RF-Energy Harvester and Its Applications in IoT: A Review

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***Abstract*—In IoT applications, battery-constrained devices face an important and crucial challenge that their lifespan depends solely on their batteries. Extending this lifespan is a key challenge. Fortunately, various energy harvesting methods such as RF, solar, thermal etc., can help to extend lifespan of such devices. Various companies prepare energy harvesting integrated circuits (ICs) using these methods. One of such company, the Powercast has developed the P2110B radio frequency-energy harvesting integrated circuit (RF-EH IC) along with an evaluation board P2110B-EVB (evaluation board). This evaluation board offers flexibility for practical and research purposes. This paper offers a comprehensive review of the RF-EH IC (P2110B) and its evaluation board (P2110B-EVB). The paper explored the configuration of P2110B-EVB for regulated output voltage using different switches (S1, S2, S3 and S4) along with various application where it can be used. A comparative analysis of similar types of RF-EH ICs from various companies has been included, which simplifying the selection and decision-making process. An experiment also performed using P2110B-EVB (evaluation board) as a power source. This information helps as a valuable resource for researchers who are exploring and needs energy harvesting for IoT devices and its various applications.**

Keywords: Energy Harvester, Integrated Circuits, Evaluation Board, Configuration, Powercast.

I. INTRODUCTION

The Internet of Things (IoT) is an extensive network that interconnects billions of devices across various applications, including smart agriculture, smart vehicles, smart homes, smart pollution control, smart healthcare, smart cities, and smart retail. These devices connect real-world to cyber world to exchange information [1-2]. These devices are battery operated and network of such devices consumes a substantial amount of energy during information exchange, leading to several critical issues such as rapid energy source depletion, and shortened device lifespans. The battery replacement is difficult in remote area. Energy harvesters are lifesaver at such remote area. Several companies such as Powercast, e-peas etc., offer energy harvesting ICs (Integrated Circuits) using radio frequency, solar, piezoelectric, thermal energy which are suitable for low-power devices [3-6]. These companies also offer evaluation boards designed for research and testing purposes, providing a comprehensive solution for exploring energy harvesting capabilities. One of these company Powercast, develops radio frequency energy harvesting ICs such as P2110B, P1110 etc. and evaluation board using these ICs which can be used for testing purpose and in different applications [7].

This paper provides a review of radio frequency energy harvesting integrated circuit (RF-EH IC) P2110B and its evaluations board P2110B-EVB along with its applications. It will be helpful for those who want to explore, and do research in the area of sustainable IoT using RF energy harvesting. The P2110B can be used in low-power devices and various remote area's applications, where battery replacement is difficult. The P2110B-EVB provides facility to perform experiment and testing for various research purposes.

The rest of the paper is arranged as follows: a brief description of P2110B integrated circuit, its block diagram and key features are discussed in Section II. Section III presents and discusses about P2110B-evaluation board. The Application of P2110B are discussed in Section IV and further P2110B is compared with of similar type of RF-EH ICs in Section V. An experiment using P2110B-EVB as a power supply is present in Section VI and Section VII concludes the review.

II. RF-ENERGY HARVESTER INTEGRATED CIRCUIT OF POWERCAST (P2110B)

The Powercast P2110B Powerharvester is an RF energy harvesting IC designed to efficiently convert radio frequency (RF) signals into direct current (DC) power (shown in Fig. 1) [8]. It is a compact IC. The P2110B receiver serves as an important component for enabling battery-free, ultra-low-power devices. Its primary function involves the conversion of RF energy into DC power, which is subsequently stored in a capacitor as shown in Fig. 2. Once a specific charge level is reached on the capacitor, the P2110B activates, regulating the voltage to the predefined output level and enabling the output. On the other hand, when the charge on the capacitor diminishes to a designated lower voltage threshold, the voltage output is automatically deactivated. To further enhance system performance, it is possible to integrate a microprocessor, which can optimize power utilization from the P2110B and gather additional data from the device, contributing to overall system enhancement and efficiency.

The block diagram of P2110B is shown in Fig.2, highlights the two crucial components: the PCC110 RF-to-DC (radio-frequency to direct current) converter and the PCC210 boost converter [8,9].

The P2110B functions by receiving RF energy as an input, which is directed to the RF-to-DC converter IC (PCC110). PCC110 converts RF energy to direct current. The output of voltage can be stored in a capacitor linked to V_{cap} or directed towards the boost converter (PCC210).

The boost converter typically delivers a default output of 3.3V at V_{out}, however this can be adjusted by incorporating resistors into V_{set}. The voltage can be decrease or increase based on the value of the resistor, which is calculated as per the following equations (1) and (2) [8, 9]:

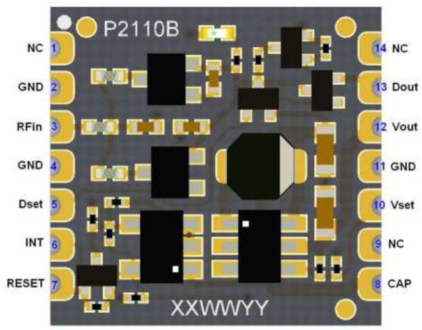

Fig. 1 Powercast P2110B IC with Pinout [8]

To decrease the voltage V_{out} :

$$R = \frac{1M(V_{out} - 1.21)}{(3.32 - V_{out})} \quad (1)$$

To increase the voltage V_{out} :

$$R = \frac{1.21M}{(V_{out} - 3.32)} \quad (2)$$

Where $M=10^6$, V_{out} refers to the required output voltage. The output voltage can be varied from 2.0 to 5.5V.

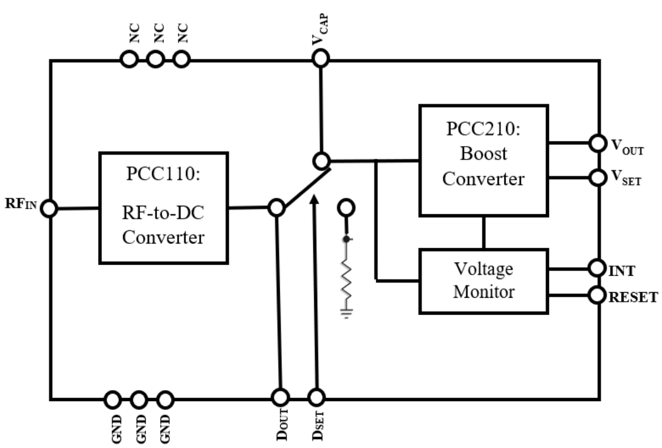

Fig. 2 Block diagram of P2110B [8]

The INT pin serves as an indicator of the boost converter's operational status, while a reset pin can be employed to deactivate the converter if needed. Additionally, the D_{SET} pin offers the option to disconnect the boost converter from the RF-to-DC block, facilitating direct energy measurements from the D_{out} pin. The block diagram explains the internal component that make this IC efficient and effective for RF- energy harvesting. However, it's essential to know about the P2110B's key features for efficient utilization, which are described as following [8]:

- *Impressive Conversion Efficiency*: Demonstrates high efficiency in converting RF signals into usable DC power.
- *Enables Long-Range Applications:* Capable of converting low-level RF signals, making it suitable for applications requiring extended transmission distances.
- *Stable Voltage Output:* Provides regulated voltage output, supporting levels of up to 5.5 volts.
- *Decent Output Current*: Offers a maximum output current of up to 50mA, accommodating the power needs of various devices.
- *Signal Strength Indication*: Includes a received signal strength indicator, aiding in signal monitoring and assessment.
- *Wide RF Operating Range*: Operates over a broad RF frequency range, enhancing versatility.
- *Low Input Signal Tolerance*: Capable of operation with input signals as low as -12 dBm.
- *Microprocessor Control*: Externally resettable, allowing for convenient control via a microprocessor.
- *Industrial-Grade Temperature Range:* Designed to operate reliably within an industrial temperature range.
- *Environmentally Compliant*: Complies with RoHS (Restriction of Hazardous Substances) standards, contributing to environmentally friendly product design.

After having the knowledge of key features, its easy to decide in which application, and where it can be used. Also, how to use it to develop prototype for research purpose. Moreover, the Powercast provides evaluation board for P2110B, specifically designed for research and testing, delivering a complete solution for investigating energy harvesting capabilities. The following section, discuss about P2110B-evaluation board.

III. Energy Harvesting Board (P2110-EVB)

The P2110B IC is embedded on a board as shown in the Fig. 3 and this energy harvester board equipped with four onboard switches: S1, S2, S3, and S4. S1 plays an important role in regulating the voltage sourced from the internal rectifier within the Powercast module [5, 10-12]. It offers three voltage settings: 4.2V, 3.3V, or ADJ, which allows for fine-tuning via resistors R5 and R6. Switch S2, on the other hand, dictates the power's destination. The power can be directed towards the LED, MEAS, or VCC. Opting for the "LED" setting activates an onboard LED, while selecting "MEAS" routes power to S3. Meanwhile, "VCC" directs power to S4. The S4 switch, having three modes – "OFF," "BATT," and "C6," serves distinct functions. "OFF" disrupts the circuit, effectively shutting down the Powercast. "BATT" channels power to the BATT terminals, primarily for battery charging purposes. Notably, "C6" refers to a 50mF supercapacitor, as detailed in the evaluation board's instruction manual. This supercapacitor's primary role is to stabilize the rectifier's output into a consistent DC voltage, thereby facilitating precise measurements taken from the capacitor. These switches collectively enable versatile control and utilization of harvested energy in any system. The battery charging, capacitor charging or direct power supply to low-power devices is possible with configuration of these switches.

After proper configuration of different switches, the energy harvester board useful in both research experiments and various applications [13,14]. It serves a variety of purposes related to such area where batteries and low power devices are used. A few of such purposes and applications will be explored in the following section.

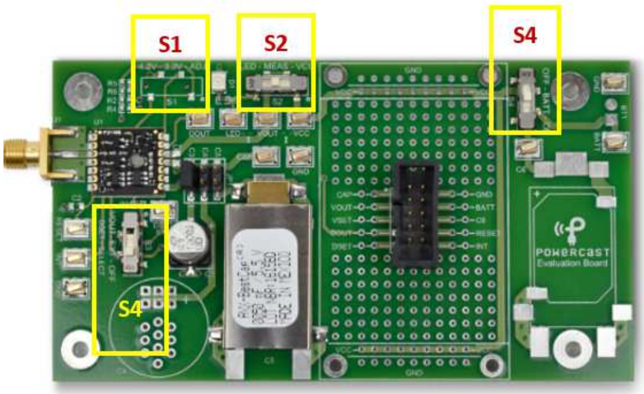

Fig. 2 Powercast P2110B-EVB board for Energy Harvesting

IV. Applications of RF- Energy Harvester (P2110B)

The P2110B and P2110-EVB have the capability to fulfil various purposes, such as enabling battery-free operation, powering low-power devices, etc., across a wide variety of applications. A few of them are discussed here.

A. Battery-free wireless sensors

The Powercast P2110B Powerharvester serves as a pivotal technology for battery-free wireless sensors in a multitude of sectors. From industrial monitoring and smart grid applications that demand constant data acquisition, to defense and building automation where reliable power sources are vital, this technology eliminates the reliance on traditional batteries. Moreover, in the oil and gas industry, where remote and rugged environments require efficient and self-sustaining sensor systems, the P2110B Powerharvester's capacity to convert RF energy into power proves to be a game-changer [8]. Overall, it underscores its versatility and indispensable role in propelling innovation across diverse domains.

B. Battery recharging

The Powercast P2110B Powerharvester is adept at battery recharging, catering to coin cells and thin-film cells. For coin cells, commonly used in small electronic devices, the P2110B Powerharvester offers a sustainable means of replenishing power, extending the lifespan of these energy sources [8]. Likewise, with thin-film cells, often employed in applications requiring lightweight and flexible power solutions, the P2110B Powerharvester's ability to efficiently recharge them without the need for conventional charging methods enhances their usability, making it a valuable technology for the future of energy-efficient devices.

C. Low power electronics

The Powercast P2110B Powerharvester finds significant relevance in the realm of low-power electronics. By harnessing radio frequency (RF) energy and converting it into usable direct current (DC) power, this technology offers a compelling solution for driving the functionality of energy-efficient devices [8]. Whether powering remote sensors, wearables, or other small-scale electronic gadgets, the P2110B Powerharvester's capacity to provide sustainable power to low-power electronics aligns seamlessly with the growing demand for energy-conscious and long-lasting technology solutions.

V. Comparison with other Existing Radio-Frequency Energy Harvesting Integrated Circuit

As discussed earlier, a few other companies like e-peas Semiconductors, RF diagnostics, Maxim Integrated etc., are also manufacturing of radio-frequency energy harvesting integrated circuits (RF-EH ICs) which are similar to P2110B. Table 1 provides a comparative analysis of RF-EH ICs from these companies, with a focus on the output voltage, output current capabilities, the availability of evaluation boards for ICs, and the types of rechargeable batteries that can be recharged using these ICs. As shown in table 1, e-peas Semiconductors RF-EH IC AEM30940 provides output voltage 1.8V - 4.2V and current 20mA-80mA [15], while RF Diagnostics's RF-EH IC RFD102A provides output voltage 40V and current 18mA [16]. The Powercast itself making P1110B which is also a RF-EH IC and provides output voltage 4.2V and current 50mA [17].

Table 1 A Comparison of RF Energy Harvester ICs/ Evaluation Boards

Integrated Circuits	Company Name	Output voltage (V)	Output current (mA)	Used in Evaluation Board	Rechargeable batteries
P2110B [8]	Powercast	2.0-5.5	50mA	P2110-EVB Evaluation Board	Yes (Coin Cells, Thin Film cells)
AEM30940 [15]	e-peas Semiconductors	1.8-4.2	20mA-80mA	AEM30940 RF Evaluation Board	Yes (Li-ion cell, Solid state battery, NiMH, Supercapacitor, Capacitor, LiFePO4 battery)
RFD102A [16]	RF Diagnostics	0- 40	18mA	RFD102A-TB evaluation board	Yes (Li-ion, Capacitor)
P1110B [17]	Powercast	1.8-4.2	50mA	P1110-EVB Evaluation Board	Yes (Alkaline, Lithium lon , Ni-MH)

Most of the IoT applications use controllers like Arduino, NodeMCU, etc. and these controllers typically operate within a voltage range of 3.3-5.5V. The RF-EH IC and its evaluation boards can be selected on the basis of specific requirement and voltage needs of the application. Considering that controllers and various sensors typically have voltage requirements within the range of 3.3-5.5V, the RF-EH IC P2110B appears to be suitable for IoT applications, and the evaluation board is well-suited for research and development purposes.

In following section, a small experiment is set up to create a sustainable IoT node which harvests the energy using the P2110B-EVB board and give supply to nodeMCU and other components.

VI. Experiment using P2110B-EVB Evaluation Board

In this experiment, P2110B-EVB board is used as a power source for nodeMCU [18,19] instead of battery or other source. The V_{out} and GND (Ground) pin of P2110B-EVB board is connected to V_{in} and GND (Ground) of nodeMCU. A temperature and humidity sensor DHT11[20] is connect to nodeMCU. The VCC and GND pin of DHT11 connected to 3V3 and GND pin of nodeMCU, while DATA pin of DHT11 [21] is connected to D4 pin of nodeMCU. The nodeMCU is connected to cloud (thingspeak.com) using built-in wi-fi module (ESP8266 [22]). The complete circuit is shown in Fig. 4.

The nodeMCU send sensed data to cloud (thingspeak.com) using wi-fi module (ESP8266). The nodeNCU is connect thingspeak server using following code:

```
const char *ssid =  "XXXXXXXXXX";
const char *pass =  "***********";
const char* server = "api.thingspeak.com";
```

A channel is created for DHT11 and using its write API key data sent to this channel. The channel stats looks like shown in Fig. 5. From this experiment, it can be concluded that P2110B-EVB board can be used to create a self- sufficient sustainable IoT node by harvesting RF energy from the surrounding.

VII. Conclusion

In IoT applications, battery constrained devices are used and such devices lifespan is completely depending on their battery. Indeed, prolonging the lifespan of such devices is an ongoing and significant challenge. However, there are several energy harvesting methods available, including RF, solar, and thermal, that can significantly extend the operational life of these devices. The Powercast company has developed an RF-EH IC known as P2110B, along with an evaluation board designed for the same. Both these components offer versatile applications for both practical use and research purposes. This paper presents a comprehensive review of the P2110B IC and its associated evaluation board, highlighting their configurations. Additionally, it explores the diverse purposes they can serve. A comparative analysis of similar type of RF-EH ICs from various companies has also been discussed which would make selection and decision-making process easy for those who want to use RF-EH in their IoT applications or where battery is a constraint. The experiment showed its performance in IOT applications. This information aims to provide valuable insights for researchers seeking to understand the capabilities of this IC and its evaluation board within the realm of energy harvesting for IoT devices.

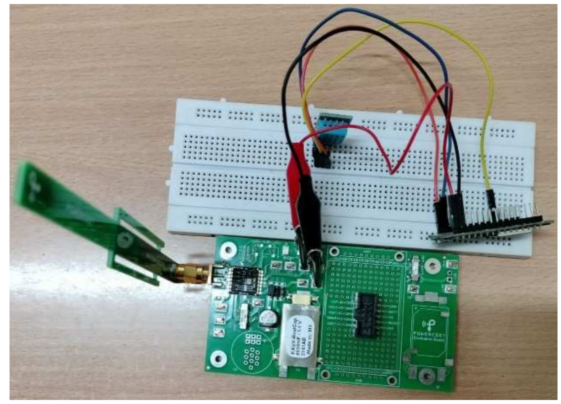

Fig. 3 Power supply using P2110-EVB or as power source

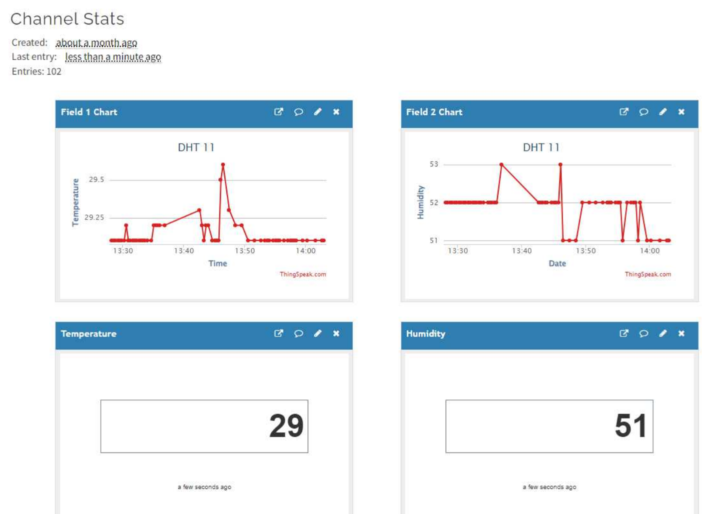

Fig. 4 Temperature and Humidity on Thingspeak

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