Worksheet 6

To accompany Chapter 3.3 Using Laplace Transforms for Circuit Analysis

Colophon

This worksheet can be downloaded as a PDF file (https://cpjobling.github.io/eg-247-textbook/worksheets/worksheet6.pdf). We will step through this worksheet in class.

An annotatable copy of the notes for this presentation will be distributed before the third class meeting as **Worksheet 6** in the **Week 3: Classroom Activities** section of the Canvas site. I will also distribute a copy to your personal **Worksheets** section of the **OneNote Class Notebook** so that you can add your own notes using OneNote.

You are expected to have at least watched the video presentation of Chapter 3.3 (https://cpjobling.github.io/eg-247-textbook/laplace_transform/3/circuit_analysis) of the notes (https://cpjobling.github.io/eg-247-textbook) before coming to class. If you haven't watch it afterwards!

After class, the lecture recording and the annotated version of this worksheet will be made available through Canvas.

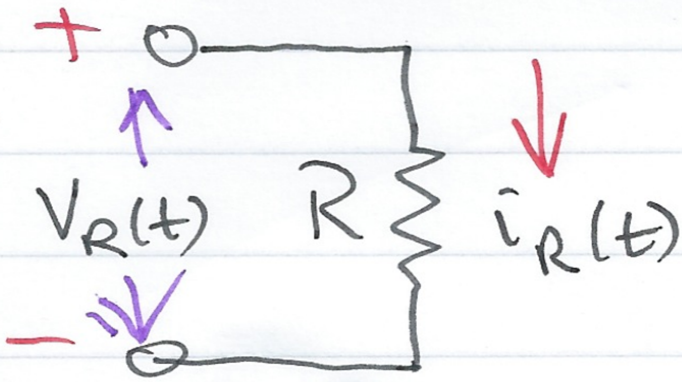
In [ ]:

```
% Matlab setup
format compact
clear all
```

Circuit Transformation from Time to Complex Frequency

Time Domain Model of a Resistive Network

Time Domain



$$v_R(t) = R\, i_R(t)$$

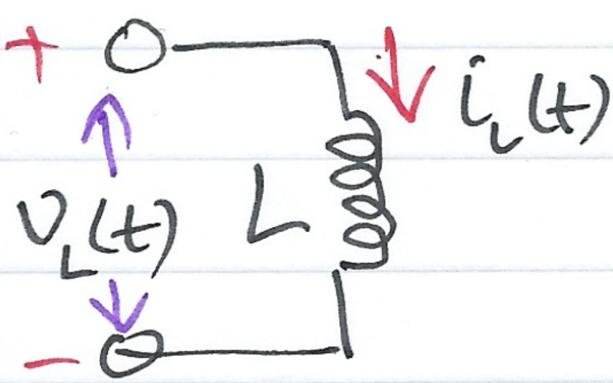
$$i_R(t) = \frac{v_R(t)}{R}$$

For the circuit shown, which of the following equations represent the Laplace transform of the current flowing through, and the voltage across, the resistor R?

-> Open poll

Time Domain Model of an Inductive Network

Time Domain



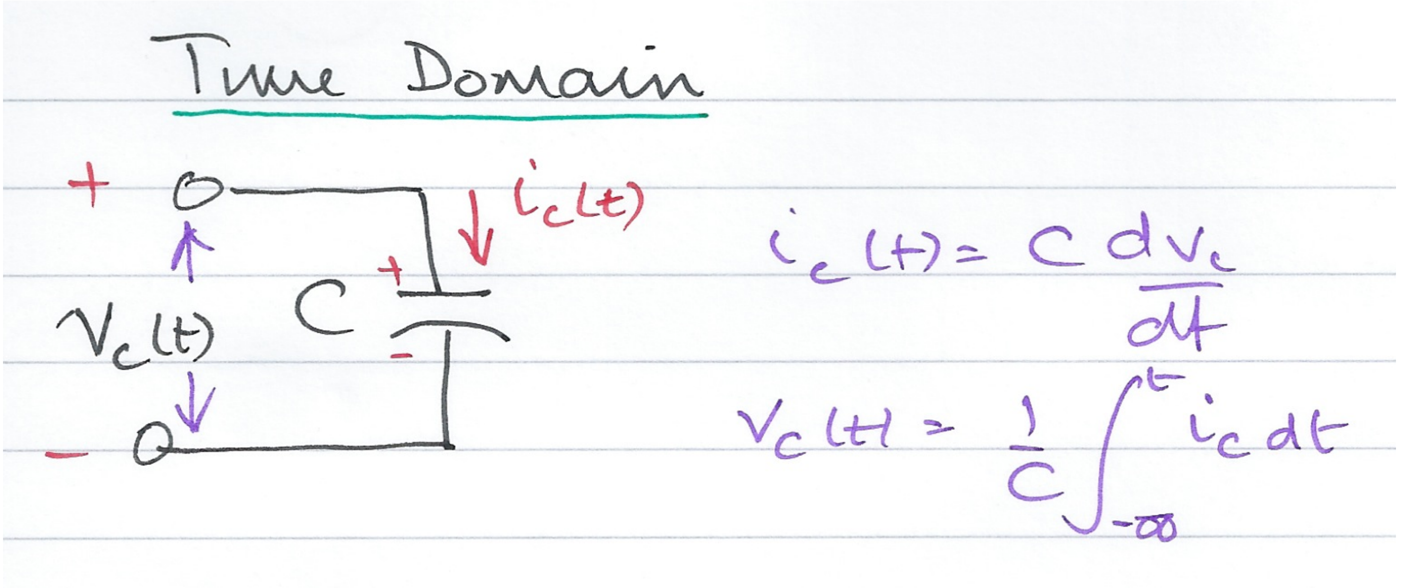
$$v_L(t) = L \frac{di_L}{dt}$$

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

For the circuit shown, which of the following equations represent the Laplace transform of the current flowing through, and the voltage across, the inductor L?

-> Open poll

Time Domain Model of a Capacitive Network



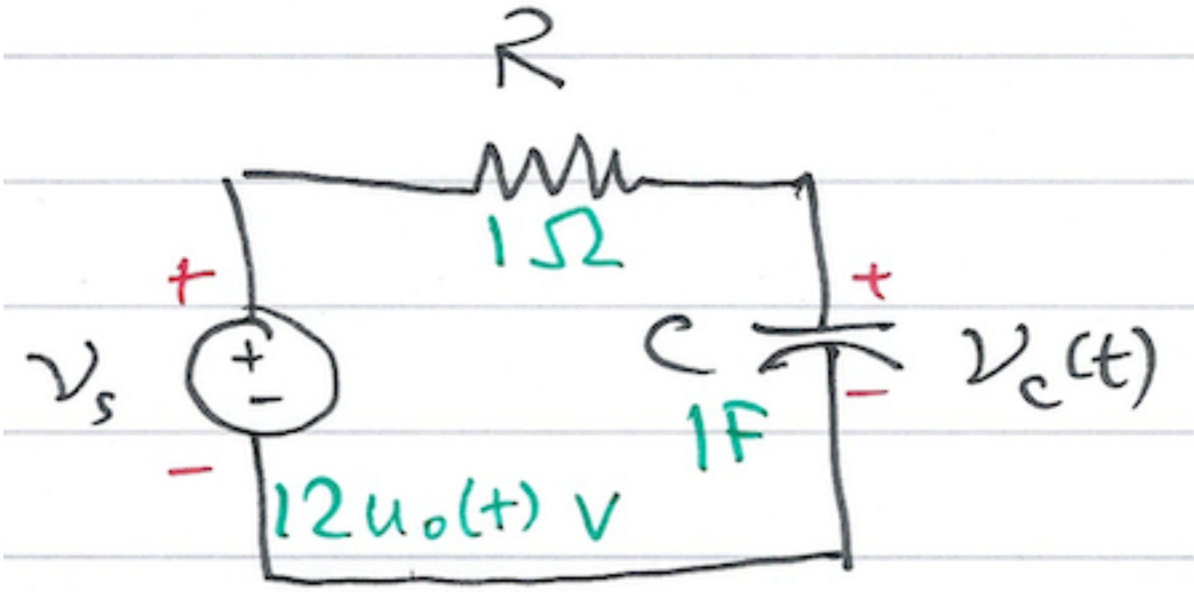
For the circuit shown, which of the following equations represent the Laplace transform of the current flowing through, and the voltage across, the capacitor C?

-> Open poll

Circuit Transformation from Time to Complex Frequency

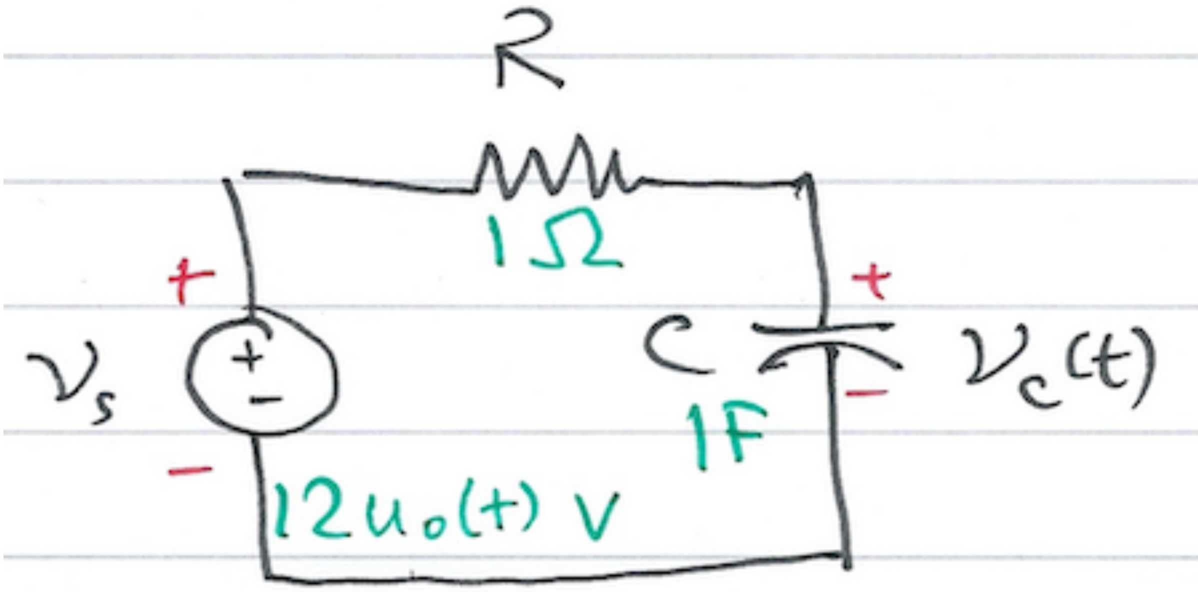
Example 1

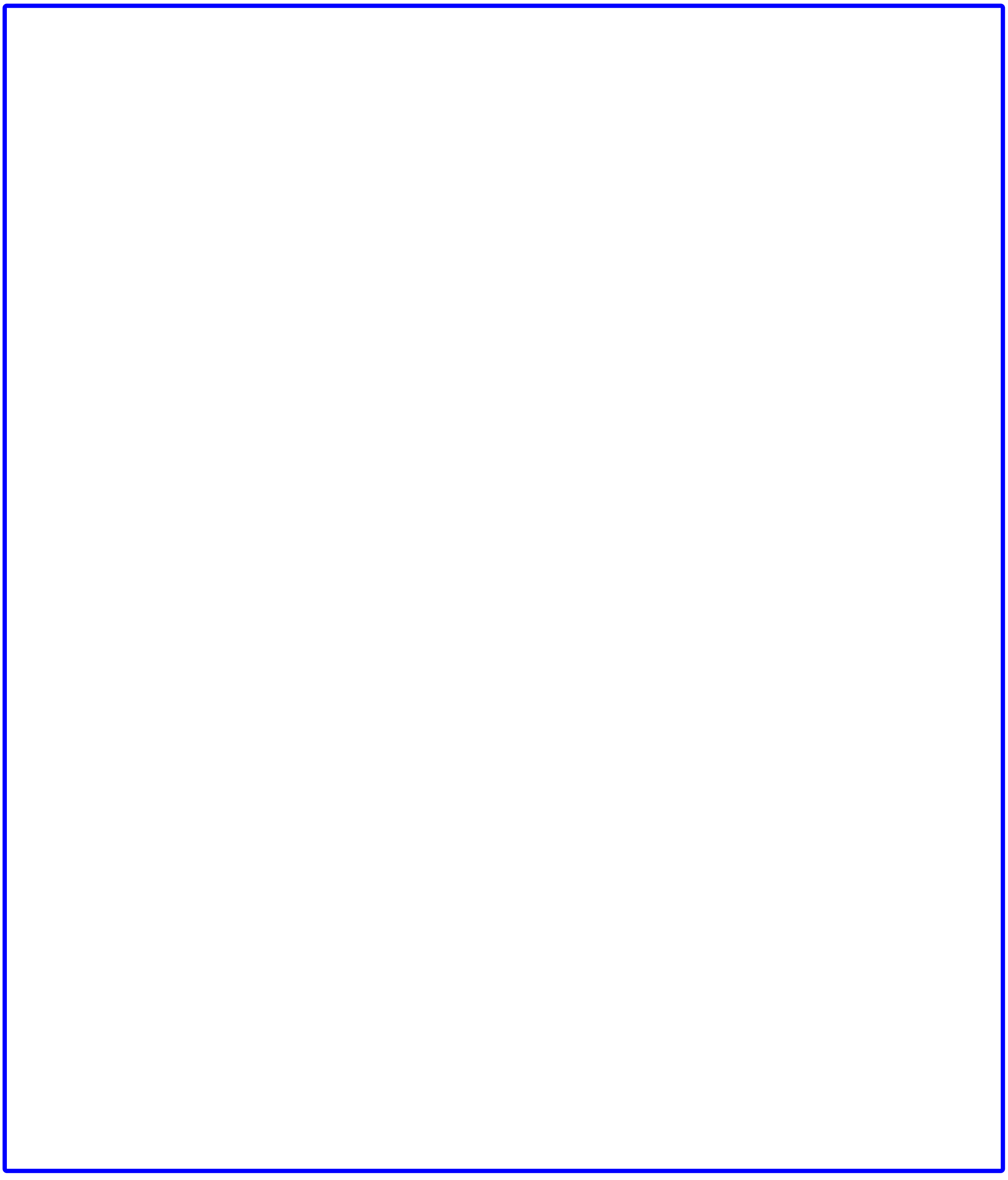
Use the Laplace transform method and apply Kirchoff's Current Law (KCL) to find the voltage $v_c(t)$ across the capacitor for the circuit below given that $v_c(0^-) = 6$ V.



Example 2

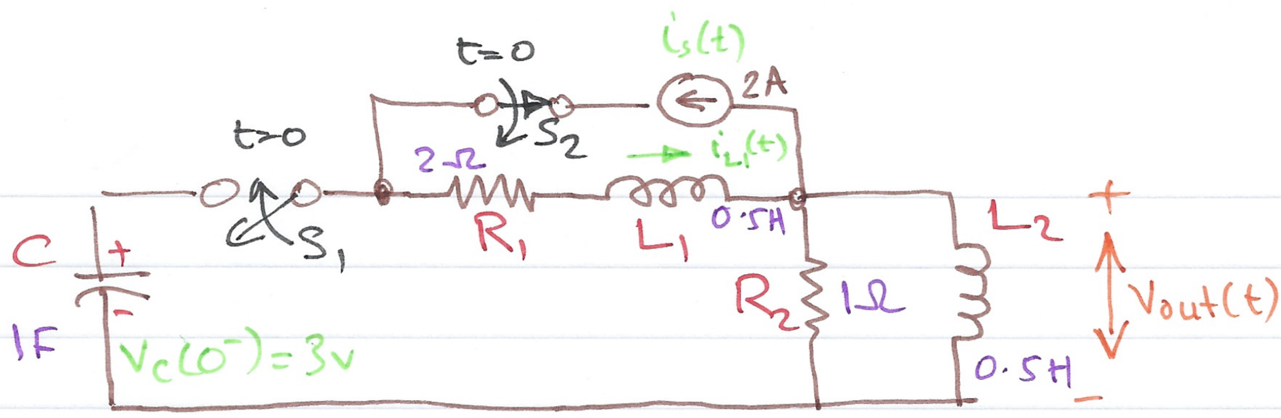
Use the Laplace transform method and apply Kirchoff's Voltage Law (KVL) to find the voltage $v_c(t)$ across the capacitor for the circuit below given that $v_c(0^-) = 6$ V.





Example 3

In the circuit below, switch S_1 closes at $t = 0$, while at the same time, switch S_2 opens. Use the Laplace transform method to find $v_{\text{out}}(t)$ for $t > 0$.



Show with the assistance of MATLAB (See solution3.m (../matlab/solution3.m)) that the solution is

$$V_{\text{out}} = \left(1.36e^{-6.57t} + 0.64e^{-0.715t}\cos 0.316t - 1.84e^{-0.715t}\sin 0.316t\right)u_0(t)$$

and plot the result.

Solution to Example 3

We will use a combination of pen-and-paper and MATLAB to solve this.

1. Equivalent Circuit

Draw equivalent circuit at $t = 0$

2. Transform model

Convert to transforms

3. Determine equation

Determine equation for $V_{\text{out}}(s)$.

4. Complete solution in MATLAB

In the lecture we showed that after simplification for Example 3

$$V_{\text{out}} = \frac{2s(s+3)}{s^3 + 8s^2 + 10s + 4}$$

We will use MATLAB to factorize the denominator $D(s)$ of the equation into a linear and a quadratic factor.

Find roots of Denominator D(s)

In [ ]:

```
r = roots([1, 8, 10, 4])
```

Find quadratic form

In [ ]:

```
syms s t
y = expand((s - r(2))*(s - r(3)))
```

Simplify coefficients of s

In [ ]:

```
y = sym2poly(y)
```

Complete the Square

Plot result

In [ ]:

```
t=0:0.01:10;
Vout = 1.36.*exp(r(1).*t)+0.64.*exp(real(r(2)).*t).*cos(imag(r
(2)).*t)-1.84.*exp(real(r(3)).*t).*sin(-imag(r(3)).*t);
plot(t, Vout); grid
title('Plot of Vout(t) for the circuit of Example 3')
ylabel('Vout(t) V'),xlabel('Time t s')
```

Worked Solution: Example 3

File Pencast: [example3.pdf (../worked_examples/example3.pdf)](../worked_examples/example3.pdf) - Download and open in Adobe Acrobat Reader.

The attached "PenCast" works through the solution to Example 3 by hand. It's quite a complex, error-prone (as you will see!) calculation that needs careful attention to detail. This in itself gives justification to my belief that you should use computers wherever possible.

Please note, the PenCast takes around 39 minutes (I said it was a complex calculation) but you can fast forward and replay any part of it.

Alternative solution using transfer functions

In [ ]:

```
Vout = tf(2*conv([1, 0],[1, 3]),[1, 8, 10, 4])
```

In [ ]:

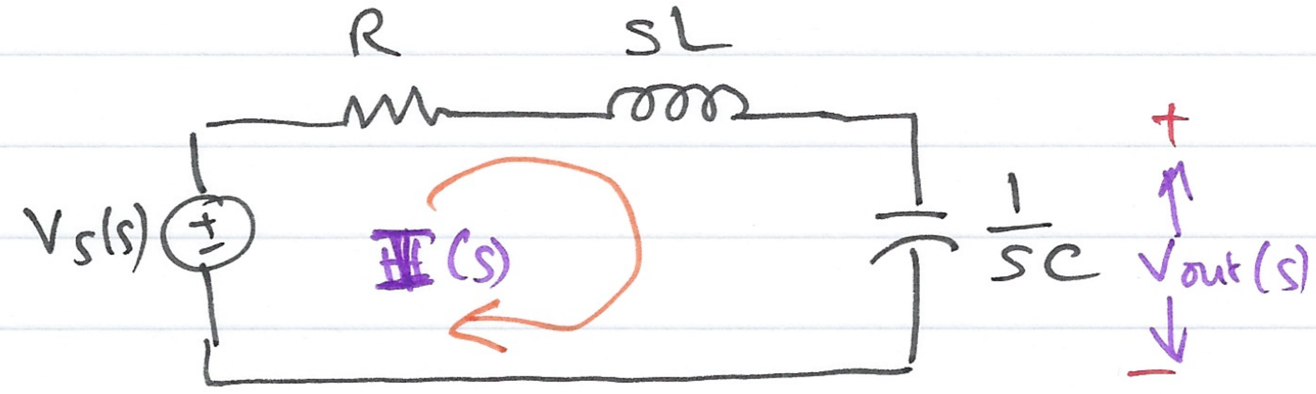
```
impulse(Vout)
```

Complex Impedance $Z(s)$

For the resistance $R\Omega$, inductance LH and capacitance CF, which of the following represent the complex impedance of the components?

Complex Impedance $Z(s)$

Consider the s-domain RLC series circuit, wehere the initial conditions are assumed to be zero.



For this circuit, the sum

$$R + sL + \frac{1}{sC}$$

represents that total opposition to current flow. Then,

$$I(s) = \frac{V_s(s)}{R + sL + 1/(sC)}$$

and defining the ratio $V_s(s)/I(s)$ as $Z(s)$, we obtain

$$Z(s) = \frac{V_s(s)}{I(s)} = R + sL + \frac{1}{sC}$$

The s-domain current $I(s)$ can be found from

$$I(s) = \frac{V_s(s)}{Z(s)}$$

where

$$Z(s) = R + sL + \frac{1}{sC}.$$

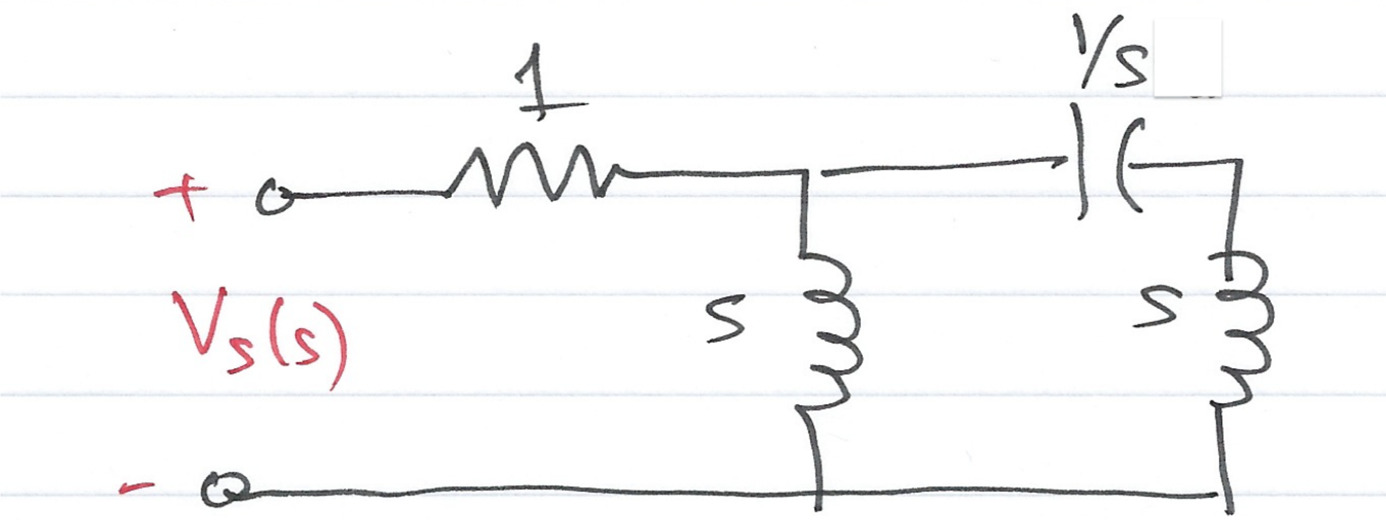
Since $s = \sigma + j\omega$ is a complex number, $Z(s)$ is also complex and is known as the *complex input impedance* of this RLC series circuit.

Exercise

Use the previous result to give an expression for $V_c(s)$

Example 4

For the network shown below, all the complex impedence values are given in Ω (ohms).



Find $Z(s)$ using:

1. nodal analysis
2. successive combinations of series and parallel impedances

Solutions: Pencasts ex4_1.pdf (../worked_examples/ex4_1.pdf) and ex4_1.pdf (../worked_examples/ex4_1.pdf) – open in Adobe Acrobat.

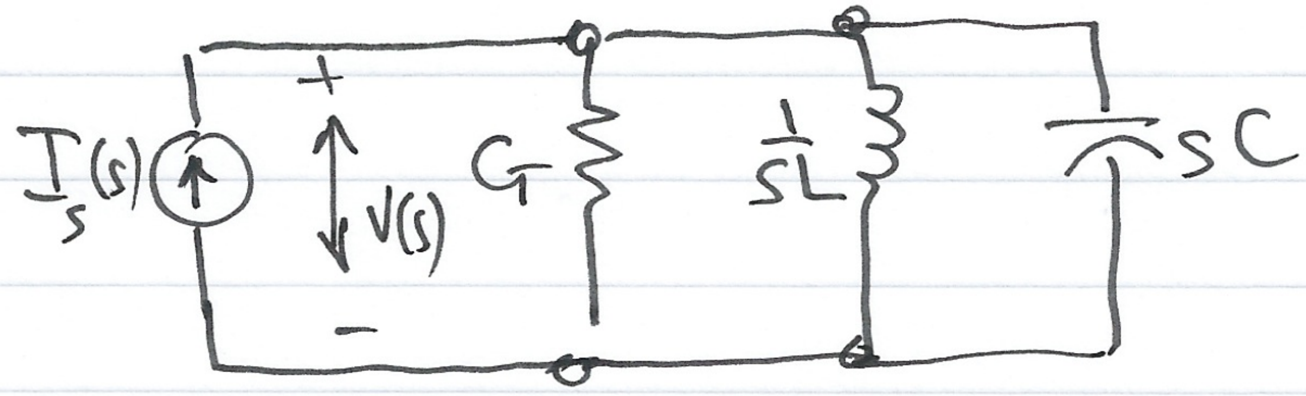
Complex Admittance $Y(s)$

For the resistor $R\Omega$, inductor LH and capacitance CF, which of the following represent the complex admittance of the components?

-> Open Poll

Complex Admittance $Y(s)$

Consider the s-domain GLC parallel circuit shown below where the initial conditions are zero.



For this circuit

$$GV(s) + \frac{1}{sL}V(s) + sCV(s) = I_s(s)$$

$$\left(G + \frac{1}{sL} + sC\right) V(s) = I_s(s)$$

Defining the ratio $I_s(s)/V(s)$ as $Y(s)$ we obtain

$$Y(s) = \frac{I_s(s)}{V(s)} = G + \frac{1}{sL} + sC = \frac{1}{Z(s)}$$

The s-domain voltage $V(s)$ can be found from

$$V(s) = \frac{I_s(s)}{Y(s)}$$

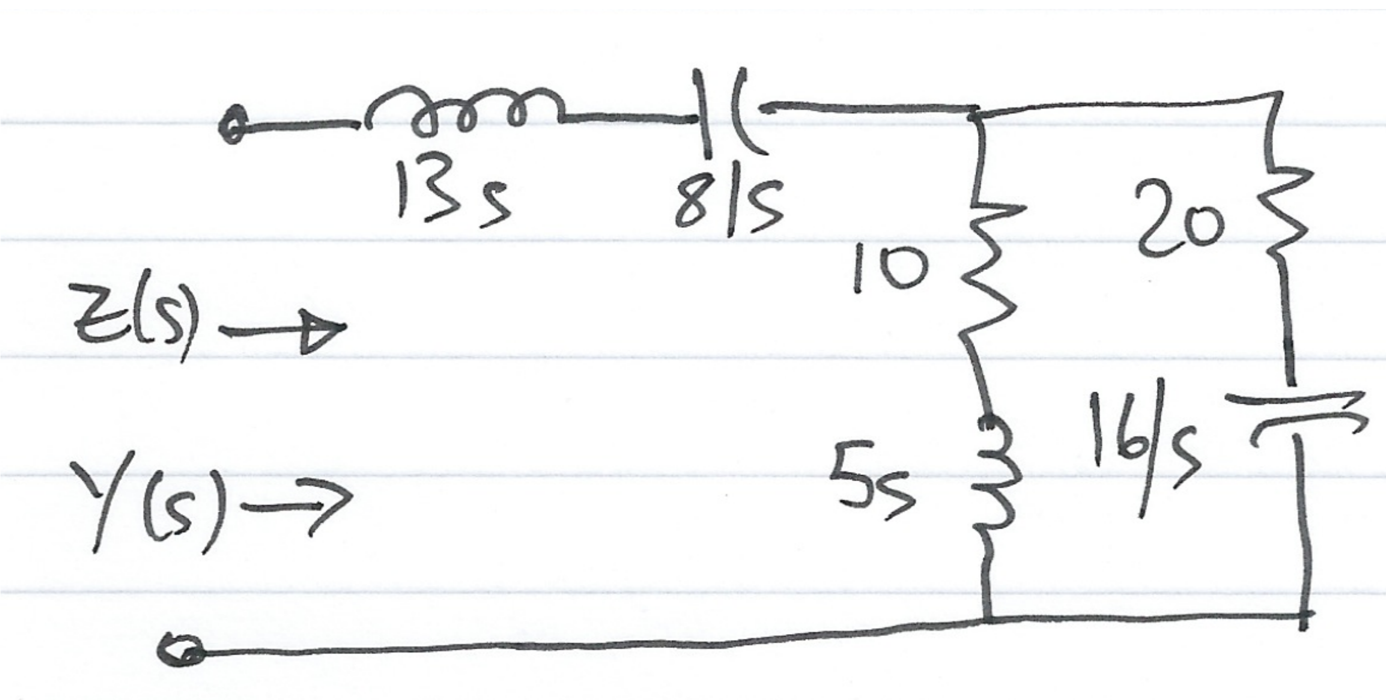
where

$$Y(s) = G + \frac{1}{sL} + sC.$$

$Y(s)$ is complex and is known as the *complex input admittance* of this GLC parallel circuit.

Example 5 - Do It Yourself

Compute $Z(s)$ and $Y(s)$ for the circuit shown below. All impedence values are in Ω (ohms). Verify your answers with MATLAB.



Answer 5

$$Z(s) = \frac{65s^4 + 490s^3 + 528s^2 + 400s + 128}{s(5s^2 + 30s + 16)}$$

$$Y(s) = \frac{1}{Z(s)} = \frac{s(5s^2 + 30s + 16)}{65s^4 + 490s^3 + 528s^2 + 400s + 128}$$

Matlab verification: [solution5.m (../matlab/solution5.m)](../matlab/solution5.m)

Example 5: Verification of Solution

In [ ]:

```
syms s;

z1 = 13*s + 8/s;
z2 = 5*s + 10;
z3 = 20 + 16/s;
```

In [ ]:

```
z = z1 + z2 * z3 /(z2 + z3)
```

In [ ]:

```
z10 = simplify(z)
```

In [ ]:

```
pretty(z10)
```

Admittance

In [ ]:

```
y10 = 1/z10;
pretty(y10)
```

Matlab Solutions

For convenience, single script MATLAB solutions to the examples are provided and can be downloaded from the accompanying MATLAB (../matlab) folder.

- Solution 3 [solution3.m (../matlab/solution3.m)]
- Solution 5 [solution5.m (../matlab/solution5.m)]

In [ ]:

```
cd ../matlab
ls
open solution3.m
```