EE499: MAJOR PROJECT - 2

HIGH GAIN DC-DC BOOST CONVERTER WITH REDUCED COMPONENT COUNT

Submitted to

NATIONAL INSTITUTE OF TECHNOLOGY

In Partial Fulfillment of the Requirement for the Award of

BACHELOR'S DEGREE IN ELECTRICAL AND ELECTRONICS ENGINEERING

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Aim and Objectives:

To develop a high gain, low ripple DC-DC Boost Converter model with reduced component count and verification with hardware implementation by comparison of simulation and hardware results.

Applications:

- High Gain Boost converters are used in the PV system applications to step-up voltage.
- Two battery-powered applications that use High Gain Boost Converters are used in Hybrid Electric Vehicles (HEV) and lighting systems.
- High Gain Boost converters also power devices at smaller scale applications, such as portable lighting systems.
- High Gain Boost Converters are required for efficient charge extraction in solar photovoltaic, wind and fuel cell based applications.

Chapter 1

Introduction

1.1 Boost Converter

A boost converter (step-up converter) is a DC-to-DC power converter that steps up voltage (while stepping down current) from its input (supply) to its output (load). It is a class of switched-mode power supply (SMPS) containing at least two semiconductors (a diode and a transistor) and at least one energy storage element: a capacitor, inductor, or the two in combination.

By law of conservation of energy the input power has to be equal to output power (assuming no losses in the circuit).

$$Input power(P_{in}) = output power(P_{out}) \tag{1.1}$$

Since V_{in} ¡ V_{out} in a boost converter, it follows then that the output current is less than the input current. Therefore in boost converter

$$V_{in} < V_{out} \tag{1.2}$$

and

$$I_{in} > I_{out} \tag{1.3}$$

1.1.1 Principle of operation of Boost Converter

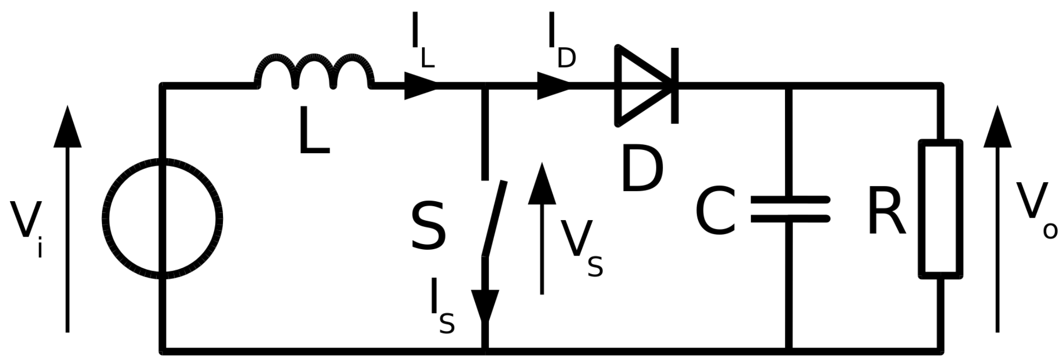

Figure 1.1: Boost converter circuit

PRINCIPLE OF OPERATION:

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current by creating and destroying a magnetic field. In a boost converter, the output voltage is always higher than the input voltage. A schematic of a boost converter circuit is shown in Figure 1.1

(a) When the switch is closed, current flows through the inductor in clockwise direction and the inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive.

(b) When the switch is opened, current will be reduced as the impedance is higher. The magnetic field previously created will be destroyed to maintain the current towards the load. Thus the polarity will be reversed (meaning the left side of the inductor will become negative). As a result, two sources will be in series causing a higher voltage to charge the capacitor through the diode D.

If the switch is cycled fast enough, the inductor will not discharge fully in between charging stages, and the load will always see a voltage greater than that of the input source alone when the switch is opened. Also while the switch is opened, the capacitor in parallel with the load is charged to this combined voltage. When the switch is then closed and the right hand side is shorted out from the left hand side, the capacitor is therefore able to provide the voltage and energy to the load. During this time, the blocking diode prevents the capacitor from discharging through the switch. The switch must of course be opened again fast enough to prevent the capacitor from discharging too much.

A boost converter has an output voltage that is greater than input voltage depending on duty cycle of switching pulse. Its voltage gain expression is given by:

$$\frac{V_{out}}{V_{in}} = \frac{1}{1-D} \tag{1.4}$$

D - Duty Cycle

1.2 High Gain Boost Converter

Conventional battery loads are rated at 12 V to 48 V. High gain is required in step up to supply the ac grid or charge a battery. Conventional isolated transformer based topologies can be designed with high gain at the expense of increase in component count and requirement of snubber circuits for protection as the leakage inductance causes a spike across the switch resulting in losses, complex control schemes and the requirement of over rated components. Non isolated converter circuits with coupled inductors are used for low power systems. The size of the converter, magnetic losses increase with increase in the inductance for higher power capability.

High Gain Converters are useful in Vehicle to Grid(V2G), Grid to Vehicle(G2V) applications for enhancing power system stability. Conventional buck-boost converter is not suitable because of the restriction in the maximum duty cycle imposed due to the capability of inductor, filter capacitor and the diodes. High gain BDC are required in UPS applications to transfer energy from low voltage battery source to high voltage for inversion and driving an ac load.

The high gain boost circuit in fig.1.2 is the proposed circuit. It is derived from the typical boost converter circuit. [Ref.: High gain bidirectional DC-DC converter with reduced component count. Authors: Lalitha Darbha ; P. Parthiban (IEEE Conference Paper)]. Fig.1.3 represents the implemented Boost Converter circuit. It is the modified version of the proposed High Gain Boost Converter (fig.1.2). Here, the switches S2 and S3 are replaced by Diodes D2 and D3.

project/images/high.png

Figure 1.2: Novel High Gain Boost converter (Proposed)

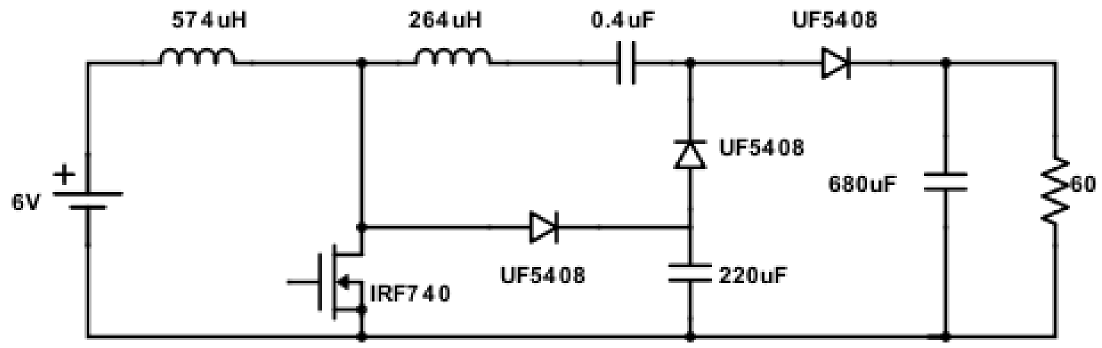

Figure 1.3: High Gain Boost converter (Implemented)

1.2.1 Principle of operation

Conventional boost circuit gives a maximum gain of twice the input with 50 percentage duty cycle. The topology is described with lower input side voltage of 48V as shown in Fig 1.2. The limitation of maximum duty cycle is overcome in the proposed circuit and the following modes are being observed.

- Mode 1: Switch is closed. When the switch is switched, the inductor L1 is charged and inductor currents starts increasing. The inductor L2 begins to discharge and simultaneously charge the capacitor through Cs.
- Mode 2: When the switch is opened, the energy stored in the inductor and the supply is transferred to the load through the body diode of D1, D2, D3. The current through the inductor L2 starts to rise from negative peak value.
- Mode 3:. When the inductor current L2 reaches zero. The inductor L1 energy along with supply discharges to the load through the path.

Advantage of using a High Gain Boost converter:

- The output of the High gain converter is higher than conventional boost converter.
- Reduction in ripples in the output.
- More efficient than other DC-DC smps converter.
- Can have Multiple outputs

Disadvantage of using a High Gain Boost converter:

- Higher input and output capacitance
- Higher losses

Chapter 2

MOSFET Switching using Microcontroller

Switching of MOSFET at a required frequency is necessary for the Boost Converter to work. For this purpose we require pulses to be generated and fed into the gate of the MOSFET. We are using the microcontroller, ARDUINO UNO to generate pulses of required frequency.

2.1 Arduino Uno

Arduino is a basic single board microcontroller designed to make applications, interactive controls, or environments easily adaptive. It is an open source electronics platform accompanied with a hardware and software to design, develop and test complex electronics prototypes and products. It is easy to use hardware. The hardware consists of a board designed around an 8-bit microcontroller, or a 32-bit ARM. The maximum operating frequency of Arduino Uno is 16MHz.

Benifits of using Arduino Uno are as follows:

- Inexpensive - Arduino boards are relatively inexpensive compared to other microcontroller platforms.
- Cross-platform - The Arduino software runs on Windows, Macintosh OSX, and Linux operating systems.
- Simple, clear programming environment - The Arduino programming environment is easy-to-use for beginners, yet flexible enough for advanced users to take advantage of as well.
- Open source and extensible software - The Arduino software is published as open source tools, available for extension by experienced programmers. The language can be expanded through C++ libraries.

- Open source and extensible hardware - The Arduino is based on Atmel's ATMEGA8 and ATMEGA168 microcontrollers. The plans for the modules are published under a Creative Commons license, so experienced circuit designers can make their own version of the module, extending it and improving it.

The Pinout Diagram of Arduino Uno board shown below:

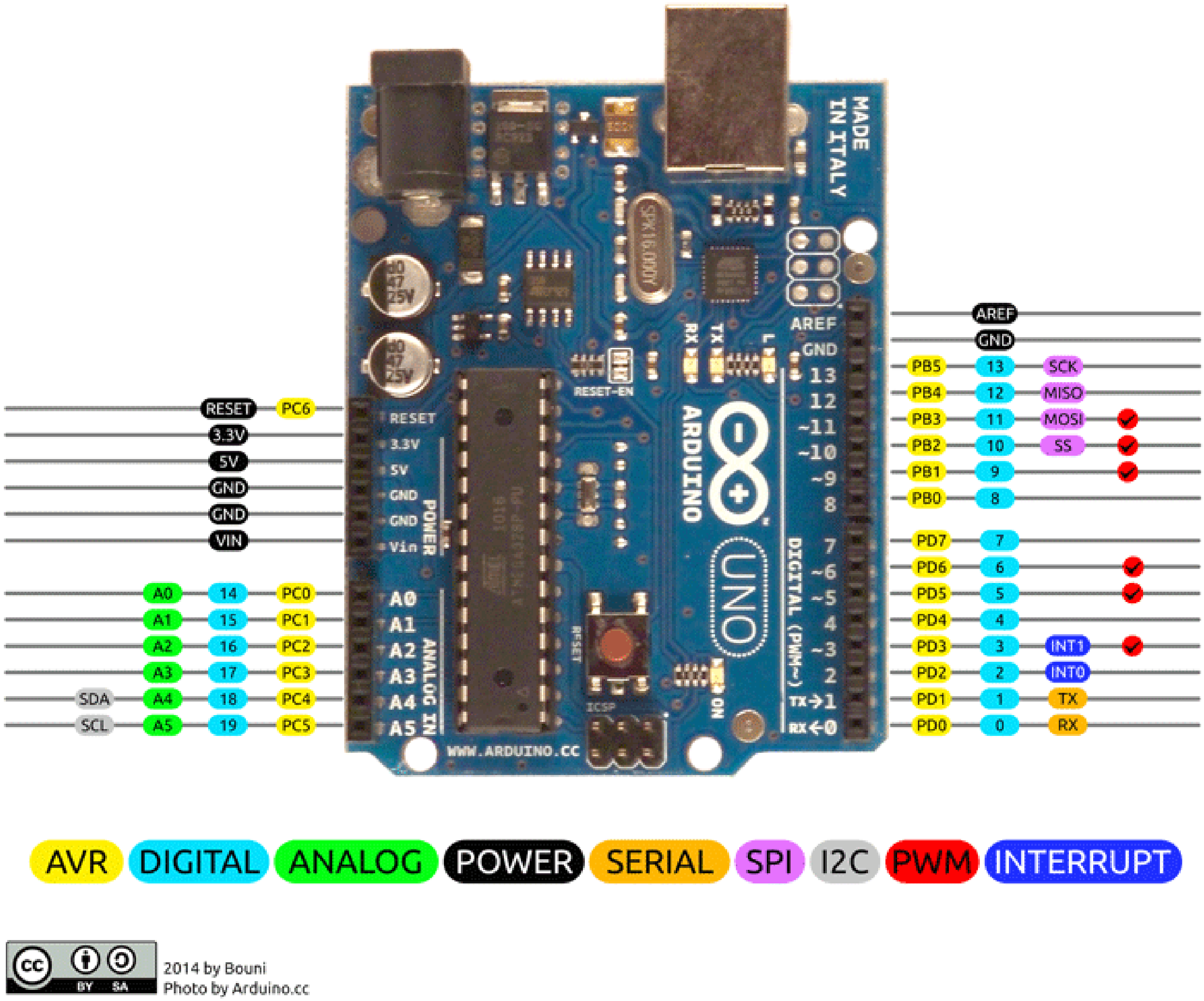

Figure 2.1: Pinout of Arduino Uno

The generated pulses from Arduino Uno are then fed into the Optocoupler 4N25 for electrical isolation of the microcontroller from the control circuit and power circuit.

2.2 4N25 (Optocoupler)

An optocoupler (also known as optical coupler, optocoupler and opto-isolator) is a semiconductor device that uses a short optical transmission path to transfer an electrical signal between circuits or elements of a circuit, while keeping them electrically isolated from each other. These components are used in a wide variety of communications, control and monitoring systems that use light to prevent electrical high voltage from affecting a lower power system receiving a signal.

In its simplest form, an optoisolator consists of a light-emitting diode (LED), IRED (infrared-emitting diode) or laser diode for signal transmission and a photosensor (or phototransistor) for signal reception.

For our purpose, we are using the optocoupler called 4N25.

The 4N25 is an optocoupler for general purpose applications. It contains a light emitting diode optically coupled to a photo-transistor. It is packaged in a 6-pin DIP package and available in wide-lead spacing option and lead bend SMD option. Response time, t_r , is typically 3μs and minimum CTR is 20 percent at input current of 10 mA.

Applications of 4N25:

- I/O interfaces for computers
- System appliances, measuring instruments
- Signal transmission between circuits of different potentials and impedances

Features of 4N25:

- Response time (tr: typ., 3 us at VCE = 10 V, IC = 2 mA, RL = 100 ohm)
- Current Transfer Ratio (CTR: min. 20 percent at IF = 10 mA, VCE = 10 V)
- Input-output isolation voltage (Viso = 2500 Vrms)

The Pinout Diagram of optocoupler 4N25 shown below:

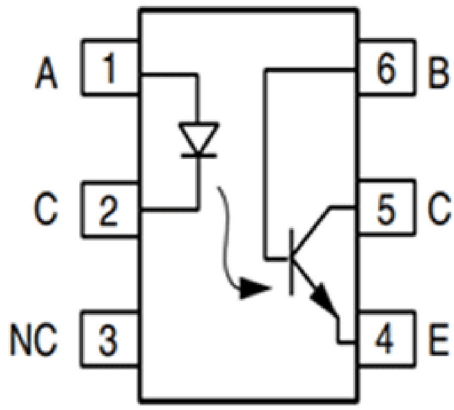

Figure 2.2: Pinout of optocoupler 4N25

The pulses generated from Arduino Uno is fed into the optocoupler. Once the electrical isolation is achieved, the pulses from the optocoupler are passed onto the MOSFET driver cicruit.

2.3 MOSFET Driver Circuit using IR2110

The pulses generated by Arduino Uno is of approximately 2V-5V and 100mA-200mA. This pulse is not enough to drive the MOSFET. In order to drive the MOSFET (IRF720), the gate signal has to be of higher current and higher voltage value(10V - 15V). To fullfill this purpose we are using the MOSFET driver, IR2110.

The IR2110 is a high voltage, high speed power MOSFET and IGBT drivers with independent high and low side referenced output channels. The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high side configuration which operates up to 500 or 600 volts.

There is a provision of driving two MOSFETs simultaneously using the High side drive and Low side drive of IR2110. For our purpose, we are using the Low side drive of IR2110 as it is simple and prone to less errors when compared to the high side drive.

The Pinout Diagram of MOSFET Driver IR2110 shown below:

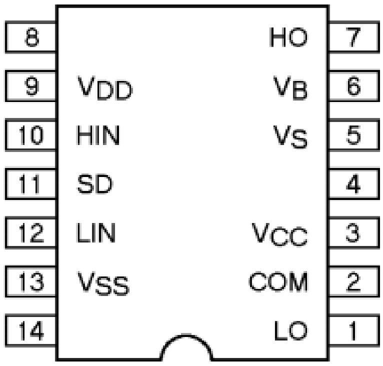

Figure 2.3: Pinout of IR2110

The pulses are received from the optocoupler by IR2110 MOSFET driver and respective output is obtained from IR2110. This output pulse (signal) is then fed into the gate of the MOSFET for switching purposes.

Chapter 3

Circuit Design

3.1 Optocoupler Circuit Diagram

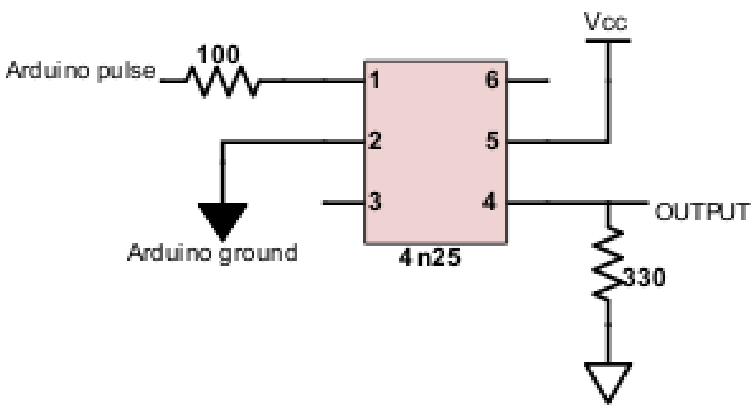

Figure 3.1: Optocoupler Circuit Diagram

Fig. 3.1 represents the optocoupler connections circuit diagram. The Arduino signal is fed into the Pin 1 of the optocoupler and Pin 2 is connected to Arduino ground. Pin 5 is given +Vcc (+5V). The output is taken across the 330ohm resistor which is connected to Pin 4 and the common ground. The purpose of using this circuit is to provide isolation from the microcontroller and the working circuit. Pins 3 and 6 are no connections.

3.2 MOSFET Driver Circuit Diagram (using IR2110)

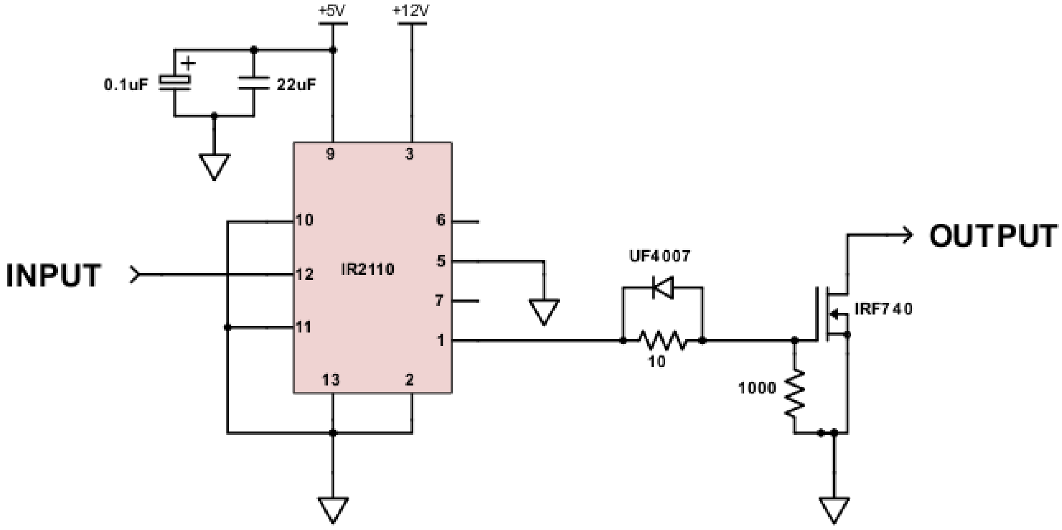

Figure 3.2: MOSFET Driver Circuit Diagram (using IR2110)

Fig. 3.2 represents MOSFET driver circuit diagram. The output from Arduino is given into Pin 12 of IR2110. Pins 10, 11, 13, 2, 5 are grounded. +12V is given to Pin 3. +5V is given to Pin 9. The output from IR2110 is taken from the Pin 1 through 10 ohm resistor and across 1k ohm resistor and ground. This output is given as a gate signal into the MOSFET and this facilitates the switching of the MOSFET.

3.3 Boost Converter Circuit Diagram

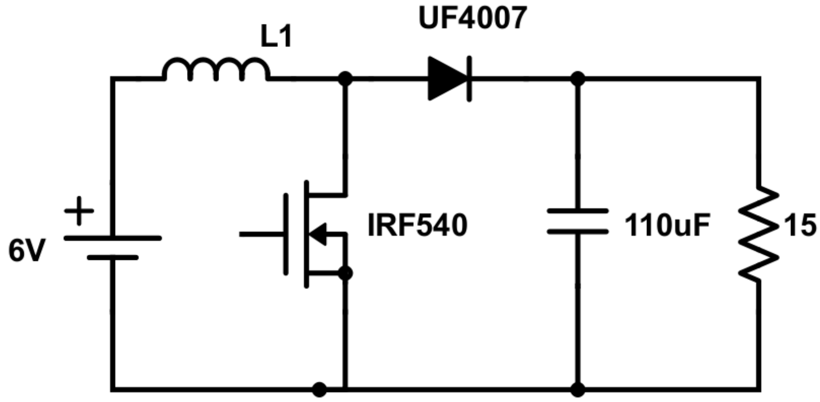

Figure 3.3: Boost Converter (Power Circuit)

Fig. 3.3 represents the typical Boost Converter Circuit. (The working is explained in Chapter 1)

3.4 High Gain Boost Converter Circuit Diagram

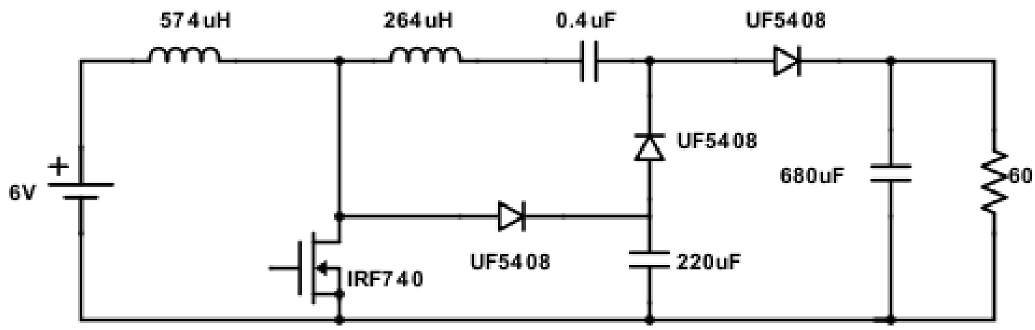

Figure 3.4: High Gain Boost Converter (Power Circuit)

Fig.3.4 represensts the High Gain Boost Converter Circuit. This circuit is derived from the typical Boost Converter Circuit. There is an addition of an inductor and 2 capacitors in this circuit when compared to the Boost Converter Circuit. This circuit provides an higher voltage boost when compared to normal Boost Converter Circuit.

3.5 Boost converter Circuit Diagram (Control and Power Circuit)

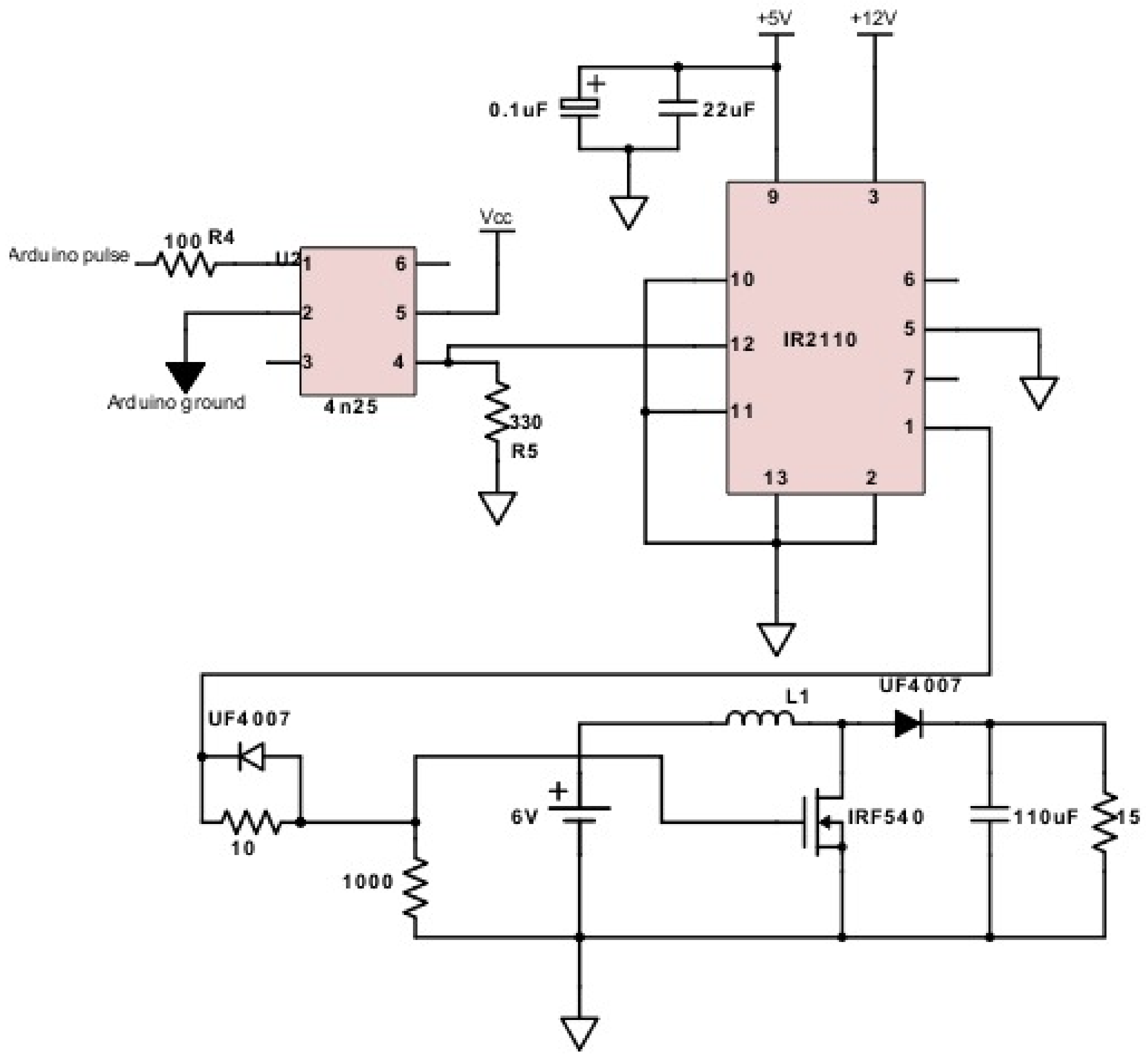

Figure 3.5: Boost converter Circuit Diagram (Control and Power Circuit)

Fig.3.5 represents both control and power circuit of boost converter. The Arduino output is fed into the optocoupler 4N25. The output from optocoupler 4N25 is fed into IR2110 MOSFET driver. This comprises the control circuit. The output from IR2110 is the gate signal and is fed into the gate of the MOSFET in the power circuit.

3.6 High Gain Boost converter Circuit Diagram (Control and Power Circuit)

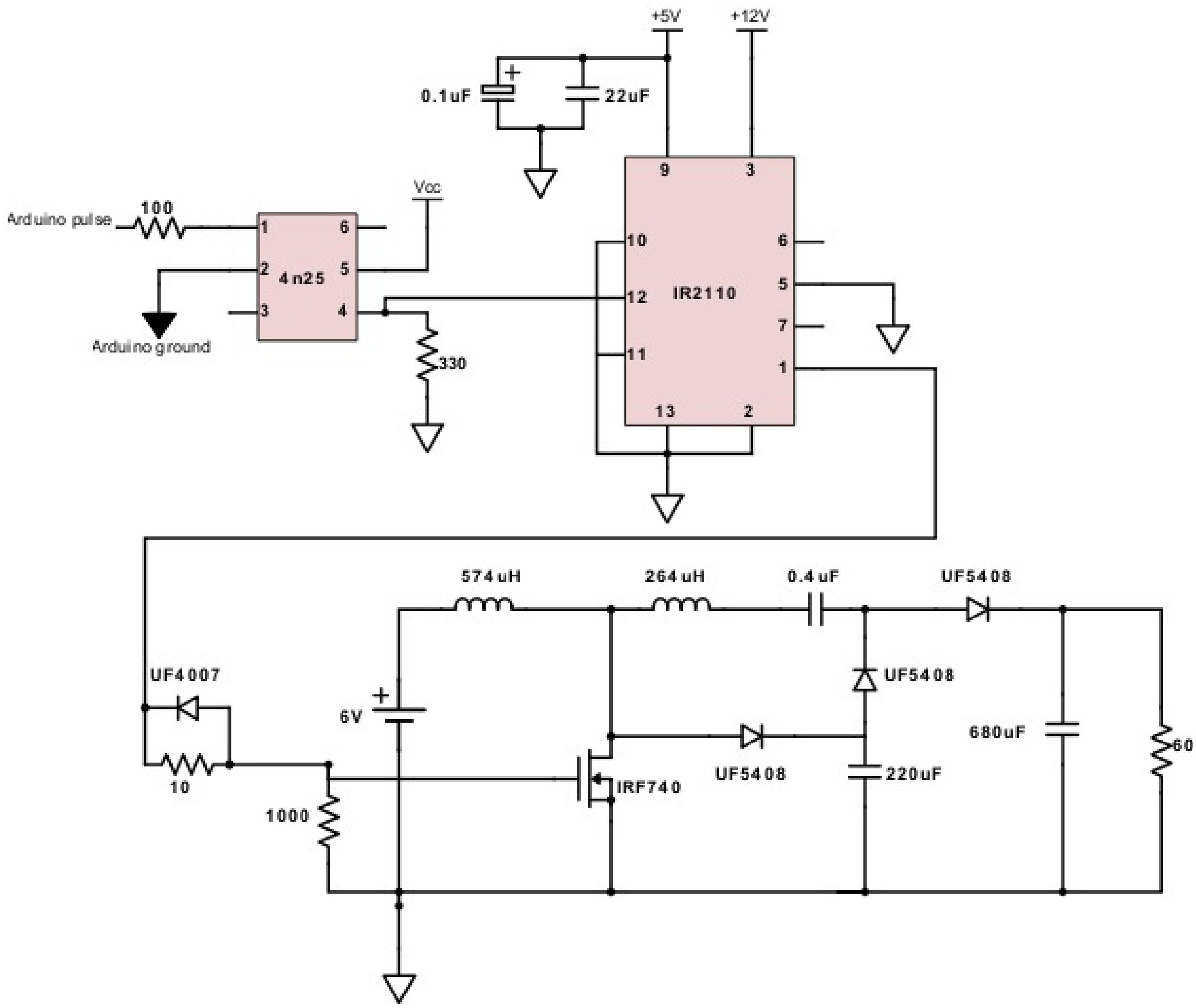

Figure 3.6: High Gain Boost converter Circuit Diagram (Control and Power Circuit)

Fig. 3.6 represents both control and power circuit of the High Gain Boost Converter. The Arduino output is fed into the optocoupler 4N25. The output from optocoupler 4N25 is fed into IR2110 MOSFET driver. This comprises the control circuit. The output from IR2110 is the gate signal and is fed into the gate of the MOSFET in the power circuit.

The parameters used during the hardware implementation of High Gain Boost Converter is as follows:

PARAMETERS	VALUE
Switching Frequency	30kHZ
Inductor L1	570μH
Inductor L2	260μH
Capacitors C1, C2	220μF
Series Capacitors Cs	0.4μF
Filter Capacitors CF1	680μF
R_L(Load)	100ohm
Duty Cycle	45 percent

Chapter 4

Observations and Experimental Results

4.1 Pulse Generated from Arduino Uno

A pulse of frequency 30kHz, Pk-Pk 3V, duty cycle 45 percent is generated using Arduino Uno. It is represented in fig.4.1.

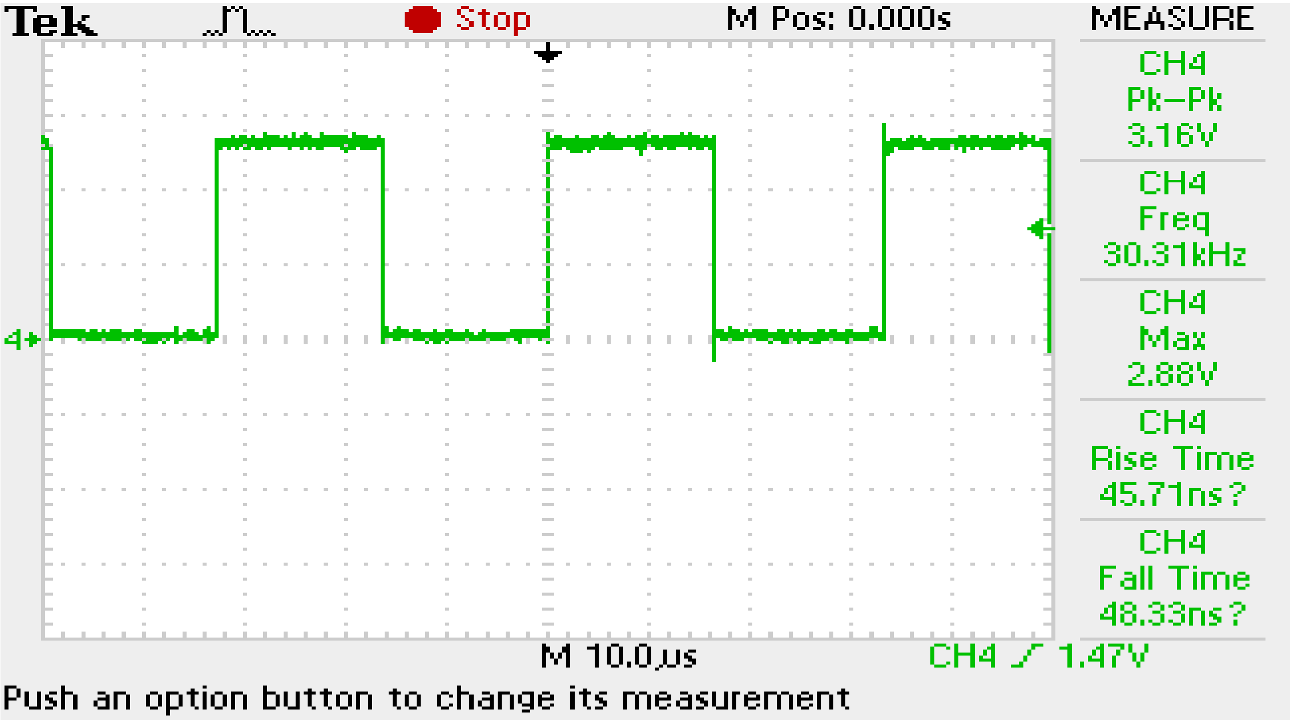

Figure 4.1: Pulse Generated from Arduino Uno

4.2 Optocoupler output

The Pulse generated using Arduino is fed into Optocoupler to provide electrical isolation between Arduino and the Boost Converter Circuit, Arduino and High Gain Boost Converter Circuit.

The pulse output from optocoupler when frequency is 1kHz is shown in fig 4.2.

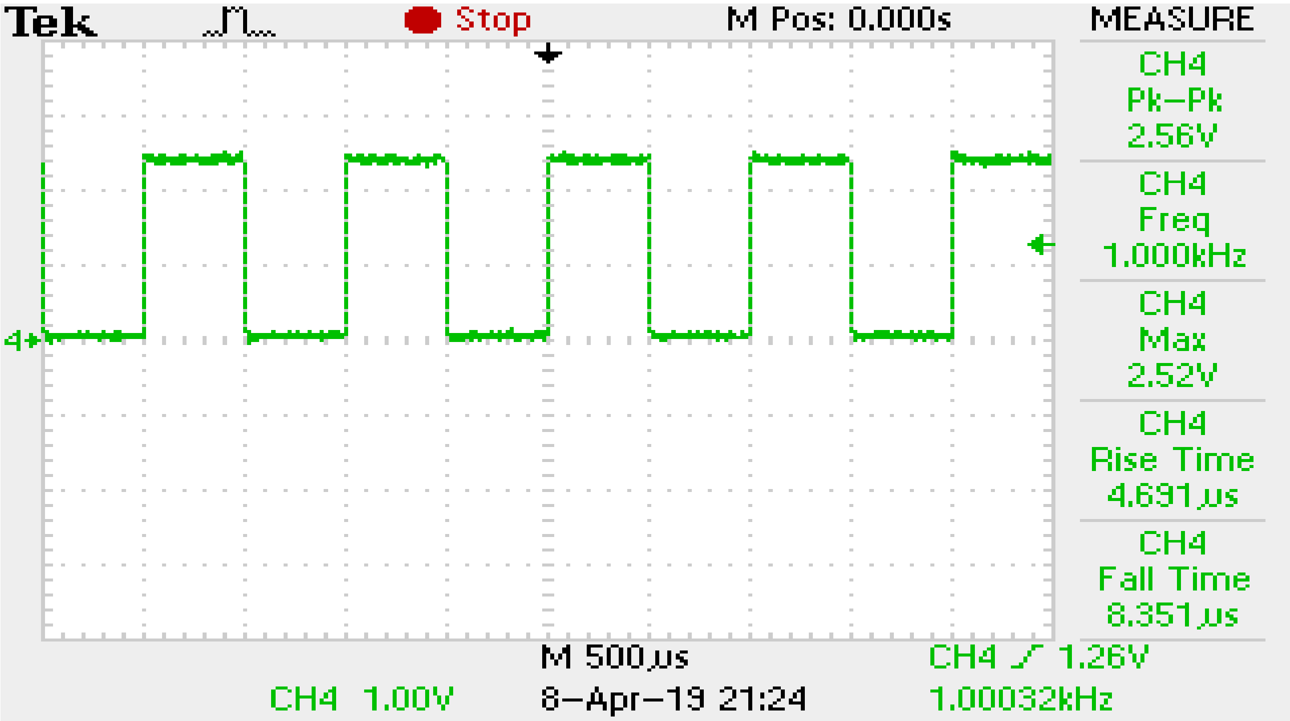

Figure 4.2: Optocoupler output (1kHz)

The pulse output from optocoupler when frequency is 30kHz is shown in fig. 4.3. A distortion of the pulse is observed. This is because of the increase in the frequency. This distortion is overcome in the Driver Circuit.

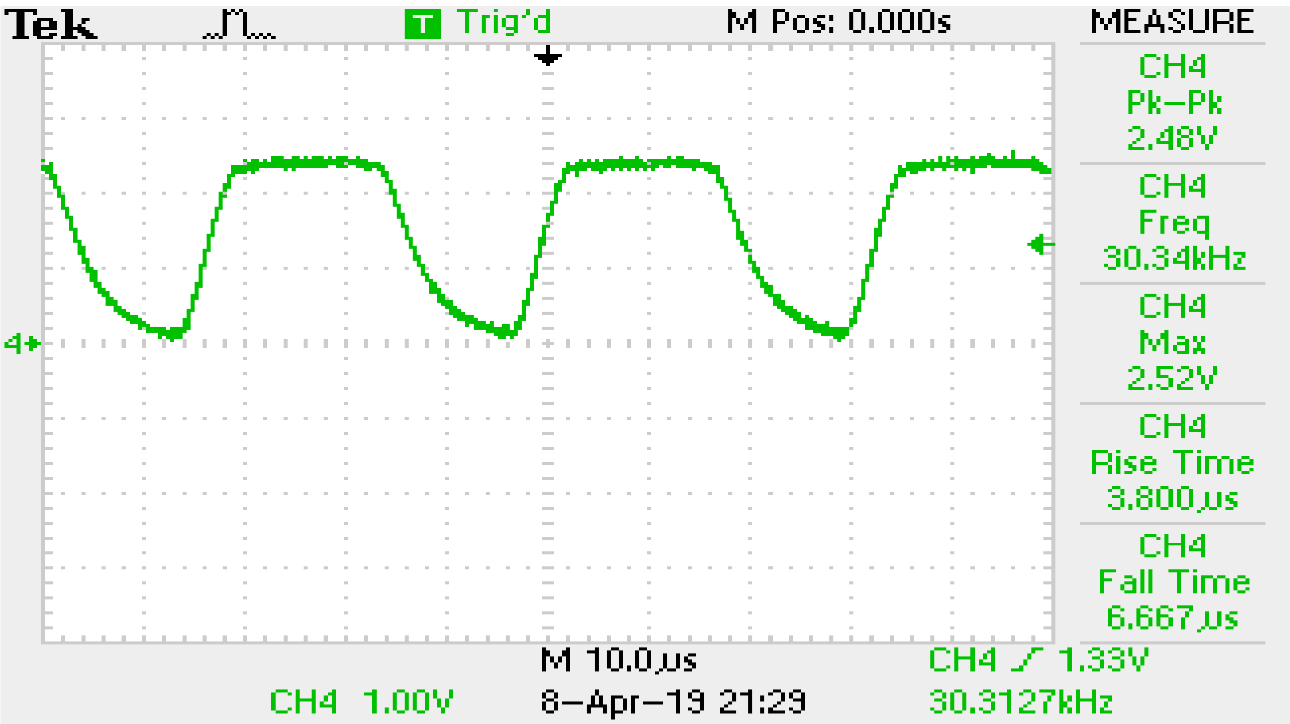

Figure 4.3: Optocoupler output (30kHz)

4.3 MOSFET Driver Output

The Output from optocoupler is fed into the IR2110 MOSFET Driver. The pulse output from the MOSFET driver of frequency 30kHz is observed. The distortion in the previous stage is eliminated in this stage. The voltage is increased from 3V (arduino) to 7.4V (driver).

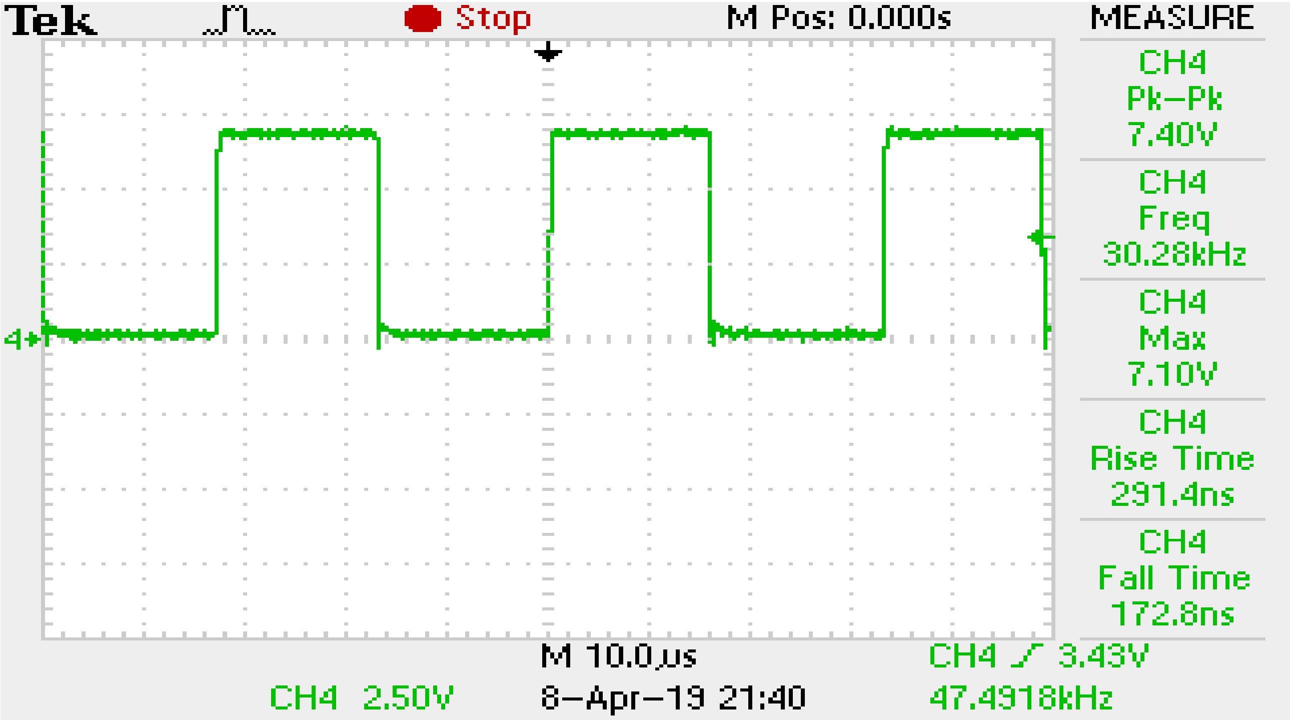

Figure 4.4: MOSFET Driver Output

This pulse is fed into the Gate of the MOSFET to facilitate the switching of the MOSFET in the Boost Converter circuit.

4.4 Output of Conventional Boost Converter

From the fig. 4.5 we can observe that for an input of 5V we are getting an output of 8.4V. The circuit is giving nearly 70 percent boost of the input.

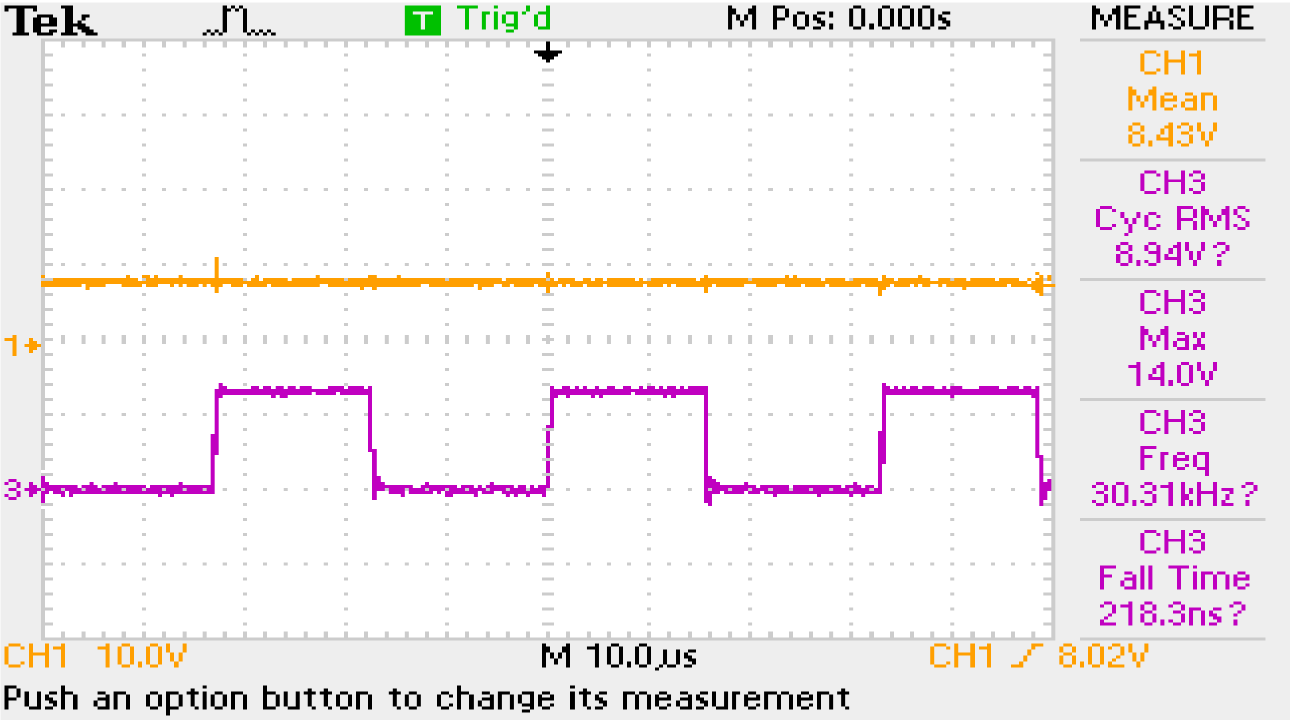

Figure 4.5: Conventional Boost Converter Output

(Here, the orange line indicates boost converter output and purple line indicates the driver output.)

4.5 Output of High Gain Boost Converter

From fig. From the fig. 4.6 we can observe that for an input of 5V we are getting an output of 9.6V. This is nearly 92 percent boost of the input. This is because of the energy stored and discharged by the additional inductor and capacitor as explained before.

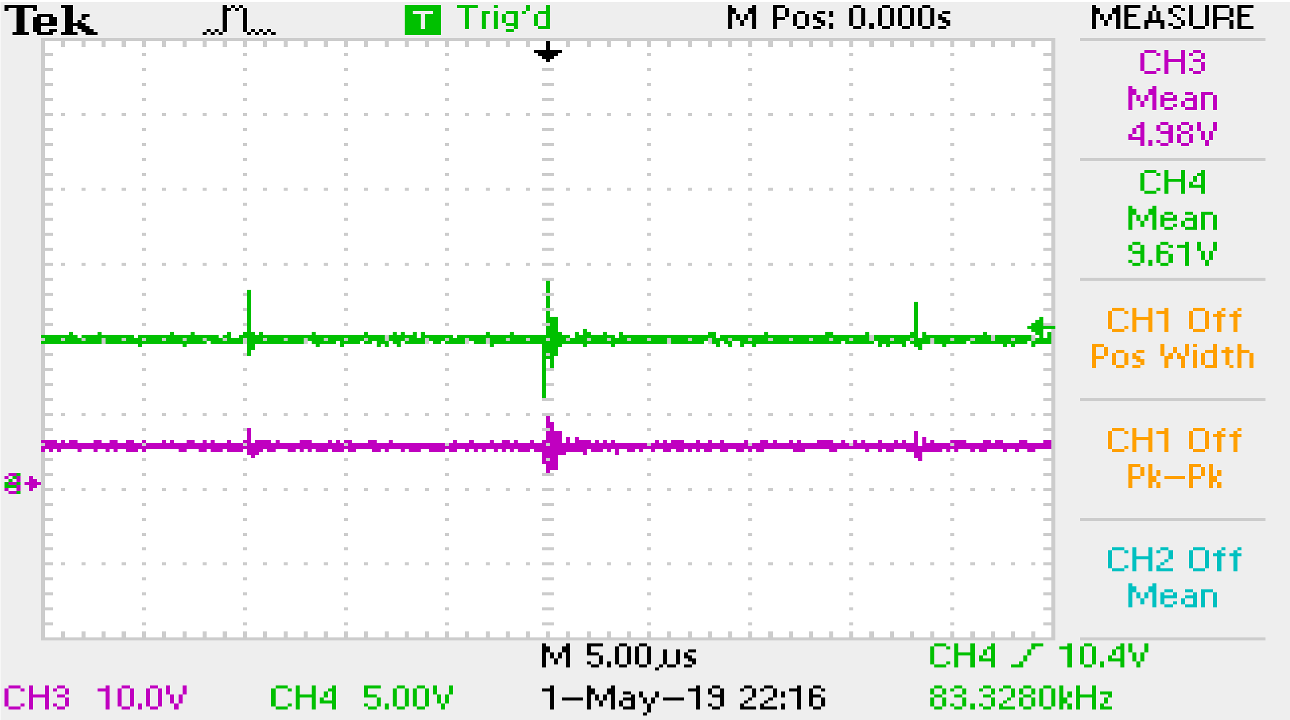

Figure 4.6: High Gain Boost Converter Output (i/p = 14V)

(Here, the purple line indicates the input to the high gain boost converter and the green line indicates the output of the high gain boost converter.)

In fig 4.7, we can observe that for an Input Voltage (V_{in}) 14V, we are getting an Output Voltage (V_{out}) of 32.8V. Here, a boost of more than 100 percent of the input voltage is observed.

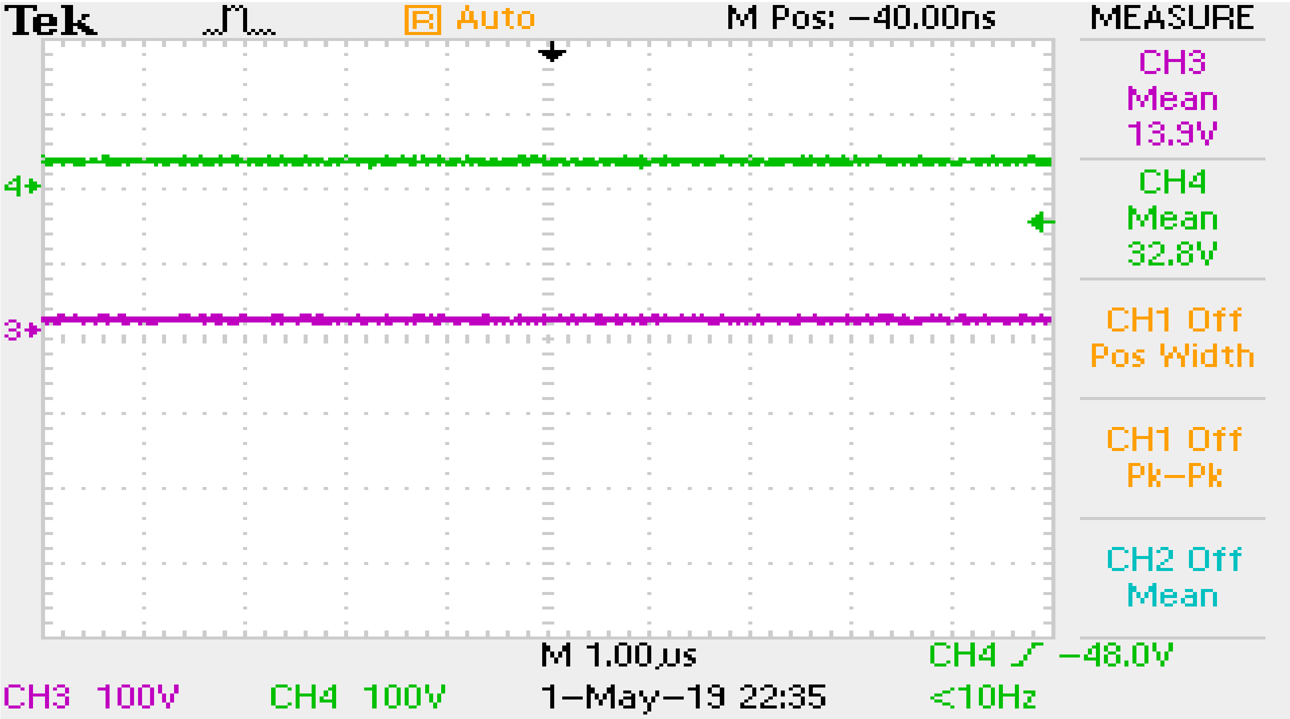

Figure 4.7: High Gain Boost Converter Output (i/p = 14V)

(Here, the purple line indicates the input to the high gain boost converter and the green line indicates the output of the high gain boost converter.)

4.6 Results

- Pulses with duty cycles D = 45 percent is shown in the Fig. 4.1. These pulses are sent to the gate of the switch to control the on/off of the switch.
- Input Voltage (V_{in}) of 5V is given to the Boost Converter (Fig. 4.5) and Output Voltage (V_{out}) of 8.5V is observed.
- Input Voltage (V_{in}) of 5V is given to the High Gain Boost Converter (Fig. 4.5) and Output Voltage (V_{out}) of 9.6V is observed.
- Input Voltage (V_{in}) of 14V is given to the High Gain Boost Converter (Fig. 4.5) and Output Voltage (V_{out}) of 32.8V is observed.

Chapter 5

Conclusion

The High Gain Boost Converter proposed is a non isolated converter requiring minimum number of switches. The proposed converter has higher gain, lower component number and reduced size. The converter offers flexibility of its simple design, arrangement and control scheme. Absence of coupled inductors makes it possible to achieve higher gain with lower inductance. Stress on the switches is reduced to half. Applications of the topology include the regulation of dc link voltage, battery charging / discharge and extracting power from solar photovoltaic panels.

References

[1] High gain bidirectional DC-DC converter with reduced component count.
Authors: Lalitha Darbha, P. Parthiban, IEEE
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