**sampling frequency for reduced energy consumption**

Sampling rate or sampling frequency defines the number of samples per second (or per other unit) taken from a continuous signal to make a discrete or digital signal. For example: if the sampling frequency is 44100 hertz, a recording with a duration of 60 seconds will contain 2,646,000 samples.

Long battery runtime is one of the most wanted properties of wearable sensor systems. The sampling rate has an high impact on the power consumption. However, defining a sufficient sampling rate, especially for cutting edge mobile sensors is difficult. Often, a high sampling rate, up to four times higher than necessary, is chosen as a precaution. Especially for biomedical sensor applications many contradictory recommendations exist, how to select the appropriate sample rate. They all are motivated from one point of view — the signal quality. In this paper we motivate to keep the sampling rate as low as possible. Therefore we reviewed common algorithms for biomedical signal processing. For each algorithm the number of operations depending on the data rate has been estimated. The Bachmann-Landau notation has been used to evaluate the computational complexity in dependency of the sampling rate.

Wearables, or wearable technology, are devices or gadgets that a person wears on their body. However, these wearable devices are more than the latest pair of headphones or a new digital watch. Wearables can be considered smart gadgets — smart meaning they're equipped with all types of sensors including accelerometers and gyroscopes, to mention a few, as well as using Bluetooth technology for making a wireless connection to your smartphone. Some wearables are designed to help you achieve goals such as staying fit, losing weight, or becoming more organized.

**Power requirements of wearables:**

Wearables, like the vast majority of other portable electrical technologies, require batteries, and the device's power requirements drive the battery form factor. Of course, we (consumers) all want products that are smaller, thinner, and have a longer-lasting battery life. There are scores of battery options for which battery technology can best fit wearables' requirements.

Some of the more common types of wearable batteries include:

- Alkaline
- Nickel-Metal-Hybrid (NiMH or Ni-MH)
- Lithium-Ion (Li-Ion) and Lithium-Ion Polymer (LiPo, LIP, Li-poly)

**Alkaline** batteries are tried-and-true — they've been around since the 1960s — and are both safe to use and are easily replaceable. A few examples of alkaline batteries are the AA and AAA.

Alkaline batteries are also available in the button cell (AKA: coin cell) form factor. These batteries have a standard voltage of 1.5 V and a size of 11.6 mm in diameter by 5.4 mm in height. However, when compared to lithium and silver oxide batteries, alkaline batteries offer both the least energy capacity and stable voltage — their voltage drops gradually with use rather than providing a steady and stable voltage before experiencing a sharp drop-off at the end of life.

A **Nickel-metal-hybrid** (NiMH or Ni-MH) battery is a type of rechargeable battery.

NiMH batteries can have two to three times the capacity of an equivalently sized nickel–cadmium battery (NiCd), and its energy density can approach that of a lithium-ion battery.

**Lithium-ion** (Li-ion) and **Lithium-ion polymer** (LiPo, Li-Po, LIP, Li-poly) batteries are the most popular batteries today for wearables. "For wearables today mostly small LiPolymer cells or LiCoin Rechargeable cells are used."

From lithium-ion batteries to coin cell batteries, and from battery life to size and fit, there are many options of which battery technology best fits your needs. Regardless of which battery is utilized, eventually it must either be replaced or recharged. In a perfect world the battery would last forever, but although the world is far from perfect, there is another option — energy harvesting. Of course solar cells (they get their energy from sunlight) and thermoelectric generators (they produce electricity from a temperature gradient) have both been around for a while, albeit neither technology would be practical for wearable devices because they cannot guarantee a continuous supply of energy — sunlight is intermit and body heat has a low thermoelectricity output. What is needed is an energy harvester that both works continuously and allows for high levels of electrical energy generation. Enter TENGs, or triboelectric nanogenerators. This energy-harvesting technology was invented to generate electricity from ambient mechanical motion such as rotary motion, vibrations, oscillating motion, and expanding/contracting motion.

Another approach of energy-harvesting technology is by generating small electric currents through the relative movement of layers, a process called triboelectric charging. "Materials can become electrically charged as they create friction by moving against a different material, like rubbing a comb on a sweater. By sandwiching layers of differently materials between two conducting electrodes, a few microwatts of power can be generated when we move."[4]

No matter how wearables get their energy, it is expected that wearables will become the "must-have" gadgets for both personal and professional use. According to Intersil, "…wearables are such a hot trend that ABI Research forecasts the category is growing at a CAGR of 56.1% and will reach 487 million units in 2018."[5] And given that we (consumers) all want products that are faster, better, and cheaper "…system designers are constantly challenged to create smaller, more efficient and cost effective solutions that will place wearables on the wrists of many more people."

## Wearable Device Architectures

Intersil states, "A typical wearable device architecture includes a microprocessor, memory, display, sensors, communication IC and battery charger blocks, among others. It uses at least three DC-DC converters and 3-5 low dropout (LDO) regulators, depending on the system application."[5] Perhaps a nice compromise between wearables that are battery-free (i.e., utilize energy- harvesting technologies) and wearables that are equipped with rechargeable batteries, is using rechargeable batteries of which incorporate wireless charging.

Texas Instruments (TI) offers their wireless charging PMP11311 reference design for wearable devices. TI appreciates the fact that wearable technology devices "…require advanced power management to achieve long battery run times with always-on functionality. Additionally, the devices need to use small rechargeable batteries and enable small footprint designs."

TI's reference design provides a wireless charging input, a highly configurable battery management solution using a Li-Ion battery charger, and a low quiescent current DC/DC buck/boost converter. Figure 8 below illustrates TI's wireless power system.

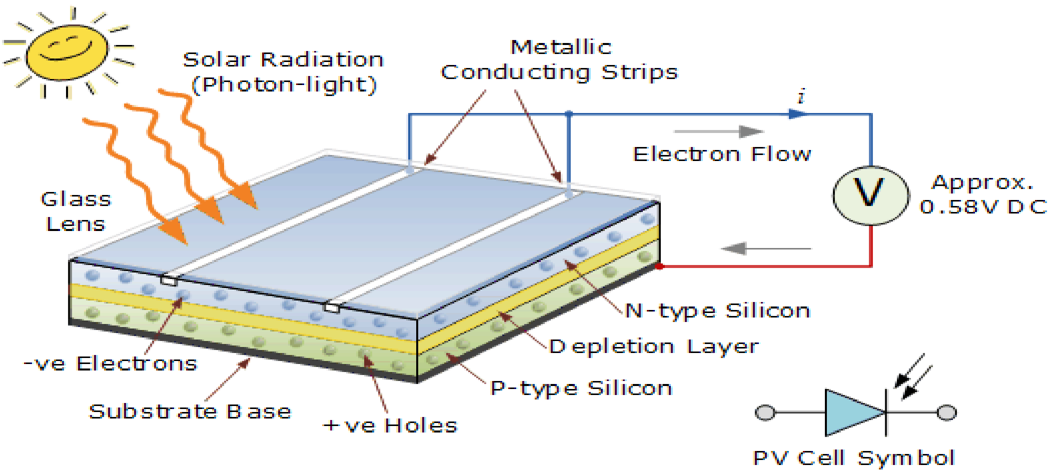
Another semiconductor company that realizes the coming growth explosion of the wearable market is Linear Technology. Linear Tech offers their LTC3331 which is a complete energy-harvesting solution that delivers up to 50mA of continuous output current when harvestable energy is available.

## Solar Cells & Batteries Used in Wearable Devices

Wearable devices have been increasingly popular in the past few years. Everything from smartwatches as a fashionable, convenient extension of one's smartphone to thin bands for fitness tracking, wearable devices are rising in popularity. Such devices can add value to everyday life by providing a way to access information more readily. These electronic devices, however, are no help when they are dead. Minimizing charging frequency is important for all portable devices, but arguably even more so for wearable devices. If the goal is to always have a device readily available, extended battery life is essential. Therefore, some companies have created wearable devices that can be recharged using solar cells. This increases charge time potential while still being able to wear and operate the device as intended without inconveniencing the user

### Basics of Solar Cells

The most common photovoltaic cells are silicon-based. Understanding semiconductor physics is critical to understanding the operation of solar cells. To create a solar cell, silicon layers will be doped to have more electrons, an n-type layer, in one (or some) layer(s) and others doped to have fewer, a p-type layer. P-type layers have an excess of holes–effectively locations where electrons are missing. These types of doped materials are configured so a p-type layer will be next to an n-type layer. The excess electrons and holes flow between the layers. This flow of charge carriers and creation of ions induce an internal electric field. Photovoltaic cells have this type of structure. When sunlight hits a photovoltaic cell, absorption of sunlight will excite electrons, creating holes in their place. The flow of the electrons creates electricity which can then be harnessed. Silicon solar cells generally have an efficiency hovering somewhere around 20 percent. The performance of solar cells is highly dependent upon the duration and intensity of the light they are exposed to.




### Solar Cells in Wearable Devices

While large solar panels installed on building roofs might be the first thing that comes to mind when talking about photovoltaic cells, they can be produced for much smaller applications. Garmin currently advertises a limited offering of solar-powered watches. These smartwatches have impressive battery lives. They list their Instinct Solar watches operating for 54 days on a single charge. Going off solar power alone and assuming 3 days outside at 50,000 lux, they claim unlimited battery life for their watch in battery saver mode. Both the watch's screen and a photovoltaic ring around the screen can convert solar energy into electricity. Employing virtually the entire watch face for capturing solar power maximizes the charging power from the sun.

PowerWatch is a company that also uses solar power to recharge their watches. It is worth noting, however, that solar power is the secondary charging method. The primary charging method is not conventional either, but is achieved through a thermoelectric power sensor. Their MATRIX Prometheus sensor uses the thermal energy from the wearer's body and converts it to an electrical output that powers the watch. This is a prime example of companies finding alternative methods for charging wearable devices.

**Dawn of Solar-Powered Textiles**

Not only are photovoltaic cells being developed for powering wearable electronic devices, but to be woven into everyday clothing. Nottingham Trent University's School of Art and Design has a group which is researching how to create solar cells small enough to be laced into textiles. The group is attempting to combine solar cells into clothing in a way that is unnoticeable to the wearer. The goal is to create clothing that appears the same as all other clothing, only while simultaneously producing electricity. The material comprises of numerous solar cells integrated into the material measuring 3mm by 1.5 mm. The cells would be coated in resin to protect it from the wear and tear of regular usage and laundering. The photovoltaic cells would produce electricity which could be used to charge a device via a USB connection integrated into the clothing.

The group out of Nottingham is not the sole party interested in creating solar cells conducive to being part of daily fashion. Researchers at Rice University have been exploring flexible photovoltaic cells to be sewn into clothing or other wearable items. They see the flexibility of the solar cells as a critical achievement as traditional solar cells are far too rigid and brittle to be practical for clothing. Flexible solar cells are able to bend with the movement of the fabric without damage to the solar cell itself while maintaining the integrity of the garment. While their flexible cells are less efficient than conventional solar cells (a difference of roughly 7%), the flexibility could be well worth the deficit. The flexibility of the solar cells is achieved through using a material that is made up of "sulfur-based thiol-ene reagents". The researchers have reported that cells with 20% thiol-ene content provide the prime combination of efficiency and flexibility.

Still other researchers have been creating flexible solar cells. Organic, ultrathin photovoltaic cells have been developed at the RIKEN research center in Japan. These solar cells were created by using an annealing process to improve the thin cell's durability while retaining flexibility. Their solar cells have an energy conversion ratio of approximately 12%. Again, this is lower than the conventional silicon-based solar cell's energy conversion ratio by about 10%. However, their research does show promising results with regards to the environments in which these ultrathin cells can be operational. They say that the solar cells are remain stable even under high temperatures and humidifies. This type of functionality and durability would indeed be beneficial for use in wearable devices.