

Name: _____

Class: _____

10.2 - Duty cycle

Experiment 10.2 - Duty cycle

The experiment

For this experiment you'll investigate the operation of a squarewave generator modified to allow a variable duty cycle.

It should take you about 40 minutes to complete the experiment.

Pre-requisites

Experiment 7.1 - Dynamic range

Experiment 10.1 - Squarewave generation

Equipment

- A desktop PC, Laptop or Tablet with Google Chrome installed

Preliminary discussion

A pulse train generator with an adjustable duty cycle is shown in Figure 1 below. The circuit is based on the relaxation oscillator introduced in Experiment 10.1.

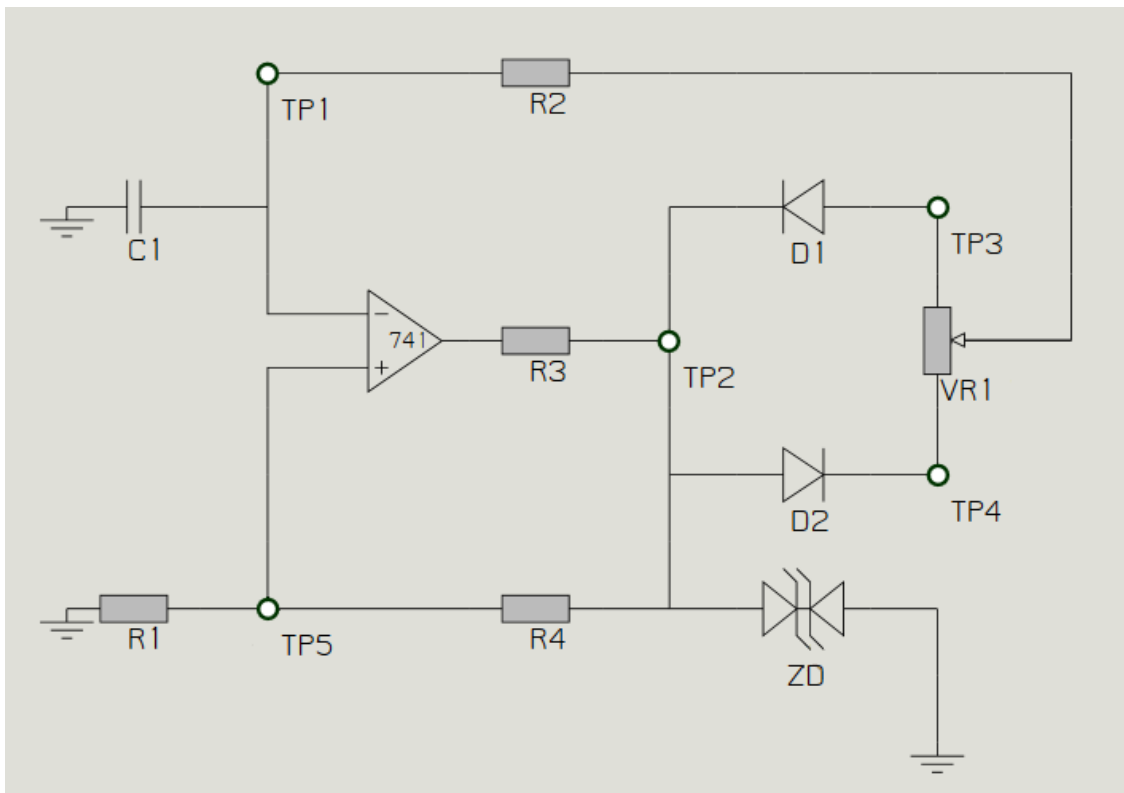


Figure 1

If you compare the circuit of Figure 1 above with the circuit of Figure 2 in Experiment 10.1, you'll notice that they're the same except for the inclusion of the potentiometer ($VR1$) and two small signal diodes ($D1$ and $D2$).

Recall that the squarewave generator in Expt 10.1 produced an op amp output that alternates between being positively and negatively saturated and the same is true for the op amp in this circuit. When the op amp's output is positively saturated, $D2$ is forward biased (while $D1$ is reverse biased) and so the resistance path responsible for charging $C1$ is provided by the series combination of $R2$ and the resistance between the end of the potentiometer connected to $D2$ and its wiper. During this time, $C1$ charges towards $+(V_{DZ} + 0.6V)$.

When the potential difference across $C1$ exceeds the positive threshold voltage on the non-inverting pin, the op amp's output reverses and becomes negatively saturated. When this happens, $D1$ is forward biased (and $D2$ is reverse biased) and the resistance path responsible for charging $C1$ (in the opposite direction) is provided by the series combination of $R2$ and the resistance between $D1$ and its wiper. Current flows in the opposite direction during this time and $C1$ charges towards $-(V_{DZ} + 0.6V)$.

When the potential difference across $C1$ exceeds the negative threshold voltage on the non-inverting pin, the op amp's output reverses again and the process repeats.

Now suppose that the wiper of the potentiometer is set to exactly the middle of its travel. The resistance path for charging the capacitor is exactly the same for a positively and negatively saturated op amp output (and is equal to $R2$ plus half of the value of $VR1$) and so the time it takes the capacitor's potential difference to reach to the positive and negative threshold voltages is exactly the same. This produces a pulse train on the output with a duty cycle of 50% (in other words, a squarewave) with a frequency that can be found using:

$$f_o = \frac{1}{2 \left(R_2 + \frac{VR_1}{2} \right) C_1 \ln \left(\frac{2R_1 + R_3}{R_3} \right)}$$

When the wiper of the potentiometer is adjusted so that it's off-centre, the resistance in one charge path increases and the resistance in the other charge path decreases by exactly the same amount. This in turn changes the time it takes the capacitor's potential difference to reach the threshold voltages with one increasing and the other decreasing by exactly the same amount of time. This changes the duration that the op amp sits on the saturated output voltages which, by extension, changes the duty cycle of the output waveform. Importantly, this occurs without changing the output frequency.

Knowing the operation of the circuit and applying a little algebra to the equation for calculating duty cycle, the minimum and maximum duty cycles can be found using:

$$\text{Duty cycle (min)} = \frac{R_2}{2\left(R_2 + \frac{VR_1}{2}\right)} \times 100$$

Which can be simplified to:

$$\text{Duty cycle (min)} = \frac{R_2}{2R_2 + VR_1} \times 100$$

And:

$$\text{Duty cycle (max)} = \frac{R_2 + VR_1}{2\left(R_2 + \frac{VR_1}{2}\right)} \times 100$$

Which can be simplified to:

$$\text{Duty cycle (min)} = \frac{R_2 + VR_1}{2R_2 + VR_1} \times 100$$

Note for new users

Hardware selection:

The experiment hardware is chosen using the drop-down list at the top of the page. The hardware that you'll be working with for this experiment is shown in Figure 2 below. It is one of sixteen discrete circuits implemented on the board shown in Appendix 2.

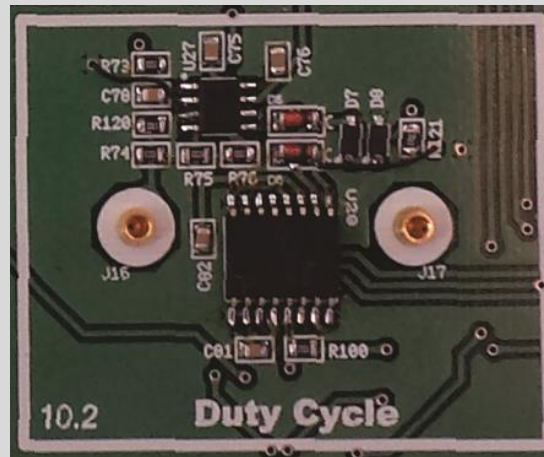


Figure 2

Scope controls:

Clicking on the switches and buttons toggles them to the next setting. The scope's input connections can be changed by clicking on the channels' input terminals (ie the red/blue circle).

Function generator controls:

The waveform is chosen using the drop-down list under the *DC Voltage* control. The Function Generator's potentiometer controls (represented by knobs) can be rotated by positioning the mouse pointer over the knob, pressing and holding the left mouse button, then moving the mouse. The knobs can also be repositioned instantly by placing the mouser pointer to the where the knob's marker needs to be and clicking once.

Switches

Switches are opened and closed by clicking on them.

Window sizing

Resize the window on your device so that the scroll bars are not needed. This will allow you to see the whole page without having to scroll across or up and down.

Procedure

1. Launch Google Chrome on your PC, Laptop or Tablet.
2. Navigate to your department's net*EREL Server.

Tip: Resize the window on your device so that the scroll bars are not needed. This will allow you to see the whole page without having to scroll across or up and down.

3. Select the "Duty Cycle" hardware from the drop-down list at the top of the webpage.
4. Ensure that the scope's Channel A is connected to the circuit's TP1 input and its Channel B to TP2.

Note: The scope's input connections can be changed by clicking on the channels' input terminals (ie the red/blue circle).

5. Make the appropriate adjustments to the scope to display the differentiator's input and output voltages. Ensure that:
 - the *Sweep Mode* controls for both channels are set to *Single*
 - the *Input Coupling* controls for both channels are set to *DC*
 - the *Voltage Scale* control for both channels is set to *1V/div*
 - the *Timebase* control is set to *500 μ s/div*
 - the *Frequency Domain (FREQ)* controls for both channels are deactivated

Note: Clicking on the switches and buttons toggles them to the next setting.

6. Adjust *VR1* so that the pulse train on TP2 resembles a squarewave (ie it has a duty cycle of approximately 50%).

Note: This control (*VR1*) can be adjusted by positioning the mouse pointer over the pot's wiper, pressing and holding the left mouse button, then moving the mouse up and down.

7. Calculate the pulse train generator's theoretical output frequency given the component values shown. Record your prediction in Table 1 below.
8. Record the pulse train generator's measured output frequency.

Table 1

Theoretical output frequency	Measured output frequency

Question 1

List all of the components that set the pulse train generator's frequency of oscillation.

C1, R1, R2, R4 & VR1



Ask the instructor to check your work before continuing.

9. Calculate the pulse train generator's theoretical minimum and maximum duty cycles. Record your predictions in Table 2 below.
10. Use *VR1* to set the duty cycle of the pulse train on TP2 to minimum.
11. Measure and record the pulse train's duty cycle.

Note: A pulse train's duty cycle can be determined by measurement and using the equation:

$$\text{Duty cycle (\%)} = \frac{\text{Mark time}}{\text{Period}} \times 100$$

12. Record the measured frequency of the pulse train output.
13. Use *VR1* to set the duty cycle of the pulse train on TP2 to maximum then repeat Steps 11 and 12.

Table 2

	Theoretical duty cycle	Measured duty cycle	Measured output frequency
Minimum			
Maximum			

Question 2

Why doesn't the pulse train's frequency change as you vary the duty cycle?

Adjusting *VR1* changes the mark and space times in equal but opposite

directions so the period of the waveform is always the same.

Question 3

What two circuit modifications could be made to reduce the pulse train generator's range of possible duty cycles (ie increase the minimum duty cycle figure **and** reduce the maximum duty cycle figure)?

1) Increase the value of *R2*

2) Reduce the value of *VR1*

Question 4

What other attribute of the pulse train generator's performance may also be changed by making the modifications that you gave in your answer to the question above.

The frequency of oscillation.



Ask the instructor to check your work before continuing.

14. Adjust V_{R1} so that the pulse train on TP2 has a duty cycle of 50%.
15. Connect the scope's Channel B to the circuit's TP5 while leaving Channel A connected to TP1.
16. Compare the two signals.

Question 5

Explain why the signals on TP1 and TP5 are the same amplitude.

The voltage on TP1 can never exceed the voltage on TP5 because it's the
comparator's reference/threshold voltage. The moment the voltage on TP1
exceeds this voltage in either polarity, the op amp's output voltage reverses
polarity which in turn causes the direction of the signal on TP1 to reverse also.



Ask the instructor to check your work before continuing.

17. Connect the scope's Channel B to the circuit's TP3 while leaving Channel A connected to TP1.

Note: The pulse train's duty cycle should still be set to 50%.

18. Draw two cycles of the signals at TP1 and TP3 **time coincident** with each other on the graph provided on the next page.

Note: Draw these signals to scale.

19. Connect the scope's Channel B to the circuit's TP4 while leaving Channel A connected to TP1.

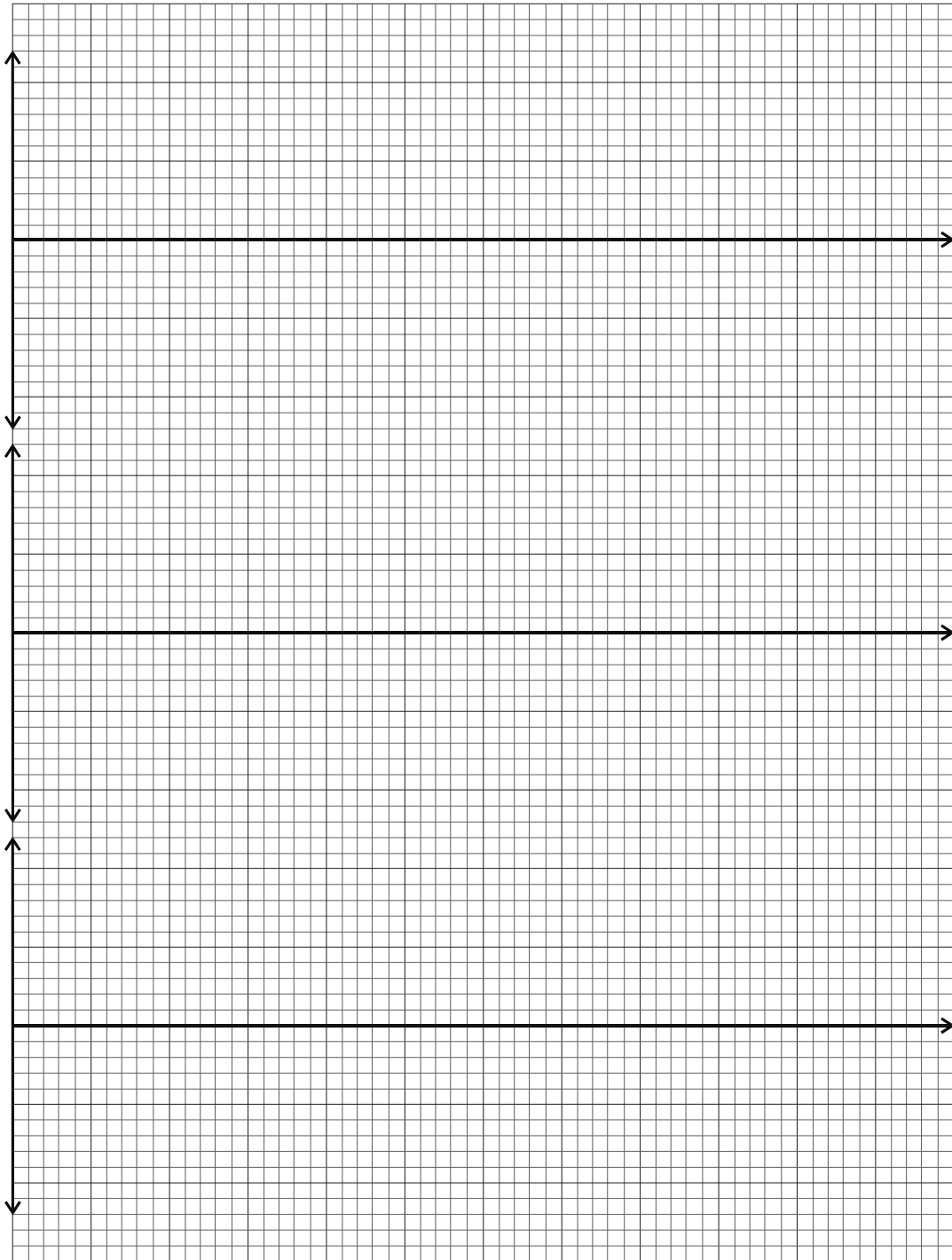
20. Draw two cycles of the signal at TP4 time coincident with the signal on TP1.

Note: Again, draw this signal to scale.

21. Indicate on the graphs of the signals for both TP3 and TP4 when the diodes D1 & D2 are forward biased (on) and reverse biased (off).



Ask the instructor to check your work before continuing.



Question 6

Why does the shape of the signals on TP3 and TP4 include a portion where the voltage is fixed?

During this portion of the waveform, the diode is forward biased and so the

voltage at the test point connected to that diode (TP3 for *D1* and TP4 for *D2*)

must be 0.6V closer to 0V than the voltage on TP2.

Question 7

Why does the shape of the signals on TP3 and TP4 include a portion where the voltage is changing?

During this portion of the waveform, the diode is reverse biased and so the

voltage at the test point connected to that diode (TP3 for *D1* and TP4 for *D2*)

must be the same as the voltage on the potentiometer's wiper which is tracking

the voltage across *C1*.



Ask the instructor to check your work before finishing.