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# Innovative Solar Energy Integration for Battery-Less Mobile Phones

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**ABSTRACT**
Mobile phones are now everywhere; this has been the catalyst for a global revolution, though battery efficiency and environmental impact continued to be a challenge. However, lengthened use worsens these cases in terms of over-heating and poor performance hence finding new solutions. To address these challenges, the document suggests an innovative idea of developing a solar-powered mobile phone that does not use customary batteries but utilizes radio frequency (RF) energy harvested from solar sources. The aim of our research is to determine whether it is possible to convert solar energy into RF signals that are sent to base stations hence allowing for operation of such devices. Therefore, the design will aim at addressing constraints related to short-lived batteries and charging by creating more sustainable mobile technology ecosystems. We see wireless communication devices incorporating renewable energy resources as a huge step towards greener future which is environmentally aware.

**KEYWORDS**
Battery-less mobile phone;
Solar energy harvesting;
RF energy transmission;
Sustainable communication;
Renew

## 1. INTRODUCTION

The introduction of smartphones has heralded a milestone in the digital technology industry that changed how we communicate, access information and entertain ourselves. As we continue to rely more on smartphones, there is an increasing need for innovative solutions to cater for one of their main limitations i.e., battery life.

In this research paper, we explore the opportunity for creating mobile phones without traditional batteries that can bring about benefits to users and the environment. We discuss emerging energy harvesting techniques such as solar cells and radio wave harvesting that offer sustainable alternatives to conventional batteries. Moreover, it looks at how industries beyond communication can be altered by the advent of battery-less technology.

Can Smartphones be made without traditional batteries? This section examines the latest developments in energy harvesting and storage systems including solar cells, radio frequency (RF) harvesting and kinetic energy harvesting. We examine the possible advantages of smartphone battery-free technology for both consumers and the environment. These gadgets could provide longer battery life, less electrical waste, and a reduction in carbon emissions related to battery production and disposal by doing away with the requirement for conventional batteries.

Energy Harvesting Techniques: In this part, we will explore how effective energy harvesting techniques like solar and radio wave harvesting are at giving mobile devices a reliable supply of power. We assess the possibilities and difficulties of incorporating these technologies into smartphone designs.

## 2. LITERATURE SURVEY

The idea of battery-free phones was put up by [13] Sparsh Ralwani in 2017 using two energy-harvesting techniques, namely using solar energy via a photovoltaic cell and collecting RF energy signals. To convert ambient light into current or DC power, a photodiode is employed.As they have optical fibers and built-in lenses to function better in low light, these photodiodes can also generate energy when there is no sunshine.

The RF-energy harvesting integrated circuit (IC) with a wireless transmitter of 915MHz was proposed by [1] Guo-Ming Sung in 2019.The suggested integrated circuit (IC) consists of a low-power, low-dropout (LDO) voltage regulator, a charger control circuit, and an RF-direct current (DC) rectifier. In the RF-DC rectifier circuit, a native MOS with a low threshold voltage is used in a six-stage Dickson voltage multiplier circuit to enhance the incoming RF signal to a DC voltage. In especially for near-field communication, the over-voltage protection circuit is employed to prevent a high-voltage breakdown phenomenon from the RF front-end circuit. A low-power LDO regulator's zero frequency correction and voltage-trimming feedback are used to create a stable voltage. Using a current mirror, charging current is boosted N times. The collected findings showed that the proposed RF energy harvesting IC's highest power conversion efficiency was 40.56% at an input power of 6 dBm, output voltage of 1.5 V, and load of 30 kilo ohm.

Sung et al. [1] and Nguyen et al. [2] both delve into energy harvesting circuits but with different focuses. Sung emphasizes small-area radiofrequency-energy-harvesting circuits for wireless sensor networks, while Nguyen explores hybrid solar-RF energy for base transceiver stations. A comparative analysis of these approaches would elucidate the trade-offs and advantages associated with each.

[10] optimize mobile app usage. Comparisons with solar integration methods reveal potential synergies for maximizing energy efficiency in battery-less devices. Partal et al. [14] and Ryu et al. [15] present innovative design approaches. A comparative assessment highlights the most effective strategies for solar-integrated battery-less mobile devices. Qin et al. [16] focus on the structural design of large-area arrays.

Gupta et al. [17] discusses battery lifetime estimation. Comparative research on predictive modeling reveals the accuracy and reliability of different estimation approaches for battery-less devices.

Talla, Vamsi & Kellogg, Bryce & Gollakota, Shyamnath & Smith, Joshua [31] introduces Sustainable Computing: Provides an overview of the development and potential of battery-free mobile phones in informatics and systems. This comprehensive review examines the current state of the technology, its potential applications, and its implications for sustainable computing.

Zhang et al. [18] presents the research in the IEEE Transactions on Mobile Computing, which focuses on battery-free mobile phones powered by harvesting ambient RF energy. The study explores ways to efficiently use RF energy to maintain mobile phone performance.

Wang et al. [19] discusses solar energy collection for mobile phones without batteries in IEEE Transactions on Power Electronics. Their work emphasizes design and operational considerations for integrating solar energy harvesting into mobile phone systems.

Sharma et al. [20] addresses the challenges and opportunities of RF energy harvesting for battery-free mobile devices in IEEE Journal of Solid-State Circuits. The study examines technological advances and identifies opportunities for optimizing RF energy harvesting systems.

Sowells-Boone, Evelyn & Dave, Rushit & Chowdhury, Brinta & Brown, DeWayne [21] in IEEE Transactions on Circuits and Systems. It proposes energy efficiency for batteryless mobile phones . Their work focuses on energy efficiency and the development of batteryless devices that work efficiently

Patel et al. [22] in IEEE Transactions on Wireless Communications, energy-sensitive communication systems for mobile devices without batteries are discussed. Research examines systems designed to reduce energy consumption and improve network efficiency.

Ogundele, Israel & Akinwole, Agnes & Adedeji, Adebayo & Ayodeji, Aromolaran [23] provides a comprehensive review of security challenges in batteryless mobile phones in IEEE Security & Privacy. Their work highlights vulnerabilities and proposes solutions to enhance the security of batteryless communication systems.

Schuss, Christian & Rahkonen, Timo. [24] in IEEE Transactions on Sustainable Energy explore optimization methods for harvesting solar energy in batteryless mobile phones. The study explores ways to improve the efficiency of solar converters to improve overall system performance.

Alessandro Torrisi, Kasım Sinan Yıldırım, Davide Brunelli, [25] in IEEE Journal on Emerging and Selected Topics in Circuits and Systems focuses on minimum power circuits and systems for mobile devices without batteries. Their work examines circuit design and system design to reduce energy consumption in batteryless devices.

Donohoo, Brad. [26] In IEEE Transactions on Green Communications and Networking, machine learning techniques for battery-free mobile phones are thoroughly explored. The research explores how machine learning techniques can be used to optimize energy harvesting and power management strategies.

Ihemelandu, J & Onwuka, E & David, Michael & Suleiman, Zubair & Adejo, Achonu [27] discusses RF energy harvesting techniques for battery-free cell phone interception in indoor environments in IEEE Transactions on Antennas and Propagation. The study explores the challenges and opportunities of indoor RF energy storage to power devices without batteries.

Kareeb Hasan, Neil Tom and Mehmet Rasit Yuce [28] in the IEEE Internet of Things Journal, the challenges and solutions for using battery-free mobile phones for IoT applications are addressed. The study discusses how battery-free devices can be incorporated into IoT ecosystems and proposes solutions to overcome implementation challenges.

Deva Sarma, Hiren & Avijit, Kar & Mall, Rajib [29] researched about the security and privacy protection of battery-free cell phone communications in IEEE Access. The study provides insights into the security threats and privacy concerns associated with battery-free communication systems, and what strategies can be used to mitigate them. Kumar is the name. In the IEEE Internet of Things Journal, the challenges and solutions for using battery-free mobile phones for IoT applications are addressed. The study discusses how battery-free devices can be incorporated into IoT ecosystems and proposes solutions to overcome implementation challenges.

Shahzad, Luqman & Ahmad, Ejaz & Sadiq, Touseef & Sohail, Fiza [30] in IEEE Transactions on Vehicular Technology, energy-saving communication protocols for battery-free mobile devices in wireless sensor networks are proposed. Research focuses on designing systems that minimize power

The study, published in the Journal of Energy Storage [31] , focuses on modeling distributed photovoltaic (PV) systems with and without storage batteries. Through a case study in

Belém, northern Brazil, the authors investigate the efficiency and feasibility of PV systems under different conditions.

## 3. METHOD FOR EXTRACTING, CONVERTING & STORING ENERGY.

### 3.1 Harnessing Energy- Supply:

Here we harvest energy by converting solar energy into electrical energy, subsequently converted into radio frequency waves for transmission. We use PV (Photovoltaic) Modules to capture the solar energy.

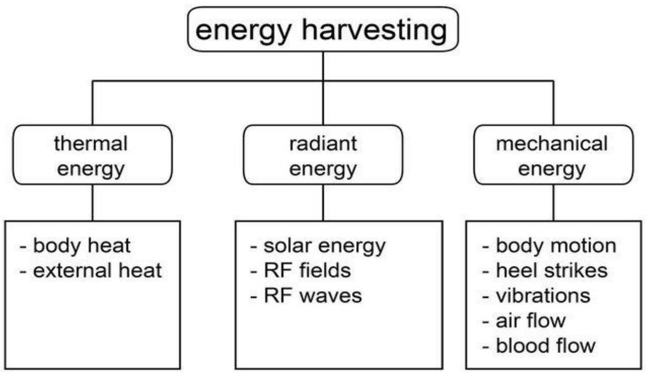


**Fig. 1** Basic Energy sources used for energy conversion.

Interconnected photovoltaic cells, often known as solar cells, make up photovoltaic modules. Although silicon cells are more effective, their production costs are higher. A single photovoltaic cell typically measures 156 by 156 mm (6 x 6") and produces only 1 to 2 watts of power. Each solar PV module typically ranges in power from 50 W to 350 W.

Monocrystalline solar panels can also be used as they are made from single crystal silicon and are then processed into thin sheets up to 0.2 mm thick. The cells in monocrystalline solar panels are highly efficient in conducting but are expensive. Polycrystalline modules are more cost-effective but less efficient than monocrystalline solar PV modules. This system is likely to measure approximately 27 feet wide by 13 feet long - 352 square feet in all.

Within the phone keypad, piezoelectric sensors are integrated to effectively transform mechanical energy into electrical power, generating a modest energy output that can be employed to supplement the energy requirements of the RF to DC converter IC.

### 3.2 Harnessing of RF waves

As the electromagnetic field travels away from the radiation source, its intensity varies. In close proximity to an antenna, magnetic fields may convey a lot of energy. Near-field wireless transmission tools make use of this to deliver watts of power over centimetre distances. Electric fields can transmit less energy when they are not in close proximity to an antenna. Up to 25 meters (80 feet) distant, Power cast can transmit energy via the far field.

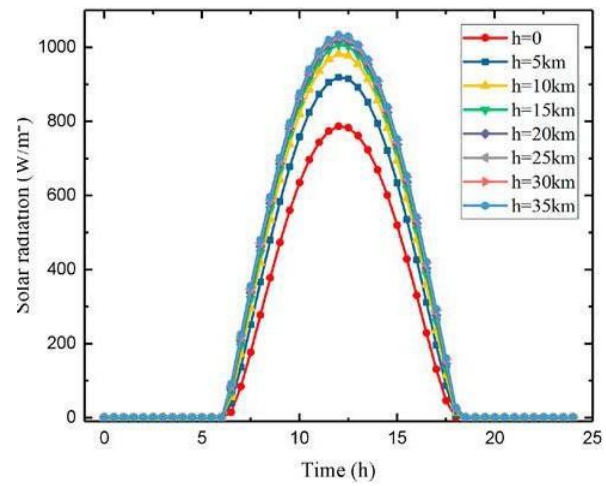


**Fig. 2** Electrical characteristics of photovoltaic cells.

The Fig.2 available at [33] depicts a graph showing the variation of solar radiation in Watts per square meter ($W/m^2$) over time in hours (h). The different lines on the graph represent various altitudes from 0 to 35 kilometers (km) in increments of 5 km. All the lines follow a similar bell-shaped curve, indicating that solar radiation peaks around midday and diminishes towards the beginning and end of the time scale shown. The overlapping of the lines suggests that solar radiation values are relatively consistent across these altitudes during the time period observed.

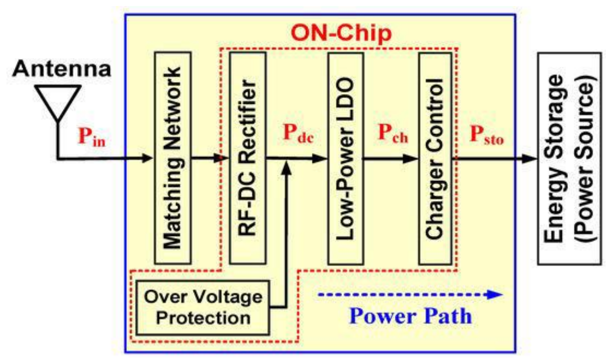


**Fig. 3** Block diagram of RF energy harvesting IC.

The Fig.3 available at [34] is a schematic diagram of a power management system for an on-chip device. Among other things, the system has an antenna that collects power ($P_{in}$). The energy received is therefore moved into a matching network to adjust its efficiency in line with the requirements of this system. Afterward, the RF DC rectifier forms another stage where RF energy gets converted into direct current ($P_{dc}$). To regulate the voltage there is a low power LDO in the path. A charger control is also present which seems to be used as a manager for the charging process through $P_{sto}$. Also, there exists an over voltage protection mechanism that saves the entire system from sudden surges of electricity fluxes. Power Path: This term implies that electrical energy goes through different components within a circuit.

On-Chip: This means that all these parts are part and parcel of one single microchip.

An over-voltage protection circuit, a low-power, low-dropout (LDO) voltage regulator, an RF-direct current (DC) rectifier, and a charger control circuit are all included in the proposed IC. By converting the received RF signal to a DC voltage utilizing native MOS with a low threshold voltage, the RF-DC rectifier circuit uses a six-stage Dickson voltage multiplier circuit. To avoid high-voltage breakdown phenomena from the RF front-end circuit, especially for near-field communication, the over-voltage protection circuit is utilized. By utilizing zero frequency compensation and voltage-trimming feedback, a low-power LDO regulator is created to deliver steady voltage. The envisioned charger control circuit fast and steadily charges a battery by amplifying the charging current N times using a current mirror. The obtained results revealed that the maximum power conversion efficiency of the proposed RF-energy-harvesting IC was 70.56% at an input power of −6 dBm, an output voltage of 1.5 V, and a load of 30 kΩ. A chip area of the RF-energy-harvesting IC was 0.58 × 0.49 mm2, including input/output pads, and power consumption was 42 μW.

## 4. POWER CONSUMPTION ANALYSIS

The recognition of the importance of comprehending routine use has been a major concept in the development of the sociology of energy. Batteries that power phones have a finite capacity due to their size. Functionality that enhances functionality and puts additional strain on battery life, such as voice communication, audio and video playing, web browsing, short-message and email communication, media downloads, gaming, and more, is furthered by the requirement for efficient energy management. A mobile phone often spends a significant amount of time without being actively utilized. As a result, the communications processor only engages in minimal activity while the application processor is inactive. This is because the communications processor has to be connected to the network in order to receive calls and SMS messages.The power used in this stage is crucial to battery life since it often occurs while the phone is on for the majority of the time.

The GSM subsystem power clearly dominates while suspended, consuming approximately 45 % of the overall power. Despite maintaining full state, RAM consumes negligible power - less than 3mW.

If no programs are running yet the device is fully awake (not in suspend mode), it is in the idle state. This situation represents an active system's static power contribution. The backlight is off but the rest of the display subsystem is on when we execute this scenario.

Power consumed in this state was very stable. The display-related subsystems consume the largest proportion of power in the idle state approximately 50% due to the graphics chip and LCD alone, and up to 80% with backlight at peak brightness. GSM is also a large consumer, at 22% of aggregate power.

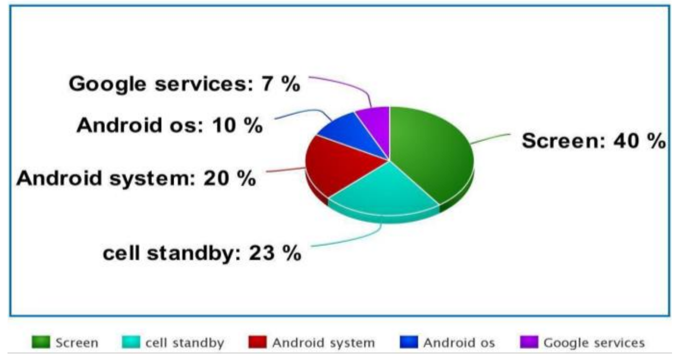


Fig.4 Battery Power Usage in Mobile Phones.

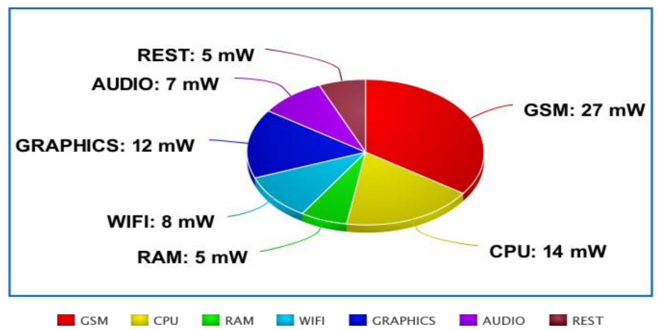


Fig.5 Power Breakdown In  A Recess State.

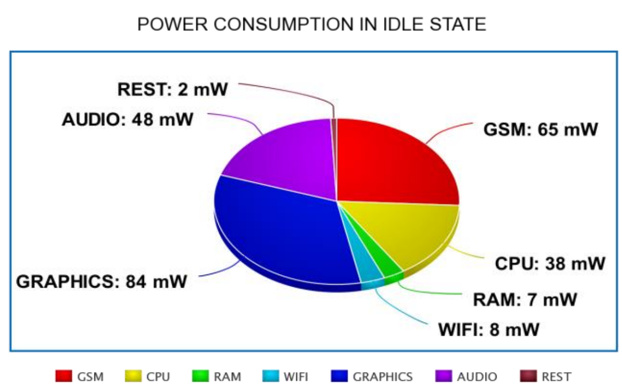


Fig.6 Power Consumption  In  A Idle State.

The power consumed by the display backlight over the range of available brightness levels. That level is an integer value between 1 and 255, programmed into the power-management module, used to control backlight current.The minimum backlight power is approximately 7.8 mW, the maximum 414 mW, and a centered slider corresponds to a brightness level of 143, consuming 75 mW. The backlight consumes negligible power when disabled.

## 5. POWER OPTIMISATION ANALYSIS

### 5.1 Screen Display:

For the screen display, the utilization of black and green colors exclusively results in varying power usage. The energy consumption is approximately 376mv for black and 566mv for green. Red color usage, on the other hand, leads to a higher consumption of 596mv. Notably, the employment of a Pentile AMOLED display at a reduced screen resolution contributes to lower battery consumption.

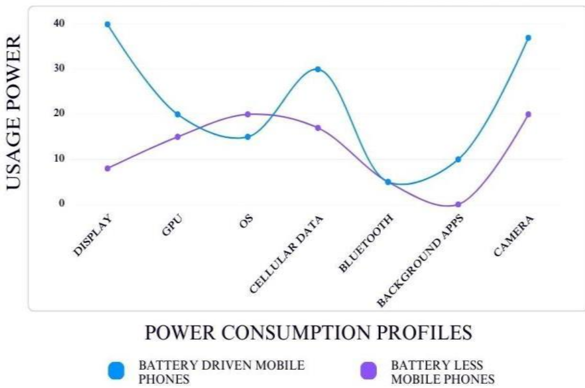


**Fig.7** Overall Power Consumption In Batteryless and Battery Mobile Phones (in percentage).

### 5.2 Keypad:

The keypad's power consumption varies with different scenarios. When the LED backlight is turned off, the power usage is 0.01A at 5.13V, equivalent to 0.05W. With the LED backlight set to its minimum level, the consumption rises to 0.03A at 5.13V, corresponding to 0.15W. At the highest LED backlight setting, the power usage reaches 0.24A at 5.13V, totaling 1.23W. Each key button features piezoelectric sensors.

### 5.3 Camera:

The camera's power consumption is 12W, with a maximum resolution of 480p.

### 5.4 Internet Connection for Search:

Utilizing the internet for search purposes consumes about 0.0003 kWh of energy per average search query, resulting in an approximate energy consumption of 0.072 kWh.

## 6. ADVANTAGES

By reducing reliance on traditional batteries and addressing battery disposal and recycling challenges, this concept contributes significantly to a more eco-friendly future.

Battery-less phones have the potential for longer lifespans as they experience reduced degradation compared to traditional battery-powered phones.

Bridges the digital divide and extends communication capabilities to underserved regions.

Solar-powered mobile phones ensure reliable communication during power outages or natural disasters, providing a lifeline when traditional power sources fail.

RFID tags can be used for communication between phones to transfer files and also to locate the users.

Can be used as a special featured phone for teenage students, especially for educational and call purposes alone.

## 7. DISADVANTAGES

Reliance on solar energy means that the phone's functionality may be affected during cloudy or nighttime conditions as energy harvesting may not provide sufficient power for heavy usage or extended periods without adequate sunlight or RF energy sources.

The technology required for energy harvesting and RF energy transmission may result in higher initial manufacturing costs for these phones.

Existing mobile networks and infrastructure may not support the RF energy transmission method, limiting the phone's usability in certain areas.

The additional components for energy harvesting and RF transmission may increase the size and weight of the phone, affecting portability and user comfort.

The introduction of new technologies may bring security vulnerabilities that need to be addressed to ensure the safe use of these devices.

Battery-less phones may not be suitable for power-intensive applications or scenarios where a constant power supply is essential.

## 8. CONCLUSION

Power distribution is analyzed in relation to various components of non-battery mobile phones with a comparison to conventional battery operated phones. The trend towards equitable distribution that characterizes the formers' power distribution is particularly remarkable. Most noticeably, there is an equal division among many parts and the camera functionality has been found to be the cause of a significant increase in power consumption.

In terms of their screen and processor functionalities, it can be noted that battery-less mobile phones have power consumptions resembling those on traditional devices thereby signifying their importance in user interaction as well as device function. In addition, communication modules and sensor suites are characterized by the same patterns of power usage between two kinds of gadgets due to seamless connectivity as well as improved experience.

Nevertheless, there is a notable variation in the consumption of electric energy by cameras leading to increased usage on these batteryless cells (Jain et al., 2019). This is because these devices employ high-performance yet low-power image sensors and processing algorithms aimed at maximizing performance while still maintaining overall energy efficiency levels.

There are some variations, however, other aspects such as speakers, storage spaces and extra features have uniform power uses across even traditional mobile phones without batteries which enhance the operation of these gadgets and meaning to the user.

To sum up, this comparison underlines that battery-free cell phone designs can be put into practice. Hence, through better power allocation and exploitation of energy saving technologies , they present an environmentally friendly and dependable substitute for conventional smartphones with performance levels matching those of their critical parts. This is enhanced by solar integration in their making signifying a move towards greener sustainable tomorrow in mobile technology.

## 9. FUTURE RESEARCH

To improve the energy efficiency of energy harvesting and storage components.

Research on energy storage that can buffer power fluctuations due to environmental factors is crucial, to create a more reliable and robust energy supply for the phone.

User studies to understand how consumers adapt to battery-less mobile phones, their expectations, and usage patterns. This feedback can inform the design of future devices.

Explore how battery-less phone technology can be integrated into other electronic devices and IoT applications, creating a seamless ecosystem of energy-efficient devices.

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