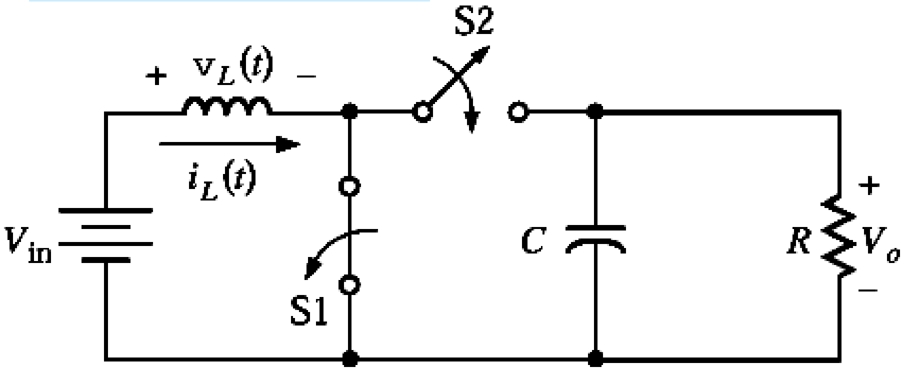


BOOSTER "ON" PERIOD
Energy is stored in inductor.
Capacitor discharges

BOOSTER "OFF" PERIOD
Inductor releases energy.
Capacitor charges

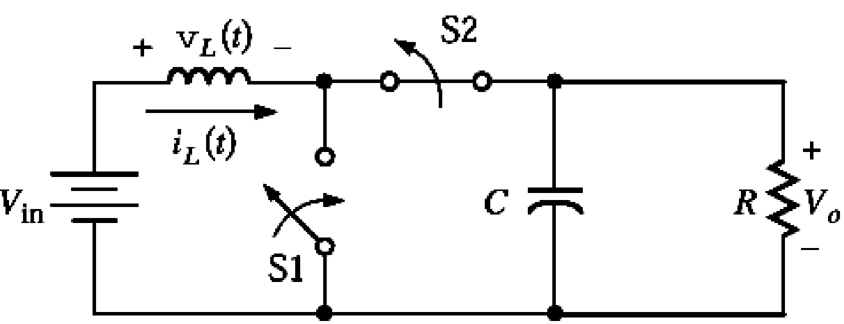
Inductor current at the beginning of ON period MUST be the same than the current at the end of OFF period

THE “ON” CYCLE



$$i_L(t_{on}) = i(0) + \frac{1}{L}\int_0^{t_{on}} v_L(x)dx = I_0 + \frac{V_{in}}{L}t_{on}$$

THE “OFF” CYCLE $t > t_{on}$



$$i_L(t_{on} + t_{off}) = i(t_{on}) + \frac{1}{L}\int_{t_{on}}^{t_{off}} v_L(x)dx$$

SIMPLIFYING ASSUMPTION: THE OUTPUT VOLTAGE (Vo) IS CONSTANT

$$v_L = V_{in} - V_0$$

$$I_0 = i(t_{on}) + \frac{V_{in} - V_0}{L}t_{off}$$

$$I_o = I_0 + \frac{V_{in}}{L}t_{on} + \frac{V_{in} - V_0}{L}t_{off}$$

$$V_o = \frac{t_{on} + t_{off}}{t_{off}}V_{in}$$

$V_0 > V_{in}$ (hence booster)

Period: $T = t_{on} + t_{off}$

Duty cycle: $D = \frac{t_{on}}{T}$

$$V_0 = V_{in}\frac{1}{1 - D}$$

By adjusting the duty cycle one can adjust the output voltage level

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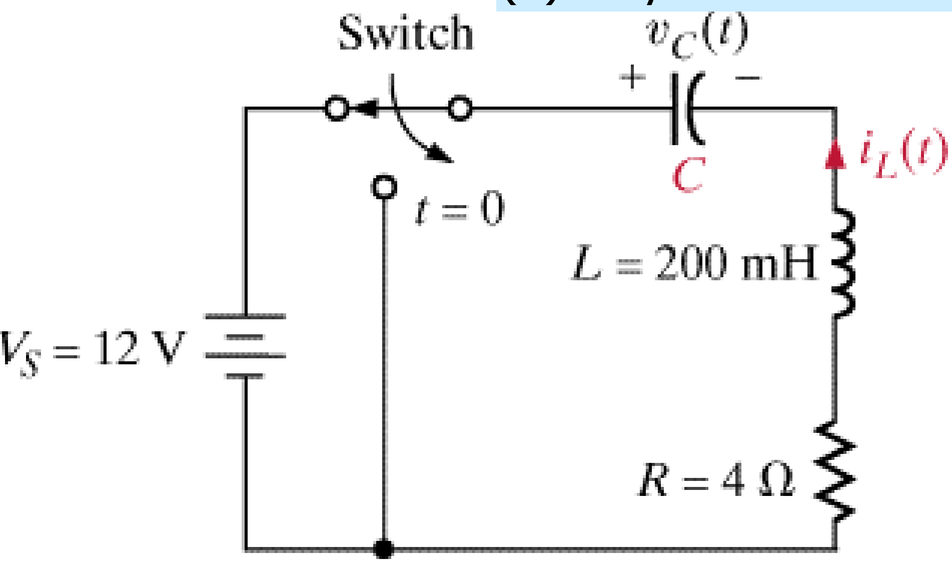
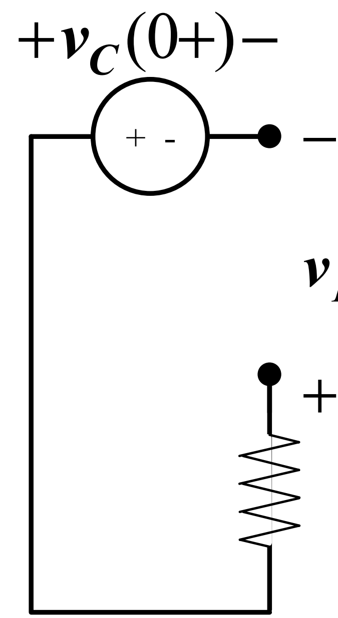
LEARNING BY DESIGN

FIND C SUCH THAT $i(t)$ IS OVERDAMPED, AND SATISFIES:

(1) Reaches 1A within 100ms;

(2) Stays above 1A between 1s and 1.5s





Circuit at t=0+

$$v_L(0+) = L\frac{di}{dt}(0+)$$

$$v_C(0+) = 12V$$

AFTER SWITCHING WE HAVE RLC SERIES

$$\frac{d^2 i_L}{dt^2}(t) + \frac{R}{L}\frac{di_L}{dt}(t) + \frac{1}{LC}i_L(t) = 0$$

DESIRED RESPONSE: $i(t) = K_1 e^{-s_1 t} + K_2 e^{-s_2 t};\ t > 0$

Ch. Eq.: $s^2 + 20s + 5/C = (s + s_1)(s + s_2) = 0$

$\therefore s_1 + s_2 = 20;\ \ s_1 s_2 = 5/C$

INITIAL CONDITIONS:

$$i_L(0) = 0;\quad v_L(0) = L\frac{di_L}{dt}(0) = 12$$

$$K_1 + K_2 = 0$$

$$-s_1 K_1 - s_2 K_2 = 60$$

For the initial conditions analyze circuit at t=0+. Assume the circuit was in steady state prior to the switching

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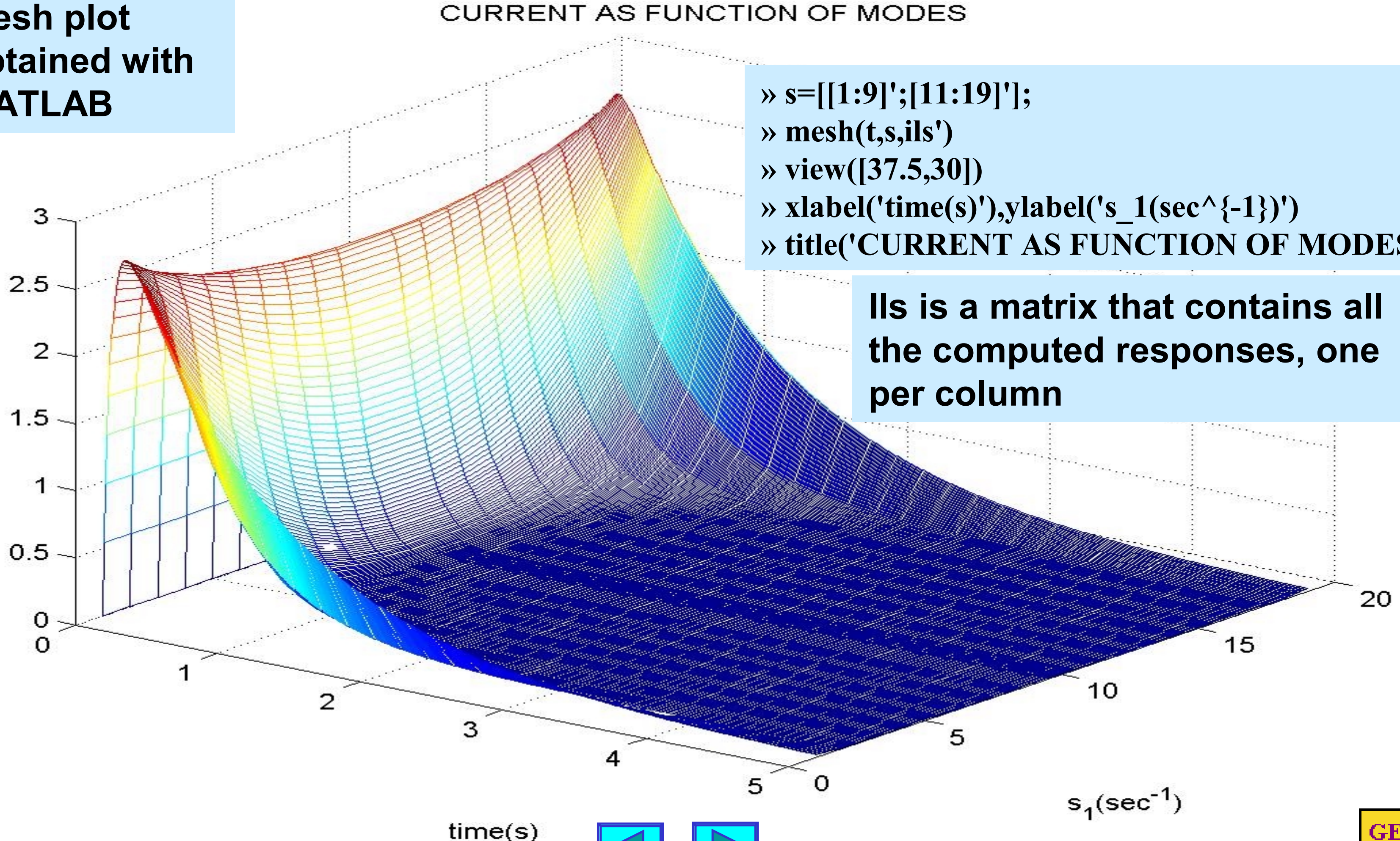
$$i_L(t) = \frac{60}{s_2 - s_1}\left(e^{-s_1 t} - e^{-s_2 t}\right)$$

NOW ONE CAN USE TRIAL AND ERROR OR CAN ATTEMPT TO ESTIMATE THE REQUIRED CAPACITANCE

IF FEASIBLE, GET AN IDEA OF THE FAMILY OF SOLUTIONS

Mesh plot obtained with MATLAB




```
» s=[[1:9]';[11:19]'];
» mesh(t,s,ils')
» view([37.5,30])
» xlabel('time(s)'),ylabel('s_1(sec^{-1})')
» title('CURRENT AS FUNCTION OF MODES')
```

Ils is a matrix that contains all the computed responses, one per column

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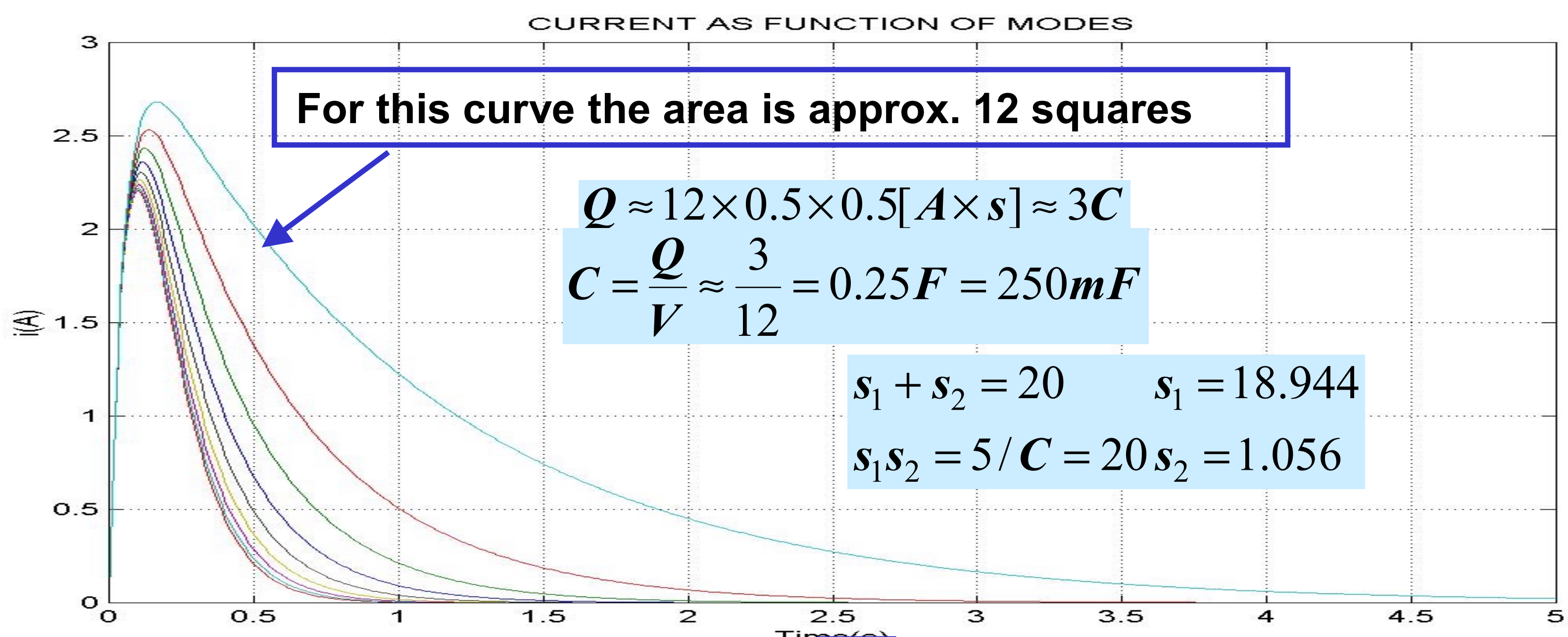
Estimate charge by estimating area under the curve

```
%example6p14.m
%displays current as function of roots in characteristic equation
% il(t)=(60/(s2-s1))*(exp(-s1*t)-exp(s2*t));
% with restriction s1+s2=20, s1~=s2.
t=linspace(0,5,500)'; %set display interval as a column vector
ils=[]; %reserve space to store curves
for s1=1:19
   s2=20-s1;
   if s1~=s2
      il=(60/(s2-s1))*(exp(-s1*t)-exp(-s2*t));
      ils=[ils il]; %save new trace as a column in matrix
   end
end
%now with one command we plot all the columns as functions of time
plot(t,ils), grid, xlabel('Time(s)'),ylabel('i(A)')
title('CURRENT AS FUNCTION OF MODES')
```



$$Q \approx 12 \times 0.5 \times 0.5 [A \times s] \approx 3C$$

$$C = \frac{Q}{V} \approx \frac{3}{12} = 0.25F = 250mF$$

$$s_1 + s_2 = 20 \qquad s_1 = 18.944$$

$$s_1 s_2 = 5/C = 20 \quad s_2 = 1.056$$

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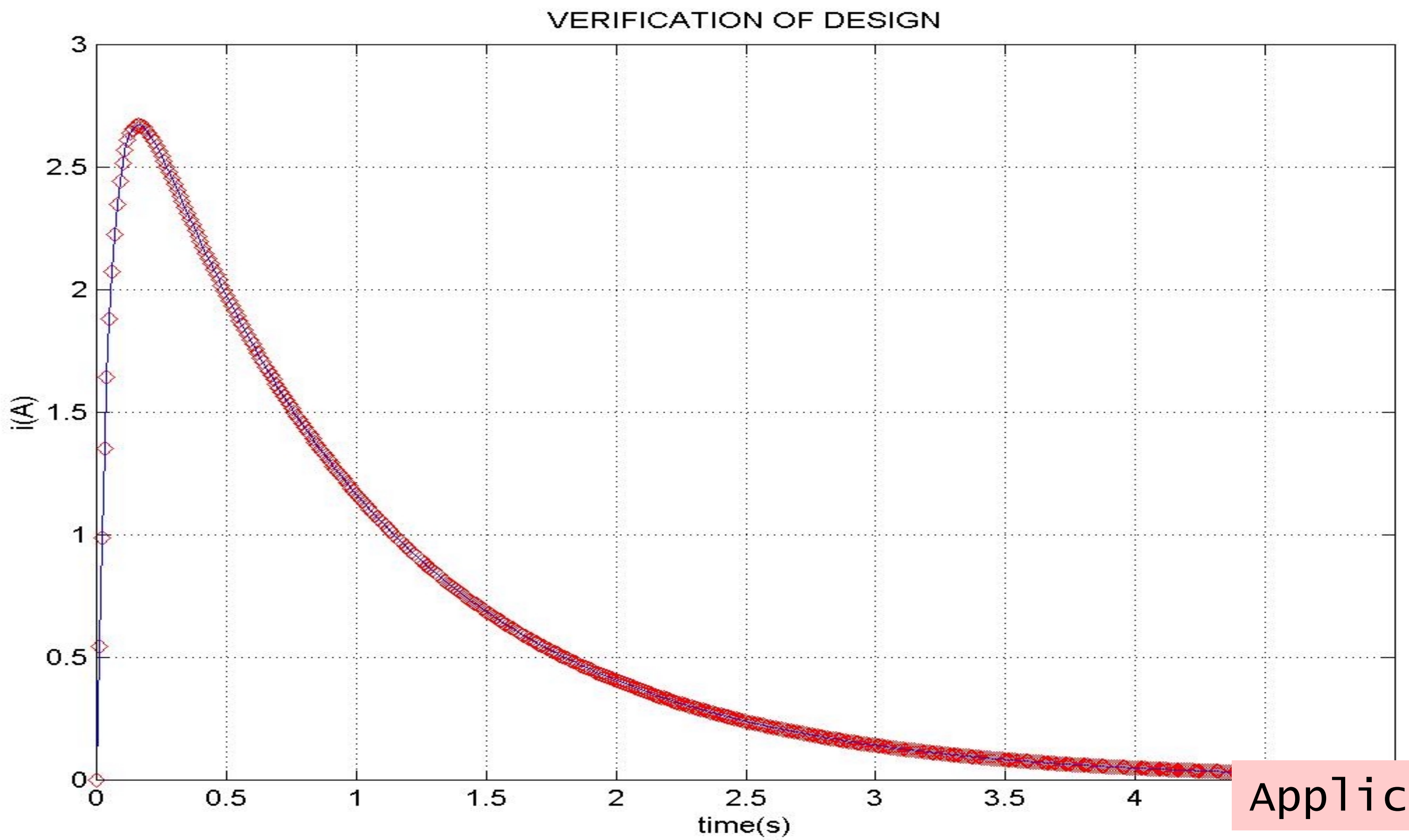
```
%verification
 s1=18.944;
 s2=20-s1;
 il=(60/(s2-s1))*(exp(-s1*t)-exp(-s2*t));
 plot(t,il,'rd',t,il,'b'), grid, xlabel('time(s)'), ylabel('i(A)')
 title('VERIFICATION OF DESIGN')
```



Applications