Evaluation of a MEMS based theft detection circuit for RFID labels

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Passive labels have no power source but obtain power from the incident RF signal.

Active Tags have an on board power source. They may backscatter a reply or may be independent reply generating labels.
Active RFID labels

- Backscatter labels.
  - Operating range of tens of meters.
  - Battery used only to power logic circuits.

- Independent reply generating labels.
  - Range of several hundred meters.
  - Battery is used for transmitting and powering the logic circuits.

- Power conservation is an important issue.
  - Labels should be turned "off" when not interrogated.
  - Life time of the label should commensurate the shelf life of the labeled commodity.

- Need to create a solution that addresses
  - Theft detection
  - Power conservation

- This paper considers Active labels operating in the UHF ISM band.
  - 902-926 MHz (FCC Regulation in the USA).
The proposed theft detection circuit is a zero power turn-on circuit for active RFID labels that will rely on generating a voltage of the order of 1V that can turn a CMOS transistor from fully off to fully on when triggered by a low frequency large volume magnetic field.
The low frequency large volume magnetic field provides the trigger for the MEMS circuit. Such a field can be setup in and around the vicinity of a large corridor exit to turn the MEMS theft circuitry “on” when a thief attempts to flee with stolen goods.
Large volume LF field

**Trigger field**

- Use of an unlicensed frequency in the LF spectrum.
- Frequency large enough to prevent false triggering.
- Consider the use of 130 kHz trigger frequency.
- Need to consider practically achievable magnetic fields at 130 kHz.
  - Coil diameter 3m, coil wire diameter 10 mm, Power 50 W,

\[
H_z(z) = \frac{Ia^2}{2\left(a^2 + z^2\right)^{3/2}}
\]

![Graph showing the magnetic field profile](image)
Magneto-electroacoustic energy conversion

- Requires a 1 V from the MEMS device
  - Approximate voltage required to turn on a FET
  - FET will form a switch that will activate the theft detection logic
  - In case of a theft
    - the label will alter the nearby readers and
    - transmit a beacon at full power for the duration of the battery.
      - Allows the thief to be tracked.

- The power generated from the MEMS device is rectified and used to turn on the theft detection circuit.
Magneto-electroacoustic energy conversion

◆ RMS voltage available to turn on a FET

\[ V_{TO} = \sqrt{k_{eff}^2 Q_m^2 (Mv\mu_0)^2 |H|^2 C_{22S}^2 \frac{2}{C_J C_{22eff}}} \]

\[ k_{eff}^2 = \frac{r k^2}{(1+r)^2 - k^2(1+r)} \]

is the effective electromechanical coupling factor of the MEMS structure.

\[ C_{22eff} = \left[ 1 - \frac{k^2}{1+r} \right] C_{22p} \]

is the effective compliance of the structure.

◆ Where
  - \( C_j \) is the junction capacitance of the diode presented to the MEMS device.
  - \( r = C_j/C_{11} \).
  - \( H \) is the magnetic field strength.
  - \( Q \) is the quality factor of mechanical resonance.
  - \( M \) is the remnant magnetisation constant.
  - \( \nu \) is the volume of the magnetic structure.
Practical evaluation

Evaluate the feasibility of the structure

- PZT piezoelectric material
- Shear coupling coefficient of 0.69
- Frequency constant of 1000 Hzm
- Height, h = 7mm
- PZT compliance of $30 \times 10^{12} \text{ m}^2\text{N}^{-1}$

Resonance frequency of the piezoelectric structure as a function of its thickness
Practical evaluation

Effect of the piezoelectric structure dimensions on $V_{TO}$ at ½ meters from the screaming corridor

Effect of the magnetic structure dimensions on $V_{TO}$ at ½ meters from the screaming corridor
Practical evaluation

- Optimal size of the structure for maximum sensitivity
  - \( w = 5 \text{ mm}, \ t_p = 2 \text{ mm}, \ t_m = 2 \text{ mm} \) and \( h = 7.5 \text{ mm} \).

- Turn on range of the theft detection label measured from a “screaming corridor” when the structure is off mechanical resonance.
Conclusions

- Sufficient energy transfer is possible and thus a feasible solution.
- Meets the demands of a high performance theft detecting RFID label for high-end goods.
  - Minimizes power consumption
  - Improved lifetime for the label
- Mechanical Q of the structure is high
  - Narrow band resonance at 130 kHz
    - prevents false turn-on from stray magnetic fields.
  - Good voltage magnification
- Future work
  - will involve the examination of other possible structures and the interplay between the electrode capacitance and the piezoelectric capacitance.
  - Simulation of the mechanical structure to confirm the results obtained from the analytical method.