INSTITUT NATIONAL DES SCIENCES APPLIQUÉES TOULOUSE

REPORT ENERGY FOR CONNECTED OBJECTS

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Introduction

Connected objects and electric devices in general require a source of power to properly work. Multiple sources of energy can provide the necessary voltage for the system. This energy can be collected from ambient energy such as thermic, mechanical, electromagnetic and luminous energy. It is also possible to provide the energy from external sources. The most common way to proceed is through the usage of batteries or wires. However, through this lab sessions, we will see a way to power a system using wireless signals, but also the possibilities and the limitations of this technology.

I - Study of the datasheet

1. Continuous Power Required for Nominal LED Operation

The SML-D12U1WT8 red LED requires continuous power to operate at its nominal brightness. To this end, by studying the data sheet, we have determined :

- **For nominal use**: The power required is 44 mW with a voltage of 2.2 V and a current of 20 mA.
- **For 50% of nominal brightness**: The power required is 20 mW with a voltage of 2 V and a current of 10 mA.
- **At 25% of nominal brightness**: power drops to 9.5 mW with a voltage of 1.9 V and a current of 5 mA.

These values were obtained by calculating the power as a function of the voltage and current required to achieve specific percentages of luminosity.

2. Energy required to light the LED for 1 second

The energy required to power the LED for one second was calculated by multiplying the power by the time:

- **For nominal operation (100% brightness)**: E = 44mJ
- **For 50% luminosity**: E = 20 mJ
- **For 25% brightness**: E = 9.5mJ

These values can be used to estimate the minimum energy that needs to be stored to ensure that the LED lights up.

3. Capacitance and voltage threshold configuration

By analysing the activation/deactivation voltage thresholds and the various capacitance options available, we have determined the potential configurations that would enable the LED to operate effectively.

The capacitance options and voltage thresholds can be combined in the following way to meet the needs of the PMU:

- **Capacitance of 6.8 mF** with a turn-off threshold at 2.2 V and a turn-on threshold at 5.25 V, providing the required power in a stable manner.
- **Capacitance of 2.2 mF** can also be used, although the losses are higher, but it may be suitable for rapid activation and a short LED supply.

$$\mathrm{C} = 2\mathrm{E}\frac{}{V_{\max}^2 - V_{\min}^2}$$

Minimum input power

In order to guarantee LED operation in the worst-case scenario, a minimum input power is required. Depending on the maximum losses of the supercapacitors and power management components, the input power must be at least 606 µW.

II - Characterization of the systems

Once the theory was done, we had the opportunity to characterise a board composed of the LED and a supercapacitor. To proceed, we had multiple tools available:

- **A potentiometer**, that will be use to measure the voltage around the capacitor depending on the given power
- **An USRP / ADALM-PLUTO SDR, a** development board used to emit/receive radio frequency. Though it might usually be used with an antenna, we will use a wire between our main board and this tool to limit losses due to environment and interference.
- **A computer** with softwares to interface and format the previous tools and data :
    - **GNU Radio**, allowing us to generate a signal with a given frequency. Combined with the USRP, it makes it possible to easily change frequency for measurement
    - **Waveforms**, a software used to visualise the data gathered by potentiometer
    - **Excel**, to create a graph from the gathered data

The different tools were then combined giving the following graph:

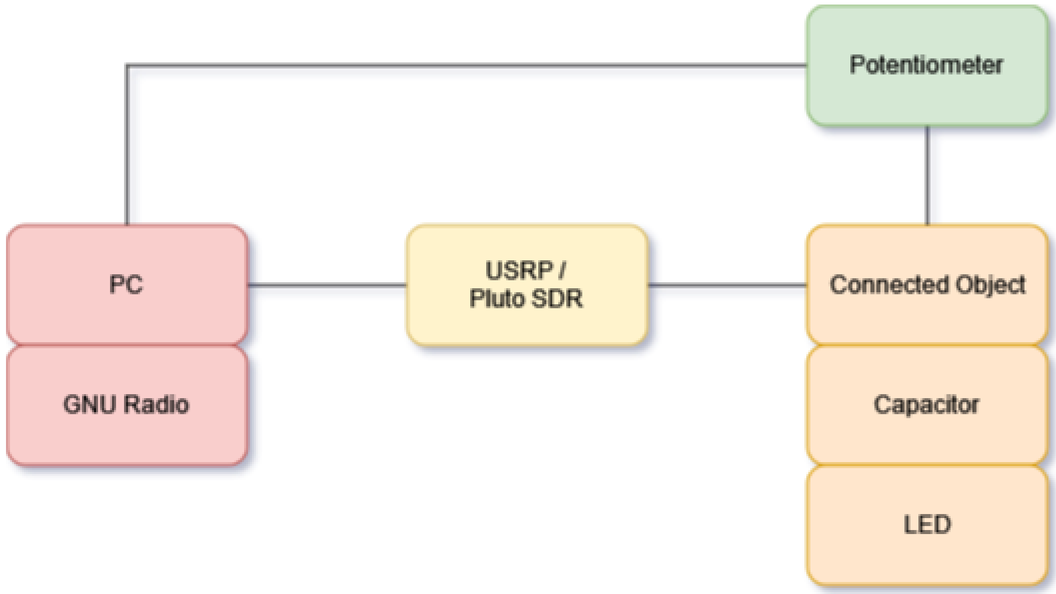

Figure 1 - Graph representing our testing mechanism

For the measurements, we decided to measure between 0 and 1.8 GHz, with a step of 100 MHz. Due to problems with our URSP, and more precisely the emitting port dysfunctioning, we had to use a PLUTO-SDR. However, this technology is not as broad as the previous URSP, so we were not able to measure above 1.8 GHz. It might have been interesting to assess the voltage around the second ISM band we studied in this course, 2.4 GHz. However, we were still able to see that we had a main peak around 900 MHz, matching with the ISM band 868MHz, as well as a secondary peak around 400MHz, matching with the ISM band 433MHz.

More measurement might have been interesting as well to verify the maximum voltage of the system, and the associated frequency.

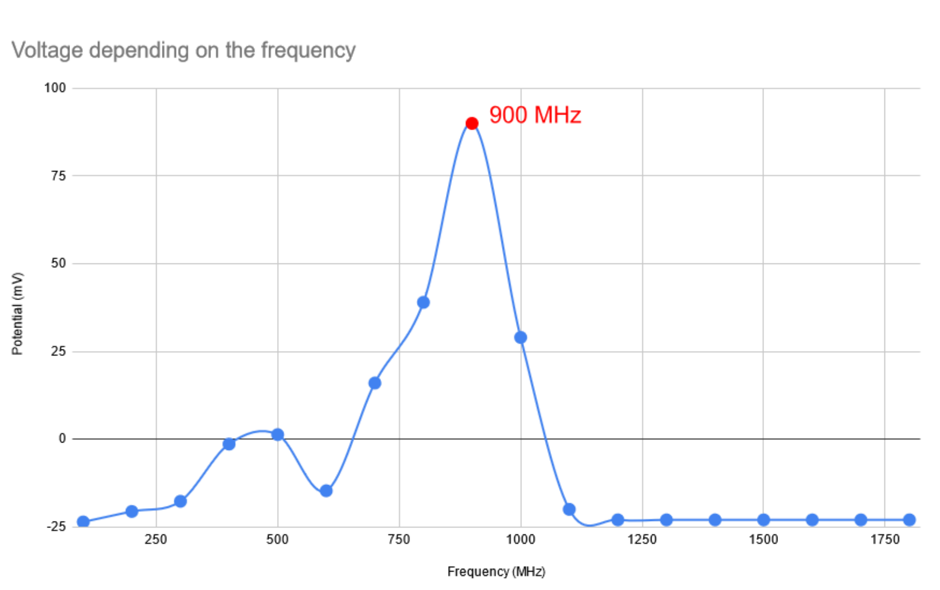

Figure 2 - Characterization of our supercapacitor

We later decided to draw on a graph the measurement of multiple capacitors, made by our class. In this figure, we can see that the black and blue are more fitted for 2.45 GHz frequencies while the capacitors represented by the red and green curves would be better associated with 800 MHz frequencies in reception.

However, we can see that all capacitors are able to function in every case, but would have better performance with some frequencies. We could imagine that an ideal behaviour would be to have the maximum voltage for every frequency in the given range, to gather a maximum of energy. This might however not be possible, or very expensive. In the case of the energy being deliberately sent to the system using an antenna, it is then possible to know the expected frequency range in which the capacitor would be able to get the biggest amount of energy from.

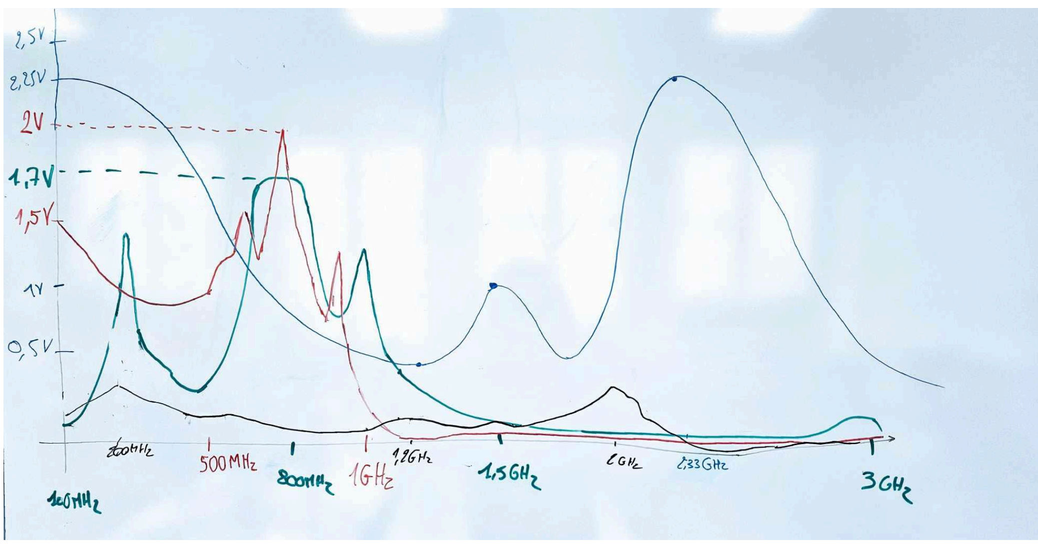

Figure 3 - Characterization of the different capacitors, representing the voltage depending on the given frequency

III - Choice of the components

1. The capacitor

A capacitor is a component that allows the storage and delivering of energy. As we have seen in the previous sections, there are multiple types of capacitor, and it is important to question ourselves about the one we might need.

The choice of the capacitor can be done base on multiple factors:

- **The frequency** on which the energy will be emitted. Likely emitted from ISM radio bands, we saw in the previous section that depending on the capacitor, the best powering frequency might vary.

- **The size of the system**, meaning the amount of power that might be required for the whole system to work. The size of the capacitor is important to fit as it allows the system to store enough energy without overestimating the system. In this case, multiple capacitors can also be implemented in series or in parallel, respectively to limit the minimal amount of stored energy and the losses.

Finally, we can also question the need for a capacitor itself. The capacitor is a useful component if the energy that a system receives is not stable or too low to power all the necessary components. In the case of wireless energy transmission, a capacitor might be crucial as it is often both unstable and low in energy.

2. Antennas

Once the characterization was done, we were able to test out the systems with a wireless source of power. To achieve this goal, we were shown multiple antennas:

- **Dipole antennas** with a radiation pattern of a thor and a linear polarisation. This made it possible to receive the transmitted energy from all around the antennas, as long as it remains on the same plane, and parallel.
  The ones we were given had three sizes allowing to emit/receive in 800MHz, 2.4GHz and the third one allowed both. However, we were legally only able to use the 800 MHz one to transmit energy, as it is on the free to use ISM band.

- **Yagis antenna**, including a larger range of frequencies, with a directional radiation pattern and a linear polarisation. We did not try this antenna for this lab, however it might have been interesting to test the antenna to observe if all the systems that are sensible to multiple wavelengths would react in a similar manner using a larger range of frequencies.

- Finally, we also saw the **Patch antenna**. This one uses a linear polarisation and a bidirectional radiation pattern. However, by adding a metallic surface on the back of the antenna, it is possible to correct the polarisation by making it just directional.
  This antenna is interesting because of its low cost to produce, but also the narrow bands it transmits on. It can also be interesting as it is a flat antenna that might be easier to implement in the environment.

Through these three types of antenna, we were able to see that the transmission of energy through an antenna offers a wide range of possibilities and variations (numerous more antennas exist than the three mentioned above). If we were to use antennas to power a connected object, we might question ourselves about the features we want the antenna to own. For a static object, a directional patch + metallic surface antenna might be a cheap and efficient option. However, if the object is planned to move around, one or more dipole antennas, potentially combined with a capacitor, might help to keep a constant source of energy, wherever it is.

Conclusion

To conclude, we were able to see that an object requiring a low energy source can be powered using electromagnetic signals through a wireless system. However, it is important to characterise the needs of our system to ensure the best and more stable source of energy for it to properly operate. This might be by the choice of using or not a capacitor, the choice of the chosen frequency or the choice of the nature of the emitting and receiving antennas. Finally, we could also question the advantage of this means of powering our system over other means, such as wire, batteries or other types of energy harvesting.