

# Design, Fabrication and Testing of a BUCK-BOOST Converter System (0-50V) a Prototype

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**Abstract**—DC-DC power converters are employed in order to transform an unregulated DC voltage input (i.e. a voltage that possibly contains disturbances) in a regulated output voltage. For example, a DC-DC power converter can transform an unregulated (i.e. distorted) 9V input voltage in a regulated (i.e. "clean") voltage of 12V at the output. Some DC-DC power converters have a fixed output reference and ensure that such voltage is always delivered, no matter what the input is; some others can have a variable output reference, which can be therefore set depending on the current needs of the device the power converter is used in. The converter discussed in this work belongs to this second category. In particular, the converter is able to deliver output voltages both higher as well as lower than (or even equal to) the input voltage; this is why it is referred to as a "buck-boost" (or "step-up/step-down") power converters.

**Index Terms**—Buck Converter, Boost Converter, PWM Generator, Voltage IC Regulator, Fly Back Diode.

## I. INTRODUCTION

The converters are the heart of the power supply and distribution system. The power source is available in two forms either in AC or DC form. The AC power can be converted to different levels by using transformer; this technique is very much convenient. Power electronic converters can be found wherever there is a need to modify the electrical energy form (i.e modify its voltage, current or frequency). Therefore, their power ranges are from some milliwatts (as in a mobile phone) to hundreds of megawatts (e.g in a HVDC transmission system). With "classical" electronics, electrical currents and voltage are used to carry information, whereas with power electronics, they carry power. Therefore the main metric of power electronics becomes the efficiency.

The first very high power electronic devices were mercury arc valves. In modern systems the conversion is performed with semiconductor switching devices such as diodes, thyristors and transistors. In contrast to electronic systems concerned with transmission and processing of signals and data, in power electronics substantial amounts of electrical energy are processed. An AC/DC converter (rectifier) is the most typical power electronics device found in many consumer electronic chargers, etc. power ranges of VSDs start from a few hundred watts and end at tens of megawatts.

The power conversion systems can be classified according to the type of the input and output power.

- AC to DC (rectification)
- DC to AC (inversion)
- DC to DC (chopping)

As efficiency is at a premium in a power electronic converter, the losses that a power electronic device generates should be as low as possible. The instantaneous dissipated power of a device is equal to the product of the voltage across the device and the current through it ( $P = V \times I$ ). From this, one can see that the losses of a power device are at a minimum when the voltage across it is zero (the device is in the On-State) or when no current flows through it (Off-State). Therefore, a power electronic converter is built around one (or more) device operating in switching mode (either On or Off). With such a structure, the energy is transferred from the input of the converter to its output by bursts.

Power electronic systems are virtually in every electronic device. For example, around us:

DC/DC converters are used in most mobile devices (mobile phone, pda...) to maintain the voltage at a fixed value whatever the charge level of the battery is. These converters are also used for electronic isolation and power factor correction.

AC/DC converters (rectifiers) are used every time an electronic device is connected to the mains (computer, television,...)

AC/AC converters are used to change either the voltage level or the frequency (international power adapters, light dimmer). In power distribution networks AC/AC converters may be used to exchange power between utility frequency 50 Hz and 60 Hz power grids.

DC/AC converters (inverters) are used primarily in UPS or emergency light. During normal electricity condition, the electricity will charge the DC battery. During blackout time, the DC battery will be used to produce AC electricity at its output to power up the appliances.

remains high. It remains high until the charging and discharging of capacitor through the resistor and C values decides the ON time. It is a consequence of the way power

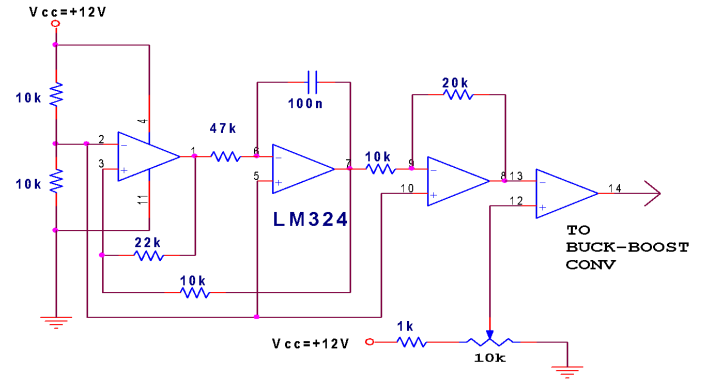


**Table1. Comparison of rectifier circuits:**

Parameter	Type of Rectifier		
	Half wave	Bridge	Full
Number of diodes	1	2	4
PIV of diodes	$V_m$	$2V_m$	$V_m$
D.C output voltage	$V_m/$	$2V_m/$	$2V_m/$
$V_{dc}$ ,at no-load	$0.318V_m$	$0.636V_m$	$0.636V_m$
Ripple factor	1.21	0.482	0.482
Ripple Frequency	F	2f	2f
Rectification Efficiency	0.406	0.812	0.812
Transformer Utilization Factor(TUF)	0.287	0.693	0.812
RMS voltage $V_{rms}$	$V_m/2$	$V_m/2$	$V_m/2$

#### (B) PWM Generator:

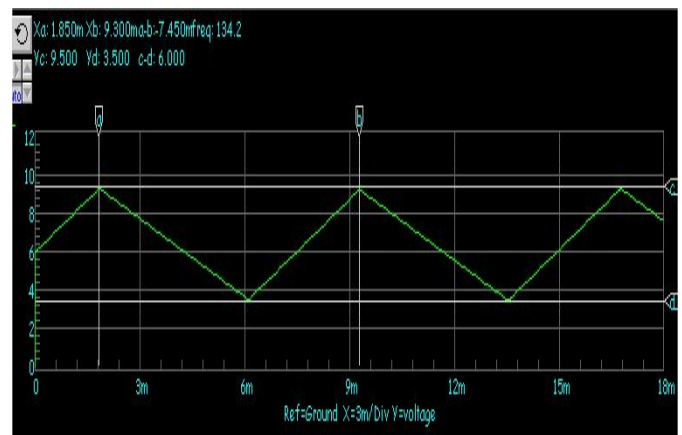
In this subsection its aspect is to generate a PWM as output signals for that a Quad OP-Amp (LM324) is used as a generator. This is an op-amp based design for generating PWM output. There are four stages of Op-amp running on a single-rail power supply. The saw tooth is generated with the circuit designed by 1<sup>st</sup> and 2<sup>nd</sup> op-amp. The function of different sections is as follows.



**Fig.3: Schematic Diagram of PWM**

- The 1<sup>st</sup> op-amp is configured as a Schmitt Trigger
- The 2<sup>nd</sup> op-amp is configured as a Miller Integrator
- The 3<sup>rd</sup> op-amp is used as a low gain amplifier
- The 4<sup>th</sup> op-amp is used as a comparator to compare the saw tooth with the reference voltage and generate PWM with different pulse width.

1. The 1<sup>st</sup> opamp is used as a Schmitt Trigger. The reference voltage for the Schmitt Trigger is set at  $V_{cc}/2$  due to the potential divider input given to the inverting input of the opamp1. The Upper limit voltage is dependent on the integrator output. Also the lower limit depends on the integrator output.



**Fig 4: Output of Schmitt Trigger**

2. The opamp2 acts as a miller's integrator this inverting type integrator. The slope of the integrated output depends on RC of the circuit. The opamp1 and opamp2 together generates one triangle wave with  $V_{cc}/2$  as reference line of symmetry.

3. The 1<sup>st</sup> two sections of the quad op-amp form a triangle-wave generator, but now the third section is used as a low-gain amplifier, bringing the trough of the wave to just above zero volts and the peak to about 10v or as required by the design.

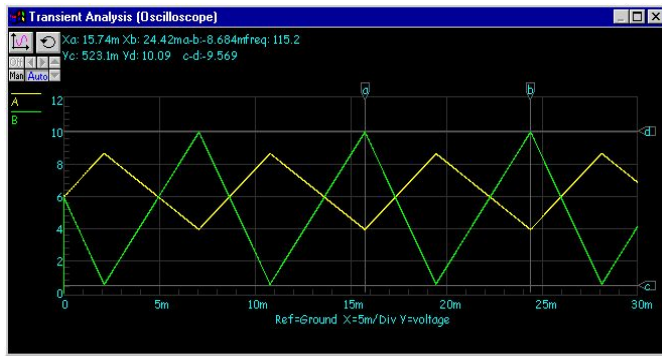


Fig 5: Output of Miller's Integrator

4. The fourth op-amp section is connected as a comparator, comparing the triangle wave voltage with a reference voltage set by the potential divider R8 & VR1. When the wave voltage goes above the voltage at the pot wiper, the comparator output goes high, else the comparator output goes low. With the pot turned fully clockwise the wiper voltage is below about 0.5v and the load is on 100% of the time. Increasing the wiper voltage (by turning the pot anti-clockwise) reduces the duty cycle, and it's easy to set a minimum speed just by changing the value of R8. Above is the effect of a low reference voltage, with the output "on" for most of the time, and below the reference voltage is near maximum giving a low duty cycle.

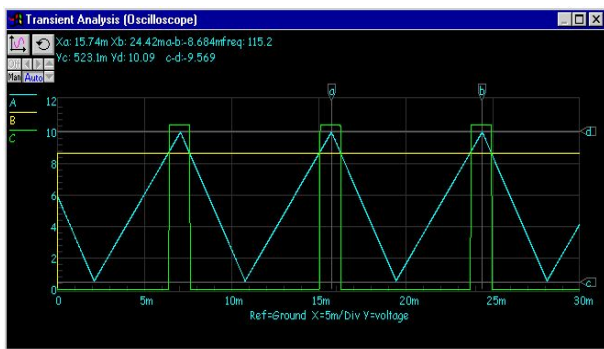


Fig 6: Output of OPAMP used as Comparator

Above is the effect of a low reference voltage, with the output "on" for most of the time, and below the reference voltage is near maximum giving a low duty cycle.

### (C) Buck Converter:

A **buck converter** is a step-down DC to DC converter. Its design is similar to the step-up boost converter, and like the boost converter it is a switched-mode power supply that uses

two switches (a transistor and a diode) and an inductor and a capacitor. The simplest way to reduce a DC voltage is to use a voltage divider circuit, but voltage dividers waste energy, since they operate by bleeding off excess power as heat; also, output voltage isn't regulated (varies with input voltage). A buck converter, on the other hand, can be remarkably efficient (easily up to 95% for integrated circuits) and self-regulating, making it useful for tasks such as converting the 12-24V typical battery voltage in a laptop down to the few volts needed by the processor.

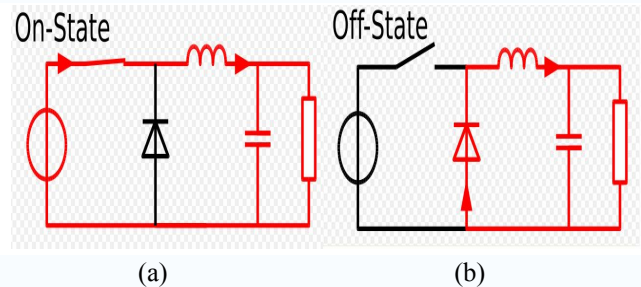


Fig 7: The two circuit configurations of a Buck converter (a) On state, when the switch is closed, and (b) off-state, when the switch is open.

The operation of the buck converter is fairly simple, with an inductor and two switches (usually a transistor and a diode) that control the inductor. It alternates between connecting the inductor to source voltage to store energy in the inductor and discharging the inductor into the load.

A Buck converter operates in continuous mode if the current through the inductor ( $I_L$ ) never falls to zero during the commutation cycle. In this mode, the operating principle is described by the chronogram :

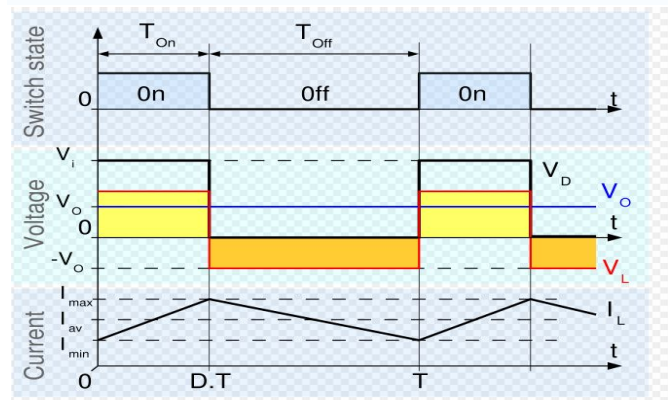


Fig 8: Operation of Buck converter in continuous mode

When the switch pictured above is closed (On-state, top of figure 6), the voltage across the inductor is  $V_L = V_i - V_o$ . The current through the inductor rises linearly. As the diode is reverse-biased by the voltage source  $V$ , no current flows through it; When the switch is opened (off state, bottom of figure 2), the diode is forward biased. The voltage across the inductor is  $V_L = -V_o$  (neglecting diode drop). The current  $I_L$



decreases. Therefore, it can be seen that the energy stored in  $L$  increases during On-time (as  $I_L$  increases) and then decrease during the Off-state.  $L$  is used to transfer energy from the input to the output of the converter.

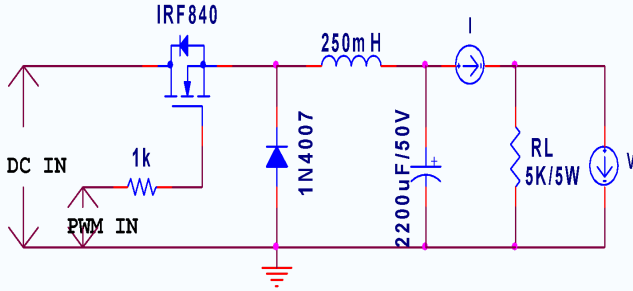


Fig 9: Schematic Diagram of Buck Converter

### (D) Boost converter:

A boost converter (step-up converter) is a power converter with an output DC voltage greater than its input DC voltage. It is a class of switching-mode power supply (SMPS) containing at least two semiconductor switches (a diode and a transistor) and at least one energy storage element. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple.

### OPERATING PRINCIPLE

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current. When being charged it acts as a load and absorbs energy (somewhat like a resistor), when being discharged, it acts as an energy source (somewhat like a battery). The voltage it produces during the discharge phase is related to the rate of change of current, and not to the original charging voltage, thus allowing different input and output voltages.

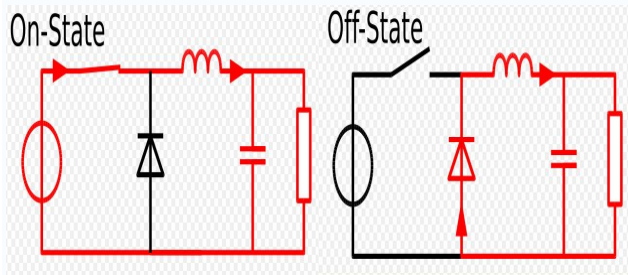


Fig 10: ON state and OFF state for Boost converter

The basic principle of a Boost converter consists in 2 distinct states (see figure 10) In the On-state, the switch  $S$  (see figure 10) is closed, resulting in an increase in the inductor current. In the Off-state, the switch is open and the only path offered to inductor current is through the **flyback diode**  $D$ , the capacitor

$C$  and the load  $R$ , results in transferring the energy accumulated during the On-state into the capacitor. The input current is discontinuous, stepping between a very high inductor current. The large ripple usually requires a large input bypass capacitor (not shown) to reduce the source impedance.

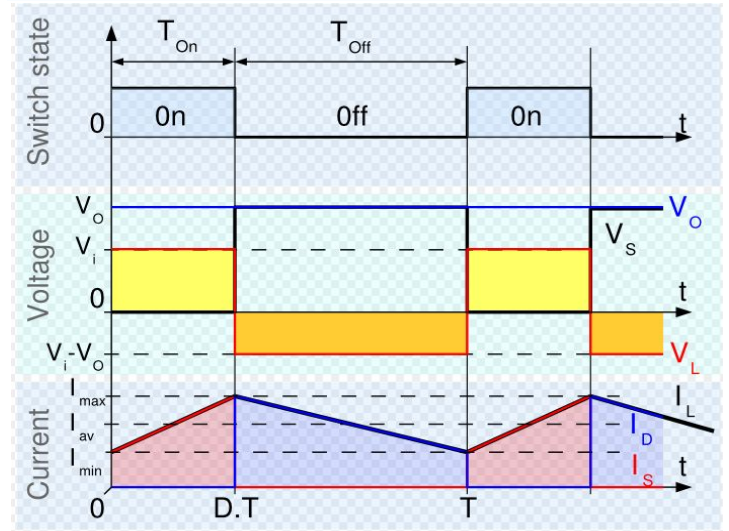


Fig. 11: Waveform of the current and voltage of Boost Converter

Waveforms of current and voltage in a boost converter operating in continuous mode is given in Fig 11. When a boost converter operates in continuous mode, the current through the inductor ( $I_L$ ) never falls to zero. Figure 3 shows the typical waveforms of currents and voltages in a converter operating in this mode. The output voltage can be calculated as follows, in the case of an ideal converter (i.e using components with an ideal behaviour) operating in steady conditions: During the On-state, the switch  $S$  is closed, which makes the input voltage ( $V_i$ ) appear.  $D$  is the duty cycle. It represents the fraction of the commutation period  $T$  during which the switch is On. Therefore  $D$  ranges between 0 ( $S$  is never on) and 1 ( $S$  is always on). During the Off-state, the switch  $S$  is open, so the inductor current flows through the load. If we consider zero voltage drop in the diode, and a capacitor large enough for its voltage to remains constant. As we consider that the converter operates in steady-state conditions, the amount of energy stored in each of its components has to be the same at the beginning and at the end of a commutation cycle. Therefore, the inductor current has to be the same at the beginning and the end of the commutation cycle. From the above expression it can be seen that the output voltage is always higher than the input voltage (as the duty cycle goes from 0 to 1), and that it increases with  $D$ , theoretically to infinity as  $D$  approaches 1. This is why this converter is sometimes referred to as a step-up converter. In some cases, the amount of energy required by the load is small enough to be transferred in a time smaller than the whole commutation period. In this case, the current through the inductor falls to zero during part of the period. The only difference in the principle described above is that the inductor is completely discharged at the end of the commutation cycle (see waveforms in figure 4). Although slight, the difference has a

strong effect on the output voltage equation. Furthermore, in discontinuous operation, the output voltage gain not only depends on the duty cycle, but also on the inductor value, the input voltage, the switching frequency, and the output current. In the project the boost converter is designed with continuous mode.

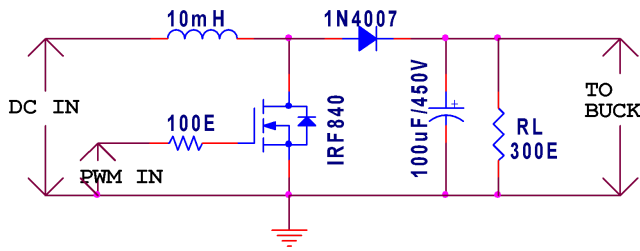


Fig 12: Boost Converter Schematic Diagram

### III RESULT ANALYSIS

In this chapter the results of practical tests of project conducted on the experimental set-up prototype are presented. The tests verify proper working of the hardware modules developed in the laboratory. Different waveforms (oscilloscope traces), tables, etc presented here; uphold the success of the entire scheme, the experimental set-up as also its parts.

#### (A) Power Supply

The circuit diagram of the power supply is given in Fig 13. All the components are inbuilt in this power supply. The output waveform of the secondary transformer is shown in Fig 14 which is sinusoidal in nature. The capacitor output voltage which is constant in DC is given in Fig 15.

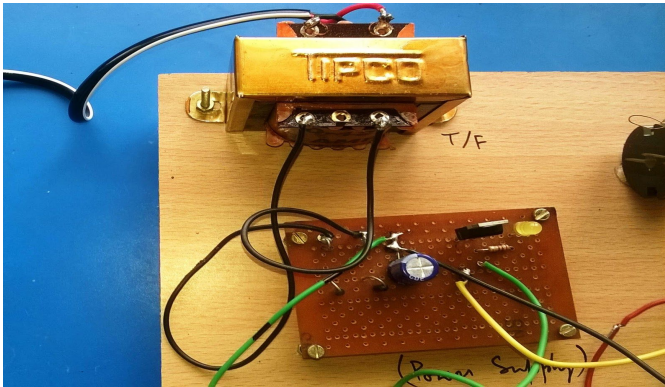


Fig 13: Circuit diagram for Power Supply

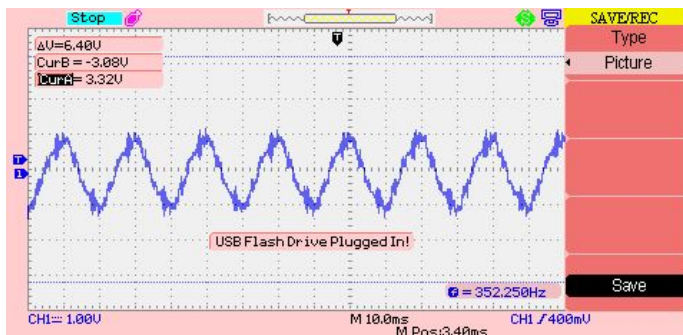


Fig 14: Input power supply (12 volts)

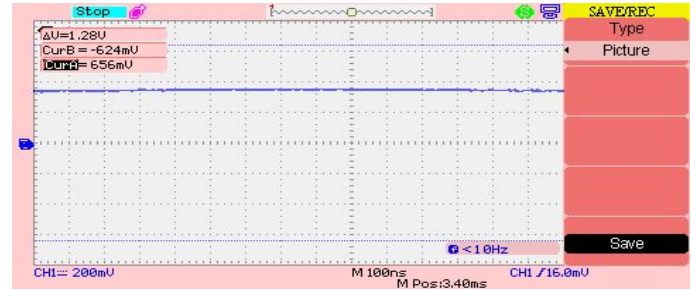


Fig 15: Output of Voltage IC Regulator

#### (B) PWM Generator

The circuit diagram of the PWM Generator is given in Fig 16. All the components are inbuilt in this PWM Generator. The output waveform of the PWM Generator before giving it to the Buck-Boost converter is shown in Fig 17. If any tap change is done, the output for the condition is shown in Fig 18.

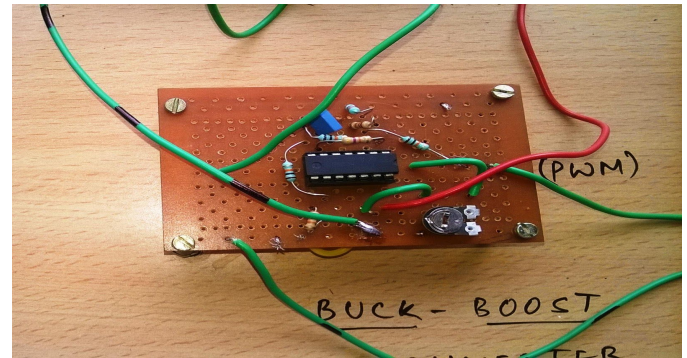


Fig 16: Circuit diagram for PWM Generator

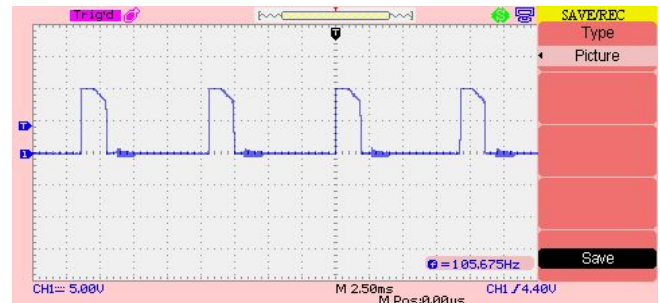


Fig 17: Output of PWM Generator

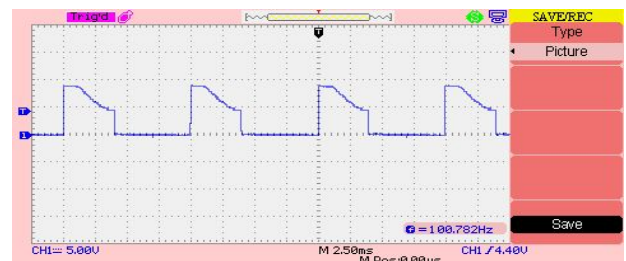


Fig 18: Output of PWM at a certain Tap

#### (C) Buck Converter

The circuit diagram of the Buck converter is given in Fig 20. All the components are inbuilt in this Buck converter. The



Final output waveform of the Buck converter is shown in Fig 19.

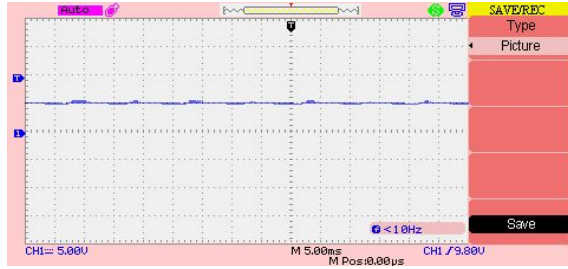


Fig 19: output of buck converter

#### (D) Boost converter

The circuit diagram of the Boost converter is given in Fig 4.9. All the components are inbuilt in this Boost converter. The final output waveform of the Boost converter is shown in Fig 21.

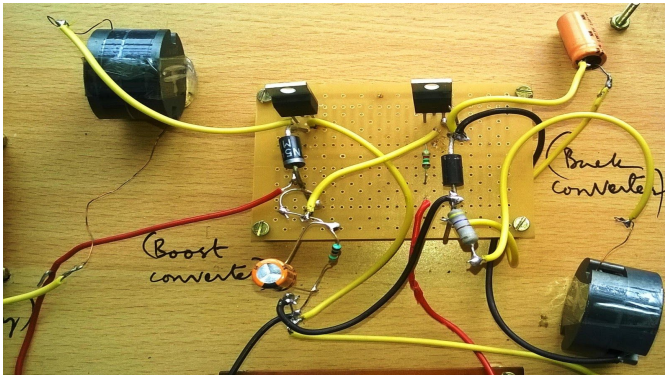


Fig 20: Boost converter

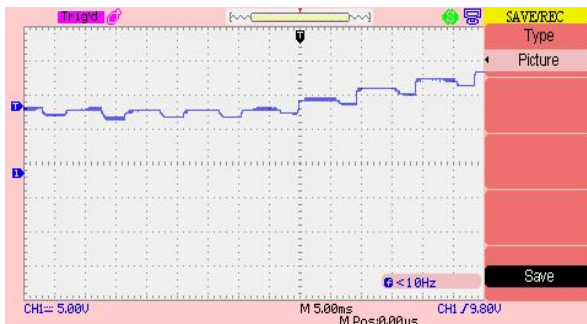


Fig 21: Output of Boost Converter

The results and the explanations of each block have been described vividly in this chapter. The conclusions, applications and future work of the project have been described in chapter-5.

## IV CONCLUSIONS

Buck and boost converter tested in the lab with laboratory condition and found to have results quite satisfactory. The results obtained are as follows:

#### BOOST CONVERTER:

$V_{min} = 12 \text{ V}$

$V_{max} = 40 \text{ V}$

#### BUCK CONVERTER:

$V_{min} = 3 \text{ V}$

$V_{max} = 7 \text{ V}$

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