Comparing the Energy Requirements of Bluetooth Smart Devices (November 2018)

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***Abstract*— A very important aspect of low-power system design is the proper choice of components. In the case of Wireless Embedded Systems that use Bluetooth Smart, one should make sure that the consumption of the load fits the energy provided. This is especially needed when battery life is an important feature of a product or when energy harvesting is used to power the device. There are several Bluetooth smart solutions on the market, all claiming to be low-power. Studying the datasheets is time consuming and only delivers partial information, sometimes difficult to interpret and to use for comparison or design. We have analysed the energy requirements of some Bluetooth Smart devices that are on the market, particularly paying attention to recent SoCs (year 2018). We present results of the measurements of important parameters that need to be considered when designing for low-power. Those results are deduced from dynamic power profiles of basic use cases needed to build more sophisticated applications. We explain the methodology behind our measurements and how the results can be used to compare devices and to predict energy requirements. The work was carried out in 2018. It is the third time we have done the comparison, at interval of about 2 years.**

Keywords—Ble; Bluetooth Smart; microcontroller; connection; advertisement; sleep mode; low-power; energy harvesting

I. About this third comparison work

There are many similarities between this report and the last 2 versions (2014, 2016) [1,2]. The arguments and explanations related to low-power are basically the same. We have therefore reproduced them, making updates where necessary. There are devices that were analysed in 2014 or 2016 and that are still on the market. Some have been included here, others not. The reader is advised to check the previous reports if interested, but exercise caution because of possible firmware updates and minor differences in the test methodologies. There are also cases where we could not yet do proper measurements. Therefore, there is missing information in this document, especially where answers from manufactures are still pending or crucial data is needed to carry out the measurement. Updates are continually made, so the reader is advised to check our web site or contact us.

II. Introduction

The proliferation of smart phones, tablets, PCs equipped with Bluetooth interfaces has opened new ways of wirelessly communicating with small embedded systems. Host devices with Bluetooth Smart Ready capability can connect to sensors with Bluetooth Smart features in a range of tens of meters, access the information and display it or use it in other processes. Recent extensions to the Bluetooth specifications (5.x) [3] add a host of new features, including an increase of the communication range and localisation. These further strengthen the dominant position of Bluetooth in the Low Data Rate space. The captured data can also be sent to other stations using the long-range communication features available on most smart phones or tablets. Sensors or other peripherals can address various needs such as the monitoring of environmental parameters, indoor navigation …etc. To be convenient in use and low-cost in maintenance, transceivers should consume as less energy as possible. Reducing the amount of energy required by the sensing system is basically a low-power design issue. The proper selection of the Bluetooth Smart radio, microcontroller and software stack is a central aspect to the design. Bluetooth Smart is also known as Bluetooth low energy (Ble).

There are several solutions on the market, with various claims about power consumption. It is not easy for application engineers to verify those claims or derive them from the datasheets that are given by the module or chip manufacturers. It is our intention to offer some help through this work. We have measured the energy consumption of several of the Bluetooth Smart solutions that can be found on the market today. We have looked at the important phases of the communication and what the datasheets say (and do not say). This paper will be helpful to application engineers in their quest of an appropriate solution for their low-power application. It will also be helpful to chip or module manufacturers and those writing communication stacks, by showing aspects in their solutions that need improvements.

In what follows, we will shortly remind the reader of the importance of controlling energy consumption. We will then discuss the critical energy phases of the communication process in Bluetooth Smart. We will list the devices we have tested. Finally, we will present and explain the power consumption measurements made and show the results in form of power profiles and tables.

III. Motivation

There are several reasons to care about the energy consumption of Bluetooth Smart solutions.

- Devices should be used for a long time without the user having to change batteries. This leads to low maintenance costs.
- Devices that do not need (frequent) battery change give more options as to the place where they can be installed and used.
- The less energy is required, the smaller a product can be, since small batteries can be used. This might also lead to lower cost for the end product.
- It is easier to use energy harvesting if the energy requirements of the target solution are low. This helps implement energy autonomous systems. A key issue as the number of connected devices grows.
- Reducing the amount of batteries needed is a good thing for the environment.
- From a marketing point of view, it is of course important to be able to say that one's solution is low-power.

In this work, we have sought to present a picture of the energy requirements that says more than the information that can be found in datasheets or application notes from manufacturers. However, it is difficult to take into account all the parameters that can influence the energy requirements. Obviously, we do not cover all the Bluetooth Smart solutions that exist, although we tried to get as many devices as possible. The solutions discussed in this document reflect the normal time evolution of the standard and the devices that address the Bluetooth Smart market.

We are not aware of any previous comparison of the energy consumption of Bluetooth Smart solutions on this scale, except the works we presented in 2014 [1] and 2016 [2].

In this new work, we have added a test with an extra-long interval between "Keep Alive" events (4 seconds) to deal with cases where the application allows the transceiver to sleep for a long time. We concentrated on devices that fulfill the 4.0, 4.1, 4.2 specifications. In a future work we will specifically look at devices that cover the 5.0 release.

IV. A short reminder of the way BLE works

In order to interpret some of the measurements in this document, a reminder of the basic principles of Bluetooth Smart is necessary. For a deeper understanding, the references or other appropriate documents can be consulted.

Bluetooth Smart operates in the 2.4 GHz ISM band, where several other radios are active (WLAN, 802.15.4, … etc.). Because many devices operate in that band, there are interference and collision issues. At 1 Mbit/s (versions 4.0, 4.1, 4.2), the raw data rate of Bluetooth Smart is high compared to that of other Wireless Personal Area Networks (WPAN) protocols. This helps keep frames short and reduce energy needs but has a negative impact on the range.

Frames are tens to hundreds of microseconds long (a frame is 10 octets to 47 octets long in total), which helps reduce collisions but increases the proportion of the overhead with respect to the whole frame. Longer frames are possible with the 4.2 specifications and the new 5.x protocols. There is no mandatory "listen before talk" process, which increases the likelihood of collisions. Retransmissions due to loss of data generally lead to an increase of the energy consumption.

40 channels are available for communication, making it possible for connected parties to hop through channels in order to avoid interference. This is also very helpful when implementing concurrent communications in the same physical space.

Communicating parties can exchange data in connected mode or in non-connected mode.

- In a non-connected mode, information is exchanged using one or several of the 3 special channels known as advertisement channels. These have been chosen to reduce interference from other popular wireless protocols. Parameters needed to establish a connection are negotiated using the advertisement channels. This mode is also popular for beacon applications where simple advertisement of data is enough.
- The connected mode implies that communicating devices have agreed upon parameters needed for their connection. This agreement is made in the non-connected mode. Devices then use these parameters to meet at the right time and proper channel in order to exchange information. Data is transferred using some of the 37 channels attributed to data transfer. Proper timing is very important in this phase to avoid missing transmission windows.

The basic network topology is star. One node acts as a central node. It can connect to several other parties and exchange data in a time multiplexed way. Smartphones and other devices with enough resources will often act as central nodes, while sensors will assume a slave role. A master connected to several slaves exchanges information with them at agreed time points. Between those "rendez-vous", the slave can sleep (and save energy). Once connected to a master, a typical slave will wake up at the "appointed time", receive data from the master, send information to the master and then go back to sleep (or other activities).

Since slaves can spend long time intervals sleeping, the energy consumption in that state is very important. It can even be dominant in certain applications. Waking up on time (not too early and not too late) is also important. This places important constraints on how well the slave keeps time and how fast it wakes up. Accurate time keeping and fast wake-up are activities that require more energy.

Accurately maintaining the frequency (band) where the device communicates is also very important. Drifts will eventually lead to communication loss. Many radios have a way of calibrating their frequency generator, which may also cost energy. Depending on the design, calibration might have to be done regularly in order to mitigate the effects of temperature and the variations of some other component values.

V. Factors that affect energy consumption

There are different factors that affect the energy consumption. One should consider the individual parameters, but also remember that the different components work together. In the end, firmware and hardware in a specific application and environment will determine the costs and characteristics of the system, including the power consumption. Some of the important elements will now be listed.

- Start-up energy at power-on. When the device is powered up, internal and external capacitors are charged. Certain registers are initialized and some basic functions such as calibration may be performed. In the case of devices that run from RAM, the copying of code from a non-volatile memory should be taken into account. All these activities require energy. The use of software patches that are read at start-up also contributes to the increase of the start-up time and energy. Devices with a high start-up energy consumption are more demanding when a frequent restart from power-off is needed (for instance the case for applications powered by intermittent energy harvesters).
- Energy needed to transmit frames. This is related to the current in transmission mode (Tx current), including the transmit power. But that is not the only parameter. Before transmission, a certain number of activities are performed by the radio. These activities draw some energy. A dynamic power profile clearly shows what happens.
- Energy needed to receive a frame. This is related to the current in reception mode (Rx current).
- Energy in low power modes and leakages. This depends on the low-power mode implemented and how long the device remains in it. The lowest power modes often lead to less accuracy in time keeping. They also lead to longer wake-up times. A correct balance should be found between the frequency of operation and the power modes. Applications that span an important temperature range should consider the effect of temperature. Unfortunately, manufacturers do not always provide information about the effect of temperature on the low power current.
- Timing system, oscillators, PLL, type of clock references. Generally, a PLL system plays an important role in generating the right frequencies for communication. A crystal (or another accurate timing component) is used to provide a stable frequency reference. These elements need time and energy to start up and to stabilize. In connection mode, they are regularly switched on and off. Temperature variations or even ageing might lead to the frequent need to recalibrate the system, thus increasing the energy intake.
- The energy consumption of the microcontroller during the different application and communication phases should be taken into account when assessing the system's energy requirements. The part of the communication stack that is in the microcontroller should be implemented such as to avoid unnecessary activities.
- The voltage at which the system works obviously influences the system's energy. Most solutions on the market will work from 3.3 V down to 1.8 V. There are more and more devices that work down to 1 V. The user is well advised to consider the voltage need of all elements in the system. Appropriate DC/DC converters can be helpful. Their efficiency at different voltages and currents, the start-up constraints and their effect on the radio input stage (extra noise) should not be ignored. Several devices now have both a DC/DC converter and an LDO (on chip).
- The way the communication host (central node) works. In a simple case this relates to how fast the host sees the advertisement frames of a sensor and initiates the connection procedure. In a more complex case, the same host might react differently, depending on its work load. There are differences between hosts (manufacturers of smart phones have different priorities and use different operating systems). Therefore, the energy consumption when working with one host can be different to what is measured while working with another. Especially during the phases when connection parameters are negotiated. Some of these effects are documented in [7,8]
- The environment of use. As discussed earlier, temperature changes and electromagnetic interference can lead to extra activities that substantially increase the power consumption. A device that is portable (e.g. wearable devices) is likely to work in different temperature and electromagnetic environments. The receiver sensitivity can also be crucial, especially when signals are weak. Connection problems (due to poor receiver sensitivity) may lead to frequent reconnects, and thus increase the overall energy

consumption. Beware the resulting loss of data and user's frustration.

Many of the parameters listed above affect the energy consumption in phases which are important for the communication system and which have been measured in this work.

- Start-up energy (very important in case of broadcast. The system can quickly be switched on or off to minimize energy needs).
- Energy requirements in advertisement phase. This is important for beacons or sensors that simply beacon their data in ADV channels (e.g. ADV NONCONN IND). It is also important as the phase before the connection mode. Devices advertise their presence and listen to potential clients (e.g. ADV CONN IND)
- Energy needed in negotiation phase. An example is shown, but this has not been systematically measured in this work. There are too many variations, depending on the host that is used. Important information pertaining to this case can still be derived from the other measurements.
- Energy requirements in connected phase. This is related to the wake-up time and how early the device wakes up before the "rendez-vous", the received current (Rx), the transmit current (Tx window), the sleep energy.

VI. LIMITATIONS

The following restrictions should be kept in mind while reading/using this document:

We concentrated on the basic operations as found in Bluetooth Specifications (4.0, 4.1, 4.2). We tested a very limited number of devices per device type. This is therefore not representative as the devices could have been the best (or worst). The values measured are of course not the maximum or minimum.

Firmware used for the tests:

- In most cases, we used the software stacks provided by the manufacturer (if available). There are differences in the optimization level and quality of those stacks, which can seriously affect the energy requirements. It is therefore possible that some solutions could be improved by using better versions of the stack (as the product matures).
- In some cases, we discussed with the manufacturers in order to improve the firmware. We then used the improved versions for our measurements.
- There are also cases where we optimized the firmware on our own, in order to get the best possible results. This is only possible if we know enough about the device to carry out such a demanding task.

We welcome suggestions from manufacturers, especially if they have improved versions of the stacks that are "fit for use" by customers. It is also a purpose of this work to challenge manufacturers to bring out more appropriate (low-power) versions of their Bluetooth stacks.

Many of the devices listed and tested are new. Thus, they might still have hardware issues that need to be corrected on the ICs themselves.

Receiver sensitivity is important. Devices with poor receiver sensitivity might miss more frames, leading to repetition of messages and thus higher energy consumption. This factor is not taken into account in our measurements but can be found in datasheet of ICs and modules.

There are more devices on the market than we could test. In some cases, manufacturers were not willing to let us test their devices. There are also cases where the support was not forthcoming, making it difficult for us to get the best out of the device. The quality of the tools is also important. In some cases, we had to deal with difficult and sometimes unreliable tools. The information about the quality of the tools is not added here. But whenever possible, we made it clear to the manufacturer.

During the tests, changes related to parameters such as clock accuracy, POR level, charged capacitors, type of NV memory, etc. led to variations in the measurement results.

Measurements were carried out at room temperature. The reader should however be aware of the dependency of certain parameters with temperature. For instance, leakages, power-down current, on-chip oscillator frequency can vary and seriously impact the energy requirements.

VII. DISCLAIMER

VIII. SET UPS FOR MEASUREMENTS

A. *General set up*

Whenever possible, we have used kits from manufacturers, loaded with their own recommended software stack. In some instances, we have made small modifications to allow the energy to be measured properly (same packet length, removal of code for not needed peripherals such as accelerometers, etc.).

In order to measure voltage, current and power, we used the N6705B power analyser from Keysight [4,5]. This tool allows forcing a given voltage and measuring the dynamic profile of the current flowing through the Device Under Test (DUT). The instrument automatically selects the best range for the measurement. The energy required within a period chosen with 2 markers is computed and displayed.

Whenever possible, measurements were made at 3 V in order to have the same comparison voltage. That voltage was chosen because the typical battery targeted by applications is the CR2032, which starts around 3 V.

For all devices, we determined the lowest allowed voltage and made measurements there. It allows the user to see how low the device can work. That VDDmin is not characterised in terms of technology or temperature. We also made measurements between 3 V and VDDnin. Due to space, we cannot include all results in this paper.

For tests needing a connection, we used different sniffers. When appropriate, we also used an RF detector to verify timings.

B. What we measured

Start-up energy. This is the energy needed by the DUT (on the provided kit) when the system starts up from power off. This parameter is especially important if the system is regularly switched off and then restarted. It could be the case if one works in non-connected mode or with some intermittent energy harvesting sources. This parameter is less important in cases where the system is in connected mode or has enough energy to keep the contents of critical memory elements.

Advertisement energy. Energy needed for events in advertisement mode was measured. The system switches the transmitter on to send the ADV frames and turns the transmitter off. In the case of connectable ADV, the radio switches the receiver on to receive a potential answer or request from a scanner. This procedure is repeated 3 times, for the 3 ADV channels (37,38,39). The measurement therefore shows the current when the system is transmitting and when it is receiving. It shows the current between ADV activities and some of the consequences of clock timing on the energy.

In the case of non-connectable ADV, the receiver stays off. This is a scenario sometimes used to transfer data in ADV mode (e.g. broadcasting of sensor data).

The measurements were made with ADV frames of the same packet length (47 octets as total frame size). The ADV frames are always sent on all three advertising channels.

Measurements were made for 2 ADV event intervals: 100 ms and 1 s. This was done to observe the effects of different clocking schemes on the energy.

Since several devices now integrate a DC/DC converter, measurements over a long period (1 minute) were also made, and the average current consumption shown in tables. This helps integrate the activity of the converter and gives more realistic values.

Connection energy. As in the case of ADV, we measured the energy used by the system during a connection. The device receives an empty packet from the host and then sends an empty packet to the host. Between 2 connections, the device goes in a low power state. After a given time, it wakes up. The oscillator is started, and the device brought to the proper communication frequency (channel). Therefore, the energy requirement results from several states: The low power mode, the wake-up procedure (timers, PLL, oscillator), the reception and transmission.

In this case as well, averaging over 1 minute was used to give a better picture of the power consumption.

C. Other.

We did not systematically measure and report the energy requirements when the devices exchange connection parameters before they can establish a connection (negotiation phase).

All measurements were done using a Tx power of 0dBm, or as close as possible. We based this on the manufacturer's data and did not verify the output power. Where there are variations, these should be taken into consideration when interpreting the results.

IX. TESTED DEVICES AND LINKS TO DEVICE DESCRIPTIONS

Contrary to previous reports, we have included little data about the features of the devices that have been evaluated in this work. These can be derived from information given by the manufacturers' website (datasheets, application notes, …). The reader is also encouraged to talk with the competent person in the manufacturer's structure if there are uncertainties.

A. Special devices.

Certain devices mentioned in this document were only partially investigated.

- The icyTRX is an IP sold by CSEM and used in some commercial products. We have measured some test devices at low voltages (1.3 V, 1.0 V). Those devices were piloted by the EM6819 in order to allow measurements at low voltages. Measurements shown emulate a non-connectable advertisement.
  In the measurements, the device is powered directly with 1V or with 1.3 V (without DC/DC or LDO). This of course leads to higher values at 1.3 V than would be in a SOC. The leakages are not yet reduced to their nominal values, which also leads to higher consumption at intervals of 1000 ms (than is in reality). This will be corrected at a later date. The icyTRX IP is used in some SOC that are found on the market. 3 devices in this document use the icyTRX:
    - The EM9304 (see press releases of Swatch Group and CSEM) [10].
    - The Apollo2 Blue that integrates the EM9304 [9]
    - The RSL10 [11]
- The Apollo2 Blue is a device integrating the Apollo of Ambiq and the EM9304 of EM Microelectronic [9]. We made some limited measurements on that combination.

B. Links.

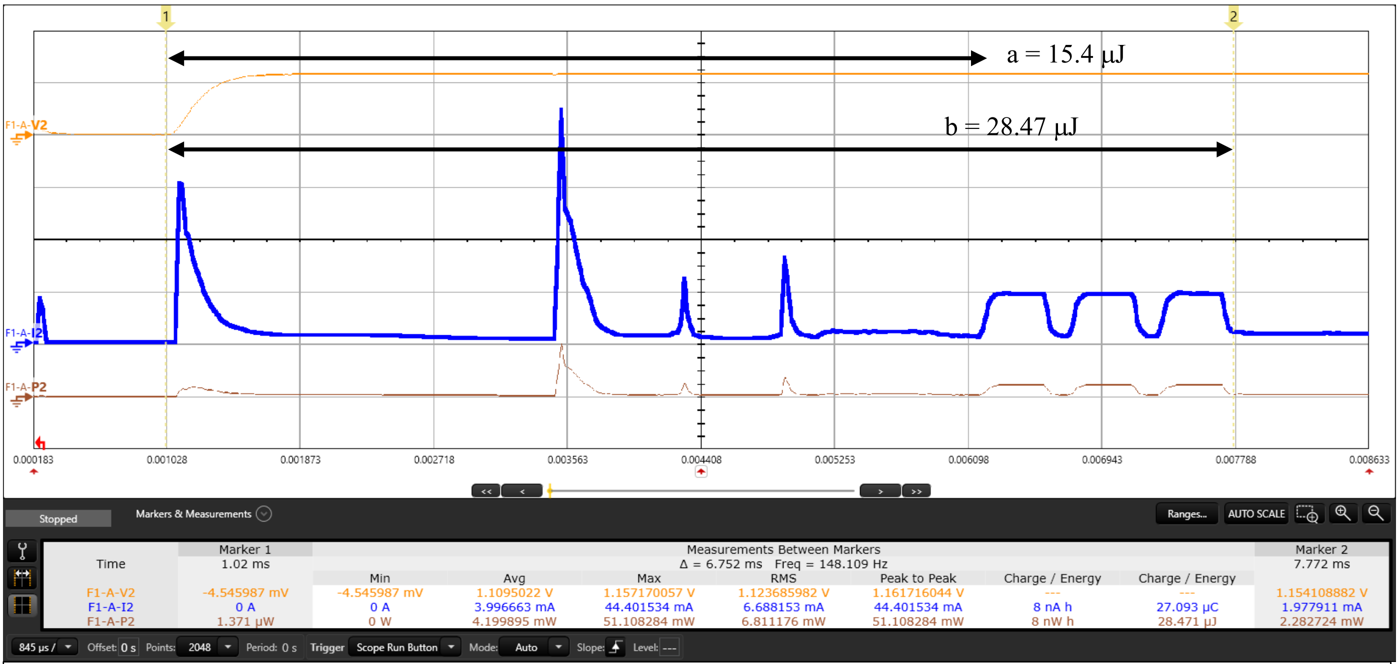
Device	Manufacturer	Information Link	Remarks
RSL10	On Semiconductor	http://m.onsemi.com/product?part=RSL10	This device can run from under 1.2 V The RSL10 integrates a power management that allows it to work between 1.18 V and 3.3 V. Below 1.4 V, the internal LDO is used. Above that, the DC/DC or LDO can be chosen. Therefore, all measurements below 1.4 V are with LDO, even if the device is set-up for DC/DC
DA14581	Dialog	https://www.dialog-semiconductor.com/products/connectivity/bluetooth-low-energy/smartbond-da14581	This is an OTP device. There are MCM variations with Flash memory
TC35678	Toshiba	https://toshiba.semicon-storage.com/eu/product/wireless-communication/bluetooth/tc35678.html	
QN9080	NXP	https://www.nxp.com/products/wireless/bluetooth-low-energy-ble/qn908x-ultra-low-power-ble-system-on-chip-solution:QN9080	The datasheet shows some of the lowest values in Tx and Rx mode. However, energy depends on several factors. In some cases, measurements at VDDmin gave very high values. This was reported to the manufacturer and no solution was available at the time of writing this report.
NRF52810	Nordic Semi	http://infocenter.nordicsemi.com/pdf/nRF52810_PS_v1.2.pdf	
NRF52840	Nordic Semi	http://infocenter.nordicsemi.com/pdf/nRF52840_PS_v1.0.pdf	
EM9304 Step-down version	EM Microelectronic	https://www.emmicroelectronic.com/product/standard-protocols/em9304	The step-down version and the step-up version are the same silicon. However, with different HW and boot configurations. It is not possible to switch from one configuration to the other on the fly. For that reason, we have 2 entries and named them SD (3 V to 1.8 V) and SU (below 1.5 V). The device has an OTP. The energy consumption sometimes shows small variations when a new program is programmed in the OTP
EM9304 step-up version	EM Microelectronic	https://www.emmicroelectronic.com/product/standard-protocols/em9304	
RL78/G1D	Renesas	https://www.renesas.com/eu/en/products/microcontrollers-microprocessors/rl78/rl78g1x/rl78g1d.html	
ATBTLC1000	Microchip (Atmel)	https://www.microchip.com/wwwproducts/en/ATBTLC1000-ZR	
PSoC6 CY8C6347BZI-BLD53	Cypress	http://www.cypress.com/part/cy8c6347bzi-bld53	
BGM113	SiLabs	https://www.silabs.com/products/wireless/bluetooth/bluetooth-low-energy-modules/bgm113-bluetooth-low-energy-module	
CC2652R	Texas Instruments	http://www.ti.com/product/cc2652r	
icyTRX	CSEM	https://www.csem.ch/Doc.aspx?id=41379	IP that is used in some SoCs. 1.3 V – 0.9 V transceiver
Apollo2 Blue	Ambiq	https://ambiqmicro.com/static/mcu/files/Apollo2_Blue_MCU_Data_Sheet_rev1p0.pdf	This is a combination of the Apollo2 and the EM9304 die.

X. RESULTS OF MEASUREMENTS

Results are shown below in form of dynamic power profiles and tables. At least one profile of each device is shown, which allows the user to derive the current consumption and see something of the “internal life” of the solution. Due to practical reasons, we could not include all the measurements in this report. The results of non-connectable mode (only ADV_NONCONN_IND) are shown first. Afterwards, the measurements in connectable mode (ADV_IND followed by a connection) are listed.

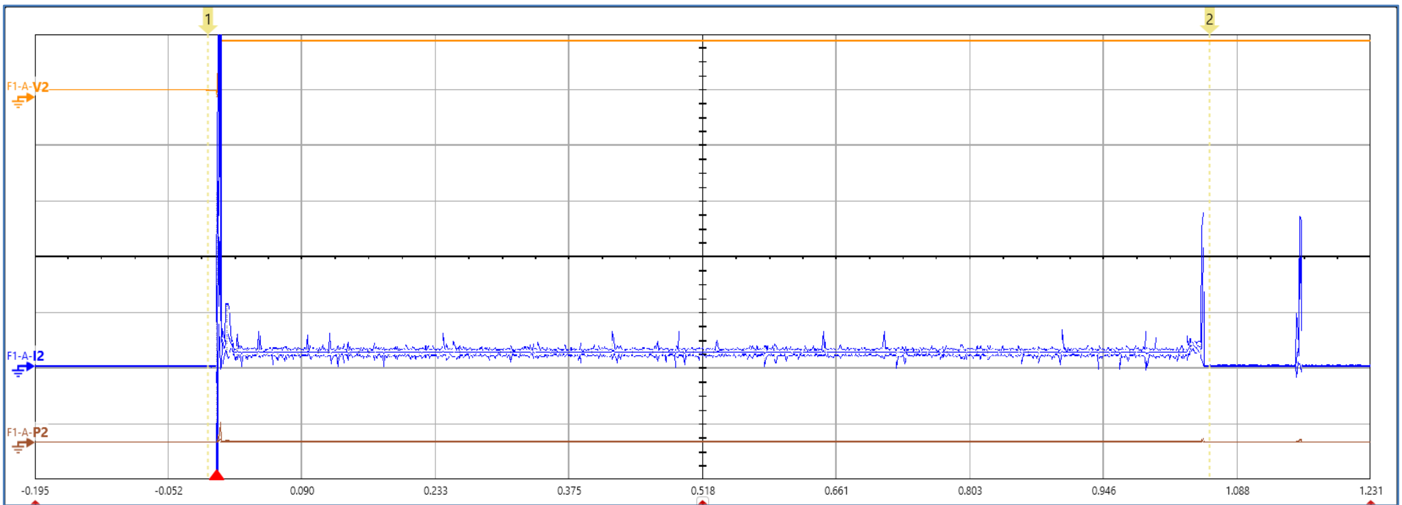
Start-up and advertisement

Some devices offer the advantage of choosing between different types of oscillators at start-up. This is good for the user as it gives more flexibility for the application. Use of a crystal in order to achieve better timing accuracy will often imply more energy than in cases where an internal RC oscillator is used, especially when a delay is built in in order to wait for the stabilization of the crystal oscillator. We indicate in the tables the options that have been used for the measurements.



Start-up of RLS10 followed by beaconing on 3 channels (with firmware optimised by ZHAW-InES)

Fig. 1. Energy at different times during Startup & ADV_NONCONN_IND (µJ)



Another Start-up of RLS10 followed by beaconing.
In a different configuration, the start-up can take more time and require more energy.
In the case above, more than 1 s and more than 1 mJ. The timing configuration and stack make more initialisations and wait for clocks to be stable.

Fig. 2. Long Startup & ADV_NONCONN_IND

TABLE I. ENERGY AND TIME REQUIRED AT START-UP (START-UP WITH FIRST ADV_NONCONN_IND, 3 V)

Devices	Parameters			
	Measurement Voltage(V)	***Start-up Time (ms)***	***Start-up Energy (µJ)***	***Remarks***
RSL10	3	32.40	91.28	DCDC on, LF RC
RSL10	3			DCDC off, LF RC
RSL10	3			DCDC on, LF XTAL
RSL10	3			DCDC off, LF XTAL
DA14581	3			Could not be measured with provided SW OTP, DCDC enabled, LF XTAL
TC35678	3	550.42	1323.22	DCDC on, LF XTAL
QN9080	3	94.24	421.04	DCDC on, LF XTAL
NRF52810	3	5.19	35.17	With some optimization of ZHAW-InES DCDC on, LF RC
NRF52840	3	454.80	142.46	DCDC on
NRF52840	3			DCDC off
EM9304 SD	3	14.14	71.56	DCDC on, LF RC 2.2uf VDD capacitor
RL78/G1D	3	96.06	650.03	DCDC on, LF On Chip OSC
RL78/G1D	3			DCDC off, LF On Chip OSC
ATBTLC1000	3			DCDC on, LF XTAL
PSoC6_revA	3	614.19	1395.93	DCDC on (0.9 V), LF XTAL
PSoC6_revD	3	579.70	1120.16	DCDC on (0.9 V), LF XTAL
BGM113	3	1065.01	13147.17	DCDC on, LF XTAL
CC2652R	3	96.41	734.13	DCDC on, LF XTAL
icyTRX	3			not possible (VDD max = 1.3 V)

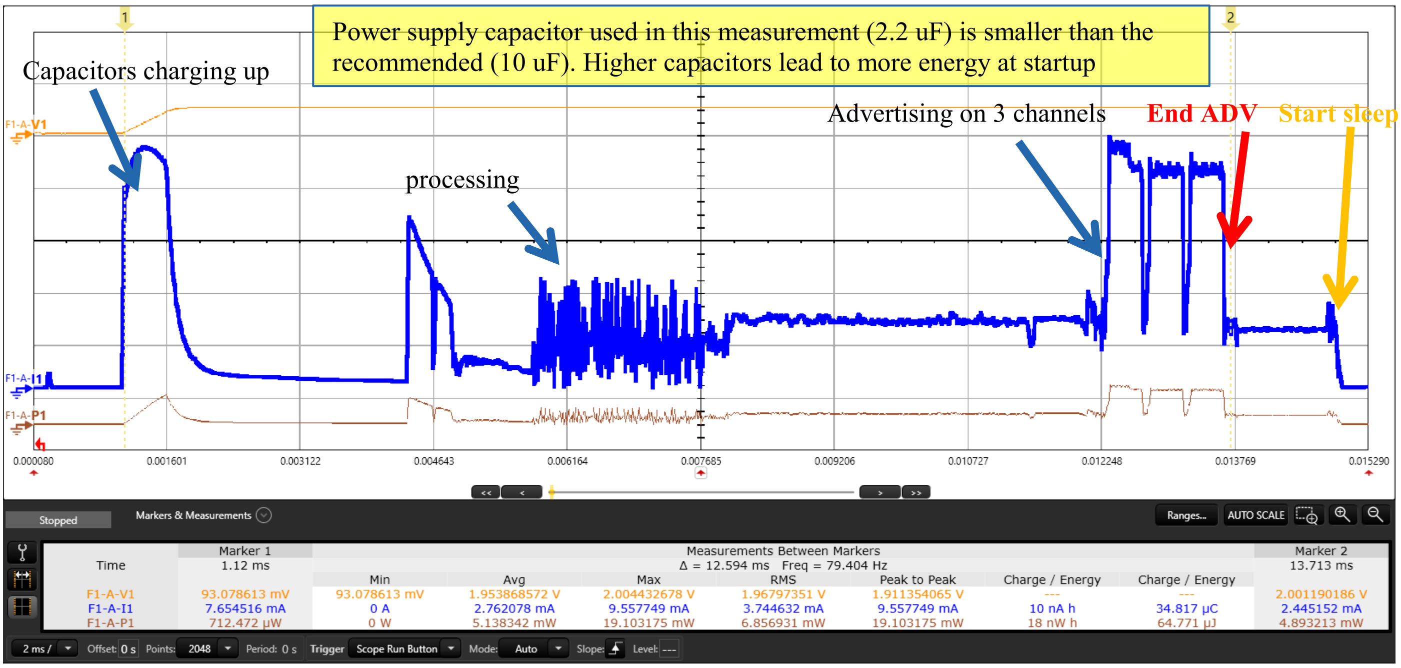


Fig. 3. EM9304 (@ 2 V). Start-up time/energy incl. ADV_NONCONN_IND 64.7µJ /12.6 ms (**end of ADV**) 70.3 µJ /14 ms (**until Start sleep**)

TABLE II. ENERGY AND TIME REQUIRED AT START-UP (START-UP WITH FIRST ADV_NONCONN_IND, MINIMAL VOLTAGE)

Devices	Parameters			
	Measurement Voltage(V)	***Start-up Time (ms)***	***Start-up Energy (µJ)***	***Remarks***
RSL10	1.12	32.85	67.20	Using stack of manufacturer. LDO on, LF RC
RSL10	1.12	6.70	28.47	Firmware optimized by ZHAW-InES
RSL10	1.12			LDO on, LF XTAL
RSL10	1.12			DCDC off, LF XTAL
DA14581	2.35			Could not be measured with provided SW OTP, DCDC enabled, LF XTAL
TC35678	1.8	550.40	1082.38	DCDC on, LF XTAL
QN9080	1.62			Issues with VDDmin DCDC on, LF XTAL
NRF52810	1.7	7.83	27.09	With some optimization by ZHAW-InES
NRF52840	1.7	454.16	100.35	DCDC on
NRF52840	1.7			DCDC off
EM9304 SD	1.8	14.34	65.79	DCDC on, LF XTAL
EM9304 SU	1.5			
EM9304 SU	1.05	13.98	41.22	LF RC
RL78/G1D	1.8			See report of 2016 DCDC on, LF On Chip OSC
RL78/G1D	1.8			DCDC off, LF On Chip OSC
ATBTLC1000	1.9	95.90	364.51	DCDC on, LF XTAL
PSoC6_revA	1.8	626.45	991.86	DCDC on (0.9 V), LF XTAL
PSoC6_revD	1.7	1155.52	1164.77	DCDC on (0.9 V), LF XTAL
BGM113	1.85	1065.29	9522.05	DCDC on, LF XTAL
CC2652R	1.8	97.28	604.19	DCDC on, LF XTAL Long non-sleep phase after first ADV
icyTRX	1.3	20.32	22.64	Transceiver only
icyTRX	1.3	47.41	38.87	Transceiver and host CPU
icyTRX	1	42.26	15.83	Transceiver only
icyTRX	1	69.46	33.53	Transceiver and host CPU

Simple advertisement

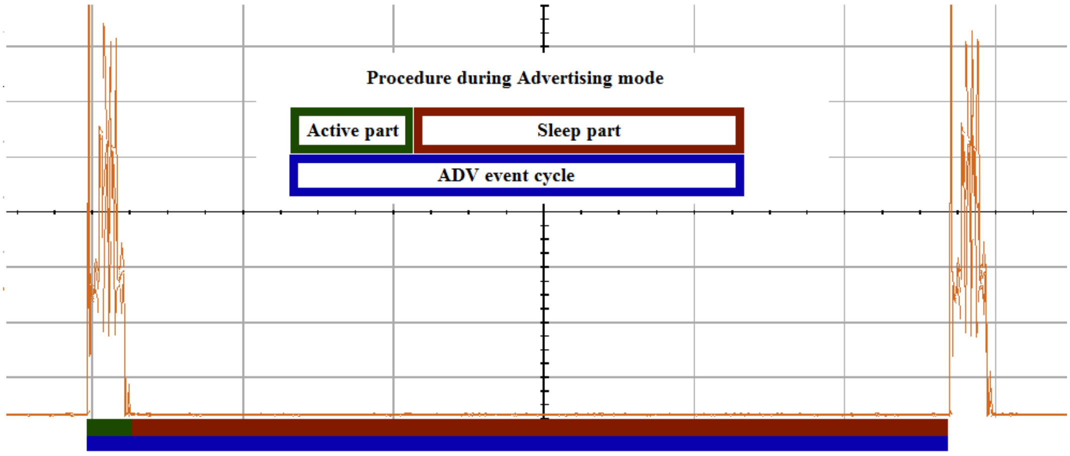
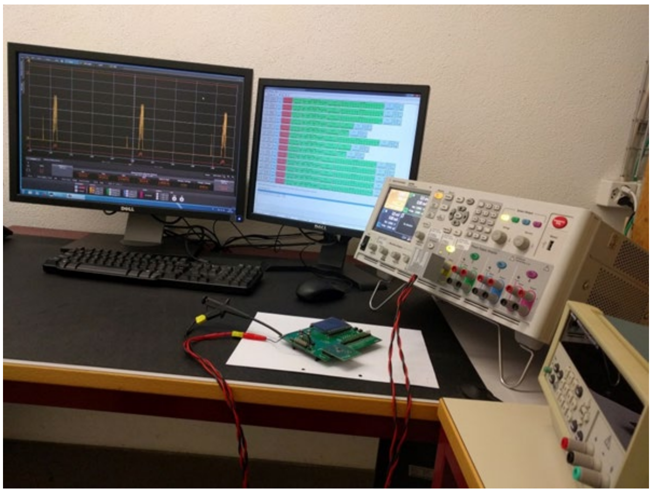
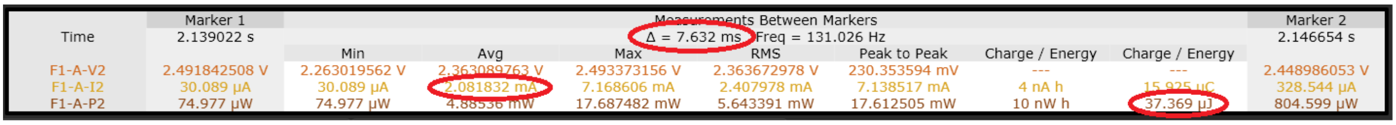


Fig. 4. The ADV event cycle consists in active and sleep parts

Advertising packets on all advertising channels are sent every 100 or 1000 ms during the active part. Between these transmissions, the devices switch into a low-power mode. This is called the sleep part. An ADV event cycle is the combination of one active and one sleep part and has a length of one interval.





	Marker 1	Measurements Between Markers							Marker 2
Time	2.139022 s		Δ = 7.632 ms	Freq = 131.026 Hz					2.146654 s
		Min	Avg	Max	RMS	Peak to Peak	Charge / Energy	Charge / Energy	
F1-A-V2	2.491842508 V	2.263019562 V	2.363089763 V	2.493373156 V	2.363672978 V	230.353594 mV	---	---	2.448986053 V
F1-A-I2	30.089 µA	30.089 µA	2.081832 mA	7.168606 mA	2.407978 mA	7.138517 mA	4 nA h	15.925 µC	328.544 µA
F1-A-P2	74.977 µW	74.977 µW	4.88536 mW	17.687482 mW	5.643391 mW	17.612505 mW	10 nW h	37.369 µJ	804.599 µW

Fig. 5. Measurement tool of Agilent 14585A Control and Analysis Software

Examples of profiles during ADV_NONCONN_IND event

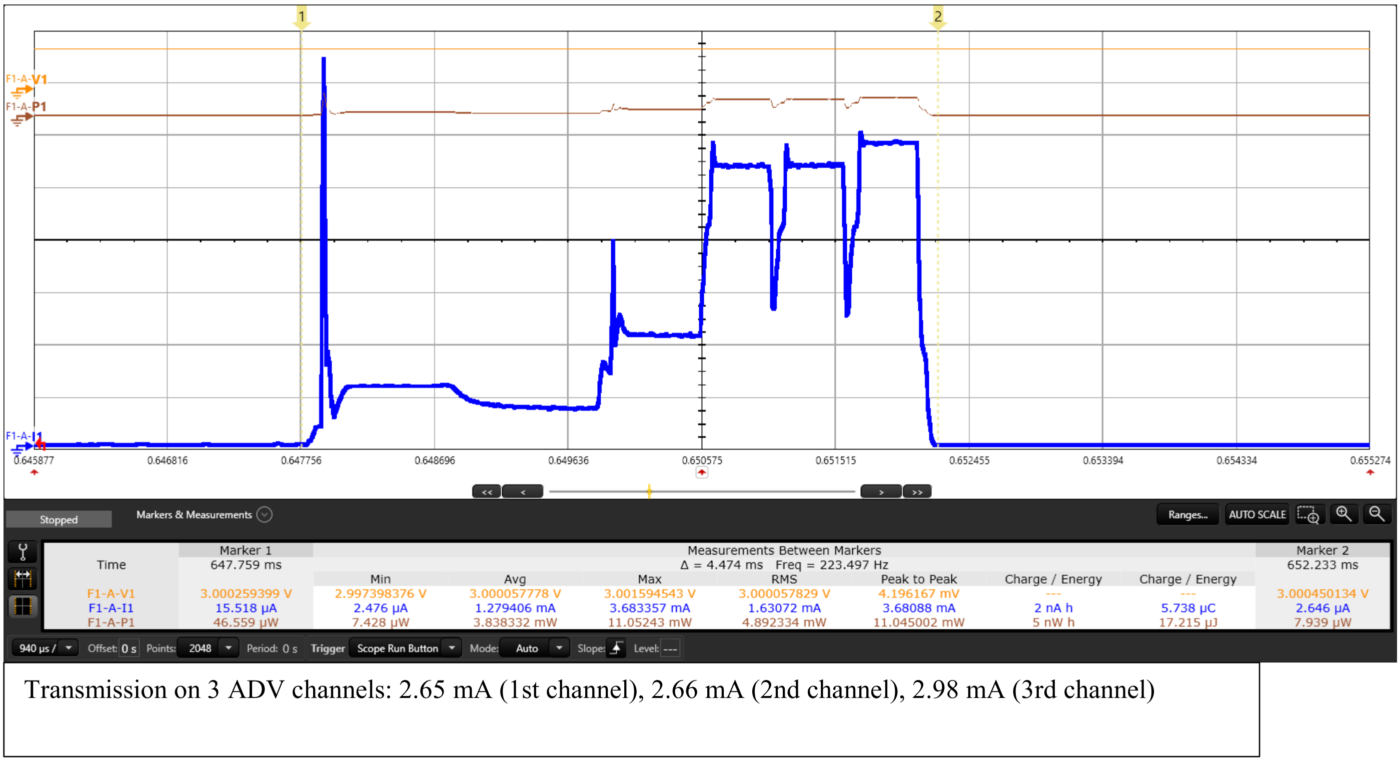


Fig. 6. Active part of ADV_NONCONN_IND event for Toshiba TC35678 device

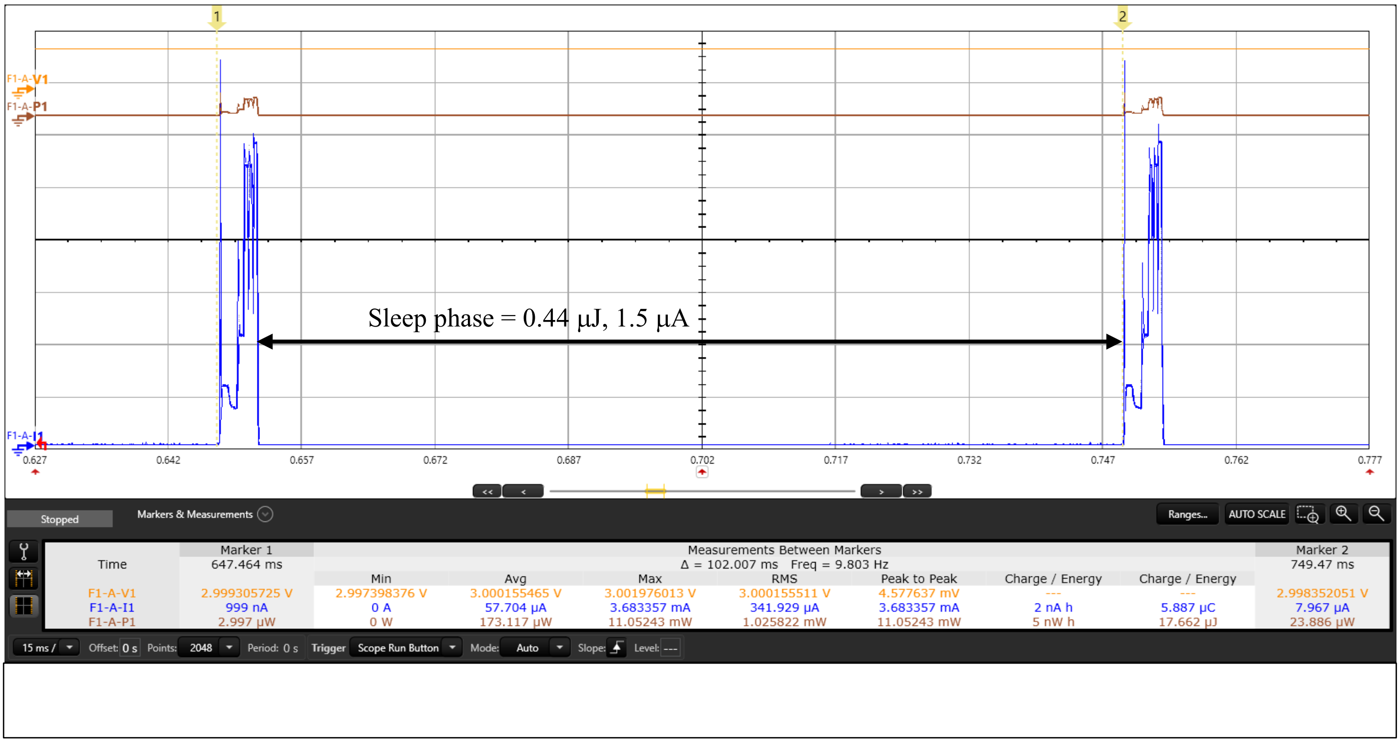


Fig. 7. ADV (ADV_NONCONN_IND) event with sleep phase for Toshiba TC35678 device

TABLE III. ENERGY AND TIME REQUIRED FOR A TOTAL ADV_NONCONN_IND EVENT CYCLE (NON-CONNECTABLE, 100 MILLISECONDS, 3 V)

Devices	**Parameters**						
	Measurement Voltage (V)	***ADV event cycle (ms)***	***Cycle Energy (µJ)***	***Active part Energy (µJ)***	***Sleep part Avg. current (µA)***	***Sleep part Energy (µJ)***	***Remarks***
RSL10	3	106.33	15.01	14.99	0.07	0.02	DCDC on, LF RC
RSL10	3						DCDC off, LF RC
RSL10	3						DCDC on, LF XTAL
RSL10	3						DCDC off, LF XTAL
DA14581	3	104.97	28.25	27.76	1.72	0.49	OTP, DCDC enabled, LF XTAL
TC35678	3	101.75	17.64	17.15	1.62	0.49	DCDC on, LF XTAL
QN9080	3	99.94	20.93	19.06	6.67	1.87	DCDC on, LF XTAL
NRF52810	3	100.22	27.27	26.63	2.16	0.64	DCDC on, LF RC
NRF52840	3	104.59	31.21	30.42	2.62	0.79	DCDC on
NRF52840	3						DCDC off
EM9304 SD	3	109.09	29.39	29.01	1.23	0.38	DCDC on, LF RC
RL78/G1D	3	101.25	31.90	31.40	1.73	0.50	DCDC on, LF On Chip OSC
RL78/G1D	3						DCDC off, LF On Chip OSC
ATBTLC1000	3	102.66	40.32	39.77	1.96	0.55	DCDC on, LF XTAL
PSoC6_revA	3	109.36	37.41	32.59	15.21	4.82	DCDC on (0.9 V), LF XTAL
PSoC6_revD	3	103.75	33.86	29.53	14.36	4.33	DCDC on (0.9 V), LF XTAL
BGM113	3	109.38	57.45	56.33	3.51	1.12	DCDC on, LF XTAL
CC2652R	3	108.98	55.90	55.87	0.12	0.04	DCDC on, LF XTAL
icyTRX	3						not possible (VDD max = 1.3 V)

TABLE IV. ENERGY AND TIME REQUIRED FOR A TOTAL ADV_NONCONN_IND EVENT CYCLE (NON-CONNECTABLE, 100 MILLISECONDS, MINIMAL VOLTAGE)

Devices	**Parameters**						
	Measurement Voltage (V)	***ADV event cycle (ms)***	***Cycle Energy (µJ)***	***Active part Energy (µJ)***	***Sleep part Avg. current (µA)***	***Sleep part Energy (µJ)***	***Remarks***
RSL10	1.12	101.37	14.39	14.38	0.05	0.01	LDO on, LF RC
RSL10	1.12						DCDC off, LF RC
RSL10	1.12						LDO on, LF XTAL
RSL10	1.12						DCDC off, LF XTAL
DA14581	2.35	103.74	26.67	26.27	1.80	0.41	OTP, DCDC enabled, LF XTAL
TC35678	1.8	101.81	13.76	13.49	1.54	0.27	DCDC on, LF XTAL
QN9080	1.62						DCDC on, LF XTAL
NRF52810	1.7	100.32	22.28	21.83	2.71	0.45	DCDC on, LF RC
NRF52840	1.7	102.95	25.49	24.94	3.27	0.55	DCDC on
NRF52840	1.7						DCDC off
EM9304 SU	1.8	105.12	34.37	34.16	1.24	0.21	DCDC on, LF RC
EM9304 SU	1.05	104.09	22.27	22.15	1.15	0.12	Step Up, LF RC
RL78/G1D	1.8	107.69	24.65	24.30	1.90	0.35	DCDC on, LF On Chip OSC
RL78/G1D	1.8						DCDC off, LF On Chip OSC
ATBTLC1000	1.9	104.00	36.60	36.28	1.72	0.33	DCDC on, LF XTAL
PSoC6_revA	1.8	108.16	29.33	25.82	18.67	3.51	DCDC on (0.9 V), LF XTAL
PSoC6_revD	1.7	108.34	27.77	24.62	17.72	3.15	DCDC on (0.9 V), LF XTAL
BGM113	1.85	102.52	47.25	46.66	3.43	0.64	DCDC on, LF XTAL
CC2652R	1.8	100.96	52.93	52.91	0.07	0.01	DCDC on, LF XTAL
icyTRX	1.3	105.81	26.46	19.19	53.99	7.27	Transceiver only
icyTRX	1.3	105.87	29.40	22.04	55.29	7.36	Transceiver and host CPU
icyTRX	1	108.41	12.30	10.01	22.15	2.29	Transceiver only
icyTRX	1	108.47	18.27	14.79	35.78	3.48	Transceiver and host CPU

TABLE V. ENERGY, TIME REQUIRED FOR A TOTAL ADV_NONCONN_IND EVENT CYCLE (NON-CONNECTABLE, 1000 MILLISECONDS, 3 V)

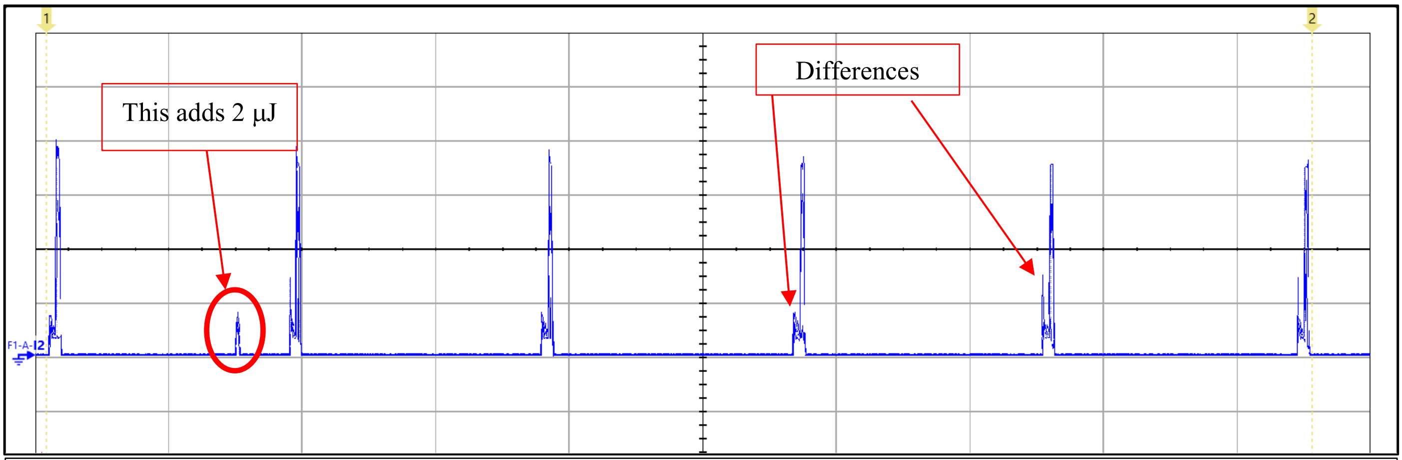
Devices	**Parameters**						
	Measurement Voltage (V)	***ADV event cycle (ms)***	***Cycle Energy (µJ)***	***Active part Energy (µJ)***	***Sleep part Avg. current (µA)***	***Sleep part Energy (µJ)***	***Remarks***
RSL10	3	1008.43	15.85	15.69	0.05	0.15	DCDC on, LF RC
RSL10	3						DCDC off, LF RC
RSL10	3						DCDC on, LF XTAL
RSL10	3						DCDC off, LF XTAL
DA14581	3	1002.34	32.88	27.74	1.72	5.14	OTP, DCDC enabled, LF XTAL
TC35678	3	1001.58	25.73	16.82	2.98	8.91	DCDC on, LF XTAL
QN9080	3	1003.45	27.30	24.07	8.79	3.23	DCDC on, LF XTAL
NRF52810	3	1003.25	35.08	26.45	2.87	8.63	DCDC on, LF RC
NRF52840	3	1001.96	40.56	30.35	3.41	10.21	DCDC on
NRF52840	3						DCDC off
EM9304 SD	3	1005.94	41.22	37.72	1.17	3.51	DCDC on, LF RC
EM9304 SD	3						
RL78/G1D	3	1008.01	37.59	31.97	1.87	5.63	DCDC on, LF On Chip OSC
RL78/G1D	3						DCDC off, LF On Chip OSC
ATBTLC1000	3	1002.64	49.62	44.01	1.88	5.62	DCDC on, LF XTAL
PSoC6_revA	3	1009.41	77.19	33.78	14.39	43.42	DCDC on (0.9 V), LF XTAL
PSoC6_revD	3	1009.40	73.33	31.19	13.97	42.14	DCDC on (0.9 V), LF XTAL
BGM113	3	1009.34	66.78	57.94	2.94	8.84	DCDC on, LF XTAL
CC2652R	3	1001.05	71.77	68.92	0.95	2.85	DCDC on, LF XTAL
icyTRX	3						not possible (VDD max = 1.3 V)

TABLE VI. ENERGY AND TIME REQUIRED FOR A TOTAL ADV_NONCONN_IND EVENT CYCLE (NON-CONNECTABLE, 1000 MILLISECONDS, MINIMAL VOLTAGE)

Devices	**Parameters**						
	Measurement Voltage (V)	***ADV event cycle (ms)***	***Cycle Energy (µJ)***	***Active part Energy (µJ)***	***Sleep part Avg. current (µA)***	***Sleep part Energy (µJ)***	***Remarks***
RSL10	1.12	1006.15	15.80	15.76	0.03	0.04	LDO on, LF RC
RSL10	1.12						DCDC off, LF RC
RSL10	1.12						LDO on, LF XTAL
RSL10	1.12						DCDC off, LF XTAL
DA14581	2.35	1002.34	30.48	26.33	1.77	4.15	OTP, DCDC enabled, LF XTAL
TC35678	1.8	1001.65	18.75	13.44	2.95	5.30	DCDC on, LF XTAL
QN9080	1.62						Issues with VDDmin DCDC on, LF XTAL
NRF52810	1.7	1003.20	26.90	21.93	2.92	4.96	DCDC on, LF RC
NRF52840	1.7	1009.13	29.94	25.03	2.87	4.90	DCDC on
NRF52840	1.7						DCDC off
EM9304 SD	1.8	1007.82	41.72	39.61	1.17	2.11	DCDC on, LF RC
EM9304 SU	1.05	1006.84	28.36	27.19	1.12	1.17	Step Up, LF RC
RL78/G1D	1.8	1006.50	28.00	24.84	1.75	3.16	DCDC on, LF On Chip OSC
RL78/G1D	1.8						DCDC off, LF On Chip OSC
ATBTLC1000	1.9	1006.48	42.40	39.29	1.64	3.11	DCDC on, LF XTAL
PSoC6_revA	1.8	1009.42	59.41	26.51	18.17	32.90	DCDC on (0.9 V), LF XTAL
PSoC6_revD	1.7	1007.52	55.45	26.00	17.26	29.45	DCDC on (0.9 V), LF XTAL
BGM113	1.85	1001.20	53.12	46.92	3.38	6.20	DCDC on, LF XTAL
CC2652R	1.8	1003.03	66.98	64.73	1.25	2.25	DCDC on, LF XTAL
icyTRX	1.3	1005.78	89.45	19.18	53.86	70.27	Transceiver only
icyTRX	1.3	1005.64	94.11	21.80	55.50	72.31	Transceiver and host CPU
icyTRX	1	1037.54	31.77	9.96	21.13	21.82	Transceiver only
icyTRX	1	1036.45	51.81	14.89	36.01	36.92	Transceiver and host CPU

TABLE VII. ENERGY NEEDED FOR THE ADV_NONCONN_IND EVENT (AVERAGING SEVERAL CYCLES, 100 MILLISECONDS, 3 V)

Devices	Parameters					
	Measurement Voltage (V)	*ADV event cycles (ms)*	*Average current (uA)*	*Energy (mJ)*	*Energy per cycle(uJ)*	*Remarks*
RSL10	3	100 ms for 1 min	46.30	8.34	14.60	DCDC on, LF RC
RSL10	3	100 ms for 1 min				DCDC off, LF RC
RSL10	3	100 ms for 1 min				DCDC on, LF XTAL
RSL10	3	100 ms for 1 min				DCDC off, LF XTAL
DA14581	3	100 ms for 1 min	89.82	16.17	28.31	OTP, DCDC enabled, LF XTAL
TC35678	3	100 ms for 1 min	53.65	9.66	16.10	DCDC on, LF XTAL
QN9080	3	100 ms for 1 min	66.83	12.03	21.10	DCDC on, LF XTAL
NRF52810	3	100 ms for 1 min	90.33	16.26	27.19	DCDC on, LF RC
NRF52840	3	100 ms for 1 min	99.44	17.90	31.35	DCDC on
NRF52840	3	100 ms for 1 min				DCDC off
EM9304 SD	3	100 ms for 1 min	95.97	17.28	30.15	DCDC on, LF RC
RL78/G1D	3	100 ms for 1 min	101.13	18.20	31.88	DCDC on, LF On Chip OSC
RL78/G1D	3	100 ms for 1 min				DCDC off, LF On Chip OSC
ATBTLC1000	3	100 ms for 1 min	128.37	23.09	40.02	DCDC on, LF XTAL
PSoC6_revA	3	100 ms for 1 min	115.70	20.83	36.47	DCDC on (0.9 V), LF XTAL
PSoC6_revD	3	100 ms for 1 min	107.94	19.43	33.97	
BGM113	3	100 ms for 1 min	180.11	32.39	56.53	DCDC on, LF XTAL
CC2652R	3	100 ms for 1 min	179.07	32.23	56.25	DCDC on, LF XTAL
icyTRX	3	100 ms for 1 min				not possible (VDD max = 1.3 V)



Averaging several events is important because the solution might introduce corrections between events. There might also be differences related to the use of the DC/DC converters. This could lead to important differences in the energy required by the events, although the interval and other settings are the same.

TABLE VIII. ENERGY NEEDED FOR THE ADV_NONCONN_IND EVENT (AVERAGING SEVERAL CYCLES, 100 MILLISECONDS, MINIMAL VOLTAGE)

Devices	**Parameters**					
	Measurement Voltage (V)	***ADV event cycles (ms)***	***Average current (uA)***	***Energy (mJ)***	***Energy per cycle(uJ)***	***Remarks***
RSL10	1.12	100 ms for 1 min	121.79	8.19	14.34	LDO on, LF RC
RSL10	1.12	100 ms for 1 min				DCDC off, LF RC
RSL10	1.12	100 ms for 1 min				LDO on, LF XTAL
RSL10	1.12	100 ms for 1 min				DCDC off, LF XTAL
DA14581	2.35	100 ms for 1 min	108.15	15.25	26.66	OTP, DCDC enabled, LF XTAL
TC35678	1.8	100 ms for 1 min	70.88	7.66	13.38	DCDC on, LF XTAL
QN9080	1.62	100 ms for 1 min				DCDC on, LF XTAL
NRF52810	1.7	100 ms for 1 min	130.51	13.31	22.26	DCDC on, LF RC
NRF52840	1.7	100 ms for 1 min	140.34	14.32	25.03	DCDC on
NRF52840	1.7	100 ms for 1 min				DCDC off
EM9304 SD	1.8	100 ms for 1 min	164.30	17.75	30.97	DCDC on, LF RC
EM9304 SU	1.05	100 ms for 1 min	205.53	12.95	22.56	Step Up, LF RC
RL78/G1D	1.8	100 ms for 1 min	129.18	13.95	24.39	DCDC on, LF On Chip OSC
RL78/G1D	1.8	100 ms for 1 min				DCDC off, LF On Chip OSC
ATBTLC1000	1.9	100 ms for 1 min	184.17	20.99	36.37	DCDC on, LF XTAL
PSoC6_revA	1.8	100 ms for 1 min	151.63	16.38	28.68	DCDC on (0.9 V), LF XTAL
PSoC6_revD	1.7	100 ms for 1 min	153.54	15.66	27.43	
BGM113	1.85	100 ms for 1 min	244.68	27.11	47.40	DCDC on, LF XTAL
CC2652R	1.8	100 ms for 1 min	281.61	30.41	53.26	DCDC on, LF XTAL
icyTRX	1.3	100 ms for 1 min	193.13	15.00	26.51	Transceiver only
icyTRX	1.3	100 ms for 1 min	211.76	16.52	29.13	Transceiver and host CPU
icyTRX	1	100 ms for 1 min	115.70	6.80	12.27	Transceiver only
icyTRX	1	100 ms for 1 min	167.658	10.06	18.16	Transceiver and host CPU

TABLE IX. ENERGY NEEDED FOR THE ADV_NONCONN_IND EVENT (AVERAGING SEVERAL CYCLES, 1000 MILLISECONDS, 3 V)

Devices	**Parameters**					
	Measurement Voltage (V)	***ADV event cycles (ms)***	***Average current (uA)***	***Energy (mJ)***	***Energy per cycle(uJ)***	***Remarks***
RSL10	3	1000 ms for 1 min	5.54	1.00	16.62	DCDC on, LF RC
RSL10	3	1000 ms for 1 min				DCDC off, LF RC
RSL10	3	1000 ms for 1 min				DCDC on, LF XTAL
RSL10	3	1000 ms for 1 min				DCDC off, LF XTAL
DA14581	3	1000 ms for 1 min	10.97	1.90	31.67	OTP, DCDC enabled, LF XTAL
TC35678	3	1000 ms for 1 min	8.39	1.51	25.17	DCDC on, LF XTAL
QN9080	3	1000 ms for 1 min	9.24	1.66	27.71	DCDC on, LF XTAL
NRF52810	3	1000 ms for 1 min	11.53	2.08	35.16	DCDC on, LF RC
NRF52840	3	1000 ms for 1 min	12.40	2.23	37.19	DCDC on
NRF52840	3	1000 ms for 1 min				DCDC off
EM9304 SD	3	1000 ms for 1 min	12.34	2.22	37.02	DCDC on, LF RC
RL78/G1D	3	1000 ms for 1 min	12.29	2.21	36.87	DCDC on, LF On Chip OSC
RL78/G1D	3	1000 ms for 1 min				DCDC off, LF On Chip OSC
ATBTLC1000	3	1000 ms for 1 min	15.51	2.79	46.48	DCDC on, LF XTAL
PSoC6_revA	3	1000 ms for 1 min	24.62	4.43	75.11	DCDC on (0.9 V), LF XTAL
PSoC6_revD	3	1000 ms for 1 min	23.66	4.26	70.97	DCDC on (0.9 V), LF XTAL
BGM113	3	1000 ms for 1 min	21.55	3.67	61.17	DCDC on, LF XTAL
CC2652R	3	1000 ms for 1 min	19.62	3.53	58.85	DCDC on, LF XTAL
icyTRX	3	1000 ms for 1 min				not possible (VDD max = 1.3 V)

TABLE X. ENERGY NEEDED FOR THE ADV_NONCONN_IND EVENT (AVERAGING SEVERAL CYCLES, 1000 MILLISECONDS, MINIMAL VOLTAGE)

Devices	Parameters					
	Measurement Voltage (V)	*ADV event cycles (ms)*	*Average current (uA)*	*Energy (mJ)*	*Energy per cycle(uJ)*	*Remarks*
RSL10	1.12	1000 ms for 1 min	13.35	0.90	14.96	LDO on, LF RC
RSL10	1.12	1000 ms for 1 min				DCDC off, LF RC
RSL10	1.12	1000 ms for 1 min				LDO on, LF XTAL
RSL10	1.12	1000 ms for 1 min				DCDC off, LF XTAL
DA14581	2.35	1000 ms for 1 min	12.75	1.80	30.48	OTP, DCDC enabled, LF XTAL
TC35678	1.8	1000 ms for 1 min	9.93	1.07	17.88	DCDC on, LF XTAL
QN9080	1.62	1000 ms for 1 min				DCDC on, LF XTAL
NRF52810	1.7	1000 ms for 1 min	15.48	1.58	26.76	DCDC on, LF RC
NRF52840	1.7	1000 ms for 1 min	16.51	1.68	28.07	DCDC on
NRF52840	1.7	1000 ms for 1 min				DCDC off
EM9304 SD	1.8	1000 ms for 1 min	19.82	2.14	36.27	DCDC on, LF RC
EM9304 SU	1.05	1000 ms for 1 min	23.86	1.50	25.06	Step Up, LF RC
RL78/G1D	1.8	1000 ms for 1 min	14.99	1.62	26.98	DCDC on, LF On Chip OSC
RL78/G1D	1.8	1000 ms for 1 min				DCDC off, LF On Chip OSC
ATBTLC1000	1.9	1000 ms for 1 min	21.15	2.41	40.18	DCDC on, LF XTAL
PSoC6_revA	1.8	1000 ms for 1 min	30.73	3.32	55.32	DCDC on (0.9 V), LF XTAL
PSoC6_revD	1.7	1000 ms for 1 min	30.40	3.10	51.67	DCDC on (0.9 V), LF XTAL
BGM113	1.85	1000 ms for 1 min	27.86	3.09	52.37	DCDC on, LF XTAL
CC2652R	1.8	1000 ms for 1 min	30.91	3.34	55.63	DCDC on, LF XTAL
icyTRX	1.3	1000 ms for 1 min	68.64	5.35	89.12	Transceiver only
icyTRX	1.3	1000 ms for 1 min	71.53	5.58	94.58	Transceiver and host CPU
icyTRX	1	1000 ms for 1 min	30.89	1.84	31.71	Transceiver only
icyTRX	1	1000 ms for 1 min	49.70	2.98	51.41	Transceiver and host CPU

The connectable advertising event allows an initiator to respond with a connect request. To establish a connection, the initiator sends a connect request (CONNECT_REQ PDU) to request the Link Layer to enter the Connection State.

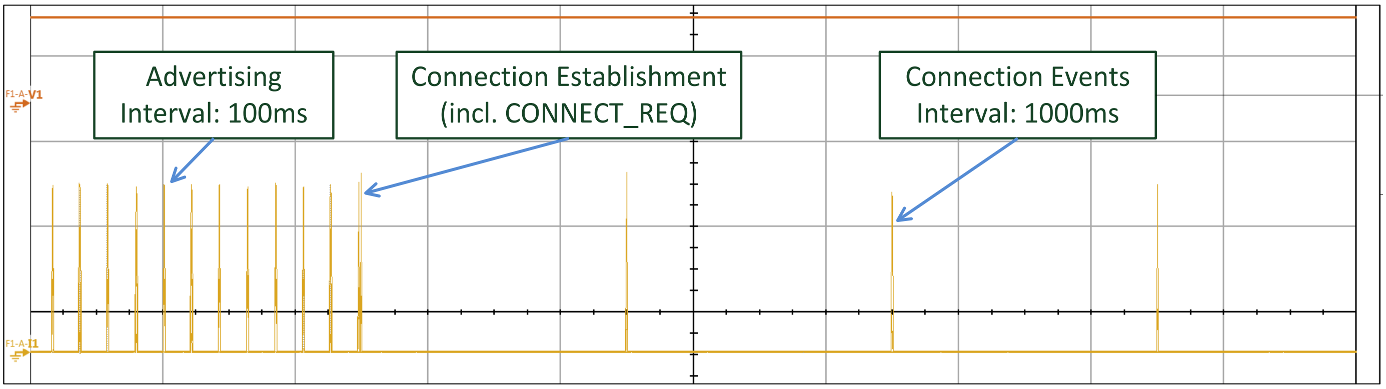
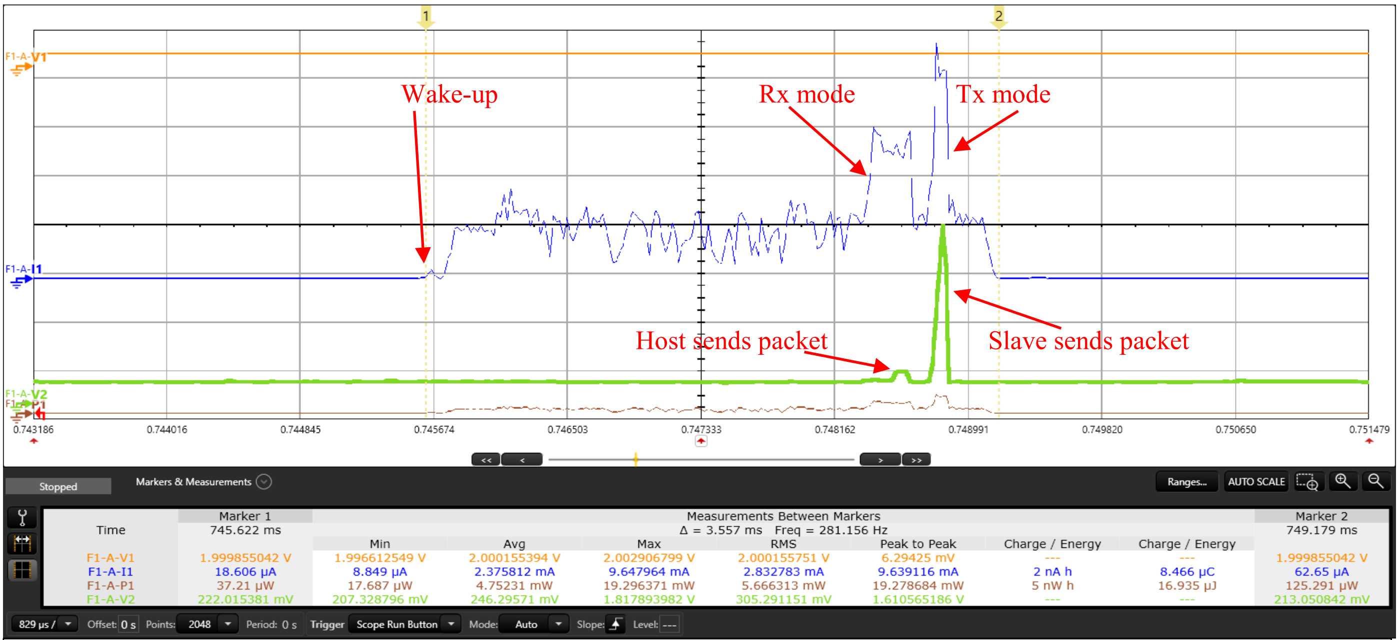


Fig. 8. Example of connection establishment



Connection activity. The profile of the slave is recorded (V1, I1)
V2 is the RF detector signal. It shows the RF activities taking place. It is placed nearer to the slave.
After wake-up, the device goes in Rx mode and waits for the Tx packet from the host.
Once the packet has been received, the slave goes in Tx mode and sends its own packet

Fig. 9. Example of connection activity

Connectable advertisement. Averaged events

TABLE XI. ENERGY NEEDED FOR CONNECTABLE ADV EVENT (AVERAGING SEVERAL CYCLES, 100 MILLISECONDS, 3 V)

Devices	Parameters					
	Measurement Voltage (V)	*ADV event cycles (ms)*	*Average current (uA)*	*Energy (mJ)*	*Energy per cycle(uJ)*	*Remarks*
RSL10	3	100 ms for 1 min				DCDC on, LF RC
RSL10	3	100 ms for 1 min				DCDC off, LF RC
RSL10	3	100 ms for 1 min	46.06	8.29	14.50	DCDC on, LF XTAL
RSL10	3	100 ms for 1 min				DCDC off, LF XTAL
DA14581	3	100 ms for 1 min	131.38	23.65	41.34	OTP, DCDC enabled, LF XTAL
TC35678	3	100 ms for 1 min	66.54	11.98	20.90	DCDC on, LF XTAL
QN9080	3	100 ms for 1 min	72.48	13.05	22.85	DCDC on, LF XTAL
NRF52810	3	100 ms for 1 min				no code available
NRF52840	3	100 ms for 1 min	147.78	26.60	46.51	DCDC on
NRF52840	3	100 ms for 1 min				DCDC off
EM9304 SD	3	100 ms for 1 min	51.14	9.21	16.04	DCDC on, LF RC
RL78/G1D	3	100 ms for 1 min				DCDC on, LF On Chip OSC
RL78/G1D	3	100 ms for 1 min				DCDC off, LF On Chip OSC
ATBTLC1000	3	100 ms for 1 min	150.39	27.05	46.89	DCDC on, LF XTAL
PSoC6_revA	3	100 ms for 1 min	167.36	30.13	52.76	DCDC on (0.9 V), LF XTAL
PSoC6_revD	3	100 ms for 1 min	156.28	28.13	49.26	DCDC on (0.9 V), LF XTAL
BGM113	3	100 ms for 1 min	234.12	42.10	73.60	DCDC on, LF XTAL
CC2652R	3	100 ms for 1 min	223.19	40.17	70.23	DCDC on, LF XTAL
icyTRX	3	100 ms for 1 min				no code available

TABLE XII. ENERGY NEEDED FOR CONNECTABLE ADV EVENT (AVERAGING SEVERAL CYCLES, 100 MILLISECONDS, MINIMAL VOLTAGE)

Devices	**Parameters**					
	Measurement Voltage (V)	***ADV event cycles (ms)***	***Average current (uA)***	***Energy (mJ)***	***Energy per cycle(uJ)***	***Remarks***
RSL10	1.12	100 ms for 1 min				LDO on, LF RC
RSL10	1.12	100 ms for 1 min				DCDC off, LF RC
RSL10	1.12	100 ms for 1 min	128.79	8.66	15.17	LDO on, LF XTAL
RSL10	1.12	100 ms for 1 min				DCDC off, LF XTAL
DA14581	2.35	100 ms for 1 min	134.81	19.01	33.29	OTP, DCDC enabled, LF XTAL
TC35678	1.8	100 ms for 1 min	86.84	9.38	16.37	DCDC on, LF XTAL
QN9080	1.62	100 ms for 1 min	311.46	30.28	53.03	DCDC on, LF XTAL
NRF52810	1.7	100 ms for 1 min				no code available
NRF52840	1.7	100 ms for 1 min	209.26	21.34	37.25	DCDC on
NRF52840	1.7	100 ms for 1 min				DCDC off
EM9304 SD	1.8	100 ms for 1 min	190.34	20.56	35.81	DCDC on, LF RC
EM9304 SU	1.05	100 ms for 1 min	232.27	14.63	25.45	Step Up, LF RC
RL78/G1D	1.8	100 ms for 1 min				DCDC on, LF On Chip OSC
RL78/G1D	1.8	100 ms for 1 min				DCDC off, LF On Chip OSC
ATBTLC1000	1.9	100 ms for 1 min	217.17	24.75	42.90	DCDC on, LF XTAL
PSoC6_revA	1.8	100 ms for 1 min	217.57	23.50	41.15	DCDC on (0.9 V), LF XTAL
PSoC6_revD	1.7	100 ms for 1 min	225.01	22.95	40.19	DCDC on (0.9 V), LF XTAL
BGM113	1.85	100 ms for 1 min	310.22	34.35	60.16	DCDC on, LF XTAL
CC2652R	1.8	100 ms for 1 min	353.89	38.22	65.78	DCDC on, LF XTAL
icyTRX	1.3	100 ms for 1 min				no code available
icyTRX	1	100 ms for 1 min				no code available

TABLE XIII. ENERGY NEEDED FOR CONNECTABLE ADV EVENT (AVERAGING SEVERAL CYCLES, 1000 MILLISECONDS, 3 V)

Devices	**Parameters**					
	Measurement Voltage (V)	***ADV event cycles (ms)***	***Average current (uA)***	***Energy (mJ)***	***Energy per cycle(uJ)***	***Remarks***
RSL10	3	1000 ms for 1 min				DCDC on, LF RC
RSL10	3	1000 ms for 1 min				DCDC off, LF RC
RSL10	3	1000 ms for 1 min	5.08	0.91	15.24	DCDC on, LF XTAL
RSL10	3	1000 ms for 1 min				DCDC off, LF XTAL
DA14581	3	1000 ms for 1 min	13.33	2.40	39.98	OTP, DCDC enabled, LF XTAL
TC35678	3	1000 ms for 1 min	9.19	1.66	27.58	DCDC on, LF XTAL
QN9080	3	1000 ms for 1 min	9.88	1.78	29.63	DCDC on, LF XTAL
NRF52810	3	1000 ms for 1 min				no code available
NRF52840	3	1000 ms for 1 min	17.11	3.08	52.20	DCDC on
NRF52840	3	1000 ms for 1 min				DCDC off
EM9304 SD	3	1000 ms for 1 min	13.97	2.51	41.74	DCDC on, LF RC
RL78/G1D	3	1000 ms for 1 min				DCDC on, LF On Chip OSC
RL78/G1D	3	1000 ms for 1 min				DCDC off, LF On Chip OSC
ATBTLC1000	3	1000 ms for 1 min	17.64	3.17	52.89	DCDC on, LF XTAL
PSoC6_revA	3	1000 ms for 1 min	31.05	5.59	94.73	DCDC on (0.9 V), LF XTAL
PSoC6_revD	3	1000 ms for 1 min	28.21	5.08	86.06	DCDC on (0.9 V), LF XTAL
BGM113	3	1000 ms for 1 min	26.75	4.81	80.17	DCDC on, LF XTAL
CC2652R	3	1000 ms for 1 min	25.99	4.68	77.98	DCDC on, LF XTAL
icyTRX	3	1000 ms for 1 min				no code available

TABLE XIV. ENERGY NEEDED FOR CONNECTABLE ADV EVENT (AVERAGING SEVERAL CYCLES, 1000 MILLISECONDS, MINIMAL VOLTAGE)

Devices	**Parameters**					
	Measurement Voltage (V)	***ADV event cycles (ms)***	***Average current (uA)***	***Energy (mJ)***	***Energy per cycle(uJ)***	***Remarks***
RSL10	1.12	1000 ms for 1 min				LDO on, LF RC
RSL10	1.12	1000 ms for 1 min				DCDC off, LF RC
RSL10	1.12	1000 ms for 1 min	14.07	0.95	15.77	LDO on, LF XTAL
RSL10	1.12	1000 ms for 1 min				DCDC off, LF XTAL
DA14581	2.35	1000 ms for 1 min	15.71	2.22	36.92	OTP, DCDC enabled, LF XTAL
TC35678	1.8	1000 ms for 1 min	11.35	1.23	20.43	DCDC on, LF XTAL
QN9080	1.62	1000 ms for 1 min	34.51	3.36	56.86	DCDC on, LF XTAL
NRF52810	1.7	1000 ms for 1 min				no code available
NRF52840	1.7	1000 ms for 1 min	23.46	2.39	39.89	DCDC on
NRF52840	1.7	1000 ms for 1 min				DCDC off
EM9304 SD	1.8	1000 ms for 1 min	22.80	2.46	41.74	DCDC on, LF RC
EM9304 SU	1.05	1000 ms for 1 min	26.64	1.68	27.97	Step Up, LF RC
RL78/G1D	1.8	1000 ms for 1 min				DCDC on, LF On Chip OSC
RL78/G1D	1.8	1000 ms for 1 min				DCDC off, LF On Chip OSC
ATBTLC1000	1.9	1000 ms for 1 min	24.30	2.77	46.15	DCDC on, LF XTAL
PSoC6_revA	1.8	1000 ms for 1 min	37.47	4.05	67.46	DCDC on (0.9 V), LF XTAL
PSoC6_revD	1.7	1000 ms for 1 min	37.40	3.81	63.57	DCDC on (0.9 V), LF XTAL
BGM113	1.85	1000 ms for 1 min	34.71	3.84	65.09	DCDC on, LF XTAL
CC2652R	1.8	1000 ms for 1 min	39.52	4.27	71.12	DCDC on, LF XTAL
icyTRX	1.3	1000 ms for 1 min				no code available
icyTRX	1	1000 ms for 1 min				no code available

Connected mode. Example of profile showing the connection event

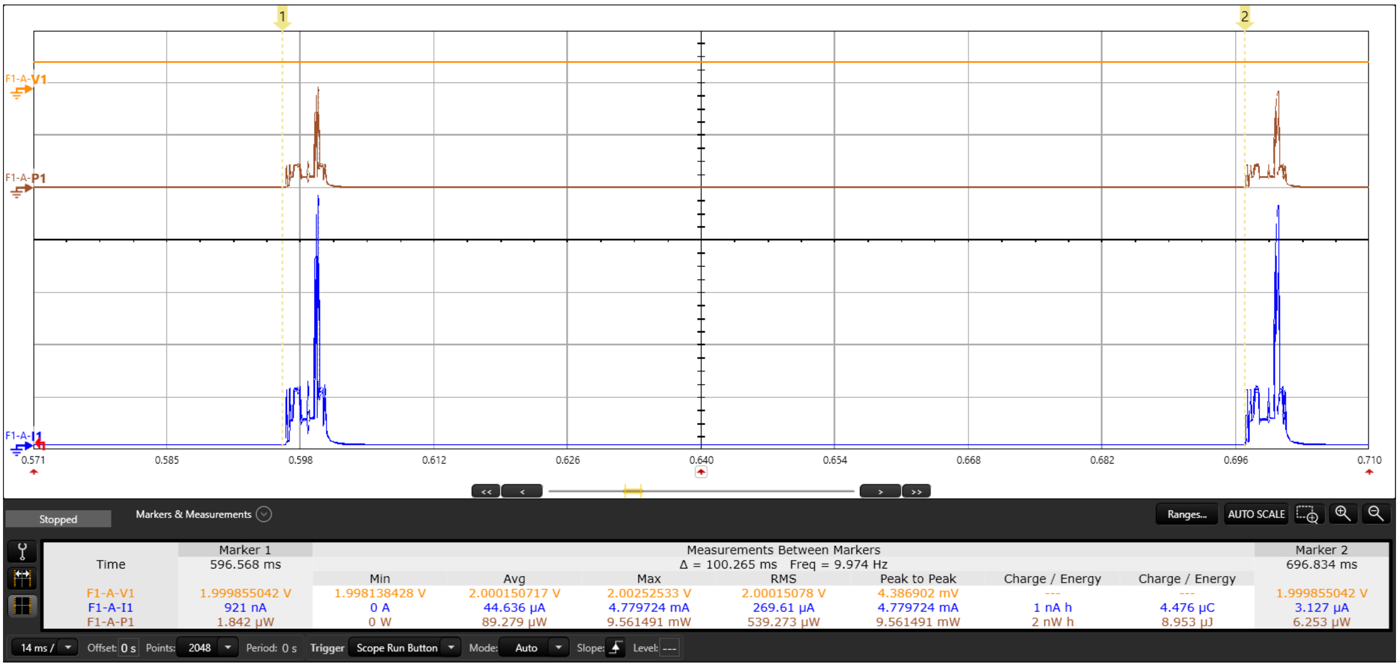


Fig. 10. Energy of Keep Alive connection. NXP QN9080 device (2 V, 100 ms)

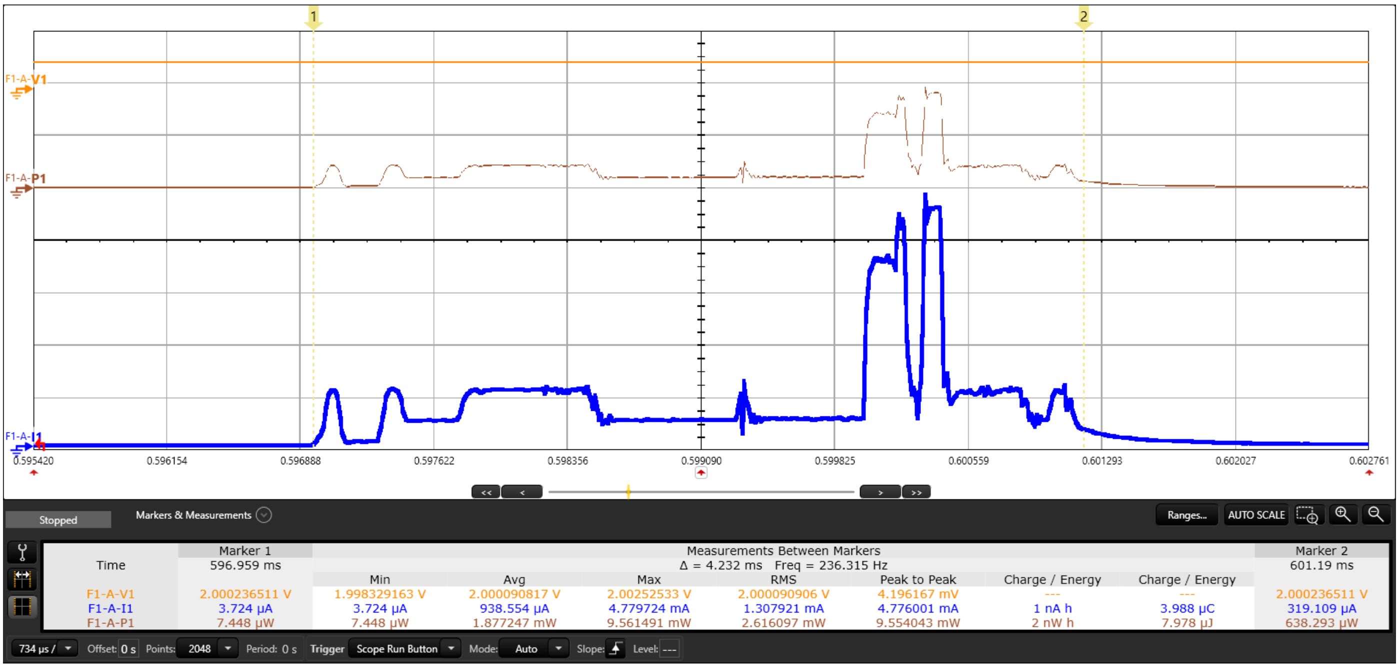


Fig. 11. Energy of Keep Alive connection. NXP QN9080 device (2 , 100 ms). Zoom on active part. RX followerd by TX can be clearly seen

Connected mode. Averaged connection events

TABLE XV. ENERGY NEEDED FOR THE CONNECTION EVENT (AVERAGING SEVERAL CYCLES, 100 MILLISECONDS, 3 V)

Devices	Parameters					
	Measurement Voltage (V)	*Event cycles (ms)*	*Average current (uA)*	*Energy (mJ)*	*Energy per cycle(uJ)*	*Remarks*
RSL10	3	100 ms for 1 min				DCDC on, LF RC
RSL10	3	100 ms for 1 min				DCDC off, LF RC
RSL10	3	100 ms for 1 min	21.56	3.88	6.47	DCDC on, LF XTAL
RSL10	3	100 ms for 1 min				DCDC off, LF XTAL
DA14581	3	100 ms for 1 min	53.01	9.54	15.90	OTP, DCDC enabled, LF XTAL
TC35678	3	100 ms for 1 min	53.65	9.66	16.10	DCDC on, LF XTAL
QN9080	3	100 ms for 1 min	33.25	5.98	9.98	DCDC on, LF XTAL
NRF52810	3	100 ms for 1 min				no code available
NRF52840	3	100 ms for 1 min	40.39	7.27	12.14	DCDC on
NRF52840	3	100 ms for 1 min				DCDC off
EM9304 SD	3	100 ms for 1 min	51.14	9.21	15.34	DCDC on, LF RC
RL78/G1D	3	100 ms for 1 min				DCDC on, LF On Chip OSC
RL78/G1D	3	100 ms for 1 min				DCDC off, LF On Chip OSC
ATBTLC1000	3	100 ms for 1 min	132.84	23.90	39.83	DCDC on, LF XTAL
PSoC6_revA	3	100 ms for 1 min	54.85	9.87	16.46	DCDC on (0.9 V), LF XTAL
PSoC6_revD	3	100 ms for 1 min	46.58	8.38	13.97	DCDC on (0.9 V), LF XTAL
BGM113	3	100 ms for 1 min	85.63	15.40	25.67	DCDC on, LF XTAL
CC2652R	3	100 ms for 1 min	98.72	17.77	29.62	DCDC on, LF XTAL
icyTRX	3	100 ms for 1 min				no code for connected mode available

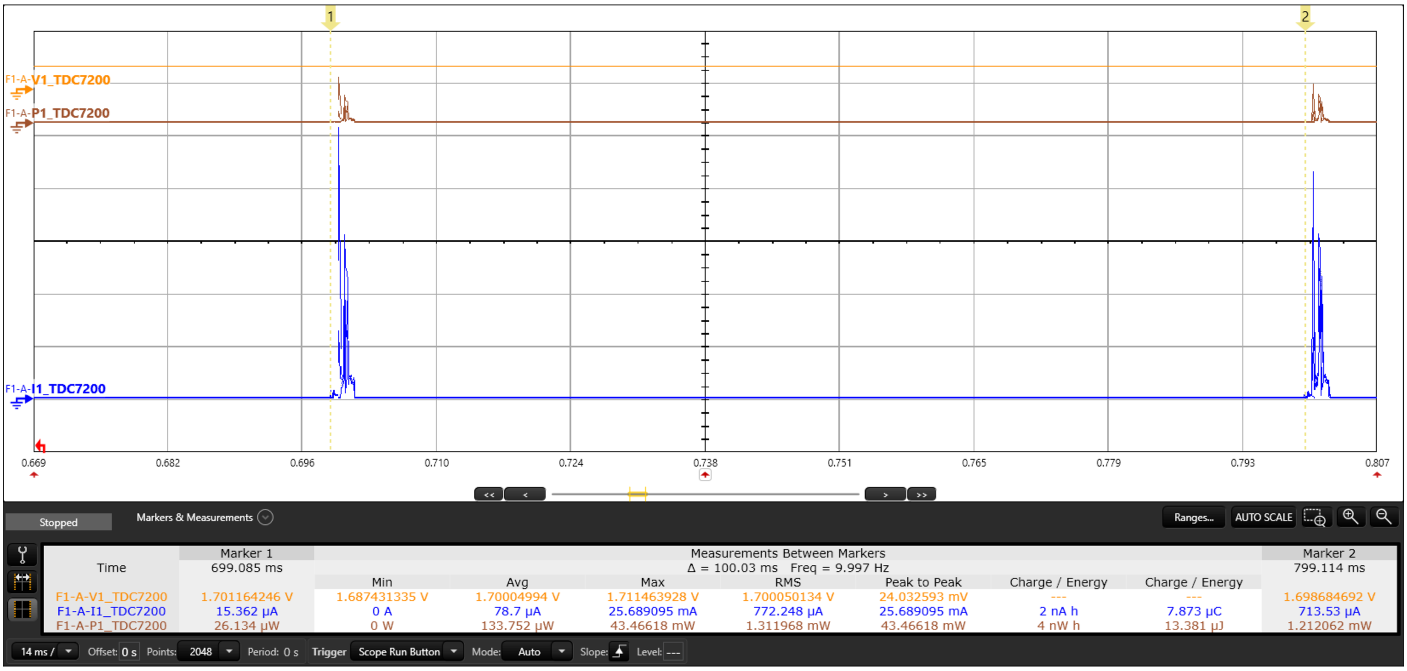


Fig. 12. Energy of Keep Alive connection. Cypress PSoC6 revD device (1.7 V, 100 ms). LDO activated

TABLE XVI. ENERGY NEEDED FOR THE CONNECTION EVENT (AVERAGING SEVERAL CYCLES, 100 MILLISECONDS, MINIMAL VOLTAGE)

Devices	**Parameters**					
	Measurement Voltage (V)	***Event cycles (ms)***	***Average current (uA)***	***Energy (mJ)***	***Energy per cycle(uJ)***	***Remarks***
RSL10	1.12	100 ms for 1 min				LDO on, LF RC
RSL10	1.12	100 ms for 1 min				DCDC off, LF RC
RSL10	1.12	100 ms for 1 min	64.16	4.31	7.19	LDO on, LF XTAL
RSL10	1.12	100 ms for 1 min				DCDC off, LF XTAL
DA14581	2.35	100 ms for 1 min	63.46	8.95	14.92	OTP, DCDC enabled, LF XTAL
TC35678	1.8	100 ms for 1 min	70.12	7.57	12.62	DCDC on, LF XTAL
QN9080	1.62	100 ms for 1 min	170.97	16.62	27.70	DCDC on, LF XTAL
NRF52810	1.7	100 ms for 1 min				no code available
NRF52840	1.7	100 ms for 1 min	53.60	5.47	9.11	DCDC on
NRF52840	1.7	100 ms for 1 min				DCDC off
EM9304 SD	1.8	100 ms for 1 min	93.70	10.12	16.87	DCDC on, LF RC
EM9304 SU	1.05	100 ms for 1 min	116.79	7.36	12.26	Step Up, LF RC
EM9304 SU	1.5	100 ms for 1 min	130.76	11.77	19.61	Step Up, LF XTAL
EM9304 SU	1.05	100 ms for 1 min	117.55	7.05	12.34	Step Up, LF XTAL
RL78/G1D	1.8	100 ms for 1 min				DCDC on, LF On Chip OSC
RL78/G1D	1.8	100 ms for 1 min	182.61	20.81	34.69	DCDC off, LF On Chip OSC
ATBTLC1000	1.9	100 ms for 1 min	67.22	7.26	12.10	DCDC on, LF XTAL
PSoC6_revA	1.8	100 ms for 1 min	107.28	11.88	19.80	DCDC on (0.9 V), LF XTAL
PSoC6_revD	1.7	100 ms for 1 min	63.12	6.44	10.73	DCDC on (0.9 V), LF XTAL
BGM113	1.85	100 ms for 1 min	107.28	11.88	19.80	DCDC on, LF XTAL
CC2652R	1.8	100 ms for 1 min	155.91	16.84	28.06	DCDC on, LF XTAL
icyTRX	1.3	100 ms for 1 min				no code for connected mode available

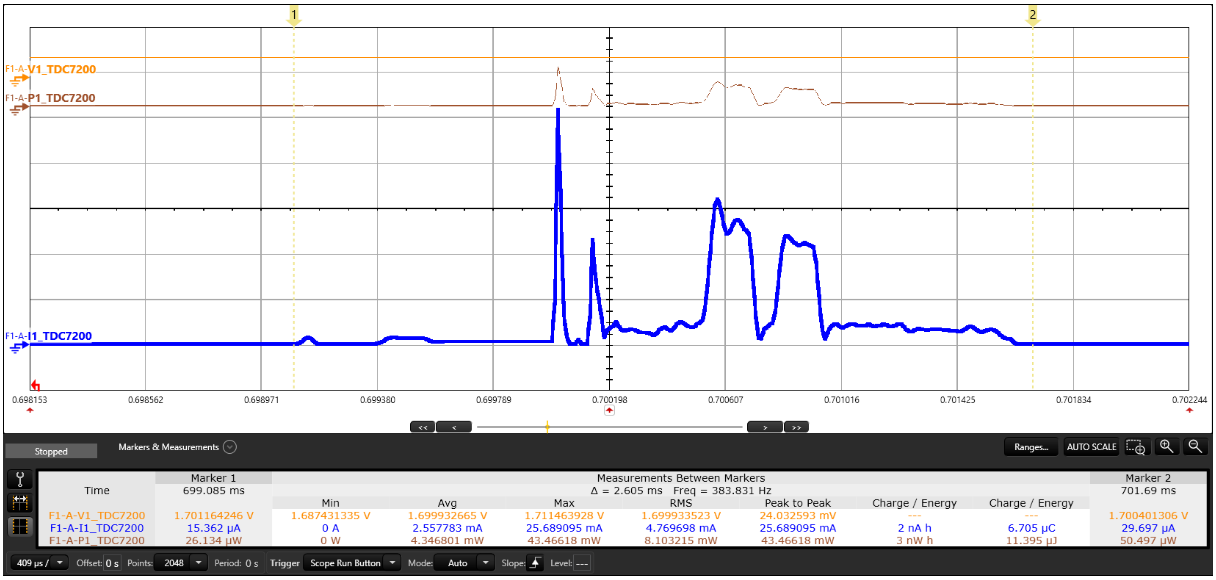


Fig. 13. Energy of Keep Alive connection. Cypress PSoC6 revD device (1.7 V, 100 ms). LDO activated. Zoom on active part

TABLE XVII. ENERGY NEEDED FOR THE CONNECTION EVENT (AVERAGING SEVERAL CYCLES, 1000 MILLISECONDS, 3 V)

Devices	Parameters					
	Measurement Voltage (V)	*Event cycles (ms)*	*Average current (uA)*	*Energy (mJ)*	*Energy per cycle(uJ)*	*Remarks*
RSL10	3	1000 ms for 1 min				DCDC on, LF RC
RSL10	3	1000 ms for 1 min				DCDC off, LF RC
RSL10	3	1000 ms for 1 min	3.56	0.64	10.67	DCDC on, LF XTAL
RSL10	3	1000 ms for 1 min				DCDC off, LF XTAL
DA14581	3	1000 ms for 1 min	9.97	1.80	29.92	OTP, DCDC enabled, LF XTAL
TC35678	3	1000 ms for 1 min	9.66	1.74	28.98	DCDC on, LF XTAL
QN9080	3	1000 ms for 1 min	7.20	1.30	21.59	DCDC on, LF XTAL
NRF52810	3	1000 ms for 1 min				no code available
NRF52840	3	1000 ms for 1 min	7.22	1.30	21.66	DCDC on
NRF52840	3	1000 ms for 1 min				DCDC off
EM9304 SD	3	1000 ms for 1 min	8.94	1.61	26.81	DCDC on, LF RC
RL78/G1D	3	1000 ms for 1 min				DCDC on, LF On Chip OSC
RL78/G1D	3	1000 ms for 1 min				DCDC off, LF On Chip OSC
ATBTLC1000	3	1000 ms for 1 min	18.77	3.38	56.27	DCDC on, LF XTAL
PSoC6_revA	3	1000 ms for 1 min	19.57	3.52	58.73	DCDC on (0.9 V), LF XTAL
PSoC6_revD	3	1000 ms for 1 min	13.93	2.51	41.78	DCDC on (0.9 V), LF XTAL
BGM113	3	1000 ms for 1 min	13.05	2.35	39.17	DCDC on, LF XTAL
CC2652R	3	1000 ms for 1 min	12.69	2.29	38.08	DCDC on, LF XTAL
icyTRX	3	1000 ms for 1 min				no code for connected mode available

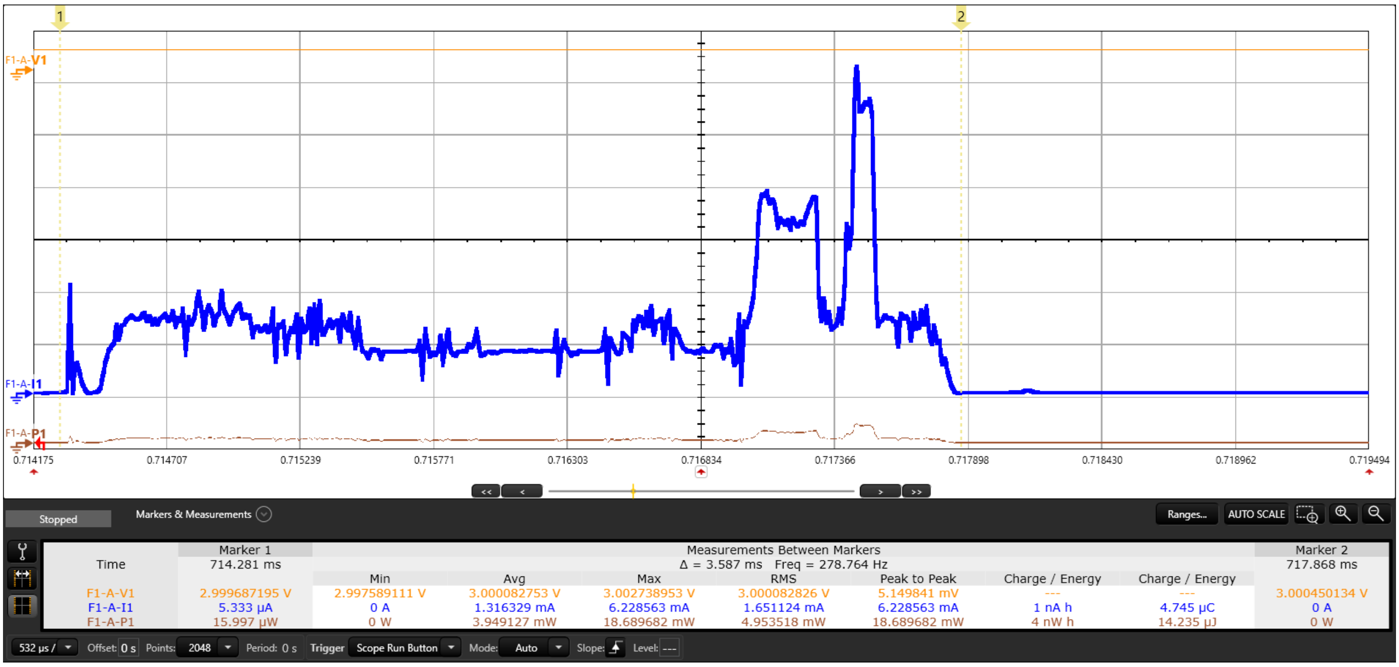


Fig. 14. Energy of Keep Alive connection. EM9304 SD (3 V, 100 ms). Zoom on active part

TABLE XVIII. ENERGY NEEDED FOR THE CONNECTION EVENT (AVERAGING SEVERAL CYCLES, 1000 MILLISECONDS, MINIMAL VOLTAGE)

Devices	Parameters					
	Measurement Voltage (V)	***Event cycles (ms)***	***Average current (uA)***	***Energy (mJ)***	***Energy per cycle(uJ)***	***Remarks***
RSL10	1.12	1000 ms for 1 min				LDO on, LF RC
RSL10	1.12	1000 ms for 1 min				DCDC off, LF RC
RSL10	1.12	1000 ms for 1 min	9.61	0.65	10.76	LDO on, LF XTAL
RSL10	1.12	1000 ms for 1 min				DCDC off, LF XTAL
DA14581	2.35	1000 ms for 1 min	11.74	1.66	27.58	OTP, DCDC enabled, LF XTAL
TC35678	1.8	1000 ms for 1 min	11.95	1.29	21.52	DCDC on, LF XTAL
QN9080	1.62	1000 ms for 1 min	25.49	2.48	41.30	DCDC on, LF XTAL
NRF52810	1.7	1000 ms for 1 min				no code available
NRF52840	1.7	1000 ms for 1 min	8.60	0.88	14.62	DCDC on
NRF52840	1.7	1000 ms for 1 min				DCDC off
EM9304 SD	1.8	1000 ms for 1 min	14.93	1.61	26.88	DCDC on, LF RC
EM9304 SU	1.05	1000 ms for 1 min	17.15	1.08	18.01	Step Up, LF RC
EM9304 SU	1.5	1000 ms for 1 min	14.44	1.30	21.66	Step Up, LF XTAL
EM9304 SU	1.05	1000 ms for 1 min	15.08	0.95	15.84	Step Up, LF XTAL
RL78/G1D	1.8	1000 ms for 1 min				DCDC on, LF On Chip OSC
RL78/G1D	1.8	1000 ms for 1 min				DCDC off, LF On Chip OSC
ATBTLC1000	1.9	1000 ms for 1 min	25.04	2.85	47.55	DCDC on, LF XTAL
PSoC6_revA	1.8	1000 ms for 1 min	23.79	2.57	42.83	DCDC on (0.9 V), LF XTAL
PSoC6_revD	1.7	1000 ms for 1 min	18.93	1.93	32.18	DCDC on (0.9 V), LF XTAL
BGM113	1.85	1000 ms for 1 min	16.69	1.85	30.83	DCDC on, LF XTAL
CC2652R	1.8	1000 ms for 1 min	19.65	2.12	35.37	DCDC on, LF XTAL
icyTRX	1.3	1000 ms for 1 min				no code for connected mode available

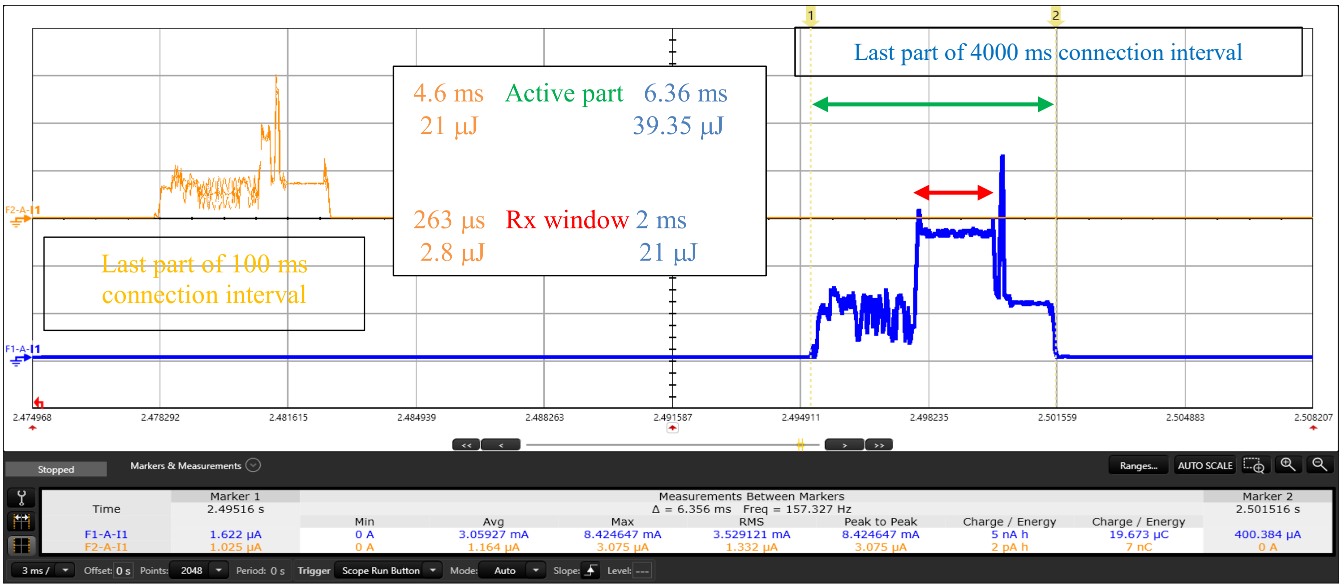


Fig. 15. Effect of clock accuracy on energy. Keep Alive connection of EM9304 SD RC (at 2 V). Zoom on active parts. The Rx window is larger for 4000 ms conn. Interval, compared to 100ms. The RC clock is not very accurate, leading to a higher wait time andmore energy for long connection intervals.

TABLE XIX. ENERGY NEEDED FOR THE CONNECTION EVENT (AVERAGING SEVERAL CYCLES, 4000 MILLISECONDS, 3 V)

Devices	Parameters					
	Measurement Voltage (V)	***Event cycles (ms)***	***Average current (uA)***	***Energy (mJ)***	***Energy per cycle(uJ)***	***Remarks***
RSL10	3	4000 ms for 1 min				DCDC on, LF RC
RSL10	3	4000 ms for 1 min				DCDC off, LF RC
RSL10	3	4000 ms for 1 min	2.05	0.37	24.63	DCDC on, LF XTAL
RSL10	3	4000 ms for 1 min				DCDC off, LF XTAL
DA14581	3	4000 ms for 1 min	6.33	1.14	75.97	OTP, DCDC enabled, LF XTAL
TC35678	3	4000 ms for 1 min	6.42	1.16	77.00	DCDC on, LF XTAL
QN9080	3	4000 ms for 1 min	5.00	0.90	60.02	DCDC on, LF XTAL
NRF52810	3	4000 ms for 1 min				no code available
NRF52840	3	4000 ms for 1 min	4.50	0.81	53.98	DCDC on
NRF52840	3	4000 ms for 1 min				DCDC off
EM9304 SD	3	4000 ms for 1 min	4.25	0.77	51.01	DCDC on, LF RC
EM9304 SD	3	4000 ms for 1 min	2.97	0.53	34.99	DCDC on, LF XTAL
RL78/G1D	3	4000 ms for 1 min				DCDC on, LF On Chip OSC
RL78/G1D	3	4000 ms for 1 min				DCDC off, LF On Chip OSC
ATBTLC1000	3	4000 ms for 1 min	8.34	1.50	99.92	DCDC on, LF XTAL
PSoC6_revA	3	4000 ms for 1 min	16.58	2.99	199.03	DCDC on (0.9 V), LF XTAL
PSoC6_revD	3	4000 ms for 1 min	11.18	2.01	134.16	DCDC on (0.9 V), LF XTAL
BGM113	3	4000 ms for 1 min	7.03	1.26	84.00	DCDC on, LF XTAL
CC2652R	3	4000 ms for 1 min	5.20	0.94	62.33	DCDC on, LF XTAL
icyTRX	3	4000 ms for 1 min				no code for connected mode available

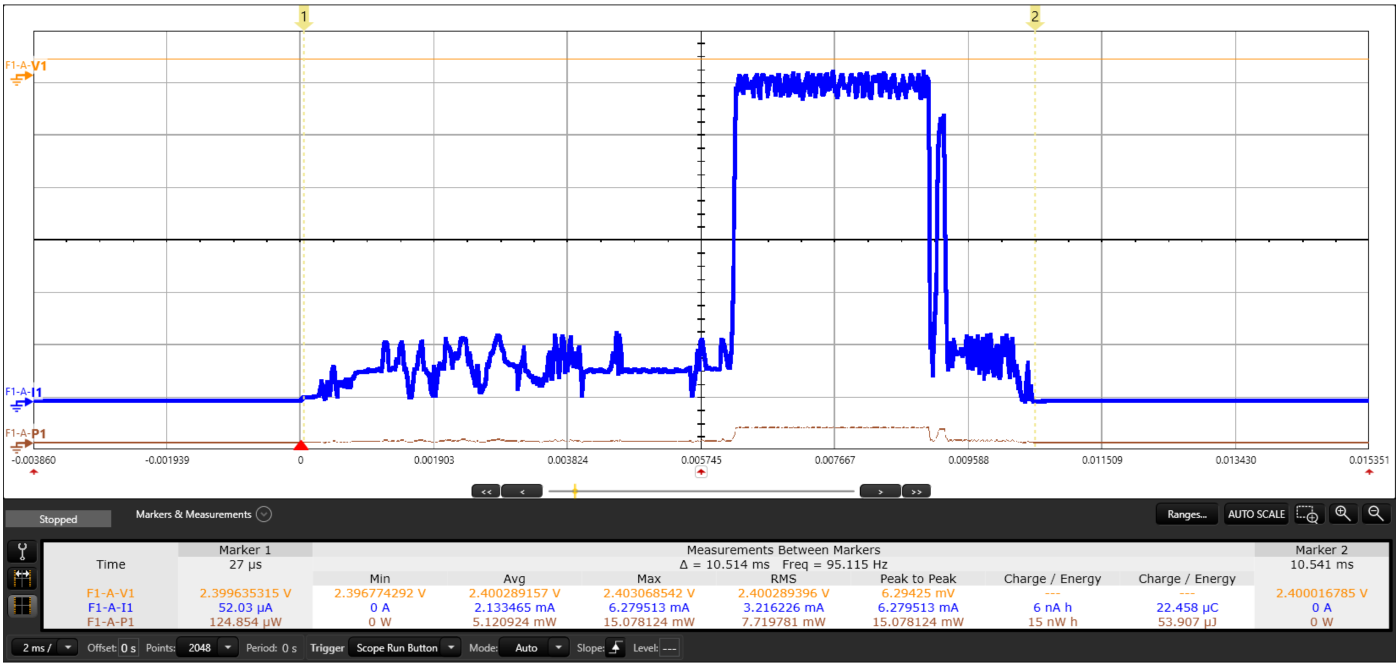


Fig. 16. Energy of Keep Alive connection. Dialog DA14581 device (2.35 V, connection interval of 4000 ms). Zoom on active part

TABLE XX. ENERGY NEEDED FOR THE CONNECTION EVENT (AVERAGING SEVERAL CYCLES, 100 MILLISECONDS, MINIMAL VOLTAGE)

Devices	Parameters					
	Measurement Voltage (V)	***Event cycles (ms)***	***Average current (uA)***	***Energy (mJ)***	***Energy per cycle(uJ)***	***Remarks***
RSL10	1.12	4000 ms for 1 min				LDO on, LF RC
RSL10	1.12	4000 ms for 1 min				DCDC off, LF RC
RSL10	1.12	4000 ms for 1 min	5.27	0.35	23.62	LDO on, LF XTAL
RSL10	1.12	4000 ms for 1 min				DCDC off, LF XTAL
DA14581	2.35	4000 ms for 1 min	7.38	1.04	69.33	OTP, DCDC enabled, LF XTAL
TC35678	1.8	4000 ms for 1 min	7.61	0.82	54.80	DCDC on, LF XTAL
QN9080	1.62	4000 ms for 1 min	12.45	1.21	80.67	DCDC on, LF XTAL
NRF52810	1.7	4000 ms for 1 min				no code available
NRF52840	1.7	4000 ms for 1 min	4.88	0.50	33.20	DCDC on
NRF52840	1.7	4000 ms for 1 min				DCDC off
EM9304 SD	1.8	4000 ms for 1 min	6.72	0.73	48.37	DCDC on, LF RC
EM9304 SD	1.8	4000 ms for 1 min	4.34	0.47	31.22	DCDC on, LF XTAL
EM9304 SU	1.05	4000 ms for 1 min	7.68	0.48	32.26	Step Up, LF RC
EM9304 SU	1.5	4000 ms for 1 min	4.88	0.44	29.27	Step Up, LF XTAL Too high energy at startup
EM9304 SU	1.05	4000 ms for 1 min	5.45	0.34	22.90	Step Up, LF XTAL Energy too high at startup fot this test
RL78/G1D	1.8	4000 ms for 1 min				DCDC on, LF On Chip OSC
RL78/G1D	1.8	4000 ms for 1 min				DCDC off, LF On Chip OSC
ATBTLC1000	1.9	4000 ms for 1 min	10.96	1.25	83.20	DCDC on, LF XTAL
PSoC6_revA	1.8	4000 ms for 1 min	19.87	2.15	143.04	DCDC on (0.9 V), LF XTAL
PSoC6_revD	1.7	4000 ms for 1 min	15.37	1.57	104.52	DCDC on (0.9 V), LF XTAL
BGM113	1.85	4000 ms for 1 min	9.17	1.02	68.00	DCDC on, LF XTAL
CC2652R	1.8	4000 ms for 1 min	8.17	0.88	58.80	DCDC on, LF XTAL
icyTRX						no code for connected mode available

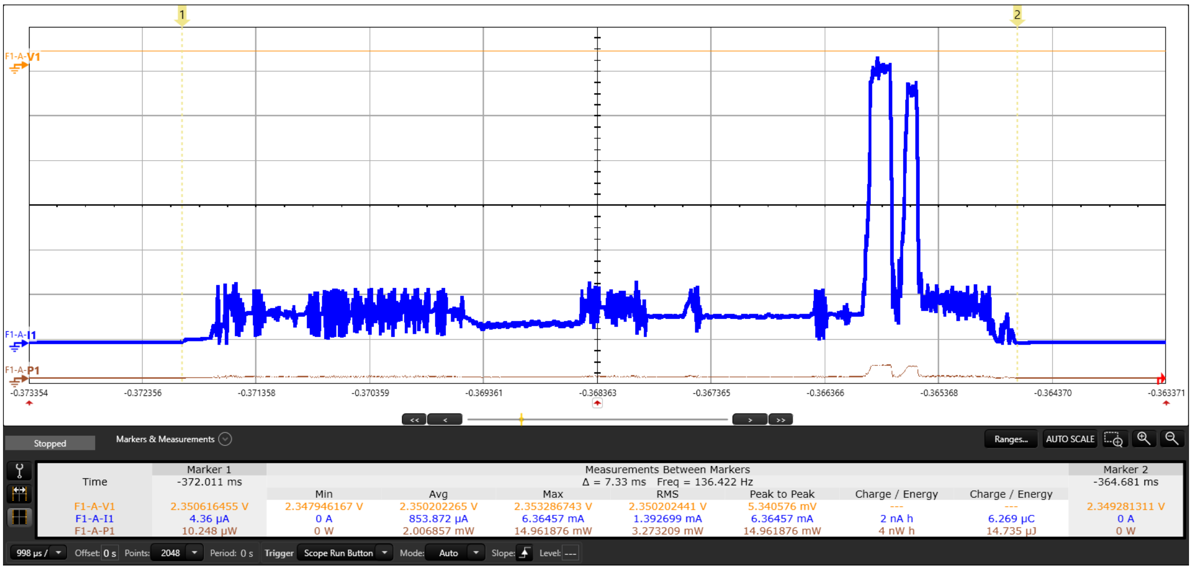


Fig. 17. Energy of Keep Alive connection. Dialog DA14581 device (2.35 V, connection interval of 100 ms). Zoom on active part

Power profiles of Apollo2 Blue

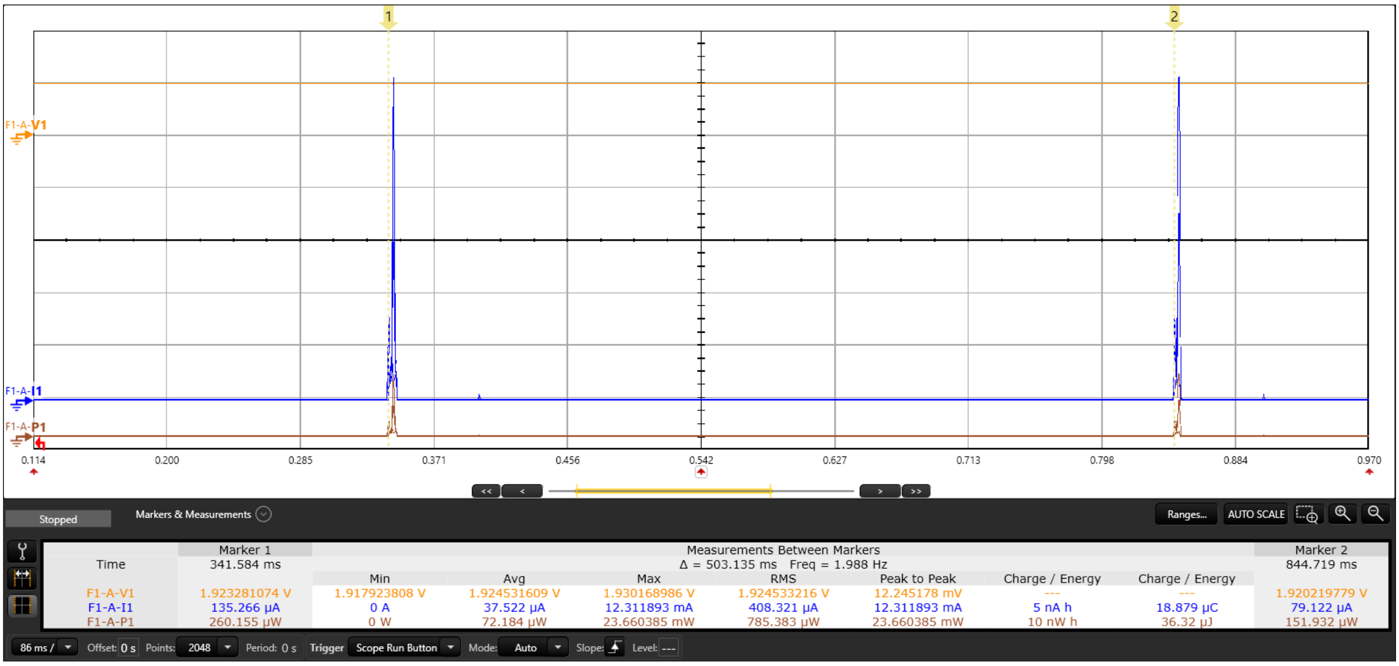


Fig. 18. Apollo2 Blue. Non-Conn ADV, 500ms, @1.92 V. 36.32 uJ, 503 ms

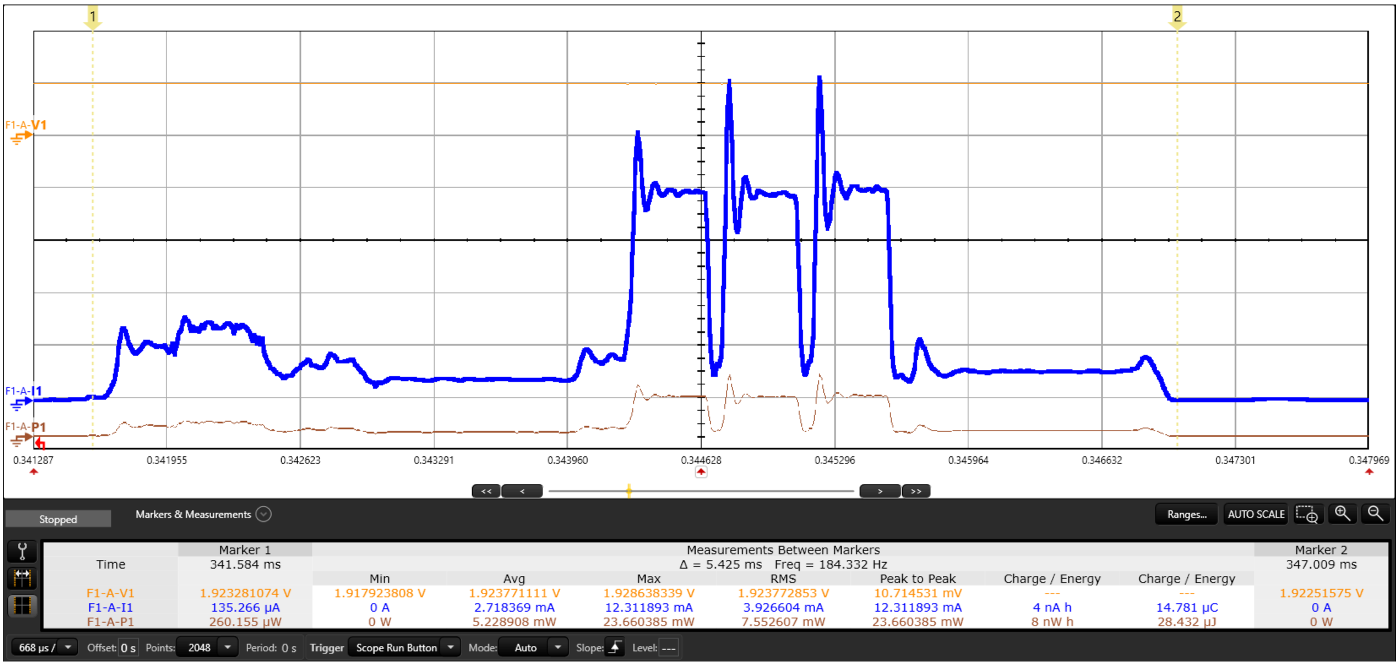


Fig. 19. Apollo2 Blue, Non-Conn ADV, 500ms, @1.92 V. 28.4 uJ, 5.42 ms. Zoom on ADV active part

P.nbr.	Time (us)	Channel	Access Address	Adv PDU Type	Adv PDU Header Type	TxAdd	RxAdd	PDU-Length	AdvA	AdvData	CRC	RSSI (dBm)	FCS
141	+100381 =19660075	0x25	0x8E89BED6	ADV NON CONN IND	2	0	0	37	0x68C90B089888	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00	0xBE4177	-42	OK
142	+100400 =19760475	0x25	0x8E89BED6	ADV NON CONN IND	2	0	0	37	0x68C90B089888	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00	0xBE4177	-39	OK
143	+100381 =19860856	0x25	0x8E89BED6	ADV NON CONN IND	2	0	0	37	0x68C90B089888	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00	0xBE4177	-38	OK

Fig. 20. ADV_NONCONN_IND format frame used for all devices (TI SmartRF Packet Sniffer)

P.nbr.	Time (us)	Channel	Access Address	Adv PDU Type	Adv PDU Header Type	TxAdd	RxAdd	PDU-Length	AdvA	AdvData	CRC	RSSI (dBm)	FCS
66	+107650 =7360006	0x25	0x8E89BED6	ADV IND	0	1	0	37	0xF6E3D717AFF4	03 19 00 00 02 01 06 17 09 4E 6F 72 64 69 63 5F 41 6C 65 72 74 5F 4E 6F 74 69 66 69 63 61 2E	0x491DB1	-36	OK
67	+104577 =7464583	0x25	0x8E89BED6	ADV IND	0	1	0	37	0xF6E3D717AFF4	03 19 00 00 02 01 06 17 09 4E 6F 72 64 69 63 5F 41 6C 65 72 74 5F 4E 6F 74 69 66 69 63 61 2E	0x491DB1	-36	OK
68	+105378 =7569961	0x25	0x8E89BED6	ADV IND	0	1	0	37	0xF6E3D717AFF4	03 19 00 00 02 01 06 17 09 4E 6F 72 64 69 63 5F 41 6C 65 72 74 5F 4E 6F 74 69 66 69 63 61 2E	0x491DB1	-36	OK

Fig. 21. ADV _IND format frame used for all devices (TI SmartRF Packet Sniffer)

XI. CONCLUSION

In this paper, we have presented results of energy consumption measurements made on various Bluetooth Smart solutions. Our focus was on devices that appeared on the market in the last 2 years. We also included older devices when we felt that their performances were still acceptable. The measurements provide information to help compare devices in various modes. Application engineers can use these results with the datasheets of the devices to determine what is suitable for their applications. IC manufacturers can use the results to improve their devices or Bluetooth stacks. The reader should not make a decision on the basis of this data alone. Several other parameters (as explained earlier in this work) should be considered.

Since new solutions are continuously appearing on the market, this work will be updated in the coming years. We readily consider the feedback of manufacturers and users for updates and improvements.

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