Journal of Engineering Science and Technology
Vol. 13, No. 2 (2018) 473 - 488

AN INVESTIGATION OF THE POWER CONSUMPTION OF 315 MHz RF ASK TRANSMITTER AND RECEIVER MODULES FOR WIRELESS SENSOR NETWORK NODE

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Abstract

Sensor node in WSNs is the major bottle neck that restricts WSNs realization due to limited processing, communication ability and power sources. The communication or wireless transmission unit has noticeable effects on wireless sensor node system, since its power consumption is dependent on the transferred data package size. This research paper presents evaluation and characterization of transmission time, minimum amount of operating voltage and current, and hence the power required to transmit certain size packets of data of an off-shelf RF ASK 315 MHz wireless module. A microcontroller with the VirtualWire library was used to provide data to the transmitter module and transmit it to the receiver, located 2 m apart, with transmitting rate of 2 kbit/s. The experimental outcome showed that the tested module would need 50 ms with 0.3 mW in order to transmit a byte of data. The transmission time increased proportionally with the data package size. Meanwhile, the transmission power increased in logarithmic manner with the data package size.

Keywords: 315 MHz RF module power consumption, Transmission time, Wireless sensor node, Energy harvesting.

1. Introduction

Wireless Sensor Networks (WSNs) play a major role in the research field of multi-hop wireless networks, ranging from environmental and structural monitoring, to border security and human health control. Researches relative to this field cover a wide spectrum of topics, leading to advancement in node hardware, protocol stack design, localization and tracking techniques, and energy management [1]. Researches on WSNs are driven (and somewhat limited) by a

Nomenclatures

D	Data packet, Byte
I_{active}	Current consumed by the transmitter at the active mode, A
I_{sleep}	Current consumed by the transmitter at the inactive mode, A
P_{active}	Power consumed by the transmitter at the active mode, W
P_{sleep}	Power consumed by the transmitter at the inactive mode, W
T_{active}	The time when the transmitter is transmitting data (Fig. 3), s
T_{sleep}	The time when the MCU is in the sleep mode and the transmitter is inactive (Fig. 3), s

Abbreviations

ASK	Amplitude-Shift Keying
BJT	Bipolar Junction Transistor
CMOS	Complementary Metal Oxide Semiconductor
CRC	Cyclic Redundancy Check
DC	Direct Current
GPIO	General Purpose Input Output
GPS	Global Positioning System
IC	Integrated Circuit
IR	Infrared
MCU	Micro Controller Unit
PV	Photovoltaic
RF	Radio Frequency
TEG	Thermoelectric Generator
UDP	User Datagram Protocol
WSN	Wireless Sensor Network

common focus: Energy efficiency. Node of a WSN hardware architecture as shown in Fig. 1 typically consist of four major parts: sensing unit, wireless communication module, microcontroller unit and power supply. Some even contain extra units like mobilizer or GPS to find a node's position in the monitoring area [2, 3].

The nodes in WSN are typically powered by batteries [4]. However, battery lifetime is a major challenge since it depends on many factors, such as the duty cycle of supported applications and the intrinsic chemical reactions within the batteries. Several battery models have been proposed to deal with WSN example by Leonardo et al. [5]. Therefore, a number of energy harvesting schemes has been proposed to alleviate this problem, which is to convert the ambient energy from the environment into electricity to power the sensor node. Ambient energy can be harvested from mechanical energy, such as from vibration [6] and mechanical impact [7]. Besides, it is common to use thermoelectric generators (TEG) to harvest waste industrial heat [8], as well as using photovoltaic (PV) cells to harvest solar energy [9]. There is also hybrid energy harvesting system as described by Pankaj et al. [10], in which photo-voltage and wind energy are combined to power up an autonomous wireless sensor node.

Another important component in the WSN node architecture is the wireless transmission unit, which is the focus of this research. Wireless transmission unit is considered the most power hungry unit among the other node components, since it consumes most of the node energy to wirelessly transmit the date to the other node. Many of the researchers have used different types of commercially available wireless units in their proposed architecture for a WSN node. For example, Murat Gürsu and his colleagues [11] used a Raspberry Pi platform, along with a WiFi module in their proposed WSN architectures for an aircraft cabin. Another researcher proposed a novel design of a WSN based on CSR BlueCore 02 Bluetooth module for wireless transmission [12]. A standard IEEE 802.15.4 Zigbee module has been used in the design of a WSN targeted for trees monitoring in the forest [13]. Some other researchers have gone beyond these by studying the losses in data for the WiFi-based WSN [14], analysing the radio propagation [15], and energy consumption estimation via simulator for the CC2420 radio chip [16]. Mark and his fellows [17] worked to characterize the voltage consumed by an RF-powered 2.4 GHz transmitter for a certain time. Karina et al. [18] studied the power consumption by the access point for different traffic rates.

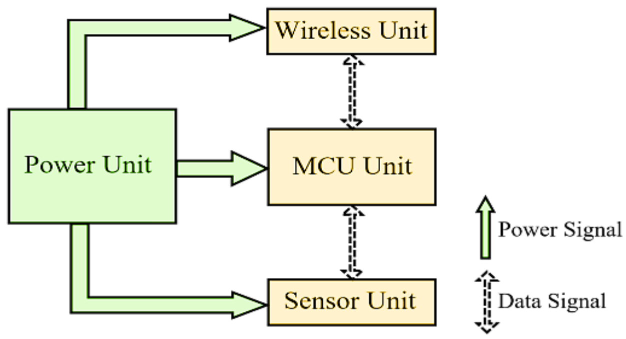

Fig. 1. Typical wireless sensor node block diagram.

Generally, most of the previous researchers had presented their work using the mentioned wireless transmission modules in their proposed WSN node architecture; and they had successfully characterized some of the wireless module parameters according to their needs. In this study, the power consumption of the 315 MHz RF wireless modules has been specifically investigated, inclusive of the characterizations of the wireless transmission module in terms of the less amount of voltage, current, power, and the transmission time in order to transmit a certain amount of data package to the next node, set at a specific distance. Consequently, this research paper provides WSN designers with reliable data about the wireless module that is not provided in the manufacturer datasheet.

2. Wireless Unit Overview

Wireless transmission unit is the second most important component in wireless sensor node architecture after the MCU. Since it consumes more power due to many factors such as the transmission distance, environment, and data packages from one node to another, this affects the lifespan, reliability and compatibility of the wireless node. This study focused on 315 MHz (RF ASK) module. Since these RF wireless modules are relatively small in size, as shown in Fig. 2, this low cost unit can be easily driven via hardware (encoders and decoders ICs) or via software (libraries), and typically have a wide operating voltage range up to 12 V.

The coverage area of this RF transmitter is up to 100 meters (which depends on the antenna design, working environment and supply voltage) with simplex manner. Therefore, it is suitable for short distance, battery power/energy harvesting device development. The only disadvantage of these modules is that they are indiscriminate and will receive a fair amount of noise. However, this kind of wireless transmitter is very popular to be used in various applications, for instance industrial remote control, telemetry and remote sensing, alarm systems and wireless transmission for various types of low-rate digital signal, remote control for various types of household appliances, and electronics projects [19].

Besides Radio Frequency (RF) transmission, Infrared (IR) transmission is also common for short distance application, but in most of the cases RF, is more superior to Infrared (IR) transmission due to following reasons:

- RF signals can travel longer distances than IR signals.
- Only line of sight communication is possible through IR, while RF signals can be transmitted even when there are obstacles.
- IR signals will get interfered by other IR sources but signals on one frequency band in RF will not interfered by other frequency RF signals.

Fig. 2. RF wireless module used in this research, left transmitter, right receiver.

Commercially, there are two types of the RF ASK wireless module, which are 315 MHz or 433 MHz, available in the market. Except for the frequency and antenna length requirements, RF_315 and RF_433 share the same product specifications, as shown in Table 1 below:

Table 1. RF wireless transmitter characteristics [16].

PARAMETERS	MIN	TYP	MAX	UNIT
Operating Voltage		3	12	V
Operating Current		9	40	mA
Oscillator	SAW (Surface Acoustic Wave) Oscillator			
Frequency	315		433.92	MHz
Frequency Error			±150	KHz
Modulation		ASK/OOP		
Transfer Rate		2	8	Kbps
Transmitting Power			25	mW
Output Power			14	dBm
Working Temperature	-20		+85	ºC

As shown in Table 1, obtained from the module datasheet, the energy consumption for transmitting is about 25 mW, and it requires an operating voltage of 3 V, which is a constraint to low power energy harvesting system. Therefore, it is crucial to know the minimum requirement of this module to enable the wireless module to run and transmit the data utilizing the available energy of an energy harvesting unit, since these modules are indiscriminate and will receive a fair amount of noise. Moreover, both the transmitter and receiver work at common frequencies and do not have IDs. Therefore, a method of filtering this noise and pairing the transmitter with the receiver will be necessary. Commonly there are two solutions to address this issue:

i. by utilizing serial remote control encoders/decoders pairs ICs such as (PT2262, PT2272) or (HT12E, HT12D) to pair the transmitter with the receiver and filter out the noise. These converters utilize CMOS Technology to encode data and address pins into a serial coded waveform suitable for RF or IR modulation; thereby, drastically reducing any code collision and unauthorized code scanning possibilities, or

ii. by utilizing a MCU with a specific software library to pair out the transmitter and the receiver, filtering out the signal, and encode the raw data into serial data. There are some libraries, available able to support this kind of wireless transmitter and receiver, for instance RCSwitch [20] to operate the MCU as a remote radio controlled devise, RadioHead [21]and VirtualWire [22].

The last two libraries (RadioHead and VirtualWire) are communications libraries for the MCU that provides features to encode short messages and send them using low cost simplex RF transmitters and receivers. VirtualWire library provides the abovementioned features, without needing of addressing, retransmit, or acknowledgment, similar to UDP over wireless, using ASK (amplitude shift keying) which supports number of inexpensive radio transmitters and receivers. With the aid of this library, the messages are sent with a training preamble, message length and checksum. Messages are sent with 4-to-6 bit encoding for good DC balance, and a CRC checksum for ensuring message integrity [22]. The role of this library is to encode the message that generated via the main MCU.

3. Characterization Circuit Setup

This section presents the methodology used to experimentally measure and validate the electrical parameters of the RF wireless model, which involved the use of VirtualWire library. A set of experiments with different data package size had been performed to assess the module power consumption in these conditions. Simple measurement circuit based on low power AVR 8-bit MCU MEGA328P had been constructed to evaluate the power consumption of the RF transmitter module while transmitting different packet size of data to a receiver node at a distance of 2 m. The circuit was set to transmit random data with size of 1, 3, 6, 9, 13, 15, 17, 20, 22, and 25 bytes generated via the MCU, and encoded with VirtualWire library, with bit rate of 2 kbps. The circuit had been programmed to send a packet every 10 seconds. Figure 3 illustrates the RF transmitter circuit operation routine.

The pseudo-code for the conventional transmitter circuit is as below:

1. Initiate the MCU.
2. Include the <VirtualWire> header.

3. Assign the transmitter Pin.
4. Set the RF bit rate to 2 kbps.
5. Create a message with specific size.
6. Encode the message by using VirtualWire.
7. Transfer the message to the RF wireless module.
8. Set MCU to sleep (10 Seconds).
9. Wake up.
10. Jump to 5.

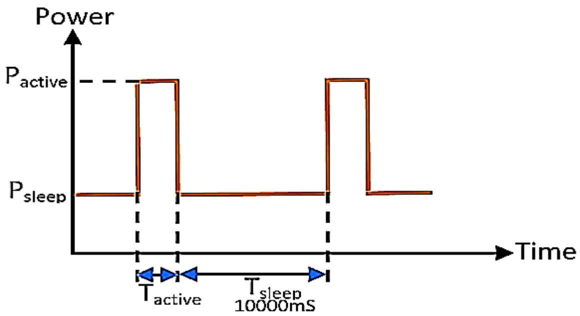

Fig. 3. RF Transmitter circuit routine.

As depicted by the pseudo code and Fig. 3 that the circuit should go into a sleep period of 10 seconds directly after sending a specific size of data packet. The duration of active (transmitting) period was differed according to the transmitted data packets size. The transmission time of a single byte of data packet was about 50ms, and then was increased proportionally to the packet's size of up to 196 ms when transmitting 25 bytes of data; which was the maximum data packet size that could be sent by the system at a time. Figure 4 shows the transmission time in millisecond versus the transmitted packet size in byte.

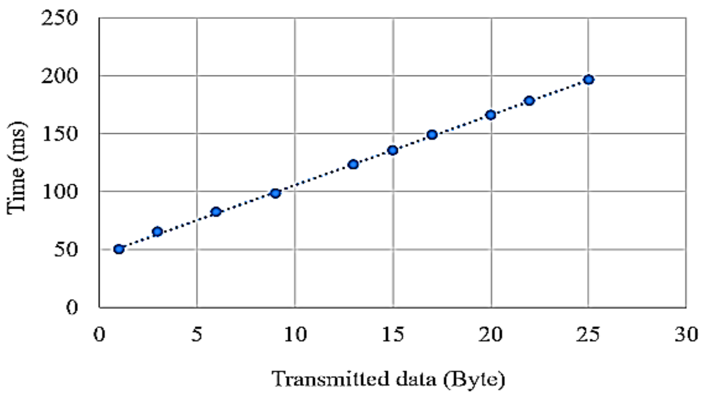

Fig. 4. Transmission time versus transmitted packets.

The circuit, as shown in Fig. 5, can be considered a conventional circuit for the wireless module to be connected to an MCU. It was designed to practically measure the power drawn by the wireless module under test with different packet sizes "as a load". The circuit consisted of the low power MCU MEGA328P with its own power supply, and an RF wireless module and its own variable power supply to easily adjust the supplied voltage to the wireless module without interrupting the MCU. A voltmeter was connected in parallel with RF module to measure the supplied voltage. An ammeter was connected in series with the RF module in order to measure the drawn current by the module, hence to be able to calculate the consumed power.

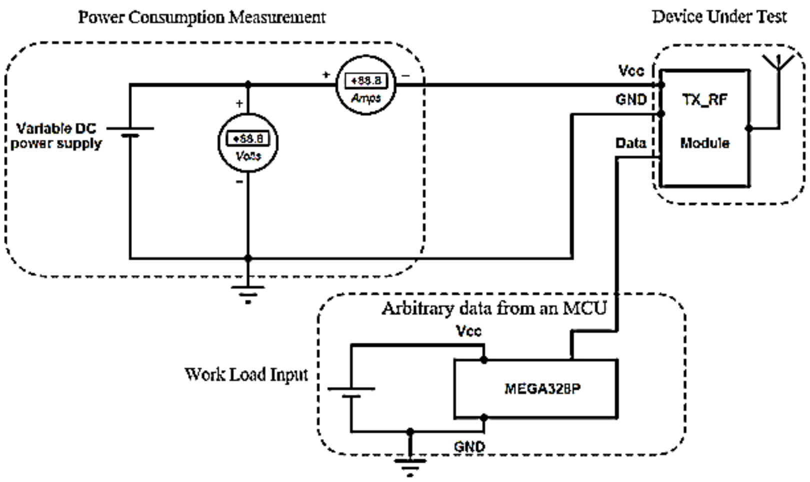

Fig. 5. Characterization of the conventional RF transmitter circuit.

4. Experimental Results

Theoretically, it was expected that the RF wireless module power consumption would start from a certain low wattage, and then would gradually increase along with the transmitted data packet size. Since higher data packet size would lead to longer transmission time, more transmission time means higher power required. Mark et al. [17] and Karina et al. [18] also showed that a wireless module would draw more wattage according to the transmitted data packets size in a logarithmic manner. Therefore, three experimental assessments had been performed to estimate the RF wireless module electrical parameters. Accordingly, all the values as illustrated in the following graphs were taken as minimum as possible to make the RF wireless module up and running.

The practical results in Fig. 6 show that while transmitting a byte of data, 0.3 mW of electrical power at minimum was required to perform the transmission to the receiver node at a distance of 2 m away. As expected, the power consumption increased in a logarithmic manner while increasing the transmitted data packet size. A power of 1.9 mW was measured when transmitting 25 bytes of data packet. The minimum voltage was about 1 volt regardless of the number of data being transmitted. This happened in the active region (P_{active}) of the transmitter circuit routine, as mentioned in Fig. 3.

From the measurements, it was found that even though the conventional circuit went into a sleep mode, and the RF transmitter module did not transmit any data, it still consumed some noticeable power. Figure 7 shows that the RF transmitter module consumed more than 0.13 µW despite it was in an inactive period, in the sleep region (P_{sleep}) of the transmitter circuit routine, as mentioned in Fig. 3. During the sleep period, any extra power consumption is considered as a wasted energy. Consequently, it will lead to rapid depletion of energy from the power source of the wireless sensor node, hence might result in out-of-service condition.

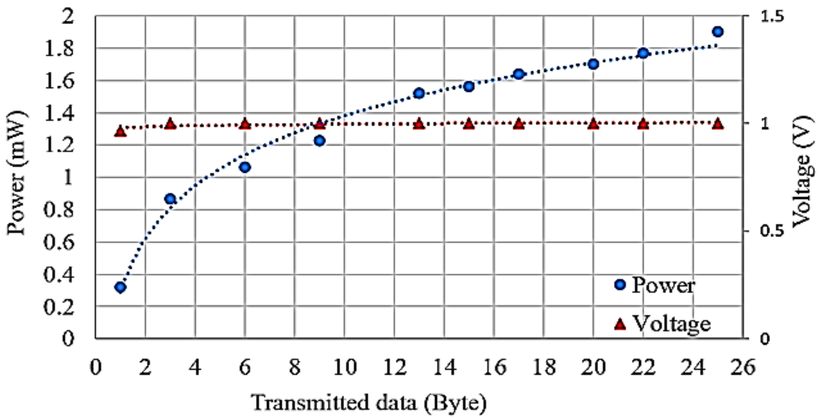

Fig. 6. Minimum power and voltage drawn by the conventional RF transmitter circuit during the active mode.

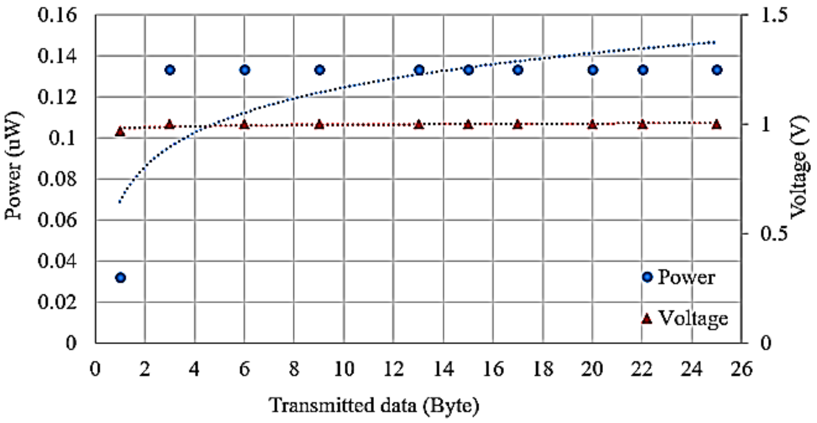

Fig. 7. Minimum power and voltage drawn by the conventional RF transmitter circuit during the sleep mode.

This serious drawback can be solved by completely isolating the RF Transmitter module from the power supply via a switch circuit during the sleep period. The working principle of the switch circuit is to connect the RF transmitter to the power supply during the transmission period, and then isolate it during the sleep period of the node's MCU. Doing so, the node can operate at lowest power consumption during the sleep period. A simple switching circuit can be achieved by employing a Bipolar Junction Transistor (BJT) PNP or NPN transistor, and bias it as a switch. In this study, a general purpose PNP transistor (PN2907) had been used to improve the previous conventional circuit, as shown in Fig. 8. The transistor was connected in series with the active line (VCC) of the RF module, and was driven via a digital GPIO from the MCU. A dropper resistor of 1 KΩ was connected in series with the GPIO and the transistor base.

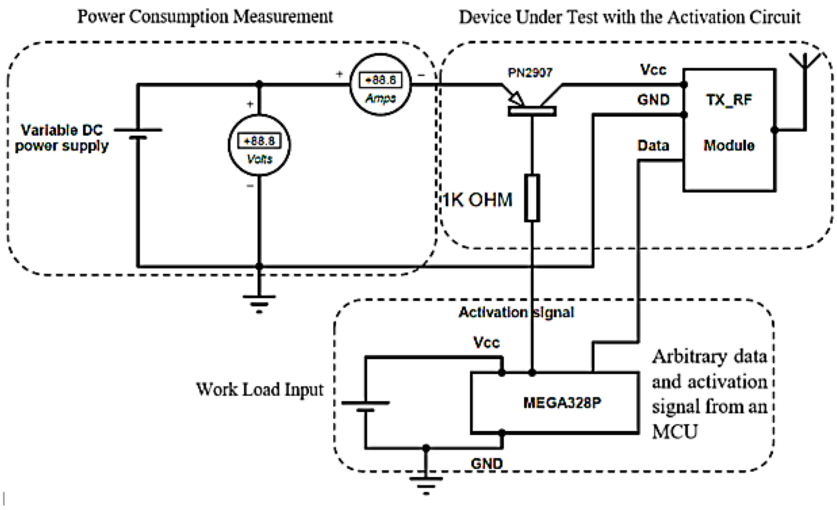

Fig. 8. Characterization of the proposed enhanced RF transmitter circuit.

Transmitter circuit software also incurred minor changes, where it had to control the activation of the wireless transmitter module by toggling the pin that was connected to the switching transistor. The enhanced pseudo-code for the transmitter circuit was as below:

1. Initiate the MCU.
2. Include the <VirtualWire> header.
3. Assign the transmitter Pin.
4. Assign the activation Pin.
5. Set activation pin to high.
6. Set the RF bit rate to 2 kbps.
7. Create a message with specific size.
8. Encode the message by using VirtualWire.
9. Set activation pin to low.
10. Transfer the message to the RF wireless module.
11. Set activation pin to high.
12. Set MCU to sleep (10 Seconds).
13. Wake up.
14. Jump to 7.

As can be seen from the pseudo code above, a specific pin from the used MCU was assigned to control the operation of the wireless transmitter module. Since the transistor switching circuit was active low, the activation pin was set to low only whenever there was a message ready to be sent. Conversely, the MCU would set it to high in order to isolate the transmitter module from the power source and preserve the energy.

The power consumption of the modified circuit as shown in Fig. 8 was still the same as the conventional circuit during the active period, as shown in Fig. 9. However, there was a substantial improvement in the power consumption during the sleep period, as shown in Fig. 10. In this case, the operating power during the sleep period dropped to a magnitude of a few tenth of nanowatt instead of microwatt, with the presence of switching transistor.

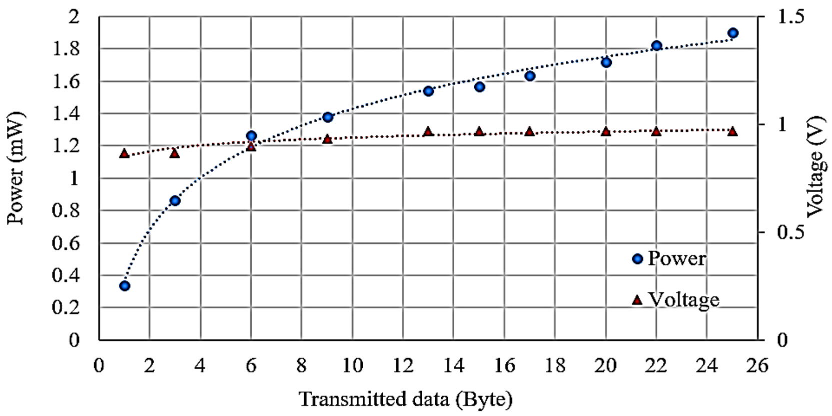

Fig. 9. Minimum power and voltage drawn by the proposed enhanced RF transmitter circuit during the active mode.

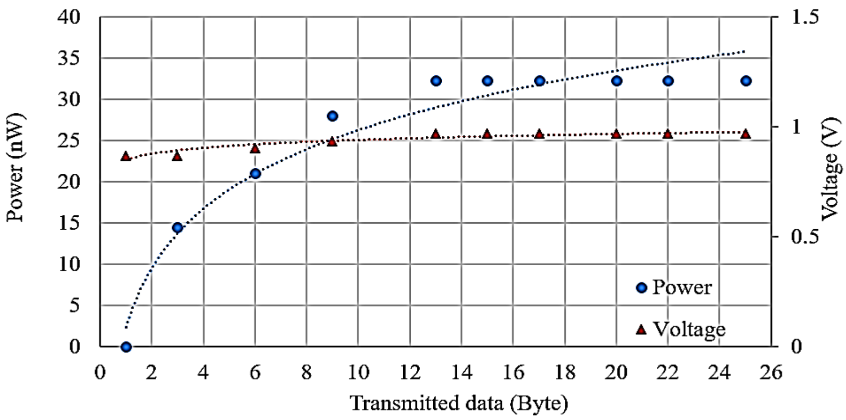

Fig. 10. Minimum power and voltage drawn by the proposed enhanced RF transmitter circuit during the sleep mode.

Consequently, it can be concluded that this 315 MHz RF wireless transmitter module is able to operate at minimum power of 0.3 mW up to 1.9 mW, while transmitting a byte up to 25 bytes of data. According to this finding, this wireless module can be considered a suitable solution to be powered via energy harvesting approaches. Thermal energy harvesting [23], piezoelectric mechanical impact harvester [24], piezoelectric mechanical vibration harvester [25], electromagnetic energy harvester [26], and hybrid systems such as [27] where the author harvested energy from the power of wind and water, etc. All of these are considered good examples of energy harvesters that can support the operation of this module. Figure 11 illustrates a comparison between the amounts of the harvested power from different approaches as previously mentioned, versus the wireless module power consumption.

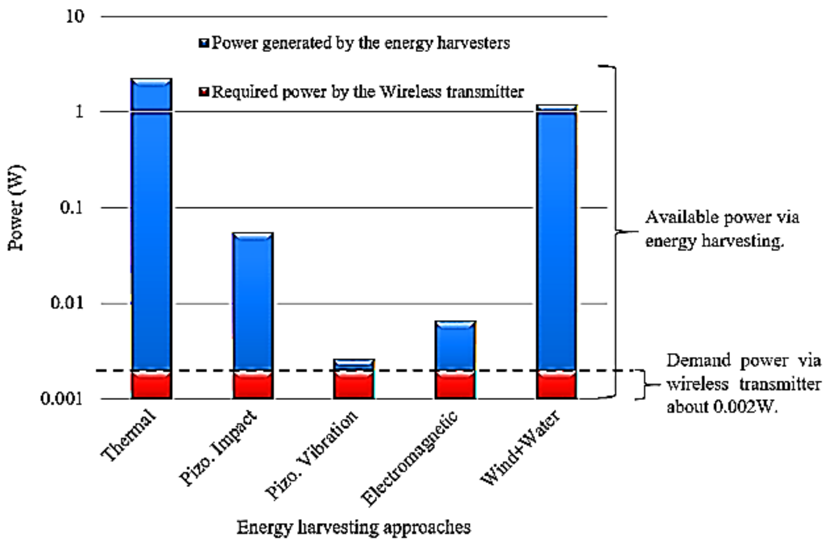

Fig. 11. Electrical power harvested via different approaches obtained from [23-27] comparing to the required power by the RF transmitter module.

The active power equation which describes the minimum power consumption in mW magnitude for the RF module as mentioned in Figs. 6 and 9 can be represented and simplified as,

$$P_{active} = 0.47 * \ln(D) + 0.3 \quad (1)$$

Where *D* is the transmitted data packet size (1~25 bytes). Accordingly, and as long as this wireless module consumes about 1 volt while in operation in active mode, the minimum current required can be calculated by using Eq. 1, to obtain:

$$I_{active} = \frac{0.47*\ln(D)+0.3}{1} \quad (2)$$

Likewise, the power drawn by the RF module in nW magnitude during the sleep period for the enhanced circuit, as shown in Fig. 10, can be calculated as:

$$P_{sleep} = 10.5 * \ln(D) + 2 \quad (3)$$

where D is the transmitted data packet size (1~25 bytes), while the sleep current can be simplified as:

$$I_{sleep} = \frac{10.5*\ln(D)+2}{1} \quad (4)$$

In order to investigate the consumption of the RF Receiver circuit, a receiver node circuit had been constructed, as shown in Fig. 12. The circuit consisted of an

MCU and its own power supply, RF receiver module with its own variable power supply, a voltmeter and an ammeter connected in parallel and series with the RF wireless module, respectively.

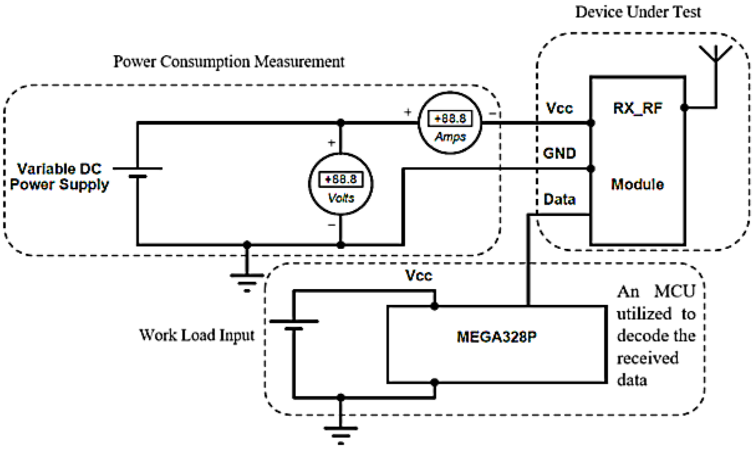

Fig. 12. Characterization circuit for RF Receiver.

The RF receiver circuit was also operated via the aid of VirtualWire library. Since the RF module supports simplex transmission manner, and due to the complexity of synchronizing the operation of the receiver with the transmitter, the receiver node was kept to be active all the time. This node was located at a distance of about 2 m from the transmitter node, as mentioned previously. As it was kept active all the time, the sleep period was omitted. The pseudo-code for receiver circuit was as below:

1. Initiate the MCU.
2. Include the <VirtualWire> header.
3. Assign the receiver Pin.
4. Set the RF bit rate to 2 kbps.
5. Sniffing the receiver pin for incoming data.
6. If a data received:
    - 6.1. Decode the message by using VirtualWire.
    - 6.2. Display the message.
    - 6.3. Jump to 5.
7. If no data received:
    - 7.1. Jump to 5.

The practical results showed that the RF wireless receiver required at least 3.9 V to operate and receive the signals. As shown in Fig. 13, it constantly consumed a minimum power of 16.5 mW regardless of the size of the received packet. The power consumption was also maintained even though no signal packet was being received. Figure 13 illustrates the voltage and power drawn by the RF receiver wireless module.

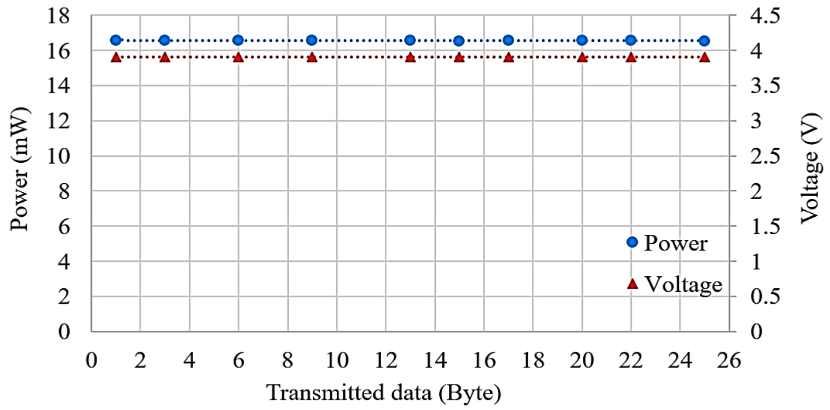

Fig. 13. Minimum power and voltage drawn by the RF receiver module.

Therefore, according to the findings, the RF module parameters as shown in Table 1 previously in this research paper can be complete, as shown below in Table 2 below. Where, now can find all the minimum electrical parameters that important for the wireless node designers.

Table 2. The completed RF wireless transmitter characteristics.

PARAMETERS	MIN	TYP	MAX	UNIT
Operating Voltage	1	3	12	V
Operating Current	0.3	9	40	mA
Oscillator	SAW (Surface Acoustic Wave) Oscillator			
Frequency	315		433.92	MHz
Frequency Error			±150	KHz
Modulation		ASK/OOP		
Transfer Rate		2	8	Kbps
Transmitting Power	0.3		25	mW
Sleep Power (conventional circuit)	0.13			μW
Sleep Power (enhanced circuit)	33			nW
Output Power			14	dBm
Working Temperature	-20		+85	ºC

For future work, in order to further reduce the power consumption of the RF receiver module, it can be set to go into a sleep period by isolating it from the power source directly after it has received a packet. The sleep period should be shorter than the transmitter node. The following pseudo-code clarifies the suggested receiver routine for the receiver node:

1. Initiate the MCU.
2. Include the <VirtualWire> header.
3. Assign the receiver Pin.
4. Set the RF bit rate to 2 kbps.
5. Sniffing the receiver pin for incoming data.

6. If a data received:
   - 6.1. Decode the message by using VirtualWire.
   - 6.2. Display the message.
   - 6.3. Set MCU to sleep (period less than transmitter node).
   - 6.4. Wake up.
   - 6.5. Jump to 5.
7. If no data received:
   - 7.1. Jump to 5.

By applying the previously mentioned algorithm, isolating the RF module and by exploiting the transistor switching circuit whenever the MCU goes into sleep period, these can mitigate the module power consumption. Furthermore, the miss-received packages can be minimized, since the receiver node will always be activated before the transmitter node is transmitting.

5. Conclusions

This paper has presented an experimental investigation of an off-shelf 315 MHz (RF ASK) module. The investigation includes module electrical parameters that are not found in the manufacturer datasheet, such as less amount of voltage, current, and power required to power up the module. The proposed wireless module operates with the aid of VirtualWire library, and it is meant for WSN context based on energy harvesting. A series of experiments have been performed using different test circuits for both transmitter and receiver modules. The test circuits has been equipped with variable power supply, ammeter, and voltmeter, which have allowed to experimentally estimate the lowest power consumption for the RF wireless module. The obtained results indicate that the lowest power drawn by the transmitter is not linear, but dependent on the size of the transmitted data. It is also found that the module requires at least 1.9 mW when transmitting 25 Bytes of data, which can be supported by an energy harvesting device.

Acknowledgment

The authors would like to acknowledge the support of this work by the Malaysian Ministry of Higher Education under the FRGS research grant No. FRGS/2/2014/SG02/FKEKK/02, and UTeM internal grant PJP/2014/FKEKK(1B)/S01293, ZAMALAH, as well as the facility support by the Faculty and ASECs Research Group, CeTRI, UTeM.

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