# WIRELESS TIRE PRESSURE MONITORING BY EMPLOYING KINETIC ENERGY HARVESTING


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## 1. Introduction

Energy harvesting is the process of collecting low level ambient energy and converting it into electric power. Harvesting of kinetic energy of vibrations via piezoelectric bimorphs is advantageous as it is characterised by design simplicity, miniaturization and integration potential and high power densities. A metallic cantilever covered with piezoelectric material is thus placed in a vibrating environment. Charge is hence accumulated at the piezoelectric surface and used to power electric loads. A special interest in these devices is evident in the development of autonomous sensor nodes for ubiquitous wireless networks (Priya and Inman, 2009). On the other hand, tire pressure monitoring (TPM) has been proven to be extremely important when considering passenger safety. Correct tire pressures save lives and drastically improve tire lifetimes (Álvarez et al., 2008). Taking, however, into consideration the recent USA and EU acts, which impose TPMs in all new vehicles, a total of 10 batteries are to be disposed into the environment in a car lifetime. In this work an original solution of a wireless TPM system powered by a piezoelectric bimorph harvester is presented.

## 2. Piezoelectric energy harvesters

In order to have a quick yet accurate tool for tuning the response of a piezoelectric harvester, a modal model of the uncoupled mechanical behaviour of a tip-loaded cantilever is considered (Figure 1). Taking into account the Euler-Bernoulli beam theory and following the modal expansion method (Genta, 1998), the uncoupled eigenfrequencies of the cantilever are thus obtained.

The coupled electromechanical behaviour of the studied devices can be modelled following the recently introduced model (Erturk and Inman, 2009). For a vibration frequency $\omega$ close to the eigenfrequency $\omega_n$ and a downstream resistive load $R_L$, the Frequency response function (FRF) voltage output $\alpha_s$ can hence be expressed, in terms of the electromechanical parameters $\kappa_n$, $\sigma_n$, $C_P$ and $\chi_n$, as:

$$\alpha_s(\omega) = \frac{\displaystyle\sum_{n=1}^{\infty} \frac{j\omega\kappa_n\sigma_n}{\omega_n^2 - \omega^2 + 2j\zeta\omega_n\omega}}{\displaystyle\frac{1}{R_L} + j\omega\frac{C_P}{2} + \sum_{n=1}^{\infty} \frac{j\omega\kappa_n\chi_n}{\omega_n^2 - \omega^2 + 2j\zeta\omega_n\omega}} \qquad (1)$$

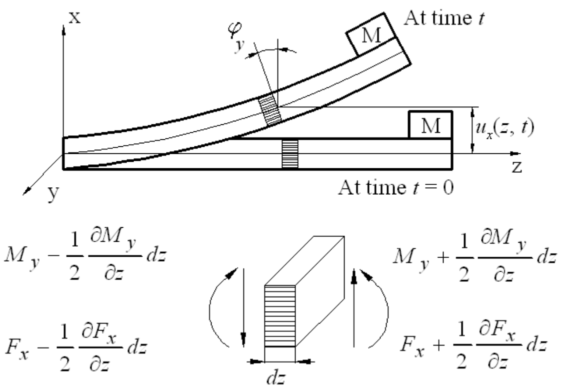


**Figure 1.** Uncoupled modal model.

The FRFs of output voltages (Figure 2) and powers of commercially available piezoelectric bimorphs, obtained on a suitable experimental set-up, correspond well to the coupled model results (Zelenika and Blažević, 2010). Due to electromechanical coupling, an increase of electrical loads has hence a nonlinear hardening effect on the dynamic behaviour.

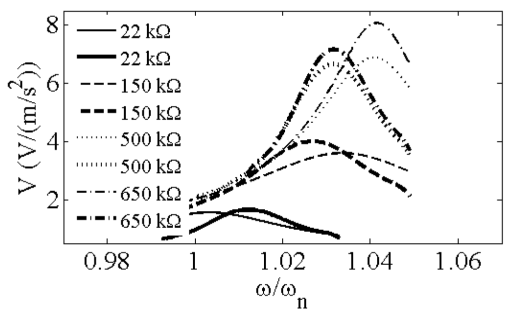


**Figure 2.** Experimental (thick) and coupled model (thin lines) voltage FRFs for $R_L$ = 22 ... 650 kΩ.

## 3. Wireless Tire Pressure Monitoring

Vibration as energy source is abundant around motor vehicles but on-road tests allowed establishing that its amplitudes and frequencies are far from the regular harmonic conditions considered in the design of piezoelectric scavenging devices – see Figure 3.

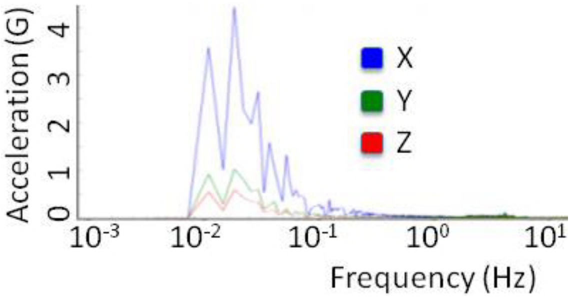


**Figure 3.** FFT diagrams of measurements on a car tire in open road conditions at 70 km/h.

Based on all of the above, an original Wireless Tire Pressure Monitoring System (WTPMS) was developed. It consists of a properly designed miniature piezoelectric bimorph with matched impedance; an off-the-shelf energy harvesting power supply chip (Linear Technology, 2011) that interfaces to the piezoelectric source, conditions and stores the produced energy and drives via a capacitor the pressure sensor; and a FreeScale MPXY8300 TPM module comprising a capacitive pressure sensor, a microcontroller and an RF transmitter (FreeScale, 2009). At specific time intervals, sensor data is hence accessed, analyzed and placed into the buffer for wireless transmission.

**Figure 4.** WTPMS device mounted on the car tire rim.

## 4. Obtained results

Experiments on the WTPMS were carried out on the set-up used for bimorphs' dynamic characterization. Tire pressure data could be successfully acquired and transmitted to the receiver proving thus the concept in laboratory conditions. By designing suitable interfaces, the WTPMS was mounted then on a tire rim (Figure 4). About 6.5 mW were obtained in open road conditions, allowing the WTPMS to be powered while acquiring pressure data and transmitting it to the receiver in the car cockpit.

## 5. Concluding remarks

The uncoupled and coupled behaviour of piezoelectric scavengers was thoroughly studied. This has allowed integrating such devices into an innovative WTPMS module. Its full functionality was proven both in laboratory and in real on-road settings. The extension of the concept to a commercial solution that could be applied also in other fields (e.g. human or structural health monitoring) is being pursued.

## Acknowledgements

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## 6. References

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