ECE 110: Introduction to Electronics
Week 11: PWM

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Overview:

We ECE 110 students were given a task: to make a car that can run straight using a new concept, instead of using photoresistors, one that runs self-sufficiently with our given battery. We took on this challenge and used our most prized possession: a potentiometer, coupled with our diodes, capacitor and resistors to make this happen.

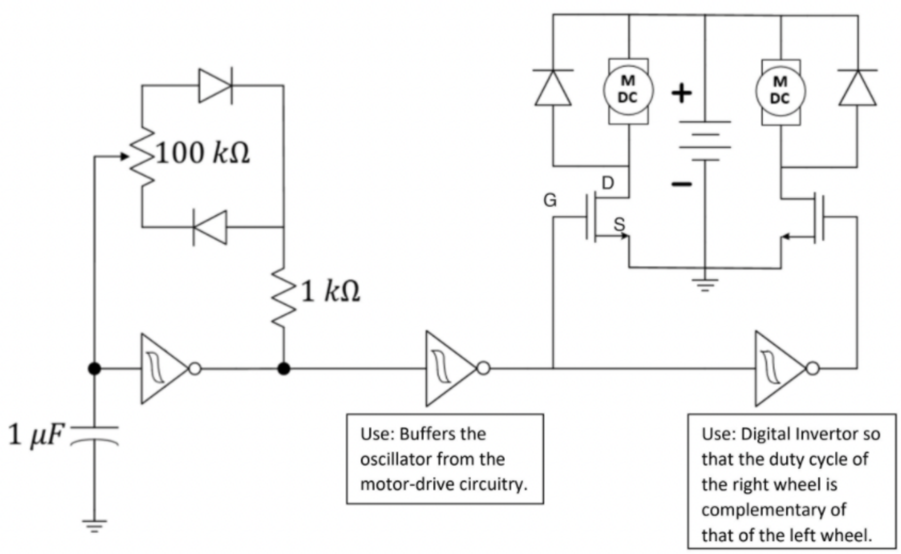


Figure 1: General Design Information
Figure taken from UIUC: ECE 110 Lab Worksheet of Week 10

Design:

We were given the design of the straight-run design and so we shall examine the components of this provided design and examine the reasons that we used these components. We use an oscillator circuit with a PWM signal to control motors that help out car run straight. The main principle we used was that if we have an inverter in between the working, we would be able to buffer this signal and so make the car run smoothly in a straight line.

Schmitt Trigger Inverter:

The Schmitt Trigger inverter (datasheet here) is a special inverter which employs a form of hysteresis where the voltage to invert the incoming signal from On to Off and Off to On are different. This was a crucial component in aiding us to build our oscillator, and design the rest of our car when we control the car. The reason is the difference in the V_p and V_n lets the oscillator buffer these values so the lag caused by the capacitor would not compromise the design while the values are changing and smoothen our Oscillator curve.

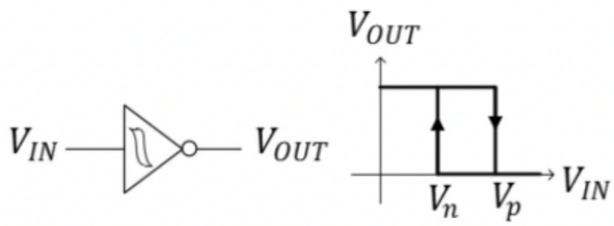


Figure 2: Hysteresis curve and image of an Inverter in Schematics
Figure derived from UIUC: ECE 110 Lab worksheets

Oscillator:

We employed the use of a capacitor near the inverter for our oscillator. This means that when the capacitor is charging and discharging, the inverter switches the values depending on the input. There was also a resistor as mentioned previously which causes a shift in the working of the output, where the output thus charges and discharges the oscillator, without relying on the input and makes the signal one that varies constantly with time, and so the oscillator is formed.

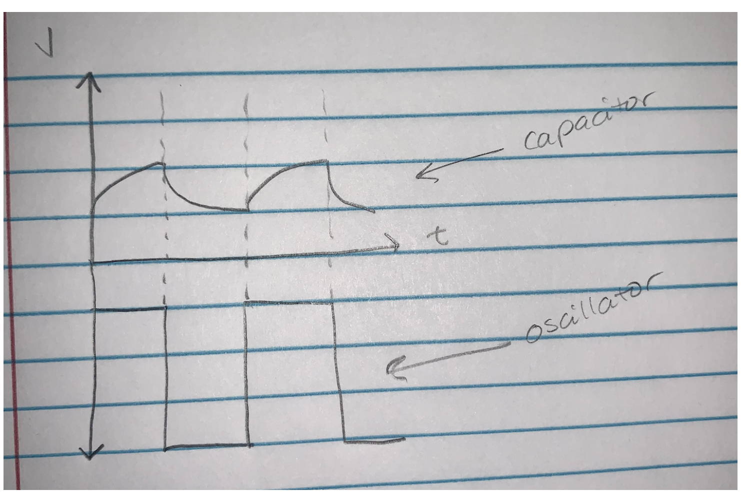
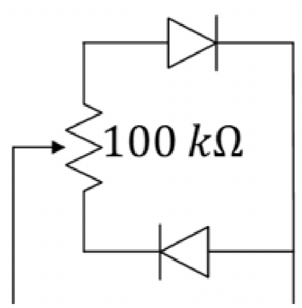


Figure 3: Transformation of a waveform of a capacitor to an oscillating waveform.
Image drawn by Holly Roach

Pulse Width Modulator:

We have some knowledge about a basic 3-input oscillator using the RC Circuit properties, employing the use of resistors, capacitors and inverters to make the oscillator. Now, we can use this information to make a pulse width modulator. First, for this we would need to use voltage divider while charging and discharging, and we can do this with the help of a potentiometer and diodes, where only one of the circuits lets the path through for the charging, and the other for discharging. This is observed in the design we were given here: The 100kOhm is the potentiometer which gets divided into diode circuit parts above and below it. When this 100k Ohm gets divided, it gives us an R1 and R2 which can be used to calculate a duty cycle, an essential concept for our PWM as it determines the running of our car's motors.



<-- equivalent to this circuit →

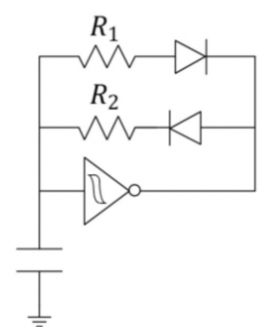


Figure 4: Images of the potentiometer being used as a variable resistor for charging / discharging circuits.

Images taken from UIUC: ECE 110 Worksheet of Week 9

Thus, using this duty cycle concept in harmony with our oscillator, we can make a PWM circuit! A simple one that we were shown in our labs is given below, and as explained in our labs in Week 10, we observe that while charging and discharging, they use different paths:

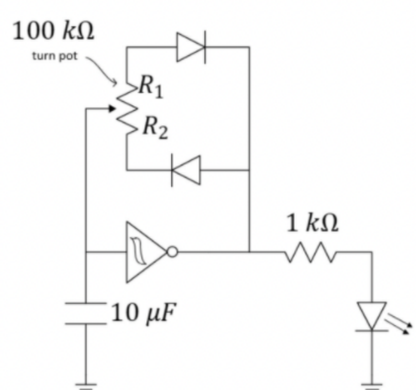


Figure 6: Image of the circuit used to test the frequency of the Oscillator

Image taken from UIUC: ECE 110 Worksheet of Week 9

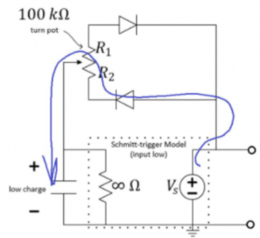


Figure 7*: Oscillator with Schmitt-trigger modeled for "input low" (charging cycle).*

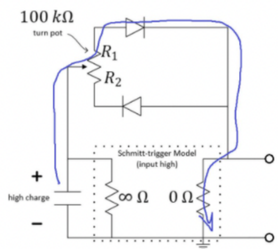


Figure 8*: Oscillator with Schmitt-trigger modeled for "input high" (discharging cycle).*

However, we notice that this circuit is still different from the ones we see in our origin design *(Figure 1)* and this is because these are not protecting the components of our circuit - any discrepancies (especially in the form of resistors) occur from the extra protection that is provided in the circuit to prevent short-circuiting of our materials like the potentiometer, motors etc.

nMOS Transistors (n-type metal-oxide-semiconductor gates):

These are transistors that essentially are used as variable resistors in our circuit, but they may have different purposes depending on their usage (datasheet here) We observe that our source of the mosfet is connected to ground (0V), our drain is connected to our motors to turn them, and our PWM signal is being inputted to our gate to act as our resistor to turn the motors on and off. We observe the use of the inverter in between the two motors: This means that as we get out duty cycle close to 0, we slowly transition into 1 motor which has high input running, turning our car toward one side. When we get our duty cycle close to 100, the first motor slowly comes to a stop while the other motor slowly starts to run, and this means that the two motors are complements of one another and they, when kept at 50% duty cycle, make the car run straight.

Diodes:

We observe the difference in uses between the diodes while creating the PWM signal, and the protection of the MOSFET. When used in PWM (shown in *Figure 6*) it alters the circuit and makes different routes for charging and discharging, but when used alongside the motors, it helps to protect the motors from any surge of power.

Potentiometer:

The potentiometer is a device that acts as a variable voltage divider. When looking at the potentiometer, we see that it provides a variable amount of resistance which sums to the value listed on the potentiometer (100k Ohms) and this is what we need to use to adjust our PWM duty cycle.

We first tried to calculate the possible duty cycles of this circuit we have made.
We know that naturally, the duty cycle equation is:

DC = Time_on / (Time_on + time_off).

However, due to the use of the potentiometer, we need to find the duty cycle in terms of resistances. Normally, with the ideal circuit shown in *Figure 7/8*, we would have used the equation:

DC = R2/ (R1+R2)

However, we know that there are extra resistances that have been added for protection, so we use those in our equation to get:

DC = (R2 + 1k) / (R1+1k + R2 + 1k)

Now, we know that our R1 and R2 can variate from 0 Ohms to 100kOhms, and so we get our maximum and minimum duty cycle as shown:

Minimum = 1kOhm / 102 KOhms *100% = 0.98%
Maximum = 101 KOhm / 102 Kohm *100% = 99%

Note:
R1 is the resistance between Pin 2 and Pin 1.
R1 is the resistance between Pin 2 and Pin 3.

Troubleshooting & Validation:

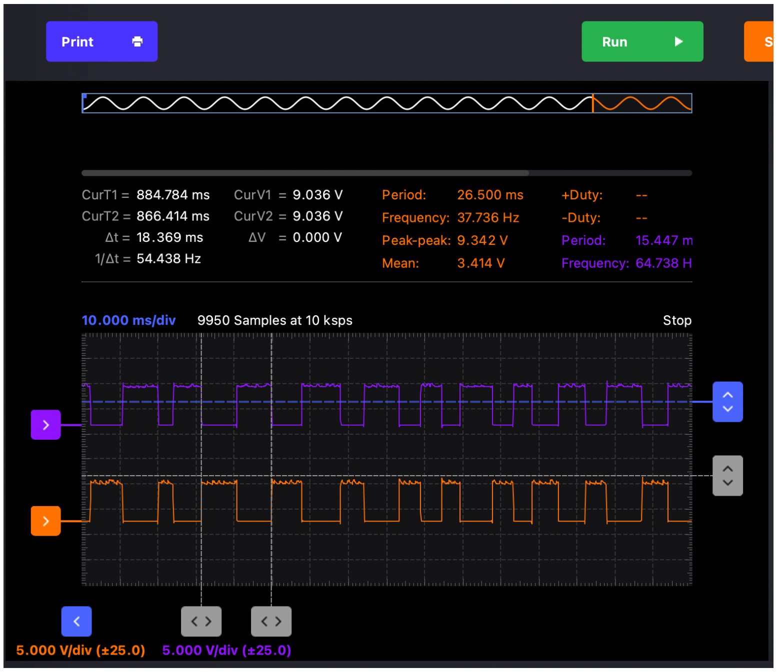
After building the circuit and testing the shadow car to ensure our circuit was constructed correctly, we needed to adjust the potentiometer to make the car steer straight. We struggled to find the perfect resistance that would provide this result. We brainstormed and discovered that by using the m2k we could measure the duty cycles to find the perfect resistance. After attaching the probes from channels 1 and 2 between ground and the gates of the nMOS we were able to use the oscilloscope to measure the duty cycles. We struggled with placing the vertical, horizontal, and triggers. After we solved that problem, with help from the lab notes we discovered that a duty cycle of approximately 49% and 51% would provide the results we are aiming for. We used the equation

DC= Time_on / (Time_on + time_off)

Conclusion & Future Work:

In the end, we were able to make our car run on a relatively straight bath by implementing the oscillator and PWM signal concepts. Our engineering tools were definitely crucial throughout every step of the process. Throughout the design and building process we were able to use our technical backgrounds to understand how the circuit schematics functioned and how we could properly implement them on our own cars. As far as for the trouble-shooting and redesign processes, engineers are meant to be problem solvers, so we were able to think about any issue that came up logically by using our different skill sets and background knowledge to resolve them. We used many circuit components that we have learned about in ECE 110 such as Schmitt Triggers, nMOS Gates, potentiometers and diodes. In addition to this, we were able to analyze our findings by calculating duty cycles and frequency (which we obtained by using RC time constants to get t_{rise} and t_{fall}). We also used our M2K measurement equipment and Scopy software to obtain oscilloscope recordings. There are also many different projects that utilize PWM's. Pulse Width Modulators can be very useful when creating light-dimming circuits. For future work, we could analyze how to change the duty cycles of a PWM and LED circuit in order to maintain a dimmed light, which would require attempts at altering the average current of the circuit.

DUTY CYCLES:



50-50%:

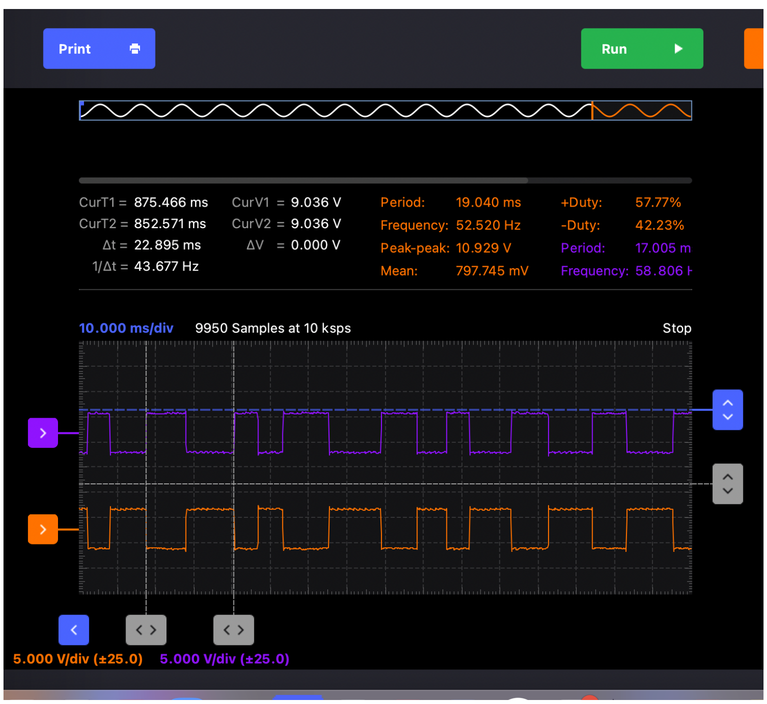
t_on = 9.318

t_total = 18.369

DC = t_on/t_total *100 %

= 0.50726*100 %

= 50.726%



45-55%:

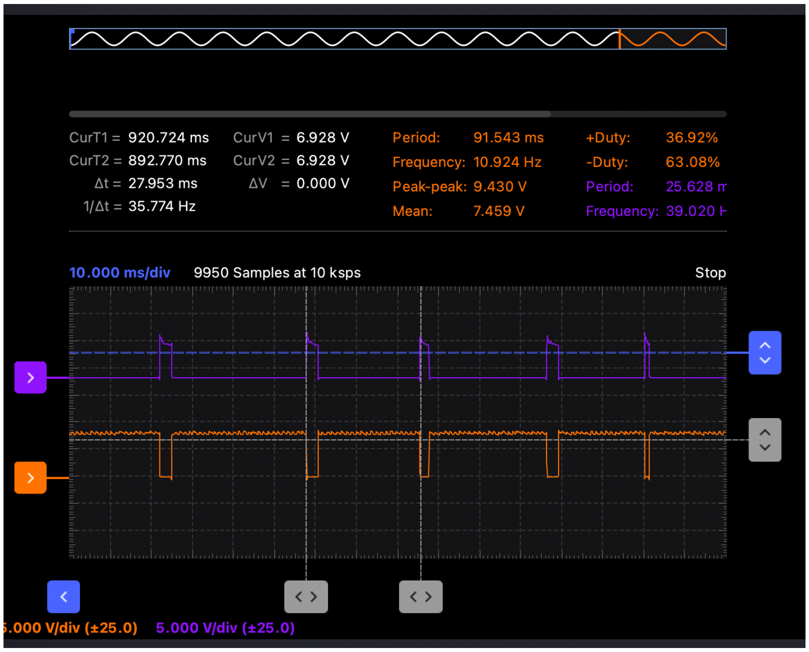
t_on = 10.383

t_total = 22.895

DC = t_on / t_total *100 %

0.4535*100 %

= 45.35%



<u>90%-10%:</u>

t_on = 2.928

t_total = 27.953

DC = t_on / t_total *100 %

0.104747*100 %

= 10.4747%