Lab 1 Report

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***Abstract*—In this lab, we constructed a basic radar system capable of processing signals at low frequencies, as illustrated in Figure 1. The system employs a microprocessor and a digital-to-analog converter (DAC) to generate a triangular wave, which is subsequently low-pass filtered. The experiment consists of four primary modules: a power supply/voltage regulator module, a precision voltage reference module, a function generator module, and an active low-pass filter module. After successfully building and testing each module, we will integrate them in Part 5 for comprehensive testing.The experiment is mainly divided into four modules to build, including Power supply/voltage regulator module, Precision voltage reference module, Function generator module and Active low-pass filter module. After each module is built and tested correctly, in the part 5, all the modules are connected for testing.**

Keywords*—*component, formatting, style, styling, insert* (*key words)

I. Power Supply/Voltage Regulator

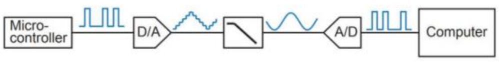


Fig. 1. Lab 1 electronic system.

A. Using Fig. 2 as a reference, build the regulator circuit on the breadboard (Fig. 3).

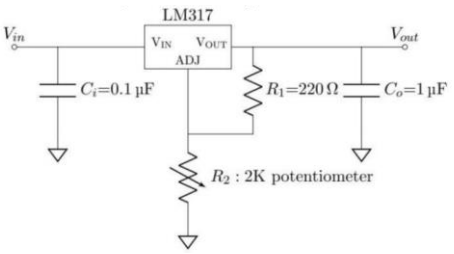


Fig. 2. Schematic of the voltage regulator circuit using LM317.

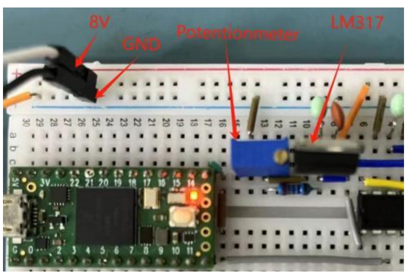


Fig. 3. Breadboard layout of the circuit in Fig. 2.

B. Set the power supply voltage to 8 V and connect it to the input of the voltage regulator circuit. Then adjust the R2 potentiometer to achieve an output voltage of 5 V.

Fig. 4. The 5V output voltage displayed by the WaveForms.

C. Vary the input voltage from 8 V to 5 V in 0.25 V increments, then adjust from 5 V to 2 V in 0.5 V increments. Use a multimeter to record the output voltage of the regulator at each interval.

TABLE I. From 8 V to 5 V at 0.25 V Intervals

Input voltage(V)	**8.0**	**7.7**	**7.5**	**7.2**	**7.0**	**6.8**	**6.6**
Regulator output voltage(V)	5.004	5.003	5.003	5.003	5.004	5.003	5.001
Input voltage(V)	**6.3**	**6.0**	**5.8**	**5.5**	**5.3**	**5.0**	
Regulator output voltage(V)	4.81	4.46	4.287	3.987	3.73	3.65	

TABLE II. From 5 V to 2 V at 0.5 V Intervals

Input voltage(V)	**5.0**	**4.5**	**4.0**	**3.5**	**3.0**	**2.5**	**2.0**
Regulator output voltage(V)	3.44	2.952	2.554	2.005	1.568	1.103	0.752

D. Plot your results. In what input voltage range does the LM317 provide good line regulation?

As can be seen from Figure 5, the input voltage rom 5 V to 2 V provides good line regulation.

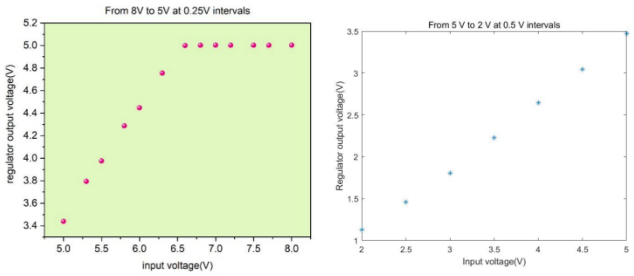


Fig. 5. The regulator output voltage as a function of the input voltage.

II. Precision Voltage Reference

A. Build circuit shown in Fig. 6 on the breadboard (Fig. 7)

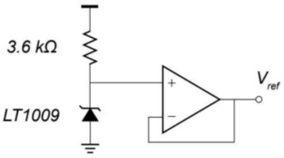


Fig. 6. Schematic of the LT1009 precision voltage reference circuit.

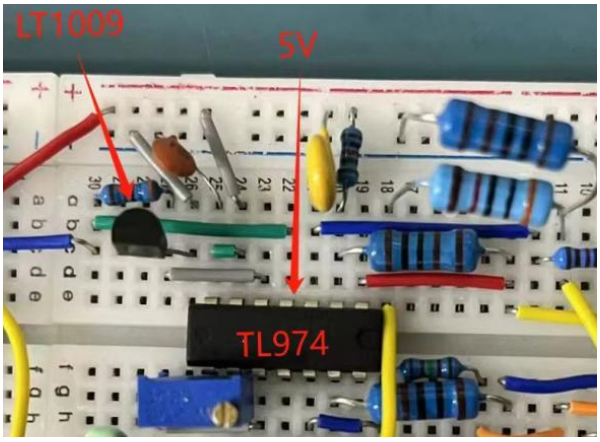


Fig. 7. Breadboard layout of the circuit in Fig. 6.

B. Verify that the output voltage of the circuit is 2.5 V.

Fig. 8. The 2.5V output voltage displayed by the WaveForms.

III. Function Generator

A. Using Fig. 9 as a reference, connect the Teensy to the MCP4921 DAC (Figure 10).

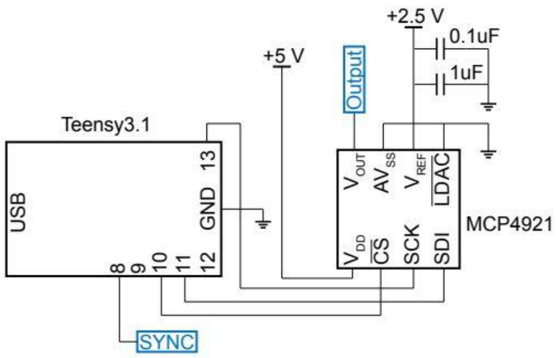


Fig. 9. Schematic of the connection between the Teensy and the MCP4921.

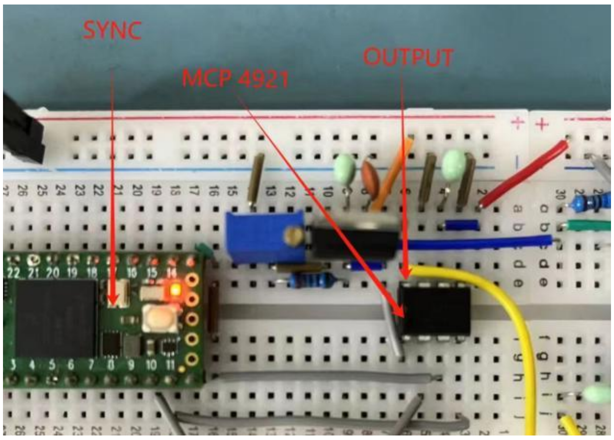


Fig. 10. Breadboard layout of the circuit in Fig. 8.

B. Compile and upload the code "Triangle Teensy McP4921.ino" to Teensy.

C. Equations

Use the Analog Discovery as an oscilloscope. Figure 11 shows the screen capture of both the triangle (at VOUT) and sync (at SYNC) output signals. The generated triangular wave period is 410.55Hz with an amplitude of 1.25V.

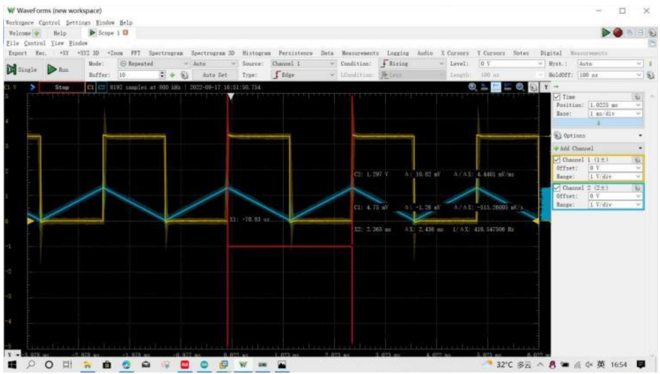


Fig. 11. The triangle (at VOUT) and sync (at SYNC) output signals image in oscilloscope.

D. Change the gain setting of MCP4921 in the code (one gain changed to double gain) so that the triangular wave amplitude becomes 2.5V. Figure 12 shows the screen capture of both the triangle (at VOUT) and sync (at SYNC) output signals. The generated triangular wave period is 208.89Hz with an amplitude of 2.5V

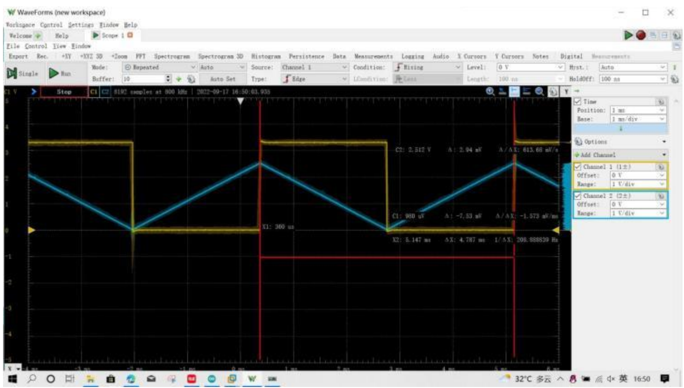


Fig. 12. The modified triangle (at VOUT) and sync (at SYNC) output signals image in oscilloscope.

E. How can you modify the code to change the amplitude and period of the output waveform? What is the fastest triangle wave you could generate? What do you think is the limitation to going even faster?

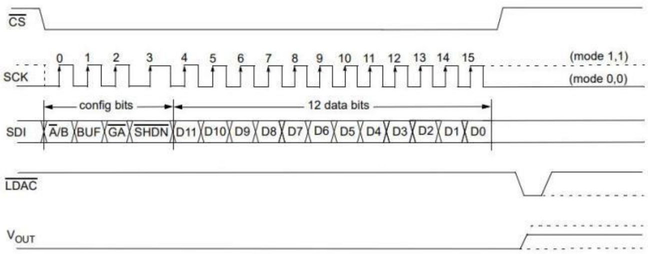
Modifying the code Line1 and Line2 (Figure 13) can change the amplitude and period of the output waveform.

```
void loop()
{
1   if (outputValue >= 4088 || outputValue <= 0){
      incr = -incr;
      digitalWrite(SYNC, !digitalRead(SYNC));
    }

    outputValue = outputValue + incr;

    byte HighByte =highByte(outputValue);    // Take the upper byte
    HighByte = 0b00001111 & HighByte;       // Shift in the four upper bits (12 bit total)
2   HighByte = 0b00110000 | HighByte;       // Keep the Gain at 1 and the Shutdown(active low) pin off
    byte LowByte = lowByte(outputValue);    // Shift in the 8 lower bits

    digitalWrite(slaveSelectPin, LOW);
    SPI.transfer(HighByte);             // Send the upper byte
    SPI.transfer(LowByte);              // Send the lower byte
    digitalWrite(slaveSelectPin, HIGH);        // Turn off the SPI transmission
}
```

Fig. 13. Part of the code used to modify the amplitude and frequency of the triangular wave.

For Line 1, adjusting the second value of "outputValue" simultaneously alters the amplitude and period of the output waveform. When this value is around 2022, the output waveform will have an amplitude and period of 2.5 V.

For Line 2, the meaning of each bit can be referenced from the MCP4921 data sheet, particularly Figure 14. Changing the third value in "HighByte" from 0 to 1 affects only the amplitude of the output waveform, reducing the gain from 2 to 1.



bit 15 **A/B:** DAC_A or DAC_B Select bit
1 = Write to DAC_B
0 = Write to DAC_A

bit 14 **BUF:** V_{REF} Input Buffer Control bit
1 = Buffered
0 = Unbuffered

bit 13 **GA:** Output Gain Select bit
1 = 1x ($V_{OUT} = V_{REF} * D/4096$)
0 = 2x ($V_{OUT} = 2 * V_{REF} * D/4096$)

bit 12 **SHDN:** Output Power Down Control bit
1 = Output Power Down Control bit
0 = Output buffer disabled, Output is high impedance

bit 11-0 **D11:D0:** DAC Data bits
12 bit number "D" which sets the output value. Contains a value between 0 and 4095.

Fig. 14. Data sheet for MCP4921.

IV. Active Low-Pass Filter

In this section of the lab, we will implement an active low-pass filter (LPF) with adjustable gain. Figure 15 illustrates the schematic of the active LPF circuit, which comprises three operational amplifiers. The first op-amp is used for amplification, while the second and third op-amps function as filters.

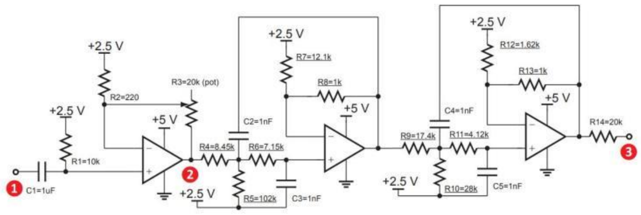


Fig. 15. Schematic of the active low-pass filter.

A. Gain stage

(1) Gain expression

Identify the gain stage between point 1 and point 2 in Fig. 15. Based on the properties of the ideal integrated op-amp, specifically the "False Short Circuit" and "False Open Circuit" principles, the gain expression can be calculated as follows:

$$A_v = \frac{R_2 + R_3}{R_2}$$

(2) Circuit construction

Build the gain stage and double-check before applying power to the circuit to avoid destroying the TL974 Op-Amp.

(3) Test

a. Generate a 1 kHz sine wave signal with a peak-to-peak voltage of 100 mV and connect it to the input of the gain stage circuit. As shown in Figure 16, the output exhibits distortion, with the maximum peak-to-peak value reaching 5 V before clipping occurs. At this point, the gain is 50.

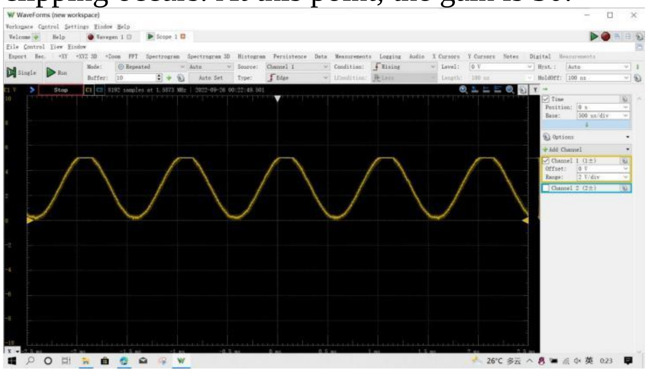


Fig. 16 Output waveform displayed by WaveForms when clipping occurs.

b. With the input signal maintained at 100 mVpp, adjust the potentiometer to achieve an output voltage swing of 3 Vpp, resulting in a gain of 30. Vary the input signal frequency from 100 Hz to 1 MHz. Figure 17 illustrates the gain versus frequency, indicating that the 3 dB cutoff frequency is approximately 350 kHz. The gain-bandwidth product of the gain stage can be calculated accordingly.

$$GBW = A \times BW = 30 \times 350kHz = 10.5MHz$$

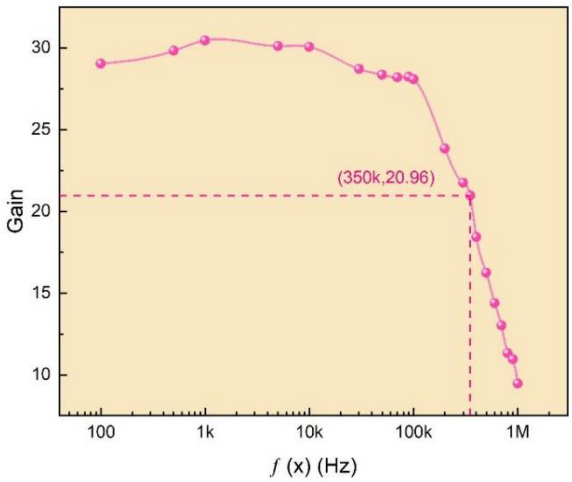


Fig. 17 Gain as a function of frequencyc.

B. Active LPF

(1) Circuit construction

The active low-pass filter (LPF) section of the circuit is located between points 2 and 3 in Figure 15. The overall filter comprises two low-pass filters. In schematic A, the second op-amp from the left serves as the first stage filter, while the third op-amp acts as the second stage filter. Proceed to build the LPF circuit on the breadboard.

(2) Test

Input a 3 Vpp signal through a series 1 μF capacitor at point 2 in Figure A and measure the output. Figure 18 illustrates the frequency response of the low-pass filter from 100 Hz to 150 kHz. Measurement data indicates that the cutoff frequency of the filter is 15 kHz.

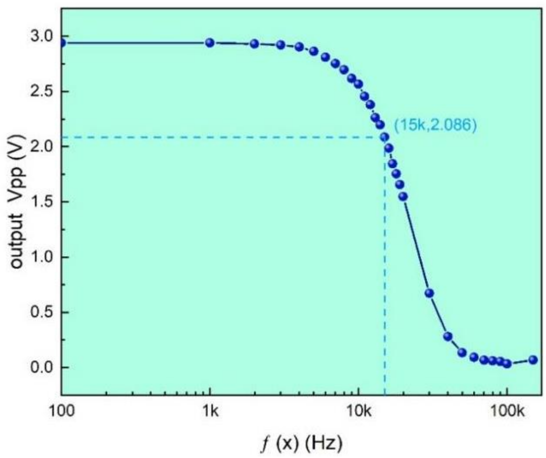


Fig. 18 LPF output Vpp as a function of frequency.

The cutoff frequency of the overall filter is determined by the main poles of the two op-amp filters. When the primary pole decreases, the cutoff frequency also decreases, while an increase in the primary pole leads to a higher cutoff frequency. For instance, the cutoff frequency can be lowered by increasing the resistance (R) or capacitance (C) of components C2 and C4, thereby reducing the primary pole.

C. Gain Stage + Filter

(1) Circuit construction

Connect the gain stage and the low-pass filter circuit.

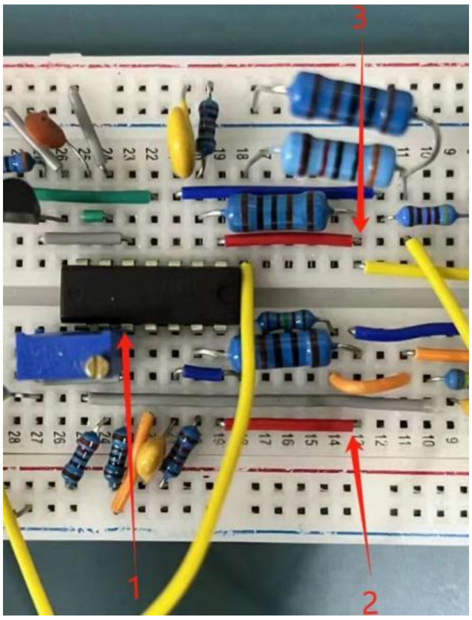


Fig. 19 Breadboard layout of the circuit in Fig. 15.

(2) Test

The cutoff frequency of the overall filter is determined by the main poles of the two op-amp filters. When the primary pole decreases, the cutoff frequency also decreases, while an increase in the primary pole leads to a higher cutoff frequency. For instance, the cutoff frequency can be lowered by increasing the resistance (R) or capacitance (C) of components C2 and C4, thereby reducing the primary pole.

The cutoff frequency of the overall filter remains largely unchanged compared to the frequency response of a circuit featuring only a filter. However, the output voltage gain is increased by a factor of 30 due to the addition of the gain stage.

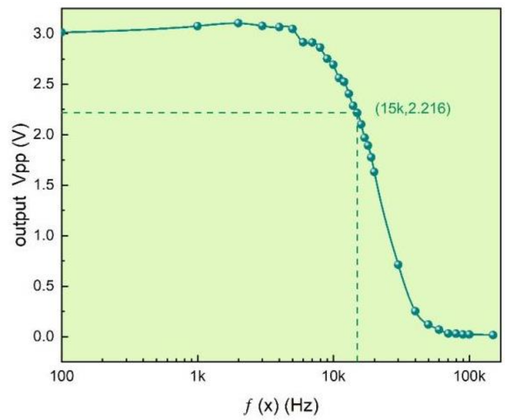


Fig. 20 Overall LPF output Vpp as a function of frequency.

V. ACTIVE LOW-PASS FILTER

A. Set up the system according to Fig. 21.

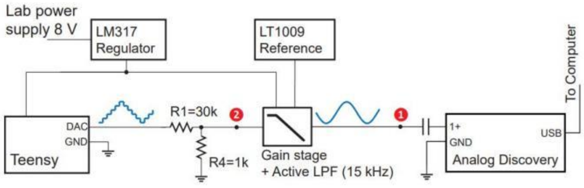


Fig. 21 Acquiring signal through Analog Discovery.

B. Import the code to generate the triangle wave in Teensy. Open the WaveForms software for display. Figure 22 and Figure 23 display the measured signal.

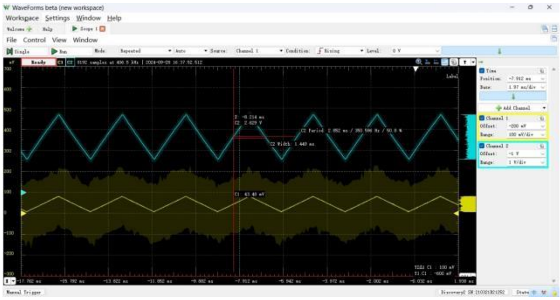


Fig. 22 Using the Analog Discovery as an oscilloscope. Shown in the measurement is a 344.03Hz triangle wave.

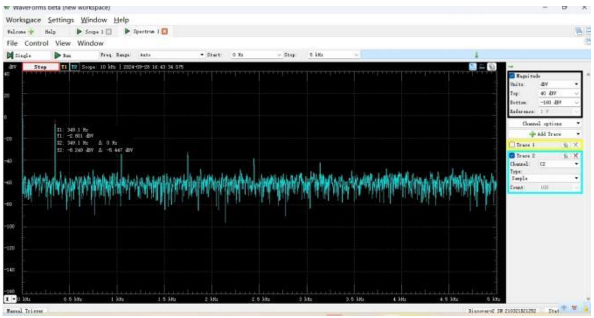


Fig. 23 Using the Analog Discovery as a spectrum analyzer. Shown in the measurement is the frequency spectrum of the 344.03Hz triangle wave.

C. Measure the frequency and time domain waveforms at points 1 and 2.

(1) At point 1

The time domain output waveform at point 1 is a triangle wave with a 2.5V offset.

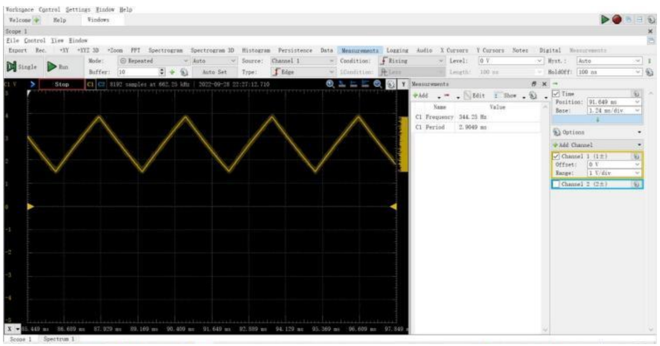


Fig. 24 Shown in the measurement is a 344.25Hz triangle wave.

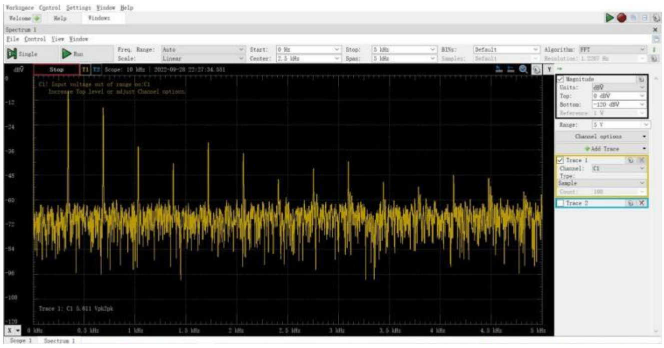


Fig. 25 Shown in the measurement is the frequency spectrum of the 344.25Hz triangle wave.

(2) At point 2

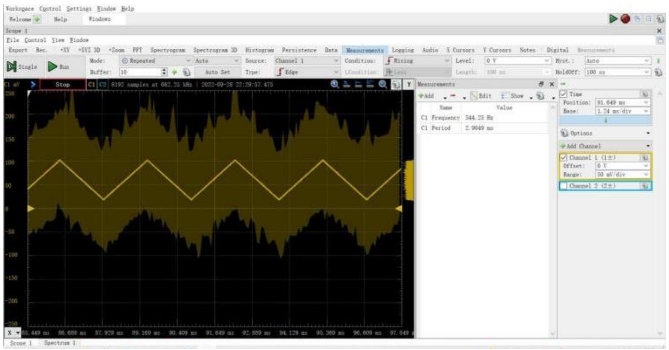


Fig. 26 Shown in the measurement is a 344.25Hz triangle wave.

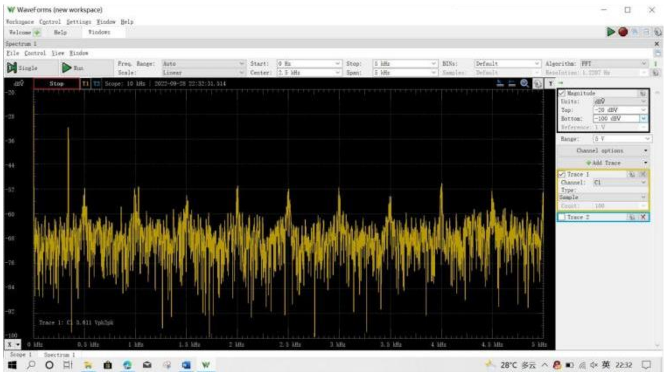


Fig. 27 Shown in the measurement is the frequency spectrum of the 344.25Hz triangle wave

CONCLUSION

In this lab, we explored the fundamental components of a typical electronic system by constructing a simple radar system. We learned to utilize a basic microprocessor and gained insights into the functions and applications of modules such as linear regulators and ADCs/DACs. This hands-on experience enhanced our practical skills in troubleshooting and problem-solving.

Building the layout on the breadboard took considerable time. When assembling a circuit on a breadboard, careful consideration of the arrangement of each electronic component is essential. A neat layout not only improves the circuit's appearance but also facilitates easier testing and troubleshooting.