

EECE 280 & APSC 201

Formal Report of

Project 2: Advanced Multimeter using VHDL

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Abstract

This report provides the Introduction, Mechanism Description, A Set of Instructions, Evaluation of the Complete System, Testing Methodologies, Conclusion, and Reference of an advanced multimeter using VHDL. The multimeter can measure voltage in the range ± 29.000 DC volts, current in the ranges ± 870.00 DC mili-Amperes, resistance in the range 10 to 4M ohms, and Beta of NPN and PNP transistors, with 5 digits display. The physical configuration of this multimeter is a black metal box enclosing the electric circuit boards and supporting an Altera DE2 board on top.

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Introduction

The objective of project 2 was to design, build and test a high-resolution multimeter comparable in performance to the multimeters available at the UBC EECE laboratories. The Altera DE2 board was an integral part of the project as it was used to implement the logic component of our circuit (programmed via VHDL) and was also utilized for its LED and LCD displays to showcase the functionalities of our multimeter. The basic design of the VHDL code was a system to

- 1) Control the flows of the following states- Reset/Display, Count-Up, Set-Sign, Countdown, and Binary-BCD Decoding
- 2) Manipulate the four registers to fluctuate between the ohmmeter, voltmeter, ammeter and the Beta calculations.
- 3) Use the LCD drivers to signal the current state

The DE2 board was synchronized with a simple voltmeter circuit, which consisted of an integrating operational amplifier, comparator, multiplexer and relay switches to perform the tasks written in the VHDL code. The voltmeter served as a platform in which all the other components relied on. The ohmmeter required the voltmeter and was built by providing a constant current of 0.01 mA through the unknown resistor. By measuring the voltage across the resistor, the value was calculated using the formula $R = V / 0.01 \text{mA}$. The ammeter also relied on the voltmeter and was built using a difference and inverting amplifier. We as a group also built our own power source that could provide our circuit with positive and negative voltages. The basic building block for the power source was a transformer to step down the AC voltage. Various other components were then used to convert the AC voltage to DC voltage. The negative

voltages were then achieved by using different sides of the diode bridge. Armed with knowledge of circuit theory, our group was successfully able to construct a complicated yet efficient circuit.

Mechanism Description

1.0 Introduction

The advanced multimeter using VHDL (AMR) is an electrical apparatus most commonly used in electrical engineering. AMR can change to different modes, which are voltmeter, ammeter, ohmmeter, and beta β calculator. It is built by chips soldering on silicon electric circuit boards, and run by Altera DE2 board. We use VHDL to control the function of the DE2 board. Then the DE2 board will send signals to the electric circuit board. A black rectangular box encloses all electric circuit boards. The DE2 board is put on top of the box.

The major parts of AMR are:

- VHDL code
- Power Supply
- Voltmeter
- Ammeter
- Ohmmeter
- Beta β Calculator
- Metal Enclosure

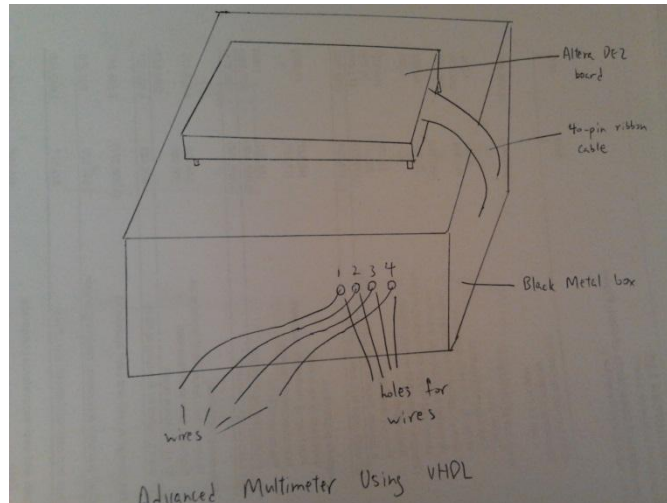


Figure 1: Appearance of the Advanced Multimeter using VHDL

2.0 Part-by-part Description

The following is a description of main parts of the advanced multimeter.

2.1 VHDL code

The De2 board and vhdl has served as a brain of our multimeter. It works as counters, registers, many types of decoders, multiplexers, drivers, range checking module, and most importantly, state machine.

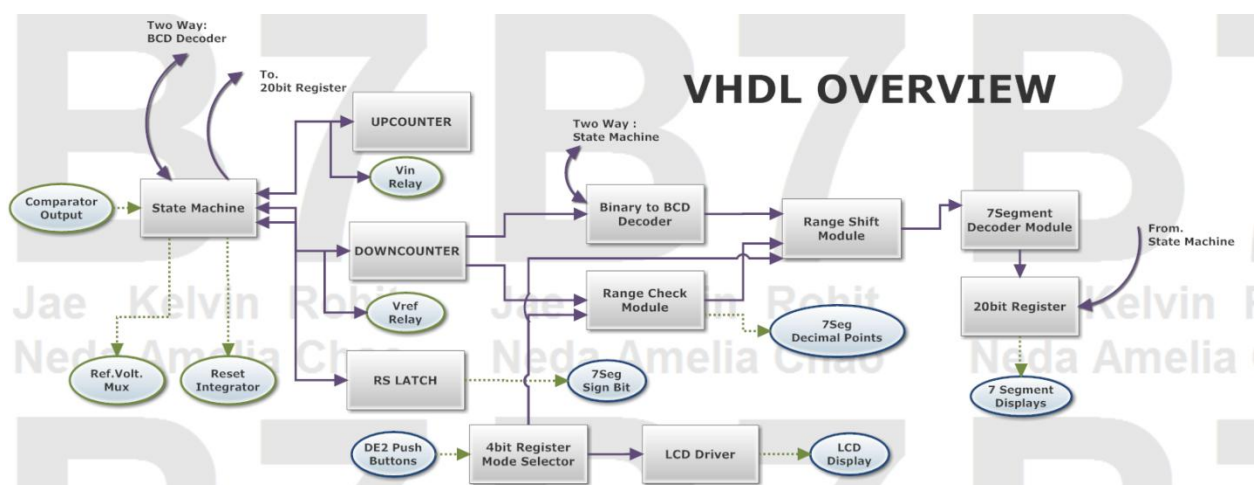


Figure 2: Overview of the VHDL code

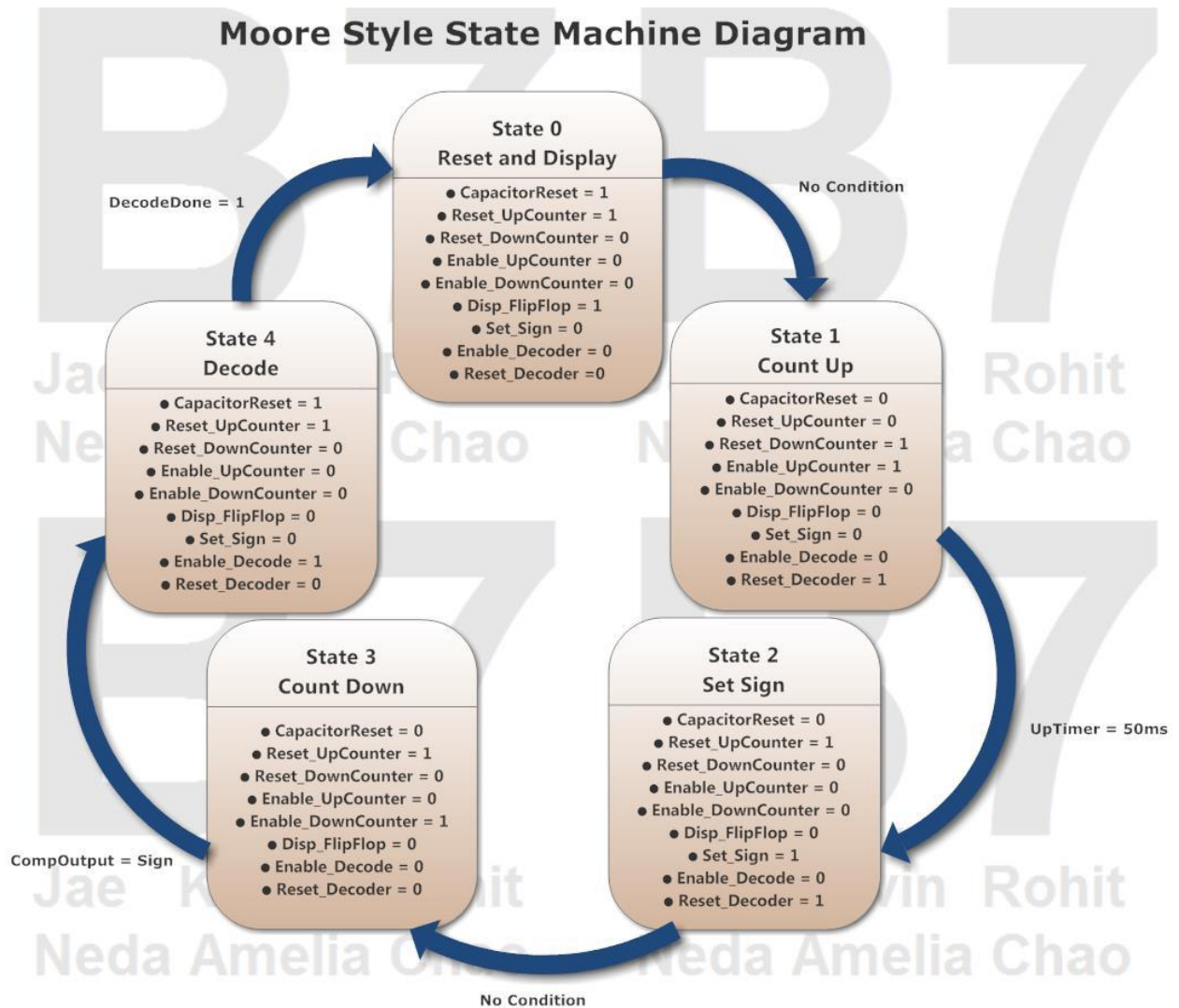


Figure 3: State Machine in VHDL

The state machine has five states: Reset/Display, Count-Up, Set-Sign, Count-Down, and Binary-BCD Decoding. When it is in Resetting state, it will reset the integrator by shortening capacitor, reset all registers (with exception to Down Counter, which is reset in Count-Up), and store the new 5 digit BCD value to register for display. This display stores this value until the end of next cycle, when it receives a new value. In Count-Up stage, up-counter is enabled to measure 500ms, while DE2 board outputs signal to enable Vin to be passed to integrator. after 500ms has passed, the counter will signal the state machine to proceed to next state. In the state Set-Sign, the output of comparator from voltmeter circuit is inverted

and stored in a latch. This value will be used as sign. If the output of integrator at this point is higher than ground, it means the V_{in} was negative, and vice versa. The output of this latch is also passed to the multiplexer on circuit to decide which reference voltage to use (+ or - 5v). The state machine will stay in the next stage, Count-Down, until the comparator output from circuit is changed, either from high to low(negative sign), or low to high(positive sign). The Down-Counter will be enabled at this stage to measure the time in binary. In the final stage, This binary value is decoded into BCD. The reason we do not count down in BCD to start with is for easier computation of the value.

4 bit register is used to hold current mode(voltmeter, ammeter, ohmmeter, beta). 4 push buttons on DE2 board are used to switch between each mode, and this register holds the value after the buttons have been released.

The Range Check is also embedded in the VHDL. However it does not take a part of state machine; it runs simultaneously. The Range Checker receives input from Down-counter. It compares the value to different ranges according to different modes. For example, in voltmeter, it compares the value to 1V and 10V, and assign one of three ranges. depending on this range, the location of decimal point and which 5 digits out of originally received 7 digits to display. Detailed chart on range checker and range shifter is shown below:

Mode	Value Range	Description	Decimal Location	Displayed Range (Decimal Digits)	Example
Voltmeter	0 ~ 9,999	0v ~ 1v	1	4 downto 0	.12345 (V)
Voltmeter	10,000 ~ 99,999	1v ~ 10v	2	5 downto 1	1.2345 (V)
Voltmeter	100,000+	10v ~ 20v	3	6 downto 2	12.345 (V)
Ammeter	0 ~ 9,999	0 ~ 10mA	2	4 downto 0	1.2345 (mA)
Ammeter	10,000 ~ 99,999	10 ~ 100mA	3	5 downto 1	12.345 (mA)
Ammeter	100,000+	100 ~ 200mA	4	6 downto 2	123.45 (mA)
Ohmmeter	0~999	0 ~ 999 ohms	NONE	2 downto 0 & "E0"	123E0 (ohm)
Ohmmeter	1,000 ~ 9,999	1k ~ 10k ohms	2	3 downto 1 & "E3"	1.23E3 (ohm)
Ohmmeter	10,000 ~ 99,999	10k ~ 100k ohms	3	4 downto 2 & "E3"	12.3E3 (ohm)
Ohmmeter	100,000 ~ 999,999	100k ~ 1M ohms	NONE	5 downto 3 & "E3"	123E3 (ohm)
Ohmmeter	1,000,000+	1M ohm +	2	6 downto 4 & "E6"	1.23E6 (ohm)
Beta	-	all values	NONE	"00" & 4 downto 2	00123

Figure 4: Chart of the Range Check

The last module in VHDL is LCD Driver. It acts as a driver to write one of five messages on LCD display. Four messages indicate the mode and units, and one as a welcome screen. The ASCII codes are pre-coded into VHDL, and message is determined by current mode.

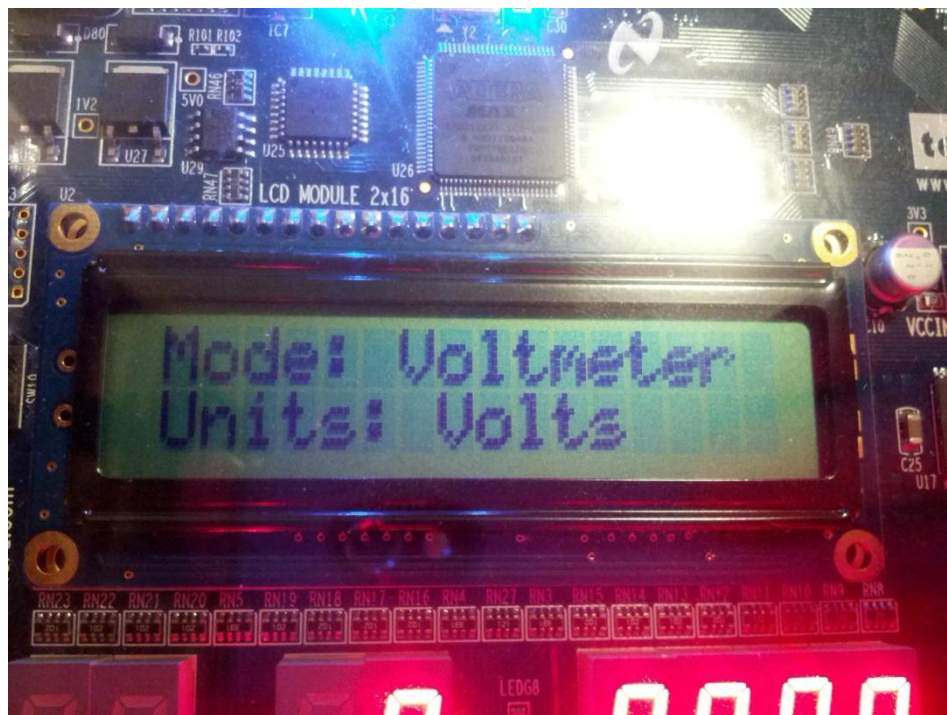


Figure 5: LCD Display of the DE2 board

2.2 Power Supply

In order to power up all the chips in our circuit, we need to create a power supply. We use a diode bridge circuit to step down and rectify the AC voltage from the transformer to get a full wave rectified voltage. Then we add a decoupling capacitor to the circuit to reduce the ripple voltage. The circuit will produce a constant DC voltage. $\pm 16\text{V}$ and $\pm 5\text{V}$ are required to power up the circuit.

For $+16\text{V}$, we can directly use the rectified DC voltage. Using the other side of the diode bridge, we can get -16V . We make 5V and -5V by using a LM7805 and LM7905 regulator.

The circuit of the power supply is shown below:

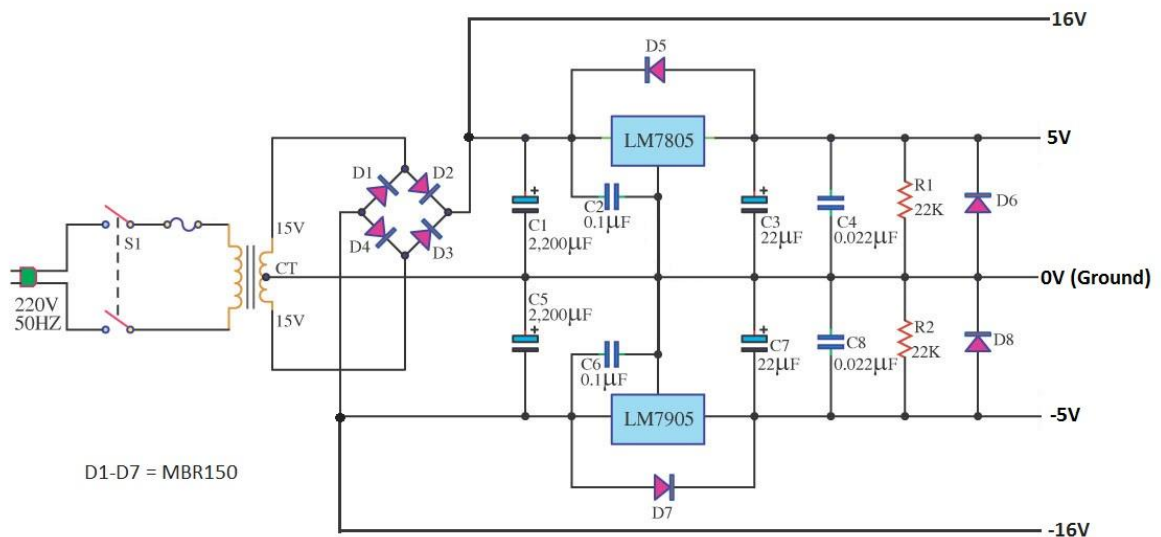


Figure 6: Schematic Diagram of Power Supply

2.3 Voltmeter

The voltmeter circuit is relatively simple and includes only few chips: integrating op amp, comparator, and a multiplexer and few switches. the multiplexer is used to provide reference voltage according to the sign of V_{in} , the 2 switches are used as a multiplexer to choose between V_{in} and reference voltage (since the multiplexer chip is unable to handle more than

11 volts). The integrating op amp and comparator as the main part of ADC. Also, a switch was used to reset the integrator. The circuit communicates with the DE2 board to work as a full voltmeter

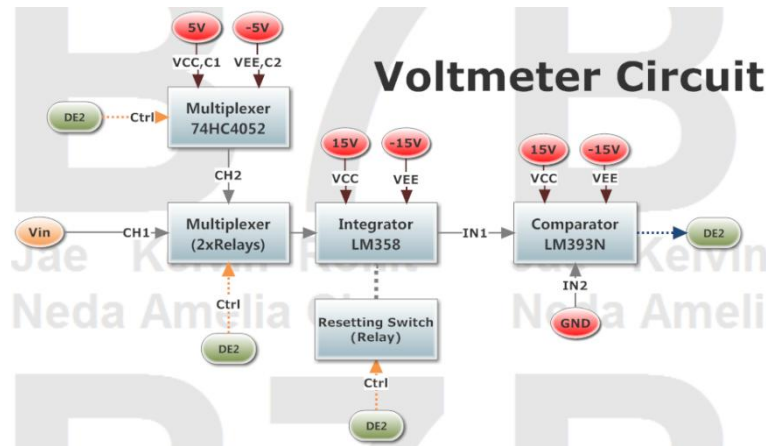


Figure 7: Diagram of the Voltmeter Circuit

2.4 Ammeter

We designed the ammeter using two LM 358 chips functioning as a difference amplifier and an inverting amplifier, a CD74HC4052 E multiplexer chip and resistors of various values. In the first portion of the ammeter, the input current is provided to the first LM 358 chip and is amplified by 10 and then inverted, obeying the formula $V_{out} = V_{th} - V_{in}$. V_{th} is 0, resulting in a negative output. The output of the first operational amplifier (the difference amplifier) goes into the second operational amplifier (the inverting amplifier) to give a final positive result. Since we are intending to change the result from mili-amps to mili-volts, we have incorporated a multiplexer which switches between three different channels, selecting three different resistance values made available for the necessary conversion, to accommodate for the required range of ± 2 , ± 20 , and ± 200 mA. When channel 00 is selected, the output voltage will be 10 mV if the input current was 1 mA since our resistor value is 1k ohm. Channel 01 and 10 are connected to 10k ohm 100K ohm resistors, resulting in outputs of 100

mV and 1 V respectively. In order to obtain an one ohm resistor, we connect eleven 10 ohm resistors in parallel before the difference amplifier. The value we obtained was 0.99 ohms, which is very accurate in calculating the resulting voltage. The schematic design of the ammeter is provided as below.

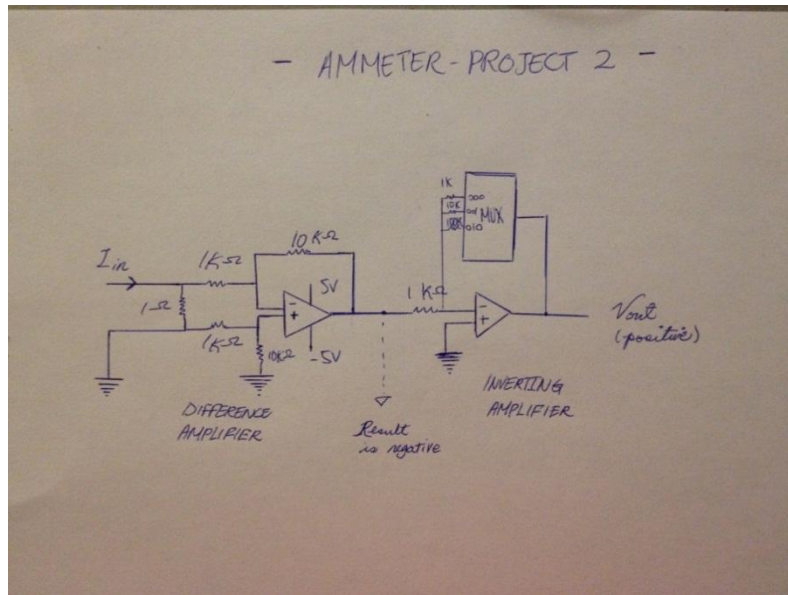


Figure 8: Schematic Diagram of Ammeter

2.5 Ohmmeter

We as a group implemented our ohmmeter to fluctuate between four ranges- 0 to 9 ohms, 10 ohms to 19-kilo ohms, 20-kilo ohms to 199-kilo ohms and 200-kilo ohms to 2-Mega ohms. This process was achieved by creating four different constant current sources for each one of the ranges. Armed with a 4 to 1 CD74HC4052E multiplexer, the task was fairly simple. The current sources were created using the following schematic diagram.

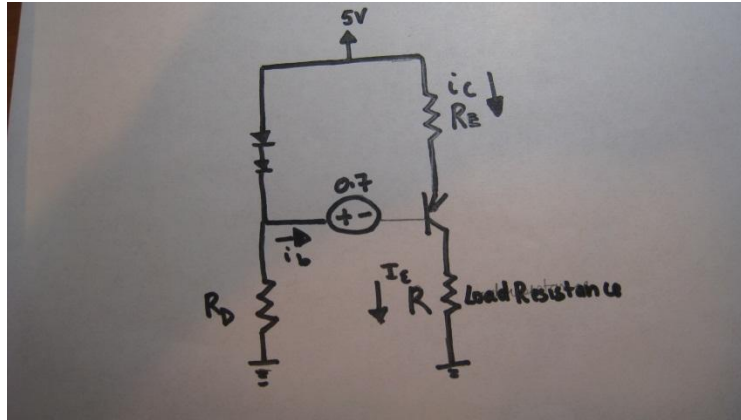


Figure 9: Schematic Diagram of a constant current source

For example, to calculate the value of an unknown resistor within the range of 200-kilo ohms to 2M-ohms, we created a constant current source of 0.01mA. We calculated R_E from the diagram above using the formula $[(5-0.7)/R_E = 0.00001 \text{ Amps}]$. The R_E calculated was then calibrated to suite our needs and through trial and error we came up with the R_E value of 233 kilo-ohms. Measuring the voltage across the passive element and multiplying the voltage value by 10000 calculated the load resistance. The current source and R_E values for the different ranges are given below

- 1) 0-10ohms Current source of 10mA, R_E value of 23 ohms
- 2) 10ohms to 20k-ohms Current source of 1mA, R_E value of 230 ohms
- 3) 20k-ohms to 200k-ohms Current source of 0.1 mA, R_E value of 23k-ohms
- 4) 200k-ohms to 2M-ohms Current source of 0.01mA, R_E value of 233k-ohms

2.6 Beta β Calculator

There are two kinds of transistors we need to measure, NPN & PNP transistor. For both transistors, we set the base current (I_b) to 0.1mA by using a constant current source circuit. A variable resistor is used to make an accurate value for the resistor to make 0.1mA. As a transistor can act as a current amplifier, I_c is amplified by β times I_b , i.e. $I_c = \beta \times I_b$. Then

we measure the voltage across the 100ohm resistor(V_{c1}, V_{c2}) in the collector, and we will know the current I_c because the voltage display divided by 100 will be the current value, from the equation $V=I \times R$. As I_b is set to 0.1mA, so the voltage display is actually showing the beta value divided by 100.

The circuit of these two transistors are shown below:

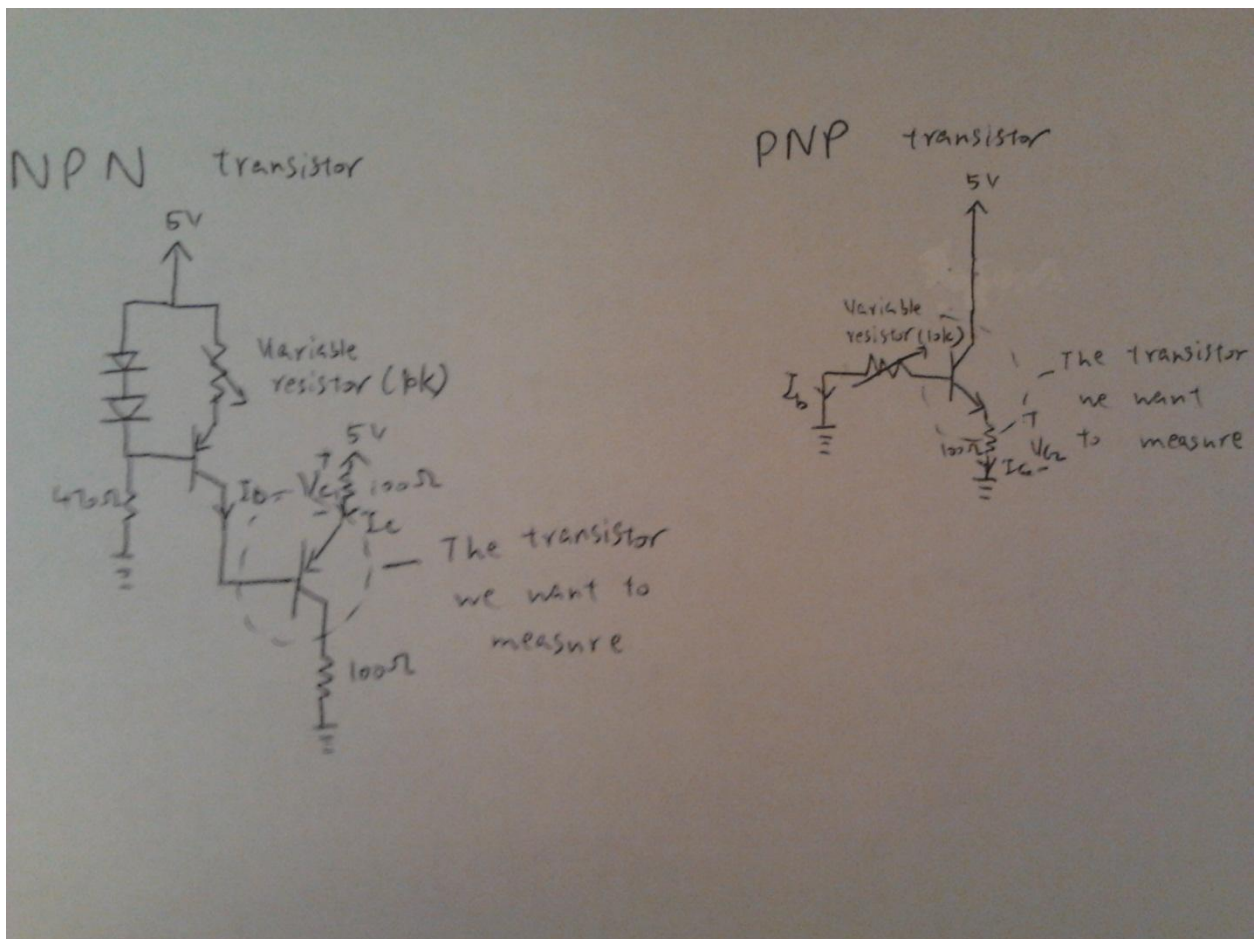


Figure 10: Schematic Diagrams of Beta β Calculator

2.7 Metal Enclosure

The box that is used to enclose our multi-meter was bought at **Lee's Electronic Store**. It is then altered using the machines at the machine shop to accommodate the multi-meter to

our design. We first drill six holes on the lid of the box. This allows the Altera DE2 board to be held firmly in place at the top of the box. There are holes drilled at the front and backside of the box for the necessary wires to flow from the circuit boards and the equipment to the transformer. The hole drilled in the backside of the box is made for three wires inside the box to reach out. Four separate holes are drilled in the front-side of the box, each allowing one wire to flow through. The holes are then smoothed to perfection. The last step is to cut a square window at the side of box for the 40-pin ribbon cable to connect to the Altera DE2 board. Different views of the box are shown below:

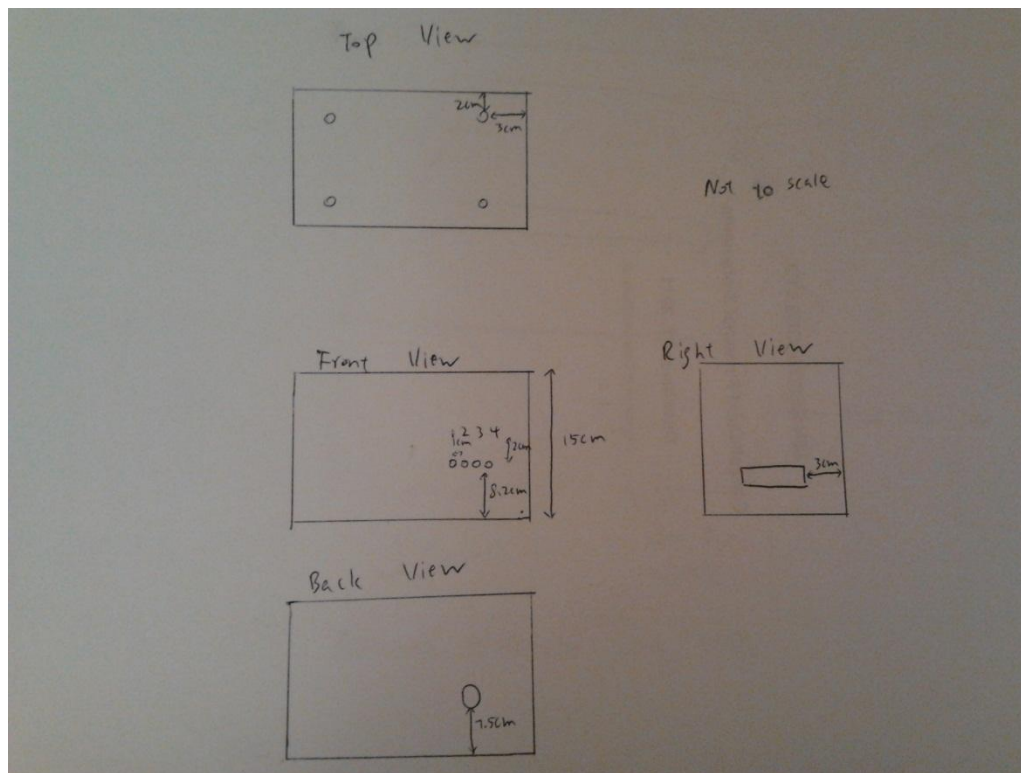


Figure 11: Top, Front, Right, Back views of the metal box

3.0 Conclusion

We use VHDL to run the DE2 board to control the voltmeter, ammeter, ohmmeter, and beta β calculator circuits. The channel to these circuits is switched when we press a button on the board. The power supply provides specific voltages for the chips in the circuits. Combining these circuits together and putting them all into a black metal box, we build the advanced multimeter using VHDL.

A Set of Instructions

1.0 Introduction

An advanced multimeter using VHDL (AMR) is an electrical apparatus most commonly used in electrical engineering. AMR can change to different modes, which are voltmeter, ammeter, ohmmeter, and beta β calculator. AMR is designed for electrical engineering students to measure voltage, current, resistance, and beta β . The set-up time for the multimeter is approximately 5 minutes. The required materials for using AMR are:

- A programmed Altera DE2 board
- An Altera DE2 power supply cable
- A 40-pin ribbon cable

2.0 Step-by-Step Procedure

Using an AMR is divided into 7 steps.

- 2.1 Plug in one end of the power supply cable to the DE2 board, the other end to any electric AC power supply of 120V, 60Hz
- 2.2 Plug in one end of the 40-pin ribbon cable to the silicon electric circuit board via the rectangular hole on the right side of the box, the other end to the DE2 board JP2 junction
- 2.3 Press the red button on the DE2 board to turn it on
- 2.4 Move down the switch on the left of the DE2 board to change it to “Run” mode
- 2.5 Press the reset button KEY0
- 2.6 Press button KEY1 to switch the mode of measurement

2.7 Measure voltage by wire1, current by wire2, resistance by wire3, beta β by wire4

3.0 Conclusion

The procedure can be summarized into 3 parts, namely powering up the DE2 board, setting the DE2 board to “Run” mode, and pressing button KEY1 to switch the mode of measurement. If you have any questions about setting up AMR, please contact our technician Kelvin Au via phone to 778-773-9809 or email to kelvinau4413@hotmail.com

Evaluation of the Complete System

A. Testing

Voltmeter and VHDL

We start designing the project by writing our own VHDL code, which is essential to the voltmeter. The VHDL code contains five states: Reset/Display, count-up, set-sign, count down, and binary BCD decoding. We write our code using Quartus II and compile the code to test if it is working before we run it on the DE2 board. We double check the Set-Sign state of the state machine to ensure it can display positive and negative values. The VHDL code we write compile and then we transfer the program into the DE2 board in Active Serial Programming mode. The voltmeter is then connected to the DE2 board and we test it with different values of current and voltage. The values displayed are accurate and it can display both positive and negative values when we change the values from the power supply. We can measure voltage in the range ± 29.000 DC volt.

Power Supply

In order to obtain negative voltages, we design the power supply such a way that the electrolytic capacitors are connected in the opposite polarity. We use four 1000 μF capacitors as the main core of the power supply. We reverse the polarity when we test them on the breadboard. We first use 100 μF capacitors but the voltage we obtained is not -15V or -10V. We design the power supply by trial and error and finally we settle with four 1000UF capacitors. We also used MBR150-ND diodes to act as rectifier to convert the AC voltage from power supply to full-wave AC voltage. The first trial we obtained -10V and -12V. We then added 0.01UF capacitors and one regulator to the circuit and finally we obtain the desired negative voltage. The polarities of the electrolytic capacitors are checked thoroughly to ensure they were connected properly on the circuit board.

Ammeter

The design we came up with the ammeter is that we use a comparator, a multiplexer, 10 ohm resistors, 1k ohm resistors and 100k ohm resistors. In order to obtain the 1 ohm resistor, we connect eleven 10 ohm resistors in parallel. We obtain 1.03 ohm in our first stage when we connect twelve 10 ohm resistors in parallel. In our second try we obtain 0.874ohm when we used nine 10 ohm resistors. We design our circuit by trial and error and finally we settle to used eleven 10 ohm resistors connected in parallel and the value we obtained is 0.99 ohm, which is accurate and close to 1 ohm. The 1 ohm resistor is then connected to other parts of the circuit.

Ohmmeter

We design the ohmmeter that it is able to fluctuate between four different ranges: 0 to 10 ohms, 10 ohms to 20k ohms, 20 ohms to 200k ohms, and 200k ohms to 2-Mega ohms.

According to Lab Module 4, we used two IN4148 diodes, one transistor and resistors of different values to make a constant current source for the measurement. We set the input voltage to be +5V. To obtain a constant current source of 0.01mA, we tried different values of resistors by trial and error method. A lower resistor value was used for the first few trials but the current we obtained was too high. So we decided to use a larger value for resistors in order to obtain a lower current. We used two 100k ohms and one 47k ohms (in total of 247k ohms) for R_e and 0.47k ohms for R_d . We chose the load resistance, R_L , to be 10k ohms. The resistors and the diodes were connected to the transistor and finally we obtained a constant current source of 0.01mA.

B. Strengths and Weaknesses of the Design

We designed the project in a unique way. We started preparing the project with writing our own VHDL code, which is essential for the voltmeter. The codes compiled and worked well as the DE2 board displayed the values of the power supply and the current correctly and precisely. The power supply, which was designed and soldered on the circuit board, was powered by the transformer and thus connected to the DE2 board. We obtained a very accurate negative and positive voltage and were displayed on the oscilloscope. The ammeter and ohmmeter worked as well when they were both connected to the DE2 board. We added the one ohm resistor to the ammeter in order to obtain a precise and accurate result on the DE2 board. The metal box was also fixed and made by our group members who are skillful in mechanics.

The values displayed on our DE2 board fluctuated every 50ms but still reflected the accurate values. We would also have to wait for about 3 seconds for the DE2 board to display the values of the voltage and current accurately. The breadboards which we were using also

showed some resistance when we designed the ammeter. When we designed and built the circuit on the breadboards, the current values displayed fluctuates and was sometimes inaccurate. We changed the breadboards and finally we obtained the desired values. All other designs were perfect and everything worked very well as the DE2 board displayed the values accurately when we were measuring the values of current and voltage.

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