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Fidelity of a Wireless Light-Based Communication System

(Case Study)

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I. INTRODUCTION

The fidelity of a communication system is critical in ensuring the accurate and reliable transmission of data. Fidelity refers to the system's ability to reproduce the input information at the output with high precision, without introducing distortion or losing essential details.

This study assesses the fidelity of a wireless light-based communication system, which uses light beams to transmit data through free space. The primary objective is to evaluate the fidelity between the transmitted input and the received output signals, identifying the degree to which the system preserves the integrity of the data during transmission.

In wireless laser-based communication, the input signal is encoded onto a laser beam and transmitted across free space to the solar panel as a receiver, which decodes and reconstructs the output signal. Discrepancies between the input and output signals indicate potential issues in the transmission process, such as distortion, data loss, or signal degradation caused by environmental factors or system limitations. This study systematically compares the waveforms to visualize the system's fidelity and identify specific areas of deviation.

This research focuses on assessing waveform differences to provide an analysis of the performance of wireless laser-based communication systems. Understanding these differences is critical for identifying the factors that influence fidelity and for developing strategies to improve system accuracy and reliability. This study contributes to the advancement of light-based communication technologies by emphasizing the importance of preserving data integrity during wireless transmission.

II. MATERIALS

I. Solar Panel (Receiver)

- **Function:** Acts as the receiver in the system.
- **Description:** The solar panel captures light signals transmitted by the laser diode. These light signals are then converted into electrical signals, which are processed to retrieve the original audio.
- **Role in the System:** Essential for receiving and converting light-based data back into an electrical form that can be processed for audio recovery.

II. Laser Diode (Transmitter)

- **Function:** Transmits audio signals through light.
- **Description:** The laser diode converts electrical audio signals into modulated light signals. It changes its brightness in sync with the audio input to encode the sound data into light.
- **Role in the System:** Acts as the transmitter, encoding audio into light signals for wireless transmission.

III. Speaker (Output)

- **Function:** Outputs the audio signal.
- **Description:** After the solar panel converts the light signals back into electrical signals, the speaker produces the recovered audio sound.
- **Role in the System:** Acts as the output component, converting electrical signals into audible sound.

IV. MAX4466 (Microphone Amplifier)

- **Function:** Amplifies weak audio signals.
- **Description:** The MAX4466 is a microphone pre-amplifier module that boosts weak audio signals from a sound source. This ensures the audio input is strong enough to modulate the laser diode effectively.
- **Role in the System:** Provides necessary amplification for the audio input, ensuring it is suitable for transmitting via the laser diode.

V. PAM8403 (Audio Amplifier)

- **Function:** Amplifies audio signals for output.
- **Description:** The PAM8403 is used to amplify the audio signal before it reaches the speaker. This ensures that the audio output is loud and clear.
- **Role in the System:** Amplifies the processed audio signal to provide sufficient volume for the speaker.

III. PROCEDURE

A. SET UP AND VERIFICATION

1. Positioning the Components

- The Transmitter and Receiver will be placed 0.5 meters apart, as this distance is expected to provide the highest quality transmission.
- Beyond this range, signal fidelity is anticipated to degrade significantly.

2. Preliminary Functionality Check

- A preliminary test will be conducted to ensure both the Transmitter and Receiver are functioning properly before proceeding with data collection.

3. Preparing the Receiver

- The Receiver casing will be opened to allow for the attachment of two alligator clips to the speaker terminals.
- One alligator clip will be connected to the current-carrying terminal, while the other will be attached to the ground terminal to establish a proper connection.

4. Preparing the Transmitter

- The earphone jack component of the Transmitter will be used to transmit monotone frequencies.
 - Two alligator clips will be attached to the jack to ensure proper transmission of the signals.

5. Connecting the Analog Discovery to the Waveforms Application

- The Waveforms software (by Digilent) will be used in conjunction with an Analog Discovery device to generate and analyze signals.

The following Waveforms functions will be utilized:

- Supply Function: Set to +5V to power the system.
- Wave Generator: Used to produce mono-tone frequencies for transmission.
- Oscilloscope (Scope): Used to visualize electrical signals in the time domain.
- Spectrum Analyzer: Performs frequency-domain analysis using Fast Fourier Transform (FFT) to transform time-domain data into a frequency spectrum.

6. Establishing Signal Pathways for Data Collection

- A Male-to-Male (M-M) jumper wire will be connected from Wave Generator 1 of the Analog Discovery to a breadboard, ensuring that only one waveform generator is used.
- Another M-M jumper wire will be connected from the positive Scope 1 of the Analog Discovery to the breadboard, establishing a direct connection between the Wave Generator and the Scope to serve as the reference signal for fidelity comparison.

7. Transmitter-to-Receiver Signal Pathway

- One of the alligator clips attached to the earphone jack will be connected to the ground of the Analog Discovery.
- The other alligator clip will be connected to the Waveform Generator via the breadboard, enabling the transmission of mono-tone frequencies through the wireless light-based communication system.
- 8. Receiver-to-Analog Discovery Signal Pathway
- One of the alligator clips attached to the receiver will be connected to the positive Scope 2 of the Analog Discovery.
- The other will be connected to the ground port of the Analog Discovery to capture the received signal after transmission through the system.
- 9. Final Verification
- A final check will be performed by transmitting a set of mono-tone frequencies to ensure all components are properly connected and functioning as expected.
- Once successful transmission and reception are confirmed, the setup phase will be deemed complete, and data collection can proceed.

B. DATA GATHERING

1. Frequency Range and Test Intervals

- Mono-tone frequencies will be transmitted within the range of 200 Hz to 3 kHz, using increments of 200 Hz (i.e., 200 Hz, 400 Hz, 600 Hz, etc.).

2. Reference Signal Generation

- Wave Generator 1, connected directly to Positive Scope 1, will produce the reference signal.
- In the Waveforms application, this reference signal will be displayed as an orange waveform in both the Scope and Spectrum functions.

3. Receiving and Capturing the Transmitted Signal

- The receiver's alligator clips will capture the fully transmitted and received mono-tone frequency via Positive Scope 2 of the Analog Discovery.
- The received signal will be displayed as a blue waveform in the Waveforms software for comparison with the reference signal.

4. Oscilloscope Data Collection

- The Scope function of the Waveforms software will simultaneously display both the orange (reference) waveform and the blue (received) waveform.
- Two screenshots will be taken for each test frequency:
- One showing both the reference (orange) and received (blue) waveforms under normal conditions.
- Another showing the reference (orange) waveform alongside a fully obstructed blue waveform, simulating a failed transmission.

5. Spectrum Analysis

- In the Spectrum function of the Waveforms software, the orange and blue waveforms will be analyzed in the frequency domain.
- The frequency spectrum will be adjusted to span 100 Hz before and 100 Hz after each mono-tone frequency to ensure optimal visualization.
- A screenshot of the most consistent spectral representation will be taken for each frequency.

6. Repeating for All Test Frequencies

- The process will be repeated for each frequency until reaching 3 kHz, marking the conclusion of data collection.

C. DATA ANALYSIS

1. Waveform Distortion Analysis

- Compare the **shape** of the blue waveform to the orange waveform in the screenshots.
- Identify any **visible alterations**, such as waveform smoothing, jagged edges, or incomplete signal reproduction.
- Use these observations to assess **distortion** in the transmission process.

2. Phase Shift Estimation

- Observe the alignment of the peaks and troughs of both waveforms in the screenshots.
- If the blue waveform appears **shifted in time** relative to the orange waveform, it suggests a **phase shift** due to transmission delay.
- Estimate the extent of the shift **visually**, noting whether it increases with frequency.

3. Amplitude Comparison

- Compare the **height of the blue waveform** against the orange waveform in the screenshots.
- If the blue waveform is consistently lower, it indicates **signal attenuation** (loss of strength).

- If there is inconsistency in amplitude, it may suggest **unstable transmission**.

4. Spectrum Analysis Using Screenshots

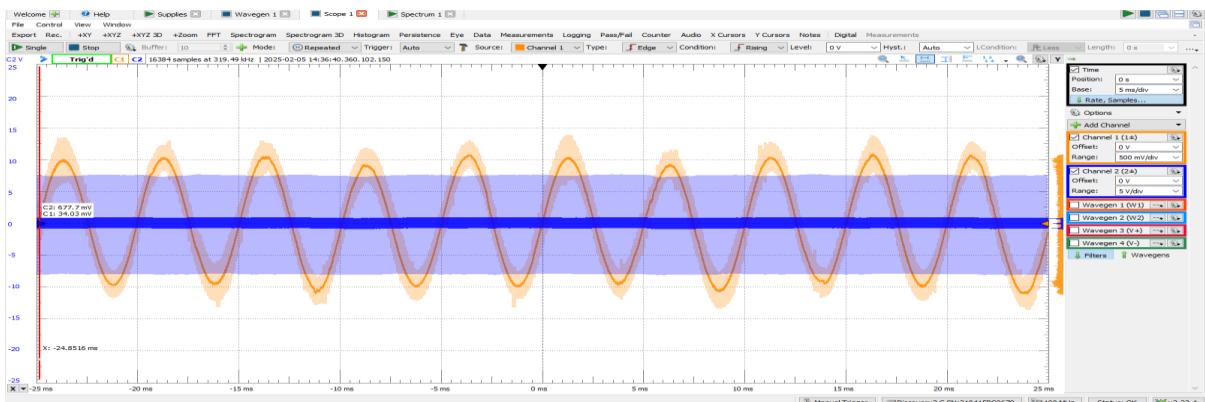
- Utilize the **Spectrum function** in the Waveforms app to analyze the frequency content of both waveforms.
- Take **one screenshot per frequency test**, ensuring both signals are visible.
- Compare the blue and orange peaks in each screenshot to observe **signal fidelity** in the frequency domain.
- If the blue peak is weaker, it suggests a **loss of fidelity** in transmission.

5. Final Documentation

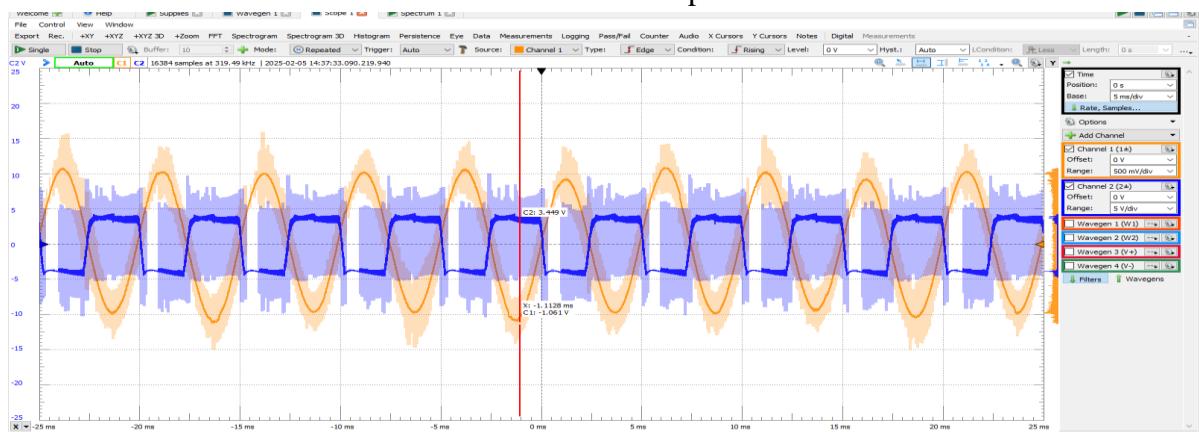
- Organize the screenshots according to frequency values for easy comparison.
- Use **visual observations** to describe changes in waveform shape, amplitude, and phase shift.
- Identify key trends based solely on the screenshots, forming the basis for further discussion.

IV. RESULT & DISCUSSION

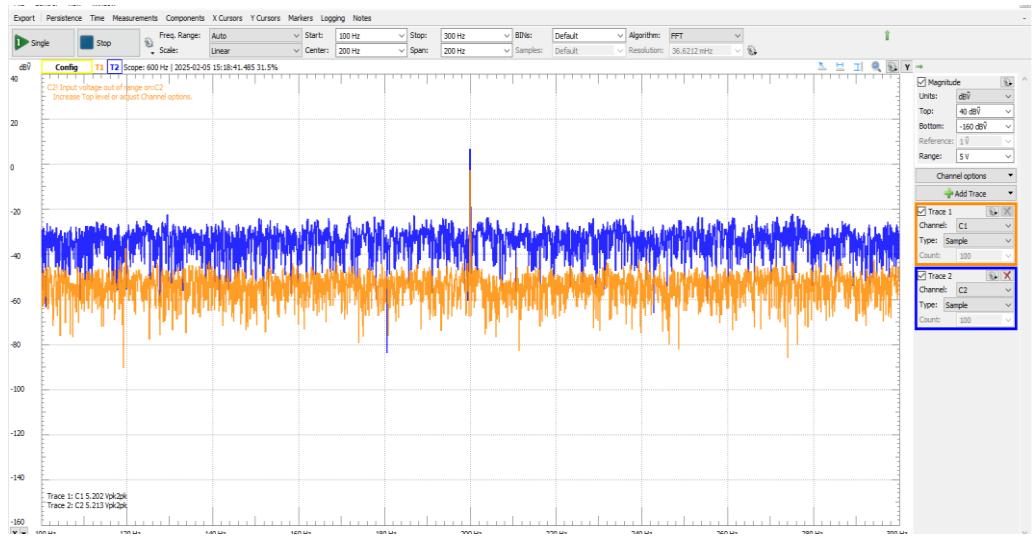
200 Hz Without Output



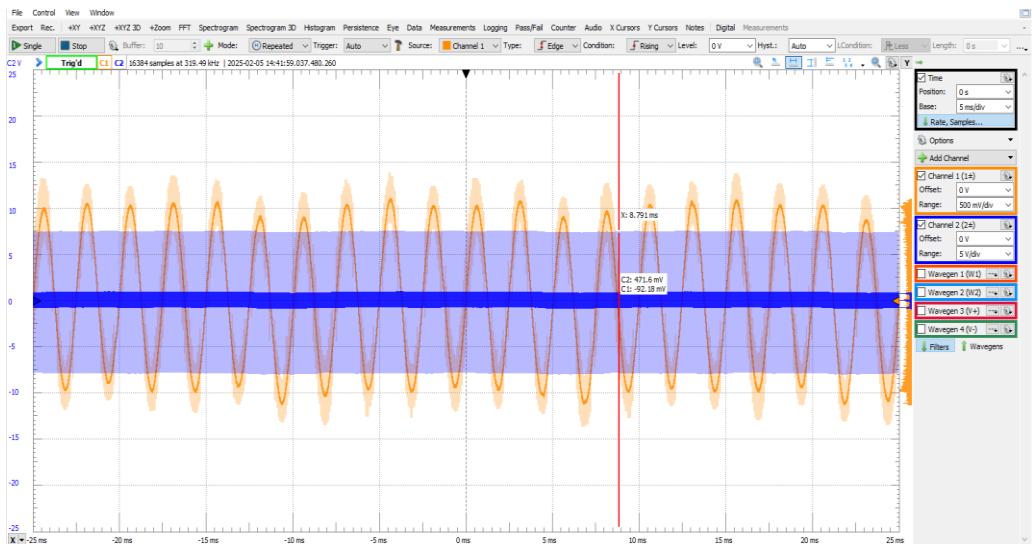
200 Hz With Output



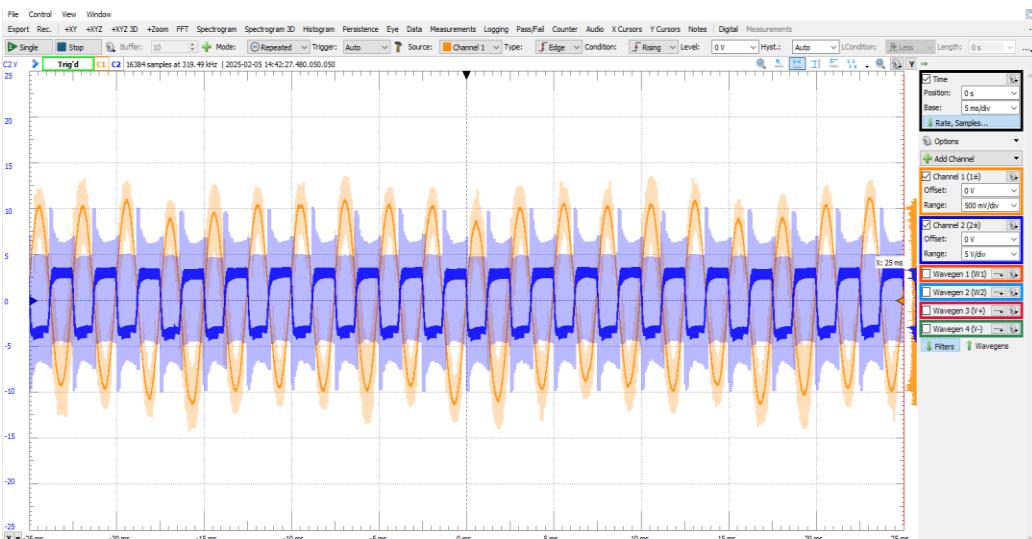
200Hz Spectrum



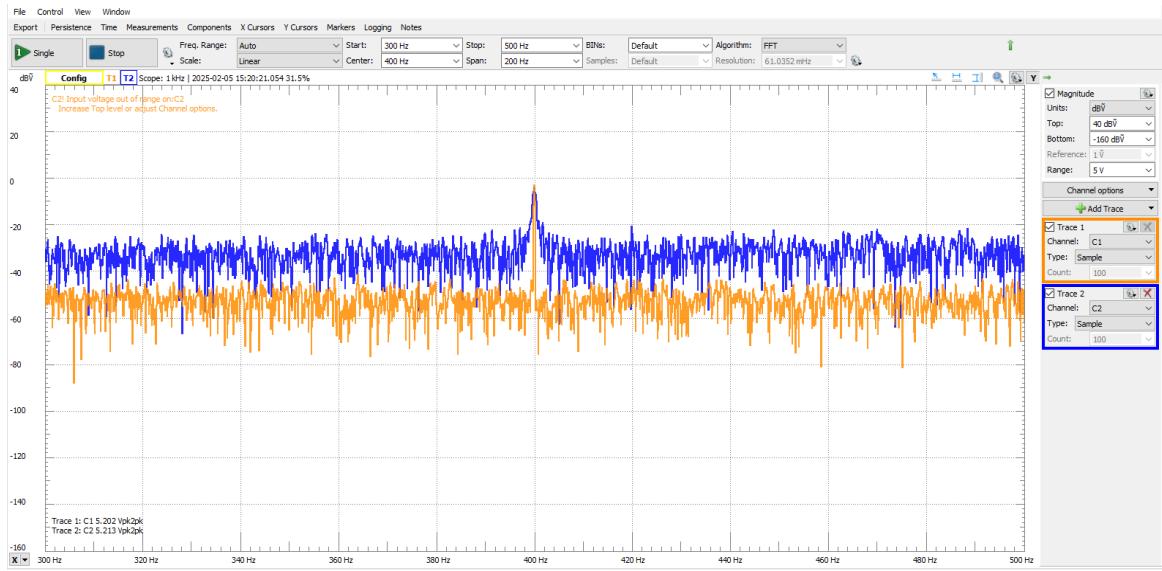
400Hz Without Output



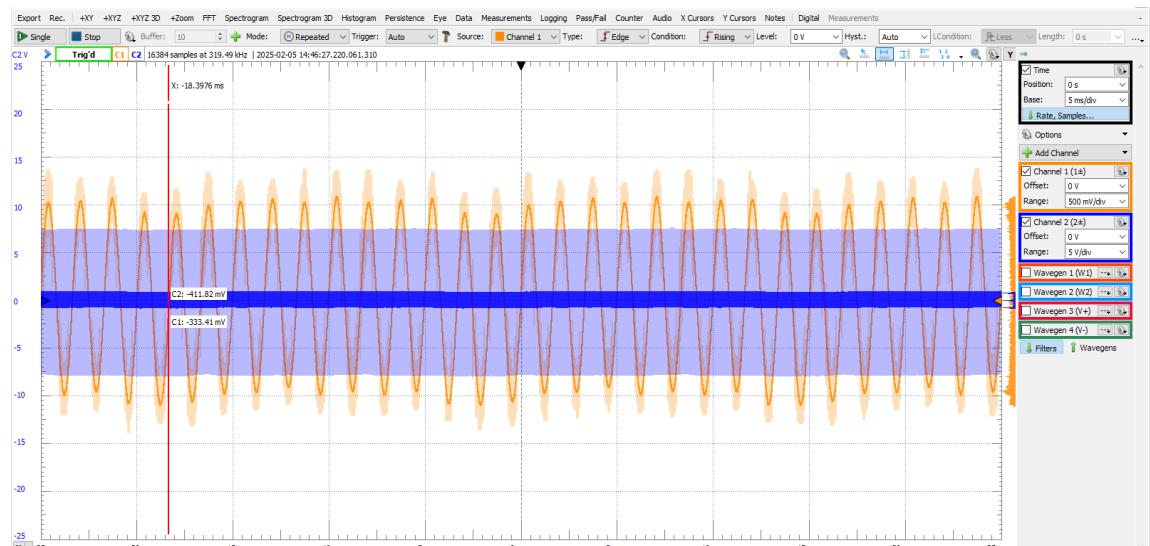
400Hz With Output



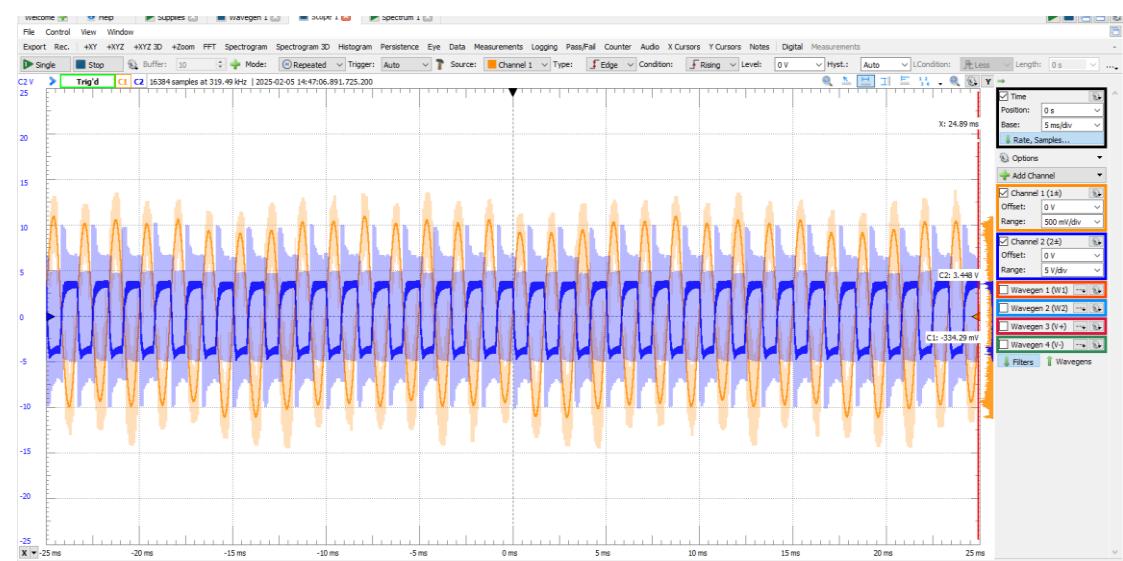
400Hz Spectrum



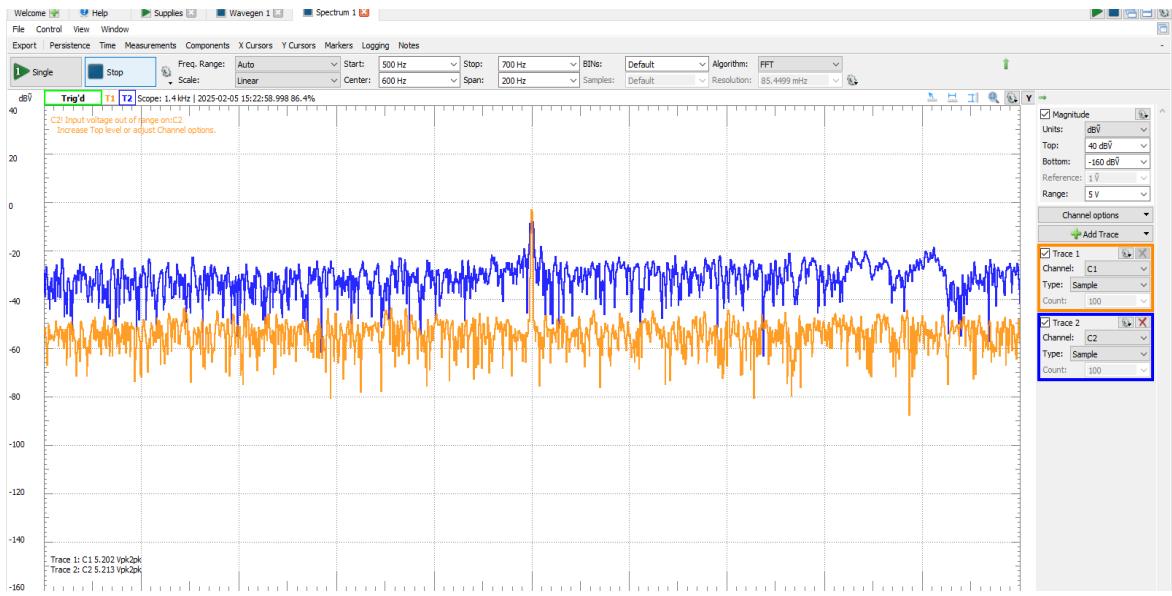
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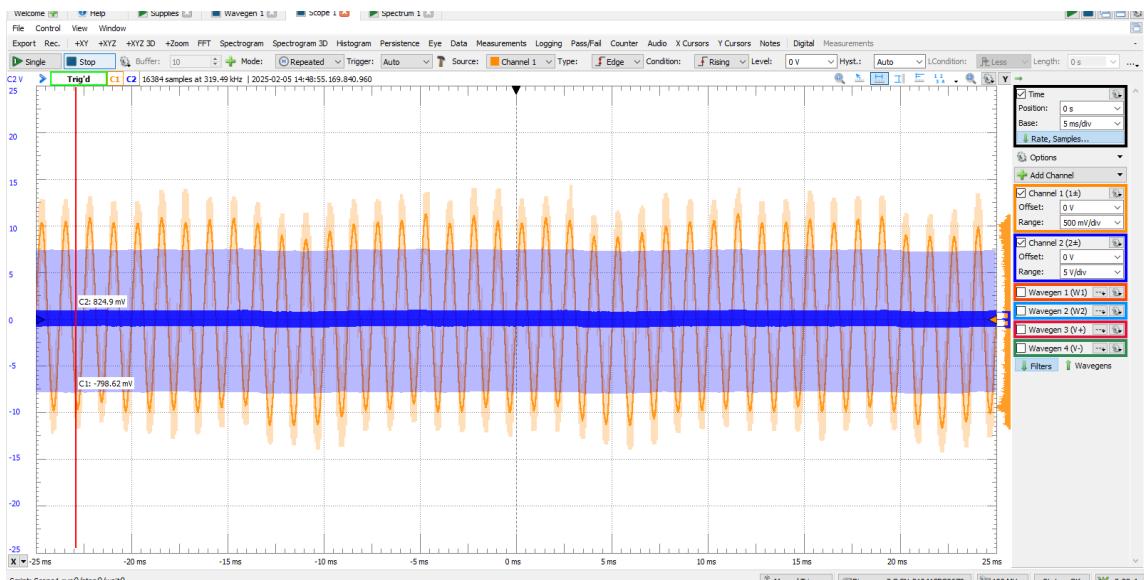
600Hz With Output



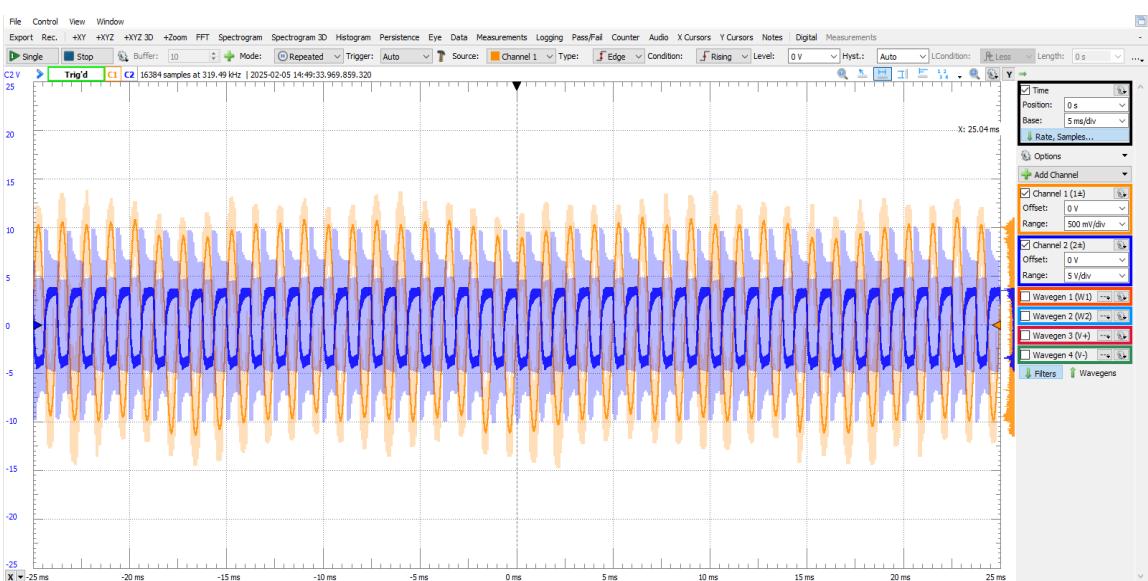
600Hz Spectrum



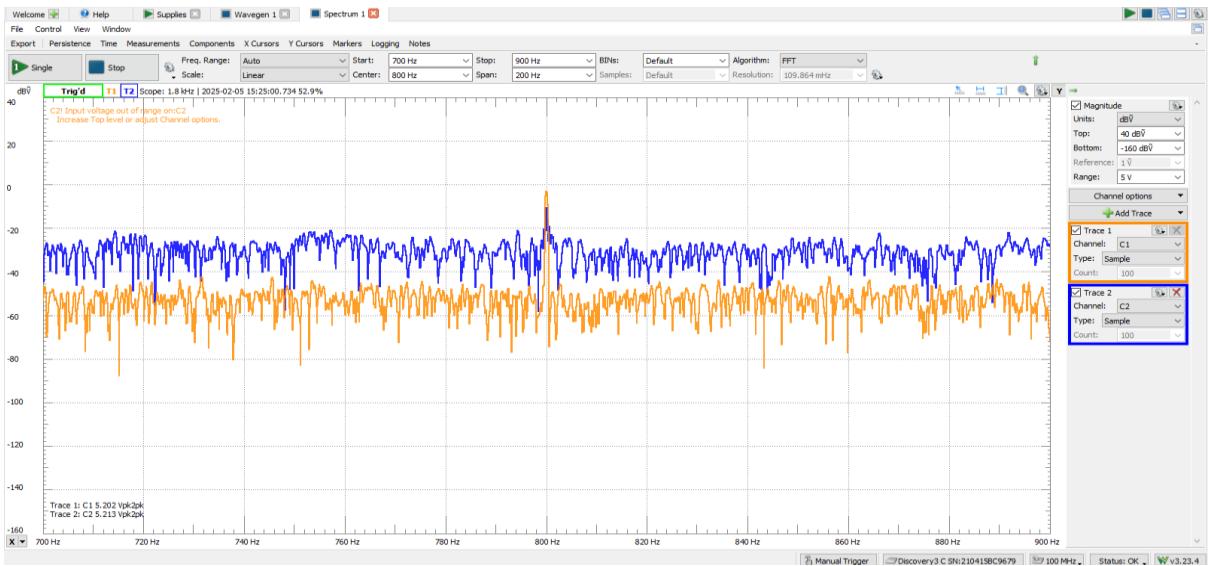
800Hz Without Output



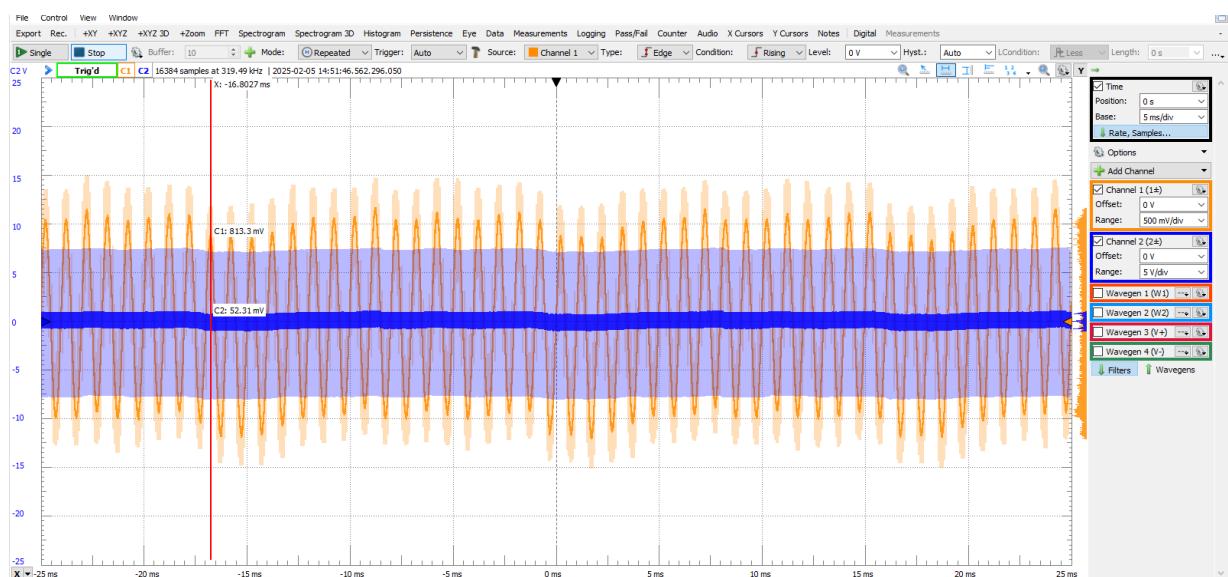
800Hz With Output



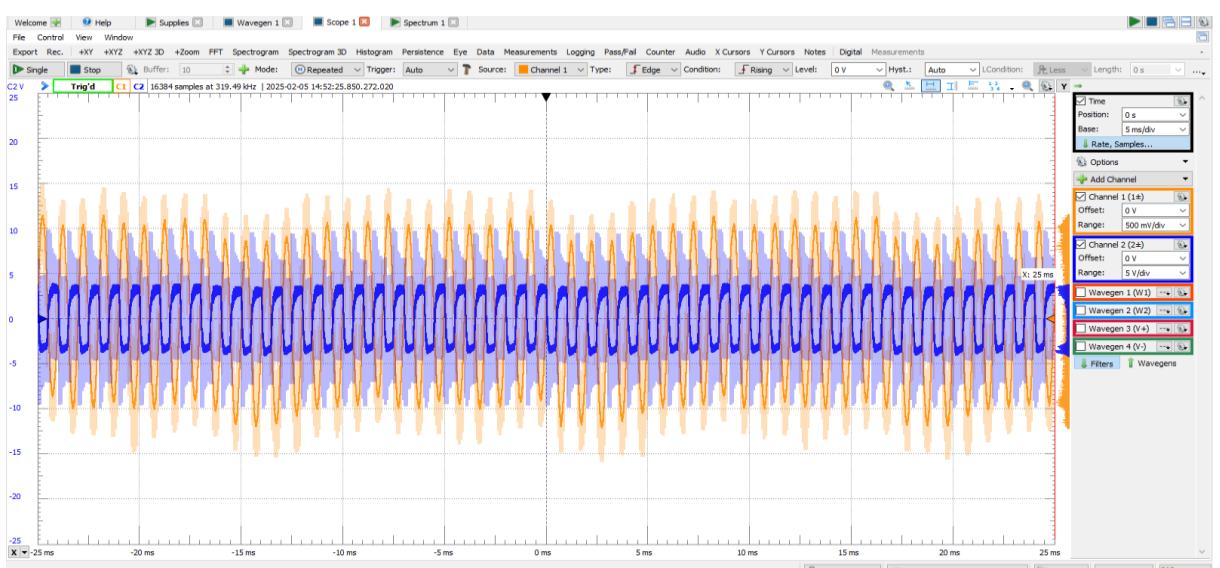
800Hz Spectrum



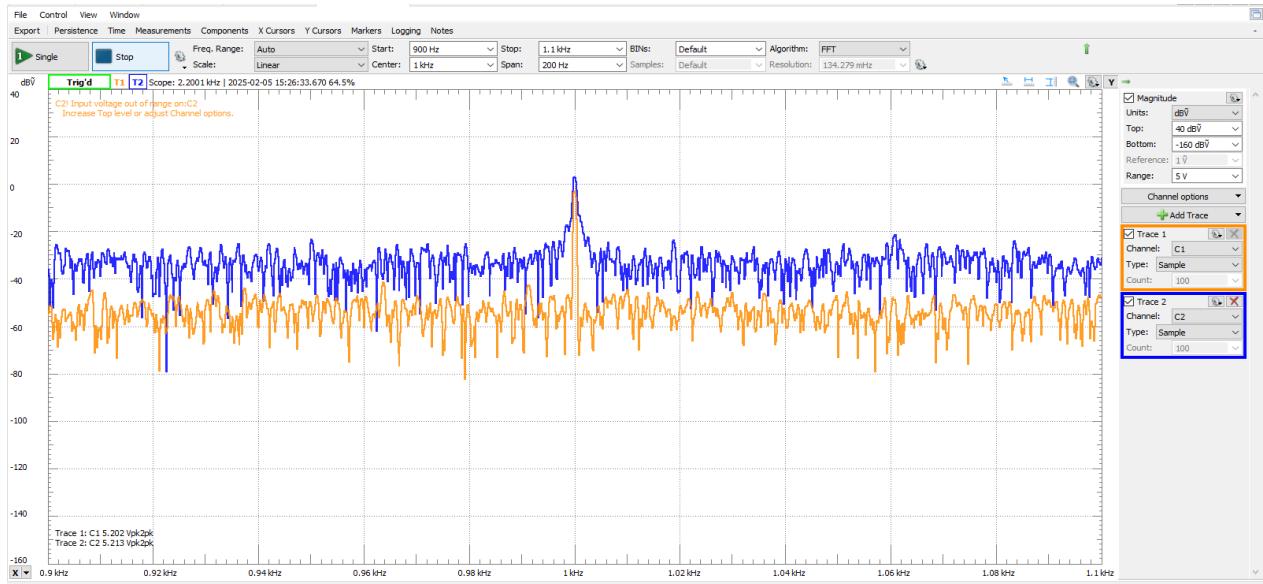
1kHz Without Output



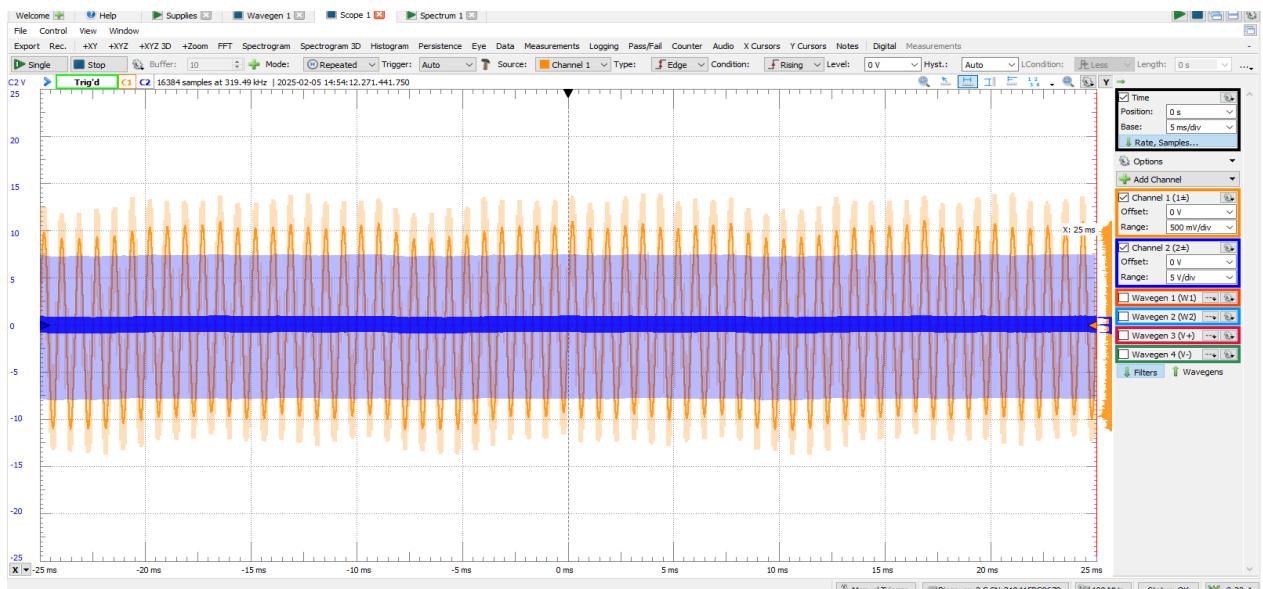
1kHz With Output



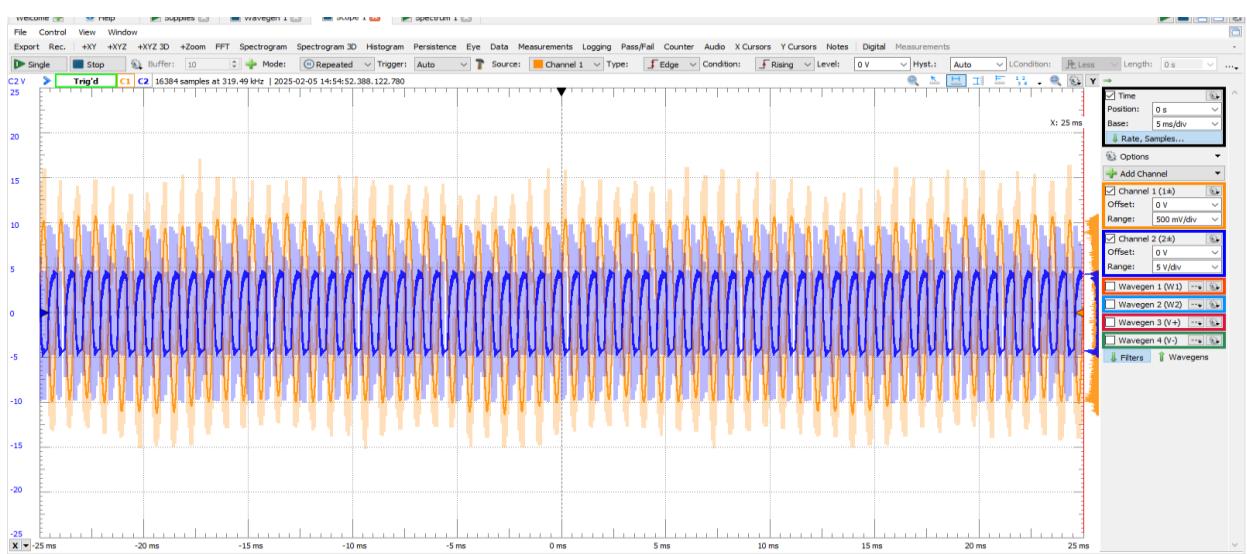
1kHz Spectrum



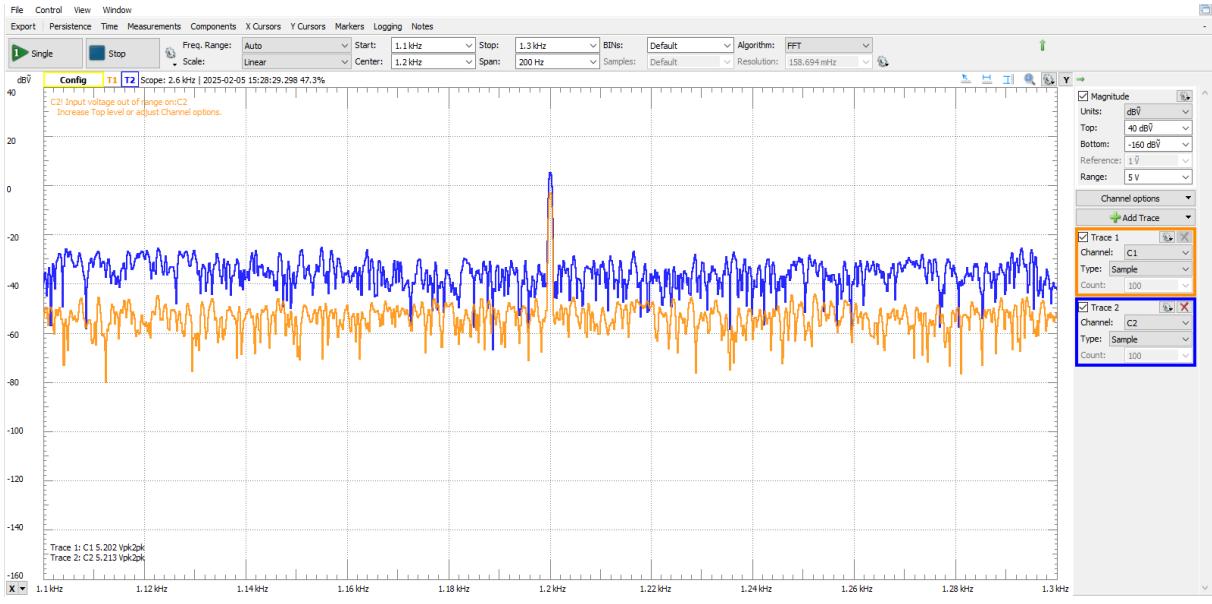
1.2kHz Without Output



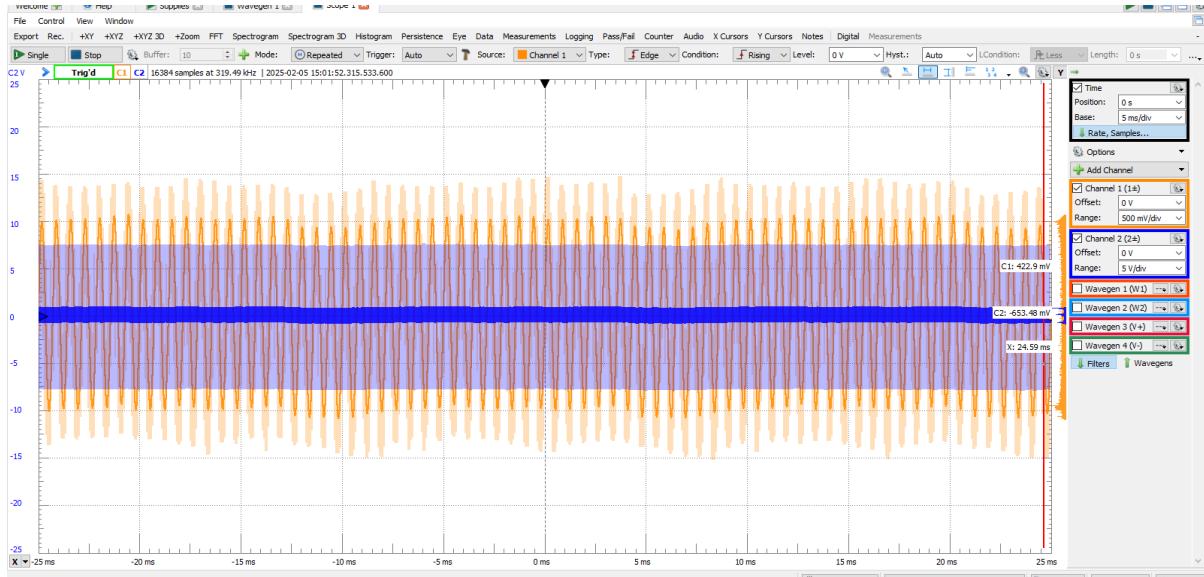
1.2kHz With Output



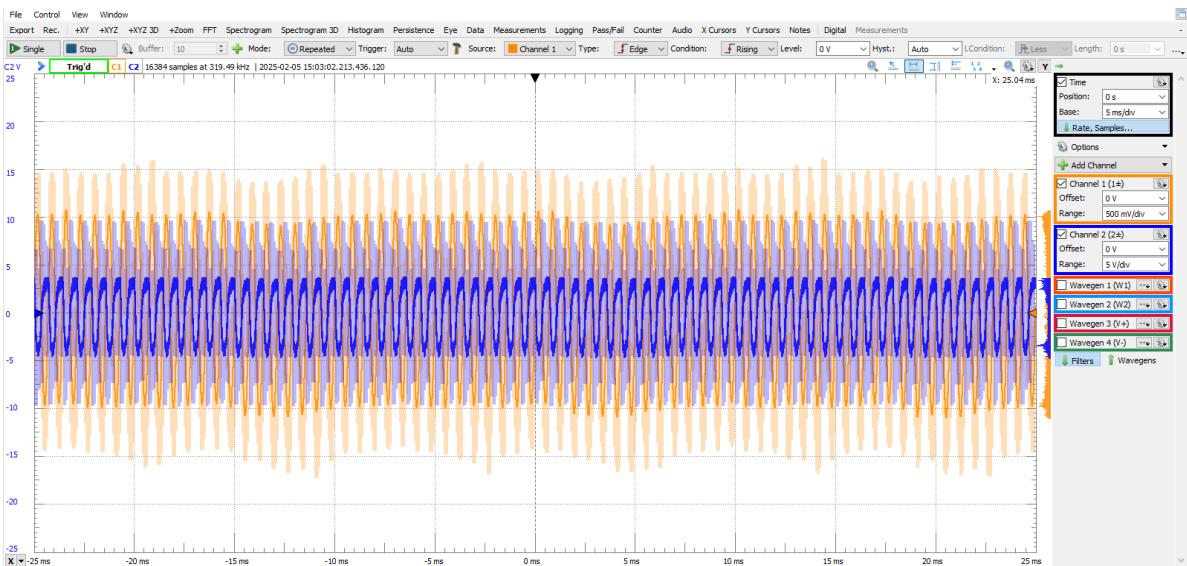
1.2kHz Spectrum



1.4kHz Without Output



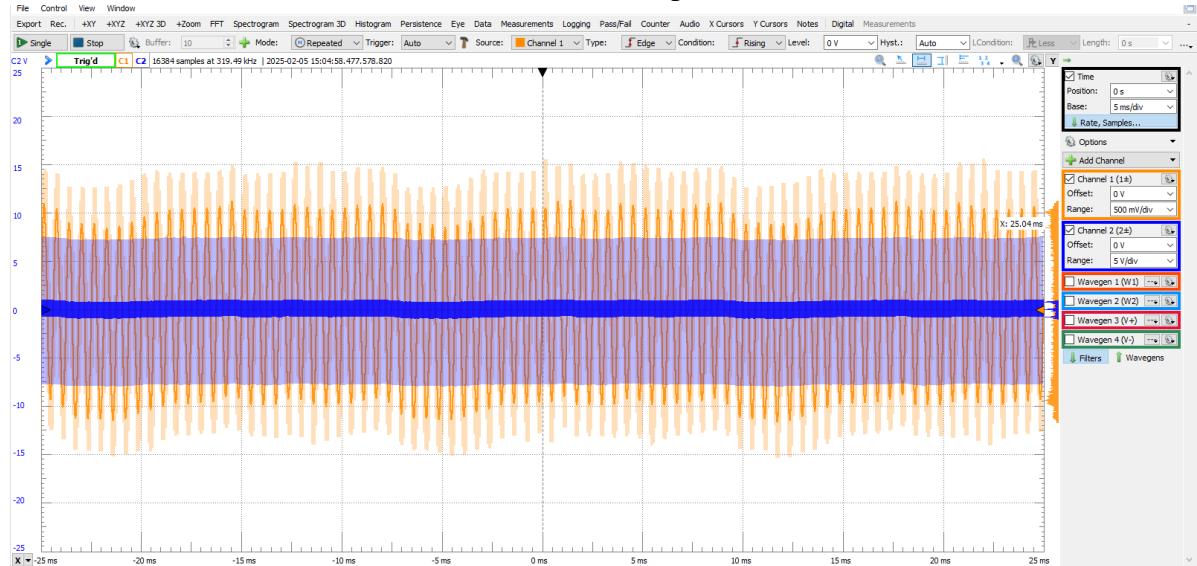
1.4kHz With Output



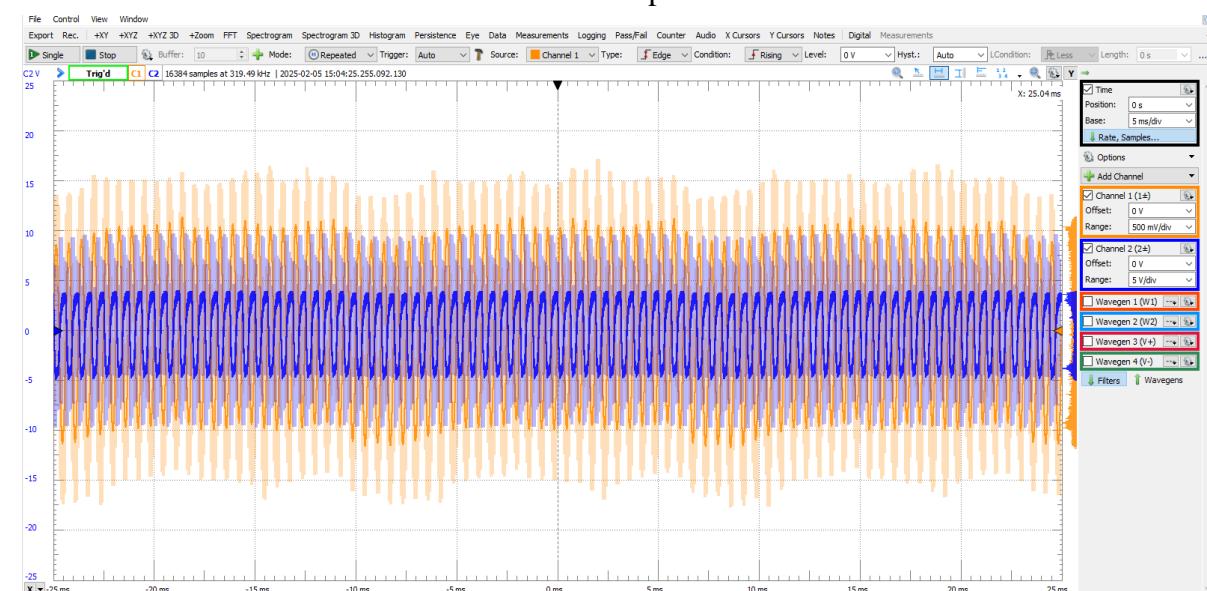
1.4kHz Spectrum



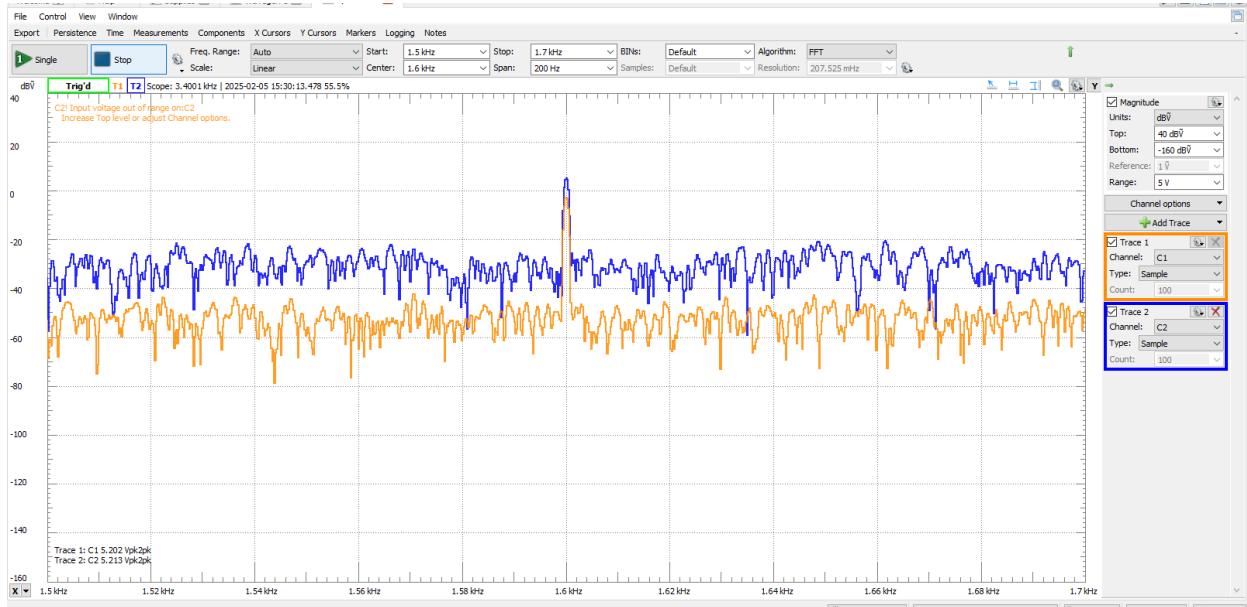
1.6kHz Without Output



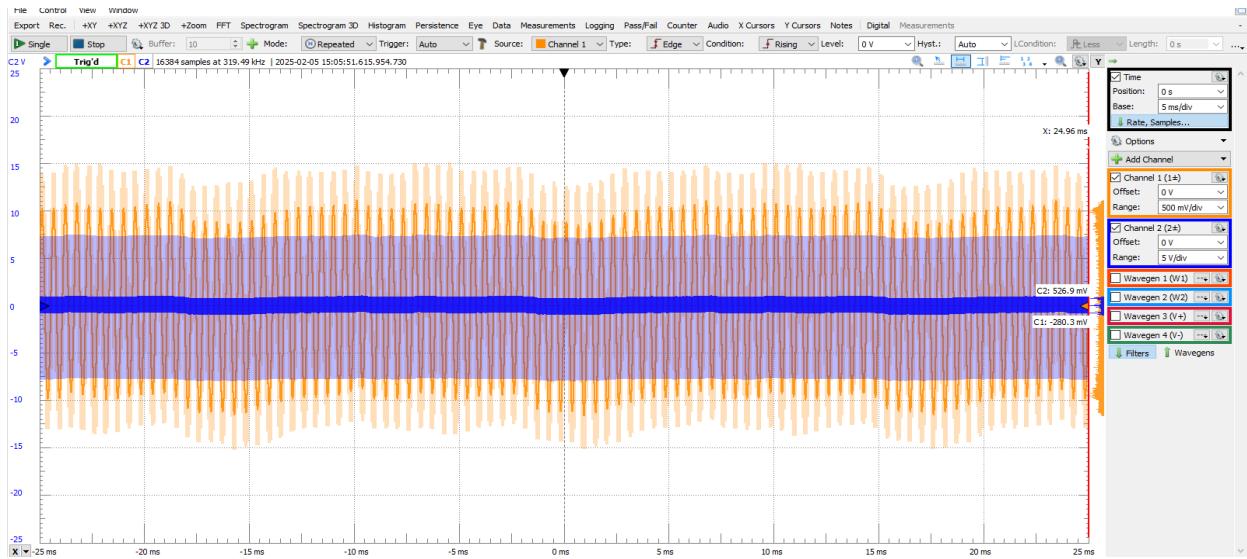
1.6kHz With Output



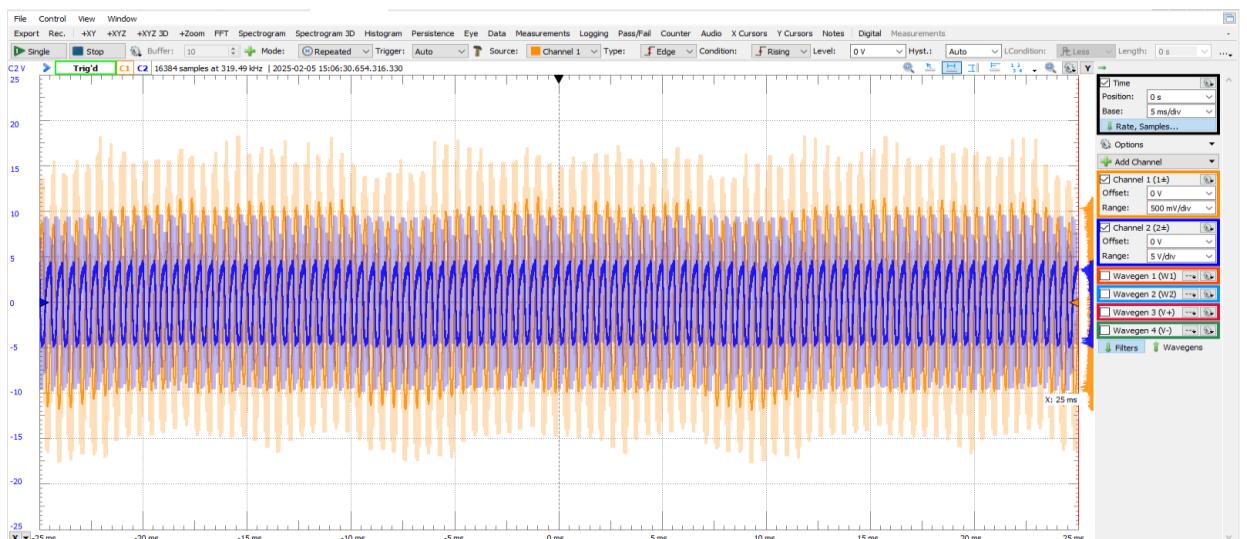
1.6kHz Spectrum



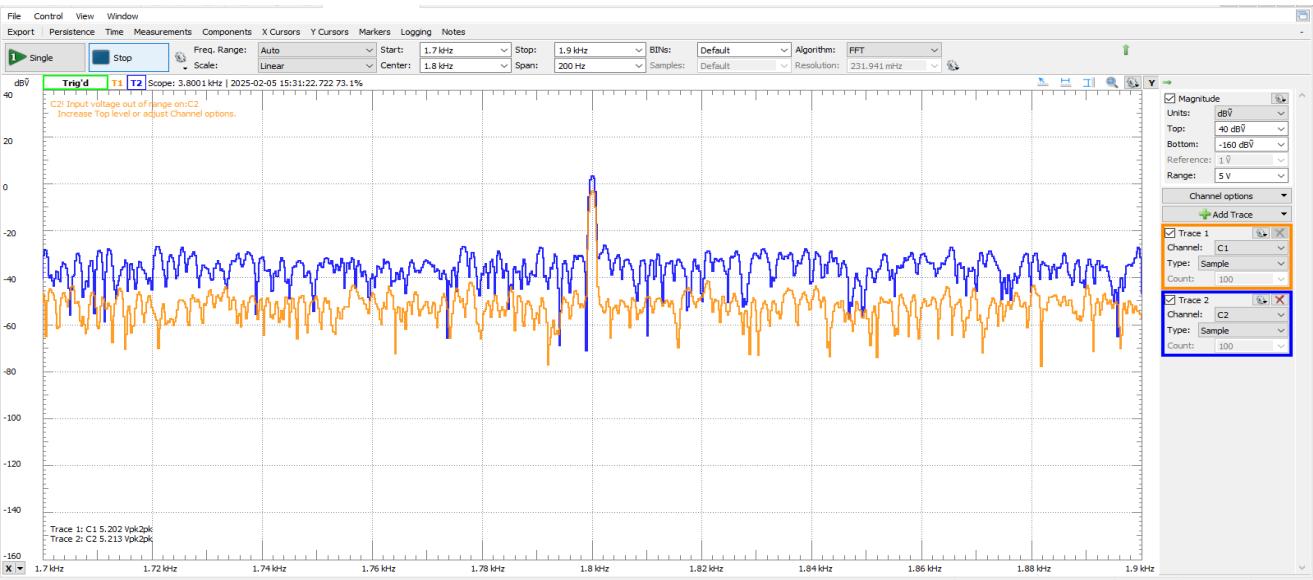
1.8kHz Without Output



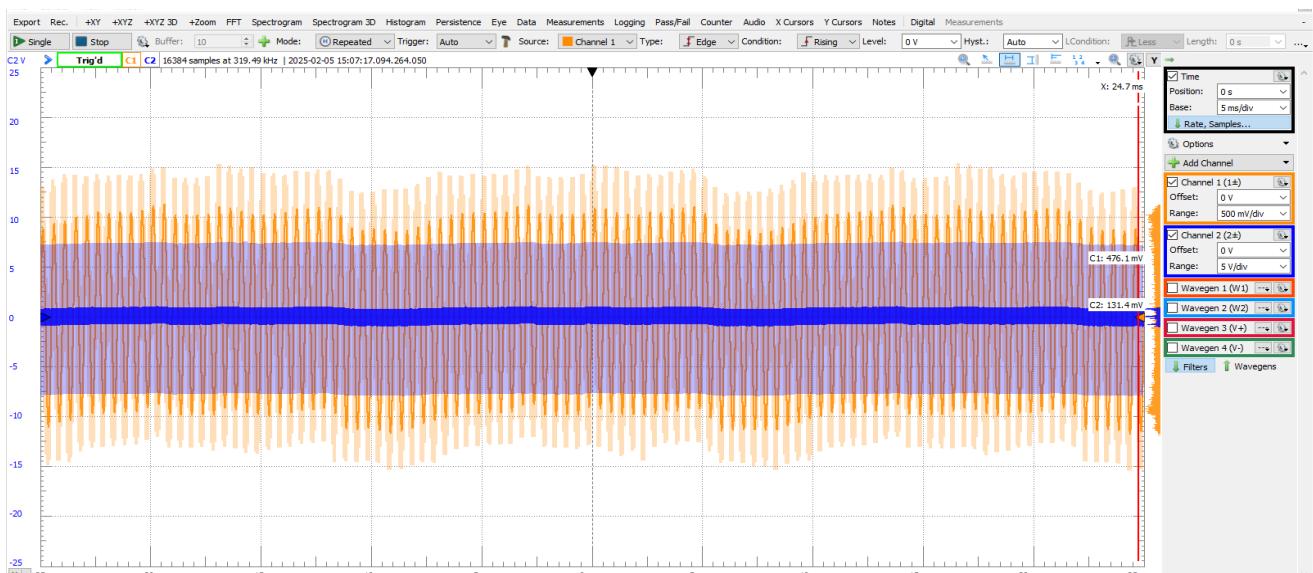
1.8kHz With Output



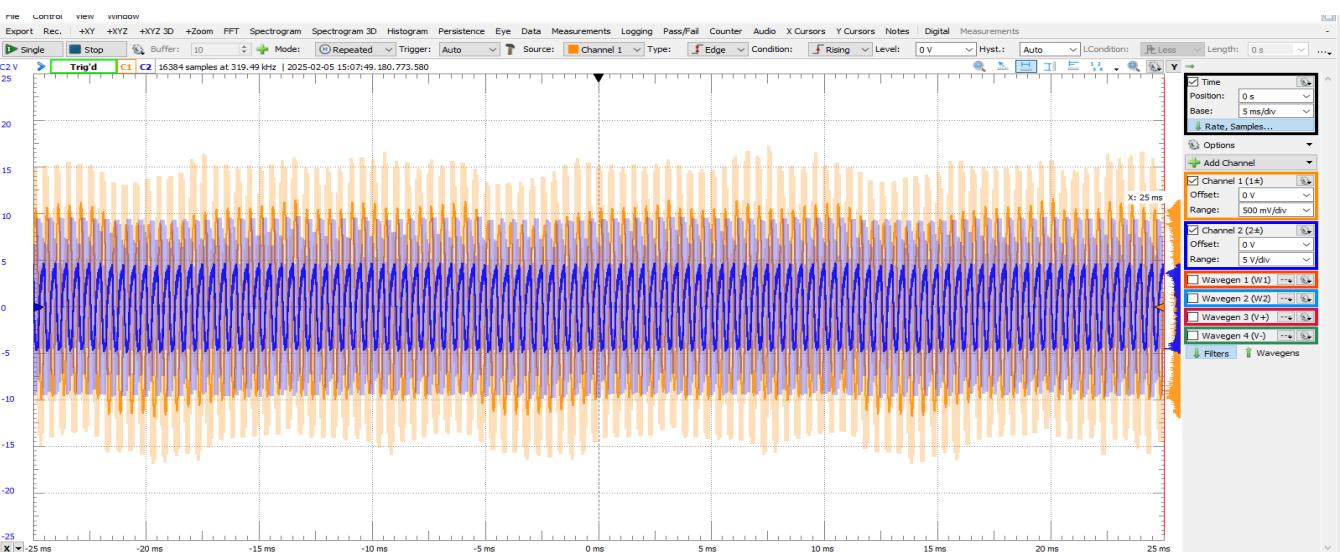
1.8kHz Spectrum



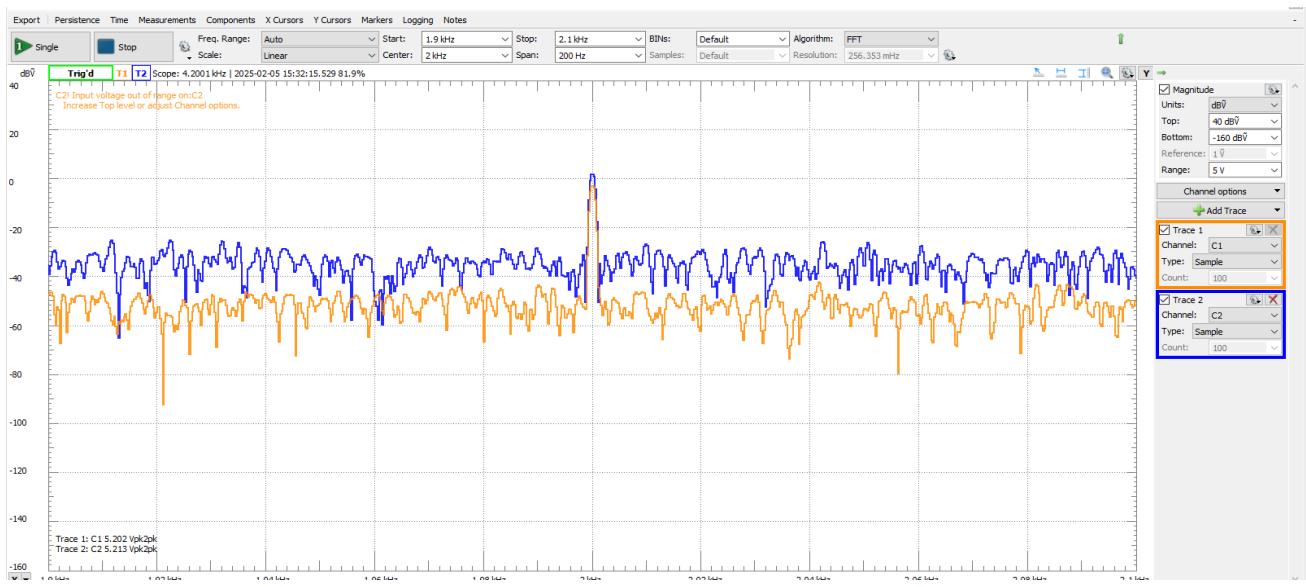
2kHz Without Output



2kHz With Output



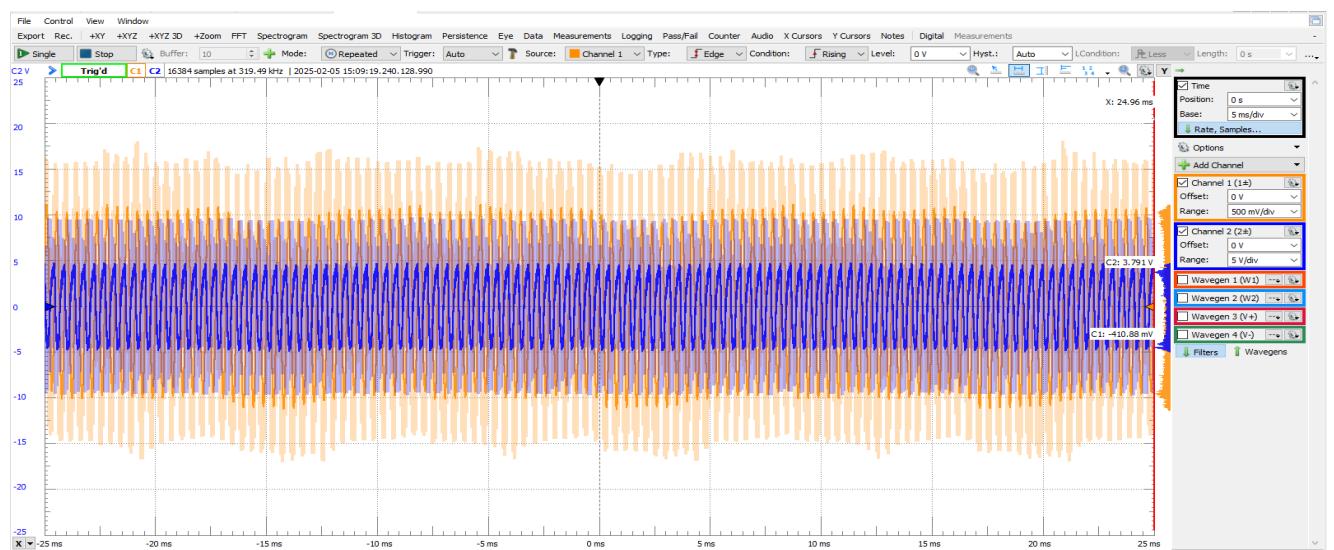
2kHz Spectrum



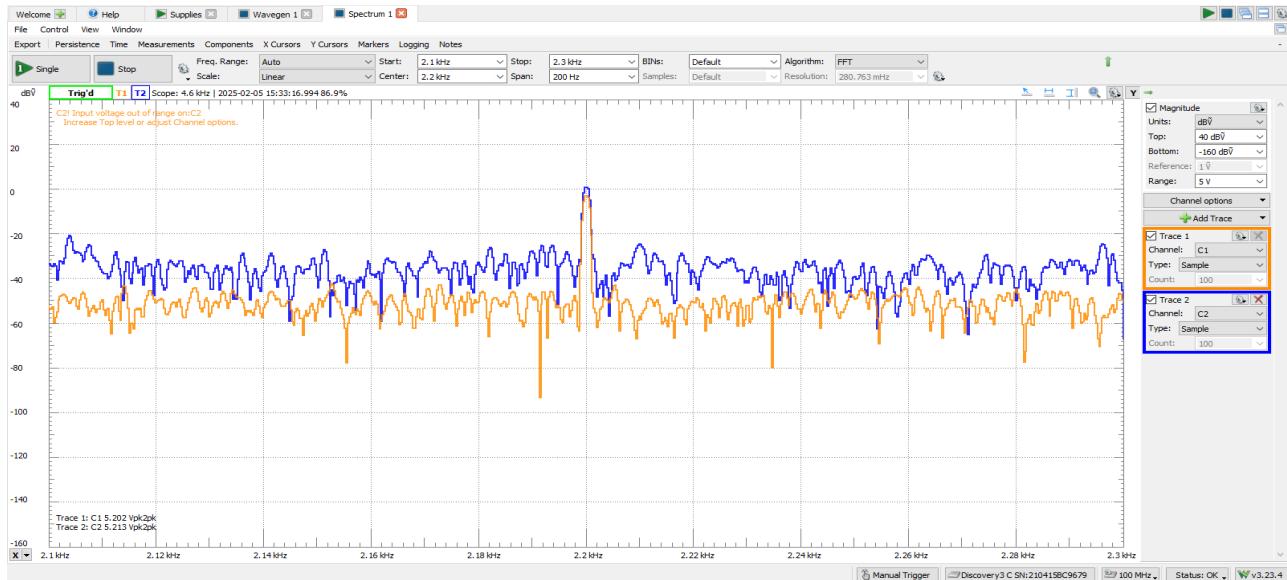
2.2kHz Without Output



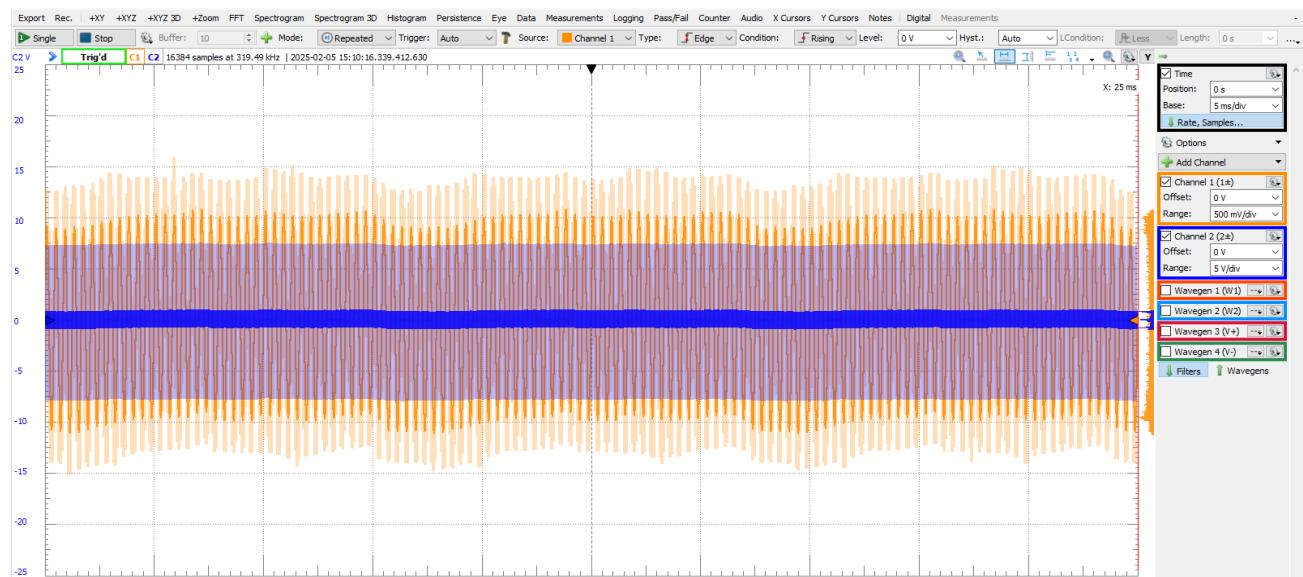
2.2kHz With Output



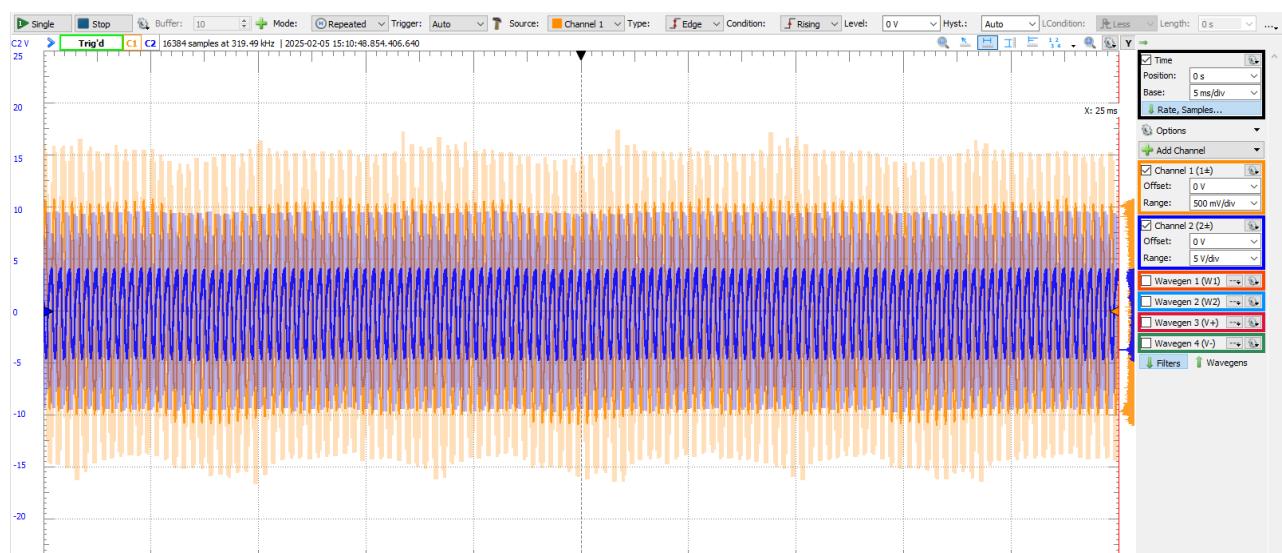
2.2kHz Spectrum



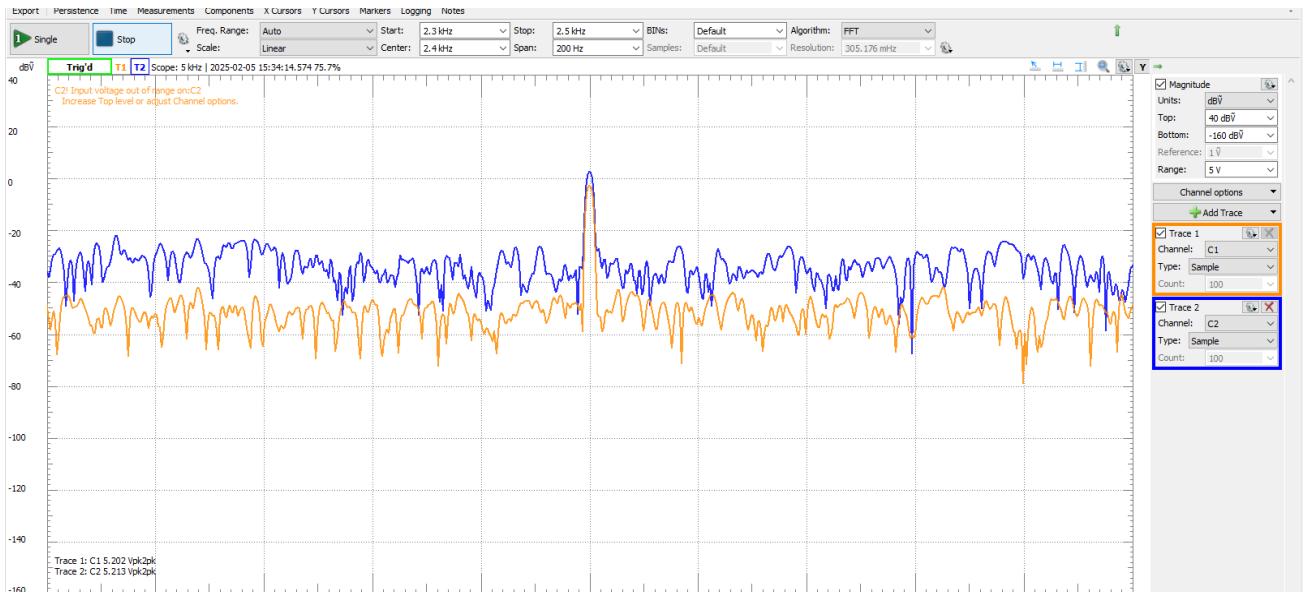
2.4kHz Without Output



2.4kHz With Output



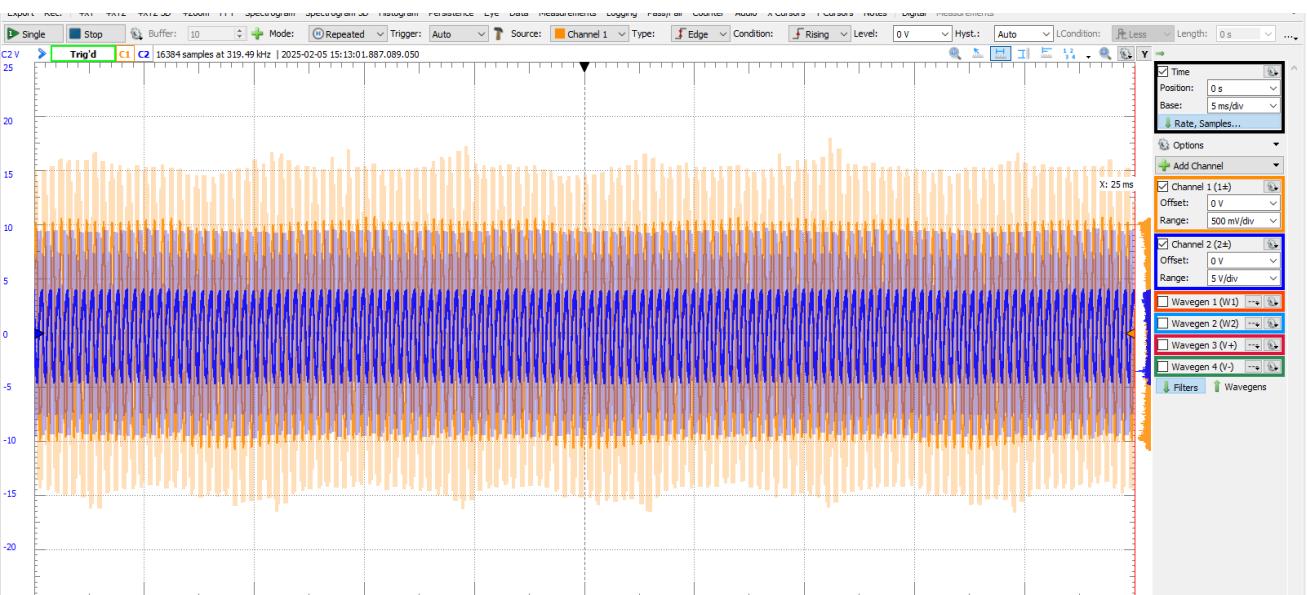
2.4kHz Spectrum



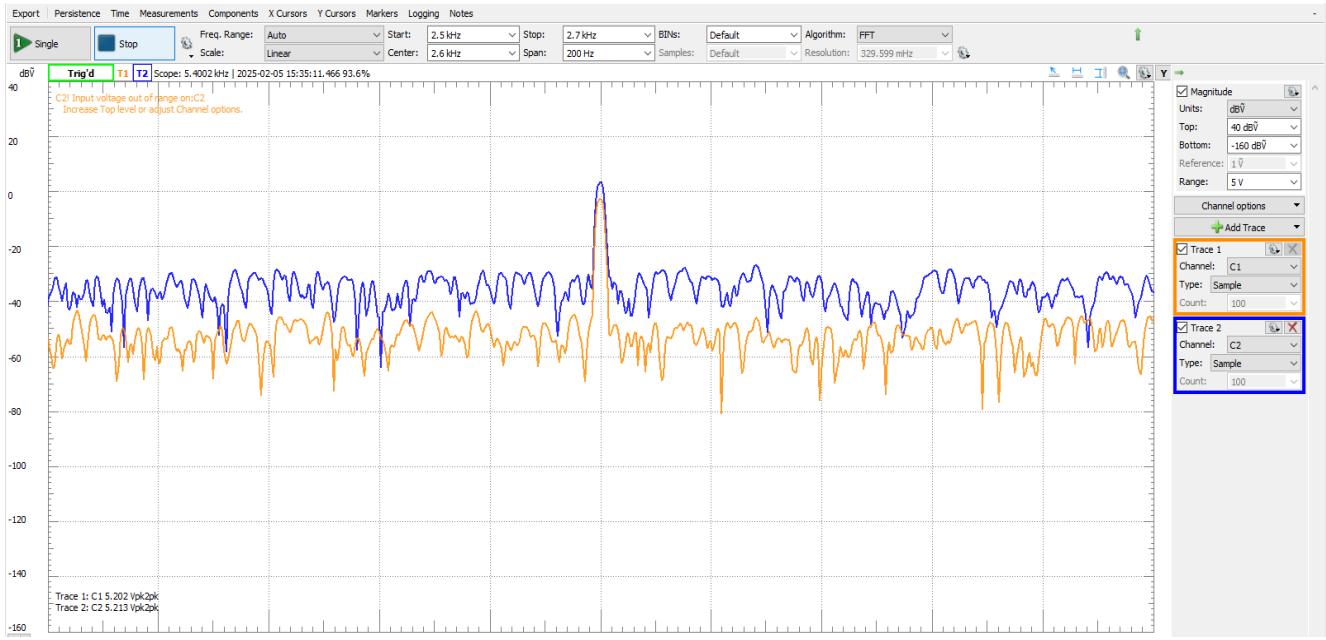
2.6kHz Without Output



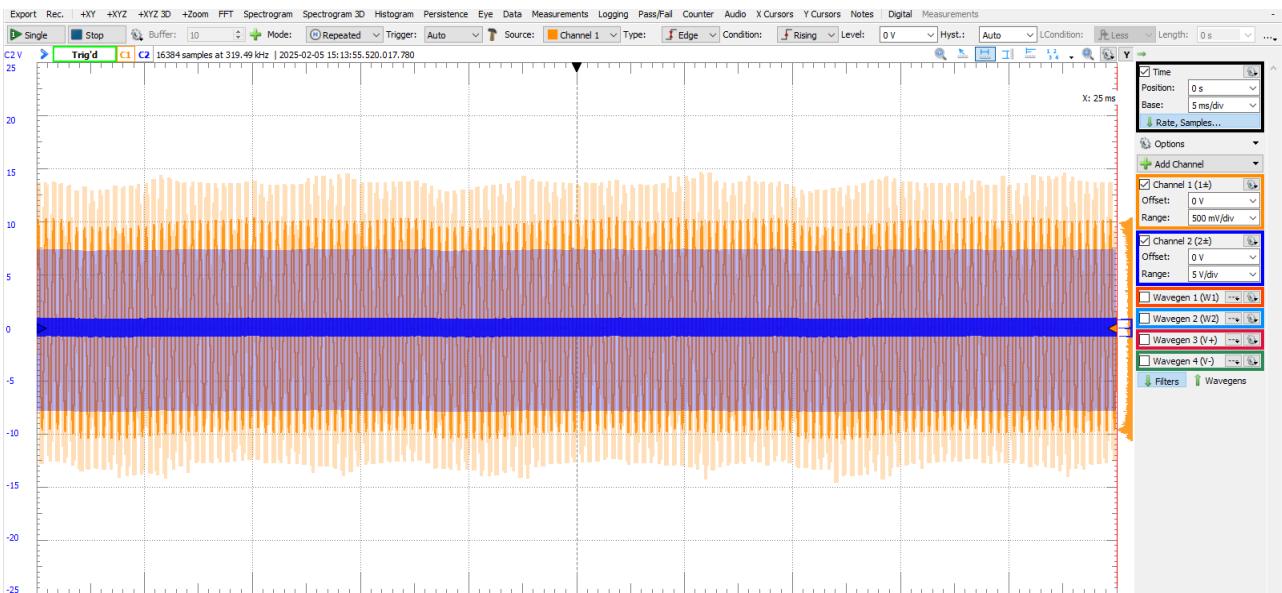
2.6kHz With Output



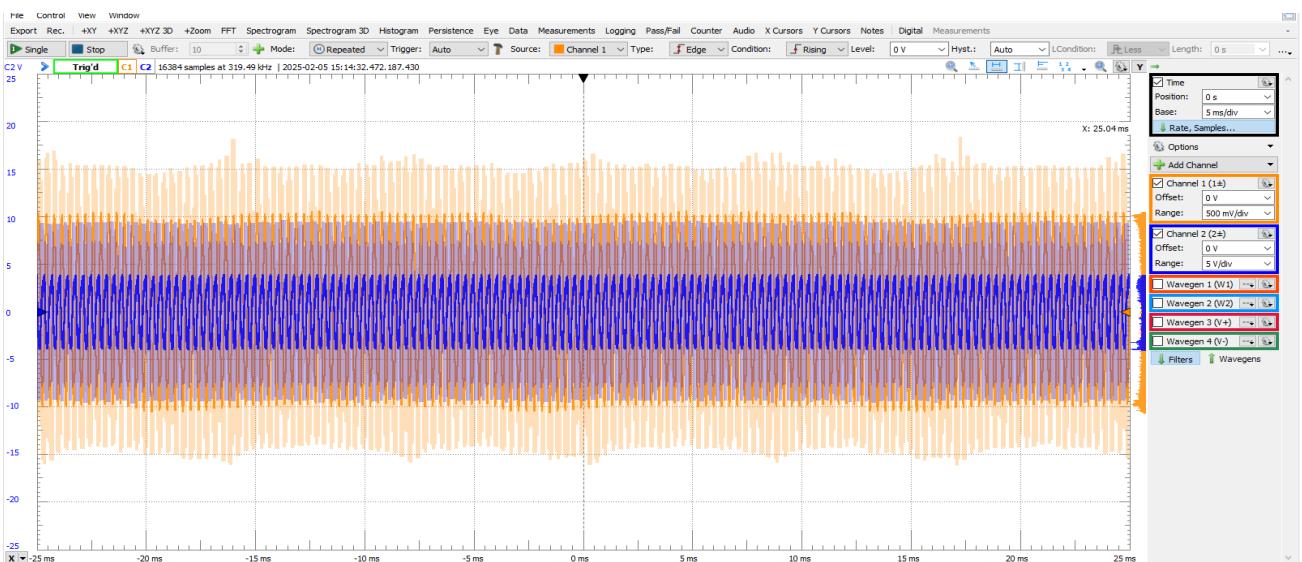
2.6kHz Spectrum



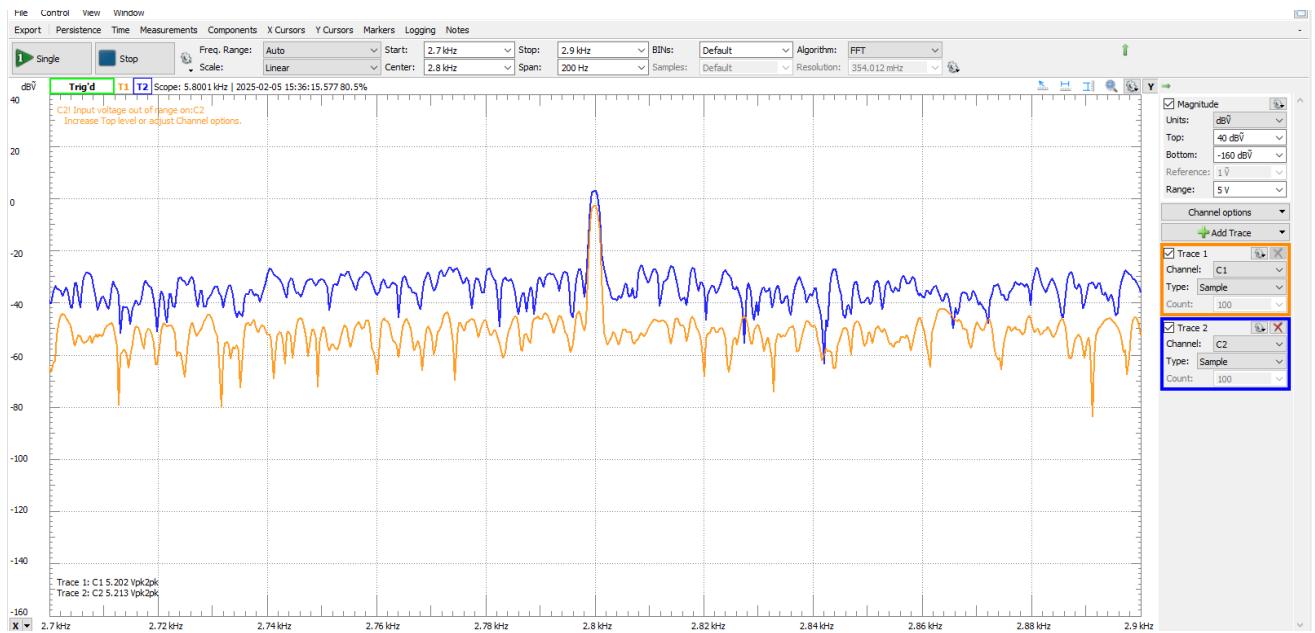
2.8kHz Without Output



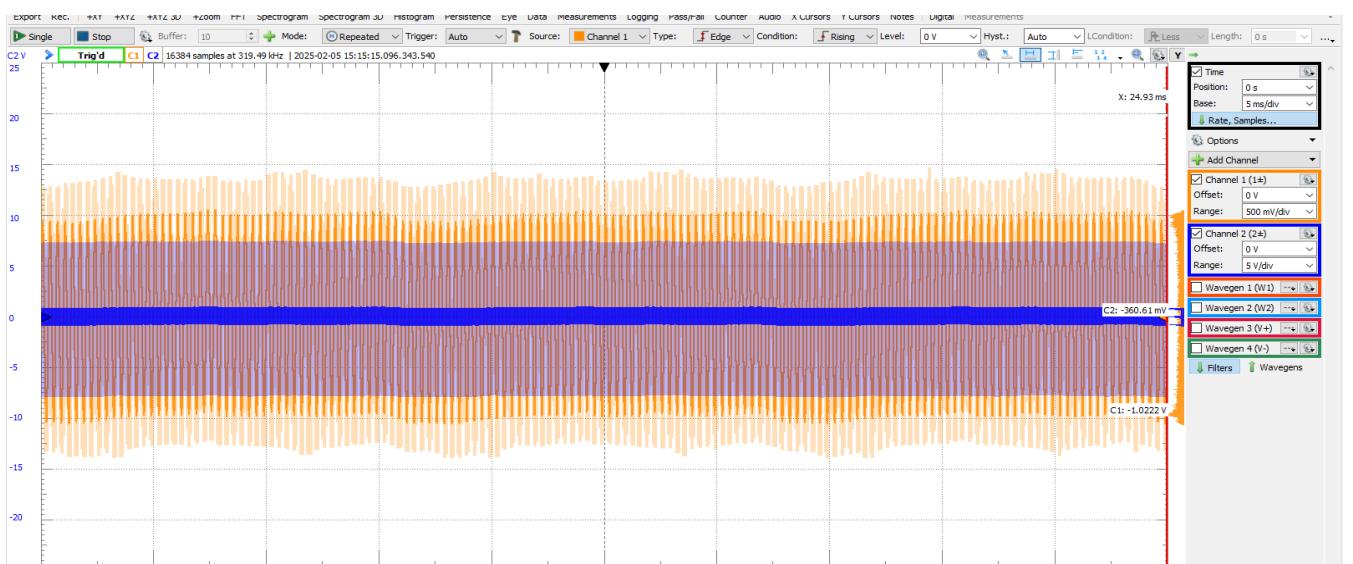
2.8kHz Without Output



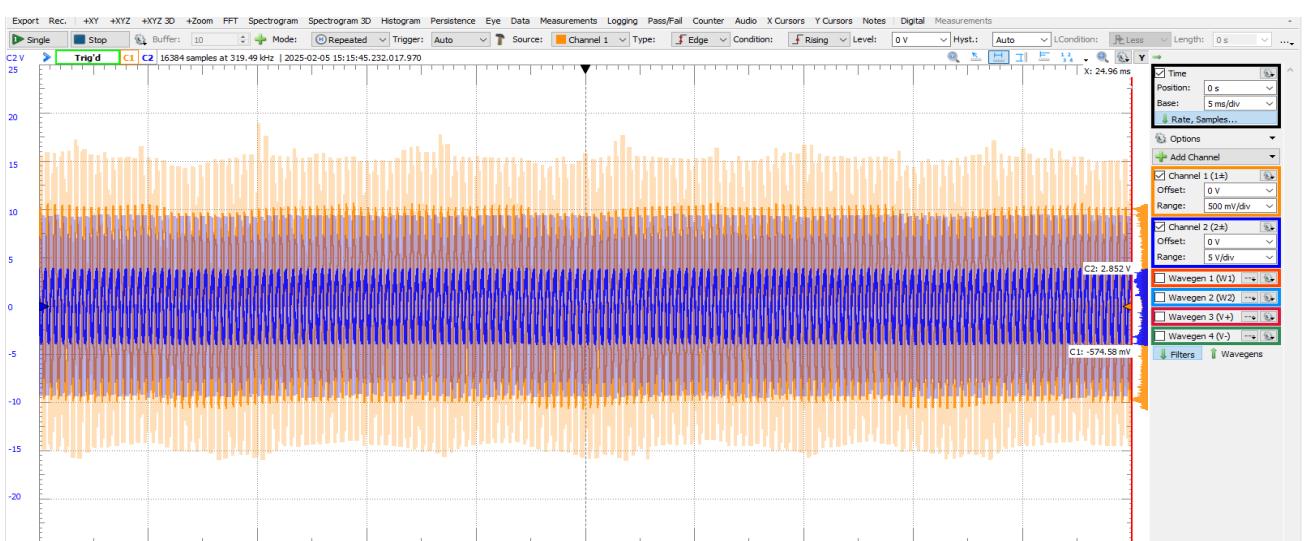
2.8kHz



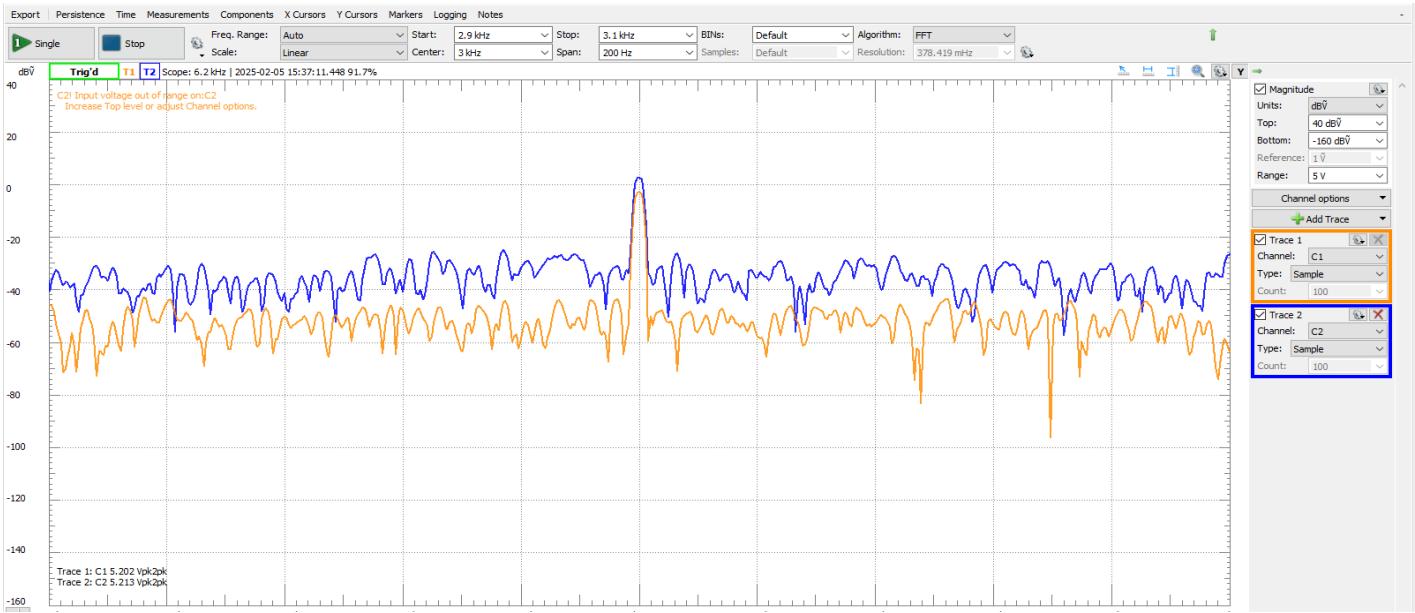
3kHz Without Output



3kHz With Output



3kHz Spectrum



200 Hz

- **Waveform Distortion:** Minimal distortion; blue and orange waveforms closely match.
- **Phase Shift:** Negligible shift observed.
- **Amplitude Comparison:** Blue waveform is nearly identical in amplitude to the orange waveform.

Spectrum Analysis: Both waveforms have strong, well-defined peaks with minimal loss of fidelity.

400 Hz

- **Waveform Distortion:** Slight smoothing of the blue waveform compared to the orange.
- **Phase Shift:** A small shift begins to appear.
- **Amplitude Comparison:** The blue waveform is slightly lower in amplitude.

Spectrum Analysis: The blue peak is still strong but shows minor weakening.

600 Hz

- **Waveform Distortion:** Some visible alterations in waveform shape.
- **Phase Shift:** Noticeable but small shift in alignment.
- **Amplitude Comparison:** The blue waveform starts to show attenuation.

Spectrum Analysis: Frequency response remains strong, but slight amplitude loss is visible.

800 Hz

- **Waveform Distortion:** More smoothing of the blue waveform; some loss of sharpness.
- **Phase Shift:** The shift increases slightly compared to 600 Hz.
- **Amplitude Comparison:** Attenuation becomes more evident.

Spectrum Analysis: The blue peak is weaker but still discernible.

1 kHz

- **Waveform Distortion:** Noticeable rounding of waveform peaks in the blue signal.
- **Phase Shift:** A visible shift is present, greater than at 800 Hz.
- **Amplitude Comparison:** Blue waveform is lower in amplitude, showing increased attenuation.

Spectrum Analysis: Signal fidelity begins to decline, with reduced peak strength.

1.2 kHz

- **Waveform Distortion:** The blue waveform has slight irregularities compared to the orange waveform, suggesting minor distortion.
- **Phase Shift:** A small but noticeable shift is observed.
- **Amplitude Comparison:** The blue waveform is slightly lower than the orange, indicating mild attenuation.

Spectrum Analysis: The blue peak is visible but slightly weaker than the orange.

1.4 kHz

- **Waveform Distortion:** More visible smoothing in the blue waveform.
- **Phase Shift:** Slightly more pronounced than at 1.2 kHz.
- **Amplitude Comparison:** Blue waveform remains slightly attenuated.

Spectrum Analysis: The frequency response remains clear but shows slight deviation.

1.6 kHz

- **Waveform Distortion:** Some jagged edges are observed in the blue waveform.
- **Phase Shift:** Noticeably increased compared to 1.4 kHz.
- **Amplitude Comparison:** The blue waveform dips further in strength.

Spectrum Analysis: Peak is present but visibly weaker.

1.8 kHz

- **Waveform Distortion:** Distortion becomes more prominent.
- **Phase Shift:** The shift continues increasing.
- **Amplitude Comparison:** Further attenuation observed.

Spectrum Analysis: Signal fidelity starts declining.

2.0 kHz

- **Waveform Distortion:** Significant waveform smoothing.
- **Phase Shift:** A larger delay between peaks is noticeable.
- **Amplitude Comparison:** Amplitude reduction becomes more obvious.

Spectrum Analysis: The frequency response starts degrading.

2.2 kHz

- **Waveform Distortion:** Increased noise-like distortions.
- **Phase Shift:** More evident shift.
- **Amplitude Comparison:** Blue waveform is consistently weaker.

Spectrum Analysis: Loss in signal strength.

2.4 kHz

- **Waveform Distortion:** Jagged edges appear more frequently.
- **Phase Shift:** Phase difference continues increasing.
- **Amplitude Comparison:** Significant attenuation.

Spectrum Analysis: Fidelity loss becomes prominent.

2.6 kHz

- **Waveform Distortion:** Blue waveform begins to deteriorate.
- **Phase Shift:** A substantial delay is observed.
- **Amplitude Comparison:** More inconsistent amplitude behavior.

Spectrum Analysis: Peak strength drops further.

2.8 kHz

- **Waveform Distortion:** Severe degradation.
- **Phase Shift:** Major time shift noticeable.
- **Amplitude Comparison:** Blue waveform struggles to maintain consistency.

Spectrum Analysis: Blue peak is significantly lower.

3kHz

- **Waveform Distortion:** Extreme distortion, waveform barely resembles original.
- **Phase Shift:** Maximum shift observed.
- **Amplitude Comparison:** Blue waveform is much weaker.

Spectrum Analysis: Transmission fidelity is severely impacted.

V. CONCLUSION

The evaluation of the wireless light-based communication system confirmed successful signal transmission within the tested frequency range of 200 Hz to 3 kHz. However, several challenges affecting fidelity were identified. Signal attenuation was observed, with the received signal consistently weaker than the transmitted one, indicating some level of signal loss. Noise interference was also present, impacting the clarity of the received waveform. Additionally, phase shifts and distortions were detected, particularly at higher frequencies, which may further degrade signal integrity.

Overall, the results show that as the frequency increases, the waveform becomes more compressed, leading to increased distortion and signal degradation. To enhance fidelity, improvements such as reducing background noise, optimizing receiver sensitivity, and addressing phase delays should be considered. While the system effectively transmits signals within the given frequency range, refinements are necessary to ensure more reliable and accurate data transmission.