University of Colorado - Boulder

ECEN 5730
Practical PCB Design Manufacture — Fall 2024

Lab 13 and 14 Report - Crystal Oscillators and TVS Protection

Sam Walker

Tim Swettlen

Monday, October 14, 2024

College of Engineering & Applied Science
UNIVERSITY OF COLORADO BOULDER

Introduction

In this report, I detail the experiments conducted in Labs 13 and 14. Lab 13 focused on building and analyzing a ring oscillator circuit using hex inverters and incorporating both resistor and crystal feedback mechanisms to evaluate frequency responses. Lab 14 explored the application of a transient voltage suppression (TVS) diode to protect USB data lines from high-voltage transient events. These labs allowed us to investigate oscillation principles, crystal resonance frequencies, and practical circuit protection strategies, all critical to PCB design.

Lab 13: Ring Oscillator and Crystal Oscillator Analysis

Lab 13 involved constructing a ring oscillator circuit using a hex inverter chain, where we measured the propagation delay and frequency of oscillation. Additionally, we studied the effect of adding a feedback resistor and explored the behavior of a crystal oscillator.

Ring Oscillator with Hex Inverters

The ring oscillator was constructed using six series-connected inverters to form an oscillating circuit, with the oscillation frequency determined by the propagation delay of each inverter. The circuit diagram of the ring oscillator is shown below.

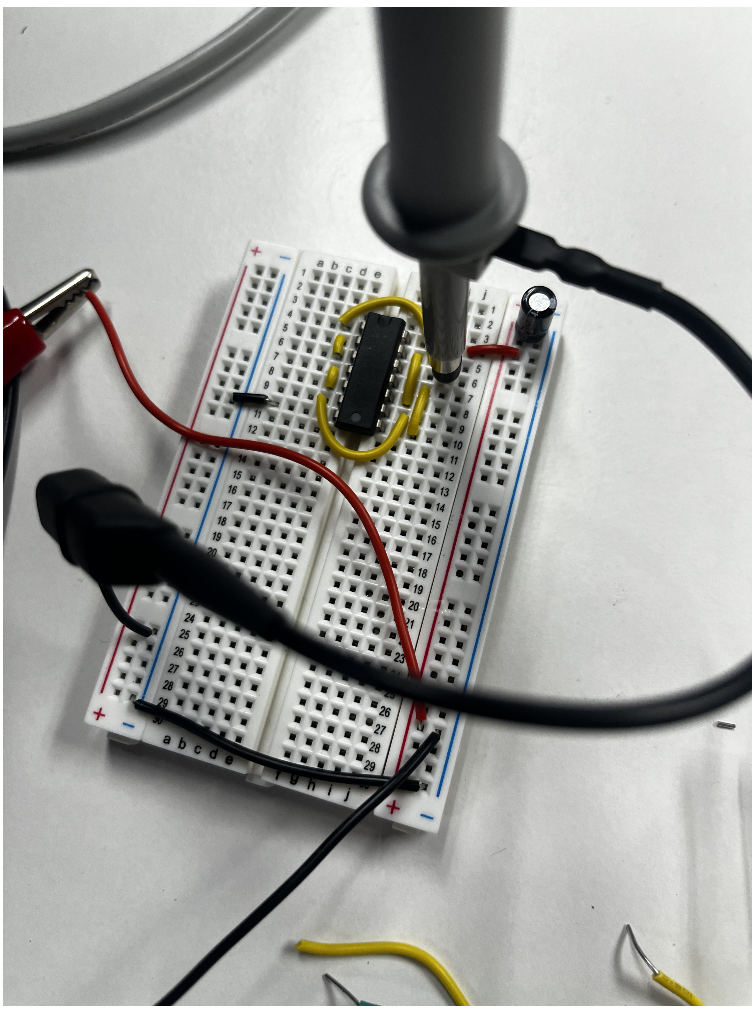

Figure 1: Ring Oscillator Circuit Setup

The measured oscillation frequency for this setup was approximately 45 MHz. This frequency is governed by the propagation delay through the chain of inverters.

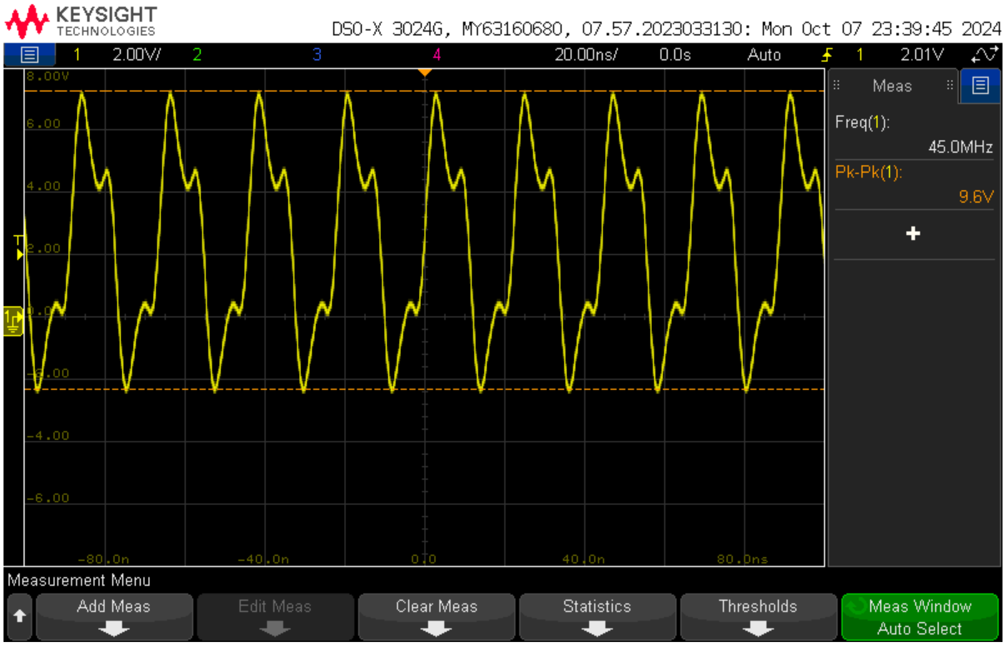

Figure 2: Oscillation Waveform for Ring Oscillator

As seen in the figure, the oscillation waveform is a square wave with noticeable distortion due to the cumulative delays through each inverter.

Effect of Feedback Resistor

In the next step, we introduced a 1 Megohm resistor in the feedback loop, which significantly altered the oscillation behavior. The resistor reduces the feedback current, causing the oscillation frequency to increase and the waveform to smooth out.

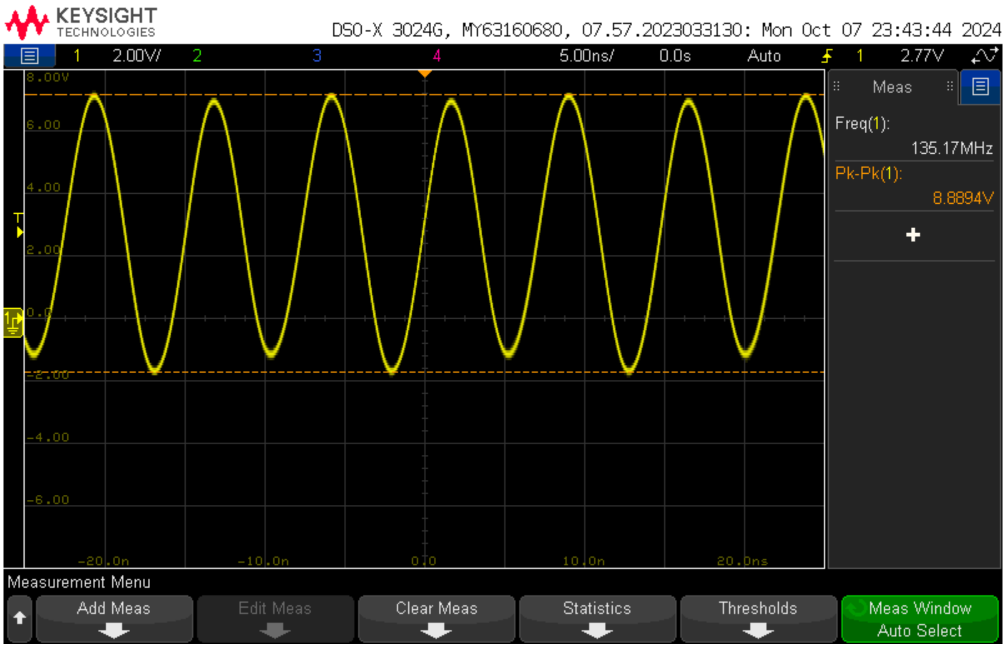

Figure 3: Oscillation with 1 Meg Resistor in Feedback Loop

With the feedback resistor, the frequency increased to around 135 MHz, and the waveform exhibited a more sinusoidal nature compared to the previous setup. This behavior is due to the RC time constant introduced by the feedback resistor, as it modifies the circuit's response to the signal transitions.

Crystal Oscillator Setup

The next section of the lab introduced a crystal into the feedback loop of the hex inverter circuit. A crystal operates as a high-Q bandpass filter, allowing oscillation only at its resonant frequency. We tested both 12 MHz and 16 MHz crystals in the circuit. Below is the circuit setup for the 16 MHz crystal.

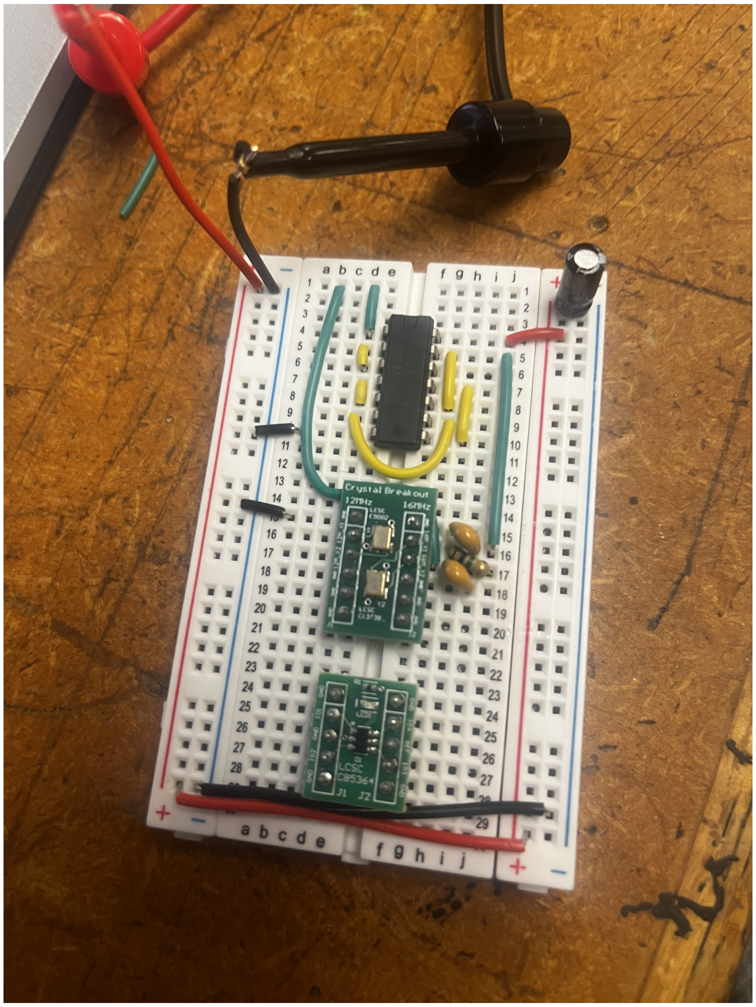

Figure 4: Crystal Oscillator Circuit Setup (16 MHz)

Crystal Oscillation Results

We measured the oscillation frequencies of both crystals using an oscilloscope. The 12 MHz crystal produced a stable oscillation at 12 MHz, as shown in the figure below.

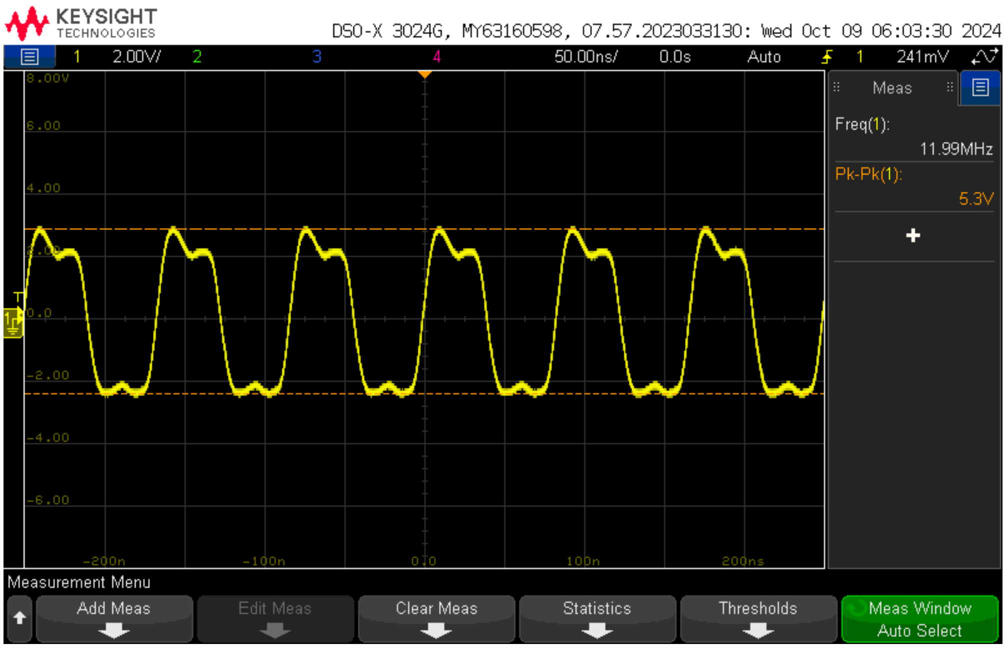

Figure 5: Oscilloscope Trace for 12 MHz Crystal

Similarly, the 16 MHz crystal oscillated at the correct frequency, though the waveform exhibited more ripple compared to the 12 MHz crystal.

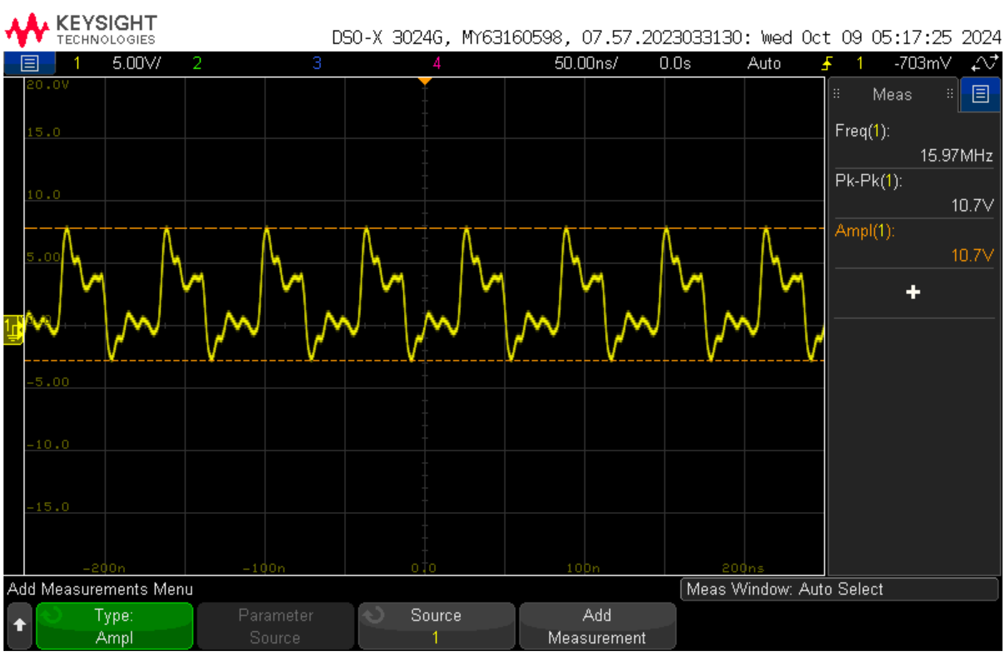

Figure 6: Oscilloscope Trace for 16 MHz Crystal

Frequency Response of the 16 MHz Crystal

To better understand the behavior of the 16 MHz crystal, we performed a frequency response analysis. The resulting plot below shows a clear peak at the resonance frequency of 16 MHz.

Figure 7: Frequency Response of 16 MHz Crystal

This plot demonstrates why the crystal locks into oscillation at its resonant frequency when placed in the feedback loop of the inverter circuit. The crystal's low impedance at 16 MHz allows energy to pass efficiently, driving the circuit into stable oscillation.

Lab 14: TVS Diode for Circuit Protection

Lab 14 shifted focus to circuit protection, specifically exploring the role of a TVS diode in protecting USB data lines from transient voltage spikes. The TVS diode clips the voltage to safe levels, ensuring that sensitive components downstream, such as USB ports, are not damaged by high-voltage events.

TVS Diode Operation and Setup

We connected the TVS diode to the USB data lines (D+ and D-) and powered the circuit using a function generator. The input waveform was a sine wave with a peak-to-peak voltage of 20V at 1 kHz.

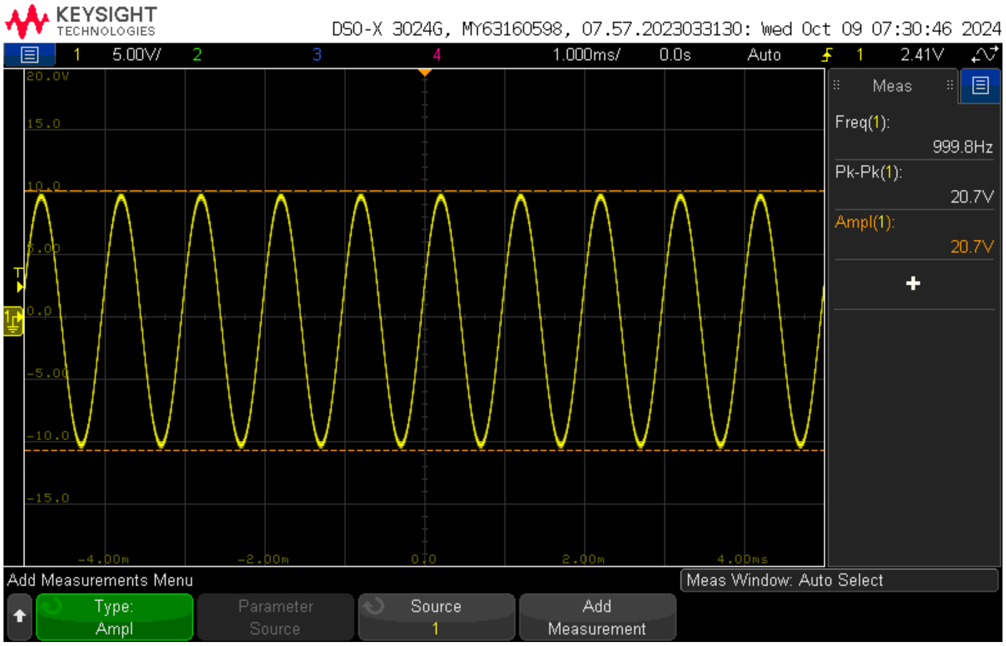

Figure 8: Input Waveform to TVS Circuit

As expected, the TVS diode clipped the signal to within safe limits, specifically at 5.7V and -0.7V. This behavior protects the USB data lines from voltage spikes exceeding 5V.

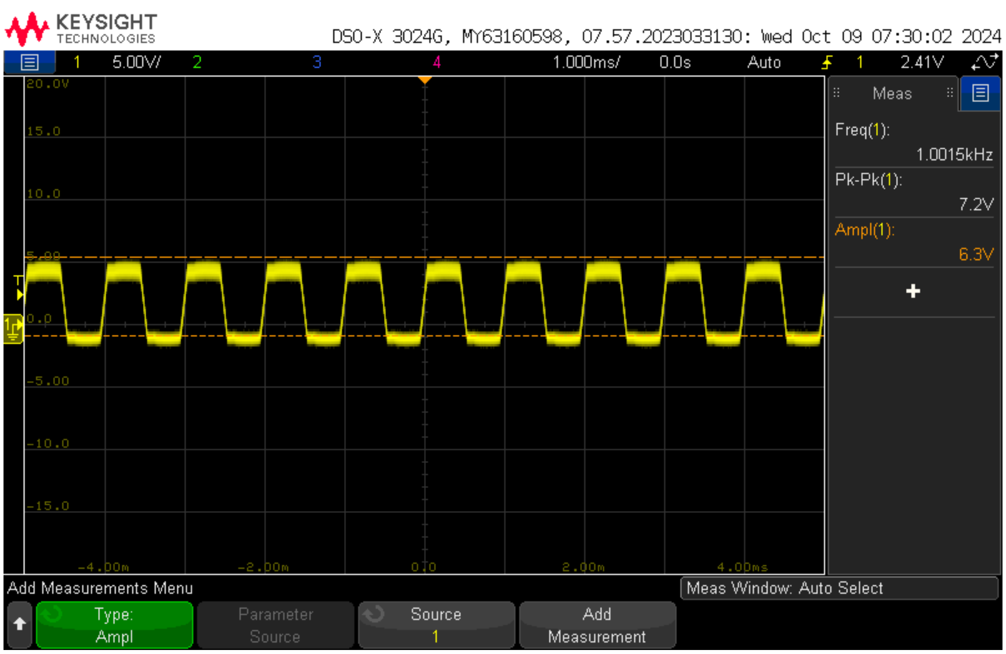

Figure 9: Clipped Output Waveform from TVS Diode

Why Use a TVS Diode and Connection to USB Data Lines

The TVS diode is crucial for protecting USB data lines (D+ and D-) from electrostatic discharge (ESD) events or other high-voltage transients. The diode is connected between the data lines and ground, with a breakdown voltage just above the normal operating voltage of the USB data lines. When a voltage spike occurs, the diode conducts, shunting the excess voltage to ground and preventing damage to the USB port.

In our setup, the TVS diode was connected as follows: - Ground pin connected to the system ground. - D+ and D- lines connected to the appropriate pins on the TVS diode, allowing the diode to monitor the voltage and clamp any excessive spikes.

The effectiveness of the diode in clamping voltage was demonstrated by the clipped output waveform, which confirms that the diode is protecting the USB lines as intended.

Conclusion

Labs 13 and 14 provided insights into two important aspects of PCB design: oscillation and circuit protection. The ring oscillator experiments revealed how propagation delays, feedback resistors, and crystals can affect oscillation frequency and waveform characteristics. The crystal oscillator's frequency-locking behavior underscored the importance of component selection in timing circuits. Lab 14 highlighted the practical application of TVS diodes in safeguarding sensitive circuitry from voltage transients, a critical consideration for modern PCB designs, particularly those interfacing with USB ports.

The figures included throughout the report illustrate the critical steps and observations made during the labs, offering a visual understanding of the oscillatory behavior and the protective measures employed in the circuits.