# CHAPTER 12

## LAPLACE TRANSFORM AND ITS APPLICATION IN CIRCUIT ANALYSIS



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# 12.1 Definition of the Laplace Transform

Pierre Simon Laplace (1749-1827) :

A French astronomer and mathematician
*First* presented the Laplace transform and its applications to differential equations in 1979.

# 12.1 Definition of the Laplace Transform

Definition:

$$L[f(t)] = F(s) = \int_{0^-}^{\infty} f(t)e^{-st}dt$$

$s = s + jw$ a complex variable

The Laplace transform is an integral transformation of a function f(t) from the time domain into the complex frequency domain, F(s).



# 12.1 Definition of the Laplace Transform

One-sided (unilateral) Laplace transform

Two-sided (bilateral) Laplace transform

$$L^{-1}[F(s)] = f(t) = \frac{1}{2p\,j}\int_{s_1 - jw}^{s_1 + jw} F(s)e^{st}ds$$

Look-up table , an easier way for circuit application

$$f(t) \Leftrightarrow F(s)$$

# 12.1 Definition of the Laplace Transform

Similar to the application of phasor transform to solve the steady state AC circuits , Laplace transform can be used to transform the time domain circuits into S domain circuits to simplify the solution of integral differential equations to the manipulation of a set of algebraic equations.



# 12.2 Useful Laplace Transform Pairs

| **Functions** | **f(t) , $t>0^-$** | **F(s)** |
|---|---|---|
| impulse | $d(t)$ | **1** |
| step | $u(t)$ | $\frac{1}{S}$ |
| ramp | t | $\frac{1}{S^2}$ |
| exponential | $e^{-at}$ | $\frac{1}{S+a}$ |
| sine | $\sin wt$ | $\frac{w}{S^2+w^2}$ |

# 12.2 Useful Laplace Transform Pairs

| Functions | f(t) , t>$0^-$ | F(s) |
|---|---|---|
| cosine | $\cos wt$ | $\frac{S}{S^2+w^2}$ |
| damped ramp | $te^{-at}$ | $\frac{1}{(S+a)^2}$ |
| damped sine | $e^{-at}\sin wt$ | $\frac{w}{(S+a)^2+w^2}$ |
| damped cosine | $e^{-at}\cos wt$ | $\frac{S+a}{(S+a)^2+w^2}$ |



# 12.2 Useful Laplace Transform Pairs

- $L\left[\frac{d}{dt}f(t)\right] = sF(s) - f(0^-)$
- $L\left[\int_{0^-}^{t} f(t)dt\right] = \frac{F(s)}{S}$
- $L[f(t-a)u(t-a)] = e^{-as}F(s),\ a>0$
- $L\left[e^{-at}f(t)\right] = F(s+a)$
- $L[f(at)] = \frac{1}{a}F(\frac{s}{a}),\ a>0$
- $\lim_{t\to 0^+}[f(t)] = \lim_{s\to\infty} sF(s)$
- $\lim_{t\to\infty}[f(t)] = \lim_{s\to 0} sF(s)$

# 12.2 Useful Laplace Transform Pairs

Example Use the Laplace transform to solve the differential equation.

$$\frac{d^2v}{dt^2}+6\frac{dv}{dt}+8v=2u(t)$$

$$v(0)=1$$

$$v'(0)=-2$$

Take Laplace transfrom

$$\left[s^2V(s)-sv(0)-v'(0)\right]+6\left[sV(s)-v(0)\right]+8V(s)=\frac{2}{s}$$



# 12.2 Useful Laplace Transform Pairs

$$\left[s^2V(s)-sv(0)-v'(0)\right]+6\left[sV(s)-v(0)\right]+8V(s)=\frac{2}{s}$$

$$(s^2+6s+8)V(s)=\frac{s^2+4s+2}{s}$$

$$\therefore V(s)=\frac{s^2+4s+2}{s(s^2+6s+8)}=\frac{s^2+4s+2}{s(s+2)(s+4)}$$

$$v(t)=\frac{1}{4}(1+2e^{-2t}+e^{-4t})u(t)$$

## 12.3 Circuit Analysis in S Domain

(1) KCL , $\sum_{n} i_k(t) = 0$ , for any node.

Take Laplace Transform

$$\sum_{n} I_k(s) = 0 \text{ , for any node.}$$

(2) KVL , $\sum_{m} v_k(t) = 0$ , for any loop.

Take Laplace Transform

$$\sum_{m} V_k(s) = 0 \text{ , for any loop.}$$



## 12.3 Circuit Analysis in S Domain

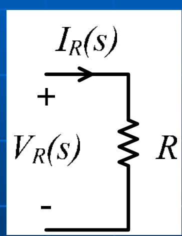
(3) Circuit Component Models

resistor

$$v_R(t) = Ri_R(t)$$

$$V_R(s) = RI_R(s)$$

$$I_R(s) = GV_R(s)$$



# 12.3 Circuit Analysis in S Domain

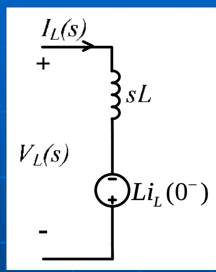
inductor

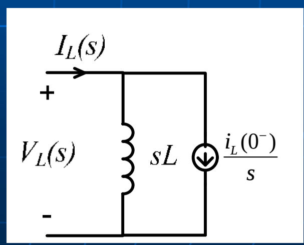
$$v_L(t) = L\frac{di_L}{dt}$$

$$i_L(t) = i_L(0^-) + \frac{1}{L}\int_{0^-}^{t} v_L(t)dt$$

$$V_L(s) = sLI_L(s) - Li_L(0^-)$$

$$I(s) = \frac{V_L(s)}{sL} + \frac{i_L(0^-)}{s}$$






# 12.3 Circuit Analysis in S Domain

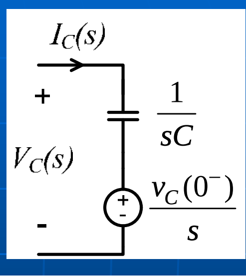
capacitor

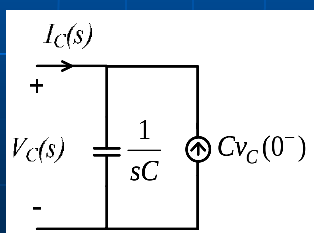
$$i_C = C\frac{dv_C}{dt}$$

$$v_C(t) = v_C(0^-) + \frac{1}{C}\int_{0^-}^{t} i_C(t)dt$$

$$I_C(s) = sCV_C(s) - Cv_c(0^-)$$

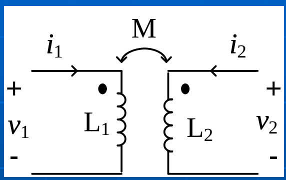
$$V_C(s) = \frac{v_C(0^-)}{s} + \frac{1}{sC}I_C(s)$$



# 12.3 Circuit Analysis in S Domain

Coupling inductors

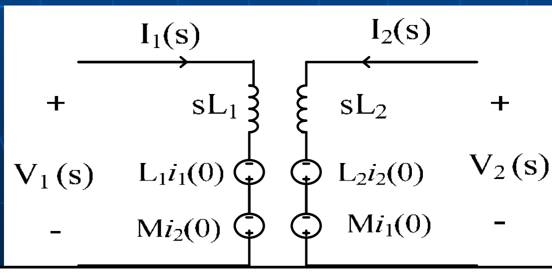



$$v_1 = L_1 \frac{di_1}{dt} + M \frac{di_2}{dt}$$

$$v_2 = M \frac{di_1}{dt} + L_2 \frac{di_2}{dt}$$

$V_1(s)=L_1SI_1(s)-L_1 i_1(0)+MSI_2(s)-Mi_2(0)$

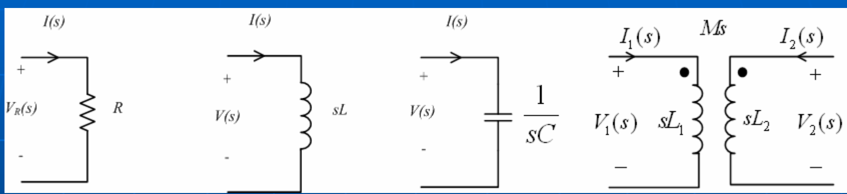
$V_2(s)= MSI_1(s)- Mi_1(0)+L_2SI_2(s)-L_2 i_2(0)$






# 12.3 Circuit Analysis in S Domain

For zero initial conditions




$$\text{impedance} \;@\; \frac{V(s)}{I(S)} = Z(s)$$

$$\text{admittance} \;@\; \frac{I(S)}{V(s)} = Y(s) = \frac{1}{Z(s)}$$

$$V(s) = Z(s)I(s) \quad ohm's\ law\ in\ s-domain$$

# 12.3 Circuit Analysis in S Domain

The elegance of using the Laplace transform in circuit analysis lies in the automatic inclusion of the initial conditions in the transformation process, thus providing a complete (transient and steady state) solution.



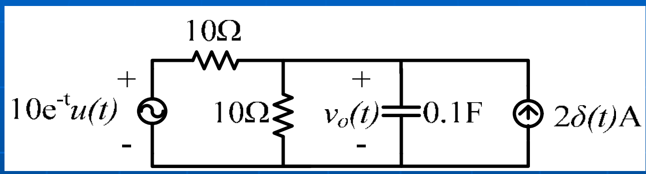
# 12.3 Circuit Analysis in S Domain

Circuit analysis in s domain

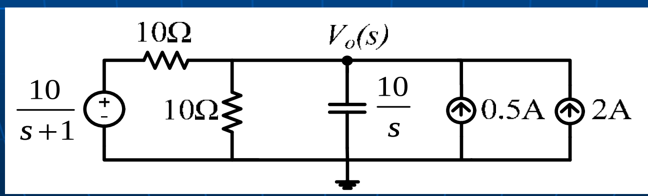
- Step 1 : Transform the time domain circuit into s-domain circuit.
- Step 2 : Solve the s-domain circuit.
  e.g. Nodal analysis or mesh analysis.
- Step 3 : Transform the solution back into time domain.

# 12.3 Circuit Analysis in S Domain

Example Find $v_o(t)$ given $v_o(0)=5V$

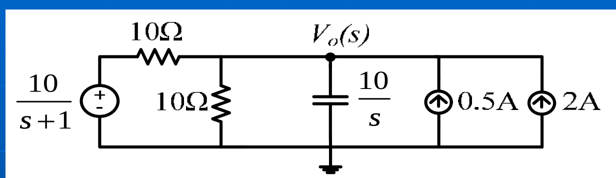



S-domain equivalent circuit






# 12.3 Circuit Analysis in S Domain




Nodal analysis

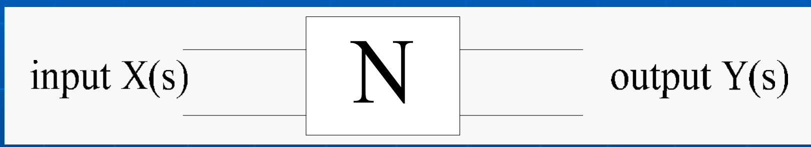
$$\frac{\frac{10}{s+1}-V_o(s)}{10}+2+0.5=\frac{V_o(s)}{10}+\frac{V_o(s)}{10/s}$$

$$\therefore V_o(s)=\frac{25s+35}{(s+1)(s+2)}=\frac{10}{s+1}+\frac{15}{s+2}$$

$$\therefore v_o(t)=(10e^{-t}+15e^{-2t})u(t) \ \ \text{V}$$

# 12.4 The Transfer Function and the Convolution Integral

Given a linear circuit N in s domain as shown below




Transfer function H(s) is defined as

$$H(s) = \frac{Y(s)}{X(s)}\Bigg|_{\text{With zero initial condition}}$$



# 12.4 The Transfer Function and the Convolution Integral

$$If\ \ Y(s) = V_o(s)\ ,\ X(s) = V_i(s)\ ;\ then\ H(s) = voltage\ gain$$

$$If\ \ Y(s) = I_o(s)\ ,\ X(s) = I_i(s)\ ;\ then\ H(s) = current\ gain$$

$$If\ \ Y(s) = V(s)\ ,\ X(s) = I(s)\ ;\ then\ H(s) = impedance$$

$$If\ \ Y(s) = I(s)\ ,\ X(s) = V(s)\ ;\ then\ H(s) = admittance$$

# 12.4 The Transfer Function and the Convolution Integral

Given the transfer funtion H(s) and input X(s) , then Y(s)=H(s)X(s)

If the input is $\delta$(t) , then X(s)=1 and Y(s)=H(s)

Hence , the physical meaning of H(s) is in fact the Laplace transform of the impulse response of the corresponding circuit.



# 12.4 The Transfer Function and the Convolution Integral

Y(s)=H(s)X(s) , in s-domain

$$y(t) = \int_{-\infty}^{\infty} h(t-\tau)x(\tau)d\tau \triangleq h(t) * x(t)$$ in time domain

Geometrical interpretation of finding the convolution integral value at t=$t_k$ is based on :

# 12.4 The Transfer Function and the Convolution Integral

(1)Approximating the input function by using a series of impulse functions.

(2)Shifting property of linear systems input

x(t)→output y(t)

x(t- $\tau$ )→output y(t- $\tau$ )

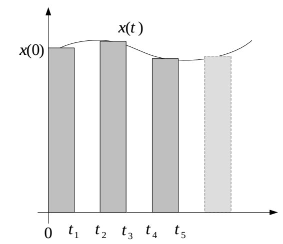
(3)Superposition theorem for linear systems

(4)Definition of integral : finding the area

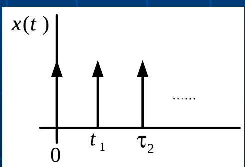


# 12.4 The Transfer Function and the Convolution Integral

(1)Input x( $\tau$ ) is approximated using impulse functions , x( $\tau$ )=0 , for $\tau$ <0




| *instant* $t_k$, | $x(t_k)$ *value* , | *area* |
|---|---|---|
| $t_0 = 0$ , | $x(0)$ | , $x(0)\Delta t$ |
| $t_1 = \Delta t$ , | $x(t_1)$ | , $x(t_1)\Delta t$ |
| $t_2 = 2\Delta t$ , | $x(t_2)$ | , $x(t_2)\Delta t$ |
| $t_3 = 3\Delta t$ , | $x(t_3)$ | , $x(t_3)\Delta t$ |




$$x(t) \cong f_0\delta(t) + f_1\delta(t-t_1) + f_2\delta(t-t_2) + \cdots$$

$$\cong \sum_{k=0}^{\infty} x(k\Delta t)\Delta t\,\delta(t-k\Delta t)$$

## 12.4 The Transfer Function and the Convolution Integral

(2) Use the linearity property

$$
\begin{array}{lcl}
\textit{input} & \longrightarrow & \textit{output(response)} \\
x(0)\Delta t\,\delta(t) & \longrightarrow & x(0)\Delta t\,h(t) \\
x(t_1)\Delta t\,\delta(t-t_1) & \longrightarrow & x(t_1)\Delta t\,h(t-t_1) \\
x(t_2)\Delta t\,\delta(t-t_2) & \longrightarrow & x(t_2)\Delta t\,h(t-t_2) \\
\vdots & & \vdots \\
\textit{up to } t = t_k & &
\end{array}
$$



## 12.4 The Transfer Function and the Convolution Integral

(3) Use superposition theorem to find the total approximate response

$$\hat{y}(t_k) = \sum_{k=0}^{n} x(k\Delta t)\Delta t \; h(t_k - k\Delta t)$$

$$n = integer[\frac{t_k}{\Delta t}]$$

# 12.4 The Transfer Function and the Convolution Integral

(4) Take the limit , $\Delta\tau \rightarrow d\tau$ , $\hat{y}(t_k) \longrightarrow y(t_k)$

$$y(t_k) = \int_{-\infty}^{\infty} x(t)h(t_k - t)dt$$

Due to causality principle , h(t- $\tau$ )=0 for $t \geq t_k$
and x( $\tau$ )=0 for $\tau$ <0

$$= \int_{0}^{t_k} h(t_k - t)x(t)dt$$



# 12.4 The Transfer Function and the Convolution Integral

*Example:*

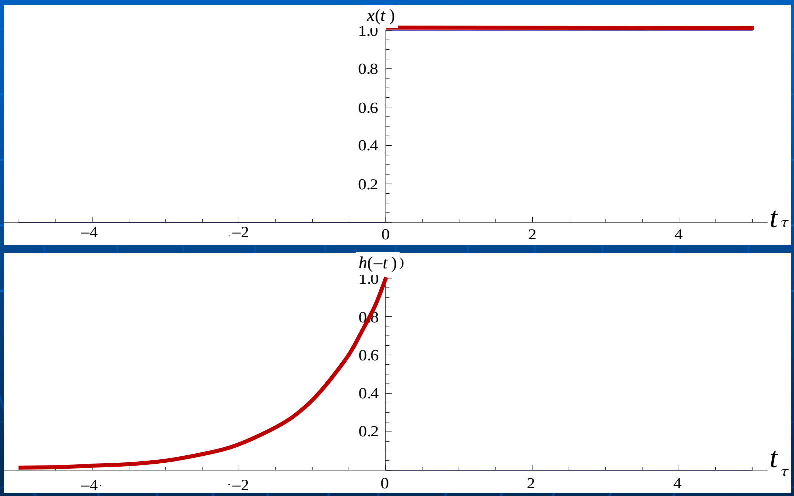
$$Given\ x(t) = u(t)\ ,\ h(t) = e^{-t}u(t)\ ,\ find\ y(4)\ ,$$

$$y(t) = \int_{-\infty}^{\infty} h(t - t)x(t)dt$$

$$\therefore\ y(4) = \int_{-\infty}^{\infty} h(4 - t)x(t)dt$$

# 12.4 The Transfer Function and the Convolution Integral

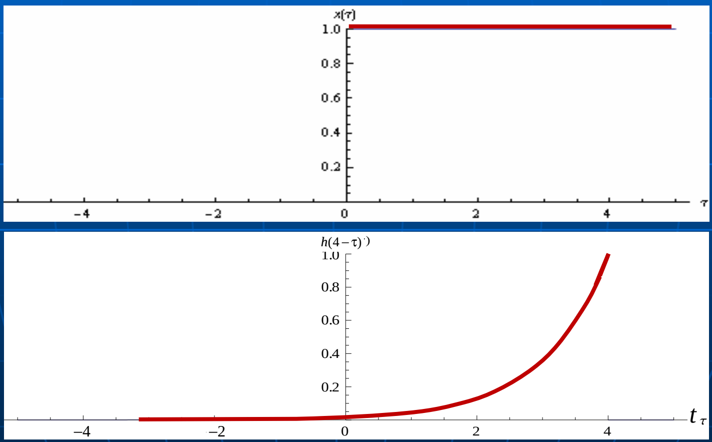
Step1.





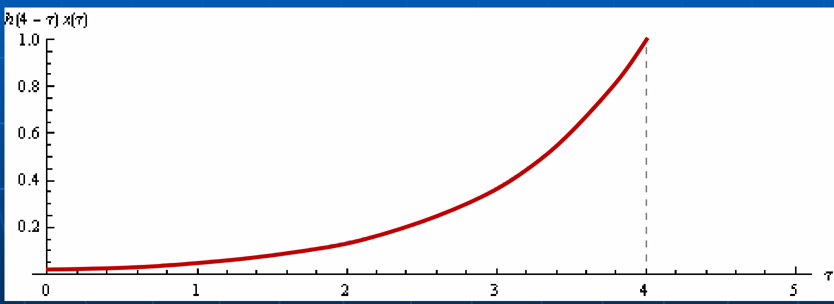

# 12.4 The Transfer Function and the Convolution Integral

Step2. Shift to $t_k=4$



# 12.4 The Transfer Function and the Convolution Integral

Step3. Find the product h(4- $\tau$ )x( $\tau$ )






# 12.4 The Transfer Function and the Convolution Integral

Step4. Find the integral (area)

$$y(4)=\int_0^4 e^{-(4-t)}dt = e^{-4}\int_0^4 e^t\,dt = e^{-4}\,e^t\Big|_0^4$$

$$= e^{-4}(e^4-1)=(1-e^{-4})$$

Step5. Check

$$Y(s)=H(s)X(s)=\frac{1}{s+a}\times\frac{1}{s}=\frac{\frac{-1}{a}}{s+a}+\frac{\frac{1}{a}}{s}$$

$$\therefore y(t)=\frac{1}{a}(1-e^{-t}),\ a=1$$

$$\therefore y(4)=(1-e^{-4})$$

## 12.5 The Transfer Function and the Steady State Sinusoidal Response

From definition of transfer function

$$H(s) = \frac{Y(s)}{X(s)}$$

$$\Rightarrow \quad Y(s) = H(s)X(s)$$

Assume input *X*(*t*)=Acos(*wt*+ *Φ*) and H(s) is given, then one can get the steady state solution without needing a separate phasor analysis.



## 12.5 The Transfer Function and the Steady State Sinusoidal Response

*proof* : $X(t) = A\cos f \cos \omega t - A\sin f \sin \omega t$

$$\therefore X(s) = \frac{A(\cos f\, s - \sin f \omega)}{s^2 + \omega^2}$$

$$\therefore Y(s) = H(s)X(s)$$

$$= \frac{K_1}{s - j\omega} + \frac{K_1^*}{s + j\omega}$$

$$+ \sum \textit{other terms due to poles}$$

*under steady state* :

$$\therefore Y_{ss}(s) = \frac{K_1}{s - j\omega} + \frac{K_1^*}{s + j\omega}$$

$$K_1 = \left. \frac{H(s)A(s\cos f - \omega \sin f)}{s + j\omega} \right|_{s = j\omega}$$

$$= \frac{1}{2} H(j\omega) A e^{jf}$$

## 12.5 The Transfer Function and the Steady State Sinusoidal Response

$$Let \quad H(j\omega) = |H(j\omega)|\, e^{jq(\omega)}$$

*and take inverse Laplace transform*

$$Then \quad y_{ss}(t) = A|H(j\omega)|\cos[\omega t + f + q(\omega)]$$

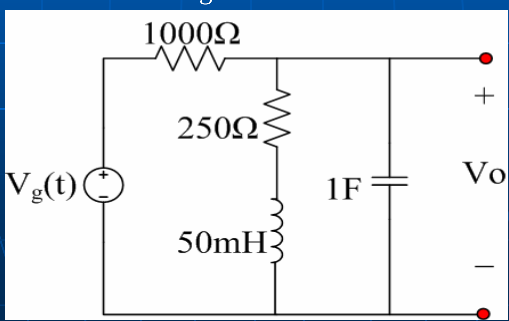
$$i.e. \quad P(X(t)) = A\angle f$$

$$then \quad P(y_{ss}(t)) = A|H(j\omega)|\,\underline{\angle f + q(\omega)}$$

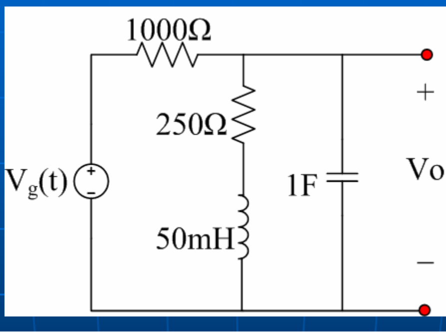


## 12.5 The Transfer Function and the Steady State Sinusoidal Response

Example : The transfer function H(s) of the circuit given below is known.
Find the steady state solution of $V_o(t)$ for the given $V_g(t)$.



# 12.5 The Transfer Function and the Steady State Sinusoidal Response




$$H(s) = \frac{1000(s+5000)}{s^2 + 6000s + 25\cdot 10^6}$$

$$V_g(t) = 120\cos(5000t + 30^\circ)\ V$$



# 12.5 The Transfer Function and the Steady State Sinusoidal Response

*Solution*: *Let* $s = j\omega = j5000$

$$\textit{Evaluate}\ \ H(j5000) = \frac{1000(j5000+5000)}{-25\times10^6 + j5000(6000) + 25\times10^6}$$

$$= \frac{\sqrt{2}}{6}\angle -45^\circ$$

$$\textit{Then}\ \ V_o^{ss}(t) = 120\times\frac{\sqrt{2}}{6}\cos(5000t + 30^\circ - 45^\circ)$$

$$= 20\sqrt{2}\cos(5000t - 15^\circ)\ V$$

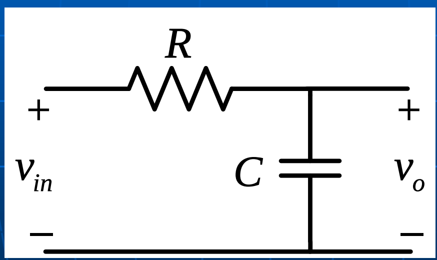
# 12.5 The Transfer Function and the Steady State Sinusoidal Response

- In theory , the relationship between H(s) and H($jw$) provides a link between the time domain and the frequency domain.
- In some cases , we can determine H($jw$) experimentally and then construct H(s) from the data.



# 12.5 The Transfer Function and the Steady State Sinusoidal Response

Example: Find the impulse response of the following circuit.



# 12.5 The Transfer Function and the Steady State Sinusoidal Response

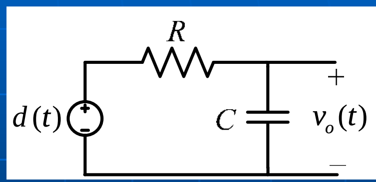
(a) Time domain solution

$$RC\frac{dv_o}{dt} + v_o = d(t)$$

$$At\ \ t = 0^-,\ \ v_o(0^-) = 0$$

$$At\ \ t = 0^+,\ \ v_o(0^+) = \frac{1}{C}\int_0^t \frac{d(t)}{R}\,dt$$

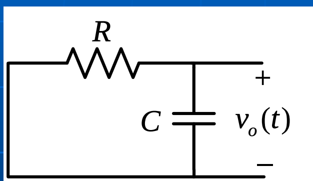
$$= \frac{1}{RC}\ \ V$$






# 12.5 The Transfer Function and the Steady State Sinusoidal Response

$$For\ t > 0^+,\ d(t) = 0$$




$$,\quad v(0^+) = \frac{1}{RC}$$

$$RC\frac{dv_o}{dt} + v_o = 0$$

$$\therefore\ v_o(t) = \frac{1}{RC}e^{-\frac{t}{RC}}u(t)$$

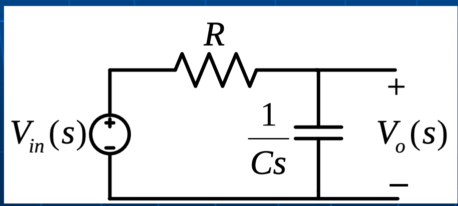
## 12.5 The Transfer Function and the Steady State Sinusoidal Response

(b) s-domain solution

Find the transfer function

$$H(s) = \left.\frac{V_o(s)}{V_{in}(s)}\right|_{zero\ I.C.}$$

Transform into s-domain circuit



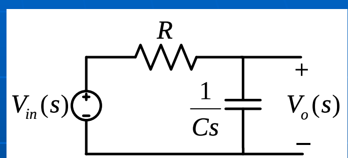



## 12.5 The Transfer Function and the Steady State Sinusoidal Response

$$\therefore\ H(s) = \frac{V_o(s)}{V_{in}(s)} = \frac{\frac{1}{Cs}}{R + \frac{1}{Cs}} = \frac{1}{1 + RCs}$$

$$\therefore\ h(t) = L^{-1}[H(s)]$$

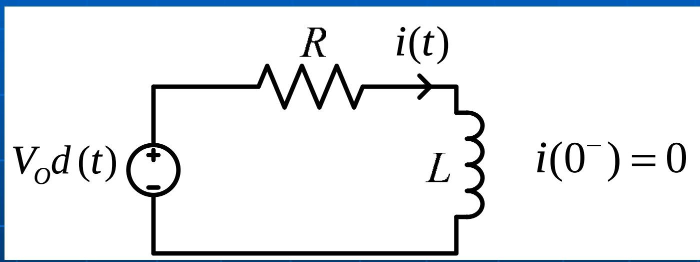
$$= \frac{1}{RC} e^{-\frac{t}{RC}} u(t)$$




Same answer.

# 12.6 The Impulse Function in Circuit Analysis

Example 1: Impulse voltage source excitation





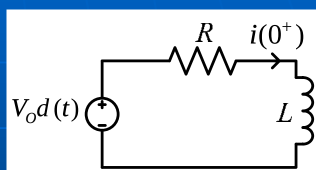

# 12.6 The Impulse Function in Circuit Analysis

(a) Time domain solution

$$At\ t = 0,\ i(0^-) = 0$$

$$\therefore\ i(0^+) = \frac{1}{L}\int_{0^-}^{t} V_O d(x)\, dx$$

$$= \frac{V_O}{L} \quad (A)$$




The impulse voltage source has stored energy, $\frac{1}{2}L(i(0^+))^2$ , in the inductor as an initial current in an infinitesimal moment.

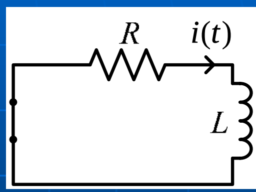
# 12.6 The Impulse Function in Circuit Analysis

For $t > 0^+, \; d(t) = 0$

$$L\frac{di}{dt} + Ri = 0 \;, \; natural \; response$$

$$i(0^+) = \frac{V_O}{L} \;\; A$$

$$\therefore \; i(t) = \frac{V_O}{L} e^{-t/t} u(t) \;, \;\; t = \frac{L}{R}$$




Note that the impulse source just builds up an initial inductor current but does not contribute to any forced response.

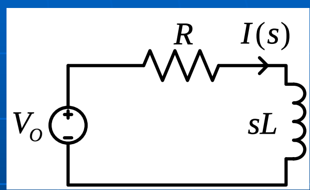


# 12.6 The Impulse Function in Circuit Analysis

(b) s-domain solution

$$\therefore \; I(s) = \frac{V_O}{R + sL} = \frac{V_O / L}{s + \frac{R}{L}}$$

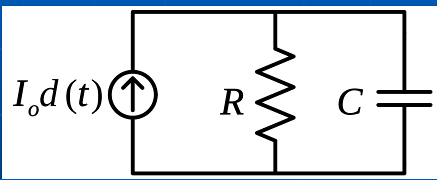
$$\therefore \; i(t) = \frac{V_O}{L} e^{-t/t} u(t)$$




Same answer but much easier.

# 12.6 The Impulse Function in Circuit Analysis

Example 2: Impulse current source excitation




$, \quad v(0^-) = 0$

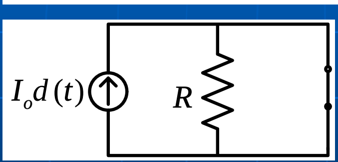


# 12.6 The Impulse Function in Circuit Analysis

(a) Time domain solution

$At \ t = 0, \ v(0^-) = 0$

$\therefore \ v(0) = 0 \ , \ short \ circuit$




$$v(0^+) = \frac{1}{C}\int_0^t I_o d(x)\, dx$$

$$= \frac{I_o}{C}$$

The impulse current source has stored energy, $\frac{1}{2}C(v(0^+))^2$ , in the capacitor as an initial voltage in an infinitesimal moment.

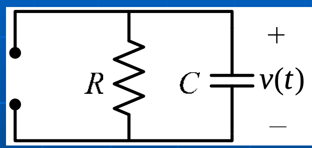
# 12.6 The Impulse Function in Circuit Analysis

$For\ t > 0^+,\ d(t) = 0,\ open\ circuit$

$$C\frac{dv}{dt} + \frac{v}{R} = 0\ ,\ natural\ response$$

$$v(0^+) = \frac{I_o}{C}$$

$$\therefore\ v(t) = \frac{I_o}{C} e^{-\frac{t}{t}} u(t)\ ,\ t = RC$$



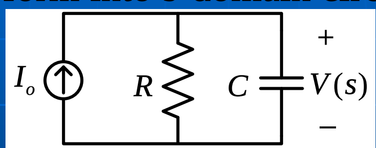

Note that the impulse current just builds up an initial capacitor voltage but does not contribute to any forced response.



# 12.6 The Impulse Function in Circuit Analysis

(b) s-domain solution

Transform into s-domain circuit




$$\therefore\ V(s) = I_o \frac{R \times \frac{1}{Cs}}{R + \frac{1}{Cs}} = \frac{I_o / C}{s + \frac{1}{RC}}$$

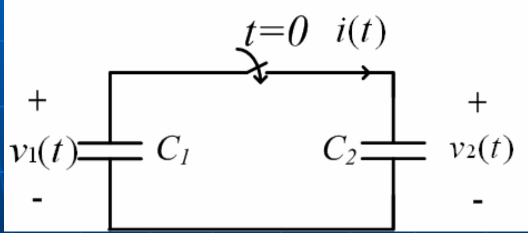
$$\therefore\ v(t) = \frac{I_o}{C} e^{-\frac{t}{t}} u(t)$$

Same answer but much easier.

## 12.6 The Impulse Function in Circuit Analysis

Example 3: Impulse caused by switching operation

The switch is closed at t=0 in the following circuit.




$v_1(0^-) = V_o$

$v_2(0^-) = 0$

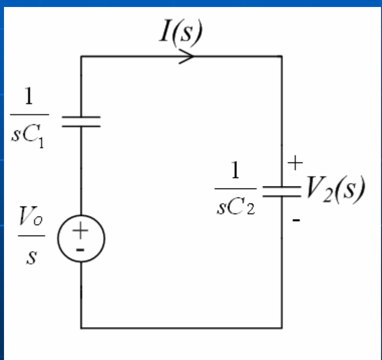
$i(0^-) = 0$

$Note\ that\ v_1(0^-) \neq v_2(0^-)$



## 12.6 The Impulse Function in Circuit Analysis

Transform into s-domain




$$I(s) = \frac{\frac{V_o}{s}}{1/sC_1 + 1/sC_2} @ V_o \cdot C_e$$

$$C_e = \frac{C_1 \cdot C_2}{C_1 + C_2},\ V_2(s) = \frac{V_o \cdot C_e}{sC_2} = \frac{V_o}{s} \cdot \frac{C_1}{C_1 + C_2}$$

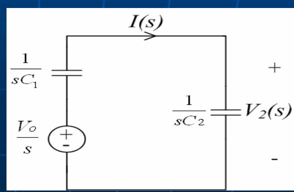
$$\therefore\ i(t) = V_o C_e\, d(t)$$

$$v_2(t) = \frac{C_1}{C_1 + C_2} V_o$$

# 12.6 The Impulse Function in Circuit Analysis

At t=0 , a finite charge of $C_1$ is transferred to $C_2$ instantaneously.

Note that , as the switch is closed , the voltage across $C_2$ does not jump to $V_o$ of $C_1$ but to its final value of the two paralleled capacitors.






# 12.6 The Impulse Function in Circuit Analysis

$$\text{Note}\quad Q_2 = C_2 \cdot V_2 = \frac{C_1 \cdot C_2}{C_1 + C_2} V_o \;,\; t > 0^+$$

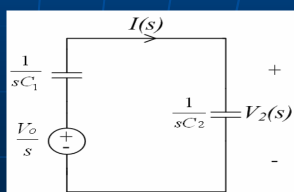
$$Q_1 = C_1 \cdot V_2 = \frac{C_1^2}{C_1 + C_2} V_o \;,\; t > 0^+$$

$$Q_1 + Q_2 = C_1 V_o \;,\; t > 0^+$$

$$\text{Also , at } t = 0^- \;,\; Q_1 = C_1 V_o \;,\; Q_2 = 0$$

$$\therefore\; Q_1 + Q_2 = C_1 V_o$$

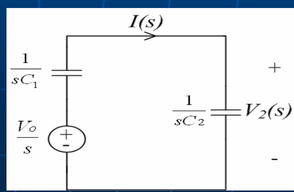
*Conservation of charge.*



# 12.6 The Impulse Function in Circuit Analysis

If we consider charged capacitors as voltage sources , then we should not connect two capacitors with unequal voltages in parallel.

Due to violation of KVL , an impulse will occur which may damage the components.

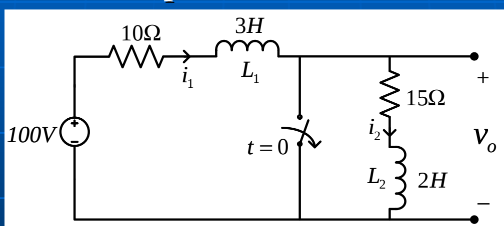





# 12.6 The Impulse Function in Circuit Analysis

Example 4: Impulse caused by switching operation

The switch is opened at $t$ = 0 in the following circuit.



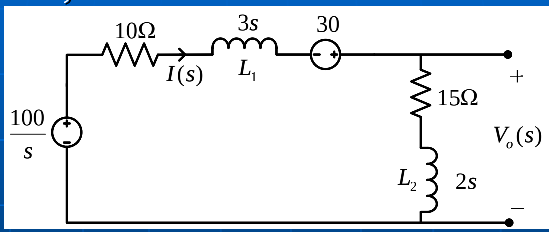

*At* $t = 0^-$, *steady state solution*

$$i_1(0^-) = \frac{100V}{10\Omega} = 10\ A$$

$$i_2(0^-) = 0\ A$$

# 12.6 The Impulse Function in Circuit Analysis

For t > 0, the S-domain circuit is




$$I(s)=\frac{(100/s)+30}{5s+25}=\frac{4}{s}+\frac{2}{s+5}$$

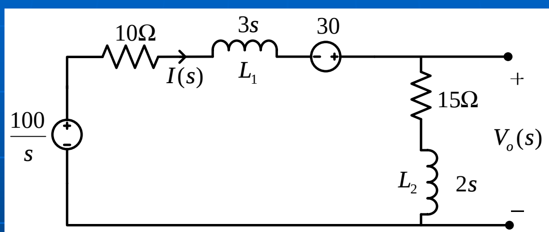
$$V_o(s)=I(s)\ (2s+15)=12+\frac{60}{s}+\frac{10}{s+5}$$

$$\therefore i(t)=(4+2e^{-5t})\ u(t)\ \ldots\ldots\ldots\ldots\ldots\ldots.(A)$$

$$v(t)=12d(t)+(60+10e^{-5t})\ u(t)\ \ldots..(B)$$



# 12.6 The Impulse Function in Circuit Analysis




$Note\ \ t=0\ ,\ i_{L1}(0^-)=10\ A\ ,\ i_{L2}(0^-)=0\ A$

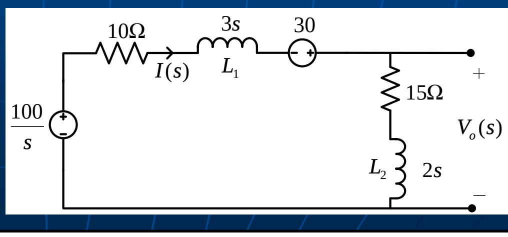
$t=0^+,\ from\ (A),\ i_{L1}(0^+)=6\ A\ ,\ i_{L2}(0^+)=6\ A$

$Also,\ from\ (B),\ there\ exists\ 12d(t)\ at\ v_o(t).$

# 12.6 The Impulse Function in Circuit Analysis

Thus, if we consider an inductor current as a current source, then two inductors with unequal currents should not be connected in series.

Due to violation of KCL, it will result in impulse voltage which may damage the components.






# SUMMARY

Objective 1 : Know the component models in s-domain.

Objective 2 : Be able to transform a time domain circuit into the s-domain circuit.

Objective 3 : Know how to analyze the s-domain circuit and transform the solution back to time domain.

## SUMMARY

Objective 4 : Understand the significance of transfer function and be able to calculate the transfer function from the s-domain circuit.

Objective 5 : Know the geometrical interpretation of convolution integral and be able to calculate the integral.



## SUMMARY

Objective 6 : Know the relation between the phasor solution technique for finding sinusoidal steady state solution and the s-domain solution technique .

Objective 7 : Know how to use s-domain solution technique to solve a circuit containing impulse sources or a switching circuit which may result in impulse functions.

# SUMMARY

Chapter problems :

13.13

13.20

13.27

13.36

13.57

13.85

13.88