Gas Sensor Data Collection Over an RF Network

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ABSTRACT

Radio Frequency Identification (RFID) is a rapidly developing technology in many services of industry, distribution logistics, manufacturing and goods flow systems. The overall project objective is to develop a hydrogen gas sensor with 'titania nanotubes' and then collect the sensor response over a wireless methodology based on RF. This paper describes the second phase of this project; designing reading mechanism for the sensor via RF. The concept of "low power (25mA in Tx/Rx modes & 2μA in sleep mode)", "low data rate (250 kbps)", "reduced size" and "real time data measuring" gas sensor was achieved through the developed system and the further miniaturizing plans also demonstrated conceptually. As IEEE 802.15.4 defined as "*multi-access network*" all sensor nodes in the sensor network have equal access to the medium of communication enabling implementation of the system in non-beacon network. Furthermore the developed system can be spread seamlessly beyond the radio range of antenna (~20 m) by taking the advantage of wireless routing of *MiWi* protocol. In this paper we report two approaches: first approach is with RFID reader with tags using commercially off the shelf 13.56 MHz and the second approach is using Microchip's RF transceiver chip *MRF24J40* and Microchip proprietary wireless Protocol *MiWi*^{TM}.

1. INTRODUCTION

The demand for sensitive, low-power, low-cost gas sensors that respond quickly to appropriate stimuli are growing. In this sense 'Radio Frequency Identification (RFID)' is successfully adapting with this type of tasks to communicate in industrial applications. RFID is a rapidly developing technology in many services of industry, distribution logistics, manufacturing and goods flow systems. It has many advantages over wired communication methods like RS232 or RS485 in maintenance, cost, upgradability, and many more. For an instance the efficiency, radio range, noise level like factors can control easily. For the passive RFID tag, since it does not have its own power supply, all power required for operation must be harvested from RF energy from reader. When this comes out of the "RFID tags" topic, there are more advance concepts of placing the sensors on a single network and handling with central workstation. In this case, 2.4GHz Zigbee like Protocols now came into the application field.

The project is to integrate newly developed highly sensitive gas sensor to a wireless communication system which can be used as a direct and ready-to-use industrial product mainly for gas leakage safety. By the rapid growth of industries, we have caused many problems related to environmental, energy exhaustion, global warming and so on. Therefore, nowadays the need of safety sensors to protect human being been is a crucial issue. To solve the necessity, authors realized and defined that the problem would be solved by utilizing nanotechnology and RFID.

Within the last couple of decades so many solid-state devices for gas sensing have immerged which utilize different materials and work on different principles [1, 2]. Today there are many gas sensors in daily use such as oxygen and hydrogen sensors. Nowadays these sensors are widely using in car emission controlling, metallurgical processes, gas sensors to detect inflammable gases in air such as CH_4, LPG and H_2 [2, 3]. Gas leakage alarms in domestic houses and humidity sensors using ceramic or organic polymer electrolytes which are useful for automating & air conditioning are few such examples [2, 3]. For several decades, nanotechnology has been the fundamental in gas sensor industries. There are many types of gas sensors such as semiconductor, CMOS, FET (Field effect transistor), and Optic Fiber and etc… but, semiconductor sensors are more popular than the others because of the production cost compared to others [4].

Because of their low cost and simplicity semiconductor metal oxide gas sensors stand out among all the other types of sensors. High sensitivity, rapid responses, long stability and simple structure can be considered as main advantages of MOX Sensors [2, 5]. Though MOX gas sensors are not perfect sensor yet, still they make the best candidate for many purposes like gas leakage monitoring and frequently used long term monitoring systems.

Gas sensors have been used in many aspects in the recent past, and nowadays most unexpected sectors have also shown keen interest in improving and adopting gas sensors for their unique requirements. It is said that the military and security forces also are now trying to develop state of the art explosive and drug detectors using the highly sensitive gas sensors or sometimes absorb their existing detection systems relate with gaseous substances to Gas Sensor systems [1, 3, 6]. There are new terms also emerging for these inventions like, artificial or electronic nose, artificial Canary Bird and Bomb Sniffers. These products looks for specific pattern or a finger print of the gas mixtures. Such a device generally consists of few chemical sensors each one sensitive to a specific gas and a pattern recognition system. It is expected that in the very near future animal based explosive and drug detection (using animals like dogs and bees) would be replaced by gas sensors and parallel electronic interfaces [3, 7].

Some of the requirements of such a system would meet, to be low cost, have reduced dimensions, sensing capability to measure both chemical and physical parameters related to purpose, and include data storage and communication methodology (more preferably wireless). Small size and low cost would enable these devices to be applied in a widespread manner and communications with data storing capability would ensure

the necessary data transmission to allow a future of consumers, logistic people and producers to trace the complete history of a certain application [8, 9].
For the gas sensor we have chosen hydrogen sensor using 'titania nanotubes(TNT)' which has remarkable sensitivity with hydrogen, as the source for this research work. However to apply this technology into many applications, wireless communication technology is needed. Therefore, we have tried to find out a solution to produce an effective wireless hydrogen sensor with low cost. As developing the sensor, the "RFID gas sensor tag" can be installed on passenger luggage in train, bus and air flight like places where it should be monitored for possible hydrogen availability or leakage.

These requirements and projected possibilities made the path for this research work on implementing a wireless communication method over RFID tags or some other RF based method. In this paper we report two approaches: first approach is with RFID reader with tags using commercially off the shelf 13.56 MHz and the second approach using Microchip Inc's MiWi™ Protocol. The signal conditioning circuit for the sensor side and relevant supporting electronics are also discussed in detail where it necessary.

2. SYSTEM ARCHITECTURE

This section describes the architecture of the both approaches stated above on gas level sensing technology, starting with the scenario of the project.

2.1 Project Definition

As Identified at the beginning of the research work:

- TNT sensor's electrical response in the presence Hydrogen gas is resistive. (This resistance variation is to be converted to voltage variation, so that it can be used as the direct input for the Microcontroller.)
- It can be implemented a peer-to-peer, star, cluster tree or mesh network configuration as per to the real application environment [4, 6] between the sensor(s) and the reader (or the main Coordinator of the sensor network).
- Reading distance also depends on the real-time application requirements. Basically this will be considered as two main cases.
  - *Case 1*: The Observer can travel with the reader to the places where sensors are located and retrieve the data stored in EEPROMs attached to sensor.
  - *Case 2*: The sensors can be connected to a network, then the all the sensor points will be a node of one single network, which can be handle with some routers and main coordinators.
- Selection of the protocol, vendor, component and the frequency also depends on the application requirements [6], distance, etc…
- The range of the RF communication is going to be decided with, whether is it going to be executed under the Case 1 or Case 2 mentioned above.

2.2 Working Approaches

If it is going to be reckoned under *Case 1*, then the RF reading range is not a critical matter as the observer/ inspector can travel with the reader to the proximity of the sensor and read out the data stored. Then the whole "sensor tag" (sensor + RF transceiver + antenna) can be arrange in a much miniature design. For this *Case* we can stay in the HF band in the RF spectrum and work with 13.56 MHz ISM band.

If a long range is expected and all the sensor points have to be communicating with a central point (example: a smart security network) then the process should go through *Case 2*. To acquire greater range we need to move for ultra higher frequencies in UHF band like 868 MHz or 2.4 GHz [6].

2.2.1 Approach 1 – Using 13.56 MHz Band

General Purpose 'RFID tags' can only be programmed with a specific code using a RFID reader/ writer and then read by the same. That is because the memory is just enough for the code and those tags don't have any interface to real time data input and store [1, 8, 9]. Therefore using such a tag(s) we can demonstrate some sort of "*Level Detection*" of Hydrogen gas.

For this task we used general COTS (commercially-off-the-shelf) 13.56 MHz HF RFID Reader (OBID i-scan ID ISC.MR100) from FEIG Electronics, Germany.

With the aim of using a transistor as switch, the collector & emitter ends were joined to the short-circuited ends of tag antenna. At this point, when the transistor is "switch ON" (connected) the antenna is short circuited and no longer detects by the reader while it is "switch OFF" the tag works properly and reader detects the tag code. The switching OFF the Transistor is controlled by resistance of the sensor and has been adjusted the circuit to toggle between switch "ON" and "OFF" modes at different levels of gas on the surface of the sensor. The RFID tag is made to detect (read) at one level (as normal), and tag is no longer read by the reader at some other level. The transistor circuit with a single tag is shown in *Figure 1.* This simple model can be extended to read out few levels of gas, by adding few tags to the circuit as shown in *equation 1*.

$$\text{Number of Levels} = 2^n - 1 \quad \text{where, } n = \text{number of tags} \qquad (1)$$

Example:
Using 2 tags : Tag 1 active + Tag 2 active + both tags active - 3 levels
Using 3 tags : Tag 1 active + Tag 2 active + Tag 3 active + Tag 1&2 active + Tag 2&3 active + Tag 1&3 active + all three tags active – 7 levels

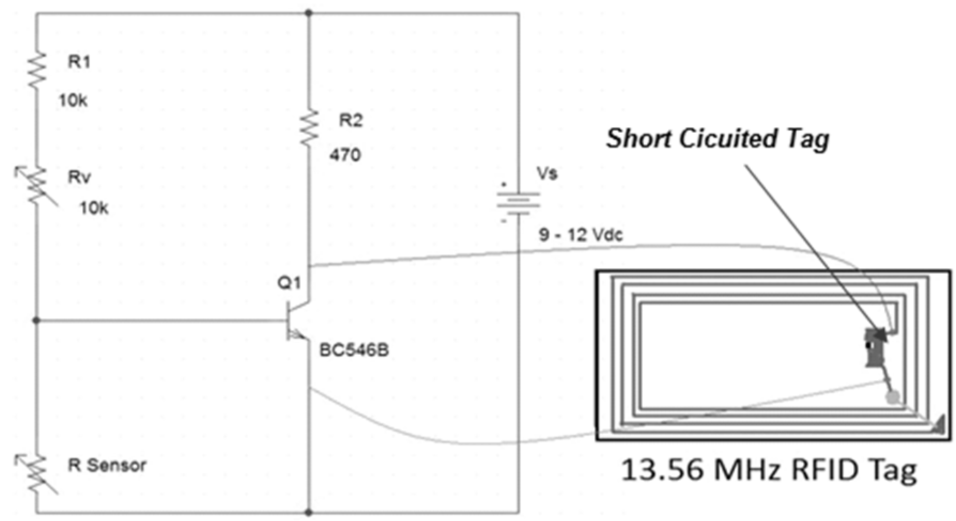

Figure 1: The transistor circuit with a single tag

In this case detection range was not more than 5 – 8 cm maximum even with RF line of sight (RF LOS). Further, attaching multiple tags acute the overlapping of tags making the reader fail to detects them separately. Due to these reasons this approach is suitable for detecting only a threshold level. Therefore users can implement this approach in applications like 'generate risk alarm after reaching an introduced threshold level'.

2.2.2 Approach 2 – Using 2.4GHz (IEEE 802.15.4 Standard complaint) Network

As mentioned earlier, the electrical response of the safety sniff sensor is resistive and it has *Negative Gas Coefficient* (NGC); that is resistance decreases with the increasing gas availability. For the data acquisition to the main control unit (MCU) constructed based on *PIC18LF4620 microcontroller IC* and data logging stage, resistance variation has been converted to voltage variation as shown in *Figure 2.*

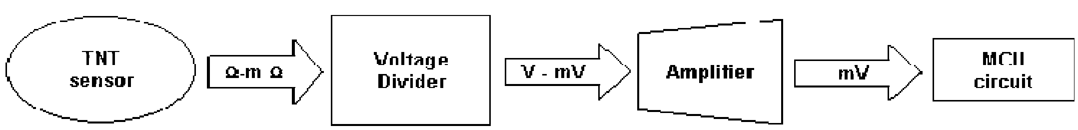

Figure 2: Stepwise conversion from sensor to MCU input

Because of the sensors resistance in Giga Ohm (GΩ) range in normal atmosphere and at the presence of little amount of hydrogen it varies in very small range, the sensitivity of the output has to be adjusted. Therefore while converting the "resistance variation" into a "voltage variation" by means of a voltage divider, an "amplification circuit" also added to the circuit to amplify the variations of the input from the Voltage divider. Consequently small variations of the sensor resistance were able to visibly capture at the end of signal conditioning circuit as shown in *Figure 3.*

As shown in *Figure 3* conversion of the resistance to the Voltage has been done using a reference dc voltage of 1 V and coupling into four-resistor network (taking the *sensor resistance* also to the account). Amplification has been done using *instrumentation amplifier*, which amplifies the resistance variation of the sensor (not the whole resistance). For that purpose Texas Instrument's TL084CN quad JFET op-amp IC has been used.

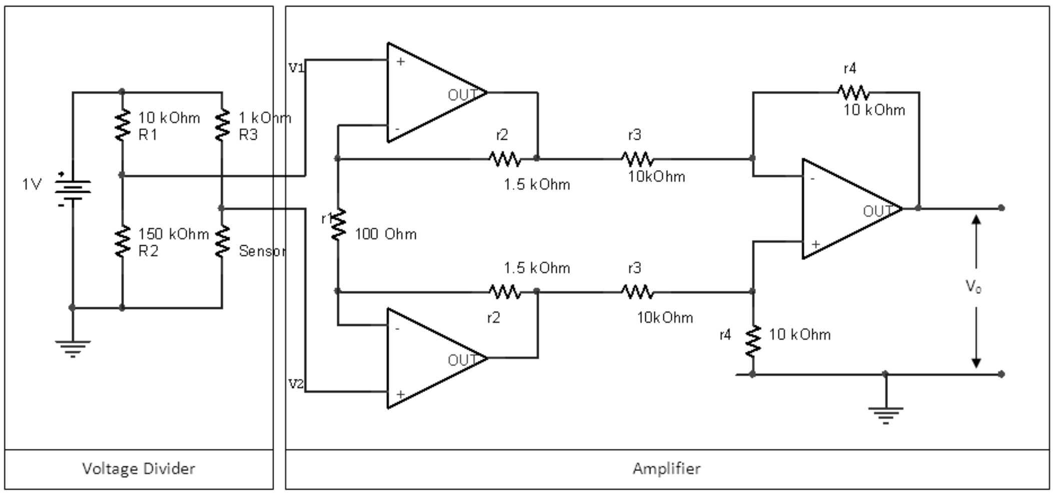

Figure 3: Signal conditioning circuit– voltage divider & amplifier

Output of the Instrumentation amplifier can be defined as,

$$V_o = -\left[\left(r_4/r_3\right)\left\{1+\left(2r_2/r_1\right)\right\}\right]\left(V_1 - V_2\right) \quad \text{.....(2)}$$

Most importantly, as can be seen from the *equation 2*, due to the common mode noise rejection noise presence at the voltage divider will not amplified.

After above, the RF selection procedure was carried out with few constrains like cost, capability of future miniaturizing plans, module availability with RF antenna and ease of programming the application code. Out of many of other companies' products and protocols, Microchip's RF transceiver chip *MRF24J40* (in 2.4GHz, 915 MHz & 868MHz frequency bands) and Microchip proprietary wireless Protocol *MiWi*^{TM} has been chosen for this project due to its efficiency as described in [10, 11].

The selected RF transceiver and Microchip's own *MiWi*^{TM} and *MiWi*^{TM} *P2P* protocols are designed for applications in low data transmission rates, short distance and cost constrained networks, such as industrial monitoring & control, home & building automation, remote control, low-power wireless sensors. Therefore it is ideally matched with constrains of this research work.

The programming is basically has two phases, *protocol stack programming* and *application programming*. *PIC18LF4620* microcontroller has been chosen as the controlling circuit in MCU because of its 64KB programming memory, enhanced data memory and SPI interface to interface with *MRF24J40 RF* transceiver IC. Though DIP package has been used for this research work, availability of said MCU in small QFN package is an advantage for reduce the package size at the production level. 64KB flash of the *PIC18LF4620* is enough to store the both *MiWi* Software stack and application code [11]. With all these designing stages, the hardware configuration of the final system is shown in *Figure 4.*

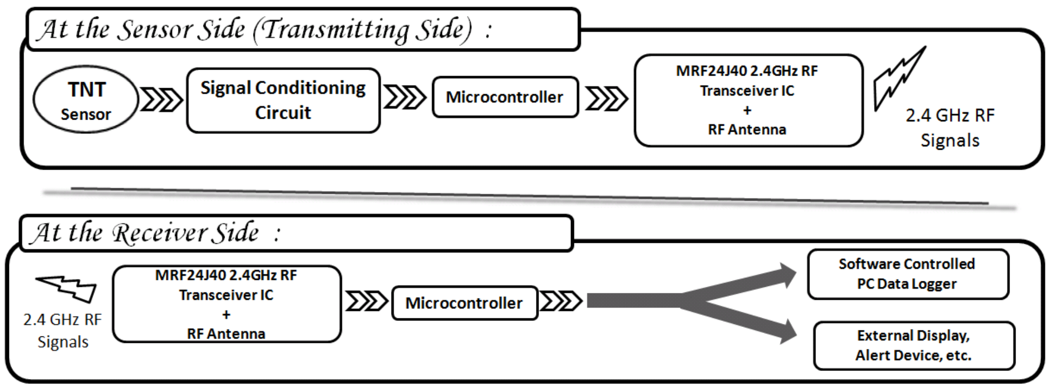

Figure 4: Hardware configuration of the final system

At the receiving side the data can be loaded to the computer via the RS-232 communication and separate data logging software can be arranged to store the data received.

3 DISCUSSION AND CONCLUSION

The total project is an innovative idea combining the RF technology, nanotechnology and sensor electronics. The overall project objective is to develop a hydrogen gas sensor with 'titania nanotubes' and then collect the sensor response over a wireless methodology based on RF technology. So the project has two primitive phases, sensor design phase and RF circuitry design phase. This paper describes the second phase of this large scaled research; designing reading mechanism for the sensor over RF signals. Since *MRF24J40* is with low current consumption of 25mA in both Tx & Rx modes and also with ultra low consumption of 2µA in sleep mode, it can be easily implemented as a low power consumption RFD device (battery powered) or in main powered FFD device [10]. As IEEE 802.15.4 defined as "*multi-access network*" all sensor nodes in the sensor network have equal access to the medium of communication enabling implementation of the system in non-beacon network. Furthermore the developed system can be spread seamlessly beyond the radio range of antenna (~20 m) by taking the advantage of wireless routing of *MiWi* protocol [11].

The concept of "low power (25mA in Tx/Rx modes & 2µA in sleep mode)", "low data rate (250 kbps)", "reduced size" and "real time data measuring" gas sensor was achieved through the developed system and the further miniaturizing plans also demonstrated conceptually. The developed system was able to communicate real-time; that is able to send/receive up-to-date data from the sensor to system and dissipates low power, has good response time and distance of communication was adequate. In this context, basic investigation methods employed to evaluate the system's operation. However complimentary and much complex experiments are still required before the implementation at the industrial level.

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