Determining maximum power output of cantilever based Piezoelectric Energy Harvester under various resonant conditions

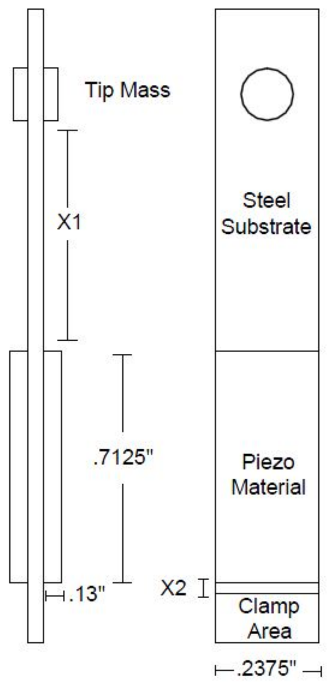
Kurt VonEhr*
Padnos College of Engineering and Computing, Grand Valley State University
(Dated: March 4, 2014)

Piezoelectric devices will produce varying outputs (voltage, current, etc) depending on the resonance of their structure. For this experiment, the structure under study will be a single bimorph piezocantilever containing a steel sheet metal substrate. Without performing a complex mathematical analysis of the systmem, a rough optimization of a piezoelectric cantilever harvesting system can be obtained through experimentation. In this experiment, the maximum power output of the energy harvesting device will be determined by measuring the charge accumlated on a storage capacitor of known capacitance, after a consistent number of plucks and pluck angle for each particular resonant configuration. The resonance will be varied by moving a tip mass to different positions along the cantilever arm. The cantilever substrate will be assumed to be massless with respect to the tip mass. The results should illustrate which length will maximize the power output of the cantilever arm when plucked. This experimentation is necessary in order to prototype design a roughly optimized Harvesting Node Device (HND). This device will contain 12 cantilever harvesting arms and be used to transmit data. The HND is the driving motivation of this experiment.

PROCEDURE

Due to the unique structure of the desired HND (not in the scope of this report), a non-commercial piezo cantilever device must be constructed. A piezo sheet of size 2.85in x 2.85in was purchased and is the starting point for the piezo dimension choices. The design of the HDN will include 12 bimorph cantilevers. To optimize the available piezo material for 12 cantilevers, the dimensions of each bimorph structure will be as shown in Fig. 1 below:

FIG. 1:



Cantilever.jpg

There are two different regimes of operation for a transistor when it is on. In the linear regime, the current that flows into the collector is proportional to the current that flows into the base:

$$I_c = \beta\, I_b\,. \tag{1}$$

The constant β is large, typically $100 - 200$, and effectively constant over the linear regime [**?**]. Because the current that flows into the collector is negligible when the transistor is operating in the linear regime, the current that flows out of the emitter is essentially equal to the current that flows into the collector

$$I_e \approx I_b\,. \tag{2}$$

Finally, the transistor maintains a fixed voltage between the base and the collector. Referred to as $V_{be} \equiv V_b - V_e$, this value is approximately

$$V_{be} \approx 0.6\,V\,. \tag{3}$$

The three equations 1, 2, and 3 may be used to analyze a transistor operating in the linear regime.

The transistor will not operate as described above if I_b becomes too large. When this happens the transistor is said to be *saturated* and β is no longer constant. When the transistor is saturated the voltage difference between the collector and the emitter drops to $V_{ce} \equiv V_c - V_e \approx$ 0.1–0.4V while for a transistor operating in the linear regime this difference is always at least as big as V_{be} so that the voltage hierarchy $V_b > V_c > V_e$ is preserved. The experiment performed here will provide a quantitative measure of how large I_b needs to be to drive the transistor into saturation mode.

PROCEDURE

The circuit used to determine β for the 2N2222 transistor is shown in Figure **??**. The base current I_b is controlled by the variable resistor R. Applying Ohm's Law to the base leg of the circuit gives

$$5\,V - I_b\,R - I_b\,4.7\,\mathrm{k}\Omega = V_b\,. \tag{4}$$

Equation 3 applies to both the linear and saturated regimes and we therefore expect the base-emitter voltage difference of the transistor to be $V_b - V_e \approx 0.6\,\mathrm{V}$. Combining this with Equation 4 we see that the base current will be given by

$$I_b = \frac{4.4\,V}{R + 4.7\,\mathrm{k}\Omega}\,. \tag{5}$$

The experiment is set up so that we will measure the collector current I_c directly. We can use this to determine the value of V_c by applying Ohm's Law to the collector leg of the circuit:

$$+12\,V - I_c\,R = V_c\,. \tag{6}$$

RESULTS

The collector current I_c was measured for a range of resistor values R between 0 and $1\,\mathrm{M}\Omega$. The results are shown in Table I. For each value of R, I_b was calculated using Equation 5 and V_c was calculated using Equation 6. From the measured value of I_c and the calculated value of I_b, β was calculated according to Equation 1.

TABLE I: Experimental data. For each value of the variable resistor R, the collector current I_c was measured, and the collector voltage V_c, base current I_b and proportionality constant β were calculated according to Equations 6, 5, and 2 respectively.

R (kΩ)	I_c (mA)	V_c (V)	I_b (mA)	β
0	11.67	0.04	0.94	12.4
47	11.54	0.17	0.09	130
100	8.33	3.3	0.04	189
470	1.90	9.78	0.01	196
1000	0.9	10.75	0.005	196

Figure **??** shows a plot of β versus the resistance R. For values of R of $100\,\mathrm{k}\Omega$ and above, the transistor is clearly operating in the linear regime and β is approximately constant and equal to $\beta \approx 190$. From Table I we see that these values of R correspond to base currents of $I_b < 50\,\mu A$. We also see from Table I that for these values of R the voltage hierarchy is satisfied with $V_c > V_b = 0.6\,V$.

DISCUSSION

This experiment has shown that the 2N2222 transistors operate in the linear regime for base currents of $I_b < 50\,\mu A$ and that for base currents in this range the voltage hierarchy is satisfied. When operating in the linear regime, it has been verified that the base and collector currents are proportional with $\beta \equiv I_c/I_b \approx 190$.

The experiment could have been improved by measuring the actual voltage of the $+12\,V$ and $+5\,V$ terminals, and by directly measuring the voltage difference V_{ce} between the collector and the emitter. Since our determination of I_b (and therefore β) relied on knowledge of these values, it would have been preferable to measure them directly.

* vonehrk@gvsu.edu