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Integrating renewable energy with conventional power grid

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Integrating Renewable Energy with Conventional Power Grid

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Abstract

This study is manly introducing a modified integrating method which is much suitable for smart grids. In smart grid the integration between the outputs of the renewable energy sources, such as solar energy, wind energy and the conventional power sources takes place. This integration may affect the power quality negatively; therefore, some considerations should be taken into account, i.e., the power magnitude, phase, and frequency should be synchronized, and be identical during the entire time of integration between the two different sources of power, the renewable energy source and the conventional power grid. To ensure this matching, Matlab/Simulink simulation and prototype were proposed to produce the optimum values of the previous parameters (power magnitude, phase, and frequency). M file was written to choose the optimum value for the Boost converter component. The verification of DC to AC model and parameters was accomplished by Matlab /Simulink simulation.
PWM codes were written to drive the Boost converter and the DC to AC inverter. Moreover, a prototype was implemented and tested.

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Chapter 1: Introduction

1.1 Background

Considerable concerns have been raised regarding the Peak oil hypothesis: the amount of petroleum extraction should reach its peak somewhere between 2025 and 2040. Beyond that, the amount of extracted oil will start to decline. The growing concerns for nuclear safety after the Japanese disaster will decrease the usage of nuclear energy as a power source. On the other hand, the demand for electricity is increasing exponentially due to the rapid increase in the world population and the spread of power hungry devices among citizens. Seeking to fill the gap between the conventional limited power sources and the increasing power demand, the integration between the conventional power sources and the renewable energy sources is inevitable. In fact, certain countries have already widely implemented such hybrid power generation systems. In December 2012, Germany's electricity production from photovoltaic systems has reached 32.2 GW. Several European countries have taken the same direction: France, Spain, and Netherlands to mention a few.

One of the major challenges facing this integration is the unconventional fluctuating nature of electricity generated from photovoltaic systems. Such nature harms the power quality. Another impediment in the way of such integration is that the photovoltaic sources produce direct current (DC) and the power produced by conventional grids is usually in alternating current (AC). Therefore, a smart DC to AC conversion method is required. This method must treat the power produced from the photovoltaic source and make it compatible with the power resulting from conventional power sources such as; power stations that generate electricity depending on combustible fuels, such as coal, and natural gas. Both constituents must be synchronized in phase and magnitude.

The power generated from photovoltaic system is highly influenced by the surrounding environment. Figure 1 illustrates the I-V characteristics of electricity generated from photovoltaic and the effect of solar irradiance as well as ambient temperature.

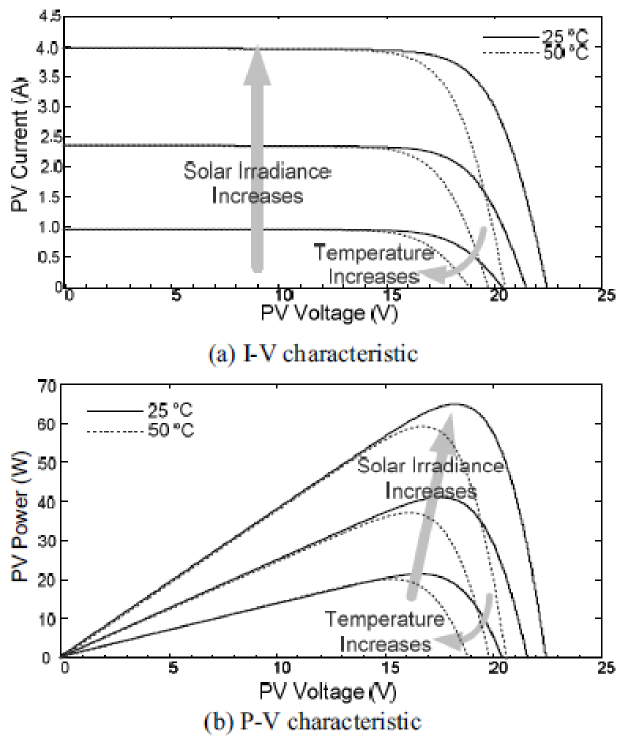

Figure 1: The effect of solar irradiance and temperature on PV I-V and P-V characteristics [1]

Maximum Power Point Tracking (MPPT) is the process that guarantees attaining the maximum power from a Photovoltaic (PV) panel. Nowadays, all MPPT controllers have Pulse Width Modulation (PWM) internally to control the energy flow. The controller changes the duty cycle of PWM to control the current flow. There are several maximum power point tracking (MPPT) algorithms which changes the equivalent resistance seen by the PV panel in order to fool it into generating the maximum possible power. The MPPT system samples the output of the Solar cells and applies the MPPT algorithm to achieve maximum power despite the variation in environmental conditions. MPPT devices are usually integrated into a system that provides voltage or current conversion, filtering, and regulation for driving various loads, including power grids, batteries, or motors.[1]

The Duty Cycle (D) is the portion of time that a device spends in the active state as a fraction of the total cycle time (period). The term is usually used pertaining to electrical devices, for example, switching power supplies (Boost converter and DC to AC inverter). In an electrical device, a 60% duty cycle means the power is on 60% of the time and off 40% of the time. One period is the length of time it takes for the device to go through a complete on/off cycle. Changing the duty cycle by modifying the PWM code would increase the extracted power from such system. [2]

1.2 Background and Literature Review

The integration process between solar generated energy and grid energy must passes by two conversion steps: DC to DC conversion and DC to AC conversion. The first step consists of converting the lower DC voltage produced by the solar harvesting system into a higher voltage value. The second step uses this boosted DC voltage to convert it to AC. We will start by exposing the DC-to-DC conversion phase followed by the DC-to-AC conversion step.

1.2.1 DC to DC converter:

Two main types of DC to DC converters exist: boost and buck converters. The former enhances the DC voltage presented at its input while the latter steps its down.

1.2.1.1 Boost converter:

Boost converters are widely used as a DC to DC step up converter that generates an output voltage higher than input voltage. The boost converter mainly consists of an inductor, a diode, a capacitor, and a transistor. The transistor is controlled by a microcontroller instrumenting the algorithm. The algorithm is adjusted to guarantee the maximum power [3]. A novel DC to DC converter with a single inductor multi-output boost (MOB) converter with a chain of regulated output voltages has been recently introduced. A significant advantage of the MOB converter is its outstanding dynamic response versus the input voltage variation. However, MOB has a highly complex design [4].

1.2.1.2 Buck converter:

The buck converter is a step down DC to DC converter. There is a similarity between the buck and boost converter in terms of components. The buck converter consists of an inductor, diode, capacitor, and a switch. However, there is a difference in the design between the boost converter and buck converter. Moreover, changing the duty cycle in the microcontroller code plays a significant role in the capturing of the maximum power. [5] One step down regulator topology with one fixed switching frequency, pulse width modulation (PWM) and operation in the continuous-current mode (CCM). The principles discussed can be applied to other topologies, but the equations do not apply directly to other topologies. Four design parameters are required: input-voltage range, regulated output voltage, maximum output current and the converter’s switching frequency. The use of the fixed topology has the advantage of the simple design; however there is a limited room for changing the input-voltage range and output voltage [6]. Another way is to apply the switched Capacitor principle that increases power efficiency and decreases output ripple of an embedded switched-capacitor based DC/DC Buck Converters. The usage of current pump based circuit limits transition current of the switched-capacitors and hence, improves power efficiency and reduces output ripple. However, the design of the switched Capacitor buck converter is complex. [7]

1.2.1.3 Transformers:

A transformer is a static electronic device that step energy either up or down by the usage of inductive coupling between winding circuits, the primary and secondary windings. The main disadvantages of using transformer are the large amount of power losses and the difficulty to match the MPPT requirements. [8]

1.2.3 Integration methods:

There are two methods to integrate renewable energy with grid energy.

1.2.3.1 Inversion first:

First, the energy from the DC source is converted into AC at low voltage levels. Afterwards, the AC low voltage level is stepped up by the means of a transformer. However, the transformer is less efficient in terms of the overall size and the cost of the system, as well as the power losses. Moreover, the analog system by nature has the disadvantage of fixed design which limits its ability to adjust the values of the inputs and the outputs.

1.2.3.2 Boosting first:

First, a boost converter is used to a gain a much higher DC voltage. Second, this high DC voltage is converted into AC voltage by the means of pulse width modulation (PWM). The inverter could implemented either analogy or digitally. However, the digital implementation is the best choice for the adjustable and universal projects.

1.2.4 Inverter:

The device inverts the DC current to AC current. The inverters are classified into two types according to the total harmonic distortion (THD) of the inverted wave.

THD is means to measure the quality of the inverter output waveform. It is defined as the ration between the sums of the power of the various harmonic components to that of the fundamental frequency..

1.2.4.1 Modified sine wave:

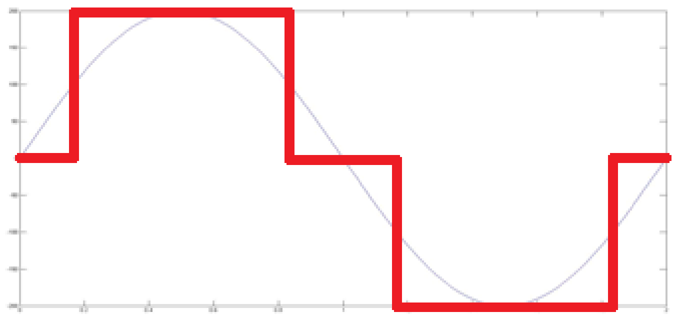

Figure2: Modified Sine Wave [5]

A modified sine wave or modified square wave is a wave in the middle between the square wave and the pure sine wave with a total harmonic distortion between 35 to 40%. We can notice in the above figure (in the red curve) the sudden sharp change from zero to one or from one to zero. The modified sine wave inverter functions well with several devices except those which contain motors. The modified sine wave inverter is an easy and cheap solution. However, it comes with a hidden cost: the harmonics. Harmonics are integer multiples of the fundamental power frequency. For example, if the operating frequency is 60 Hz another harmonics would appear in the third harmonic 120Hz and the fifth harmonic 300Hz. Sensitive devices such as medical equipment cannot run of a modified sine wave. The most common negative effect of harmonics is amplified current flow which leads to the burn out of components as well as the overall failure of the system. [9]

1.2.4.2 Pure sine wave:

A pure sine wave inverter is another common method of generating AC power by the means of PWM with total harmonic distortion of 5%. The inverter can guarantee maintaining the worst case 5% total harmonic distortion by changing the duty cycle PWM and using effective low pass filter. The electricity that is provided by the service provider in our home is in the pure sine waveform. The inverter could be implemented either analogy or digitally. However, the digital implementation is the best choice for the adjustable and universal projects. The core of the inverter device is the PWM signal that controls the switching operation mode. The switch is usually used in the DC to DC converter and the DC to AC converter. There are many approaches to generate the PWM signal, such as specific PWM integrated circuits, analog component, and a digital microcontroller. [9]

1.2.4.2.1 Analog circuit

The PWM signal is generated by feeding a reference and a carrier (triangle) signal through a comparator which generates the output signal according to the difference between the two inputs. The reference is a sine wave signal has the same frequency of the desired output signal (50 Hz in Egypt). The carrier wave is a triangle wave and should be chosen at a much greater frequency than the reference signal. In addition, the designer should take into consideration the inverse relationship between the carrier frequency and the value of the components of the low pass filter (inductors and capacitors). There are two scenario:

1) The carrier (triangle signal) is greater than the reference signal (50 Hz in Egypt): the output high state.
2) the reference signal (50 Hz in Egypt) is greater than The carrier (triangle signal): the output low state

Therefore, hardware implementation for the sine wave generator (oscillator) and triangle wave generator is needed. [10]

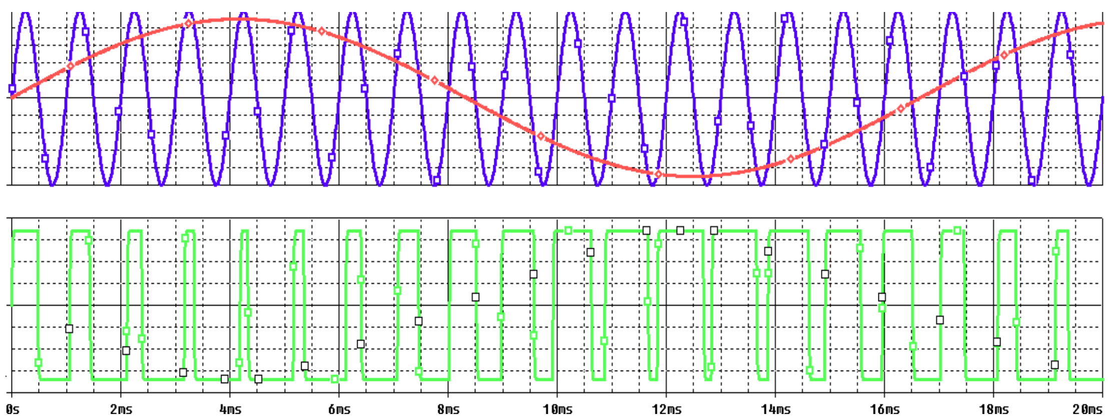

Figure 3: Level PWM Signals [5].

1.2.4.2.2 Digital microcontroller:

Several solutions exist to implement a digital PWM controller. In a first step, for most solutions, a PWM algorithm is written in Assembly, C, or even Basic language to control the switches. For example, PIC 18f4431 uses the C language, Atmel 90s52 uses C and Assembly, and PIC 16f77A uses Basic. The main criterion to choose the optimum microcontroller is the microcontroller's instructions' execution speed. The microcontroller is used to control a switch. The switch is either an IGBT or a MOSFET.

The insulated-gate bipolar transistor (IGBT) is a three-terminal transistor primarily used as an electronic switch. In newer devices, it is used for combining high efficiency and fast switching.

The metal–oxide–semiconductor field-effect transistor (MOSFET) is a transistor used for amplifying or switching electronic signals.

Rich and Chapman [6], use a microcontroller to control a three level PWM DC to AC inverter. The microcontroller is used to control an H-bridge which is consisted of four MOSFET switches. IR2110 driver is used to derive the four switches. Some designers prefer to use the MOSFET as a switch in an inverter design due to its wide availability in the market as well as the different available options in terms of voltage, current, and price. However, the MOSFET is not guaranteed to work at a power higher than 1000Watts. [11]

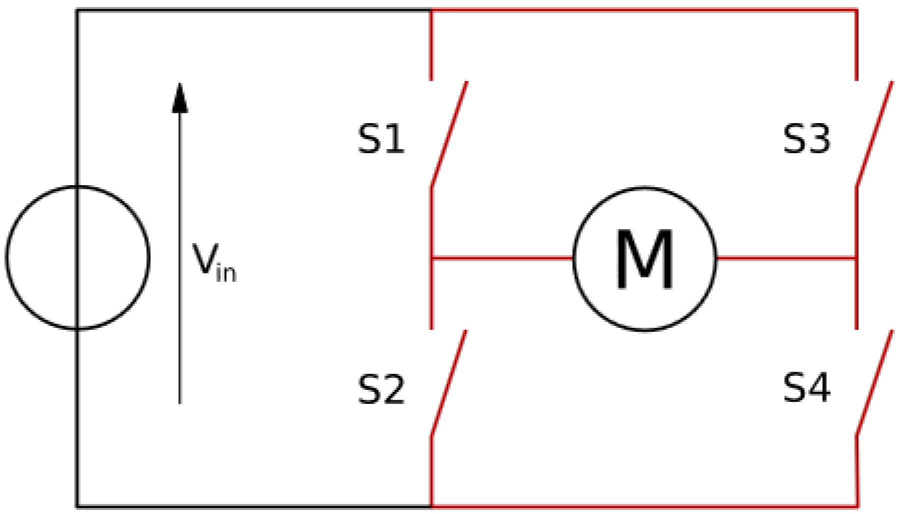

Figure4 Structure of an Hbridge (highlighted in red)[6]

Inveters in the market:

Most of the inverters in the Egyptian market are either made in China or Taiwan. They are expensive and unreliable.   Moreover, they are known for their imprecise or even fake decrpiction in terms of the device efficiency and capability to deliver such power and voltage. One can easily find a modified sine wave inverter that delivers a power of 2000 W while taking a 12V input delivering 220 V. The price for such a system ranges between 3000 and 3500 LE. The pure since wave inverters on the market cost between 2200 and 2800 LE. They operate at the same voltages as the previous type while delivering 1000W.

1.3 Scope of Work

The aim of this study is to integrate the renewable energy with the conventional power grid without affecting the power quality. Since the quality of the conventional grid is very sensitive to any fluctuation, many issues should be taken in consideration. Three important parameters should be identical from the two sources, renewable energy and the conventional power grid. These three parameters were the amplitude, phase, and frequency. Taking into consideration the fluctuating nature of renewable energy sources, measuring and comparing the values of these parameters once is not enough. The goals of this project were to create a working three phases DC to AC sine wave inverter that could efficiently provide three kilowatt of power using PWM and comparing it to other methods currently on the market in terms of price and affiance. M file and Matlab/ Simulink simulation were used to test the model of a Boost converter and a pure sine wave DC to AC inverter monitoring. PWM codes were used to control the DC to DC converter (Boost converter) and DC to AC inverter.

In the following chapters, we expose the different steps to accomplish the objectives of our study. In the following chapter we discuss the implementation of the project as well as the primary results obtained. In chapter 3, we illustrate the prototype design, and components selection. Chapter 4 concludes this study and pinpoints some important improvements and possible future research axis.

Chapter 2: Methodology and Primary Results

This study proposes an integration method between the conventional electricity grid and renewable energy. In a first step, the system was designed and simulated by the means of Matlab/Simulink simulation. A prototype was then built and tested. In order to better understand this process, we have broken it down in the following sections where we detail the function of each part, how it was constructed, and its interaction of other system constituents.

2.1 Block Diagram:

The following figure5 shows the entire system's block diagram. The figure traces the consecutive steps followed by the signal from end to end. The first step is extracting the low DC voltage signal from the solar cells (PV). The second section takes the low DC voltage from the PV and steps it up by the means of Boost converter. The high DC voltage is then inverted into AC voltage by the means of DC to AC inverter which consists of an IGBT module. Finally the inverted signal is treated by an inductive low pass filter to remove the undesired harmonics. The signal is then fed to the resistive load. The resistive load used is three standard light bulbs.

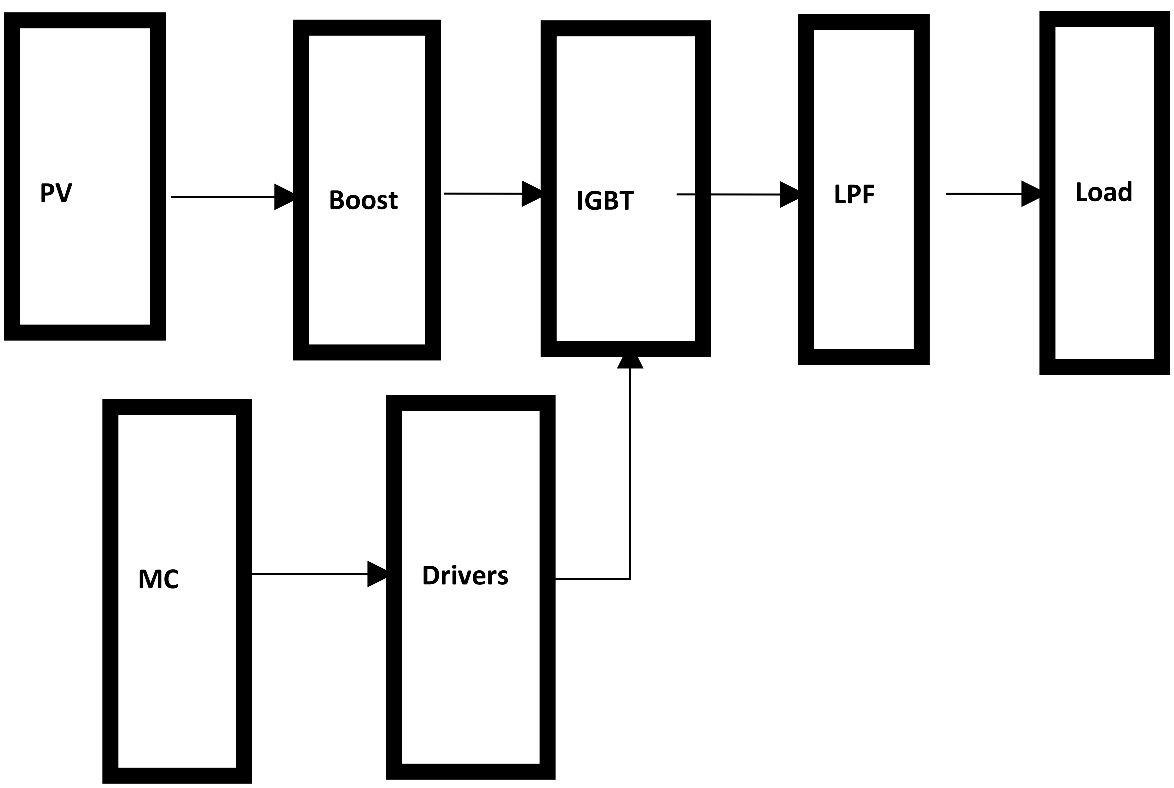

Figure5: the system block diagram.

2.2 System analysis and simulation

Matlab simulation was used In order to design this project. The optimum values in terms of frequency, amplitude and phase were chosen based on the Matlab simulation. The various parts were simulated in MATLAB, to predict an accurate output. Figure 4 illustrates the Matlab model used and its interconnection.

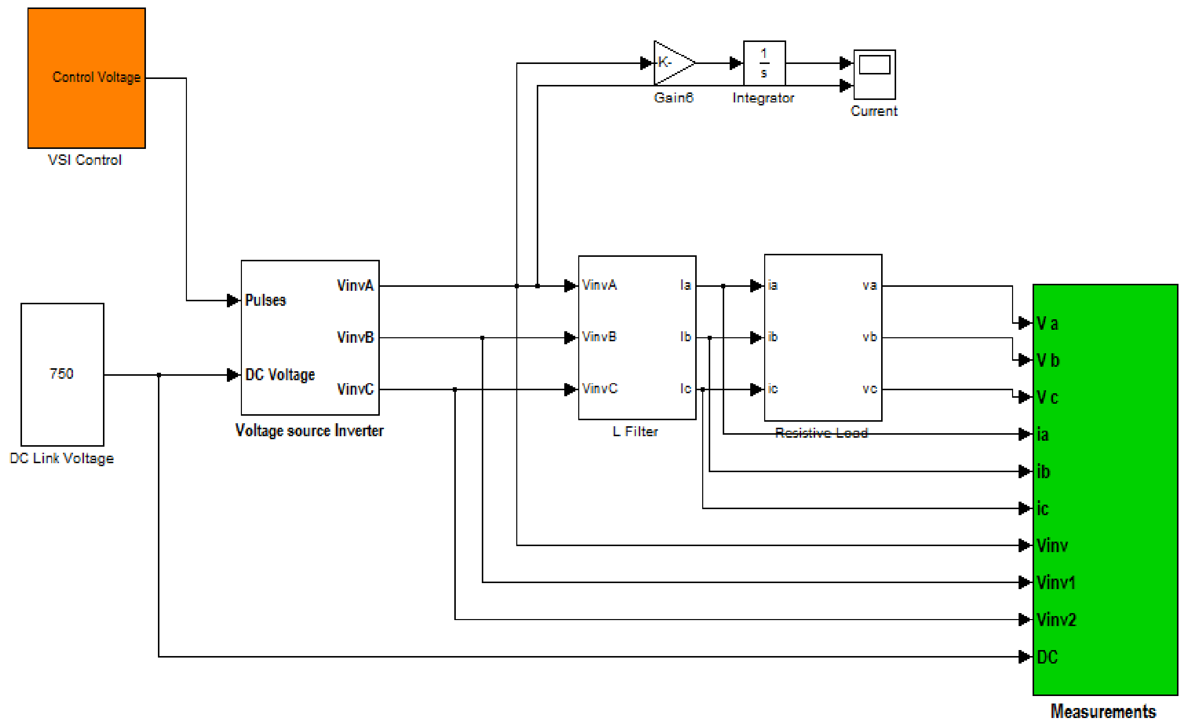

Figure 6: the system Simulink model

In order to obtain the required DC voltage of our system (from 220V to 380V), we found that we must use a DC source of 750V. This is the DC Link Voltage component that is shown in figure 6. A voltage Source Inverter model was built. Since we are building a system to integrate the harvested energy with the standard grid energy, the system must generate electricity with 3 phases. Three voltage constituents exist: Va, Vb, and Vc. The three voltages have different phases with 120^0 phase shift between each of them. The equations below, used in the modeling, guarantee a 120^0 phase shift between the three voltages. E is the input DC source [12]. W is the angular frequency of the voltage constituents.

$$Va= E/3(2Sa-Sb-Sc) \quad (1)$$

$$Vb= E/3(2Sb-Sa-Sc) \quad (2)$$

$$Vc=E/3(2Sc-Sa-Sb) \quad (3)$$

$$Sa= \cos wt \quad (4)$$

$$Sb= \cos(wt - 2/3\pi) \quad (5)$$

$$Sc= \cos(wt - 4/3\pi) \quad (6)$$

To build the voltage source inverter (VSI) control, three pure sine waves were assigned with a frequency of 50 HZ (314 rad/sec) the same as the desired frequency that is used in the electricity grid in Egypt, a modulation index of .85, and phase of 120° between each phase. The 360° were divided into three sections each with 120° .

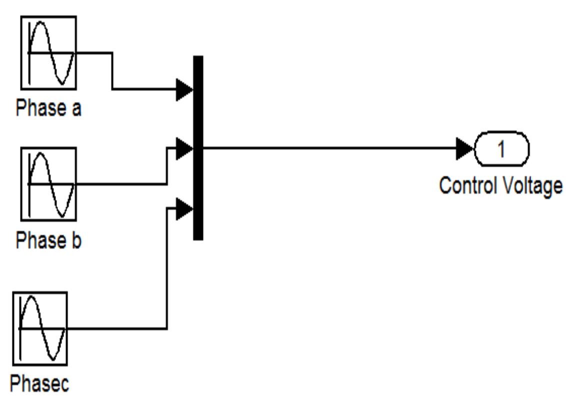

Figure 7: Three pure sine wave

In Figure 7 the three current signals are separated by 120 a phase shift. However, they have the same frequency.

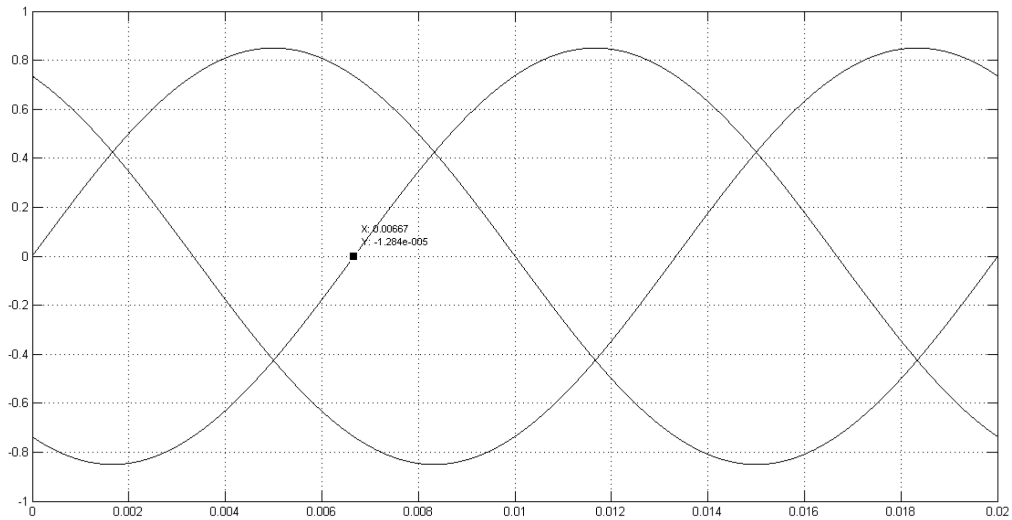

Figure8: Three current signals with a phase shift 120.

The next step was to design the L Filter. Equation 7 governs the selection of the appropriate value of the inductor L. Vdc is the input DC source (750 V) while ΔiLmax is the maximum expected value the ripples would have which is assumed to be 10% of the desired output current. The desired current for output current is 10 Amperes leading to a ΔiLmax of 1 Ampere.

$$\Delta iLmax = 1/8 * Vdc / L * fs \quad (7)$$

The switching frequency (Fs) is set to 10 Khz. The value of the Fs has been chosen as much bigger as possible taking into consideration the inverse relationship between the switching frequency and the inductor (L) value as in the equation below. L is set to 10 mH.

$$L = \frac{\frac{1}{8} Vdc}{\Delta i\ max * FS} \quad (8)$$

The next step was the transfer function choice. We chose the transfer function (equation 9) because if provides the lowest harmonics and ripples during the simulation.

The transfer function= 1/ (L*S) +1 (9)

To calculate the optimal load equivalent resistance at which the system would deliver the highest current in a given voltage setup we substitute in equation 10. The desired values of power that system should deliver 3000W. The expected output voltage which is varies between 220V and 380V. In case of 220V, the maximum current that can be drawn out of the system is 13,6 at a maximum load equivalent resistance of 16.17 ohms. In case of 380 V, We obtain a current I equal to 7.9A. In this case R is equal to 47.5 ohms.

I= output power/ output AC voltage (10)

2.3 Results:

Input DC voltage:

A DC source of 750V was assigned with respects to the expected value the of the output voltage which should be between 220 and 380 according to our design. Figure 8 shows the output signal of the source.

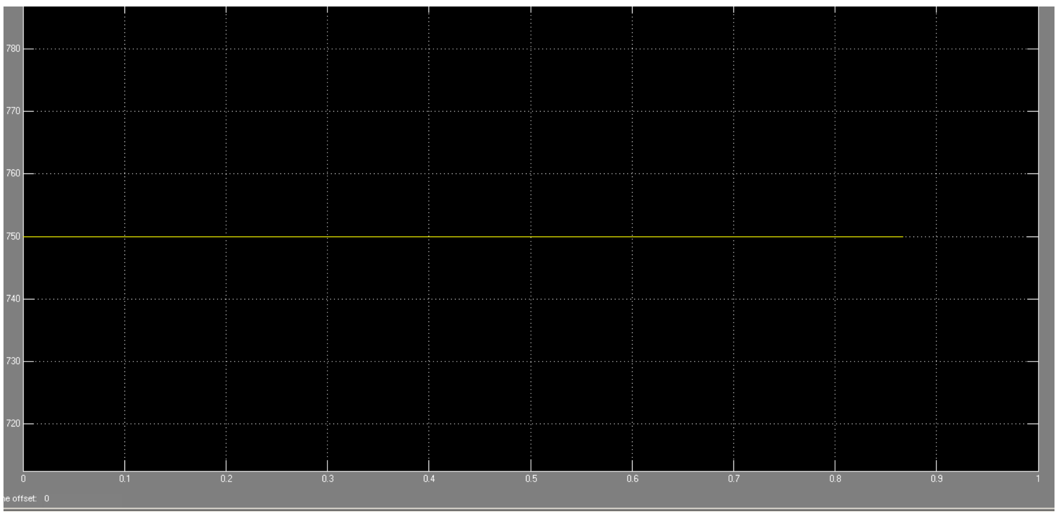

Figure9: A constant DC 750 voltage

The three inverted voltages:

Figure 10 shows the three inverted voltages obtained from the inversion phase. We can see 6 steps. We can see inside of each of these steps the PWM signal.

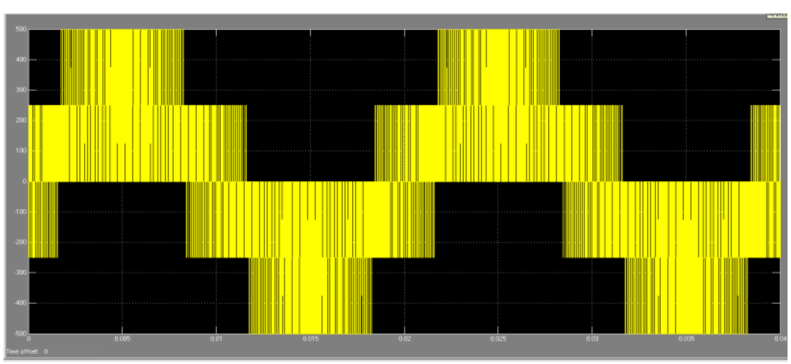

Figure 10: The three inverted voltages in the shape of 6 steps signals.

Three output inverted voltage and current after the resistive load:

Figure 11 and 12 illustrate the three inverted voltage and the current signals obtained after the inversion phase respectively. In both cases, the three voltage and current signals have the same frequency of the desired signal which 50 Hz.

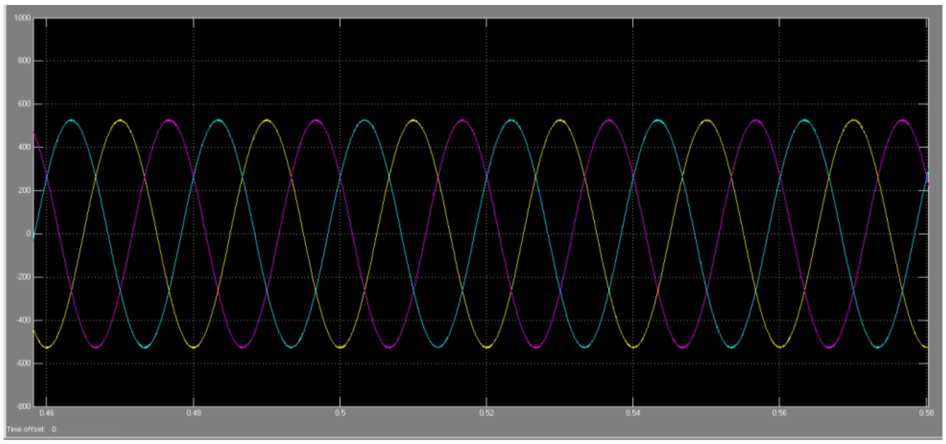

Figure 11: The three inverted voltage after the resistive load are in the form of pure sine wave.

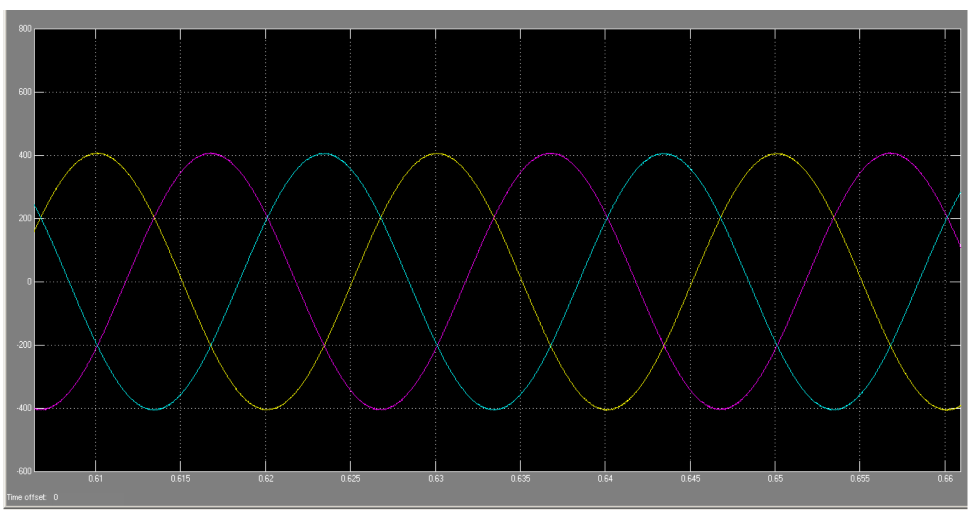

Figure 1: The three current signals after the LPF are the form of pure sine wave with lower amplitude.

In this chapter we presented the block diagram and the primary results used for the implementation of our system. the system is formed from the interconnection of PV, Boost Converte. IGBT modules as Inverter, Drivers, Microcontrolers, Lowpass filter, andResistive Load in the following chapter we show the prototype of our full system as well asits compoments.

Chapter 3: Prototype

In the previous chapter, we showed the primary design and calculations for the various components of the system. The system was modeled in Matlab/Simulink. In this chapter, we illustrate the prototype building phase. The prototype was built, tested and was found to be fully operational.

3.1 Circuit Diagram:

Figure 12 shows the complete circuit diagram of the system. The values of the components were calculated through the Matlab/Simulink simulation. We use those values for all the components in the system.

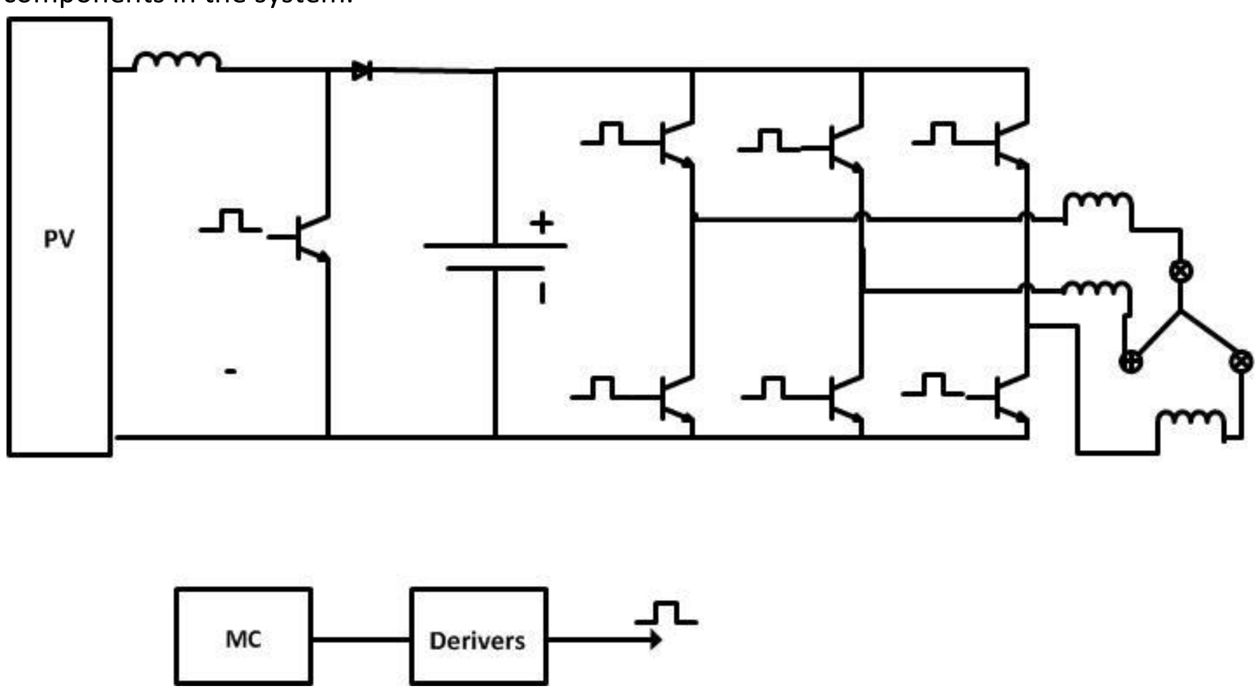

Figure 13: Circuit Diagram.

In the early stage, 60 DC voltages were delivered from the power supply in the Lab during the testing phases. In a second stage, four solar panels were used each delivering 20V. However, it was necessary to check the value of the output of each solar panel before and after the serial connection. Moreover, the solar irradiance fluctuation plays a negative role that would lower the voltage value of the solar panel.

The boost converter was used to step up the 60(v) to become 300 (v) according to the following equation:

$$Vo/Vi = 1/(1-D) \qquad (11)$$

Where D is the duty cycle, Vi the input DC voltage, and Vo is the out voltage after the step up operation by the Boost converter. The duty cycle was set to 0.5 (50%) to avoid the components damage due to the electric spark that may occur due to the improper switching. In other words, choosing high duty cycle, for example, 75% would increase the probability of improper switching to take place thus increasing the probability of components damage.

The maximum voltage (Vi) that we can obtain from combining the two channels of the power supply is 60V. By substituting these values equation (10) we get an output voltage Vo of 300V.

The calculation of the inductor (L) proper value for boost converter:

$$R=V/I \qquad (12)$$

$$R=30 \text{ ohms}$$

$$L \geq [R*D(1-D)^2]/2Fs \qquad (13)$$

Where L is the inductor and Fs is the switching frequency.

Let Fs=10000

By apply the same concept that used in the simulation phase that we should keep in our mind that there is an inverse relationship between the switching frequency and the inductor (L) Value as mention in equation (13)

$L \geq 1$ mH

The next component in the circuit diagram is the diode. Any diode that can pass 1200V and 10A safely could be used. To illustrate, the diode has a significant role that in the Off-state, the switch is open and the only path offered to the inductor current is through it. Moreover, the diode prevents the current from returning to the voltage source and damaging it. Therefore, the selection of the diode that capable to pass 15 A and 1200V has been made.

We now inspect the capacitor used in the circuit. Choosing the Capacitor as big as possible is recommended according to equation 13. The capacitor would able to operate the load alone in case of assigning low duty cycle for the switch. Moreover, choosing Capacitor with high value makes it possible for the capacitor to operate the load during the instantaneous failure in the input voltage source. Equation 13 is shown below. ΔVo is the change that may take place in the output voltage. In our case, ΔVo is 5% of Vo, then ΔVo equal 15V. By substituting in the equation we obtain: C=470 mF.

$$C \geq (Vo*D)/(Fs*\Delta Vo*R) \quad (13)$$

The extracted 300V DC power from the Boost Converter was fed to the FP10R12YT3 IGBT module that works as Dc to AC inverter. AC voltage is almost always quoted in RMS values, and not peak values.

$$Vdc= Vrms \quad (14)$$

$$Vpeak=Vrms*0.707 \quad (15)$$

Let Vdc=300(v)

Vpeak=212 (V)

Vpeak to peak= 424

Our next step consisted of building the low pass filter (LPF). There inductors have been chosen; one for each phase. The desired inductor value was not available in the local market. Therefore, we bought four used power supply of PCs(personal computer) and we extracted their inductors to be used in the low pass filter as well as in the Boost Converter (three for LPF+ one for Boost Converter). We built our own inductor by measuring the inductor value then removing turns till we reached the desired value of 1 mH .

Three standard light bulbs were used to test the output signal of each of the three phases. The testing process is started by three 15W standard light bulbs. After that three 40W standard light bulbs were used and finally, three 100W standard light bulbs. Our system can operate a higher load than the ones selected.

After comparing our system's components vis-à-vis other commercial systems, we found that ours is more efficient. It has a lower. The overall cost of the system is cheaper when compared to its peers in the local market. The total cost of the project was 1500 LE. The most expensive components were the IGBT modules at the price of 500 LE and the rest of the money was divided among the other components.


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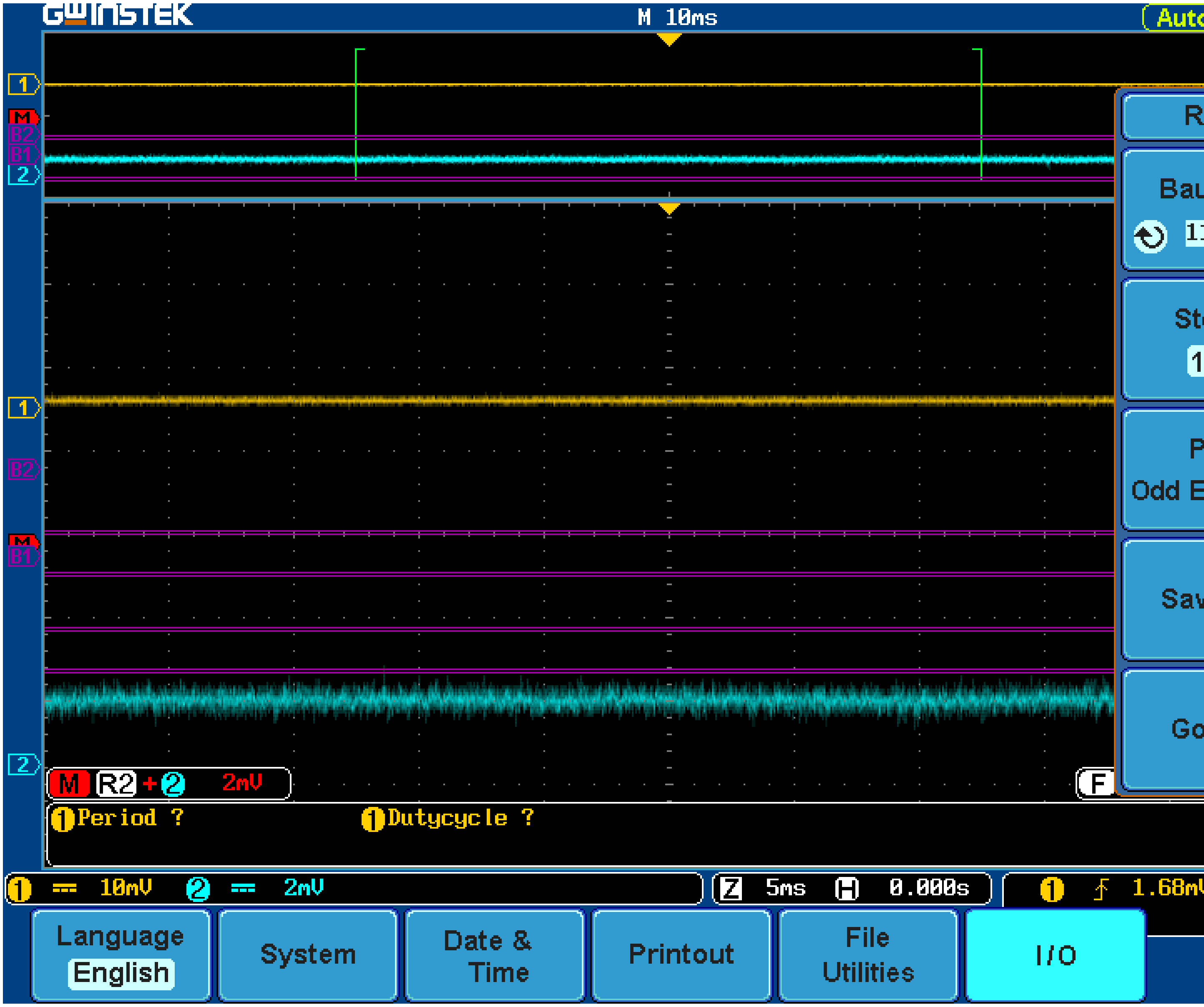
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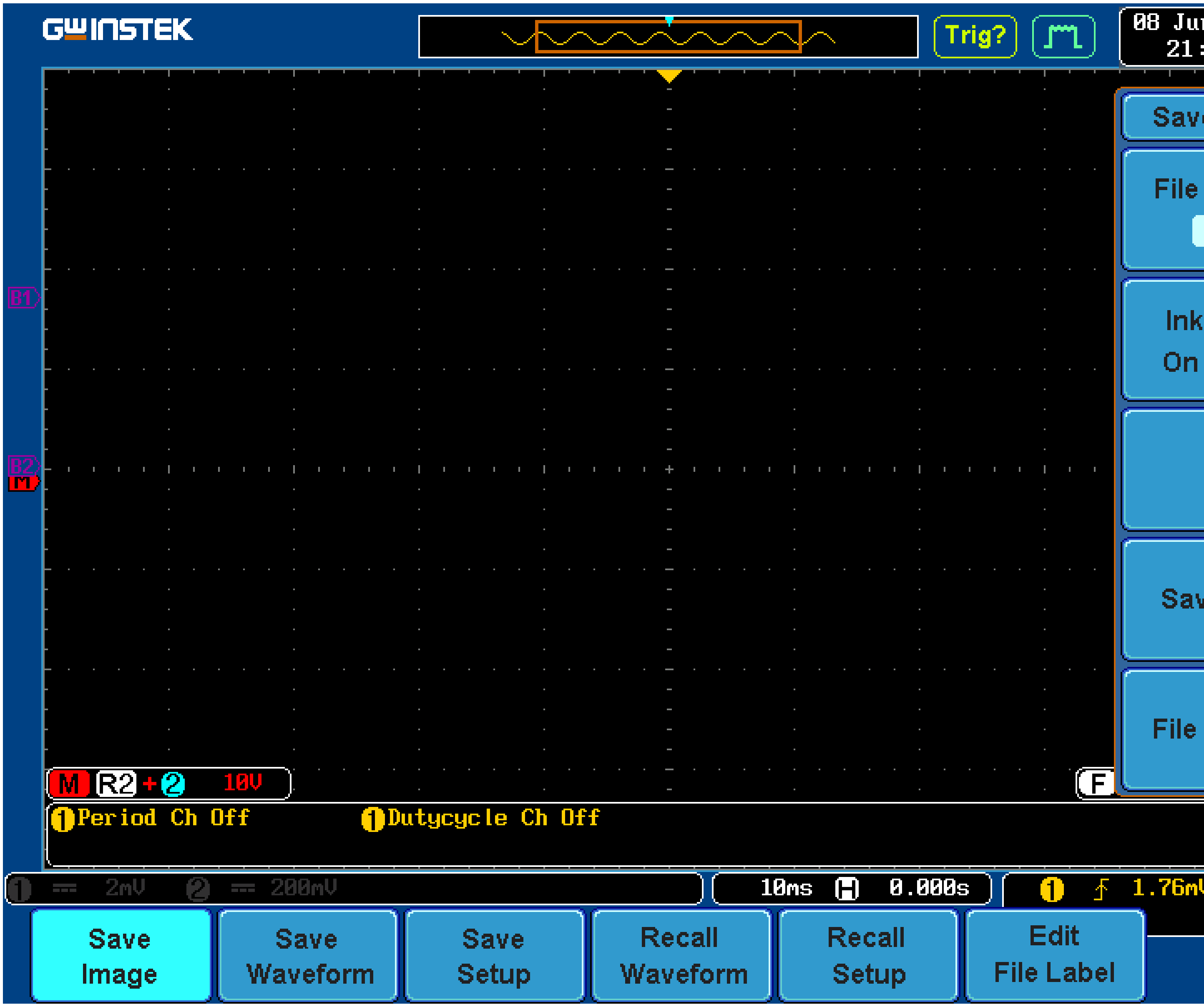
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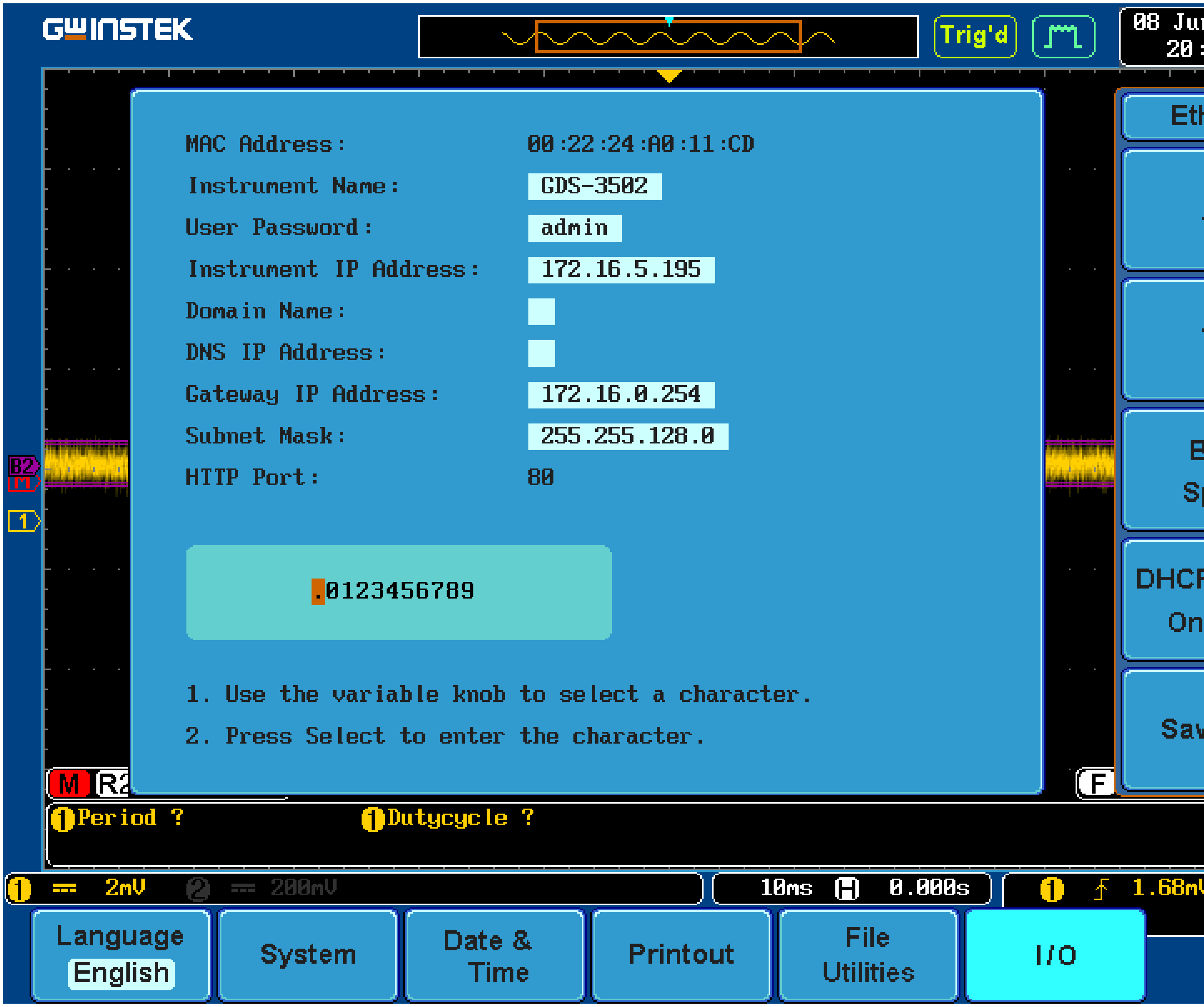
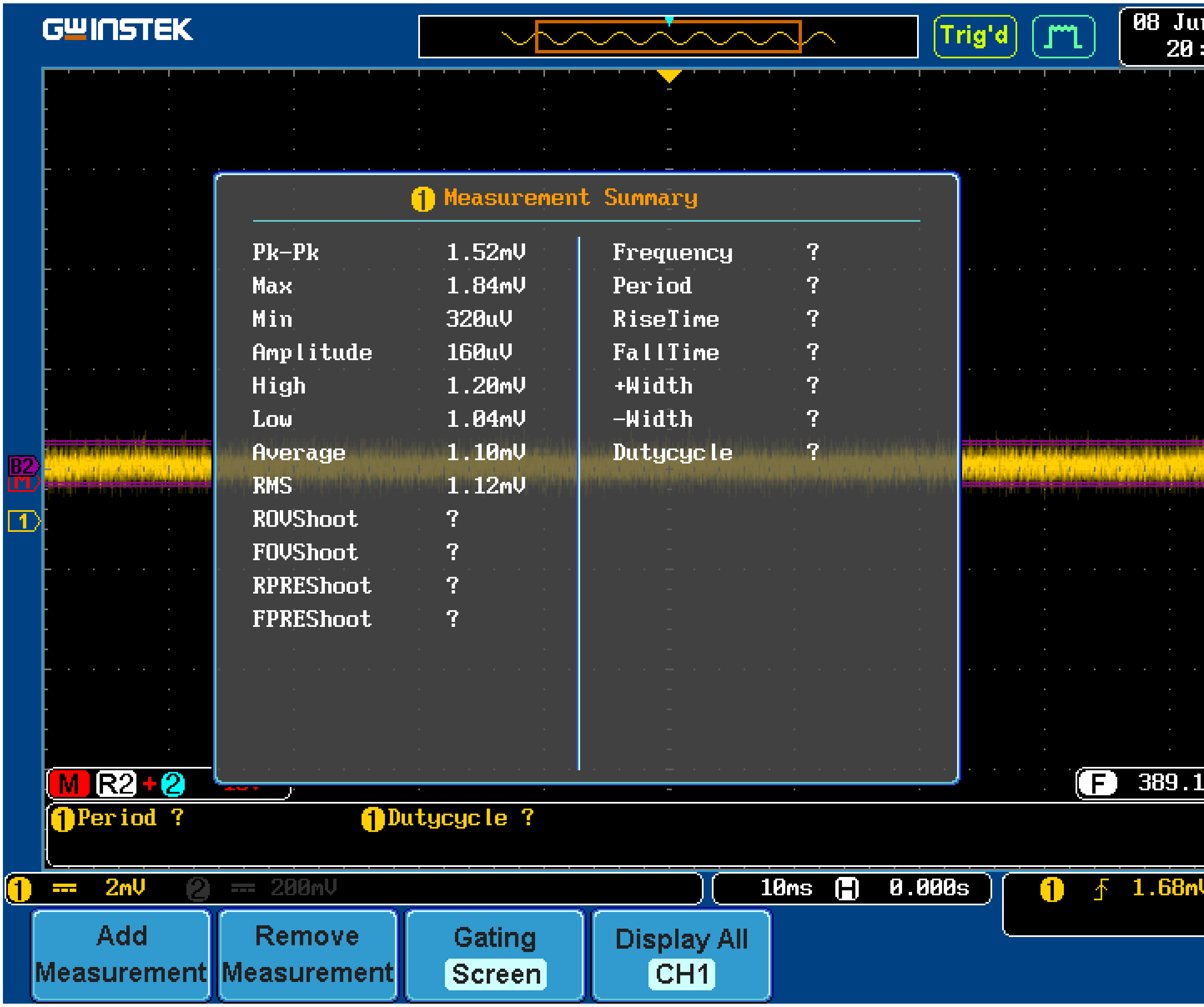
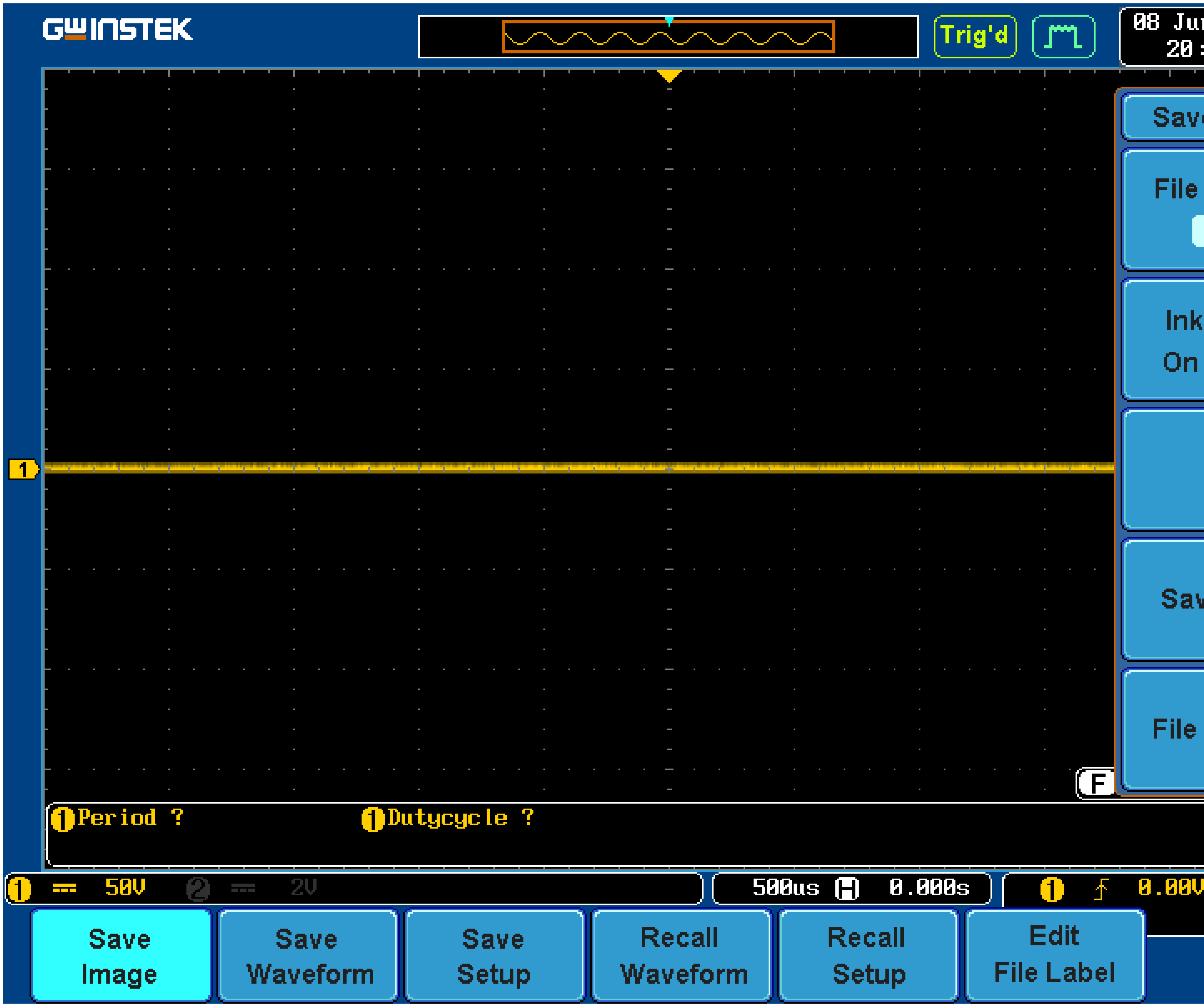
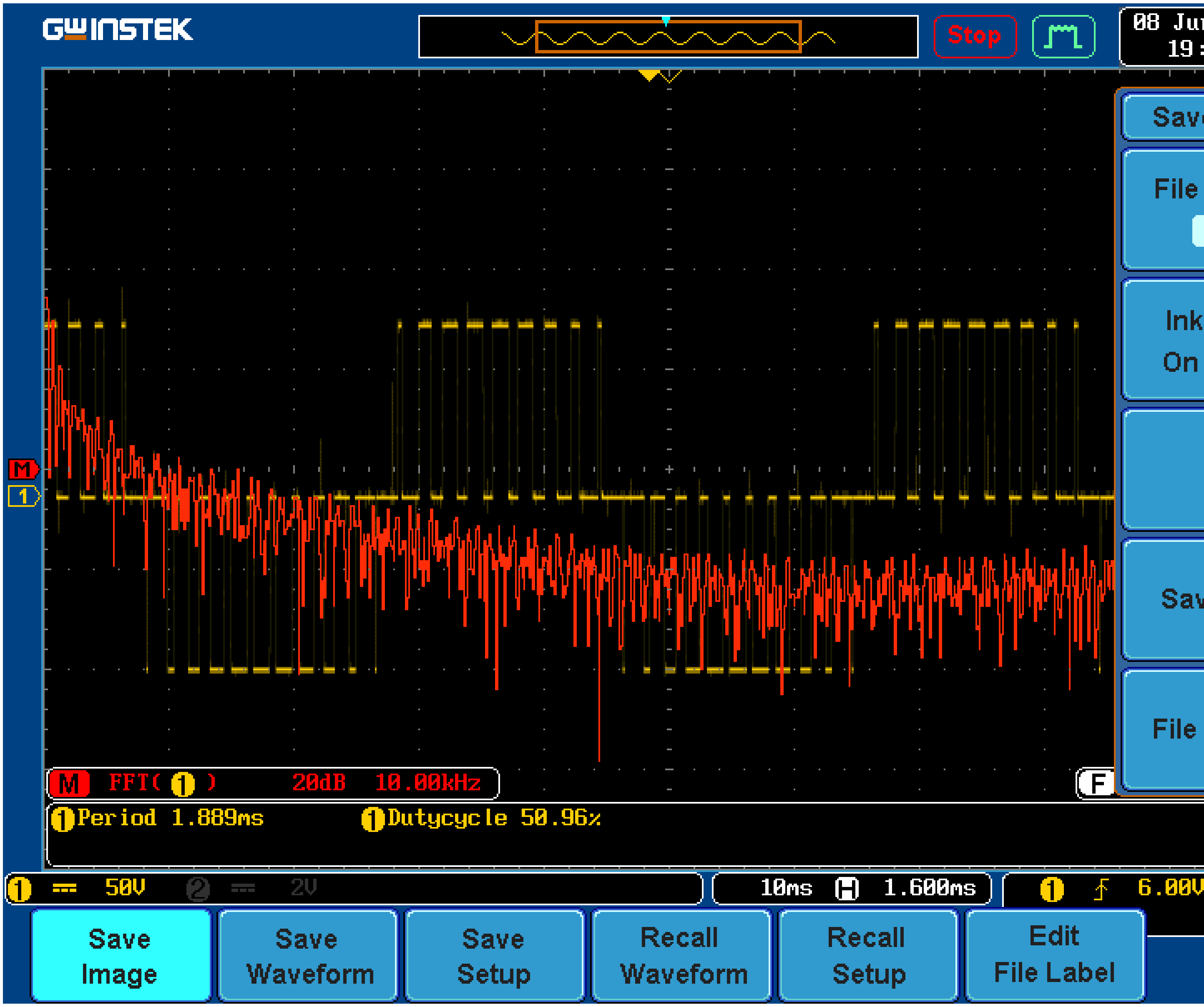
Utilities
I/O

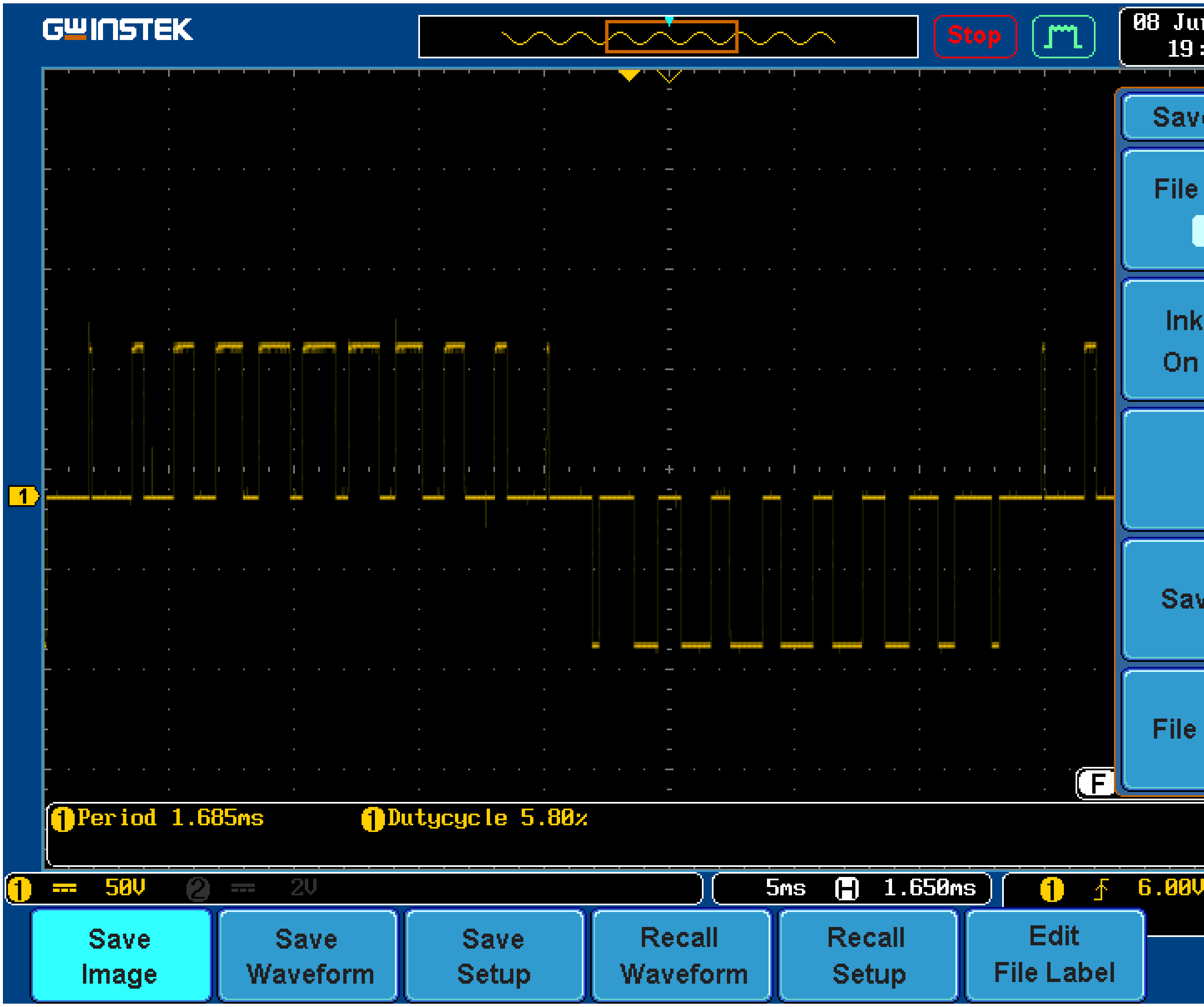

GW INSTEK
Trig'd
MAC Address: 00:22:24:A0:11:CD
Instrument Name: GDS-3502
User Password: admin
Instrument IP Address: 172.16.5.195
Domain Name:
DNS IP Address:
Gateway IP Address: 172.16.0.254
Subnet Mask: 255.255.128.0
HTTP Port: 80
.0123456789
1. Use the variable knob to select a character.
2. Press Select to enter the character.
Period ?
Dutycycle ?
2mV
200mV
10ms
0.000s
Language
English
System
Date & Time
Printout
File Utilities
I/O

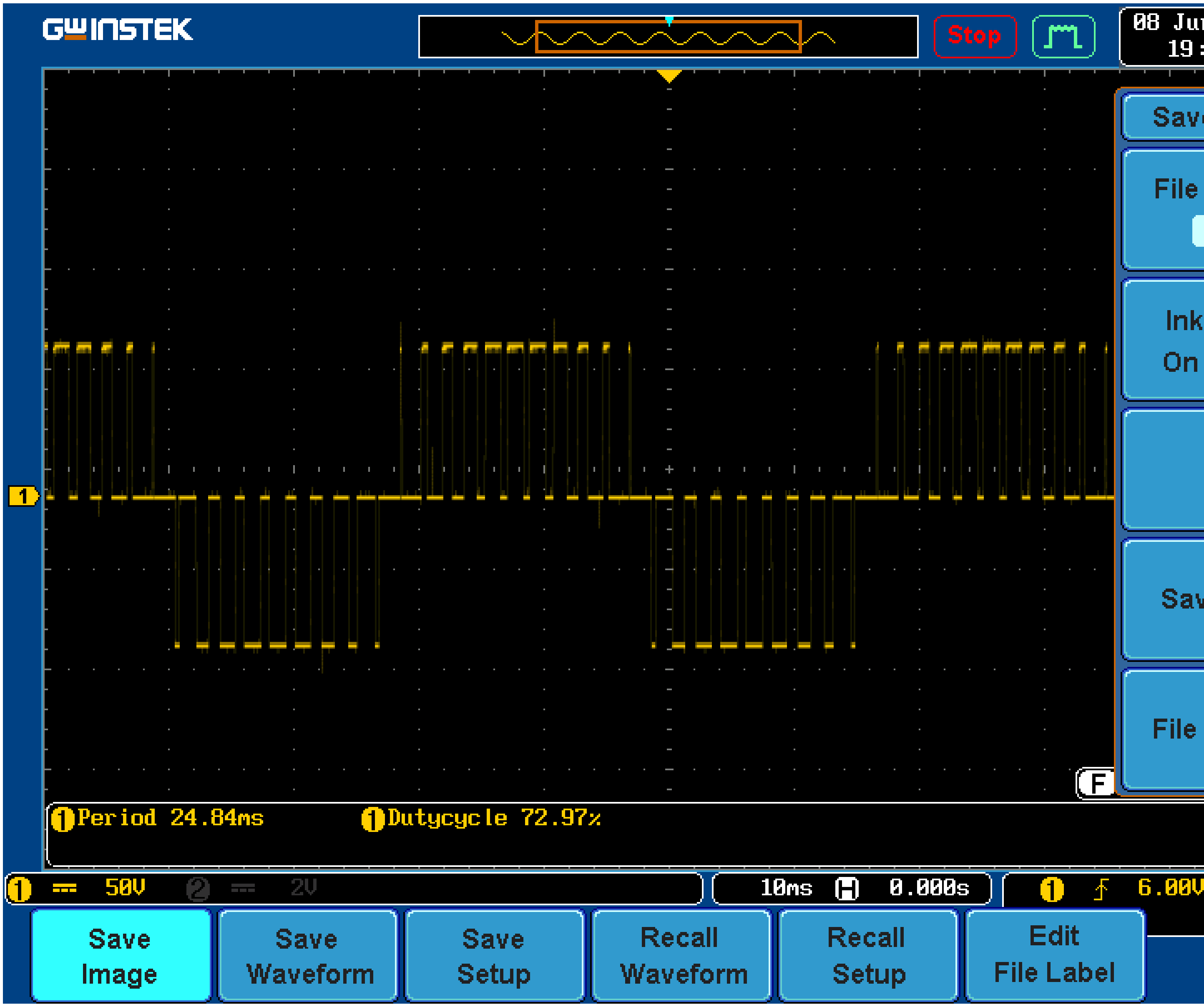

GW INSTEK
Trig'd
Measurement Summary
Pk-Pk 1.52mV
Max 1.84mV
Min 320uV
Amplitude 160uV
High 1.20mV
Low 1.04mV
Average 1.10mV
RMS 1.12mV
ROVShoot ?
FOVShoot ?
RPREShoot ?
FPREShoot ?
Frequency ?
Period ?
RiseTime ?
FallTime ?
+Width ?
-Width ?
Dutycycle ?
Period ?
Dutycycle ?
2mV
200mV
10ms
0.000s
Add Measurement
Remove Measurement
Gating Screen
Display All CH1

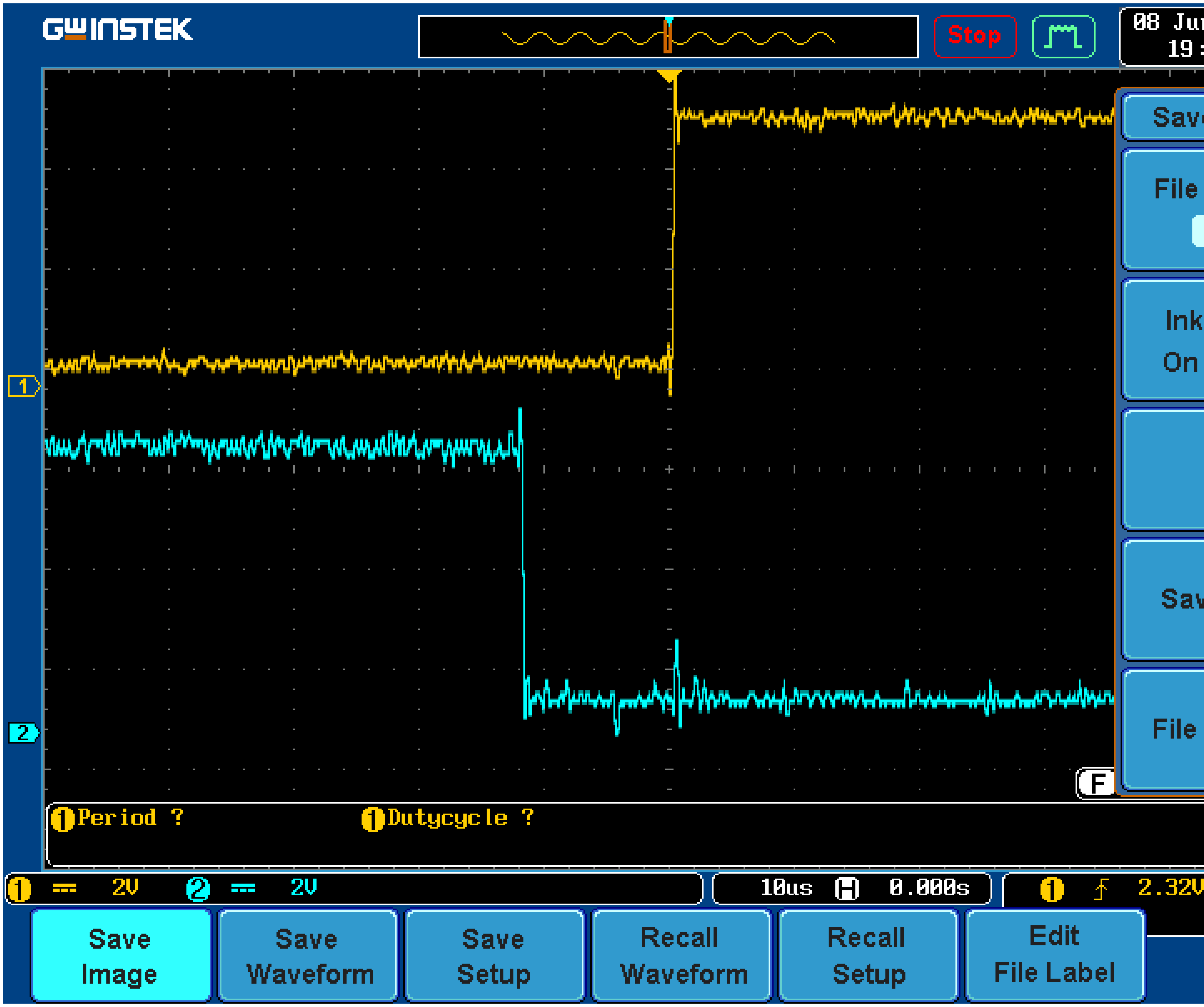

GW INSTEK
Trig'd
Period ?
Dutycycle ?
50V
2V
500us
0.000s
Save Image
Save Waveform
Save Setup
Recall Waveform
Recall Setup
Edit File Label

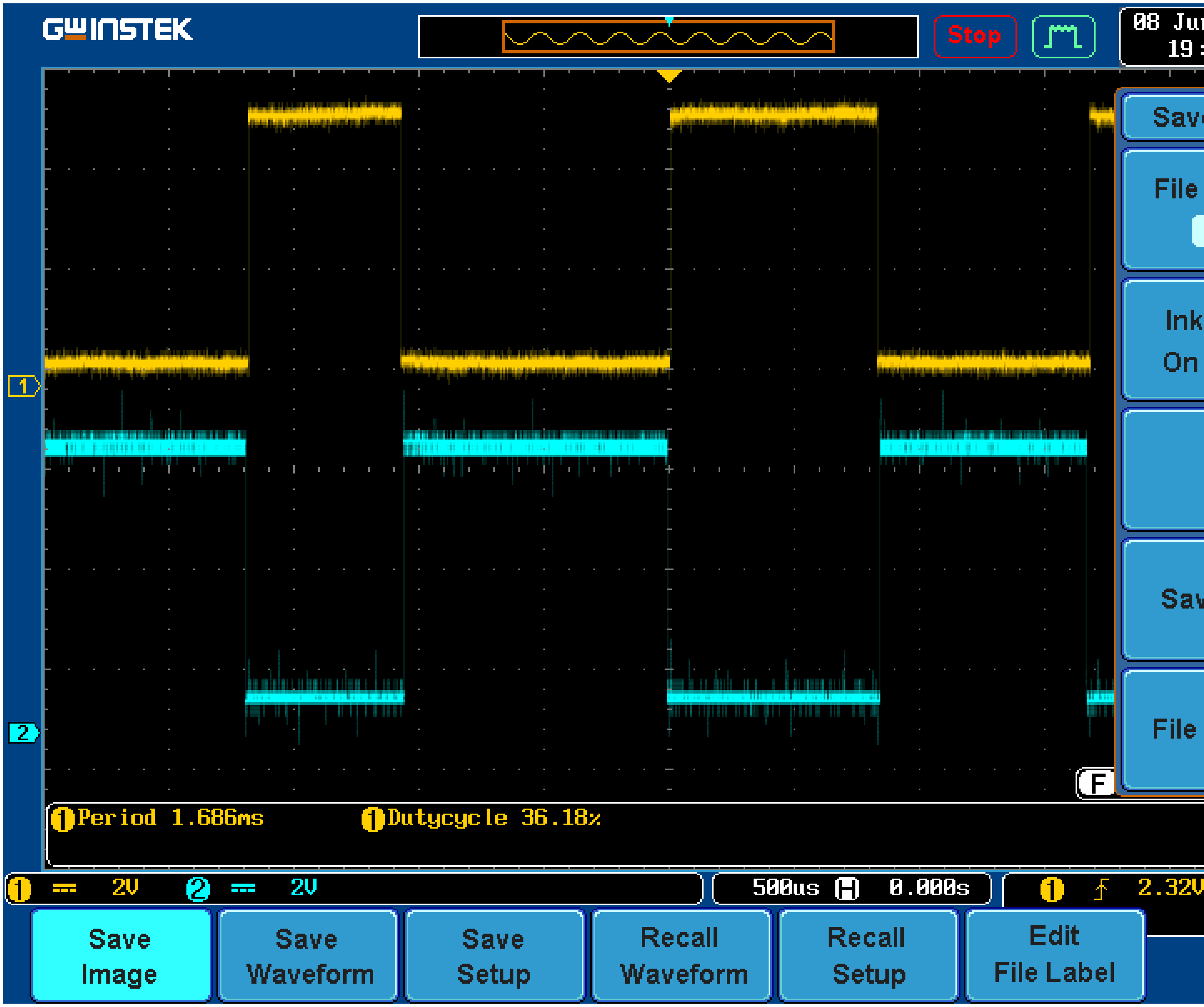


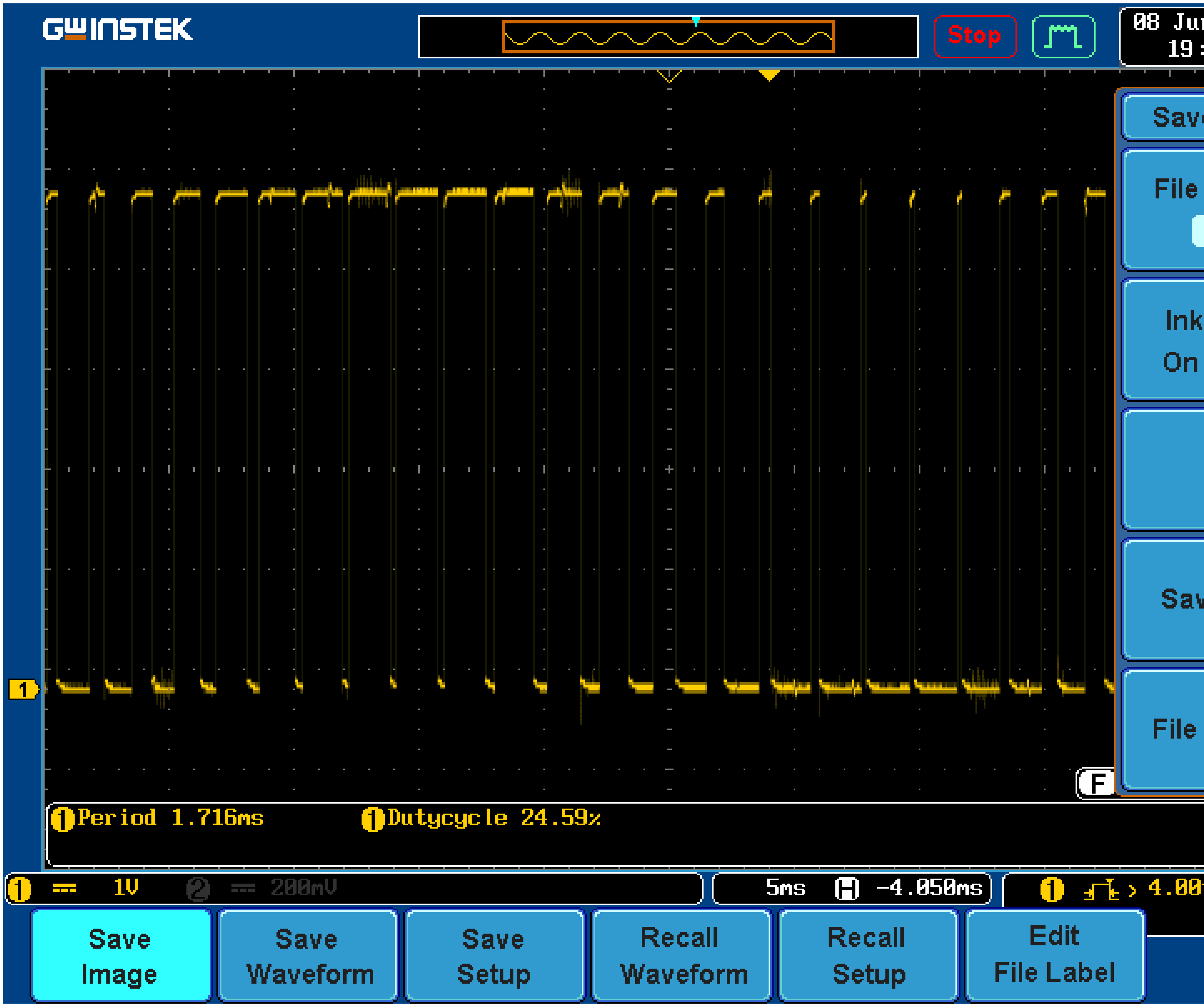
GW INSTEK
Stop
08 Ju
19 :
Sav
File
Ink
On
Sav
File
M
1
M FFT(1) 20dB 10.00kHz
F
1 Period 1.889ms
1 Dutycycle 50.96%
1 50V
2 2V
10ms
H 1.600ms
1 6.00V
Save Image
Save Waveform
Save Setup
Recall Waveform
Recall Setup
Edit File Label

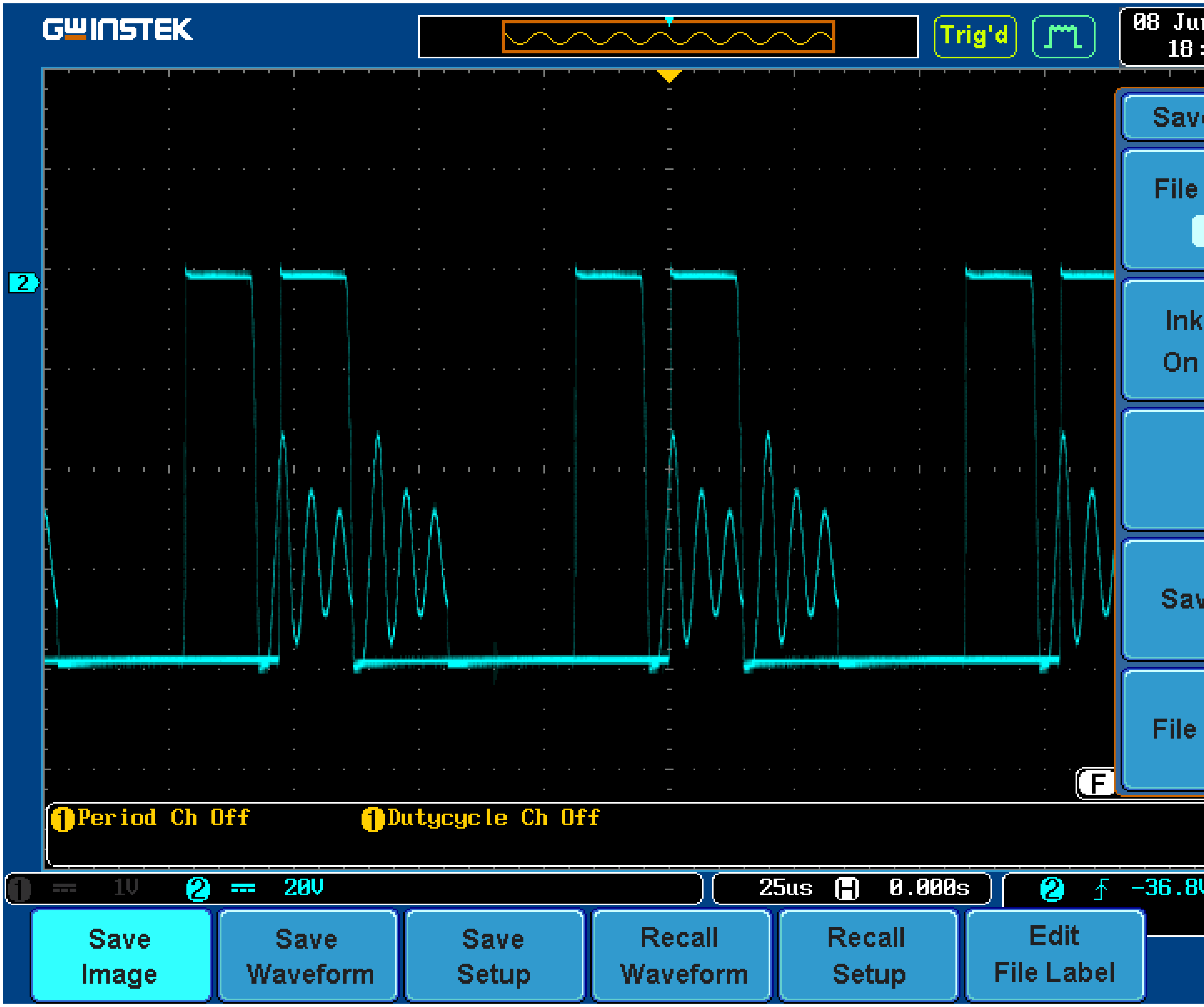

GW INSTEK
Stop
Period 1.685ms
Dutycycle 5.80%
50V
2V
5ms
1.650ms
6.00V
Save Image
Save Waveform
Save Setup
Recall Waveform
Recall Setup
Edit File Label

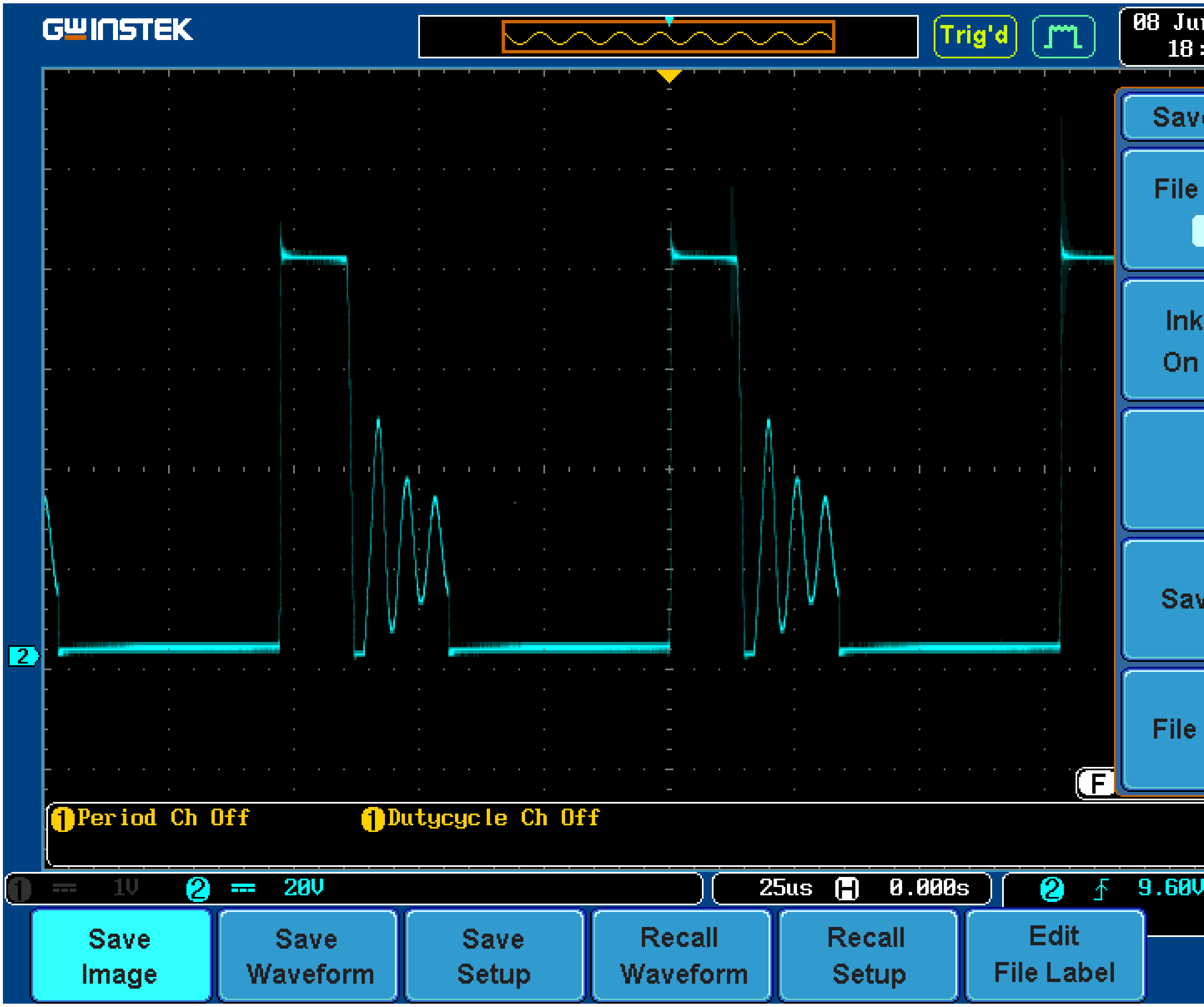

GW INSTEK
Stop
08 Ju
19
Sav
File
Ink
On
Sav
File
Period 24.84ms
Dutycycle 72.97%
50V
2V
10ms
0.000s
6.00V
Save
Image
Save
Waveform
Save
Setup
Recall
Waveform
Recall
Setup
Edit
File Label

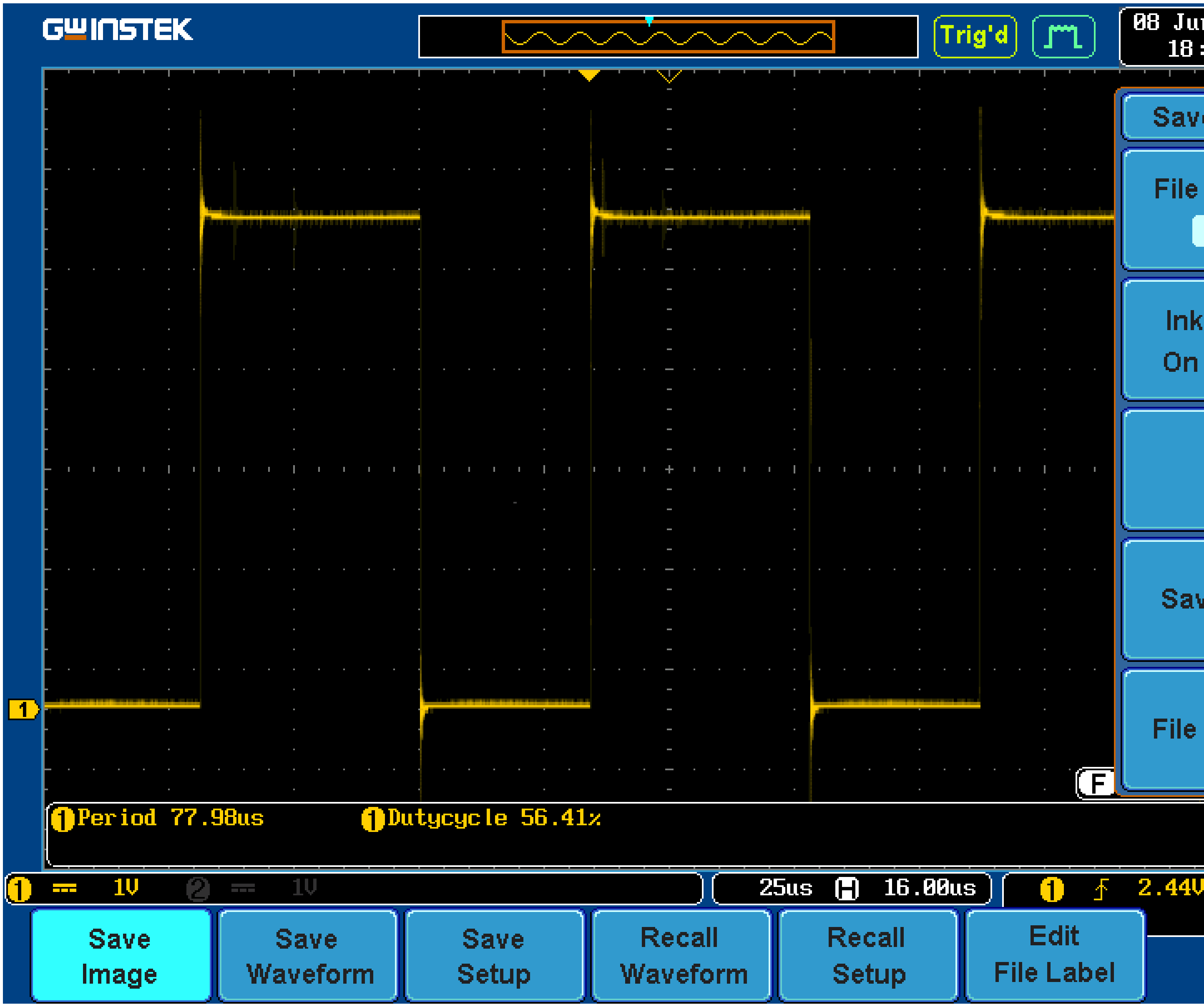

GW INSTEK
Stop
Period ?
Dutycycle ?
2V
2V
10us
0.000s
2.32V
Save Image
Save Waveform
Save Setup
Recall Waveform
Recall Setup
Edit File Label

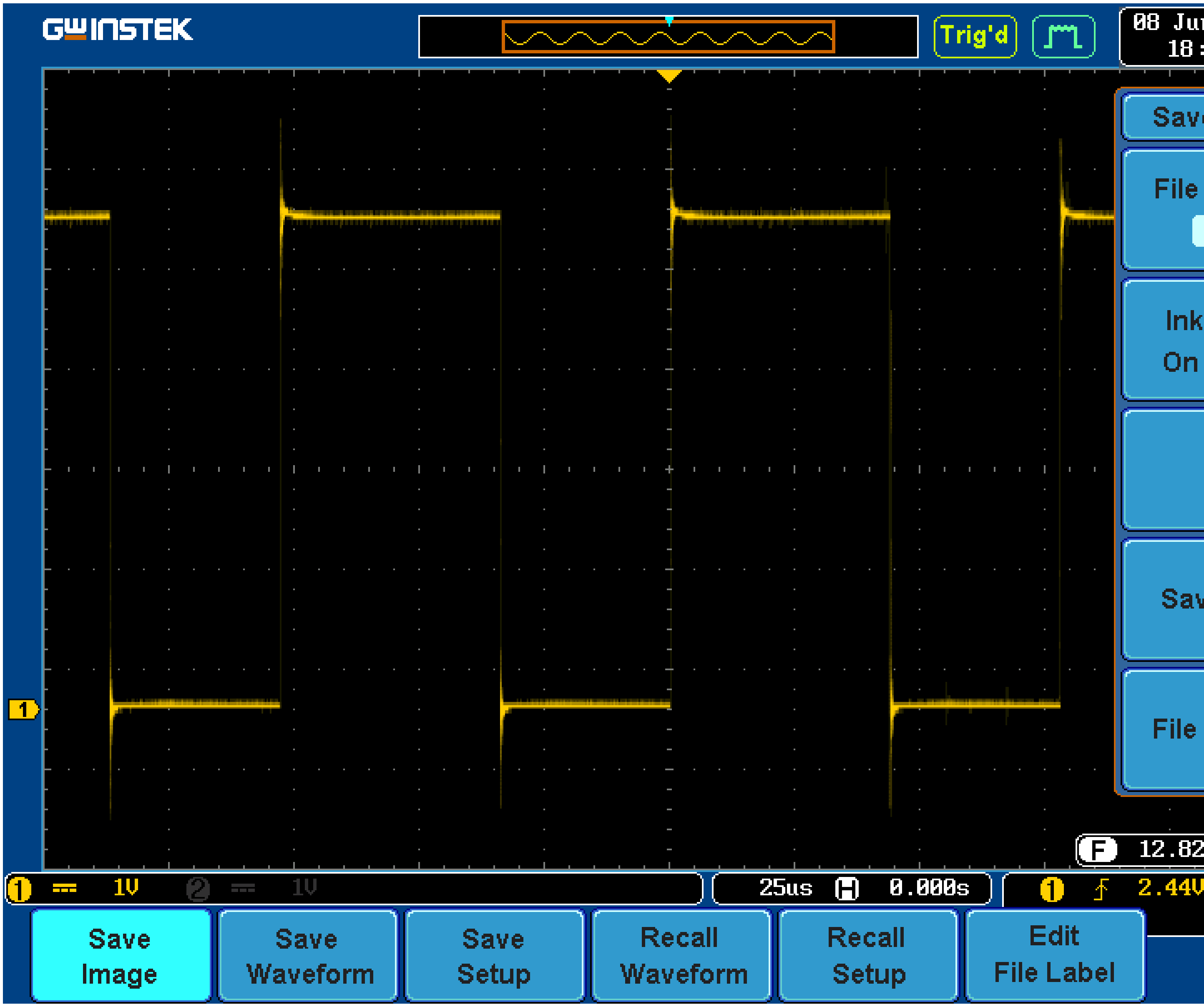

GW INSTEK
Stop
08 Ju
19 :
Sav
File
Ink
On
Sav
File
F
Period 1.686ms
Dutycycle 36.18%
2V
2V
500us
0.000s
2.32V
Save Image
Save Waveform
Save Setup
Recall Waveform
Recall Setup
Edit File Label


GW INSTEK
Stop
08 Ju
19 :
Sav
File
Ink
On
Sav
File
F
Period 1.716ms
Dutycycle 24.59%
1V
200mV
5ms
-4.050ms
4.00
Save
Image
Save
Waveform
Save
Setup
Recall
Waveform
Recall
Setup
Edit
File Label

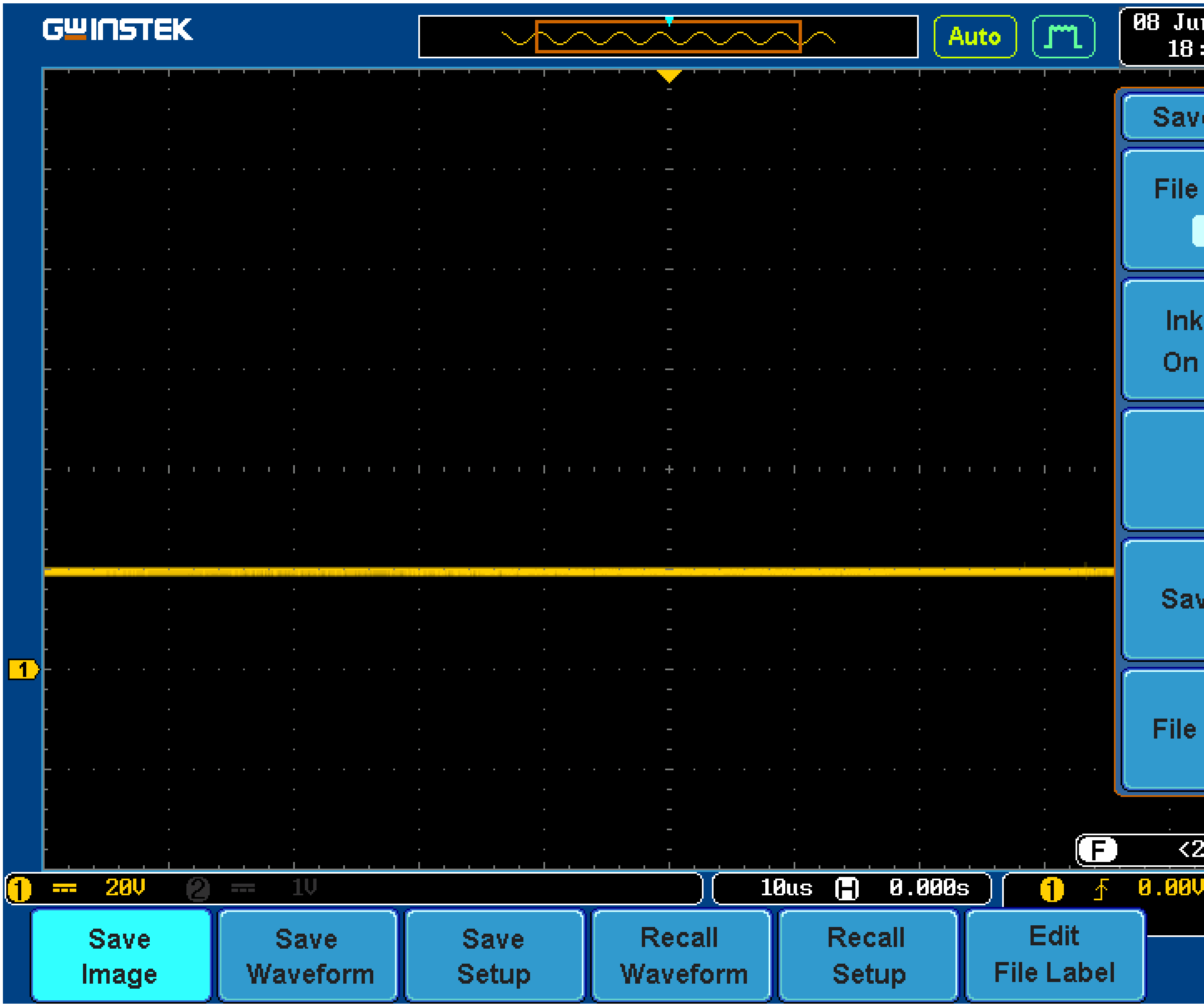

GW INSTEK
Trig'd
08 Ju
18 :
Sav
File
Ink
On
Sav
File
F
Period Ch Off
Dutycycle Ch Off
1V
20V
25us
0.000s
-36.8V
Save Image
Save Waveform
Save Setup
Recall Waveform
Recall Setup
Edit File Label

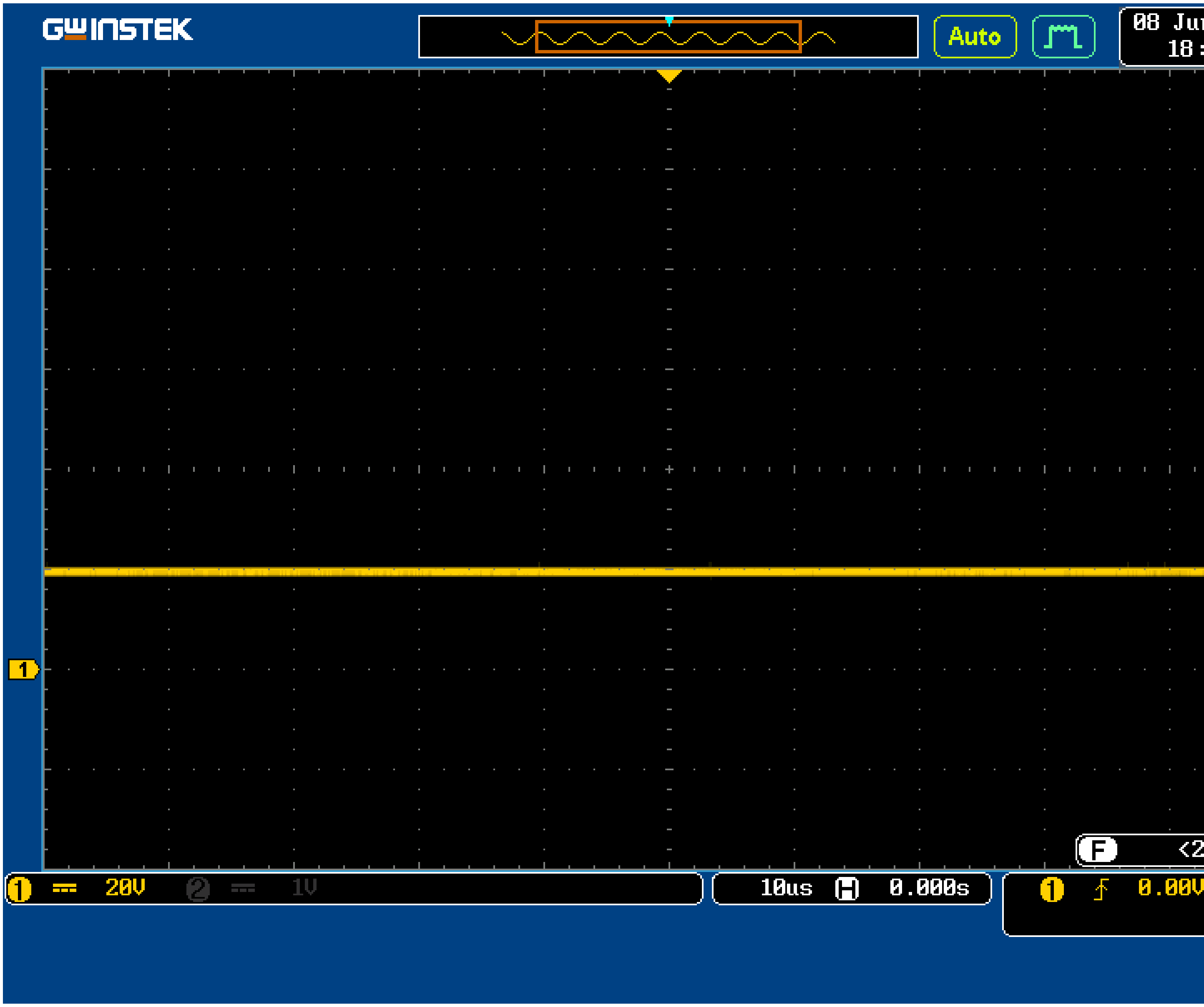

GW INSTEK
Trig'd
08 Ju
18
Sav
File
Ink
On
Sav
File
Period Ch Off
Dutycycle Ch Off
1V
20V
25us
0.000s
9.60V
Save Image
Save Waveform
Save Setup
Recall Waveform
Recall Setup
Edit File Label

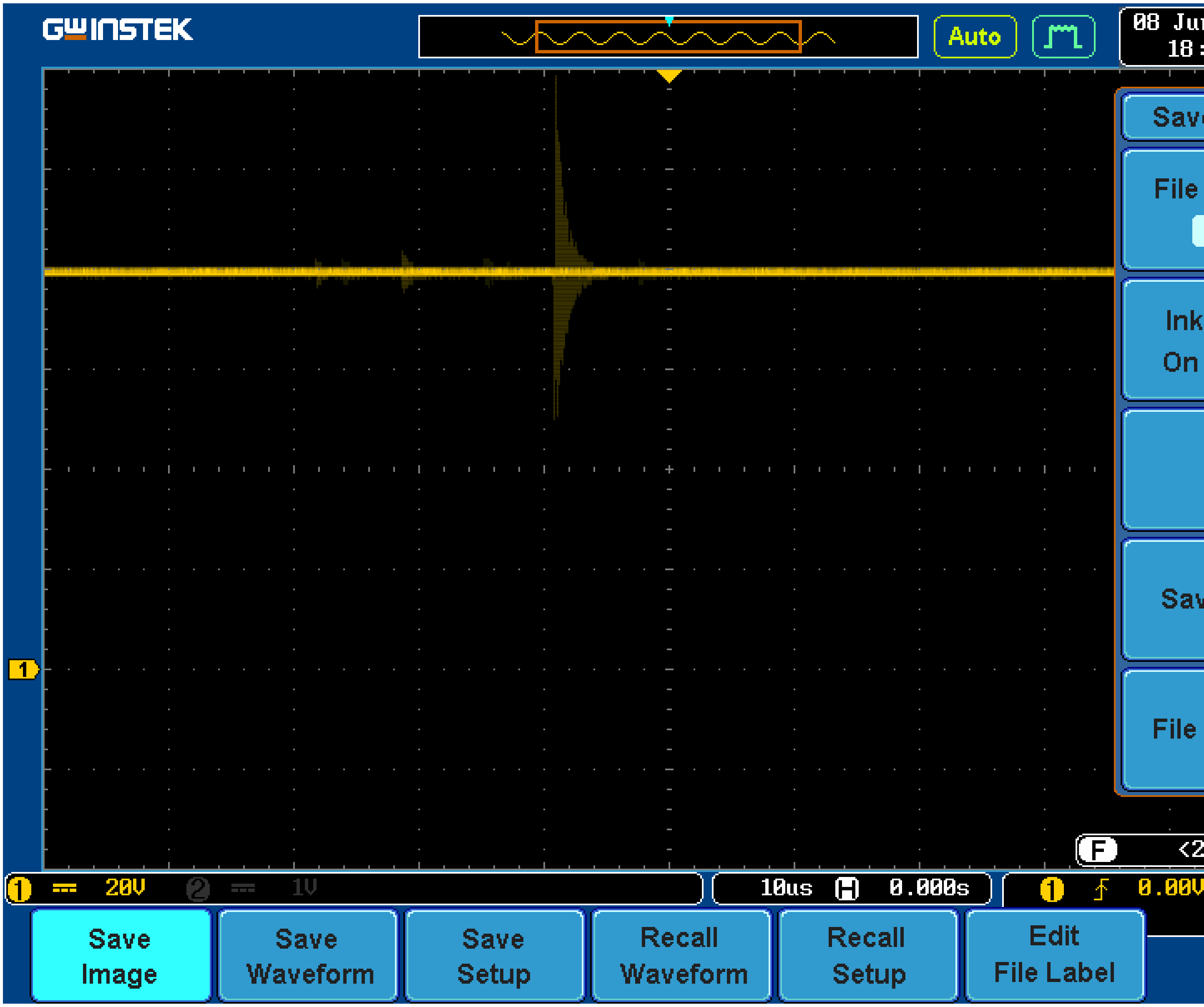

GW INSTEK
Trig'd
08 Ju
18 :
Sav
File
Ink
On
Sav
File
F
1
Period 77.98us
Dutycycle 56.41%
1V
1V
25us
16.00us
2.44V
Save Image
Save Waveform
Save Setup
Recall Waveform
Recall Setup
Edit File Label



GW INSTEK
Trig'd
08 Ju
18
1
Sav
File
Ink
On
Sav
File
F 12.82
1 1V
2 1V
25us
H 0.000s
1 2.44V
Save Image
Save Waveform
Save Setup
Recall Waveform
Recall Setup
Edit File Label


GW INSTEK
Auto
08 Ju
18 :
Sav
File
Ink
On
Sav
File
<2
20V
1V
10us
0.000s
0.00V
Save
Image
Save
Waveform
Save
Setup
Recall
Waveform
Recall
Setup
Edit
File Label


GW INSTEK
Auto
08 Ju
18
20V
1V
10us
0.000s
0.00V



In this chapter we presented the entire system prototype and the components selection used for its implementation. The system was built from the interconnection of between Boost Converter, inverter, LPF, and Resistive Load. We showed our system is better than the commercially available ones in the market in terms of probability of failure as well as cost.

Chapter 4: Conclusion and Prospective

This study proposes a partial of the entire system for integrating renewable energy especially solar energy with a conventional power grid. The study analyzed, measured, and compared the values of significant parameters. According to the change in the values of these key parameters, certain adjustments were made to obtain the optimal efficiency and power quality. This was implemented by Matlab/Simulink simulation and prototype. Boost converter and DC to AC inverter were connected together. The goals of this project were to create a working three phases DC-AC sine wave inverter that could efficiently provide three kilowatt of power using PWM and comparing it to other methods currently on the market in terms of price and affiance. A full working system was built and tested. However, further improvements are required to reach a fully functional product ready for marketing.

A great concern should be raised regarding modeling and implementing such types of projects. As many electronic engineers are focusing on one of the two converters: the DC to DC converter or the DC to AC inverter. To illustrate, many papers are proposing and implementing new DC to DC designs (3, 4, 5, 6, 7, and8). Many papers propose new DC to AC designs (9, 10, 11, and12). However, combining the DC to DC converter and DC to AC inverter together would raise some technical issues. As a result implementing a model which contains the two converters together would introduces some solutions to these issues instead of encountering these issues during the actual operating time which may result in a negative impact on the power quality. More advanced techniques should be included, such as

- PHASE LOACKED LOOP (PLL) to synchronize with the grid.
- PID CONTROL: to keep the capacitor voltage constant and inject a sinusoidal current into the grid.
- DSP CARD: to execute the whole control algorithm with a suitable sampling time sufficient to connect to the grid.

References

[1] Tan C.W, Green T.C, and Hernandez-Aramburo C.A, “Analysis of Perturb and Observe Maximum Power Point Tracking Algorithm for Photovoltaic Applications,” *IEEE International Conference on Power and Energy, Dec. 2008.*

[2] Brunton,S.L., Clarence Rowley,W., and Sanjeev R., Maximum Point Tracking for Photovoltaic Optimization Using Extremism Seeking, Princeton University, Princeton, NJ 08544.

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[5]. Ebrahim ,B., and Ali,N., Flexible Multilevel Boost DC-AC Converter in IEEE Catalog Number: CFP121IJ-ART.

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[7] Schelle,D.and Castorena,J., Buck-ConverterDesign Demystified,.

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[10] Blooming, T., Carnovale , D., Application of IEEE STD 512-1992 Harmonic Limits.

[11] Doucet, J., Eggleston, D., and Shaw, J., Dc/Ac Pure Sine Wave Inverter, 2007.

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Appendix A: M file to calculate the value of L and C of the boost converter

```
D=0.5;
fs=15e3;
R=600;
vo=600;
Dvo=0.01;
Lb=1*(R*D*(1-D)^2)/(2*fs);
Cb=1*(vo*D)/(fs*Dvo*R);
```

Appendix B: Code for Microcontroller of the Boost convert

```
void main ()
{int d;
unsigned short duty_ratio;
unsigned long freq;
char vd [4],id[6], pd[4], dpd[4], dd[5];
float x,y,v,i,p,v0,p0,dp,dv, v1;

TRISA=0xff;    //Port A as input port to use A0, A1 as Analogue inputs
TRISB=0x00;    //Port B as output port for the LCD
TRISE.F1=0;    // configure E1 as output pin for PWM test
TRISC.F2=0;   //RC2 as output for PWM output
PORTE.F1=PORTC.F2;   // TO SEE THE LED FLASHS

                      Lcd_Config(&PORTB, 0, 2,1, 7,6, 5, 4);    // LCD
configuration based on the help as per its H/W connection
Lcd_Cmd(Lcd_Clear);
Lcd_Cmd(LCD_CURSOR_OFF);
                      ADCON1=0x84;   //Configuration of the register ADCON1
                      Pwm_Init(30000);
p0=0; // initial condition
v0=0; // initial condition
d=50; // initial condition: Duty cycle = 30 %

start:

// Volatge Measurment
   x=Adc_Read(0);
   v=(x/204.8)*20; // voltage equation
   floatToStr(v,vd);

// Current Measurment
   y=Adc_Read(1);
   i=(y/204.8)*1000;
   floatToStr(i,id);

// Power calculation
   p=v*i/1000;
   floatToStr(p,pd);

// Power and volatge differences calculation
dp=p-p0;
dv=v-v0;
p0=p;
v0=v;

// Display on LCD
 Lcd_Out(1, 1, vd);           // Display Voltage
 Lcd_Out(1, 6, "V   ");

 Lcd_Out(2, 1, id);           // Display Current
 Lcd_Out(2, 6, "mA    ");

 Lcd_Out(1, 10, pd);          // Display Power
 Lcd_Out(1, 15, "W ");
```

```
floatToStr(dp,dpd);
 Lcd_Out(2, 10, dpd);
 Lcd_Out(2, 15, "W ");

//P & O program
if (dp>1)                      // power dead band
         {
           if (dv>=0)          // d=d+(dv/100)*d;
           d=d++;      // Increase Voltage d=d++; (0.5 V) Voltage dead band
           if (d>=92)    d=92;

           if (dv<= -0)
           //d=d-(dv/100)*d;  //
        d=d--;      // Decrease Voltage d=d--;
           if (d<=10)    d=10;
          }

if (dp<-1)

          {
            if (dv>=0)
            //d=d-(dv/100)*d;    //
            d=d--;   // Decrease Voltage
            if (d<=10)    d=10;

            if (dv<= -0)
            //d=d+(dv/100)*d; //
            d=d++;      // Increase Voltage
           if (d>=92)    d=92;
           }

if (0<=dp<=1)     d=d;        //no change


/* Display Duty ratio on LCD
 intToStr(d,dd);
Lcd_Out(2, 9, dd);
Lcd_Out(2, 15, "% ");
  */

// PWM operation

      duty_ratio=(d*255)/100;
      Pwm_Change_Duty(duty_ratio);
      Pwm_Start();


delay_ms(1000);



/* Temp program
duty_ratio=(d*255)/100;
Pwm_Change_Duty(duty_ratio);
Pwm_Start();

delay_ms(1000);
```

```
d=d++;
if (d>=85)
         {
         pwm_stop();
         d=20;
         }
 */

goto start;

}
```

Appendix C: Code for Microcontroller of the DC to AC

```
#include <built_in.h >
 #include "PWM_table.c "

char i;
unsigned int y;

 void interrupt() {

 PWMCON1.UDIS=1 ;
 i=i+1;
 y=md8[i];
 PDC0L=Lo(y);
 PDC0H=Hi(y);

 y=md8[i+14];
 PDC1L=Lo(y);
 PDC1H=Hi(y);

 y=md8[i+7];
 PDC2L=Lo(y);
 PDC2H=Hi(y);

if(i==20){i=0;}

PWMCON1.UDIS=0 ;
PORTD.f0=~PORTD.f0; // test interrupt
PIR3.PTIF=0; // clear interrupt flag
}
void main(void)
{
char x;

TRISC=0x00;
TRISB=0x00;
TRISD=0x00;
TRISA=0x00;
TRISE=0x00;
PORTD=0x00;
PORTB=0x00;
i=0;




INTCON.GIE=1;// enable Global interrupt
INTCON.PEIE=1;// enable all peripheral interrupt
PIE3.PTIE=1; // enable PWM timer interrupt
IPR3.PTIP=1; /// PWM Timer interrupt hig periority




PTCON1.PTEN=0;           // stop PWM timer
```

```
PTCON1.PTDIR=0;          // PWM Timer 0 up direction
PTCON0=0b00000000;       // event postscallar (xxxx) timer prescaller (xx)
Timer mode (xx) free runing

PWMCON0=0b01000000;      //  PWM enable (0xxx) PWM mode (xxxx3210 and 0
complementary)
PWMCON1.UDIS=0 ;         // update disable bit 1=disable
DTCON=0b01000110;        // dead time
FLTCONFIG=0b00000000;




PTPERL=0xB7;         //  PWM periode low  8 bit
PTPERH=0x03;         // PWM periode High (0x0x 4 bit only)

y=md10[0];
PDC0L=Lo(y);         // Duty low 6 bits xxxxxx00
PDC0H=Hi(y);         // duty high 6 bit 00xxxxxx

y=md10[14];
PDC1L=Lo(y);         // Duty low 6 bits xxxxxx00
PDC1H=Hi(y);         // duty high 6 bit 00xxxxxx

y=md10[7];
PDC2L=Lo(y);         // Duty low 6 bits xxxxxx00
PDC2H=Hi(y);         // duty high 6 bit 00xxxxxx

PTCON1.PTEN=1;       // PWM TImer start



// chek for program operation
xx:
PORTC=0xff;
delay_ms(1000);
PORTC=0x00;
delay_ms(1000);

goto xx;


}

**********************PWM_TABLE.C PROGRAM***************
const unsigned int
md10[35]={0x0770,0x09A0,0x0BA0,0x0D40,0x0E58,0x0ED8,0x0EAC,0x0DE0,0x0C7C,0x0A
A8,0x088C,0x0654,
0x0434,0x0260,0x0100,0x0030,0x0018,0x0084,0x01A0,0x0340,0x053C,0x0770,0x09A0,
0x0BA0,
0x0D40,0x0E58,0x0ED8,0x0EAC,0x0DE0,0x0C7C,0x0AA8,0x088C,0x0654,0x0434,0x0260}
;
```

```
const unsigned int md9[35]={
0x0770,0x0968,0x0B34,0x0CA8,0x0DA8,0x0E1C,0x0DF4,0x0D38,0x0BFC,0x0A54,0x086C,
0x0670,
0x0488,0x02E0,0x01A4,0x00E8,0x00C4,0x0134,0x0234,0x03AC,0x0574,0x0770,0x0968,
0x0B34,
0x0CA8,0x0DA8,0x0E1C,0x0DF4,0x0D38,0x0BFC,0x0A54,0x086C,0x0670,0x0488,0x02E0}
;

const unsigned int
md8[35]={0x0770,0x0930,0x0AC8,0x0C14,0x0CF8,0x0D5C,0x0D3C,0x0C94,0x0B7C,0x0A0
4,0x0850,0x068C,
0x04DC,0x0364,0x0248,0x01A4,0x0180,0x01E4,0x02C8,0x0414,0x05B0,0x0770,0x0930,
0x0AC8,
0x0C14,0x0CF8,0x0D5C,0x0D3C,0x0C94,0x0B7C,0x0A04,0x0850,0x068C,0x04DC,0x0364}
;

const unsigned int
md7[35]={0x0770,0x08F8,0x0A5C,0x0B80,0x0C48,0x0CA0,0x0C80,0x0BF0,0x0AF8,0x09B
0,0x0834,0x06A8,
0x052C,0x03E4,0x02EC,0x025C,0x0240,0x0298,0x035C,0x0480,0x05E8,0x0770,0x08F8,
0x0A5C,
0x0B80,0x0C48,0x0CA0,0x0C80,0x0BF0,0x0AF8,0x09B0,0x0834,0x06A8,0x052C,0x03E4}
;

const unsigned int
md6[35]={0x0770,0x08C0,0x09F0,0x0AEC,0x0B94,0x0BE0,0x0BC8,0x0B4C,0x0A78,0x096
0,0x0818,0x06C4,
0x0580,0x0468,0x0394,0x0314,0x02FC,0x0348,0x03F4,0x04EC,0x0620,0x0770,0x08C0,
0x09F0,
0x0AEC,0x0B94,0x0BE0,0x0BC8,0x0B4C,0x0A78,0x0960,0x0818,0x06C4,0x0580,0x0468}
;

const unsigned int
md5[35]={0x0770,0x0888,0x0988,0x0A58,0x0AE4,0x0B24,0x0B10,0x0AA8,0x09F4,0x090
C,0x07FC,0x06E0,
0x05D0,0x04E8,0x0438,0x03D0,0x03BC,0x03F8,0x0488,0x0558,0x0658,0x0770,0x0888,
0x0988,
0x0A58,0x0AE4,0x0B24,0x0B10,0x0AA8,0x09F4,0x090C,0x07FC,0x06E0,0x05D0,0x04E8}
;

const unsigned int
md4[35]={0x0770,0x0850,0x091C,0x09C0,0x0A34,0x0A64,0x0A54,0x0A00,0x0974,0x08B
8,0x07E0,0x06FC,
0x0624,0x0568,0x04DC,0x0488,0x0478,0x04AC,0x051C,0x05C4,0x0690,0x0770,0x0850,
0x091C,
0x09C0,0x0A34,0x0A64,0x0A54,0x0A00,0x0974,0x08B8,0x07E0,0x06FC,0x0624,0x0568}
;

const unsigned int
md3[35]={0x0770,0x0818,0x08B0,0x092C,0x0984,0x09A8,0x099C,0x095C,0x08F4,0x086
8,0x07C4,0x0718,
0x0678,0x05EC,0x0580,0x0544,0x0534,0x055C,0x05B0,0x062C,0x06C8,0x0770,0x0818,
0x08B0,
0x092C,0x0984,0x09A8,0x099C,0x095C,0x08F4,0x0868,0x07C4,0x0718,0x0678,0x05EC}
;
```

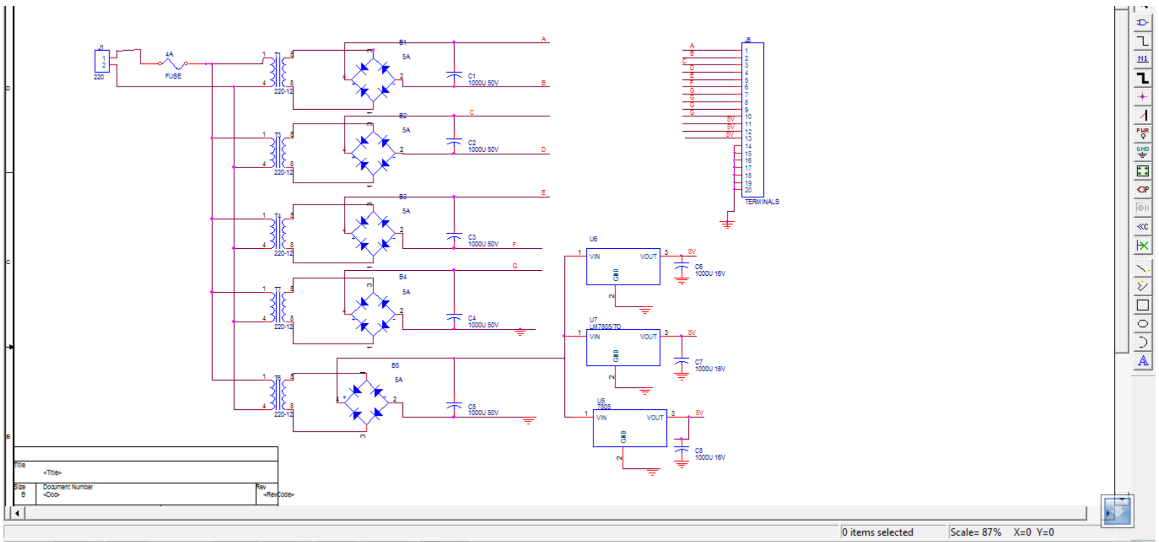
```
const unsigned int
md2[35]={0x0770,0x07E0,0x0844,0x0898,0x08D0,0x08EC,0x08E0,0x08B8,0x0870,0x081
4,0x07A8,0x0738,
0x06C8,0x066C,0x0624,0x05FC,0x05F4,0x060C,0x0644,0x0698,0x0700,0x0770,0x07E0,
0x0844,
0x0898,0x08D0,0x08EC,0x08E0,0x08B8,0x0870,0x0814,0x07A8,0x0738,0x06C8,0x066C}
;

const unsigned int
md1[35]={0x0770,0x07A8,0x07D8,0x0804,0x0820,0x082C,0x0828,0x0814,0x07F0,0x07C
0,0x078C,0x0754,
0x071C,0x06EC,0x06C8,0x06B4,0x06B0,0x06BC,0x06D8,0x0704,0x0738,0x0770,0x07A8,
0x07D8,
0x0804,0x0820,0x082C,0x0828,0x0814,0x07F0,0x07C0,0x078C,0x0754,0x071C,0x06EC}
;
```

Appendix D: Parts List

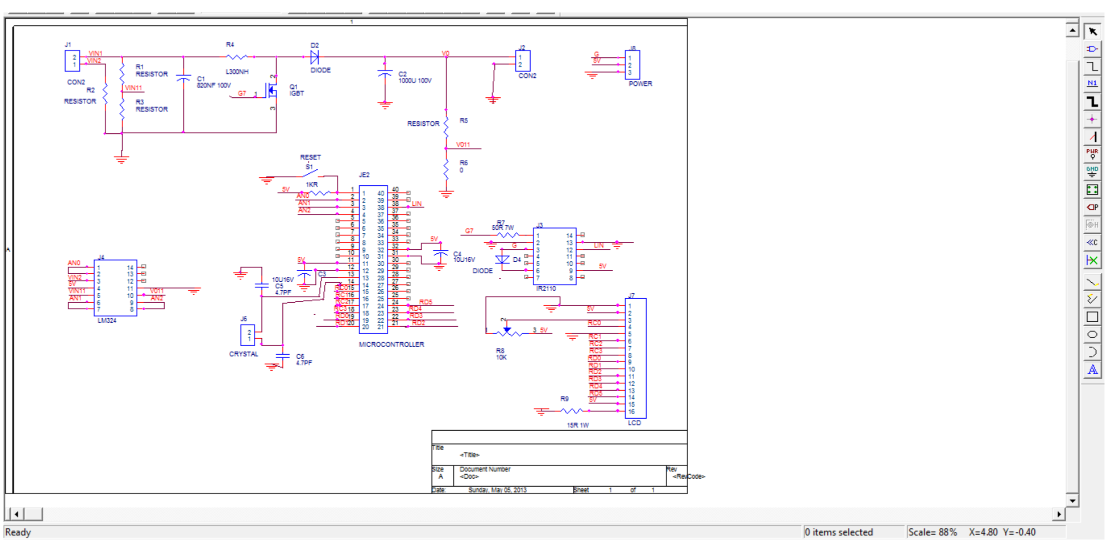
- ✓ 3 PIC18f4431
- ✓ 2 LCD display
- ✓ 4 IR2110 deriver
- ✓ 2 IGPT Module FP10R12YT3
- ✓ capacitors 470 micro Farad
- ✓ three inductor 1mH
- ✓ diode
- ✓ leds for measurement
- ✓ three light bulbs
- ✓ Three resistor 30 ohms

Appendix E: Schematics

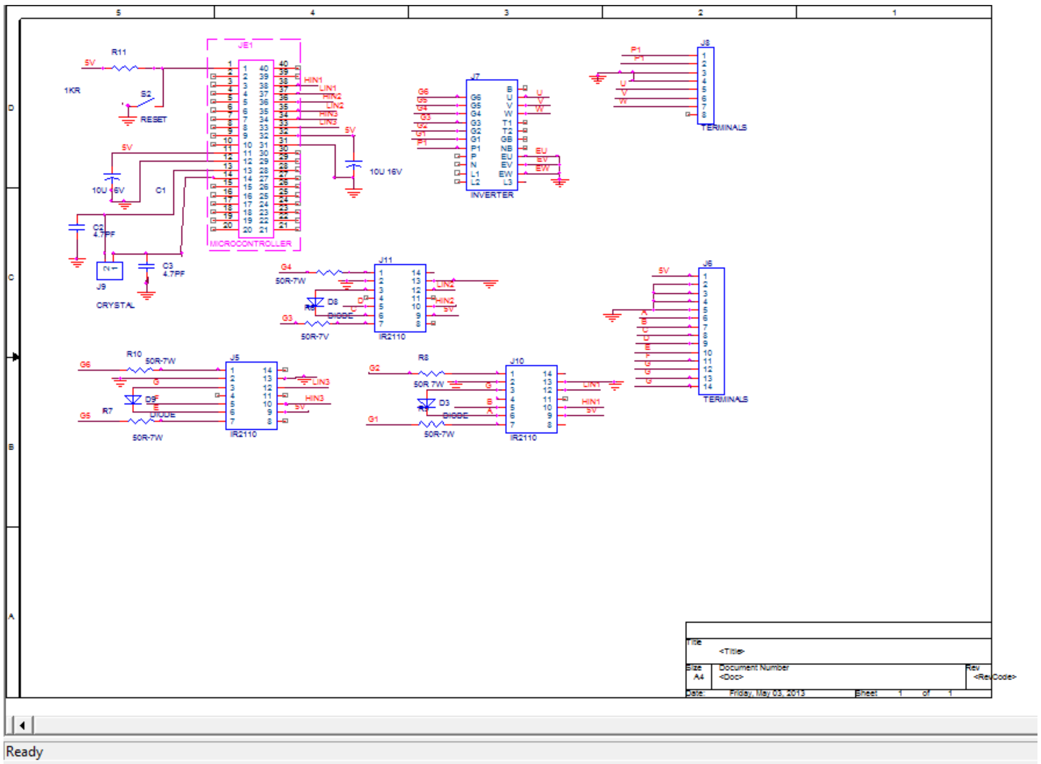
Power supply



Boost



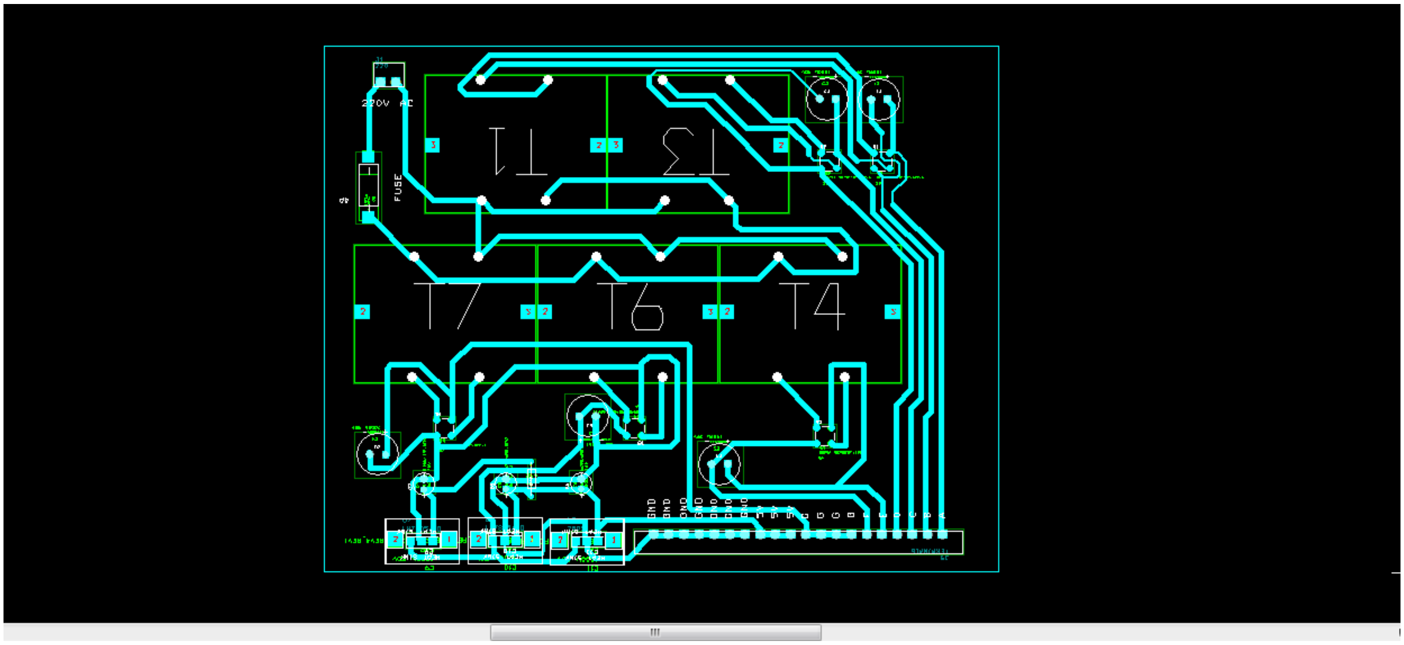
Inverter

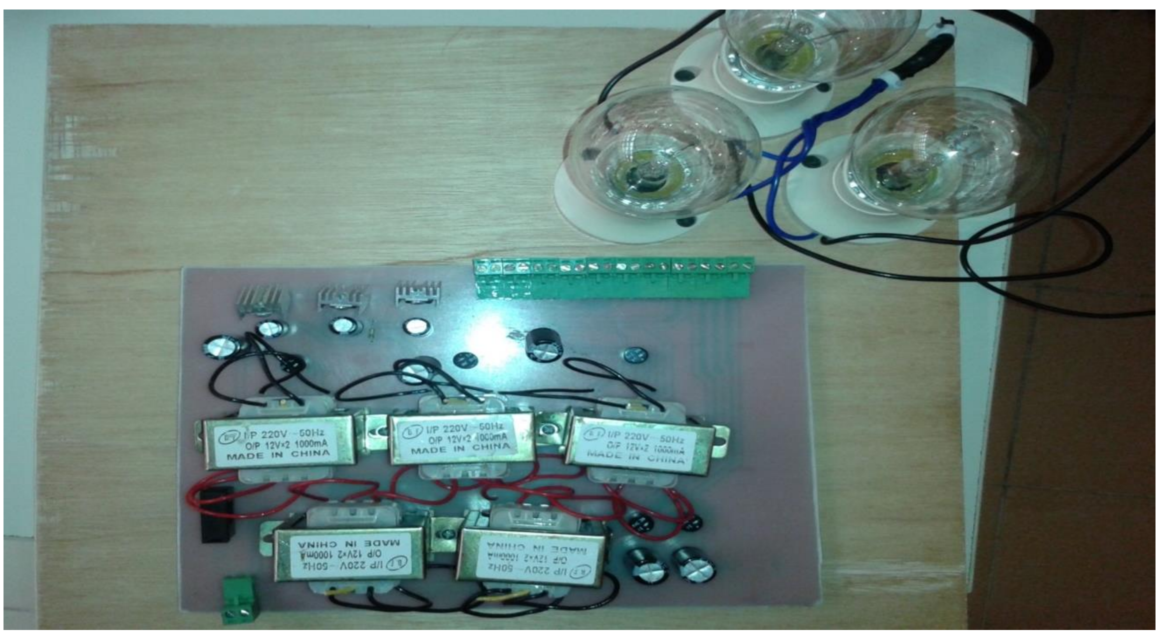


MICROCONTROLLER
INVERTER
TERMINALS
CRYSTAL
RESET
IR2110
Ready

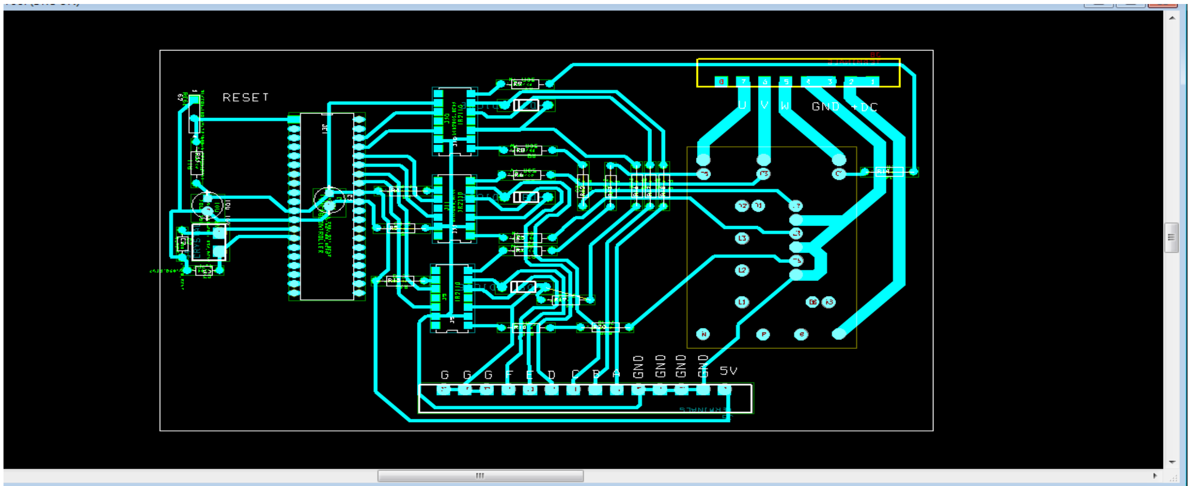
Appendix F: Layouts and pictures

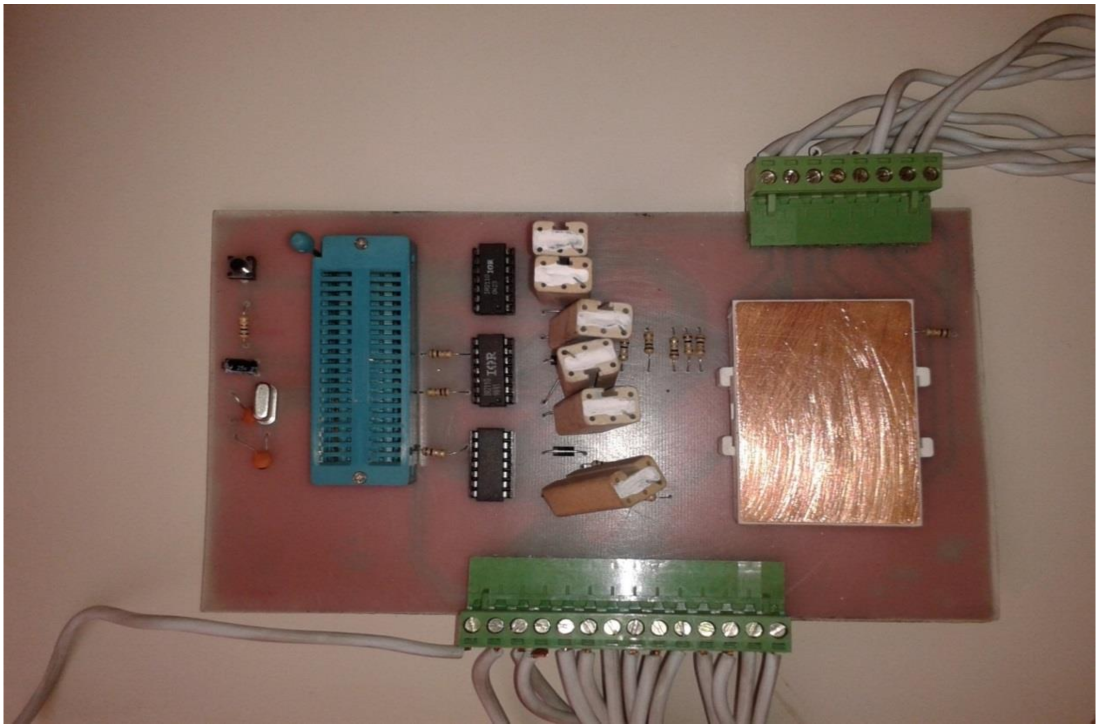
Power supply





Inverter





Boost