Energy for connected objects

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Introduction

This lab report is about how we looked into powering connected devices, focusing on getting energy from electromagnetic fields and sending power without wires. We checked how much power a small red light needs, tried out ways to use power directly or save it for later, and worked with different tech parts to manage and convert energy. The plan is to build devices that can power themselves, improving how they charge, sense different things, work better with Bluetooth, and send data securely.

I. Study of the load and design

1. The current needed for the LED to work in its nominal use case is 20mA.

The voltage needed is 2,2V. The power is 2,2 * 20 = 44 mW
For the LED to work at 50% luminosity : 9mA and 2V power = 18 mW
For 25% luminosity : 5 mA and 1,9V power = 9,5mW

Nominal current for connecting objects : 12mA
Nominal voltage for connecting objects : 1.8 V

2. The energy required to light the led for 1s :

Nominal (100%° : E = P*t = 44 *1 = 44 mJ
50 % : E = 18 mJ
25 % : E = 9 ,5mJ

3. - How much power must be provided to the LED to work?

Minimum current (1mA) ⇒ 1,75 V ⇒ P=1,75 mW
Maximum current(20mA) ⇒ Max power dissipation : 54mW

- What will be the luminosity of the LED?

Less than 5% of luminosity for minimum power

4. In this question we will see which configurations of capacitance and activation and deactivation voltage thresholds can be employed, and what is the minimum input DC power required to work in the worst case.

Choosing the right supercapacitor is crucial for our project to work as an energy buffer for the LED. We calculated the supercapacitor's capacity based on the energy needed to fully power the LED.

E = ½ *C *(Vmax^2 -Vmin^2) ⇒ usable energy

We choose C first, how do we choose it?

7.3 Recommended Operating Conditions

		MIN	NOM	MAX	UNIT
$V_{IN\ (DC)}$	DC input voltage into VIN_DC[1]	0.13		3	V
VBAT	Battery voltage range[2]	2.5		5.25	V
C_{HVR}	Input capacitance	4.23	4.7	5.17	µF
C_{STOR}	Storage capacitance	4.23	4.7	5.17	µF
C_{BAT}	Battery pin capacitance or equivalent battery capacity	100			µF
C_{REF}	Sampled reference storage capacitance	9	10	11	nF
$R_{OC1} + R_{OC2}$	Total resistance for setting for MPPT reference.	18	20	22	MΩ
$R_{OK}1 + R_{OK}2 + R_{OK3}$	Total resistance for setting reference voltage.	9	10	11	MΩ
$R_{UV1} + R_{UV2}$	Total resistance for setting reference voltage.	9	10	11	MΩ
$R_{OV1} + R_{OV2}$	Total resistance for setting reference voltage.	9	10	11	MΩ
L_{BST}	Input inductance	19.8	22	24.2	µH
T_A	Operating free air ambient temperature	–40		85	°C
T_J	Operating junction temperature	–40		105	°C

(1) Maximum input power ≤ 300 mW. Cold start has been completed
(2) VBAT_OV setting must be higher than VIN_DC

We have Vmin=2.5 V and Vmax=5.25V

⇒ C=2E/(Vmax^2 -Vmin^2) = 2*44mJ/(5.25^2 - 2.5^2) > 5mF
This is the ideal C with the smallest loss

To optimize we choose the smallest threshold for the Vmin so E doesn't get bigger
⇒ we change the Vmax threshold for C=6.8mF
Vmax=sqrt(2E/C + Vmin^2) =4.4 V and C=6.8 nF and Vmin=2.2V

Worse case scenario : P = 16.62 µW
Pin=16.62 + 52.5 = 69.12 µW

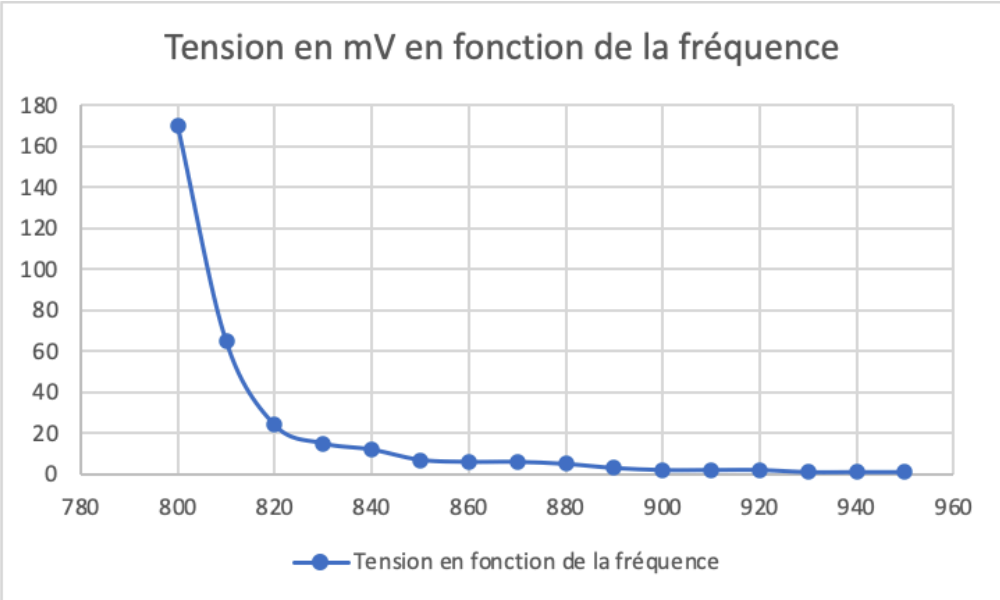
50% : 20mJ of energy, with a C=2,2mF, Vmax = 4.9V, Vmin =2.2 V.
P=622 µW.

25% : 9 mJ of energy, with a C=1.5 mF, Vmax = 4.1 V, Vmin = 2.2 V.

P=430 µW.

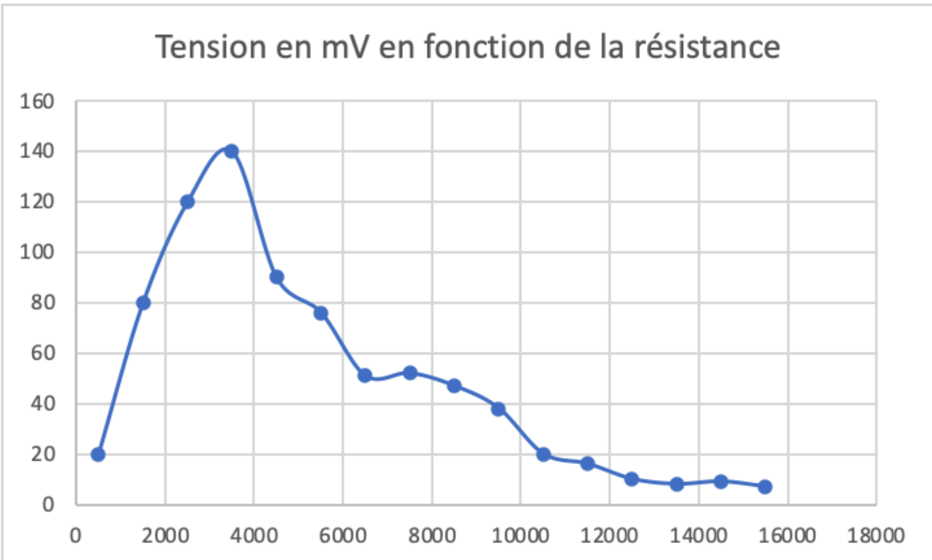
II. Rectifier characterisation

1. In this part, we first aimed to figure out if our rectifier worked best with frequencies of 2.45 GHz or 868 MHz. By using a USRP device, we tested the rectifier at both frequencies and discovered it performs optimally at 868 MHz. Next, we varied the frequency between 800 MHz and 900 MHz, in 10 MHz increments, to measure how the voltage across the potentiometer changed with these adjustments.



Analyzing the curve, we can conclude that the optimal frequency for our system is around 800 MHz. At this frequency, the LED achieves its brightest luminosity, indicating that the system is operating most efficiently.

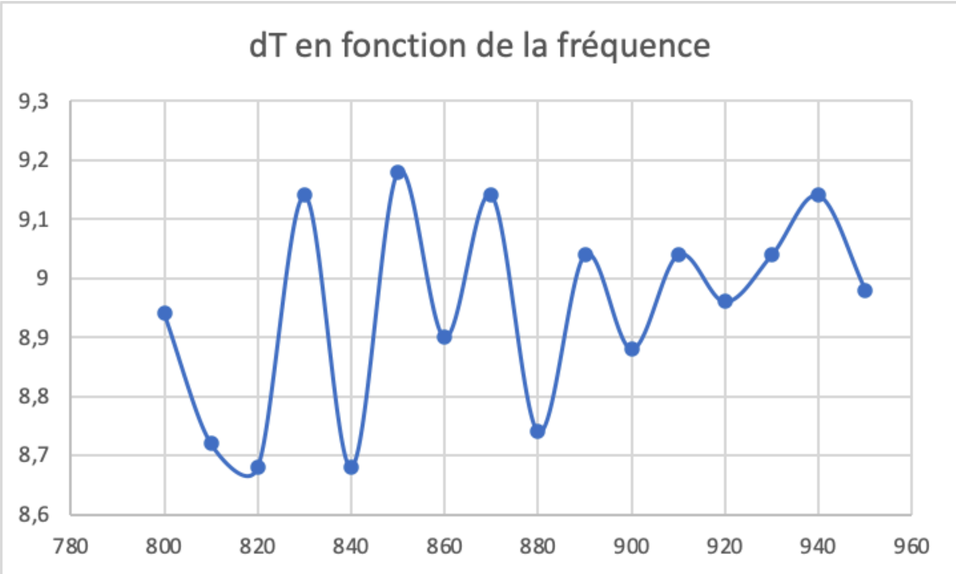
2. To determine the optimal load, we measured the voltage across the potentiometer terminals while varying the load between 500 Ω and 1 MΩ, at the optimal frequency of 800 MHz with an RF input power of -15 dBm.



Analyzing the curve, we can conclude that the optimal load for our system is around 3kOhm.

3. We didn't have the time to measure the optimal gain during the lab.
4. By using the targeted loads (LED or board), we searched the minimum RF input power allowing a good functioning.

We observed on the oscilloscope the period while varying the frequency.

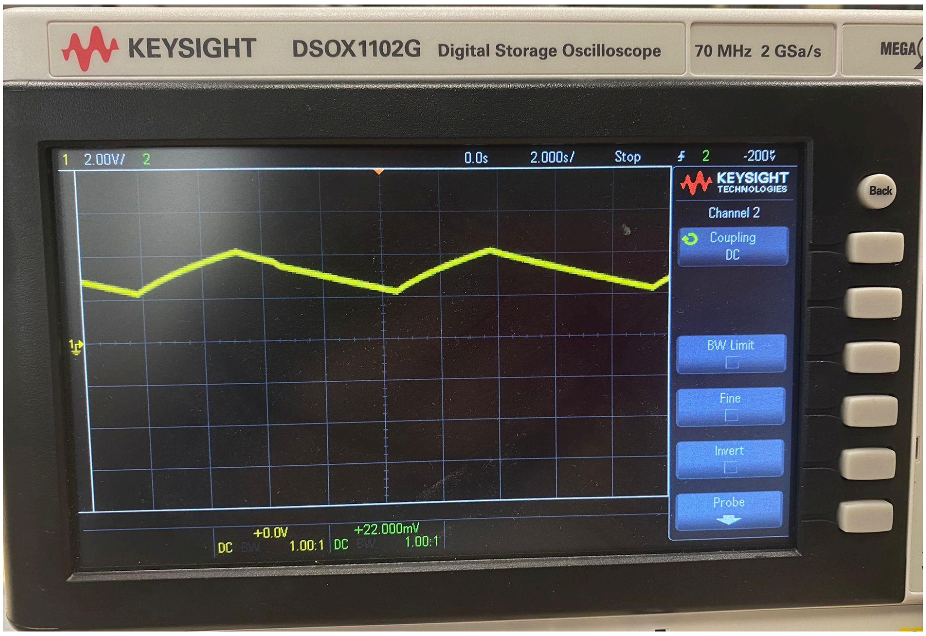


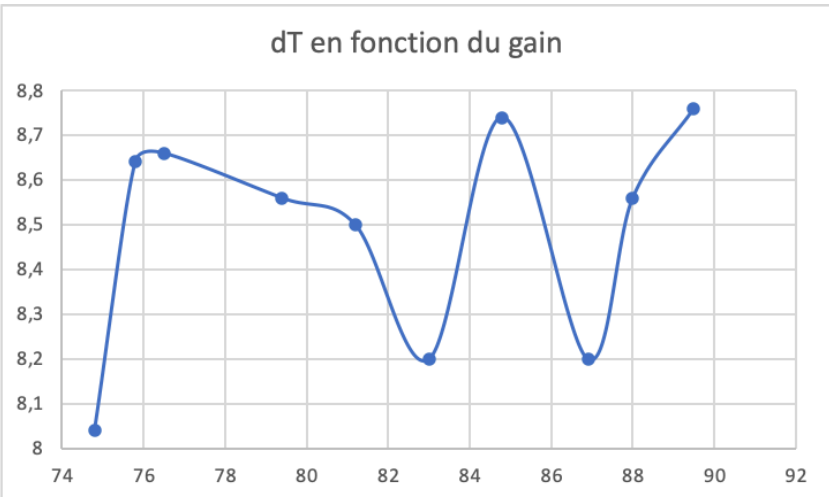
Freq USRP	dT
800MHz	8,94s
810MHz	8,72s
820MHz	8,68s
830MHz	9,14s
840MHz	8,68s
850MHz	9,18s
860MHz	8,90s
870MHz	9,14s
880MHz	8,74s
890MHz	9,04s
900MHz	8,88s
910MHz	9,04s
920MHz	8,96s

930MHz	9,04s
940MHz	9,14s
950MHz	8,98s

5. For the load dedicated to the "store then use" strategy, we characterized the time required for a recharge versus the RF input power (between +15 dBm and the minimum value measured, with a step of 1 dBm)

We observed on the oscilloscope the period while varying the gain.





Gain	dT
74,8	8,04
75,8	8,64
76,5	8,66
79,4	8,56
81,2	8,50
83	8,20
84,8	8,74
86,9	8,20
88	8,56
89,5	8,76

III. Antenna choice

When choosing an antenna for our project, we considered that most antennas are designed to be half the wavelength of the emitted frequency. For the radiation pattern, directional antennas are preferable for fixed objects with a known source direction, while omnidirectional antennas suit situations where the object's position and source direction are variable. The polarization should match the source if known; otherwise, circular polarization ensures at least half of the energy is captured regardless of the source's polarization. Our tests concluded that ambient energy recovery wasn't feasible with our antennas due to low power. However, in specific settings like a room, harvesting light energy could be viable. We observed that the big black antenna had a good intensity lasting 3 seconds for a distance of up to 12 meters. Increasing the distance required more time for activation, but using two large antennas together could extend the operational range.

Testing the antennas

Two large antennas together

IV. Ambient electromagnetic energy harvesting

We didn’t have time to do this part.

V. Radiative electromagnetic wireless power transfer

- From these formulas given by the lab instructions :

Efficiency

$$\eta_{rectenna} = \frac{P_{DC\_out}}{P_{RF\_in}} = \frac{P_{DC\_out}}{S \cdot A_{eff}}$$

Effective electric field

$$\mathrm{E} = \frac{\sqrt{30 \cdot P_{TX} \cdot G_{TX}}}{d} \ (V \cdot m^{-1})$$

Incident electromagnetic power density

$$\mathrm{S} = \frac{E^2}{120 \cdot \pi} (W \cdot m^{-2})$$

Effective area of the antenna

$$\mathrm{A}_{eff} = G_{RX} \cdot \frac{\lambda^2}{4 \cdot \pi} (m^2)$$

We can extract :

$$d = \sqrt{\frac{P_{\mathrm{tx}} \cdot G_{\mathrm{tx}} \cdot G_{\mathrm{rx}} \cdot c^2}{\mathrm{PRF}_{\mathrm{in}} \cdot 16 \cdot \pi^2 \cdot f^2}}$$

After computing, we found that the distance is approximately 100m.

- We've imagined some applications and deployment strategies of WSN powered by WPT, one of them is in order to monitor the traffic flow.

WSN powered by WPT can be strategically deployed across the city to collect real-time data on vehicle movements, congestion, and road conditions. This setup allows for dynamic traffic management, enabling city planners to adjust traffic signals, identify congestion hotspots, and plan infrastructure improvements more effectively. The continuous power supply from WPT eliminates the need for battery replacements, ensuring that sensors remain operational without maintenance interruptions. This can significantly enhance traffic efficiency, reduce emissions, and improve overall urban mobility.

VI. Link to your innovative project

For our project, we initially planned to use the STWLC86 wireless power transmitter and the STWBC68 wireless power receiver to make an inductive battery as their features were perfect for our needs.

This battery is very powerful, it can provide up to 5W of output power, which is a lot for a device like our beacon. It's designed to work really well with wireless charging systems, and it follows the Qi standard.

One of the advantages about the STWLC68 is that it's very flexible with its voltage. It can adjust anywhere between 3.6V to 20V, and you can fine-tune it in small steps. This meant we could have tailored the power supply to match exactly what our beacon needed, making it super efficient. Efficiency was an important requirement for us as we wanted our beacon to work for a long time without needing to recharge it.

The STWLC68 is also designed with safety in mind. There are features included that protects it from overheating and other problems, which is necessary for a product like ours as the last thing you want is your battery causing issues.

But, even with all these great features, we ended up not using these components in our project due to timing constraints. Ordering, testing, and making sure these batteries worked perfectly with our beacon would have taken a significant amount of time, and we had strict deadlines to meet for our project.