A Novel and Miniaturized 433/868MHz Multi-Band Wireless Sensor Platform for Body Sensor Network Applications

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Abstract— **Body Sensor Network (BSN) technology is seeing a rapid emergence in application areas such as health, fitness and sports monitoring. Current BSN wireless sensors typically operate on a single frequency band (e.g. utilizing the IEEE 802.15.4 standard that operates at 2.45GHz) employing a single radio transceiver for wireless communications. This allows a simple wireless architecture to be realized with low cost and power consumption. However, network congestion/failure can create potential issues in terms of reliability of data transfer, quality-of-service (QOS) and data throughput for the sensor. These issues can be especially critical in healthcare monitoring applications where data availability and integrity is crucial. The addition of more than one radio has the potential to address some of the above issues. For example, multi-radio implementations can allow access to more than one network, providing increased coverage and data processing as well as improved interoperability between networks. A small number of multi-radio wireless sensor solutions exist at present but require the use of more than one radio transceiver devices to achieve multi-band operation. This paper presents the design of a novel prototype multi-radio hardware platform that uses a single radio transceiver. The proposed design allows multi-band operation in the 433/868MHz ISM bands. Its low complexity, power consumption and small form factor, make it suitable for a wide range of BSN applications.**

Keywords: body sensor networks, wireless sensor networks, multi radio, impedance matching, simulation, embedded systems

I. INTRODUCTION

BSN sensors are gaining rapid applicability in many areas including mobile health, security as well as fitness and sports monitoring. To accommodate the requirements of these applications, a significant number of platforms have been proposed in both commercial and academic works. A recent and comprehensive review of these platforms [1] shows that the current trend is to employ a single low power RF transceiver for radio communications. The study finds that that the majority of these platforms use a radio chip that conforms to the IEEE 802.15.4 standard. In addition, the review shows that only a small percentage of these motes employ a multi-radio feature, typically employing separate radio transceivers to achieve multi-band operation.

The manner in which these solutions are implemented is illustrated in Fig. 1, where a separate radio transceiver and antenna are used for each of the *n* frequency bands employed.

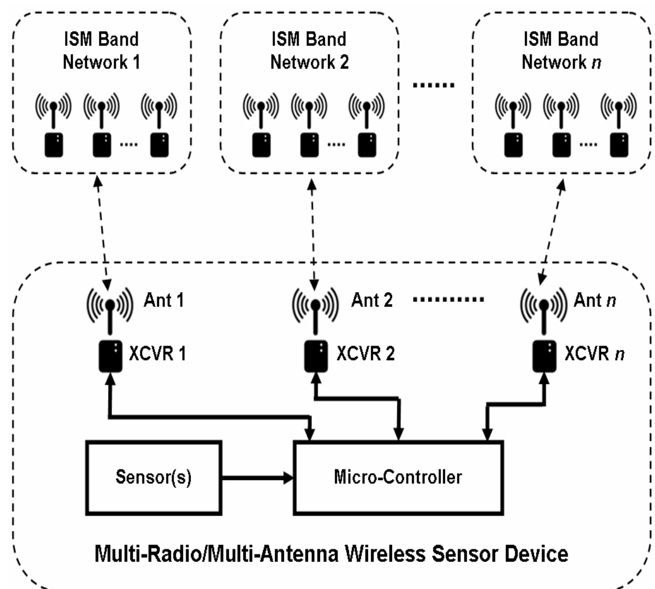

Figure 1. Current multi-radio wireless sensor architecture.

Depending on the configuration, the design can be implemented by using separate plug-in radio modules or by employing separate radio ICs and antennas on-board. This approach presents a number of challenges as the size, complexity and cost of the device increases and the additional requirements for more complex programming and maintenance also contribute to increased cost.

Fig. 2 shows the recently developed 's-Mote' platform [1] which provides a powerful and flexible means of achieving multi-radio capability. The architecture of the s-Mote is developed around the concept of a stackable modular system [2-3]. Connectors (A and B) provide a means to combine two types of radio from a wide range of available radio layers including Zigbee, ISM Band, Bluetooth etc. A wide range of sensors (ECG, Wireless Inertial Measurement Unit (WIMU), Accelerometers, GPS, etc) can be connected via a standard modular interface. There is also the provision to combine these radio layers with a powerful on-board DSP processor (C) as illustrated.

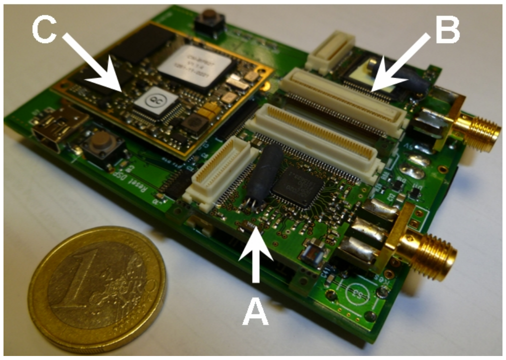

Figure 2. s-Mote Heterogeneous Multi-Radio Platform.

The current art requires the use of independent radios, interfaces, matching components and crystal circuits which adds cost and complexity and is not easily scalable beyond a 2-radio system. Implementing a truly integrated multi-radio solution would employ a single radio IC together with reconfigurable external circuitry (replacing the traditional fixed matching network) as well as a single antenna. As a first step towards this goal, this paper presents the design and development of a dual-band radio platform using a single radio transceiver.

II. Circuit Design

This work is specifically focused on the design, simulation and development of a dual-band radio platform that covers the 433 and 868MHz ISM bands. These low frequency ISM bands were chosen to provide greater communications range for on-body BSN applications. To illustrate the benefit, a simple, free-space propagation model for free-space path loss (FSPL) is given by (1) where distance d is in km and frequency f is in MHz [4].

$$\mathrm{FSPL\ (dB)} = 32.45 + 20\log10\,(d) + 20\log10\,(f) \qquad (1)$$

Fig. 3 plots the path loss for a transmitter-receiver separation of 10m. For a constant level of transmit power, operating at 433 and 868MHz allows an increase in received power of 14.5dB and 8.5dB respectively compared to 2.4GHz. In addition, the lower frequency ISM bands provide reduced RF absorption or specific absorption rate (SAR) due to the body and this is an important advantage in BSN applications.

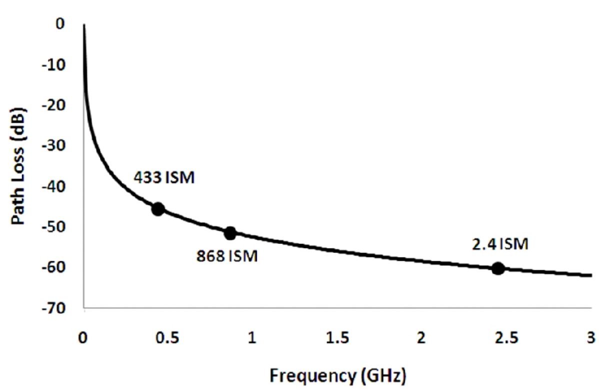

Figure 3. Free-space path loss with 10m Tx-Rx seperation

To illustrate the concept, the proposed solution uses a single, dual-band radio IC and a reconfigurable antenna matching circuit as illustrated in Fig. 4.

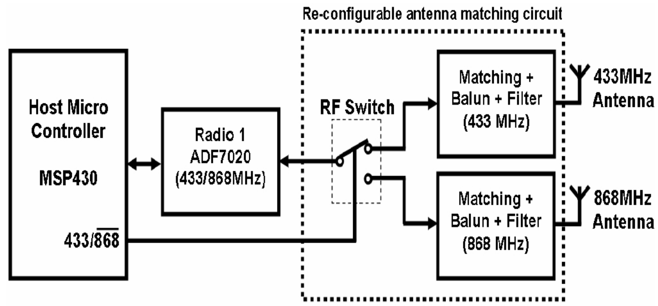

Figure 4. Proposed multi-band wireless mote architecture.

The reconfigurable matching circuit allows switching between the 433 and 868MHz ISM bands during normal operation, under the control of a host microcontroller. A key research challenge for this implementation is the design of a low cost, low-loss, low power consumption impedance matching and balun (balanced-to-unbalanced) network that can operate over both frequency bands. The design is based on the ADF7020 ISM band radio transceiver from Analog devices [5]. The ADF7020 is a high performance, ISM Band FSK/ASK radio transceiver covering two frequency bands (431 MHz to 478 MHz) and (862 MHz to 956 MHz). The transceiver can operate at data rates of up to 200kbps that makes it attractive for applications where high data throughput is critical. This design also uses the MSP430 micro-controller from Texas Instruments [6]. The MSP430 is an ultra-low power 16-bit reduced instruction set (RISC) type microcontroller with a broad variety of interfaces combined with extensive low-power modes, making it suitable for low power, battery operated BSN applications.

The ADF7020 exhibits optimum performance in terms of sensitivity, transmit power, and current consumption only when the PA and LNA are properly matched to the antenna impedance. For cost-sensitive applications, the ADF7020 provides an internal Tx/Rx switch that facilitates the use of a simple, single-band combined passive PA/LNA matching network. The proposed dual-band matching network is shown in Fig. 5. Two individual matching networks (one tuned for 433MHz and the other tuned for 868MHz) are shown. Low loss SPDT RF switches (SW1 to SW3) are used to select either network via the microcontroller. Looking at the 433MHz matching network, in transmit mode, lumped-element components L1 and C1 match the antenna impedance Z_{ANT} (which is typically 50Ω) to the PA output impedance Z_{OPT_PA}. The switch SW1 (internal to the ADF7020) also short circuits the differential LNA input in transmit mode, providing a high level of resilience against spurious reception. In receive mode, components C2, L2 and C3 match the 50Ω antenna impedance to that of the LNA input ($Z_{OPT\text{-}RFIN}$) while also implementing a balanced-to-unbalanced (BALUN) function. It is possible to use an external RF switch option with this radio transceiver that offers slightly better performance. For simplicity, the internal switch option was chosen for the first prototype.

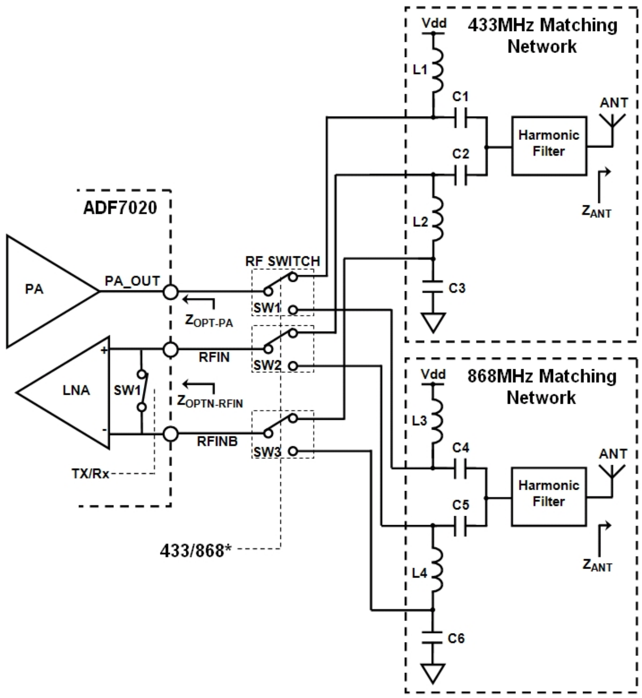

Figure 5. Dual-band combined matching network.

For the chosen implementation, the RF performance of the switches is critical and Table I summarizes some important performance parameters for the chosen devices [7]. The switch has low insertion loss in the on-state and also exhibits good isolation in the off-state. The device also presents a good impedance match to a 50Ω environment and the switching time allows fast band switching in hardware.

TABLE I. RF SWITCH CHARACTERISTICS

PE4210 SPDT UltraCMOS RF Switch			
Parameter	***Units***	***Value***	***Condition***
Insertion Loss	dB	0.3	1Ghz
Isolation - RFC to RF1/RF2	dB	35.5	1Ghz
Isolation - RF1 to RF2	dB	35.5	1Ghz
Return Loss	dB	24.5	1Ghz
Switching Time	ns	200	2GHz
Supply Voltage	V	3.0	1Ghz
Supply Current	nA	250	Vdd = 3V

The chosen switches consume minimal DC power (compared to other solutions using PIN diodes for example) which is an important consideration for battery powered BSN devices. Adding RF switches to the matching circuit causes additional parasitics to be placed on the PA output and LNA input and these effects are considered in the following Section. Fig. 6 shows the printed circuit board implementation of the dual-band combined matching network. A 6-layer implementation was specified using standard, low cost 1.6mm FR4 with dielectric constant of 4.4 and loss tangent of 0.02. Short-open-load (SOLT) vector network analyzer calibration structures are included (shown on the right-hand side of the PCB) to allow accurate extraction of PCB material properties and verification of the circuit simulation model.

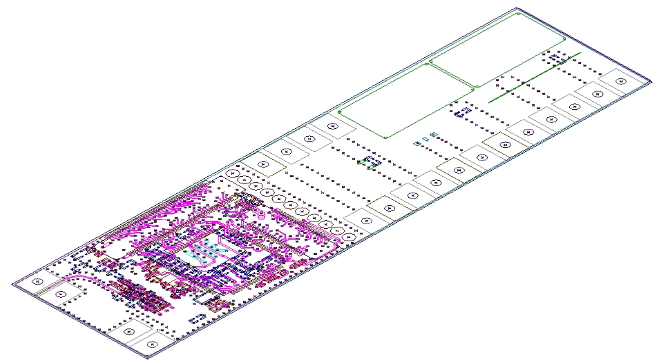

Figure 6. Printed circuit with calibration structures shown on the right.

III. CIRCUIT SIMULATION

The successful implementation of the reconfigurable matching circuit is critically dependent on the availability of an accurate electrical model of the circuit. An electrical model of the circuit was therefore developed that includes PCB stackup and substrate information as well as the traces, vias, pads and lumped elements. Measured s-parameter data for the switches is also included. Fig. 7 shows a simplified model of the 433MHz matching circuit (868MHz path not included) between the ADF7020 (Port 1) and the antenna port (Port 2).

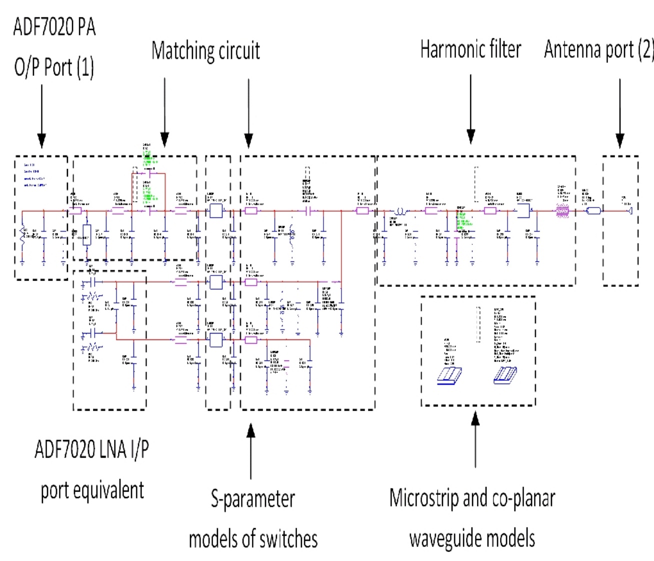

Figure 7. Circuit simulation model of 433MHz matching network.

To accurately model the lumped elements, important parameters such as ESR, Q and self resonant frequency were specified. The circuit was simulated and optimized using AWR Microwave Office [8]. Fig. 8 shows the simulated responses of the 433 and 868MHz transmit paths.

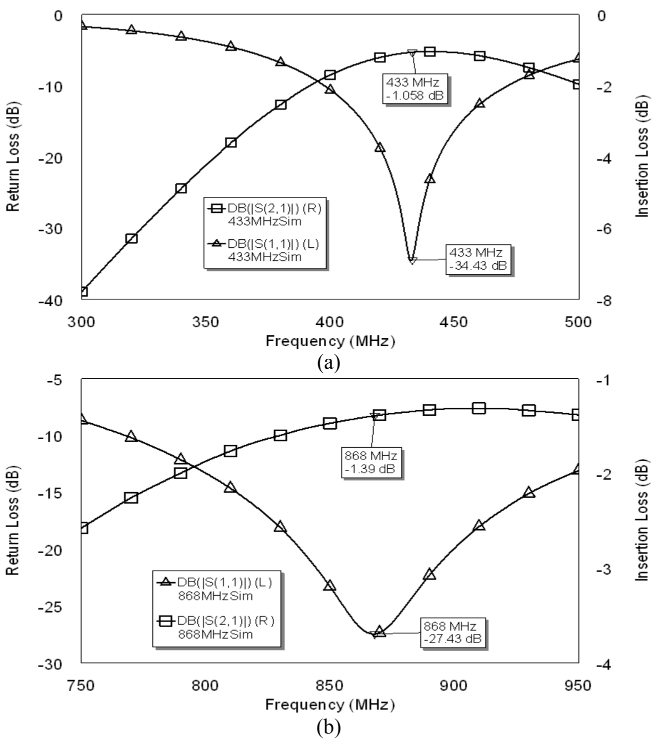

Figure 8. Simulated Tx-Path Performance. (a) 433MHz, (b) 868MHz.

Fig. 8(a) shows a simulated return loss of -34dB with a bandwidth (-10dB) of 80MHz approximately. The insertion loss is approximately 1dB at 433MHz, dominated by the lumped element and RF switch losses. Fig. 8(b) shows a simulated return loss of -27dB at 868MHz with a bandwidth (-10dB) of greater than 200MHz. Increased insertion loss of 1.4dB is observed at 868MHz compared to 433MHz with the lumped elements accounting mostly for the increased losses. The use of higher-Q inductors allows for better insertion loss figures. Having seen the potential performance of the circuit in simulation, a hardware prototype was then fabricated to allow for measurement of performance and extraction of accurate PCB parameters for use in the simulation model.

IV. Prototype and Initial Testing

The fabricated hardware prototype of the dual-band radio is shown in Fig. 9. The radio is extremely compact, measuring 4 x 2.5 cm. Sensors and supply are connected via the sensor interface shown.

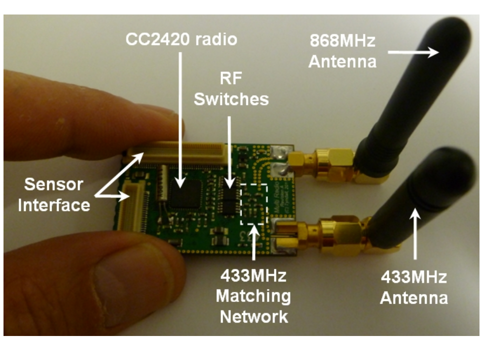

Figure 9. Fabricated protoype of the dual-band radio.

Initial power-up measurements for the prototype system are shown in Table II. The combination of MSP430/ADF7020 show good figures for power consumption but improved figures are anticipated with further optimization.

TABLE II. Preliminary Prototype Results

Power Consumption Measurements			
Parameter	***Condition***	***Units***	***Value***
Sleep Current	LPM4, radio off	mA	0.43
Transmit Current	+13dBm, 433MHz	mA	34.99
Transmit Current	+13dBm, 868MHz	mA	32.34
Receive Current	433MHz	mA	26.63
Receive Current	868MHz	mA	24.91

V. Conclusions

A miniaturized, dual-band wireless sensor system using a novel reconfigurable matching circuit has been presented. Future work will concentrate on thorough characterization, optimization and verification of the prototype system in terms of RF and power consumption performance. Additional work will focus on further miniaturization of the system (including the integration of a low profile, dual-band antenna) as well as the development and testing of the proposed platform in a range of target applications.

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