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Vision Box Calculations and Electrical Design Justification
Cornfleis Team

Abbreviations
IC: Integrated Circuit
AC: Alternating Current
DC: Direct Current
LED: Light Emitting Diode
PCB: Printed Circuit Board
A: Ampere
V: Volt
W: Watt
F: Farad
m: Meter

General Power Supply Design

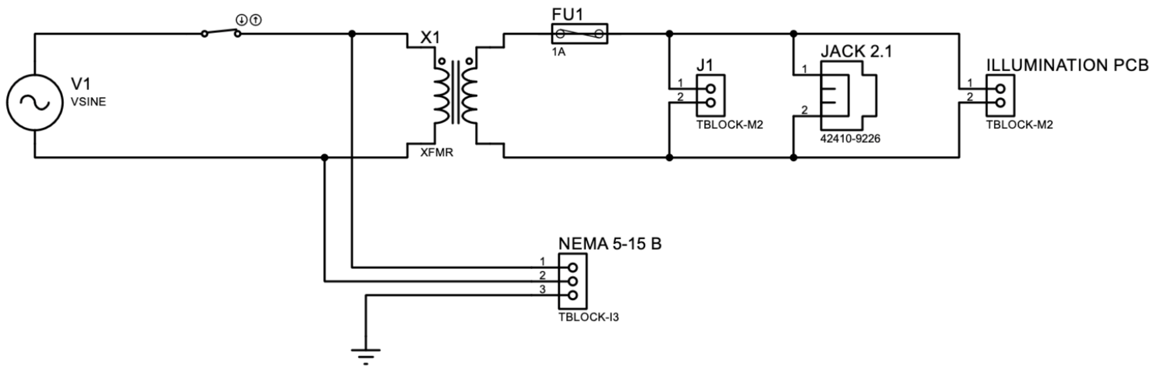


Figure 1: General Power Supply Schematic

As seen in Figure 1, a switch is included at the beginning of the circuit to control the power supply input, this way you can shut down the whole Vision Box if you need to. A fuse is connected just after the transformer in order to protect the delicate components of the circuit in case a current spike occurs.

The Vision Box is connected to 127V AC, we take that directly from the source to a NEMA 5-15 socket connection inside the box, and we also convert that input to 24V AC using the transformer, where a 2.1 Jack, a terminal block and the output to the Illumination PCB is linked.

The source current from the power supply is restricted by the 1A Fuse and can therefore supply currents below 1A, which is more than enough for the total consumption of the Vision Box, which is expected to be around 300 mA at full light intensity.

Illumination System Power Supply Design

Rectification Process

From the 24V AC output from the power supply, the required 12V DC and 5V DC voltage levels for the LED strip and the microcontroller development board are obtained by using a full-wave bridge rectifier and LM7812 and LM7805 linear voltage regulators.

In order to convert the AC output, the GBU406 rectifier was used. The decision to use this IC instead of four diodes in the PCB was made to save space and facilitate design. The specific model of the IC was chosen due to easy availability in local stores. Figure 2 shows a simulation in LTSpice of the bridge rectifier, while Figure 3 shows the measured output on the oscilloscope, where Resistor R simulates a load.

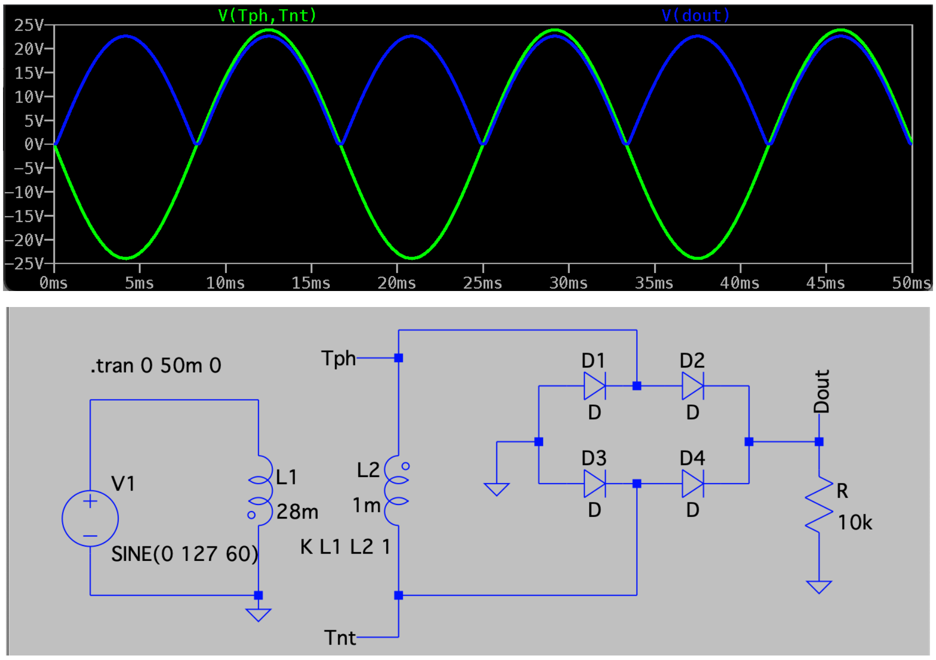


Figure 2: Bridge Rectifier Simulation

(a) 24 V AC after Transformer (b) Rectified Output

Figure 3: Rectifier Oscilloscope Output

Expected Current Consumption of the system

According to specifications of the LED Strip manufacturer [1], the power consumption is 2.6W per meter. It is expected that a total of 1.2m will be used to illuminate the Vision Box. Hence total power of the LED strip is:

$$P_{LED} = (2.6\,W)(1.2) = 3.12\,W$$

Therefore, the maximum current consumed by this load, knowing it is rated at 12V will be:

$$I_{LED} = 3.12W/12V = 0.26\,A$$

In regards to the microcontroller used, according to the ESP32 datasheet [2], current consumed while running on a single core at 80MHz speed is between 20mA and 25mA ($I_{ESP} = 25\,mA$).

Additionally, as seen in Figure 4, a 330 Ohm resistor R1 is connected to the gate of Q1. When output is high (at 3.3V) from the PWM GPIO, current consumed is:

$$I_{GPIO} = 3.3V/330\Omega = 10mA$$

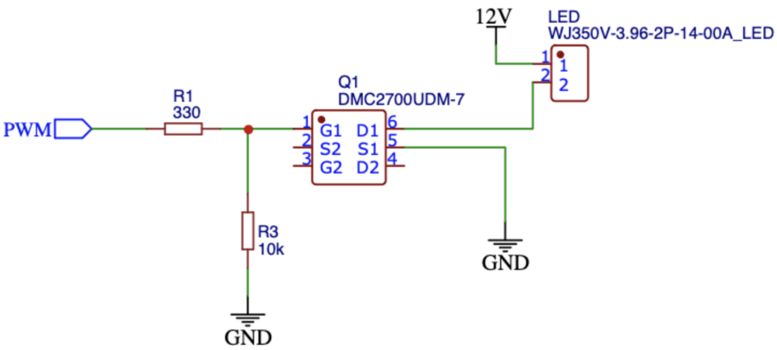


Figure 4: PWM GPIO connection

Hence, total current consumption of the system is approximately about 300mA on maximum conditions (Light at full brightness).

$$I_{Total} = I_{LED} + I_{ESP} + I_{GPIO} = 0.295\,A$$

Note that current consumption of other components such as pull-up or pull-down resistors were not taken into consideration, due to them being negligible in comparison to the other currents in the system.

Voltage Leveling

There are two voltage levels required to power the Illumination system, 12V for the LED strip and 5V for the ESP32 development board (powered via VIN pin). For this reason, the LM7812 and LM7805 linear voltage regulators were used, as they are easily available in local stores and fulfill all requirements of the system while being cheaper than buck converters.

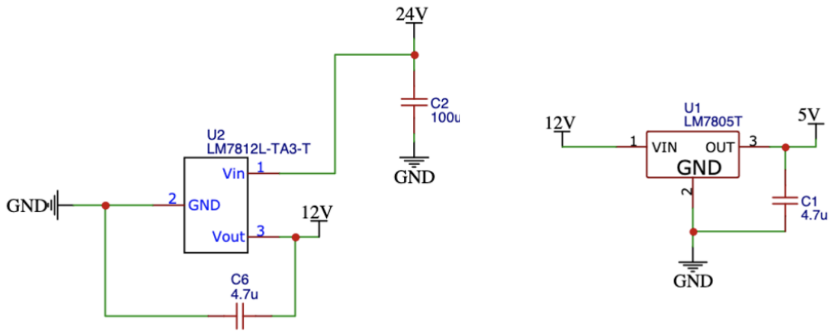


Figure 5: LM78xx connections

Figure 5 shows the connections of the voltage regulators, where the 24V net is the output of the bridge rectifier (as seen on Figure 3). C2 acts as both a smoothing capacitor for the rectified signal and the input to the LM7812.

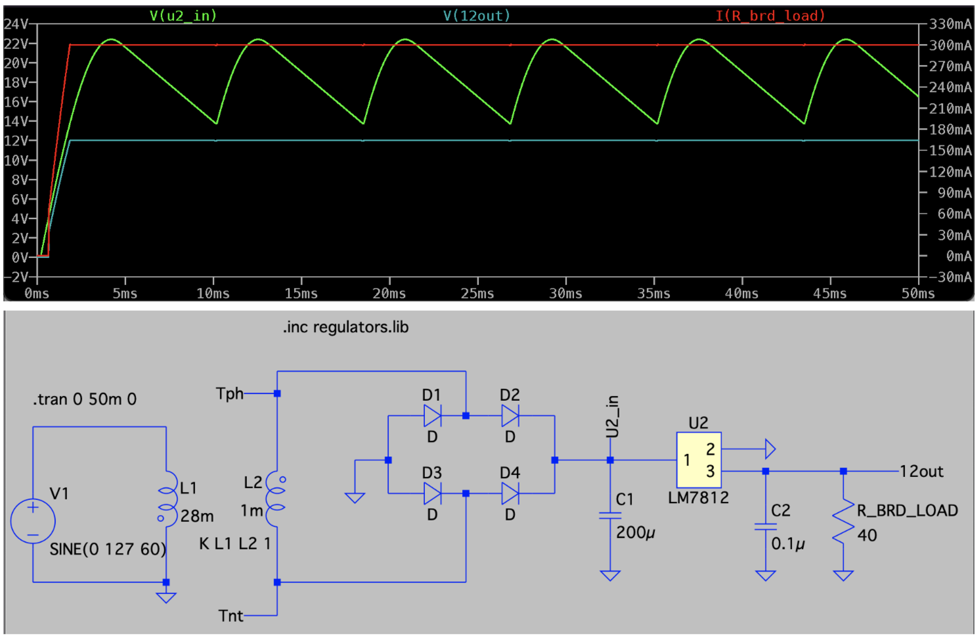
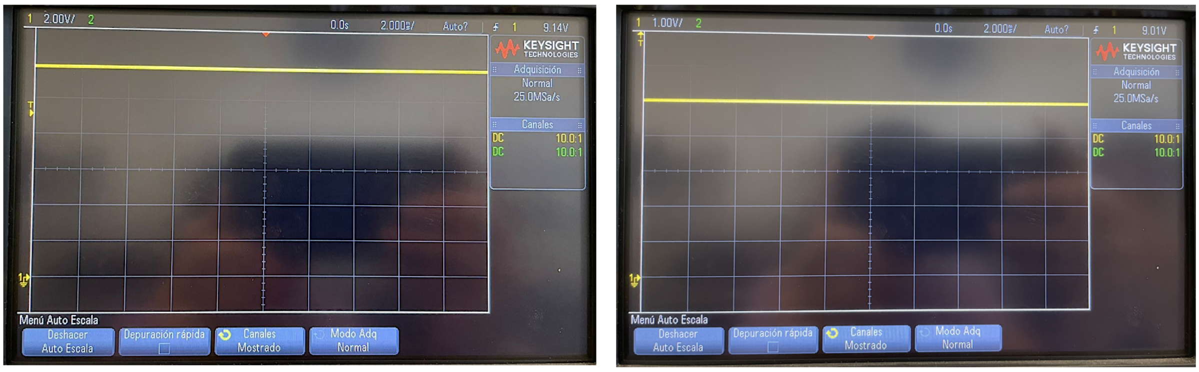


Figure 6: LM7812 Output simulation

Values of 200uF for C2 combined with C6 = 0.1uF (as recommended by the manufacturer) were seen to provide a smooth voltage level at the output of the regulator when loaded with a 40Ω resistive load (simulating the 300mA current draw of the system), while with values for C2 below this, the ripple effects of the rectification can still be seen at the output. However, a 0.1uF capacitor was not found at local stores and instead one rated at 4.7uF was used. Figure 6 shows the output of an LTSpice simulation, while Figure 7a shows the actual measured output of the LM7812 on the oscilloscope.

As seen in the schematic from Figure 5, a LM7805 (U1) is cascaded at the output of U2. C6 (4.7uF) can then be seen to act as both the output capacitor from U2 and the input capacitor to U1. C1 at the output of U1 also holds a 4.7uF value for the same availability reasons as C6. The measured output of U1 can be seen on Figure 7b.



(a) LM7812 Output (b) LM7805 Output

Figure 7: Voltage Regulators measured output

TODO: Power dissipation and generation of components

Power dissipation and supply

The power supplied to the system by the power supply is:

$P_S = (24\,V)(0.295\,A) \;=\; 7.08\,W$

Power dissipated by the load (LED Strip):

$P_{LED} = 3.12\,W$ as stated previously

Power dissipated by the board (ESP32 plus GPIO connections):

$P_{ESP} = (5V)(0.035\,A) = 0.175\,W$

where $I_{ESPT} = I_{ESP} + I_{GPIO} = (0.025 \;+ 0.01)A = (0.035\,A)$

Power dissipated by the LM7805:

$P_{U1} = P_{U1IN} + P_{U1OUT}$

where P_{U1IN} and P_{U1OUT} are the powers at the input and output of U1. Hence:

$P_{U1} = (12\,V)(0.035\,A) - (5\,V)(0.04\,A) \approx 0.22\,W$

where the current values were determined by simulation and are approximate values.

Power dissipated by the LM7812:

$P_{U2} = P_{U2IN} + P_{U2OUT}$

where P_{U2IN} and P_{U2OUT} are the powers at the input and output of U2. Hence:

$P_{U1} = (24\,V)(0.303\,A) - (12\,V)(0.304\,A) \approx 3.624\,W$

where the current values were determined by simulation and are approximate values.

LED Strip driver

TODO

References

[1] (No date) *Tira led Blanca de 5 m, Para Exterior - Steren*. Available at: https://www.steren.com.mx/tira-led-blanca-de-5-m.html (Accessed: 29 May 2023).

[2] (No date) *ESP32 series - espressif systems*. Available at: https://www.espressif.com/sites/default/files/documentation/esp32_datasheet_en.pdf (Accessed: 29 May 2023).