ELECTRONIC WORKSHOP-2 THE DESIGN OF BOOST CONVERTER CIRCUIT

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WHAT DOES A BOOST CONVERTER DO?

A boost converter is an electronic circuit that helps us amplify the input DC voltage to a higher DC voltage. It's commonly used in applications where the required output voltage is higher than the input voltage, such as in battery-powered devices or LED drivers.

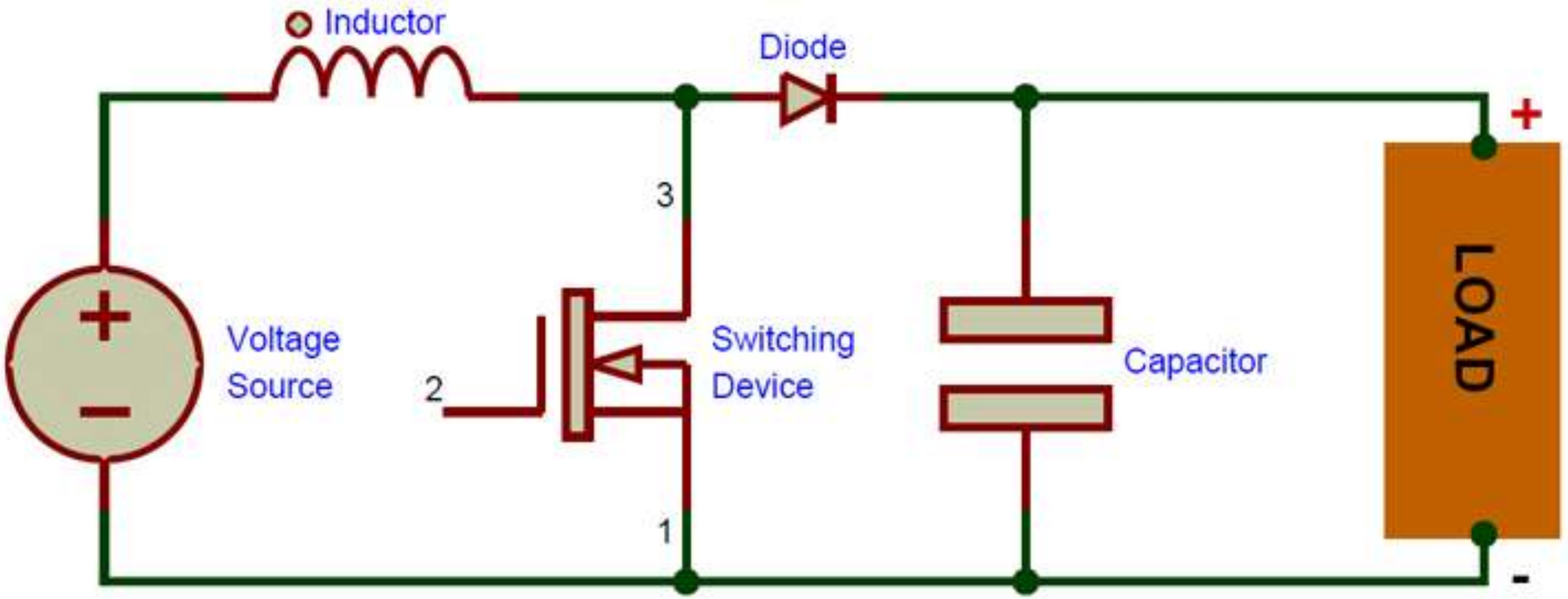
BOOST CONVERTER GENERAL USES

- Boost converter is required to convert a set voltage DC source into a variable-voltage DC output. A DC-DC switching converter converts voltage directly from DC to DC and is simply known as a DC Converter. A DC converter is equivalent to an AC transformer with a continuously variable turns ratio. It can be used to step down or step up a DC voltage source,as a transformer.

POWER OF BOOST CONVERTER

- Power for the boost converter can come from any suitable DC sources, such as DC generators, batteries, solar panels and rectifiers. The method that changes one DC voltage to a different DC voltage is called DC to DC conversion. Generally, a boost converter is a DC to DC converter with an output voltage greater than the source voltage. It is sometimes called a step-up converter since it “steps up” the source voltage.

CIRCUIT DIAGRAM OF A BOOST CONVERTER



THE WORKING OF A BOOST CONVERTER

- For a given DC input voltage from the circuit diagram, here we are using a MOSFET as a switch (on and off switch). In the first mode when the switch is open, current goes through the inductor, diode, and charges the capacitor, and this path has some impedance $Z1Z1$.
- Now in the second mode when the switch is closed, the switch will be shorted so current will go through only the first single loop with an impedance $Z2Z2$ which is much lesser than $Z1Z1$. So, current through the inductor increases. Here is the crucial property of the inductor which we will utilize: current across the inductor does not change instantaneously. Current here will have to be higher than in the previous case due to low impedance.

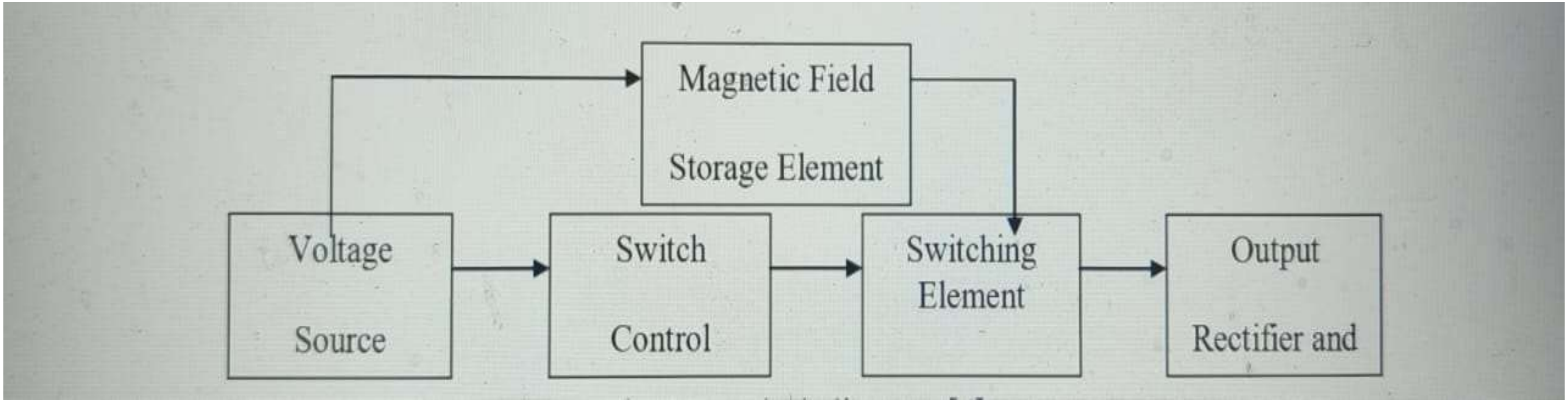
WORKING OF A BOOST CONVERTER

- Now, when the switch again opens, the current in the inductor is already high but should be low since the switch is open and the impedance is high, which can decrease the current. However, due to the property of the inductor to not change the current instantaneously, it reverses its polarity. So, the input voltage and the voltage across the inductor get added, increasing the current despite the higher impedance.

WHY ARE WE USING A DIODE?

- As we discussed before, the capacitor is charged when the switch is open.
- The diode has a very crucial role to play, which is that it prevents the discharging of the capacitor. When the capacitor is charged with the appropriate polarity, it cannot discharge through the pathway with the diode and the inductor because in this scenario the diode becomes reverse biased, hence blocking this discharge.

BLOCK DIAGRAM FOR UNDERSTANDING THE FULL WORKING



THE OUTPUT OF THE CIRCUIT

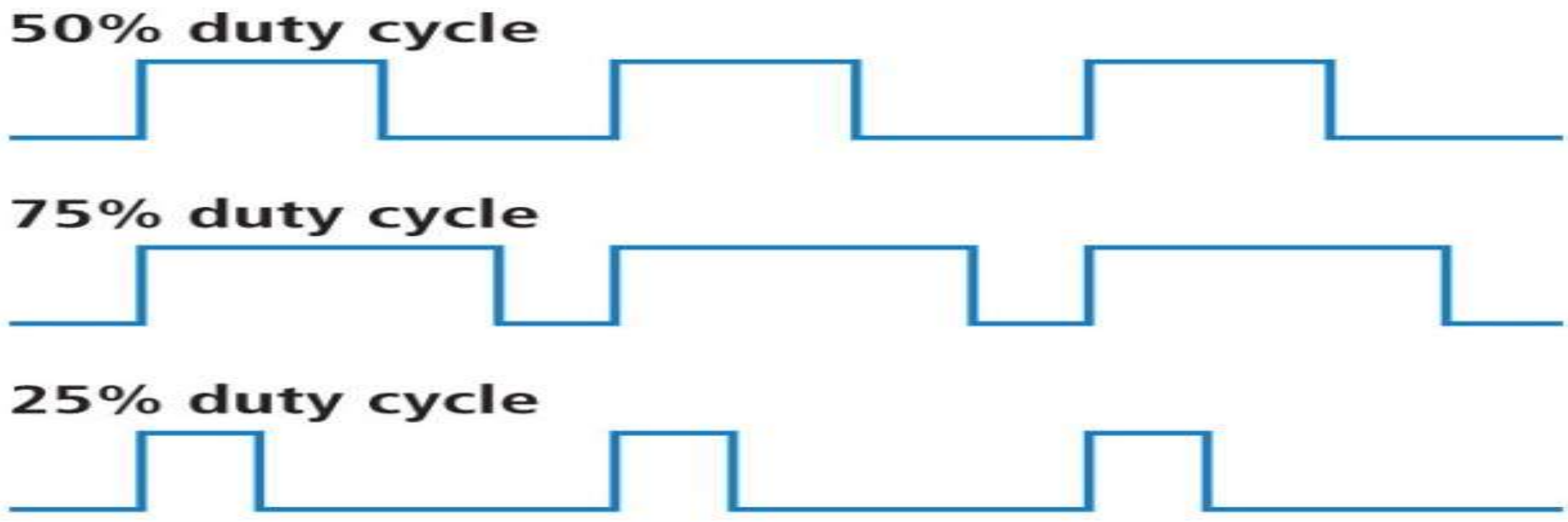
- the output of the circuit is DC amplified input voltage since, for many iterations or cycles of the on and off of the switch, similarly voltage across inductor and the input voltage will keep on adding, giving us the desired output.
- The reason why the output saturates at some DC level is because at some point in time, the rate at which the inductor passes energy after accumulating current is equal to the rate at which the capacitor discharges. This equilibrium point is reached when the energy stored in the inductor (in the form of magnetic field) and the energy stored in the capacitor (in the form of electric field) balance each other out, resulting in a steady-state DC output voltage

THE TIME FOR REACHING STEADY STATE

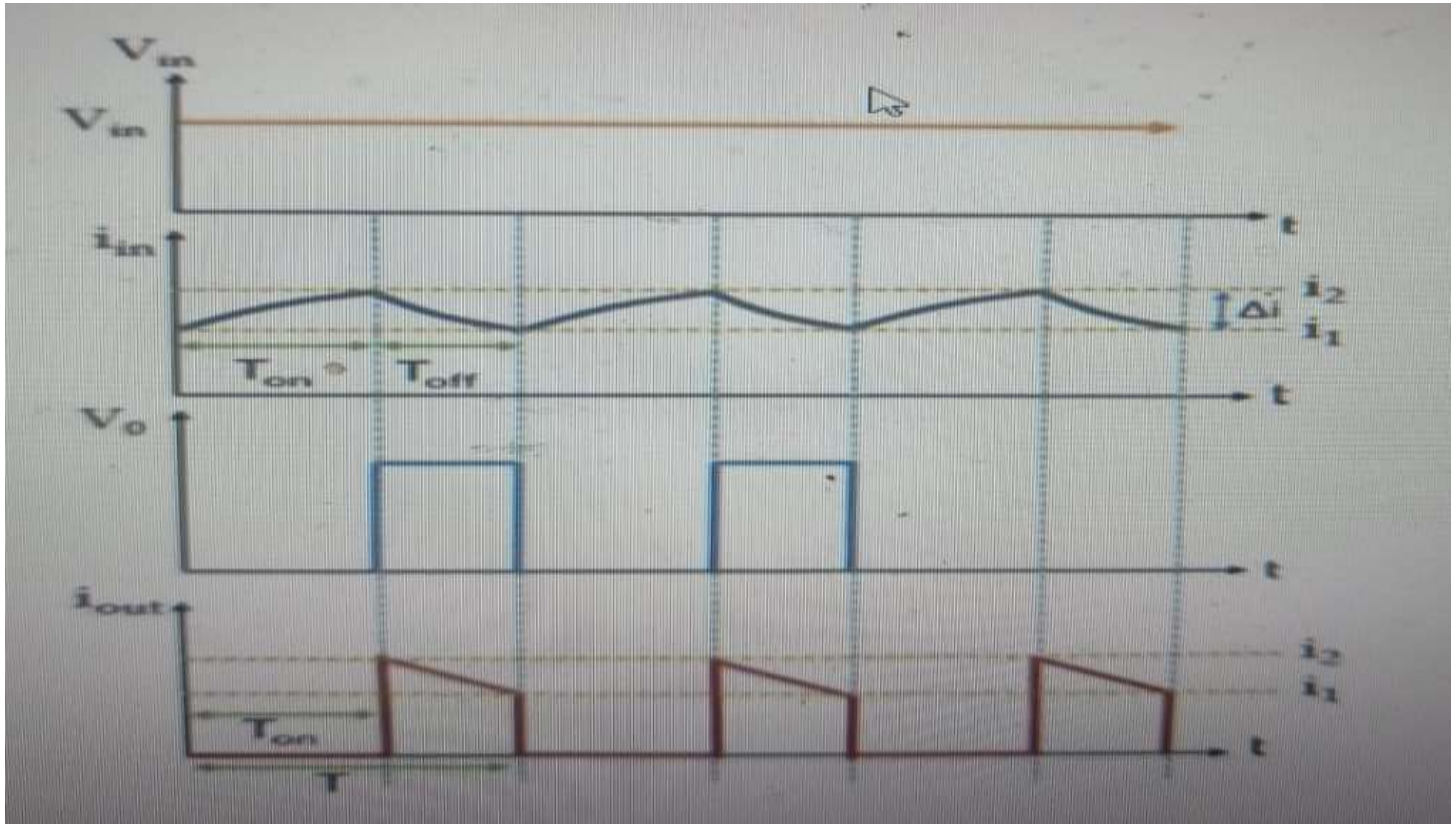
- When the switch is on, the inductor gets charged, and simultaneously, the voltage in the capacitor gets discharged through load resistance.
- The output voltage increases as long as the energy being increased in the inductor is more than the energy being discharged through the capacitor
- . A steady voltage is reached when an equilibrium is reached

WHAT IS DUTY CYCLE?

- IF AN ELECTRONIC COMPONENT IS ON FOR TIME Ton AND IT IS OFF FOR TIME Toff AND ALSO Ton + Toff=T then duty cycle is defined as Ton/T.



WAVEFORMS OF BOOST CONVERTER



WAVEFORMS EXPLANATION

- "Note: we are considering these waveforms when steady state reached, that is when rate at which inductor passes energy that is equal to the rate at which capacitor discharges.
- So as shown in the waveform we have a fixed (constant) DC input voltage.
- The graphs for all parameters varies between TONTON and TOFFTOFF for a switch cycle

WAVEFORM EXPLANATION FOR INPUT CURRENT

- During the TONTON period when the switch (MOSFET) is on, the inductor charges so Iin increases till a maximum value. Note here that impedance is low. As soon as the switch is off, the impedance of the circuit increases and the current decreases from the maximum value to the initial value it started from. This continues for every switch cycle.

WAVEFORM EXPLANATION FOR VO(OUTPUT VOLTAGE)

- When the switch is on, current only flows through the single loop containing the inductor, so at this time, there is no current in the outer loop, and hence the output voltage Vo is zero.
- When the switch becomes off, the current flows through the full outer loop containing the inductor, capacitor, the load, and the diode. The impedance of the circuit also increases, so as the capacitor gets charged by this process, it discharges through the load, and hence we get DC amplified output at the load, which is equal to Vo (output voltage), since we are assuming steady state has reached in the waveforms. Therefore, this DC level will remain the same in further cycles when the switch is off; otherwise, it would be increasing. Now, the same pattern would repeat for each switch cycle.

WAVEFORM EXPLANATION FOR IO(OUTPUT CURRENT)

- When the switch is on, the impedance of the circuit is low, and no current flows through the load since it flows only in the single loop containing the inductor. So, there is no output current in the load, thus Io (output current) is equal to zero (0).
- When the switch is off, the current flows across the full loop containing the inductor, diode, capacitor, and the load with high impedance. Here, as the capacitor discharges, its charge decreases as current is the rate of flow of charge. So, it will decrease from a maximum value to a minimum value as shown in the waveform.

DESIGN OF THE BOOST CONVERTER CIRCUIT

- **Boost Converter Design**
- **STEP – 1**
- To begin with, we need a thorough understanding of what our load requires. It is highly recommended (from experience) that if you attempt to build a boost converter at the beginning it is very important to know the output voltage and current independently, the product of which is our output power.
- **STEP – 2**
- Once we have the output power, we can divide that by the input voltage (which should also be decided) to get the average input current needed.
- We increase the input current by 45% to account for ripple. This new value is the peak input current.
- Also the minimum input current is 0.75 times the average input current, so multiply the average input current by 0.75.
- Now that we have peak and minimum current, we can calculate the total change in current by subtracting the peak and minimum current

DESIGN OF THE BOOST CONVERTER

STEP – 3

Now we calculate the duty cycle of the converter, i.e. the ratio of the on and off times of the oscillator.

DUTY CYCLE=

D.C. = (Vout – Vin)/(Vout)

This should give us a reasonable decimal value, above 0 but below 0.999.

STEP – 4

Now it is time to decide upon the frequency of the oscillator.

Once the frequency is determined, we can find out the total time period by taking an inverse.

Now the time period is multiplied by the duty cycle value to get the on time.

THE DESIGN OF BOOST CONVERTER

Note : In general, a peak to peak ripple that's between 25 and 45% of the maximum input current gives a good compromise between the size of the inductor, that's proportional to weight and cost, and the RMS currents throughout the converter.

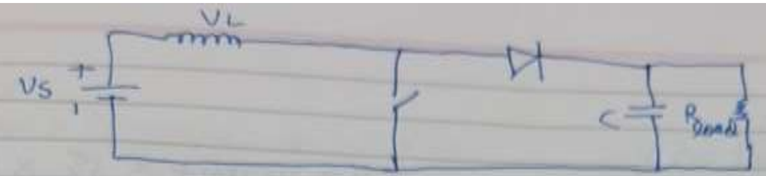
STEP – 5

Since we have determined the on time, input voltage and change in current, we can plug those values into the inductor formula which has been rearranged a little:

L=V*dt/dI

Where V is the input voltage, dt is the on time and dI is the change in current

CALCULATIONS FOR GAIN FACTOR(DC)



(A) When Switch is on:-

$V_L(ON) = V_S$

$I_L(ON) = -I_o$

Parameters Designed:- ***

1. V_S → input voltage
2. Rload → Load resistor
3. V_o → output Voltage
4. D → Duty cycle fraction
5. T → Total time = TON + TOFF for each switch cycle

(B) When switch is off:-

KVL:-

$-V_s + V_L(OFF) + V_o = 0$

$V_L(OFF) = V_s - V_o$

$I_C(OFF) = I_L - I_o$

No voltage is stored in the inductor:-

By voltage second Balance

$$V_S DT + (V_S - V_o)(1-D)T = 0$$

$$\cancel{V_S DT} + V_S T - \cancel{V_S TD} - V_o T + V_o TD = 0$$

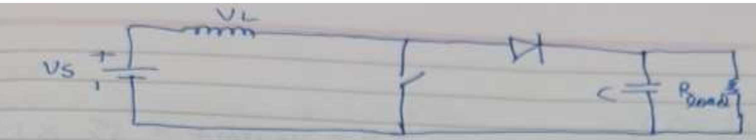
$$V_s - V_o + V_o D = 0$$

$$V_s = V_o(1-D)$$

$$\boxed{V_o = \frac{V_s}{1-D}}$$

Voltage

CALCULATIONS FOR GAIN FACTOR(DC)



(A) When switch is on:-

$V_L(ON) = V_S$

$I_L(ON) = -I_o$

Parameters Designed:- ***

1. V_S → input voltage
2. Rload → load resistor
3. V_o → output voltage
4. D → Duty cycle fraction
5. T → total time = $T_{ON} + T_{OFF}$ for ea… switc… cycle

(B) When switch is off:-

KVL:-

$-V_s + V_L(OFF) + V_o = 0$

$V_L(OFF) = V_s - V_o$

$I_C(OFF) = I_L - I_o$

No voltage is stored in the inductor:-

By voltage second balance

$$V_s DT + (V_s - V_o)(1-D)T = 0$$

$$\cancel{V_s DT} + V_s T - \cancel{V_s TD} - V_o T + V_o TD = 0$$

$$V_s - V_o + V_o D = 0$$

$$V_s = V_o(1-D)$$

$$\boxed{V_o = \frac{V_s}{1-D}}$$

voltage

CALCULATIONS FOR CURRENT GAIN FACTOR:-

Current Second Balance:-

No current in capacitor

$$-I_0 DT + (I_L - I_0)(1-D)T = 0$$

$$-I_0 \cancel{DT} + I_L T - I_L TD - I_0 T + \cancel{I_0 DT} = 0$$

$$I_L - I_L D - I_0 = 0$$

$$I_L = \frac{I_0}{1-D} \quad \cancel{\frac{V_0}{R(1-D)}}$$

Current

Parameters:-

$D \rightarrow$ Duty Cycle

$I_0 \rightarrow$ output Current

$I_L \rightarrow$ Load Current

$T \rightarrow$ Total time $(T_{ON} + T_{OFF})$

DESIGN CALCULATIONS FOR VIN=5V AND VOUT=15V AND IOUT=100 MILLI AMPERES(STEP1 AND STEP2)(BY RIPPLE ASSUMPTION AS DISCUSSED EARLIER FOR OPTIMALITY):-

Step1:-

$V_{input} = 5\,V$

$V_{output} = 15\,V$

$I_{out} = 100\,mA$

$$R = \frac{V_{output}}{I_{out}} = \frac{15}{100} \times 10^3 = 150\Omega$$

Step2:-

$I_{max} = 1.4 (I_{avg})_{in}$ $\quad$ $I_{min} = 0.8 (I_{avg})_{in}$

$P_{in} = P_{out}$

P_{in}: given by source

P_{out}: dissipated in resistor

$$5 (I_{in})_{avg} = 15 \times \frac{100}{1000}$$

$$(I_{in})_{avg} = 300\,mA$$

$$\Delta I = (1.4 - 0.8)(I_{in})_{avg} = 180\,mA$$

DESIGN CALCULATIONS(STEP 3)

\# Step 3:-

$V_{out} = \frac{V}{1-D}$

$D = 1 - \frac{5}{15} = \frac{2}{3}$

\# $V_{out} = \frac{V}{1-\frac{2}{3}} = \frac{V}{1/3} = 3V$

DESIGN CALCULATIONS STEPS 4 AND 5(WE GET REQUIRED INDUCTANCE VALUE):-

step4:-

Assume frequency as 100 kHz

$$L = \frac{dt\,V_{in}}{dI} = \frac{V_{in}\,dt}{dI}$$

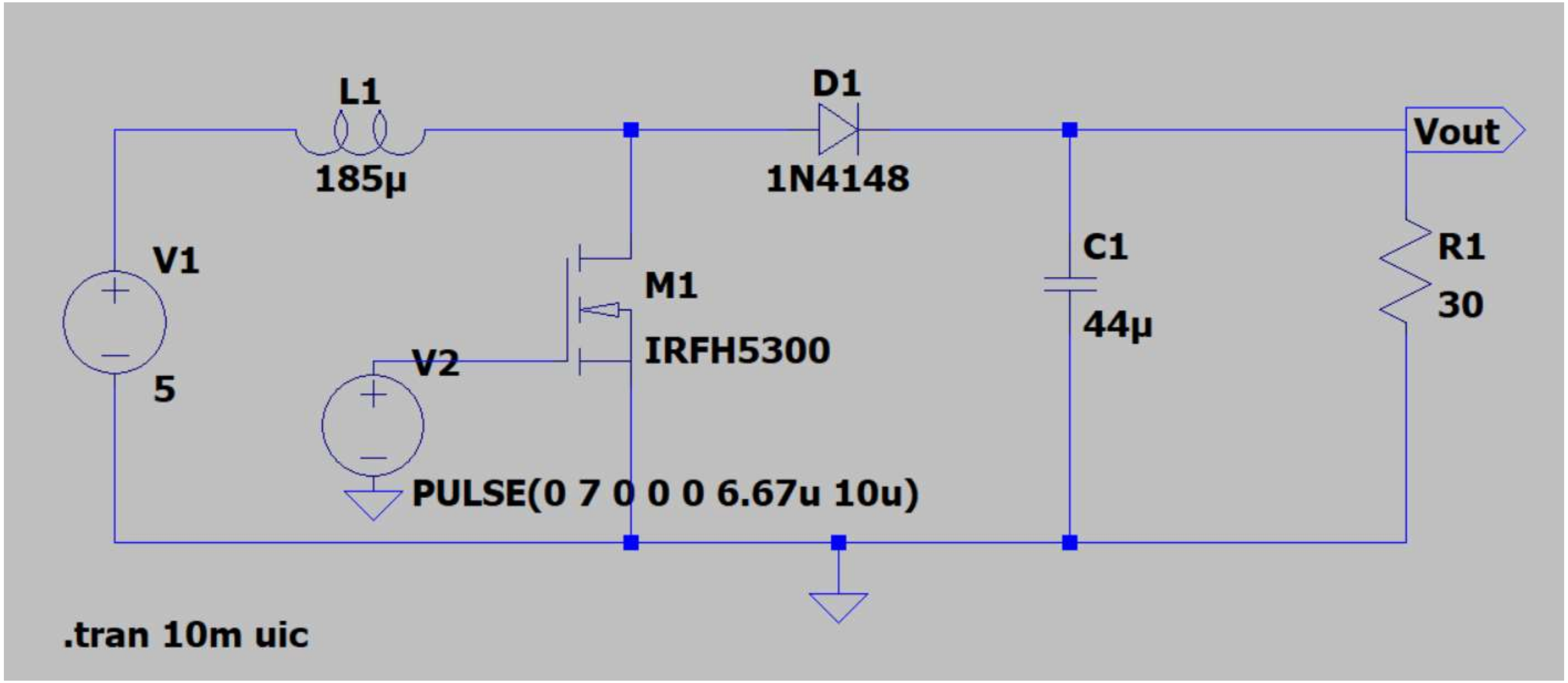
step5:-

$$L = \frac{V_{in}\,D\,T_{period}}{\Delta I_L}$$

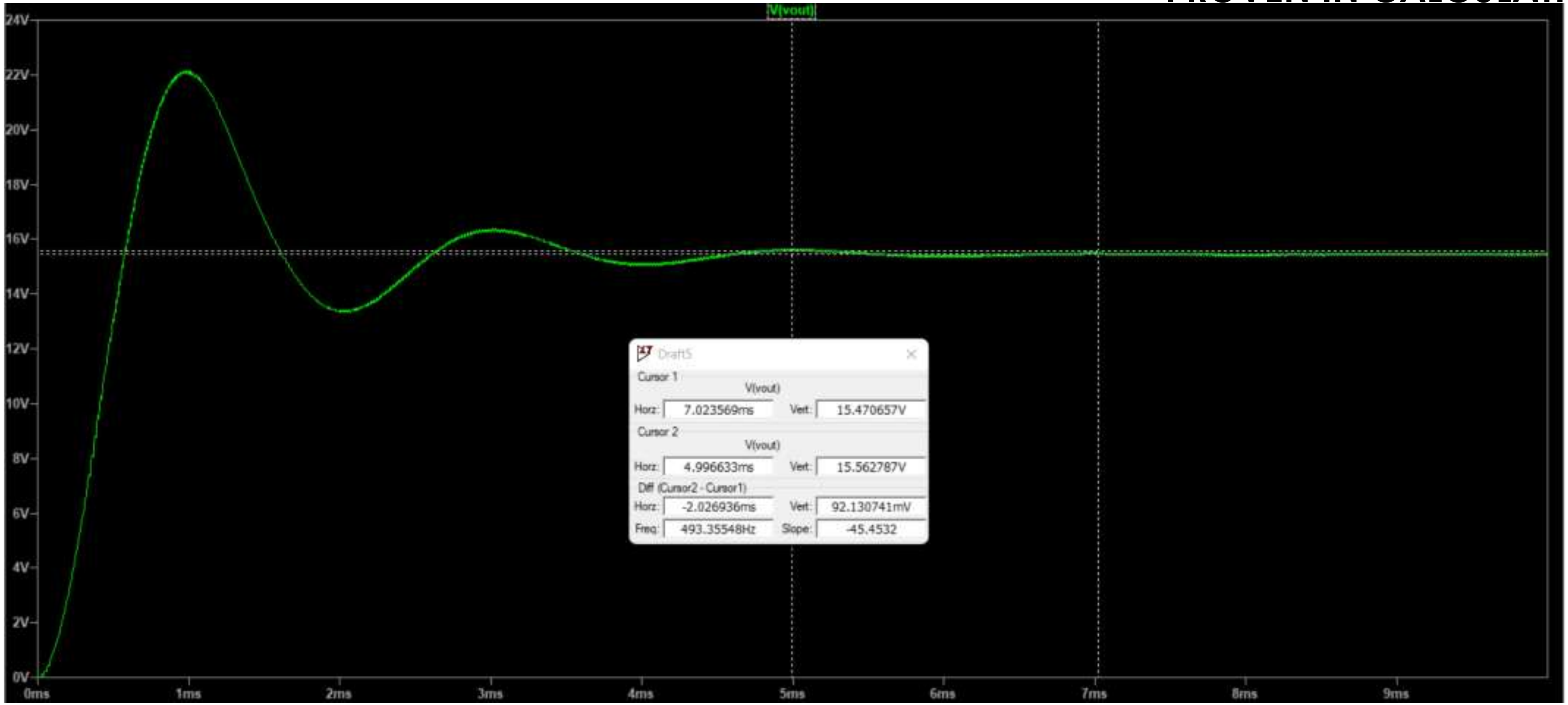
$$L = 5 \times \frac{2}{3} \times \frac{1}{10^5} \times \frac{1}{180} \times 10^3$$

$$L = \frac{1}{3 \times 10 \times 180} = \frac{1}{30 \times 180} = \frac{1}{5400}\ H = \boxed{185.18\ MH}$$

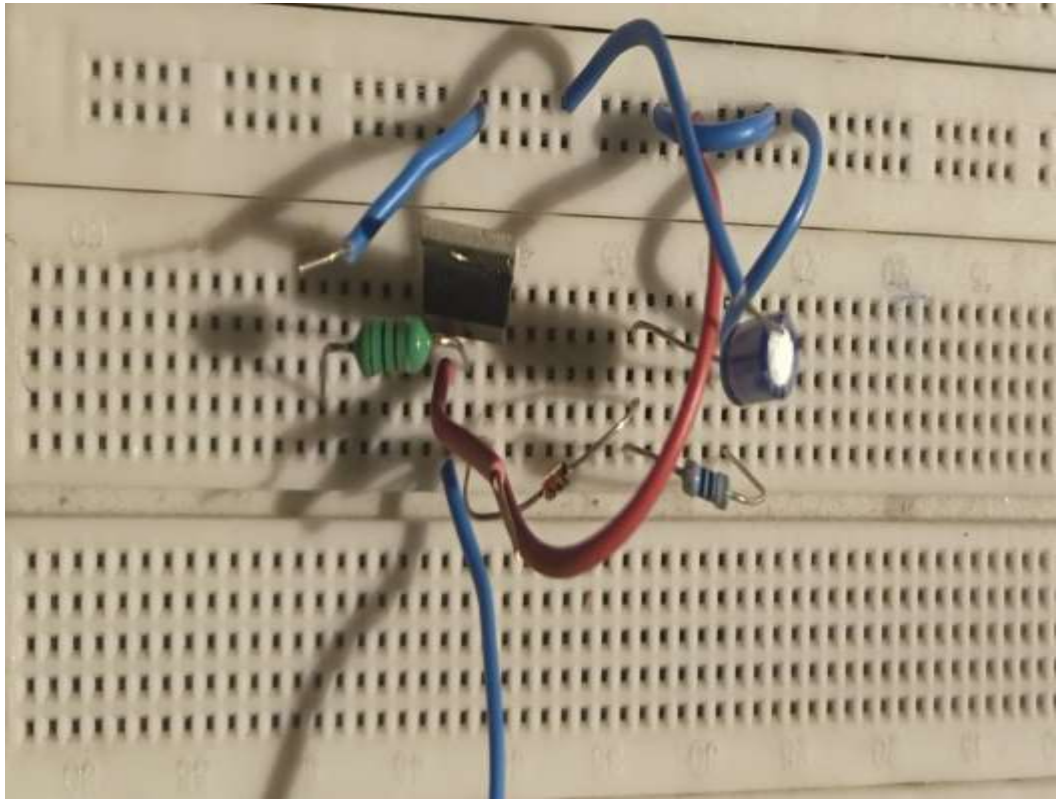
SIMULATION OF DESIGN (POST ANALYSIS AND CALCULATIONS) ON LTSPICE:CIRCUIT SIMULATED ON LTSPICE



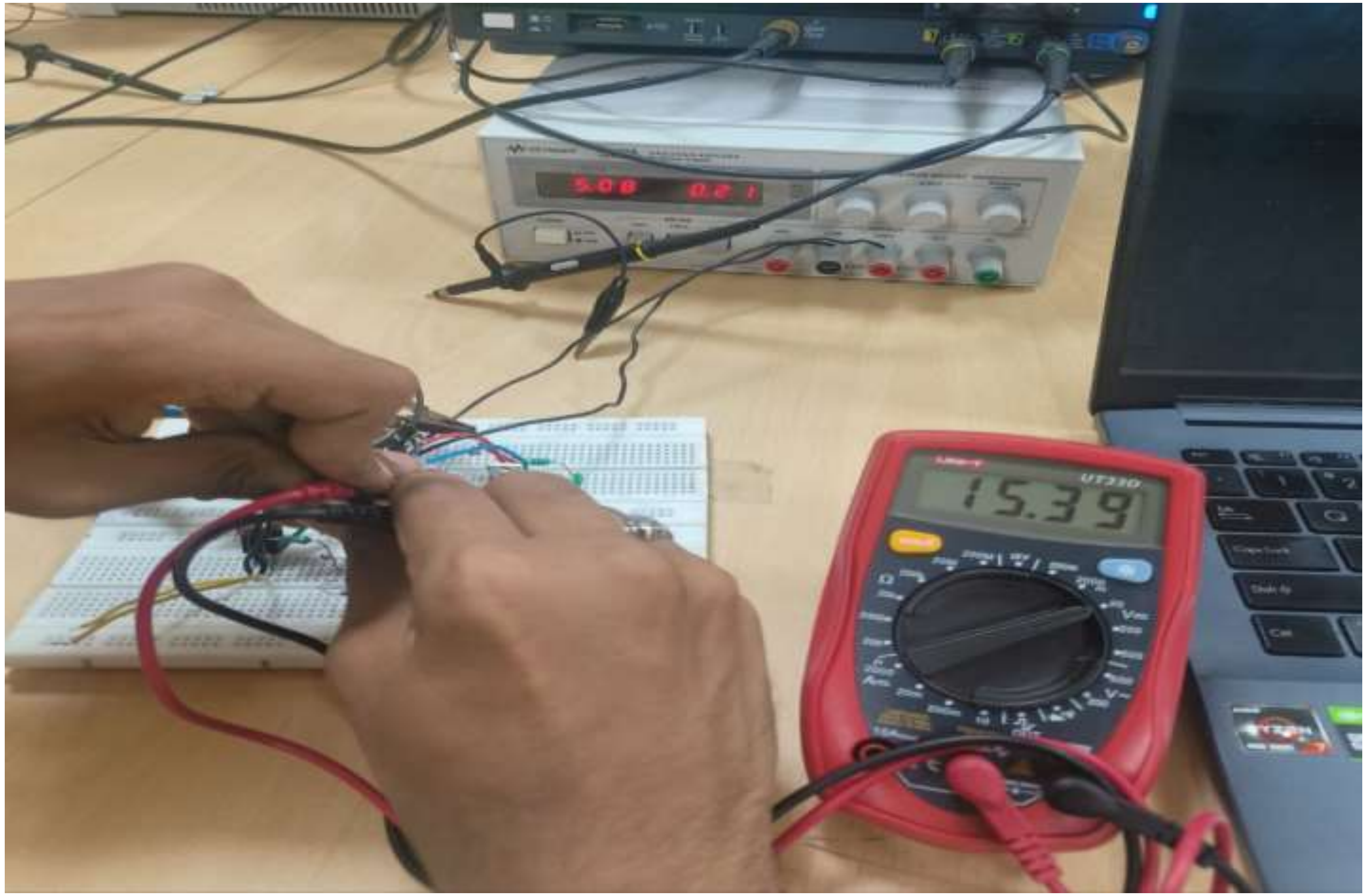
SIMULATION RESULT FROM LTSPICE
OUTPUT OBSERVED AT SHOWN ROUGHLY 15.4 VOLTS FOR 5 V INPUT AS PROVEN IN CALCULATIONS



HARDWARE OUTPUT AND PHOTOS(BOOST CONVERTER CIRCUIT):-



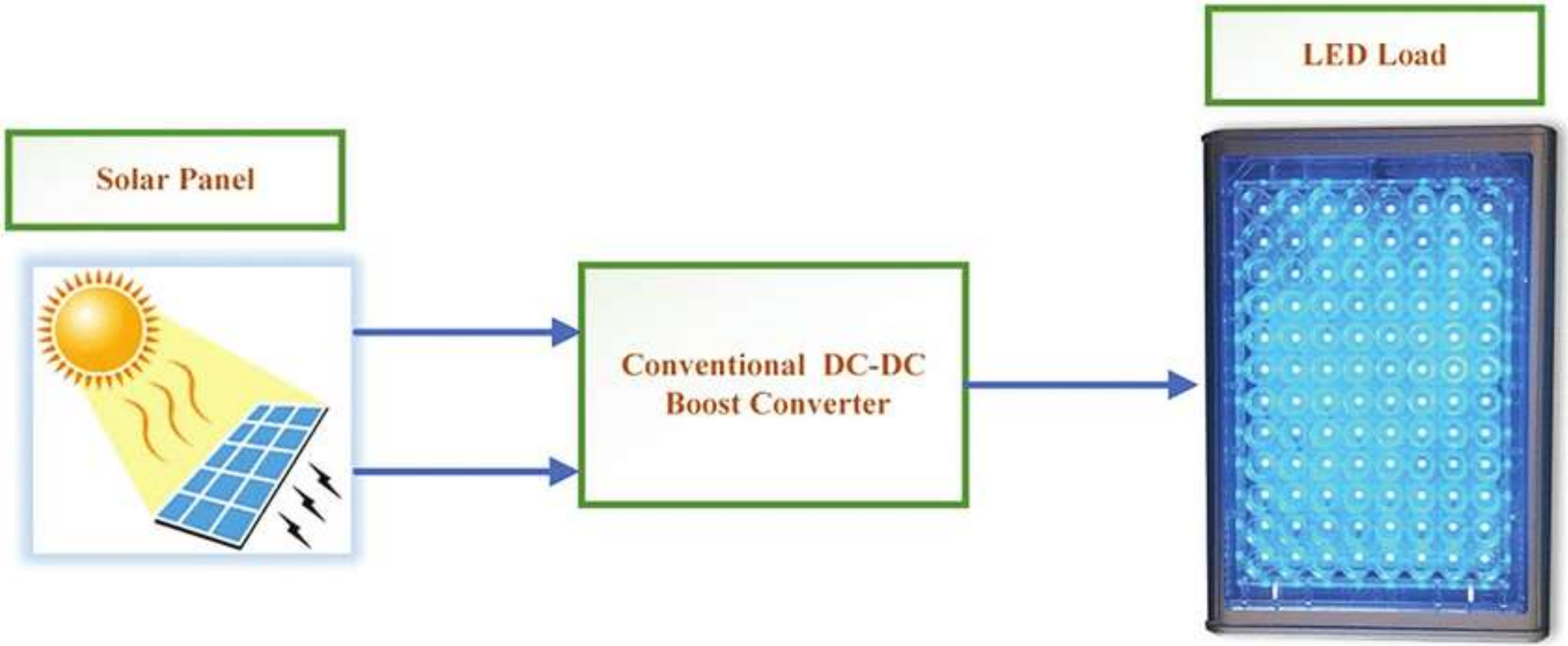
HARDWARE OUTPUT AND PHOTOS:-(OUTPUT OF BOOST CONVERTER FOR 5V INPUT):-



APPLICATION:-

- We have shown the application of boost converter through the lighting of LEDs by the solar energy voltage. This is done by capturing the solar voltage of roughly 1 volt and DC amplifying it to glow up the LED (which is nearly 2 volts).
- This application is very powerful since in this we are using natural sunlight which would otherwise be complicated and costly. This application is also very good since renewable energy is the future.

APPLICATION REPRESENTATION:-



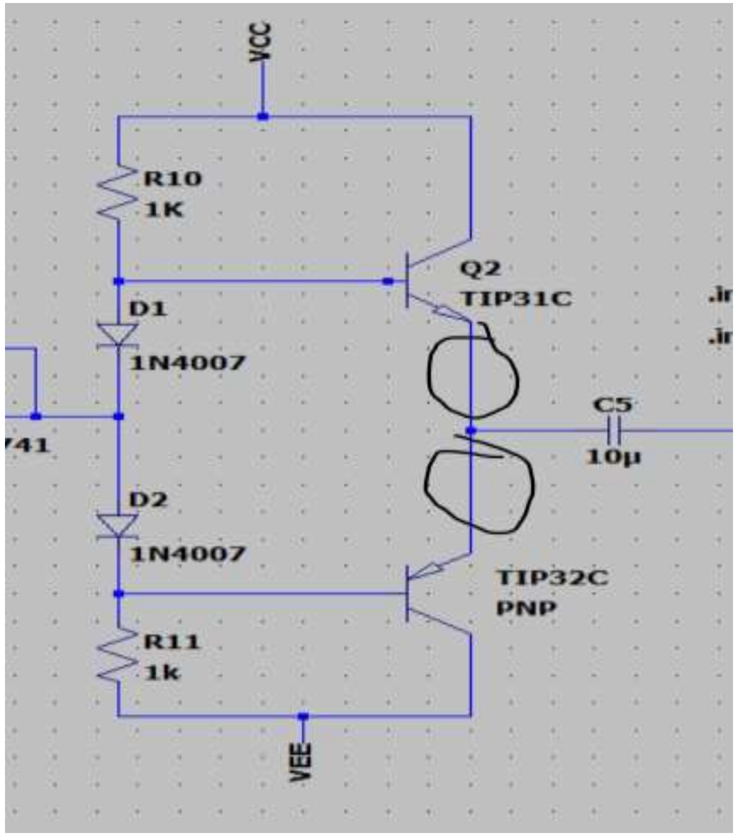
STEPS INVOLVED FOR THE APPLICATION

- **Solar Panel**: Converts sunlight into DC voltage.
- **Boost Converter**:Increases DC voltage to power the LED efficiently.
- **LED Illumination**: Receives the boosted voltage and emits light.
- **Efficiency**: Boost converters ensure energy from the solar panel
is used effectively.

APPLICATION DESIGN OF BOOST CONVERTER

- We have used the already implemented boost converter circuit for DC amplification of the input voltage but there is one thing we need to take care of that is the fact that resistance of the solar cell is very high (in our case 1.2 mega ohm) so this significantly reduces the voltage so we have used a power amplifier so that proper voltage from sunlight is captured at the input and proper voltage is amplified to glow up the LED.
- Current Boosting: The current output of the solar diode might have been too low to power the LED effectively. By adding a power amplifier, you could boost the current output, ensuring that there's enough current flowing through the circuit to illuminate the LED.

CLASS AB POWER AMPLIFIER DESIGNED USED (AT THE ENCIRCLED PLACES SMALL RESISTORS ABSORBING MORE CURRENT CAN BE USED TO AVOID OVERLOAD OF CURRENT)



WHY USE OF CLASS AB POWER AMPLIFIERS?
TO DECREASE “ CROSS OVER DISTORTION”

- Reduced Crossover Distortion:

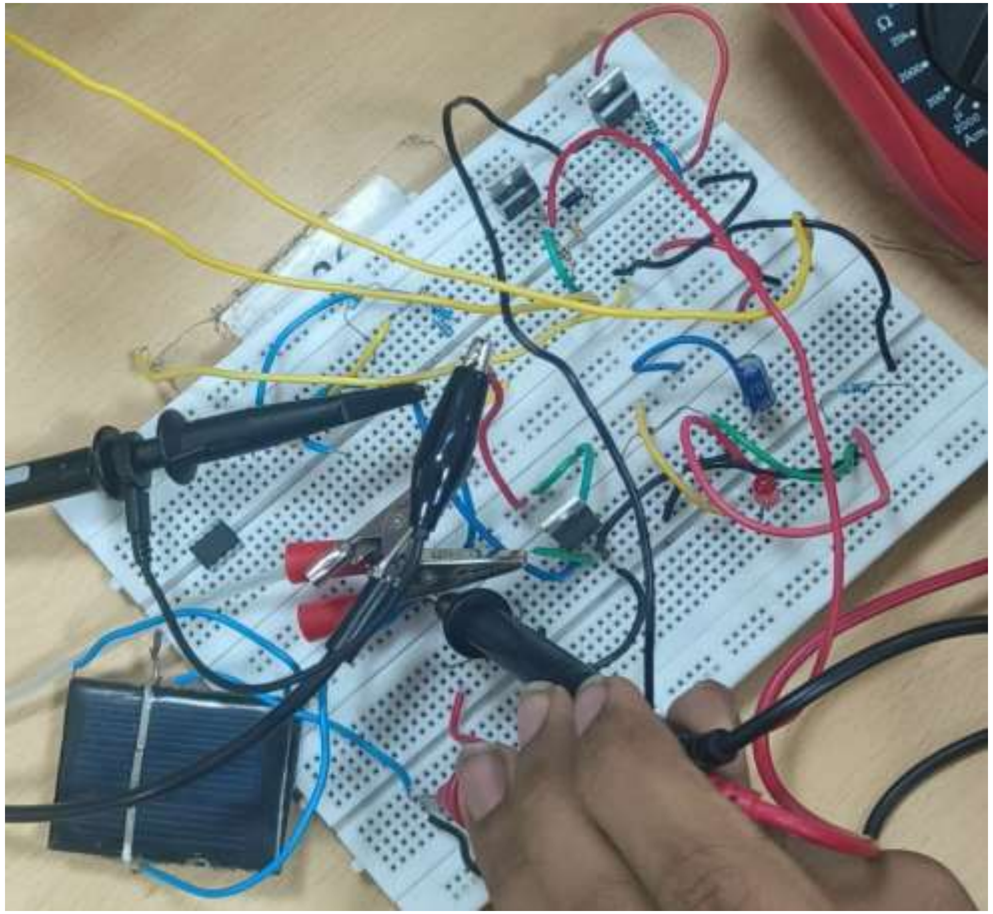
One of the primary advantages of Class AB amplifiers is their ability to minimize crossover distortion. Crossover distortion occurs when there is a gap between the positive and negative halves of the input signal, leading to distortion at the crossover point. Class AB amplifiers use a small bias current to operate the output transistors in a slightly conducting state, reducing the crossover distortion compared to pure Class B amplifiers

- ALSO IT HELPS IN IMPROVING EFFICIENCY GENERATING HEAT AND ENHANCES LINEARITY

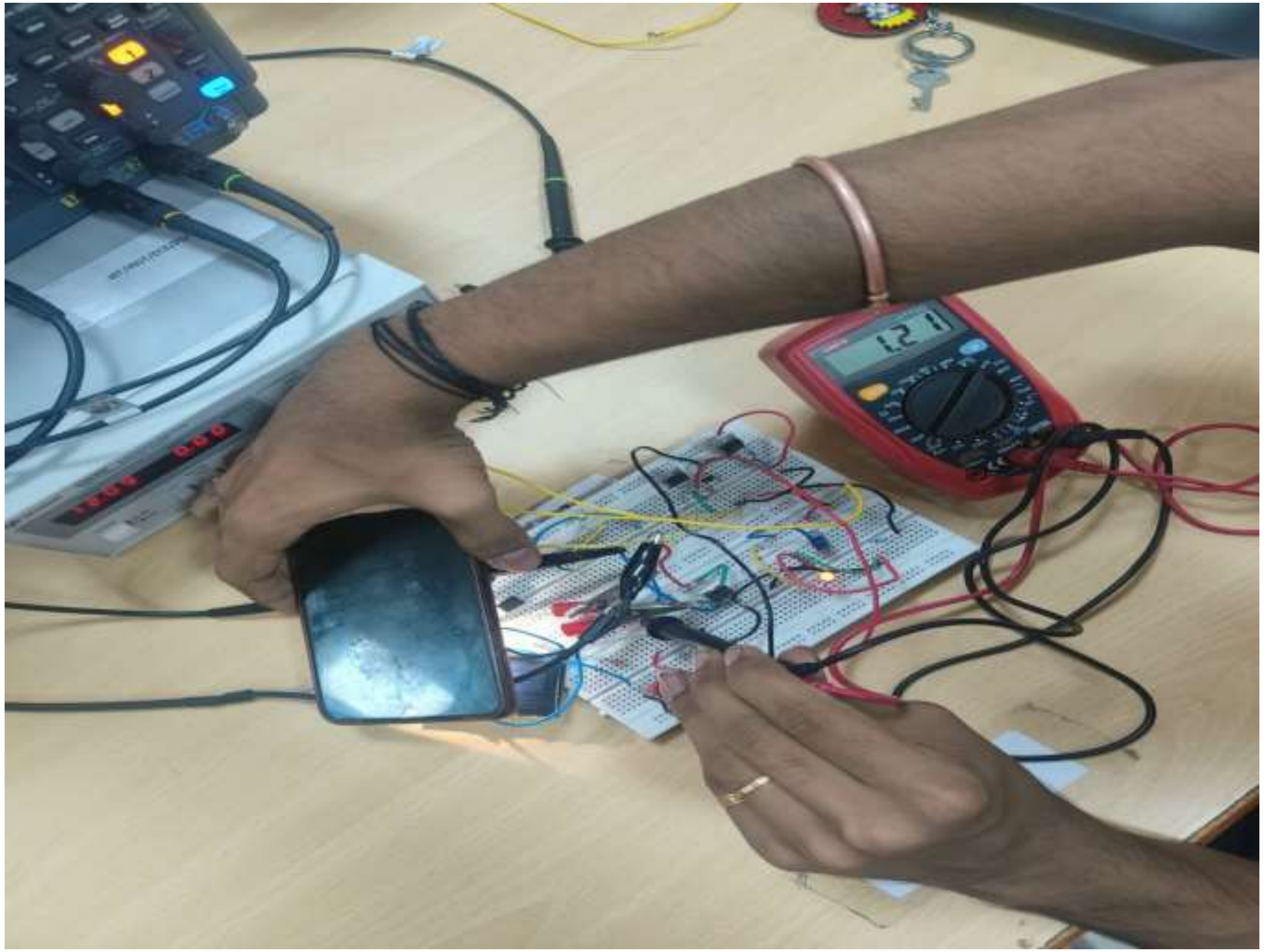
POWER AMPLIFIER

- Note: In the given design of the power amplifier, we need only a single diode since in our case we have only positive DC voltage as the input and no negative input, so only one diode will fulfill the purpose. The values of resistances have been tuned for full functioning of the circuit.

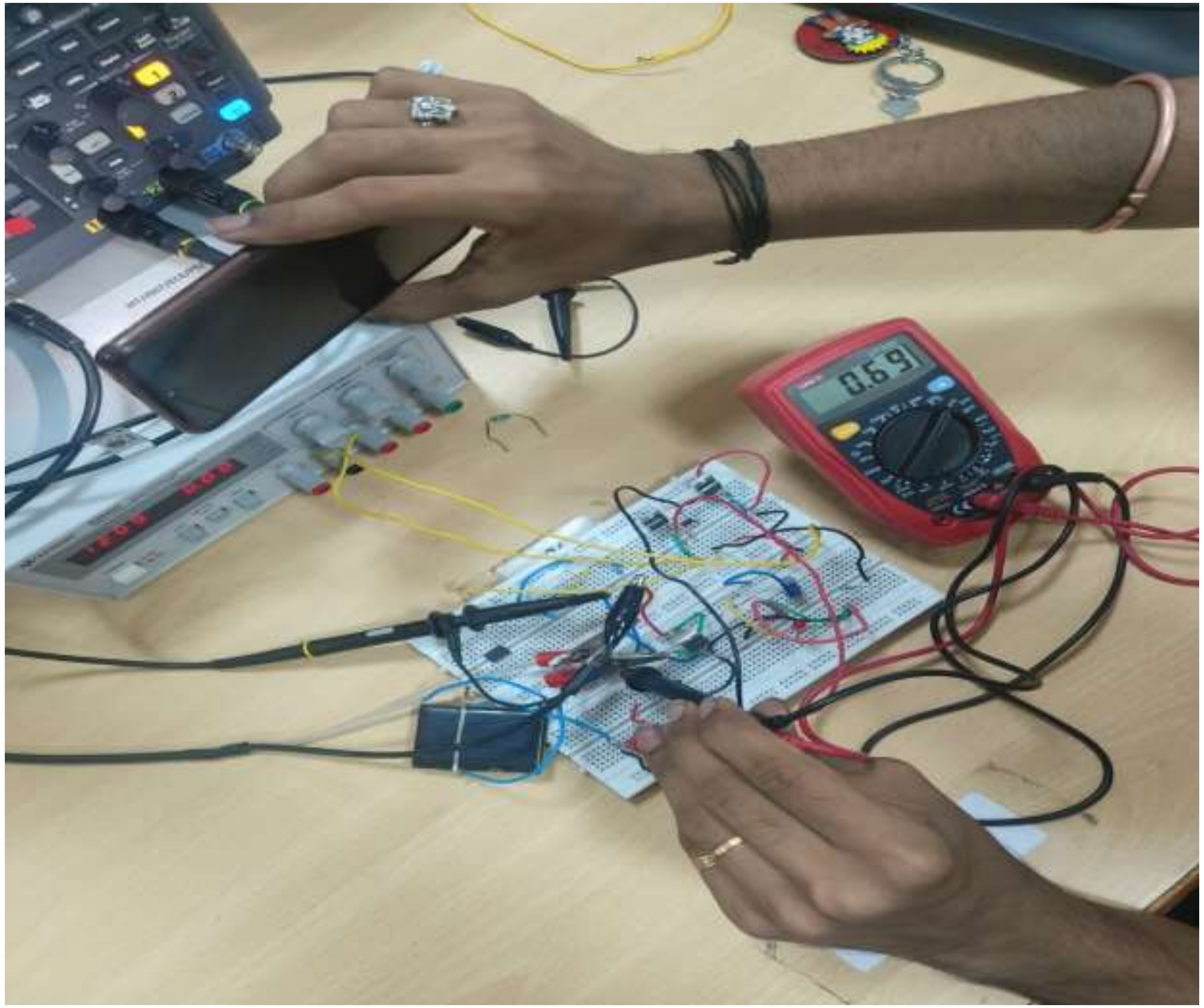
CIRCUIT IN HARDWARE FOR APPLICATION(TUNED DUTY CYCLE TO 15 PERCENT FOR FULL WORKING OF OUR CIRCUIT:-



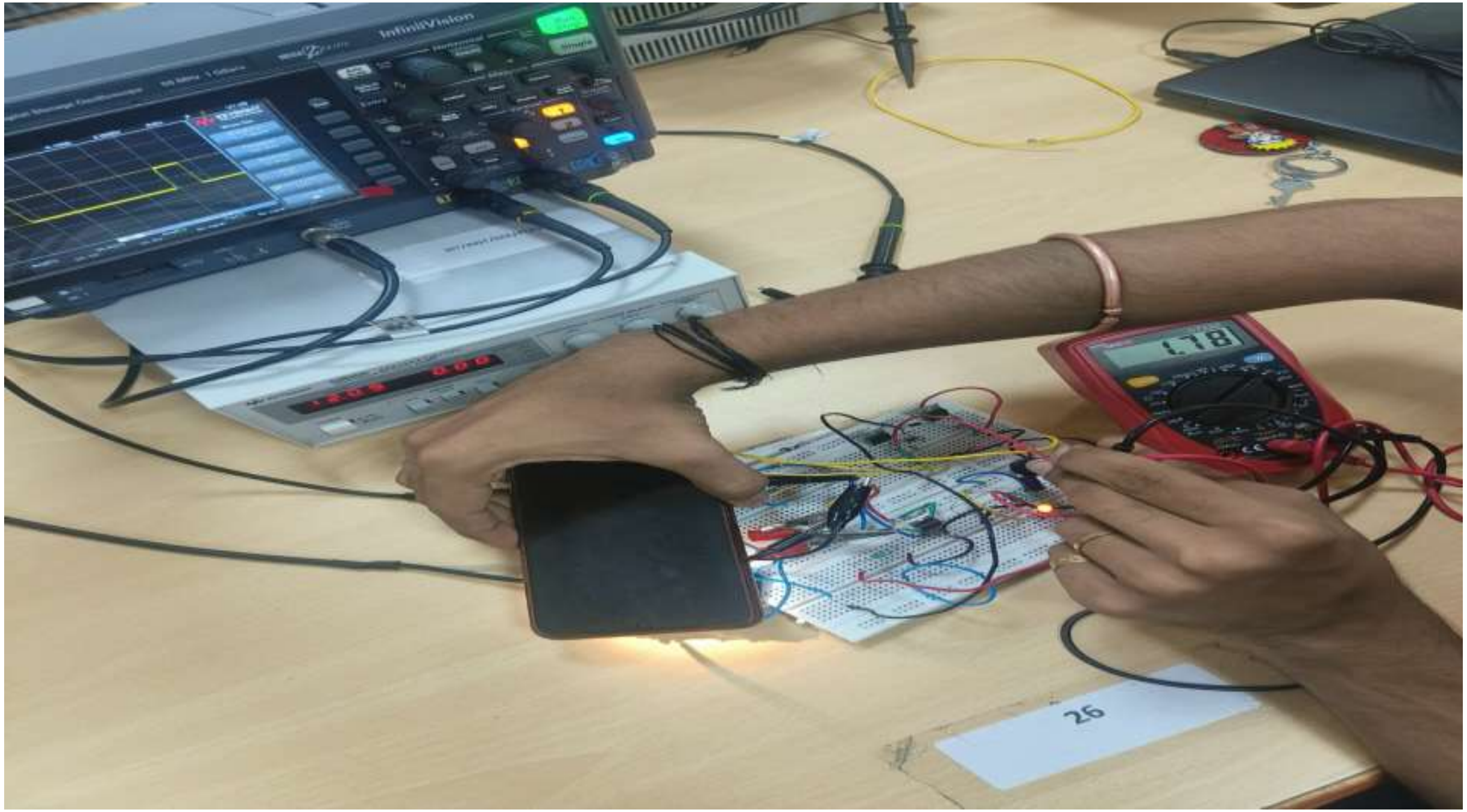
HARDWARE OUTPUT AND PHOTOS FOR APPLICATION (LED GLOWING WHEN FLASHLIGHT IS ON)



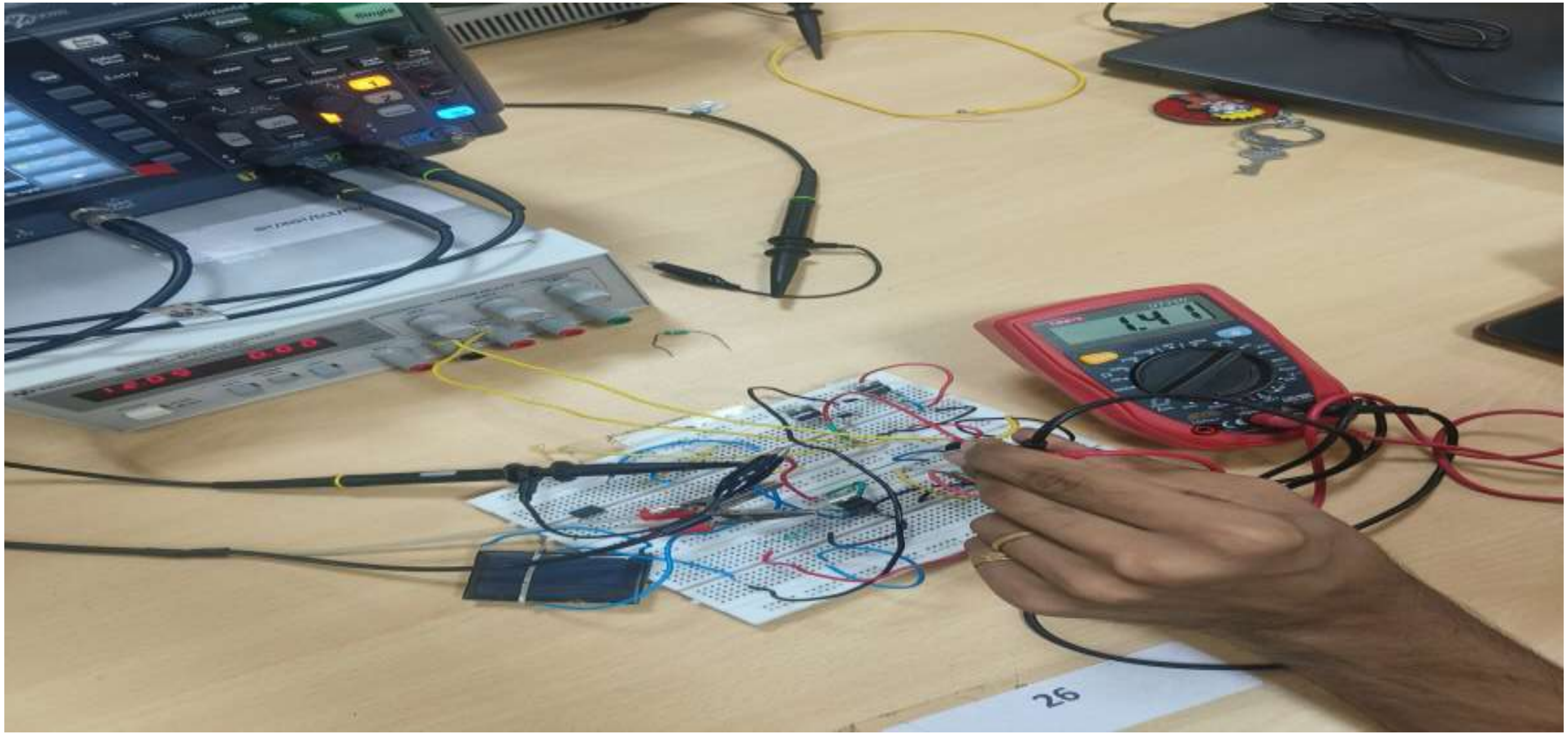
HARDWARE OUTPUT AND PHOTOS FOR APPLICATION (LED NOT GLOWING WHEN FLASHLIGHT IS OFF)



DC VOLTAGE WHEN LED IS GLOWING



DC VOLTAGE WHEN LED IS OFF(CAPTURED FROM SUNLIGHT)



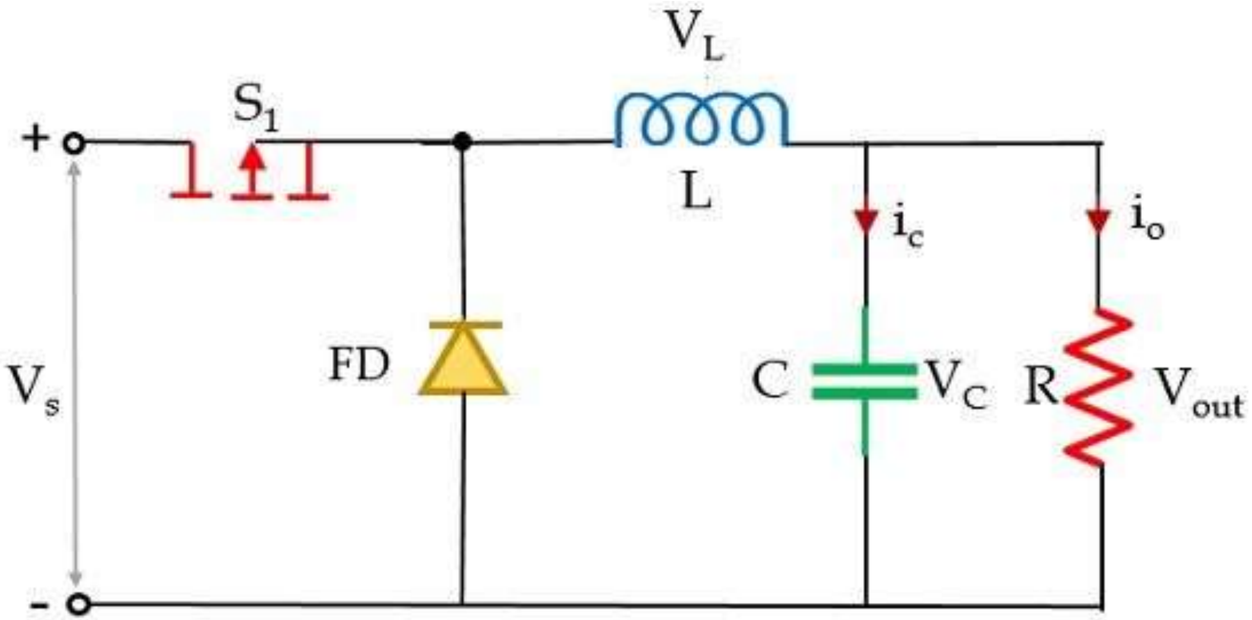
MAIN USES /APPLICATIONS OF BOOST CONVRTER

- **1) Power Supplies:** Boost converters are commonly used in power supplies to increase the voltage level
efficiently, such as in battery-powered devices or renewable energy systems.
- **2) LED Lighting:** They're utilized in LED drivers to efficiently regulate and boost voltage for powering LED lighting systems.
- **3) Battery Charging:** Boost converters can be employed in battery chargers to raise the voltage
from a lower input source to charge batteries effectively.
- **4) Photovoltaic Systems:** In solar power systems, boost converters are used to increase the voltage generated
by solar panels to match the required voltage for charging batteries or feeding into the grid

MORE USES OF BOOST CONVERTER

- **5) Electric Vehicles:** Boost converters are crucial in electric vehicle (EV) powertrains to step up the
voltage from the battery to drive the motor efficiently.
- **6) RF Power Amplifiers:** They're used in RF power amplifiers to boost the voltage of the input signal,
enhancing the power output to the desired level.
- **7) Wireless Communication:** Boost converters can be employed in wireless communication systems to
regulate voltage levels for efficient transmission and reception of signals.

BUCK CONVERTER/STEP DOWN CONVERTER USED IN USB/DRAM /CPU TO STEP 12 V MAIN SUPPLY TO (1.8-4.2V)

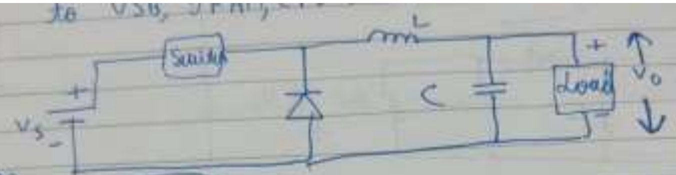


Buck Converter

WORKING OF BUCK CONVERTER

- When the switch is on, current passes through inductor, load, and capacitor charging the inductor with energy.
- When switch is off the inductor releases stored energy through load (Vs input voltage Vo output voltage)
- By KVL VL(ON)=Vs-V0
- IL(ON)=IL-Io V
- L(OFF)=-Vo IL(OFF)=IL-Io
- So by voltage second balance we get Vo=DVs since $0<D<1$ Vo will be less than Vs(input DC voltage)

BUCK CONVERTER CALCULATIONS:-



Parameters

ON

$V_{L(ON)} = V_S - V_o$

$I_{C(ON)} = I_L - I_o$

OFF

$V_{L(OFF)} + V_o = 0$

$V_{L(OFF)} = -V_o$

$I_{C(OFF)} = I_L - I_o$

Switch ON: loop I inductor + load + C

Switch off: inductor releases energy through load

Volt Second Balance

$$V_{LON} \times T_{ON} + V_{LOFF} \times T_{OFF} = 0$$

$$(V_S - V_o) \times DT + (-V_o)(1-D)T$$

Avg $V_o = DV_S$ — avg out always less than V_S

Since $0 < D < 1$

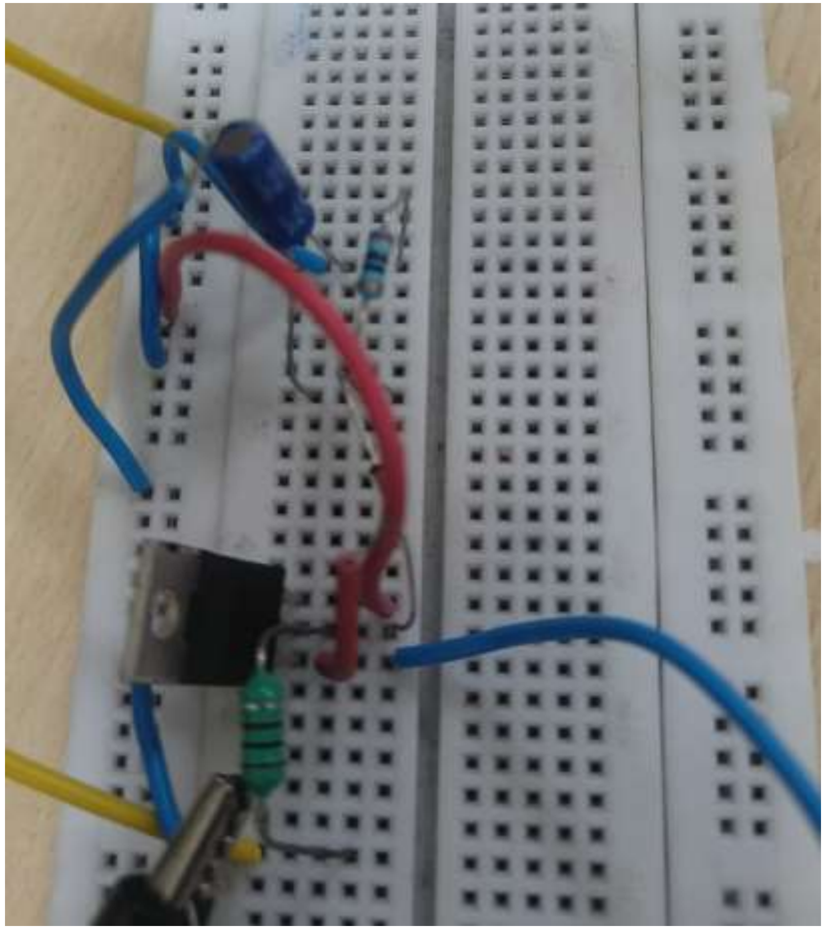
V_o is always less than input V_S

$V_o \rightarrow$ output voltage

$V_S \rightarrow$ input voltage

$D \rightarrow$ Duty cycle

BUCK CONVERTER HARDWARE PHOTO OF CIRCUIT:-



BUCK CONVERTER HARDWARE OUTPUT PHOTO9STEP DOWNS 5V TO 1.47 VOLTS

APPLICATIONS OF BUCK(STEP DOWN)CONVERTER

1.Mobile Phone Chargers

2.Automotive Electronics

3.Solar Power Systems

4.Portable Electronic Devices(Communication ,data processing and computing)

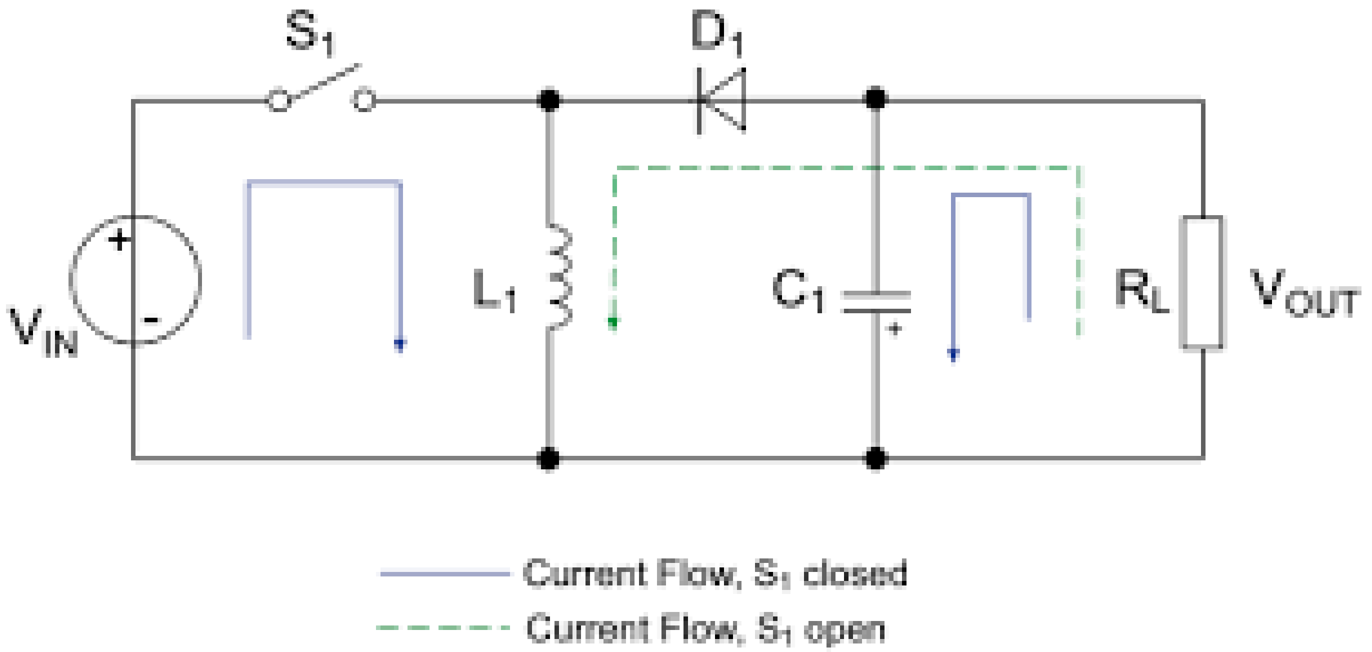
5.IoT Devices

6.Power Banks

7.In USB,DRAM(low cost high capacity(dynamic) computer memory) and

and CPU(Central Processing Unit)

BUCK BOOST CONVERTER(STEP DOWN/UP CONVERTER)



BUCK BOOST CONVERTER WORKING

- Mode 1: When the switch is on the diode is off and inductor stores energy.
- Mode 2: When switch is off diode on and inductor releases energy

- When energy of inductor is fully released then diode, switch is off
- then capacitor (with complementary polarity) transfer its charge from mode 2 to the load

BUCK BOOST CONVERTER CALCULATIONS

Again applying voltage second balance we get:

- V * D * T + (-Vo) * (1 - D) * T = 0
- On solving this we get:
- Vo = V * D / (1 - D)
- Where D is the duty cycle, V is the input voltage, and Vo is the output voltage.
- So if D is less than 0.5, it acts as a buck converter. And if D is greater than 0.5, it acts as a boost converter and performs both operations.
- Note: A buck-boost converter will have applications of both boost converter and buck converter, both of which have been mentioned in two different slides before.

IMPORTANCE OF TESTING ,DEBUGGING AND BIASING IN THE PROJECT

- Testing:
- Functionality Verification: Testing is essential to verify that all components of the audioamplifier work as intended. This includes checking inputs, outputs, signal processing stages, and power supply.
- Performance Evaluation: Through testing, engineers can evaluate the performance of theamplifier under different conditions, ensuring that it meets specified criteria such as frequencyresponse, distortion levels, and signal-to-noise ratio.
- Reliability Assessment: Rigorous testing helps identify potential issues that might lead tofailures over time. This includes stress testing to ensure the amplifier can handle prolonged use without degradation

IMPORTANCE OF BIASING MOSFET WHILE USING IT AS A SWITCH

- We need to use MOSFET as a switch, so we need to make sure that it remains in the saturation region. Therefore, we need to ensure that Vgs (gate-source voltage) is greater than the threshold voltage, and Vds should be greater than or equal to (Vgs - threshold voltage).
- This is extremely essential, as otherwise, the MOSFET can go into the cutoff or linear region of operation, which can falter the working of our circuit.

DEBUGGING CIRCUIT IN DESIGN OF BOOST CONVERTER

- Debugging is crucial in boost converter design for several reasons:

1. **Efficiency Optimization:** Debugging helps identify and rectify inefficiencies in the circuit, such as excessive power loss or voltage drop, ensuring that the converter operates at its highest efficiency.
2. **Stability and Reliability:** Debugging ensures that the boost converter operates within its specified parameters under all conditions, enhancing its stability and reliability in real-world applications.
3. **Component Stress:** By identifying and addressing issues such as overcurrent or overvoltage conditions, debugging helps prevent excessive stress on components, prolonging their lifespan and improving overall system reliability.

DEBUGGING OF CIRCUIT IN BOOST CONVERTER DESIGN

- **Performance Optimization:** Debugging allows designers to fine-tune parameters such as
switching frequency and duty cycle to optimize the converter's performance for specific applications,
such as minimizing output ripple or maximizing transient response.
- **Safety Assurance:** Debugging helps ensure that the boost converter operates safely, preventing hazards such as short circuits, thermal runaway, or component failure
that could pose risks to the user or the system

DATASHEET AND VARIATIONS IN COMPONENT VALUES

- The datasheet was extremely useful in our project for various purposes:
- - Understanding the resistance characteristics of the solar cell
- - Determining the voltage capturing capabilities of the solar cell
- - Identifying the maximum voltage sustained and minimum voltage required for glowing of the LED
- - Obtaining information about the MOSFET's current drawing properties and the voltages required to keep it in saturation
- - Standard design properties for current amplifier circuits
- Having access to this detailed information from the datasheet greatly assisted us in designing and implementing our project effectively and efficiently.

CHALLENGES FACED WHILE DESIGNING CIRCUIT:-

- 1) Selection of a MOSFET which can be biased in saturation region for all switch cycles to ensure proper working of the circuit and also draws less amount of current to avoid overload of current/voltage.
- 2) Non-availability of exact inductance as done in the simulations so tuning of resistors and capacitors to account for the same.
- 3) Handling the tradeoff between duty cycle and current.
- 4) Ensuring and tuning the switching frequency given to the MOSFET for getting desired output voltage and current.

CHALLENGES FACED WHILE DESIGNING CIRCUIT:-

- 5) In the application part, due to high resistance (1.2 megaohm) of the solar cell, the use of a current amplifier to amplify current and to ensure that proper voltage reaches the input and we get the desired output, and tuning that current amplifier.
- 6) Tuning values of resistances, capacitors accommodating factors like parasitic capacitance of the probe and available inductance value.
- 7) Taking into account MOSFET model and frequency signal given as input to it both simultaneously.
- 8) Adjusting loading effect for components for ensuring proper functionality.

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THANK YOU!