CAMBRIDGE UNIVERSITY ENGINEERING DEPARTMENT

Part IA – IEP Design Project Report

THE LEVEL SYNTHESISER

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Abstract

This report presents the design, implementation, and testing of a Level Synthesizer, an electronic circuit that converts the acceleration of a circuit due to it being tilted into an audible signal. The system employs an ADXL327 accelerometer to measure inclination, followed by signal processing stages to generate a corresponding frequency output. Key components include a DC offset removal circuit, a frequency synthesizer, and a loudspeaker driver. Experimental results confirm that the system effectively translates tilt angle variations into changes in sound pitch, with the frequency range aligning well with design expectations.

1 Introduction

In this project, we aim to design and implement a Level Synthesiser, an electronic system that translates the tilting angle of a circuit into an audible signal. The system will utilize an accelerometer to measure the inclination of the circuit relative to the horizontal plane. Based on the detected tilt angle, a processing unit will generate a corresponding frequency signal, which will then be output to a loudspeaker driver. As a result, the pitch of the sound will vary dynamically with the tilting angle, providing an intuitive auditory representation of the circuit's orientation.

2 Design

The system consists of several key components working in sequence to achieve this functionality. The basic structure of the system is outlined as follows:

- **ADXL327 Accelerometer**: The ADXL327 is a low-power, analog-output accelerometer used to measure the tilt angle of the circuit. It provides an output voltage proportional to acceleration along the X, Y, and Z axes. The tilt angle can be derived from these acceleration values.
- **DC Offset Removal**: Since the accelerometer's output includes a DC bias, a high-pass filter is used to remove the DC offset. This ensures that only the varying component of the tilt signal is processed further.
- **DC Amplifier**: The filtered signal is passed through an amplifier circuit to scale the voltage levels appropriately for signal processing. This helps in improving sensitivity and ensuring that small variations in tilt result in noticeable changes in frequency.
- **Frequency Synthesizer**: The processed signal is fed into a frequency synthesis circuit that converts the tilt angle into a corresponding frequency. This is implemented using a voltage to frequency converter. The frequency increases or decreases depending on the degree of tilt.
- **Amplifier**: The synthesized signal is then passed through a power amplifier to drive the loudspeaker effectively. This ensures that the audio output is loud enough to be clearly perceived.
- **Loudspeaker**: The final stage is a loudspeaker driver, which converts the electrical signal into sound. The pitch of the sound varies with the tilt angle, providing an intuitive audio representation of the system's orientation.

2.1 Power Supply Design

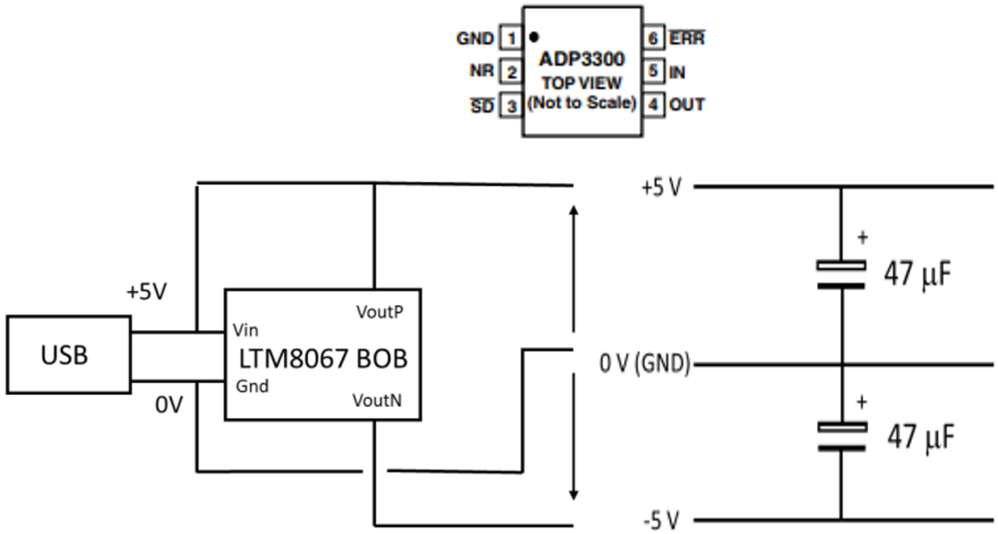

Figure 1: Circuit Diagram of the Power Supply

The dual rail power supply circuit is designed using the **LTM8067 BOB** (Breakout Board) to generate regulated voltage outputs, which are further conditioned and utilized to power additional components, including the **ADP3300** voltage regulator. In this circuit, two **47 µF** capacitors are connected at the output of the LTM8067 to smoothen out voltage fluctuations and reduce ripple in the generated power rails. These capacitors improve the stability of the power supply and ensure clean voltage delivery.

The **ADP3300** is a low-dropout (LDO) regulator used to generate a stable **3.3V** output from one of the voltage rails supplied by the LTM8067. The connections to the ADP3300 are as follows:

- **Vin (Pin 5)**: Connected to the +5V ouput of the LTM8067.
- **Vout (Pin 4)**: Provides a stable 3.3V output for powering low-voltage circuits.
- **GND (Pin 1)**: Connected to the system ground.
- **ERR (Error Output, Pin 6)**: Connected to the system ground

Also, two **1 µF** capacitors are placed:

- **Between Vin and GND**: This capacitor helps to filter noise and stabilize the input voltage before it enters the ADP3300 regulator.
- **Between Vout and GND**: This capacitor smooths out the regulated 3.3V output, ensuring minimal voltage fluctuations and enhancing load transient response.

2.2 ADXL327 Accelerometer Design

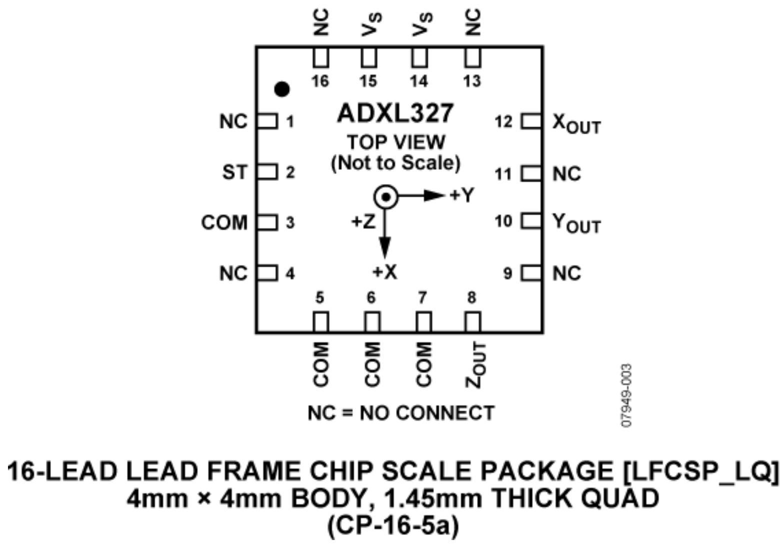

Figure 2: Circuit Diagram of the ADXL327 Accelerometer

The connections to the ADXL327 are as follows:

- **Vin (Pin 15)**: Connected to the +3.3V output of the ADP3300.
- **Xout (Pin 12)**: Outputs an analog voltage proportional to the acceleration along the X-axis.
- **GND (Pin 3)**: Connected to the system ground.

2.3 DC Offset and Amplifier Design

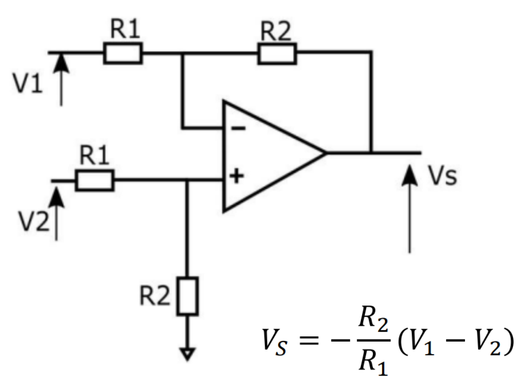

Figure 3: Circuit Diagram of the Difference Amplifier

The **Xout** pin of the **ADXL327 accelerometer** provides an analog voltage output that varies with acceleration along the X-axis. However, the output voltage is biased, meaning it has a **DC offset** that needs to be removed before further processing.

We use the **OP27 operational amplifier** in a **differential amplifier configuration** to both remove the DC offset and amplify the signal.

- **Xout from ADXL327** is connected to **V2** (non-inverting input).
- A **potentiometer** is used to generate a fine-tuned reference **offset voltage (V1)**. This voltage is applied to the inverting input of the op-amp.
- **Resistors R1 and R2** determine the gain of the amplifier.

The gain of a differential amplifier is given by the formula in the circuit diagram. We choose:

- **R1 = 10k**
- **R2 = 47k**

Thus, the gain amplifies the signal so that the transformed voltage range (**Vout**) falls between **0V and 1.6V**, making it suitable for further processing.

2.4 Loudspeaker Driver Amplifier Design

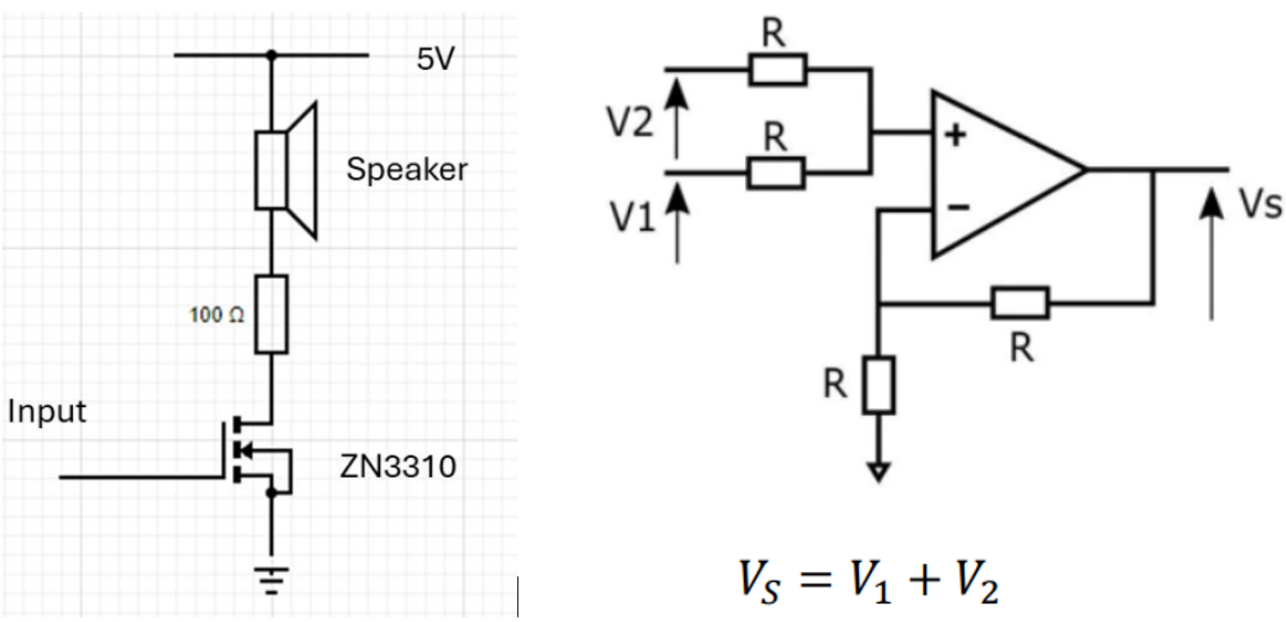

Figure 4: Circuit Diagram of the Audio Amplifier

The Loudspeaker Driver Amplifier Circuit utilizes the ZN3310A MOSFET to switch the loudspeaker on and off based on the input voltage, with the addition of a summing amplifier using the OP27 operational amplifier (Op-Amp). This circuit is designed to ensure that the MOSFET operates reliably by adding a DC bias = 2.5V (using 2 equal resistors to form a potential divider) to the input signal, allowing the speaker to be activated.

2.5 Audio Frequency Tone Generator Design

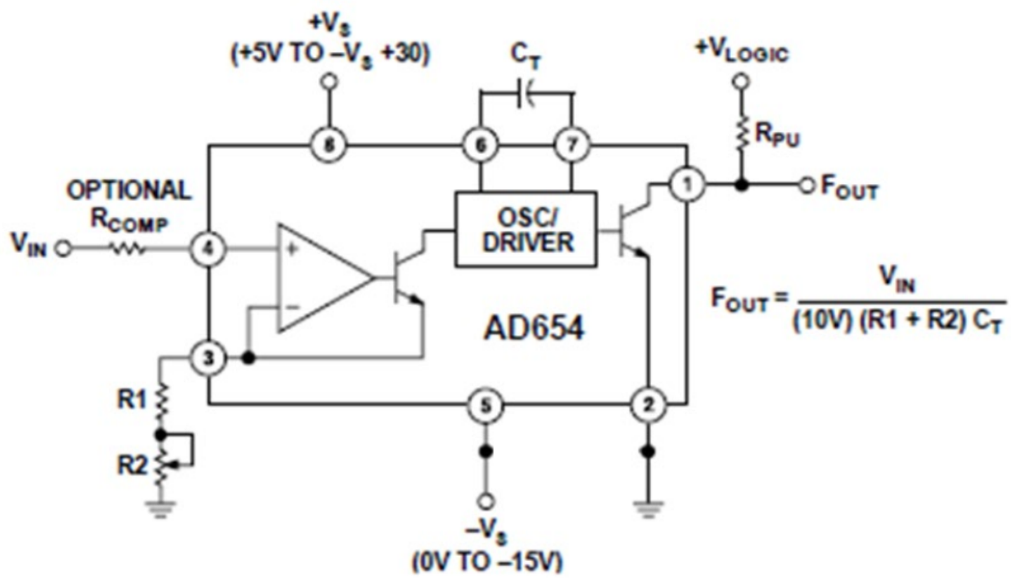

Figure 5: Circuit Diagram of the AD654 Frequency Generator

The input voltage V_{IN} will generate a square wave output of frequency F_{OUT}. We build the circuit using the following values: $V_s = \pm 5\,\text{V}$, $C_T = 200\,\text{nF}$, $R_{\text{PU}} = 10\,\text{k}\Omega$, $(R_1 + R_2) = 10\,\text{k}\Omega$, and $R_{\text{COMP}} = 47\,\text{k}\Omega$. When we vary the value of Vin up to 5V, we find that the best range of voltages for Vin is between 600 mV to 2.5 V which outputs the range of frequencies between 25 Hz and 1000 Hz. Therefore, we use the summing amplifier once again to amplify the signal from the accelerometer to match the range of Vin measured above (using a potentiometer again for DC biasing)

3 Build

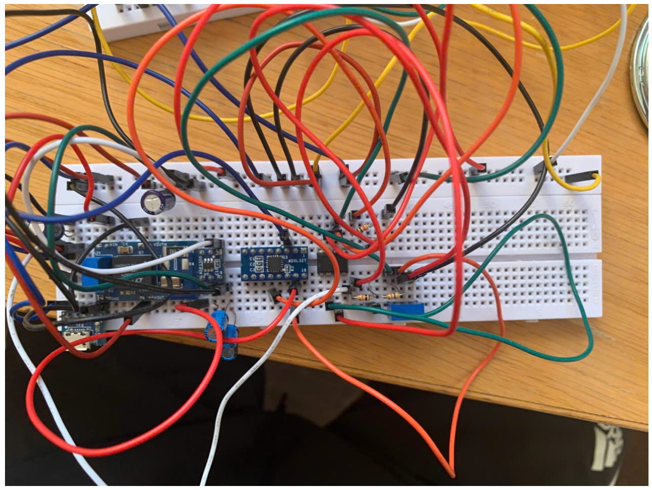

Figure 6: Circuit built for Power Supply, Accelerometer, and DC Offset and Amplifier

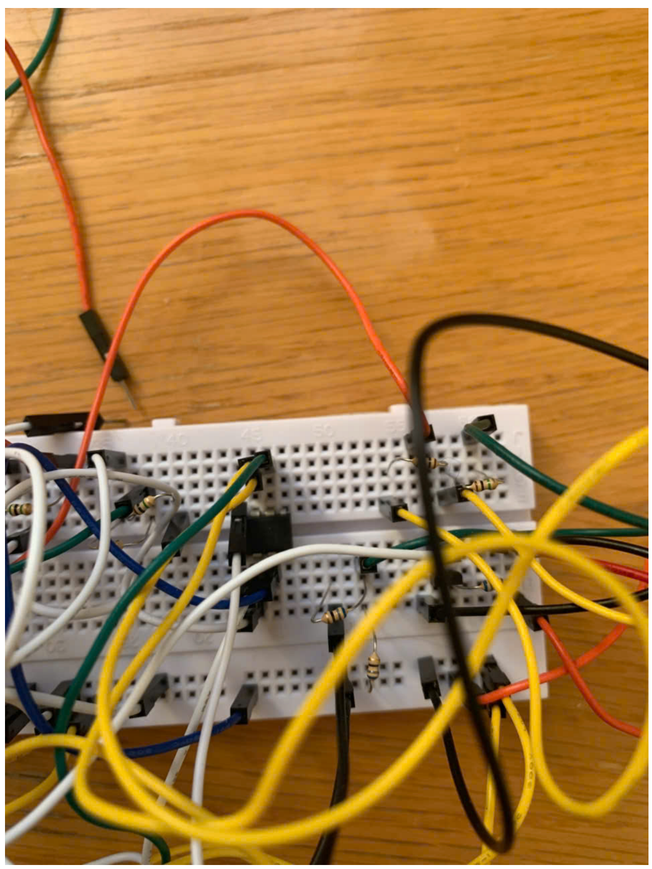

Figure 7: Circuit built for Loudspeaker Driver Amplifier

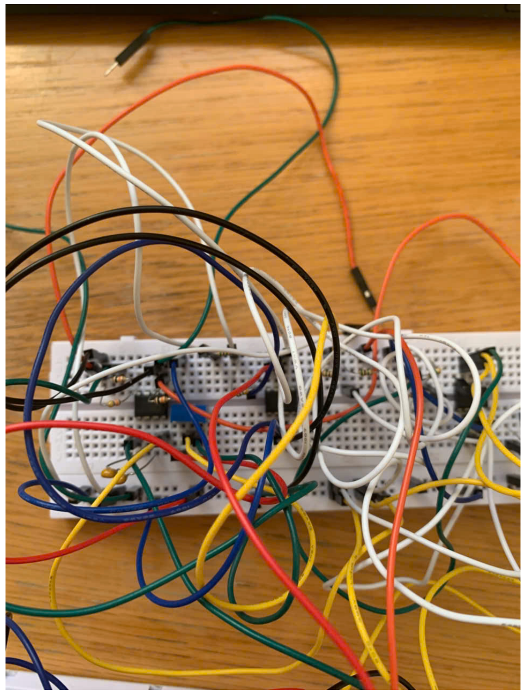

Figure 8: Circuit built for Audio Frequency Tone Generator

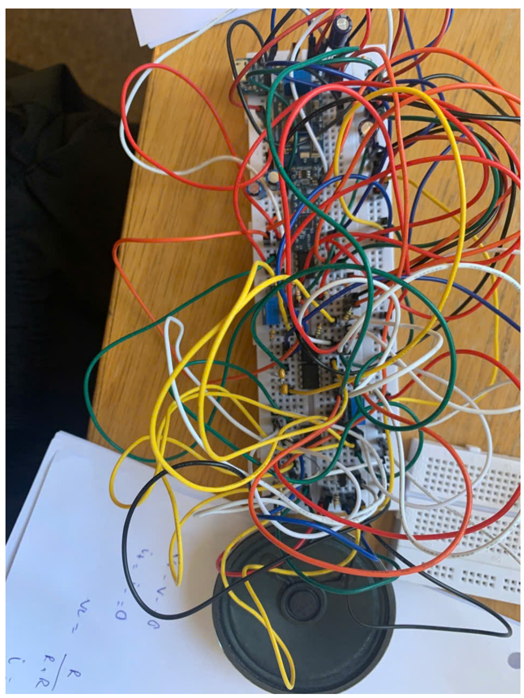

Figure 9: Complete circuit built on 1 breadboard

4 Test

4.1 Accelerometer

The range of voltages measured in x-direction is between 1.427 V and 2.322 V.

The range of voltages measured in y-direction is between 1.427 V and 2.322 V.

The range of voltages measured in z-direction is between 1.785 V and 2.322 V.

We chose the x-direction to measure for the rest of the experiment.

4.2 DC Offset Removal

The minimum voltage measured when we tilt the circuit by -90 degrees is 47.0 mV (which is very close to 0).

The maximum voltage measured when we tilt the circuit by 90 degrees is 1.735 V (which is in the range between 1 and 2 V).

4.3 Audio Driver Amplifier

We use the AWG signal with amplitude = 800 mV with DC offset = 800 mV. This signal is being amplified by our summing amplifier circuit. We measured the minimum output voltage = 2.356 V and the maximum output voltage = 4.133 V from the loudspeaker driver.

4.4 Audio Frequency Tone Generator

As we increase the value of Vin, the output also increases. The best range of voltages for Vin is between 600 mV and 2.5 V, which outputs the range of frequencies between 20 Hz and 1300 Hz.

After we connect the audio frequency tone generator to the loudspeaker driver, the range of frequencies the loudspeaker driver can produce is between 23.70 Hz and 1100 Hz.

4.5 Complete Circuit Test

As we tilt the circuit from 0 to -90 degrees, the frequency of sound from the loudspeaker driver decreases. As we tilt the circuit back from -90 degrees to 90 degrees, the frequency of sound from the loudspeaker driver increases. This confirms that our circuit behaves as we expect.

5 Conclusion

The Level Synthesizer successfully demonstrates the feasibility of using an accelerometer-based system to generate an auditory representation of tilt angle. The experimental results validate the theoretical design, with the observed frequency response closely matching expected values. The circuit reliably produces frequency variations in response to changes in tilt angle, making it a useful tool for intuitive orientation feedback.