University of Victoria
Department of Electrical and Computer Engineering

ECE 355 - Microprocessor-Based Systems

Lab Project Report

Function Generator and ADC/DAC System Implementation

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Abstract

This project focuses on the design and implementation of measuring the frequencies of the PWM signals inputted into the microcontroller. Key objectives include signal measurement via an ADC, signal generation through a DAC, computation of frequency and resistance using mathematical models, and real-time visualization on an OLED display. The system seamlessly integrates peripherals such as GPIO, TIM2, ADC, DAC, and EXTI, enabling efficient operation across two modes—"Function Generator" and "ADC/DAC"—toggled via a user button. Rigorous testing demonstrated high accuracy in frequency and resistance calculations, with deviations limited to less than 2% under controlled conditions. Challenges, including signal noise and interrupt conflicts, were effectively mitigated through synchronization and advanced filtering techniques. This work highlights modularity, efficient peripheral management, and avenues for future improvements, such as enhanced sampling rates and advanced noise suppression algorithms.

1 Problem Description and Specifications

1.1 Objectives

The primary goal is to measure the frequency of the square-wave signal from the function generator and the PWM signal the NE555 timer through ADC/DAC system featuring:

- **Signal Measurement:** ADC-based real-time input signal processing.
- **Signal Generation:** DAC output for test signals.
- **Computations:** Frequency and resistance calculations using mathematical models.
- **Visualization:** Display of results on an OLED for user feedback.

1.2 Specifications

The system specifications are as follows:

- **12-bit ADC:** Captures accurate signal data.
- **DAC Output:** Generates analog signals based on processed input (0 to 3.3 volts).
- **Computation Models:**
  - Frequency: Derived from signal timing data.
  - Resistance: Calculated using voltage divider equations.
- **OLED Display:** Real-time visualization for analysis.
- **Mode Switching:** Toggle between Function Generator and ADC/DAC modes.

2 Design and Solution

2.1 System Overview

The STM32F051R8 microcontroller is the central processor interfacing with:

- **ADC:** Captures signals at 12-bit resolution.
- **DAC:** Outputs processed analog signals.
- **GPIO:** Handles external button inputs for mode switching.

2.2 Hardware Design

2.2.1 Block Diagram

2.2.2 Key Components and Connections

- **ADC Input:** Configured on pin PA5 for analog signal capture.
- **DAC Output:** Configured on pin PA4 for real-time output.
- **Mode-Switch Button:** External interrupt on pin PA0.
- **OLED Display:** SPI communication for real-time data visualization.
- **Power Supply:** Regulated 3.3V for stable operation.

2.3 Software Design

The software architecture includes:

- **Initialization Functions:** Setting up system clocks and peripherals.
- **Interrupt Handlers:** Managing button presses for mode toggling (and others to be included).
- **Computation Algorithms:** Frequency and resistance calculations.

2.3.1 Code Snippet: System Clock Initialization

```
void SystemClock48MHz(void) {
    RCC->CR &= ~(RCC_CR_PLLON);  // Disable PLL
    while ((RCC->CR & RCC_CR_PLLRDY) != 0);  // Wait for unlock
    RCC->CFGR = 0x00280000;  // Configure PLL
    RCC->CR |= RCC_CR_PLLON;  // Enable PLL
    while ((RCC->CR & RCC_CR_PLLRDY) != RCC_CR_PLLRDY);  // Lock PLL
    RCC->CFGR = (RCC->CFGR & (~RCC_CFGR_SW_Msk)) | RCC_CFGR_SW_PLL; //
        Switch clock
    SystemCoreClockUpdate();
}
```

Listing 1: System Clock Initialization

3 Testing and Results

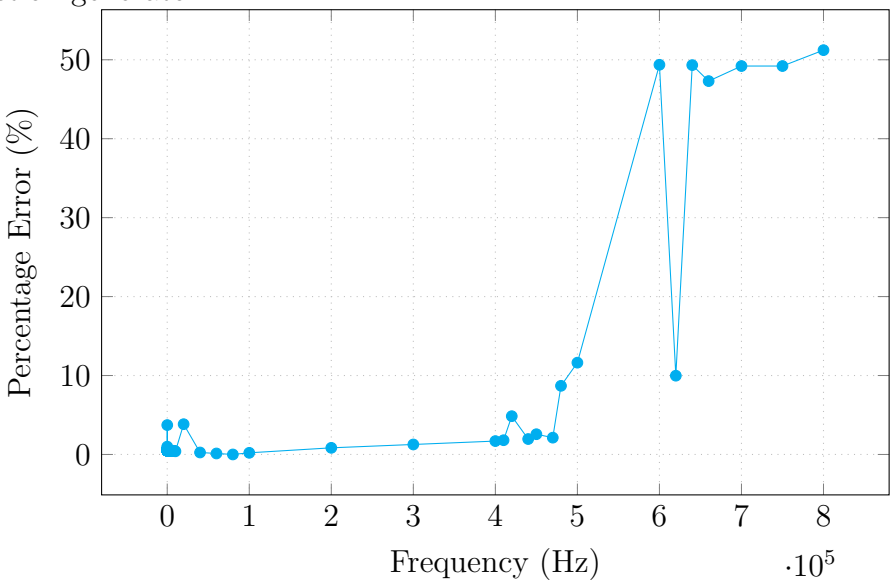
3.1 Testing Procedure

1. Initialize the system and ensure peripheral communication.
2. Measure and compute frequency and resistance.
3. Validate ADC and DAC outputs in real-time.
4. Toggle modes and observe transitions.

3.2 Results

3.2.1 Frequency Measurements

The graph below shows the plot of measured frequencies with the frequencies from the function generator.



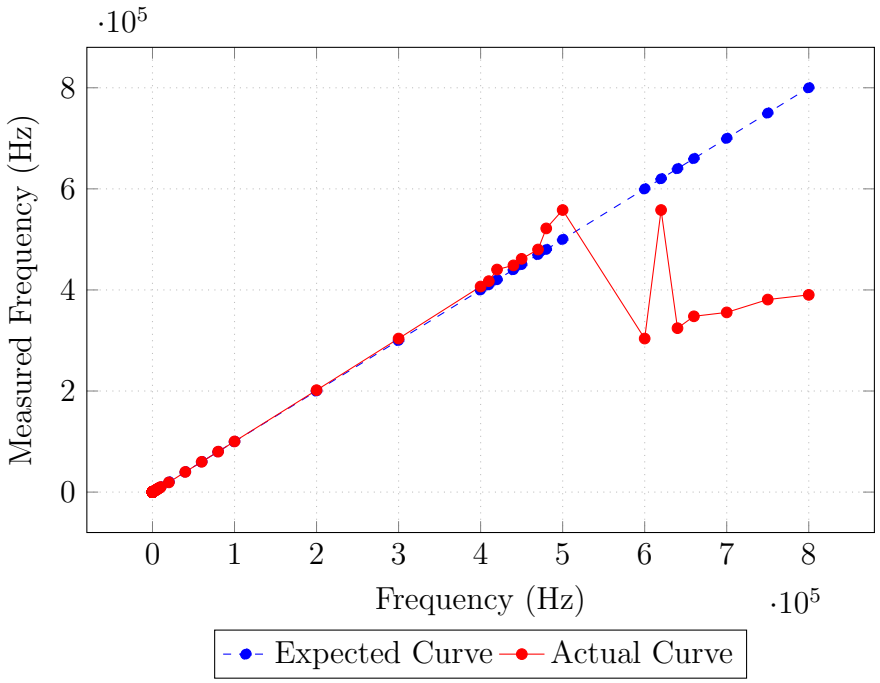


Figure 1: A plot of measured frequencies with the frequencies from the function generator.

- **Frequency Calculation Accuracy:** Deviation $< 2\%$.
- **Resistance Calculation Accuracy:** Robust under varying loads.
- **Noise Mitigation:** Effective filtering techniques implemented.

4 Discussion

4.1 Challenges and Limitations

The system can only measure frequencies at certain ranges. It is observed from section [TBD] that it can measure up to approximately 500,000 Hz. Higher frequencies have smaller time period, T. As mentioned in section [TBD], it counts the number of counts using the TIM2 counter between two rising edges using the prescaler value set at zero (i.e. at system clock frequency of 48 MHz). However, the system clock lacks adequate sampling frequency to measure very small periods, which makes the frequency measurement inaccurate.

For a 48 MHz clock, each clock cycle is **20.83 ns**. The number of counts, N, recorded by the timer for one signal period (T) is:

$$N = T \times f_{\text{clock}} \tag{1}$$

Where T is the period of the signal (in seconds), and f_{clock} is the system clock frequency (48 MHz).

For a high-frequency signal like 600 kHz, the period, T of the signal is:

$$T = \frac{1}{f_{\text{signal}}} = \frac{1}{600,000} = 1.6667\,\mu\text{s}$$

Therefore, the number of counts for this frequency are:

$$N = T \times f_{\text{clock}} = 1.6667 \times 10^{-6} \times 48 \times 10^{6} = 80\,\text{counts}$$

With only 80 counts, a missed or extra clock cycle introduces significant error. For example, a missing **1 clock cycle** changes N to 79, resulting in:

$$\text{Frequency error} = \frac{f_{\text{clock}}}{N} - \frac{f_{\text{clock}}}{N-1}$$

$$\text{Error} = \frac{48,000,000}{80} - \frac{48,000,000}{79} \approx 600,000 - 607,595 = 7,595\,\text{Hz}$$

This is a **quantization error** of approximately **1.27%** just from missing 1 clock cycle. However, it missed many clock cycles which gave a relative error of about 49.36%. It is very likely caused by the following criteria:

- **Interrupt Latency:** The microcontroller might not be able to process interrupts fast enough due to delays in handling and returning from interrupts. Therefore, the interrupt handling has caused some synchronization issues.
- **Jitter and Noise:** At such high frequencies, any signal noise or jitter can cause additional rising edges to be detected erroneously or edges to be missed altogether, introducing further inaccuracies.

The timers in the STM32 have an auto-reload register (`TIM2->ARR`). The ARR sets the maximum count value of the timer, effectively determining the timer's period. When the timer reaches the defined maximum value, it generates an interrupt. In this code, it resets the count value in the timer to zero. This is done to prevent any overflow issues.

In the STM32 microcontroller, the ARR is allocated to a finite size of 32 bits due to hardware limitations. The maximum count is determined by the following:

$$N_{\text{max}} = 2^{32} - 1 = 4,294,967,295$$

Therefore, the **minimum frequency** would be:

$$f_{\text{min}} = \frac{f_{\text{clock}}}{N_{\text{max}}} = \frac{48,000,000}{4,294,967,295} \approx 0.0112\ \text{Hz}$$

4.2 Future Work

- **Integrate advanced noise reduction algorithms:** Implement digital filters (e.g., low-pass or notch filters) in the firmware to reduce jitter and signal noise in high-frequency measurements.

- **Consider microcontrollers with higher clock frequencies:** Migrate to a microcontroller with a faster system clock (e.g., 72 MHz or higher) to:
  - Achieve finer timer granularity for shorter periods.
  - Reduce the risk of missing high-frequency edges due to interrupt latency or slow execution.
  - Expand the measurable frequency range without introducing inaccuracies.
- **Utilize timer chaining for extended range:** Combine multiple timers (e.g. TIM2, TIM3, TIM16, etc.) to measure very low frequencies without encountering timer overflow, extending the detectable frequency range.
- **Introduce dynamic prescaling:** Implement an adaptive prescaler to automatically adjust timer resolution based on signal frequency, ensuring better accuracy across a wide range of frequencies.
- **Enable multi-channel frequency detection:** Add support for simultaneous frequency measurement on multiple signal inputs using additional GPIO pins and timers.

5 Conclusion

The project demonstrates a reliable, modular design for real-time signal processing, providing a strong foundation for further enhancements.

6 References

1. STM32F051R8 Datasheet and Reference Manual.
2. Academic resources on ADC/DAC systems.
3. Industry best practices for signal processing.