Acoustic Energy Harvesting using Helmholtz Resonator with tapered neck

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Introduction: This work focuses on the increase in output voltage of the acoustic energy harvester which makes use of the increased amplification rate of a Helmholtz resonator due to the tapered nature of its neck.

Figure 1 shows the schematic of the proposed acoustic energy harvester. When the acoustic resonator is excited by an incident sound wave at its resonant frequency, acoustic energy in the form of standing resonant waves get collected inside the resonator. A flexible piezo-film (PVDF) cantilever with same frequency as that of the resonator is placed inside the cantilever, to generate maximum output voltage. The standing waves produced inside the resonator drives the piezo-film cantilever to vibrate producing electricity.

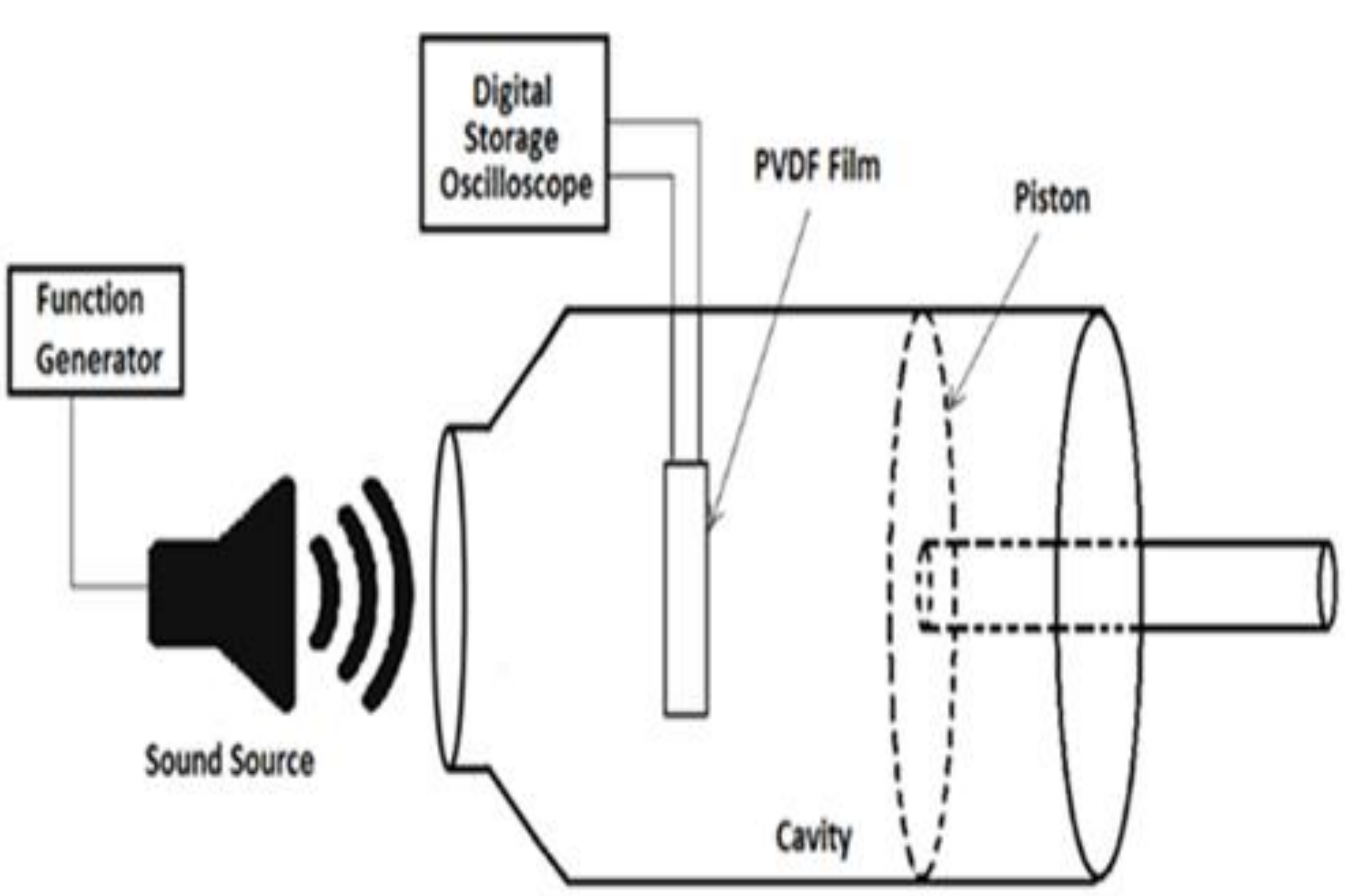


Figure 1. Schematic of the proposed energy harvester

The resonant frequency of the Helmholtz resonator with tapered neck is given by

$$f = \frac{c}{2\pi}\sqrt{\frac{\pi {r_i}^2}{LV} + \frac{m\pi r_i}{V}} \qquad (1)$$

where V= volume of the cavity
L= effective length of the neck
m= slope of the tapered region
r_i = inlet radius of the neck
C=speed of sound

Amplification factor, G of the resonator at its resonance frequency is the ratio of the acoustic pressure amplitude, P_c, within the cavity to the external driving pressure amplitude, P_i, of the incident sound wave and given as

$$G = \frac{P_c}{P_i} = 2\pi\sqrt{\frac{VL^3}{S^3}} \qquad (2)$$

where S= surface area of the neck

Since the pressure amplification factor of the resonator is proportional to the dimensions of the neck, the tapering of the neck towards the cavity; i.e. the smoother area change from the neck towards the cavity will reduce the flow of resistance of the sound waves and will increase the sound absorption capacity of the Helmholtz resonator.

Simulation: In COMSOL 4.2, pressure acoustics - piezoelectric - structural mechanics physics has been used to do frequency analysis. Since sound in a hollow tube is described by a plane wave, the input acoustic plane wave is simulated by background acoustic pressure. Inorder to avoid the meshing difficulties and increased calculation time, a sub-model approach is used to calculate the output voltage.

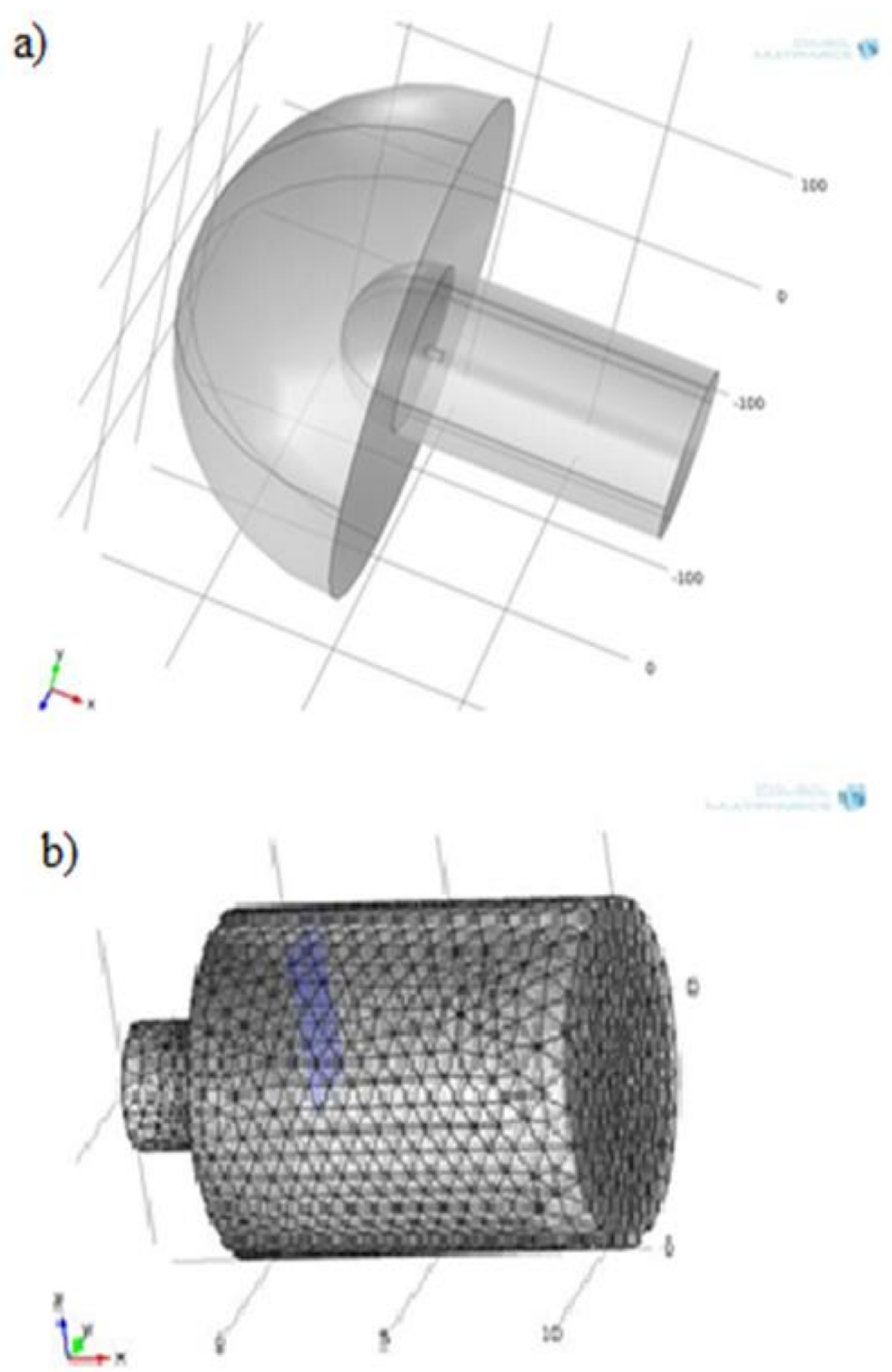


Figure 2. a) Global model of the harvester b) Helmholtz resonator with tapered neck having PVDF cantilever beam placed inside

Experimental setup: The experimental set up of acoustic energy harvester is shown in figure 3. The sound source used is Sony 2.1ch multimedia speakers equipped with 27W output power and high quality digital amplifier. The input to sound source is provided through a function generator. Helmholtz resonator used is made of acrylic

Figure 3. Experimental setup of the acoustic energy harvester.

material and has an air tight piston arrangement for varying the resonator cavity volume. A hole is made at 33mm from the neck region through which the PVDF film (LDT1-028K from measurement specialitites) is placed. The output voltage has been measured using a digital storage oscilloscope.

Results: The eigen frequency of the Helmholtz resonator with tapered neck for the designed dimensions has been calculated to be 284Hz using COMSOL Multiphysics 4.2 . At resonance the total acoustic pressure and sound pressure level is lowest at the neck of the resonator and is increasing towards the cavity. (figure 4 and figure 5 respectively). The maximum pressure inside the resonator is 94dB corresponding to a pressure of 4.28 Pa.

A sound wave of 95dB fed directly to the resonator of resonant frequency 284 Hz and a slope of the tapered neck as 210 produces an output voltage of 396 mV (Figure 6) which closely resembles the simulation results (Figure 7).

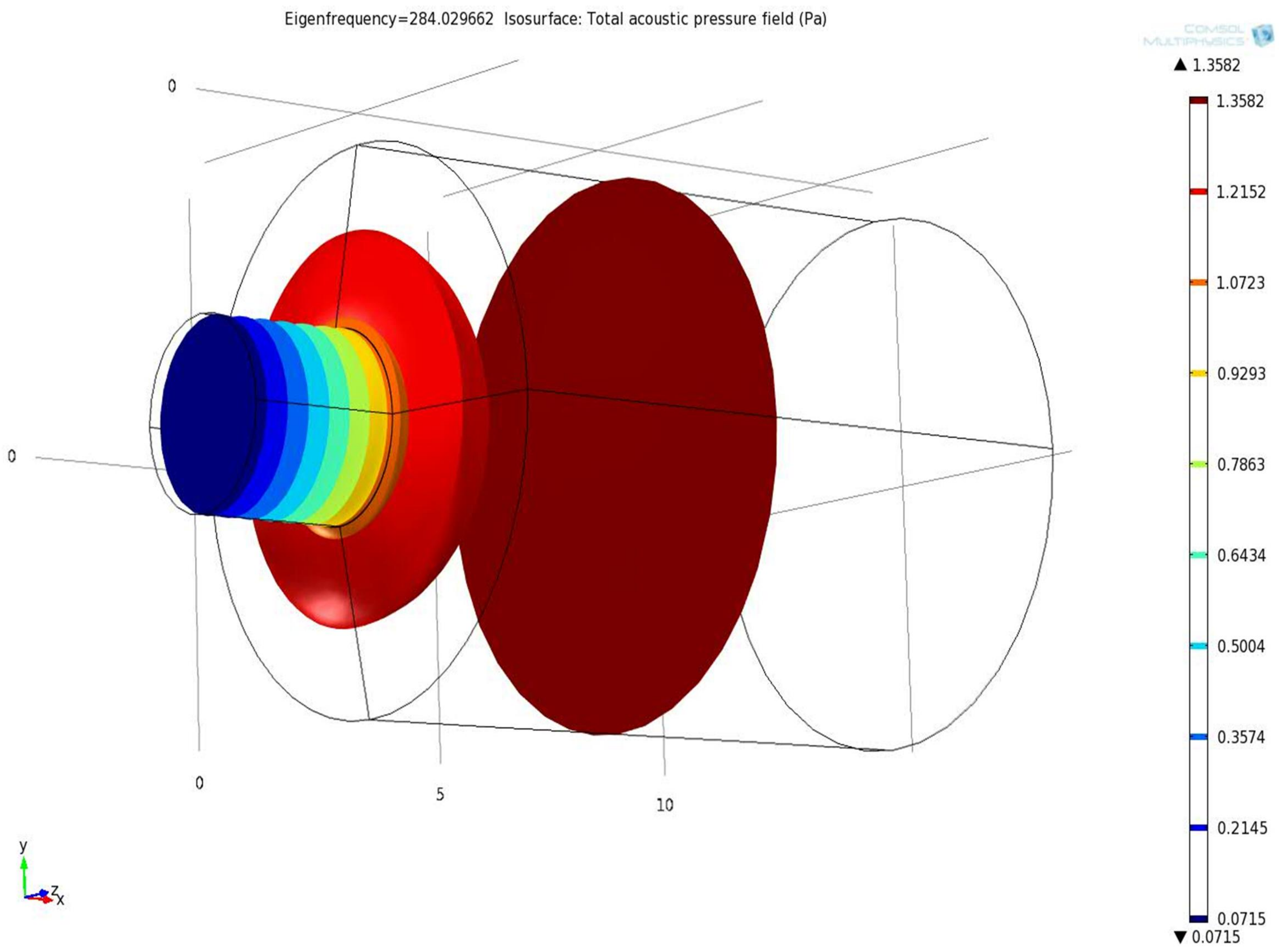


Figure 4. Total acoustic pressure inside the resonator

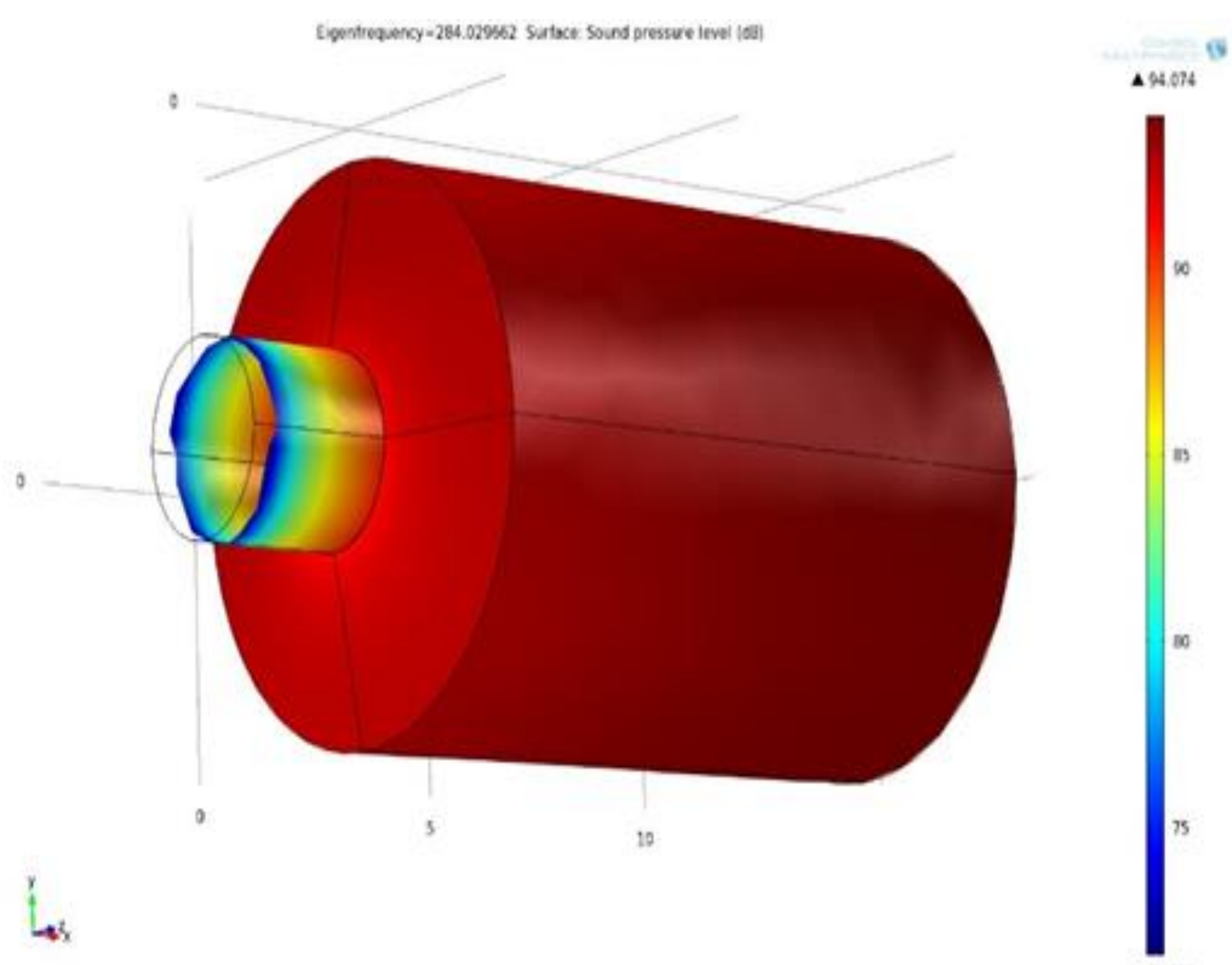


Figure 5. Sound pressure level inside the resonator

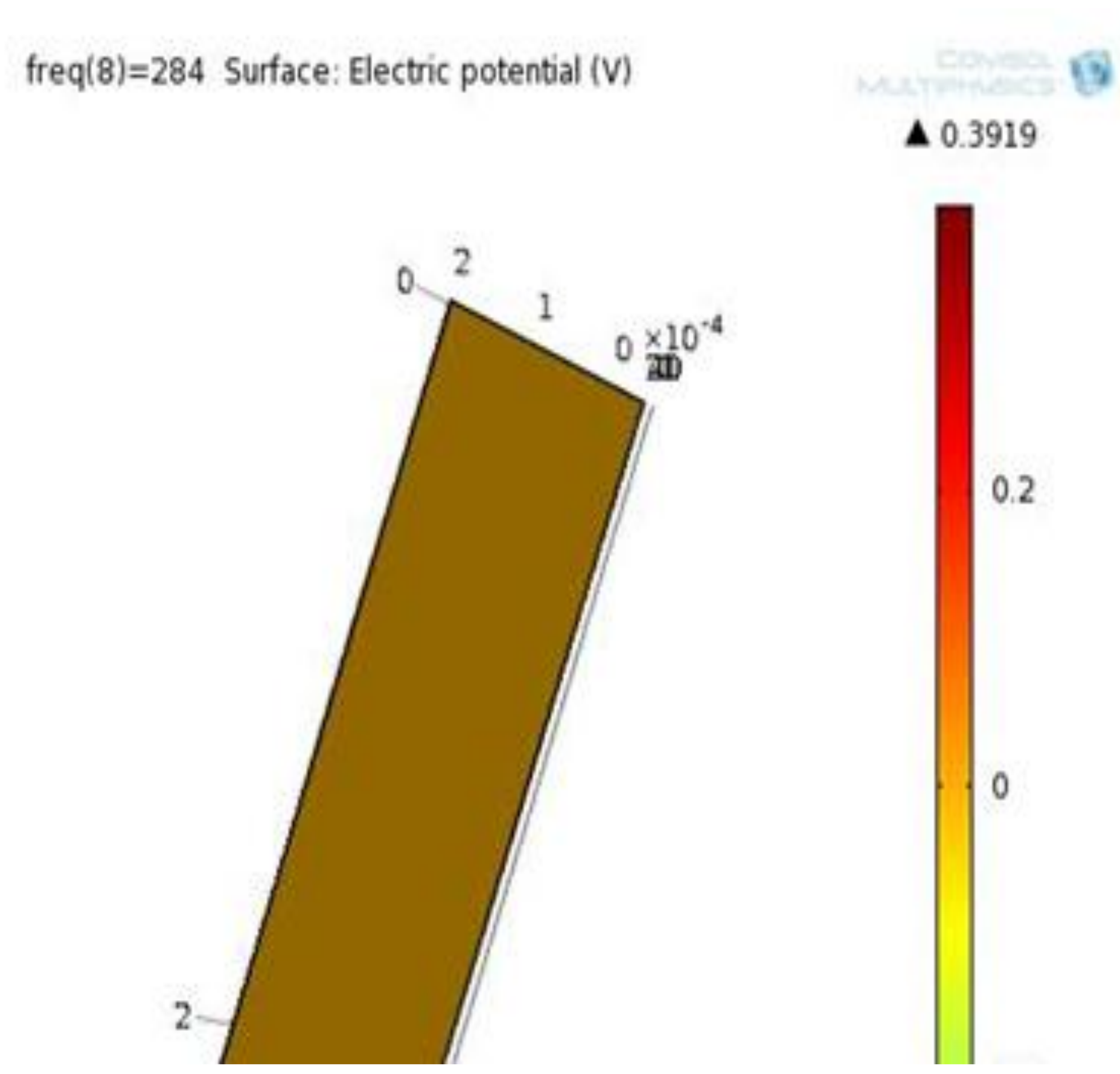
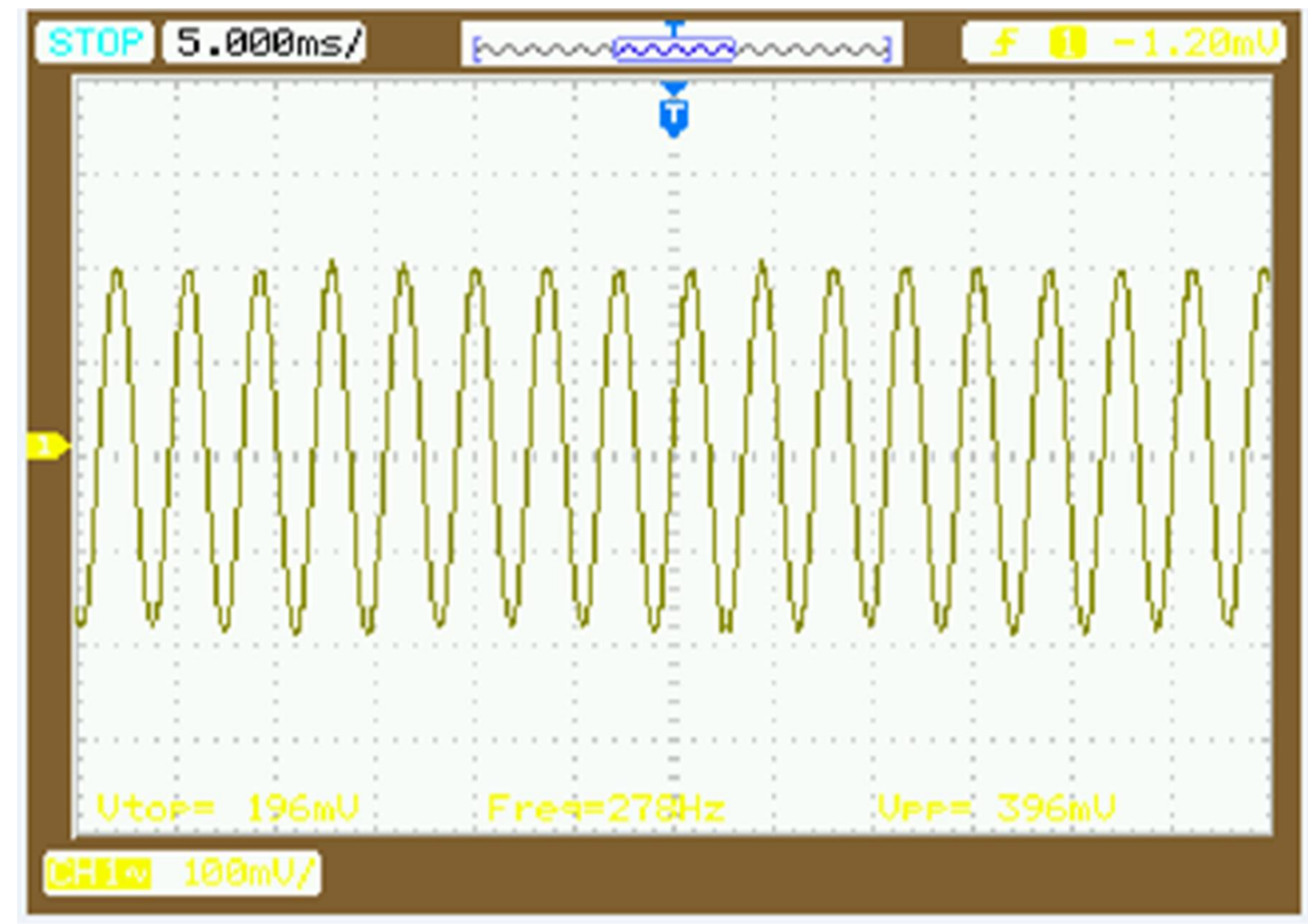


Figure 6. Harvested output voltage (Simulation)



Frequency= 278Hz, Vmax = 396mV

Figure 7. Output voltage measured using DSO

Eventhough the harvester was designed for a resonant frequency of 284Hz, during experimentation the maximum output voltage was obtained at 278Hz. This slight change in resonant frequency might be due to the imperfection in clamping the flexible piezo cantilever beam along the walls of the resonator.

Conclusion: When the resonator was geometrically tuned with piezoelectric cantilever the ratio of voltage obtained from the resonator with tapered neck to that of the resonator without tapered neck was about 0.60. After a particular value of slope of the tapered section the output starts decreasing as the tapered region hinders the plane waves inside the resonator. By optimizing dimension of the resonator and the coupling of the resonator to piezoelectric transducer, the harvested energy can be augmented.

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