# Comparison of Monostable and Bistable Configurations for Wideband Energy Harvesters

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***Abstract*—Extracting energy from ambient vibration to power wireless sensors and other electronic devices is well needed. Many existing harvesters are linear systems working at one resonant frequency. To overcome this limitation, different strategies has been developed to increase the frequency range and to broaden the bandwidth of the harvester. For the electromagnetic energy harvester type, nonlinear behavior introduced by magnetic interactions is currently a central issue to enlarge the frequency bandwidth. A new feature in this study is to create a bistable potential well by inserting an external ring magnet to broaden the frequency spectrum of the non-linear generator. A finite element model to compare the proposed bistable configurations with monostable is developed. An experimental Set-up is realized for the adopted solutions.**

***Index Terms*—Electromagnetic, Energy Harvester, Bistable, Non-linear, Bandwidth**

## I. Introduction

Scavenging energy from vibration source can be performed using several methods: electrostatic, magnetostrictive, piezoelectric and electromagnetic. Most of existing vibration converters is based on linear resonance. It generates power when the resonant frequency of the harvester matches the frequency of the ambient vibration. This approach is limited since the resonant peak is very narrow and very little power is generated near the peak resonance.

Based on the literature review, many solutions are developed to increase the bandwidth of the operating frequency. It includes the use of resonant tuning methods [1]–[3]. The principle of this method is to adjust the resonant frequency of the generator that it matches the ambient vibration at all time. The adjusting can be done manually by the variation of dimension or automatically, the main drawbacks of such solution that it consumes external power that is well needed for piezoelectric beam.

Another proposed method is using generator array [4]. It consists of a generator's assembly with different dimensions and so different resonant frequencies. However the frequencies can be selected to have a large wideband. Instead of that, the output power is too small and this method is used only with piezoelectric beam and leads to a bulky system. Two multimodal configurations are used to solve this problem: the amplitude limiter [5] and coupled oscillators [1], those methods have a wide frequency band but an increased output power. Another interesting method consists on introducing non-linearity using magnetic interactions for electromagnetic harvester or nonlinear stiffness for piezoelectric beam. Bistable nonlinear configuration [6] presents better performance than the monostable one [5] due to its two equilibrium position and larger bandwidth.

In this study, different solutions are proposed to broaden the frequency bandwidth of the electrodynamic harvester. The converter is based on electromagnetic interaction between magnets and coil. The presence of a vibration source due to the magnet's or coil's movement leads to an induced voltage. Evaluation for the generated energy using finite element method is treated. A comparison of the power output/frequency bandwidth of the monostable and the bistable configurations is provided.

## II. Working Principles of the Monostable and the Bistable Harvester

In this section, a description of the monostable and bistable energy harvester is presented. These two principals have a common part design. It includes a ring magnet which is placed in the top box and a disc magnet placed in the bottom box. For monostable architecture, a center ring magnet is inserted through the moving axis. When the system excited by external vibration, the axis and the center magnet is free to move vertically between the two fixed magnets. The magnets are placed in such a way they create repulsive forces. All used magnets are neodymium magnets NdFeB.

A coil is wrapped around at the middle. The relative motion between magnets and coil creates an electrical current through the coil due to the electromagnetic induction.

To create bistability, an external ring magnet is introduced around the moving magnet in order to repel the center magnet away from the midpoint (Fig 1).

## III. Finite Element Analysis of the Monostable and Bistable Architectures

A finite element model to evaluate the monostable and bistable configurations is presented. By the variation of many

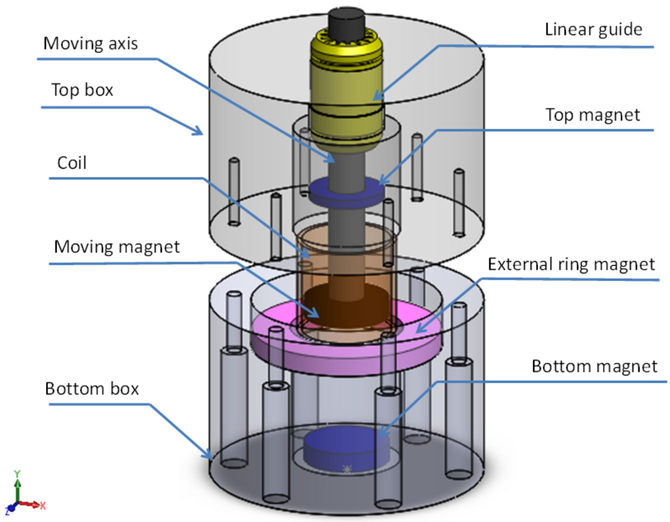


Fig. 1. Bistable energy harvester

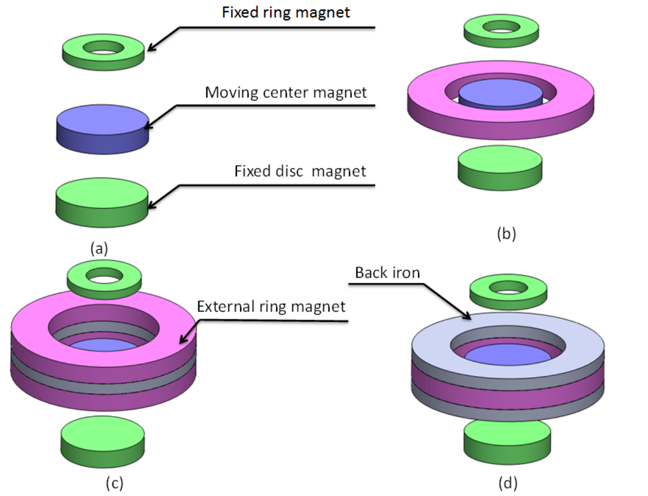


Fig. 2. (a) monostable configuration, (b) bistable configuration with one external ring magnet, (c) bistable configuration with two external ring magnet and one back iron, (d) bistable configuration with one external ring magnet and two back irons

parameters, such as geometrical parameters, adding external magnets and ring steel (back iron), a comparison of the voltage output and the frequency bandwidth is performed. Design parameters are shown in the following table.

| Parameters | Value (mm) |
|---|---|
| Center magnet | 12.7 x 6.4 x 1.6 |
| Top ring magnet | 12.7 x 6.4 x 1.6 |
| Bottom disc magnet | 14.3 x 3.2 |
| External ring magnet | 31.8 x 19.1 x 3.2 |
| Coil turn | 100 turns |
| Coil material | Copper |
| Magnets material | NdFeB |

TABLE I
FIXED PARAMETERS FOR NUMERICAL SIMULATION

Based on the presence and the emplacement of external ring magnet and back iron, four solutions are proposed and compared (Fig.2).

### A. Voltage Output

Using Comsol multiphysics software, a 2D axisymmetric model is used to reduce time calculation since it consists of a cylindrical design. The AC/DC electromagnetics module and the moving mesh module are combined to obtain the magnetic flux variation and the induced voltage respectively. The output voltages for the proposed configurations are presented in the following (Fig.3). All curves present a sinusoidal aspect with different amplitudes.

The maximum voltage is generated by the bistable configuration using one external ring magnet and two back irons. This is due to the presence of the back iron which enables to concentrate the magnetic flux. In the following, the resulting magnetic flux distribution is detailed.

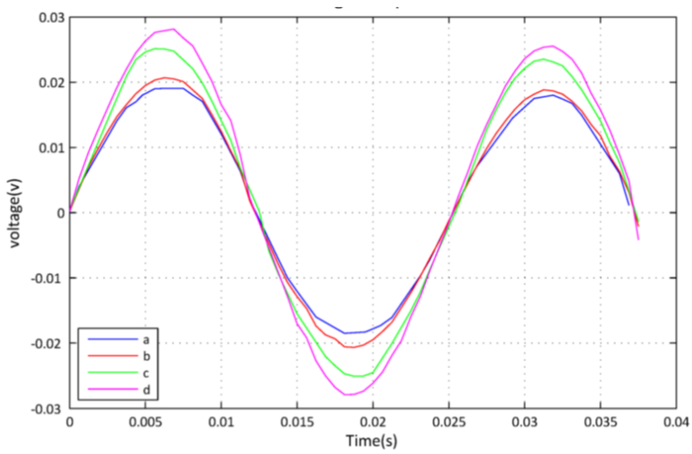


Fig. 3. Voltage output for different configurations

### B. Magnetic Flux

Using finite element method, the magnetic flux distribution through the coil is calculated for a maximum vibration amplitude which is equal to 3 mm and a frequency excitation 20 Hz for different configurations (Fig.4).

As it is shown for a monostable configuration, the magnetic flux is concentrated along 0.3 mm and it is limited to 0.24 T. Using a bistable configuration enables to obtain more higher magnetic flux which can reach 0.5T. The main difference between the three bistable configurations is the decrease of the magnetic flux. The optimal one consists on the use of one external ring magnet and two back irons performances due to the capacitance to concentrate the magnetic field. More than the magnetic flux norm‘s curve presents a high value with large band more the configuration is efficient

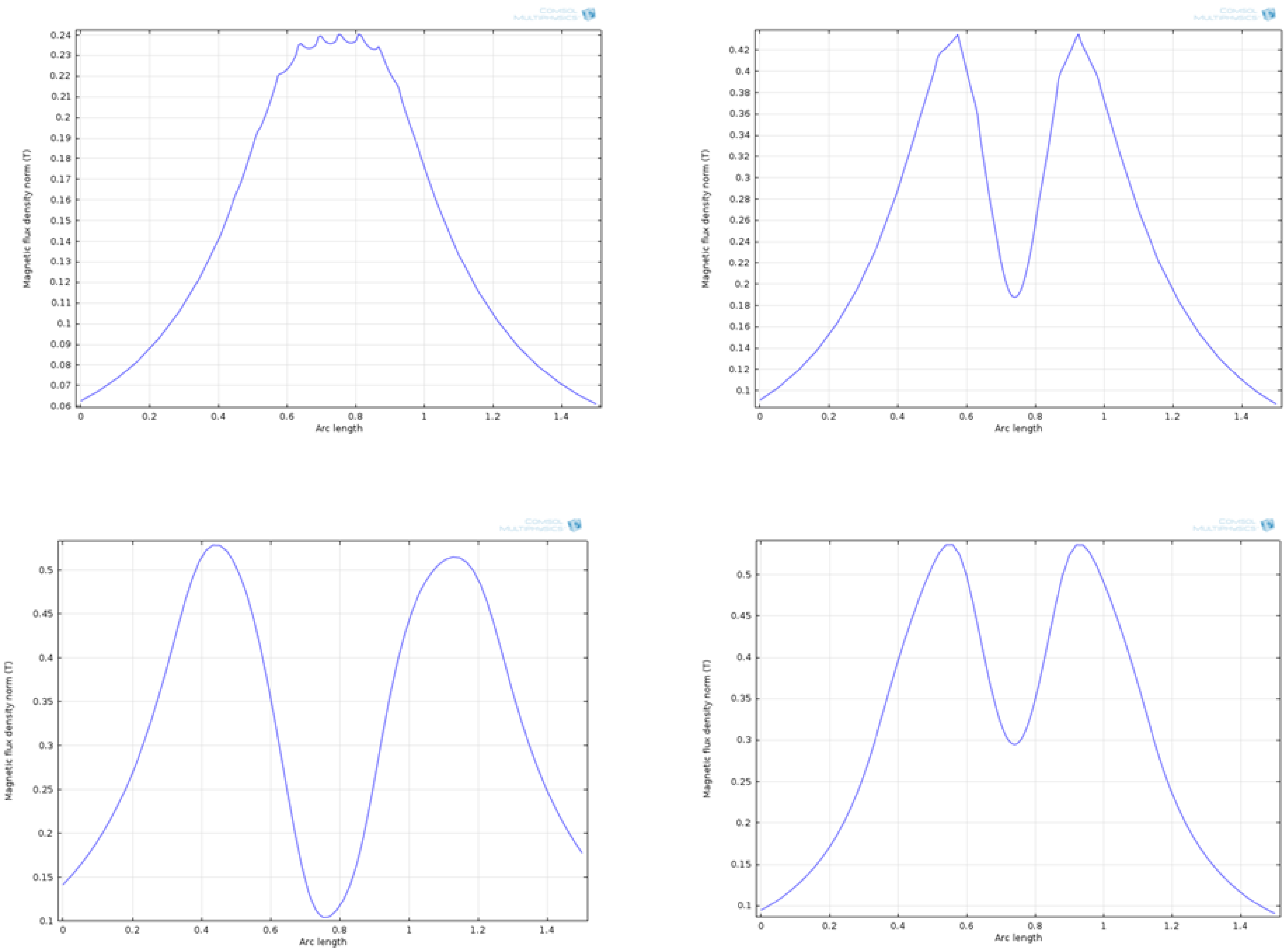


Fig. 4. Magnetic flux variation (a) monostable configuration, (b) bistable configuration with one external ring magnet, (c) bistable configuration with two external ring magnet and one back iron, (d) bistable configuration with one external ring magnet and two back irons

### C. *Influence of the Back Iron Size*

As noted in the previous section, the configuration with one external ring magnet and two back irons presents the better performance. Due to those ring steel on both faces of the permanent magnet, the magnetic flux is concentrated and then the magnetic field is increased. For better optimization, the back iron size is studied in this section. As result, it can be found that the maximum voltage output is obtained with a back iron‘s thickness equal to 2 mm as shown in Fig.5

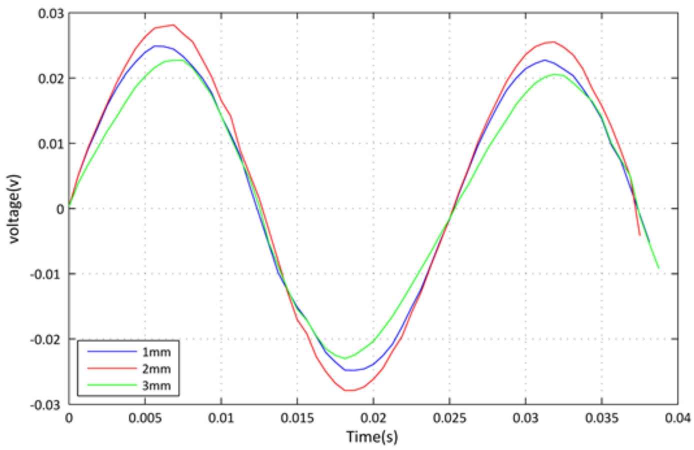


Fig. 5. Influence of the back iron size on the induced voltage

## IV. Experimental Setup and Measurements

In order to compare and enhance the simulation results, an experimental set up is performed to obtain the power output for different frequencies. As experimental setup, a shaker is utilized as vibration source. An oscilloscope is used to compute the voltage output across the terminals of the coil for a given frequency and amplitude, the output power can be then calculated. In the following, the variation of the output power for different configurations relative to the excitation frequency is presented. As detailed in Fig.7, the bistable configuration with external ring magnet presents a narrow bandwidth around 5Hz with an output power equal

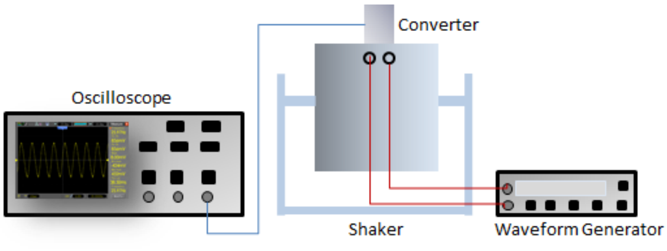


Fig. 6. Experimental setup

to 294mW. The monostable solution and the bistable solution with two external ring magnets display a large bandwidth and a very little amount of power. The better result corresponds to the bistable solution with one external ring magnet which is situated between two back irons. For this case the frequency band range is 10Hz with an output power 209 mW.

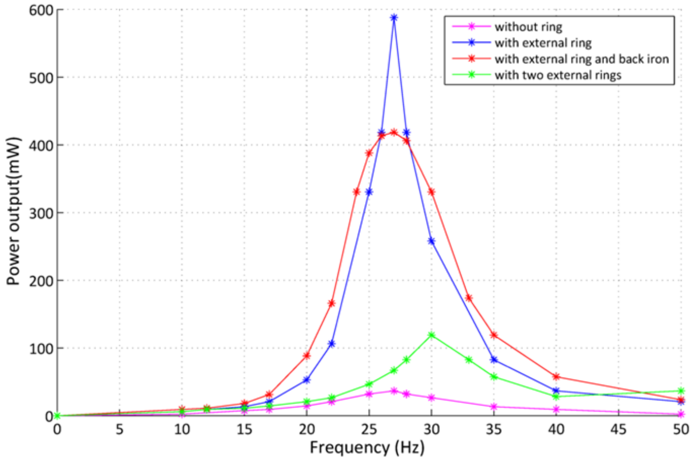


Fig. 7. Power output for different magnets configurations

## V. Conclusion

Generation of electrical power from ambient vibration has been studied. The principle of generating power is based on the relative movement between magnets and coil. Many nonlinear configurations are proposed to obtain a compromise between high output power and large frequency bandwidth. A comparative study of the monostable energy harvester and the bistable one is presented. The bistable configuration is characterized by external ring magnet or/and back iron around the center magnet which enable to increase the magnetic field in this region and to generate a much amount of power. Simulation results and experimental study have clearly shown that the bistable configuration with one external ring magnet and two back irons have the good performances in terms of output power and large bandwidth comparing with the other configurations. Further investigations and improvements will be studied to reduce the harvester size and to have a good results with random input excitations.

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