# Vibrating Diaphragm using Piezo Film

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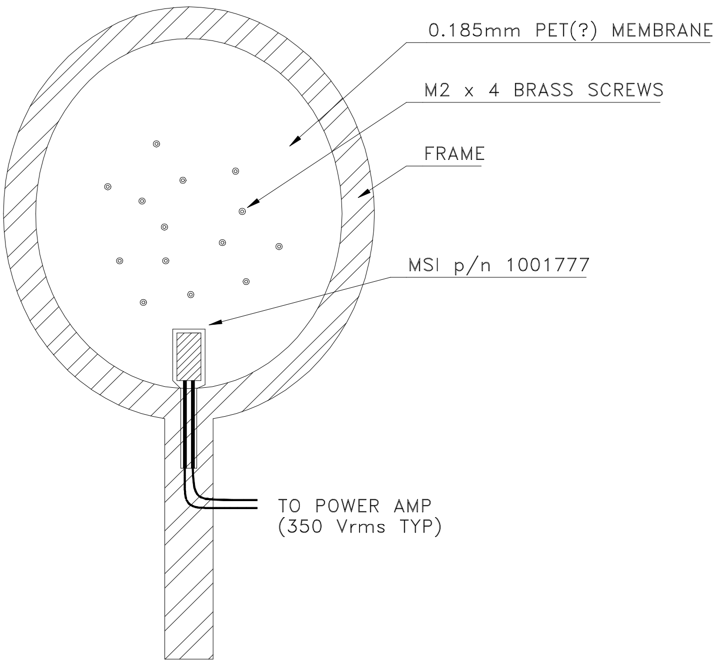
## Introduction

Responding to a customer's enquiry regarding the feasibility of using piezo film in "stretch mode" to induce reasonable vibration levels in a thin polymer membrane, a few simple trials were performed using a standard piezo film component driven as a vibration exciter. To ensure adequate mechanical output, a high voltage drive was used (up to 800 V peak-peak approx). Vibration output was monitored qualitatively using a microphone to detect the sound pressure level created by the diaphragm over a range of frequencies, and also using a piezo film element, identical with the vibration exciter, but connected with some additional electrical shielding as a dynamic strain gauge.

The example membrane comprised a toy racquet consisting of a rigid plastic frame and handle, with a tensioned transparent sheet (probably polyester) of 0.185 mm thickness and elliptical geometry (190 x 210 mm approx). After some initial exploration, loose brass screws (M2 x 4, approx 0.19 g mass) were distributed over the diaphragm to determine approximate vibration amplitude by analysing the noise output caused by the screws rattling.

Representation of experiment:



**Instrumentation:**

The receiver film element was buffered using a charge amplifier with 10 mV/pC sensitivity. The element had 1300 pF capacitance, and so a 0 dBV measurement at output of the charge amp corresponds with 100 pC rms charge output, and thus 77 mVrms (-22.3 dBV) true open-circuit sensitivity.

The microphone (B&K 4004) had a sensitivity of 10 mV/Pa, and so 0 dBV equates to 100 Pa rms or +134 dB SPL.

A high voltage drive was obtained using a MOSFET audio amplifier driving a 1:20 set-up transformer.

Signals were captured and analysed using an HP 3561A Dynamic Signal Analyzer. Signal sources for the transmitter comprised an HP 3314A function generator with continuous, N-cycle, and swept sine modes. A Crystal Audio sound card, installed in a Toshiba laptop computer, was used in some instances to record and process audio signals from the microphone, using GoldWave 4.02 waveform editor.

**Experiments:**

**1) Single versus dual transmitters**:

In first trials, a single transmitter film was used to supply mechanical energy to the diaphragm. Subsequently, an identical element was mounted on the opposite surface of the diaphragm, and connected in antiphase (one element pulling, the other pushing). The signal gain using two elements so connected was measured at approx +6.7 dB over a wide range of frequencies.

This dual transmitter arrangement was used in the further experiments listed below.

A separate trial was made using two transmitters diametrically opposed. In this case, the effect was more a modification of the apparent frequency response curve. Two different plots could be obtained (depending on the phase of the transmitter connections), with neither showing significant broadband gain over the response using a single element, but showing significant difference in the location of maximum amplitude.

**2) Comparison of piezo film receiver with microphone**

The “transmitter” pair of film elements (see above) was driven by a swept sine source (200 to 1 kHz) feeding a high voltage power amp (500 V pk-pk approx), and the response was detected by both an acoustic microphone located 75 mm normal to the center of the diaphragm, and a film element mounted diametrically opposite to the transmitter.

(See Fig 1)

This low frequency scan showed that many discrete resonances occurred over the surface of the diaphragm, although the piezo film "dynamic strain gauge" and the microphone showed slightly different profiles. Maximum amplitude of strain, as seen by the film receiver, occurred at around 650 Hz, while the sound pressure level measured at 75 mm stand-off was highest at 960 Hz.

It is natural to expect that, for a constant surface strain amplitude, the SPL (proportional to particle velocity) will increase with frequency - in fact, a single integration of the microphone signal matched the piezo film response curve quite closely. The difference in detail most likely arose from acoustic effects due to placement of the microphone, air resonances between the diaphragm and bench, and the location of the film receiver.

Under maximum possible voltage drive at 650 Hz (around 267 Vrms), the receiver film detected a strain level in the region of 8 µå (rms), corresponding to an absolute change in length of the sensor of 0.7 µm pk-pk.

### 3) Higher Frequencies

A sweep from 200 Hz to 20 kHz showed relatively "flat" overall frequency characteristic (as measured using the microphone), with maximum SPL occurring at 1850 Hz.

(See Fig 2)

### 4) Mechanical Power Output

To investigate the mechanical power output, a number of small brass screws (M2 x 4, mass 0.19 g) were laid out on the diaphragm with random spacing, heads downwards. The drive frequency (continuous sine) was stepped from 300 to 1400 Hz in 100 Hz steps, while the acoustic output was recorded for each frequency using the microphone. Sufficient screws were used to cover entire diaphragm area with reasonable density.

It was found that the vibration induced in the screws (which caused a characteristic rattling sound) was relatively constant for frequencies between 500 and 1000 Hz. It seemed that, once the amplitude was sufficient to create rattling, this condition tended to persist without reflecting the individual resonance frequencies of the diaphragm too strongly.

To give a relative measurement of this acoustic "noise", the spectral energy within a band from 3 kHz to 12.5 kHz was computed. This band was chosen to avoid too much contribution to the band spectral energy sum from the discrete harmonics of the drive signal.

(See Fig 3)

The experiment was repeated, using the sound card to acquire a 16 s "sweep", again using microphone detecting "rattle" mixed with the drive signal. The time trace is shown in Fig 4.

Finally, the above waveform was played back and viewed as a spectrogram (frequency as y-axis, time as x-axis, magnitude represented by colour variation. The screen-shot is shown in Fig 5.

The spectrogram shows the relative uniformity of “noise” generation by the screws during the sweep, with peak level judged to occur at around the same instant as peak amplitude on the time plot above, corresponding to approx 850 Hz.

At several frequencies, the vibration amplitude was sufficient to cause at least one screw to topple over. All screws were noted to “walk” or move about while any frequency in the range of 500 to 1000 Hz was applied.

## 5) Effect of damping

Some attempts were made to damp the diaphragm, by pressing it firmly down over a thickness of open-cell foam. Strain levels (as measured by the piezo film receiver) were reduced by approximately 10 to 12 dB, as can be seen in the overlaid plots of Fig 6.

## 6) Further Observations

The voltage drive to the transmitter(s) was dependent on a step-up transformer, which showed signs of core saturation at high levels. This resulted in increasing levels of distortion (for a pure input sine wave). The harmonics themselves were able to stimulate resonances within the diaphragm, so the detected strain signals showed even higher THD (distortion) than the applied drive voltage.

A single transmitter had 30 x 12 mm active area, equivalent to 1.1% of exposed diaphragm area. Increasing the driven (active) area would be expected to increase vibration levels accordingly.

In order for an M2 x 4 screw, initially placed with its head lying the diaphragm, to topple over, the screw must be tipped up through an angle of 47°. The head has a bevelled edge which makes toppling easier. Toppling could occur within the first second of application of excitation, depending on the placement of the screw. If the diaphragm was tilted slightly, a wide variety of objects would slide downwards when excitation was applied, but remain stationary if no drive signal was applied. The vibration on the diaphragm significantly reduced the friction between the object and the diaphragm.

**Conclusions:**

- Significant vibration levels can be induced on a polymer membrane using piezo film elements to induce longitudinal forces, using field strengths in the region of 25 to 30 V/µm.
- A pair of transmitter elements, co-located with one on each side, driven in opposite phase, results in twice the vibration level of a single transmitter.
- A tensioned diaphragm shows a complex pattern of resonances, most of which can be successfully excited by piezo film. Different geometries will show different responses.
- The acoustic output of a driven diaphragm (from normal acceleration of regions of the surface) shows a different profile to the strain signals detected at the edge. Vibration “effect”, as detected by rattling of loose pieces, appeared to follow the strain profile more closely.

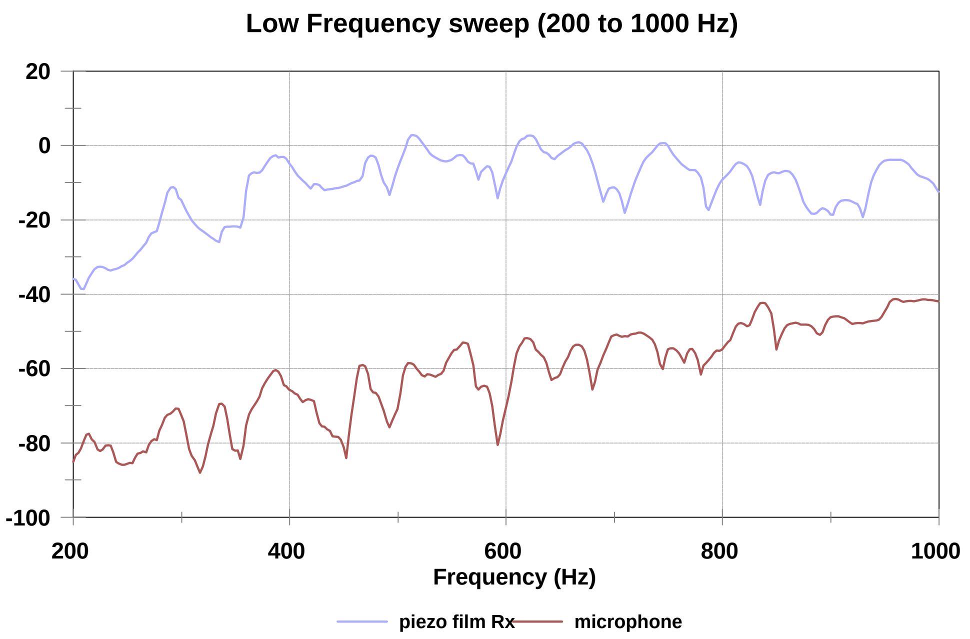



**Figure 1: Low frequency response of diaphragm, driven by swept sine**

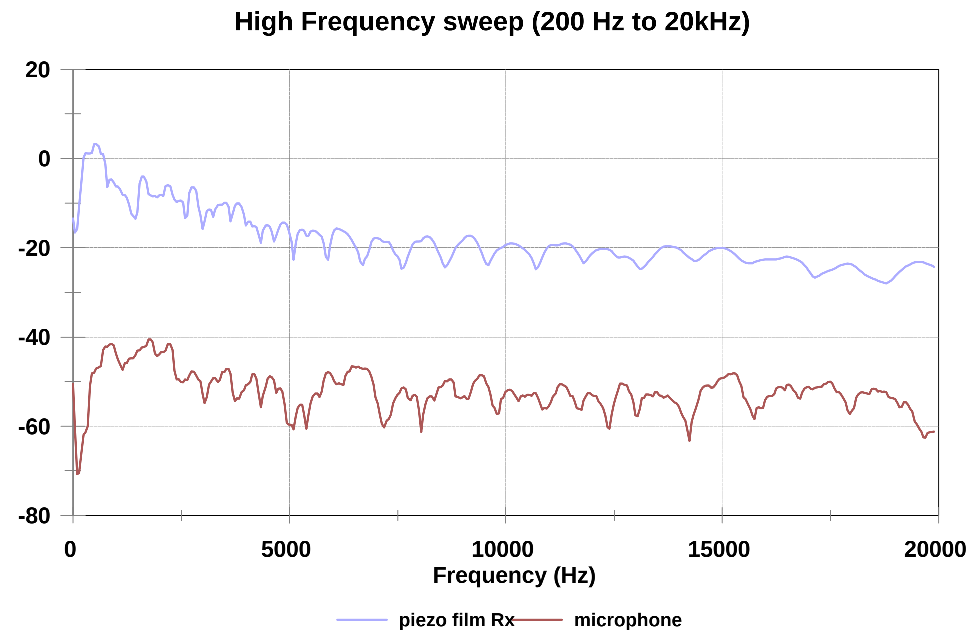



**Figure 2: High frequency response of diaphragm**

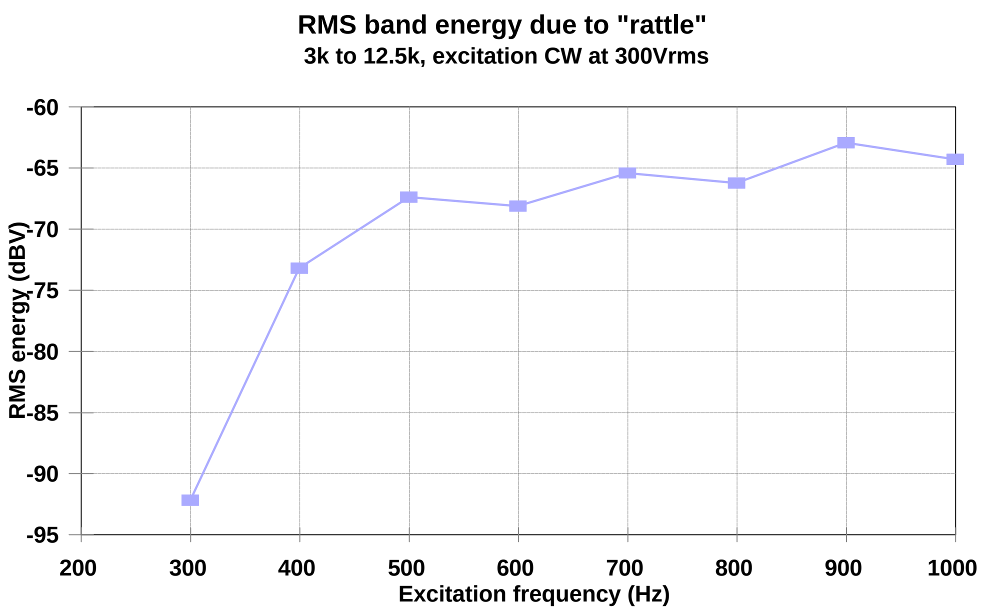



**Figure 3: “Noise” output due to screws rattling, at selected frequencies**

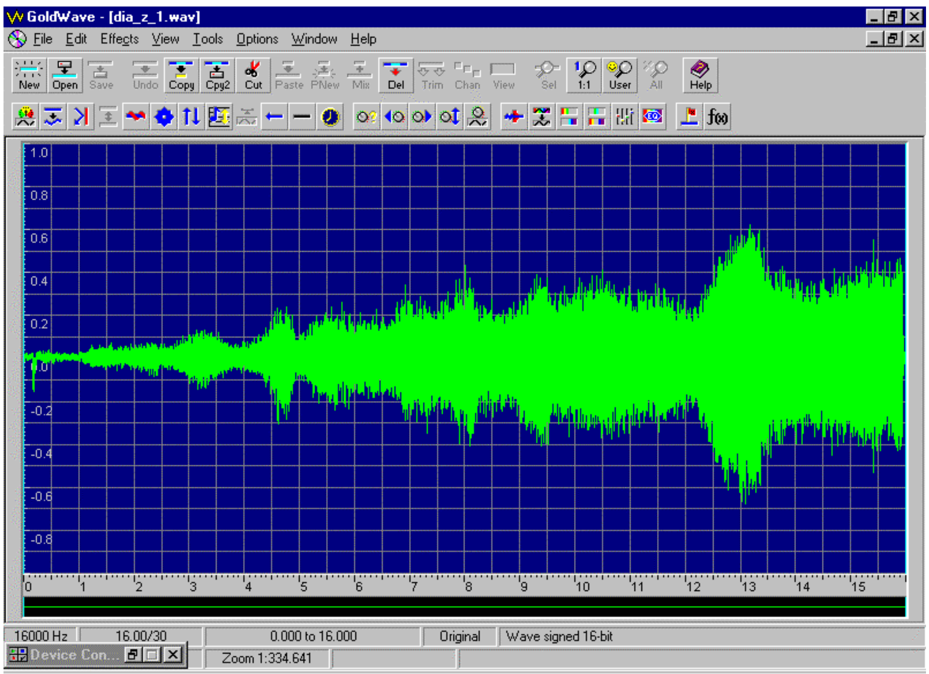



**Figure 4: Microphone output, 200 to 1000 Hz sweep, with screws rattling on diaphragm**

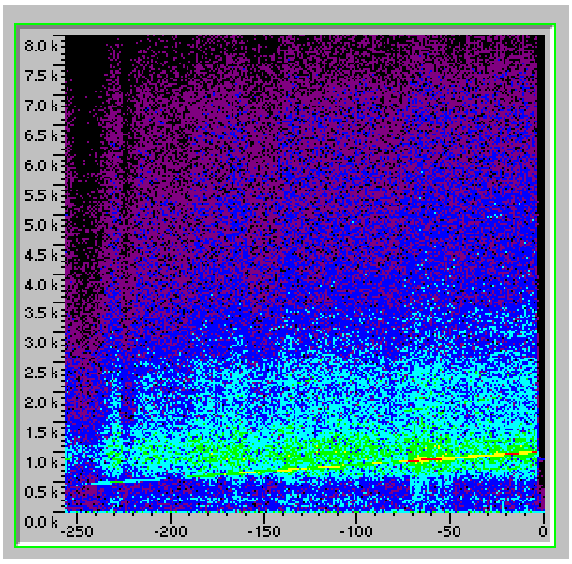



**Figure 5: Spectrogram from trace of Fig 4, showing relatively uniform noise generation over 500 to 1000 Hz approx**

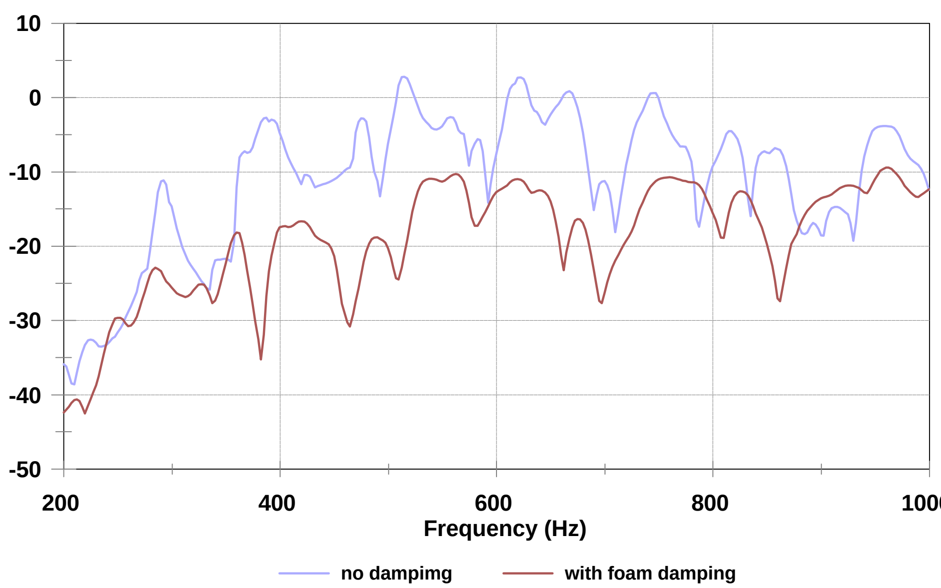



**Figure 6: Effect of adding damping foam behind diaphragm on strain signals seen by piezo film receiver**

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