International Journal of Advance Engineering and Research Development (IJAERD)
Volume 1,Issue 6,June 2014, e-ISSN: 2348 - 4470 , print-ISSN:2348-6406

Tire Pressure Monitoring System Using Ambient Backscatter Technology Containing RF Harvesting Circuitry.

Patale Vijaykumar Bharat[1], Nitin Sihna[2], K. Eswari Pujitha[3]

[1]*M.Tech Embedded System SENSE Department, VIT University, patale.vijaykumar2013@vit.ac.in*

[2]*M.Tech Embedded System SENSE Department, VIT University, nitin03ece@outlook.com*

[3]*M.Tech Embedded System SENSE Department, VIT University, eswaripujitha@gmail.com*

Abstract*:* The main objective behind designing this TPMS is safety of vehicle which leads towards the human life safety. System indicates current tire pressure of individual tire to the vehicle operator wirelessly. It maintains accuracy of tire pressure during running condition of vehicle. TPMS is designed to display real time tire pressure and to give alert at low pressure. This system will help to built smart vehicle along with that it leads to built fuel efficient vehicle. It reduces tire related accidents by checking & transmitting information of tire pressure continuously. In previous TPMS there is unnecessary power consumption in the sensor unit because generation of RF signals continuously accordingly to data from pressure sensor at a regular interval. Previous TPMS is designed in such a way that it will transmit the data when threshold condition is achieved, some systems are proposed with long life battery because in conventional TPMS there is always problem with battery replacement at the transmitter section, in this proposed work to overcome stated drawback of replacement of battery in RFID & other technologies which are used for wireless communication. RF harvesting circuitry generates the power from ambient RF signal and same signal is used to backscatter information to receiver section of TPMS which makes the battery free system and RF harvesting circuitry acts as the only source of power supply. This is battery free technology is used to perform wireless communication in remote areas where battery replacement is very difficult.

Keywords— TPMS system, (RF)Radio frequency signal, Pressure sensor, Transmitter section, Receiver section, Ambient Backscatter, RF Energy Harvesting system, Microcontroller.

I. INTRODUCTION

Tire Pressure Monitoring System is the system which leads to built smart vehicle, quality of vehicle is also depends upon tire pressure. Appropriate tire pressure condition maintains the vehicle under good condition & it helps to prevent the failure of vehicle. Maintenance of vehicle is reduced on large scale. In case of low tire pressure more surface of tire comes contact with the road surface causes more friction which disturbs the properties of material used for manufacturing tire. This leads the wear & tear of tire. Tire pressure of front wheel directly affects on the satiability of vehicle and along with that it disturbs the handling of vehicle which leads to accident [1]. Tire pressure is an important factor of fuel efficiency. Low pressure means low fuel efficiency it causes wastage of fuel. Low tire pressure is harmful for nature also because in low pressure condition combustion of fuel is not takes properly so it produces emissions emission of hazards gases. 85% of tire punctures happen due to low tire pressure. According to the Road Transport ministry report, in 2011 total 4.97 lakh road accidents was reported and cause of most of these accident was punctures in Tire because of low Tire pressure.

II. HARDWARE DESIGN FOR TPMS

@IJAERD-2014, All rights Reserved

TPMS consist of four pressure sensor and transmitter which is able to measure the pressure and transmits to the receiver section which is fixed on dashboard of vehicle. Transmitter module is fixed inside the tire. System transmits measured pressure using RF signal and there is no need to generate own RF signal to transmit the data. It will take the signal which are present in environment and backscatter them.

Fig 1. TPMS system

As per most of the systems are facing problems with battery replacement problem at remote places where difficult to reach for battery replacement like hazards places, in such condition this system plays very important role to make efficient solution. It is like deployment of self-energised or powered node instead of using any external dedicated power supply which was main cause of making bulky system also. It technology reduces cost of maintenance involved in battery replacement. RF energy module consist of patch antenna which receives RF signal from environment it has very low signal strength is given to voltage doubler as shown in fig2. It doubles the signal strength of input RF signal because of functioning of biasing of diode and capacitor. RF harvesting circuit is formed by cascading number of voltage doubler in series. 7-10 voltage doubler can harvest sufficient amount of energy to use as a power supply for various microcontroller. By increasing more number of doubler in series charging time of capacitor may increase but it will not problematic for many cases because system needs to charge initially only, after charging once capacitors are not going to discharge because RF signals are present continuously as a input. Voltage multiplier converts continuous RF signal into DC voltage at the output.

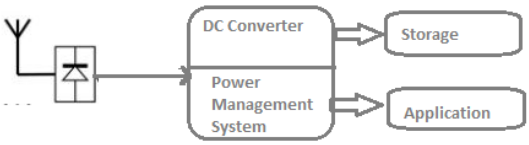

Fig 2. Block diagram of RF energy harvesting circuit

Block diagram of RF energy harvesting consist receiving antenna. Received small voltage of RF signal is converted in DC voltage by using DC converter. DC converter is nothing but rectifier for RF signal & stored in capacitor. Power management system takes care of utilization of stored power which can be used for different application.

Diode used is schottky diode which is also known as zero biased diode. Forward voltage (Vf) of schottky diode is very less if conducts even very small amount of voltage is applied across it. Schottky diode is used because RF signal having very low strength so in this condition diode should conduct even though very small signal is applied across it. Fig 1 shows the circuitry for voltage doubler. If v Volt is applied at the input then 2v Volts is produced at the output terminal. Such 10 voltage doubler circuit are cascaded forms voltage multiplier with 10 stage of voltage doubler.

@IJAERD-2014, All rights Reserved

RF energy harvesting circuit plays important role in wireless sensor node, in the sense it provides energy to drive the node with self-harvested energy. Also it can be used as the only source for node and microcontroller or processor which are able to drive on low power.

As we increase the voltage multiplier it produces proportional large amount voltage but due to distribution of current through each branch reduces the current flowing though load. This affects on the charging time of capacitor connected at the load.

A. *Transmitter Section of TPMS*

Transmitter section consists of pressure sensor whose analog output is given to the ADC channel of microcontroller. ATMEGA 32 AVR microcontroller is used, because it has on chip 8 ADC channel each of 10 bit resolution. It has internal timer, UART (Universal Asynchronous Transmitter Receiver). UART is having facility of sleep mode & wakeup mode when interrupt comes. By initializing UART, data can be transmitted. It will transmit data in the form of 0 and 1. According to output ambient backscatter transmitter perform switching operation of transmitting antenna. This will transmit current pressure of tire.

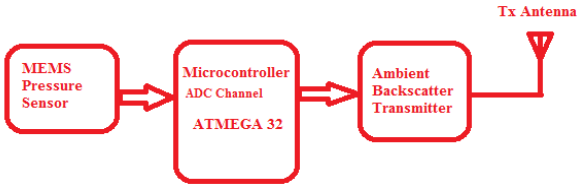

Fig 3. Block diagram of Transmitter section

Pressure Sensor: Ultra small silicon pressure sensors use innovative MEMS technology to provide extremely high resolution measurements of pressure, and therefore also of altitude, in ultra-compact and thin packages.

B. *Receiver Section of TPMS:*

It consist of Receiver antenna which is connected to ambient backscatter receiver which receives backscatter signal which are transmitted by transmitter & contains current pressure data. There is no requirement of dedicated power supply for Ambient Receiver to receive data. Using RF Energy Harvesting circuitry it can manage power requirement.

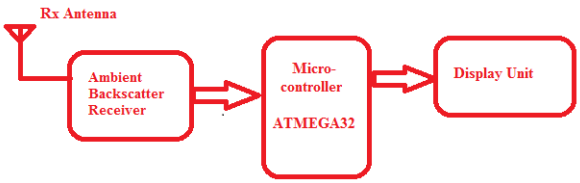

Fig 4. Block Diagram of Receiver section.

Received information is forwarded to microcontroller unit for further processing. This can be achieved by initializing UART of microcontroller. Received value of current pressure is displayed on display unit.

III. LITERATURE SURVEY TPMS AND CIRCUITRY

In previous TPMS there was major problem regarding replacement of battery so depending on that in this proposal paper on low power TPMS wireless communication scheme based on a duplex

@IJAERD-2014, All rights Reserved

communication. Purpose of this is that this system transmits data depending upon road condition & threshold values which will be used in future. It will not send data continuously. Author tells to fix the TPMS compulsory on every passenger car, heavy vehicle since 2013[1]. Author finds drawback of ABS wheel speed sensor system for measurement of tire pressure that the system is not sophisticated for the speed more than 100 km/hr so he proposed ad hoc method of micro targeted smart sensor node and he focused on improving battery life of TPMS [2]. Conventional TPMS contains battery inside the Tubeless Tire that was problematic for replacement in case failure of battery. In proposed idea he developed system which is can be fixed on the RIM of Tire, which can be screwed easily at the time of maintenance [3]. Now days many Luxuries vehicle included this facility for safety purpose with extensive application of microcontroller, cost is reduced on large scale, and many people worked for space complexity & for low power consumption. In this paper author proposed use of ad hoc network for interfacing of intelligent sensor which are very small in size and which consumes very less power which leads to improve battery life [5]. In this paper author Ambarish is concentrated on pressure sensor development. He overcome piezoresistive type pressure sensor & used the sensor which compares with the atmospheric pressure [6]. In conventional TPMS system there was unwanted power consumption occurring due to continuous data transmission to remove this drawback author communication scheme such that measured pressure value keeps on comparing with the reference previously stored value based on temperature condition & road condition if it get mismatched then only it will transmit the signal to receiver section. It will avoid reducing unwanted signal processing [8]. Found that up to till date in TPMS there were sensors present like acoustic sensor, RFID, Optical sensor, vibrating string sensor, capacitive sensor. As its extension author introduced "Capacitive MEMS sensor" which is having highest potential [9]. TPMS related researches are taken place very widely but this author contributed for improvement of very intelligent safety applications. To improve system performance he introduced algorithm for Manchester encoding, concept of Data acquisition and protocol for communication [10].

To designed individual power supply for system power of RF power receiver and power generated for thermocouple is combined and charge is stored in micro battery [12]. From many years people are interested in RF transmission and to recollect the amount of energy transmitted from transmitter. Online RF power harvesting for increasing efficiency of received signal by using microcontroller management system. It will track the point where maximum power is delivered and it is found that system collects more power nearby cellular tower [13]. Radio frequency radiations are harmful for human body so author suggest transmission of Ultrasonic signal having frequency around 38 MHz and energy can be harvested up to 21.4nW, simulated by using electrical equivalent electrical circuits [14]. Array of ratenna is very good concept for harvesting energy from RF signal. In whole system receiving antenna is an important factor to get maximum energy and author suggest to use array of antenna to get signal and from these received signal energy can be harvested with the help of separate voltage multiplier. This voltage is combined further to get large amount of voltage which can easily satisfy different application. This can be achieved by two different ways i.e. by combining RF energy before multiplying or by combining output voltage produced by different multiplier circuits [15]. Improvement of an efficiency of Harvested energy is achieved by designing 17 stage rectifier which is self-compensated and fabricated in a 90 mm CMOS technology. It overcomes the drawback of input dead zone i.e. it responds to very small signal even at high frequency. It is used in self-powered wireless sensor mode [16]. To create device battery free and to make it accessible from remote places RF energy harvester circuit is designed in 0.13 micrometer technology. This system is proposed to power up wireless sensor node which consist of bulk acoustic transmitter and on-chip temperature sensor [17]. There are many conventional ways of energy harvesting like energy from solar, wind and existed RF harvesting method is effective over narrow frequency range. Author suggest two types of harvesting using 7 and 10 stages of doubler circuitry. Also guideline is provided for component selection [18]. Concept of built in transformer is well explained here to double the input voltage and high step up converter is used for satisfying

@IJAERD-2014, All rights Reserved

distributed photovoltaic. Built in transformer is made up of three different windings one for diode and other for capacitor. Used to improve flexibility of voltage ratio, circuit gives good performance in application where dealing with large current is present. Author introduced very new concept of Ambient Backscatter communication which communicates by using RF signal which are present in surrounding and uses same RF signal as the main source of power. This device avoids whole process of generating individual RF signal for sending data which was very expensive and was a cause of creating system very bulky. For generation of RF signal dedicated power supply was needed which is not required in this case. Device transmits information at rate of 1 kbps up to 2.5 feet distance [22].

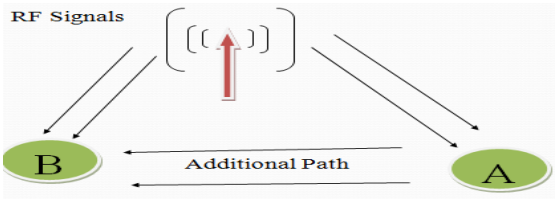

Fig 5. Ambient Backscatter.

IV. PROPOSED WORK

Current Tire Pressure Monitoring System became very efficient system because lots of improvement are carried out in every sector i.e. communication algorithm, protocol, power, size required for system, packaging of system, pressure sensor technology, microprocessor but still everybody facing problem regarding with the power system required for TPMS i.e. replacement of battery used in the system during maintenance & life of battery. To overcome this drawback system can be designed in such a way that which communicates using the signal which is present surrounding technically Ambient RF signal as only the basic source of power. It means that this system do not requires any external power supply for performing communication. This is the main advantage over all previous systems. Previously in all system lots of energy spend was taken place to generate RF signal for transmission of our coded data for transmitter to receiver [13]. To approach towards this a very efficient & new concept can be introduced i.e. Ambient Backscatter, in which device communicates with each other by backscattering Ambient RF signal. This technology do not requires any separate dedicated power supply as used in old methods like RFID. Ambient Backscatter technology takes signal from TV tower, mobile tower and just backscatters it. In surrounding, it will produce RF signal anywhere that is in urban area can get signal on large scale. Fig 6 shows block diagram of Ambient Backscatter technology. It consist of RF harvesting & Power management block which is consist of no of cascaded voltage doubler circuitry which can be used for switching of antenna.

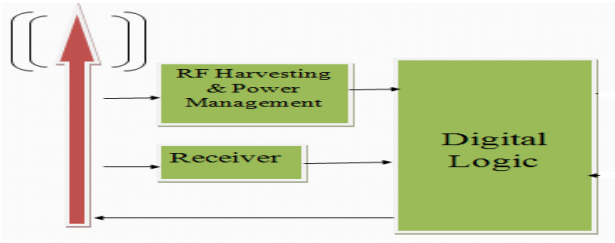

Fig 6. Block diagram of Ambient Backscatter Technology.

All blocks uses same RF signal. Function of receiver is to receive RF signal & which are forwarded to digital logic. Digital Logic block is used for modulation purpose to send information to

@IJAERD-2014, All rights Reserved

receiver so by using same modulation & demodulation technique transmitter & receiver can communicate Here Ambient Backscatter Technology as a Black box is considered.

To overcome difficulties related to battery in wireless
Sensor node where maintenance is not easy this system is proposed. This is an effective solution to use as only source of power. This is better than conventional methods like solar & wind, because main drawback of these system is that they are not available for all time as a continuous source. As in case of RF energy harvesting the input source is environmental radio frequency signal which is freely available for all time and present on most of the part of an earth. Here this concept is inspired from Tire Pressure monitoring System (TPMS). All present TPMS system are facing problem with battery replacement after battery life because system is fitted in tubeless tire so we can't afford replacement cost each time, so this concept can be used as the source of power independently.

Proposed work include design of voltage multiplier and PCB design for multiplier circuit. Fabrication of PCB includes tracing circuit footprint on PCB, etching process, drilling to PCB, component mounting and soldering. In this paper we are giving input from single antenna but for better performance it is better to connect no of antennas parallel, so received signal will be more and harvested voltage also will be large.

V. HARDWARE DESIGN FOR RF HARVESTING CIRCUIT

RF harvesting circuit consist of Magnetic antenna which is capable of receiving signal up to 2.4GHz frequency. This extracts the very high frequency Wi-Fi signal present in surrounding. It contains voltage multiplier circuit.

A. *Patch antenna or Microstrip antenna*

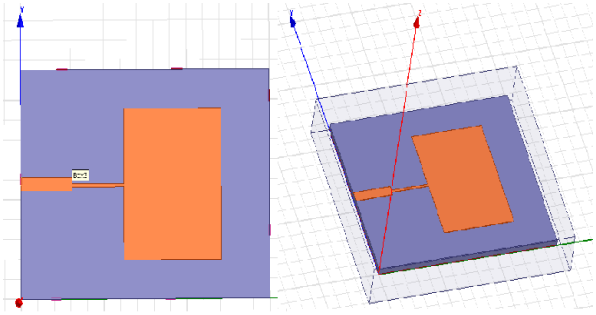

Fig 7 Microstrip Antenna, (a) Top view, (b) 3D view

Fig 7 shows Microstrip antenna designed in HFSS design tool by Ansys. It is designed based on length, width of patch. Dielectric material is provided in between patch and ground. Antenna is designed to receive signal of frequency 2.4 GHz radio frequency which has peak gain at frequency 2.4 GHz. Impedance of antenna is 50 Ohm. Feed line of patch antenna consist of Quarterwave transformer. At the end point of Quarterwave port is created used to take signal out. Operation of antenna is analysed through software package results are shown in fig3 highest gain of designed patch antenna is around -17dBi.

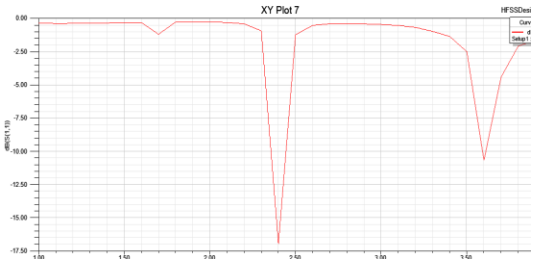

Fig 8. Gain of Microstrip antenna.

@IJAERD-2014, All rights Reserved

B. ***Voltage Doubler:***

Cockcroft-Walton generator is nothing but voltage doubler. Give Vin as an alternating input voltage then it produces 2Vin as output voltage. It doubles the input voltage. This phenomenon is used to improve the voltage of RF signal which is going to use for switching of antenna. Very small voltage get from RF signal i.e. around 150mv but by cascading such number of voltage doublers can produce collectively large voltage.

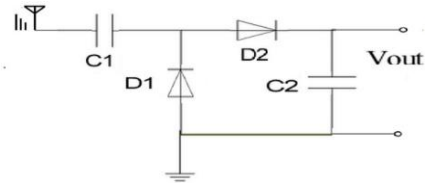

Fig 9. RF energy harvesting circuit

As shown in fig 9. In positive cycle of RF signal diode D2 conducts and capacitor charges up to input voltage applied. During negative cycle diode D1 conducts but this time voltage applied will be combination of input voltage and voltage of charged capacitor C1. This stores charge into capacitor C2 thus voltage measured will be twice of input voltage.

C. ***Voltage Multiplier:***

Voltage multiplier boost strength the low power input RF signal. Fig 10 shows the Villard Multiplier, this paper suggest Silicon schottky diode BAT15-099E6327 (Infineon technologies) which is used for application having frequency up to 12GHz.

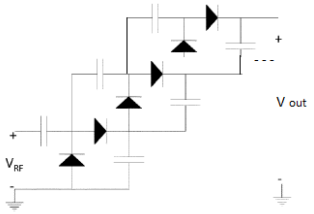

Fig 10. Block Diagram of Voltage Multiplier.

Here package of schottky diode used is SOT140 SMD (surface mounting device). Peak reverse voltage is 4 V, peak forward current is 130 mA and peak forward voltage is 0.30 V. Capacitor used is of value 1pf, it is proposed that use of super capacitor will be the best solution instead of normal capacitor .

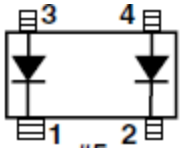

Fig 11. Packaging of Schottky Diode.

VI. SIMULATION

A. ***Proteus design for TPMS.***

As shown in design TPMS it consist of two different section i.e. Transmitter & Receiver section. In proteus Temp sensor LM35 IC is used instead of pressure sensor because both will give analog output which is given to the ADC channel of microcontroller. LCD is connected to see whether it

@IJAERD-2014, All rights Reserved

will get same value at transmitter section & receiver section. Tx pin of Transmission controller is connected Rx pin of Receiver and wise versa. By initializing UART, it can write & read data, here wired communication is performed instead of wireless only because of wireless communication is not possible in software simulation mikroC pro for AVR compiler is used for programming purpose & programming.

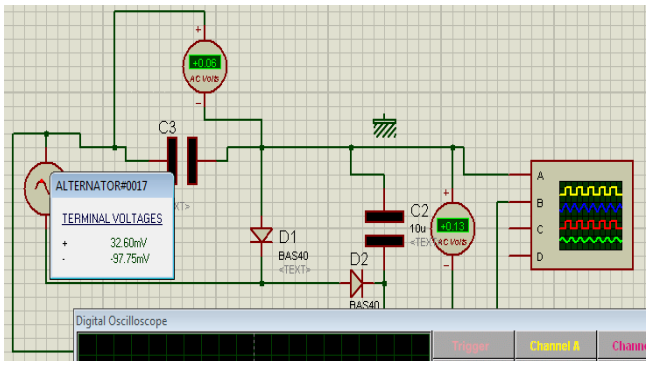

Fig 12. Proteus simulation of voltage doubler.

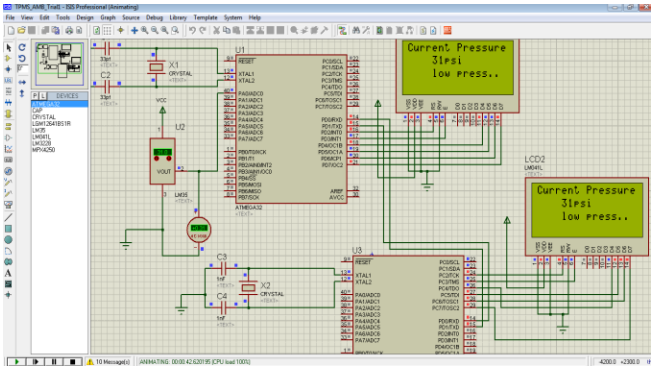

Fig 13. TPMS for one input

Steps involved in development of Transmission section programming are:

- Sbit declaration
- Define Port A= 0X00 & Port D= 0XFF
- LCD initialization & LCD command
- print Message on LCD
- Enable ADC
- Access ADCSRA, ADMUX,SFIOR Reg
- Load ADC value in ADC data reg.
- Display ADC value
- Compare with ref value & Display Result.
- Initialize UART &Transmit measured value to receiver section.

Steps involved in development of Receiver section programming are :

- Sbit declaration
- Define Port D= 0X00 & Port C= 0XFF
- LCD initialization & LCD command
- print Message on LCD
- Initialize UART

@IJAERD-2014, All rights Reserved

- Receive transited data from TX
- Display ADC value
- Compare with ref value & Display Result.

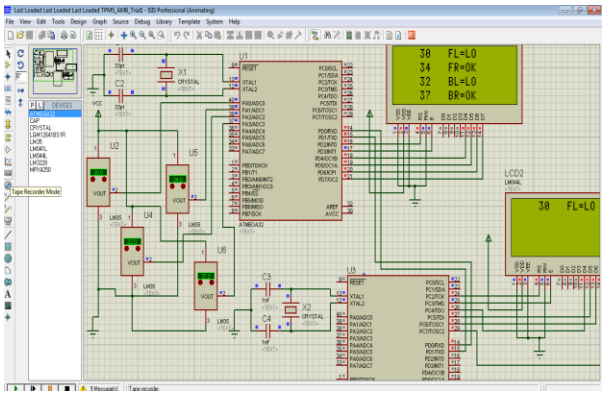

Fig 14. TPMS for different 4 input.

B. ***Voltage multiplier at low frequency with 3 stage doubler***

Fig 15 consist of 3 stage multiplier circuit it produces output voltage of 9.534 V when input of 1 V is applied across input with a frequency of 1Hz.

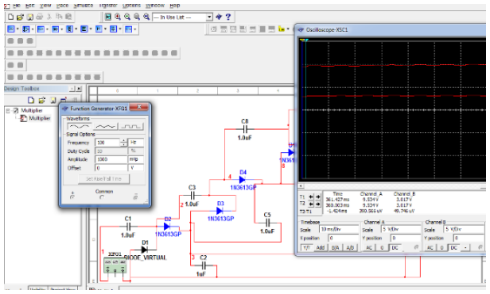

Fig 15. Voltage multiplier Multisim simulation.

C. ***Voltage multiplier using 10 stage doubler in Multisim.***

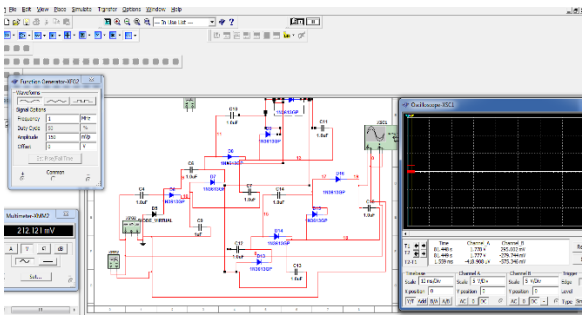

Fig 16. Voltage multiplier Multisim simulation.

As shown in fig 16 input provided to multiplier circuit is 150mv with high frequency of 1MHz. 10 stages of voltage doubler is cascaded in series. Output voltage measured across last capacitor is 1.778 V. Output voltage is approximately boosted up to 11 times of input voltage.

D. ***PCB design***

PCB is designed in Express PCB software as shown in Fig8.

@IJAERD-2014, All rights Reserved

According to footprint of components called layout. Layout is printed on Butter paper by using laser printer. This laser print is traced on copper clad board by putting printed butter paper on PCB & ironing it till it get printed on copper clad board. Etching process is done by steering PCB board into the solution of Ferric Chloride for long time.

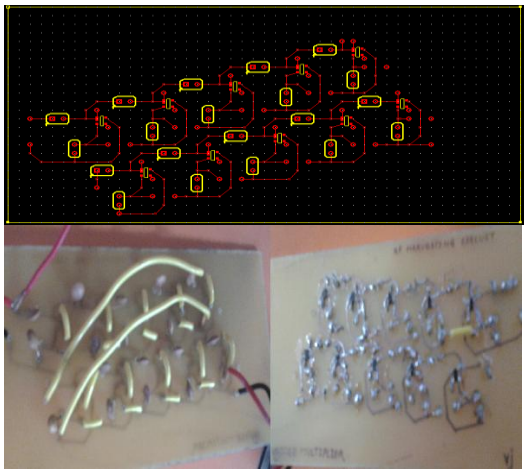

Fig 17. Layout and PCB Design of voltage multiplier circuit

Fig 17 also shows top and bottom layer of PCB after mounting components. Output voltage is measured across capacitor i.e. red and black wires are taken out.

VII. CONCLUSION

An efficient device is capable of driving low power devices like TPMS transmitter section which requires around 2-3 V voltage to operate. Series of retenna can improve voltage level. Hardware is tested in laboratory at different frequency at very small input voltage i.e. in millivolts. Tire pressure monitoring system helps to keep alert to the driver when it required which improves performance & reduces accidents. As per proposed idea, it can design the systems which do not require dedicated power supply to transmit & generate RF signal which was main drawback in all previous system. This will lead to design very efficient & maintenance free TPMS & helps to reduce maintenance cost of Vehicle. Future works of this paper includes fabrication of Microstrip antenna gives the signal instead of function generator. Wireless node takes power from only ambient signal nothing more than that. This design improves the reliability of systems so it can be implemented on system on-chip as the only power supply with low cost.

ACKNOWLEDGMENT

I would like to take this opportunity to thank my research guide prof. M. Kalyan Chakarvarti and prof. P. Vijaykumar for his support and guidance throughout the completion of the work. I also wish to acknowledge my sincere gratitude to Dr. Usha kiran and to all those persons who have helped me during the course of my research. I also wish to acknowledge my sincere gratitude to all those persons who have helped me during the course of my research. Last but not the least I thank the Almighty for his immense blessings upon me.

REFERENCES

[1]. Santossh KV, Pankaj Kumar Bhowmik, *An Intelligent Online Vehicle Tire Pressure Monitoring System*, in the IJECE, Vol.2, No.3, pp.301~308, June 2012. ISSN: 2088-8708.
[2]. Jiaming Zhang, Quan Liu, Yi Zhong, *A Tire Pressure Monitoring System Based On Wireless Technology*.

@IJAERD-2014, All rights Reserved

[3]. Ho I-Hsiu, Jia-min Chung, hasiao-Chin Chen; Hung-Wei Chiu(2009),*A Battery-Less Tire pressure Monitoring System*, Vehicular Technology Conference, 2009. VTC Spring 2009. IEEE 69th, Vol. no., pp.1-5, 26-29 April 2009.doi:10.1109/VETECS.2009.5073285

[4]. k. Joshi, J.Rana, *Wireless Communication for Tire Pressure Monitoring System Bases on ARM7TDMI* International Journal of Recent Trends in Engineering, Vol 2, No. 8, November 2009.

[5]. Ambarish G. Mohapatra, *Design and Implementation of Diaphram Type Pressure Sensor in a Direct Tire Pressure Monitoring System (TPMS) for Automotive Safety Application*, Vol. 3No. 8 August 2011.

[6]. Qi Zhang, Bo Liu, Guofu Liu, *Design of Tire Pressure Monitoring System based on resonance frequency method*, IEEE/ASME International conference on Advance Intelligent Mechatronics, 2009.AIM 2009.AIM2009.

[7]. Suk- seung Hwang, Seong-min Kim, Jae-Young pyun, *Low –power TPMS Data Transmission Technique based on Optimal Tire Condition*, IARIA, 2013. ISBN: 978-1-61208-288-2.

[8]. Afolbi A. Ogunwemimio, *Economic Analysis of Continuous Monitoring of Commercial Truck Tire Pressure Monitoring System and RFID Technologies* (12.1.2011) Industrial and Management System Engineering.

[9]. N A Hannan, A Hussain, A Mohamed, S A Samad, H Basri, *TPMS for Intelligent Vehicle Safety Application* The Hong Kong Institute of Engineers Transaction Vol 16, No2,pp46-51 Technical Note: 2013

[10]. Le Et Al, *Efficient far field radio frequency energy harvesting for passively powered Sensor Networks*. IEEE Journal of solid state Circuits, Vol.43, No.5, may 2008.

[11]. Vincent Liu, Aaron Parks, Vamsi Talla,Shyamnath Gollakota, David Wetherall, Joshua R. Smith, *Ambient Backscatter: Wireless Communication Out of Thin Air* SIGCOM'13,August 12- 16 2013,hong Kong, China., ACM 978-1-4503-2056-6/13/08.

[12]. Arseny Dolgov, Regan Zane and Zoya Popovic, *Power Management System for Online Low Power RF Energy Harvesting Optimization*, IEEE transaction on Circuit and System, VOL. 57, NO. 7, JULY 2010

[13]. Yong Zhu, S. O. Reza Moheimani and Mehmet Rasit Yuce, *A 2-DOF MEMS Ultrasonic Energy Harvester*, IEEE Sensors journal, VOL. 11, NO. 1, JANUARY 2011.

[14]. Ugur Olgun, Chi-Chih Chen and John L. Volakis, *Investigation of Rectenna Array Configurations for Enhanced RF Power Harvesting* IEEE antennas and wireless propagation letters VOL. 10, 2011.

[15]. Giuseppe Papotto, Francesco Carrara and Giuseppe Palmisano, *A 90-nm CMOS Threshold-Compensated RF Energy Harvester*, IEEE Journal of solid- state circuits, VOL. 46, NO. 9, SEPTEMBER 2011.

[16]. Hannes Reinisch, Stefan Gruber, Hartwig Unterassinger, Martin Wiessflecker, Günter Hofer, Wolfgang Pribyl, and Gerald Holweg, *An Electro-Magnetic Energy Harvesting System With 190 nW Idle Mode Power Consumption for a BAW Based Wireless Sensor Node*, IEEE Journal of solid- state circuits, VOL. 46, NO. 7, JULY 2011

[17]. Suk- seung Hwang, Seong-min Kim, Jae-Young pyun, Prusayon Nintanavongsa, Ufuk Muncuk, David Richard Lewis, and Kaushik Roy Chowdhury, *Design Optimization and Implementation for RF Energy Harvesting Circuits*, IARIA, 2013. ISBN: 978-1-61208-288-2. IEEE Journal on Emerging and Selected Topics in circuit and System, VOL. 2, NO. 1, MARCH 2012

[18]. Weichen Li, Xin Xiang, Chushan Li, Wuhua Li, and Xiangning He, *Interleaved High Step-Up ZVT Converter With Built-In Transformer Voltage Doubler Cell for Distributed PV Generation System*. IEEE Transaction on Power Electronics, VOL. 28, NO. 1, JANUARY 2013

[19]. Rushi J. Vyas, Benjamin B. Cook, Yoshihiro Kawahara, and Manos M. Tentzeris, *E-WEHP: A Batteryless Embedded Sensor Platform Wirelessly Powered From Ambient Digital-TV Signals*, IEEE Transaction On Microwave Theory and Techniques, VOL. 61, NO. 6, JUNE 2013 2491.

[20]. Manuel Piñuela , Paul D. Mitcheson and Stepan Lucyszyn, *Ambient RF Energy Harvesting in Urban and Semi-Urban Environments*, IEEE Transaction on Microwave Theory and Techniques, VOL. 61, NO. 7, JULY 2013.

[21]. Seunghyun Lee, Rui Zhang, and Kaibin Huang, *Opportunistic Wireless Energy Harvesting in Cognitive Radio Networks*, IEEE Transaction on Wireless Communications, VOL. 12, NO. 9, SEPTEMBER 2013

[22]. Hélène Lhermet, Cyril Condemine, Marc Plissonnier, Raphaël Salot, Patrick Audebert, and Marion Rosset, *Efficient Power Management Circuit: From Thermal Energy Harvesting to Above-IC Micro battery*, IEEE Journal of solid- state circuits, VOL. 43, NO. 1, JANUARY 2008.

@IJAERD-2014, All rights Reserved