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UNIVERSITI TUNKU ABDUL RAHMAN

FACULTY OF INFORMATION & COMMUNICATION TECHNOLOGY

BACHELOR OF INFORMATION TECHNOLOGY (HONS)
COMPUTER ENGINEERING

UCCE3033 / UCCE3034 EMBEDDED SYSTEMS DESIGN

TITLE: 2-in-1 Instruments for Educational Purpose (Digital Multimeter and Oscilloscope)

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1 General Information and Product Specifications

1.1 Introduction

Oscilloscope, or formerly known as an oscillograph, is an electrical instrument that allow us to visualize electrical signal by graphically display the changes of signal over a period of time (Vinci, 2021). The output waveforms are useful for debugging circuits, analysing and verifying design and so on. On the other hand, digital multimeter (DMM) is a versatile electronic device that can be used to measure various electrical properties such as voltage, current and resistance accurately (Anon, n.d.). The design of our product has integrated the functionalities of both dual-channel oscilloscope and digital multimeter (DMM) to form a 2-in-1 instrument for a better educational purpose.

First, user can choose to enter oscilloscope mode or DMM mode by touching the LCD screen after startup. For both oscilloscope and DMM mode, user should connect 2 inputs to PC0 and PC1. Then user can start to observe and analyse the waveform of both inputs on the LCD screen. User can also choose to display the waveform in a few different time base, show metrics of waveforms or store the current waveform and recall it back later. For DMM mode, user should connect an extra input to PC11. After that, user can choose to measure the values of temperature, voltage, current, resistance, capacitance and change the prefix of unit by pressing each corresponding buttons. With this design, our product provides more affordable price, portable and user-friendly tool which supports students learning in electronics and embedded systems.

1.2 Product Specifications

The following are the functionalities provided by the product

- Startup picture: to display product logo
- Menu Selection: allow user to select oscilloscope mode or digital multimeter mode
- Oscilloscope mode
  User should first plug in input on PC0 and PC1
  - ➢ Menu button: tap to back to menu selection
  - ➢ CH1 button: tap to hide or show waveform from PC0
  - ➢ CH2 button: tap to hide or show waveform from PC1
  - ➢ Show metrics button: tap to hide or show metrics of both waveform (eg: Duty cycle, peak to peak, average and frequency)
  - ➢ Store button: tap to store current waveform
  - ➢ Restore button: tap to show waveform stored (after tap → become cancel button)
  - ➢ Cancel button: tap to clear the stored waveform and back to oscilloscope mode
  - ➢ Change Division button: tap to change the time base of waveform display (1s/div, 500ms/div, 250ms/div, 100ms/div)

- Digital multimeter mode
  User should first plug in input on PC11 for temperature measurement and PC0 or PC1 for others.
  - ➢ Menu button: tap to back to menu selection
  - ➢ Temperature button (°C): tap to display temperature measured (input PC11)
  - ➢ Voltage button (V): tap to display voltage measured (input PC0 and PC1)
  - ➢ Current button (A): tap to display current measured (input PC0 and PC1)

- Resistance button (Ω): tap to display resistance measured (input PC0 and PC1)
- Capacitance button (F): tap to display capacitance measured (input PC0 and PC1)
- Arrow up button: tap to change to a higher prefix value
- Arrow down button: tap to change to a lower prefix value button
- Available prefix value: G (Giga) → M (Mega) → k (kilo) → none (hundred, tens, ones) → d (deci) → c (centi) → m (mili) → u (micro) → n (nano)

- Connectivity: A buzzer is connected to pin PC12, and it will beep if the detected resistance is between 0 to 1 ohm.

2 Hardware and Software Architecture

2.1 Hardware Architecture

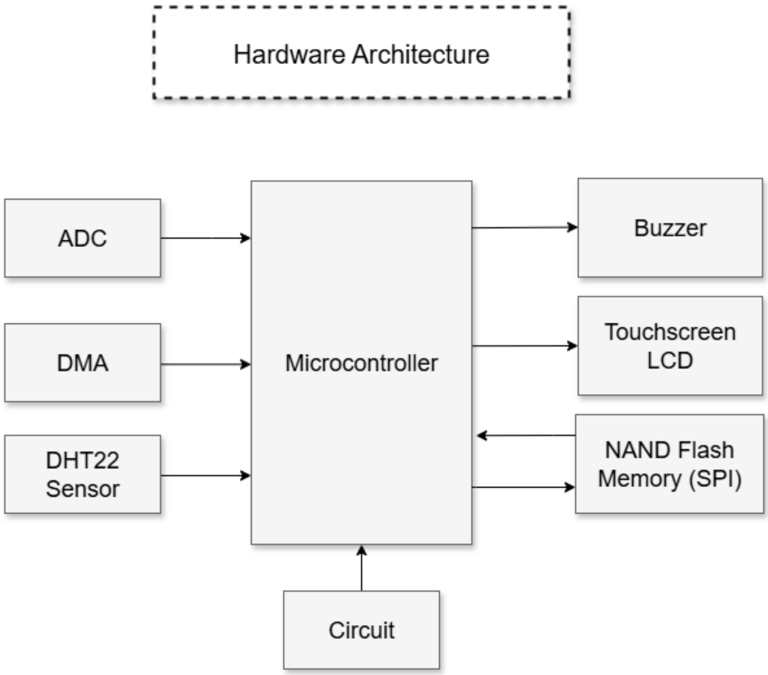


Diagram 2.1.1 Hardware architecture

Hardware	Description
Microcontroller (STM32F429I)	• central processing unit of the system • runs all the code, manages peripherals • performs calculations for both the Oscilloscope and DMM
ADC (Analog-to-Digital Converter)	• converts the analog voltage signals from the input probes into digital values • used to read and plot the waveforms on the Oscilloscope • use to read voltage for DMM

DMA (Direct Memory Access)	• allows data to be transferred from the ADC to the oscilloscope_data_buffer in memory without continuous intervention from the CPU
DHT22 Sensor	• external sensor used in DMM mode to measure ambient temperature
NAND Flash Memory (SPI)	• A type of non-volatile storage used to save and recall waveform data for later analysis
External Circuits	• used to test the value of resistance, current and capacitance for DMM
Buzzer	• to buzz when detected 0-1 ohm

Table 2.1 Hardware and their descriptions

2.2 Software Architecture

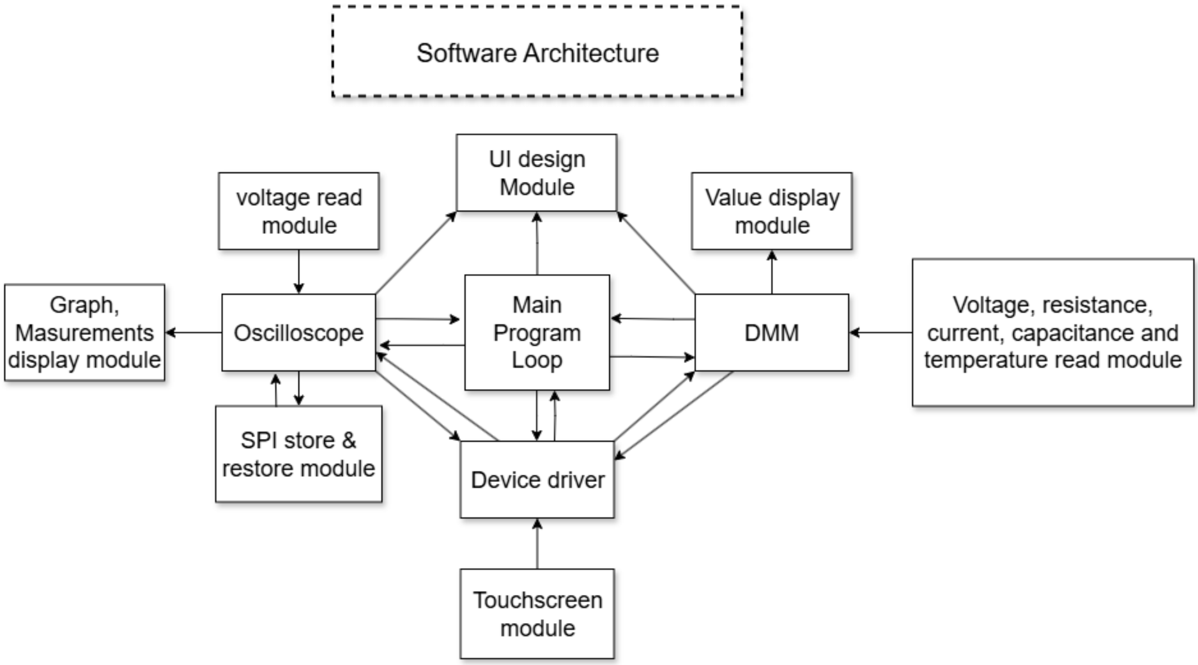


Diagram 2.2 Software Architecture

Module	Description
Main Program Loop	• initializes the hardware • handles user input for mode selection (Oscilloscope or DMM • calls the respective mode functions.
Device Driver Module	• provides functions to interface with the hardware peripherals like the LCD, touch screen, and timers. • handles low-level communication protocols and interrupt handling.

Touchscreen Module	• Manages touch input by detecting coordinates and interpreting them as button presses or actions
UI Design Module	• rendering all user interface elements on the LCD screen, including menus, layouts, and button label
Oscilloscope Module	• Encapsulates the core oscilloscope functionality, handles user input in oscilloscope mode
Voltage read module	• Handles real time ADC input and store them into buffer array for graph plotting
Graph & Measurement Display Module	• Plots the graph and displays key waveform measurements like Duty cycle, Average and frequency on the UI
SPI Store & Restore Module	• Manages storing and recalling waveform data from external NAND flash memory via the SPI interface
DMM Module	• Contains the logic for the Digital Multimeter, handles user input in DMM mode
Voltage, Resistance, Capacitance & Temperature Read Module	• A logical module under the ADC responsible for reading data from external circuits and sensors • Contains the specific driver for the DHT22 sensor and the logic for the various DMM measurements
Value Display Module	• Formats a numerical value into a string with the correct unit prefix and decimal places for the DMM display

Table 2.2 Software Architecture and description

3 Algorithm

3.1 Oscilloscope

The process of an oscilloscope displaying a graph involves three core stages: data acquisition, coordinate transformation, and dynamic display management.

Data Acquisition

The system continuously captures data from two channels using an ADC (Analog-to-Digital Converter). This raw data is stored in an efficient 480-element circular buffer via DMA (Direct Memory Access), which handles the data transfer from the ADC to memory without needing continuous CPU intervention. The two channels' data are interleaved within this buffer, with Channel 1 (CH1) data at even indices and Channel 2 (CH2) data at odd indices.

Before plotting, the system copies the data from either the live oscilloscope_data_buffer or the read_spi_buffer (if the Restore button was pressed) into a local buffer. This ensures the graph displays either a live, updated waveform or a recalled waveform from NAND flash (SPI) which allowed to show the matrices menu (measurements) to display.

Coordinate Transformation

This stage converts raw ADC data into screen coordinates. The ADC values, which range from 0 to 4095, correspond to a voltage range of 0V to 3.3V. Each data point's y coordinate is calculated in two steps. First, the ADC value is converted to voltage using the formula voltage_current = (float)adc_current * (3.3f / 4095.0f). This scales the ADC's 12-bit value to the 3.3V reference. This voltage is then scaled for the display, where y = 180 - (voltage * 40.0f). The 40.0f multiplier sets the vertical scale, as every 1V of change corresponds to 40 pixels. The x coordinate is determined by a loop counter. The data point from the circular buffer is selected using the formula current_idx = ((read_start_idx) + (x) * 2 + data_offset) % 480. The data_offset is used to select the correct channel, and the modulo operator handles the buffer's circular nature.

Dynamic Display Management

This stage handles how the time base is adjusted. It is achieved by changing the period of a timer (TIM2) that triggers the ADC to sample data using the adc_timer() function. A smaller adc_rate results in a faster sampling rate, effectively "zooming in" on the waveform. A larger adc_rate slows down the sampling, providing a "zoomed-out" view of a longer time period. The decimation_factor variable in the osc() function is now used only to track the current time division setting, and the horizontal scaling in the drawing loop is fixed.

Oscilloscope Mode	**Determination factor**	**ADC rate**	**Sampling Frequency (Hz)**
100ms/div	1	100	400
200ms/div	2	200	200
500ms/div	5	500	80
1s/div	10	1000	40

3.2 DMM

In Digital Multimeter mode, users can choose to detect 5 main type of values which is temperature, voltage, current, resistance and capacitance.

Temperature

To measure the surrounding temperature, we have used a digital-output relative humidity and temperature sensor which is DHT-22 sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air, and DHT22 output calibrated digital signal on the data pin (Instructables, 2015). Therefore, we can get the value read from DHT-22 sensor and display it during Digital Multimeter mode.

Voltage

Voltage is the potential difference between 2 points in any circuit. Thus, to measure the voltage, user should first connect PC0 and PC1 to 2 different points on the circuit. After that, the system will continuously capture data from two channels using an ADC (Analog-to-Digital Converter). The raw data captured are then converted to real voltage value by using formula (raw data / 4095) * 3.3V. The final value of voltage will be voltage read from first point (PC0) minus voltage read from second point (PC1).

Current

To measure the current flow over a fixed resistor (10k ohm), user should connect PC0 and PC1 at the front and back of the resistor. Ohm's Law (V = I/R) are then applied to calculate the current by using the voltage calculated as above and the fixed resistance value.

Resistance

To calculate the resistance over any resistor, we have formed a Wheatstone bridge circuit.According to Wikipedia (2020), it is a more accurate way to measure an unknown resistance by balancing two legs of the bridge circuit, where one of the legs contains the unknown resistor. Thus, we have the formula Vg = ((R2 / (R1+R2)) - (Rx / (Rx+R3))) * Vs. We fix Vs = 3.3V and all R1, R2 and R3 at the same value (10k ohm) while Vg are calculated same as mentioned above between point B and point D (Figure 1). After rearranging we will obtain the formula to calculate the resistance:

Rx = (R3*(3.3*R2 - Vg*R1 - Vg*R2)) / (Vg*R1 + Vg*R2 + 3.3*R1)

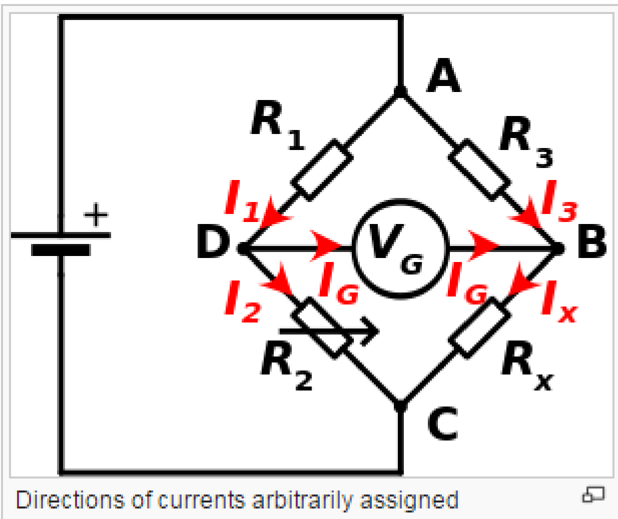


Figure 1: Wheatstone bridge circuit

Capacitance

Capacitance is the ability of an object to store electrical charge. To calculate the capacitance, we applied voltage divider rule which is Vx = Vtotal * (Rx / Rtotal). After substitute the value of Vtotal (3.3V) and rearrange the equation, we will obtain a new equation for capacitance:

$$Cx = (Vx * C1) / (3.3 - Vx)$$

where C1 is a fixed capacitor value (10uF) and Vx is calculated through value from ADC same as mentioned above.

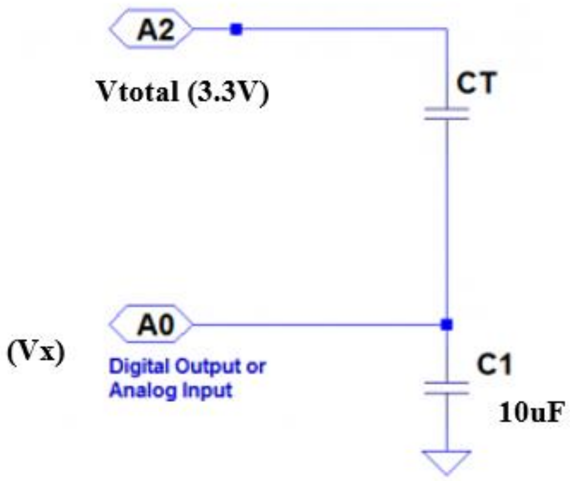
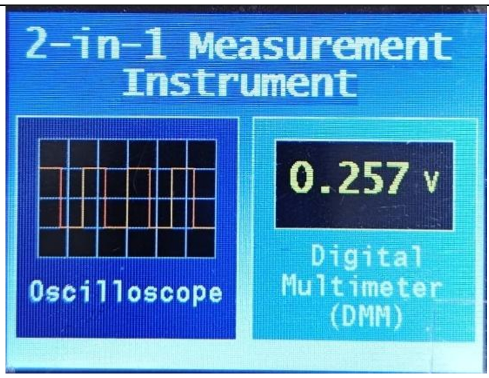
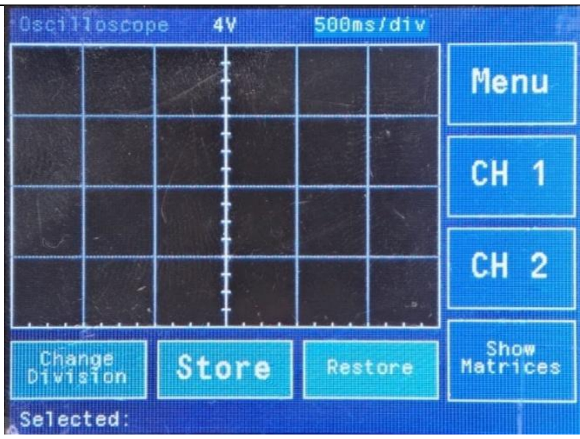
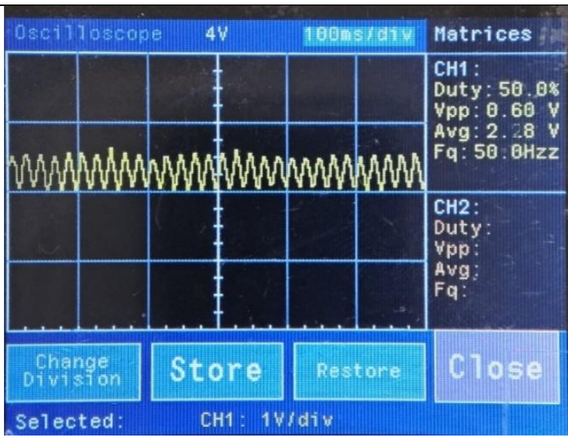
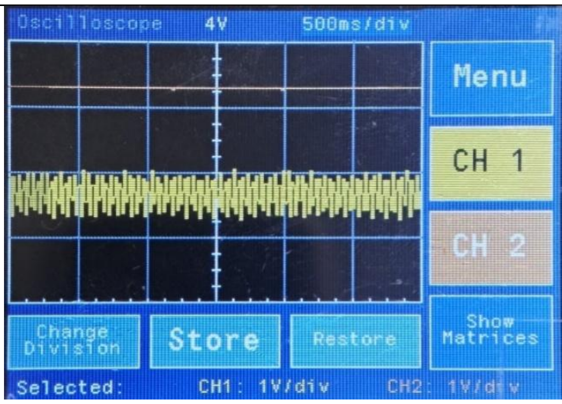
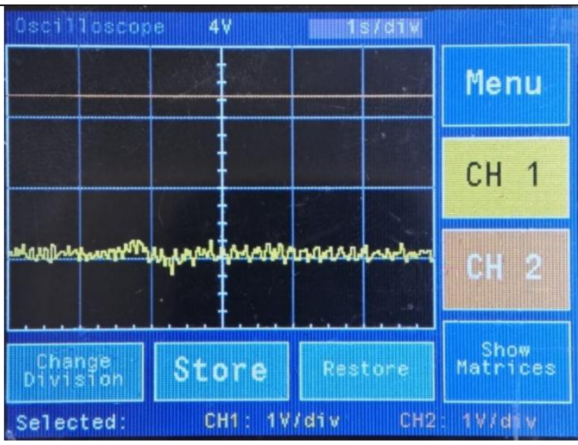
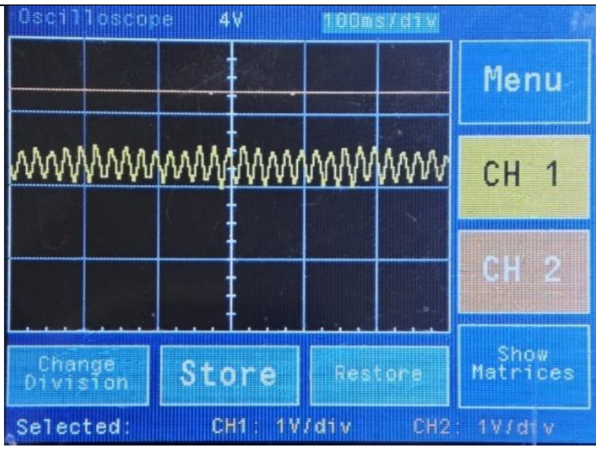
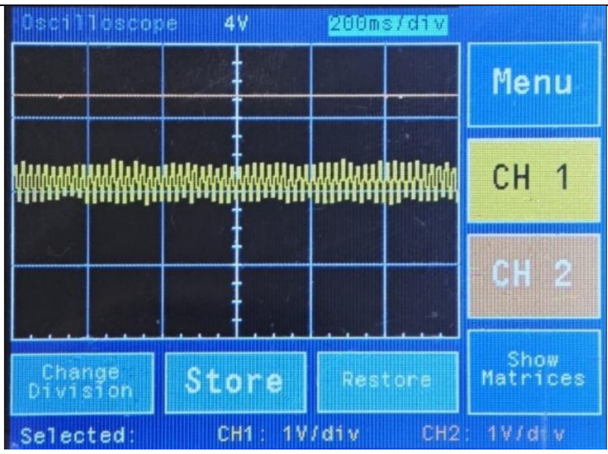


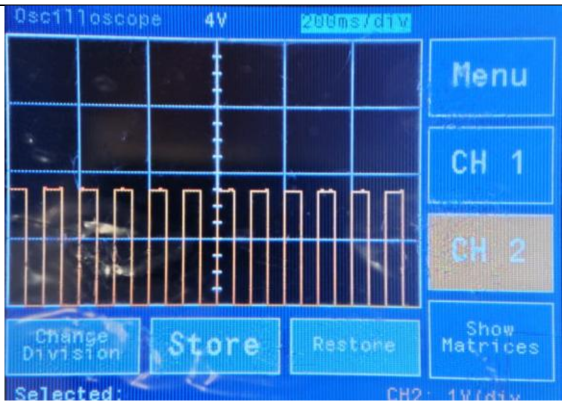
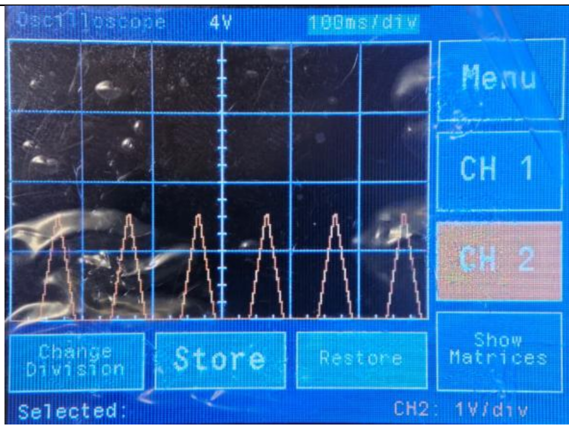
Figure 2: Voltage Divider

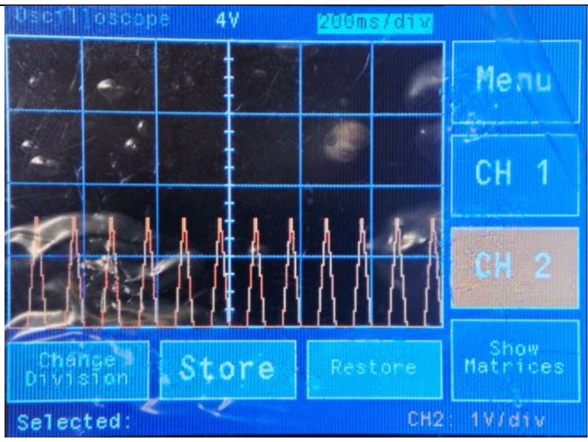
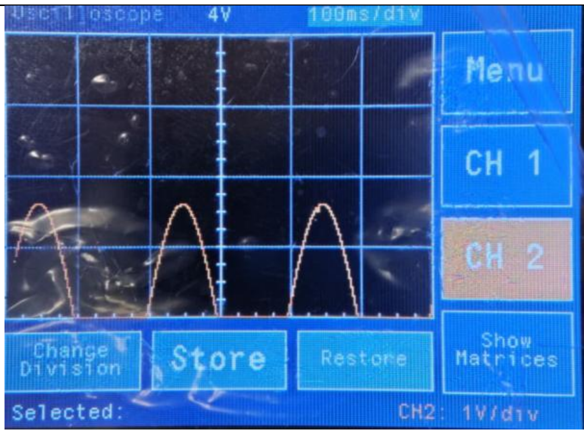
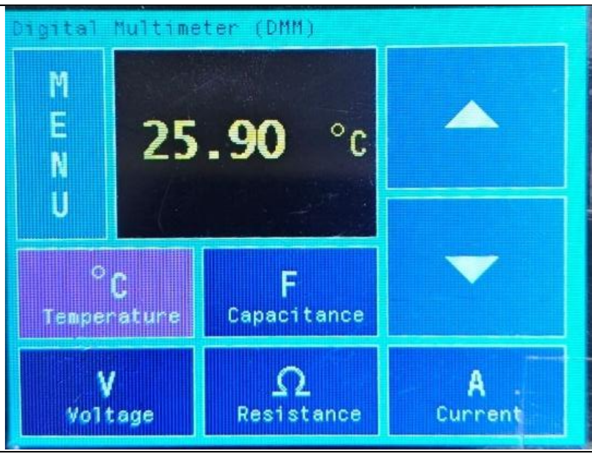
4 Test and verification

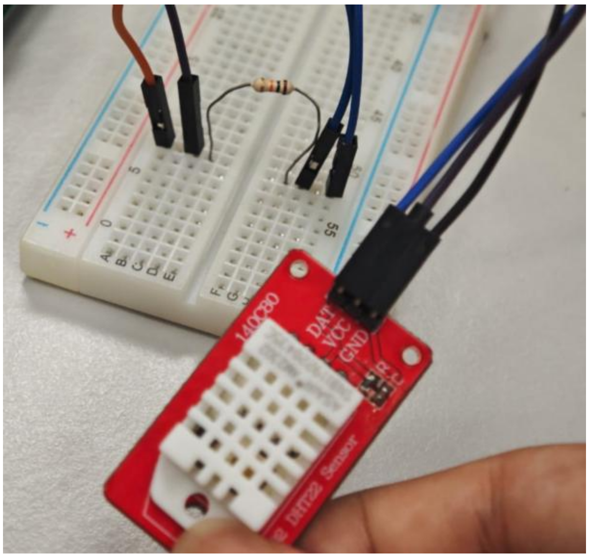
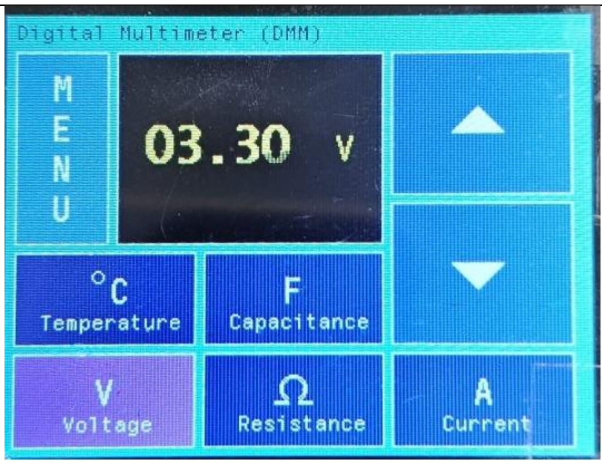
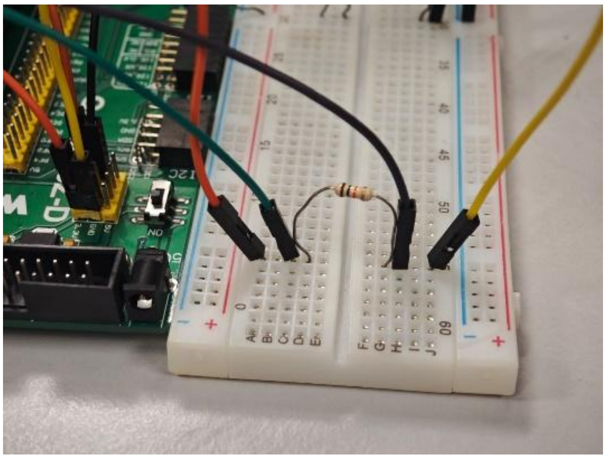
No	Test case	Description	Test result	Status
1	Display splash screen logo	1. Start the system		PASS
2	Menu Display	1. Wait for the splash screen logo print done		PASS

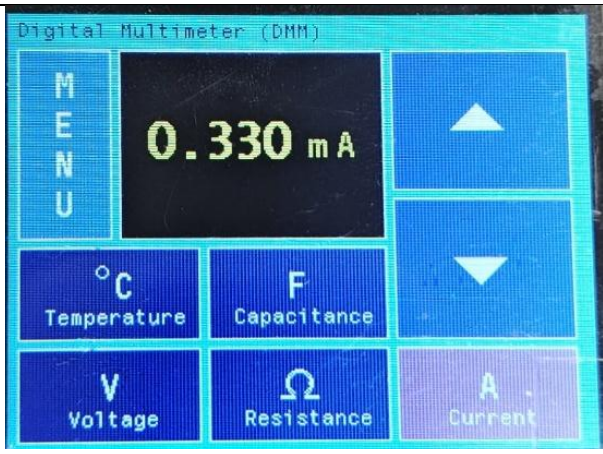
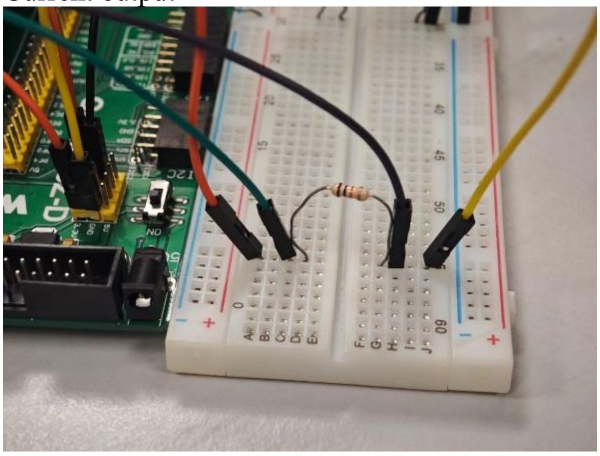
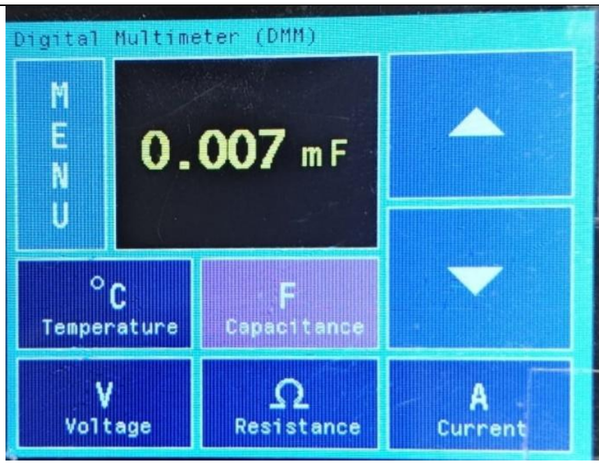
3	Oscilloscope off	1. Start the system 2. Press the “Oscilloscope” button		PASS
4	Oscilloscope measurement (matrices display)	1. Start the system 2. Press the “Oscilloscope” button 3. Press the “ch1” button 4. Press the “Display Matrices” button	 Matrices show on the right side Press close button can close the matrices	PASS
5	Oscilloscope 500ms/div mode (default)	1. Start the system 2. Press the “Oscilloscope” button 3. Press the “ch1” button 4. Press the “ch2” button	 top right side division = 500ms/div mode	PASS

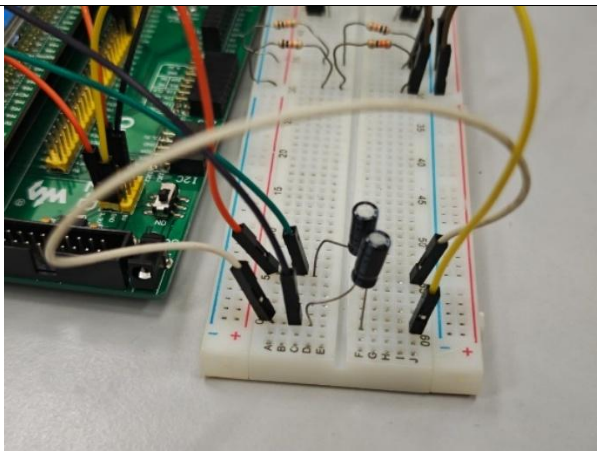
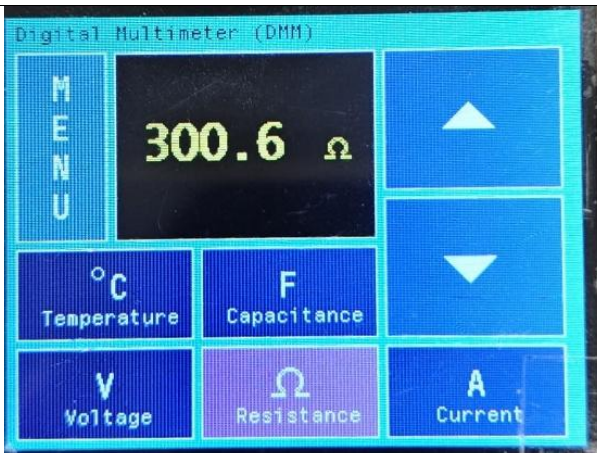
6	Oscilloscope 1s/div mode	1. continue from previous test case 2. Press "Change Division" button	 top right side division = 1s/div mode	PASS
7	Oscilloscope 100ms/div mode	1. continue from previous test case 2. Press "Change Division" button	 top right side division = 100ms/div mode	PASS
8	Oscilloscope 200ms/div mode	1. continue from previous test case 2. Press "Change Division" button	 top right side division = 200ms/div mode	PASS

9	Oscilloscope square wave display (10Hz, 100ms/div)	1. continue from previous test case 2. Close ch1 3. Connect to the function generator 4. Change the wave to square wave 5. Set frequency to 10 Hz 6. Manually set the amplitude 7. Change the division to 100ms/div		PASS
10	Oscilloscope square wave display (10Hz, 200ms/div)	1. continue from previous test case 2. Change the division to 200ms/div		PASS
11	Oscilloscope triangle wave display (10Hz, 100ms/div)	1. continue from previous test case 2. Change the division to 3. Change the wave to square wave 4. Change the division to 100ms/div		PASS

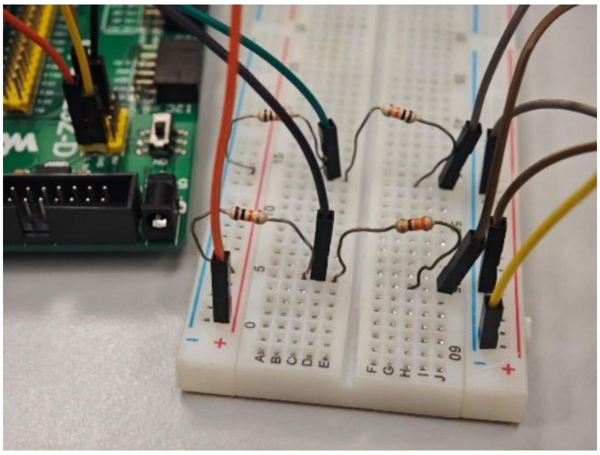
12	Oscilloscope triangle wave display (10Hz, 200ms/div)	1. continue from previous test case 2. Change the division to 200ms/div		PASS
13	Oscilloscope sine wave display (5Hz, 100ms/div)	1. continue from previous test case 2. Change the wave to sine wave 3. Set frequency to 5 Hz 4. Change the division to 100ms/div		PASS
14	Oscilloscope sine wave display (1Hz, 200ms/div)	1. continue from previous test case 2. Change the division to 200ms/div		PASS
15	DMM temperature	1. Start the system. 2. Press the "Digital Multimeter (DMM)" button. 3. Press the "Temperature (°C)" button.		PASS

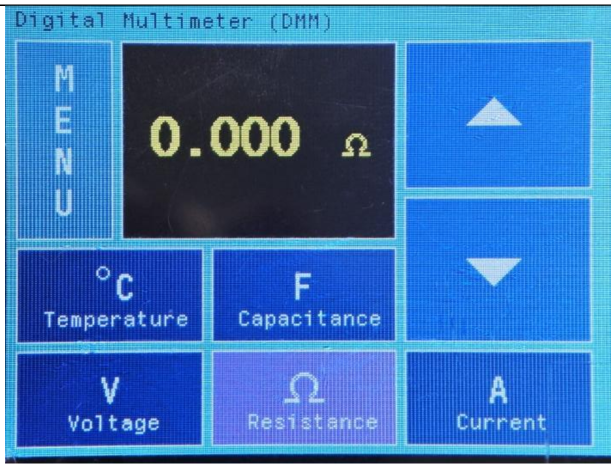
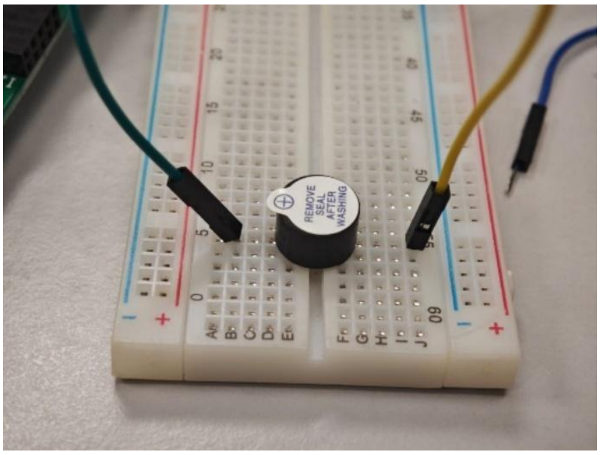
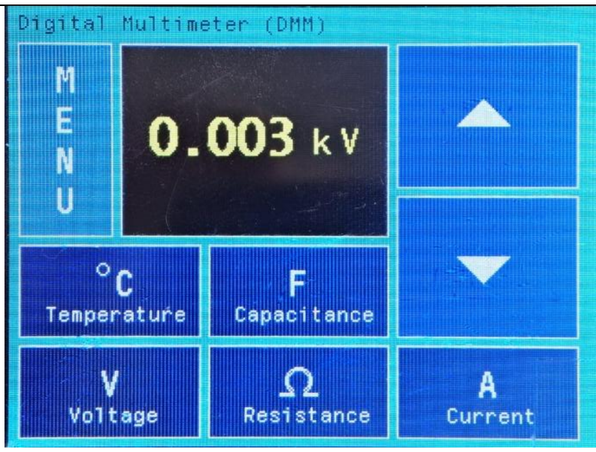
			Temperature output  Hardware connection of DHT-22 sensor	
16	DMM voltage	1. Continue from previous test case. 2. Press the “Voltage (V)” button.	 Voltage output  Hardware connection of voltage measuring	PASS

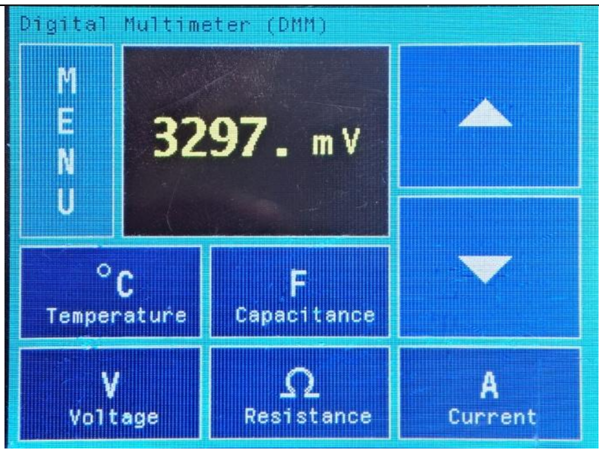
17	DMM current	1. Continue from previous test case. 2. Press the "Current (A)" button.	 Current output  Hardware connection for current measuring	PASS
18	DMM capacitance	1. Continue from previous test case. 2. Press the "Capacitance (F)" button.	 Capacitance output	PASS

<table>
<tr><td></td><td></td><td></td><td>
Hardware connection for calculating capacitance (voltage divider)</td><td></td></tr>
<tr><td>19</td><td>DMM resistance</td><td>1. Continue from previous test case.
2. Press the “Resistance (Ω)” button.</td><td>

resistance output


Hardware connection of Wheatstone bridge circuit</td><td>PASS</td></tr>
</table>

20	Buzzer Connectivity	1. Start the system. 2. Press the “Digital Multimeter (DMM)” button. 3. Press the “Resistance (Ω)” button.	 If resistance between 0 to 1 Ohm, buzzer will beep  Hardware connection of buzzer	PASS
21	Change prefix value (increase)	1. Continue from test case 16. 2. Press the “▲” button.	 For initial value (03.30V) please refer to test case 16. After pressing the button 3 times, Output: prefix change to kilo(k)	PASS

22	Change prefix value (decrease)	1. Continue from test case 16. 2. Press the "▼" button.	 For initial value (03.30V) please refer to test case 16. After pressing the button 3 times, Output: prefix change to mili(m)	PASS

5 Conclusion

This assignment successfully demonstrates the design and implementation of a versatile "2-in-1" portable test instrument, combining the functionalities of a dual-channel digital oscilloscope and a multi-function digital multimeter (DMM) on a single STM32F429i microcontroller platform. By leveraging the powerful peripherals of the STM32, including its high-speed ADCs, flexible timers, and GPIOs, the device is capable of both visualizing time-varying signals and performing precise measurements of key electrical properties.

The oscilloscope successfully captures and displays two simultaneous analog signals on a LCD, complete with a time base and voltage grid for accurate visual interpretation. A key achievement of this project is the implementation of automatic waveform analysis, which provides immediate, calculated measurements of a signal's peak-to-peak voltage, average value, frequency, and duty cycle.

The DMM mode effectively measures DC voltage, current, resistance and temperature transforming the device into a comprehensive tool for general electronics diagnostics. Through meticulous debugging of ADC behaviour, issues such as channel crosstalk and sampling inaccuracies were resolved by implementing software solutions like dummy reads, resulting in stable and reliable measurements.

Ultimately, this project serves as a robust proof-of-concept, integrating complex hardware peripherals with sophisticated software algorithms to create a single, cohesive, and highly functional piece of test equipment.

This project can be improved by adding measurement cursors to add user controllable vertical cursors to display and allowing for precise manual measurement of change of time and voltage change of a waveform. Using charge/discharge method to measure capacitor for more accurate capacitance.

6 References

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