Bidirectional 868/915 MHz wireless module powered with energy harvester.

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Abstract:

In this paper, we present a work that allows bidirectional communications in the 868/915 MHz ISM bands, using the power generated by energy harvesters. Our investigations show that a clear channel assessment, receive of acknowledge and resend of the message are possible within a limited, but reasonable time. The design relies on the use of low power microcontrollers and transceivers, and low energy management techniques.

1 Introduction

There is a case for the use of wireless switches in automated meter reading, industrial monitoring, building automation, alarm systems, wireless door bells, etc. In some of these applications, a bidirectional link might be necessary, to enhance the communication or to provide feedback to the person (or system) that generated the message. Currently most, solutions require the use of a battery. This leads to maintenance costs which negatively affect the acceptability of the wireless device. There are some solutions on the market that rely on energy harvesters to generate the needed power, in order to send information from a switch [3],[4]. Much work has also been done that shows how to use different types of energy harvesters to power wireless sensors [2],[4],[6],[9],[10],[13]. These solutions are mostly unidirectional. Using only a transmitter has the advantage of eliminating the extra power consumption needed for the receiver. Also, the amount of data sent is often small. This will do in certain circumstances, but not if a feedback is required, or if tens of bytes need to be sent.

2 Our investigation

In this work we investigated the use of recently introduced microcontrollers and transceivers with some energy harvester (EH) devices. The new devices which are destined for the consumer market, require less power, and offer a lot of flexibility. This combination allows battery-less (or very low power) applications with some form

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of feedback, increasing the reliability of the wireless link. Most of the results shown here are based on a student's project work, and work at our Institute [5].

Some typical steps for a reliable communication are:

- Making a Clear Channel Assessment before sending the message to reduce the probability of having collisions (receive mode).
- Sending the message (transmit mode).
- Getting an acknowledgement from the receiving station (receive mode).
- Giving a feedback to the user (or calling routine) for an eventual resend (processing and transmit).

Elements that affect the power consumption are:

- The receive current of the transceiver (I_{tx})
- The sending power of the transceiver (I_{rx})
- The active power consumption of the microcontroller (I_{micro})
- The energy in the standby mode (I_{stdby})

The energy needed by the system is related to the factors above multiplied by the time spent in the given states and the supply voltage.

$$E_{total} = E_{tx} + E_{rx} + E_{micro} + E_{stdby} = V_{supply} *(T_{tx}*I_{tx} + T_{rx}*I_{rx} + T_{micro}*I_{micro} + T_{stdby}*I_{stdby})$$

Many systems will spend a long time in receive mode, waiting for a message. In case an acknowledgement is required, the power needed in receive mode can increase dramatically. This makes the receive current very dominant in wireless systems, especially if a high link budget is needed.
Very important in the case of EH is also the minimum supply voltage of the components ($V_{supplymin}$). Most devices will work only down to 1.8 Volt, meaning that the energy below 1.8 Volt is lost. Working well above $V_{supplymin}$ will result in using more power that necessary, with the consequence that less power will be available for other functions.

In the next paragraphs, we will briefly describe some of the devices at the heart of this work. For a more detailed description, the user should consult the appropriate datasheets

2.1 Energy Harvesters.

There are several kind of EH on the market. Figure 1 shows a picture of some of the devices that were used.
The power that can be generated for each type is given in the table below.

Harvester type	*Internal resistance*	*Energy generated RL=100 Ohms*	*Energy generated RL=1000 Ohms*
Hand dynamo (EH1)	14 Ohms	132 mJ	43 mJ
Hand dynamo (EH2)	21 Ohms	117 mJ	23 mJ
Shake generator (EH3)	113 Ohms	36 mJ	21 mJ
ECO 100 (EH4)	51 Ohms	277 uJ	91 uJ

Near these EH, we also made some trials with small solar cells, of type XOB17-04-03 from IXYS (22 x 7 x 1.4 mm) [14]. Our measurements showed that one of them could deliver enough power in normal office conditions to start the microcontroller. In order to activate the transceiver, a supercapacitor and a DC/DC converter are needed. Piezo harvesters were not used in this work.

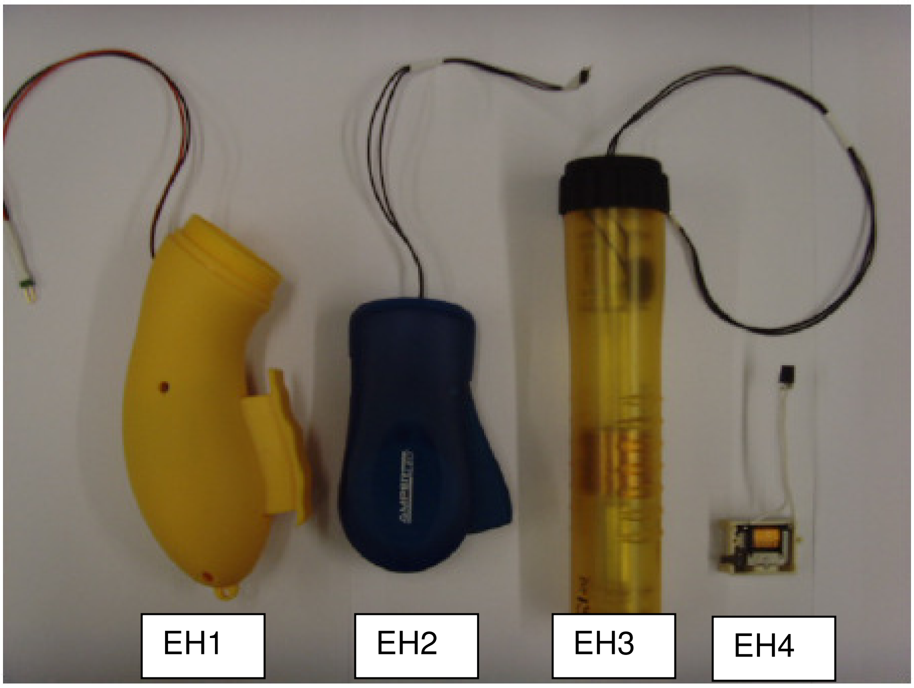


Figure 1: Picture of some of the EH used in the work

2.2 The EM6819

The EM6819 is a microcontroller developed by the firm EM Microelectronic Marin, based in Switzerland, and known for its expertise in low power design for the watch industry, RFID and other applications. The controller belongs to the CoolRISC family. It is an 8-Bit architecture especially developed for low power. Instructions execute in 2 clock cycles. The energy consumption performance of the coolRISC compares very favourably with other low power microcontrollers [1],[5],[12]. In fact, it outperforms several 8-Bit devices in factors such as Operating Current.
The EM6819 boasts several dedicated digital and analog blocks such as: SPI, A/D converter, low power VLD (Voltage Level Detector), a programmable DC/DC converter to supply external devices. It also includes many timers. 16.5 Kbytes of Flash memory and 256 Bytes of RAM are available for program and data storage. The device can run up to 15 MHz (7.5 MIPS). It works with internal RC oscillators, or appropriate external quartz.
An interesting low power feature of the EM6819 is its ability to run with a supply voltage between 0.9 Volt and 3.6 Volts. Its operating current at 3 Volts and 1 MIPS is less than 150 uA. The device uses an integrated low power voltage multiplier which allows the device to start working as early as 0.9 Volt, without assistance of any external circuitry. The use of the voltage multiplier however results in a higher current consumption between 0.9 Volt and 1,6 Volt. As soon as a critical voltage is reached, the multiplier stops, leading to a reduction of the operating current.

The device offers several current reduction modes, with various functions switched off. In power down mode, the CPU is halted resulting in a consumption of about 500 nA @ 3 Volts.

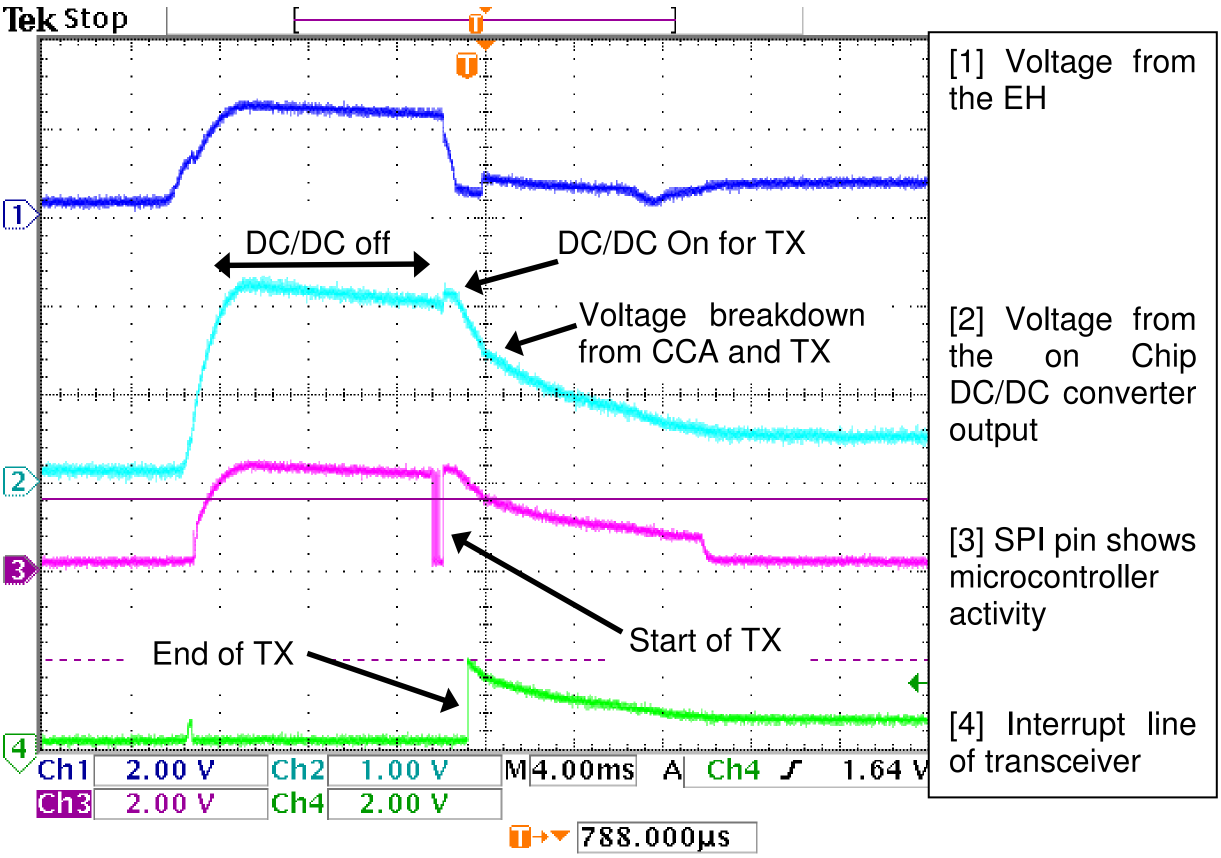


Figure 2 Use of internal DC/DC for TX

Figure 2 shows how the EM6819 can be set up to optimize the use of the energy provided by the harvester. In this case, the microcontroller was used to control a 802.15.4 compatible 2.4 GHz transceiver, and to send about 40 bytes. A ECO100 type EH generated the needed electrical power.
The instantaneous power is used to start the microcontroller (Power On Reset) when the voltage reaches 0.9 Volt. This voltage is not enough for the transceiver, but will get the microcontroller running, so that some initialization tasks can be performed (including power up sequence).
The microcontroller will then start the communication with the transceiver (SPI pin) if the voltage needed for the transceiver is sufficient. Otherwise, the DC/DC converter could already be switched on.
When the transceiver is ready for sending the data, the DC/DC converter can be started (if not yet done), to ensure that the voltage is high enough when CCA and TX are started. In the case shown above, CCA and TX last about 1 ms.

2.3 The SX1211

The SX1211 is a transceiver developed by Semtech Switzerland (formerly Xemics) [2]. It can operate in the frequency ranges 863-870 MHz, 902-928 MHz and 950-960

MHz. The main feature of this device is its very low power consumption in receive mode (typically 3 mA, that is 3 to 5 times better as most competitors). The device can use FSK or OOK. It includes a 64-Byte FIFO, and allows communication in bit, byte or packet modes. Transmit power of more that 10dBm is possible. Reception sensitivity is -107 dBm @ 25Kb/s for FSK and -113 dBm @ 2Kb/s In OOK. The device automatically delivers CRC and RSSI. These features allow the user to optimize for processing needs, speed and power consumption.
Near this transceiver, the AT86RF230 (2.4 GHz 02.15.4 compatible) from Atmel was also used in combination with the EM6819. This device is in many ways similar to its recently introduced 800/900 MHz equivalent (AT86RF212).

2.4 Block diagrams of the designs

Different configurations are possible depending on the EH used:
For EH1 and EH2, EH3, EH4 the configuration shown on Figure 3 was used. If the voltage is too high, a regulator or voltage limiter can be included. The capacitor ensures that energy is stored for the work needed. This capacitor should be chosen according to the EH type, and the initial voltage required.

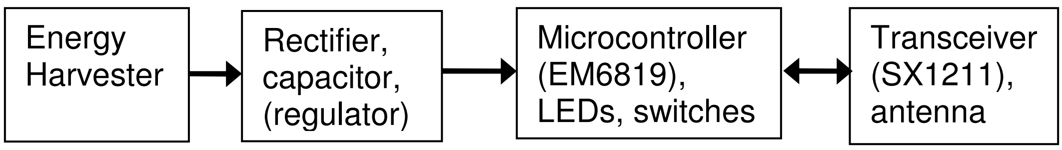


Figure 3: Block diagram of the design for EH1,EH2,EH3,EH4

When using solar cells (Figure 4, Figure 5), there is not always enough energy available at once. The capacitor is charged slowly, and a low power comparator is used to control a semiconductor switch. Once the voltage on the capacitor has reached the value needed, the power is applied and the system starts. The energy depends on the capacitor value and the difference between the 2 thresholds. A large capacitor will also lead to longer charging times. The internal Voltage Level Detector of the EM6819 (VLD) can also be used for monitoring the capacitor voltage.

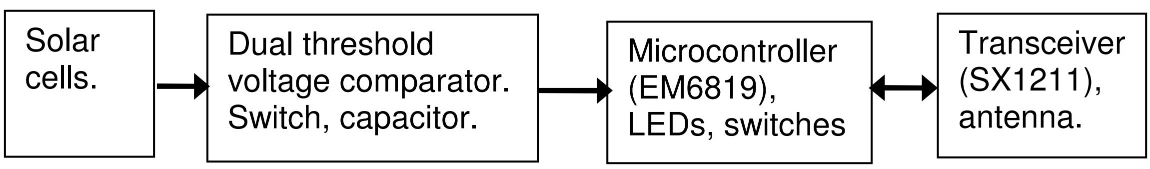


Figure 4: Using solar as energy source

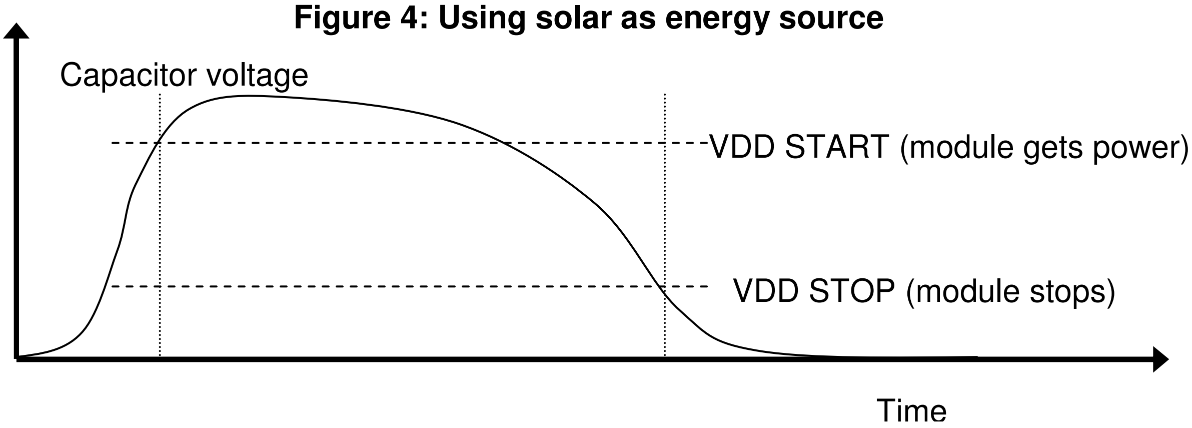
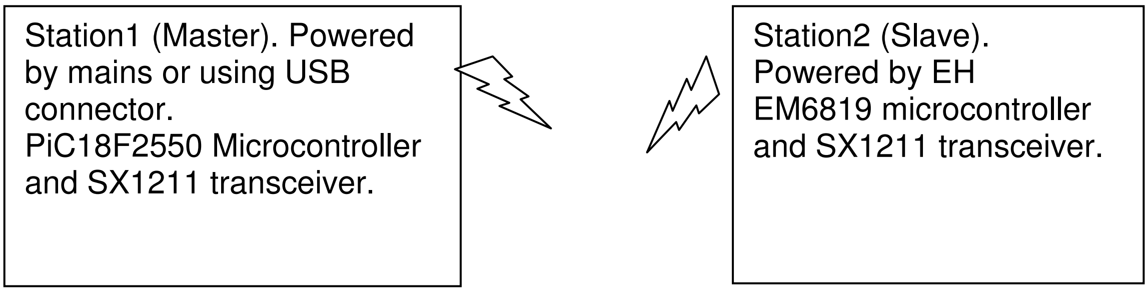


Figure 5: A voltage detector controls when the module is powered

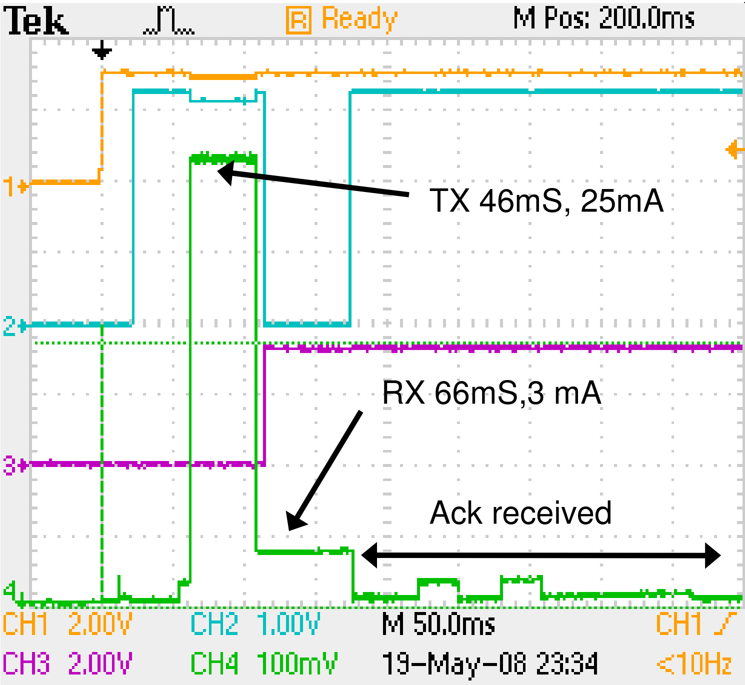
3 Tests and results

We conducted tests with several EH modules and low cost small size solar cells. In all cases, we wrote the needed programs to establish a bidirectional communication between 2 stations. The protocol overhead chosen for each EH was adapted to the energy available. For EH supplying several mJ, a protocol with a larger overhead and payload was used. For EH supplying tens of uJ, the overhead was reduced and the message simplified.
The first station served as coordinator. It was attached to a PC, and had sufficient power.
The second station was powered by the energy harvester, and included the EH, the EM6819 microcontroller and the SX1211 transceiver.
Upon a user action (pressing a switch or generating energy by activating the EH), a message was sent by the second station to the first. Upon reception of the message, the first station sent an acknowledgement message back.



3.1 Tests with EH1, EH2, EH3

These EH generate sufficient energy to send large packets of data at maximal transmit power, wait tens of milliseconds for an answer, and visually inform the user (with an LED) of the results of the communication. Tests with these EH gave the best results.
Test parameters: packets with 61 bytes payload, maximum transmit power, FSK, Manchester coding activated.



[1] Supply voltage

[2] Port pin of EM6912
[3] Port pin of EM6918

[4] Current consumption (micro + Transceiver)

The energy is enough to send data, receive an acknowledgment and inform the user (or resend). Tens of milliseconds can pass between the message and its acknowledgement.

Figure 6: Measurements for EH1

3.2 Tests with EH4 (ECO 100)

When activated, the EH4 generates less that 100 uJ of energy that can be used for the microcontroller and the transceiver. We found that this energy was just enough to send a short packet of data. With the SX1211, the energy was not enough to get an acknowledgement back. This was partly due to the time that the Master station needed to unload the message before sending the acknowledgment back. Some optimization of the programs is still needed here. It is however clear that the time between the message and the acknowledgement can only be in the order of a couple of milliseconds (see Figure 7).
Using another transceiver that integrates an automatic acknowledgement (AT86RF230), it was possible to send a 30 bytes payload and get the acknowledgment back (see Figure 8).

Test parameters with SX1211: 2 bytes payload, OOK 25Kb/s, Manchester mode activated, minimal transmission power. No automatic Acknowledgment from receiving station. Program not yet optimized. DC/DC converter not activated.

Test parameters with AT86RF230 (2.4 GHz) 30 Bytes payload sent at 250Kb/s, DSSS, maximum transmit power (+3dBm). Program optimized, support for automatic acknowledgement in sender and receiver. DC/DC converter activated.

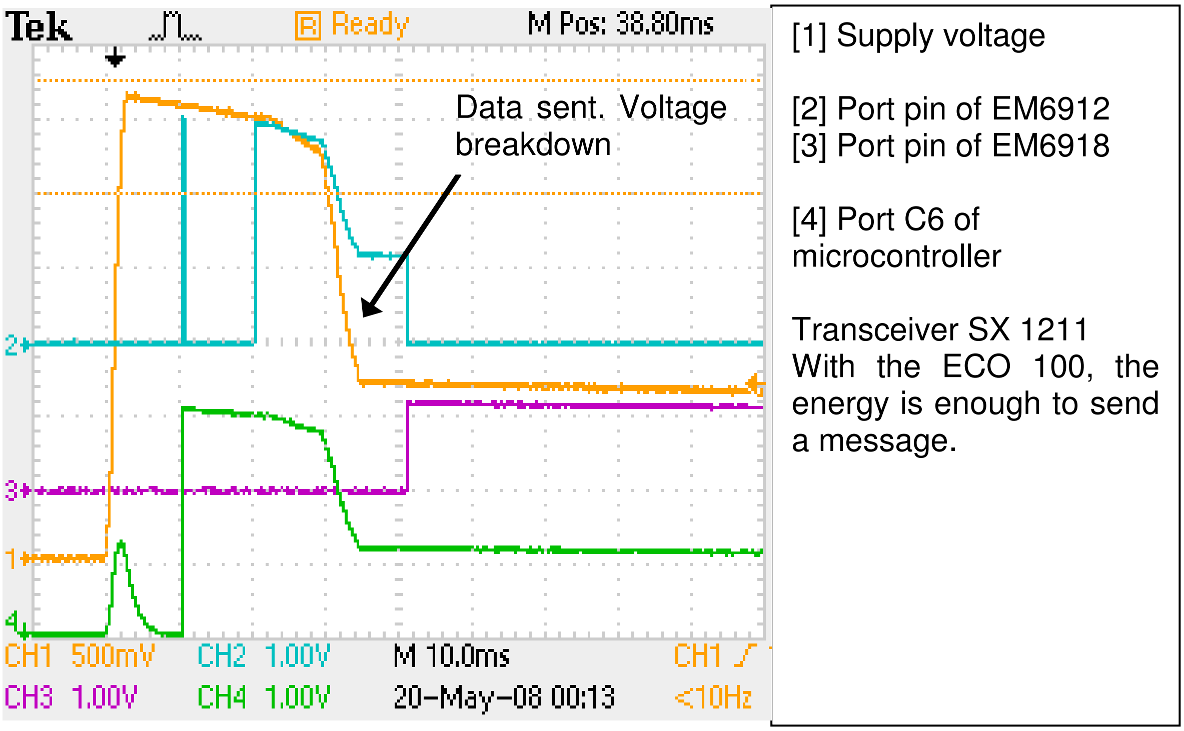


Figure 7: Measurements for EH4

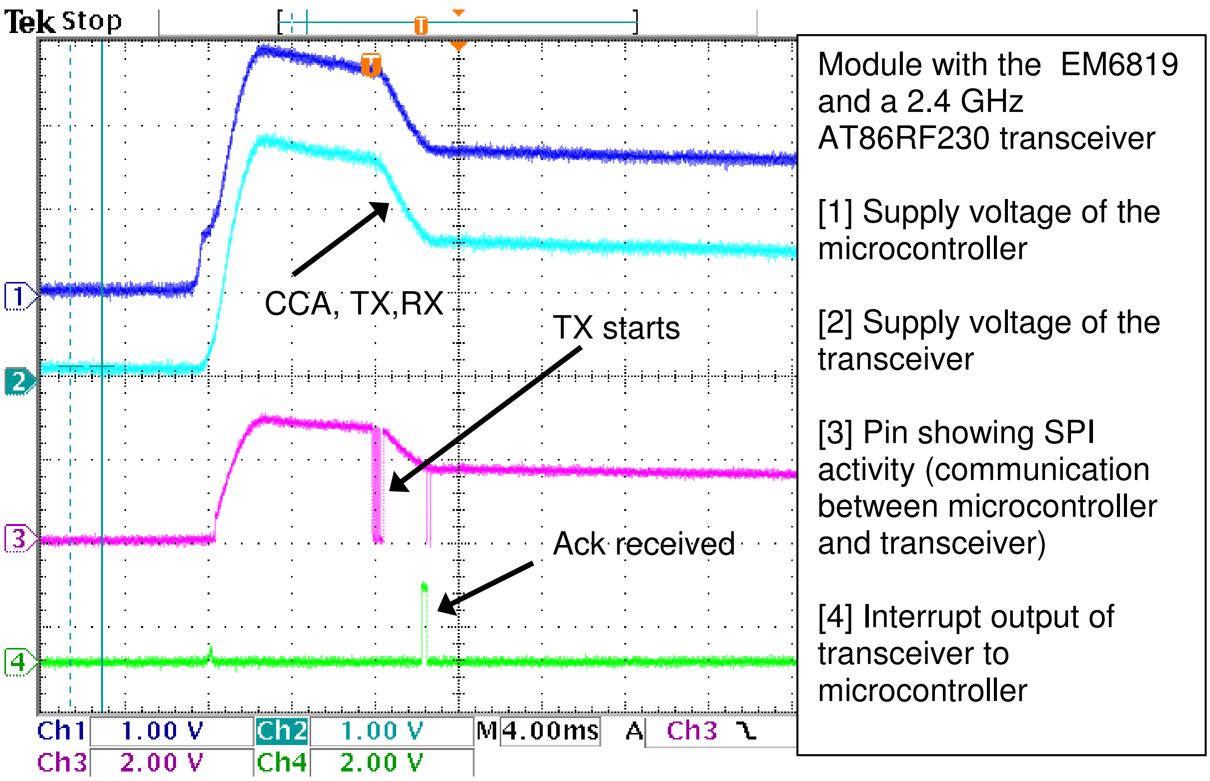


Figure 8: Use of transceiver featuring automatic acknowledgement

3.3 Tests with solar cells

The test with the solar cells showed also that it is possible to send data and get the acknowledgement, once the capacitor is properly charged. The important aspect here is the time needed to charge the capacitor. This time depends on the ambient light, and the power consumption of the dual threshold voltage comparator (a couple of uA in our design).
Test parameters: Maximal transmit power, 4 information bytes, FSK, Manchester coding on, 25Kb/s.

4 Conclusions and directions of future work

4.1 Conclusions

In this work, we have shown that it is possible, using the newest low power transceivers and microcontrollers to build reliable bidirectional communication systems powered by low cost energy harvesters. The reliability of the transmission does not need to be sacrificed. The use of a low power receiver such as the SX1211, allows in some cases the confirmation of the reception of the sent message (or a retransmission of the message). The trend towards better transceivers can also be seen in other ISM bands such as 2.4 GHz. The use of hardware to automatically generate acknowledgement simplifies the procedure.
The introduction of very low power microcontrollers and transceivers make it possible to introduce new features in wireless systems, enabling a new category of user friendly battery-less wireless products for the consumer market [7],[8],[11]. The same techniques and components can also be used to extend the battery life of systems that require batteries. Using on Chip programmable DC/DC converters and low power detection modules, a high enough voltage can be generated for transceivers that require 1.8 Volt or more.
We expect that more devices, requiring even less power will find their way to the market in the next years, which will accentuate the trends described above.

4.2 Future work

For future work we will follows 2 lines:
- Optimize the design (programs) with the SX1211 to allow a faster acknowledgement to be sent.
- Improve the efficiency of energy transfer between the load and the EH.

4.3 Thanks

We will like to express our thanks to the following firms that have enabled this work by supplying us with valuable components and information:
- EM Microelectronic Marin in Switzerland
- Semtech in Switzerland

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