Journal of Advanced Research in Technology and Management Sciences
Volume: 01 Issue: 03 ISSN: 2582-3078 November 2019
Available online at: http://www.jartms.org

LOW POWER CMOS PIEZOELECTRIC ENERGY HARVESTING CIRCUIT FOR VEHICLE TYRE PRESSURE SENSOR

N.VITHYALAKSHMI[1], P.GEETHA[2], M.VISHNU VARDHAN REDDY[3], S.RAKESH[4]
[1] Associate Professor, Department of Electronics and Communication Engineering,
Sree vidyanikethan Engineering College, Tirupati.
[2] Associate Professor, Department of Electronics and Communication Engineering ,
Sree vidyanikethan Engineering College, Tirupati.

[3] UG Student, Department of Electronics and Communication Engineering,
Sree vidyanikethan Engineering College, Tirupati.

[1] vidhyavinoth@gmail.com, [2] mailpgeetha@gmail.com,

ABSTRACT:-

Most low-power electronics, such as remote sensors and implantable devices are powered by batteries. However, even long-lasting batteries have a limited lifespan and must be replaced every few years. The replacements become costly when there are hundreds of sensors in remote locations. Energy harvesting technologies, on the other hand, provide unlimited operating life of low-power equipment and eliminate the need to replace batteries where it is costly, impractical, or dangerous. Most energy harvesting applications are designed to be self-sustaining, cost-effective, and to require little or no servicing for many years. In addition, the power is used closest to the source, hence eliminating transmission losses and long cables. If the energy is enough to power the device directly, the application or device powered by the energy can operate battery less. Tyre pressure monitoring systems (TPMS) are becoming increasingly important to ensure safe and efficient use of tyres in the automotive sector and powered by batteries. These pressure sensors mounted an inside of the rim and the batteries are not exchangeable. When a battery reaches the end of its life span the whole sensor has to be replaced. In order to provide a maintenance free and battery less sensor solution there is growing interest in using energy harvesting technologies to provide power to TPMS.

Key words: Energy harvesting, piezoelectric sensor, CMOS, Low power, TPMS.

1. INTRODUCTION

In recent years powering of low power sensors has remained a major problem, since in build traditional batteries have less life time and requires periodic replacement. To overcome these effects energy harvesting has emerged as one of the key factor for powering the sensor electronics. Due to rapid growth of automobile industry, the vehicle running on the roads are increasing day by day. Hence the numbers of accidents are increasing along with the growth of vehicles. One of the main reasons for accidents are due to bursting or inflation of tyres. Tyre bursting is a main concern for the drivers since prediction is very difficult. Tyre burst is mainly caused by abnormal tyre pressure and higher tyre temperature. Thus accidents can be prevented if the tyre pressure is regularly monitored during driving. In order to provide a maintenance free and battery less sensor solution there is growing interest in using energy harvesting technologies to provide power for tyre pressure monitoring system.

1.1. TYRE PRESSURE MONITORING SYSTEM

A tyre's inflation pressure is the largest single factor in determining how it will perform. It influences the tyre's speed capability, its load carrying capacity, response in handling, cornering power, its service life and above all its safety. Under inflation also causes increased fuel consumption and if prolonged and significant can cause structural damage, especially to low profile tyres. TPMS is a system fitted on a vehicle that is able to evaluate the inflation pressure of the tyres or the variation of the inflation pressure over time and to transmit corresponding information to the user while the vehicle is running. Figure.1 shows classification of tyre pressure monitoring system[7]

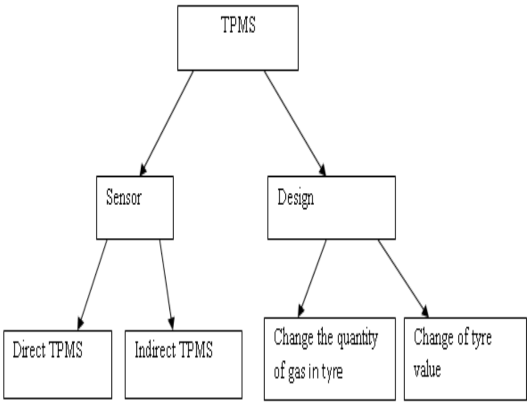


Figure.1 shows classification of TPMS

There is direct and indirect tyre pressure monitoring systems. The direct system uses sensors mounted inside of each vehicle's tyres to measure the inflation pressure. If any deflation occurs, it is continuously monitored by Electronic Control Unit and the driver is quickly alerted by a dashboard-mounted display.. Figure 2 shows direct tyre pressure monitoring system architecture consists of remote sensing module, low frequency initiator, RF receiver to collect the information directly from the vehicle wheels.

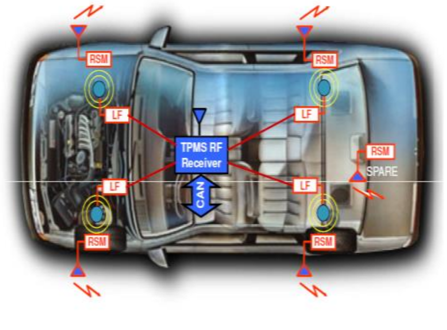


Figure 2. Direct Tyre pressure monitoring system

The indirect tyres Pressure Monitoring Systems are do not have any sensors inside the tyres. Instead, they detect a low tyre pressure by comparing relative wheel speeds through wheel speed sensors. When a tyre loses air, its diameter decreases slightly The indirect system uses the Anti-lock Braking System (ABS) sensors to measure and compare the rotational speeds of the tyres. The ECU analyses this data to deduce tyre under inflation and alerts the diver by a dashboard warning light is shown in figure 3. Direct systems are quicker and more sensitive in detecting under inflation than indirect systems that typically only react to a 20% to 30% loss of tyre inflation.

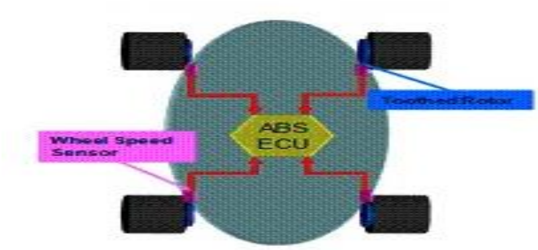


Figure 3. Indirect TPMS Architecture

Direct systems may require replacement or maintenance of sensors due to damage or sensor battery failure. Indirect systems do not normally require maintenance. However, it is necessary to recalibrate an indirect system every time a tyre is changed.

2. ENERGY HARVESTING

Energy harvesting is the capture and conversion of small amounts of readily available energy in the environment into usable electrical energy. The electrical energy is conditioned for either direct use or accumulated and stored for later use. This provides an alternative source of power for applications in locations where there is no grid power and it is inefficient to install wind turbines or solar panels. Most low-power electronics, such as remote sensors and embedded devices, are powered by batteries. However, even long-lasting batteries have a limited lifespan and must be replaced every few years. The replacements become costly when there are hundreds of sensors in remote locations. Energy harvesting technologies, on the other hand, provide unlimited operating life of low-power equipment and eliminate the need to replace batteries where it is costly, impractical, or dangerous[3]. Most energy harvesting applications are designed to be self-sustaining, cost-effective, and to require little or no servicing for many years. In addition, the power is used closest to the source, hence eliminating transmission losses and long cables. If the energy is enough to power the device directly, the application or device powered by the energy can operate battery less.

Sources of Energy harvesting

2.1.1. Wind energy harvesting / Vibration energy harvesting

Convert vibration energy into electric signal. It can include wind power energy also. Energy of vibration depends on amplitude and frequency. Mass of harvesting device is equivalent to vibrating mass. We know that vibration is typically made up of number of fundamental frequencies and their harmonics. This phenomenon is utilized in different ways to convert vibration energy into electrical form. The methods include piezoelectric conversion. Commonly used materials are PZT, BaTiO3, PVDF etc. electrostatic conversion using parallel plate capacitor and electromagnetic conversion using magnetic fields and coil.

Figure 4. Wind energy harvesting

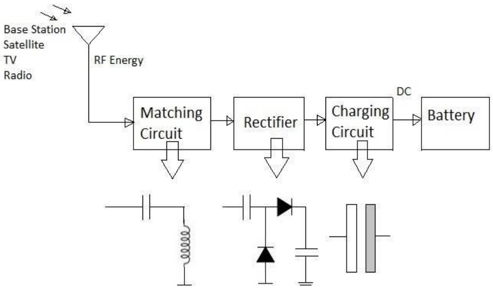


Figure 5. RF Energy harvesting

2.1.2. RF/Wireless/Electromagnetic energy harvesting

Convert energy available in electromagnetic waves transmitted from various radiating sources (e.g. TV, radio, cellular towers) into equivalent electric current. This method utilizes ambient EM waves available due to radiations from cellular base stations, satellites, TV and radio broadcasting stations. These RF harvesters convert RF energy into DC energy for storage. It does this using matching and rectifier circuits.

2.1.3. Thermoelectric energy harvesting / Photovoltaic energy harvesting

It uses ambient sun energy to convert temperature differences across the material into equivalent electric voltage or electric current. The temperature difference on two sides of crystal (i.e. one warmer and the other cooler) causes voltage across crystal device. Steady voltage is available when difference in temperature remains unchanged[8]. Any light source can also be used to generate energy at small invisible amounts. For example, artificial lights produce 60Hz signal along with photons. Sun generates energy due to solar radiations. Photovoltaic devices usually are made using silicon. They convert solar radiation into electric current.
For example cars, trucks and Lorries which are equipped with such energy harvesting systems will have good amount of fuel savings.

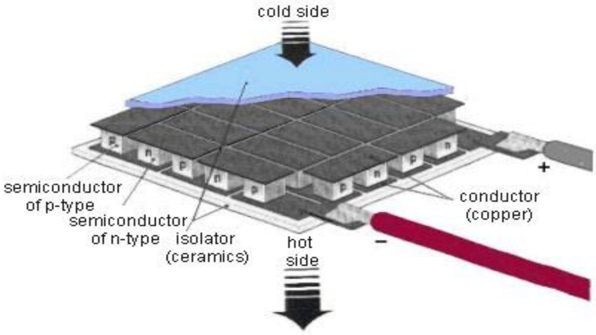


Figure 6. Thermoelectric Energy harvesting

2.1.4. Piezoelectric energy harvesting

Convert mechanical stress into electrical Signal.The charge gets accumulated in solid materials due to application of mechanical strain. The reverse of this i.e. mechanical strain gets induced due to subject of electric field on such solid materials will also occur[1][5]. The common sources which can be exploited in piezoelectric energy harvesting are low frequency vibrations, acoustic noise, human motion etc. These sources can be harvested by piezoelectric materials. Examples of thermoelectric energy harvesting systems are piezoelectric floor tiles, car tyre pressure sensors or monitors, battery less remote control[9]

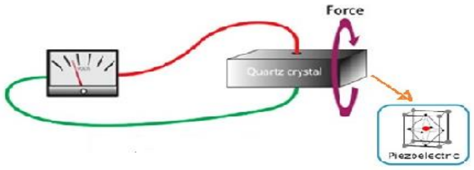
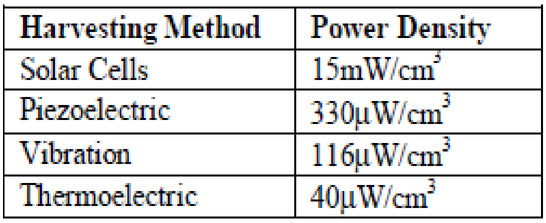


Figure 7. Piezoelectric Energy harvesting

Table 1. Power generation from various energy harvesting Sources[10]



Harvesting Method	Power Density
Solar Cells	15mW/cm^3
Piezoelectric	330μW/cm^3
Vibration	116μW/cm^3
Thermoelectric	40μW/cm^3

3. PROPOSED METHOD

In this paper piezoelectric energy harvesting method is introduced to energies the Tyre pressure monitoring system. Here piezoelectric sensor with transducer modules is placed in three strips all along the inner circumference of the tyre. The load experienced by the tyre is profound in the contact patch area where the modules also experience the mechanical stress. The electrical voltage produced in the modules is fed to the capacitor bank for storage. The flowchart of the working of the system is described in the following figure 8

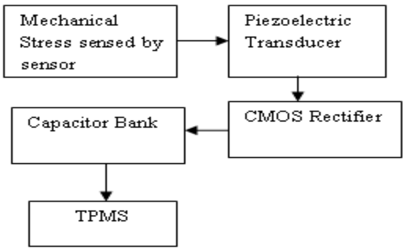


Figure 8. Flow diagram of proposed method

3.1. **Piezoelectric Transducer**

The piezoelectric transducers work on the principle of piezoelectric effect. When mechanical stress or forces are applied to some materials along certain planes, they produce electric voltage. This electric voltage can be measured easily by the voltage measuring instruments, which can be used to measure the stress or force [11]. The physical quantities like stress and force cannot be measured directly. In such cases the material exhibiting piezoelectric transducers can be used. The stress or the force that has to be measured is applied along certain planes to these materials. The voltage output obtained from these materials due to piezoelectric effect is proportional to the applied stress or force. The output voltage can be calibrated against the applied stress or the force so that the measured value of the output voltage directly gives the value of the applied stress or force [6]

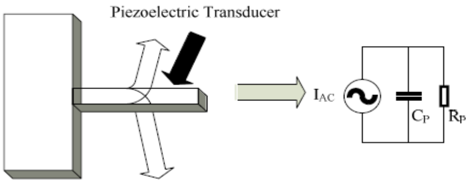


Figure.9. Piezoelectric Transducer

3.2. **CMOS Rectifier**

A piezoelectric transducer is a device that converts vibration energy into electrical energy. The output of a piezoelectric transducer produces an AC type output voltage. As a result, an AC-to-DC converter or a rectifier is required to obtain a useful DC type output voltage. In general, the energy produced by the rectifier output is stored in a battery. There are two types of conventional rectifier's voltage-doublers and full-bridge rectifier. The major drawbacks of conventional structures are usually low extraction and conversion efficiencies. Low extraction efficiency is caused by charging and discharging of the internal capacitances of a piezoelectric transducer itself.. To improve the conversion efficiency of a rectifier, a diode shown in figure 10 can be replaced by a CMOS circuit.[2][4]

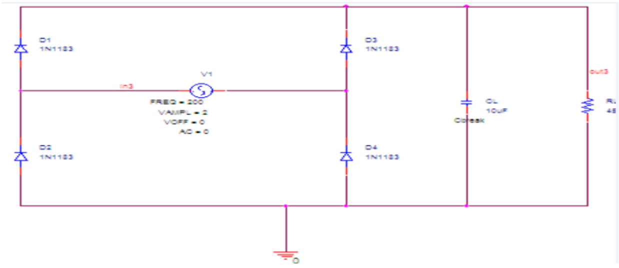


Figure.10 Conventional passive diode full wave rectifier

To reduce the voltage drop across a diode which affects the conversion efficiency, a CMOS based full wave bridge rectifier is presented in this paper. By using a CMOS technology instead of a passive diode, the voltage drop reduces to |Vds|. In addition, a switch can be added in a piezoelectric transducer circuit to reduce the waste charge which charges or discharges the parasitic capacitance of a piezoelectric device. Figure. 11 shows the circuit diagram of the proposed circuit. Unlike conventional rectifiers, the proposed rectifier is composed of fully digitally controlled system to minimize current consumption by a control circuit except the low-power analog CMOS comparator which consumes a static current of 60nA. Power is minimized using an analog circuit since the main power consumption of the most of the control circuits is attributed to the static current consumed by the analog circuits.

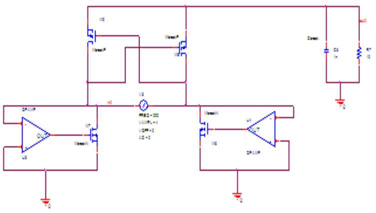


Figure.11. CMOS Full wave rectifier

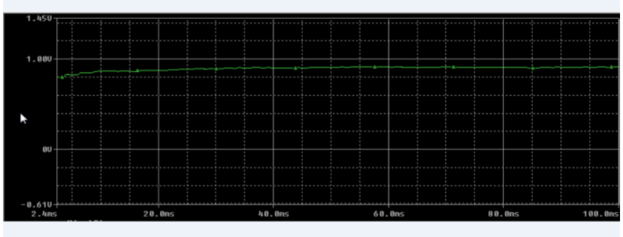


Figure.12. Diode rectifier output

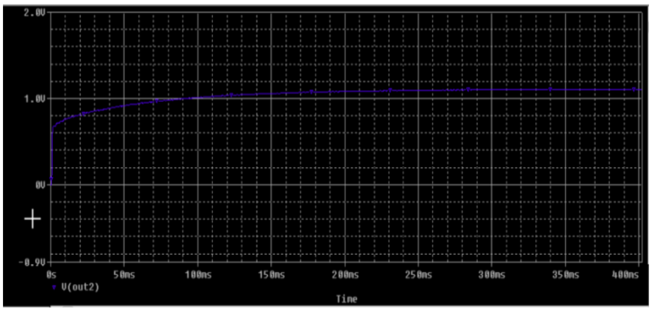


Figure.13. CMOS Full wave rectifier output

Table 2 Comparison of Diode And CMOS Rectifier Circuit Parameters

Parameter	Diode	CMOS
Voltage(V)	3.0	4.0
Power(uW)	195	340
Current(uA)	63	88
Amplitude (v)	2	2
Frequency(Hz)	200	200

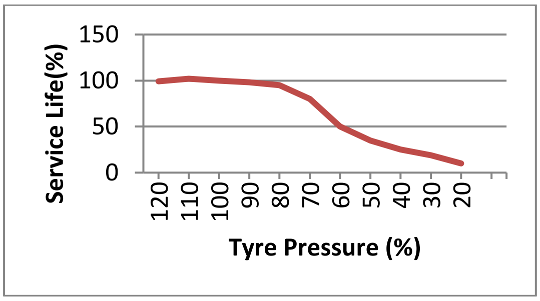


Figure 14. Decreased Tyre life with Low Pressure

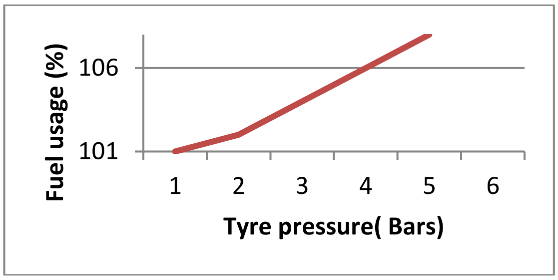


Figure 15. Increased fuel use with Low Pressure

4. CONCLUSIONS

In later years, TPMS will most likely be expected to incorporate new and more features owing to the increasing safety standards in automotive industry. This could be achieved in a number of ways like adding more sensors to the TPMS module in order to provide data other than pressure, temperature, wheel alignment, indication of puncture, load of the heavy vehicles, etc. or combining different information sources like the integration of TPMS communicating more effectively with other parts of the vehicle. Due to the non-replacement of the battery in TPMS. Further improvements on the conversion efficiency of the energy harvester as well as on the data rate and power consumption of the TPMS might enable the use of power MEMS devices in automotive applications. However, there is the constraint that the overall costs for energy harvesting systems cannot be significantly higher than a similar possible battery powered solution

REFERENCES

[1] Y. K. Ramadass and A. P. Chandrakasan, "An efficient piezoelectric energy harvesting interface circuit using a bias-flip rectifier and shared inductor," IEEE J. Solid State Circuits, Vol. 45No.1, P. 189-204, Jan. 2010.

[2] S. Guo, and H. Lee " An efficiency-enhanced CMOS rectifier with unbalanced-biased Comparators for transductanceous-powered high current implants," IEEE J. Solid-State Circuit, vol. 44, no. 6, Jun. 2009.

[3] J.Sankman, D. Ma, "A 12µW to 1.1mW aim piezoelectric Energy harvester for time-varying vibrations with 450nA IQ," IEEE Transactions on Power Electronics, Vol. 30, No. 2 Feb. 2015.

[4] S. Lu, F. Boussaid, "A highly efficient P-SSHI for piezoelectric energy harvesting," IEEE Transaction on Power Electronics, Vol. 30, No. 10,Oct. 2015.

[5] N. Krihely and S. Ben-Yaakov, "Self-contained resonant rectifier for piezoelectric sources under variable mechanical excitation," IEEE Trans. Power Electron., vol. 26, no. 2, pp. 612-621, Feb. 2011

[6] R. Vaddi, S. Dasgupta, "Enhanced bias-flip rectifier with ultra-low power control for piezoelectric energy harvester in the microwatt application scenario," Microelectronics and Electronics (PrimeAsia),2012 Asia Pacific Conference on Postgraduate Research, Dec. 2012.

[7]. Federal Motor Vehicle Safety Standards; Tire Pressure Monitoring Systems; Controls and Displays, 49 CFR Part 571, Docket No.NHTSA 2000–8572, RIN 2127-AI33,"
US Department of Transportation, National Highway Traffic Safety Administration (NHTSA) .
[8] ItikaTandon and Alok Kumar, "Unique step towards generation of electricity via new

methodology" in International Journal of Advanced Research in Computer and Communication Engineering (IJARCCE), Volume-3, Issue-10, October 2014.

[9] Xiaofeng Li and Vladimir Strezov ,"Modelling Piezoelectric energy harvesting in an educational building" in Energy Conversion and Management 85(2014) 435-442, ELSEVIER

[10] Atwood B, Warneke B and Pister K S J, "Smart Dust mote forerunners," Proceedings of 14th Annual International Conference on Microelectromechanical Sytsems, 2001, pp 357–360

[11] J. A. Paradiso, T. Starner, "Energy scavenging for mobile and wireless electronics," IEEE Pervasive Computing, Vol. 4, Issue 1, P. 18 -27, 2005.