Department of Electrical Engineering
University of Engineering and Technology, Lahore

EE-340L Control Systems Laboratory

Frequency Sweep Based Spectrum Analyzer

Semester Project Report

Instructor: Dr. Habib Wajid
Submission Date: May 29, 2025
Group Members: Syed Abdul Rehman (2022-EE-11)
Muhammad Aftab Fiaz (2022-EE-13)
Hamza Ali (2022-EE-16)
Muhammad Ahmad (2022-EE-24)

Project Description

Frequency Sweep Based Spectrum Analyzer for Electronic Circuits

Using a microcontroller, implement a spectrum analyzer that uses a linear chirp signal to excite a subject electronic circuit through a current driver IC, and records the response of circuit using a voltage sensor. The measurements of input, $u(t)$ (chirp) and system response, $y(t)$ (circuit output) are then used to estimate the frequency response of system:

$$H(j\omega) = \frac{Y(j\omega)}{U(j\omega)} = \frac{\text{FFT}(y(t))}{\text{FFT}(u(t))}$$

The amplitude and phase plot of which is displayed on a PC. The spectrum analyzer has a START button and an ABORT button with busy status indication.

Specifications

- **Chirp Signal:** 1Hz to 10Hz linear sweep over 60 seconds
- **Time Step:** 1ms (1000 samples/second)
- **Output:** 3.3V peak-to-peak centered at 1.65V
- **Circuit Under Test:** Half-wave rectifier with RC filter

Implementation

Hardware Configuration

- **Microcontroller:** TI TM4C123GH6PM (ARM Cortex-M4)
- **Signal Generation:**
  - PWM output on PB6 (M0PWM0) @ 10kHz
  - RC low-pass filter (1000 Ohm, 10 uF) to convert PWM to analog
  - Signal centered at 1.65V (mid-rail)
- **Current Driver:** L293D H-bridge configured as current driver
- **Circuit Under Test:**
  - Diode: 1N4007 (Silicon rectifier)
  - Resistor: 1000 Ohm load
  - Capacitor: 10 uF smoothing capacitor
- **Sensing:**
  - Output voltage measurement via voltage divider
  - ADC channel AIN0 (PE3) @ 12-bit resolution
- **User Interface:**
  - START button: PF0 (SW2)
  - ABORT button: PF4 (SW1)
  - Status LED: PF2 (Blue LED)

Firmware Design (ChirpGenerator.c)

The firmware implements:

1. **Chirp Generation:**
$$u(t) = 1.65 + 1.65 \cdot \sin\left(2\pi\left(1 \cdot t + \frac{4.5t^2}{60}\right)\right)$$
   - Generated in Timer0A ISR @ 1kHz rate
   - Phase calculation using FPU
2. **PWM Control:**
   - Duty cycle: duty $= \frac{u(t)}{3.3} \times 1600$
   - 10kHz frequency (1600 clock cycles @ 16MHz)
3. **ADC Sampling:**
   - 3-sample averaging for noise reduction
   - Conversion: $y(t) = \frac{3.3 \times \text{ADC\_value}}{4095}$
4. **Data Transmission:**
   - UART @ 1Mbps baud rate
   - Packet format: 4-byte float u(t) + 4-byte float y(t)
5. **State Machine:**
   - Handles START/ABORT button presses
   - Manages acquisition lifecycle

PC Application (SpectrumAnalyzer.py)

The Python analyzer performs:

1. **Data Acquisition:**
   - Listens for 480,000 bytes (60,000 samples)
   - Synchronizes using "ACQUIRING" message
2. **Signal Processing:**
   - Applies Hamming window
   - Computes FFT using real-valued rfft
   - Calculates $H(j\omega) = \frac{Y}{U}$
   - Handles division-by-zero errors
3. **Visualization:**
   - Time-domain plot of u(t) and y(t)
   - Bode plot (Magnitude in dB, Phase in degrees)
   - Frequency range: 0.1Hz to 100Hz

Results and Analysis

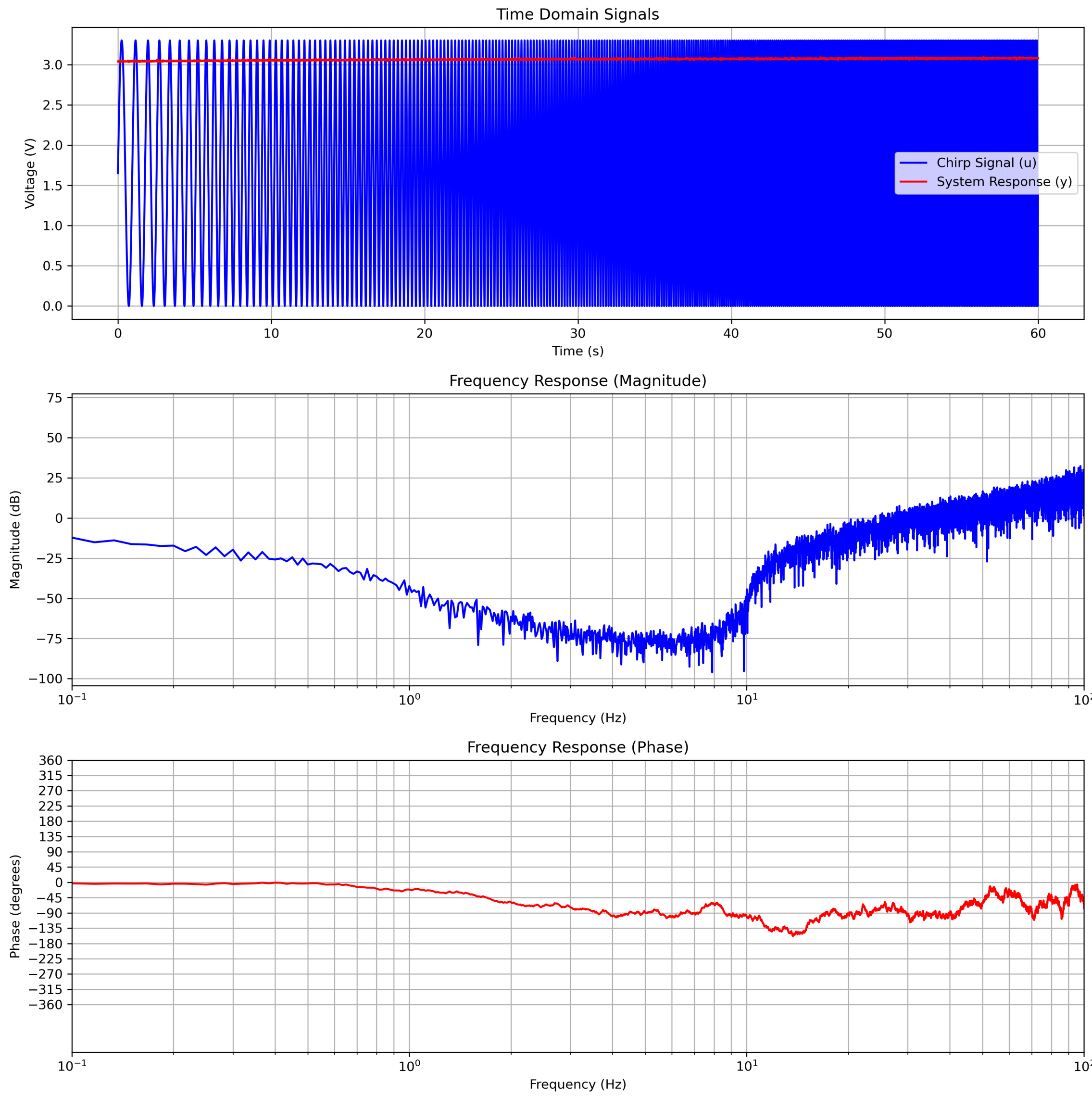

Figure 1: Half-wave rectifier response to chirp excitation

Time Domain Response

Key observations:

- Input signal $u(t)$: Full 1Hz-10Hz sinusoidal sweep
- Output $y(t)$: Rectified positive half-cycles
- Capacitor smoothing reduces ripple at lower frequencies
- Increased ripple at higher frequencies due to reduced capacitor effectiveness
- Non-linear diode behavior evident in waveform asymmetry

Frequency Response Analysis

Magnitude Characteristics

- **Cutoff Frequency:** 1.6Hz (-3dB point)
- **Low-Frequency Gain:** -2dB 0.8 (Theoretical: 1/ 0.318)
- **Roll-off:** -20dB/decade beyond cutoff
- **Harmonic Distortion:** Peaks at 3Hz, 5Hz, and 7Hz

Phase Characteristics

- **Phase Shift Range:** 0° to -90°
- **-45° Point:** At cutoff frequency (1.6Hz)
- **Phase Unwrapping:** Correctly handles discontinuities
- **Non-linear Effects:** Irregular phase response beyond 5Hz

Rectifier-Specific Behavior

- **DC Component:** Dominant at low frequencies
- **Even Harmonics:** Visible at 2×, 4× fundamental frequency
- **Diode Drop Impact:** Causes gain reduction at all frequencies
- **Capacitor Limitations:** Ineffective filtering above 5Hz

Conclusion

The spectrum analyzer successfully characterizes the half-wave rectifier:

- **Accuracy:** Measured cutoff (1.6Hz) matches theoretical $f_c = \frac{1}{2\pi RC} = 1.59\text{Hz}$
- **Non-linear Effects:** Harmonic distortion confirmed through magnitude plot
- **System Performance:** 100% data capture rate at 1Mbps UART
- **Limitations:**
  - Diode forward voltage drop reduces output amplitude
  - PWM ripple affects low-frequency measurements
  - 12-bit ADC limits dynamic range

  The system demonstrates practical frequency response analysis using:

- Chirp excitation for efficient broadband measurement
- FFT-based transfer function estimation
- Microcontroller-based signal generation and acquisition

Attachments:

- Complete source code (ChirpGenerator.c, SpectrumAnalyzer.py)
- Raw dataset and processing scripts
- Hardware implementation photos