DESIGN OF A SINE WAVE INVERTER USING ARM LPC1768 CONTROLLER

A Project report submitted in partial fulfilment

of the requirements for the degree of B. Tech in Electrical Engineering

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Full Signature of the Student

Place :

Date:

CERTIFICATE

To whom it may concern

This is to certify that the project work entitled **SINE WAVE INVERTER USING ARM LPC1768 CONTROLLER** is the bona fide work carried out by **Bikash Jaiswal, Ayan Mondal, Subharthi Sarkar** a student of B.Tech in the Dept. of Electrical Engineering, RCC Institute of Information Technology (RCCIIT), Canal South Road, Beliaghata, Kolkata-700015, affiliated to Maulana Abul Kalam Azad University of Technology (MAKAUT), West Bengal, India, during the academic year **2018-19**, in partial fulfillment of the requirements for the degree of Bachelor of Technology in Electrical Engineering and that this project has not submitted previously for the award of any other degree, diploma and fellowship.

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Designation:

ABSTRACT

The reliability of power company for the generation of sine wave of frequency 50hz using ARM LPC1768 controller for PWM technique. We are using wein bridge oscillator using LM741 op amp. The basic idea here is to generate or synthesize a sine wave by passing a digitally generated PWM through a low pass filter. This technique can be also used to generate other waveforms like sawtooth, square etc. The reliability of power company electricity service varies greatly due to many factors including the design of the power grid, protective features, power system maintenance practices and severe weather. This project aims to design a microcontroller based pure sine wave inverter using Pulse Width Modulation (PWM) switching scheme to supply AC utilities with emergency power. It involves generating of unipolar modulating signals from a Programmable Interface Computer (LPC1768) and using them to modulate a 12V dc MOSFET based full H-Bridge. The focus is on designing an inexpensive, versatile and efficient pure sine wave inverter that gives a 240V pure sine wave output.

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1. INTRODUCTION

1.1 BACKGROUND OF STUDY

Electrical power exists in two main forms: alternating current (AC) and direct current (DC). The nature of alternating current is that the voltage level can be stepped up or down by use of transformers while that of direct current is that it's possible to store in batteries. Most electrical devices in the world today are designed around AC/DC power conversion. It's therefore necessary to convert the DC power from storage batteries to AC power to power such devices. In practice, DC/AC conversion is done by a power inverter. In today's market, there are two different types of inverters, modified sine wave and pure sine wave inverter. The modified sine wave is similar to a square wave which is less efficient in power consumption. It produces high number of harmonics which affects the devices, hence, reducing its life time. Whereas, a pure sine wave inverter reduces the harmonics to minimum, thus increasing the efficiency of power consumption and life time of AC appliances. It also reduces the audible and electrical noise in audible equipment, TV's, Fluorescent lights and allows inductive load, like fan to run faster and quieter.

1.2 STATEMENT OF THE PROBLEM

In some countries power outage have become more frequent owing to the lack of incentives to invest in aged national grid, transmission and distribution infrastructures, as well as the fact that energy from decentralized, “volatile” renewable sources is not well aligned to work on electricity grids. With an example of April 15th 2012 fault at the Kenya Power national control center and July 2011 power rationing regime due to East Africa's drought these brings a challenge to power facilities like medical centers, households and businesses. Frequent power outages are inconvenient, expensive and difficult to mitigate without very expensive backup power systems. Some of solution to this problem is an auxiliary AC power generator and solar panels but the cost of fossil fuels continues to increase rapidly thus it will not be cost effective in the future while solar power has some aesthetic, economic and technical drawbacks. A more effective and reliable alternative is battery power back-up system.

1.3 MOTIVATION FOR PROJECT

Since ARM controller has not been used so far for producing SPWM inverter, so there is scope to try for it.

LITERATURE REVIEW

2.1 INVERTER

An inverter is a device that converts the DC sources to AC sources. The purpose of a DC/AC power inverter is typically to take DC power supplied by a battery, such as a 12 volt car battery, and transform it into a 220 volt AC power source operating at 50 Hz, emulating the power available at an ordinary household electrical outlet. Inverters are used in applications such as adjustable-speed ac motor drivers, uninterruptible power supplies (UPS) and ac appliances run from an automobile battery.

2.2 CLASSIFICATION OF INVERTERS

On the market today there are two different types of inverters:

- Modified Square Wave (Modified Sine Wave)
- Pure Sine Wave (True Sine Wave)

These inverters differ in their outputs, providing varying levels of efficiency and distortion that can affect electronic devices in different ways.

Modified Sine Wave A modified sine wave is similar to a square wave but instead has a "stepping" look to it that relates more in shape to a sine wave. This can be seen in Figure 1, which displays how a modified sine wave tries to emulate the sine wave itself. The waveform is easy to produce because it is just the product of switching between three values at set frequencies, thereby leaving out the more complicated circuitry needed for a pure sine wave hence provides a cheap and easy solution to powering devices that need AC power. However it does have some drawbacks as not all devices work properly on a modified sine wave, products such as computers and medical equipment are not resistant to the distortion of the signal and must be run off of a pure sine wave power source Modified sine wave inverters approximate a sine wave and have low enough harmonics that do not cause problem with household equipment's. The main disadvantage of the modified sine wave inverter is that peak voltage varies with the battery voltage.

Pure Sine Wave Pure sine wave inverter represents the latest inverter technology. The waveform produced by these inverters is same as or better than the power delivered by the utility. Usually sine wave inverters are more expensive than the modified sine wave inverters due to their added circuitry.

There are two methods in which the low voltage DC power is inverted to AC power;

 The low voltage DC power is first boosted to high voltage power source using a DCDC booster then converted to AC power using pulse width modulation.

 The low voltage DC power is first converted to AC power using pulse width modulation then boosted to high AC voltage using a boost transformer.

The second method is used in modern inverters extensively because of its ability to produce a constant output voltage compared to the first method that require additional circuit to boost the voltage.

2.3 PULSE WIDTH MODULATION

Pulse width modulation (PWM) is a powerful technique for controlling analogue with a processor's digital outputs. . It is also known as pulse duration modulation (PDM). The leading edge of the carrier pulse remains fixed and the occurrence of the trailing of the pulses varies. PWM signals find a wide application in modern electronics. Some of these reasons are:

- **Reduced Power Loss** – switched circuits tend to have lower power consumption because the switching devices are almost always off (low current means low power) or hard-on (low voltage drop means low power). Common circuits that utilize this feature include switched-mode power supplies, Class D audio power amplifiers, power inverters and motor drivers. Frequently, these circuits use semi-analogue techniques (ramps and comparators) rather than digital techniques, but the advantages still hold.

- **Easy to Generate** – PWM signals are quite easy to generate. Many modern microcontrollers include PWM hardware within the chip; using this hardware often takes very little attention from the microprocessor and it can run in the background without interfering with executing code. PWM signals are also quite easy to create directly from a comparator only requiring the carrier and the modulating signals input into the comparator.

- **Digital to Analogue Conversion** – pulse width modulation can function effectively, as a digital to analogue converter, particularly combined with appropriate filtering. The fact that the duty cycle of a PWM signal can be accurately controlled by simple counting procedures is one of the reasons why PWM signals can be used to accomplish digital-to-analogue conversion.

The desired PWM technique should have the following characteristics.

 Good utilization of DC supplies voltage possibly a high voltage gain.

 Linearity of voltage control.

 Low amplitude of low order harmonic of output voltage to minimize the harmonic content of output currents.

 Low switching losses in inverter switches.

 Sufficient time allowance for proper operation of the inverter switches and control system.

There are many types of PWM techniques used in sine wave inverters. The commonly used techniques are:

 Single or 2 level PWM; it's the simplest way of producing the PWM signal. It's through

.comparison of a low-power reference sine wave with a triangle wave as shown in figure 3. Using these two signals as input to a comparator the output will be a 2-level PWM signal as shown in figure 2. It's the most common and popular technique of pulse-width-modulation (PWM).

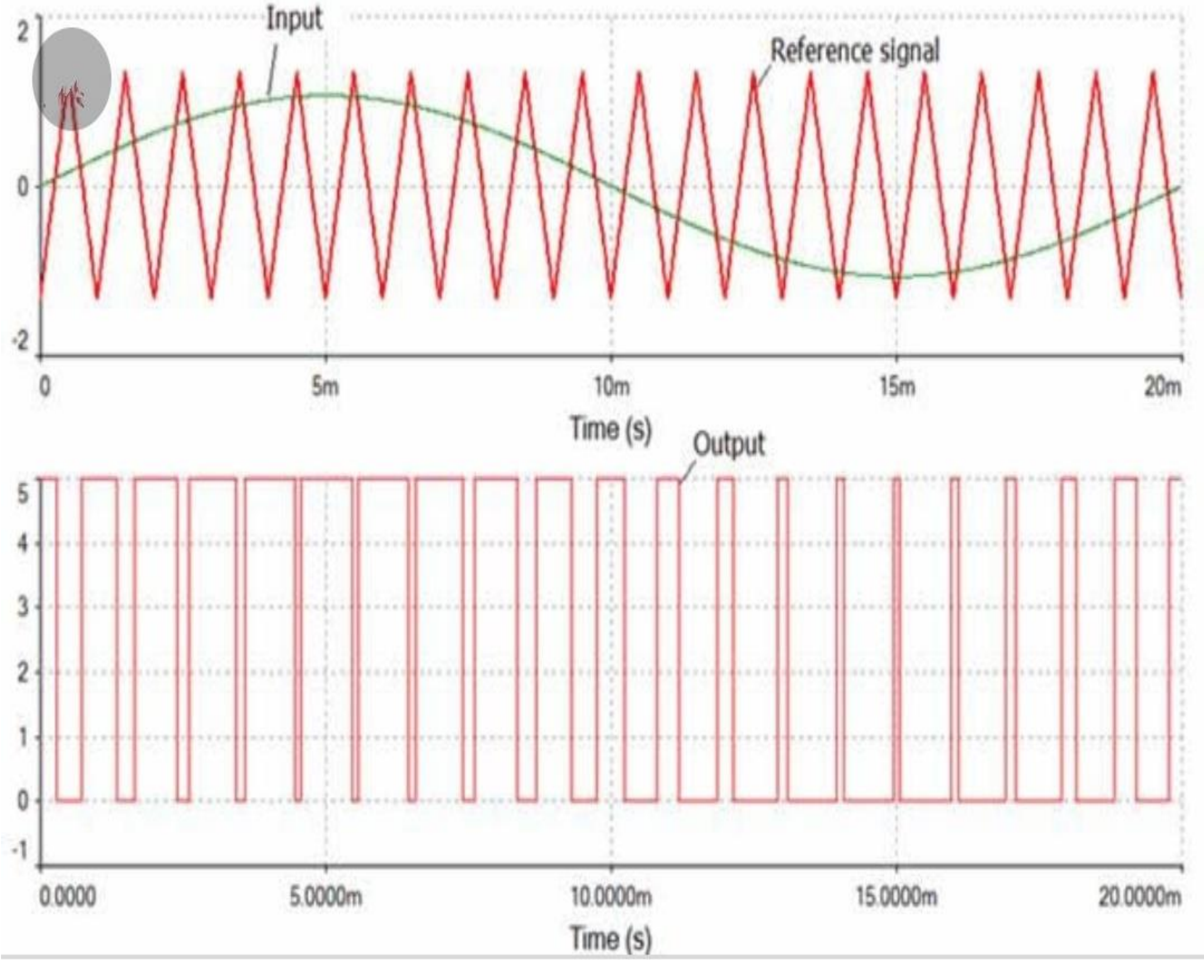


FIG: TWO LEVEL PWM

 Multilevel PWM; The harmonic content can be reducing significantly by using several pulses in each half- cycle of the output voltage. There exist different levels of multiphase PWM producing an improved output with increase of the level of the PWM used. The most common ones are: 3 levels PWM, 5 levels PWM, 7 levels PWM and 9 levels PWM. The choice of which PWM level to use is determined by the cost of the inverter and the quality of the output. To balance between cost and quality of the inverter, a 3level PWM is commonly used.

Figure 3 shows a 3 level PWM. Comparing the 3-level PWM to the 2-level PWM, the harmonics plot shows no higher level harmonics of significant magnitude. This represents the 3-Level signal following much more closely the desired sine wave. However, the primary frequency has a much lower voltage magnitude than that of the 2-Level design. The reason for this is the presence of other frequencies which are not harmonics of the 50Hz signal, which are caused by the switching of the signal from one polarity to the other, and back.

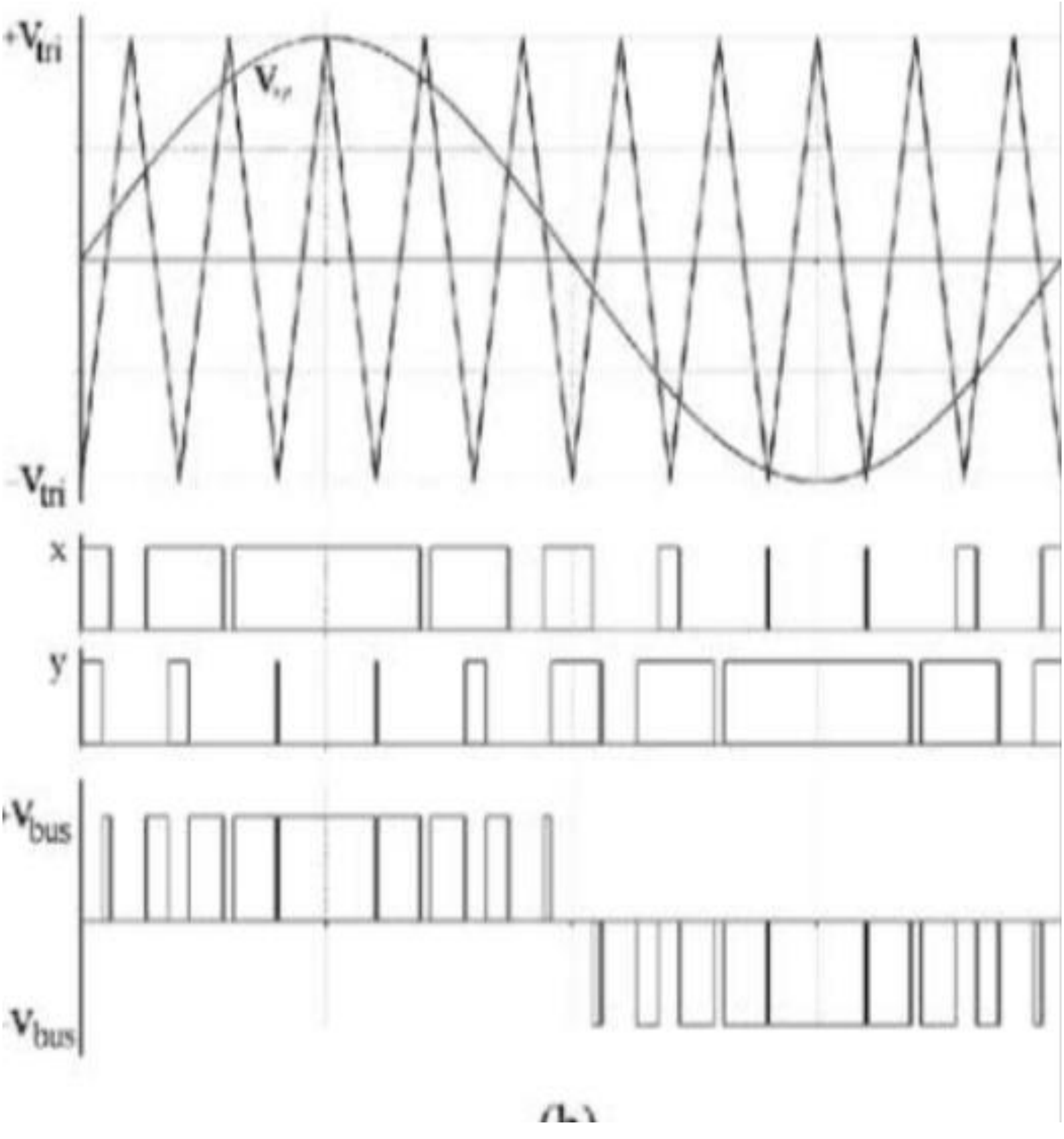


FIG: THREE LEVEL PWM

In electronic power converters and motors, PWM is used extensively as a means of powering alternating current (AC) devices with an available direct current (DC) source or for advanced DC/AC conversion. Variation of duty cycle in the PWM signal to provide a DC voltage across the load in a specific pattern will appear to the load as an AC signal, or can control the speed of motors that would otherwise run only at full speed or off. The pattern at which the duty cycle of a PWM signal varies can be created through simple analogue components, a digital microcontroller, or specific PWM integrated circuits.

Analogue PWM control requires the generation of both reference and carrier signals that feed into a comparator which creates output signals based on the difference between the signals. The reference signal is sinusoidal and at the frequency of the desired output signal, while the carrier signal is often either a saw tooth or triangular wave at a frequency significantly greater than the reference. When the carrier signal exceeds the reference, the comparator output signal is at one state, and when the reference is at a higher voltage, the output is at its second state. This process is shown in Figure 3 with the triangular carrier wave in black, sinusoidal reference wave in blue, and modulated and unmodulated sine pulses.

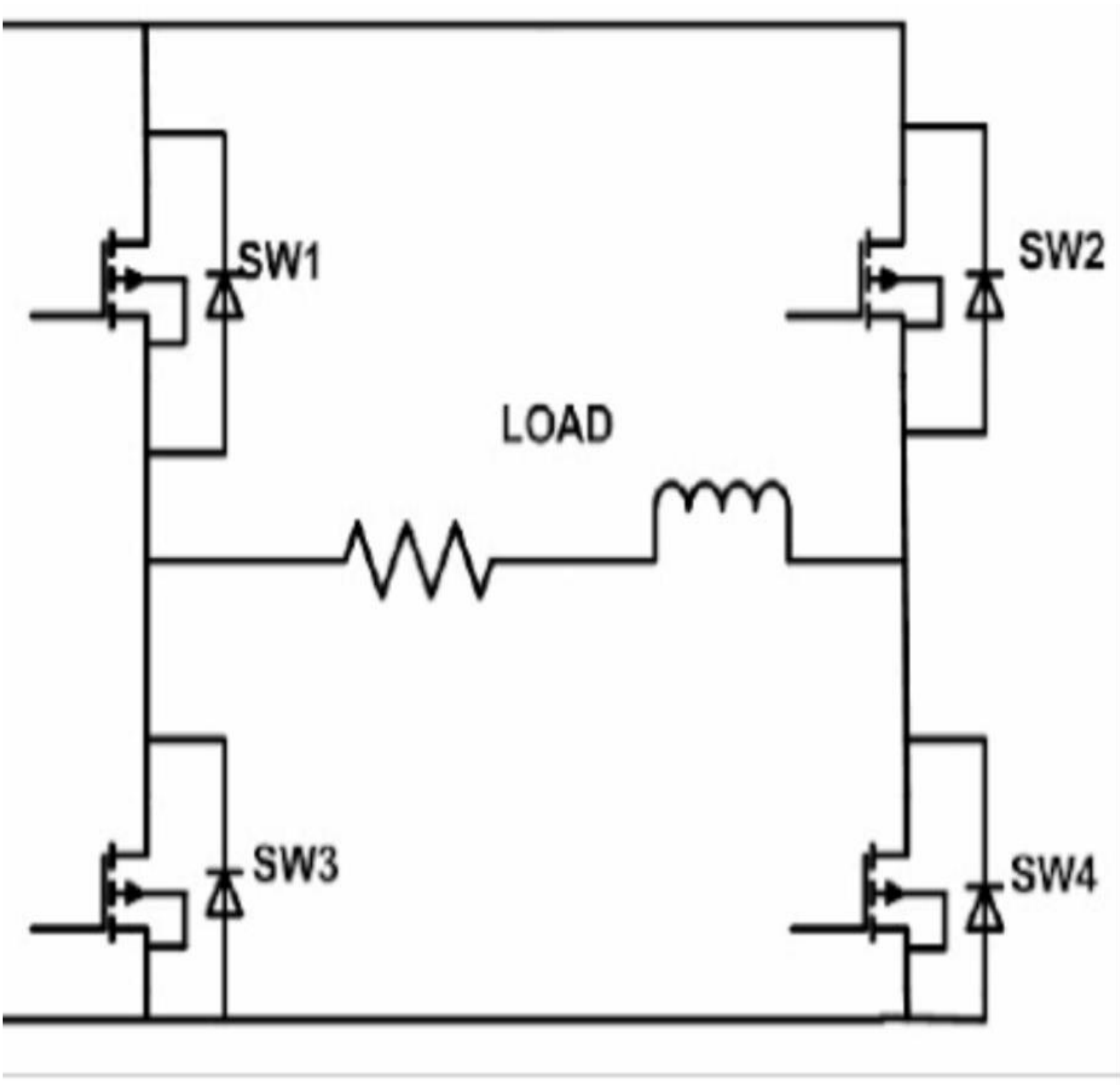
A digital microcontroller PWM requires a reference signal, sometimes called a modulating or control signal, which is a sinusoidal in this case; and a carrier signal, which is a triangular wave that controls the switching frequency. Microcontroller modules are used to compare the two to give a PWM signal.

The applications of PWM are wide variety used like ranging from measurement and communications to power control and conversion. In PWM inverter harmonics will be much higher frequencies than for a square wave, making filtering easier.

In PWM, the amplitude of the output voltage can be controlled with the modulating waveforms. Reduced filter requirements to decrease harmonics and the control of the output voltage amplitude are two distinct advantages of PWM. Disadvantages include more complex control circuits for the switches and increased losses due to more frequent switching.

2.4 H-BRIDGE CONFIGURATION

A H- Bridge or full- bridge converter is a switching configuration composed of four switches in an arrangement that resembles a H. By controlling different switches in the bridge, a positive, negative, or zero- potential voltage can be placed across a load. When this load is a motor, these states correspond to forward, reverse, and off. The use of an H- Bridge configuration is shown in Figure



As shown in Figure the H- Bridge circuit consists of four switches corresponding to high side left, high side right, low side left, and low side right. There are four possible switch positions that can be used to obtain voltages across the load. These positions are outlined in Table 1. Note that all other possibilities are omitted, as they would short circuit power to ground, potentially causing damage to the device or rapidly depleting the power supply.

The switches used to implement an H- Bridge can be mechanical or built from solid state transistors. Selection of the proper switches varies greatly. The use of P- Channel MOSFETs on the high side and N- Channel MOSFETs on the low side is easier, but using all N-Channel MOSFETs and a FET driver, lower “on” resistance can be obtained resulting in reduced power loss. The use of all N- Channel MOSFETs requires a driver, since in order to turn on a high- side

N- Channel MOSFET, there must be a voltage higher than the switching voltage (in the case of a power inverter, 12V). This difficulty is often overcome by driver circuits capable of charging an external capacitor to create additional potential.

2.5 MICRO CONTROLLER

A microcontroller (also microcontroller unit, MCU or µC) is a small computer on a single integrated circuit consisting of a relatively simple CPU combined with support functions such as a crystal oscillator, timers, watchdog, serial and analog I/O etc. Neither program memory in the form of NOR flash or OTP ROM is also often included on chip, as well as a, typically small, read/write memory.

Microcontrollers are designed for small applications. Thus, in contrast to the microprocessors used in personal computers and other high-performance applications, simplicity is emphasized. Some microcontrollers may operate at clock frequencies as low as 32 kHz, as this is adequate for many typical applications, enabling low power consumption (milliwatts or microwatts). They will generally have the ability to retain functionality while waiting for an event such as a button press or other interrupt; power consumption while sleeping (CPU clock and most peripherals off) may be just nanowatts, making many of them well suited for long lasting battery applications.

Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, remote controls, office machines, appliances, power tools, and toys. By reducing the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to digitally control even more devices and processes.

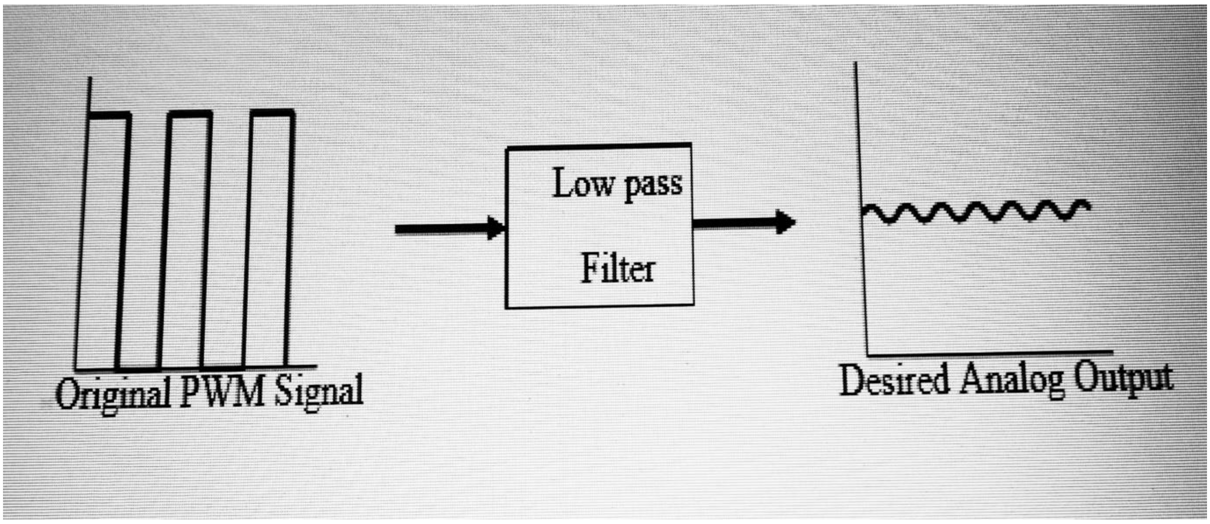
In order to use the H-bridge properly, there are four MOSFETs that need to be controlled. This can be done either with analog circuits or a microcontroller. In this case, we chose the microcontroller over the analog system for several reasons:

 It would be simpler to adapt. With an analog system, it would be difficult to make changes for the desired output. In many cases, this is a desired trait, as it would be designed for a single purpose and therefore a single output. However, as this is something that is designed to be available all over the world, it needs to be adjustable to different standards of frequency and voltage. With an analog circuit, this would require a different circuit that it would have to switch over to, while with a micro- controller, it merely requires a change in the program's code.

 It can allow for easy feedback to control the power flowing through the load. One of the problems that can occur with systems like this is that the variances in load can cause variances in the supplied current and voltage. With a microcontroller, it is possible to have it "look" at the power output and change the duty cycle based on whether or not the load requires additional power or is being oversupplied.

2.6 FILTER

The idea behind realizing digital-to-analog (D/A) output from a PWM signal is to analog lowpass filter the PWM output to remove most of the high frequency components, ideally leaving only the D.C. component. This is depicted in Figure 6. The bandwidth of the low-pass filter will essentially determine the bandwidth of the digital-to-analog complexity.



Filters are classification is based on performance. They include:

- Active filters (built using op-amps)
- Passive filters (composed solely of resistors, inductors, and capacitors).

Active filters avoid the impedance loading issues suffered by passive filters, where the upstream or downstream impedances surrounding the filter can change the filter properties. Passive filters can offer lower cost and reduced design complexity.

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With active filters, one must also consider the gain bandwidth of the op-amps used. The gain bandwidth represents the upper frequency that the op-amp can effectively handle when used in a closed-loop circuit configuration with small signal input. In terms of active low-pass filters, input signal components with frequency above the gain bandwidth will be attenuated since the op-amp will not have the ability to handle such frequencies. Op-amps with sufficient gain bandwidth to handle these frequencies are relatively expensive, and at some point one may as well just use an actual DAC chip.

Passive filters do not suffer as much from a gain bandwidth problem. The biggest drawback of passive is always impedance related. Upstream and downstream impedances can affect the performance properties of the filter. In the PWM/DAC application, upstream of the filter will be the PWM output from the DSP. This is a low output-impedance source that will not significantly affect the filter. In the downstream direction, one can use a low-cost voltage follower op-amp to create a high-impedance input. Since the op-amp is in the signal chain after the low-pass filter, an op-amp with large gain bandwidth is not needed.

Filters are further classified as

 1st order linear time-invariant filters. The continuous-time domain transfer function for a 1st order filter is given by the equation;

(vout/vin=1/(Ts+1));

Where the time constant τ is in units of seconds. It may be constructed from a single resistor and capacitor.

 2nd order linear time-invariant filters. The transfer function is given by the equation;

(vout/ vin=ωn2/(s2+2 ζ ωn+ωn2));

where ωn is the un-damped natural frequency in units of (rad/s)2, and ζ is the nondimensional damping ratio. It’s constructed by cascading two 1st order RC filters in series or a resister inductor and a capacitor.

2.7 TRANSFORMER

A transformer is an electrical device that transfers energy between two circuits through electromagnetic induction. A transformer may be used as a safe and efficient voltage converter to change the AC voltage at its input to a higher or lower voltage at its output. Other uses include current conversion, isolation with or without changing voltage and impedance conversion. A transformer consists of two windings of wire that are wound around a common core to provide tight electromagnetic coupling between the windings. The core material is often a laminated iron core. The coil that receives the electrical input energy is referred to as the primary winding, the output coil is the secondary winding.

The ideal transformer induces secondary voltage VS as a proportion of the primary voltage VP and respective winding turns as given by the equation (Vp/vn)=(Np/Ns)=(Is/Ip)=a, Where,

a is the winding turns ratio, the value of these ratios being respectively higher and lower than unity for step-down and step-up transformers, VP designates source impressed voltage, VS designates output voltage, and,

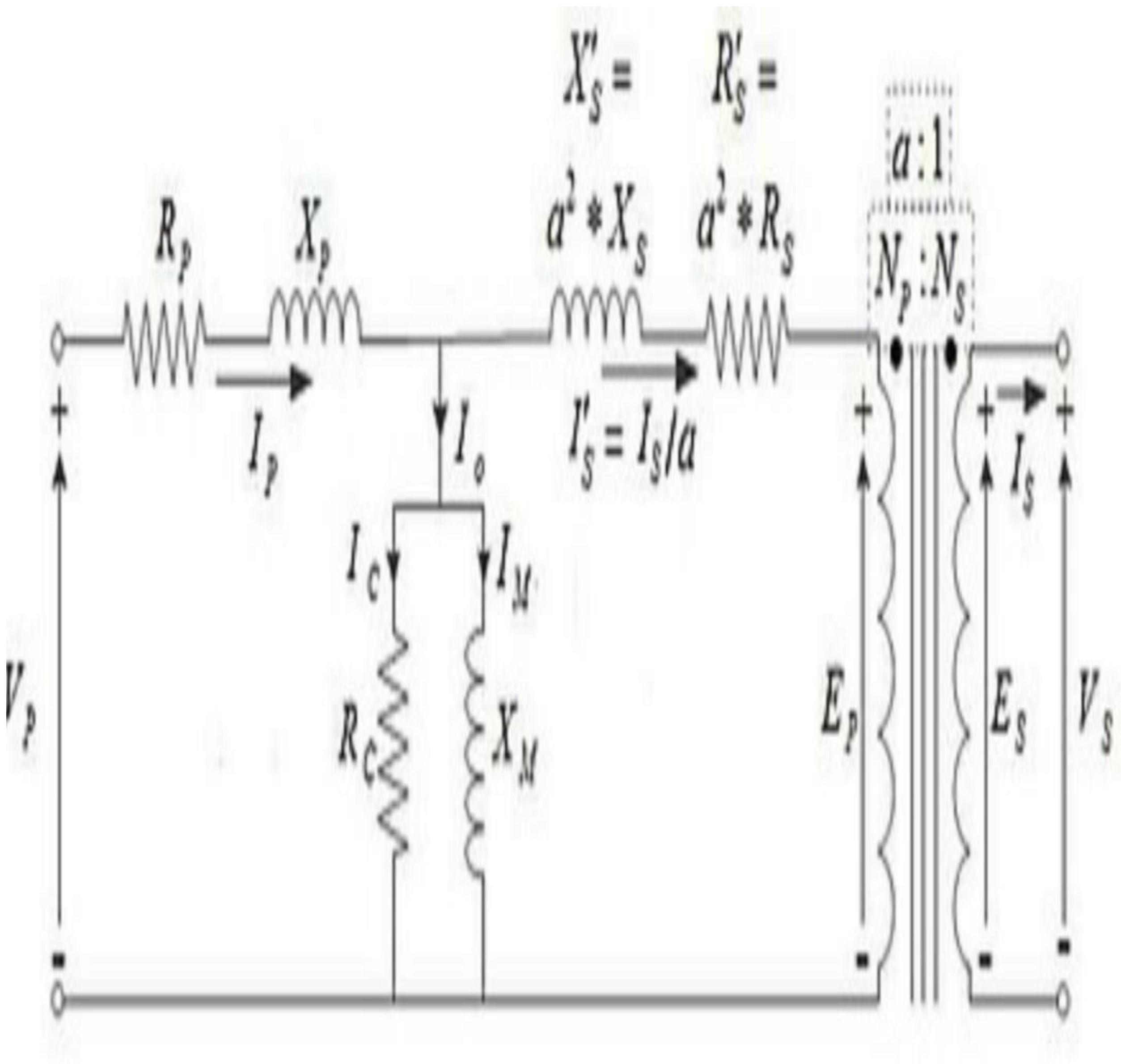


FIG: TRANSFORMER EQUIVALENT CIRCUIT

Core form and shell form transformers include;

 Laminated steel cores. They have cores made of high permeability silicon steel.

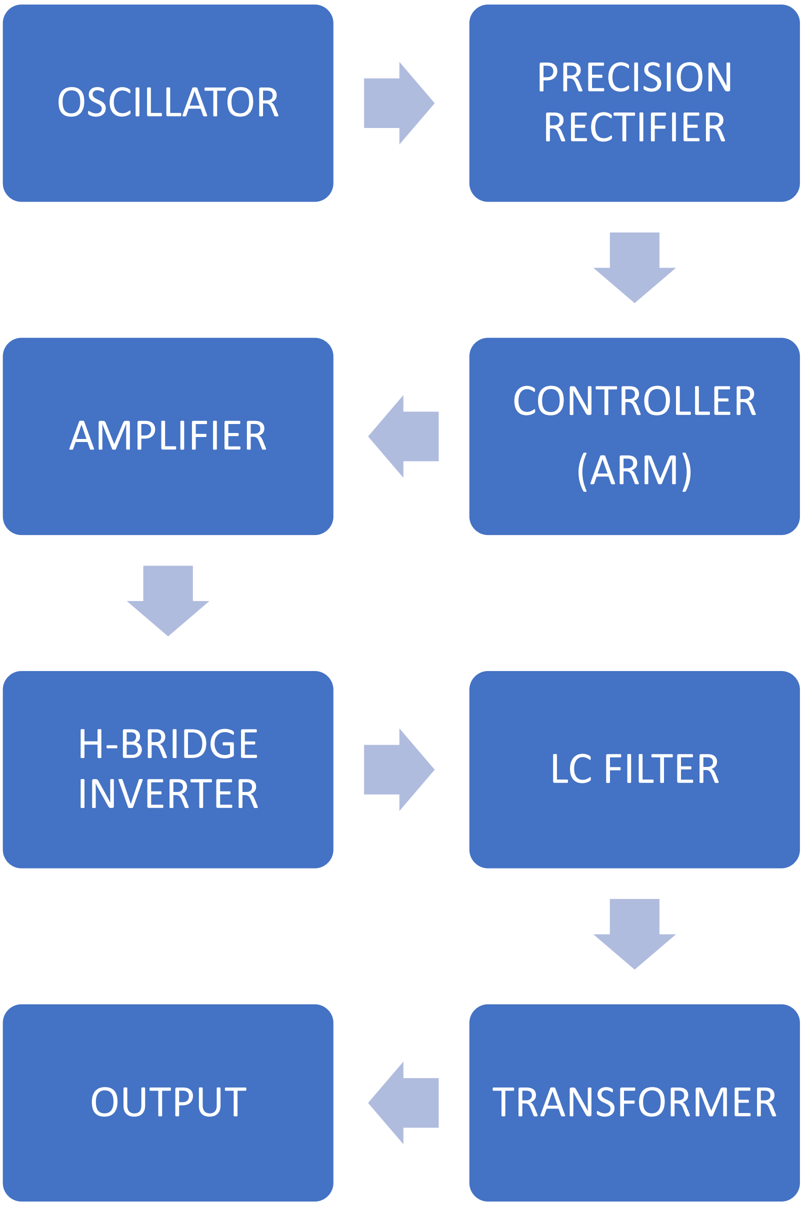
 Solid cores. Their cores are made from non-conductive magnetic ceramic materials called ferrites, a combination of a high magnetic permeability and high bulk electrical resistivity material.

 Toroidal cores. They are built around a ring-shaped core, which, depending on operating frequency, is made from a long strip of silicon steel or permalloy wound into a coil, powdered iron or ferrite.

 Air cores. It’s produced by simply by placing the windings near each other. The air, which comprises the magnetic circuit, is essentially lossless and so an air-core transformer eliminates loss due to hysteresis in the core material. The leakage inductance is inevitably high, resulting in very poor regulation, and hence such designs are unsuitable for use in power distribution.

3. DESIGN

3.1 BLOCK DIAGRAM



3.2 WEIN BRIDGE OSCILLATOR

In this project, we will build a wien bridge oscillator circuit with an LM741 op amp. A wien bridge oscillator circuit is a circuit that produces sine waves as output. It's the same of waveform that is output from AC electricity in homes.Wien bridge oscillators always use an op amp chip to create oscillations along with resistors and capacitors in order to shape the waves into sine waves and to determine the frequency and gain of the sine waveform.

The Wien Bridge Oscillator uses a feedback circuit consisting of a series RC circuit connected with a parallel RC of the same component values producing a phase delay or phase advance circuit depending upon the frequency. At the resonant frequency fr the phase shift is 0^{o}.

Even though when wien bridge oscillators were first created by Max Wien in 1891 used a lamp in the circuit, today there are many variations that can be done instead but that create the same output. Back during that time, lamps were used often. Today there aren't used as much. This is why there have been modifications to the original circuit design that was created by Mr. Wien.

So in this circuit we're going to use a variation. We don't have to use a lamp, because today it's not very common to use lamps anymore. And you may not have it. If you do, of course you can use it. But in place a lamp, we can substitute a resistor.

So to build this circuit, all you need is an LM741 op amp and resistors, capacitors, and potentiometers. Potentiometers are variable resistors which allow us to adjust the gain of the circuit.

Through the resistor and capacitor values we choose, we can determine the frequency and gain of the output sine wave signal.

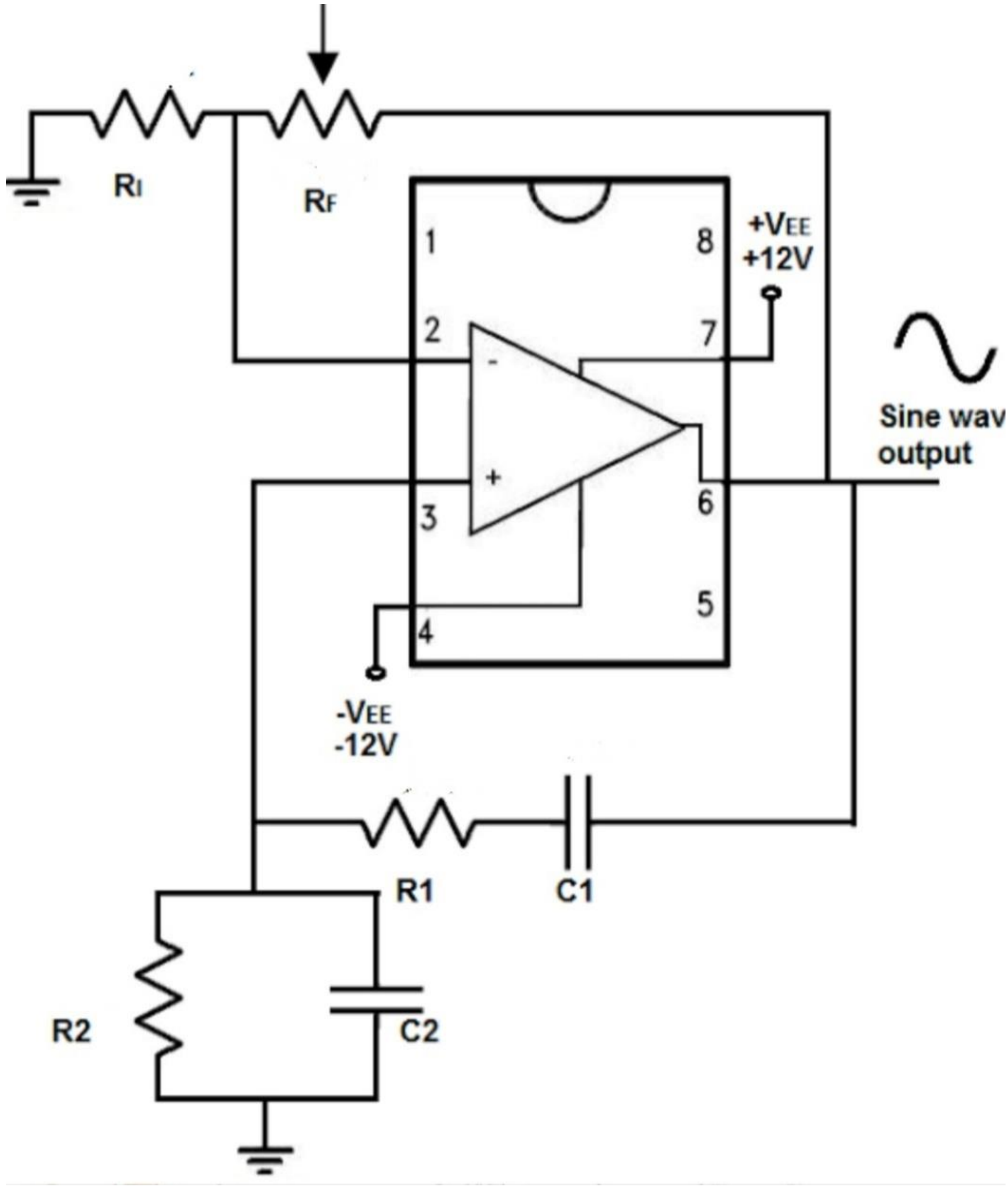


FIG: WEIN BRIDGE OISCILLATOR CIRCUIT DIAGRAM

3.3 PRECISION RECTIFIER

Full-wave rectifier circuit converts complete cycle of the input signal into unidirectional signal output. This process is called as rectification. Rectification use the one-directional-conductivity of the diode. The cut-in voltage of diode affect the rectification of small signals - this shortcoming can be addressed by precision rectifier circuits that use OPAMP.

The precision rectifier, also known as a super diode, is a configuration obtained with an operational amplifier in order to have a circuit behave like an ideal diode and rectifier. It is useful for high-precision signal processing.

Precision rectifiers use op amp based circuits whereas ordinary rectifiers use simple diodes. The advantages of precision rectifiers are:

- No diode voltage drop (usually 0.7) between input and output.
- The ability to rectify very small voltages (very much smaller than the diode forward voltage of 0.7V).
- The rectified output can be amplified if required.
- Low output impedance.
- Precision rectifier is a close approximation of an ideal diode because of absence of forward voltage drop.

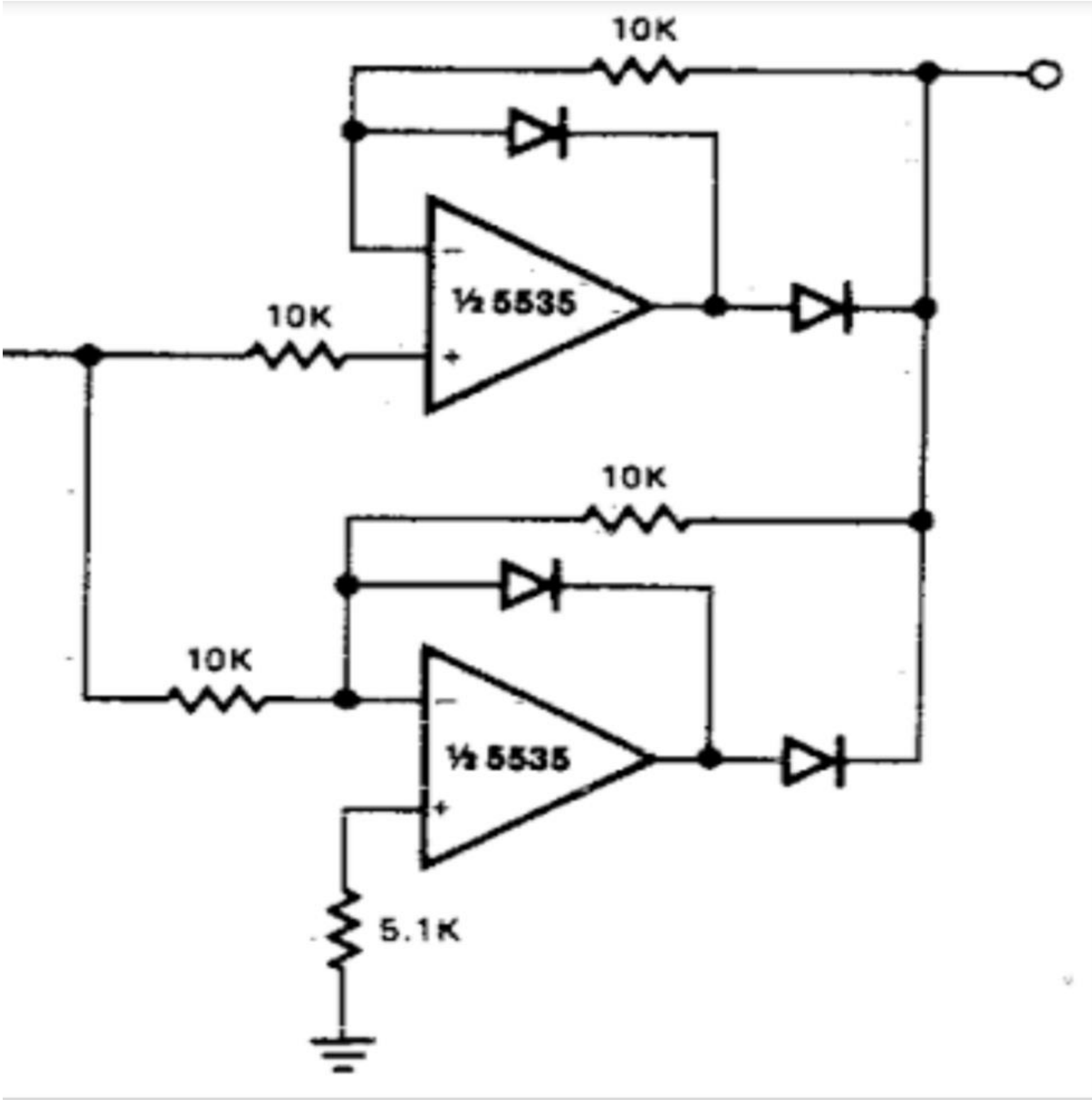


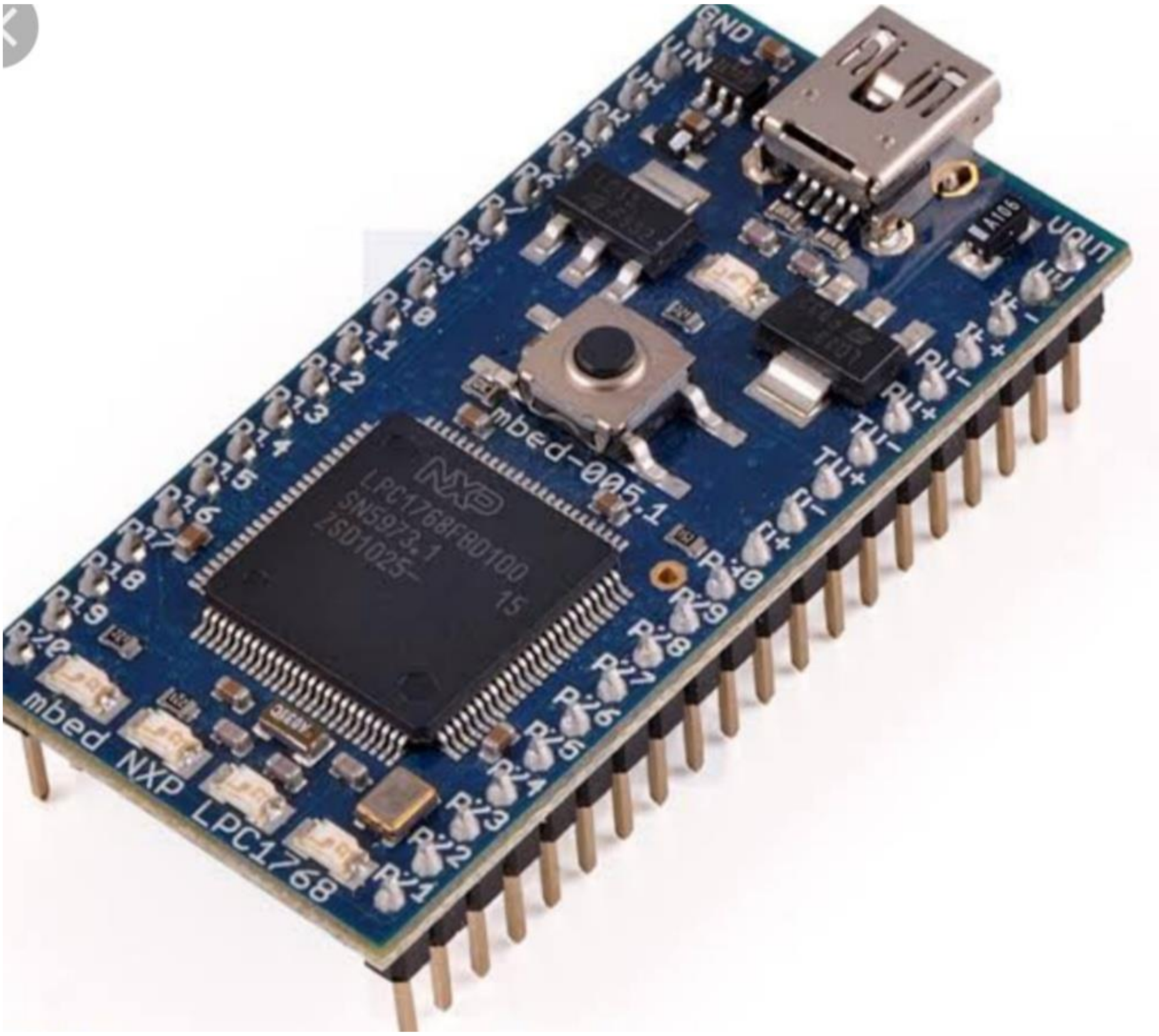
FIG: PRECISION RECTIFIER

3.4 LPC1768 CONTROLLER

The LPC1768 is a Cortex®-M3 microcontroller for embedded applications featuring a high level of integration and low power consumption at frequencies of 100 MHz. Features include 512 kB of flash memory, 64 kB of data memory, Ethernet MAC, USB Device/Host/OTG, 8-channel DMA controller, 4 UARTs, 2 CAN channels, 3 SSP/SPI, 3 I2C, I2S, 8-channel 12-bit ADC, 10-bit DAC, motor control PWM, Quadrature Encoder interface, 4 general purpose timers, 6-output general purpose PWM, ultra-low power Real-Time Clock with separate battery supply, and up to 70 general purpose I/O pins. The LPC1768 is pin-compatible to the 100-pin LPC2368 Arm7™ MCU

FEATURE

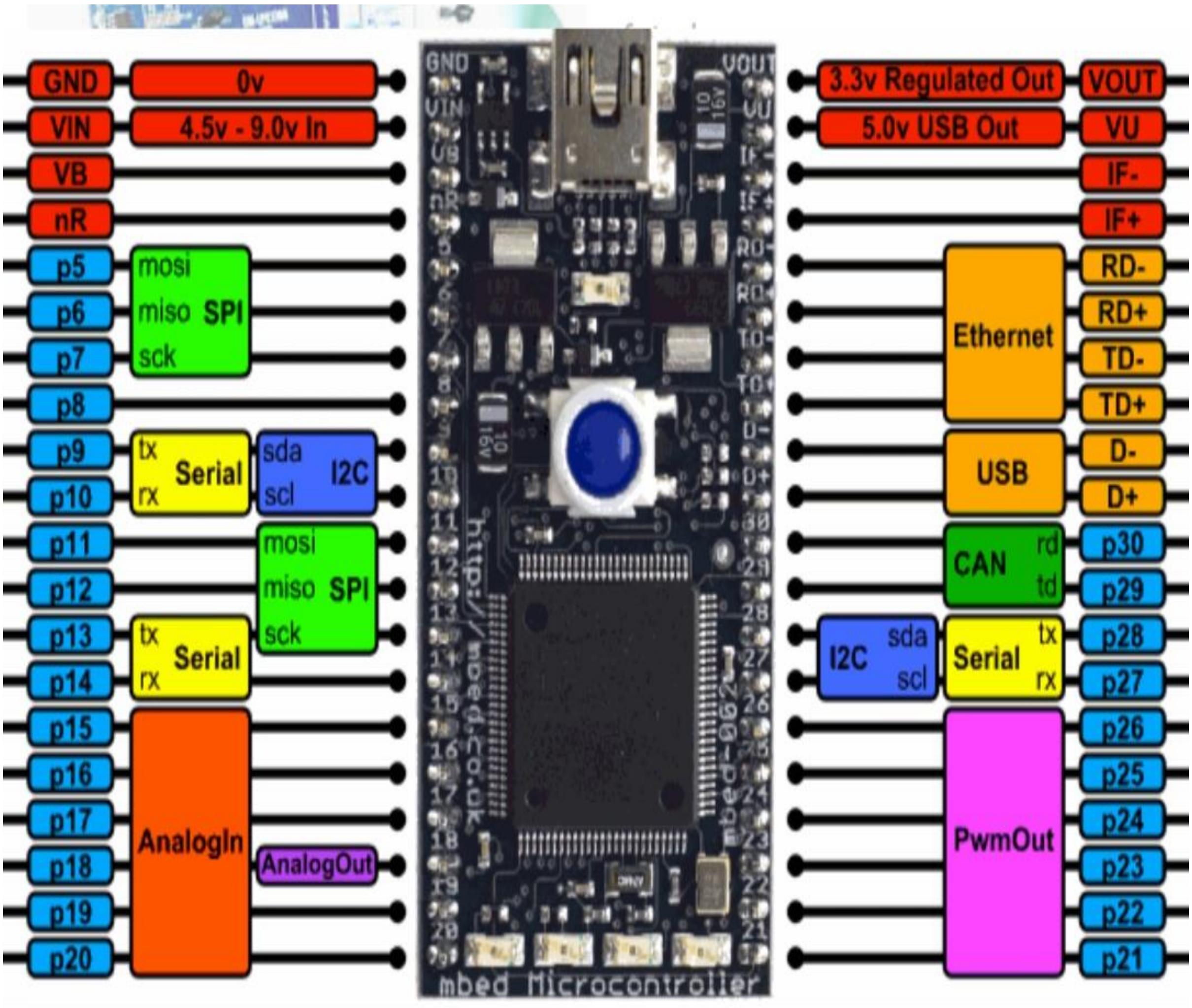
- Arm® Cortex-M3 processor, running at frequencies of up to 100 MHz
- Arm Cortex-M3 built-in Nested Vectored Interrupt Controller (NVIC)
- Up to 512 kB on-chip flash programming memory
- Up to 64 kB On-chip SRAM
- In-System Programming (ISP) and In-Application Programming (IAP)
- Eight channel General Purpose DMA controller (GPDMA)
- Ethernet MAC with RMII interface and dedicated DMA controller
- USB 2.0 full-speed device/Host/OTG controller



LPC 1768 CONTROLLER

ARM CONTROLLER PROGRAMMING

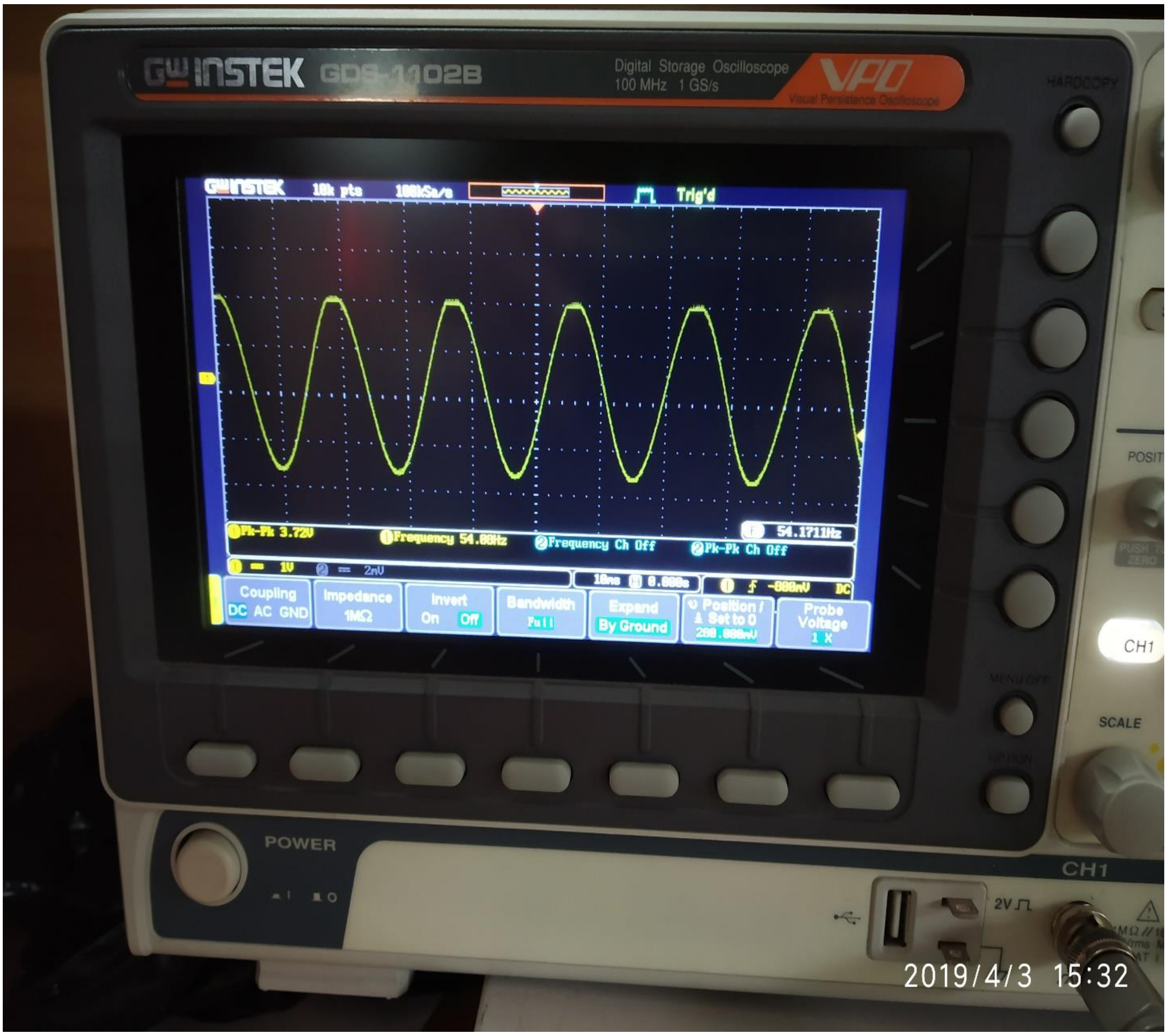
```
#include "mbed.h"


PwmOut led(LED1);  // Led on board

PwmOut green(p25); // A green led is connected at Pin25 with resistor to ground


AnalogIn ain(p20); // Potmeter 810k connected between VOUT(3.3V Pin40) and GND (Pin1) with the
wiper connect to Pin20


int main() {
  green.period_us(100); // Set the period to 100uS = 10kHz
  led.period_ms(10);    // Set the period to 10mS = 100Hz
                    // Both periods will be set on 10mS, because the same timer is used for both
                    // Changing the period for one wil change the period for the others also
  while(1) {
       led = ain;     // Set duty cycle for LED1
       green = ain/2; // Set duty cycle for the green led, the "on" time will only the half of the period
    }
  }
```



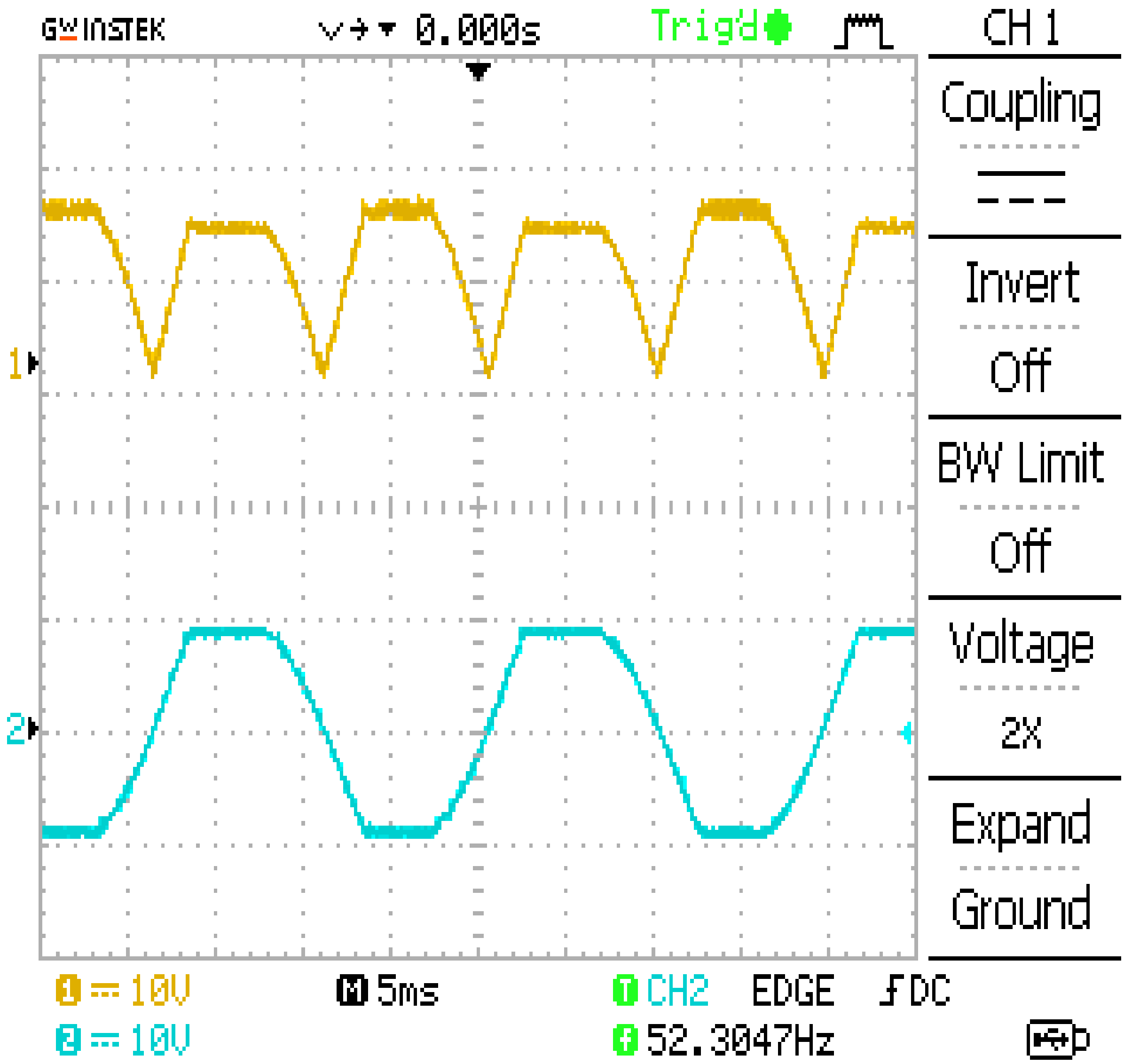
PIN CONFIGURATION OF LPC1768 CONTROLLER

4. RESULT AND OUTPUT

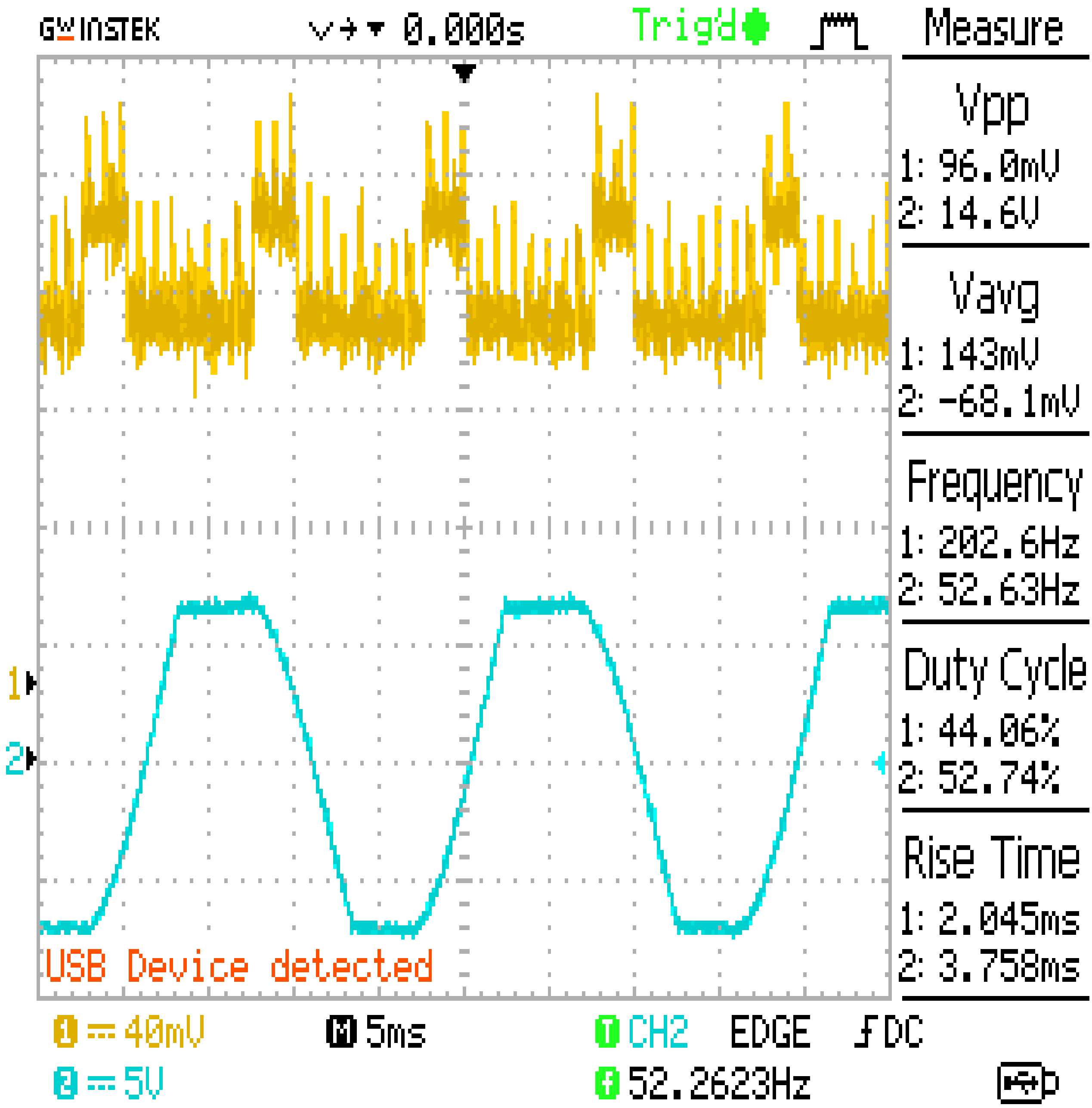
4.1 OSCILLATOR OUTPUT



4.2 PRECISION RECTIFIER OUTPUT



4.3 ARM CONTROLLER OUTPUT



5. CONCLUSION

The basic goal of this project, which is designing and implementing a working DC-AC sine wave inverter that could efficiently provide clean power using 2-level PWM, has been achieved. Different signals were generated to control MOSFET switches arranged in an Hbridge. The aim was to modulate the bridge with a 2 level PWM and obtain a 3 level PWM and filter the bridge output to get a pure sine wave. Although the final output waveform was not the desired waveform, the design went along in trying to design an affordable sine wave inverter.

This project provides a good building block that can be added in to many general-use high-power applications, as well as a base to work off for a self-regulating power supply.

6. RECOMMENDATION

An improvement that can be made is a feedback system which would give the microcontroller a view of the output across the load so that the signals controlling the system could be adjusted according to certain parameters in the programming. As different loads are connected and disconnected, the efficiency and output of the system will change. In order to keep the system running at 240Vrms and 50Hz, it has to be able to adapt to changes in its load and battery levels. Implementing a voltage booster at the bridge input is one recommended method as it would minimize the effect battery voltage drop on the output

7. REFERENCE

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