ABSTRACT

Nowadays, numerous daily life applications related to wireless networks, sensors, low power electronics, biomedical applications etc. demand small amount of electrical power for their operation. These applications are rapidly increasing and bringing to the fore the need for small scale electrical power generation. To this end, strong efforts are being made to exploit ambient and man made energy sources such as electromagnetic radiation including sun, infrared and RF radiation, thermal sources, mechanical stress and strain, vibrations, biochemistry etc.

Acoustic signals seem to be such an alternative ambient energy source. Firstly, this work gives an overview of the proposed harvesting methods and systems derived from related patent applications during the past decade. Moreover, a first estimation of the available ambient acoustic power density is presented and then is compared to the ambient power density of the aforementioned energy sources.

Categories and Subject Descriptors
J.2 [Physical Sciences and Engineering]: Engineering

Keywords
Acoustic Energy Harvesting, Acoustic to Electric Transduction, Patents

1. INTRODUCTION

Each ambient energy source is characterized by a different power density and of course its utilization is directly dependent on the type of application and the specific characteristics of its site. Fig. 1, being based on [1], illustrates the indicative available power density of energy sources which are used for small-scale electrical power generation. As it is shown, the available power density may range from $100 \text{ mW/cm}^2$ down to $0.1 \text{ mW/cm}^2$, i.e. the highest power density is approximately $10^6$ times higher than the lowest.

2. CURRENT PROPOSALS FOR ACOUSTIC ENERGY HARVESTING SYSTEMS

Harvesting of acoustic signals seems to be feasible for small-scale electrical power generation. An Acoustic Energy Harvesting process may include a range of sequences as illustrated in Fig. 2. Several methods, devices and circuit components may correspond to its block shown in the figure. Here, an overview of current and past proposals for acoustic energy harvesting methods and devices, drawn from related patent applications, will be presented.

In 2000, Jurgen Michel and Bernard Raaf disclosed a passive microphone for wireless transmission of acoustic data to a receiver unit, utilizing properly an antenna and a piezoelectric device. It was stated that the relevant embodiment provides considerable advantages especially for telephone applications [2].

In 2004, Matsunaga Masahiro revealed a power generation mechanism, comprising a permanent magnet and an electromagnetic induction coil arrangement that exploits the vibration of a sound proof wall [3].

In 2006, Jeffrey L. Schrader revealed a method and device to convert existing ambient acoustic energy to an electric voltage utilizing a coil and a magnet arrangement combined optionally with a cone, funnel etc., a converter, a diode, and a flywheel having imbedded magnets and a set of windings. The inventor claimed that the device may be used as a back-up power source in an embodiment with another power source.
In 2006, James K. Thurber and Jonathan L. Thurber disclosed among others a generator for converting sound energy to electrical energy. In its basic realization the invention consists of a stator and a rotor being able to spin about its axis due to a low frequency oscillator. Refinements utilize additionally a shaft and more than one oscillators mounted equidistantly around it [5].

In 2007, John D. Adamson and George P. O’Brien, disclosed a tire assembly with energy harvesting capabilities including a tire structure and an acoustic-electric transducer to convert acoustic energy generated upon movement of the tire structure to electrical energy. The invention comprises an electrodynamic microphone which also may correspond to other types of microphones, that is coupled to additional power conditioning elements such as a rectifier, an energy storage device for example a capacitor or rechargeable battery and a voltage regulator. Sufficient accumulations of harvested energy was claimed that can power tire electronics systems, including various conditioning-responsive devices (i.e. Sensors etc.) revolution counter, an RF device, a rechargeable battery or a lighting device [6].

In 2008, Tseng-Shen Lee disclosed a device which combines a crystal microphone and a solar cell to generate electric power via forming a vibratible magnetic field [7].

In 2011, James K. Thurber and Jonathan L. Thurber disclosed a method and apparatus that can generate both kinetic and electrical energy using sound waves and could probably be used in high frequency motors and electrical generators. Especially, sound waves at particular frequencies are propagated across one side of a plate or other barrier element, causing flow of air across the surface of the plate which, in turn, causes reduction in the ambient air pressure near the surface of the plate. The difference in air pressure on opposite sides of the plate results in a net positive thrust on the plate, thereby causing its movement. This movement is claimed that can be harnessed using a windmill type of rotor and stator arrangement to generate both useful kinetic and electrical energy [8].

In 2011, In-Ho Jee disclosed a sound wave resonance generator which could be placed on underground railways of subways, in tunnels of surface streets, and around a landing field of the air plane of an airport where significant amount of acoustic energy is produced for electrical energy production. The suggested device comprises a horn-like tube having a spiral protruding part formed along its inside wall and a resonance tank connected to the rear end of the sound-collecting tube. Resonators attached to the outer periphery of the resonance tank are resonated by the sound waves and generate vibration. An actuator is disposed on one side end portion of each resonator in an appropriate direction to realize a reciprocal movement. Each one has a plurality of magnets arranged in such a manner as to have different polarities from each other, while a stator having coils is mounted over and below it. The apparatus further comprises a voltage-stabilizing circuit and a dual-voltage circuit in order to charge a battery or drive a load directly. Also, there is an outer casing spaced apart from the resonance tank by a predetermined distance which forms a resonance chamber and is used for mounting the stators. Diaphragms are disposed between each of the both end surfaces to close the resonance chamber and to allow air to flow during resonances. Finally, a plate inside the resonance tank and an adjuster mounted at its rear end portion are used for adjusting the internal volume of the resonance tank and affecting its resonance [9].

3. POTENTIAL FOR HARVESTING ACOUSTIC ENERGY

Acoustic signals are produced by numerous human activities via speech and music reproduction, household apparatuses, industry machinery, road, railway and airport noise etc. As will be shown below, a typical classification of sound sources is attempted and a primary estimation of the available ambient acoustic power density is made.

Here, we broadly classify sound sources according to their reference sound pressure level i.e. the sound pressure level at 1m, assuming spherical radiation. We refer to:

- Strong sources (S) : jet engines, air planes, racing cars and motorbikes, jackhammers, sirens etc.
- Medium sources (M) : gas lawn mowers, snowblowers, hand drills, subway, railway, passing vehicles etc.
- Weak sources (W) : busy traffic, vacuum cleaners, human activity etc.

Then, it is possible to derive a first approach of the available ambient acoustic power density as a function of potential distances to the receiver, related to their most typical range of applications and topography. Hence, the acoustic power density in each case is here estimated for distances between source and receiver that an energy harvesting method and device would make practically sense. Thus, in acoustic environments where Strong sources are operating, we assume distances that range from 1m to 10m and for such cases the ambient acoustic power density could range from $0.3 \frac{\text{W}}{\text{cm}^2}$ to $3 \frac{\text{W}}{\text{cm}^2}$ approximately, as it is illustrated in Fig. 3.

In Fig. 4 it is shown that in acoustic environments where Medium sources are operating, the distance between source and receiver should be ten times shorter in order to extract similar amount of acoustic power density. In this case, the typical ambient acoustic power density varies from $0.1 \frac{\text{W}}{\text{cm}^2}$ to $1 \frac{\text{W}}{\text{cm}^2}$.

Finally, in Fig. 5 it is shown that the ambient acoustic power density related to Weak sources has to be considered at distances very close to the source i.e. 1 cm to 10 cm in order to obtain from $0.03 \frac{\text{W}}{\text{cm}^2}$ to $0.3 \frac{\text{W}}{\text{cm}^2}$.
From this overview, it is becoming evident that methods and devices that would exploit the acoustic energy of Weak sources should be necessarily almost attached to or be positioned extremely close to the specific sound source in order to be appropriate for an Energy Harvesting process. From this point of view, this would be mainly useful in microphones, speakers, mobile applications like cell phones and tablets and other small portable devices. On the other hand, those methods which intend to extract acoustic energy from Medium and Strong sources is possible to be placed at fixed positions and at longer distances. Examples would probably be sensors positioned to an airport’s runway, on noise barriers beside a road with high traffic daily load, or on flexible surfaces inside the noisy environment of a factory.

As it happens with every ambient energy source, it is obvious from the above that the acoustic ambient energy could change significantly depending on the application site and its specific characteristics. However, the maximum available acoustic power density is strictly comparable, and sometimes may exceed that from the other sources illustrated in Fig. 1. Outdoor solar radiation is an exception and its maximum available power density is of a $10^2$ times higher order.

4. CONCLUSION

This work presented a short review of the applications submitted worldwide for patenting related to harvesting of acoustic energy and transduction to electrical energy in the past decade. Sensors, wireless networks and low power electronics seem to be the most famous applications till now. In addition, the potential for acoustic energy harvesting was evaluated through the assessment of the available ambient acoustic power density which showed that acoustic energy is an important and promising energy source for exploitation.

5. ACKNOWLEDGMENTS

The research activities that led to these results, were co-financed by Hellenic Funds and by the European Regional Development Fund (ERDF) under the Hellenic National Strategic Reference Framework (ESPA) 2007-2013, according to Contract no. MICRO2-38/E-II-A.
6. REFERENCES


