LOW COST HVPS WITH PSOC EMBEDDED CONTROL FOR PORTABLE APPLICATIONS

A project report submitted in partial fulfilment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted by

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Under the Guidance of

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PRAGNANAM BRAHMA

ANITS

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY AND SCIENCES

(UGC AUTONOMOUS)

(Permanently Affiliated to AU, Approved by AICTE and Accredited by NBA & NAAC with 'A' Grade)

Sangivalasa, Bheemili mandal, Visakhapatnam dist.(A.P)

(2021-2022)

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CERTIFICATE

This is to certify that the project report entitled **"LOW COST HVPS WITH PSOC EMBEDDED CONTROL FOR PORTABLE APPLICATIONS"** submitted by B. Bharath (318126512010), NSS Charan (318126512035), V. Tirumala Rao (318126512059) and Y. Raghavareddy (318126512060) in partial fulfilment of the requirements for the award of the degree of **Bachelor of Technology** in **Electronics & Communication Engineering** of Andhra University is a record of bonafide work carried out under my supervision.

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CONTENTS

ABSTRACT

Portable radiation monitors, personal dosimeters, optical and analytical instruments, often require a regulated high voltage power supply (HVPS) for biasing the detector stage. The regulated high-voltage is generated from a low voltage battery-based supply using DC-DC boost converters. DC-DC converters with voltage boosters are widely used in a large number of power conversion applications from fraction of volts to tens of thousands of voltages at power levels from milliwatts to megawatts. Presently the feedback control of these converters is designed with commercial switching regulator ICs. However, design using these ICs limits the level of reconfigurability in the power supply, usually required for system level tuning operations. Embedded design of the feedback control with Programmable System on Chip (PSoC®) mixed signal array, enables the addition tuning and remote reconfigurability feature in HVPS. The objective of present work is to design a PSoC® based HVPS with remotely programmable output voltage level and ramping rate.

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

1.1 Aim and Scope:

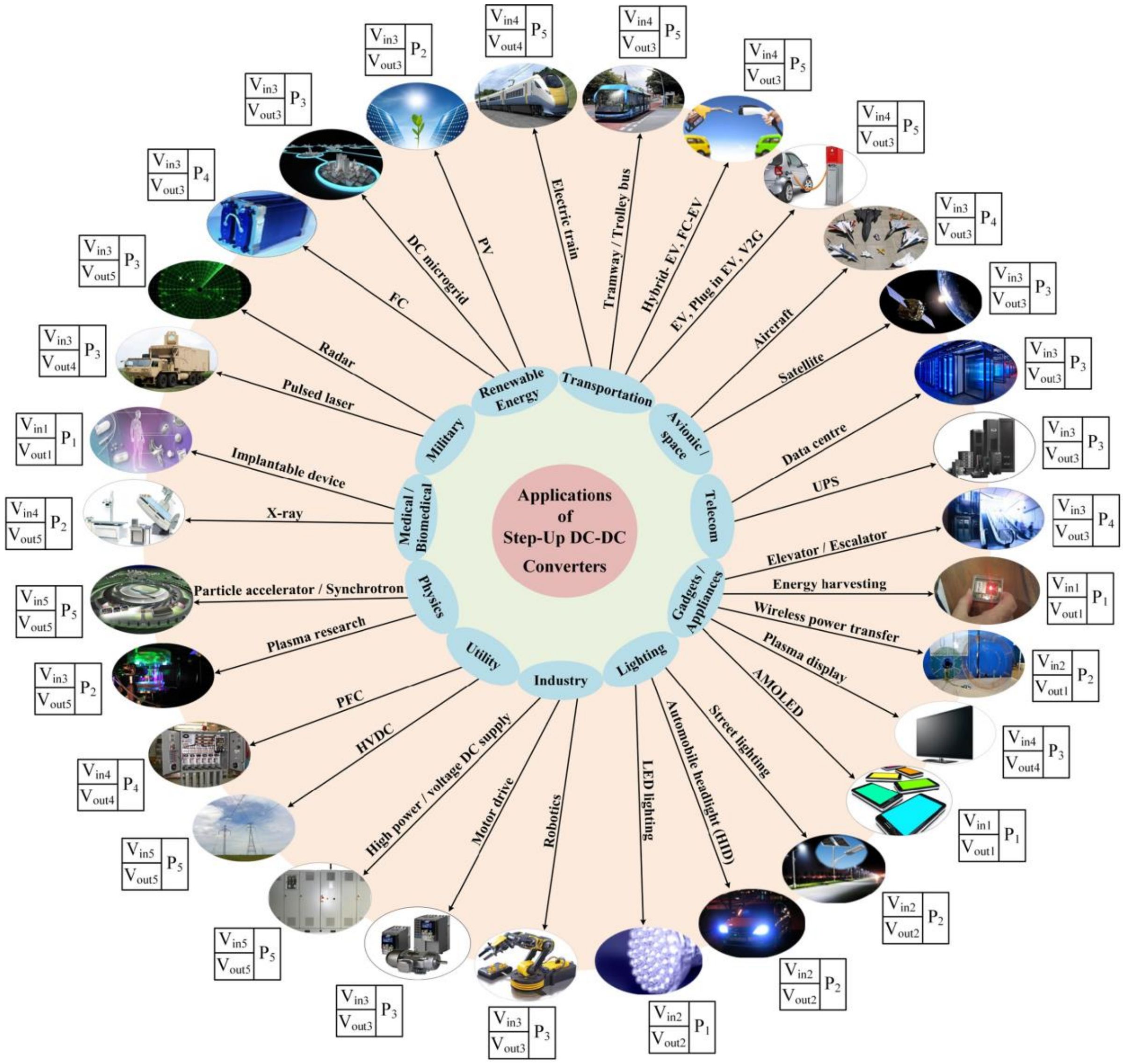
Step up DC-DC converters with switched mode [1] came from the development of transformers that develop pulse width modulated (PWM) boost converters. Step-up dc-dc topology converts lower dc voltage levels to higher voltage levels by temporarily storing the input power and then releasing the output at high voltage. Such storage can take place in the final magnetic fields (single/coupled inductor) or in electric field storage components (capacitors) through active or passive switching elements (power switches and diodes). With the introduction of semiconductor switching in the 1950s, rising DC-DC converters achieved slower performance and their use accelerated in the 1960s when semiconductor switches became commercially available through integrated production technology.

The growth of the aerospace and telecommunications industries has continued to expand the research limits of advanced transformers, especially those used where efficiency, density, and weight have been a major concern. Efficiency has been steadily improving since the late 1980s due to the use of field-effect transistors (FETs), which are able to switch more efficiently at higher frequencies than bipolar junction transistors while making lower switching losses and require a driving circuit complex. In addition, FET replaces the output diode with the use of the corresponding adjustment, which in its resistance is much lower and increases the efficiency of the step-up DC-DC converter, which requires a higher number of diodes to maximize power.

The regulated high-voltage [2] is generated from a low voltage battery-based supply using DC-DC boost converters. DC-DC converters with voltage boosters are widely used in a large number of power conversion applications. Here LT Spice software is used to simulate the circuit to check functionality of the circuit. The circuit which we are implementing consists of multipliers, Zener diode, MOSFET, Op-Amp.

1.2 Applications of HVPS:

We will be experiencing high voltage power supply [18] devices in our daily lives in industrial, military and scientific applications. Many electronic devices require high voltages to function. Some of the examples are Satellites, X-ray machines, EVs, Electric trains etc. Many of the electric trains operates at voltage range in between 750V- 25KV. Electric engines are mostly of two kinds one runs with DC traction and another with AC traction. Pantograph which is present above the engine collects the electricity from the overhead wires. Mostly high speed electric trains uses 25KV for functioning. But in India the operating voltage is 750V [1].



	V_{in1}	V_{in2}	V_{in3}	V_{in4}	V_{in5}		V_{out1}	V_{out2}	V_{out3}	V_{out4}	V_{out5}		P_1	P_2	P_3	P_4	P_5
V_{in}	<5V	<20V	<200V	<600V	>600V	V_{out}	<20V	<100V	<750V	<2 kV	>2 kV	P	<10W	<200W	<1kW	<20kW	>20kW

Figure 1-1. Applications of step-up dc–dc converters for milliwatt to megawatt levels (courtesy [1])

X ray unit emits high concentration beam i.e., X ray photons. These photons passes into our body and make contact with tissues and produce a metal film. But soft tissues like skin and organs are sensitive towards these rays. X ray units mostly operates 220V, some of them operates at 110V and 440V also. Their operating frequency is 60Hz.

Satellites require high amounts of voltages to operate. There are two kinds of HVPS used in satellites one is fixed HVPS and another one is sweeping HVPS. These HVPSs are installed in satellites to supply voltage to the detectors present in the satellite. Output voltage range for fixed HVPS is 0V - 2000V, input voltage required is 11.5V to 13V, output current is more than 100μA. In case of sweeping HVPS output voltage range is 0V-5000V, input voltage range is -11.5V to -13V and output current is more than 5μA(Meisel data sheet).

EVs are also the important application for HVPS. World is moving towards electric vehicles over vehicles that runs over petroleum products(petrol, diesel, CNG). EVs usually requires 400V for good balanced operation. Some of the high performance EVs requires 800V for operation. Porsche, Nissan uses EVs. These EVs are eco-friendly and affordable compared to vehicles that run over petroleum products. EVs are good at specifications also, Tesla EV takes 3sec to accelerate from 0 to 60 KMPH.

CHAPTER 2
MOTIVATION

In most industrial systems, it is necessary to convert a fixed-voltage dc source into a variable-voltage source dc. DC-DC converters are electronic devices used to convert DC electrical power efficiently from one voltage level to another. DC-DC conversion is very important for many applications, from low power applications to high-power applications.

Power management is an understanding of how to effectively optimize energy consumption of each system component. The proper use of power management results in increased efficiency [6] and heat reduction. The detailed methodology of power management and reconfigurability are discussed in the following section.

2.1 Power Management:

Power management allows users to control the amount of electrical power consumed by a device, with minimal impact on performance. It enables switching of devices in different power modes, each with different power consumption features related to device performance. DC-DC converters are important blocks in power management systems. They need to meet specific requirements and consume at the same time as little energy as possible [6]. DC-DC converters with fast switching frequencies are becoming more popular due to their ability to reduce the size of external components.

Digital communication and control benefit systems under power converters and the systems that are part of it. Digital interface provides the power design engineer a great flexibility to optimize and finalize certain parameters (e.g., feedback compensation, sequencing of voltage rails) after system board returns from assembly.

The physical layer (PHY) for most power converters is the I^2C serial interface, or its derivative, the SMBus. The I^2C interface defines a bidirectional clock signal (SCL) and a bidirectional data signal (SDA). The SMBus adds an optional alert signal and utilizes fixed logic levels for the signalling. Signal timing for clock and data are the same for both standards.

These PHY choices allow multiple converter circuits to share a single interface with a host controller and are used in many server and PC subsystems, such as fan control and power/sleep functions. The data link layer defines the information to be communicated between the host and voltage converter circuit. One such standard for power management is the PMBus [5] standard, which provides a defined set of registers/commands to communicate status.

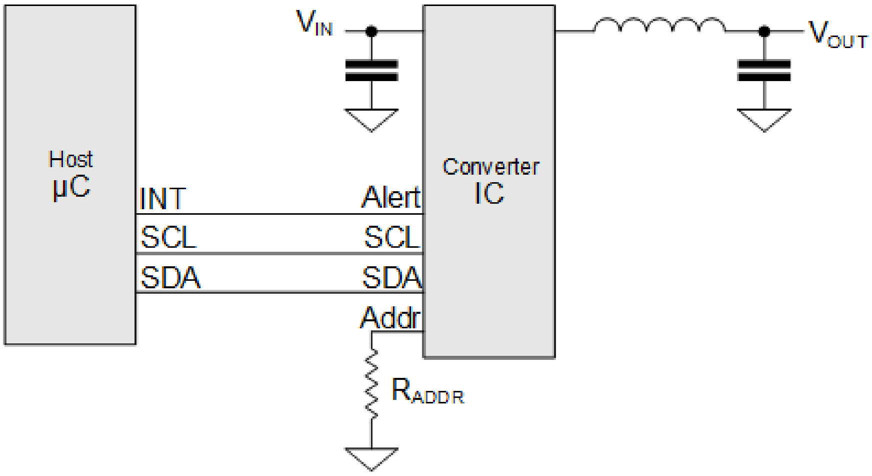


Figure 2-1. The I^{2}C / PMBus signals used in communications to power converters

2.1.1 Power Management functions:

Power sequencing:

Power sequencing is a major function of any power management IC. The supply voltages to different subsystems of a complex system are required to be sequenced, depending on operating conditions such as power up, power down, and fault conditions to ensure proper operation of all the devices. As the system becomes more complex, the number of different supply voltages in a single system increases. Therefore, an accurate and reliable power sequencing solution is required. During powering up of the system, each of the voltage regulators needs to be powered up one after another in a sequential order with programmable delays between each of them. During sequencing, the controller enables the voltage regulator, monitors its rail for the voltage level, and proceeds to the next rail only if the voltage level is within the user-defined Under Voltage(UV) / Over Voltage(OV) range.

Power ramping:

Power ramping means how much fast or slow we have to switch on the power. It is the way in which the signal increases (power-on ramp) or falls off (power-down ramp).

Fault detection:

Fault detection is a critical function of power management. Whenever there is some short circuit in the device, immediately it has to detect that fault and take some action. Each subsystem has a strict power supply operating range for its reliable operation. To ensure reliable operation of the subsystem, it is necessary to detect UV and OV fault conditions when any of the supply rails deviates from its safe operating range.

2.2 Limitations of existing power converter ICs:

The present commercially available dc-dc converters implement only a single protocol which is based on the I^2C protocol. This restricts the integration of the power converter with existing applications which use a variety of popular communication protocols.

In the present design, the above drawback is overcome by using PSoC platform, which contains several communication protocols on the single chip in addition to the I^2C/PMBus/SMBus.

Another drawback is that the switching frequency is generally not reconfigurable. This eliminates any possibility of frequency tuning which is essential for electromagnetic interference(EMI) and Electromagnetic compatibility(EMC) compliance.

2.3 Protocols in PSoC:

- I^2C/PMBus/SMBus
- I2S
- UART
- USB
- LIN
- CAN
- SPI

I²C/PMBus/SMBus Protocol:

The I²C component supports I²C slave, master, and multi-master configurations. The I²C bus is an industry-standard, two-wire hardware interface developed by Philips. The master initiates all communication on the I²C bus and supplies the clock for all slave devices. The I²C component supports standard clock speeds up to 1000 kbps. It is compatible1 with I²C Standard-mode, Fast-mode, and Fast-mode Plus devices as defined in the NXP I2 C-bus specification. The I²C component is compatible with other third-party slave and master devices.

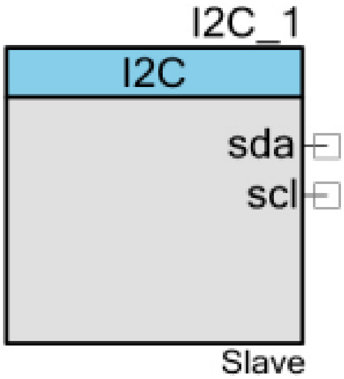


Figure 2-2. I²C Slave component

When to use I²C

The I²C component is an ideal solution when networking multiple devices on a single board or small system. The system can be designed with a single master and multiple slaves, multiple masters, or a combination of masters and slaves

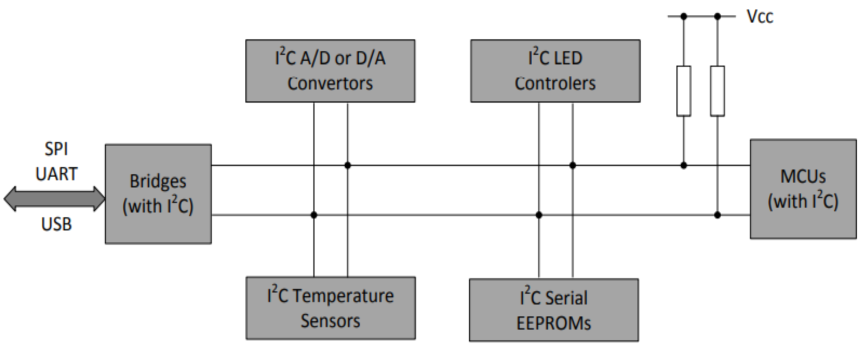


Figure 2-3. Network model of multiple I²C components

I2S Protocol:

The Integrated Inter-IC Sound Bus (I2S) is a serial bus interface standard used for connecting digital audio devices together. The specification is from Philips® Semiconductor. The I2S component operates in master mode only. It also operates in two directions, as a transmitter (Tx) and a receiver (Rx). The data for Tx and Rx are independent byte streams. The byte streams are packed with the most significant byte first and the most significant bit in bit 7 of the first word. The number of bytes used for each sample is the minimum number of bytes to hold a sample.

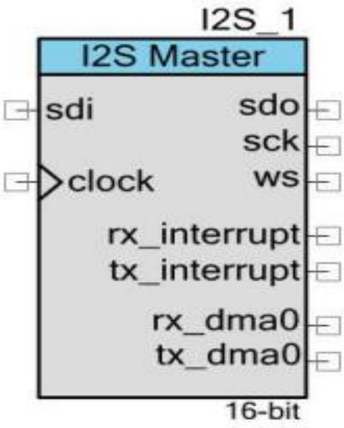


Figure 2-4. I2S Master component

When to use I2S

The I2S component provides a serial bus interface for stereo audio data. This interface is most commonly used by audio ADC and DAC components

UART Protocol:

The UART provides asynchronous communications commonly referred to as RS232 or RS485. The UART component can be configured for Full Duplex, Half Duplex, RX only, or TX only versions. All versions provide the same basic functionality. They differ only in the amount of resources used. To assist with processing of the UART receive and transmit data, independent size configurable buffers are provided. The independent circular receive and transit buffers in SRAM and hardware FIFOs help to ensure that data will not be missed. This allows the CPU to spend more time on critical real time tasks rather than servicing the UART.

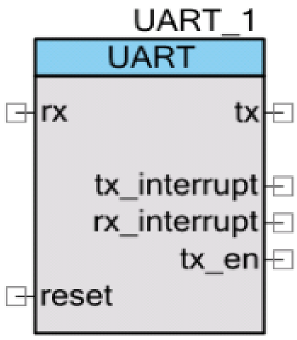


Figure 2-5. UART component

When to use UART

Use the UART any time a compatible asynchronous communications interface is required, especially RS232 and RS485 and other variations. UART can also be used to create more advanced asynchronous based protocols such as DMX512, LIN, and IrDa, or customer or industry proprietary.

USB Protocol:

The USBFS Component provides a USB full-speed, compliant device framework for constructing HID-based and generic USB devices. It provides a low-level driver for the control endpoint that decodes and dispatches requests from the USB host. Additionally, the Component provides a GUI-based configuration dialog to aid in constructing your descriptors, allowing full device definition that can be imported and exported.

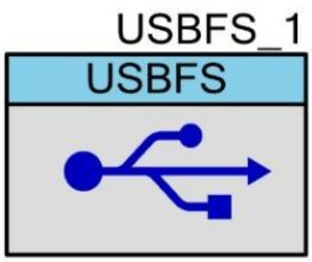


Figure 2-6. USBFS component

LIN Protocol:

The LIN Slave Component implements a LIN 2.2 slave node on PSoC 3, PSoC 4, and PSoC 5LP devices. Options for LIN 2.0, LIN 1.3 or SAE J2602-1 compliance are also available. This Component consists of the hardware blocks necessary to communicate on the LIN bus, and an API to allow the application code to easily interact with the LIN bus communication.

The Component provides an API that conforms to the API specified by the LIN 2.2 Specification. This Component provides a good combination of flexibility and ease of use. A customizer for the Component is provided that allows you to easily configure all parameters of the LIN Slave.

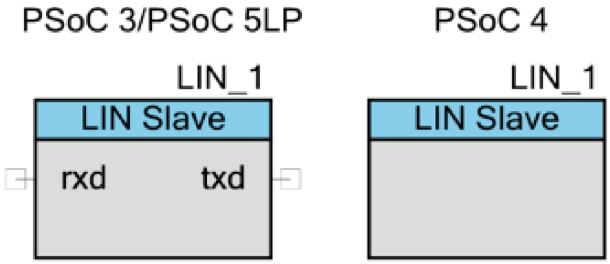


Figure 2-7. LIN slave component

For PSoC 4 devices only, the LIN Slave Component is certified by the C&S group GmbH based on the standard protocol and data link layer conformance tests. A complete certification report can be made available on request. Contact Cypress Technical Support or check the Component web page for details. For PSoC 3 and PSoC 5LP devices, the LIN Slave Component is a prototype Component, because it is not certified for these devices.

CAN Protocol:

The Controller Area Network (CAN) controller implements the CAN2.0A and CAN2.0B specifications as defined in the Bosch specification and conforms to the ISO-11898-1 standard. The CAN Component is certified by the C&S group GmbH based on the standard protocol and data link layer conformance tests. A complete certification report can be made available on request.

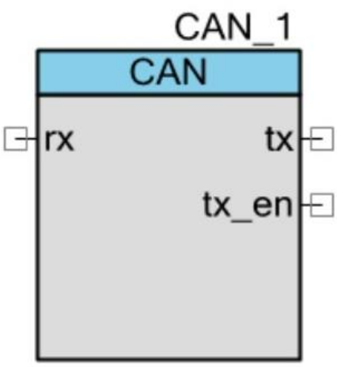


Figure 2-8. CAN component

When to use CAN

CAN was defined by Bosch and is widely used in Industrial and Automotive applications for high reliability systems. In the Automotive market, it is used in engine control units, sensors, safety systems, etc. and is used as a network connection bus for vehicle body electronics (lamp clusters, electric windows etc.).

SPI Master Protocol:

The SPI master provides an industry-standard 4-wire master SPI interface. The interface supports all 4 SPI operating modes, allowing interface with any SPI slave device. In addition to the standard 8-bit interface, the SPI Master supports a configurable 2 to 16-bit interface for interfacing to nonstandard SPI word lengths. SPI signals include the standard SCLK, MISO and MOSI pins and multiple Slave Select (SS) signal generation.

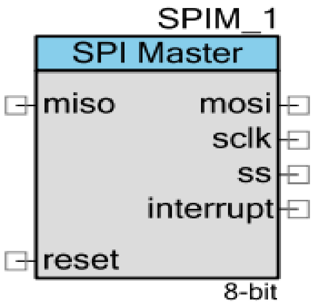


Figure 2-9. SPI Master component

When to use the SPI Master

The SPI master component should be used any time the PSoC device is required to interface with one or more SPI slave devices. In addition to 'SPI slave' labelled devices, the SPI master can be used with many devices implementing a shift register type interface. The SPI slave component should be used in instances requiring the PSoC device to interface with a SPI master device. The Shift Register component should be used in situations where its low level flexibility provides hardware capabilities not available in the SPI Master component.

SPI Slave Protocol:

The SPI Slave provides an industry-standard, 4-wire slave SPI interface. It can also provide a 3-wire (bidirectional) SPI interface. Both interfaces support all four SPI operating modes, allowing communication with any SPI master device. In addition to the standard 8-bit word length, the SPI Slave supports a configurable 3-bit to 16-bit word length for communicating with nonstandard SPI word lengths. SPI signals include the standard Serial Clock (SCLK), Master In Slave Out (MISO), Master Out Slave In (MOSI), bidirectional Serial Data (SDAT), and Slave Select (SS).

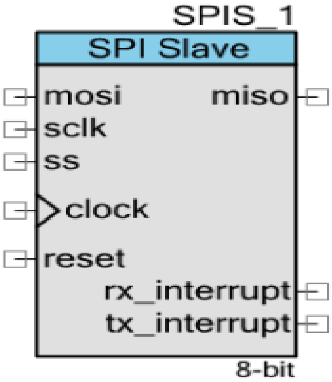


Figure 2-10. SPI Slave component

When to use the SPI Slave

SPI Slave component can be used any time a PSoC device is required to interface with an SPI Master device. In addition to SPI Master labelled devices, you can use the SPI Slave with many devices implementing a shift register type interface. Use the SPI Master component in instances requiring a PSoC device to communicate with an SPI Slave device. Use the Shift Register component in situations where its low-level flexibility provides hardware capabilities not available in the SPI Slave component.

2.4 Switching Frequency:

Switching power supplies [8] use a switching action to transform DC power into a specific frequency of pulsed current energy. The electrical energy is released according to predetermined requirements, and the inductive and capacitive energy stored in components. Similar to how our pulses can indicate our health, both regular and self-regulating switching frequencies indicate the quality of the switching power supply (see Figure 2-11). Therefore, switching frequency [7] is one of the critical indicators for a switching power supply.

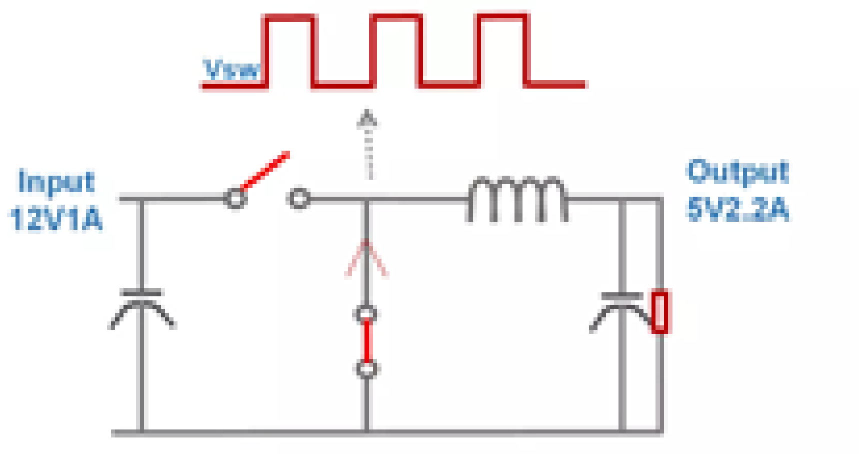


Figure 2-11. Switching Frequency as an Indicator of Switching Power Supply Quality

The regular switching action is the primary mechanism during switching power supply operation, and the frequency plays a decisive role in the circuit calculations. Consider a buck circuit where the frequency (f_S) determines the inductor current ripple (ΔI_L) and output voltage ripple (V_{RIPPLE}). f_s and the ripple amplitude are approximately inverse, meaning a higher frequency [7] corresponds with a smaller ripple.

ΔI_L can be calculated using equation

$$\Delta I_L = (V_{IN} – V_{OUT})V_{OUT}/(V_{IN}*L*f_s)$$

Increasing f_S can simultaneously reduce the inductance and capacitance while optimizing the device’s volume. Increasing f_S means less energy can be stored at a time, which reduces the requirements for energy storage components. In addition, a higher f_S reduces V_{RIPPLE} while improving power quality.

According to the EMI standard, the switching frequency is set below 75kHz. The peak doubling noise falls within the <150kHz range (see Figure 2-12). Since the <150kHz frequency band has looser restriction standards, there are larger general inductor and power capacity values as a result.

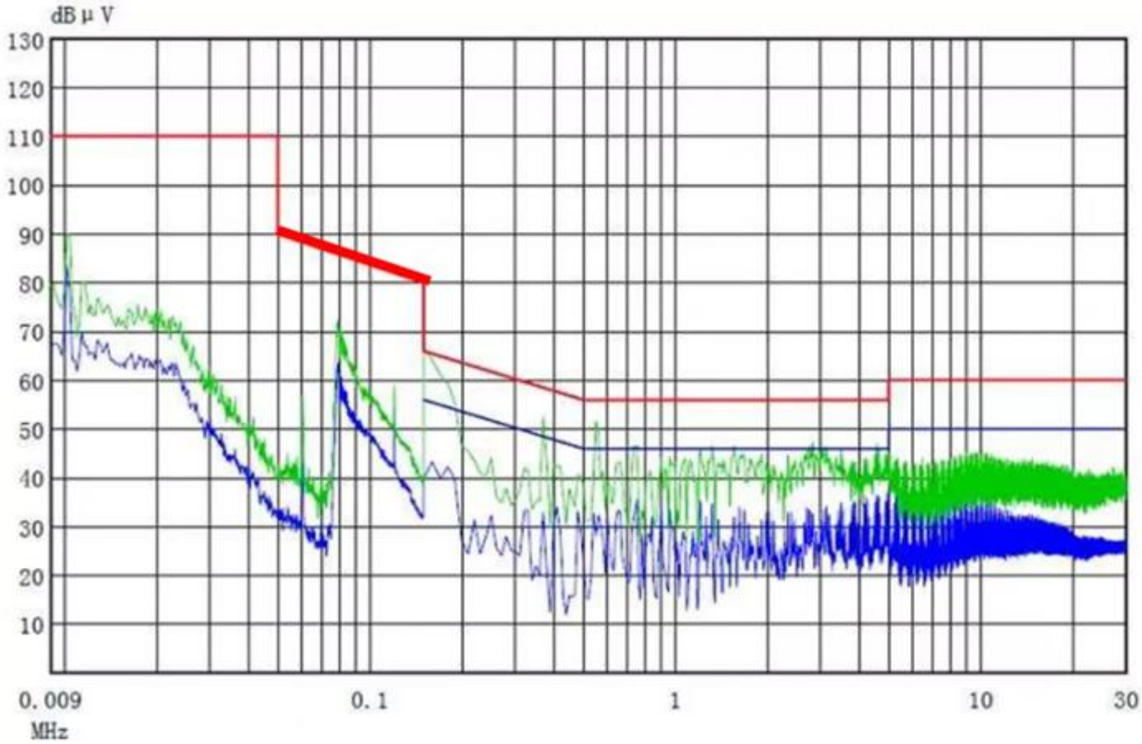


Figure 2-12. Peak Doubling Noise at a <75kHz Switching Frequency

2.5 Motivation / objective of the present design:

In summary we need to integrate power management, reconfigurability into a single chip design. Power management enables switching of devices in different power modes, each with different power consumption features related to device performance.

The motive of present work is to design a PSoC based HVPS with remotely programmable output voltage level and ramping rate. PSoC enables the addition of tuning and remote reconfigurability feature in HVPS.

CHAPTER 3
CIRCUIT DESIGN

3.1 Design of HVPS Circuit:

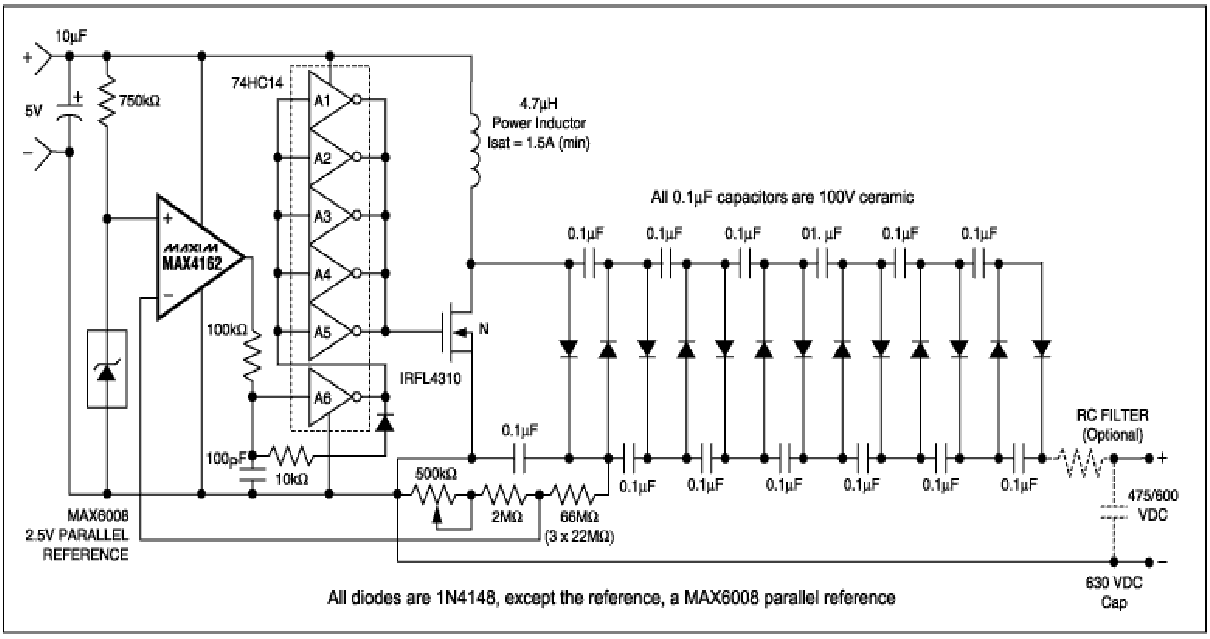


Figure 3-1. HVPS Reference design

3.1.1 Working of circuit:

Let say we require 600V at the output, we have multiplier circuit, MOSFET, Load, Buffer etc. Initially we'll be considering some reference voltage say(2.5V). Here we're using Zener diode for reference voltage. This circuit also contains resistances, these resistances(66M)ohms are arranged in such a way that we'll be getting the voltage that is equal to or nearer to the reference voltage taken. This will be done with the help of voltage divider. If the load changes then simultaneously the voltage and current also changes. If the Output voltage is 600V then the voltage obtained would be 2.5V. If the output voltage reduces due to decrease in load then the voltage obtained would also be less than the reference voltage i.e., 2.5V. Similarly if the Output voltage reduces due to increase in the load then the voltage obtained would also be greater than the reference voltage i.e., 2.5V. This voltage is given to the buffer, it is used to avoid the loading effect as it is having high input impedance.

This buffer circuit gives the same voltage to integrator. Buffer here is unity gain buffer. Schmitt trigger circuit is used as buffer here. Integrator has reference voltage, whenever the voltage produced is greater than the reference voltage then negative ramp signal is generated, similarly if the voltage produces is less than reference voltage then positive ramp is generated. Output voltage is '(V_{in}-V_{ref})(-T/RC)'. If Vin and V_{ref} are same then no ramp is generated it is constant. Different kind of sensors we're representing here as load. Now this ramp signal is given to the comparator +ve terminal. -ve terminal is fed with saw tooth generator.

Whenever the +ve terminal value is greater than -ve terminal value then output will be positive saturation and similarly +ve terminal value is less than -ve terminal value then output will be negative saturation. Now pulse will be generated, if same condition continues for some time, then the ON time increases similarly duty cycle also increases(duty cycle = ON time / (ON time + OFF time)). In DC-DC converter V_{out} = Vin/(1-D). D is duty cycle and it lies between 0 to 0.99. If D value increases then V_{out} also increases and vice versa. Integrator output will control the actual output.

MOSFET is voltage controlled switch, it has Source, Drain, Gate terminals. If voltage is given to the MOSFET it acts as a closed switch otherwise it acts as an open switch. If MOSFET is closed then current passes through the inductor then it creates a magnetic field around it, then if suddenly the switch is open current cannot stops suddenly and inductor reaches high voltage(V_L = -L(di/dt)). Initial current is some value but final current is 0A, it takes sometime to reach 0A then inductor voltage reaches high value. In this way the circuit operates. Only difference between open loop circuit and feedback circuit is feedback. In the case of open loop we cannot obtain the required voltage whenever the load changes but in the case of feedback circuit we'll get the requires voltage for change in the load.

3.2 DIODE

Diode: A diode is an electrical component designed to allow the flow of electrons on one side and the flow of a block from the other side. It consists of two electrodes: the cathode and the anode. A cathode is an electrode that emits electrons. The anode collects electrons and uses them.

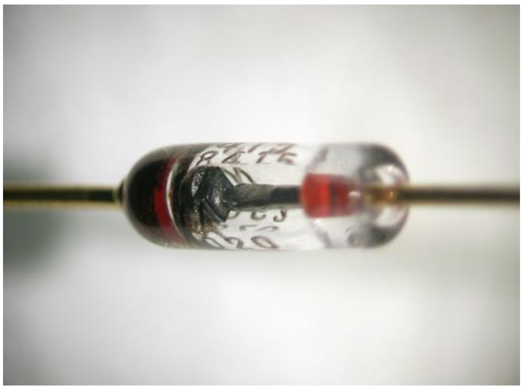


Figure 3-2. Diode

Semiconductor diode:

A semiconductor diode is the result of an interaction between a small N-type crystal and a P-type crystalline. When two crystals meet, the carriers (electrons and holes) tend to disperse. Some electrons travel across the barrier to join the holes. Some holes run across the barrier to join electrons. Remember that unlike charges are attractive.

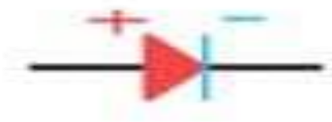


Figure 3-3. Symbol for a semiconductor diode

The P crystal region near the junction becomes negative. It took electrons from the N crystal. The N-crystalline surface near the junction becomes positive. It lost some electrons but gained holes. This electric current or power is called a potential mountain or potential barrier. The barrier prevents other electrons and holes in the crystal from collapsing.

Forward and Reverse Biasing

The voltage (potential) is connected to the diode in Figure 3. The positive terminal of the source is connected to the P crystal and the negative source connected to N crystal.

Forward Bias

The negative electrons in the N crystal go toward the barrier. The positive holes in the P crystal go towards the barrier. The source voltage contradicts the potential barrier and reduces its barrier effect. This allows electrons and holes to join the barrier. Therefore, the current flows in a cycle. It flows into the P crystal through holes. It flows into the N crystal with electrons. Diode is biased in a forward direction or forward biased.

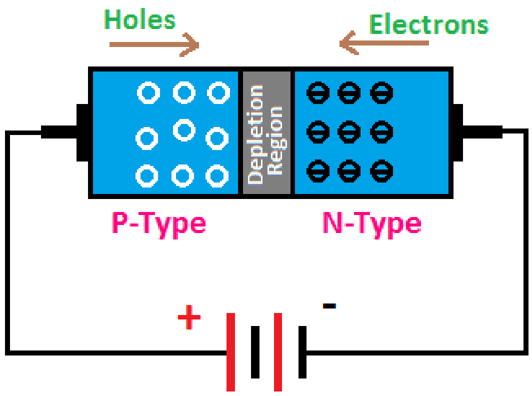


Figure 3-4. Forward Bias Circuit

A small forward bias voltage is required to overcome a potential current flow in the circuit. This minimum voltage depends on the type of semiconductor material used. It requires approximately 0.6 volts of transmission capacity of silicon diode and 0.2 volts of germanium diode. When this blocking voltage is exceeded, the current flows through the circuit.

Reverse Bias

The positive source is connected to the N crystal and the negative source is connected to the P crystal. This indicates the same junction diode biased in reverse direction or reverse biased.

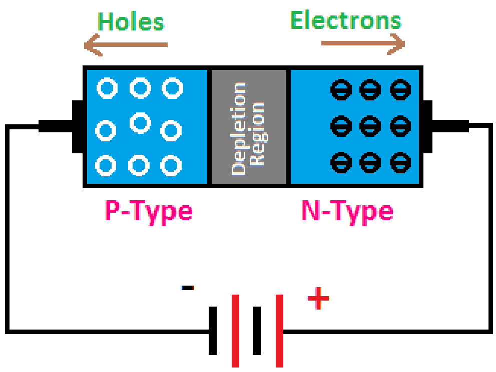


Figure 3-5. No conduction through a junction diode biased in a reverse direction

In reverse bias, the source voltage aids the potential barrier. The electron / hole combination is limited to the junction. The electrons in the N crystal are attracted to the end of a positive source. The smallest current will flow in a cycle. The reverse voltage can be increased to the point where the diode will break down. The amount of distortion will vary depending on the diode details.

Types of Semiconductor Diodes

Diodes are used for many purposes. Electrical adjustment, power control, and even light production are just some of the many uses. The following is a brief description of some of the diode types you may encounter.

Zener Diode

The Zener diode is widely used as a voltage reference, where its back-up feature provides stable voltage across the entire diode over a range of flow waves through it. Zener diode is a type of semiconductor diode that is widely used in electronic circuit designs as an electrical reference.

The Zener diode or voltage reference diode is an electronic component that provides stable and defined electricity. As a result, Zener diode circuits are often used in power supplies and in other circuit projects where controlled output is required. These diodes are used in many other applications where stable and defined voltages are required. They can also be used for electronic circuits where voltage is limited or reduced by a number of factors for a variety of reasons including the removal of temporary spikes from signal lines, etc.

Zener diodes or voltage reference diodes are cheap and they are also easy to use and these electronic components are easily available for use in a variety of electronic circuit designs with a variety of voltages and with a variety of power ratings, etc. They are cheap and easy to use and these electronic components are readily available for use in a variety of electronic circuit designs with different voltages and power levels, etc. The Zener diode acts as a normal PN junction diode in the forward direction, but provides a very sharp divergence in the opposite direction at the specified voltage. This is the voltage drop-down used for voltage indicators or cutting systems.

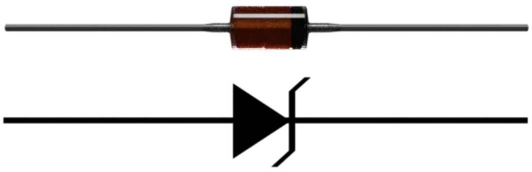


Figure 3-6. Zener Diode Symbol

Zener diode V-I characteristics:

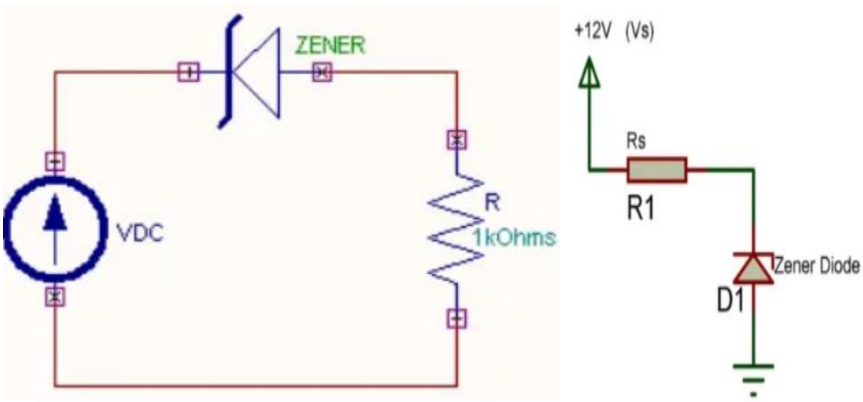


Figure 3-7. Zener diode circuit

Ordinary diodes are forward biased and work in the forward direction. They have a large forward current flowing through them with a negligible voltage drop. If we operate a simple diode in reverse biased, it conducts negligible current until the voltage applied across them exceeds the reverse breakdown voltage. When this happens, large current flows through the junction and the diode may be destroyed. Zener diode is a special type of diode that solves this problem. We operate a zener diode under reverse biased conditions, and this diode is not damaged even when the voltage across it exceeds the reverse breakdown voltage. Let's learn about this exciting and unique type of diode. Zener diodes are heavily doped compared to normal diodes. They have extra thin reduction area. When we apply a voltage higher than the Zener breakdown voltage (can be from 1.2 V to 200 V), the depletion region disappears, and large current begins to flow through the junction. There is an important difference between a simple diode and a zener diode. In Zener diodes, the depletion region returns to its original state after the reverse voltage is removed whereas in regular diodes, they are not, and hence they are destroyed.

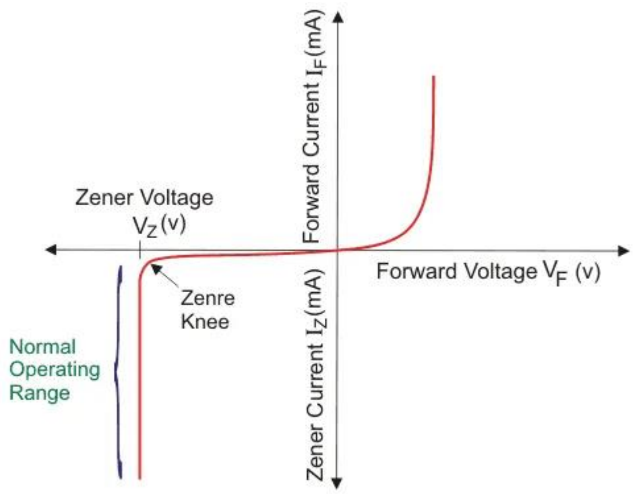


Figure 3-8. V-I characteristics of Zener diode

Here the zener diode acts like a simple diode. When a forward voltage is applied, current flows through it. But due to the high doping concentration, high current flows through the zener diode. Magic happens in the third quadrant. The graph shows the current vs voltage curve when we apply reverse bias to the diode. Zener breakdown voltage is the reverse bias voltage after which a significant amount of current begins to flow through the zener diode.

Here in the diagram, V_Z refers to the Zener breakdown voltage. A small amount of current flows through the diode until the voltage reaches the Zener breakdown level. Once the reverse bias voltage exceeds the Zener breakdown voltage, a significant amount of current begins to flow through the diode due to Zener breakdown. The voltage remains at the Zener breakdown voltage value, but the current through the diode increases as the input voltage increases. Due to the unique property of Zener diodes, the depletion region returns to its original state when the reverse voltage is removed. The zener diode is not damaged even though such a large amount of current flows. This unique functionality makes it very useful for many applications.

Since the voltage remains at the Zener break down voltage, we use Zener diodes to control the voltage. We use them on voltage stabilizers and various other safety circuits. We also use clipping circuit and clamping circuit. They offer the cheapest solution for voltage regulation.

Zener Diode / Voltage Reference Diode Specification

When selecting a zener diode or voltage reference diode for use in circuits, several specifications need to be considered to ensure that the optimum diode is selected for the application. The obvious zener diode specification is reverse voltage, but other specifications such as power dissipation, reverse current and so on are important for any circuit design that may include a diode.

3.3 RESISTORS

Resistor: A resistor is a two-terminal passive electrical component that provides electrical resistance to current flow. Resistance is a measure of the opposition to the flow of current in a circuit. In an electrical and electronic circuit, the primary function of a resistor is to “resist” the flow of electrons, i.e., electric current. That is why it is called a “resistor”. This means they cannot deliver any energy to the circuit, and instead, they receive energy and dissipates it in the form of heat as long as a current flowing through it. For example resistors are used to protect the LED lights against voltage spikes because LED lights are sensitive to high electrical current.

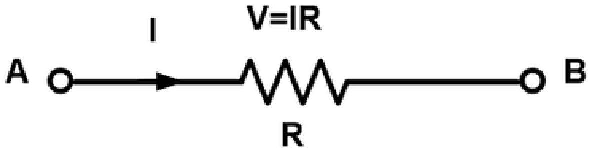


Figure 3-9. Symbol of Resistor

Voltage Drop Across a Resistor

The voltage drop across a resistor is nothing but simply a value of voltage across the resistor. The voltage drop is also known as IR drop. According to ohm’s law, the voltage (V) across a resistor is directly proportional to the current (I) flowing through it. Where the resistance R is the constant of proportionality.

$$\mathbf{V \propto I}$$

$$\mathbf{V = IR}$$

Pull-up Resistors

Pull-up Resistors are resistors used to ensure a known state for a signal in electronic logic circuits . When there is no input condition Pull-up resistors are used to ensure that a wire is pulled to a high logical level. A pull-down resistor works similar to the pull-up resistors, except that they pulled a wire to a logical low level. Pull-up resistors are used in combination with transistors, switches, buttons, etc., which interrupt the physical connection of subsequent components to the ground or VCC. For example, the pull-up resistor circuit is shown in the image below.

As shown in the figure, when the switch is closed, the input voltage (Vin) at the micro controller or gate goes to the ground, and when the switch is open, the input voltage (Vin) at the micro controller or gate is pulled up to the level of input voltage (Vin).

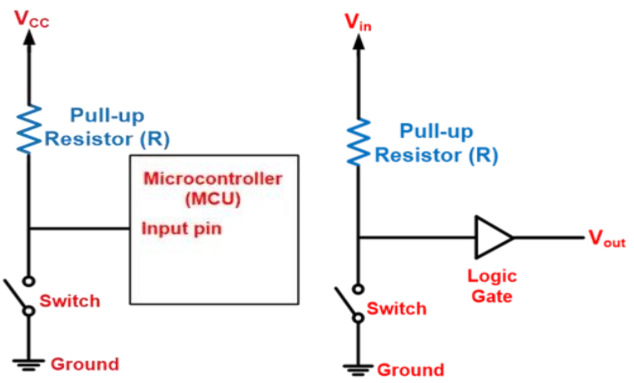


Figure 3-10. Pull-up Resistor Circuit

Hence, the pull-up resistor can bias the micro controller's input pin or gate when the switch is open. Without a pull-up resistor, the inputs at the micro controller or gate would be floating, i.e., in a high impedance state. A typical value of pull-up resistor is 4.7 kΩ but it can vary depending on the application.

3.4 CAPACITORS

Capacitor: The capacitor is a passive electrical component that stores the energy in the form of electrical charges that creates a potential difference, which is a static voltage, like a small rechargeable battery.

Figure 3-11. Capacitors

Capacitor consists of two parallel conductors (Metallic plate), separated with a dielectric material. When a voltage source is attached across the capacitor, the capacitor plate gets charged up. The metallic plate attached to the positive terminal will be positively charged, and the plate attached to the negative terminal will be negatively charged.

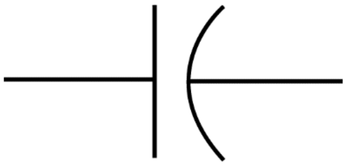


Figure 3-12. Symbol of Capacitor

The accumulation of charges in the conductors causes a potential difference across the capacitor. The amount of charge accumulated is called the charge holding capacity of the capacitor. This charge holding capacity is what is known as capacitance. The accumulated charge in the capacitor is directly proportional to the voltage developed across the capacitor.

$$\mathbf{Q \propto V}$$

$$\mathbf{Q = CV}$$

$$\mathbf{C = Q/V}$$

C is the constant of proportionality, also called the capacitance of a capacitor. The unit of capacitance is Farad(F) - 1 coulomb per volt.

The value of capacitance depends upon the physical features, area of the capacitor plates is A, distance between the plates is d, and the permittivity of the dielectric medium is ε.

$$C = (\varepsilon * A)/d$$

Energy of Capacitor

The energy is stored in joules and is equal to half of the capacitance times the square of the capacitor's voltage.

$$E = 1/2 * C * V^2$$

Types of Capacitors:

Film Capacitors: Film capacitors are the ones that use plastic film as the dielectric medium. They are available in nearly any value and voltages up to 1500 volts. They range from 10% to 0.01% in any tolerance. Additionally, film condensers arrive in a combination of shapes and case styles. There are two types of film condensers, radial type lead, and axial type lead.

Ceramic Capacitors: Ceramic capacitors are the ones that use ceramic as the dielectric material. It is used in high-frequency circuits such as audio to RF. In ceramic capacitors, one can develop both high capacitance and low capacitance by altering the thickness of the ceramic disc.

Electrolytic Capacitors: Electrolytic capacitors are the ones that use the oxide layer as the dielectric material. It has a wide tolerance capacity. There are mainly two types of electrolytic capacitors, tantalum, and aluminum. They are available with working voltages of up to approximately 500V, but the maximum capacitance values are not available at high voltage, and higher temperature units are available but are rare.

Variable Capacitor: Variable capacitors mostly use air as the dielectric medium. A Variable Capacitor is one whose capacitance can be mechanically adjusted several times. For example, this form of the capacitor is used to set the resonance frequency in LC circuits to change the radio to match impedance in antenna tuner devices.

Factors affecting Capacitance

Surface Area: The surface area of the two plates affects the capacitance value. Higher the value of the surface area, the higher the capacitance.

Distance: The distance between the plates affects the value of the capacitance. Lower the value of distance, the higher the capacitance.

Dielectric Medium: The type of material separating the two plates called "the dielectric." The higher the dielectric's permittivity, the higher the capacitance value.

Uses of a Capacitor

- The capacitors have both electrical and electronic applications. They are used for several things such as filters, energy storage systems, engine starters, signal processing devices, etc.
- Capacitors are used for storing energy, which can be used by the device for temporary power outages whenever they need additional power.
- Capacitors are used for blocking DC current after getting fully charged and yet allow the AC current to pass through the circuit of a circuit.
- Capacitors are used as sensor for several things like measuring humidity, fuel levels, mechanical strain, etc.

3.5 SCHMITT TRIGGER

The Schmitt trigger is a comparator circuit with hysteresis applied by applying a positive feedback to the non-inverting input of a comparable or differential amplifier. It uses two different input threshold voltage levels to avoid noise in the trigger input signal. The Schmitt trigger was discovered in 1934 by the American scientist Otto H. Schmitt.

Normal comparators have only one threshold signal. And it compares the threshold signal to the input signal. But, if there is noise in the input signal, it can affect the output signal. The output of the comparator is affected by the noise in the input signal. And the comparator is not protected from the noise. The "trigger" in the name "Schmitt trigger" comes from the fact that the output retains its value until the input changes sufficiently to "trigger" a change.

Working of Schmitt Trigger:

The Schmitt trigger provides the right results even if the input signal is noisy. It uses two threshold voltages; one is the high voltage (VUT) and the second is the low voltage (VLT). Schmitt trigger output remains low until the input signal crosses the VUT. If the input signal crosses the VUT limit, the Schmitt trigger output signal remains high until the input signal is below the VLT level.

Let’s understand the function of the Schmitt trigger for example. Here we think that the first input is zero. Here, we assume that the initial input signal is zero and grows slowly as shown in the picture above. The Schmitt trigger output signal remains low until point A. In point A, the input signal exceeds the maximum limit (VUT) level and generates a high output signal. The output signal remains high until point B. In point B, the input signal falls below the lower limit. And this lowers the output signal. And again, in point C, when the input signal falls above the upper limit, the output is higher. In this case, we can see that the input signal is sound. But the sound is not affected by the output signal.

Schmitt Trigger Circuit

The Schmitt trigger circuit uses a positive feedback. Therefore, this region is also known as the refreshing comparison region. The Schmitt Trigger circuit can be designed with the help of Op-Amp and Transistor. And it was divided into two parts;

1. Op-Amp based Schmitt trigger
2. Transistor based Schmitt trigger

1. Op-Amp based Schmitt Trigger

The Schmitt trigger circuit can be designed using Op-Amp in two ways. When the input signal is connected to the Op-Amp variable, it is known as the Inverting Schmitt Trigger. And when the input signal is connected to the Op-Amp constant, it is known as the Non-inverting Schmitt Trigger.

Inverting Schmitt Trigger

In this type of Schmitt trigger, input is supplied to the negative terminal. As well as the constructive response from the outgoing to the input. The circuit diagram of the inverting Schmitt Trigger is shown in the image below.

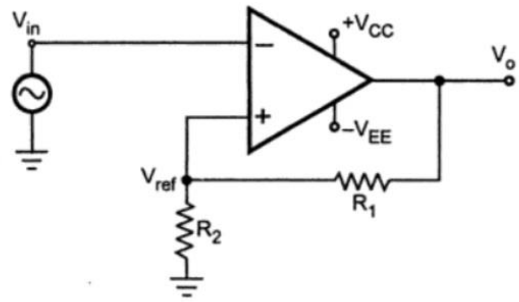


Figure 3-13. Inverting Schmitt Trigger

The voltage is V_{ref} and the voltage applied (input voltage) is V_{in}. If the voltage applied to V_{in} is greater than V_{ref}, the circuit output will be lower. And if the voltage applied to the V_{in} is less than V_{ref}, the circuit output will be higher.

i.e., **If $V_{in} > V_{ref}$ then $V_o = V_L$**

If $V_{in} < V_{ref}$ then $V_o = V_H$

Upper threshold voltage, $V_{UT} = R_1/(R_1+R_2) * V_H$

Lower threshold voltage, $V_{LT} = R_1/(R_1+R_2) * V_L$

Non-Inverting Schmitt Trigger

On the Schmitt trigger, the input signal is applied to the Op-Amp positive terminal. And feedback is used from the output to the input. The negative terminal is connected to the ground terminal. The circuit diagram of the non-inverting Schmitt trigger is as shown below.

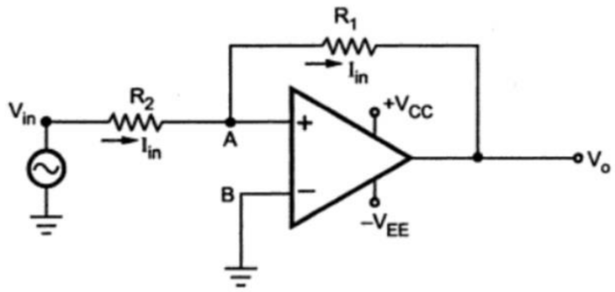


Figure 3-14. Non Inverting Schmitt Trigger

In this circuit, the output of the Schmitt trigger will be high when voltage V is greater than zero. And the output will be low when voltage V is less than zero.

i.e., **If $V_{in} > 0$ then $V_o = V_H$**

If $V_{in} < 0$ then $V_o = V_L$

Upper threshold voltage, $V_{UT} = -R_1/R_2 * V_L$

Lower threshold voltage, $V_{LT} = -R_1/R_2 * V_H$

2. Transistor based Schmitt Trigger

The Schmitt trigger circuit can be designed with the help of two transistors. A circuit diagram of the transistor-based Schmitt trigger is provided in the circuit below.

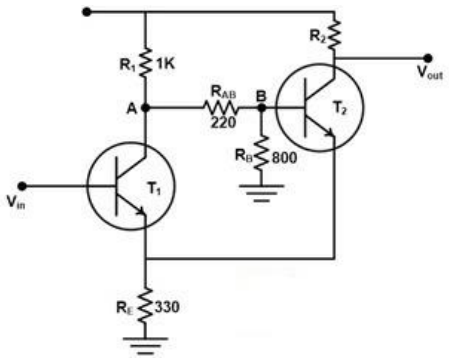


Figure 3-15. Transistor based Schmitt Trigger

Let us assume that, at first, the Vin input voltage is zero. The input voltage is supplied to the base of transistor T1. Therefore, in this case, transistor T1 operates in a limited area and does not run. V_A and V_B node voltage. The reference voltage is given to 5V. Therefore, we can calculate the value of V_A and V_B by the law of voltage division. Voltage V_B is supplied with the base of transistor T2. And it is 1.98V. Therefore, transistor T2 is running. And because of this, Schmitt trigger output is low. Emitter drop is about 0.7V. Therefore, the base voltage of the transistor is 1.28V. The emitter of transistor T2 is connected to the emitter of transistor T1. Therefore, both transistors operate at the same level at 1.28V. It means that the transistor T1 will operate when the input voltage is 0.7V above 1.28V or above 1.98V (1.28V + 0.7V).

Now, we increase the input voltage above 1.98V, and transistor T1 will start operating. This causes a voltage drop of the base of the transistor T2 and will disconnect the transistor T2. And because of this, the Schmitt trigger output is high. The input voltage starts to decrease. Transistor T1 will disconnect when the input voltage is 0.7V below 1.98V and 1.28V. In this case, the transistor T2 receives a sufficient voltage from the reference voltage, and will turn on. This puts Schmitt output low. Therefore, in this case, we have two thresholds, low threshold at 1.28V and high threshold at 1.98V.

Schmitt Trigger Oscillator

The Schmitt Trigger can be used as an oscillator by connecting a single integrated RC circuit. A circuit diagram of the Schmitt trigger oscillator is shown in the figure below.

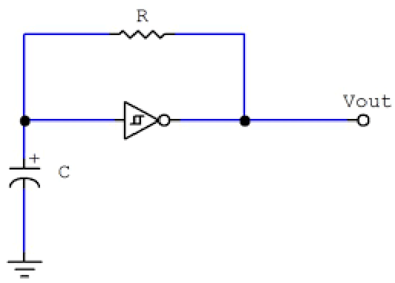


Figure 3-16. Schmitt Trigger oscillator

Circuit output is a continuous square wave. And the waveform frequency depends on the value of R, C, and the Schmitt Trigger limit point.

f=K/RC

Where k is a constant and it ranges between 0.2 and 1.

CMOS Schmitt Trigger

A simple signal inverter circuit provides an output signal opposite the input signal. For example, when the input signal is high, the output signal is low in a simple inverter cycle. But if the input signal has spikes (sound), the output signal will respond to changes in spike. That we do not want. Therefore, the CMOS Schmitt trigger is used.

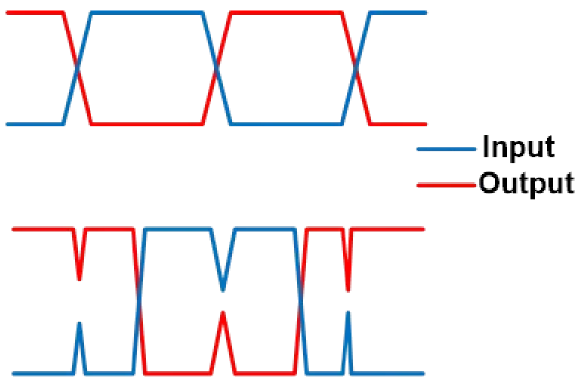


Figure 3-17. Waveform of Simple Signal Inverter Circuit

In the first wave format, the input signal has no sound. So, the output is perfect. But in the second picture, the input signal has a certain sound. The output also responds to this sound. To avoid this situation, the CMOS Schmitt trigger is used.

The figure 3-18 shows the construction of the CMOS Schmitt trigger. The CMOS Schmitt Trigger contains 6 transistors including PMOS and NMOS transistors.

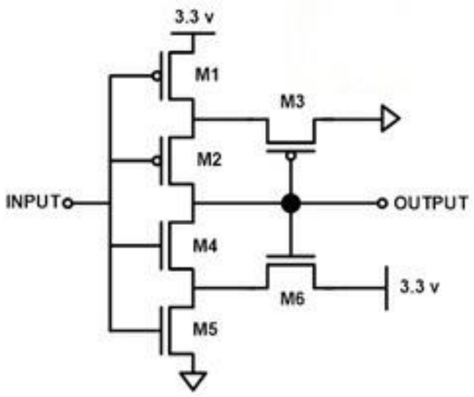


Figure 3-18. CMOS Schmitt trigger

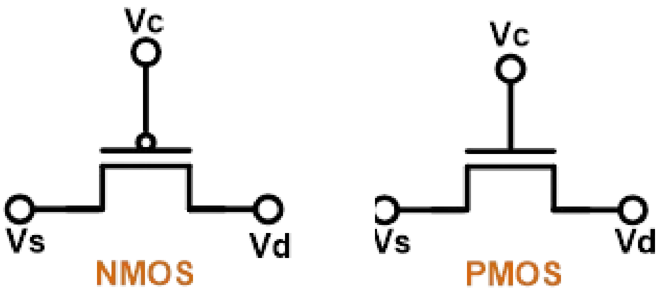


Figure 3-19. NMOS and PMOS transistors

NMOS transistor operates when VG is larger than VS or VD. And the PMOS transistor operates when VG is less than VS or VD. On the CMOS Schmitt trigger, one PMOS and one NMOS transistors are added to the simple inverter circuit.

In the first case, the input voltage is high. In this case, the PN transistor is ON and the NN transistor is OFF. It also creates a path to node-A ground. Therefore, the trigger output of the CMOS Schmitt will be zero. In the second case, the input voltage is high. In this case, the NN transistor is ON and the PN transistor is OFF. It will create a path to voltage VDD (High) for node-B. Therefore, the output of the CMOS Schmitt trigger will be higher.

Hysteresis

Hysteresis occurs in most cases throughout science, but in the case of Schmitt trigger hysteresis means that the cycle begins at different voltages to switch the output from one region to another. To explain this in more detail, take an example where the reference voltage is, it is 5 volts. As the voltage rises, it depends on the circuit for example 5.5 volts. Then to switch to the other side, the input voltage should fall, for example 4.5 volts. In this way, there is a 1V difference between switching in any direction, and this provides the essential noise free switching.

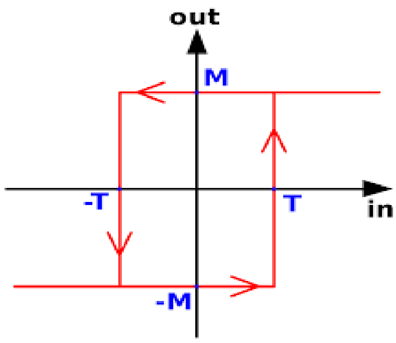


Figure 3-20. Hysteresis of Schmitt trigger

The problem with not using hysteresis with a comparator is that if the input signal rises slightly, then the sound in the waveform will cause a lot of change in the position of the comparator output. With the use of hysteresis, this problem is overcome, unless the noise levels are too high. The Schmitt trigger circuit is ready for most applications in overcoming this issue. Fortunately the direct component can be converted into a Schmitt trigger with the addition of a single electronic component in most cases.

Many changes in output due to noise can cause many problems with subsequent digital circuits, and in very many cases, electronic circuit engineers have spent hours repairing circuits with this type of problem as it can sometimes be difficult to track.

Schmitt Trigger Applications

The applications of Schmitt trigger are as below.

- Schmitt trigger is used to a sine wave and triangular wave into square waves.
- The most important use of the Schmitt triggers to remove noise in the digital circuit.
- It is also used as a function generator.
- It is utilized to implement an oscillator.

Schmitt triggers with the RC circuit is used as switch debouncing.

3.6 OPERATIONAL AMPLIFIER

Op-Amp or Operating Amplifier is the backbone of Analog Electronics and without many applications, such as amplifier overview, separate amplifier, amplifier too, OP-AMP will use the most closely related cycle in analog application. For simple Op-Amp applications, the output corresponds to the input amplitude. But if the op-amp is configured as a connector, the duration of the input signal is considered. Therefore, an op-amp-based connector can perform statistical integration with respect to time. The integrator generates the output voltage across the entire op-amp, which is directly proportional to the input voltage value; therefore the output depends on the input voltage over time.

Design and operation of the Op-amp Integrator Circuit

Op-amp is the most widely used component in Electronics and is used to build many useful amplifier circuits.

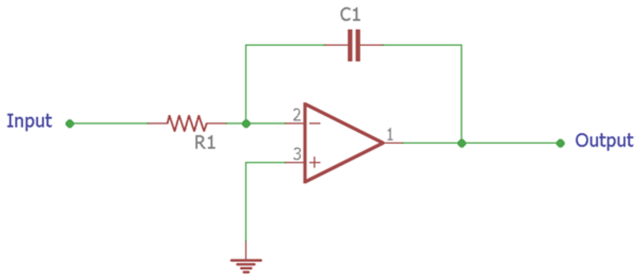


Figure 3-21. Op amp Integrator Circuit

Op-Amp or Operating Amplifier is the backbone of Analog Electronics and without many applications, such as amplifier overview, separate amplifier, amplifier too, OP-AMP will use the most closely related cycle in analog application. For simple Op-Amp applications, the output corresponds to the input amplitude. But if the op-amp is configured as a connector, the duration of the input signal is considered. Therefore, an op-amp-based connector can perform statistical integration with respect to time. The integrator generates the output voltage across the entire op-amp, which is directly proportional to the input voltage value; therefore the output depends on the input voltage over time.

Design and operation of the Op-amp Integrator Circuit

Op-amp is the most widely used component in Electronics and is used to build many useful amplifier circuits. The construction of a simple Integrator circuit using op-amp requires two non-voice components and one active component. The two passive components are the resistor and the capacitor. Resistor and Capacitor create a low-cost first order filter for all active part of Op-Amp. The Integrator circuit is exactly the opposite of the Op-amp separator circuit. The simple Op-amp configuration contains two opposing elements, which create a feedback loop. In the case of the Integrator amplifier, the response resistance is replaced by a capacitor. In the picture above, the basic integration circuit is shown with three simple components. Resistor R1 and capacitor C1 are connected throughout the amplifier. The amplifier is in Inverting configuration.

The benefits of Op-amp are limitless, so the Inverting input of the amplifier is a visible area. When the voltage is applied across R1, the starting current flows to the resistor as the capacitor has a very low resistance. The capacitor is connected to the response area and the capacitor resistance is not important.

In this case, if the amplifier gain rate is calculated, the result will be less than one. This is because the profit margin, XC / R1 is very small. In fact, the capacitor has a very low resistance between the plates and whatever the value R1 has, the output effect of XC / R1 will be much lower.

The capacitor starts charging upwards at the input voltage and at the same rate, the capacitor impedance also starts to increase. Charging rate is determined by RC - fixed time R1 and C1. The optical op-amp world is now disturbed and a negative response will generate the output voltage across the entire op-amp in order to maintain a visible ground state in all inputs. The Op-amp produces a ramp output until the capacitor is fully charged. The current capacitor charger is reduced by the impact of the potential difference between the Virtual world and the negative output.

Op-amp Integrator behavior for Square Wave input

If a square wave is supplied to the Integrator Amplifier, the output will be a triangular wave or saw tooth wave. In such a case, the circuit is called the Ramp generator. In square waves, the voltage levels change from Low to High or upward, causing the capacitor to be charged or discharged.

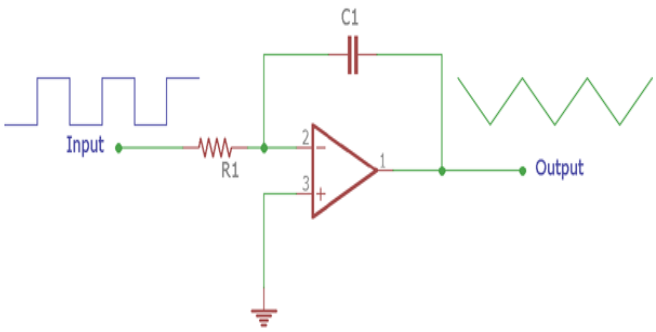


Figure 3-22. Op-Amp behavior on square wave input

During a good square wave height, the starting current flows to the resistor and in the next phase, the current flows through the capacitor. Since the current flow in the op-amp is zero, the capacitor is charged. A reversible object will occur during a high negative value of a square wave input. To get the highest frequency, the capacitor gets very short charging time.

The charge and discharge level depends on the combination of the resistor-capacitor. For complete integration, the frequency or duration of the input square frequency needs to be less than the regional constant, called: T must be less than or equal to CR (T <= CR).
A wave-generating circuit can be used to produce square waves.

Op-amp Integrator Behavior for Sine Wave Input

If the input in the op-amp based Integrator cycle is a sine wave, the Op-amp in the configuration generates 90 degrees without the sine wave phase in all output. This is called a cosine wave. During this process, if the input is a sine wave, the coupling circuit acts as an effective filter for low throughput. As mentioned earlier, whether at low frequencies or at DC, the capacitor produces a blocking current that ultimately reduces the response and output voltage output. In such a case, the resistor is connected to the capacitor. This additional feature provides the feedback path.

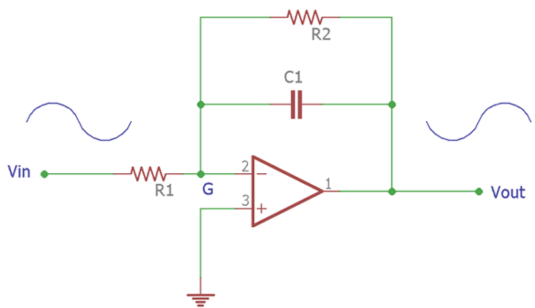


Figure 3-23. Op-Amp Integral behavior of sine wave input

In the picture above, an additional resistor R2 is connected in parallel to capacitor C1. The outgoing sine wave is 90 degrees outside the phase.

Gain = -R2 / R1

A Sine wave generator circuit can be used to generate sine waves for a composite input.

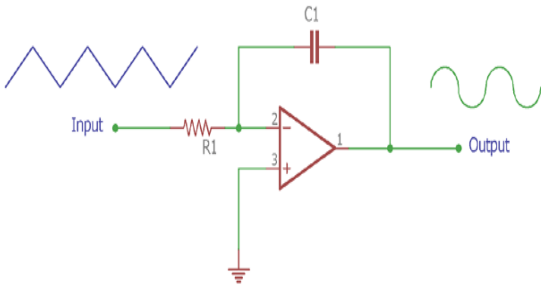


Figure 3-24. Op-Amp Integral behavior of Triangular wave input

In a triangular wave input, the op-amp also produces a sinusoidal wave. As the amplifier acts as a low pass filter, the high-frequency harmonics are greatly reduced. The outgoing sine wave contains only low frequency harmonics and the output will be low amplitude.

Op-Amp Integrator applications

- Integrator is an important component of metals and is used in the production of Ramp.
- In the work generator, the coupling circuit is used to produce a triangular wave.
- The Integrator is used in a wave formation cycle as a separate type of charging amplifier.
- It is used in analog computers, where integration is required to be done using an analog circuit.
- Integrator is widely used in analog to digital converter.

3.7 COMPARATOR

The Op-amp comparator compares one analogue voltage level with another analogue voltage level, or some preset reference voltage, VREF and produces an output signal based on this voltage comparison. In other words, the op-amp voltage comparator compares the magnitudes of two voltage inputs and determines which is the largest of the two.

The operational amplifier can be used with negative feedback to control the magnitude of its output signal in the linear region performing a variety of different functions. We have seen that the standard operational amplifier is characterized by its open-loop gain A and that its output voltage is given by the expression:

$$\mathbf{V_O = A(V+ - V-)}$$

where V+ and V- correspond to the voltages at the non-inverting and the inverting terminals respectively.

Voltage comparators on the other hand, either use positive feedback or no feedback at all (open-loop mode) to switch its output between two saturated states, because in the open-loop mode the amplifiers voltage gain is basically equal to AVO. Then due to this high open loop gain, the output from the comparator swings either fully to its positive supply rail, +Vcc or fully to its negative supply rail, -Vcc on the application of varying input signal which passes some preset threshold value.

The open-loop op-amp comparator is an analogue circuit that operates in its non-linear region as changes in the two analogue inputs, V+ and V- causes it to behave like a digital bistable device as triggering causes it to have two possible output states, +Vcc or -Vcc Then we can say that the voltage comparator is essentially a 1-bit analogue to digital converter, as the input signal is analogue but the output behaves digitally.

Op-amp Comparator Circuit

With reference to the op-amp comparator circuit above, lets first assume that VIN is less than the DC voltage level at VREF, (VIN < VREF). As the non-inverting (positive) input of the comparator is less than the inverting (negative) input, the output will be LOW and at the negative supply voltage, -Vcc resulting in a negative saturation of the output.

If we now increase the input voltage, VIN so that its value is greater than the reference voltage VREF on the inverting input, the output voltage rapidly switches HIGH towards the positive supply voltage, +Vcc resulting in a positive saturation of the output. If we reduce again the input voltage VIN, so that it is slightly less than the reference voltage, the op-amp's output switches back to its negative saturation voltage acting as a threshold detector.

Then we can see that the op-amp voltage comparator is a device whose output is dependent on the value of the input voltage, VIN with respect to some DC voltage level as the output is HIGH when the voltage on the non-inverting input is greater than the voltage on the inverting input, and LOW when the non-inverting input is less than the inverting input voltage. This condition is true regardless of whether the input signal is connected to the inverting or the non-inverting input of the comparator.

We can also see that the value of the output voltage is completely dependent on the op-amps power supply voltage. In theory due to the op-amps high open-loop gain the magnitude of its output voltage could be infinite in both directions, (±∞). However practically, and for obvious reasons it is limited by the op-amps supply rails giving VOUT = +Vcc or VOUT = -Vcc.

We said before that the basic op-amp comparator produces a positive or negative voltage output by comparing its input voltage against some preset DC reference voltage. Generally, a resistive voltage divider is used to set the input reference voltage of a comparator, but a battery source, zener diode or potentiometer for a variable reference voltage can all be used as shown.

Comparator Reference Voltages

In theory the comparators reference voltage can be set to be anywhere between 0v and the supply voltage but there are practical limitations on the actual voltage range depending on the op-amp comparator being device used.

Positive and Negative Voltage Comparators

A basic op-amp comparator circuit can be used to detect either a positive or a negative going input voltage depending upon which input of the operational amplifier we connect the fixed reference voltage source and the input voltage too. In the examples above we have used the inverting input to set the reference voltage with the input voltage connected to the non-inverting input.

But equally we could connect the inputs of the comparator the other way around inverting the output signal to that shown above. Then an op-amp comparator can be configured to operate in what is called an inverting or a non-inverting configuration.

Positive Voltage Comparator

The basic configuration for the positive voltage comparator, also known as a non-inverting comparator circuit detects when the input signal, VIN is ABOVE or more positive than the reference voltage, VREF producing an output at VOUT which is HIGH as shown.

Non-inverting Comparator Circuit

In this non-inverting configuration, the reference voltage is connected to the inverting input of the operational amplifier with the input signal connected to the non-inverting input. To keep things simple, we have assumed that the two resistors forming the potential divider network are equal and: R1 = R2 = R. This will produce a fixed reference voltage which is one half that of the supply voltage, that is Vcc/2, while the input voltage is variable from zero to the supply voltage.

When VIN is greater than VREF, the op-amp comparators output will saturate towards the positive supply rail, Vcc. When VIN is less than VREF the op-amp comparators output will change state and saturate at the negative supply rail, 0v as shown.

Negative Voltage Comparator

The basic configuration for the negative voltage comparator, also known as an inverting comparator circuit detects when the input signal, V_{in} is below or more negative than the reference voltage, V_{ref} producing an output at VOUT which is HIGH as shown.

Inverting Comparator Circuit

In the inverting configuration, which is the opposite of the positive configuration above, the reference voltage is connected to the non-inverting input of the operational amplifier while the input signal is connected to the inverting input. Then when V_{in} is less than V_{ref}, the op-amp comparators output will saturate towards the positive supply rail, Vcc.

Likewise the reverse is true, when V_{in} is greater than V_{ref}, the op-amp comparators output will change state and saturate towards the negative supply rail, 0v. Then depending upon which op-amp inputs we use for the signal and the reference voltage, we can produce an inverting or non-inverting output. We can take this idea of detecting either a negative or positive going signal one step further by combining the two op-amp comparator circuits above to produce a window comparator circuit.

Op-amp Comparator with Positive Feedback

We have seen here that operational amplifiers can be configured to operate as comparators in their open-loop mode, and this is fine if the input signal varies rapidly or is not too noisy. However if the input signal, VIN is slow to change or electrical noise is present, then the op-amp comparator may oscillate switching its output back and forth between the two saturation states, +Vcc and -Vcc as the input signal hovers around the reference voltage, VREF level. One way to overcome this problem and to avoid the op-amp from oscillating is to provide positive feedback around the comparator.

As its name implies, positive feedback is a technique for feeding back a part or fraction of the output signal that is in phase to the non-inverting input of the op-amp via a potential divider set up by two resistors with the amount of feedback being proportional to their ratio.

The use of positive feedback around an op-amp comparator means that once the output is triggered into saturation at either level, there must be a significant change to the input signal VIN before the output switches back to the original saturation point. This difference between the two switching points is called hysteresis producing what is commonly called a Schmitt trigger circuit. Consider the inverting comparator circuit below.

3.8 MOSFET:

MOSFETs or Metal Oxide Semiconductor Field Effect Transistors were invented to overcome the disadvantages posed by FETs, such as the slow operation, high drain resistance, and moderate input impedance. In this article, let us learn about the basics of MOSFET.

Metal Oxide Silicon Field Effect Transistors commonly known as MOSFETs are electronic devices used to switch or amplify voltages in circuits. It is a current controlled device and is constructed by three terminals. The terminals of MOSFET are named as follows:

- Source
- Gate
- Drain
- Body

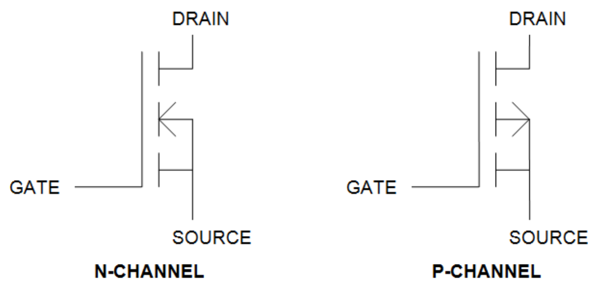


Figure 3-25. N-channel and P-channel MOSFETs

MOSFET Construction

The circuit of MOSFET is typically represented as follows:

- The p-type semiconductor forms the base of the MOSFET.
- The two types of the base are highly doped with an n-type impurity which is marked as n+ in the diagram.
- From the heavily doped regions of the base, the terminals source and drain originate.
- The layer of the substrate is coated with a layer of silicon dioxide for insulation.
- A thin insulated metallic plate is kept on top of the silicon dioxide and it acts as a capacitor.
- The gate terminal is brought out from the thin metallic plate.
- A DC circuit is then formed by connecting a voltage source between these two n-type regions.

Working Principle of MOSFET

When voltage is applied to the gate, an electrical field is generated that changes the width of the channel region, where the electrons flow. The wider the channel region, the better conductivity of a device will be.

MOSFET Types

MOSFETs are of two classes: Enhancement mode and depletion mode. Each class is available as n-channel or p-channel; hence overall they tally up to four types of MOSFETs.

Depletion Mode

When there is no voltage across the gate terminal, the channel shows maximum conductance. When the voltage across the gate terminal is either positive or negative, then the channel conductivity decreases.

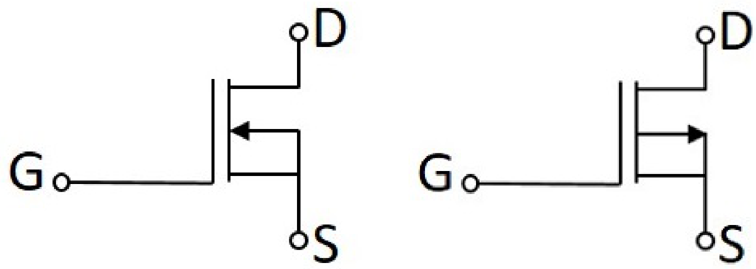


Figure 3-26. N-channel and P-channel Depletion mode MOSFETs

Enhancement Mode

When there is no voltage across the gate terminal, then the device does not conduct. When there is the maximum voltage across the gate terminal, then the device shows enhanced conductivity.

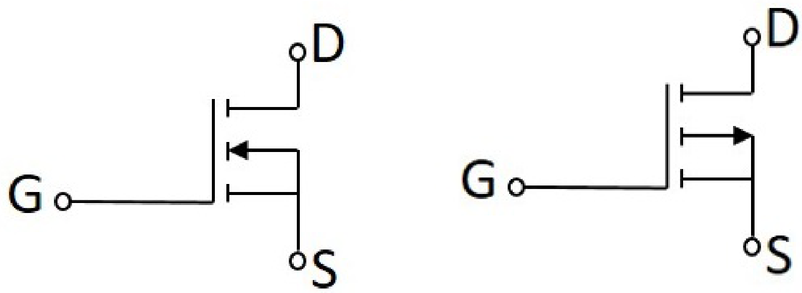


Figure 3-27. N-channel and P-channel Enhancement mode MOSFETs

Operating Regions of MOSFET

A MOSFET is seen to exhibit three operating regions.

Cut-Off Region

The cut-off region is a region in which there will be no conduction and as a result, the MOSFET will be OFF. In this condition, MOSFET behaves like an open switch.

Ohmic Region

The ohmic region is a region where the current (I_{DS}) increases with an increase in the value of V_{DS}. When MOSFETs are made to operate in this region, they are used as amplifiers.

Saturation Region

In the saturation region, the MOSFETs have their I_{DS} constant in spite of an increase in V_{DS} and occurs once V_{DS} exceeds the value of pinch-off voltage V_P. Under this condition, the device will act like a closed switch through which a saturated value of I_{DS} flows. As a result, this operating region is chosen whenever MOSFETs are required to perform switching operations.

MOSFET applications

- Radiofrequency applications use MOSFET amplifiers extensively.
- MOSFET behaves as a passive circuit element.
- Power MOSFETs can be used to regulate DC motors.
- MOSFETs are used in the design of the chopper circuit.

Advantages of MOSFET

- MOSFETs operate at greater efficiency at lower voltages.
- Absence of gate current results in high input impedance producing high switching speed.

Disadvantages of MOSFET

- MOSFETs are vulnerable to damage by electrostatic charges due to the thin oxide layer.
- Overload voltages make MOSFETs unstable.

3.9 DC – DC CONVERTERS:

Switched mode step-up dc-dc converters has started with improved pulse modulated frequency (PWM) upgrade converters. Step-up dc-dc topology converts low dc power levels to higher levels by temporarily maintaining inputs power and release the output at high voltage level. Such storage may occur in a magnetic field parts (single inductor / integrated inductor) or electrical field storage components (capacitors) through various applications active or inactive switching elements (power switches as well diodes) . With the introduction of semiconductor switching to in the 1950s, step-up dc-dc converters [1] achieved stable performance development and implementation accelerated during the 1960's semiconductor switches are available for sale with integrated production technology.

Increased aerospace and the telecommunications industry continued to expand research limits for boost converters, especially for programs their efficiency, energy density, and weight were the main concerns.

Performance has improved slightly since the late 1980s as a result the use of field-effect power transistors (FETs), capable a much better switch to higher frequencies than bipolar power the transistors converge while experiencing low switching losses and requires a less complicated drive cycle. In addition, the FET replaces output diodes through synchronous correction, which in its “opposition” is very low rather than also increase the efficiency of step-up dc-dc converter, which requires a high number of voltage diodes to strengthen.

3.9.1 Functions of DC-DC converter

The DC-DC converter has some functions. They are:

- Convert a DC input voltage into a DC output voltage.
- Regulate the DC output voltage against load and line variations.
- Reduce AC voltage ripple to DC output voltage below required level.
- If required provide isolation between the input source and the load.
- Protect the system provided and the source of electromagnetic input disturbance.

The DC-DC converter [4] is considered to be the heart of the power supply, so it will affect the overall performance of the power supply system. The converter accepts DC and produce a controlled DC output.

3.9.2 Categories of DC-DC Converter

- Buck converters
- Boost converters
- Buck boost converters

3.9.2.1 BUCK CONVERTER

Buck converters are used to convert high input voltage into low output voltage. In this converter continuous output current gives the output ripples less power**.** The AC / DC converter that we use as an example is often called the "buck" converter. Initially a buck converter meant a down-to-earth converter, but the term came to be used for DC / DC converters so.

While there were different perspectives, standard down-to earth converters were available diode-rectified (asynchronous) devices, too it was customary to refer to diode-rectified downward converters like buck converters. Apart from the words used, there is a number of grounding methods used on the ground switches, as well as the ground switch of this example is the one mentioned earlier diode-adjusted device. A buck converter could be used to charge a lithium ion battery to 4.2 V, from a 5 V USB source.

Operation of Buck Converters

Below, a basic down-to-bottom converter model is used to define circuit performance. By gaining and understanding of the structures of current methods and nodes from the basic performance, standards for peripheral component selection and issues that need attention clear. In diagrams, we replace the high-side transistor and low-side diode with it switches to define system performance. The circulation principles are the same as those of the diode adjustment is on the DC-DC converter, but high voltage is obtained by adjusting the AC voltage switch directly to perform voltage drop conversion, as well as transistor and diode operating as the switches have to withstand high voltage, for example 600 V or so.

- When the overhead button (transistor) opens, the IL current flows into inductor L, and power is stored.
- At this time, the low-side switch (the diode) is turned off.
- Current inductor IL is expressed by the following equation (T_{ON}: TIME)

$$\mathbf{I_L = ((VIN - VOUT)/L)*T_{ON}}$$

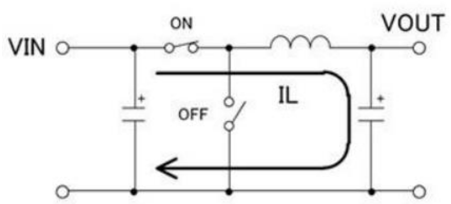


Figure 3-28. ON mode

- When the overhead switch (transistor) closes, the energy stored in the inductor exits using a low-side switch (diode).
- At this time, the high-side switch (the transistor) is turned off.
- Current inductor I_L is expressed by the following equation (T_{OFF}: TIME).

$$\mathbf{I_L = (VOUT/L) * T_{OFF}}$$

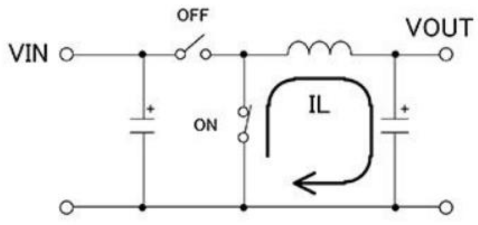


Figure 3-29. OFF mode

Below graph illustrates how inductor current, diode current and input current varies when switch status is changing from one mode to another mode (on to off or off to on). We can observe from the graph the value of inductor current depends on the value of slope which changes from on mode to off mode.

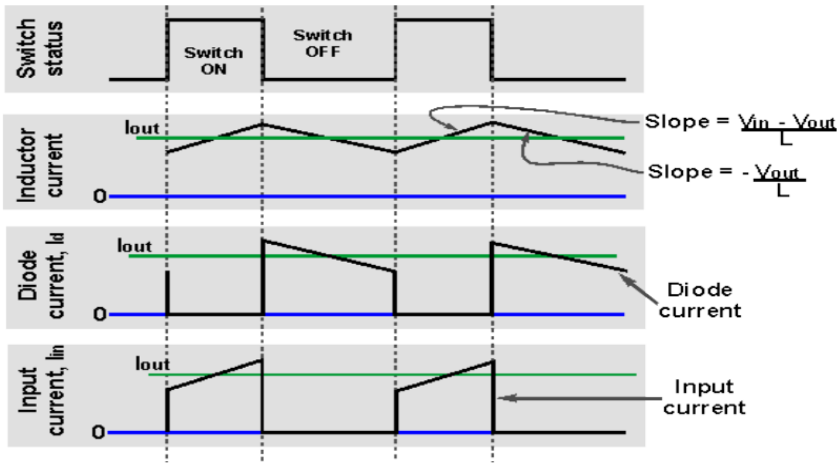


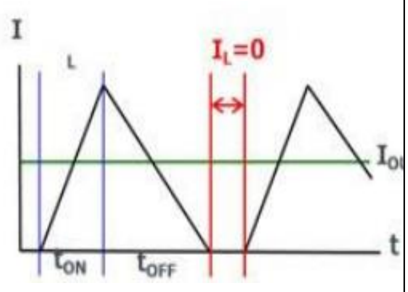
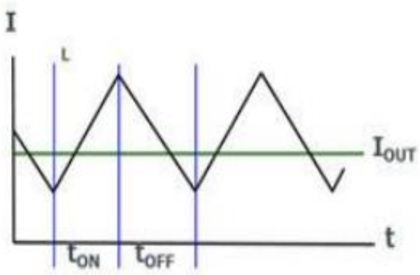
Figure 3-30. Graph of Switch Status, Input Current, Diode Current, Inductor Current

Discontinuous Mode and Continuous Mode:

In switching operation, there are two modes, a discontinuous mode and a continuous mode. The "operation" item for comparison is the waveform of the currents flowing in the primary windings and secondary windings of the transformer. In discontinuous mode, there is a period in which the inductor current IL is interrupted, when the inductor current is interrupted the value of inductor current becomes zero, hence the name discontinuous mode. In contrast, in continuous mode there is no period in which the inductor current is zero.

In the case of the continuous mode, when the switches are ON, a reverse current flows during the reverse recovery time (T_{rr}) of the rectifying diode, and losses occur due to this reverse current. In low-voltage switching DC/DC conversion, the reverse voltage of the rectifying diode is low and the reverse current is also small, and so generally the continuous mode is used, giving priority to reducing the output ripple voltage and harmonics. However, in AC/DC conversion, the diode reverse voltage is high and a large reverse current flows, and so discontinuous mode, in which a reverse current does not flow and losses are reduced, is generally used. However, the peak current becomes large, and when the load is large, sometimes operation in continuous mode is preferred.

Table 3-1. Comparison of continuous and discontinuous mode

Comparison item	Discontinuous mode	Continuous mode
Operation	There is a zero-inductor current period between on and off, so that the inductor current is not continuous.  	The inductor current flows continuously, which turns on and off at the same frequency as the switching frequency. 
Inductor	Increase in inductance, size and cost.	Decrease in inductance, size and cost.
Rectifying diode	Fast recovery type and decrease in cost.	Requires a fast recovery type and cost increases.
Switching transistor	Allowable power, size and cost increases.	Allowable power, size and cost decreases.
Switching loss	Efficiency increases and switching loss decreases.	Switching loss increases and efficiency decreases.

3.9.2.2 BOOST CONVERTER

Boost Converter is a simple converter. It is used to convert DC voltage from low to high. Boost Converter is also called DC to DC converter. Boost Converters (DC-DC Converters) was founded in the early 1960s. These converters are designed using semiconductors switching devices.

The main operating principle of the boost converter is that the inductor in the input circuit resists sudden variation in power input. When the switch is CLOSED the inductor retains the power in the state of magnetic field also removes when the switch is off. The capacitor in the output circuit is it is assumed to be large enough that the fixed time of the RC circuit in the output phase is high. Great the constant time compared to the switching time confirms the constant voltage of Vo (t) =Vo (always).

When the switch is in ON mode, the inductor output is connected to the ground and the voltage Vin is placed across it. The current inductor rises in value equal to Vin/L. When the switch is set to OFF position, the voltage across the inductor changes and changes is equal to Vout-Vin. At present the flow in the inductor decays at a cost equivalent to (Vout-Vin)/L.

Without using the Boost Converter: For semiconductor switching devices, Linear controlled circuits (DC power controlled circuits) reach a voltage from an uncontrolled input field (AC power supply) and as a result there is a power loss. Loss of power is accompanied by a decrease in electrical power.

Using the Boost Converters: In switching devices, converters convert AC or DC uncontrolled input voltage into a controlled DC output voltage.

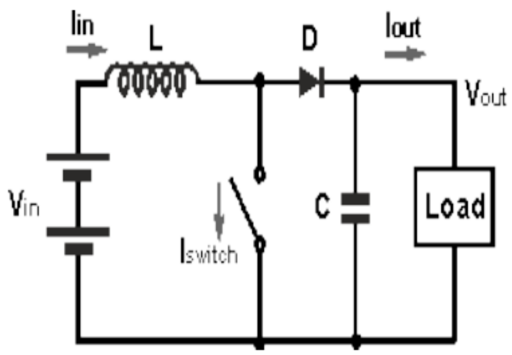


Figure 3-31. Boost Converter Circuit

Referring to the boost converter circuit diagram, the current waveforms for the different areas of the circuit can be seen as below.

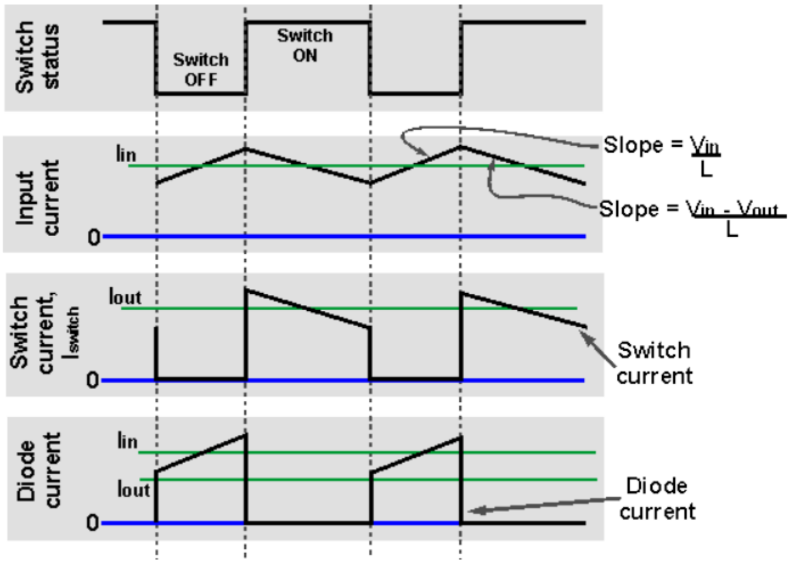


Figure 3-32. Graph of Switch Status, Input Current, Diode Current, Switch Current

It can be seen in the waveform diagrams that the current input to the boost converter is high has a current effect. It is thought to be the most efficient converter, i.e., non-loss, boost converter, power the output must be equal to the force in, i.e., Vin * Iin = Vout *Iout. In this case it can be seen if the output The voltage is higher than the input voltage, then the input power must be higher than the output yet.

Modes of operation of Boost converter:

The boost converter can be operated in two modes

Continuous conduction mode:

The Boost Converter Continuous Switching Mode is made up of a combination of inductor, capacitor and input power source as well as a single switching device. In this inductor it acts as an energy storage device. The boost converter switch is controlled by PWM (pulse width modulator). When the switch is ON power is developed in the inductor and more power is brought to the output. It is possible to convert high voltage capacitors from a low voltage input source. The input voltage is always greater than the output voltage. In continuous operation mode, the current increases with respect to the input voltage.

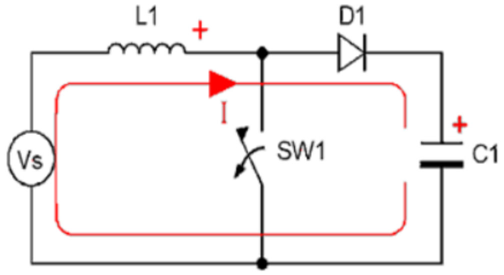


Figure 3-33. Boost converter in conduction mode

Case-1: When switch S is ON

When switch in ON the diode will be open circuited since the n side of diode is at higher voltage compared to p side which is shorted to ground through the switch. During this state the inductor charges and the inductor current increases. The current through the inductor is given as

$$\mathbf{I_L = (1/L) * \int V\, dt}$$

Case-2: When switch S is OFF

When switch in OFF the diode will be short circuited. The inductor now discharges through the diode and RC combination. Assume that prior to the closing of switch the inductor current is $I_{L,OFF}$. The current through the inductor is given as

$$\mathbf{I'''_{L,OFF} = -(1/L) * \int (V_{in} - V_{out})\, dt + I'''_{L,OFF}}$$

Discontinuous conduction mode:

The discontinuous operating mode circuit is made up of an inductor, capacitor, switching device and input voltage source. Inductor is part of the same energy storage as the continuous operation mode. In continuous mode, when the switch is ON power is brought to the inductor. And when the switch is OFF for some time the inductor current reaches the egg when the next switching cycle is turned on. The outgoing capacitor charges and discharges relative to the input voltage. The output voltage is small compared to continuous mode. The inductor in discontinuous mode drains all the current which it piled up in charging interval of same switching cycle. The current through the inductor is given as

$$\mathbf{I_L = (1/L) \int V_L\, dt = (1/L) * (Area\ under\ the\ curve\ of\ voltage\ vs\ time)}$$

Advantages:

- Gives the high output voltage.
- Good quality of wave forms even the line frequency is present.
- Output voltage with low distortion.
- Lower voltage on MOSFET.

Applications of Boost converter:

- Boost converters are used in battery-powered systems where there is a space limit pack an additional number of batteries in the series to achieve higher voltages.
- Communication Applications Battery Charging circuits.
- Low power boost converters are used in portable device applications.
- They are used in regulated DC power supplies.
- In applications like automotive, power amplifier, adaptive power, consumer electronics and dc motor drives.

3.9.2.3 BUCK-BOOST CONVERTER

Buck - boost converter is a dc-dc converter that can increase or decrease input Voltage level. The increase or decrease of the input voltage depends on the level of activity. Activity measurement or cycle of operation is a measure of the output voltage from the input voltage to a circuit. Buck – boost converter provides controlled DC output.

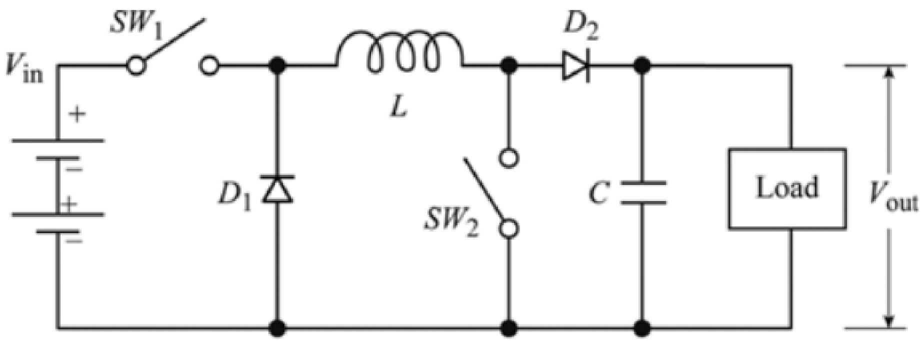


Figure 3-34. Buck-boost converter circuit

In buck mode, the output voltage obtained is less than the applied voltage applied. In this mode, the current output is more than the current input. However, the output power is equal to input power.

When in boost mode, the output voltage is greater than the applied voltage applied. In this mode, the output current is less than the current input. However, the output power is equal to input power.

To use the buck-boost converter, two switches will work simultaneously. When switches off, the inductor stores energy in the magnetic field. When the switches are on, inductors are discharged and provide a load supply. Inductors in the circuit do not allow sudden fluctuations. The capacitor throughout the load provides a controlled DC output.

This buck-boost converter circuit setting uses the same number of parts like simple coins or boost converters. However this is a buck-boost controller or the dc-dc converter produces a negative output of the positive input. Although this may be required or can be accommodated with a limited number of applications, no usually a very simple format.

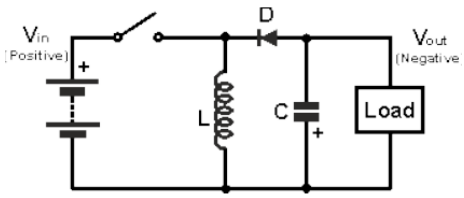


Figure 3-35 SW1 open

The second buck-boost converter circuit allows both input and output to be the same polarity. However to achieve this, more components are required. The circuit for this buck boost converter is shown below.

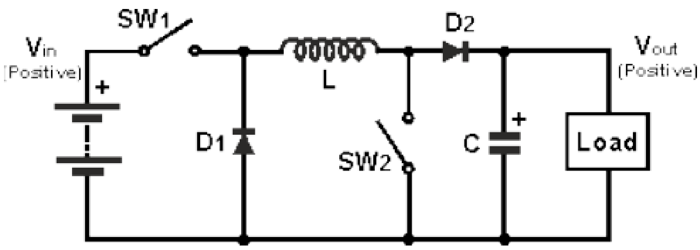


Figure 3-36. SW1 and SW2 Both open

In this circuit, both switches work together, i.e., both are closed or open. When the switches turn on, the inductor current builds up. In the normal case, the switches are turned on. Inductor supplies current power to the load through a method that combines both diodes, D1 and D2.

CHAPTER 4
SIMULATION

Before fabricating any circuit, it is advisable to first simulate it in order to know the theoretical limits of circuit performance and to verify the correctness of the design. One of the primary advantages of simulators is that they are able to provide users with practical feedback when designing real world systems. This allows the designer to determine the correctness and efficiency of a design before the system is actually constructed. Consequently, the user may explore the merits of alternative designs without actually physically building the systems. By investigating the effects of specific design decisions during the design phase rather than the construction phase, the overall cost of building the system diminishes significantly. For that purpose, our present design is simulated using a software called LTspice.

4.1 LTSPICE:

LTspice [9] is high performance SPICE simulator software, including a graphical schematic capture interface. It is a SPICE-based analog electronic computer software, developed by Analog Devices.

LTspice provides scheduled recording for the installation of an electronic circuit system, an advanced SPICE analog electronic model, and a waveform viewer to display simulation results. Circuit simulation analysis based on pass, audio, AC, DC, DC transfer function, DC workspace can be performed and programmed with four analysis. Partial heat dissipation can be calculated and can be performed with efficient reports. It has special enhancements and models to accelerate the simulation of modified electric current mode (SMPS) in DC-DC converters.

LTspice does not produce printed circuit board (PCB) structures, but lists can be submitted to PCB architecture software. Although LTspice supports simple logic gate simulation, it is not specifically designed to simulate logical circuits. It is used by many users in fields including radio frequency electronics, electric power, audio electronics, digital electronics, and other fields.

4.2 Preliminary simulation:

4.2.1 Open loop with 2 stages

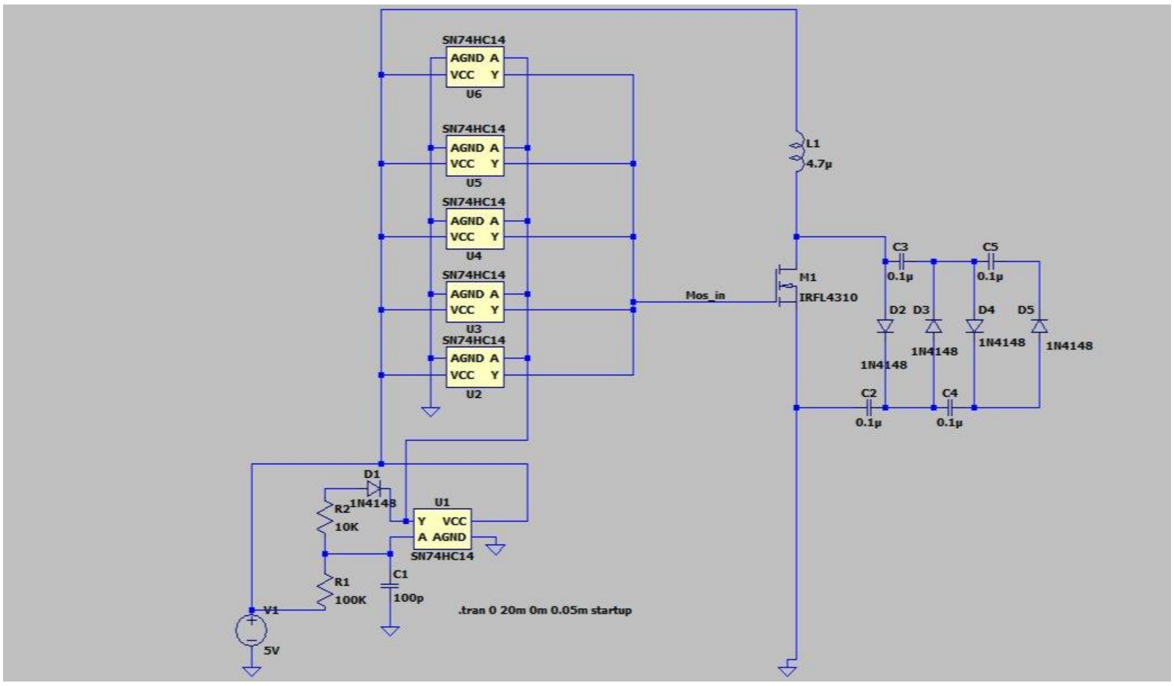


Figure 4-1. Open loop circuit with 2 multiplier stages

The circuit (Figure 4-1) is an open loop circuit which is having 2 multiplier stages. The input voltage is 5V. This circuit is simulated upto 30ms. The output voltage obtained is 230V.

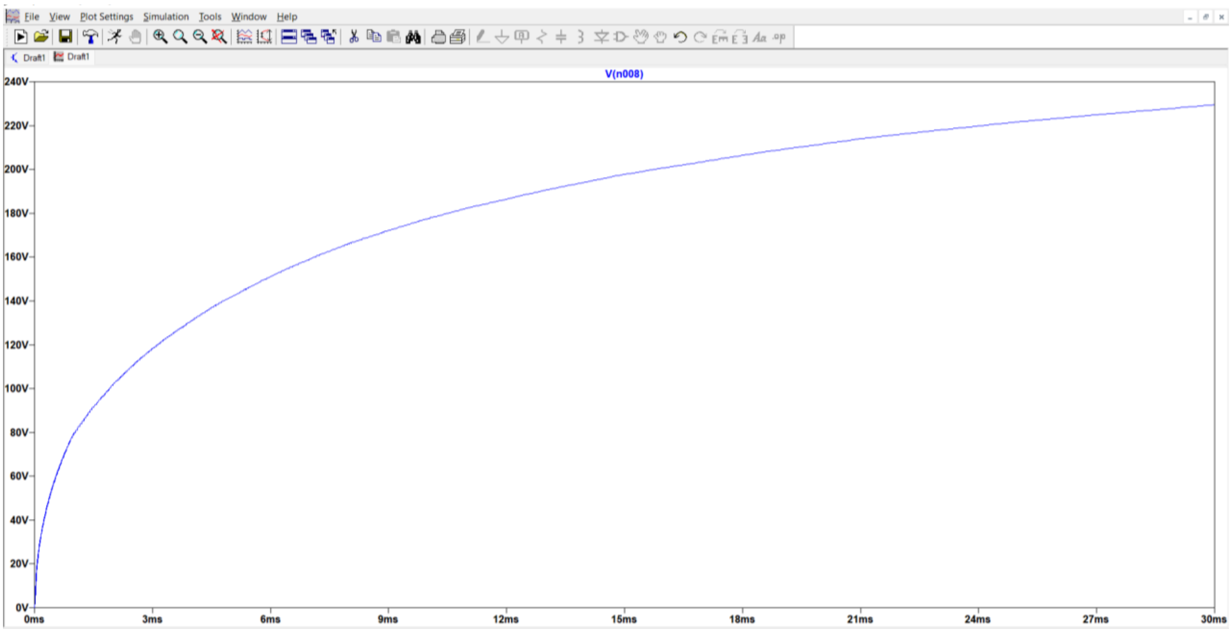


Figure 4-2. Simulation of open loop circuit with 2 multiplier stages

4.2.2 Open loop with 6 stages

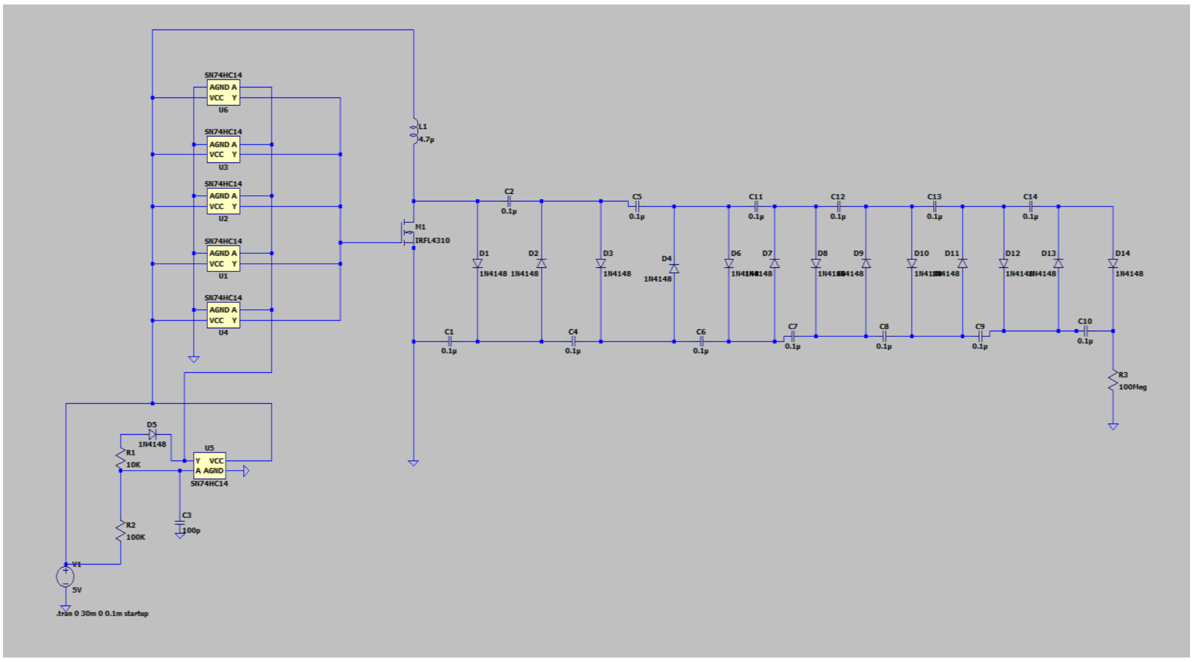


Figure 4-3. Open loop circuit with 6 multiplier stages

The circuit (figure 4-3) is an open loop circuit which is having 6 multiplier stages. The input voltage is 5V. This circuit is simulated upto 30ms. The output voltage obtained is 596V.

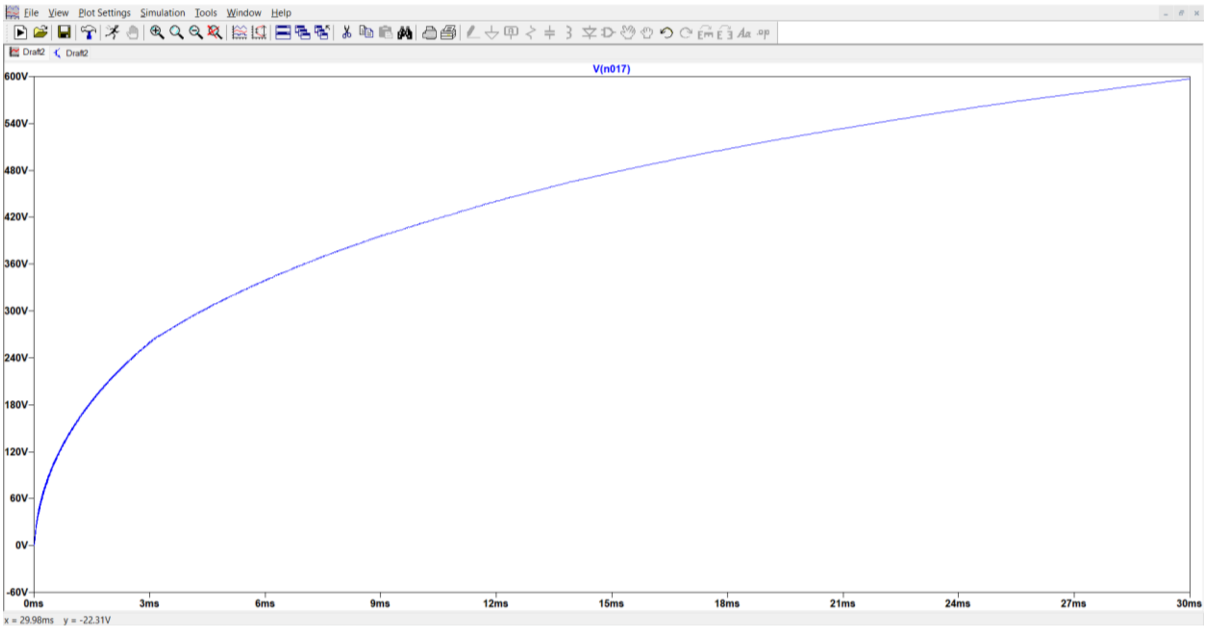


Figure 4-4. Simulation of open loop circuit with 6 multiplier stages

Thus, as we increase the number of multiplier stages, the voltage will also increases. Thus, the more the number of multiplier stages, the more will be the output voltage.

4.2.3 Load Resistance vs Output Voltage

The circuit (figure 4-3) is simulated upto 30ms by keeping input voltage constant at 5V. By varying the load resistance from 1 MΩ to 100 MΩ, the output voltage is observed.

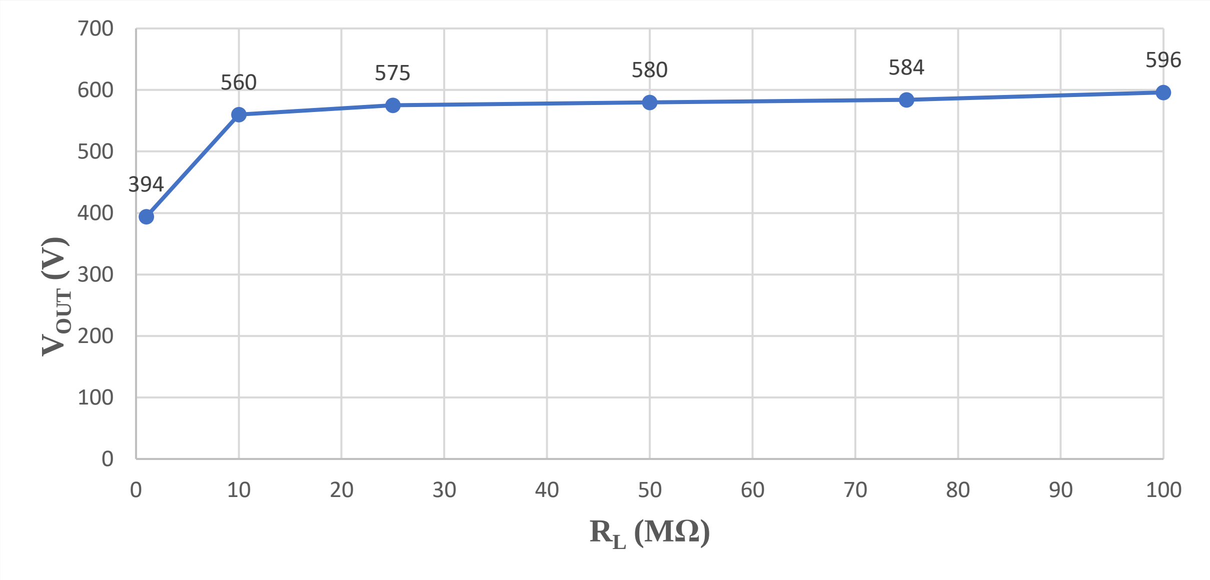


Figure 4-5. Graph of R_L vs V_{OUT} at constant i/p voltage

4.2.4 Input Voltage vs Output Voltage

The circuit (figure 4-3) is simulated upto 30ms by keeping load resistance constant at 100 MΩ. By varying the input voltage from 3.5V to 5V, the output voltage is observed.

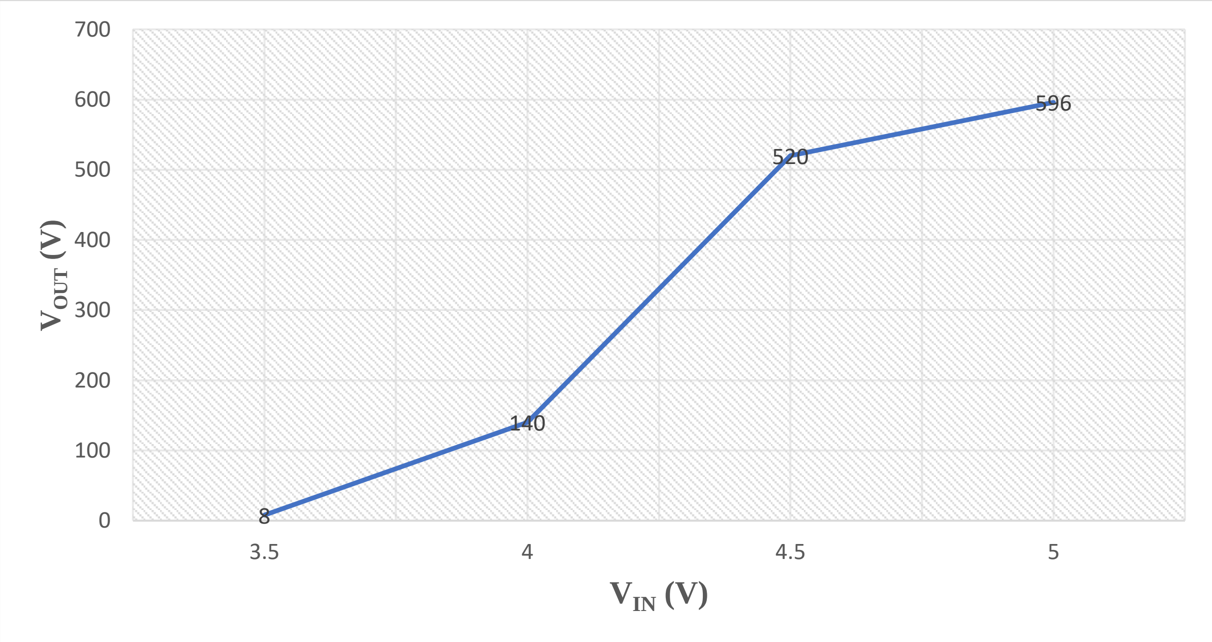


Figure 4-6. Graph of V_{IN} vs V_{OUT} at constant load resistance

CHAPTER 5
DESIGN IMPLEMENTATION WITH PSOC AND EXPERIMENTAL RESULTS

5.1 Existing commercial system design:

The production and control of high voltage (~ 500 V) to bias the GM tube [15,19] is a basic design requirement for GM testing meters. For portable applications, the only source of power from the battery (9V), is the maximum voltage. Generally, voltages higher than battery level are generated using a DC-DC boost converter circuit in portable systems. This cycle operates with the goal of generating high voltage through a rapid change in the size of the current inductor between two different values. This method was also adopted in the past for applications at the GM counter. The figure 5-1 illustrates the conceptual framework of a simple boost converter that describing current switching principle.

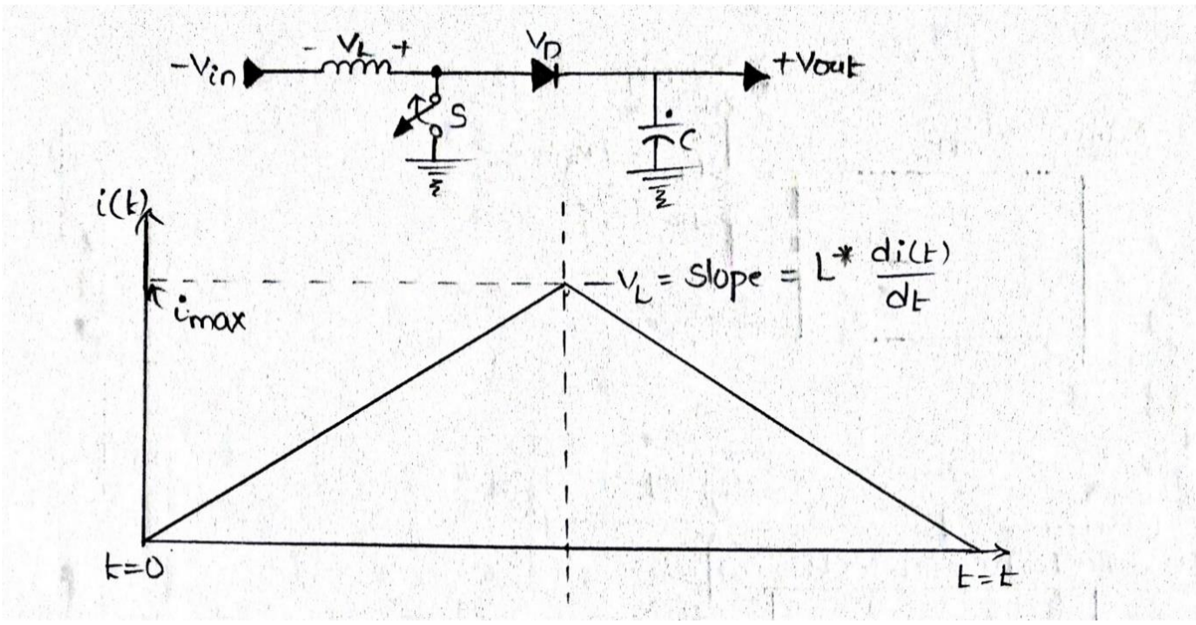


Figure 5-1. Simple boost converter showing the current variation in inductor w.r.t time

In the diagram shown, switch S is closed at the beginning for a long time and the static i_{max} current is established in inductor L. When the current i(t) is abruptly changed from the fixed value of the i_{max} to zero by turning on the switch, high temporal voltage is generated on the side of the pole (marked '+'). This temporary V_L of high voltage power is stored in capacitor C by a temporary current pulse, passing through a diode D forward. The stored pulse voltage is recalculated to act as a source. It should be noted here that capacitor charging is always complemented by a switching action, because any opposing load connected to capacitor C discharges it. This recurring shift is achieved by the mechanical rotation in Figure 5-1 with the transistor/MOSFET switch as shown in Figure 5-2. While the transistor/ MOSFET switch Q1 is controlled by a pulse train in its base/ gate terminal, its collector/ source terminal and the emitter/drain terminal emulate the pole side and the free contact side of the mechanical switch. In practical circuits, the inductor L in Figure 5-1 is usually replaced by transformer T1 as shown in Figure 5-2.

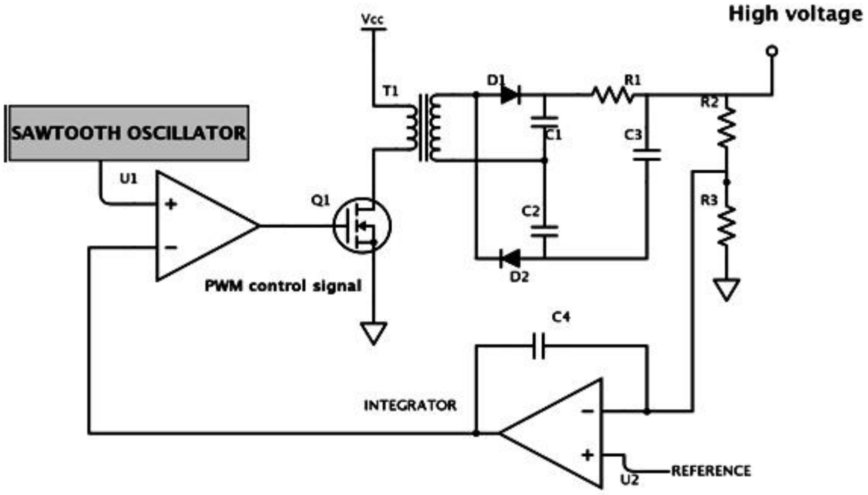


Figure 5-2. Schematic of a practical high voltage generation circuit with closed loop regulation

The use of a transformer serves two purposes, namely

1) Limiting the maximum voltage developed across the switching elementQ1 to safe levels

2) Provides galvanic separation between primary and secondary circuits.

In addition to these, the transformer also enables the utilization of the high voltage developed during both the turn-on and turn-off cycles of the primary coil, in conjunction with the diode-capacitor based voltage-doubler network (D1, D2, C1, C2).

A simple relation between the input voltage V_{in} and the output voltage V_{out} of a boost converter in terms of the duty cycle D of the pulse train is

$$V_{out} = V_{in}/(1-D) \quad (5.1)$$

where, $$\text{Duty cycle, } D = T_{on}/(T_{on} + T_{off}) \quad (5.2)$$

The duty cycle as described in the above equation (5.2), the average time when the switch is kept closed (Ton), to enable the current to pass through inductor L, to the time cycle (T_{on} + T_{off}), where the Toff is the time when the switch it opens there. Therefore, as the work cycle D approaches unity, the outgoing voltage of V_{out}, larger than the input Vin can be generated. It should be noted that the duty cycle D cannot take zero values or ones.

Both of these conditions are associated with a situation where the switching waveform itself is a non-volatile DC value, either zero or with a fixed positive value less than the supply voltage of the switching circuit. This prevents any change in the i(t) of the current inductor. This relationship of equation (5.1) finds that a high voltage constant power source with a wide range of voltage can be created using the frequency control of the signal functions fed to the base of the switching transistor (Q1). This is also known as the Pulse Width Modulation (PWM) process. However, high voltage fluctuations should be adjusted, using the feedback system.

5.2 Added advantages of PSoC based design:

It is imperative that any mobile system works best in terms of battery power and adapts to modern communication conditions. The current system, which uses on-chip DMA based waveform generation from PSoC, ensures longer operating time of the research meter compared to other systems that use a blocking oscillator. Obviously, a blocking oscillator scheme has advantages in terms of features such as start-up capability and simplicity. But in terms of its efficiency, (~ 61%) it becomes poorer compared to the existing system which is almost 75%.

Many other low-cost schemes for producing HV for GM tubes [2,19] have been reported in the literature. However, these are based on COTS HV block or Villard cascade-based topologies, which do not lend themselves to closed loop control as access to the current scheme. In line with current data communication trends using high-speed USB connections on PCs, the current PSoC-based design [13,16] provides USB 2.0 full-speed communication over a RS232 virtual interface.

Implemented embedded single-chip design, very compact, durable, and ensures better reliability and accuracy. The stability of this embedded design is excellent, as high voltage is found to be stable for ~9 hours of continuous operation.

5.3 PSoC-5 Platform features:

PSoC is a mixed signal software developed with the built-in content of the Microcontroller Unit (MCU). The PSoC IC has a CPU core, adjustable analog and digital blocks, a Programmable Logic Device (PLD) based on custom user modules, all integrated into a single chip. The PSoC 5 LP [12] is the latest version and has a 32-bit ARM® cortex M3 processor core with speeds of up to 80 MHz. In this function, the IC CY8C5868 AXI LP035 device is used as the basic platform. The creator of the PSoC 3.0 IDE [13,14], as well as the coordinator of the Cypress Joint Test Action Group (JTAG) are used to design and organize the application board.

The main functions of the spectrometer namely, firmware and state machine are operated with a high-speed CPU and PLD location, respectively. The connection of the on-chip user modules to perform peripheral and key functions is shown in Figures 5-3, 5-4. Figure 5-3 shows the connection of the on-chip PSoC blocks for maximum power control and ramping operations. required for detector selection. High power control in this system is done using a modified mode scheme. While the switching transistor and boost converter are used as external components and filters for high voltage response, active components are implemented using on chip modules.

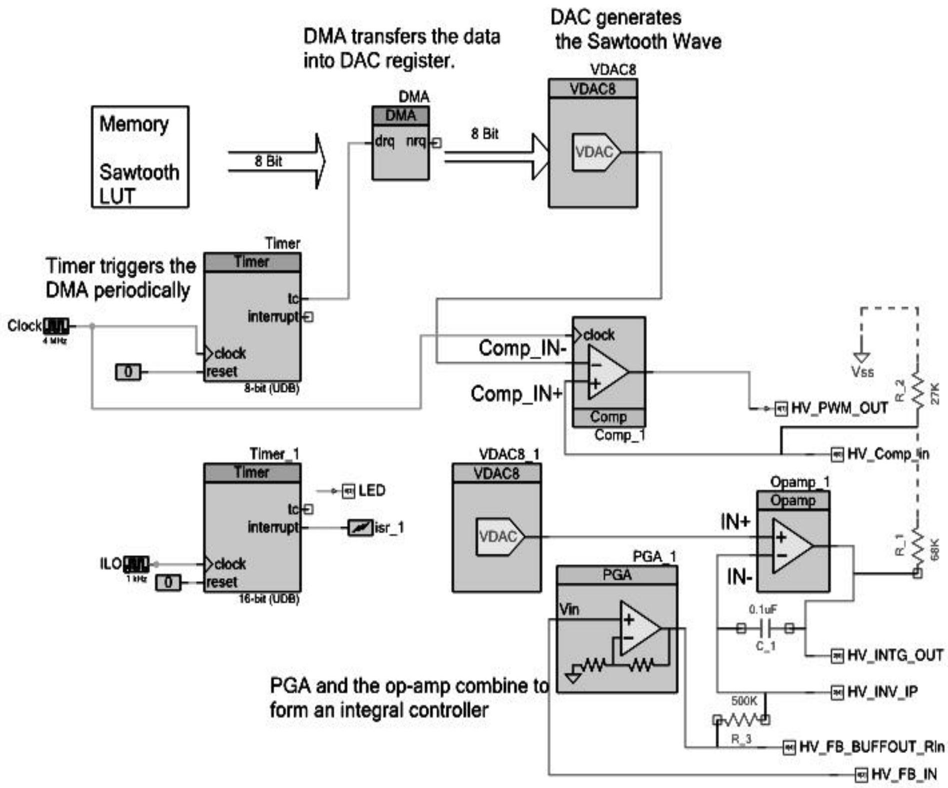


Figure 5-3. PSoC creator schematic for the on chip high voltage ramping and regulation module

In addition, the VDAC8_1 DAC module serves as an electrical reference for the HV system and hence, the output is a static input (IN+) component. Internal Op-Amp OPAMP_1 is configured as a connector where the outgoing HV component is provided in response to the input transformer (IN-). The connecting output can be a positive or negative voltage ramp and is determined by the error signal of the HV discharge. This ramp signal is given the COMP_1 component in terms of its COMP_IN + input. This comparison compares this slow signal with the saw tooth waveform fed to its COMP_IN- input PWM signal (HV_PWM_OUT). This PWM signal is given to an external switching transistor (see Figure 5-2) for a controlled HV loop similar to that described in section 5.2.1. The saw tooth waveform essential for the PWM signal is generated in this system by periodically discarding data from the Look-Up-Table (LUT) in the DAC VDAC8 module. This is done using a direct memory transfer (DMA). The use of the DMA method ensures that waveform generation is independent of the CPU.

While the first one is fed directly, the last one produced from the transistor-coupled edge acquisition cycle in the pre-amplifier output switches forward into the Transistor-Transistor Logic (TTL) level. The standard adjustment is done using a high-speed 'Comp' component with an internal reference of 250-mV. The state-of-the-art mechanical clock is selected in accordance with the shortest pulse logic length obtained by the PE signal. State machine output signals are M1_ABORT and M0_PROCESS.

Digital and data communication functions are implemented using the on-chip delta-sigma ADC- ADC_1 and the universal asynchronous receiver transmitter (UART) UART_TX_1 module, respectively. Figure 5-4 shows the implementation of this function in the PSoC IC. Delta sigma ADC is used in 12-bit or 14-bit configuration software using a maximum sample rate of 250 Kbps.

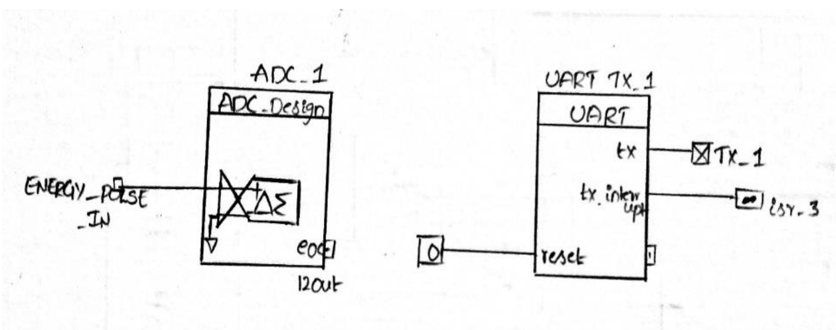


Figure 5-4. PSoC schematic for the on-chip digitizer and UART communication modules

5.4 PSoC Components:

The components [20] are analog and digital peripherals that represent a brand that users pull down on their designs and customize it to suit a wide range of application requirements. Each section in the Infineon Component Catalog section is prepared with a custom dialog and includes a full set of dynamic API libraries. After setting up all peripherals, the firmware can be written, compiled, and edited within the PSoC Creator or exported to IDEs by third parties such as the IAR Embedded Workbench, Arm Microcontroller Development Kit, and Eclipse.

5.4.1 M8C CPU:

The PSoC family contains several Mixed-Signal Array with On-Chip Controller devices. These devices are designed to replace multiple MCU-based system components with a single, less expensive single-chip system. PSoC devices include adjustable analog and digital blocks, as well as systematic connections. This setting allows the user to customize a custom configuration that suits the needs of each application. Additionally, faster CPU, Flash system memory, SRAM data memory, and configurable IO are included in the list of simple PINs and packages. The PSoC structure, as shown on the left, consists of four key areas: PSoC Core, Digital System, Analog System, and System Resources. Adjustable bus travel around the world allows all device resources to be integrated into a complete custom system.

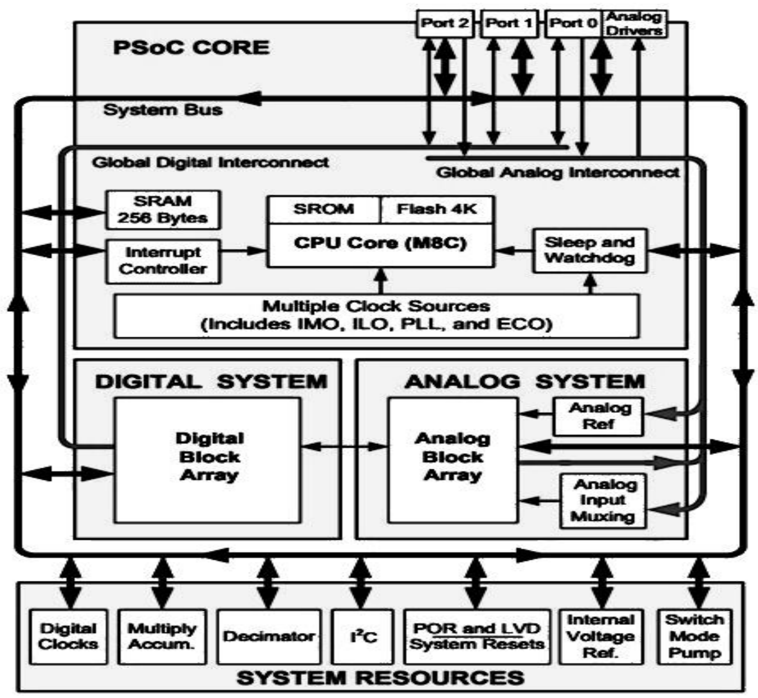


Figure 5-5. M8C CPU

The PSoC Core:

PSoC Core is a powerful engine that supports a rich feature set. The core includes CPU, memory, clocks, and configurable GPIO (General Objective IO). The M8C CPU core is a powerful processor with speeds of up to 24 MHz, providing a small Harvard MIPS 8-bit processor. The CPU uses an 11-vector interference controller, to simplify real-time embedded event settings. The system execution is timed and protected using the Sleep and Watchdog Timers (WDT) installed. Memory includes 4 KB of Flash storage system, 256 bytes of SRAM to store data, and up to 2 KB of EEPROM embedded using Flash. System Flash uses four levels of protection on 64-byte blocks, allowing custom software IP protection.

The PSoC device incorporates flexible internal clock generators, including a 24 MHz IMO (main internal oscillator) that is 2.5% accurate above temperature and voltage. The 24 MHz IMO can be doubled to 48 MHz for digital system use. A low power 32 kHz ILO (low internal speed oscillator) is provided with the WDT sleep timer. If crystal accuracy is required, the ECO (32.768 kHz external crystal oscillator) is available for use as a Real Time Clock (RTC) and can optionally produce a 24 MHz crystalline system clock using PLL. Clocks, as well as adjustable watch separators (such as System Device), offer the flexibility to integrate with almost any time requirement on a PSoC device. PSoC GPIOs provide connectivity to CPU, digital and analog telephone services. The driving mode for each pin can be selected in eight options, allowing for greater flexibility in external communication. Each pin has the capability to generate a system interrupt on low level, high level and change from last read.

5.4.2 Comparator:

The comparator component provides a hardware solution for comparing two input analog input volumes. The output can be sampled in software or digitally transferred to another component. Three speed levels are provided to allow you to adjust the speed or power consumption. External reference or voltage can be connected to any input.

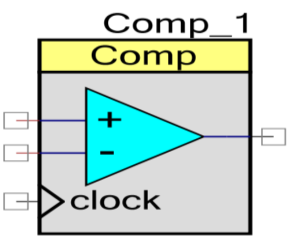


Figure 5-6. Comparator component

When to use a Comparator:

The comparator can provide faster comparisons between two voltages, compared to using ADC. Although ADC can be used with software to compare multiple power levels. applications that require faster response or less software intervention are good candidates for this comparison. Other example applications include CapSense, power tools, or simple translation from analog level to digital signal.

Input / Output (I/O) Connections:

This section describes the inputs and connections of the Comp. An asterisk '*' symbol in the I/O list indicates that the I/O may be hidden in a symbol under the conditions listed in the description of that I/O.

Positive Input - Analog:

This input is usually connected to a comparable voltage. This input can be transferred to the GPIOS or to the internal reference selection.

Negative Input - Analog:

This input is usually connected to a reference voltage. This input can be transferred to the GPIOS or to the internal reference selection.

Comparator Out - Digital Output:

Comparison effect. With a fixed configuration, this output goes up if the positive input voltage is greater than the negative input voltage. If the polarity is set to the converter, the output will be higher if the negative input voltage is greater than the positive input voltage, in this case a converter from the UDB block is used to convert the output signal of the comparator. The output can be transferred to other digital components such as interruptions, timers, etc.

Clock - Digital Input:

The clock input synchronizes the output of the comparator on the rising edge of the clock when the sync parameter is set to Normal. This compels the output of the comparator to be sampled at the ascending edges of the clock.

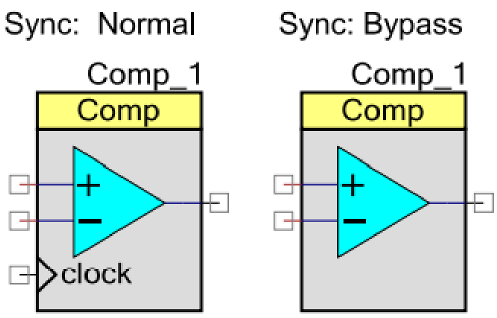


Figure 5-7. Clock input of comparator

When the sync parameter is set to Bypass, the output is not synchronized with the bus clock on the rising edge and synchronized with the bus clock on the falling edge. In this case the terminal of the clock is no longer displayed in the section mark.

Component Parameters:

Drag a Comparator onto the design and double-click it to open the Configure dialog.

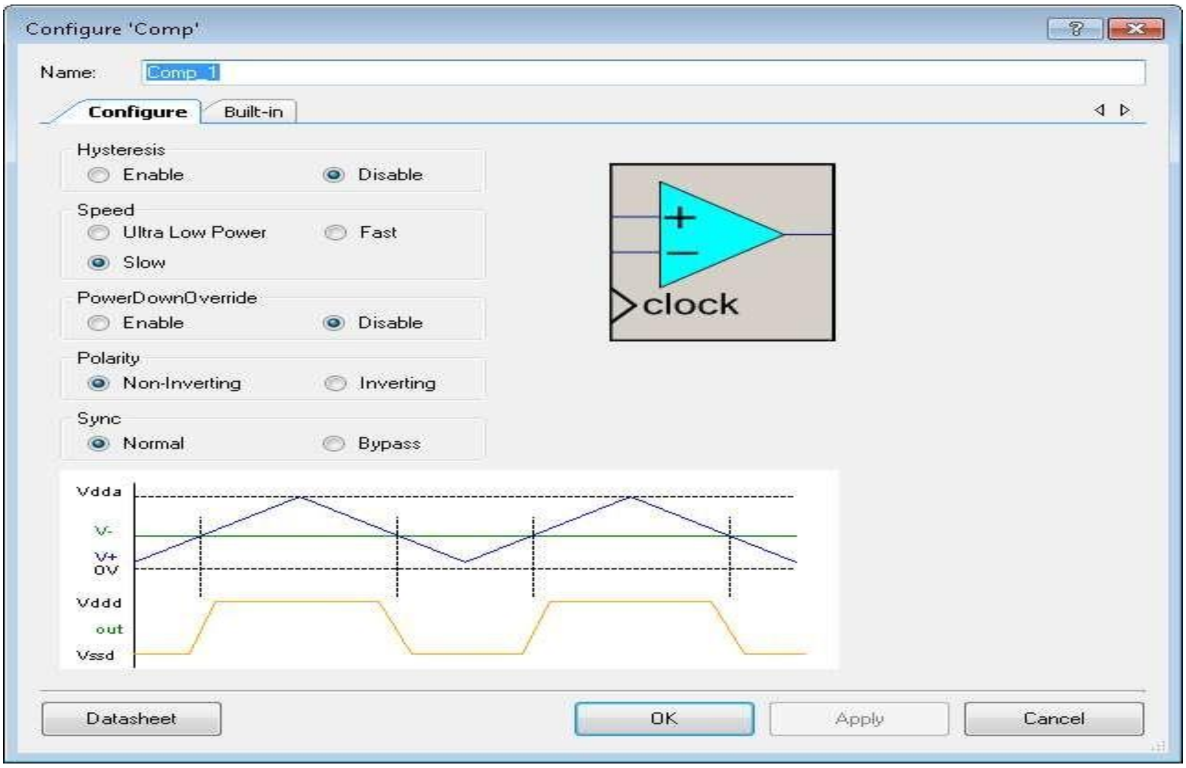


Figure 5-8. Configure dialog box of Comparator

Application Programming Interface:

Application Programming Interface (API) programs allow us to configure a component using software. PSoC Creator assigned the model name "Comp_1" at the beginning of the segment to a specific design. We can rename an event to any unique value that follows the syntactic rules of the identifier. The model name becomes the starting point for all the global function names, dynamics, and a fixed symbol.

Functional Description:

The comparator acts as a high-gain amplifier for high frequency bandwidth. The component is cut in the factory to achieve the lowest offset voltage. It can be cut during operation in the customer code to achieve improved precision input of offset voltage in a particular area. Hysteresis is enabled by adding offsetting currents to the input phase. The so-called hysteresis is 10 mV (33 mV maximum), which is enough to be larger than the amount of any input noise of comparator and internal routing interference. The offset voltage is usually specified as the absolute value of the difference between the two inputs when the comparator state is switched.

5.4.3 Timer:

The Timer provides a method to measure intervals. It can implement a basic timer function and offers advanced features like capture with capture counter and interrupt/DMA generation.

For PSoC 3 [11] and PSoC 5LP [12] devices, the component can be implemented using fixed-function (FF) blocks or Universal Digital Block (UDB). PSoC4 devices support only the UDB implementation. An UDB implementation has more features than a FF implementation. If the design is simple, consider using FF and save UDB resources for other purposes.

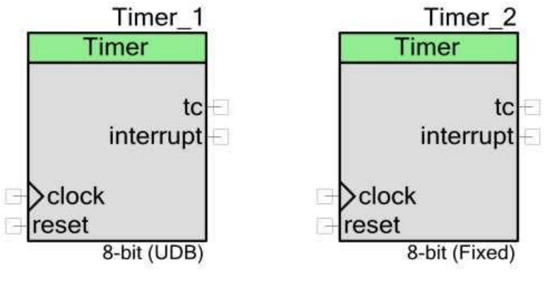


Figure 5-10. Timer component

When to use a Timer:

The usage of the timer is to generate a periodic event or signal interruption. A timer is usually used to record the number of clock cycles between events. An example of this is measuring the number of clocks between two ascending ends as a tachometer sensor can be generated. The most complex application is to measure the time and frequency of PWM input functions. In the PWM scale, the timer section is set to start at the rising edge, capture the next falling edge, and then scan and stop at the next rising edge.

Input/Output (I/O) Connections:

This section describes various input and output (I/O) connections for the Timer. Some I/O's may be hidden on the symbol under the conditions listed in the description of that I/O.

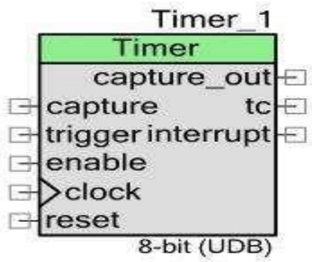


Figure 5-11. I/O connections of Timer

Component Parameters:

Drag a Timer onto the design and double click it to open the Configure dialog.

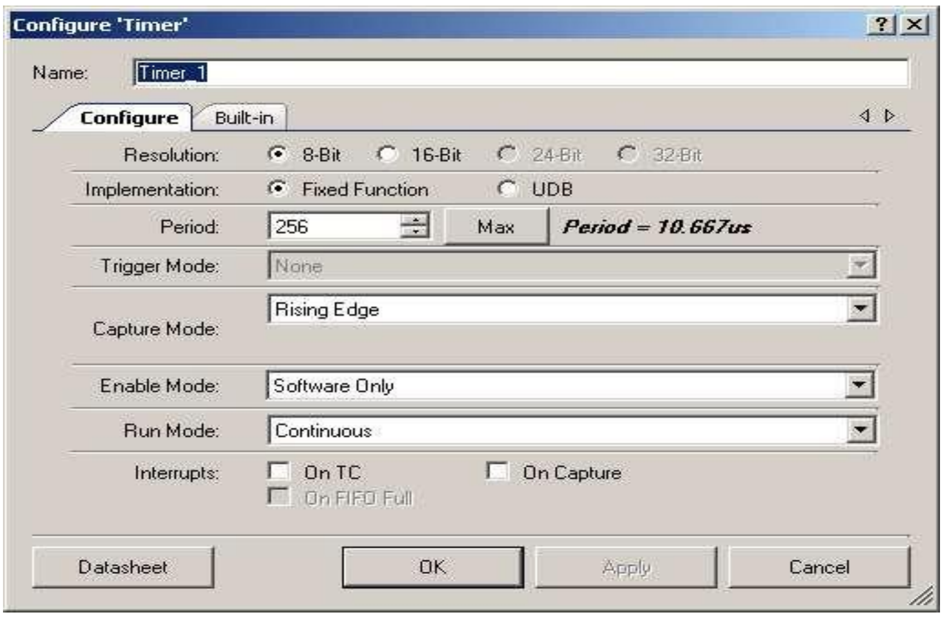


Figure 5-12. Configure dialog box of Timer

Application Programming Interface:

Application Programming Interface (API) processes allow you to configure a Section using software. By default, PSoC Creator assigns the name "Timer_1" to the original Part of the Part in a specific design. We can rename it to any unique value that follows the syntactic rules for identifiers. The instance name becomes the starting point for all the global function names, dynamics, and a fixed symbol.

5.4.4 Counter:

The Counter provides a method to count events. It can implement basic counter function and provide advanced features such as compare output, capture and count direction control. For PSoC 3 and PSoC 5LP devices, the component can be implemented using fixed-function (FF) blocks or Universal Digital Block (UDB). PSoC4 devices support only the UDB implementation. An UDB implementation has more features than a FF implementation. If the design is simple, consider using FF and save UDB resources for other purposes.

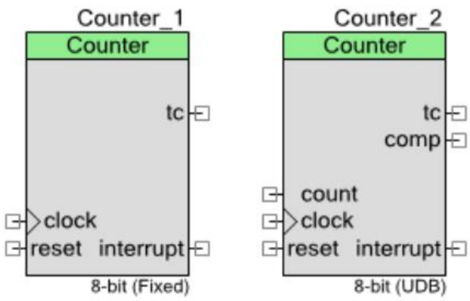


Figure 5-13. Counter components

When to use a Counter:

The default use of Counter is to count the number of events on the edge of the count input. However, there are a few other things that Counter can use:

- Clock divider: By clocking in the count input and using the comparative or output of the terminal matrix as a split clock output.
- Frequency counter: By connecting a signal with a known time to enable counter input while counting signal to measure calculation input.
- A tool for measuring related events such as quadrature decoder output

Input/Output (I/O) Connections:

This section describes various input and output (I/O) connections for the Counter. Some I/O's may be hidden on the symbol under the conditions listed in the description of that I/O.

Component Parameters:

Drag a Counter onto the design and double click it to open the Configure dialog.

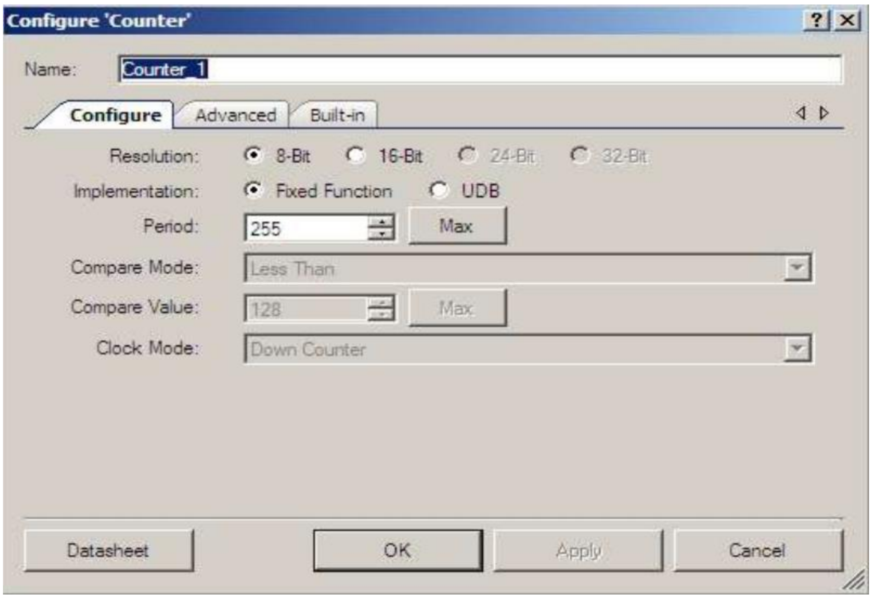


Figure 5-14. Configure dialog box of Counter

5.5 RESULTS:

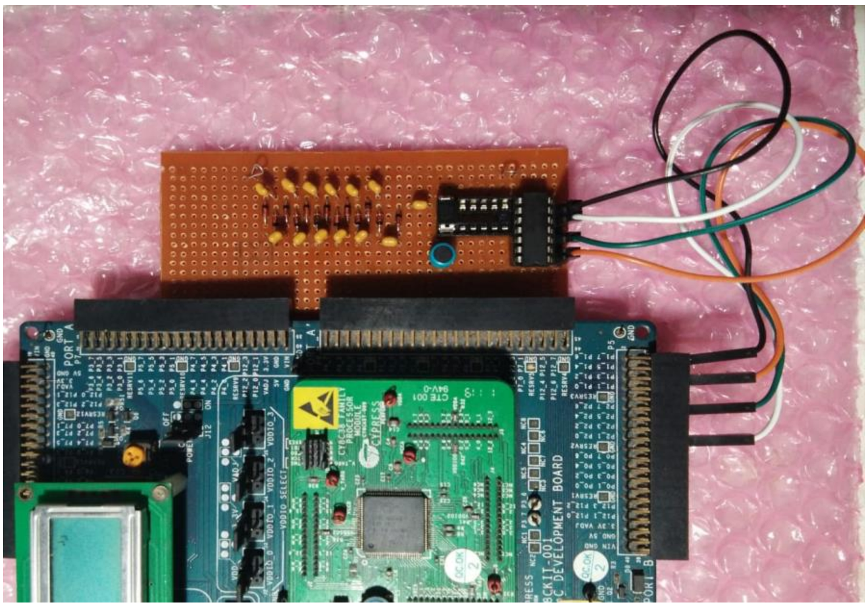


Figure 5-15. Implementation of HVPS circuit

CHAPTER 6
SUMMARY AND FUTURE SCOPE

6.1 Summary:

At the beginning of this project, planning was made to design a device that produces high voltage i.e., HVPS [10,18]. Later another feature was added which is not there at present market i.e., Remote Programmability. With this feature changes can be made to the circuit without being in physical proximity to it. LTSpice software was used for simulating the desired circuit virtually to check the functionality of the circuit. 5V is given as input voltage and obtained output voltage as around 590V with 1mA current and 1W power. In this circuit MOSFET, Zener Diode, Diodes and Resistors as multiplier circuit, Comparator, Schmitt trigger and Integrator are used.

Later two kinds of simulations are done; one is open loop and another one is with feedback. In open loop, only the output voltage was concentrated, it doesn’t produce constant voltage whenever load changes. This was done for various loads to know the circuit functionality. But in case of feedback loop, whenever load changes, initially output voltage decreases then with the help of feedback circuit, within less time output voltage will reach to the initial output. With this simulations it is confirmed that whether the circuit (which is about to use in hardware) is getting proper output or not. Next PSoC (Programmable System on Chip), which is a microcontroller on chip was studied. Various kinds of features were explored in the PSoC creator 4.2 software. With the PSoC microcontroller and PSoC creator 4.2, Remote Programmability feature was successfully implemented. [14]

6.2 Future scope:

There are still some scope for the further improvement of the HVPS for better results and performances. At present the generated power is up to 1W, but in future high power can be generate by adding additional functionalities. Optimization of the physical size issue has to be worked on in next phase which will be helpful to achieve more improved performances.

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