

# Battery Less Phones: A Deep Assessment on Device for Long Range Scavenging of Wireless Power

<sup>1</sup>Spارش Rawlani, <sup>2</sup>Purvash Biyani, <sup>3</sup>Apoorv Joshi

<sup>1</sup>St. Mary's Convent School, Ujjain, MP, India

<sup>2</sup>Delhi Public School, Indore, MP, India

<sup>3</sup>Pioneer Convent School, Indore, MP, India

## Abstract

If we just date back to January 9, 2007, it's the date when the world first witnessed a smart phone, and in fact, the first 'Touch screen phone'. Mr. Jobs, the owner of Apple Inc. launched the "I-phone" aiming to turn everyone's life uncomplicated. And then, it has been ten years since the launch of the smart phone, and in these 10 years, the world has observed a revolutionary change in the era of smart phones. One of the most drastic changes was witnessed in the batteries of these smart phones, ranging from 1000mAh to 5000mAh on an average. In the past couple of years, intense usage of smart phones for various purposes has resulted in battery draining at a rapid rate. Many types of research have been done in order to find the exact reason for the battery drain at a rapid rate and its solutions, although none of them were able to accomplish anything special, and hence, rather than to find a solution to battery's long life, a different solution was established, and it was to construct phones, which can be operated without batteries.

This research paper focuses on the implementations of "Battery Less Smart phones", and on its pros and cons. It will also state some of the economic and possible changes that can be made as per our research.

## Keywords

Invention, Advantages, Disadvantages, Incentives, Economy Factor, Astonishing Technology, Computer Science, Battery drain.

## I. Introduction

The smart phones we are using these days are indeed smart, however, are they really that smart as the companies claim? The answer to this question is yes, but aren't those really dumb if discussed in terms of battery life? Yes, they are. Even the companies that sell smart phones at phenomenal rates have the issue of battery's performance [1]. The performance is better as compared to others, but it is still a mystery if discussed in terms of long life. The idea of battery less smart phones was initiated by a group of researchers from "The University of Washington", who invented the phone with a dial pad, and to the next level of astonishment, the phone was designed so that it could harvest energy from "Radio Signals". The phone developed, features a dial pad, a small led light, and will also include an E-ink display.

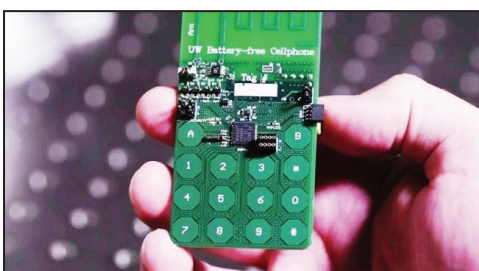


Fig. 1: A Look at the Prototype Invented Recently

## A. Perspective for Battery Less Phones

A lot of discrepancies about the battery's performance were going on around the world. The issue about the battery's anomalous drain lead to the research of innovative stuff, which furthermore lead to the invention of these Battery Less Mobiles. Smart Phones these days are a real help for the human race, the way they are used to reduce our burden and anxiety by saving our time is just unexplainable, And to the fact that everyone knows about the battery affair, people still purchase phones to stay connected to the world, and hence, these battery less phones were created to replace the battery's draining issue and to offer an effective method of staying connected to the world [2].

## B. Battery Less Smart Phones Vs Battery Saving Applications

The multi task calculating apps can increase your battery's life, but to a very small extent. These apps maintain your phone's battery life by clearing other apps from the background and by suggesting you the precautions about how to use your phones effectively, but battery less phones are way different as the battery doesn't exist and hence they will be greatly helpful in the future, especially for upcoming generations [3].

So, this paper will completely focus on the methods about how to implement the technology as soon as possible and what could be the effective changes in it.

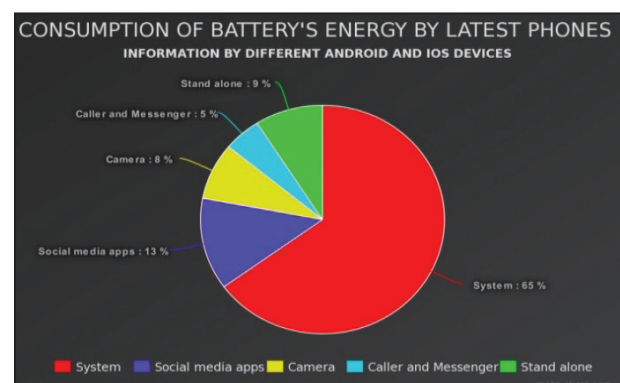


Fig. 2: Consumption by Normal Smart Phones

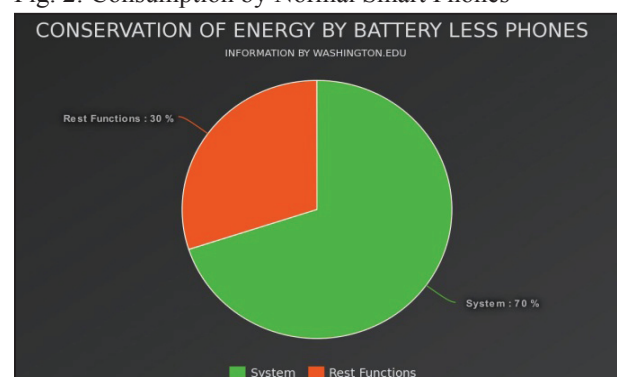


Fig. 3: Energy Savings by Battery Less Smart Phones

The researchers developed this technology with an aim of getting rid of the charging issues. The phone recently developed obtains energy from “Thin air” or from the “Radio Frequency Waves” (RF) [4]. The zero power frameworks can only attend and make calls and contains a dial-pad screen, making it obsolete according to the present technology [5], although, keeping the fact in mind that doesn’t require any power; the phones can really be helpful in crucial situations where it is hard to find electricity.

- The low power model also lacks a data connection but the technology is still under development so everything would get stabilized in future.
- The model doesn’t work without headphones or earphones.
- A special microphone is being designed to generate some electromagnetic waves to enhance the device’s output.
- The range of the signals is quite less, and hence the range of the distance can be increased by a significant amount, if a licensed mobile frequency is used, making it a better hope for the future.
- The next advanced step would be to introduce an E-ink display that would be powered by radio frequencies, which would look similar to that of Kindle, except for the battery.

## II. Framework for Battery Free Phones

The prototype invented a few months back, yields energy from ambient sources, and surprisingly those ambient sources are “Radio Signals or Radio Waves”, and the device uses a minute photo diode to harvest energy from the ambient light or RF sources. It consumes only 3.5 microwatts of power from these energy sources. The device has a limited range of just 31 feet from the base station and the range can be expanded to 50 feet with the help of a small “Solar Cell” [6].

### A. Procedure for Fetching Energy from Ambient Sources

#### 1. Harnessing Energy

In order to harness energy from the ambient sources, a base station is required and the base station is placed as per the range specified (31 feet-50 feet), RF energy can be transmitted in unlicensed bands or grids ranging from 868MHz to 5.4GHz from their respective base stations [7]. It is then, that this RF energy is transfigured into DC power through some energy harnessing devices such as “Powercast’s Powerharvester Receivers”, these receivers also contain criterion or conventional antennas having an average resistance of 40-50 ohms.

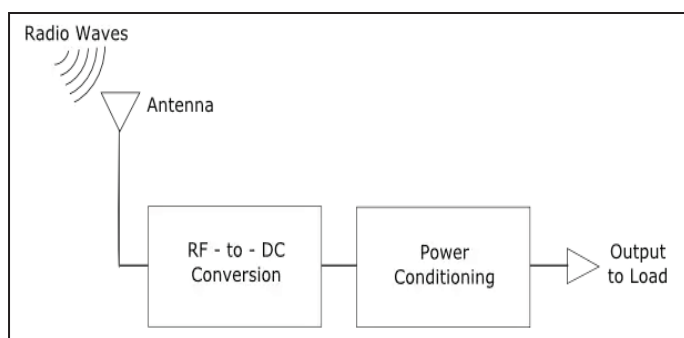


Fig 4: Diagram Stating Conversion of RF Waves to DC Power

The main feature of these harvesters is to maintain the effectiveness while maintaining the disparities of RF to DC transfiguration in order to make the output stable. Although heading with the new technology of battery free phones, the procedure was way different

as compared to the described one. In the phone, a “photo diode” was used to convert the ambient light into current or DC power. These photo diodes can also produce energy in absence of light as they contain optical filters and in-built lenses to perform better in dark conditions.

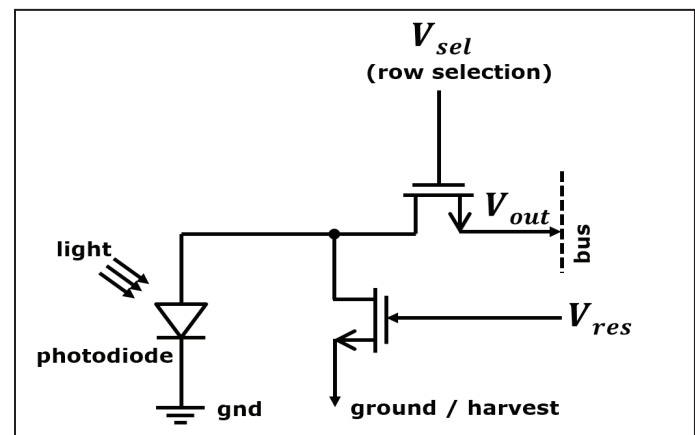


Fig 5: Flow Diagram Explaining the Working of a Photo Diode

### 2. Conversion of Ambient Signals to Power with the Photo Diode

The researchers at the University easily found the fact that using a photo diode for converting ambient signals and light into current is much efficient and economical than installing a power harvester since the amount of power required for the functioning of the prototype was very less. A Photodiode is a semiconductor, with p-n junction diode and an intrinsic layer between two junctions [8]. The photocurrent is provoked by the electron hole pair because of the assimilation of light between depletion region. When photons of energy greater than 1.1 electron volt (eV) strike the diode, electron-hole pairs are originated. The potency of photon absorption depends on the energy of photons – the lower the energy of photons, the deeper the assimilation is. If the absorption occurs in the depleted region of the p-n junction, these hole pairs are wiped from the junction - due to the inbuilt electric field of the depletion region. Hence, the holes proceed toward the anode and the electrons move toward the cathode, thereby generating photocurrent. The sum of photocurrents and dark currents, which flow with or without light, is the amount of current progressing through the photodiode, And this is how a small amount of power is generated in the battery less phone with the assistance of a tiny photo diode [9].

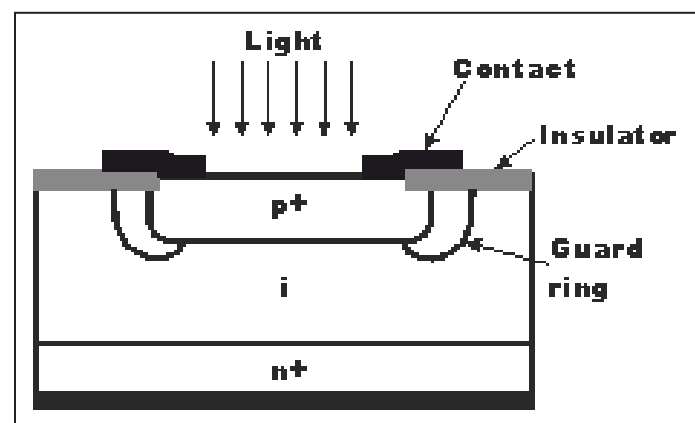


Fig. 6: Structure of a Simple Photodiode

### III. Prototype & Working of Battery Less Smart Phones

In the given model, the user undertakes a button to twig in between the two transmitting and listening notes. The team of researchers utilized the shell components on a printed circuit board and the team corroborated and ensured that the battery free prototype can perform basic functions like calling someone up and then hanging up the call without any inadequate call drops. A custom base station collects the data in form of digital packages with the help of a “Backscatter” and connects our call through “Skype” and the person at the other end answers the call and responds. The device inherits the signals with a technology referred as “Zero Power Amplitude Modulation” and plants the audio onto the earphones. For making a call, the user has to dial the number on the dial pad and has to speak into the microphone. For attending the call at receiver’s end, the user has to pick up the call and respond, the call is transported to a long distance with a backscatter, which helps in the cycling of data packages [10].

#### A. Shell Component and its Working

The Shell, which is used with the Kernel (part of operating system), is a part of the operating system of the battery free device that is utilized for recasting the Human made programming into the machine language. When the user enters the command for executing any sort of operation, the request proceeds to the shell parts, also known as Interpreter which then translates the code and transfers it to the Kernel [11], the kernel then receives and accepts the request and exhibits it on to the display area or screen. The kernel also provides memory for the running processes on the prototype.

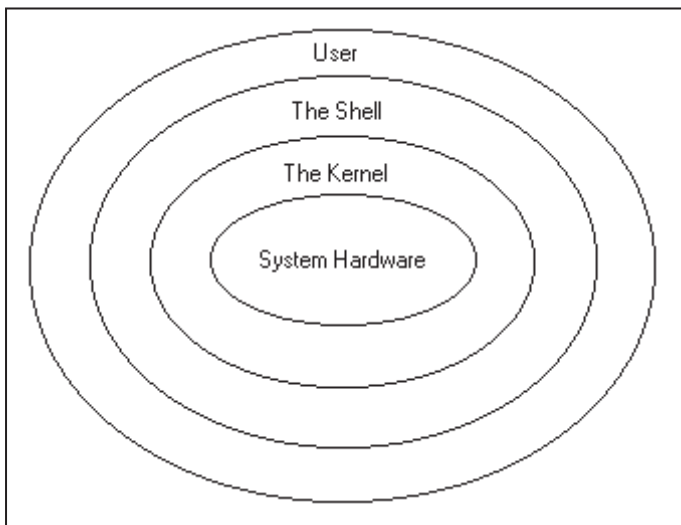


Fig. 7: Simple Diagram Showing the Positions of Shell and Kernel in Parts, of an Operating System

#### B. How is Power Saved?

If we head back again towards the mobiles and devices of today’s generation, the phenomenon behind the battery’s hunger for power is the process of converting analog signals into digital data packages that a phone can interpret. This process consumed the highest amount of power in smart phones that we are operating at present, however that’s not the case with battery free cell phones as the battery free prototype takes the dominance of minute vibrations that occur in the phone’s microphone and speaker when the user speaks into the microphone or listens to an incoming call. An antenna connected to the shell and speaker components receives the analog radio signals, which are emitted by the cellular base station and then these signals are transmitted back to the cellular

base station by the use of a “backscatter” in order to maintain a cycle of transferring digital packages that furthermore helps in retaining signal strength so that the call doesn’t hang up in an insufficient manner [12].

#### 1. Backscatter-Working and Performance

A backscatter is a device that reflects or deviates any particle through an angle measure of approximately 180 degrees. RFID (Radio Frequency Identification) backscattering is a technology which uses the RF power transmitter in accordance to the tag reader to vitalize the tag(objects that are to be identified). Necessarily, they “deviate” part of the power conveyed by the reader, although it affects some of the properties, and in this manner, it sends backs information to the reader. With the help of RFID backscatter, some tags obtain their data transmission by converting the properties of the tags themselves, where as the rest twig between a load resistor in and out of the antenna circuit [13]. RFID backscatter conversion controls outside the field region, and the radio signal proliferates away from the RFID reader. When the signal approaches the RFID tag, this inter communicates with the ongoing signal and some energy is deviated towards the RFID reader [14]. Over momentary ranges, the quantity of power outstretching the tag from the reader is quite enough to allow operation of low current circuits inside the tag, and so even with these low currents, the battery less device was able to reflect digital data packages.

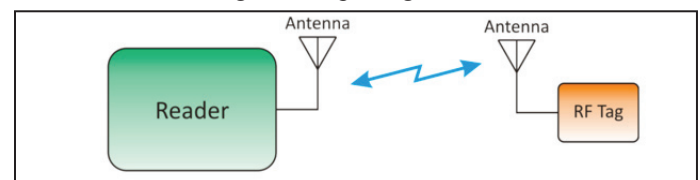


Fig. 8: Reversing of Data Packages With Backscattering

#### C. Encoding of Speech Patterns

The process of obtaining power from the minute vibrations of the microphone and speaker was indeed a great idea, but how does it happen? or what are the basic steps behind it?

The answer to all these questions relates directly to the title. This process inherently involves encoding of Speech Patterns through the reflected radio signals in a way that hardly uses any power. To dispatch speech, the phone encodes speech patterns through the deviated or reflected signals with the help of those minute vibrations in the microphone. To acquire speech, it translates encoded radio signals into sound vibrations, which are harvested by the speaker of the receiver’s phone [15].

#### 1. Why is Speech Patterns Encoded?

Any sort of audio is constructed with the involvement of waveforms, which furthermore are made up of frequencies and amplitudes. The capability of a device to remake frequencies is known as Frequency Response and the capability of the device to create an adequate amount of loud or soft sound is referred as Dynamic Range. So, when sound is being encoded, it simply means that both of these primary principles are capable of accumulating and transporting data productively. An audio encoded is completely different to the type of audio formats that we use presently. For example, audio formats like .mp3, are first encoded into file formats before being encoded to mp3. Some of the basic file formats like WAV or FLAC, are both file formats and form of encodings [16]. FLAC being the only file format that needs a header for encoding, the others help to encode Speech API without the use of extensive headers and hence resulting in encoding Speech output at a faster



rate. So if an audio is not encoded, it will let to great disturbance in the Speech Output and therefore audio formats are encoded before they are used, and in the battery free prototype, the minute vibrations helped in encoding the formats at that instant, to be precise those vibrations acted as a source for encoding speech patterns for both the incident and reflected signals [17].

#### D. Zero Power Amplitude Modulation-Working and Importance

The zero power amplitude modulation is that the electron with the greatest intensity is used in almost all wireless receivers and these can be easily substituted with electronic components that can even sustain without a battery. With amplitude modulation, compact range receiver can be manufactured which can work without a battery supply then the RF signal is obtained. Amplitude modulation might be shifted using pulse coding to impart an idiosyncratic device ON signal, to the Zero-Power Receiver [18]. When engulfed into a phone or GPS, it withdraws the requirement for the devices ON and OFF feature, resulting in extreme battery life. It can also increase the range of the current RFID's in an appreciable manner, And it can also provide an exceptionally wide input bandwidth. In the battery, less phone zero power amplitude modulation helped in receiving the signals and placed the audio on to the earphones, as describes earlier the phone cannot be operated without earphones. The audio is transmitted using zero power analog backscatter [19]. Since the device uses RF signals to manipulate few microwatts of power, it was necessary to use earphones so that the signal strength is not lost, as earphones worked as an antenna as where they were used in FM radios on cellular phones.

#### E. Skype - Usage and Information with Battery less Phones

For The biggest task that the researchers did with Skype, was to answer the incoming calls and to keep those calls on hold whenever required. Skype is a VoIP (Voice over Internet Protocol), which helps us to communicate with anyone around the globe, free of cost. The best feature was the video calling that was launched by Skype a few years ago [20].



Coming to its working, Any VoIP application uses SIP(Standard IP or TCP protocols) to produce data packs and transmits it to the same network that you use for surfing the internet actually it works as per IP address, also known as your network address. VoIP is one of the best Internet Protocols, since, the transmission is not just limited to audio, but also to text, images, and videos as well. The working starts with the receiver that ranges from hardware products to software applications. User's voice is first captured by the microphone and then encoded into a digital package that it is transferred to a compressor which compresses an audio format so it can work on slow connections as well. The audio clips are then divided into parts and are finally sent to the required destination from your network. Then at the receiver's end, the audio is

reconstructed once again to make it clear to the user.

In the battery less phone, the backscatter helps in maintaining the strength of the signals by sending them back to the cellular base station by deviation of signals, and finally, the call is connected to the phone number and the receiver's audio is heard through headphones.

#### F. Increase in the Range With a Solar Cell

Earlier in this paper, we saw that the range under which the battery free model worked, was just limited to 31 feet, that is the phone stopped working, once it was taken beyond the specified range. Although, there was a solution implemented that the range could be extended to few more feet, making it 50 feet from the cellular base station. So the importance of that minute solar cell was unimaginable, and hence at this point, the use of solar cell became a much important factor [21].

#### 1. How do solar cell work and increases range by saving energy?

Solar cell constitutes of P-N junction diode, which is assembled from Silicon and Germanium. With the help of vapor deposition, P type layer is diffused over N type semiconductor with p type having some electrodes. This process constructs open space for light to fall on P layer and hence underlying the P-N junction [22]. The bottom of N layer comprises of current assembling electrode. When a light photon arrives at the junction, they exhilarate electrons from valence band to conduction band, discarding behind an equal number of holes in the valence band. This electron hole generated in the depletion region accelerates in opposite direction because of the barrier field. Photo generated electrons accelerate in direction of n type and electrons directed towards p side. The hoard of these charges carriers formulates p side, a positive electrode, and N side, a negative electrode. Hence photo voltage is set up across the junction. When load resistance is connected in the circuit, the current flows through the solar cell [23]. This current from the solar cell is greater than that produced by the RF signals and hence a reason ,the capacity of backscatter increases in order to send digital packages back to the base station, and finally the range increases [24].

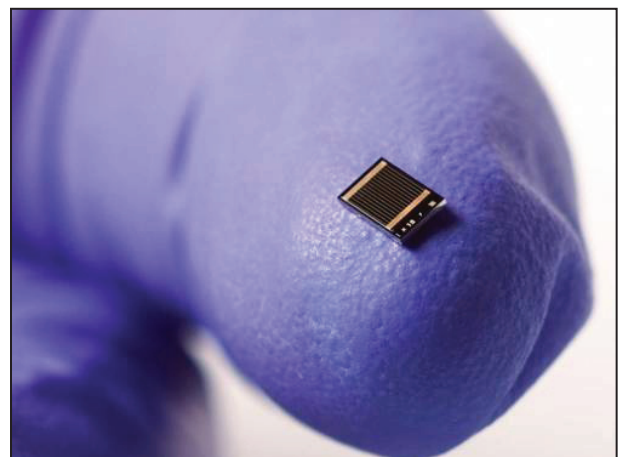


Fig. 9: A Solar Cell as used in the Battery Less Phone

#### IV. Advantages

The advantages of this battery-less phones are exceptional, though the implementation of these phones completely, is still a mystery. From saving energy to utilizing new technology, this outstanding prototype stands rigidly in every part of the platform, when it comes to energy saving.

### A. Conserves Electricity

Since the phone doesn't consist of a battery, it saves electricity to a great amount. As per a survey, it approximately costs a person around 5\$ a year to charge a phone. The amount may not seem that big, but it increases to 500 \$ for 10 years and around 5000\$ in a century. So now it can be easily figured that battery less phone can save electricity and money by large amounts.

### B. Saves Time

From some of the latest facts and figures, it was estimated that a person usually spends approximately 2.5 hours in a day while waiting for the phone to charge. The amount of time increases to around 1000 hours in a year.

### C. Low Power Consumption

As explained earlier, the battery free cell-phone consumes only 3.5 microwatts of power, which is captured from ambient power sources. On an average, it was found that charging your phone consumes 1kWh of power in a year. The power is quite low as compared to the time period of one year, Although if we imagine that if a normal mobile with battery consumes this much power, then how many years would it take for a battery less cell phone to use 1kWh of power? The answer goes even beyond hundred thousand years, so it saves power by a huge amount.

### D. No Charging Issues

The fact is not hidden that charging a phone, again and again, annoys a person, the most. Charging a phone completely and plugging it once more after using it for some hours, displeases the user in emergency and crucial situations. With the battery less phone, anyone can operate the phone anytime and anywhere without worrying about the sudden drain of the battery.

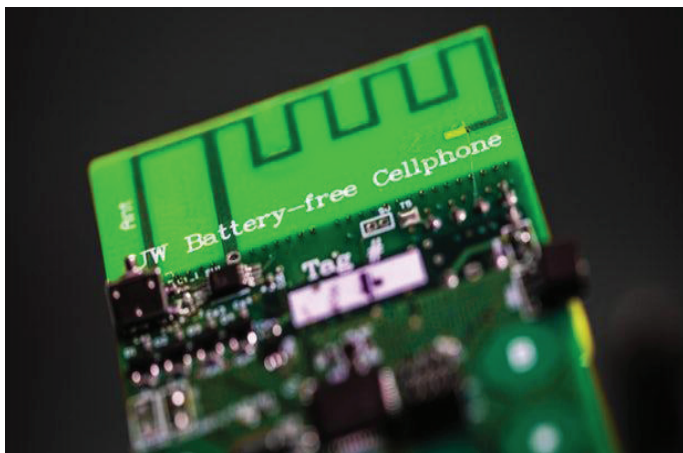


Fig 10: Chip set used for battery free Smartphone

### V. Conclusion

It was extremely astonishing to witness that a group of researchers have finally developed a phone that uses no power, which means the phone has no battery and harnesses energy from ambient signals and light sources. Even Mr. Jobs, who designed the first ever smart phone, might have never thought that smart phones would be that smart that someday we would be able to use it without a rechargeable option, that is without a battery. The phone just consumes 3.5 microwatts of power and harvests energy from ambient radio and light sources with the help of minute diodes that convert light and signal strength into a current which is furthermore converted into few microwatts of power. With the phone, we can just dial a number and call to another person. The

phone possesses a backscatter that sends the digital packages back to the cellular base station. The base station then receives the signals and connects the call through Skype. The battery less phone obtains signals with the help of zero power amplitude modulation and transfers audio onto our earphones. To respond, the user has to press a button and speak into the microphone. Even after combining these amazing technologies, the phone has multiple disadvantages, Range being the biggest one. As per the rate of growing technology, these limitations will be fixed soon with all the Wifi routers having RF emission sources, and we would soon witness an 'Advance Battery less Phone' with multiple features.

### A. Limitations

It is not a hidden factor that anything in the world which is in existence has a disadvantage or a negative factor behind the convenience of that object. The same truth applies for the battery free prototype. Even after having tremendous advantages, it has some limitations too, which restricts the implementation of the device completely.

#### 1. Limited Range

This paper already illustrated that the range under which the device works is extremely limited, which is just 31 feet from the cellular base station, and can be extended to 51 feet with the help of a solar cell when the energy is obtained from ambient light. So as soon as the user leaves the area covered by the RF signals, the signal strength is lost and the device stops working. Even though a solar cell increases the range, it still remains very less in terms of using it worldwide, and that's the biggest reason why the phone is not implemented completely, as researchers are still establishing a definite way to increase the range.

#### 2. Connecting to calls with ear/head phones

Another issue faced by this device is that the user was unable to call someone without the use of earphones, since the earphones worked as a sort of an antenna for receiving signals using zero power amplitude modulation. However, this process consumed extremely low power for calling, using earphones every time while having a conversation was not a good deal.

#### 3. Use of solar cell

A solar cell was used in the device in order to increase the range by few feet, the solar cell only worked when the energy was harvested from ambient "light".

Therefore, to obtain energy in the absence of light was not possible as the solar cell harnessed energy from the light, hence increasing the range was not always possible.

#### 4. Lacking multiple operational Features

This new technology of operating phones without a battery was a mind-boggling invention, although the phone had many disadvantages and lacked multiple features, still, it was praised a lot due to the tremendous efforts of the researchers. One of the important disadvantages was that the phone just had a capacitive touch screen with a keypad used to dial a number, so, even after being the latest invention, it was way back as compared to the battery devices we use nowadays. It was not possible to use the prototype for multiple uses such as for social media purposes or for entertainment purposes, as the advance version of this phone is still under development, and the phone still requires some more amount of energy to perform special tasks.

## VI. Future Scope & Possible Enhancements

The team of researchers already explained the major pros and cons of the battery free cell phone and demonstrated the model with a hope of making major enhancements in the future. The prototype lacked multiple features and in-fact, the phone was limited to a capacitive dial pad which was made upon a plane mother board with all the crucial parts(photo diodes and solar cell ) exposed. Hence, some of the betterments that can be implemented are:-

### A. Increase in the Range

The biggest limitation that restricts the phone is its range which is extremely less. As a reason, the biggest improvement yet to be made is to increase the range by multiple factors. The reason behind the limited range was the lack of cellular base stations that emitted RF signals, so the easiest way to increase range is to reconstruct the usual Wifi routers and antennas so that they start emitting RF signals. This is the best way to increase the range by hundreds and thousands of miles.

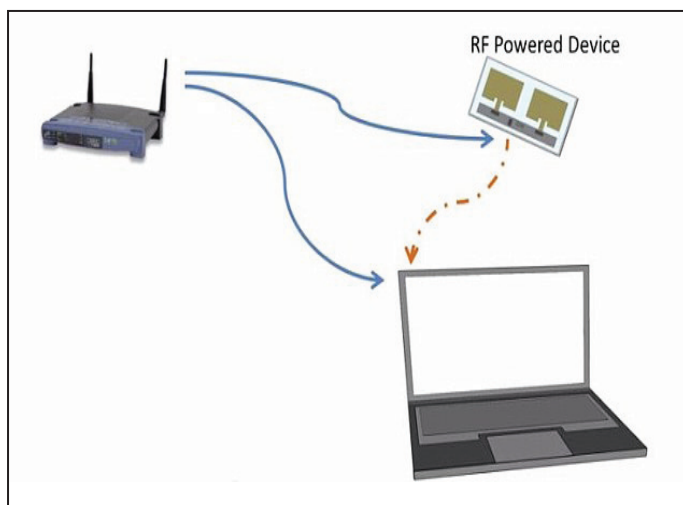


Fig 10: The Figure Below Represents How an RF Powered Device Can Gain Signal Strength from WiFi Routers

### B. Encryption

The procedure of recasting information or data packages into different codes to prevent unauthorized access is known as Encryption. Since the researchers are trying to make the device more enhanced, it is obvious that the phone will include messages and confidential content in the future, hence encryption of the phone and conversations would be necessary to make the device secure.

### C. Video Streaming and Internet Access

The completely advanced phone would be incomplete without the access to the internet and streaming of videos. It would be surprising to see that how the group of researchers implement the video streaming over internet access. Since the advance model will receive signals from Wifi routers, it would be great to observe the way it acquires Wifi signals together with the RF signals from the router, this is possible but the process would require a lot of research and efforts before it is implemented.

### D. Low power E-ink Display

The world has already witnessed “Kindle”- one of Amazon’s best products for avid readers. One of the models of Kindle has a black and white E-ink display which consumes relatively low power from its battery.

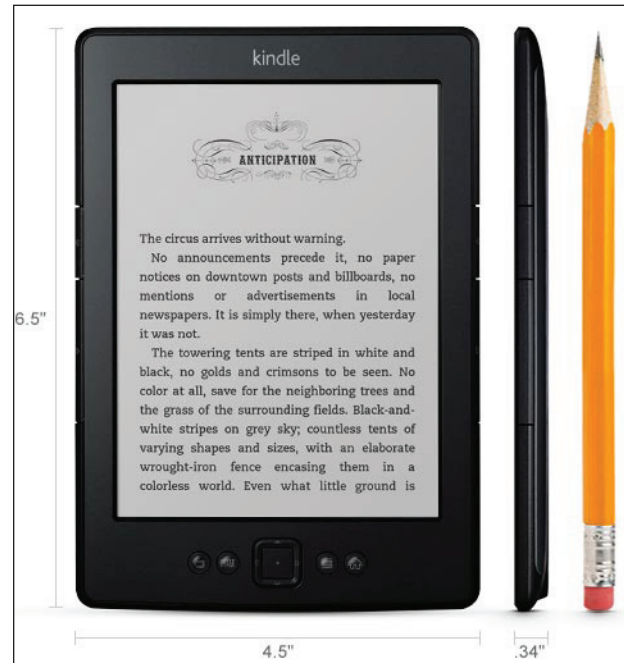


Fig 11: Amazon’s Kindle with E-ink Display

A similar form of the screen would be implanted in an advanced model of battery less phone. Unlike Kindle, it will obtain energy from the RF signals and not from any sort of battery. The team of researchers tried to implant it now but the attempt failed due to an error.

## References

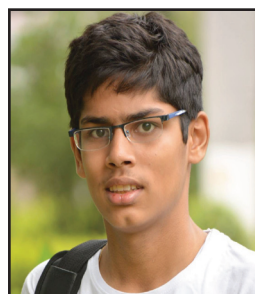
- [1] Shin, Choonsung, Jin-Hyuk Hong, Anind K. Dey, "Understanding and prediction of mobile application usage for smart phones", In Proceedings of the 2012 ACM Conference on Ubiquitous Computing, pp. 173-182. ACM, 2012.
- [2] Goodenough, John B., Kyu-Sung Park, "The Li-ion rechargeable battery: A perspective." Journal of the American Chemical Society 135, No. 4, pp. 1167-1176, 2013.
- [3] Cuervo, Eduardo, Aruna Balasubramanian, Dae-ki Cho, Alec Wolman, Stefan Saroiu, Ranveer Chandra, Paramvir Bahl. "MAUI: Making smartphones last longer with code offload." In Proceedings of the 8th international conference on Mobile systems, applications and services, pp. 49-62. ACM, 2010.
- [4] Paret, Dominique. RFID at ultra and super high frequencies: Theory and application. John Wiley & Sons, 2009.
- [5] Haitani, Robert, Gregory Shirai, Nancy Gayed, Ramachandran Venkataraman, Thomas Kier, Skrikiran Prasad. "Method and apparatus for accessing a contacts database and telephone services", U.S. Patent 8,332,553, Issued Dec 11, 2012.
- [6] Kurth, Derek, George Kantor, Sanjiv Singh, "Experimental results in range-only localization with radio." In Intelligent Robots and Systems, 2003. (IROS 2003). Proceedings. 2003 IEEE/RSJ International Conference on, Vol. 1, pp. 974-979. IEEE, 2003.
- [7] Chandrakasan, Amirtharajah, Rajeevan Amirtharajah, Seong Hwan Cho, James Goodman, Gangadhar Konduri, Joanna Kulik, Wendi Rabiner, Alice Wang, "Design considerations for distributed microsensor systems", In Custom Integrated Circuits, 1999. Proceedings of the IEEE 1999, pp. 279-286. IEEE, 1999.
- [8] Matyba, Piotr, Hisato Yamaguchi, Goki Eda, Manish Chhowalla, Ludvig Edman, Nathaniel D. Robinson, "Graphene



- and mobile ions: The key to all-plastic, solution-processed light-emitting devices", *Acs Nano* 4, no. 2 (2010): pp. 637-642.
- [9] Pantheri, Lucio, Mauro Scandiuozzo, Gian-Franco Dalla Betta, David Stoppa, Fabrizio De Nisi, Lorenzo Gonzo, Andrea Simoni, "A silicon metal-semiconductor-metal photodetector macromodel for circuit simulations", *Solid-state electronics* 49, no. 2, pp. 175-181, 2005.
- [10] Vyas, Rushi, Vasileios Lakafosis, Manos Tentzeris, Hiroshi Nishimoto, Yoshihiro Kawahara, "A battery-less, wireless mote for scavenging wireless power at UHF (470–570 MHz) frequencies", In *Antennas and Propagation (APSURSI)*, 2011 IEEE International Symposium on, pp. 1069-1072. IEEE, 2011.
- [11] Pathak, Abhinav, Y. Charlie Hu, Ming Zhang, "Where is the energy spent inside my app?: Fine grained energy accounting on smartphones with eprof", In *Proceedings of the 7th ACM european conference on Computer Systems*, pp. 29-42. ACM, 2012.
- [12] Zhang, Lide, Birjodh Tiwana, Robert P. Dick, Zhiyun Qian, Z. Morley Mao, Zhaoguang Wang, Lei Yang, "Accurate online power estimation and automatic battery behavior based power model generation for smartphones", In *Hardware/Software Codesign and System Synthesis (CODES+ ISSS)*, 2010 IEEE/ACM/IFIP International Conference on, pp. 105-114. IEEE, 2010.
- [13] Lurton, X., G. Lamarche, C. Brown, E. Heffron, V. Lucieer, G. Rice, A. Schimel, T. Weber, "The GeoHab Backscatter Working Group: definition of guidelines and recommendations for seafloor backscatter measurements by hydrographic multibeam echosounders", In *ICES Symposium: Marine Ecosystem Acoustics-Observing the Ocean Interior in Support of Integrated Management*, pp. 28. 2015.
- [14] Azad, A. K. M., Joarder Kamruzzaman, Nemai Chandra Karmakar, "Wireless sensor network protocols applicable to RFID system", In *Chipless and conventional radio frequency identification: Systems for ubiquitous tagging*, pp. 251-284. IGI Global, 2012.
- [15] Cox, Richard V., Joachim Hagenauer, Nambi Seshadri, and C-EW Sundberg, "Subband speech coding and matched convolutional channel coding for mobile radio channels", *IEEE Transactions on signal processing* 39, no. 8, pp. 1717-1731, 1991.
- [16] Petitto, Laura Ann, Robert J. Zatorre, Kristine Gauna, Erwin James Nikelski, Deanna Dostie, Alan C. Evans, "Speech-like cerebral activity in profoundly deaf people processing signed languages: implications for the neural basis of human language", *Proceedings of the National Academy of Sciences* 97, No. 25, pp. 13961-13966, 2000.
- [17] Gersho, Allen, Vladimir Cuperman, "Vector quantization: A pattern-matching technique for speech coding", *IEEE Communications Magazine* 21, No. 9, pp. 15-21, 1983.
- [18] Staszewski, Robert Bogdan, John L. Wallberg, Sameh Rezek, Chih-Ming Hung, Oren E. Eliezer, Sudheer K. Vemulapalli, Chan Fernando et al., "All-digital PLL and transmitter for mobile phones", *IEEE journal of Solid-State circuits* 40, No. 12, pp. 2469-2482, 2005.
- [19] Su, David K., William J. McFarland, "An IC for linearizing RF power amplifiers using envelope elimination and restoration", *IEEE Journal of Solid-State Circuits* 33, No. 12, pp. 2252-2258, 1998.
- [20] Baghel, Sudhir Kumar, Kirti Keshav, Venkateswara Rao Manepalli, "An investigation into traffic analysis for diverse data applications on smartphones", In *Communications (NCC)*, 2012 National Conference on, pp. 1-5. IEEE, 2012.
- [21] O'regan, Brian, Michael Grätzel, "A low-cost, high-efficiency solar cell based on dye-sensitized colloidal TiO<sub>2</sub> films." *nature* 353, No. 6346, pp. 737-740, 1991.
- [22] Juang, Philo, Hidekazu Oki, Yong Wang, Margaret Martonosi, Li Shiuan Peh, Daniel Rubenstein, "Energy-efficient computing for wildlife tracking: Design tradeoffs and early experiences with ZebraNet", *ACM SIGARCH Computer Architecture News* 30, No. 5, pp. 96-107, 2002.
- [23] Kim, Jin Young, Kwanghee Lee, Nelson E. Coates, Daniel Moses, Thuc-Quyen Nguyen, Mark Dante, Alan J. Heeger. "Efficient tandem polymer solar cells fabricated by all-solution processing", *Science* 317, No. 5835, pp. 222-225, 2007.
- [24] Zhang, Pei, Christopher M. Sadler, Stephen A. Lyon, Margaret Martonosi, "Hardware design experiences in ZebraNet." In *Proceedings of the 2nd international conference on Embedded networked sensor systems*, pp. 227-238. ACM, 2004.



**Sparsh Rawlani** received his high school graduation from St. Mary's Convent School, Ujjain, Madhya Pradesh, India, in May 2017. His primary subjects at the high school included Physics, Chemistry, Mathematics, English and Informatics Practices (computers). His research interests include the implementations of Battery Less Phones which can harvest power from RF waves. At present, He is researching on a technology related to IR and RF waves



**Purvesh Biyani** received his high school graduation from, Delhi Public School, Indore, Madhya Pradesh, India, in May 2017. His primary subjects at the high school included Physics, Chemistry, Mathematics, English and Physical Education. His research interests include the implementations of Battery Less Phones which can harvest power from RF waves. At present, He is researching on a technology related

to IR and RF waves.



**Apoorv Joshi** is currently in 12th grade in Pioneer Convent High School, Indore, Madhya Pradesh, India. His primary subjects include Physics, Mathematics, Chemistry, and Physical Education. His research interest includes the implementation of Battery Less Phones which can harvest power from RF waves. He will be graduating in May 2018. At present he is also researching on a technology

related to IR and RF.