Department of Electrical
and Computer Engineering
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T.U. Security and Energy optimization for IoT
Energy for connected objects

Electromagnetic energy harvesting and wireless power transfer

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Gaël LOUBET
gael.loubet@laas.fr

I. Study of the load and design

We want to activate a red LED SML-D12U1WT8 from Rohm Semiconductor (https://fscdn.rohm.com/en/products/databook/datasheet/opto/led/chip_mono/sml-d12x1-e.pdf) thanks to the harvesting of ambient or specifically generated electromagnetic power.

1) How much DC power is required by the LED to work in its nominal use case? For 50 % of its nominal luminosity? For 25 % of its nominal luminosity?

2) How much energy is required to light on the LED during 1 second?

First, we want to implement the "direct consumption" strategy.
3) How much power must be provided to the LED to work? For which voltages? What will be the luminosity of the LED?

Then we want to implement the "store then use" strategy. For that, a bq25504 power management unit (PMU) (https://www.ti.com/lit/ds/symlink/bq25504.pdf) associated with a TPS63031 DC-DC buck-boost converter (https://www.ti.com/lit/ds/symlink/tps63030.pdf) both from Texas Instruments will be employed, as well as a supercapacitor as energy buffer. To properly work, the power management part (PMU and DC-DC converter) requires a maximum of 16.62 µW during the cold start and 14.725 µW in normal charging. Its minimum deactivation threshold is 2.2 V, and its maximum activation threshold is 5.25 V. Only 100 µF, 220 µF, 1.5 mF, 2.2 mF, 6.8 mF, 10 mF and 22 mF supercapacitors from various manufacturers (Taiyo Yuden (for the 2 first), Panasonic (for the 2 next), AVX (for the 3 last)) are considered. Their maximum losses are respectively: 26.25 nW, 26.25 nW, 413 µW, 606 µW, 52.5 µW, 289 µW and 26.25 µW.
4) Which configurations of capacitance and activation and deactivation voltage thresholds can be employed? What is the minimum input DC power required to work in the worst case?

II. Rectifier characterisation

For doubler 868 MHz and 2.45 GHz rectifiers, and with an USRP and GNURadio:

1) Measure the voltage at the ports of the potentiometer during a frequency sweep (between 800 MHz and 950 MHz and between 2.4 GHz and 2.5 GHz, with a step of 10 MHz) for a resistive load of 1.5 kΩ and an RF input power of -15 dBm. Give the frequency for which the rectifiers work the more efficiency. Measure their frequency bandwidth.

2) Measure the voltage at the ports of the potentiometer during a load sweep (between 500 Ω and 1 MΩ, with a relevant step) for the optimal frequency found previously and an RF input power of -15 dBm. Give the optimum load at 868 MHz or 2.45 GHz.

3) Measure the voltage at the ports of the potentiometer during a RF power sweep (between -20 dBm and 0 dBm, with a step of 1 dBm) for the optimal frequency found previously and the optimal load found previously. Give the best efficiency and the RF input power associated.

$$\eta_{rectifier} = \frac{P_{DC\_out}}{P_{Rf\_in}} = \frac{U \cdot I}{P_{Rf\_in}} = \frac{R \cdot I^2}{P_{Rf\_in}} = \frac{U^2/R}{P_{Rf\_in}}$$

4) By using the targeted loads (LED or board), search the minimum RF input power allowing a good functioning. Is it consistent with the efficiencies and minimum input DC power of the loads previously computed?

5) For the load dedicated to the "store then use" strategy, characterize 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).

III. Antenna choice

1) Chose the more appropriate antenna for your application. Justify your choices.

IV. Ambient electromagnetic energy harvesting

1) By using a spectrum analyser (or an USRP) and for the chosen antenna, measure the power available at the input of the rectifier for the targeted frequency.

2) Propose and test a rectenna design for powering the different loads (LED or board) thanks to the ambient electromagnetic energy harvesting. Analyse.

V. Radiative electromagnetic wireless power transfer

1) Estimate the maximum reachable distance between a power source and the rectenna according to the targeted frequency (868 MHz or 2.45 GHz), the power limit imposed by the regulators (respectively, +33 dBm or +27 dBm) and the used system (rectenna (antenna gain and rectifier efficiency) and LED or board).

- 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

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

2) Propose and test a rectenna design for powering the different loads (LED or board) thanks to electromagnetic wireless power transfer. Check the maximum distances computed.

3) Propose improvements to increase the range of use and efficiency, always respecting the regulations.

4) Imagine some applications and deployment strategies of WSN powered by WPT.

VI. Link to your innovative project

Propose solution(s) to make energy autonomous the prototype(s) designed and implemented during your innovative project. Justify your choices.

868 MHz		*2.45 GHz*	
UHD: USRP Sink gain	*Output power (dBm)*	*UHD: USRP Sink gain*	*Output power (dBm)*
73.0	*-16*	*72.3*	*-16*
73.9	*-15*	*73.3*	*-15*
74.8	*-14*	*74.2*	*-14*
75.8	*-13*	*75.2*	*-13*
76.5	*-12*	*76.2*	*-12*
77.5	*-11*	*77.2*	*-11*
78.4	*-10*	*78.2*	*-10*
79.4	*-9*	*79.2*	*-9*
80.2	*-8*	*79.9*	*-8*
81.2	*-7*	*80.9*	*-7*
82.0	*-6*	*81.9*	*-6*
83.0	*-5*	*82.9*	*-5*
83.9	*-4*	*83.8*	*-4*
84.8	*-3*	*84.7*	*-3*
85.9	*-2*	*85.8*	*-2*
86.9	*-1*	*86.8*	*-1*
88.0	*0*	*87.9*	*0*
89.5	*+1*	*89.4*	*+1*

Table I: *Correspondence table between the gain configured in GNURadio and the gain measured at the output of the USRP.*

Frequency	*Antenna*	*Gain (dBi)*
868 MHz	*Patch*	*+9*
	Whip	*+3*
	Printed rounded quarter wavelength dipole antenna with resonant rectangular ring	*+2.6*
	Printed folded quart wavelength dipole antenna with capacitive arms	*+1.5*
2.45 GHz	*Horn*	*+11*
	Whip	*+3*
	Modified bow-tie	*+2.5*

Table II: *Characteristics of the available antennas.*