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Optimization of an Energy Recovery Circuit for a Low-Voltage Lighting System

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***Keywords*— transistor, coil, ferrite, simulation, primary, diode.**

Abstract*— This work is devoted to the study of the physical properties of a circuit that allows both the last remaining charges of a pile or a accumulator yes cells unique to be used in other devices and to save energy stored in a new battery and all this in the lighting domain . The corresponding device is made from a transistor, a resistor and a coil. The coil is made up of a standard ferrite core with two windings of which the primary contains 34 turns and the secondary, 58 turns. Most components are local components. The study is based on the Proteus simulation software. The experiment of the device consists of comparisons of the energy consumed by an electroluminescent diode without the designed circuit and with this circuit to see its performance. In particular, the circuit can use a very low voltage of about 0.37V and can power the electroluminescent diode for a week without interruption if it is powered by a R6S/1.5V battery.

I. INTRODUCTION

From time immemorial, energy has always been of great importance to man. Aside from their curiosity, this is one of the reasons why certain scientists research energy.

In each country, the energy needs of each individual do not cease to grow over the course of these last decades and their dependence, among others, on electrochemical storages is increasing.

Since its first appearance, the manufacture of batteries is becoming more and more frequent and its use is becoming more and more important. The presence of batteries is felt que ce soit en ville et que ce soit à la campagne. However, batteries contain heavy metals (mercury, lead, cadmium, zinc, nickel) but also other chemical species (carbon, manganese, etc.) human health.

In effect, one of the most toxic, most polluting and richest in chemical elements is the used battery. However, the implementation of measures to control used batteries is still insufficient, even non-existent, in developing countries such as Madagascar.

Faced with this sad reality, it is the duty of each citizen to sensitize the consumers and seek adequate solutions to these problems.

This article titled OPTIMIZATION OF AN ENERGY RECOVERY CIRCUIT FOR A LOW VOLTAGE LIGHTING SYSTEM aims to propose a circuit capable of both extracting the remaining charges from used batteries in order to revalorize them in the form of radiant energy and to save the use of new batteries from for lighting purposes.

The scientific interest of this research consists later to reuse this form of energy to reduce human waste and pollution and to satisfy part of our lighting needs in an economic manner.

II. METHODOLOGY

2.1 Junction diode

2.1.1. Description

A junction diode is a nonlinear electronic dipole that contains a metal, a P-type semiconductor, and another N-type semiconductor.

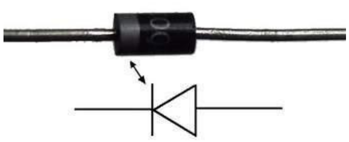

Fig. 3: Schematic representation of a junction diode.

There are two types of polarization for the diode:

- The polarization directly;
- The polarization in reverse.

2.1.2. Direct polarization

The direct polarization consists of introducing a current "I" to the positive pole of the diode, starting from point "A" and heading towards point "C".

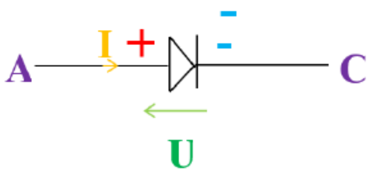

Fig.1. Direct polarization of a diode.

2.1.3. Reverse polarization

The reverse polarization consists on the other hand of introducing a current "I" to the negative pole starting from point "C" and directed towards point "A".

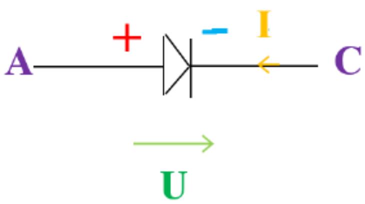

Fig..2. Reverse polarization of a diode.

2.2 Electroluminescent diode

2.2.1. Definition, [12]

An electroluminescent diode (LED) is a device optoelectronics capable of emitting light when it is traversed by an electric current. Unlike a classic diode, it only reacts if the polarization is in the forward direction.

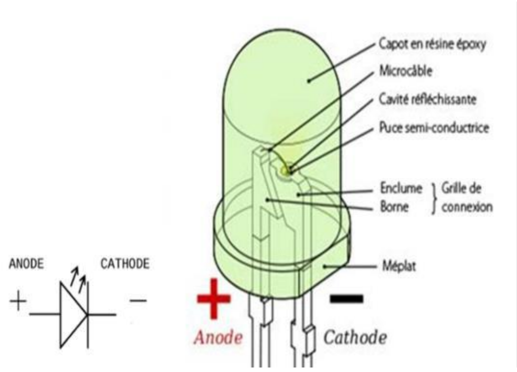

Fig. 3. Schematic and structural representation of an LED.

2.3. Transistor

2.3.1. Description

A transistor is an electronic device that is found in several applications namely oscillators, converters, microcontrollers, microprocessors, switches, current amplifiers, voltage amplifiers, power amplifiers, etc. Or, there are several types of transistor according to their structure.

Table 1: Types of transistors according to their structure.

Compone nt	Order	Application type	Intensity maximu m	Band passin g
Bipolar	Curren t	Amplificatio n, commutation	10 A	0 →1 GHZ
MOS, FET, JFET, MOSFET	Tensio n	Commutati on	5 A	0 →10 MHZ
IGBT	Curren t	Power electronic commutation	200 A	0 →1 MHZ

2.3.2. Bipolar transistors, [14]

A bipolar transistor is made in a single crystal with three different doping zones namely the base "B", the emitter "E" and the collector "C":

- The transmitter "E" is heavily doped. Its role is to inject electrons into the base. It is identified by an arrow that indicates the direction of the current in the junction between base and collector.
- The "B" base is weakly doped and very thin. It transmits most of the electrons coming from the emitter to the collector.
- The collector "C" collects the electrons that come from the base of its name.

According to the mounting sense, we can have two types of bipolar transistor referring to the PN junctions (diodes), one of which is polarized directly and the other, inversely:

- An NPN transistor (two negative terminals and one positive terminal); A PNP transistor (one negative terminal and two positive terminals).

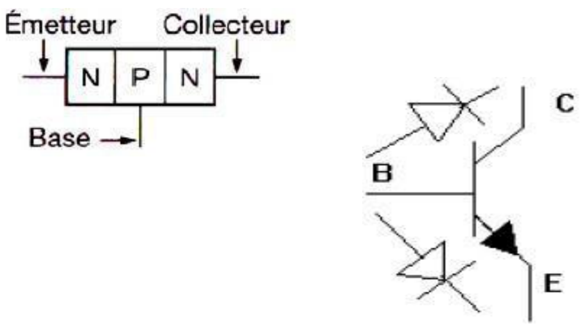

Fig.4. Schematic representation of an NPN transistor.

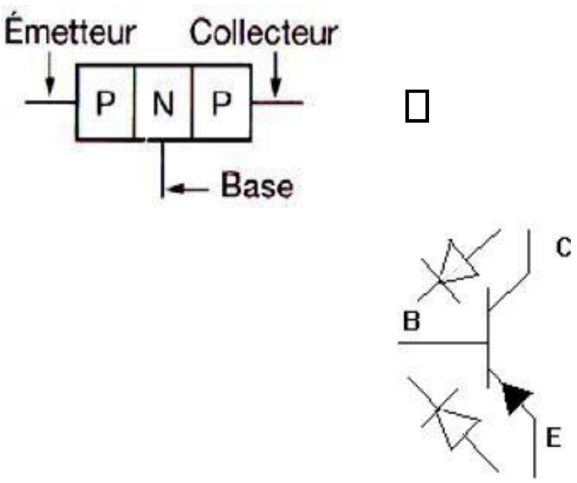

Fig.5. Schematic representation of a PNP transistor.

2.3.3. Operating regime

The purpose of the polarization of the junctions is to fix the values of the voltages UBE, UBC and the currents IC, IB to impose the localization of the points and to know the operating regime of the transistor in the network.

Table 2: Mode of operation of the bipolar transistor.

Voltage of junctions		Polarization of junctions		Operating regime
U_{BE}	U_{BC}	BE	BC	
Positive (+)	Positive (+) $U_{BE} > U_{BC}$	Direct	Direct	Saturé Direct (SD)
	Positive (+) $U_{BE} < U_{BC}$	Direct	Direct	Saturated Inverse (SI)
	negative (-)	Direct	Inverse	Normal Direct (ND)
negative (-)	Positive (+)	Inverse	Direct	Inverse Normal (NI)
	negative (-)	Inverse	Inverse	Blocked

At the saturation point, the transistor is equivalent to a closed switch while at the blocking point, the transistor is equivalent to an open switch.

The fundamental relationships between the three doping zones are given by:

$$I_C = \beta * I_B$$

$$UBC = UBE + UEC$$

with:

β, the amplification gain;

I_C, the current intensity at the terminal of the collector;

I_B, the current intensity at the terminal of the base;

I_E, the current intensity at the terminal of the transmitter;

U_{BC}, the tension at the terminal of BC junctions; U_{BE}, the voltage at the terminal of

BE junctions; EC , the voltage at the terminal of the EC junctions.

2.4. Resistance

2.4.1. Definition, [15]

Resistance is un electronic component don't the main role is to oppose more or less to the circulation du electric current .

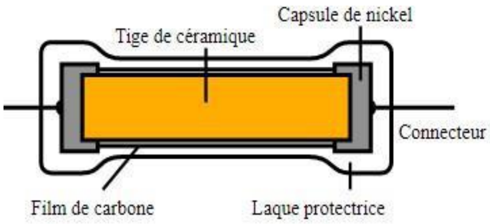

Fig. 6. Detailed structure of a resistance.

2.4.2. Ohm's Law **,** [16]

Resistance is linked to notions of resistivity and of electrical conductivity . It is designated by the letter "R" et son unit of measure is the ohm of the "Ω" symbol. Ohm's law is defined from these magnitudes such that:

$$U = R * I \quad (18)$$

With:

U , the tension;

R , the resistance;

I , the current intensity.

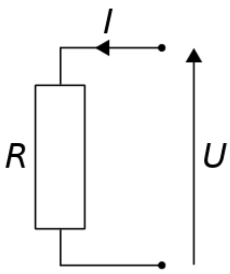

Fig.7. Schematic representation of a resistor.

2.4.3. Joule effect, [17]

The Joule effect is responsible for the dissipation of energy in the form of warmth in an electrical component. This production of heat is sometimes a desired effect (heating resistance) and sometimes a harmful effect (loss of energy due to the Joule effect). This property bears the name of the Joule effect and the energy dissipated between two instants t1 and t2 is written:

$$Q = R * I^2 * \int_{t_1}^{t_2} dt \quad (19)$$

2.5. Coil

2.5.1. Description, [18]

A coil is an electronic component made up of a coil of conductive wire around a core. It is diagrammed in an electric circuit according to Fig. 11.

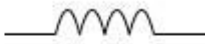

Fig. 8. Schematic representation of a coil, [19]

A core is the space in the middle of these windings or turns. It can be empty or include a piece of material favoring electromagnetic induction, in order to increase the value of the inductance.

2.5.2. Classification of magnetic materials, [20]

There are terrestrial substances that have magnetic properties and can therefore become magnetized.. However, these magnetic properties are not equal for all these materials. Some of these are due to the rotation of electrons on themselves in the atom. This phenomenon is called "spin" and causes a magnetic moment.

The magnetization M is defined in function of the excitation field H and the magnetic susceptibility χ_m of the environment. It can be written in the following form:

$$M = \chi_m * H \quad (22)$$

The magnetic induction B is defined by:

$$B = \mu_0 * H \quad (23)$$

The materials can be classified into three categories according to their magnetic properties, as shown in Fig.9:

- Diamagnetism: the magnetic susceptibility is generally very small. Therefore, the diamagnetic materials are weakly magnetic in the opposite direction to the magnetizing field. Their magnetization ceases as soon as the magnetizing field is suppressed. Example: gold, silver, copper , zinc.
- Paramagnetism: magnetic susceptibility is small. Therefore, the paramagnetic materials are weakly magnetized in the direction of the magnetizing field. Their magnetization ceases as soon as the magnetizing field is

suppressed. Example: aluminum, platinum, manganese, air, oxygen, etc.

- Ferromagnetism: the magnetic susceptibility is very large. Therefore, ferromagnetic materials can be strongly magnetized. Their magnetization persists plus or minus when the magnetizing field is suppressed. Examples: cobalt, nickel, iron , steel , ferrite, martensitic , etc.

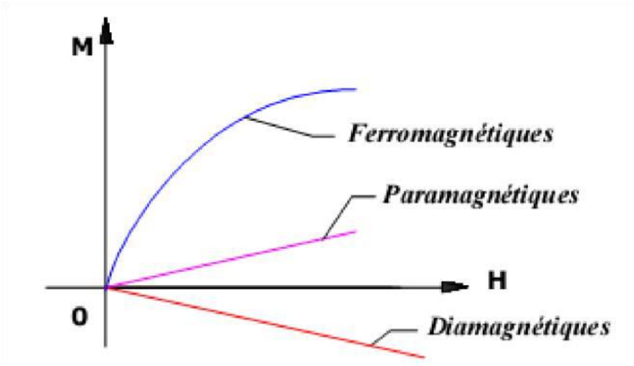

Fig. 9. Illustration of the magnetic behavior of substances .

2.5.3. Power transformer, [21]

The conversion of electrical energy makes use, in general, of two types of physical phenomena:

- Electrical phenomena associated with current;
- Magnetic phenomena associated with magnetic flux.

A power transformer is a static device that transfers electrical energy thanks to electromagnetic induction. For a transformer, two windings are at least necessary to be able to modify the level of the input signal without modifying the frequency.

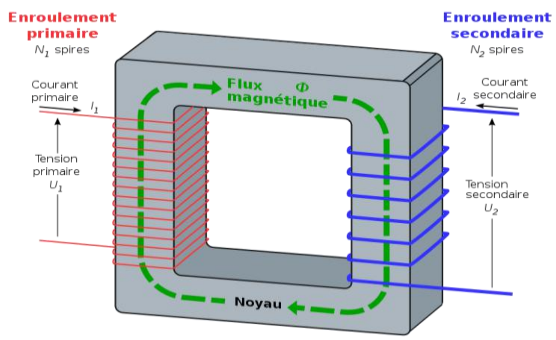

Fig. 10. Diagram of a power transformer with two windings, [22].

Posted by:

Φ, the magnetic flux generated in the core

N_1, the number of turns of the primary winding;

I_1, the intensity of the current that crosses the primary conductor;

U_1, the voltage at its terminals;

N_2, the number of turns of the secondary winding;

I_2, the intensity of the current that crosses the secondary conductor; U_2, the voltage of its terminals.

The circulation of the current through the primary winding generates a variable magnetic flux in the core such that:

$$\Phi = B*S \tag{24}$$

The magnetizing force is expressed as follows:

$$H = \frac{N*I}{l} \tag{25}$$

The transformer is at no load when the secondary winding has not been connected to a receiver but open. Thus, the flux variation induces a voltage in the secondary winding but does not flow any current. The primary winding behaves like a simple inductance that opposes the passage of the current.

The transformer works in charge when a receiver is connected to the output of the secondary winding. In this case, the variation in flux induced in the secondary winding generates another current which creates a magnetic field opposite to the field produced by the primary. In the end, there is perfect equality between the power generated by the secondary and the power consumed by the primary winding.. From the equality of apparent powers, we obtain:

$$P1 = P2 \tag{26}$$

With:

P 1, the power consumed by the primary winding;

P 2, the power generated by the secondary winding.

Thus :

$$U_1 * I_1 = U_2 * I_2 \tag{27}$$

If the tension applied at the entrance is lower than the cell recovered at the exit, the transformer works as an elevator, in the opposite case, as a step-down transformer.

And if we suppose that the number of turns of the primary compartment is higher than that of the secondary compartment, we obtain a voltage reducer and the previous relation can then be written by:

$$\frac{[N_2]}{[N_1]} = \frac{[U_2]}{[U_1]} = \frac{[I_1]}{[I_2]} \quad (28)$$

On the other hand, if the number of turns of the primary compartment is lower than that of the secondary compartment, a voltage riser is obtained and the relationship becomes:

$$\frac{[N_2]}{[N_1]} = \frac{[U_2]}{[U_1]} = \frac{[I_1]}{[I_2]} \quad (29)$$

III. RESULTS

3.1. Simulation of the direct supply of an LED without device.

The various components of the circuit in the presence of the device require a resistor, an electroluminescent diode, a bipolar transistor of the NPN type reference 2N2222 and a coil with two windings. Among other things, we need essentially three (3) other additional components apart from the others we saw previously. The simulation of the complete circuit is visualized on Fig. 11.

When we simulated the circuit in the presence of the prototype, we noticed that the electroluminescent diode does not shine below an input voltage of 2.20 V. The minimum threshold voltage remains the same so that the electroluminescent diode can emit of the light. For the output voltage at the level of the diode, we found that the voltage collected still remains equal to that of the input voltage generated by the battery. Here, the transformer reacts neither as a tension reducer, nor as a tension rectifier.

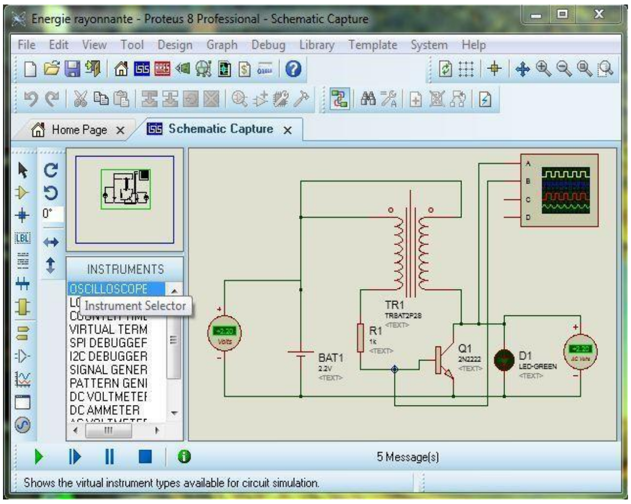

Fig. 11. Simulation of the circuit in the presence of the prototype.

When we visualized certain curves in the oscilloscope as the shape of the tension curve on the base of the transistor and the cell at the entrance of the electroluminescent diode, they are identical. However, the shape of the voltage curves changes when we change the resistance of each winding to be equal to 1 μΩ(see Fig. 13) and then to 1m□ (see Fig. 20). The shape of the curves obtained seems to be a function of the resistances of the respective windings. The signal is alternative to the output of the coil.

For the diagrams of the voltage curve, the yellow curve shows the voltage received by the diode at its input, while the blue curve shows the voltage at the base of the transistor (see Fig. 12 and Fig. 13) .

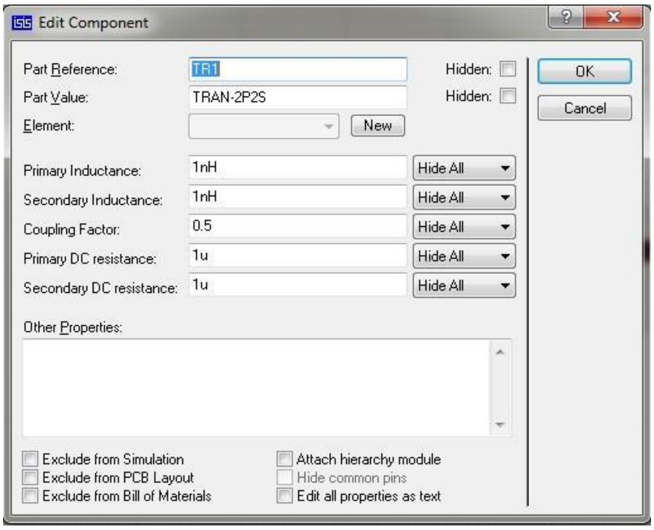

Fig. 12. Adjustment of the resistance of the respective windings of the transformer for 1 μΩ.

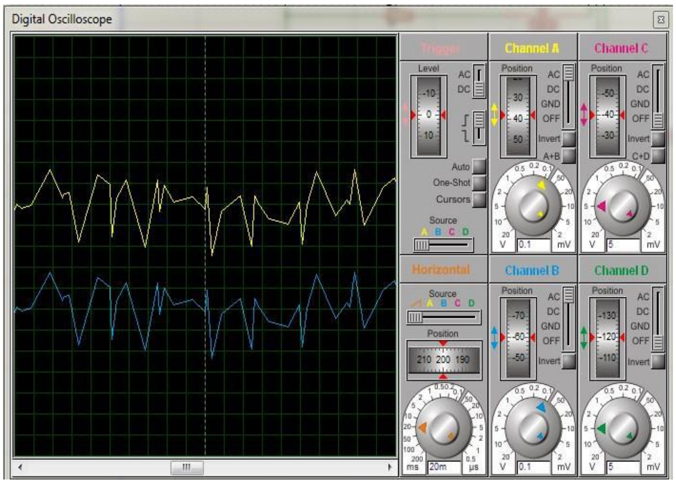

Fig. 13: Voltage curve at the level of the electroluminescent diode and the base of the transistor for a resistivity of 1 μΩ.

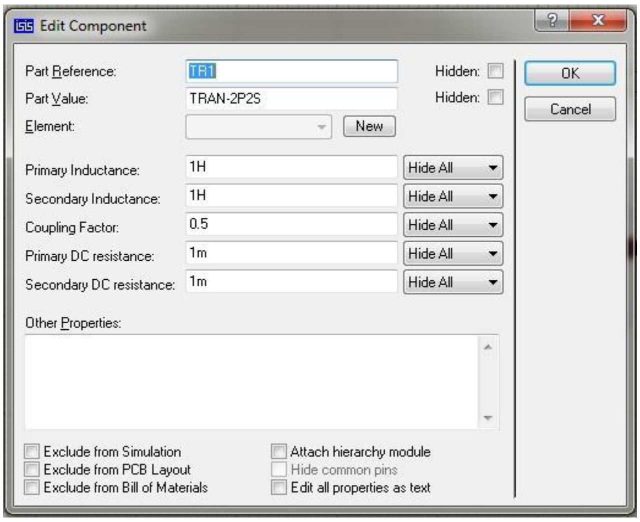

Fig. 14. Adjustment of the resistance of the respective windings of the transformer for 1m Ω.

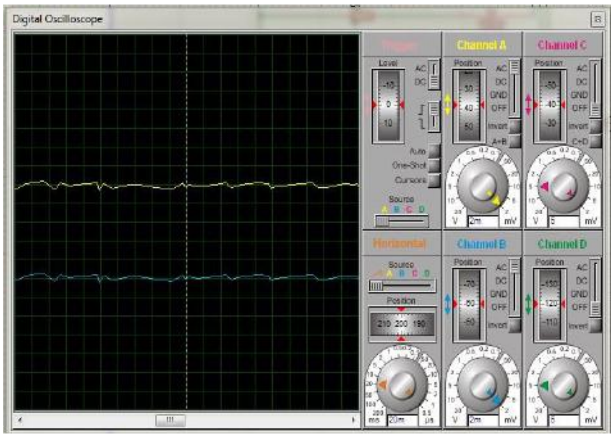

Fig. 14: Voltage curve at the level of the electroluminescent diode and the base of the transistor for a resistance of 1m Ω.

3.2. Achievements

3.2.1. Montage and interpretation

The realization of the combined circuit with its prototype is made from a resistance of value 1k□, of power 1/4W, of a reference NPN type bipolar transistor 2N2222, an electroluminescent diode with a nominal voltage of 3.5V and a coil with a ferrite core.

Fig. 15 : Photo of the components necessary for the study of the circuit.

The coil is designed from a ferrite core of section 66mm2 (11mm height*6mm width). For its windings, we used five (5) identical wires of the same length l= 83cm and the same diameter d=0.6mm but of a different color to distinguish their placement. For the primary winding, we combined 3 wires of white, yellow and orange colors, the length being equal to l1=166cm for the equivalent of the number of turns N1=34. On the other hand, for the secondary winding, we combined 2 wires of black and blue colors, the length being equal to l2=249cm and the number of turns, to N2=58.

Fig. 16. Photo of the device powered by a BEXEL brand AAA battery.

When we directly fed the electroluminescent diode with any battery of nominal voltage 1.5V, it did not arrive to emit light because the output voltage was lower than the input voltage. Here, the simulation is verified.

When we then introduced the device into the circuit, the electroluminescent diode reacted to the effect of a battery of size AAA, nominal voltage 1.5V (see Fig. 19). This is explained by the presence of the coil and cell of the transistor because the power required was largely exceeded. The simulation predicted a voltage of 2.20V, but during the experiment, we got the value of 2.10V.

The circuit uses the self-oscillating properties of the oscillator block to form a converter tension (elevator). Like all power conversion technologies and in accordance with the law of energy conservation, none energy is created by the circuit. In fact, there tension de sortie est relevée en contrepartie d'une consumption de current increased at the entrance.

3.2.2. Efficiency test

To study its effectiveness, we tested the circuit with batteries of different shapes, or with different nominal voltages.

Tableau 8 shows the study of the efficiency of the circuit in presence of the device through some varieties of batteries used.

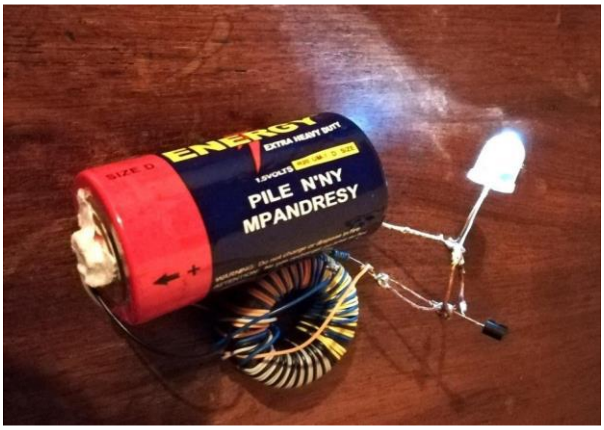

Fig. 17. Test d'évaluation of a pile of dimension D of brand ENERGY.

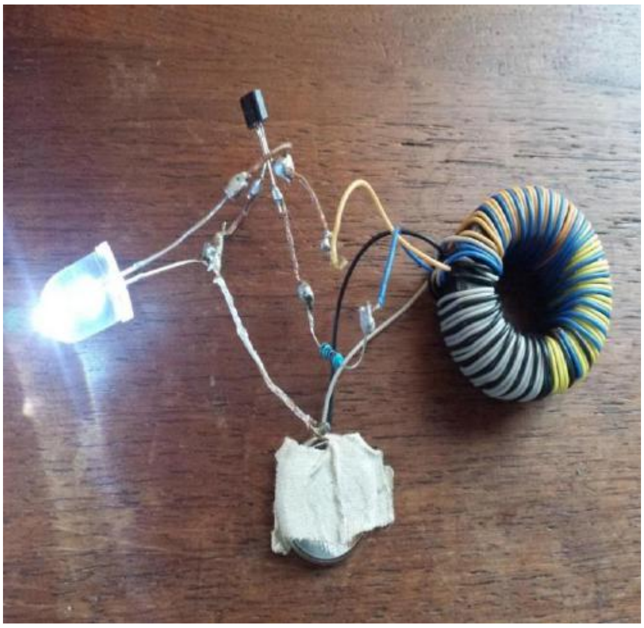

Fig. 18. Evaluation test of a CR2032 button cell.

Fig. 26: Evaluation test of a pile of size N (see table 4) , brand ALKALINE.

Table 8: Study of battery efficiency with the device.

Dimensions of the batteries		AAA	AA	D	CR2032	N
Mark		BEXEL	HUATAI	ENERGY	PARASONIC	ALKALINE
Nominal voltage (V)		1.5	1.5	1.5	3	9
Electromotive force (V)		1.64	1.65	1.65	3.36	9.05
Threshold voltage (V)		0.39	0.37	0.36	0.40	0.32
Voltage drop (V)	in 04 h	0.092	0.020	0.042	0.126	0.018
	in 08 h	0.198	0.041	0.083	0.251	0.039
	in 12 h	0.303	0.059	0.124	0.359	0.058

	at 4 p.m	0.395	0.089	0.166	0.485	0.086
	in 20 h	0.499	0.105	0.208	0.605	0.102
	in 24 hours	0.592	0.121	0.249	0.736	0.116
Debit average (v/h)		0.026	0.006	0.011	0.031	0.005
Calculation of error		□ 0.01	□ 0.002	□ 0.007	□ 0.5	□ 0.8
Autonomy (days)		3	11	7	5	-

The Fig. 27 presents the battery voltage drop curve as a function of time, at intervals of 4 hours during a day.

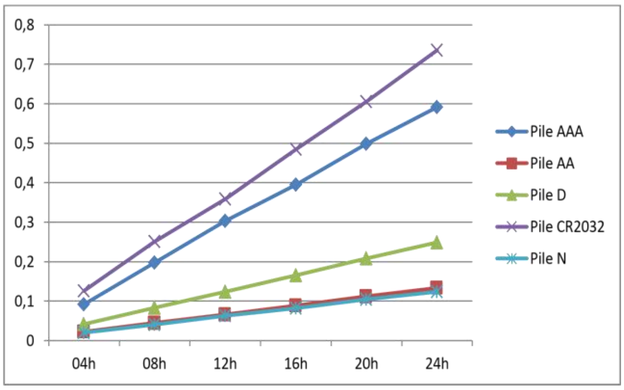

Fig. 27. Representative curve of the tension drops of each pile tested.

Fig. 29. Installation of a single new battery of size AA with the circuit.

3.2.3. Longevity study

Afterwards, we studied the circuit in presence of the device but the batteries used are all identical (of the same nominal voltage, of the same size AA and of the same brand HUATAI). We measured the electromotive force of a pile and found that the electroluminescent diode reacted normally.

Fig. 28: Measurement of the electromotive force of a new AA battery.

Fig. 30. Measurement of the electromotive force of three new batteries combined of size AA.

To see the longevity of the circuit, we have developed another branch so that three new batteries identical to the previous one (of the same brand HUATAI, of the same size

AA) are combined. Ainsi, their total electromotive force is added to give 4.93V.

For the electroluminescent diode to directly emit white light, the circuit logically needs an input voltage higher than or equal to its output voltage. The voltage of the direct branch requires a value of 2.10V while the circuit in the presence of the device requires a cell of 0.37V at least.

By directly feeding the electroluminescent diode with the three (3) combined batteries, we have seen that the electroluminescent diode shines without interruption for 12 days. However, the presence of the device strongly influences the energy consumption of the circuit. L'utilisation sans interruption d'une seule pile avec le prototype atteint presque l'equivalent d'un branchement direct avec ces trois piles. In fact, it only shifted by a day. Ainsi, the insertion of the prototype is very effective because it reduces the efficiency of the batteries needed for the lighting of the electroluminescent diode by almost a third.

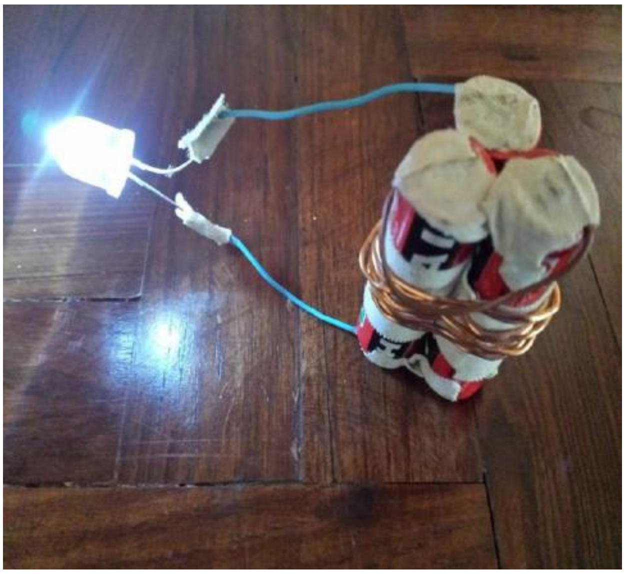

Fig. 31. Direct power supply of an LED by three new batteries of size AA.

Tableau 9 shows the results of comparing the circuit without the device and then with its presence.

Table 9: Longevity comparison between the direct branching and the presence of the circuit.

Montage			With device	Without device
Time / Autonomy (h)			Voltage (V)	
1 era day	Morning	12 o'clock	0.113	0.059
	Evening	24h	0.225	0.121
2nd day	Morning	36h	0.339	0.177
	Evening	48 hours	0.441	0.244
3rd day	Morning	60 hrs	0.554	0.296
	Evening	72h	0.665	0.351
4th day	Morning	84h	0.776	0.410
	Evening	96 h	0.890	0.468
5th day	Morning	108h	0.992	0.526
	Evening	120 hrs	1.103	0.547
6th day	Morning	132 h	1,215	0.658
	Evening	144 h	1,327	0.703
7 th day	Morning	156 h	1,438	0.761
	Evening	168 h	1,540	0.817
8th day	Morning	180 hours	1,651	0.884

	Evening	192 h	1,763	0.924
9th day	Morning	204 h	1,875	0.995
	Evening	216 h	1,988	1,065
10 th day	Morning	228 h	2,092	1,126
	Evening	240 hours	2.204	1,187
11 th day	Morning	252 h	2,317	1,249
	Evening	264h	2,428	1,311
12 th day	Morning	276 h	2,539	-
	Evening	288 h	2,640	-

IV. DISCUSSION

The realized circuit presents several advantages. First of all, it's easy to do. Then, its use allows you to save a lot more electricity. It is very practical for special lighting, at home because it happens to feed an electroluminescent diode for more than a week, without interruption for good quality batteries. In addition, the device can be integrated into various electronic devices.

Its use also favors the protection of the environment because once the used batteries are flat, they are no longer immediately thrown away because they can now be revalued by this device. As a consequence, the uncontrolled waste of batteries is now likely to decrease and the pollution of our environment is thus reduced and the risks threatening the health of living beings are less harmful.

The use of the prototype also allows you to save money because the acquisition of the raw materials used is often cheaper than the purchase of finished products, this is valid, at the same time, for the purchase of batteries but also for The purchase of electronic components and their assembly.

This circuit is marketable and especially profitable considering the criteria of energy saving.

Disadvantages

Despite its advantages, the device also has some disadvantages. The fabrication of the prototype requires more time because the components must be controlled un par un and all must be soldered before assembly.

Sometimes, these components are imported by retail boutiques.

The injection of this prototype also requires additional space in an electronic device.

V. CONCLUSION

To conclude this work, we can say that the prototype designed gives satisfactory results because its efficiency far surpasses our expectations.

The simultaneous presence of the coil and the transistor are essential for the realization of the circuit because one allows increasing the input voltage, while the other increases the current intensity. The prototype can be adapted to all types of new or used batteries. It also has a great longevity and its use allows well to extract the remaining charges from a used battery provided that the input voltage remains above 0.37V for the prototype made.

In a developing country like Madagascar, the conventional price of energy continues to increase while the purchasing power of the population decreases. Non-renewable energies are more or less accessible depending on the income of each household. But, they are becoming more and more coveted and recommended throughout the world.

In anticipation of the implementation of measures conforming to the disposal of used batteries, it is preferable to insert this type of prototype in various electronic devices because it allows energy and money to be saved. Above all, its utilization favors the protection of the environment because the revaluation of these used batteries reduces their uncontrolled discharge and the diminution of toxic waste harmful to human health.

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