Lab 04: Generating and Measuring Sinusoidal Signals: A Sound System

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Contents

1 Abstract

Building off from the introduction of the Operational Amplifier, this weeks experimental work introduces a practical perspective on the utilization of the chip: An Audio Amplifier. High quality audio systems are almost synonymous with high quality electrical engineering design, which is to say that designing and creating an electrical system which can take a signal and amplify it through several stages and produce an output which is not distorted, but also clear enough to be understood and interpreted on a wide spectrum of uses is difficult. This experiment work introduces a simple way to accomplish this through the use of rudimentary speakers and microphones, as well as the operational amplifier circuit. It also serves as an introduction to utilizing oscilloscopes for signal analysis and troubleshooting.

2 Introduction

The heartbeat of a discrete signal is its ability to be interpreted through different domains of which the time domain is the most easily understood by humans. The human interprets time well and is able to define lengths of data quite well in this domain, for example how long a piece of music lasts, or a film on the big screen. We measure and base our experiences off this, and with rudimentary time measuring devices some of the most important discoveries in science have been made, propelling us to the modern understanding of the world around use today.

In order to interpret these signals in an electrical circuit, oscilloscopes have been developed to be able to display waveforms depending on the target signals we wish to obtain. Varying signals such as an AC voltage, a response to a digital circuit, or the multiplexed analog signal of hundreds of signals can be read and interpreted using these scopes which allow for the further troubleshooting of electrical circuits.

This experimental work starts out straight forward with realizing what has only been seen in schematics thus far, the ideal current source, which on paper supplies a constant current without changing other physical values of the circuit. In order to achieve this, two abstract switches in the form of P-Type and N-Type MOSFETs are utilized in conjunction with an operational amplifier at the output in order to create a circuit called a ”push-pull” amplifier. The details of the MOSFET are kept ambiguous at this stage, and thus will not be covered in this report. The other sections of the experiment however has a rudimentary audio amplifier get realized which can be used as a loud speaker.

3 Theory

3.1 The Signal Generator

The ADALM2000 device has many applications, several of which have been explored in this experimental work. One of its key features is the signal generator, which allows for the creation of various waveforms. In this experiment, a mixture of signals is generated, specifically the sine wave, square wave, and triangle wave. These waveforms serve distinct purposes in electronics and signal processing, and their characteristics significantly influence the behavior of connected circuits.

3.1.1 The Sine Wave

A sine wave is a smooth, continuous waveform that represents a pure frequency with no harmonics. Mathematically, it is described by the function:

$$v(t) = A\sin(2\pi ft + \phi) \tag{1}$$

where A is the amplitude, f is the frequency in hertz, t is time, and ϕ is the phase shift. Sine waves are fundamental in audio signal processing, telecommunications, and AC circuit analysis.

In this experiment, sine waves are used to test audio equipment, specifically an electret condenser microphone and an 8W speaker. The smooth nature of the waveform ensures that only a single frequency component is being tested at a time, making it ideal for assessing the frequency response of the system.

3.1.2 The Square Wave

A square wave is a non-sinusoidal waveform that alternates between two distinct voltage levels with instantaneous transitions. It is mathematically represented as:

$$v(t) = \begin{cases} A, & 0 \leq t < \frac{1}{2f} \\ -A, & \frac{1}{2f} \leq t < \frac{1}{f} \end{cases} \tag{2}$$

where A is the peak amplitude and f is the frequency. Square waves contain a fundamental frequency and an infinite series of odd harmonics, making them useful for testing frequency response and transient behavior in circuits.

3.1.3 The Triangle Wave

A triangle wave is a periodic waveform that linearly ramps up and down between a maximum and minimum amplitude. It is described by:

$$v(t) = \begin{cases} \frac{4A}{T}t - A, & 0 \leq t < \frac{T}{2} \\ -\frac{4A}{T}t + 3A, & \frac{T}{2} \leq t < T \end{cases} \tag{3}$$

where A is the peak amplitude and T is the period. Unlike square waves, triangle waves contain fewer high-frequency harmonics, making them suitable for testing linearity in audio applications.

3.2 The Electret Condenser Microphone

An electret condenser microphone is a type of microphone that uses a permanently charged dielectric material (electret) to generate an electrical signal in response to sound waves. It consists of a diaphragm, a backplate, and a built-in Field-Effect Transistor (FET) for impedance matching.

When sound waves strike the diaphragm, it moves relative to the backplate, causing a variation in capacitance. This change is converted into a voltage signal that can be further amplified and processed. The microphone typically requires an external bias voltage, often supplied through a resistor.

In this experiment, the electret condenser microphone is used to capture the generated signals and convert them into electrical waveforms. Its response to speech signals is analyzed and used in the calculation to create an amplifier suitable for the speaker.

3.3 The 8W Speaker

The 8W speaker is an electroacoustic transducer that converts electrical signals into sound waves. It operates on the principle of electromagnetic induction, where an alternating current passing through the voice coil creates a magnetic field that interacts with a permanent magnet. This interaction causes the diaphragm to move, producing audible sound.

The speaker's performance is characterized by:

- **Frequency Response:** The range of frequencies the speaker can effectively reproduce.
- **Impedance:** The electrical resistance the speaker presents to the driving circuit, typically measured in ohms.
- **Power Handling:** The maximum electrical power the speaker can handle without distortion or damage.

In this experiment, the speaker is driven by the ADALM2000's signal generator to analyze its ability to reproduce different waveforms. The interaction between input waveforms and the speaker's mechanical response is observed to assess proper amplification stage levels.

3.4 The Summing Amplifier

A summing amplifier is an operational amplifier (op-amp) configuration that outputs the weighted sum of multiple input signals. It follows the equation:

$$V_{out} = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \cdots + \frac{R_f}{R_n}V_n\right) \tag{4}$$

where R_f is the feedback resistor, $R_1, R_2, \ldots, R_n$ are input resistors, and $V_1, V_2, \ldots, V_n$ are input voltages.

Summing amplifiers are widely used in audio mixing, signal processing, and control systems. They allow multiple signals to be combined into a single output while maintaining proportional relationships.

4 Experimental Procedures

4.1 Oscilloscopes and Signals

To begin, the utilization of Scopy software alongside the ADALM2000 is introduced by generating signals and displaying them as read by the hardware.

The specific wiring is gone over in detail to differentiate between the signal generation leads and the oscilloscope leads. The ADALM2000 provides two signal generator channels and two channels to read using the oscilloscope function within Scopy.

1. A 2kHz Sine Wave is generated with a Peak-to-Peak value of 4V and a DC offset of 2V. See Figure 1 for the Oscilloscope output.

Figure 1: A Sine Wave Output

2. A 2kHz Square Wave is generated with the same Peak-to-Peak values of 4V and a 2V DC Offset. Noise is introduced and gets interpreted by subtle quivers in the square wave signal as shown in Figure 2

Figure 2: A Square Wave Output

3. Finally, a 2kHz Triangle Wave is generated with the same values. This provided a challenge in utilizing the oscilloscope trigger as the signal was quite dirty, nevertheless it was able to be displayed in crisp resolution as in Figure 3

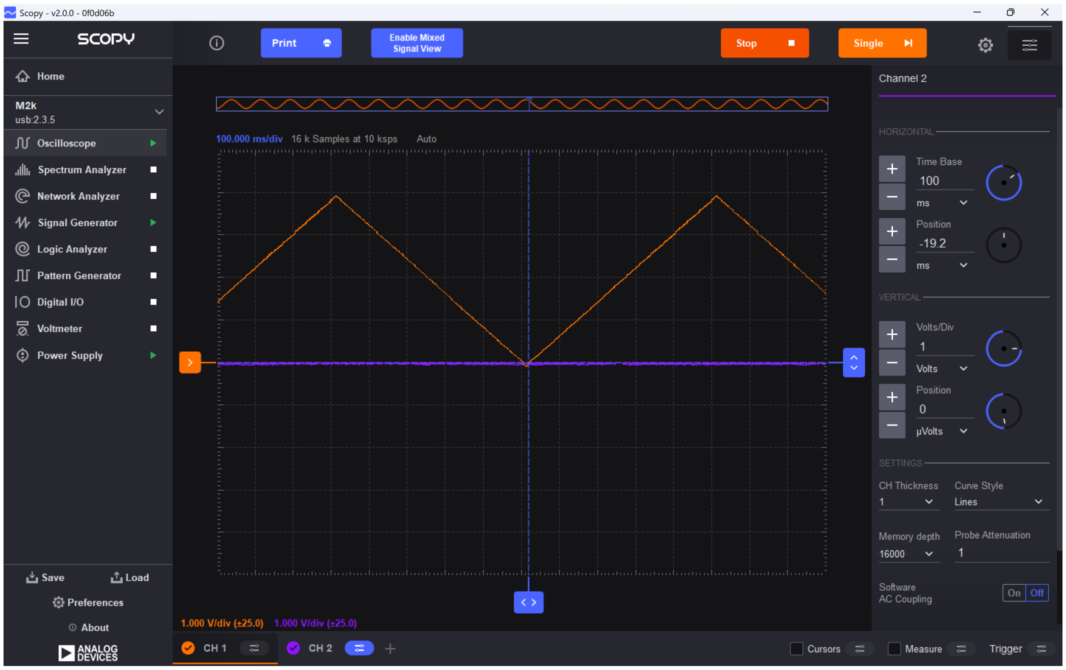

Figure 3: A Triangle Wave Output

On all three of the signals, the signal was transformed upwards by the DC Offset by 2V. This allowed for the signals to stay positive for the most part and have a minimum of 0V.

4.2 The Speaker's Amplitude Calculation

Once the initial setup of the "push-pull" amplifier was completed, the next steps were to combine the signal generator, the amplifier, and the 8W speaker to come up with a value which corresponds to an amplitude for a "Reasonable" listening volume.

1. The circuit in Figure 4 was constructed with the signal generator acting as the input to the operational amplifier.

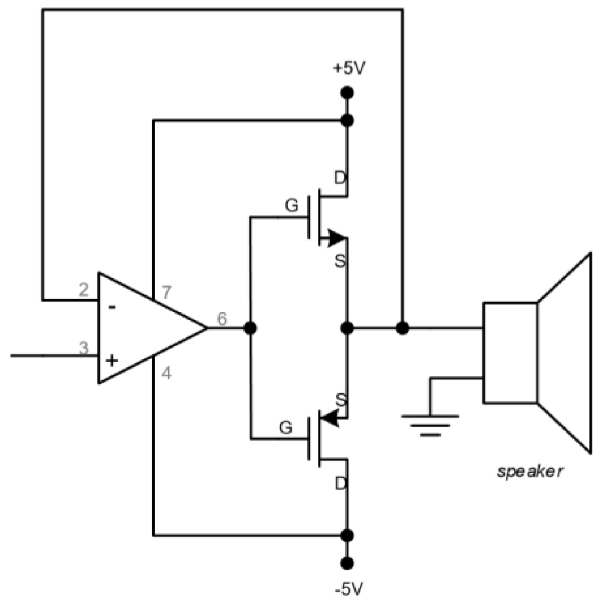

Figure 4: A Basic Speaker Circuit

2. A 800Hz sine wave with zero DC offset was generated within Scopy and applied to the circuit.
3. The amplitude of the signal was adjusted until a tone was produced which correlated to a "reasonable" volume.
4. This was recorded at 3.3V for my experimental setup.

4.3 The Electret Microphone

The next portion of the experiment worked on the input stage of the circuit, the microphone. The goal here was to find the amplitude of the voltage recorded from the output of the microphone driven by a 5V circuit shown in Figure 5

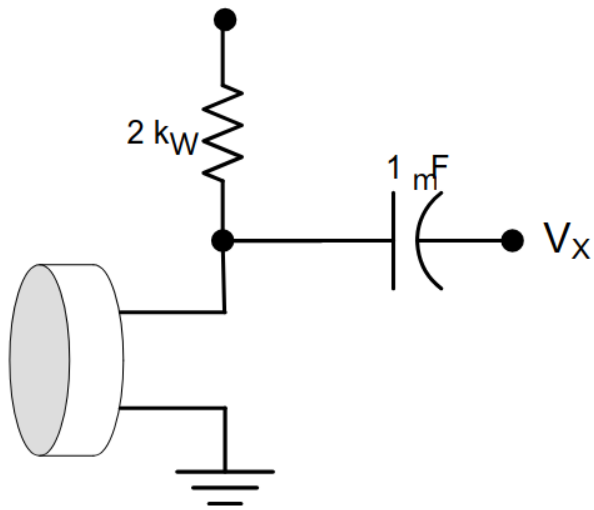

Figure 5: A Microphone Circuit

1. The circuit was constructed.
2. The Oscope was connected to the output and dialed in to display the output waveform of the microphone.
3. Several passes were made with a vocal signal produced 4 inches away from the microphone.
4. Average peak-to-peak amplitude was recorded at 9mV.

4.4 An Amplifier Circuit

As a precursor to the first design project, a theoretical amplifier circuit was designed in schematic form utilizing the sensitivities recorded in the past parts.

1. The Speaker Sensitivity was $3.3V$ and the Microphone sensitivity was $9.9mV$ This means that an amplifier capable increasing the signal by a factor of 368 was necessary.
2. In order to not saturate the operational amplifier, stages were designed such that they did not exceed 100, and cascaded.
3. Use of resistors were chosen to not exceed $1M\Omega$ and be greater than $1K\Omega$ and standard 5% tolerance.
4. The outcome was the first stage utilizing a ratio of 10, and the second stage utilizing a ratio of 36.

$$V_{out} = (\frac{-R_B}{R_A})(\frac{-R_D}{R_C})$$

When substituted:

$$V_{out} = (\frac{-100K\Omega}{10K\Omega})(\frac{-270K\Omega}{7.5K\Omega})$$

5. The Circuit is shown in Figure 6

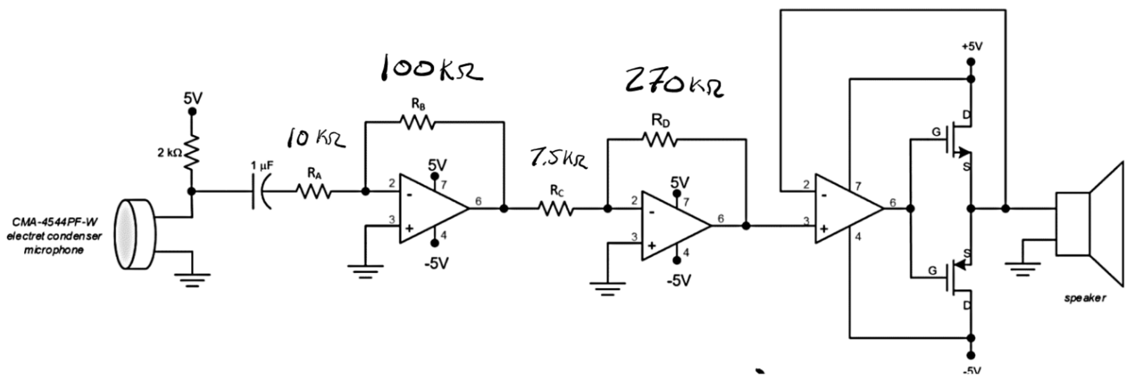

Figure 6: Amplifier Circuit with Resistor Values

4.5 Combining Signals

The last portion of the experiment combined portions of the previous experiment and this ones, with a summing amplifier built in hardware. The inputs this time however are two separate signals from the signal generator.

1. The circuit shown in Figure 7 is implemented in hardware.

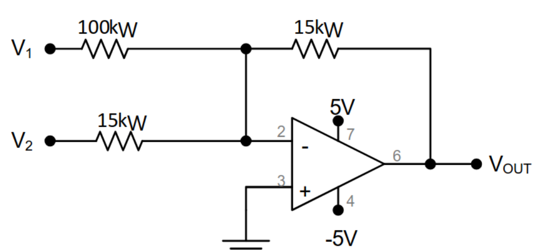

Figure 7: Summing Amplifier Circuit

2. The two different signal generator inputs are affixed to the circuit at V_1 and V_2 respectively.

3. Within Scopy, a Sine Wave of 15kHz and 2V peak-to-peak is generated for the first signal.

4. A square wave with frequency of 2 kHz and amplitude of 2V peak-to-peak is generated for the second input signal.

5. The signal is read from Scopy utilizing the oscilloscope function. This signal is displayed in Figure 8

Figure 8: A Combined Signal

5 Results and Discussion

5.1 The Signal Generator and Oscilloscope

Utilizing these new tools provided a new challenge in learning how to not only connect the equipment correctly to monitor signals, but also in utilizing the scope to lock in on a variety of alternating signals.

The sine wave was easily able to be locked into with minimal setting change. The Scopy software provides a way to zoom in horizontally and vertically, known as the Time Base and the Volts/Div settings. These settings effectively change the windowing mode within the software and allow for very small signals to be analyzed.

Understanding the use of waveform/optical physics equations such as the derivation of period is key for being able to use the oscope correctly. Recall that Period, T is calculated by the formula:

$$f = \frac{1}{T}$$

Which show the direct correlation between frequency and period. This insight provided a huge benefit to find and clean up the signals that were observed in this portion of the experiment.

5.2 Testing the Speaker

Due to electronic components being manufactured over a wide range of tolerances, the output amplitude of the signal generator had to be found and calculated in the first step of the design of this circuit.

The sine wave input at 800Hz produced an audible tone from the speaker which was getting its input from the push pull amplification stage. This served as an ideal current source which drove the speaker. Because speakers have an internal impedance to them, a wide variety of input signals need to overcome this. The amplification stage here acted as that driver.

The input amplitude that was deemed to be "reasonable" was calculated at 3.3V for my circuit.

5.3 Testing the Microphone

This portion of the experiment introduced more experimental ambiguity as different microphones have different responses. The tricky part of this was to dial in the scope to be able to accurately trigger, or freeze, on an input waveform which signified the theoretical input to the eventual amplifier circuit.

As this was done in a noisy environment, several attempts and passes were made and an average of 9.9mV was recorded as a solid sensitivity for the electret microphone. Learning how to use the Scopy software to calculate the peak-to-peak amplitude and the triggering commands was challenging, but offered reward in intuition and understanding of the actual microphone sensitivity itself.

The microphone itself is a somewhat complex circuit as it requires its own 5V power supply alongside a drain resistor and a capacitor which have not been introduced yet as part of the course. Ultimately, the capacitor acts as a filter which blocks DC noise input in effect.

5.4 Preliminary Design

This section was straightforward as two inverting amplifier stages are cascaded by design to achieve the desired circuit characteristics while existing within constraints.

The two stages were chosen such that the first stage does not take too much of the burden, relying on a ratio of 10 to implement a tenfold amplification. The subsequent stage then ups the ante by being a ratio of 36. This turns out to fit nicely within the constraints of the resistors and the stages. However, this experiment only delved in the conceptual design of the circuit and not actually implementing it in hardware. Going back to last weeks experiment, the inverting amplifiers are the most easy to calculate gain for as they are simply a function of the ratio of the negative feedback loop and input. With this in mind, two cascaded inverting amplifiers make the output the correct orientation again in regards to polarity, so this works quite nicely.

5.5 A Combined Signal

The last portion of the experiment hints at the potential use cases of the oscilloscope in a production or test environment. With two different shaped signals being input into a summing amplifier, an interesting output waveform is displayed which show the concatenation of two different shaped signals with different frequencies (15kHz and 2kHz).

Recalling the experimental work in the previous lab, the use of a summing amplifier results in an output that combines the inputs into a single one. The operational amplifier was originally used as a chip to perform mathematical operations, and coming from the purely mechanical world of the early 20th century to the beginning of the digital era (not quite yet though) this offers insight into what made sense to engineers of the era.

With two different shaped signals input into the operational amplifier, a really strange output is observed which shows a square sine wave... or is it a sine square wave? Nevertheless, the interpretation is such that the overlying shape of the signal is a combined form of the two inputs, which is expected behavior of the circuit. The screen grab shows an additional waveform, which is in the green color that is not to be confused with the triggered waveform in orange. This is simply leftover of the measure function of Scopy, which was used to tune in on the waveform within the viewing window.

6 Conclusion

Audio amplifiers are used everywhere from playing music to making announcements on a nuclear submarine to keep the crew on the same page and are a vital step in understanding electric circuitry.

This experiment successfully introduces the signal generator and oscilloscope into our arsenal of test equipment for further enrichening knowledge of electrical circuits. By gradually introducing the use of these tools, the expectation to design a circuit that can amplify an acoustic signal is prepared for. Without diving too deep into things like silicon doping and the gating of the MOSFETs, the use of the operational amplifier is elaborated upon and shown in a practical way as well as the mystical ideal current source built. The utilization of Scopy alongside the ADALM2000 as a signal generator and oscilloscope offer a novel way to analyze these signals without the need for an extensive lab setup. The introduction of different wave shapes and frequencies allows for further insight into audio generation.