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Department of Electrical Engineering
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Project Report:
DC-to-DC Voltage Multiplier

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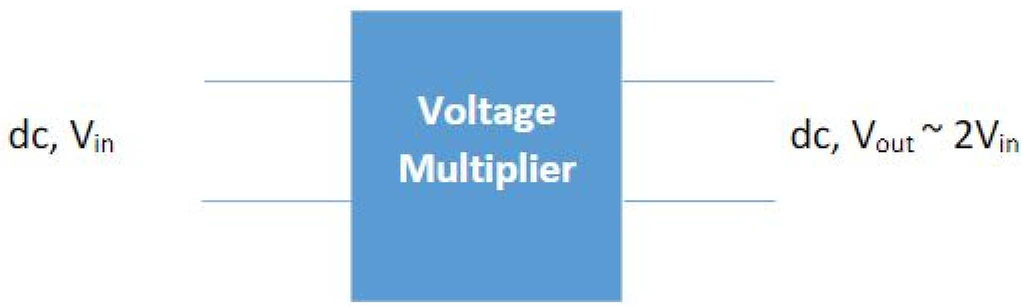
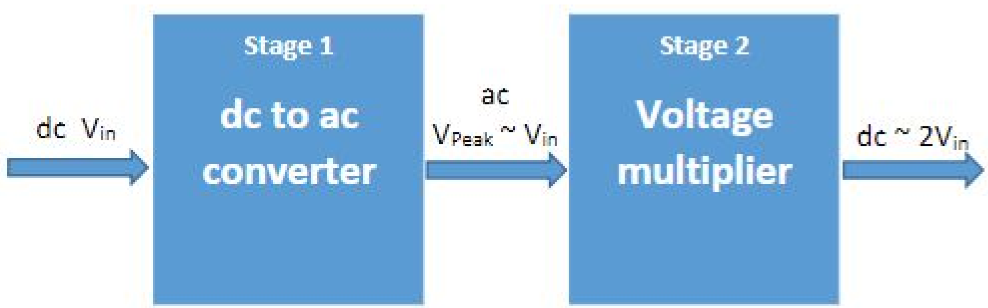
INTRODUCTION

The DC-to-DC Voltage Multiplier is a device with many applications, hand-held electronics and beyond. A number of electronic devices have a fixed voltage source, the battery. However, subcircuits in the device may need more than one DC voltage source, including voltage values that are larger than the battery voltage.



DC-to-DC Voltage Multiplier circuits are usually based on taking the input DC voltage (V_{in}) and creating an AC voltage with amplitude of V_{in}. The AC voltage does not have to be sinusoidal. This AC voltage then serves as an input to an AC-to-DC voltage multiplier circuit,whose output is a rectified DC voltage with a magnitude of approximately $2V_{in}$.



DESIGN

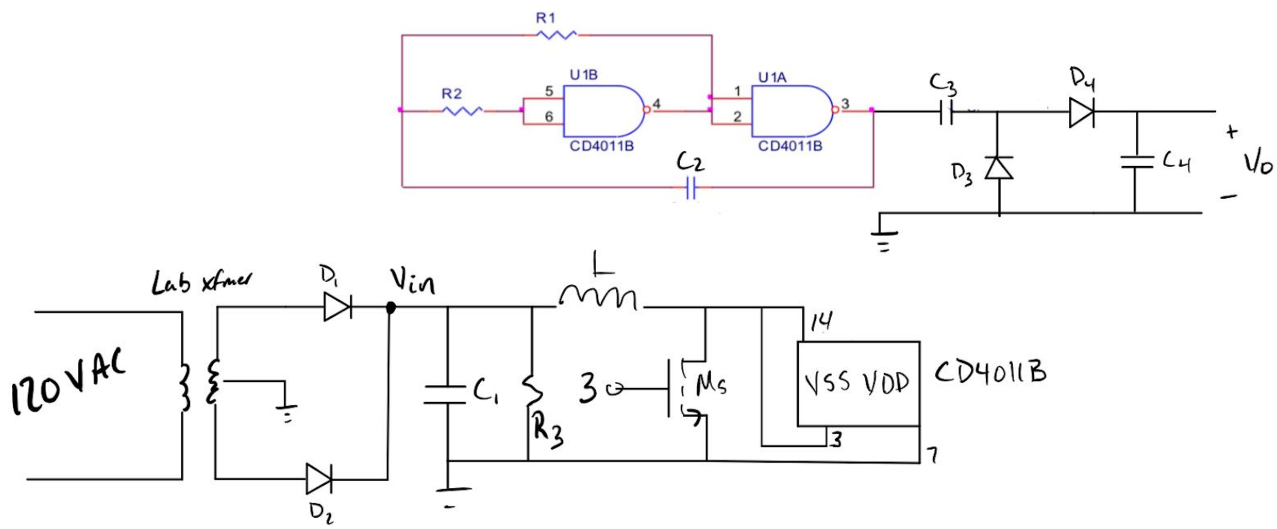


Figure 1: Initial design of voltage doubler circuit

In our original design, we converted the 120VAC from the wall outlet to roughly 10V DC through a full-wave rectifier center tapped transformer. The diodes D1 and D2 rectify the AC, while C1 and R3 control the voltage ripple. We want a large resistor and capacitor to keep the ripple small.

Vin is connected through a CD4011B IC. The IC uses two NAND gates, a capacitor, and resistors to create a CMOS square wave oscillator. R1, R2, and C2 generate the discharge time constant for the circuit. We want large values for these components to get as close to the ideal sq***uare wave as possible.

The output square wave is connected to and inductor L1 and the gate of the switching transistor Ms. The transistor allows the inductor to charge and discharge current at a set frequency. When Ms is turned off, the surge of current from the inductor passes through the diodes D3 and D4 to charge the capacitors C3 and C4. The diodes D3 and D4 also prevent the capacitors from discharging back into the circuit. With every current surge from the inductor, the charge builds across the capacitors until we get to the desired 20V Vo.

Transformer	Rectifier	Oscillator	Doubler
10.6 VAC	10.05 VDC	10.05 VAC	20.1 VDC

Table 1: Theoretical Voltage

Lab Transformer: 10.6V (from spec sheet)
Ideal Rectifier: $V_p - V_{on,\,diode} =$ 10.6V - 0.55V = 10.05V
Ideal Oscillator: 10.05 V
Ideal Doubler: 20.1 V (no load)

SIMULATION

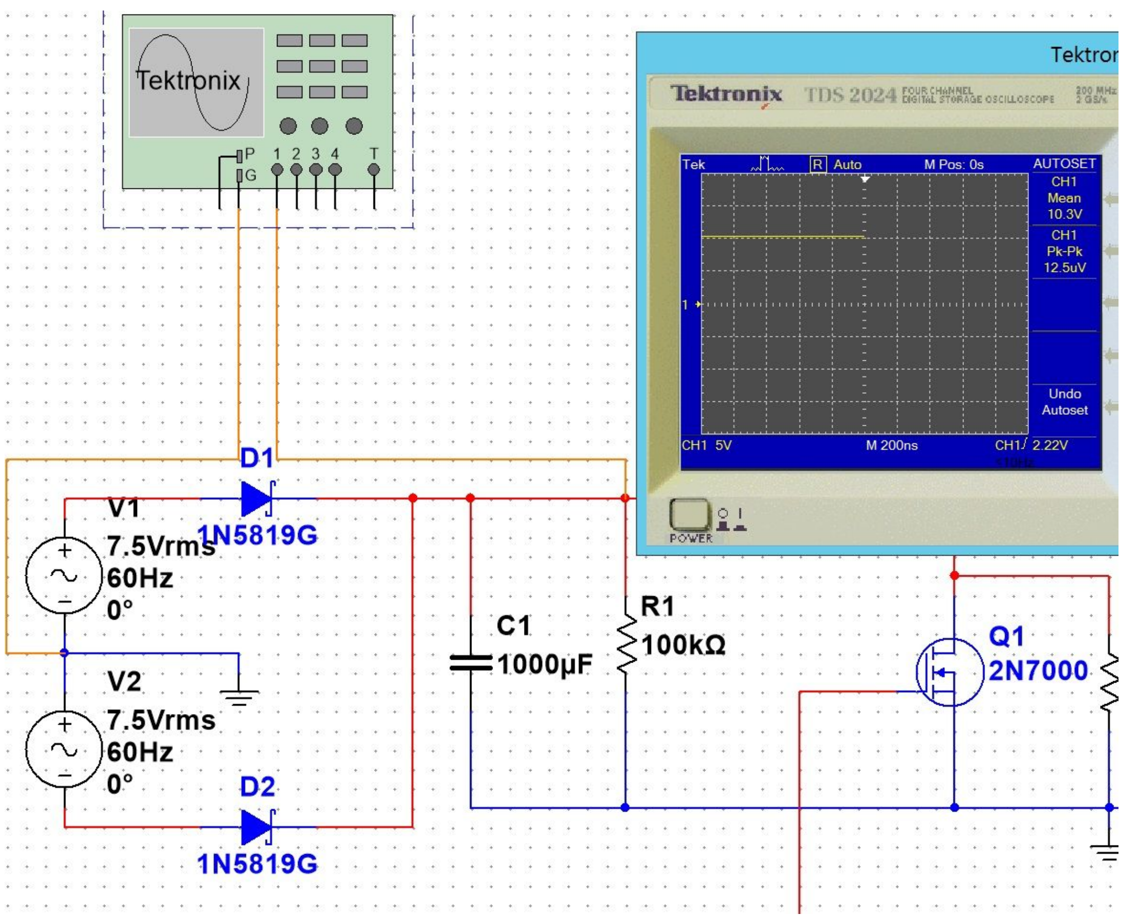


Figure 2: AC-DC Split Full wave Rectifier 10.3 Vdc output Vr = 12.5uV

$$\Delta T = \frac{1}{\omega}\sqrt{\frac{2Vr}{Vp}}$$

$$Vr = \frac{Vp - 2Von}{RC} \times \frac{T}{2}$$

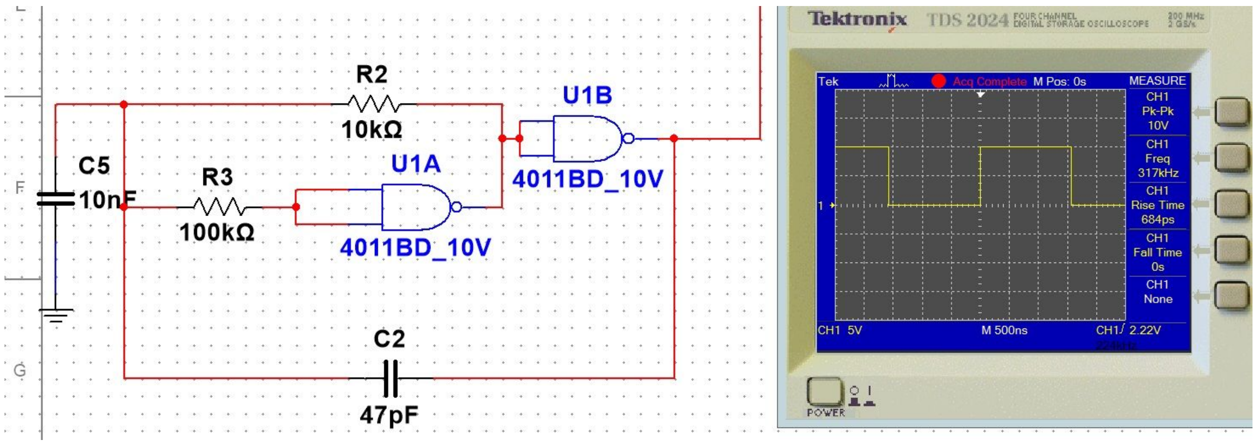


Figure 3: Square Wave Generator Output 10Vpp 317 kHz

$$f = \frac{1}{t_{on}}$$

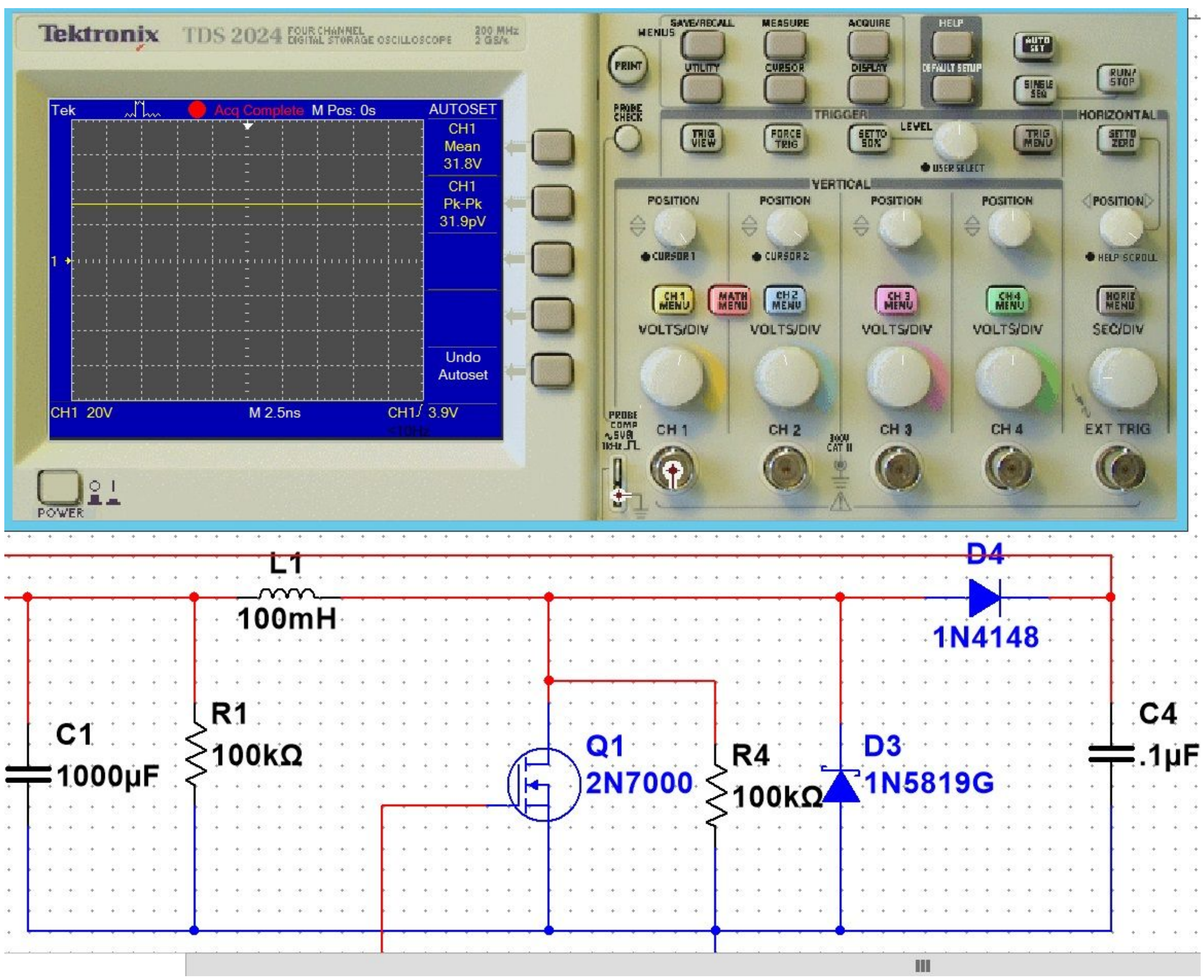


Figure 4: Voltage Multiplier Circuit 31.8 Vdc with ripple of 31.9pV.

$$Vr = \frac{Vp - 2Von}{RC} \times \frac{T}{2}$$

$$\Delta T = \frac{1}{\omega}\sqrt{\frac{2Vr}{Vp}}$$

$$V_t = V_s + L\frac{\Delta i_{off}}{t_{off}} = V_s(1 + \frac{t_{on}}{t_{off}})$$

$$f = \frac{1}{t_{on}}$$

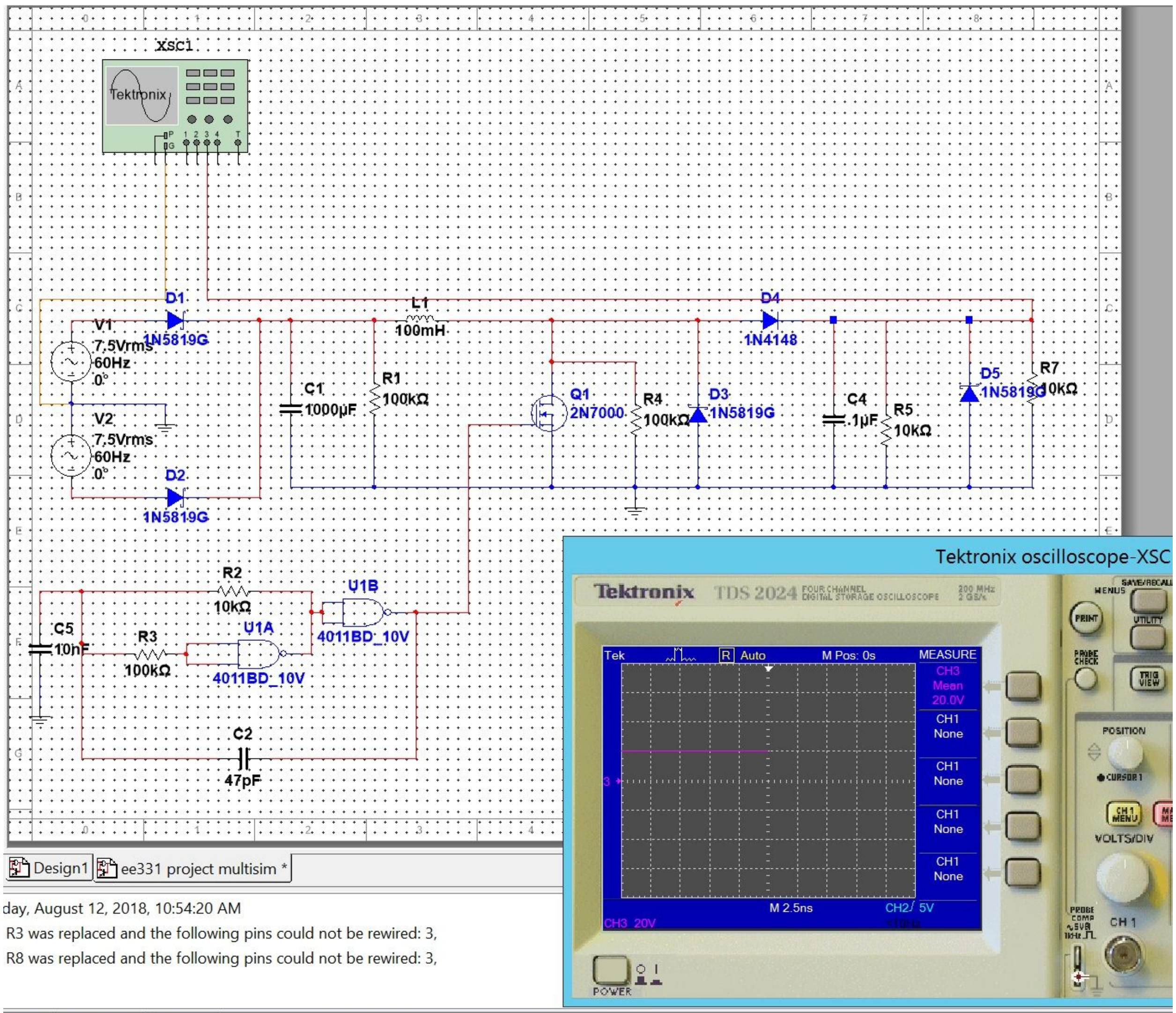


Figure 5: Voltage Regulator Output with 10k Load 20.0V out.

$$V_L = \frac{\left(\frac{Vz}{Rz} + \frac{Vs}{R} I_L\right)}{\left(\frac{1}{R} + \frac{1}{Rz}\right)}$$

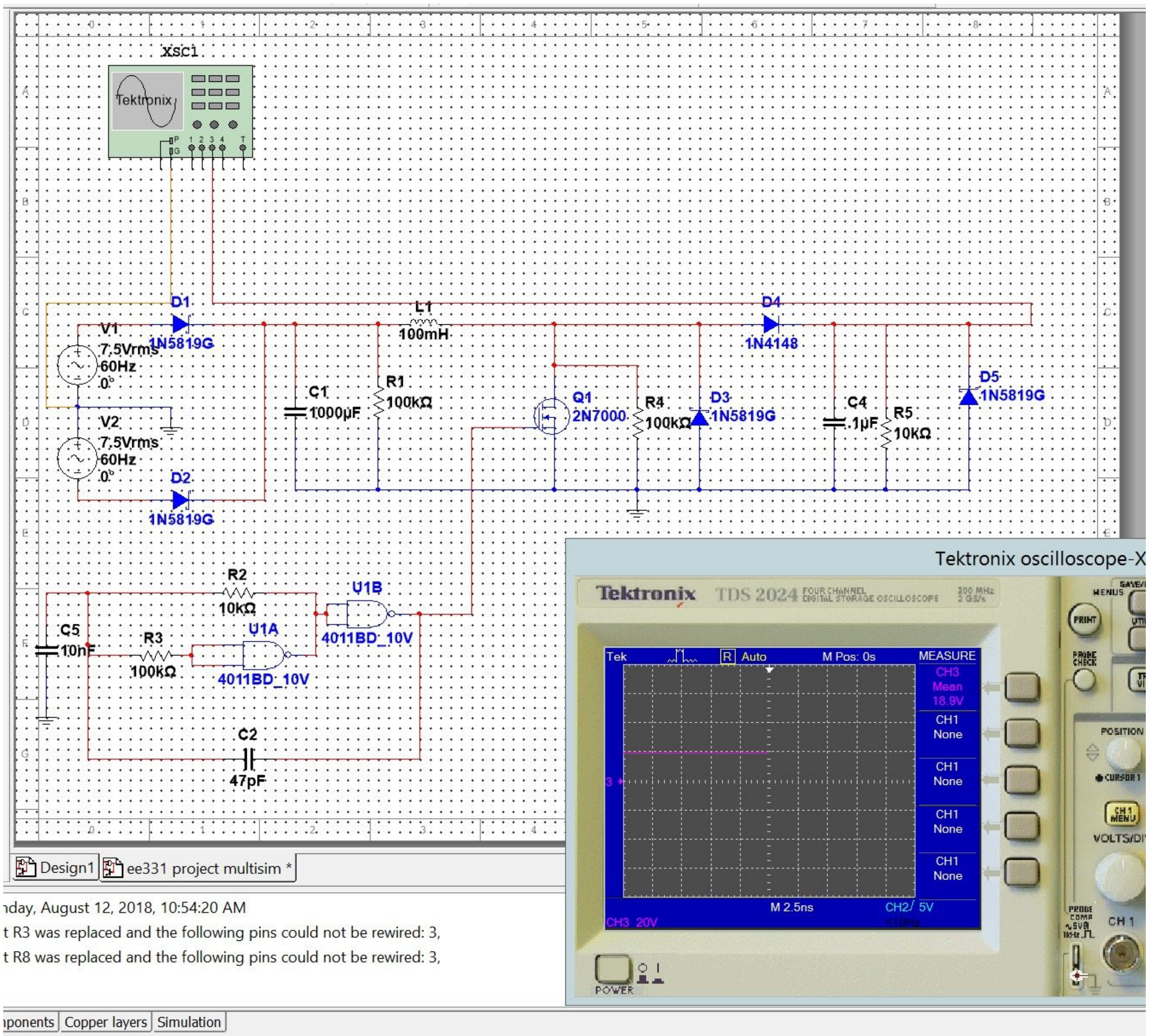


Figure 6: No load w/ output 18.9V

Transformer	Rectifier	Oscillator	Doubler
10.6 VAC	10.3 VDC	10 VAC	18.9V

Table 2: Simulated Voltage

IMPLEMENTATION

Now that our designed and simulated our circuit with the desired results it is time to build the circuit. Our constructed circuit is shown in Figure 7. The top breadboard contains the CMOS square wave oscillator circuit. The bottom breadboard contains from left to right: the full wave rectifier, voltage step-up switch-mode power supply, voltage multiplier, and voltage regulator circuits.

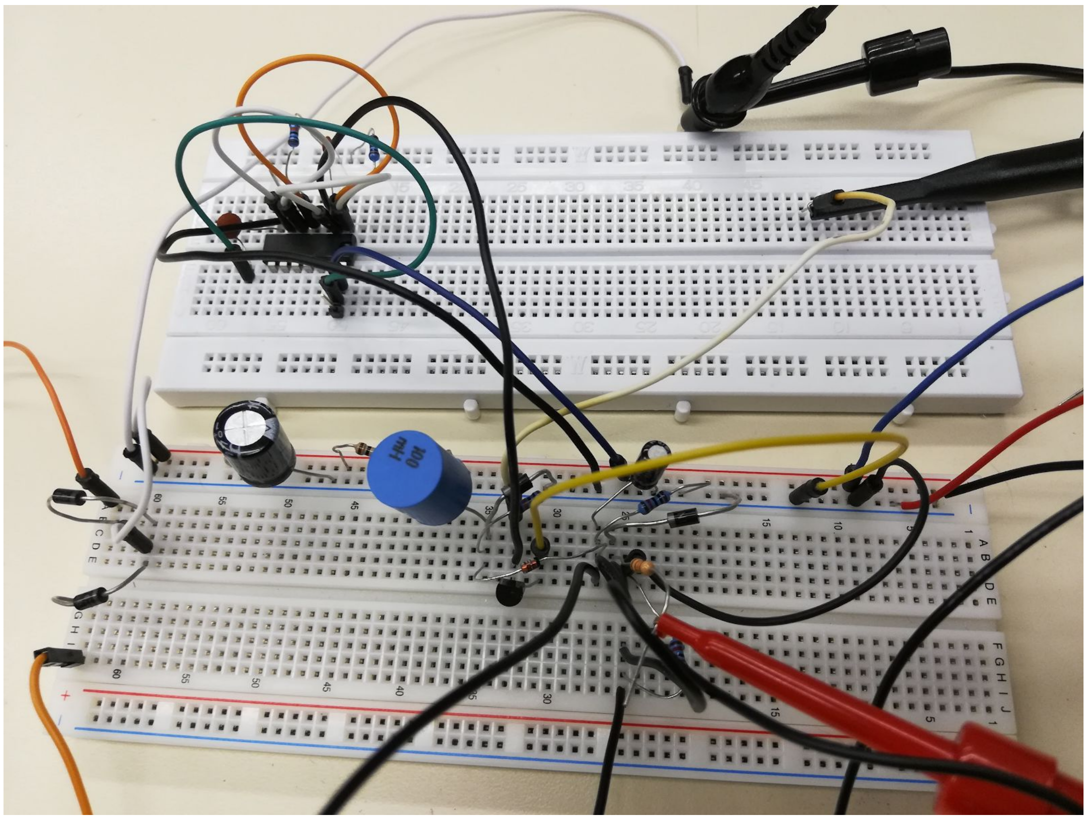


Figure 7: The constructed circuit

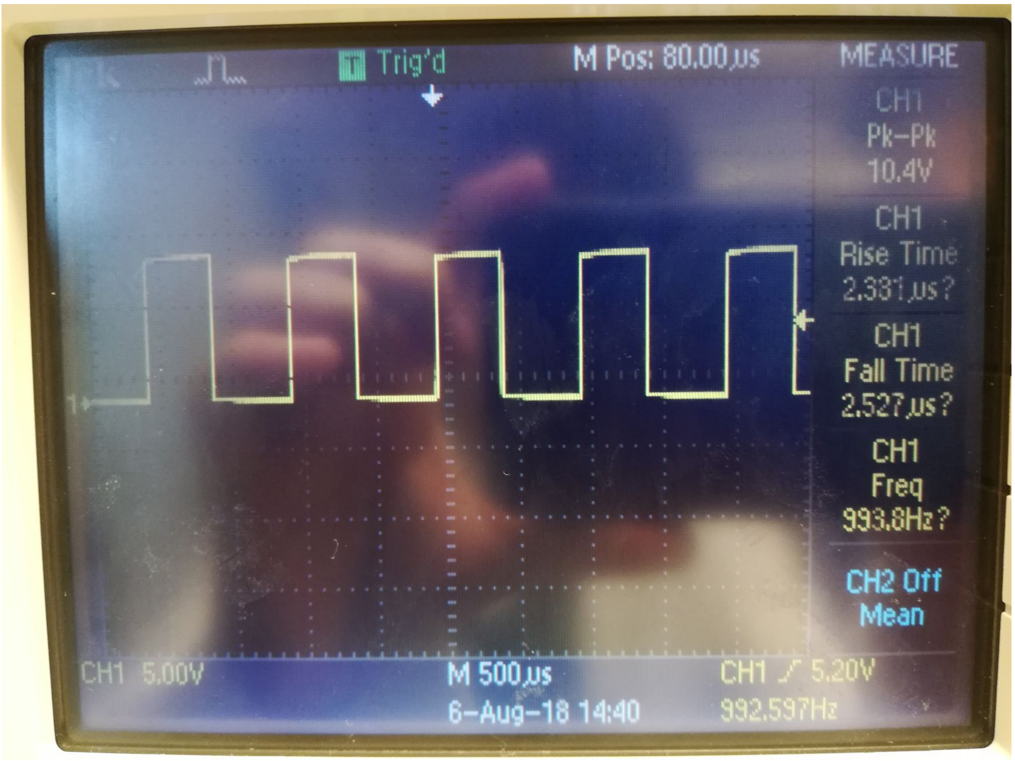


Figure 8: CMOS square wave oscillator output

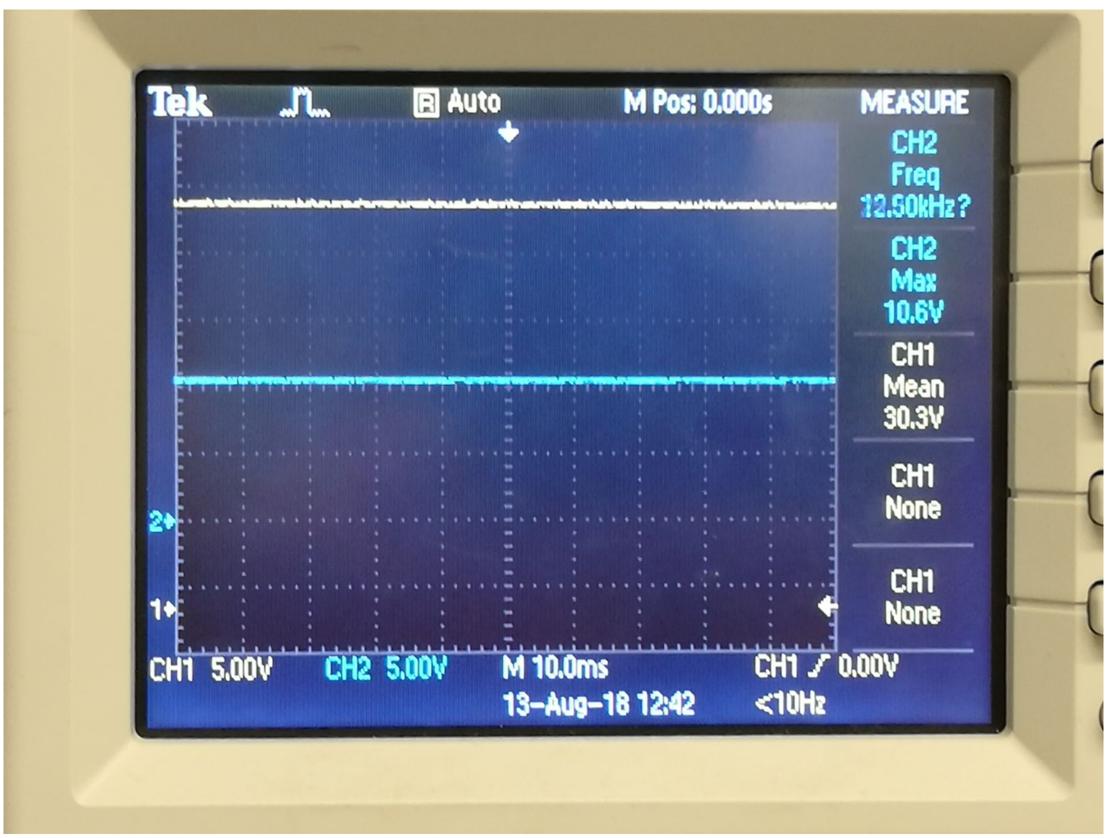


Figure 9: Voltage output for Voltage step-up switch-mode power supply

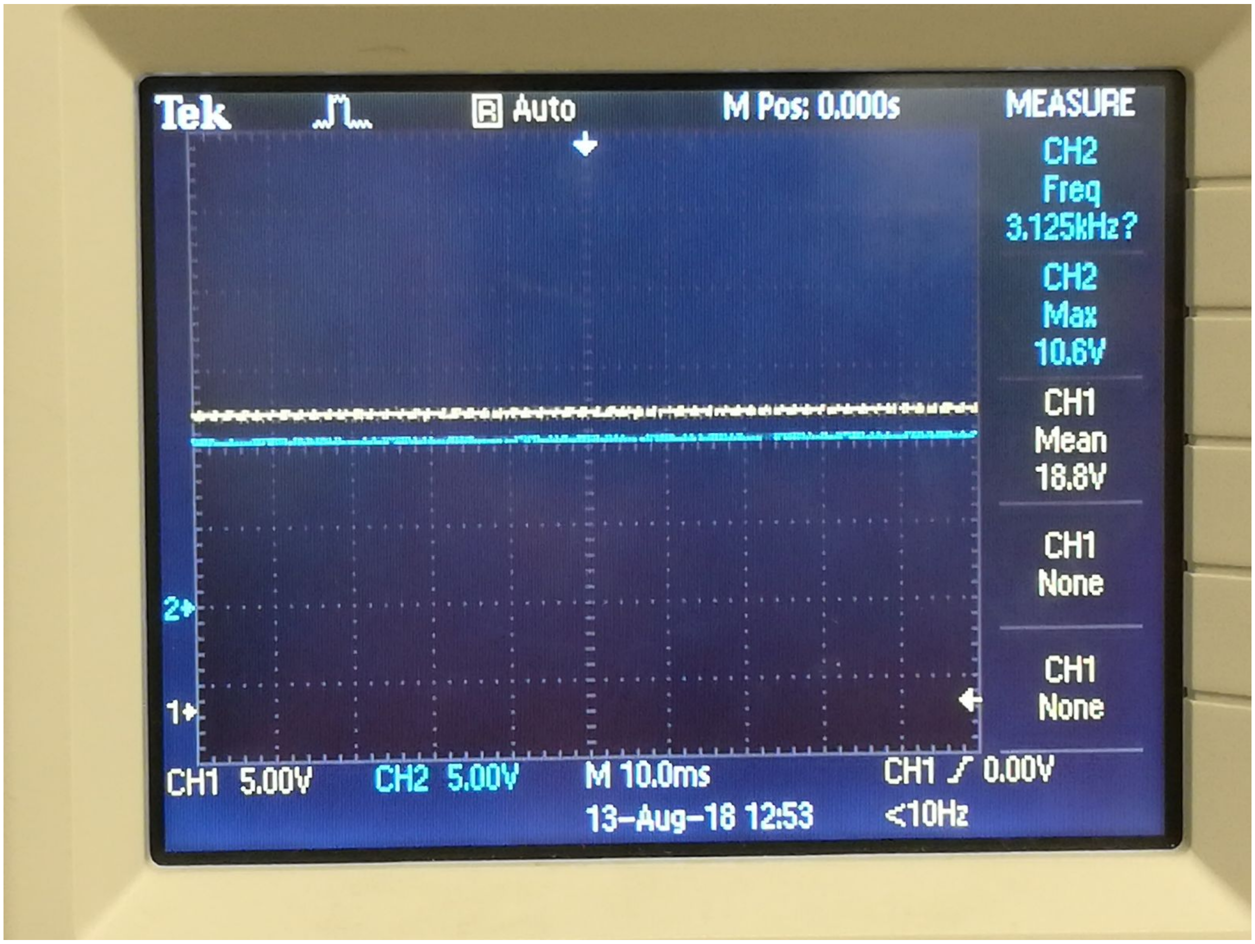


Figure 10: Voltage of load resistor

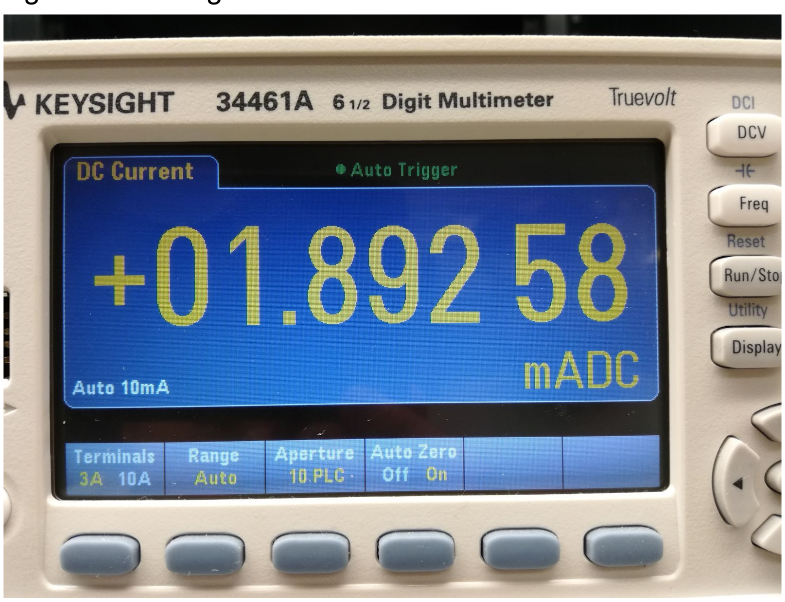


Figure 11: Current of load resistor

Figure 11: Voltage without load resistor

Transformer	Rectifier	Oscillator	Doubler	w/ Load	w/o Load
10.6 V	10.3V	10.4V	18.9 V	18.8 V	18.9 V

Table 3: Actual Voltage

I = 0 mA: $V_o = 18.9\ V$

I = 2 mA: $V_o = 18.8\ V$

As the load draws more current, the output voltage decreases. The equation $\frac{dV_L}{dI_l} = -\frac{RR_Z}{R+R_Z}$ describes how a voltage regulator controls the load regulation. To decrease the the change in output voltage we would want to increase the line resistance R.

ANALYSIS

	$V_{TRANSFORMER}$	V_{DCIN}	V_{AC}	V_{DCOUT} w/ L	V_{DCOUT} w/o L
Calculated	10.6 V_{peak}	10.05 V	10.05 V_{peak}	20.1 V	20.1 V
Simulated	10.6 V_{peak}	10.3 V	10 V_{peak}	18.9 V	18.9 V
Observed	10.6 V_{peak}	10.3 V	10.4 V	18.8 V	18.9 V

Table 4: All of the values from the different stages in the project for quick comparison.

Our output values clearly differ in the observed case from our simulated and calculated cases. This is likely due to the the non-ideality of real physical devices, with a cascade of small differences adding up to a larger change in the overall output.

The TA, Xu Xu, tested our circuit earlier before the demo and said it was fine, the professor also said it was fine. We expect the demo to go smoothly.

Overall, our group is very happy with the result. We feel that this project has been a good example of the knowledge and skills learned in this class, and has provided us more design skills to carry into the future for further classes, and in our careers.

In the future, if we were to improve the circuit, we would try to minimize the time it takes for the output to react to a change in the input.