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AN031: Running RIIoT™ on Solar Energy

By: Omar Khalil

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Summary

To prove that RIIoT supports one of the most critical features of IoT, i.e., very low-power consumption, we removed all traditional power-sources from a RIIoT board and connected it to a solar panel. The result obtained is that in normal office-lighting conditions, with a 53 x 25 mm solar cell, a RIIoT leaf node can read sensors and send data to the gateway every 30 seconds.

Background

One of the main distinguishing features of IoT is that it promises a huge number of connected devices. Though, one can't envision a network of hundreds or thousands of devices where their batteries need to be replaced every week, as that would be totally inconvenient. Thus, low-power consumption is one of the main pillar stones to achieving true IoT networks.

In alignment with our policy to constantly pursue technological advances which would keep our solutions always up-to-date with the latest trends in technology, the R&D team at Radiocrafts has created a prototype circuit where we power a RIIoT sensor board from an energy-harvesting solar panel.

In this document, we demonstrate how the boards and connections are setup. We also present the relevant power and current parameters in addition to certain tweaks to run the same setup of the test on a smaller solar panel.

Test circuit setup

In Figure 1 the main components of an energy-harvesting system are shown. It consists of, a harvesting device (solar panel in our test setup), an-energy harvesting IC which converts the energy to usable voltage levels, a storage device (could be a chargeable battery or super capacitor) and a device that needs to be powered.

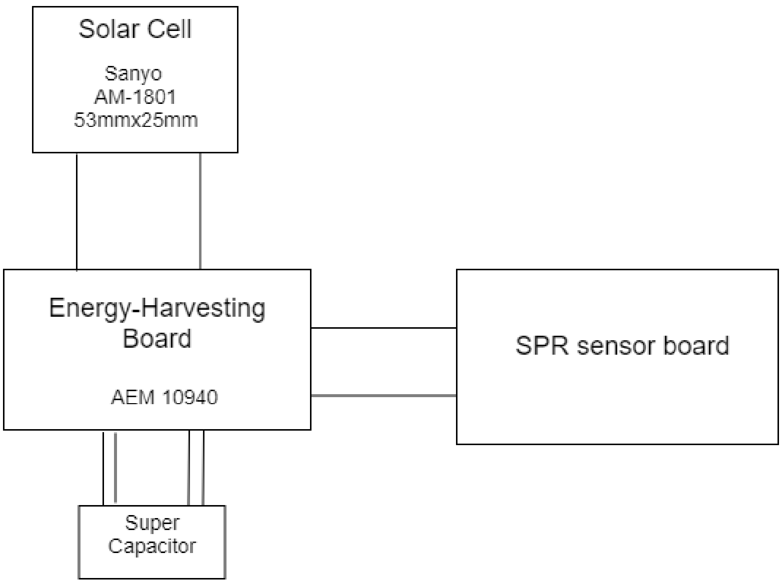

Figure 1. Block schematic of the test setup.

For our test scenario, we used:

1- Radiocraft's RIIoT sensor board containing the SPR module.
2- Sanyo AM-1801 solar cell.
3- E-peas AEM10940 Energy-harvesting board.
4- A super capacitor.

Sanyo AM-1801 solar cell

Solar cells generate power when light hits the surface of a semiconductor, with certain light intensity, causing movement of electron and proton pairs. Being a clean and cheap energy source, solar power is forecasted to replace fossil fuel. A number of technologies are available to create and build solar cells, one of which is the amorphous silicon solar cells, which Sanyo has been working with. Amorphous silicon solar cells are expected to be the new generation after the earlier crystalline silicon solar cells, as they allow for larger cell-surface areas than their predecessor.

As shown in Table 1, a variety of indoor solar cells models are available from Sanyo, for our application, we choose the AM-1801 as its voltage and current specification plus its size best suit our RIIoT sensor board.

Model	Typical operating characteristics (Initial)		External dimensions (mm)	Weight (g)
	FL-200lux	FL-50lux (Reference value)		
AM-1456	1.5V- 5.3μA	1.4V- 1.30μA	25.0X10.0	0.7
AM-1411	1.5V- 8.0μA	1.4V- 2.00μA	29.6X11.8	1.0
AM-1437	1.5V- 8.0μA	1.4V- 2.00μA	29.6X11.8	1.0
AM-1407	1.5V- 11.5μA	1.4V- 2.85μA	38.0X12.5	1.3
AM-1417	1.5V- 12.5μA	1.4V- 3.10μA	35.0X13.9	1.3
AM-1424	1.5V- 20.0μA	1.4V- 5.00μA	53.0X13.8	2.0
AM-1454	1.5V- 31.0μA	1.4V- 7.75μA	41.6X26.3	3.0
AM-1513	1.8V- 15.0μA	1.6V- 3.75μA	55.0X13.5	2.0
AM-1805	3.0V- 15.5μA	2.6V- 3.85μA	55.0X20.0	3.0
AM-1801	3.0V- 18.5μA	2.6V- 4.60μA	53.0X25.0	3.6
AM-1815	3.0V- 42.0μA	2.6V- 10.50μA	58.1X48.6	7.8
AM-1816	3.0V- 84.0μA	2.6V- 21.00μA	96.7X56.7	15.6

Table 1. Different Sanyo solar cells models and their respective specifications

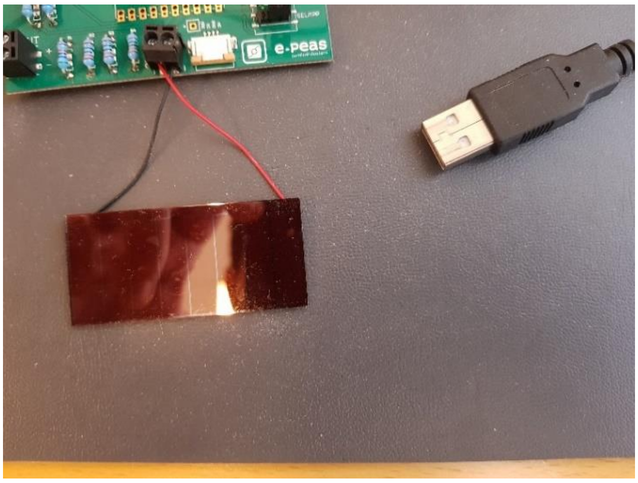

Figure 2. The AM-1801 solar cell with a reference to show its size compared to a USB connector

E-Peas AEM10940 Energy-Harvesting Board

The purpose of an energy-harvesting board is that it acts as an energy management subsystem. Typically, the output voltage from a PV (photovoltaic) cell is not stable nor regulated. Thus, an energy-harvesting board is needed to extract DC power from PV cells and to regulate the voltage which will then be used to charge an external power-saving device, such as a capacitor for example.

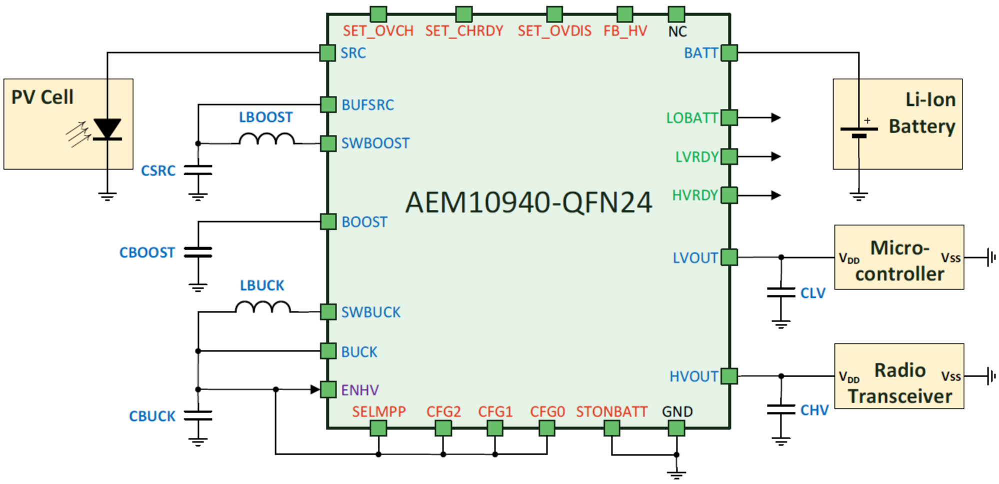

Figure 3. AEM10940 Circuit

The AEM10940 operates with available input currents of up to 25mA and its boost convertor operates with input voltages in the range of 100mV to 2.5V. The boost convertor is responsible for charging the energy-saving device (capacitor or battery). The board supports several configuration settings which can suit nearly all applications. Configurations can be chosen via four configuration pins, CFG0, CFG1, CFG2, and SELMPP. As shown in Table 2, the recommended setting when using a supercapacitor as an energy-storage device is to set the CFG2 pin to High and both CFG0 and CFG1 to Low.

Configuration pins			Charge Management Threshold Voltages			High voltage Output Voltage	Typical use
CFG2	CFG1	CFG0	*OverCharge*	*ChargeReady*	*OverDischarge*		
High	Low	Low	4.50 V	3.92 V	3.00 V	2.50 V	Capacitor, Supercapacitor
	Low	High	4.12 V	3.67 V	3.00 V	2.50 V	Li-Ion cell, 2.5 V radio
	High	Low	4.12 V	4.05 V	3.60 V	3.30 V	Solid State battery
	High	High	4.12 V	3.67 V	3.60 V	3.30 V	Li-Ion cell, 3.3 V radio
Low	Low	Low	As per R1, R2, R3, R4			As per R5,R6	Custom usage
Low	Low	High	Reserved for future revisions of the component. Do not set the configuration to these combinations.				
	High	Low					
	High	High					

Table 2. Configuration pins and their settings

Vitzrocell VSCM-series Super Capacitor

In general, there are two main ways to store electric power, either in rechargeable batteries or capacitor. However, each suffer its own drawback, Batteries can store relatively high amounts of energy but need much time to charge, whereas capacitors charge nearly instantly but can only store that little energy.

A middle-way solution is super capacitors, which differs from a regular capacitor in, the area of its plates which is much bigger in super capacitors, and the spacing between them which is much smaller in super capacitors.

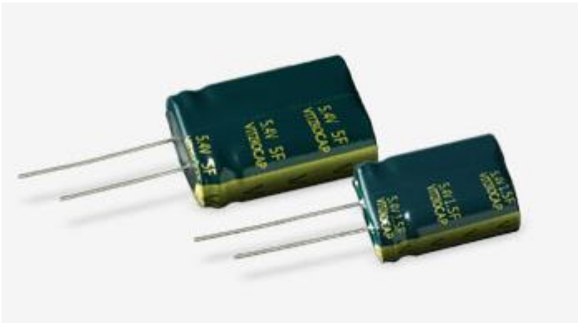

Figure 4. Super Capacitors

Power Generation Calculations

Many resources are available to try to estimate the correct illuminance (lux) value in an indoor environment. For the sake of simplicity, we can assume lux values are around 150 in deep indoor well-lighted environments, while this value might jump to 200 lux when assuming a solar cell is placed in a well-lighted office next to a window in an average (not so sunny nor so dark) day. These values are low, true values might be higher than this, but for the purpose of this document it is more practical to assume least lighting conditions to have a long margin when concluding power consumption.

According to the Solar Cell AM1801 data sheet (https://www.mouser.com/ds/2/315/EP120B-775610.pdf), the solar cell is able to generate a maximum power of 7µW for every cm^2. In our case, the solar cell's size is 5.3cm^2 x 2.5cm^2, which means the output power of the solar cell when assuming 200 lux is 92.75µW.

Typical Cell Characteristics (25°C)

Open-circuit voltage	Short-circuit current	Maximum output	Light source
0.63 V/cell	17.0µA/cm^2	7.0µW/cm^2	FL200lux

Table 3. Power characteristics of the solar panel used

By following Figure 3 we can trace the output power of the solar cell till it is translated to actual consumed current by RIIoT's sensor board. Output power from the solar cell goes through an 80%-efficiency boost converter, to boost the voltage to a level sufficient to charge the super capacitor. The super capacitor receives 74.2µW, it draws 8µW and thus the buck converter receives 66.2µW in its input. The buck converter lowers the voltage to a certain (configurable through previously mentioned pins) limit. As its efficiency is 70%, the remaining power entering the RIIoT sensor board is reduced to 46.34 µW. Knowing that the sensor board has a 2.5V, we can deduce that the maximum current delivered to the RIIoT sensor board is 18.563 µA.

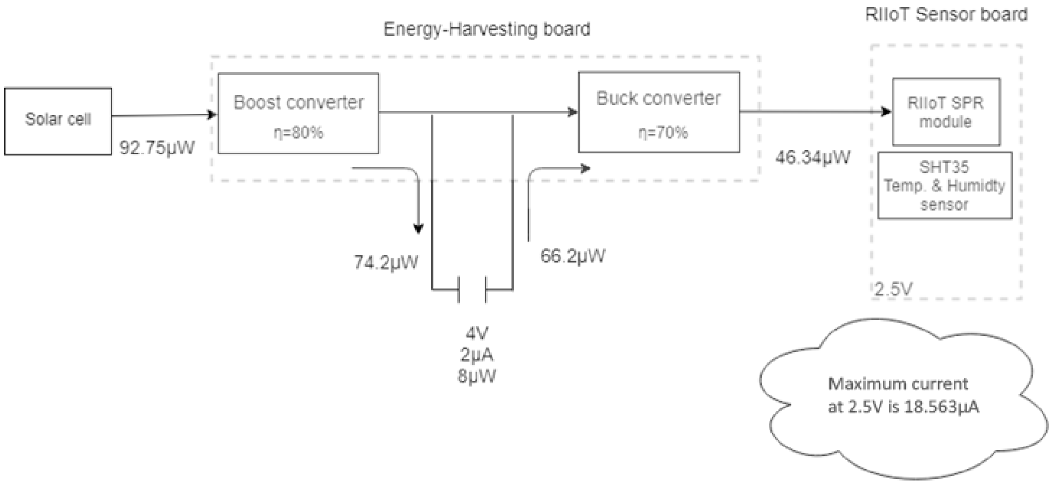

Figure 3. Power and efficiency calculations

Power consumption calculation

RIIoT is optimized for low current consumption and usage with coin cell battery or energy-harvesting. Using the sensor running and the temperature/humidity reading example, we modified the example code to read the sensor every 30 seconds and configured the device as a sleepy device.

The board was powered from a 2.5V source and the dynamic current consumption was measured, during sensor reading, transmission, and reception.

Based on this measurement the current used during a sensor read + radio transmission is 0.41 mA /second. If this is done every 30 seconds, it gives an average current consumption of 13.7 µA.

$$I_{Avg} = \frac{0.41\ mA*s}{T}$$

Where:

I_{Avg}: Average current consumed
T= Time between sensor readings

Adding in the contribution from sleep current of max 2 µA, the overall current consumption is 15.7 µA.

This proves that the test setup used generates enough energy to power the sensor application with 30 second update rate.

The use case was also verified during a real operation over 3 days. Voltage at the super-cap increased during the day as the lighting was > 200 LUX, and during night the voltage dropped as the energy generated in low light was lower than estimated above.

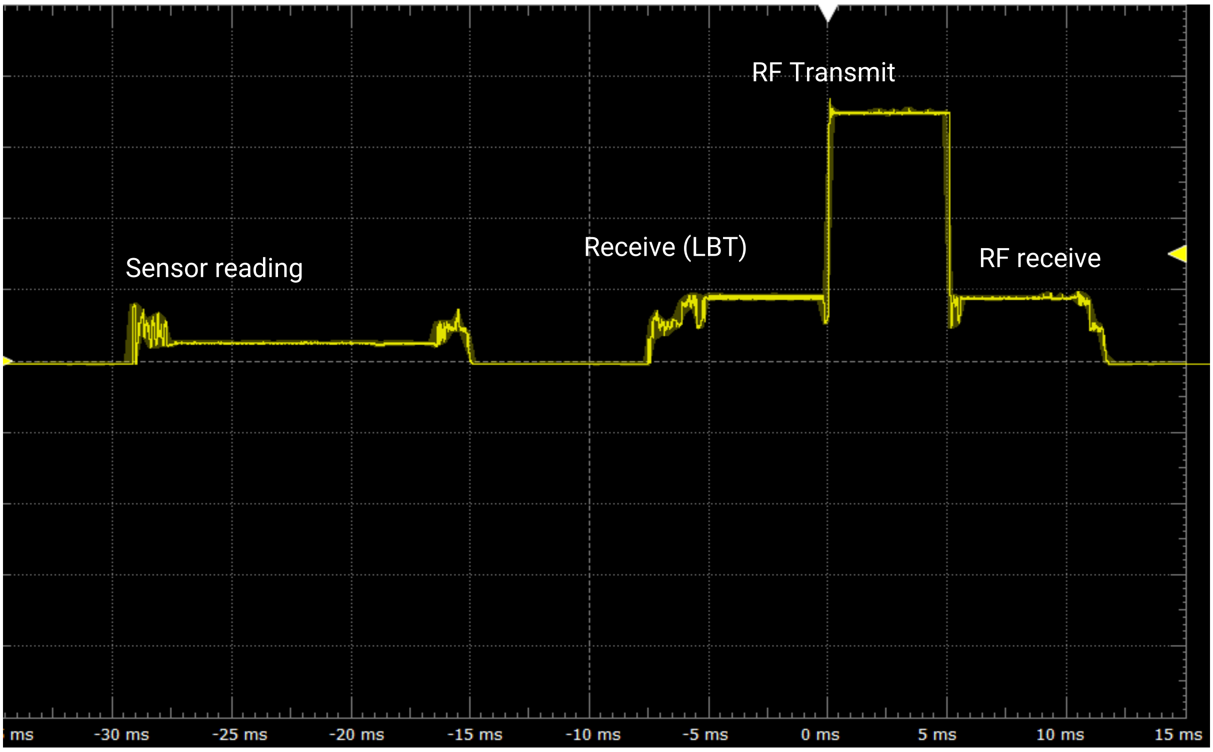

Figure 4. Current consumption profile in one sensor reading + RF transmission

Trade-offs

As you already know by now, the two most important parameters in this setup, or in fact in any solar-cell-powered application, are, the power generated, and the power consumed. When the generated power is more, the circuit works, otherwise it does not. Thus, any tweaks to enhance system performance should be done on these two parameters.

To apply this on our setup, the power generated is simply just a function of the solar-cell's surface area, assuming fixed lighting conditions. Whereas the power consumed is a function of:

1- Transmission power.
2- Frequency of transmissions.
3- Operation mode (sleepy or continuously awake).

In our setup, we used 14 dBm transmission power for sending sensor readings every 30 seconds and the module was set to "sleepy", which means it went to sleep between each transmission. However, a user can manipulate the 4 critical parameters above to make it better suit his own application. For example, in an environment where a user has much space, a bigger solar cell can be used, which will generate more power. Or, maybe a use-case does not need transmissions every 30 seconds, in that case, a user might extend the period between transmissions and use a smaller solar cell.

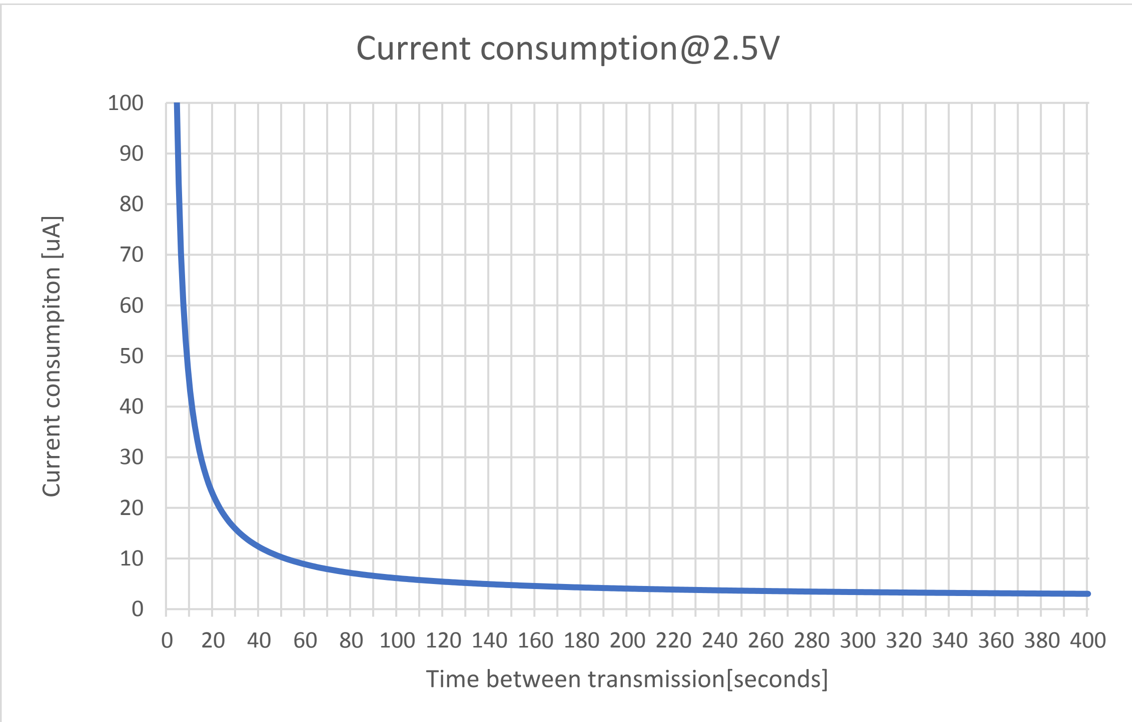

Figure 7. Average current consumption vs. sensor polling rate.

Document Revision History

Document Revision	Changes
1.0	First release

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