Current Consumption in Radio Modules for Wireless Sensor Networks

Felipe Antonio Moura Miranda and Paulo Cardieri

***Abstract*— This paper presents results of an experimental work designed to investigate current consumption in radio modules commonly used in Wireless Sensor Networks (WSNs). Using high speed measurement setup, we collected current consumption profiles (waveforms) of several radio modules in different states, including transmitting, receiving and idle states. Results showed a much more detailed current consumption when compared with the information provided in datasheets. Radio modules used in WSN usually operate under energy-limited conditions and detailed current consumption profiles, such as those presented in this paper, can be useful when designing energy-aware protocols or subsystems.**

Keywords—Current Consumption, Radio Modules, Measurement, Wireless Sensor Networks.

I. INTRODUCTION

The energy constraint is an issue that affects any study or implementation of wireless sensor networks (WSNs), due to the fact that terminals in these networks, usually called *motes*, typically have limited energy available and battery replacement is either impossible or expensive [1].

Among all the sub-systems that compose a mote, the radio module alone represents a substantial share of their energy consumption [2]. As the energy constraint is a key issue when using WSNs, analyzing and understanding the way radio modules use the energy available is an important topic.

The main documentation about technical characteristics of electronic part is always its respective *datasheet*. Manufacturers gather mechanical and electrical characteristics, sometimes in many different scenarios, and compile them in datasheets. The problem is that, sometimes, even when a static value presented in a datasheet is precise, that information is just a small portion of a much bigger and more complex characterization of that part.

As there is no standard radio technology used by WSNs, different transmission schemes have been adopted by radio modules manufacturers. There are radio modules employing analog, digital or even spread spectrum modulation [3] and, due to the fact that each modulation needs a specific circuitry, it is reasonable to expect different consumption profiles for different radio technologies. With the emerging technology of energy harvesting [4,5], based on collecting small amounts of energy from the surrounding environment, understanding how an electronic part uses the available energy can be a valuable information when designing energy harvesting systems.

This paper presents an exploratory work, aiming at presenting a detailed analysis of the current consumption of several different radio modules commonly used in WSN. We present fairly detailed waveforms of current consumption, showing how a single task can delineate distinct and complex consumption profiles, which may impact the design of other components and subsystems of the whole network.

II. RELATED WORKS

Accurate current consumption profiles are quite helpful information for designing energy-constraint motes [6] or for designing efficient power supplies, especially the sensible energy harvesting power supplies [7,8].

Embedded systems usually require constant voltage to operate, simplifying the process of estimating their energy consumption by just measuring their current consumption [9]. Techniques for measuring current consumption in WSN motes/parts can be divide into two categories: benchtop measurements and embedded measurements.

Benchtop measurements, which is the adopted approach in this work, tend to have the most accurate and precise results, due to possibility of using high-precision equipment, hardware and others resources. Works like [9]–[14] use very specific circuitry, usually current mirrors or a single shunt resistor, together with high-grade measuring instruments, such as oscilloscopes, proprietary data acquisition devices or even microprocessors.

On the other hand, embedded measurements have more hardware, space and energy constraints when compared to the benchtop approach. However, embedded measurements have the advantage of being part of a mote, allowing for real-time data acquisition, even when the mote is deployed in the field. Works like [15]-[18] show how add-on boards or specific testbeds can provide in-field real-time data acquisition with fairly reliable results.

In this present exploratory work, the benchtop approach was selected in order to retrieve more detailed current consumption profiles of various motes commonly used in WSNs. Details about the hardware setup and measurements approaches are described in the next section.

III. METHODOLOGY

In order to perform the current consumption measurements presented in this work, we designed a methodology considering the following main objectives:

- Enough measurement resolution,
- Noise and interference avoidance,
- Measurement of different states of consumption.

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The following subsections describe the methodology used to meet the aforementioned objectives and other topics related to this work, like the circuitry and radio modules specifications.

A. Measurement Resolution

In order to be able to visualize small and fast variations in the waveform of the current consumption, we connected a high-speed oscilloscope with an active shunt resistor and placed them between the radio modules and the power supply. The scheme for the setup used in this work is based on assessing the current flow by measuring the voltage between the terminals of a shunt resistor. The simplified schematic of the measurement setup is shown in Fig. 1.

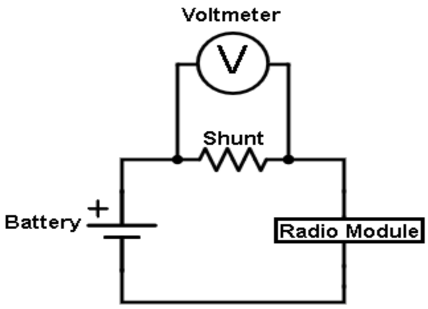

Fig. 1 – Schematic of the measurement circuit used in this work.

The active shunt employed is the Valhalla 2575A [19], which is capable of performing high accurate AC/DC measurements and has a wide-range output amplifier, which allows the use of low resistance values when performing the measurements.

An Agilent DSO-X 2002A oscilloscope [20] was employed to capture the waveform measurements. This oscilloscope is capable of performing measurements at 2 G Samples/s, allowing a fairly high-resolution measurement of the resulting waveforms outputted by the active shunt.

The measurement setup used in this work is shown in Fig. 2.

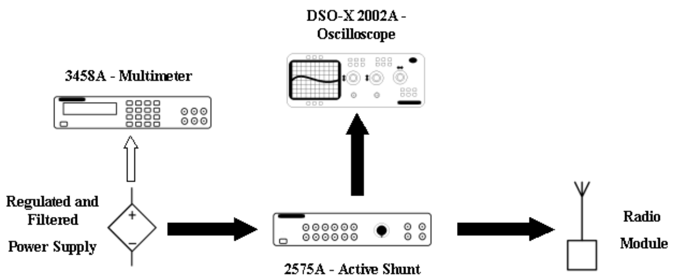

Fig. 2 – Measurement setup.

B. Noise and Interference Avoidance

During measurements, noise and other interference signals were avoided as discussed below.

In order to avoid external electromagnetic interference (EMI), both in the communication link between the radio modules and in the measured waveforms, we performed all measurements inside an EMI double-shielded room, as shown in Fig. 3. Transmitters and receivers were placed at the same height and the distance between their antennas was adjusted to 1 m.

The power supplies for the instruments were filtered by an external unity, protecting the measurement setup from interference coming from the power line. Additionally, we used batteries and voltage regulators as power supplies for the radio modules, in order to minimizing the noise effect in these modules.

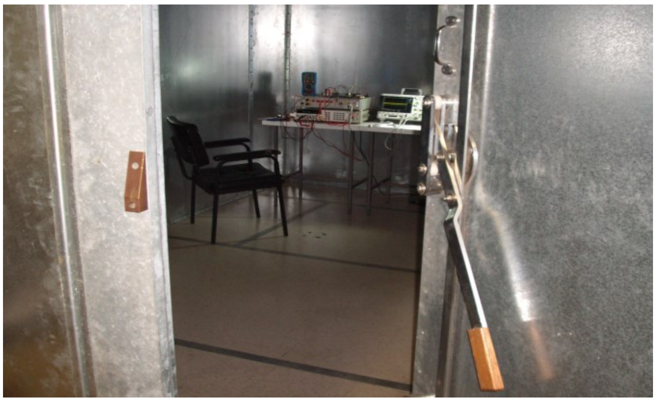

Fig. 3 – Measurement setup inside the EMI shielded room.

All waveforms shown in this work resulted from averaging 64 measurements.

C. Transmitted Signal and Measurement of Different States

The measurement of the current consumption profile in both transmission and reception modes was made while the radio module was transmitting or receiving a single-byte message, consisting of the "U" character. In ASCII code, this character corresponds to a perfect square waveform of four cycles, i.e., the bit array "01010101".

The UART (Universal Asynchronous Receiver/Transmitter), which was used to generate the messages, adds one extra bit, the start bit "1", and uses high-voltage for no data state. For a better visualization of the measurements, the signal was inverted before transmission, as shown in Fig. 4. The only exception to the signal inversion was in the case of the radio module XBee PRO, which needs standard UART signals as input signal.

The transmission data rate of all modules, excluding the XBee PRO module, was the same as the data rate of the generated signal, i.e., 1.2 kbit/s. The XBee PRO module has a fixed transmission data rate of 250 kbit/s.

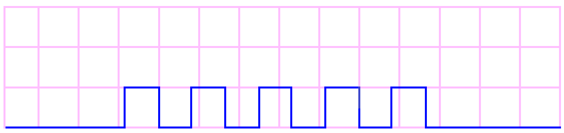

Fig. 4 – The content of a message: "U" character plus the start bit.

D. Radio Modules

Five different radio modules, listed in Table I, were used in this work.

Table I. Radio modules specifications.

Radio	Modulation	Role	Frequency	Vdc	Max . Output Power
DR3000	OOK/ASK	Tx/Rx	916 MHz	3.3 V	>0.75mW
TRM 433	OOK	Tx/Rx	433.92 MHz	3.3 V	12.5 mW
RT4 433	ASK	Tx	433.92 MHz	3.3 V	10 mW
RR3 433	ASK	Rx	433.92 MHz	5 V	-
XBee PRO	DSSS	Tx/Rx	2.4 GHz	3.3 V	63 mW

The output power of all modules, excluding the XBee PRO module, is directly related to its power supply voltage (Vdc column in Table I). For the case of XBee PRO, the output power can be configured by software. In the cases reported here, the output power of the XBee PRO module was set to its maximum value, 63 mW.

IV. RESULTS

The measurements show that, in most of the cases reported here, the current waveforms of active states (transmission and reception) were not time-invariant and, in some cases, the resulting waveforms of current consumption are different from the message sent.

A. Idle and Sleep States

All measurements for idle and sleep states (also called "power down" or "power saving" states) show time-invariant current consumption. The results of our measurements presented no significant difference when compared with results presented in datasheets. The current consumption for idle and sleep states are presented in Table II.

Table II. RADIO MODULES SLEEP AND IDLE CURRENT CONSUMPTION.

Radio	Sleep State	Idle State
DR3000	0.7 µA	2 mA (ASK)/ 0 mA (OOK)
TRM 433	11.5 µA	4 mA
RT4 433	Not Available	0 mA
RR3 433	Not Available	3 mA
XBee PRO	0.1 µA	58 mA

B. Murata DR3000

DR3000 is a radio transceiver manufactured by *Murata Manufacturing Co.* [21]. It operates at 916.5 MHz and offers two options of modulation scheme: Amplitude Shift Keying (ASK) and On-Off Keying (OOK).

1) Transmission using ASK modulation

The current consumption measurement of DR3000 is presented in Fig. 5, and shows a close resemblance to the transmitted signal (shown in Fig. 4), switching between approximately 2 mA and 7 mA. One distinction between the transmitted signal and the current consumption is a small bias on the current consumption (~2 mA), indicating a non-zero current consumption when no signal is being transmitted. The DR3000 datasheet [21] does not report any data of the current consumption for ASK modulation in transmitting mode, but the current measured in our experiment was below the maximum current consumption indicated in the datasheet, which is equal to 12 mA at 3 V when using OOK modulation.

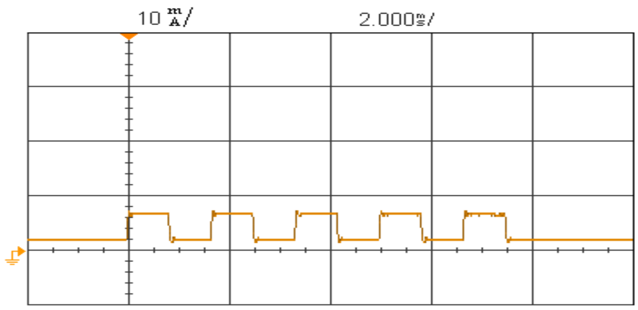

Fig. 5 – DR3000 current consumption when sending a message using ASK modulation.

2) Transmission using OOK modulation

As in the ASK transmission case, OOK transmission resulted in a current consumption profile very similar to the transmitted signal waveform. As can be observed in Fig. 6, both the amplitude and the width are close to the measured in the ASK transmission case. The measured current switched between 0 and approximately 7 mA. A key difference is that with OOK modulation there is no current consumption when no signal (or a "0" bit) is transmitted. The measured values are below the maximum current consumption of 12 mA at 3 V reported in the DR3000 datasheet [21].

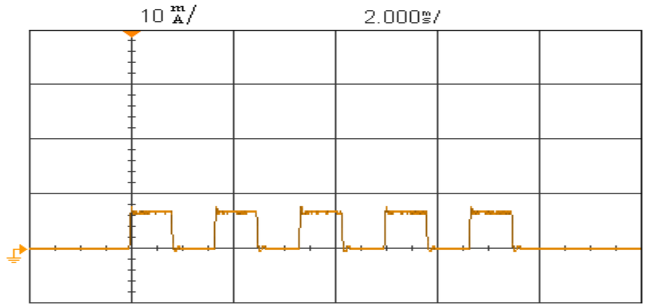

Fig. 6 – DR3000 current consumption when sending a message using OOK modulation.

3) Reception using ASK or OOK modulation schemes

The DR3000 module employs the same reception mode for both OOK and ASK modulation schemes. For both modulation schemes, the measured current was the same constant value, as shown in Fig. 7. It should be noted that the consumed current remains constant, even when no message is received. The measured value, approximately 4 mA at 3.3 V, is slightly above the maximum current consumption of 3.1 mA at 3 V, reported in the DR3000 datasheet [21].

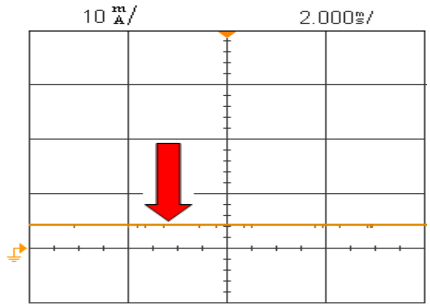

Fig. 7 – DR3000 current consumption when receiving a message.

C. Linx TRM 433 LT

The *TRM 433 LT* is a radio transceiver manufactured by *Linx Technologies* [22], and operates at 433.92 MHz, using OOK modulation.

1) Transmission

The measurements are presented in Fig. 8, and show a close resemblance to the transmitted signal (see Fig. 4).

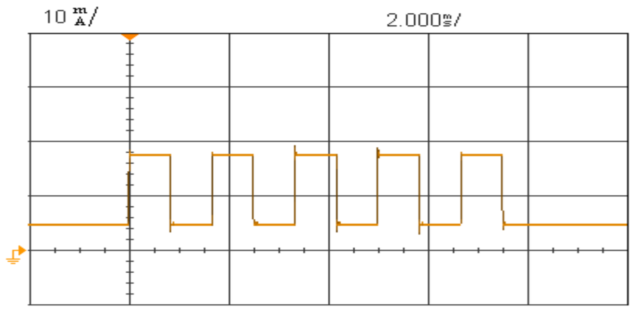

Fig. 8 – TRM 433 LT current consumption when sending a message.

The consumption of TRM 433 is also biased, switching between 4 mA and 17 mA. The high level (~17 mA) is above the maximum current consumption of 14 mA specified in the TRM 433 datasheet [22]. This discrepancy may be explained by the fact that in the measurements the TRM 433 module was powered with a 3.3V power supply, while the maximum current consumption reported in the datasheet corresponds to a 3V power supply.

2) Reception

The results for the TRM 433 LT module in reception mode is shown Fig. 9. Differently from the case of the DR3000 module (Fig. 7), the current consumption of TRM 433 LT is not constant. In fact, the waveform has almost the same shape of the transmitted message (Fig. 4), switching from approximately 6 mA to 8 mA. These measured values agree with the maximum current consumption of 7.9 mA at 3 V, reported in the TRM 433 datasheet [22].

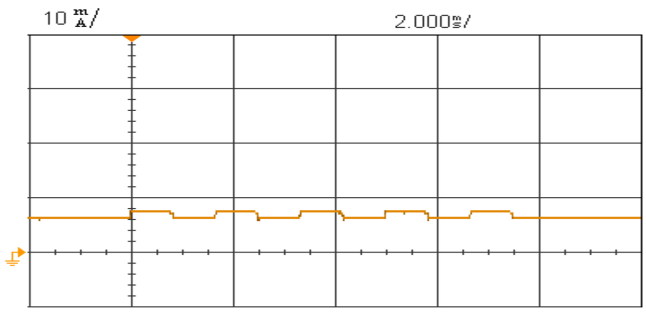

Fig. 9 – TRM 433 current consumption for receiving a message.

D. Telecontrolli RT4–433

The *RT4–433* module is a radio transmitter manufactured by *Telecontrolli SRL* [23]. It operates at 433.92 MHz and uses ASK modulation.

1) Transmission

The measured current consumption is presented in Fig. 10, and shows that consumption profile of the RT4–433 has a close resemblance to the transmitted signal (Fig. 4). As in the case of OOK transmission of the DR3000 module, shown in Fig. 6, the consumption of RT4–433 in the transmission mode has no bias. The measurements present peak values near the typical current consumption of 4 mA at 5 V, reported in the RT4 datasheet [23].

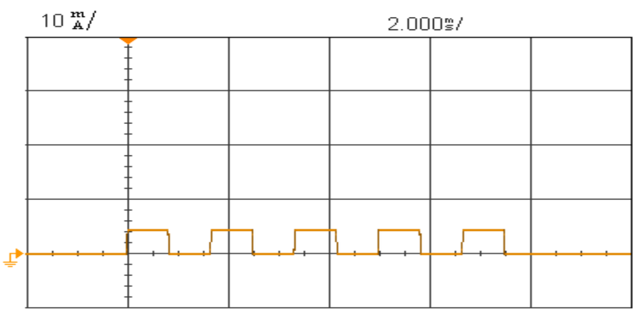

Fig. 10 – RT4-433 current consumption when sending a message.

E. Telecontrolli RR3–433

The *RR3–433* module is a radio receiver manufactured by *Telecontrolli SRL* [24]. It operates at 433.92 MHz and uses Amplitude Modulation (AM).

1) Reception

The result is shown in Fig. 11 and we can see that the current consumption profile is similar to that for the DR3000 module (see Fig. 7).

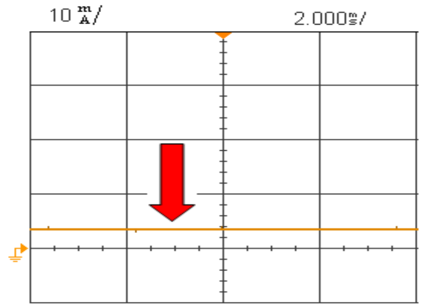

Fig. 11 – RR3-433 current consumption for receiving a message.

We can also see that, even when the *RR3-433* module is receiving a message, no variation in its current consumption is observed. The measured values are close to the maximum current consumption of 3 mA at 5 V, specified in the RR3 datasheet [24].

F. Digi XBee Pro 2.4 GHz 802.15.4

The *XBee Pro 2.4 GHz 802.15.4* module is a radio transceiver manufactured by *Digi International Inc.* [25]. It operates at 2.4 GHz and uses Direct-Sequence Spread Spectrum (DSSS) modulation.

Among the radio modules investigated in this work, the *XBee Pro* module is the most complex device, having many embedded functionalities, like carrier sensing, routing protocols, multi-channel operation and encryption.

1) Transmission

Differently from all measurements shown before, the current consumption profile of the XBee Pro module, shown in Fig. 12, has no resemblance to the transmitted signal. As the XBee Pro module is a complex radio device, it is reasonable to associate this current profile to internal routines related to message transmission processing. The measured peak current (~230 mA) is below the maximum current consumption of 250 mA at 3.3 V, reported in the XBee PRO datasheet [25].

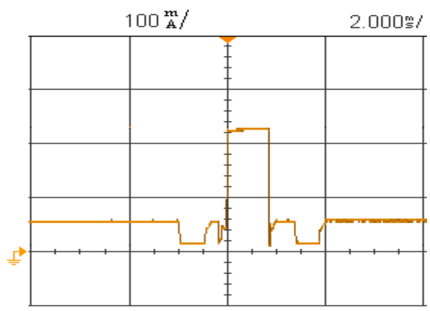

Fig. 12 – Xbee Pro current consumption when sending a message.

2) Reception

Again, the XBee Pro module in reception mode presented a current consumption profile, shown in Fig. 13, with no resemblance to the transmitted signal. The shape of the resulting waveform is similar to the waveform observed in the transmitting case. The waveform presented a narrow pulse, less than 0.5 ms long, with high amplitude, reaching approximately 260 mA.

We can also see that, in the idle state (before and after the portion related to the reception), the measurements showed a constant current consumption close to the typical current consumption of the idle state, 55 mA at 3.3 V, reported in the XBee PRO datasheet [25]. However, the datasheet does not report any difference between the current consumption of "idle" and "reception" states, and no further information about the reception current consumption is provided.

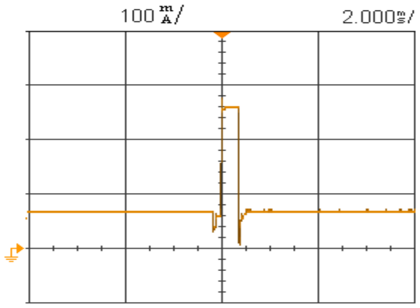

Fig. 13 – Xbee Pro current consumption when receiving a message.

V. CONCLUSIONS AND FUTURE WORKS

The measurements presented in this work showed how the current consumptions of radio modules typically employed in WSN can be more complex and intricate than the constant values presented in their respective datasheets. The complexity of the observed waveforms is closely related to the complexity of the radio module.

All measurements showed, as expected, that the datasheets present reliable information about an electronic device. However, when precise information about current consumption is required, the information available in datasheet may not be enough, and a more detailed analysis of the current consumption profile of the involved devices may be necessary. This may be the case when designing energy-aware techniques for WSN, or when motes in a WSN are powered by alternative power supply, such as energy harvesting power supplies.

The measurement setup employed in this work provided both sufficient resolution and clear waveforms, being suitable for the future steps of this work, namely, analysis of other radio modules and evaluation of external factors that affect current consumption in WSN.

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