Week 9: Series RC Circuit

Experiment 14
Circuit to be constructed

It is good practice to short the unused pin on the trimpot when using it as a variable resistor.
Current Measurement: Shunt Resistor

• Oscilloscopes can measure voltage as a function of time, but they can’t measure current.
  – To measure time-varying current, we include a small resistor at the bottom of the branch in which the current measurement is desired.
    – The value of the resistor chosen should be at least a factor of 10 times smaller than the other resistors in the branch.
  • The voltage across the small resistor divided by its resistance yields the current through the branch.
Measurement point for input voltage

Measurement point for current through resistor where $V(t)/10\Omega$ equals the current.

Measurement point for voltage across capacitor
The time constant ($\tau$) is defined as the time it takes the circuit to reach 63.2% of the maximum or fall to 36.8% of the minimum possible voltage or current.

$$(at \ t = \tau, \ [1 - e^{t/\tau}] = [1- e^{-1}] = 0.63212)$$

- After 2 time constants, the circuit has reached $\approx 86\%$ of maximum.

- After 5 time constants, $V_C$ and $I_L$ are near 100% of the maximum, and $V_L$ and $I_C$ are near 0.
Transient Response: Period of Input Voltage $\geq 5\tau$

Steady state values for the capacitor’s voltage and current are assumed to be reached by the time $t = 5\tau$.

Plot your data in Matlab as a single plot (do NOT plot in XL!).
Transient Response: Period of Input Voltage < $5\tau$

In these cases, the generator changes voltage before the voltage and current waveforms approach steady state.
MatLab Program

Include the appropriate plots into the report template

• Plot a graph of $v_c(t)$ versus $t$ for Equations (1) + (2) and (7) + (8) as described in the lab manual for Experiment 14. Set the frequency of the square wave to create the clock signal in Figure 4.

• Plot a graph of $i_c(t)$ versus $t$ given by Equations (5) + (6) and the derivative of Equations (7) + (8) as described in the lab manual for Experiment 14. Set the frequency of the square wave to create the clock signal in Figure 4.
PSpice Simulations: Transient Analysis

- Plot of the voltage across the capacitor as a function of time
  - Use either Vpulse or Digclock as the voltage source
    - Instructions on setting up a transient simulation using these sources are posted under Resources/Technical Support: Circuit Simulation
    - Include the input voltage in the plot and show three periods.
- Plot of the current through the capacitor as a function of time
  - Plot of the voltage across the shunt resistor divided by its resistance as a function of time
    - Instructions on how to perform calculations in the PSpice plotting routine are posted under Resources/Technical Support: Circuit Simulation.
    - Use a current marker instead of a voltage marker
      - Show three complete waveform periods.
Time Constant of RC Circuit

• Calculated using multiple methods:
  – Analytically (Step 1)
  – Experimentally after measurements of R, C, and Rshunt
    • Note that you have the ability to measure capacitance on your digital multimeter
  – From a curve fit of V(t) as the voltage across the capacitor decreases when the input voltage changes from +5V to ground.
    • This is done for each time constant.
Voltage Measurements

• Set the scope function generator such that Vin is a square wave that swings from 0V to +5V.
  • Settings for the square wave are 5V amplitude with 2.5V offset.
  • The duty cycle is 50%.
  • Frequency should be set to 1 kHz.

– Use DC coupling on Channel 1 and Channel 2
  • Ignore the comments in the lab manual about AC coupling unless you select AC Coupling when performing the measurements.
  • Ignore all comments in the instructions about a sound card or the Zeitnitz oscilloscope software program.
No Extra Credit

• No credit will be given for “Extra Credit Question” step 32, so you do not need to complete this step.
Square Wave Sources: Digclock and Vpulse

Directions given for PSpice Schematics
## Setting the Attributes of Digclock

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DELAY</td>
<td>The time delay before the pulses are started.</td>
</tr>
<tr>
<td>ONTIME</td>
<td>The length of time that the pulse is at the voltage set by OPPVAL.</td>
</tr>
<tr>
<td>OFFTIME</td>
<td>The length of time that the pulse is at the voltage set by STARTVAL.</td>
</tr>
<tr>
<td>STARTVAL</td>
<td>The voltage that will be outputted at time = 0s by Digclock. The values used are “0” for 0V and “1” for 5V.</td>
</tr>
<tr>
<td>OPPVAL</td>
<td>The voltage that will be outputted by Digclock when either the DELAY has been completed or the first OFFTIME has been completed if no DELAY has been set. The values used are “0” for 0V and “1” for 5V and should be the opposite logic value to what was entered for STARTVAL.</td>
</tr>
</tbody>
</table>
Setting the Attributes of Vpulse

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC</td>
<td>Value that will be used when calculating the bias point and allows Vpulse to be used as a DC source in DC Sweep. It does not add a DC offset to the pulse train</td>
</tr>
<tr>
<td>AC</td>
<td>Value that will be used when performing a AC Sweep using Vpulse as the voltage source</td>
</tr>
<tr>
<td>V1</td>
<td>The first voltage level of the pulse</td>
</tr>
<tr>
<td>V2</td>
<td>The voltage level that the pulse changes to, can be larger or smaller than 1V</td>
</tr>
</tbody>
</table>
Setting the Attributes of Vpulse (con’t)

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TD</td>
<td>The time delay before the pulse (or pulses) is started</td>
</tr>
<tr>
<td>TR</td>
<td>The length of time that it takes to ramp the voltage of the pulse from V1 to V2. This can be 0 seconds</td>
</tr>
<tr>
<td>PW</td>
<td>The length of time that the output voltage of Vpulse is equal to V2</td>
</tr>
<tr>
<td>PER</td>
<td>The length of time of the period of a continuous output of pulses. If this attribute is left unchanged (blank), only one pulse will be outputted by Vpulse</td>
</tr>
</tbody>
</table>
Examples
Digclock

The continuous set of pulses do not start until time = 2μs (DELAY = 2us). The initial voltage is 0V (STARTVAL = 0). Once the pulses start, the pulse length at 0V is 0.5μs (OFFTIME = 0.5us) and the pulse length at 5V is 0.5 μs (ONTIME = 0.5us).
Output of Digclock

Note the 2µs start delay
The continuous set of pulses start at time = 0s (DELAY = ) . The initial voltage is 5V (STARTVAL = 1). Once the pulses start, the pulse length at 0V is $1\mu$s (ONTIME = 1us) and the pulse length at 5V is $0.5\mu$s (OFFTIME = 0.5us).
Output of Digclock

Note that there is no start delay
Vpulse

A single pulse (PER = ) that does not start until time = 2\(\mu\)s (TD = 2us). The initial voltage is 0V (V1 = 0). After the delay, the output rises to 3V (V2 = 3V) in 1\(\mu\)s (TR = 1us), stays at 3V for 3\(\mu\)s (PW = 3us), and then takes 2\(\mu\)s to return back to 0V (TF = 2us).
Voltage signal obtained from the settings on the previous slide for $V_{\text{pulse}}$

Note the start delay of 2μs, the 1μs rise time, and the 2μs fall time.
Vpulse

Continuous pulses that repeat every 4\(\mu\)s (PER = 4\(\mu\)s) that start immediately (TD = 0 ). The initial voltage is +5V (V1 = 5V). The output drops to -5V (V2 = -5V) in 0\(\mu\)s (TR = 0), stays at -5V for 1\(\mu\)s (PW = 1\(\mu\)s), and then return back immediately (TF = 0) to +5V.
Not quite what is expected!

There appears to be a rise and fall time (TR and TF, respectively) that is used by PSpice even when you set these values to 0s. This results from the use of the default Step Ceiling when setting the parameters for the Transient Analysis.
More abrupt transitions between 0V and 5V can be obtained if you specify a Step Ceiling that is a small fraction of the period of the voltage signal.
Adding a DC source to Vpulse

Setting DC to 2V allows you to add a DC Sweep to the simulation without having to include a Vdc into the schematic. This DC source is only used in the DC Sweep and does not cause a voltage offset to be added to the pulse when performing a transient analysis.

Pulse attributes in this case are continuous pulses that repeat every 1μs (PER = 1us) that start immediately (TD = 0). The initial voltage is 0V (V1 = 0V). The output rises to 5V (V2 = 5V) in 0μs (TR = 0), stays at 5V for 0.5μs (PW = 0.5us), and then return back immediately (TF = 0) to 0V.
After selecting DC Sweep in addition to Transient in the Simulation Setup and then running the simulation, you can select which output is plotted by clicking on the DC or Transient in the Analysis Type pop-up window.
When Transient is selected, the 2V DC value entered as an attribute in the Part Name pop-up window does not cause an DC offset voltage.
The value of DC entered as an attribute in the Part Name pop-up window is overridden by the Start Value and End Value that you enter in the DC Sweep pop-up window that is launched when you select DC Sweep in the Analysis Setup pop-up window. However, you must enter some value for DC in the Part Name pop-up window to have the DC Sweep option enabled.

Similarly, you must enter some value for AC in the Part Name pop-up window to have the AC Sweep option enabled during the simulation run.
Plot from DC Sweep