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2007 Smart Mater. Struct. 16 2137

(http://iopscience.iop.org/0964-1726/16/6/016)

IOP Publishing — Smart Materials and Structures
Smart Mater. Struct. **16** (2007) 2137–2145 doi:10.1088/0964-1726/16/6/016

Development of an impedance-based wireless sensor node for structural health monitoring

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Received 8 May 2007, in final form 14 August 2007
Published 8 October 2007
Online at stacks.iop.org/SMS/16/2137

Abstract
This paper presents the development and application of a miniaturized impedance sensor node for structural health monitoring (SHM). A large amount of research has been focused on utilizing the impedance method for structural health monitoring. The vast majority of this research, however, has required the use of expensive and bulky impedance analyzers that are not suitable for field deployment. In this study, we developed a wireless impedance sensor node equipped with a low-cost integrated circuit chip that can measure and record the electrical impedance of a piezoelectric transducer, a microcontroller that performs local computing and a wireless telemetry module that transmits the structural information to a base station. The performance of this miniaturized and portable device has been compared to results obtained with a conventional impedance analyzer and its effectiveness has been demonstrated in an experiment to detect loss of preload in a bolted joint.

Furthermore, for the first time, we also consider the problem of wireless *powering* of such SHM sensor nodes, where we use radio-frequency wireless energy transmission to deliver electrical energy to power the sensor node. In this way, the sensor node does not have to rely on an on-board power source, and the required energy can be wirelessly delivered as needed by human or a remotely controlled robotic device.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Structural health monitoring (SHM) is the process of detecting and assessing damage in structures. The goal of SHM is to improve the safety, reliability and/or ownership costs of aerospace, civil and mechanical systems by detecting damage before it reaches a critical state. These processes are implemented using both hardware and software with the intent of achieving more cost-effective condition-based maintenance (Worden and Dulieu-Barton 2004). As the SHM field grows and matures, numerous techniques have emerged. A very promising SHM technique that utilizes the benefits of piezoelectric materials is impedance-based health monitoring methods (Sun *et al* 1995, Park *et al* 2000, 2003, Giurgiutiu *et al* 2002, 2004, Bhalla and Soh 2003, 2004).

The principle behind the impedance-based structural health monitoring technique is to apply high-frequency ultrasonic excitations (typically higher than 30 kHz) to the structure through surface-bonded piezoelectric transducers. The mechanical impedance of the structure is coupled with the

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electrical impedance of the piezoelectric patches. Therefore, changes in mechanical impedance, which is directly related to fundamental structural properties such as mass, stiffness and damping, can be identified by monitoring the electrical impedance, which in turn indicates that structural damage has occurred. The impedance method also has applications in the field of sensor self-diagnostics and validation where one determines the operational status of piezoelectric active sensors in SHM (Park *et al* 2006a, 2006b).

While assessing the health of a localized area through the use of a single active sensor is efficient, once integrated into a large-scale structure, the required realistic number of active sensors easily reaches into the tens or even hundreds. Conventional approaches that consist of running wires between the local sensors and a centralized data acquisition system will no longer be trivial. The cost associated with management and maintenance of such a system can be very high. In addition, the deployment of such a system can be challenging, with potentially over 75% of the installation time attributed to the installation of system wires and cables for larger-scale structures such as long-span bridges (Lynch *et al* 2003a). The integration of wireless communication technologies into SHM methods has been, therefore, widely investigated in order to overcome such limitations. Straser (1998) was the first to propose the integration of wireless radios with sensors to reduce the cost of structural monitoring systems. Lynch *et al* (2003b) has extended the functionality of wireless sensors by integrating sophisticated microcontrollers with them to enable sensor-based execution of embedded data processing and damage-sensitive feature extraction algorithms. Tanner *et al* (2003) integrated microelectromechanical system (MEMS) sensors with wireless communication and embedded systems for structural health monitoring. Because one byte of data transmission consumes the same energy as approximately 11 000 cycles of computation in the employed hardware platform, the use of embedded processors prolongs the battery life of the sensor unit and minimizes the maintenance cost related to battery replacement. To implement computationally intensive SHM processes, Farrar *et al* (2006a) selected a single board computer coupled with a wireless networking capability as a compact form of true processing power. Spencer *et al* (2004) and (Lynch and Loh 2006) provides the state-of-the-art review of current 'smart sensing' technologies that includes the compiled summaries of wireless work in the SHM field using small, integrated sensor and processor systems. Wireless communication can remedy the cabling problem of the traditional monitoring system and significantly reduce the maintenance cost.

Piezoelectric active-sensing SHM techniques require relatively high electrical power to complete the operation, if compared to passive-sensing systems. Because of this power requirement, only a few studies have addressed the development of wireless hardware systems that takes full advantage of active-sensing technologies for SHM. Lynch (2005) pioneered the expansion of the wireless structural monitoring paradigm by including the actuation capabilities in the design of a wireless active-sensing unit. Grisso *et al* (2005) developed a standalone prototype of an active-sensing unit, which incorporates impedance data acquisition, local computation, wireless communication of the results and a renewable power supply via piezoelectric-based energy harvesting.

An important aspect of the impedance method is that the method requires significantly less power compared to other active-sensing technologies, which makes the method an ideal candidate for being implemented with a wireless active-sensing device. Furthermore, a new advance in integrated circuit impedance measurement technology at Analog Device Inc. (2007) has opened the door for an efficient and low-cost solution for real-world SHM impedance measurements. Analog Device's AD5933/AD5934 impedance measurement chip is the size of a small coin. The chip is equipped with analog-to-digital (A/D), digital-to-analog (D/A) and fast Fourier transform (FFT) functions and has a useable frequency up to 100 kHz. This chip can be used to create a self-contained, miniaturized impedance measuring system.

The focus of this paper is to describe the design, fabrication and testing of a prototype impedance-based SHM wireless sensor node based on this single-chip solution. The proposed sensor node is equipped with an impedance chip that measures the electrical impedance of a piezoelectric transducer, a microcontroller that performs local computing and a wireless telemetry module that transmits the structural information to a base station. In order to provide the power to the sensor node, a radio-frequency (RF) wireless energy delivery system is proposed so that the sensor nodes do not have to rely on an on-board power source, and the required energy can be wirelessly delivered as needed. This device significantly reduces the cost and miniaturizes the equipment needed for active-sensing SHM.

2. Description of the impedance-based sensor node

In this section, a sensor node utilizing an impedance chip is described. This sensor node is designed with the intent that they can be applied to a wide range of field applications.

2.1. AD5933/AD5934 impedance chip

Analog Device Inc. (2007) has recently developed two new single-chip impedance measurement devices, AD5933 and AD5934. These two chips are nearly identical in operation, power requirements and basic performance features. The only difference between the two chips is that the AD5933 has a 1 mega-samples per second (MSPS) sampling rate and the AD5934 has a 250 kilo-sample per second (kSPS) sampling rate. Because of this higher sampling rate, the remainder of the work in this paper has been performed with the AD5933.

The general operation of the chip in sine-sweep mode can be outlined as follows. A 24 bit direct digital synthesis core produces a digitized sine wave at the desired interrogation frequency. The excitation signal is then passed through a programmable gain stage and output into the device of interest. The current output from the device due to the excitation signal is then passed through a current-to-voltage amplifier, which features a user-selectable feedback resistor in order to vary the amplifier gain. The amplifier feedback resistor must be sized appropriately in order to ensure that the signal remains in the linear range of the analog-to-digital converter (ADC). The output from the current to voltage amplifier is then sent through

Figure 1. AD5933 impedance chip developed by Analog Device, Inc.

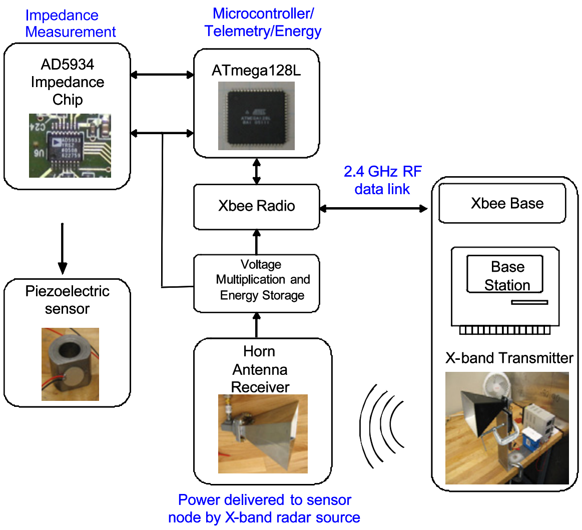

Figure 2. Block diagram of the proposed sensor node.

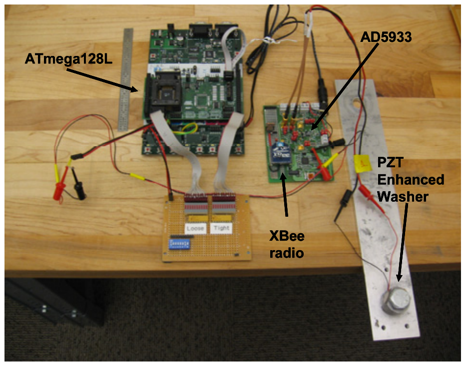

Figure 3. Prototype impedance-based wireless sensor node on the development platform.

a low-pass anti-aliasing filter and sent to a 12 bit, 1 MSPS ADC. A Hanning window is applied to the digital data, and a 1024-point discrete Fourier transform (DFT) is performed at the frequency point of interest. The resulting real and imaginary values of the DFT are passed to a microcontroller in twos complement format. This procedure is repeated for every point in the desired frequency sweep. The AD5933 is shown in figure 1.

2.2. Sensor node layout and its components

A block diagram of the proposed impedance-based wireless sensor is presented in figure 2. The sensor node utilizes a piezoelectric (PZT) transducer, an AD5933 impedance measurement chip, an ATmega128L microcontroller and a 2.4 GHz Xbee radio for wireless communication. In addition, the sensor node includes an X-band horn antenna for wirelessly receiving the required electrical energy that powers the node.

The ATmega128L was selected as the microcontroller for the impedance-based wireless sensor node. The ATmega128L is the low voltage (3.3 V) version of one of the larger microcontrollers in the AVR family. It features 128 KB of flash memory and 4 KB of static random access memory (SRAM). In addition, the ATmega128L contains dual universal asynchronous receivers/transmitters (UARTs) and a two wire interface (TWI), which are both essential for communicating with the telemetry system and the AD5933. The UART also allows communication with the RS-232 port on a PC. Another helpful feature of the ATmega128L is that it includes an 8 MHz internal oscillator. The internal oscillator eliminates the need for an external oscillator, hence reducing the size of the sensor node.

The microcontroller sends an initialization signal, commanding the sensor node to perform a frequency sweep. Once the 'initiate sweep' command has been received, the microcontroller programs the appropriate frequency sweep parameters into the AD5933 registers using a TWI. The sweep parameters include start frequency, frequency increment, number of frequency points and settling time between frequency points. Once the registers have been programmed, the microcontroller sends the 'start sweep' command over the TWI and the AD5933 excites the PZT active sensors with the initial frequency value. The current output from the device under test is converted into a voltage value, which is then run through the ADC and recorded by the microcontroller. The microcontroller then sends a command to the AD5933 to move to the next frequency point. Once the data from all the frequency points have been recorded, the microcontroller implements a damage detection algorithm. The outcome information from the damage assessment is then sent via the UART from the microcontroller to the telemetry module.

The wireless telemetry system selected for the sensor node was the 2.4 GHz Xbee radio from Maxstream. The Xbee radio comes in a variety of antenna configurations. The radio can operate from a 3.3 V supply, and consumes between 45 and 50 mA for receive and transmit (Rx/Tx) operations. Typical range for the radio is 90 m line-of-sight, and 30 m in an office setting. The ease of use of the Xbee radio was the main driver for its integration into the wireless sensor node. The only requirements beside the power and ground lines are the connections to the UART Rx/Tx pins. More detailed information on the sensor node layout and its components can be found in Mascarenas (2006).

It is important to note that the operation of this particular sensor node is very flexible. The microcontroller can be easily programmed to perform a number of different operations with the data. The current incarnation of the sensor node prototype in the development board platform is shown in figure 3. At this stage, no electromagnetic interface and/or ground loop effect was discovered with the current prototype. All of the

Table 1. Power requirements for both normal operation and power-down condition.

Component	Normal power (mW)	Power-down power (μW)
AD5933	33	2.31
XBee	148.5	33
ATmega128L, 8 MHZ CLK	31.35	16.5
Total power	212.85	51.81

integrated circuits used in the sensor node only come in surface mount packages, so development boards were used to ease the initial prototyping stage. We are currently working on fitting the sensor node onto a single printed circuit board (PCB) roughly the size of a credit card. The 4 KB of SRAM in the current design is sufficient for our initial investigation. Most other SHM applications that require the memory intensive algorithms would probably call for additional memory. The possibility of adding additional SRAM, or even a USB mass storage device, is currently also being explored for more general SHM applications.

2.3. Wireless sensor node power requirements

The low energy availability in wireless sensor nodes mandates that the power requirements of the individual components be carefully considered. Table 1 shows the power requirements of the various sensor node components during both normal operation and the power-down or sleep mode.

The table shows that the Xbee radio is by far the greatest single power consumer in the sensor node, accounting for nearly 70% of the total power. It is important to note, however, that the radio will have a very small duty cycle. In most cases of SHM applications, the radio only needs to transmit a couple of bytes of data to indicate either the 'healthy' or 'damaged' condition. Typically, the power consumption of the sensor node during normal operation is around 64.35 mW. This power requirement is much smaller than any other active-sensor node currently under development (Lynch 2005).

The power consumption in the power-down mode is also vitally important, especially in sensor nodes that utilize energy harvested from ambient energy. The energy harvesting device must supply more than the power-down power consumption in order to ensure a positive energy flow into the energy storage device (Calhoun *et al* 2005). The power-down requirements of the wireless sensor node are rather high at 51 μW and a large percentage of the power provided by the energy harvesting solution will be consumed just to keep the sensor node in power-down mode. This preliminary power analysis shows that ambient mechanical vibration energy harvesting may not be a suitable power solution for this sensor node. For this reason alternative power supply schemes, such as microwave wireless energy transmission, were explored, and this scheme is discussed in a later section.

3. Experimental results with the sensor node

Once the impedance-based sensor node was designed and fabricated, experimental investigations have been carried out in order to determine its performance as a SHM sensor node.

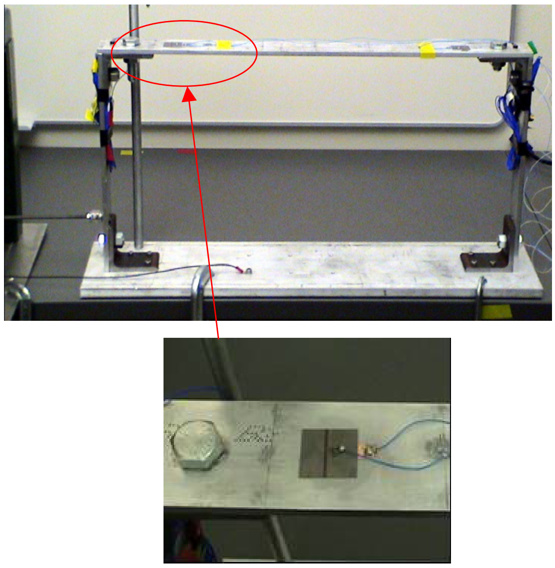

Figure 4. The portal frame structure tested and a PZT transducer installed on the top beam near the bolted connection.

A number of structures were tested with the proposed sensor node, including a portal frame structure and a bolted joint. In the tests, measurements obtained from the sensor node were compared with impedance measurements taken with a conventional data acquisition system described below. In all of these tests, the data measured from the sensor node is transmitted to the PC via a standard RS-232 serial cable. In normal operation, sending kilobytes of data over a wireless link would generally be avoided for power consumption reasons. For these preliminary tests it was deemed unimportant to send the data wirelessly because the main concern of this investigation was to evaluate the performance of the proposed sensor node, especially an AD5933 impedance chip.

A bolt-connected, moment-resisting frame structure was used as a test bed in this study, shown in figure 4. The structure consists of aluminum members connected using steel angle brackets and screws, with a simulated rigid base. Two columns (6.35 mm $\times$ 50.8 mm $\times$ 304.8 mm) are connected to the top beam (6.35 mm $\times$ 50.8 mm $\times$ 558.8 mm) using an angled bracket and the bolts tightened to 17 N m in the healthy condition. PZT patches (25.4 mm$\times$25.4 mm$\times$0.254 mm) were mounted on the left side of the symmetric structure (Corner 2), with a PZT sensor mounted on the beam, as shown in figure 4.

The impedance measurements were made with both a National Instruments DAQ system and the proposed sensor node connected to the same PZT patch. The swept frequency ranged from 75 to 90 kHz. Figure 5 shows that the peaks in the impedance magnitudes obtained with the two different systems, which correspond to the resonant frequencies of the structure, are exactly the same. It should be noted that the absolute magnitude of the impedance values are different in the two measurements. This result is the due to the fact that the AD5933 contains inherent electrical impedance inside the chip. Also, the sensing resister used to estimate the impedance value in the sensor node influences this reading. However, this difference would not affect the SHM performance as we are interested in relative changes

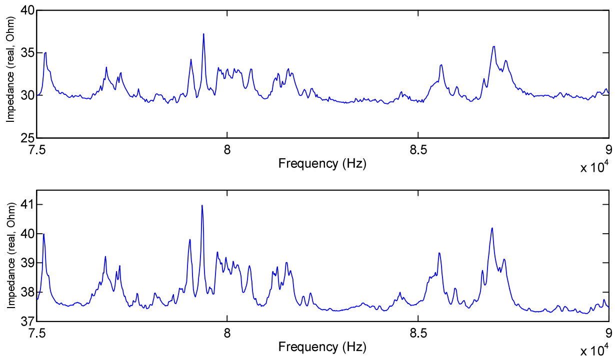

Figure 5. Impedance measurement from AD5933 (top) and National Instruments system (bottom).

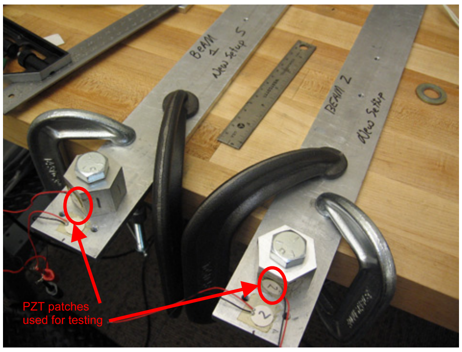

Figure 6. Experimental set-up with PZT-enhanced washers.

in the impedance signature for damage identification. Both devices produce the same shape of impedance responses, demonstrating that the measurements from both systems contain the same information regarding impedance of the piezoelectric sensor and this reading is directly coupled to the mechanical characteristics of the test structure. Furthermore, the time required for data acquisition, transmission and processing is almost the same for both hardware, which confirms that the proposed low-cost, lightweight sensor node can produce reliable impedance measurements suitable for structural health monitoring applications.

Another bolted joint monitoring experiment was performed as shown in figure 6. PZT active sensors (12.5 mm diameter) were bonded to the washer via superglue. The bolted joint was progressively tightened to the beams with a torque wrench. At each level of tightening, an impedance measurement was made with both a National Instruments data acquisition system and the sensor node. The resulting measurements can be found in figure 7. From the sensor node data shown in figure 7, one can clearly see that the identified resonant frequencies show the same behavior as the corresponding data obtained with the NI measurement system. The dominant peak at 87 kHz is very pronounced under no preload, and then once the bolt is tightened, the dominant peak essentially disappears. Furthermore, the smaller peak slightly above 84 kHz is also captured by each impedance measurement. Clearly the main dynamic behavior, as identified by the resonances of the structure, is captured in both measurements. Furthermore, a simple peak picking algorithm would be able to determine whether or not the peak has been repressed, in order to make the decision as to whether or not the bolt has loosened (Mascarenas *et al* 2005).

Advantages of this new device include its low cost, light weight and smaller size. The price of the parts required to make one sensor node was less than $150. It can be assumed that the cost would be reduced even more if the parts were manufactured in bulk. It should also be noted that, although the new device is tested only for SHM in this study, the device can be applicable to sensor diagnostics and validation for piezoelectric active sensors as discussed in (Park *et al* 2006a, 2006b).

4. Microwave wireless energy transmission

This section describes the experimental investigation of wireless radio frequency (RF) energy transmission systems. A feasibility study using 10 GHz X-band signals to wirelessly deliver the electrical energy to operate the proposed impedance sensing node is presented

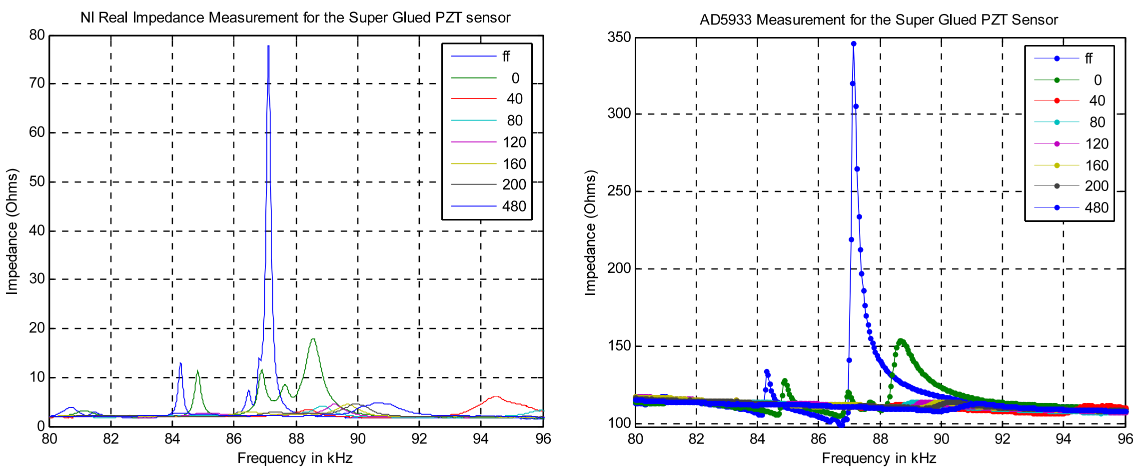

Figure 7. Experimental results with NI system (left) and the sensor node (right).

A major concern for all wireless sensor networks is the available energy supply. The conventional power supply for wireless sensor nodes is generally some form of battery. As sensor networks become more widespread and involve more active elements, the battery power supply quickly becomes unsuitable from both an operational and maintenance standpoint. The ideal solution would be to design sensor nodes with a power supply that does not need replacement over the entire projected lifetime of the sensor network. A number of different approaches have been studied in an attempt to obtain this ideal. A possible solution to the problem of localized power generation is technologies that enable the harvesting of ambient energy, whether thermal, vibration, acoustic or solar, to power the instrumentation. Although extensive research work has been focused on energy harvesting, either the amount of harvested energy appears to fall significantly short of the level required by SHM sensing systems (a conversion efficiency issue) or the structure simply may not have the direct ambient energy sources available. Therefore, methods of increasing the amount of energy generated by the power harvesting device or developing new and innovative methods of accumulating the energy are the key technologies that will allow energy harvesting to become a practical source of power for wireless SHM systems (Park *et al* 2007).

An alternative power supply scheme that is being investigated by authors is RF wireless energy transmission. Recently, Todd, Farrar and colleagues (Todd 2005, Farrar *et al* 2006b) have proposed a new SHM sensing network paradigm, which involves using an unmanned mobile host node (delivered via unmanned aerial vehicles (UAV) or robots) to generate an RF signal near embedded sensors on the structure. The sensors measure the desired responses at critical areas on the structure and transmit the signal back to the mobile host again via the RF communications. This 'wireless' communications capability draws power from the RF energy transmitted between the host and sensor node and uses it to both power the sensing circuit and to transmit the signal back to the host. This research takes traditional sensing networks to the next level, as the mobile hosts will travel either on ground or in the air to sensor nodes embedded in critical infrastructure based upon a pre-defined locator, deliver the required power and then begin to perform an inspection without human intervention. The mobile hosts will search for the sensors on the structure and gather critical data needed to perform the structural health evaluation. This integrated technology will be directly applicable to rapid structural condition assessment of buildings and bridges after a natural or man-made disaster, for example, where human inspection protocols pose life-safety issues. Also, this technology may be adapted and applied to damage detection in a variety of other civilian and defense-related structures such as pipelines, naval vessels, hazardous waste disposal containers and commercial aircraft.

The wireless energy transmission technology that has received the most attention in the last fifty years is that of microwave transmission. Originally thought of as a concept for use with space-based solar power satellites, it has been significantly improved in the last several decades. Microwaves are transmitted across the atmosphere or space to a receiver, which can either be a typical antenna (with rectifying circuitry to return the microwaves to DC power) or a rectenna (rectifying antenna) which integrates the technology to receive and directly convert the microwaves into DC power. This design typically allows for much higher efficiencies. A pair of excellent survey articles were written to discuss the history of microwave power (Brown 1996, Maryniak 1996). With the use of rectennas, efficiencies in the 50%–80% range of DC to DC conversion have been achieved. Significant testing of microwave energy delivery has also been done across long distances and with kilowatt power levels (Choi *et al* 2004). Their study showed the feasibility of the energy delivery systems for actuating large devices, including DC motors and piezoelectric thunder actuators. However, the application of this technology to low-power electronics has not been substantially studied. In particular, the application of wireless power delivery for SHM sensor nodes in order to alleviate the challenges associated with power supply issues has never been addressed in the literature. Therefore, in this study, we experimentally investigate the RF wireless energy transmission as an alternative power source for wireless SHM sensor nodes.

4.1. Experimental set-up

In order to investigate the feasibility of wireless power transmission for sensor node operations, a proof of concept experiment was set up to test the ability of wirelessly delivered energy to power the telemetry of the sensor node. This method was chosen because, as previously discussed, the Xbee radio is the greatest power consumer in the sensor node, and the wireless sensor node is still on the development platform. The X-band at 10 GHz was chosen as the RF energy propagation frequency in order to facilitate the design of small antennas with high gain. A layout of the RF power delivery system is given in figure 8. Rectenna (rectifying-antenna) performance was evaluated based on how quickly the rectenna can supply the required voltage to charge the energy storage medium, in this study a supercapacitor, and on how many receive/transmit (Rx/Tx) operations can be successfully completed. Both the power and voltage requirements must be met in order for the wireless energy transmission to be a suitable substitute for conventional batteries in sensor node power supplies.

In this set-up, 1 W of X-band radiation is transmitted from a horn antenna over a distance of 0.6 m. At the receiving end, a rectenna is constructed from a horn antenna and an eight-stage voltage multiplication circuit. The DC voltage from the rectenna is used to charge up a 0.1 F supercapacitor. Once a sufficient amount of voltage has built up in the supercapacitor, the stored energy is used to power a Xbee radio.

4.2. Experimental evaluation of RF power transmission performance

Once the components for the X-band wireless power delivery system were designed and built, the ability of the rectenna to provide energy to a sensor node component was evaluated. The Xbee radio was connected to the supercapacitor through a switch. The horn antennas were placed 0.61 m apart and were lined up to ensure similar polarizations. A Tektronix oscilloscope was placed across the terminals of the 0.1 F supercapacitor in order to monitor the charge/discharge voltage of the capacitor. The first test was to monitor the

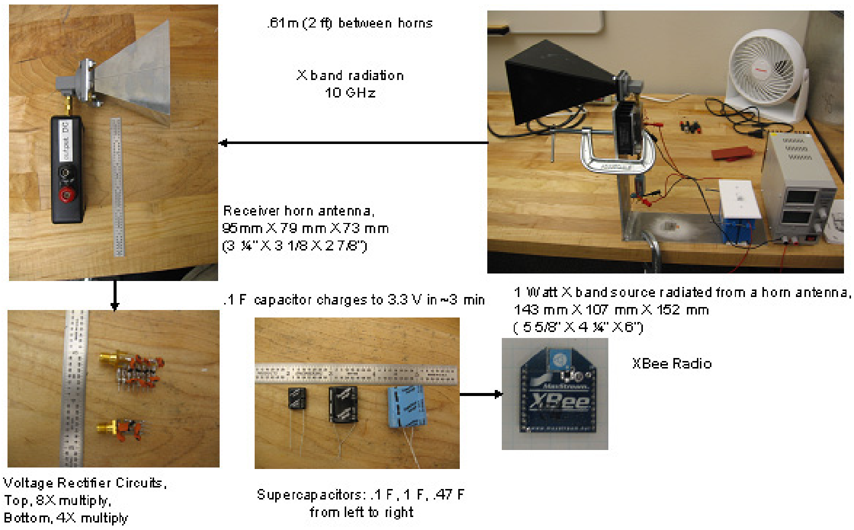

Figure 8. RF power delivery test set-up.

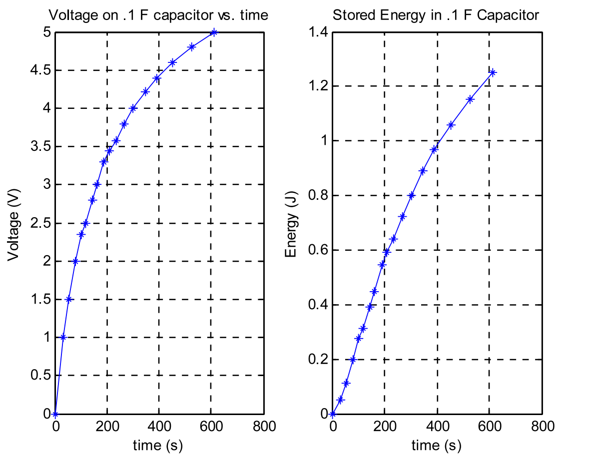

Figure 9. Voltage and energy storage across 0.1 F supercapacitor as the X-band source transmits power.

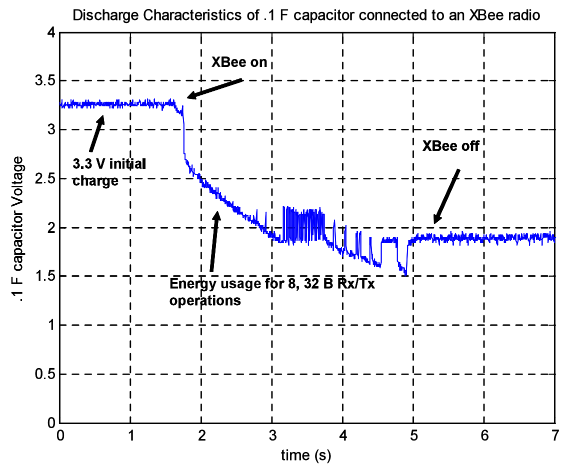

Figure 10. Discharge characteristics of the 0.1 F capacitor during the range test.

supercapacitor's voltage over time, as power was transmitted by the X-band source. Figure 9 shows the results of this test as the supercapacitor charges from 0 to 5 V.

The Xbee radio operates on 3.3 V levels, so the voltage across the radio needs to be between 3.3 and 2.8 V for proper operation. Clearly the X-band source is capable of delivering the required voltage levels. The supercapacitor is able to achieve 3.3 V in 200 s. The average delivered power was estimated at 2.5 mW, while it was analytically estimated to 85 mW by the one-way radar equation for power incident on a target. Possible reasons for the discrepancy include errors in the efficiency estimate of the antennas, the efficiency of the circuit such as the voltage drops caused by the diodes, electromagnetic reflections off the walls causing destructive interference and a possible impedance mismatch between the receiver and the transmitter.

Once the capacitor is charged to 3.3 V (0.54 J of energy stored), the Xbee radio was allowed to perform Rx/Tx operations and the number of these operations was measured. The voltage across the capacitor was recorded during this process, and the resulting discharge characteristics are shown in figure 10. This plot shows the capacitor is initially charged to 3.3 V. Once the Xbee radio is allowed to drain current from the capacitor, the voltage quickly drops down to a little less than 2 V. While the capacitor is discharging, the radio is able to successfully receive and transmit 256 bytes of data using the asynchronous RS-232 protocol over a distance of 5.2 m. The data received by the range test software is displayed in figure 11.

The Xbee radio is by far the largest power consumer in the proposed sensor node, using between 45 and 50 mA for Rx/Tx operations at 3.3 V. The ATmega128L microcontroller actively running with an 8 MHz clock only uses 11 mA at 3.3 V and the AD5933 typically uses 10 mA at 3.3 V. This experiment has shown that RF power delivery can be used to successfully operate the largest power consumer in the sensor node. Furthermore, the Xbee radio would generally have a very small duty cycle in comparison to the rest of the sensor node. A

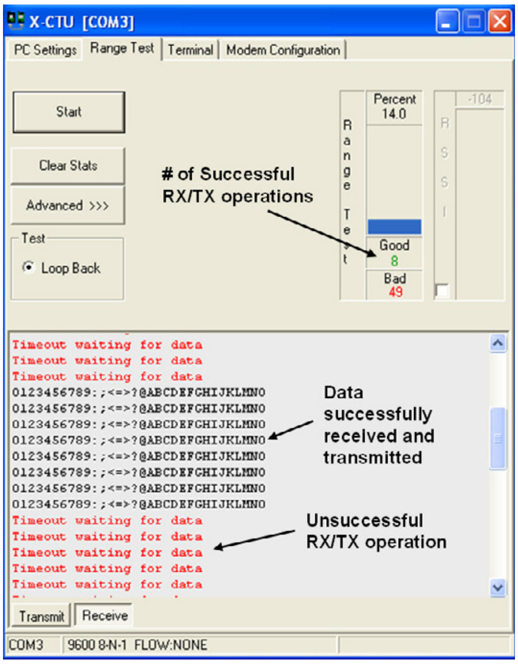

Figure 11. Range test software summary of Xbee radio performance.

typical measurement would require transmitting only a couple of bytes of data in the case of the SHM applications. With this experiment, we demonstrated that the wireless power delivery has promise as a suitable solution for providing power to long-term wireless sensor nodes.

The advantage of this transmission system is that power does not have to be embedded with the sensing system, but transported to its vicinity and then wirelessly transmitted to the sensor node. It is anticipated that such a sensor network will have improved reliability and will have inherent advantages when monitoring must be performed over long periods of time in locations that are physically difficult to access such as those that might be associated with monitoring structural damage to a large suspension bridge subject to seismic excitation. It is also anticipated that these systems will evolve to hybrid systems that couple local energy harvesting at the node level with the RF energy delivered by the robotic vehicle.

5. Summary and conclusions

This paper presents the design and fabrication of an impedance-based wireless sensor node based on recently developed impedance measurement technology. The sensor node utilizes the AD5933 impedance measurement chip, an Atmel ATmega128L microcontroller and an Xbee 2.4 GHz radio from MaxStream. The proposed sensor node has demonstrated the capability of making active dynamic measurements in the tens of kilohertz range at the same precision obtained with a traditional impedance analyzer, which shows its promise as an active sensor node for SHM applications. It is further proposed that the radio-frequency wireless energy transmission can be used as a possible power solution for this sensor node. The advantage of this transmission system is that power does not have to be embedded with the sensing system, but wirelessly transmitted to the sensor node as need. It is anticipated that such a sensor network will have improved reliability and will have inherent advantages over more conventional battery-powered sensor nodes. Our current effort is to implement more memory for the comprehensive data interrogation, to implement power-efficient electronics for the sensor node and RF energy transmission, and to improve the ruggedness and robustness of the sensor node for field deployment.

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