Energy for Connected Objects

Lab Report

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Introduction

Powering a connected device is an important step in its conception. Wireless power transfer is a way of powering a connected device that should be taken into account for some applications with strong constraints. During these two labs, we will power a LED thanks to wireless power transfer. A LED is not really a connected object as it does not send information, but it is very easy to see if it is powered, which makes it a very good demonstrator. Furthermore, it will allow us to go through all the necessary steps in the conception of a connected device powered through wireless power transfer: characterization of the application, definition of the power needed, choice of the components to optimize the received power… In the end, we will use the experience we gained around the topic to think about ways to power our innovative project.

Study of the load and design

First, we looked at the datasheet of the LED we were going to use in order to define its main characteristics. The first step is to identify the DC power used by the LED to function at 100%, 50% and 25% of its luminosity. We will use a red LED SML-D12U1W. The information on the following table has been extracted from its datasheet[1].

Luminosity	**Voltage**	**Current**	**Power**
100%	2.2V	20mA	44mW
50%	2V	10mA	20mW
25%	1.9V	5mA	9.5mW

Table 1: Voltage, Current and Power needed by the LED

Then, we can extract from Table 1 the energy needed to light the LED during one second, as we know $W = J/s$.

Luminosity	**Energy to light for 1s**
100%	44mJ
50%	20mJ

[1] https://fscdn.rohm.com/en/products/databook/datasheet/opto/led/chip_mono/sml-d12x1- e.pdf

25%	9.5mJ

Table 2: Energy needed for different luminosities

We can put this energy consumption in relation with the energy consumed by a connected object. A connected object will typically consume more when it is sending data, but as it is not always sending, we can consider that our LED is approaching the consumption of a connected object. Indeed, the voltages are similar (more recent connected devices are powered in 1.8V).

To power our LED through wireless power transfer, we could adopt different strategies. For the first one, direct consumption, we would have to transmit directly the powers featured in Table 1. However, a much more interesting strategy would be to implement a store then use strategy. We will see that this allows us to power the LED by transmitting way less power, i.e. we can put the object farther from the power source.

We will use a bq25504 power management unit and a TPS63031 DC-DC buck-boost converter. We have to choose a supercapacitor as energy buffer. To choose the better one for the LED, we need to compute the capacity of the supercapacitor considering the energy we want to harvest (here, 44mJ to power the LED at 100% for one second), the maximum activation threshold for our components (5.25V), and the minimum deactivation threshold (2.2V).

$$E = \frac{1}{2}C(Vmax^2 - Vmin^2) \Rightarrow C = \frac{2E}{Vmax^2 - Vmin^2} = \frac{2*44e^{-3}}{5.25^2 - 2.2^2} = 3.87e^{-3}F$$

This leads us to choose a supercapacitor of 6.8mF. We then have to compute the maximum activation threshold to get the energy we want. We do not move Vmin, because that would mean increasing the lost energy. We consider an energy 20% higher that what we need in order to compensate for the tolerance on components and eventual aging of the supercapacitor.

$$Vmax = \sqrt{\frac{2E*1.2}{C} + Vmin^2} = 4.9V$$

In this configuration, the minimum DC power on the entrance of the system is the power needed for cold start plus the loss of the supercapacitor. If we apply this power, we can light the LED at 100% for 1s once in a while.

$$P = 16.62 + 52.2 = 69.12\mu W$$

This is almost 1000 smaller than the power needed for direct consumption!

Rectifier characterisation

Once these parameters are determined, we need to characterize the rectifier we will use. We first determine the central frequency for our rectifier by powering it with an USRP around 868MHz and 2.45GHz. Our rectifier is on the 868MHz band. We first measure the tension on the potentiometer with different frequencies, with the resistance at 1.5kOhm and the gain at -6dBm, to determine the optimal frequency. Then, we vary the resistance and finally, the gain.

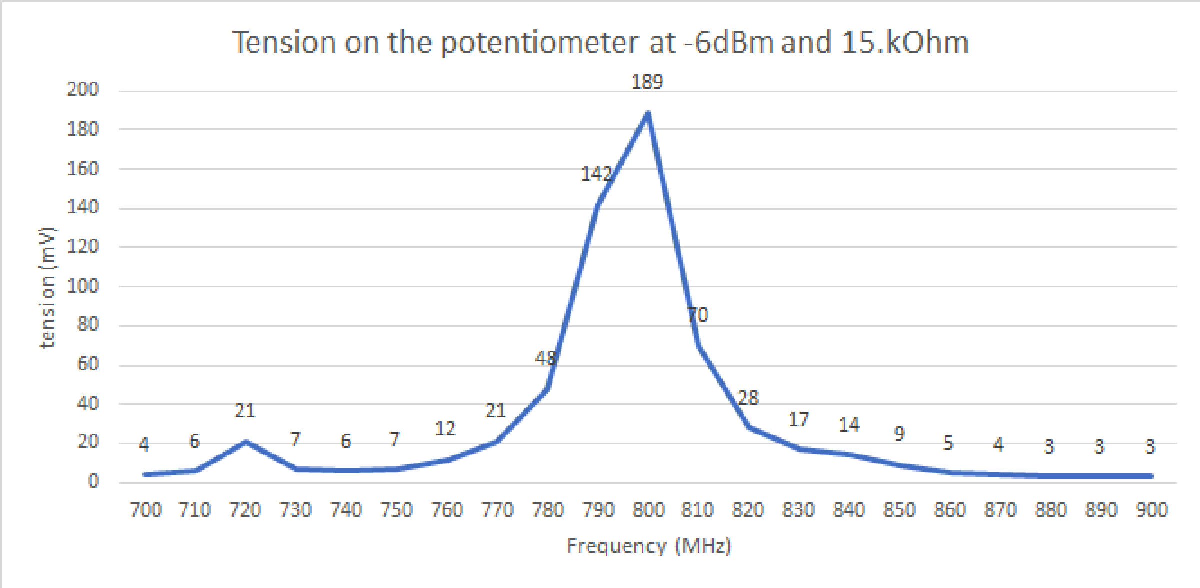

Figure 1: Evolution of the tension on the potentiometer

We place ourselves at the optimal frequency, i.e. 801MHz, and we vary the resistance.

Resistance (kOhm)	**Tension on the potentiometer (mV)**
1.5	100
3.5	170
4.5	85

Table 3: Tension variation with the resistance

The optimal resistance for our rectifier is 3.5kOhm. We then determine the optimal gain by varying the gain, at 801Mhz and 3.5kOhm.

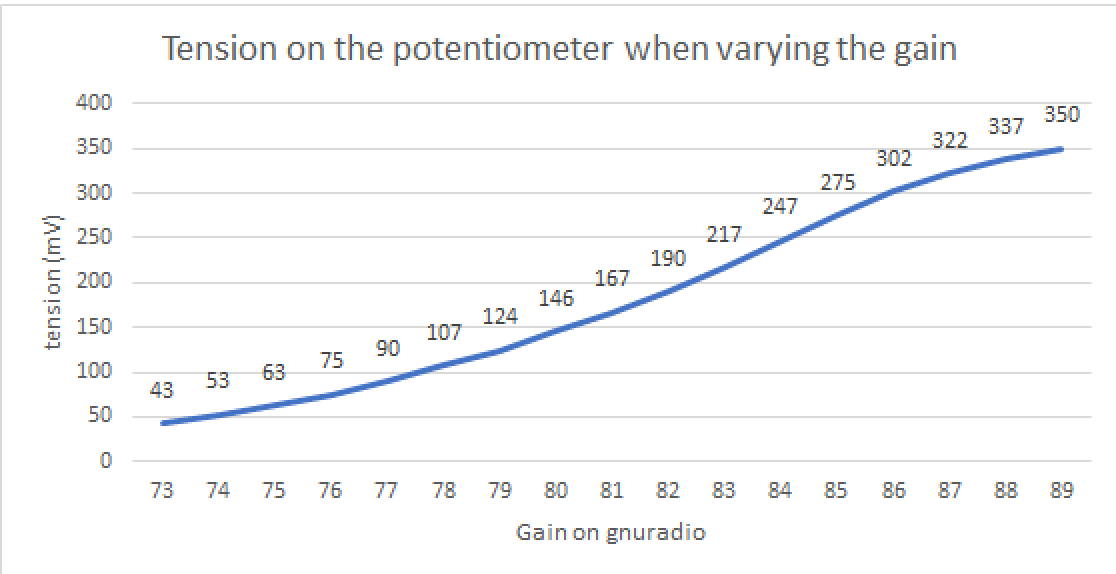

Figure 2: Tension on the potentiometer when varying the gain

The best gain in our case is 89 on gnuradio, which is approximately 1dBm.

Frequency band	**Optimal frequency**	**Optimal resistance**	**Optimal gain**
868MHz	801MHz	3.5kOhm	1dBm

Table 4: Summary of the characteristics of our rectifier

We can compute the rectifier efficiency like the following.

$$\eta_{rectifier} = \frac{\frac{U^2}{R}}{P_{RF\_in}} = \frac{\frac{(189e^{-3})^2}{3.5e^{3}}}{1.3e^{-3}} = 7.9e^{-3}$$

Then, we will characterize the given PCB (rectifier + supercapacitor + LED). It works on the 868MHz frequency band. As we have a supercapacitor, we have to wait a little to see if the LED lights up when applying power. We try different frequencies with a frequency range on gnuradio and figure out the 870MHz frequency works fine. Then, we try to determine the minimum gain mandatory to light up the LED with another slider on gnuradio. This minimum gain is 66 on gnuradio, which is roughly equivalent to -23dBm.

We also measured the time necessary to recharge the supercapacitor with different RF input powers, from 66 to 75 in gnuradio (-23dBm to -13dBm). With powers superior to -13dBm, recharge time was almost instantaneous.

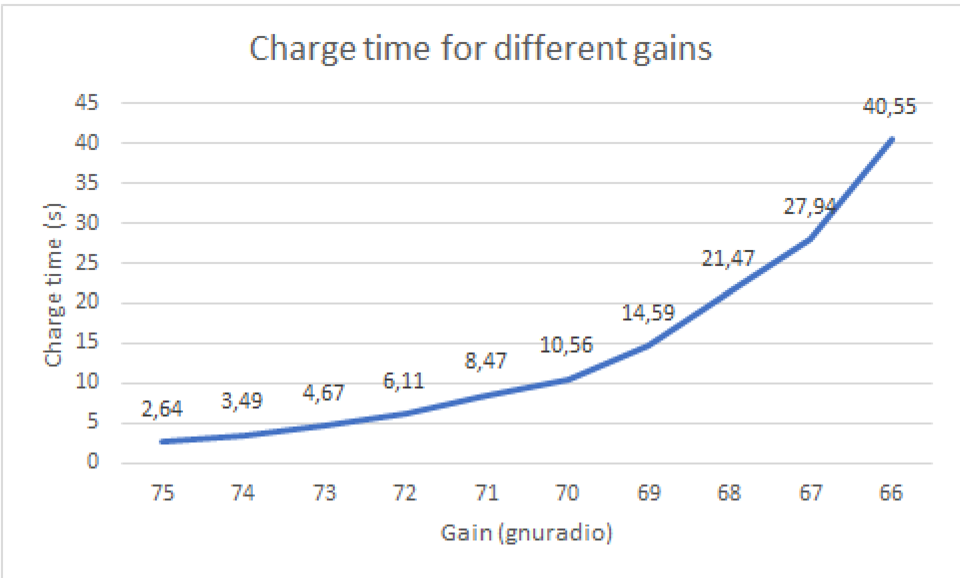

Figure 3: Charge time of the supercapacitor for different gains

Antenna choice

The goal is now to harvest ambient energy with our system. We have to choose the better antenna for this goal. The antenna choice relies on finding the best compromise between the antenna size, its radiation pattern, its gain and its polarization. Indeed, polarization and radiation pattern conditions the orientation of the antenna in space. To power our LED, we used a patch antenna on the source (radiation pattern on a plane), and a whip antenna for our powered device. The patch antenna has a high gain of 9dBi. We were able to observe that if we changed the orientation of the antenna by 90°, we were not receiving power anymore.

Ambient electromagnetic energy harvesting

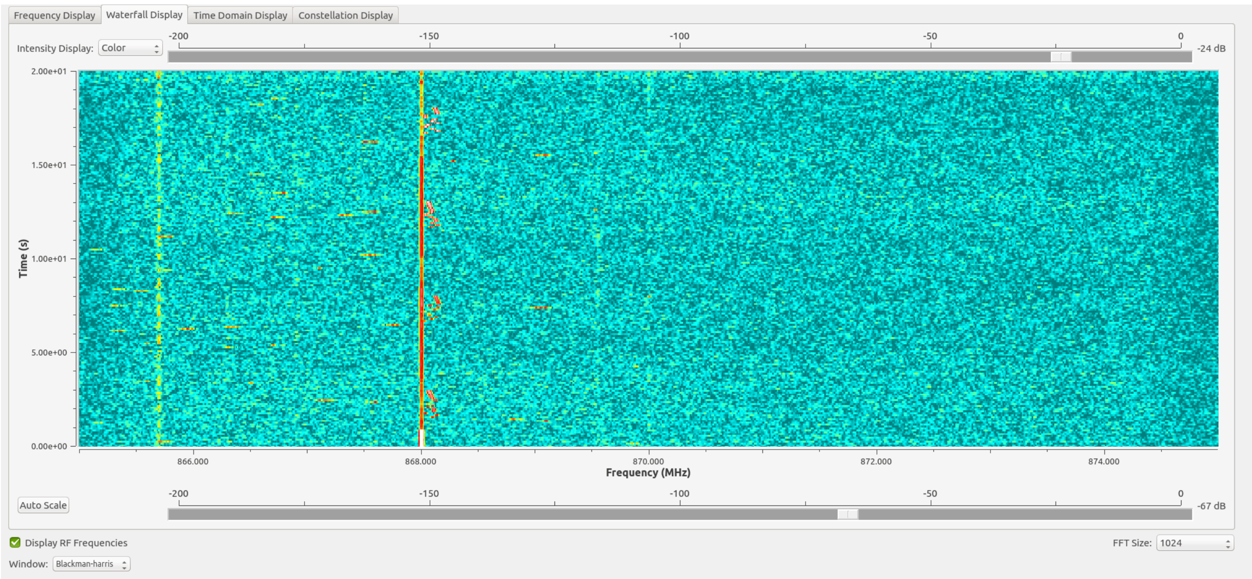

Figure 4: Waterfall display of spectral analysis at 870MHz

This graph shows the environmental energy available at 870MHz with a bandwidth of 12MHz. We can see that the ambient energy is not enough to power a LED. Indeed, with a spectral analyzer, we have an average noise level of -63dbm which is not enough to power our LED.

In our opinion, the whip antenna is the most appropriate one as it has the best compromise between being compact, having a good radiation pattern and reasonable gain.

Radiative electromagnetic wireless power transfer

From the equations of the lab we deduct the following formula for the maximum distance between the source and our device powered by wireless power transfer.

$$d = \sqrt{\frac{P_{TX} * G_{TX} * G_{RX} * \eta_{rectenna} * c^2}{P_{DC\_out} * 16 * \pi^2 * f^2}} = \sqrt{\frac{P_{TX} * G_{TX} * G_{RX} * c^2}{P_{RF\_in} * 16 * \pi^2 * f^2}}$$

$$d = \sqrt{\frac{1 * 2 * 2 * c^2}{5e^{-6} * 16 * \pi^2 * (868e^6)^2}} = 98m$$

We use 0.5 for the rectenna efficiency.

To improve the range of our system, always respecting the regulation, we can change the antenna for the receiving device. Indeed, by increasing the RX gain, we increase the range. We can also modify our system to reduce as much as possible $P_{RF\ in}$ by optimizing as much as possible the power consumption of our LED (potentially take another LED that consumes less power).
An example of a WSN application using WPT can be the introduction of sensors in concrete in order to check its health. As it is placed in a hostile environment the most appropriate method to power it is to use WPT. We could use electromagnetic sources in order to power the sensors. More generally, WPT is suited for long lifetime devices placed in a hostile environment. On the contrary, WPT is not suited for applications with high node mobility where we cannot control the orientation of devices (it is more efficient to consider polarization of antennas for WPT), and when devices are expected to send data at a precise moment with a small period (a few seconds) because of the time of charge of the supercapacitor that we cannot control.

Link to your innovative project

For our innovative project, we worked on the ACAS project (Advanced Cyclist Assistance System). The objective is to increase cyclist security by filming behind the bike, detecting danger with AI and sending a warning to the cyclist. The warning can take two different forms: either a notification on a phone application or a vibration on a vest that the cyclist wears.
We can think about two examples to power our device. The first idea would be to use photovoltaic cells to power both the vest and the embedded system that runs the AI. However this is probably a bad idea as this would mean that when there is no sun, we cannot power our security system. In addition to that, our system has to run permanently and has an AI that needs to analyze the images in real time.
The other idea would be to power our system through the mechanical energy of the cyclist. The problem is that it is way harder to pedal with a dynamo which is unpleasant for the user.

In the end, for our project, we think that it is not really relevant to implement WPT or power harvesting. In our case, the implementation of an embedded secondary battery.

Conclusion

All along these labs, we put into application what we saw in the theoretical classes about wireless power transfer and harvesting. We were challenged to develop a reflection about the applications of WPT, the ways of powering our innovative project, and by that develop our critical mind.