# Accelerometer-based wireless remote control powered with harvested energy

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**Summary:**
**We present a design that can be used with a wireless battery-less switch in order to provide extra information to characterize the activity that should be performed. The low power design allows a microcontroller, an accelerometer and a radio to be powered using harvested energy. The data is then processed to yield the relevant information for the process. This device can be used for instance as an intuitive input element for dimming a light. It allows complex and expensive mechanical constructions to be replaced by reliable and low cost silicon.**

## Introduction

In the last years there have been many efforts to use energy harvesting in automation, especially in conjunction with low power wireless systems. Energy harvesting enables energy autonomy, which also leads to installation and maintenance costs reduction. A more energy friendly product might result from the use of harvesters.
However, it is not always easy to find one to one replacements for products that have been on the market for years and have “tuned” customers to certain expectations. One reason is that harvested energy is not always sufficient to allow the implementation of certain user-friendly features. This difference can, in certain circumstances, influence the acceptability of a product.
In this work we are concerned with remote controls used for dimming or for other applications in automation. In these products it is not easy to replace the battery (or mains) with energy harvesting and at the same time keep the simplicity of use. It is relatively straightforward to fit an off/on switch with an electromechanical or piezo harvester in order to send on/off or toggle information to control a light or a motor. There are several examples of such products [6,7,8]. Generating different levels with the same harvesters in order to mirror the activity of a dimmer is more difficult.
In a battery or mains powered dimmer, the microprocessor can regularly pole the position control sensor and initiate communications as often as necessary. This makes a visual (or audio) control by the user easy and allows a very simple and intuitive user interface. The same level of comfort for the user cannot be easily achieved if the energy source is intermittent. The harvester generates energy upon a mechanical action, but just for a short time. The energy available will hardly be enough to allow the continuous change, polling and setting of the dimmer level.
As a result, complex and expensive mechanisms have been suggested to allow the use of energy harvesting in remote controls [11].
In this work, we describe an easy and low cost way to achieve acceptable comfort while using intermittent or continuous generators as energy sources for the remote control.
The method described is protected by a patent [12]

This work builds on low power projects presented at previous conferences where similar systems were used to read sensors and forward the results. The reader is therefore advised to refer to those early works [3,4,13,15].

## 1. The principle

An accelerometer is at the heart of the system. Thanks to universal use and mass production, such devices are now low power and low cost products.
We take advantage of the gravity to allow the detection of a relative angular position of the sensor. That information which is related to the level of activity the user wishes to have is sent to the process controller.
This use of the gravity will in certain cases reduce the number of steps required by the user, making the use of the system more comfortable. Thanks to its small size, an accelerometer can easily be integrated in a switch. The same switch could be coupled with an electro dynamic harvester, a piezo harvester. Harvesters such as Seebeck elements or a solar cell can also be used as power sources. Once enough energy is available (say the user activate the harvester), the angular position is read and wirelessly sent to a receiver.
Such a system can be mounted on a wall or freely held by the user.
In the case of a wall, a rotation mechanism coupled with a push activity will allow the user to send a certain value to the control process.
In the case where the remote is freely held in hands, holding the remote in a certain way and pressing the switch will allow an intuitive control by sending the actual angular position value to the control process. The body temperature (hand) can also be used to generate some energy. Several applications models are possible using this concept

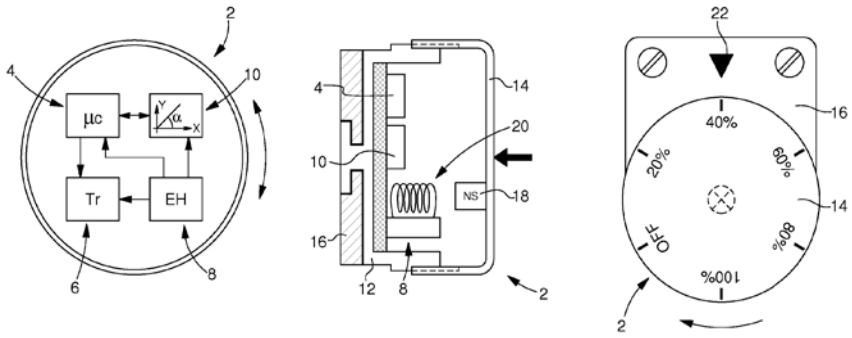



**Figure 1**: A possible application with an electro-dynamic harvester. Some marked positions help the user to choose the correct angular position before energizing the system by mechanical activity.

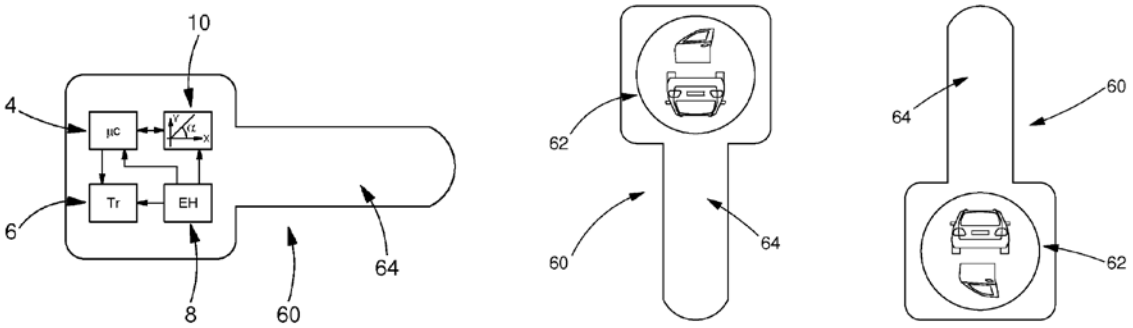



**Figure 2:** Hand held remote control. Activities can be selected according to the way the remote control is held

## 2. The design

Several demonstrators were built to prove the concept. One used a proprietary wireless system for communication and was powered using an electro-dynamic harvester. The second demonstrator used Ble (Bluetooth Low Energy) for communication and was powered by RF energy.

### 2.1. Hardware

Figure 3 shows a general block diagram of the demonstrators.
When there is enough energy, the XYZ values of the accelerometer are read and sent. A Dual ported NFC memory can be used to make some configuration via a smart phone. The harvester can be of continuous or intermittent type.

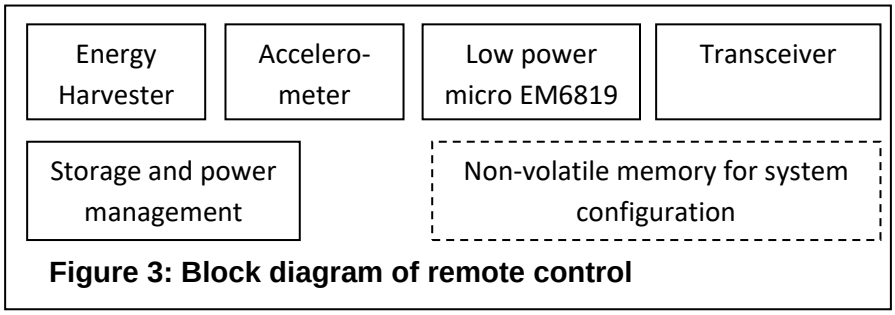



**Figure 3: Block diagram of remote control**

In order to minimize energy needs, low power components were selected.

**EM9301 [5]**
The EM9301 is used in this application to transmit Ble radio frames to host stations.
It is a single-mode Master/Slave controller, optimized for low voltage and low energy systems such as wireless sensors, wireless remote controls and wireless monitoring. With operating supply voltage as low as 0.8V, the circuit allows applications to take advantage of a wide range of common single-cell batteries or of energy harvesters such as solar cells, piezo-electric and electro-magnetic elements.

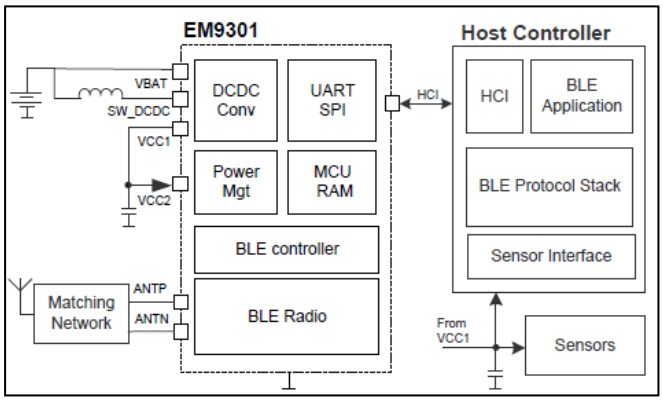



**Figure 4: EM9301-based system**

The output power can be programmed between -20dBm and +4 dBm. The device typically needs 14.5 mA in active mode (radio on).

**EM6819 [14]**
This microcontroller is based on the 8-bit CoolRISC CPU. It can start as low as 0.9 volt, and consumes around 140µA @ 1MIPS, 3 volts. In this application, it reads the accelerometer and controls the radio. Its low energy timer can also be used to schedule events.

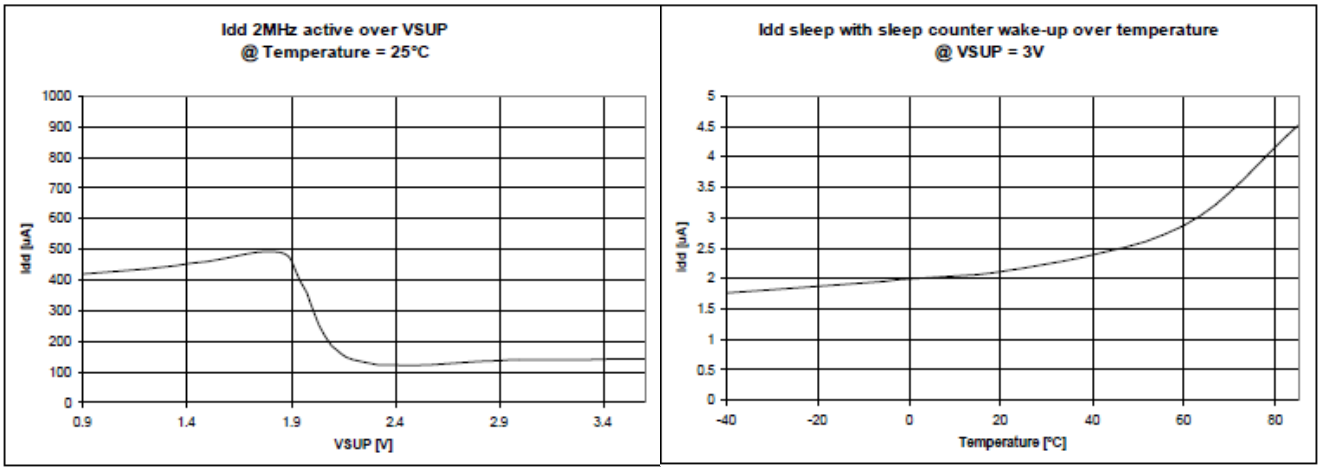



**Figure 5: current consumption of the microcontroller**

**Proprietary transceiver**

We have also used a proprietary protocol for the remote control. The use of such a protocol allows further optimisation in energy and costs, which may be more suitable for certain class of harvesters. The downside is that there is no compatibility with existing standards.

**Accelerometer [10]**

There are several accelerometers on the market that could be used in this application.
We used the BMA250 device from Bosch Sensortec
It is a Digital, tri-axial acceleration sensor with intelligent on-chip motion-triggered interrupt controller. It sports SPI and I2C serial interfaces and 2 interrupt outputs that can be used to alert a microcontroller on certain events. The voltage and energy consumption fit the power budget of the demonstrators that were built in this work.

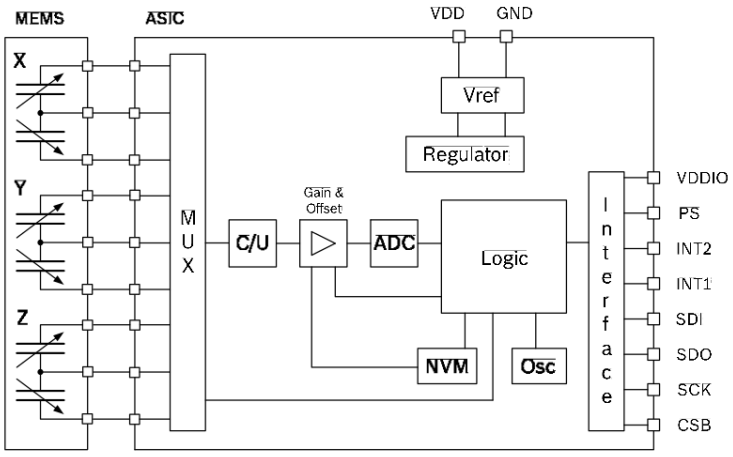



**Figure 6:** Block diagram of the Bosch Sensortec BMA250

**Power management** and storage

This block is responsible for making sure that enough energy is available before the system is started. It also protects the electronics against voltages that are too high. A capacitor is used as low cost energy storage element. It should be chosen to keep leakages low. A good combination with software and power management could even

allow the systems to scan the accelerometer several times and collect enough data to allow a dynamic analysis, paving the way to a more sophisticated intuitive control.

**Other**

A dual ported RFID device can be used In order to customise the system and/or to set some communication parameters. In the case of an NFC device, a smart phone with the passing APP can be used for configuration. When the system starts, the dual ported memory can be read by the microcontroller and values used for different settings.

### 2.2. Communication

Wireless communication can be done with different protocols. Proprietary, Ble, ZigBee, we used a proprietary system for intermittent harvesters and Ble for RF, seebeck or solar harvesters.

With proprietary protocols, the receiver and sender were set to work on the same channel and remained there. This allowed working with one wireless frame, thus reducing the energy needs.

Ble was used in broadcast mode, with data included in ADV frames.

Basically, Ble allows data exchange to take place in “connected” mode or in special ADV mode. In the first method, a connection needs first to be established (the 2 parties “meet” and exchange vital information). This is done using one of the 3 ADV channels. After that, the exchange of data takes place using a data channel.

In the case of the application considered, a peer to peer communication is not really necessary. The data should be “broadcasted” for anyone that needs them. Propagating data using the ADV has the added advantage of requiring just one broadcast message, which also helps to keep the communication short and limit energy and computing resources.

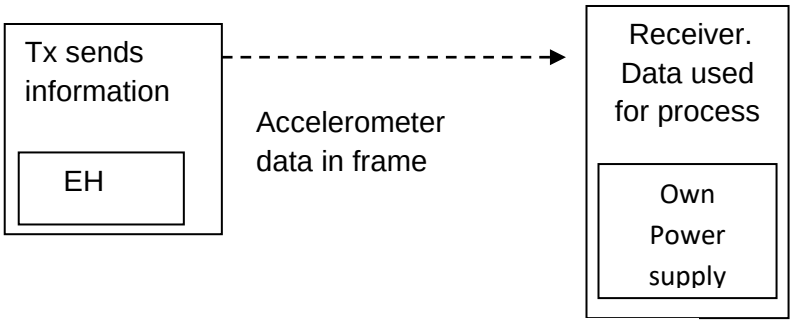



**Figure 7: Advertiser of accelerometer data and process controller**

The elements required in the frame while sending data in advertising mode are shown in Table 1. It is possible to use only 1 channel. This will reduce the energy needs. However, it is preferable to send the data on all 3 ADV channels to facilitate the reception by the host that scans ADV channels one after the other. This is also good since many public places have several wireless systems that are active (WLAN). More information about the frame format and the timings to meet can be found in the Ble specifications [1,2].

| | lsb | | | msb |
|---|---|---|---|---|
| LL packet format | Preamble (1 octet) | Access address (4 octets) | PDU (2 to 39 octets) | CRC (3 octets) |

**Table 1: Elements needed in the Ble sent frame**

The useful information that one would like to broadcast can be packed in the AVD Data field. The packet sent is formatted as shown in Table 2.

| Format of frame used to send data | | | | | |
|---|---|---|---|---|---|
| Preamble | Access adr. | Header | ADVA | ADV data | CRC |
| 1 octet | 4 octets (0x8E89BED6) | 2 octets | 6 octets | Accelerometer data (e.g 16 bytes) | 3 octets |

**Table 2: Final format of the frame**

### 2.3. Software

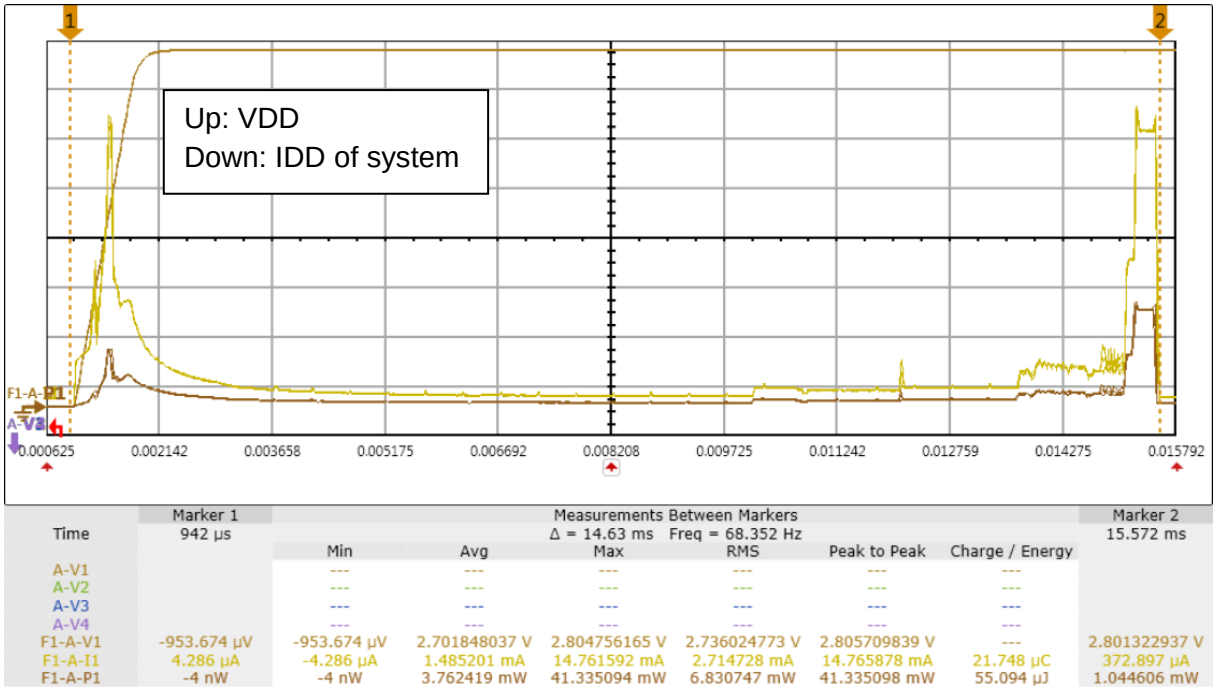
The software is written to allow an efficient use of energy. It starts and stops different blocks at the right time, in order to make use of sleep and power down modes as often as possible. It should also allow the system to recover/restart properly in case there are energy problem.
The software will control the selection of channels and the timings to respect the specifications. For example, in case only 1 ADV channel is chosen to send data, it should be ensured that minimal time between ADV events is respected.

## 3. Tests and results

A demonstrator allowing a lamp to be dimmed with a battery-less remote control was built and successfully tested. The depth of dimming depends on the position the user holding the remote control. The user activates an electro-dynamic harvester every time he holds the remote controller in the appropriate position.
The second demonstrator uses RF energy from a dedicated 868 MHz RF source to power the remote control. In the same way as above, the angular position is read and sent. The frames are Ble compatible and could be observed on a sniffer.

### 3.1. Energy profile

Figure 8 shows the dynamic energy profile of the remote control.
When the system starts, the decoupling capacitors are first charged, leading to a peak in the current. The microcontroller and the radio which are directly connected to VDD also start up. After the POR, the EM6819 microcontroller boots up, initialises the radio (channel, output power …etc.) powers up and initialises the accelerometer. It then reads the accelerometer data, write them in the radio and gives the transmit order. If more than 1 channel is used, the order to select another channel is given and data sent. The communication between the microcontroller and the radio is done over the HCI interface.




| | Marker 1 | Measurements Between Markers | | | | | | Marker 2 |
|---|---|---|---|---|---|---|---|---|
| Time | 942 µs | Δ = 14.63 ms Freq = 68.352 Hz | | | | | | 15.572 ms |
| | | Min | Avg | Max | RMS | Peak to Peak | Charge / Energy | |
| A-V1 | | --- | --- | --- | --- | --- | --- | |
| A-V2 | | --- | --- | --- | --- | --- | --- | |
| A-V3 | | --- | --- | --- | --- | --- | --- | |
| A-V4 | | --- | --- | --- | --- | --- | --- | |
| F1-A-V1 | -953.674 µV | -953.674 µV | 2.701848037 V | 2.804756165 V | 2.736024773 V | 2.805709839 V | --- | 2.801322937 V |
| F1-A-I1 | 4.286 µA | -4.286 µA | 1.485201 mA | 14.761592 mA | 2.714728 mA | 14.765878 mA | 21.748 µC | 372.897 µA |
| F1-A-P1 | -4 nW | -4 nW | 3.762419 mW | 41.335094 mW | 6.830747 mW | 41.335098 mW | 55.094 µJ | 1.044606 mW |

**Figure 8: At VDD= 2.8 volts, 0dBm, data sent on 3 channels**
**Total energy ~ 55 µJ**

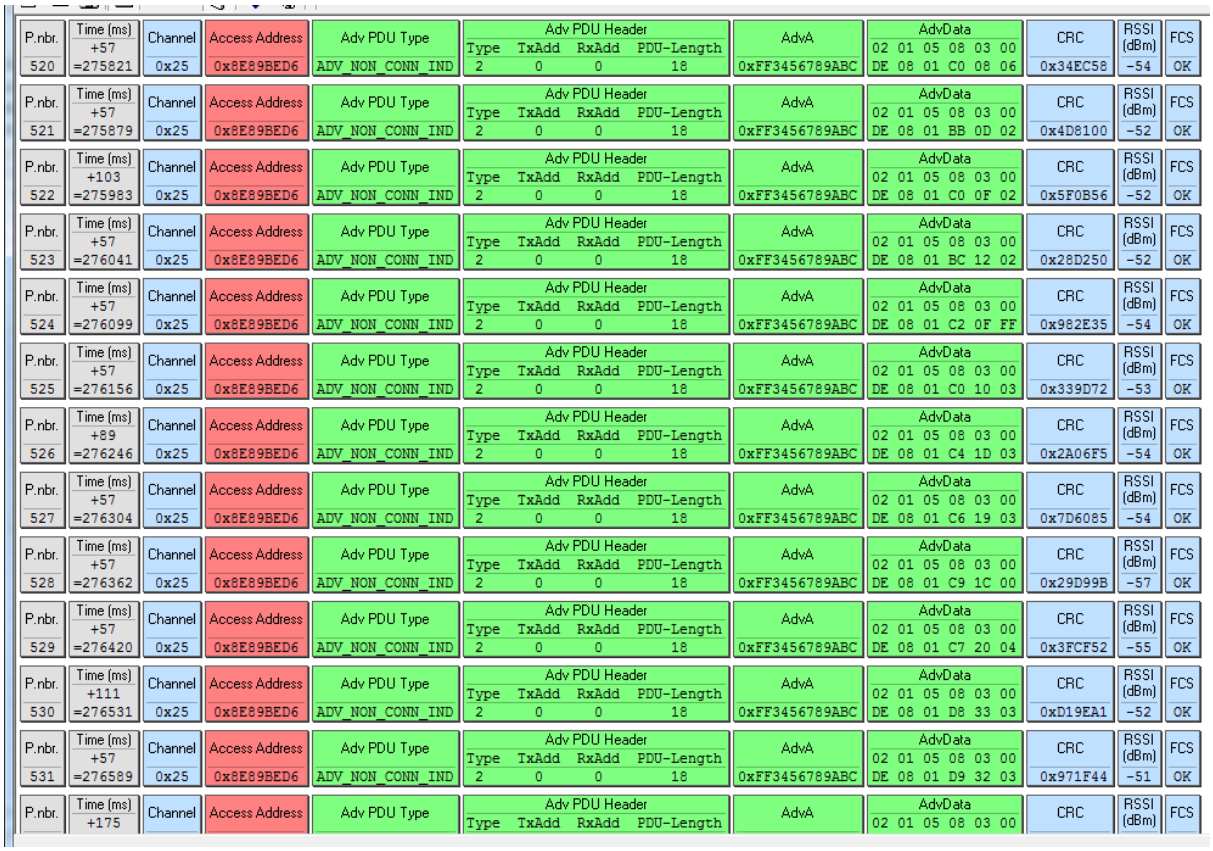
### 3.2. Receiving data on advertisement channels

Data is normally received by a Ble scanner. In principle, it will scan all 3 Ble ADV channels, one after the other, looking for devices that are broadcasting.

If the scanner is exactly on the same channel as the tag when it is advertising, and in the proper range, the ADV signal will be seen, and the scanner can read the data, interpret them and use them for the control process.

If the scanner and the tag are not on the same channel, or too far away from one another, the frames will not be seen.

By broadcasting on all 3 channels, there is a higher probability for scanner and tag to find each other (if they are within range).



| P.nbr. | Time (ms) | Channel | Access Address | Adv PDU Type | Adv PDU Header | AdvA | AdvData | CRC | RSSI (dBm) | FCS |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Type TxAdd RxAdd PDU-Length | | | | | |
| 520 | +57 =275821 | 0x25 | 0x8E89BED6 | ADV_NON_CONN_IND | 2 0 0 18 | 0xFF3456789ABC | 02 01 05 08 03 00 DE 08 01 C0 08 06 | 0x34EC58 | -54 | OK |
| 521 | +57 =275879 | 0x25 | 0x8E89BED6 | ADV_NON_CONN_IND | 2 0 0 18 | 0xFF3456789ABC | 02 01 05 08 03 00 DE 08 01 BB 0D 02 | 0x4D8100 | -52 | OK |
| 522 | +103 =275983 | 0x25 | 0x8E89BED6 | ADV_NON_CONN_IND | 2 0 0 18 | 0xFF3456789ABC | 02 01 05 08 03 00 DE 08 01 C0 0F 02 | 0x5F0B56 | -52 | OK |
| 523 | +57 =276041 | 0x25 | 0x8E89BED6 | ADV_NON_CONN_IND | 2 0 0 18 | 0xFF3456789ABC | 02 01 05 08 03 00 DE 08 01 BC 12 02 | 0x28D250 | -52 | OK |
| 524 | +57 =276099 | 0x25 | 0x8E89BED6 | ADV_NON_CONN_IND | 2 0 0 18 | 0xFF3456789ABC | 02 01 05 08 03 00 DE 08 01 C2 0F FF | 0x982E35 | -54 | OK |
| 525 | +57 =276156 | 0x25 | 0x8E89BED6 | ADV_NON_CONN_IND | 2 0 0 18 | 0xFF3456789ABC | 02 01 05 08 03 00 DE 08 01 C0 10 03 | 0x339D72 | -53 | OK |
| 526 | +89 =276246 | 0x25 | 0x8E89BED6 | ADV_NON_CONN_IND | 2 0 0 18 | 0xFF3456789ABC | 02 01 05 08 03 00 DE 08 01 C4 1D 03 | 0x2A06F5 | -54 | OK |
| 527 | +57 =276304 | 0x25 | 0x8E89BED6 | ADV_NON_CONN_IND | 2 0 0 18 | 0xFF3456789ABC | 02 01 05 08 03 00 DE 08 01 C6 19 03 | 0x7D6085 | -54 | OK |
| 528 | +57 =276362 | 0x25 | 0x8E89BED6 | ADV_NON_CONN_IND | 2 0 0 18 | 0xFF3456789ABC | 02 01 05 08 03 00 DE 08 01 C9 1C 00 | 0x29D99B | -57 | OK |
| 529 | +57 =276420 | 0x25 | 0x8E89BED6 | ADV_NON_CONN_IND | 2 0 0 18 | 0xFF3456789ABC | 02 01 05 08 03 00 DE 08 01 C7 20 04 | 0x3FCF52 | -55 | OK |
| 530 | +111 =276531 | 0x25 | 0x8E89BED6 | ADV_NON_CONN_IND | 2 0 0 18 | 0xFF3456789ABC | 02 01 05 08 03 00 DE 08 01 D8 33 03 | 0xD19EA1 | -52 | OK |
| 531 | +57 =276589 | 0x25 | 0x8E89BED6 | ADV_NON_CONN_IND | 2 0 0 18 | 0xFF3456789ABC | 02 01 05 08 03 00 DE 08 01 D9 32 03 | 0x971F44 | -51 | OK |
| | +175 | | | | | | | | | |

**Figure 9: Frame sent as seen by the sniffer**

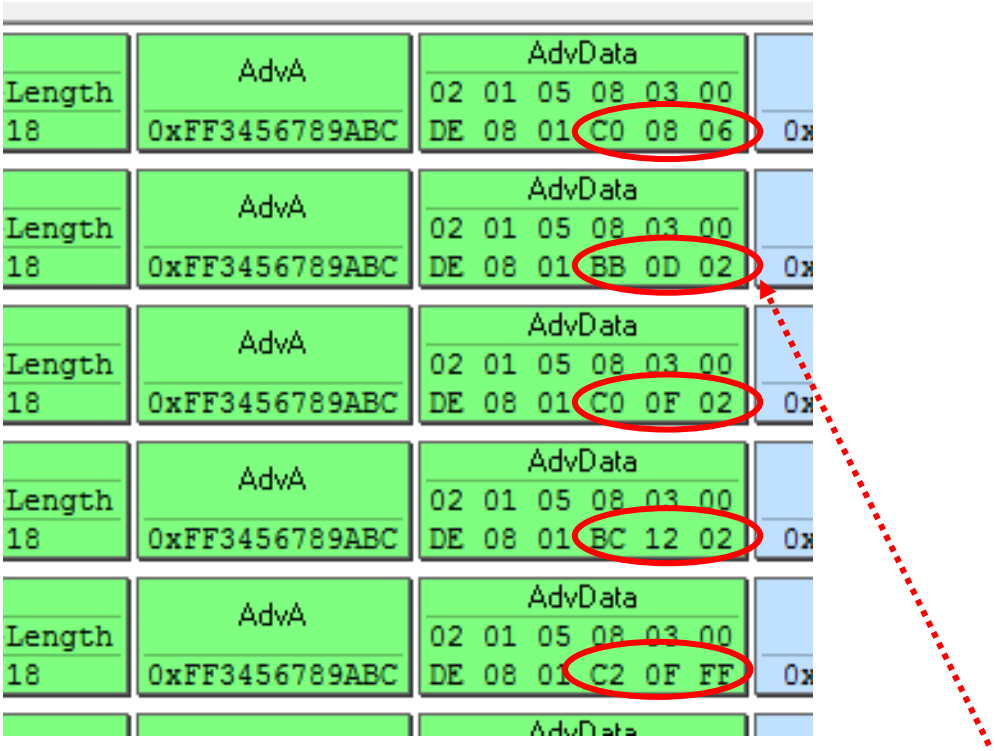



**Figure 10 : Data sent by tags was captured using a sniffer. The field "AdvData" shows accelerometer data in hexadecimal (accelerometer is moved).**

## Conclusion

Accelerometers can be used in conjunction with different types of energy harvesters and the appropriate transceivers to deliver information based on the angular position. This data can be generated by intuitive actions of the user, allowing user friendly and battery-less remote control.

## Acknowledgements

We wish to express our thanks to the following firms for their help and support:

- EM Microelectronic Marin, Switzerland for providing microcontrollers and Ble radios

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