Frequency Response of Piezoelectric Sensor

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Abstract: In this study, we sought to further our understanding of the piezoelectric sensor. The widespread applications of a sensor capable of converting mechanical energy into an electric signal that too without the need for an external voltage fueled our curiosity. This report outlines our process and learnings.

INTRODUCTION

A. Aim of the experiment

1. To study the working principle of a piezoelectric sensor by modulating the frequency of the input to the sensor and observing its response.
2. To identify the resonance and sub-resonance frequencies of a particular piezoelectric sensor.

B. Working Principle

Piezoelectric sensors are electronic devices which work on the principle of piezoelectric effect.

Piezoelectric Effect: The piezoelectric effect is a phenomenon that occurs primarily in dielectric materials, such as quartz and tourmaline, wherein an electric charge is produced owing to a voltage being generated when pressure is applied. This capability allows for the measurement of changes in force and other variables. In addition, piezoelectric materials have a linear relationship between the input and output energy domains. [1].

In this particular experiment, the sensor detects mechanical stress caused by sound waves from a speaker and converts it into electrical signals.

C. Piezo Electric Sensor

Image 1: Structure of a simple Piezoelectric Sensor [2]

When the outer metal plates apply mechanical force on the Piezoelectric element, electric charges forced within the Piezoelectric element are out of balance. Next, the excessive negative and positive charges appear on the top and bottom electrodes respectively. This produces a potential difference allowing flow of current through the circuit, if complete. [3]

PROCEDURE

A. Apparatus Used

1. Piezoelectric sensor
2. Speaker
3. Breadboard
4. Jumper wires
5. Resistor(100kΩ)
6. Digital signal generator
7. Digital signal Oscilloscope (DSO)
8. Crocodile clips

Digital Signal Generator: A device used to produce electrical signals of a set frequency, amplitude, and wave shape. [4]

DSO: An electronic instrument that converts analog signal into a digital format and displays it, allowing measurement and analysis. [5]

B. Circuital Set-up

The Digital Signal Generator generates a 10V (peak-to-peak) sine wave of variable frequency which is communicated to the speaker through its first channel. The Piezoelectric sensor is attached to the back of the speaker. Its output is received via jumper wires, which further used the breadboard to connect it to the 100k resistor in parallel, before passing the signal to the crocodile clips. The signal was then received and displayed on the DSO.

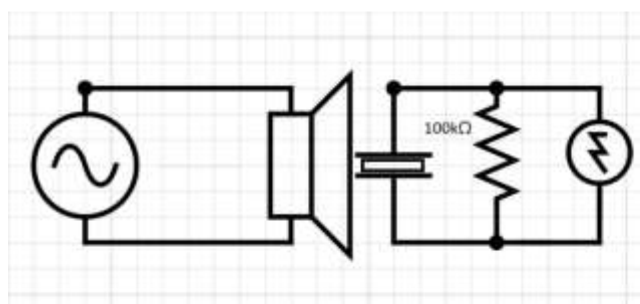


Image 2: Diagrammatic Representation of Circuit

C. Methodology

After completing the above-mentioned set-up,

1. Generate a 10V (peak-to-peak) sine wave on the Digital Signal Generator. Its frequency may initially be set to 100Hz (i.e. 0.1 kHz)

2. The speaker will now produce sound corresponding to the signal (in the time domain).

   (The speaker's vibrations will consequently be picked up by the sensitive Piezoelectric crystal attached to it. The signal is relayed to the DSO.)

3. Note the Input Voltage of the DSO (i.e. the output voltage of the Piezoelectric Sensor) using the measure feature, after confirming that the received frequency is equal to frequency of the sine wave generated on the Digital Signal Generator.
4. Repeat the above procedure for frequencies at an interval of 0.1kHz till a continued drop in Output Voltage is observed.

OBSERVATIONS

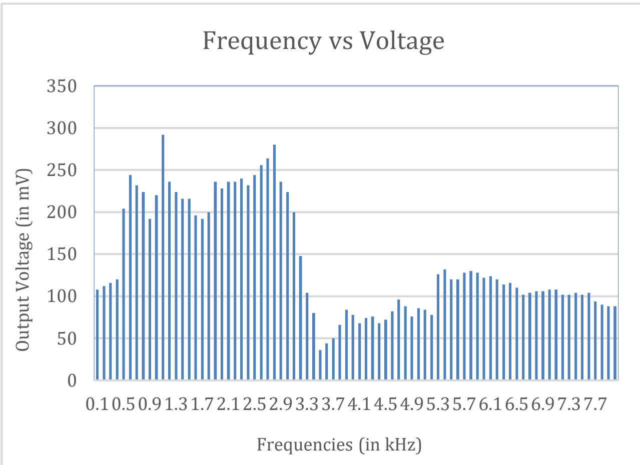
A. *Readings*

Sr. No	Frequency (in kHz)	Input Voltage (in V)	Output Voltage (in mV)	Voltage Gain (V/V)	Voltage Gain (in dB)
1	0.1	10	108	0.0108	-39.33
2	0.2	10	112	0.0112	-39.01
3	0.3	10	116	0.0116	-38.71
4	0.4	10	120	0.0120	-38.41
5	0.5	10	204	0.0204	-33.80
6	0.6	10	244	0.0244	-32.25
7	0.7	10	232	0.0232	-32.69
8	0.8	10	224	0.0224	-32.99
9	0.9	10	192	0.0192	-34.33
10	1.0	10	220	0.0220	-33.15
11	1.1	10	292	0.0292	-30.69
12	1.2	10	236	0.0236	-32.54
13	1.3	10	224	0.0224	-32.99
14	1.4	10	216	0.0216	-33.31
15	1.5	10	216	0.0216	-33.31
16	1.6	10	196	0.0196	-34.15
17	1.7	10	192	0.0192	-34.33
18	1.8	10	200	0.0200	-33.97
19	1.9	10	236	0.0236	-32.54
20	2.0	10	228	0.0228	-32.84
21	2.1	10	236	0.0236	-32.54
22	2.2	10	236	0.0236	-32.54
23	2.3	10	240	0.0240	-32.39
24	2.4	10	232	0.0232	-32.69
25	2.5	10	244	0.0244	-32.25
26	2.6	10	256	0.0256	-31.83
27	2.7	10	264	0.0264	-31.56
28	2.8	10	280	0.0280	-31.05
29	2.9	10	236	0.0236	-32.54
30	3.0	10	224	0.0224	-32.99
31	3.1	10	200	0.0200	-33.97
32	3.2	10	148	0.0148	-36.59
33	3.3	10	104	0.0104	-39.65
34	3.4	10	80	0.008	-41.93
35	3.5	10	36	0.0036	-48.87
36	3.6	10	44	0.0044	-47.13
37	3.7	10	50	0.005	-46.02
38	3.8	10	66	0.0066	-43.60
39	3.9	10	84	0.0084	-41.51
40	4.0	10	78	0.0078	-42.15
41	4.1	10	68	0.0068	-43.34
42	4.2	10	74	0.0074	-42.61
43	4.3	10	76	0.0076	-42.38
44	4.4	10	68	0.0068	-43.34
45	4.5	10	72	0.0072	-42.85
46	4.6	10	82	0.0082	-41.72
47	4.7	10	96	0.0096	-40.35
48	4.8	10	88	0.0088	-41.11
49	4.9	10	76	0.0076	-42.38
50	5.0	10	86	0.0086	-41.31
51	5.1	10	84	0.0084	-41.51
52	5.2	10	78	0.0078	-42.15
53	5.3	10	126	0.0126	-37.99
54	5.4	10	132	0.0132	-37.58
55	5.5	10	120	0.012	-38.41
56	5.6	10	120	0.012	-38.41
57	5.7	10	128	0.0128	-37.85
58	5.8	10	130	0.013	-37.72
59	5.9	10	128	0.0128	-37.85
60	6.0	10	122	0.0122	-38.27
61	6.1	10	124	0.0124	-38.13
62	6.2	10	120	0.012	-38.41
63	6.3	10	114	0.0114	-38.86
64	6.4	10	116	0.0116	-38.71
65	6.5	10	110	0.011	-39.17
66	6.6	10	102	0.0102	-39.82
67	6.7	10	104	0.0104	-39.65
68	6.8	10	106	0.0106	-39.49
69	6.9	10	106	0.0106	-39.49
70	7.0	10	108	0.0108	-39.33
71	7.1	10	108	0.0108	-39.33
72	7.2	10	102	0.0102	-39.82
73	7.3	10	102	0.0102	-39.82
74	7.4	10	104	0.0104	-39.65
75	7.5	10	102	0.0102	-39.82
76	7.6	10	104	0.0104	-39.65
77	7.7	10	94	0.0094	-40.53
78	7.8	10	90	0.009	-40.91
79	7.9	10	88	0.0088	-41.11
80	8.0	10	88	0.0088	-41.11

Table 1: Output Voltage at Different Input Frequencies

B. Analysis

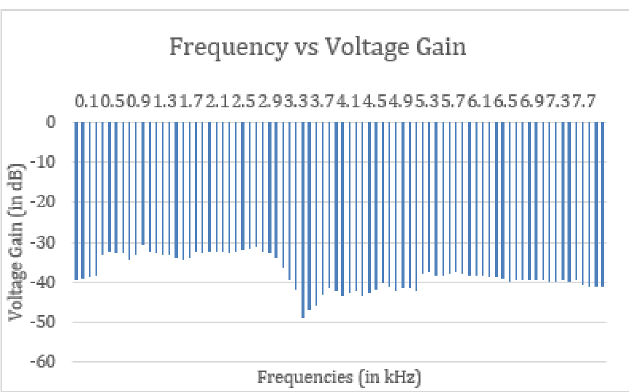
1. The output voltage, and consequently the voltage gain, exhibits a gradual rise and peaks prominently at 3 specific frequencies (0.6kHz, 1.1kHz, 2.8kHz) It then drops consistently and never fully recovers in value.



Graph 1: Voltage measurements at different frequencies

2. At the said peaks, one may also note the peaking values of the Voltage Gain (in dB), calculated using the formula:

$$v_{gain} = 20\, log_{10}\left(\frac{v_0}{v_i}\right)\, dB$$



Graph 2: Voltage Gain measurements at different frequencies

Frequency (in kHz)	Output Voltage (in mV)	Voltage Gain (in dB)
0.6	244	-32.25
1.1	292	-30.69
2.8	280	-31.05

Table 2: Voltage and Voltage Gain measurements at Peaks

3. The FFT Plot at the frequency with the highest Output Voltage showed the presence of noise. However, the strongest present frequency was that of 1.1kHz only.

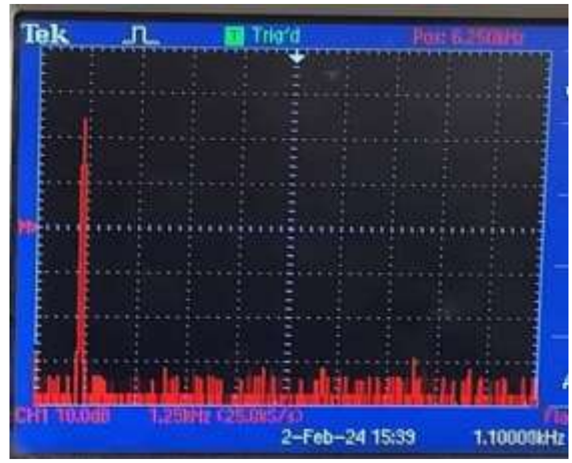


Image 3: FFT Graph when Frequency was set to 1.1kHz

RESULTS

The resonance frequency of our Piezoelectric sensor is 1.1kHz. Sub-resonance frequencies are observed at 0.6kHz and 2.8kHz. This resonant frequency corresponds to the point where the sensor exhibits its strongest response to mechanical vibrations. As the frequency approaches the resonant frequency of 1.1 kHz, the voltage gain increases, indicating that the sensor becomes more sensitive and responsive to vibrations within this frequency range.

CONCLUSION

In conclusion, the frequency response data of the piezoelectric sensor underscores its ability to effectively detect and respond to mechanical vibrations, with the resonant frequency at 1.1 kHz representing its optimal operating condition. Understanding the frequency characteristics of the sensor is essential for optimizing its performance and reliability in various sensing applications.

A. Applications

Products:

1. Pressure Sensors
2. Diesel Fuel Injectors
3. Inkjet Printers
4. Microphone
5. Intruder Alarm

Case Study:

Tilt sensors measure the inclination of an object or a surface with respect to a reference axis, most notably with respect to the vertical gravitational field. They are commonly employed in smartphones and are critical for functions like screen rotation and gyroscopic calibration of phones.

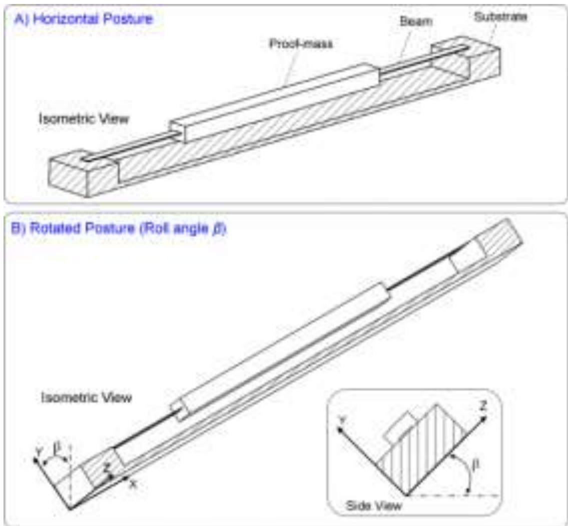


Image 4: Tilt Sensors for single axis measurement [7]

In a simplified model, the tilt sensors rely on Piezoelectric sensors attached at the end-face of the substrates. As the phone tilts, the proof-mass shifts due to gravitational force thus generating electric signals in a particular Piezoelectric crystal, whose signals are received and processed by the phone's processor. In reality, multiple-axis measurements are simultaneously carried out.

B. Future Scope for Development

The identification of less expensive alternatives for Quartz and Tourmaline could expand the utilization of Piezoelectric sensors. Additionally, there is potential to engineer sensors with exceptional resistance to heat and pressure. Cost-effective production of Piezoelectric materials might enable energy generation in high-footfall areas.

C. Media from our Study

Image: Oscilloscope Reading Signal at 1.9kHz

Image: Oscilloscope Reading at 1.1kHz

Image: Oscilloscope FFT at 1.1kHz

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