

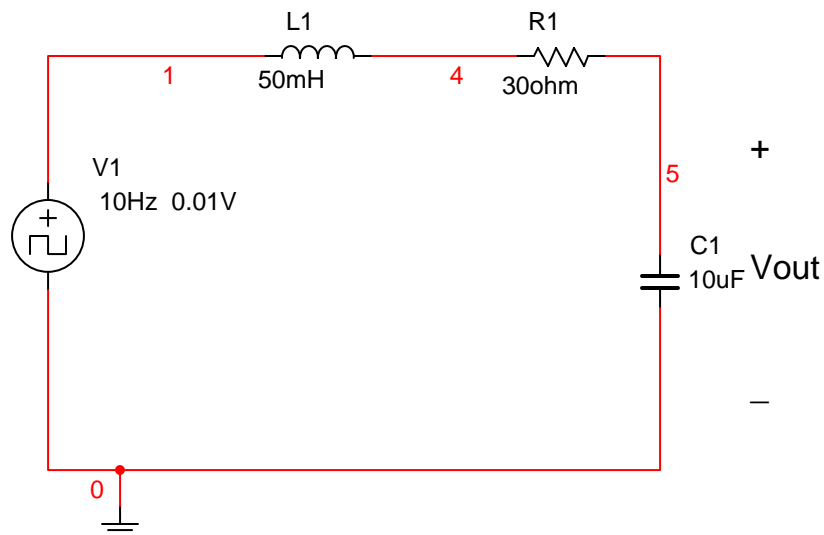
ECE617 Junior Laboratory I - 2008  
Design of Operational Amplifier Circuits

1. Introduction

Operational amplifiers (op-amps) have many applications in electrical and computer engineering designs. They can be used in circuits to implement: gain or power amplifiers, active filters, comparators, peak detectors, current sensors, signal generators, instrumentation amplifiers, mathematical functions, etc. Op-amps can be configured to realize most mathematical functions:

- Addition
- Subtraction
- Multiplication
- Division
- Integration
- Differentiation
- Logarithmic

This laboratory exercise will illustrate how an op-amp circuit (acting as a basic analog computer) can be configured to solve a differential equation. A good illustration of the implementation of mathematical functions with op-amps circuits is to solve the differential equation describing the input/output response of a RCL series circuit. In particular, the response of the RLC series circuit, shown in Figure 1, to an input step will be calculated.



**Figure 1, RLC Circuit Showing Input Step Voltage Source and Vout.**

This laboratory exercise will be performed over a two week period:

- Week one: complete the pre-laboratory exercise (no in-lab session)
- Week two: implement and test the circuit designed in the pre-laboratory exercise (requires going to your regularly scheduled laboratory period)

2. Pre-laboratory Exercise (week one of two)

A differential equation solver circuit will be designed and simulated in the pre-laboratory exercise. First confirm that Equation 1 is the differential equation that describes the transfer function ( $V_{out}/V_1$ ) for the RLC circuit in Figure 1.

$$\frac{d^2V_{out}}{dt^2} + \frac{R}{L} \frac{dV_{out}}{dt} + \frac{1}{LC} V_{out} = V_1 \frac{1}{LC}$$

**Equation 1, Equation Describing the Transfer Function for the RLC Circuit**

The solution to this equation takes on one of three forms depending on whether the circuit is under damped, critically damped, or over damped. Review your basic circuits and differential equation textbooks if you do not recall the solutions. The solution has two parts: the transient part and the steady state part.

Before the op-amp circuit is designed it would be nice to be able to plot the output's ( $V_{out}$ ) response to the step input. That way when the circuit is simulated in Multisim the correct output response will be known. There are a number of methods that can be used including deriving the solution by hand (then use Matlab to plot the solution) and using Matlab to solve the differential equation and plot the output's response.

- First Method: Derive the solution to the differential equation and plot the output response using Matlab (see sample code below). Hint, you need to determine which form the solution takes (eq2, eq3 or eq4) and value of the constants and parameters.

$$V_{out} = V_f + B_1 e^{-\alpha t} \cos(w_d t) + B_2 e^{-\alpha t} \sin(w_d t) \text{ (under damped)}$$

**Equation 2, Solution for Under Damped Response**

$$V_{out} = V_f + A_1 e^{s_1 t} + A_2 e^{s_2 t} \text{ (over damped)}$$

**Equation 3, Solution for Over Damped Case**

$$V_{out} = V_f + D_1 t e^{-\alpha t} + D_2 e^{-\alpha t} \text{ (critically damped)}$$

**Equation 4, Solution for Critically Damped Case**

```

%Derived solution of differential equation for an RLC series circuit
%Frank Hludik 10/1/2008
t=0:.1e-3:40e-3;
vout =                                % note: put solution here
plot(abs(vout));                       %now plot the output response, absolute value (magnitude)
title('Response of Vout to Step Input Using Derived Solution');
xlabel('Time in 10-4 secs');
ylabel('Voltage in v');

```

- **Second Method:** There are functions in Matlab that can solve differential equations and plot transfer functions. The following code listing does exactly that:

```

%Solution of the differential equation for an RLC series circuit
%Frank Hludik 10/1/2008

clear all                               %clear all symbols
c=10e-6;                                %define values for RLC
l=50e-3;
r=30;
V1=.01;                                 %define value of input step
                                           %set up diff eq. with symbols and initial conditions

v=dsolve(' (D2Vout)+(DVout)*(r/l)+(Vout/(l*c))=V1/(l*c) ', 'Vout(0)=0', 'DVout(0)=0');

                                           % v holds the solution
v=subs(v);                               %substitute values for symbols

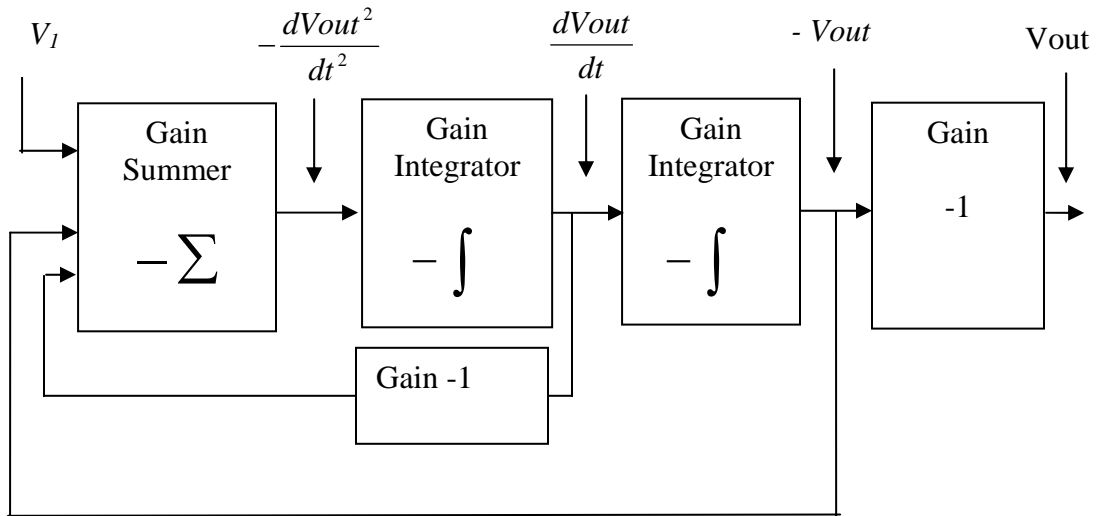
pretty(simplify(collect(v)));            %print out complex solution, it isn't pretty at all
t=0:.1e-3:40e-3;                         %define time span to plot results
v=subs(v,t,'t');                          %substitute value for time symbol
plot(abs(v));                             %now plot the output response, absolute value (magnitude)
title('Response of Vout to Step Input');
xlabel('Time in 10-4 secs');
ylabel('Voltage in v');

```

Confirm that the above Matlab listing is correct and does indeed solve and plot the output response. Compare the results of the first method to the results of the second method. When you are satisfied that both methods are correct, proceed to design and simulate the op-amp circuit to realize the solution to the differential equation (equation 1). The Matlab plots should match the output from your op-map circuit when simulated in Multisim and constructed in the laboratory.

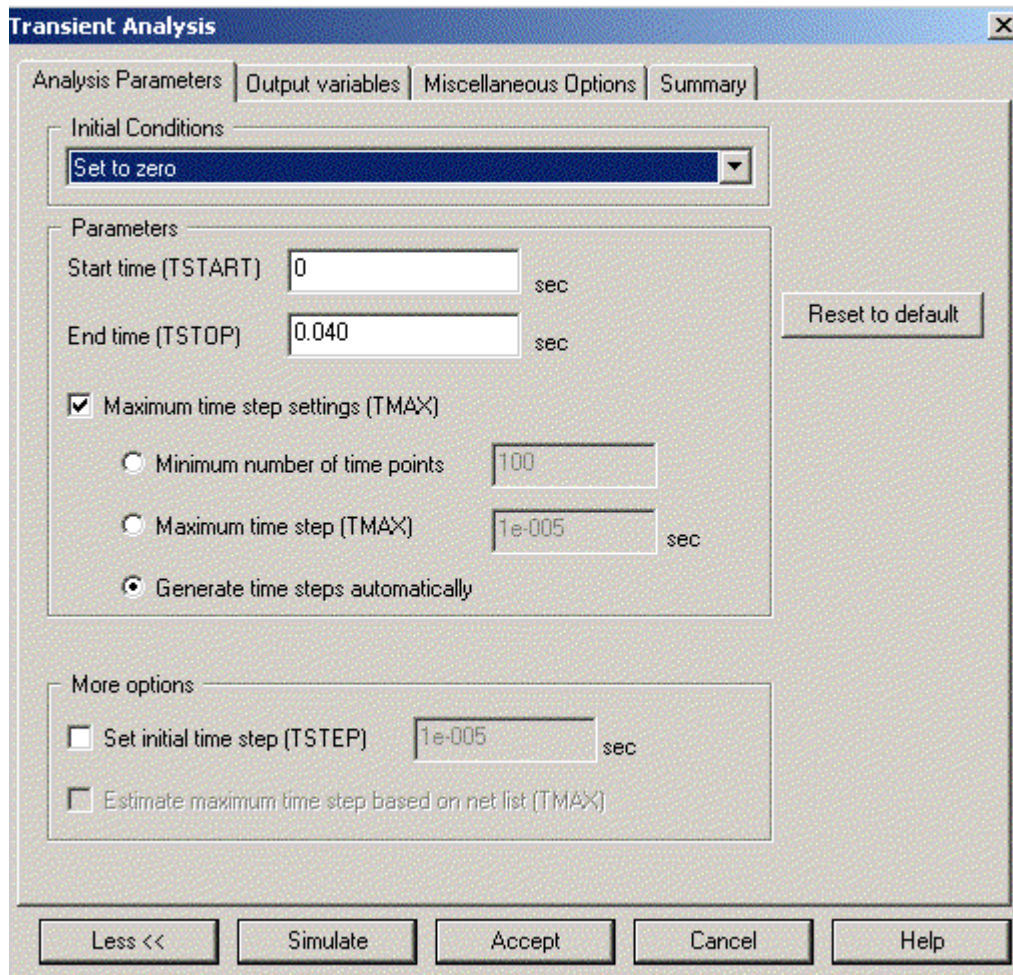
Now design an op-map circuit to solve the differential equation in Equation 1. Rearrange the differential equation in such a manner that it can be implemented in an op-amp circuit. You will need to use summer circuit(s), integrator circuit(s), and gain circuit(s) as shown in Figure 2. You may combine stages. Treat the op-amp device as ideal, ie., neglect I/O offset voltages and currents, assume infinite open-loop gain, infinite bandwidth, infinite input resistance, and zero output resistance. Recall that an integrator circuit has the transfer function of  $a/jw$  (a/s), where 'j' is the complex operator, 'w' is the frequency in radians, and 'a' is the gain. Summer circuits can be constructed in both non-inverting and inverting configurations. Hint: **You should**

**combine summer and integrator circuits into one op-amp configuration.** Use the 741 op-amp model in Multisim to realize this circuit. A 741 data sheet is attached to this handout, and complete data for the 741 is available on the ECE617 web site. Use readily available capacitor values, such as 1.0uf, 0.1uf, 0.01uf, and 0.001uf. We have precision capacitors available in these values.



**Figure 2, Block Diagram of Solution of DE**

Simulate your circuit to confirm that its response is the same as that obtained in the Matlab transfer function plots. Use the **transient response** command in Multisim and **set the initial conditions to zero as shown in Figure 3**. Use a dual power supply of  $\pm 12$  volts for the op-map circuit.



**Figure 3. Multisim Transient Analysis Dialog Box**

### 3. In-Laboratory Exercise (week two of two)

Construct the differential op-amp circuit designed. Apply an appropriate input signal and measure/record the output response. Record the settling time (time to reach steady state value), maximum/minimum overshoot (if any), response's oscillation frequency, decay time constant of the response's oscillation envelope,

and amplitude of the steady state response. Confirm that the output matches the predicted response from the Matlab analysis and Multisim simulation. Demonstrate your working circuit to the laboratory instructor. No credit will be given for this exercise without the circuit being demonstrated.

4. Report (due one week after completion of section 3)

- Cover page
- Abstract
- Derivation used to solve the differential equation, Matlab code used to plot the output response, and plot of output response obtained
- Matlab code used to solve the differential equation and plot of output response obtained
- Multisim schematic and plots of input and output response
- Sketch of the output response observed in the laboratory
- Include the rearranged differential equation block diagram used to implement the op-amp circuit
- Table comparing Matlab data, Multisim data, and in-lab measurement data for:
  - settling time (time to reach steady state value)
  - decay time constant of the responses oscillation envelope
  - response's oscillation frequency
  - maximum/minimum overshoot
  - amplitude of the steady state response
- Summarize results obtained and the design process used