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Development Of A Digital Oscilloscope At Federal Polytechnic Bonny Using Arm Cortex-M3 Processor And TFT LCD Technology

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ABSTRACT
We intend to develop a digital oscilloscope by integrating ARM 32-bit Cortex-M3 Microcontroller with full color TFT LCD display. The seamless integration of these devices aims to construct a low cost and adjustable instrument applicable in the educational laboratories for adequate signal analysis. Employing the ARM 32-bit Cortex-M3 Microcontroller particularly the STM32F103C8 makes for adequate real-time signal processing, appropriately displayed by TFT LCD display in a user-friendly manner. The research emphasizes the need to achieve a high resolution signal representation with features such as signal storage, measurement tools, and real-time signal analysis capability incorporated. The ARM 32-bit Cortex-M3 Microcontroller offers the features for proper programmability and interfacing with the display unit. Achieving this project is an added advantage in our education systems to offer low cost educational resources in electronic laboratories aimed at offering students the opportunity to have hands-on solutions for signal processing and oscilloscope features.
Keywords: Oscilloscope, TFT LCD Display, Microcontroller, Laboratory, Digital

1. INTRODUCTION
In the field of Engineering, particularly in Electrical and Electronic, teaching students to adequately understand theoretical concepts without laboratory experiments is difficult. A critical factor in these experiments is the availability and accessibility of laboratory equipment such as advanced measuring devices like oscilloscope. According to [1] life will be basically difficult without measurements; hence, in a fast evolving world like ours, both engineers and Engineering students need to easily and quickly solve their measurement challenges with precision and accurate tools. One characteristic feature of a digital storage oscilloscope is its ability to process and store signals in a digital format, typically represented as 1s and 0s, with a preference for storing them as analog signals. This category of oscilloscope digitizes an input signal, and subsequently displays it on the screen. It is integrated with advanced features such as storage, triggering, and measurement capabilities. Additionally, the digital oscilloscope provides visual and numerical displays of the signal characteristics, enhancing its adaptability and analytical capabilities.
Digital oscilloscopes offer students the opportunity to processes and analyze electronic signals with applied experience in the laboratory, enhancing a wholesome and practical understanding of circuit behaviors. The development of a digital oscilloscope and wave generator tailored for teaching and learning purposes in the polytechnic laboratory is central to this project. Till recent times, conventional analog oscilloscopes has dominated our laboratories, however, significant improvements has emerged through the invention of digital technology. Digital oscilloscopes are commonly known as either digital storage oscilloscopes (DSOs) or digital sampling oscilloscopes (DSOs) [2]. Digital

oscilloscope is trending due to attractive advantages it offers such as enhanced accuracy, portability, and data storing capability [3],[4]. Undertaking to construct a digital oscilloscope for teaching and learning purposes involves the incorporation of a high-resolution LCD display, signal processing unit, and user-friendly interfaces. The addition of characteristic features like signal storage, measurement facilities, and practical data analysis capabilities is an extra value to the educational significance of the instrument.

Digitization, signal storage and display is optimally achieved in digital oscilloscope through the incorporation of color TFT LCD screen and digital memory. The elements of Figure 3.1 are the fundamental building blocks of the digital oscilloscope. The process of digitization is achieved by sampling input signals at periodic intervals, often determined from the sample waveform. Determining the maximum frequency applicable in a digital oscilloscope depends on two critical factors: the sampling rate and the nature of the DAC converter. In signal analysis, the sampling theory must be maintained, which states that the sampling rate is twice the maximum frequency of the input signal. A high-speed conversion rate is critical in enhancing the efficiency of analog-to-digital converter used in digital oscilloscope. However, the resolution of the analog-to-digital converter and the bandwidth is considerable reduced when the sampling rate is high even if it has a flash memory. To address the challenge, a shift register is used which has the capability to sample, store and steadily produce and transform the signal into its corresponding digital form. With this technique, cost and speed of the converter can be scaled up to 100msps. More importantly my students will be effectively improved as they get involved in this project intended for educational teaching and learning.

2.0 Literature

No circuit can be accurately analyzed in Electronic Engineering field without precise measurement using laboratory equipment. Consequently, significant efforts dedicated towards ensuring accurate measurements, especially to improve analog and digital signal analysis as well as circuits is displayed in the research community. Central to this effort is the development of both digital and analogue oscilloscope which has significantly provided the features needed to analyze systems and signals. Various categories of oscilloscopes are obtainable in the market, with the primary categories of analog oscilloscopes, digital oscilloscopes, and PC-based oscilloscopes toping the list. Due to the attractive features such as improved accuracy, portability, high speed, high resolution, and data storage capabilities [8], digital oscilloscope is prevalent among others. The improved functionalities integrated into digital oscilloscope have increased its market value, which reduces its cost-effectiveness. To address the issue of cost, designers applied an alternative approach that would keep it affordable while retaining its attractive functionalities. The alternative approach offered the development and introduction of digital oscilloscopes into the Electronic market. Unlike conventional oscilloscopes with dedicated screens, some digital oscilloscope can interface with a computers and utilize the screen and processing capacity of the computer to generate signals. This invention offered a cost-effective solution for signal measurement and analysis, however, the initial cost of implementation could be high.

2.1 Cathode Ray Oscilloscope (CRO) Probes

To link a test circuit to an oscilloscope, a probe serves as the connecting interface. In the case of a basic oscilloscope like the CRO, the associated probe is commonly referred to as a CRO probe. The choice of a probe is crucial to prevent loading issues in the test circuit, ensuring accurate signal analysis on the CRO screen. Optimal CRO probe has high impedance and operates at a high bandwidth. The block diagram illustrating the configuration of a CRO probe is depicted in the figure 2.1 below. This selection is fundamental to maintaining the integrity of signals during analysis on the oscilloscope.

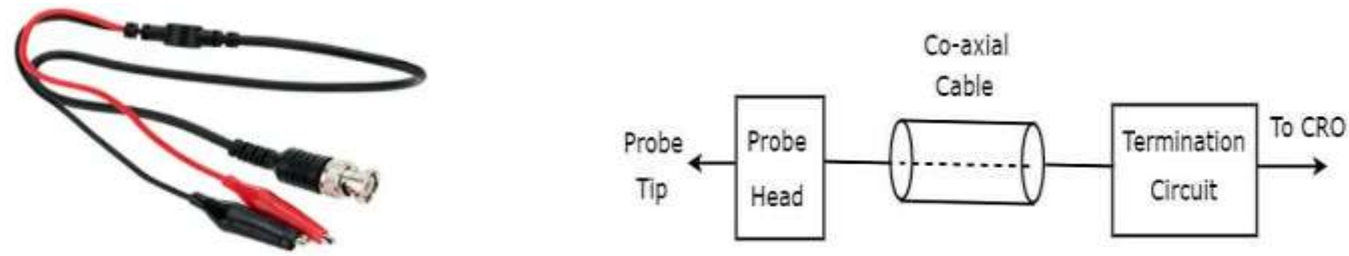

Figure 1- (a) CRO Probe **(b) block diagram of CRO probe [9]**

The CRO probe is primarily composed of three key elements: the probe head, co-axial cable, and termination circuit, with the co-axial cable serving as the connection between the probe head and termination circuit.

CRO probes fall into two distinct categories:

- Passive Probes
- Active Probes

Starting with Passive Probes, when the probe head incorporates passive elements, it is designated as a passive probe. The circuit diagram for a passive probe is presented in the figure 2.2 below.

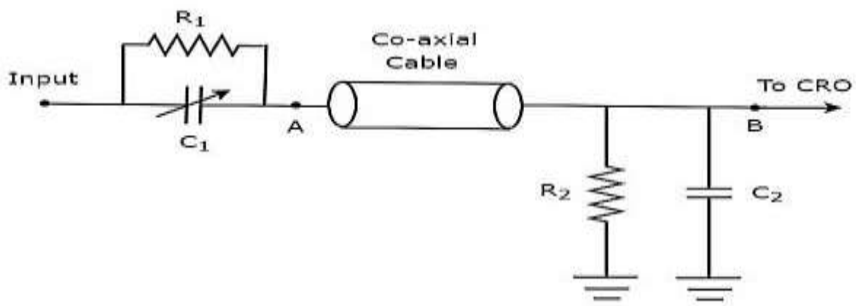

Figure 2 - The circuit diagram of passive probe

The probe head is formed by a parallel arrangement of variable capacitor C1 and resistor R1, whereas the terminal circuitry is a combination of capacitor C2 and resistor R2. As shown in figure, the circuitry is further modified into a bridge circuit, tuned to equilibrium by adjusting the capacitance of the variable capacitor, C1. In addition, active electronic components form the major parts of the probe head in active probes, hence it is referred to as active probes. In figure 2.3, Active probes is illustrated in the block diagram.

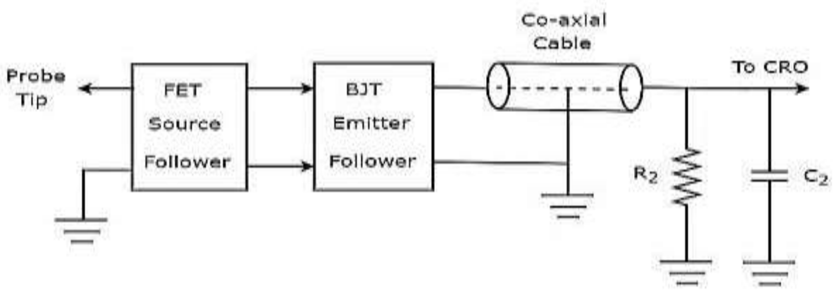

Figure 3 - The block diagram of active probe

As shown in the diagram, an FET source follower is cascaded with BJT emitter follower to form the probe head. The function of the FET source follower is to deliver high and low impedances to the input and output respectively. On the other hand, impedance mismatching is eliminated by the BJT emitter follower. It is vital to note that in both passive and active probes, the coaxial cable and termination circuit are same.

2.2 Related Works

Recent technologies such as Arduino and Raspherry Pi offered designers, students, and hobbyist the platform to construct their own simple and low cost oscilloscopes. Researcher who desire to create affordable systems with only critical specification initiated and achieved the following projects.

Some researchers introduced software called MegunoLink when developing an oscilloscope using arduino. This software displayed an interesting feature of being able show measurement values in real-time [5] unlike the Matlab Approach in [6] where the measurement information cannot be produced in real-time. However, the Matlab approach still holds some advantage because their codes are relatively comprehensible when compared to processing. Interestingly, the GRIET approach resulted in the possibility of extending capability of arduino-based oscilloscopes to accept six different inputs [10]. However, limitations arises when the need to explain how arduino-based oscilloscopes can efficiently take inputs from analog signal sources. More work was put in to address this challenge which succeeded in developing a voltage card sensor that transforms input analog signals to formats compatible with arduino platforms. Another arduino-based approach is carried out in [7], where the arduino-based oscilloscope is interfaced with a personal computer; this approach has the advantage of being able to save the plotted data. However, the same approach can be employed but an LCD can be used alternatively instead of a computer. The later approach suffers the limitation of no storage facility and the inability to separate the data into distinct signals due to the inherent monochrome feature of the LCD [10]. More advanced work on arduino-based oscilloscope is carried out in [11] to achieve a higher sampling rate. This was achieved using a different Arduino pre-scaler to maintain the designers specifications but resulted in degrading the accuracy of the system.

3.0 MATERIAL AND METHODOLOGY

The section explains the construction procedure of the proposed digital oscilloscope based on ARM Cortex-M3 processor, a Thin-Film-Transistor Liquid-Crystal Display (TFT LCD), and other necessary electronic components. The complete insight into the assemblage and integration of vital elements needed for the functionality and performance of the oscilloscope is also presented.

3.1 Materials

The key materials used for the construction of the proposed digital ARM CORTEX-M3 Processor–based Oscilloscope using Thin-Film-Transistor Liquid-Crystal Display (TFT LCD) are tabulated in Table 1.

Table 1 - Electronic Components used

Materials	Quantity
ARM Cortex-M3 processor integrated PCB	1
thin-film-transistor liquid-crystal display (TFT LCD) with board	1
Probe	1
HF-Chokes	3
Crystal (8MHz)	1
Mini USB Socket	1
Pin header (for power)	1
transistors	2
regulators	2
Capacitor Trimmers	2
Power Inductor	1
Power Connector	1
Pin Header (Male)	2
Pin Header (female)	3
Resistors	23
Electrolytic Capacitors	6
Ceramic Capacitors	18
LED	1
Tact Switches	5
Slide Switches	3
BNC Connector	1
PN Diodes	2
Test signal ring	1
Jumper Wires	20

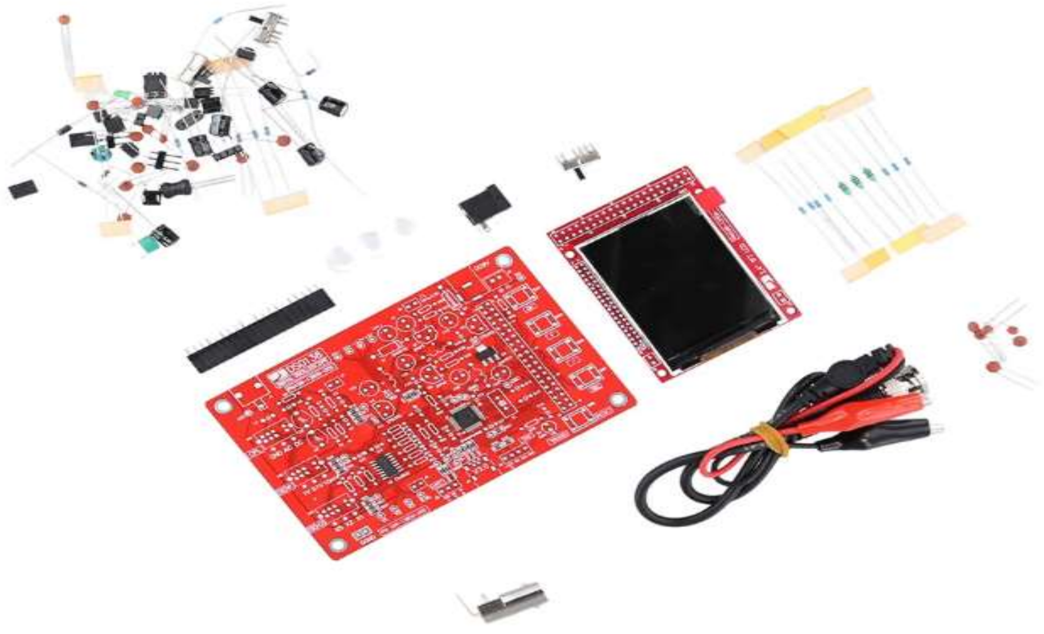

Figure 4 - Electronic Components used

3.1.1 TFT LCD

The TFT LCD is a 42.72 x 60.26 mm Module with a 2.4-inch TFT LCD showing an impressive 240x320 resolutions display in complete color. Integrated in this advanced display module is the ILI9341V integrated circuit (IC) which supports the 8/16-bit 8080-series Parallel MCU Interface with active display dimensions of 36.72 x 48.96 mm. The integrated ILI9341V controller operates within the supply voltage range of 2.4V to 3.3V. It is in portrait mode by default; however, the module can be adapted for landscape display mode with suitable technical assistance made available from the manufacturer on request. The device’s display maintains a characteristic brightness of about 500 cd/m² and performs optimally within the temperature range of -20℃ to +70℃. Ideally, it is suitable for a range of applications, such as home automation systems, medical devices, and digital portable oscilloscope.

Figure 5 - TFT LCD

3.1.2 ARM Cortex-M3 processor

Among the ARM's Cortex-M series is the static and synchronous Cortex-M3 processor designed particularly for microcontrollers. The processor is optimized for deterministic real-time applications with adequate amount of FLASH and RAM for efficient performance. It uses minimal gate count, specialized clocks for critical components, and interesting integrated power-saving such as “sleeping” and “sleepdeep” to ensure considerable power is saved. Some of the advanced features such as bit-band operation and fault-handling techniques including fault status register and several exception types also contribute to its efficient performance and easy fault location processes. Several manufacturers have been licensed to produce cortex-M3 Processor leading to several products with slightly varying processor speed, size of memory, interface connections etc.

Figure 6 - ARM Cortex-M3 processor

3.1.3 Crystal (8MHz)

The function of the crystal is for the provision of a stable signal for accurate timing of the internal circuitry of the ARM 32-bit Cortex-M3 Microcontroller such as the Central Processing Unit, Memory, and other peripherals. The stability of the clock signal also ensures that the the oscilloscope’s graphical display updates are smooth and flicker-free. The timing is critical because data acquisition, sampling rate which determines the accuracy of the signal reconstruction and the general performance of the oscilloscope depend on it. The maximum sampling rate of the oscilloscope is affected by the crystal’s frequency. Generating and maintain a consistent clock is necessary for efficient execution of instructions and data flow management. Moreover, refresh rate of the display is also affected by the crystal’s clock signal.

Figure 7 - Crystal (8MHz)

3.1.4 HF chokes

The work of HF chokes is to ensure that power-sensitive components in the circuitry are fed with filtered and steady power by eliminating noise with high frequencies and power surges from the power supply. In addition, it also filters out signals with frequencies beyond the frequency of the desired input signals to guarantee that the input to the ADC is only the intended signal frequencies. In addition, all interfering signals emitted by the circuitry of the oscilloscope are eliminated by HF chokes to mitigate radiations and interferences.

3.2 METHODOLOGY

Our approach to constructing a digital ARM Cortex-M3 processor-based oscilloscope with a thin-film-transistor liquid-crystal display (TFT LCD) took a logical and staged methodology, which emphasizes accuracy, effectiveness, and the actualization of our stated objectives. The methodology is structured based on four critical stages: Planning and assembling of Main Board and TFT LCD board, Hardware Implementation and Integration, and Testing, Optimization, and Documentation.

3.2.1 Planning and Design

This is the preliminary phase which involves careful planning to create a comprehensive basis for the work. The project scope, objectives, and specifications were defined, which fundamentally lay the foundation for successive stages. Detailed system circuit diagram is developed with focus on the ARM Cortex-M3 processor and full color TFT display to maintain accessibility and compatibility. More importantly the interactions between the ARM Cortex-M3 processor and critical components were determined such as signal acquisition connections, digital signal processing, and display and user interface connections.

3.2.2 Software Development

The software development and implementation stage is critical. In this phase the ARM Cortex-M3 processor is programmed to handle all signals processing that facilitate the features to analyze data in real-time. Software algorithms that handles signal storage, measurement tools, and control user interface are systematically developed and integrated. Due to complex and critical nature of the software, we opted to use an already programmed ARM Cortex-M3 processor integrated into the printed circuit board. The success of this construction work is based on this phase which is intended to emulate the performance of conventional oscilloscopes.

3.2.3 Hardware Implementation and Integration

Having put in place the software requirements by purchasing an already programmed ARM Cortex-M3 processor, we transited to the hardware implementation and integration stage. Electronic components are assembled on the board based of available schematic diagram, enabling us to interface the ARM Cortex-M3 processor with the color TFT display and other critical components. In this stage all the components were metered especially the resistors before soldering them; also the polarity and orientation of all polar components were determined. Through extensive testing the functionality of individual hardware modules were validated and were seamlessly integrated. We promptly addressed any identified issues to ensure that our digital oscilloscope is robust and reliable.

Figure 8 – Constructed Digital Oscilloscope with TFT LCD Display

3.2.4 Testing, Calibration, and Documentation

In the final stage, we carried out comprehensive testing, system optimization, and documentation. System testing are conducted to assess the general performance, signal analysis features, and real-time data processing capabilities of the digital ARM Cortex-M3 processor-based oscilloscope. User interface optimization is undertaken to enhance the device's usability. Our documentation, including specifications, and circuit diagrams, is carefully finalized.

The test modes are used to find out possible opens (for all port pins) and shorts (for pins PB0-15 and PC 13-15) on the board. When entered it first check PB and PC pins with special patterns to find out possible shorts. If any opening is found, the LED will be fast blinking. Otherwise, it generates 3.3v and 0v alternatively at each port pin (PA, PB, PC, and PI) in cycle of about 4 seconds. It is noteworthy that before using the test mode, U1 and LED must be functioning properly. Hold down SW4 and press RESET to enter the test mode. If the LED fast blinks, it signifies there are shorts on PB or PC pins but if the LED blinks slowly, a volt-meter is used to check each pin related connections that are suspected open. If no voltage change is noticed at a spot which should be connected to a port pin, it shows there may be opening between the spot and the port pin. There exist capacitance between scope input and ground terminals, probes needs to be calibrated to achieve better measurement for high frequency signals. This is achieved with the help of test signal.

3.2.5 Specifications

The digital oscilloscope is specifically constructed for educational and training purposes in electronics laboratory. It features an ARM Cortex-M3 processor and a color TFT screen, emphasizing a straightforward and reliable circuit design with a moderate level of production difficulty, which ensures a high success rate. This work effectively illustrates the fundamental aspects of oscilloscope circuits, providing students with a comprehensive understanding of its structure and principles while enhancing their practical assembly skills. The resulting oscilloscope is highly practical, offering students a valuable tool that will significantly aid their future studies in electronic technology. The following are specifications of the constructed digital oscilloscope.

Table 2 – Oscilloscope Specifications

Feature	Value
Real-time sampling rate	1Msps
Accuracy:	12Bit
Sample buffer depth	1024 bytes
Analog frequency bandwidth	0 - 200KHz
Vertical sensitivity	10mV/Div - 5V/Div (in steps of 1-2-5)
Input impedance	1MΩ
Input voltage	50Vpp (1:1 probe), 400Vpp (10:1 probe)
Coupling methods	DC/AC/GND
Horizontal time base range	10μs/Div - 50s/Div (progressively in 1-2-5 manner)

4.0 CONCLUSION

Through hard work we have achieved the construction of digital oscilloscope using ARM 32-bit Cortex-M3 Microcontroller and full-color TFT LCD. Through this project we have demonstrated the possibility of constructing an affordable and adaptable instrument applicable in the laboratory for teaching and educational purposes. The required real-time signal processing features was achieved by ARM Cortex-M3 microcontroller, particularly the STM32F103C8. The construction will effectively support hands-on laboratory exercises for our students in the department of Electrical Electronic Engineering Technology department by showing the significance of incorporating recent digital technology into learning tools. By incorporating some significant features such as various input power sources, measurement tools, and real-time signal analytical capabilities, this device offers considerable learning opportunities, which will enables our students to have clearer understanding of circuit behaviors.

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