Application Note: Pyroelectric Response in PVDF

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The pyroelectric sensitivity of PVDF is well known, and the material has been used within a variety of commercial applications, including passive infra-red "people detectors", infra-red imaging arrays, and fingerprint sensors. For more details of the pyroelectric properties of PVDF and comparison with other sensing materials, see the Piezo Film Sensors Technical Manual, Part 7 "Pyroelectric Basics", http://www.msiusa.com/PART7-INT.pdf

This article is split into two distinct sections: the first presents some measured results obtained using a large sheet of film as a detector, while the second part extrapolates data obtained from a small area detector used with a chopped source, to provide an overview of sensitivity as a function of chopping frequency.

(a) Experimental results using 15 x 30 cm sheet of 28 µm thickness PVDF

A large sheet was selected, to demonstrate that the material may serve as a large-area detector of radiation. The silver-ink electrodes (screen-printed on each side of the flm) reflect much incident light, but absorb a little. To enhance the absorption for this experiment, the ink surface was crudely coloured black using a felt marker pen. For custom devices, carbon-based ink is offered by Measurement Specialties, Inc as an alternative electrode material and is an excellent absorber.

The PVDF sheet was bonded onto a large surface of cardboard packaging material, and connected to the input of a charge preamplifier (modified B&K Type 2635, with lower limiting frequency to –1% of 0.02 Hz). The blackened target area was then exposed to four sources of radiation:

1) a battery-powered flashlight, held at 2.2 m distance, creating a central beam of approximately 20 cm diameter
2) a 60W incandescent light bulb (frosted), creating quite uniform diffuse light field, mounted at 1.7 m distance
3) an adult wearing dark clothing, standing at 1.7 m distance
4) beam from a low power HeNe laser (approx 0.5 mW, 633 nm wavelength)

In cases 1, 2 and 4, the exposure was instantaneous. In case 3, the person walked quickly into position from side, which created a noticeably slower initial change in response.

The charge outputs for each event are plotted in the attached page. All show an apparent rise to maximum output at 12 to 18 seconds after initial exposure, but note that the time constant of the charge preamplifier was 15.9 s, and therefore it is very likely that the true peaks were higher, and occurred after a longer elapsed time. The thermal time constant of the pure PVDF film is estimated to be around 0.9 s, and these observed plots reflect the longer time constant of the whole film/adhesive/cardboard assembly.

Note that the plots show "one-shot" events, with no signal averaging. Small corrections to subtract any DC offset present at time of exposure have been made.

Peak charge outputs:

1)	flashlight:	92.4 nC	equivalent to 0.71 V open-cct
2)	60 W bulb:	23.9 nC	equivalent to 0.20 V open-cct
3)	adult:	8.8 nC	equivalent to 68 mV open-cct
4)	HeNe laser:	0.21 nC	equivalent to 1.6 mV open-cct

(the quoted equivalent open-circuit voltages relate to this particular large sheet, with capacitance 130 nF).

Technical notes: the Type 2635 charge preamplifier normally offers low frequency limits of 2 Hz and 0.2 Hz. The unit used in the above experiment had been modified by the manufacturer to offer 0.02 Hz response (all to –1%). The equivalent –3 dB roll-off frequency is 0.01 Hz, giving a time constant of 15.9 seconds.

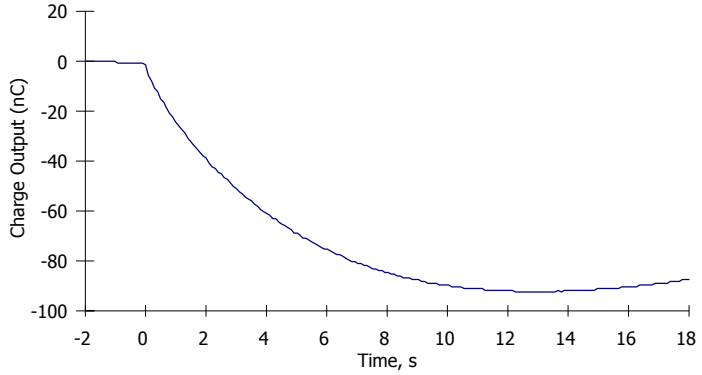
An input sensitivity of 10.00 pC/unit, and output gain of 0.1 mV/unit was used for trials 1 to 3 above, giving overall preamplifier sensitivity of 10 mV/nC. In trial 1, using the flashlight, the charge signal almost overloaded the input stage of the preamplifier (for this reason, the distance between source and target was increased to 2.2 m, rather than 1.7 m as used in 2, 3 and 4). For trial 4, the preamplifier sensitivity was increased by a factor of 10.

Signals were recorded on an HP 3561A dynamic signal analyzer, set to 40 s time length, input range selected according to signal strength, but generally 0 dB to –20 dB.

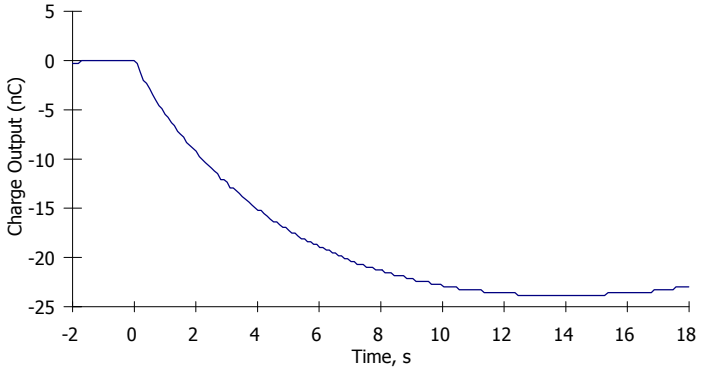
The long time constant of the measuring circuit naturally resulted in prolonged settling time after any disturbance to the signal. In particular, "recovery" from a stimulus (such as the cooling down after source illumination was turned off) tended to create long, slow oscillation. Background thermal "noise" events such as draughts or even changes in sunlight could be seen to create significant response. Although distinct signals were successfully recorded from each form of stimulus, only the flashlight beam was sufficiently strong to be easily recorded without patiently waiting for a "quiet moment".

Because of exactly this kind of resolution issue, it is generally preferable to arrange a chopped (interrupted) source of illumination, which is dealt with in the next section.

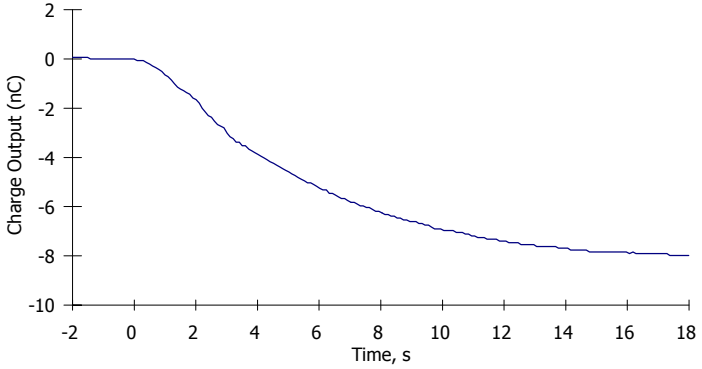
Flashlight @ 2.2 m



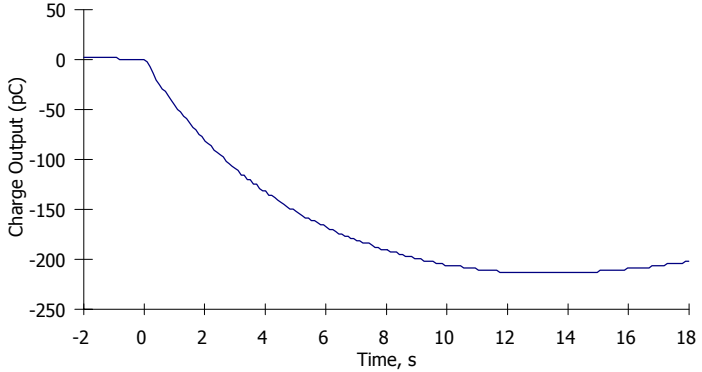
60W bulb, @1.7 m



Adult, @1.7 m



HeNe Laser



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(b) Chopped Irradiation

As mentioned in section (a), chopping a source of illumination or irradiation has an advantage in that a specific frequency of signal can be looked for, rather than the very slow excursions resulting from continuous exposure. A test was set up, where a low power (0.5 mW approx) HeNe laser beam was directed through a slotted rotating disc, with the chopped beam falling on small samples of PVDF film (colored with marker pen) supported over an aperture so that the film was unrestrained and un-backed at the area of incidence. By controlling the motor drive to the disc, a wide range of chopping frequencies could be applied.

Testing of both 9 µm and 52 µm samples confirmed that the charge response, at very low frequency, was independent upon the film thickness, but that each film showed a thermal time constant proportional to its thickness. For the 9 µm film, the thermal TC was 0.48 s, corresponding to a single-order low-pass roll-off frequency of 0.33 Hz.

From these results, a family of curves have been generated which show the effect of chopping frequency on charge sensitivity, open-circuit voltage sensitivity, and observed sensitivity using practical elements of film in voltage mode, connected to fixed resistive input loads.

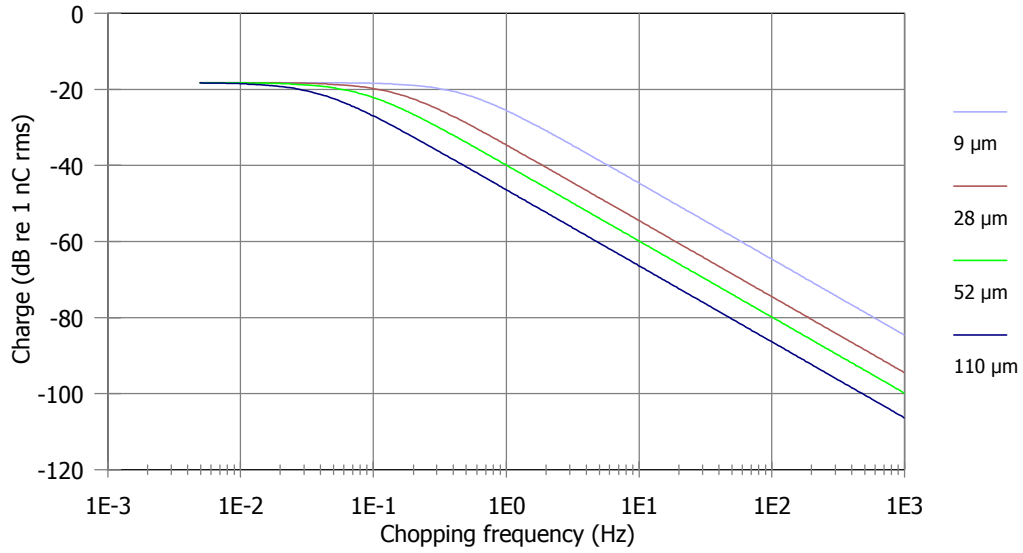
As noted above, the charge response of any PVDF film thickness is identical (within normal film tolerance limits) at very low chopping frequency. The measured value for this particular arrangement was found to be around 123 pC rms (for approx 0.5 mW laser at 633 nm). The curves for each film thickness in the first of the attached plots show the various "low-pass" roll-off frequencies.

If the active film area is assumed to be a 3 mm diameter spot, then the effective open-circuit voltage sensitivity corresponding to these pure charge outputs can be calculated simply by dividing each result by the source capacitance. The displayed open-circuit sensitivities indicate that, at extremely low chopping frequency, the thickest film gives highest voltage output (as expected), but that as chopping frequency increases, the response curves for any thickness fall along the exact same line.

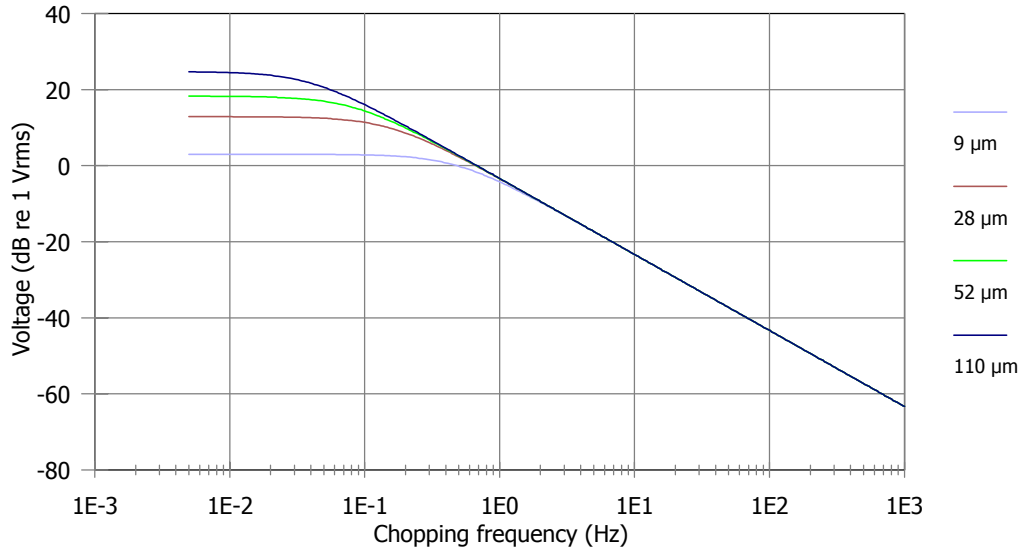
True open-circuit conditions for such a small target area are, of course, virtually impossible to create. The calculated open-circuit curves were then used in conjunction with R-C high-pass filter curves (assuming fixed input R, and film C varying with film thickness), to obtain practical results for several different input resistance values.

The result of this product of low- and high-pass filters are quite interesting. At R = 100 Megohm, the thinnest film gives around 10x (+20 dB) the output of the thickest film, in the region of 1 to 10 Hz chopping frequency. As the input R value is increased to 1 G, the sensitivities of all thicknesses rise accordingly, but the "flat" frequency band narrows, and moves to lower center frequency. For R = 50 G, the response from all 4 thicknesses is very close to identical, with the extreme thicknesses (9 and 110 µm) actually giving lower output in the region of 0.1 Hz. Not until the input R reaches 1 T (10^{12} ohms) does the overall profile begin to resemble the open-circuit condition.

Charge Output

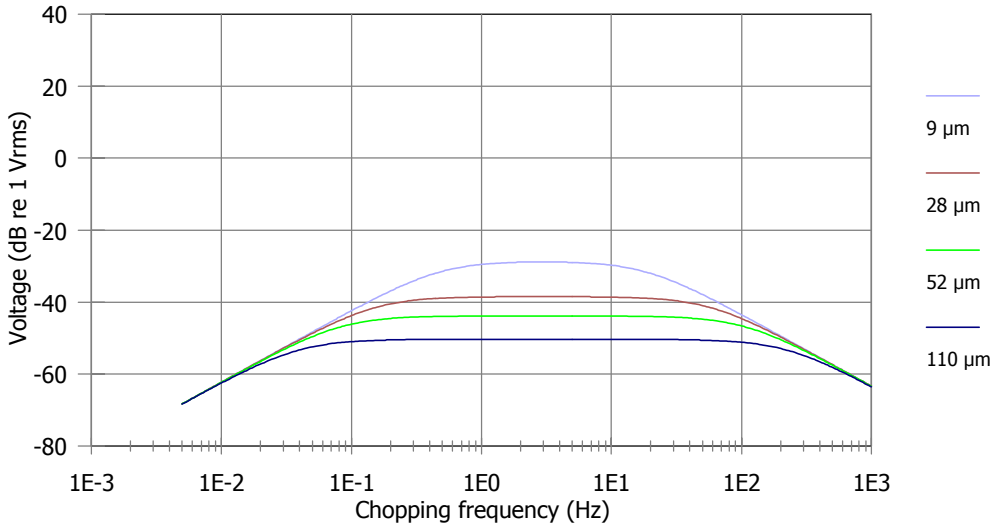


Open-circuit Voltage Output



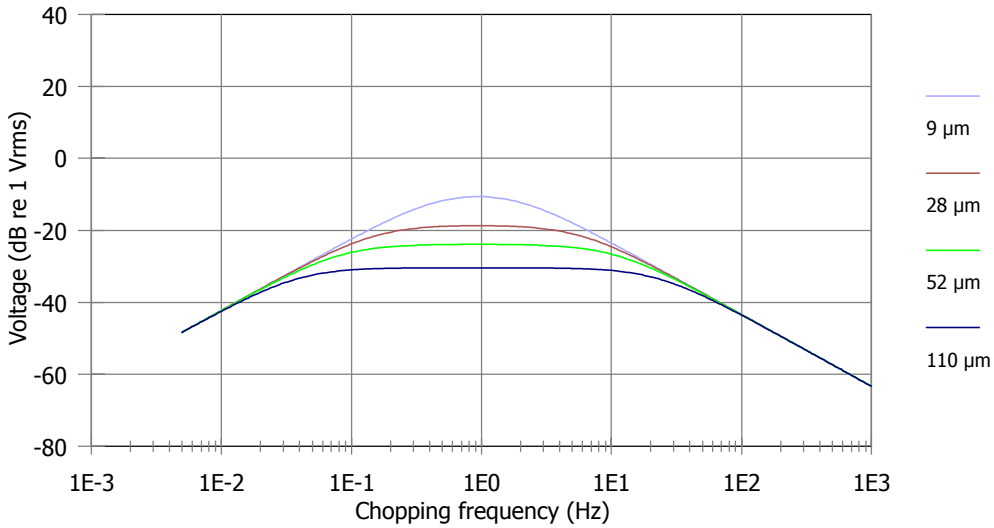
Voltage Output into fixed load R

R = 100 M ohm



Voltage Output into fixed load R

R = 1 G ohm



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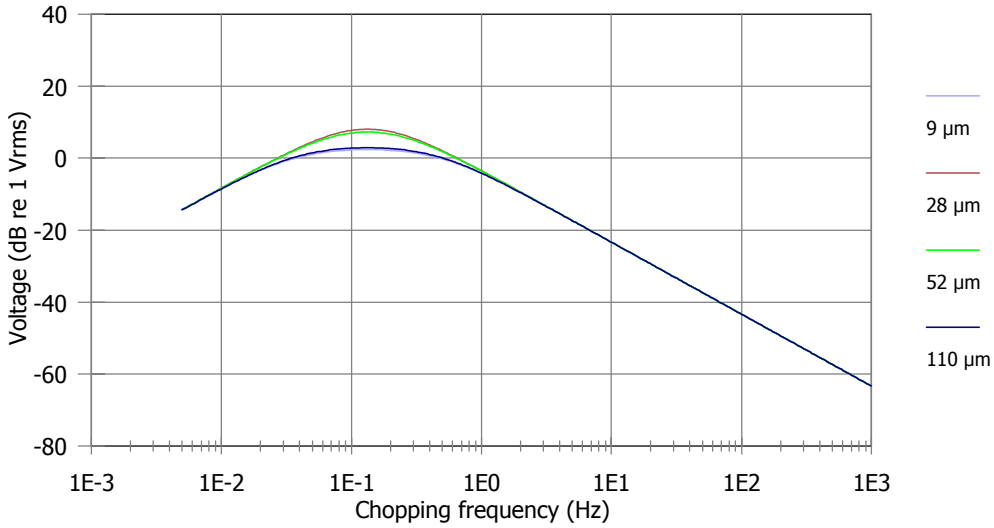
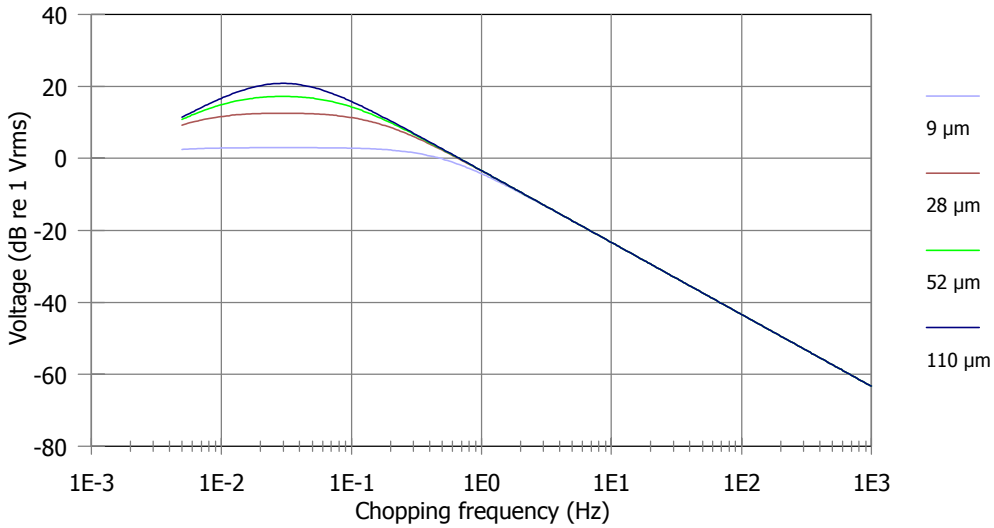
Voltage Output into fixed load R

R = 50 G ohm



Voltage Output into fixed load R

R = 1 T ohm



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