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# AN EFFICIENT MULTISENSING SYSTEM FOR SHM OF OIL AND GAS PIPELINES

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## ABSTRACT

*A comprehensive mapping of pipeline, which includes the information about leaks, cracks, corrosion, pressure, material degradation, and hydrocarbon permeation requires a number of sensors ensure the safety and reliability of the infrastructure. In this paper, a power efficient passive RF system is proposed for real-time communication with multiple sensor elements for internet-of-things (IoT) based applications. The proposed RF tag with integrated sensors eliminates the need for power hungry analog to digital converters as it uses an ultra-low power oscillator to generate a unique single frequency signal associated with different sensing values of each sensor element.*

Keywords: Battery-free, Multi-sensing, Sensor Network, Structural Health Monitoring (SHM), Wireless communication

## 1. INTRODUCTION

Structural health monitoring (SHM) of massive infrastructures is necessary due to the rapidly growing urban infrastructure as it has huge impact on human safety and well-being [1,2] Structurally deficient infrastructures over time increase the possibility of catastrophic failures leading to loss of human life and economy. There has been several thousand deaths reported around the globe due to infrastructure collapse or failure in the last decade. For example, in the United States alone, PHMSA and NTSB reported numerous pipeline failures in last decade leading to billions of dollars in monetary loss [3-5]. Although the exponential growth in the number of massive structures has mandated regulatory authorities to enforce rigorous maintenance protocols to mitigate risks for improved safety, the failure incidents are not uncommon. Hence, there is always a growing need to develop SHM technologies for efficient condition monitoring and evaluation for predictive maintenance [6,7].

For developing an efficient SHM system, the following challenges should be addressed: (i) Design a system capable of providing a comprehensive map of multiple monitoring parameters for evaluating the structural integrity of a large infrastructure; (ii) Realize a practical and a scalable solution that is compatible with monitoring and evaluating any type of large infrastructures; and (iii) Provide an economical solution that can be easily adopted.

A number of sensors are necessary to monitor different parameters of interest. There are two methods for probing these sensors, wired and wireless. The conventional wired techniques involves employing physical wires or probes to connect and obtain data from different sensor nodes. A major limitation of wired approach is that it is tedious to run wires on the external surface of the target object from the cluster of sensor nodes making this approach expensive as well as impractical for monitoring large infrastructures.

To overcome the impracticality of wired systems, wireless probing of the sensors is an excellent choice. The wireless sensors needs to be battery-free and long lasting, which makes it viable and economical to deploy in large quantity. The sensor node will be communicating the information wirelessly to the interrogator for evaluating the structural integrity of large objects as shown in Figure 1.

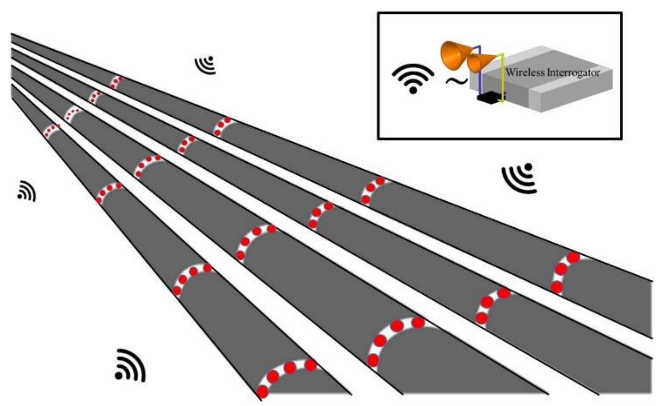


**FIGURE 1:** Battery-free wireless sensor network for SHM of pipelines

In order to provide a comprehensive mapping of the structural integrity of the target, multiple parameters of the target should be monitored and evaluated simultaneously. There is a need for developing an efficient high-performing passive multi-sensing system with improved read range and with higher noise immunity. In this paper, a passive wireless multi-sensing system compatible with existing UHF RFID infrastructure is presented with a power efficient, noise immune analog frequency modulation scheme for long range real-time communication. The proposed design exploits the available 300 kHz bandwidth

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of a single UHF RFID channel to modulate the multiple sensing information for efficiently transmitting the sensor data eliminating the need for power hungry analog to digital conversion.

## 2. PRINCIPLE OF OPERATION

The passive multi-sensor system consists of a custom designed UHF RFID interrogator and a multi-sensor tag. The communication between the reader and the multi-sensor tag is initiated by the interrogator by sending a continuous single frequency RF query signal within the range of 902-928 MHz. The multi-sensor tag antenna receives the RF query signal and feeds it to the rectifier through a matching circuitry that generates the required DC bias in order to activate the frequency oscillator.

The oscillator generates specific single tone frequency signal to represent each of the sensing parameters (for example, temperature, luminescence, humidity, etc.) and a switch is used to select in between different sensors with a specific periodicity. A low frequency source or an oscillator is used to generate a unique low frequency signal within a limited RFID channel bandwidth, corresponding to each sensing parameter value for a single sensor element, as shown in Figure 2.

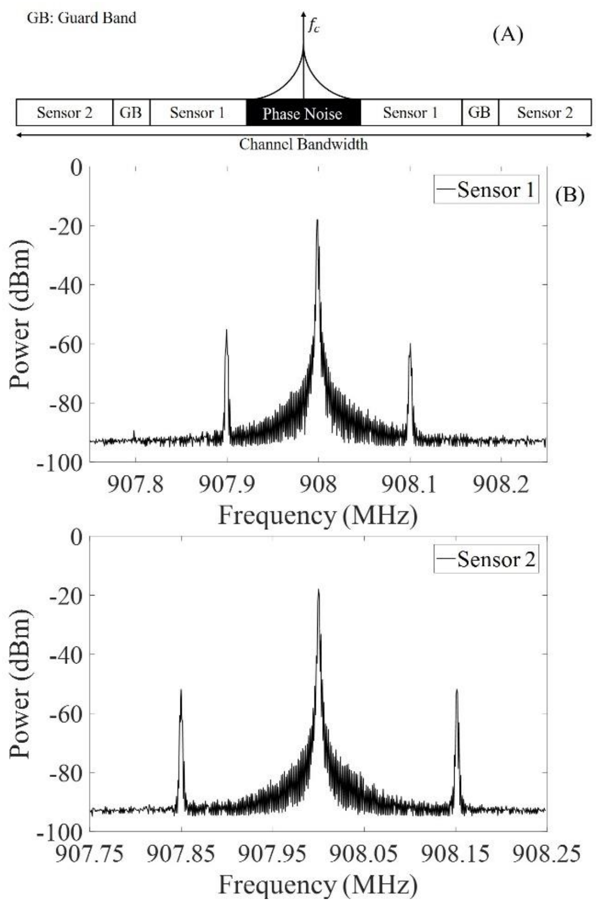


**FIGURE 2:** Sensing information modulation: A) Schematic of the modulation scheme and B) Modulated sensor information of 100 kHz and 150 kHz on 908 MHz carrier frequency

## 3. DESIGN

The passive wireless multiple sensing system is composed of an RF tag and an RF interrogator as shown in Fig.2. The design details of each fundamental block of the multi-sensor RF tag and RF interrogator is discussed in this section.

### 3.1 RF Tag

The multi-sensing tag consists of four units, a receiving antenna, a rectifying unit, a multi-sensing module with an oscillator and a modulation unit. A number of sensors can be integrated to the RF tag based on the total available bandwidth. For example, consider two sensors, a temperature sensor and a light sensor, the first sensor, temperature (-25ºC to +25ºC) is assigned a bandwidth of 25 kHz within the frequency range of 75-100 kHz, with every 0.5 kHz representing a degree in temperature change. The second sensor, luminescence (0 fc to 20 fc) is assigned a similar 25 kHz bandwidth within the frequency range of 125-150 kHz. The available single channel bandwidth for UHF RFID communication is 300 kHz, and with an example bandwidth requirement of 25 kHz per sensor, up to 6 different sensors can be integrated to the RF tag simultaneously. The low frequency signal generated by the oscillator is modulated on to a high frequency carrier backscattered by the tag. The backscattering modulation is performed using a non-linear device (MOSFET) that can mix the carrier and the low frequency sensor signal, and the modulated signal is re-transmitted using the tag antenna. The interrogator receives the modulated signal and demodulates the information to extract the sensing data. For example, consider two different sensors are integrated with the multi-sensor RF tag and the time period of switching is fixed at 6 kHz (~160 us).

### 3.1 RF Interrogator

The wireless communication with multi-sensor RF tag requires a custom designed RF interrogator, which transmit and receive the UHF RF signal. The interrogator consist of an RF source that can generate UHF continuous wave, which is radiated towards the multi-sensor RF tag using a commercial patch antenna with 6 dBi gain. The multi-sensor RF tag receives a single frequency signal using the tag antenna and reflect back the information modulated RF signal, which is received by using the same transceiver antenna. A circulator is connected at the front end of the interrogator to isolate the forward and backward propagating signal to and from the transceiver antenna. The reflected signal from the multi-sensor RF tag is visualized using a spectrum analyzer and an oscilloscope. The received low frequency signal is demodulated using an RF mixer by feeding a reference UHF signal into LO port and the back reflected modulated signal into the RF port after 36 dB amplification. The demodulated signal is acquired at the IF port of the mixer.

## 4. RESULTS AND DISCUSSION

A wireless communication in between the RF interrogator and the multi-sensing RF tag is demonstrated by transmitting an RF power of +9 dBm using a 6 dBi gain patch antenna. The operating frequency is 908 MHz and the multiple sensor tag


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measurements are acquired with 6 to 14 inches of separation from the interrogator's antenna.

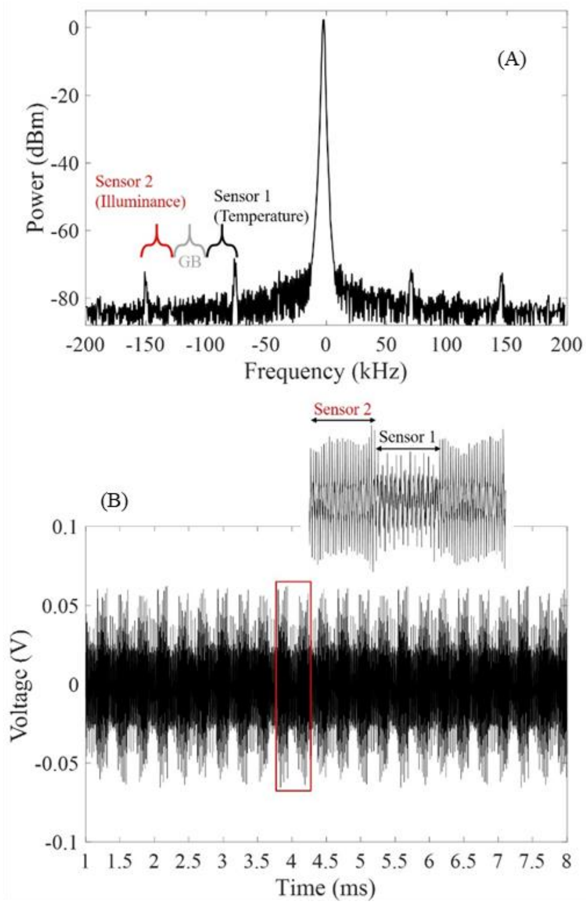


**FIGURE 3:** Wireless demonstration with 9 dBm transmitted power at 908 MHz: A) Frequency spectrum of the demodulated sensor data, and B) Received sensor information in time domain with a switching frequency of 6 kHz (~160 μs)

The temperature and luminescence sensors reflect back the information signal in form of modulated side band frequencies. The received frequency for temperature and luminescence sensor are 82.34 kHz and 149.59 kHz, which corresponds to 27.8°C and 13 fc. The temperature and lighting conditions of the experimenting lab are verified using a commercial temperature and light measuring instrument from URCERI. The frequency spectrum of the received demodulated signal is shown in Figure 3A. The frequency signal (sensor data) peaks are clearly visible, the frequency modulation of sensor data is immune to any multi-path interference or noise in the propagation. The time domain representation of the demodulated RF signal is shown in Figure 3B, where the information signal from first and second sensor are repeating in time with a time period of approximately 160 μs. The temperature and luminescence signals with 82.34 kHz and 149.59 kHz frequency, respectively are shown in zoomed section. The demodulated signal is amplified using a 40 dB low frequency amplifier before acquiring the data using an oscilloscope. The wirelessly received data is shown in its raw form. Additional data processing and filtering can further increase the SNR.

## 4. CONCLUSION

In this paper, a passive multi-sensing RF system is shown for real-time communication with the multiple sensors coupled to an RF tag. The demonstrated multi-sensor RF tag is able to communicate with an RF interrogator up to a read range of 10 ft. The backscattered frequency modulated signal is immune to noise or interference due to multi-path propagation, and is power efficient as it eliminates the requirement of any analog to digital conversion. The demonstrated analog frequency modulation based passive RF system shows an efficient, real-time and long range multi-sensor information transmission method for IoT based SHM applications.

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