Development of Astable Multivibrators Powered by Photovoltaic Cells

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***Abstract*—This article describes the simulation results of an astable multivibrator aimed to be fed by a photovoltaic cell, with the purpose of energy harvesting for electronic systems. The circuit was simulated using metal-oxide-semiconductor field effect transistors (MOSFETs) and bipolar junction transistors. The use of half wave and full wave rectifiers for DC output voltage supply was also simulated. The circuit reached a peak efficiency of 28 % when using MOSFETs PMDXB550UNE and half wave rectifier.**

Keywords—MOSFET, energy harvesting, oscillator, DC converter

I. Introduction

Energy harvesting is the process of capturing and adapting ambient energy to power electronic systems. This area of knowledge is the object of intense study, as it allows autonomous systems not to need batteries or supercapacitors as a power source. Devices with the ability to draw energy from the environment through sunlight, vibration, heat or electromagnetic waves are being used more and more.

The capture of light energy is carried out by photovoltaic cells, normally produced with semiconductor material. The most used material in the case of photovoltaic systems is silicon. Photovoltaic silicon cells typically supply voltages from 0.5 V to 0.6 V, with the maximum power dependent on their size [1].

The energy conversion from photovoltaic cells are object of intense research, especially for the highest levels of energy. Patents from Kim [2] and Matan [3] are some examples of circuits for this purpose. Commercial solutions for micro- and nanopower are already available [4], [5]. This work proposes an energy harvesting circuit to be powered by a photovoltaic cell with efficiency above 50% and minimum operating voltage of 0.5 V. The objective is to provide a minimum DC voltage of 4.0 V at the load, sufficient to power a low voltage drop regulator. The circuit is an astable multivibrator that has already been published [6]. In that work, the circuit was powered by a minimum voltage of 0.6 V and provided an output of 5.6 V with a power of 1 mW from a supply of 700 mV.

The performance of the circuit is evaluated by experimenting with metal-oxide-semiconductor field effect transistors (MOSFETs) and bipolar junction transistors (BJTs). Half wave and full wave rectifiers were used to obtain the DC voltage in the load. The circuits were analyzed using the LTSpice simulation program.

II. Circuit with Half Wave Rectifier

The circuit with half wave rectifier and MOSFETs is shown in Fig. 1. L1, L2 and L3 are magnetically coupled. L3 powers the half wave rectifier. An equivalent circuit was used replacing the coils of the transformer. This circuit was extracted from a transformer with an EE gapped core, which was characterized using an RLC meter. The parallel capacitance is calculated from the resonance frequency of 1.6 MHz. The equivalent circuit for L1 to L3 is illustrated in Fig. 2. The values of the components of the equivalent circuits are given at Table I.

The turn ratio between L1 or L2 and L3 is approximately 9.6. D1 is a signal rectifier diode RRE02VS4S, which has low junction voltage. C1 is a 1 µF capacitor. R1 represents the load of the circuit.

The circuit was simulated with BJTs MAT02 (BJT) and with MOSFETs BSH103 (MOS1) and PMDXB550UNE (MOS2).

In order to have 4.0 V output voltage, the circuit oscillated with 0.60 V supply and 1 MΩ load using BJT; with 0.59 V and 3 kΩ using MOS1 and with 0.50 V and 5 kΩ using MOS2.

Due to the half wave rectifier, the currents in the collectors (or drains) are different, causing an imbalance in the circuit (Fig. 3). Fig. 4 shows the circuit efficiency as a function of the supply voltage using the three transistors for a fixed load of 5 kΩ.

As can be seen from Fig. 4, the circuit with MOS1 needs a higher voltage to oscillate and, therefore, to deliver power. It must be said that, even with low performance, the circuit with BJT was not able to supply the minimum voltage of 4.0 V specified. The circuit with MOS2 operated over the required voltage range.

III. Circuit with Full Wave Rectifier

The circuit with full wave rectifier is illustrated in Fig. 5. L4 and another diode RRE02VS4S (D2) were added. L4 is magnetically coupled to the other coils. This way it was possible to balance the currents in the collectors (or drains), as shown in Fig. 6. The graph with the circuit yield using the three transistors for a fixed load of 5 kΩ is illustrated in Fig. 7.

The circuit did not oscillate with a voltage below 0.60 V with any of the transistors. With MOS1, an even higher voltage, 0.62 V, was necessary in order it could oscillate with the specified load.

TABLE I COMPONENTS OF THE COILS EQUIVALENT CIRCUITS

Component	L	C	R
L1 & L2	9 µH	1 nF	0.2 Ω
L3	780 µH	16 pF	8 Ω

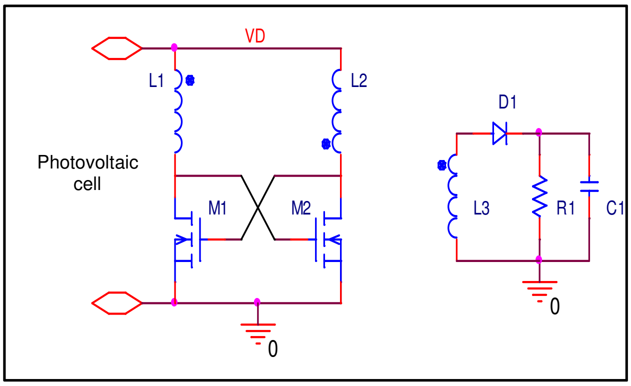
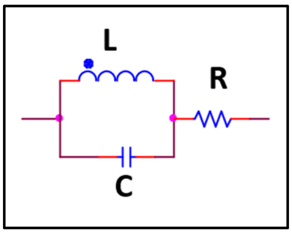


Fig. 1. Oscillator circuit using MOSFETs and half wave rectifier.



Fig, 2 Equivalent circuit of the transformer coils.

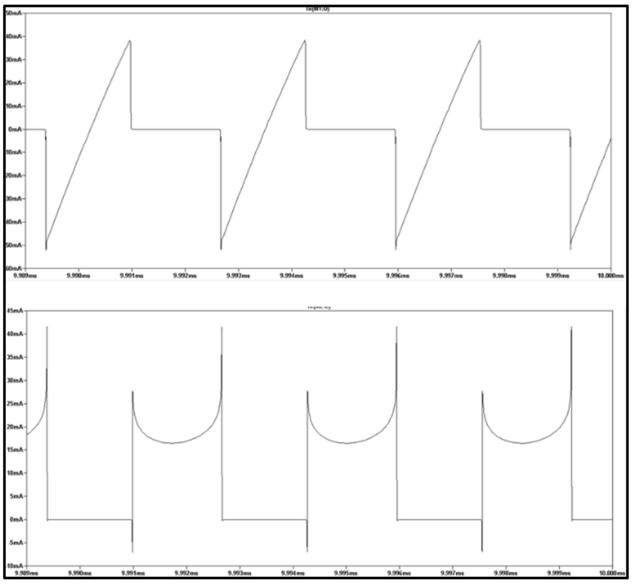


Fig. 3. Current waveforms in the circuit drains with MOS2 and 600 mV supply voltage using half wave rectifier.

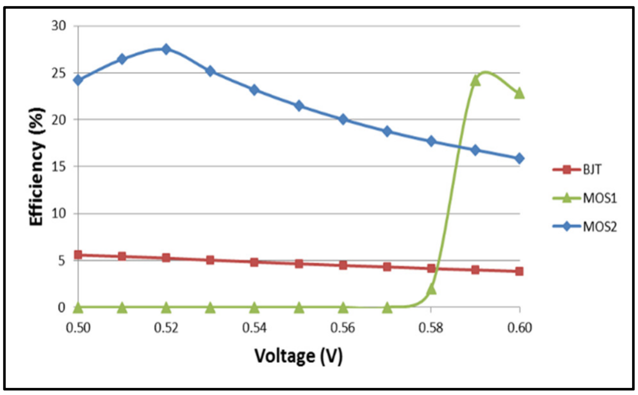


Fig. 4. Efficiency as a function of the supply voltage for the oscillator with half wave rectifier.

As in the previous case, the circuit with MOS2 operated over the required voltage range.

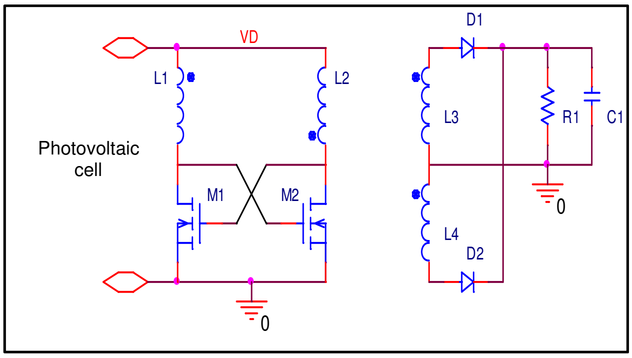


Fig. 5. Oscillator circuit using MOSFETs and full wave rectifier.

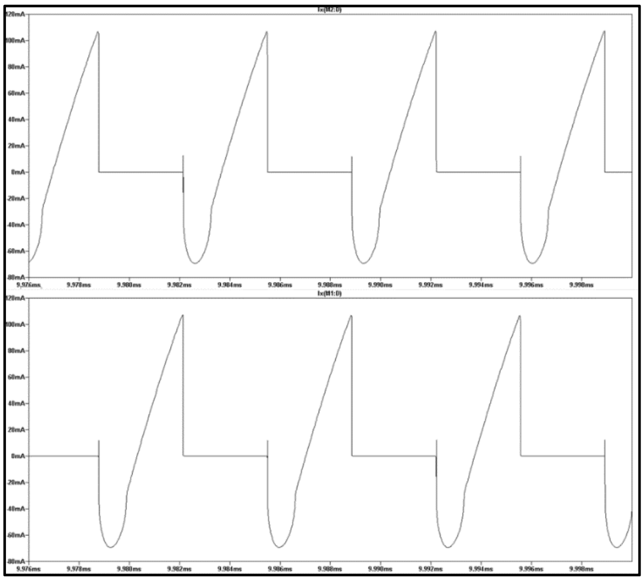


Fig. 6. Current waveforms in the circuit drains with MOS2 and 500 mV supply voltage using full wave rectifier.

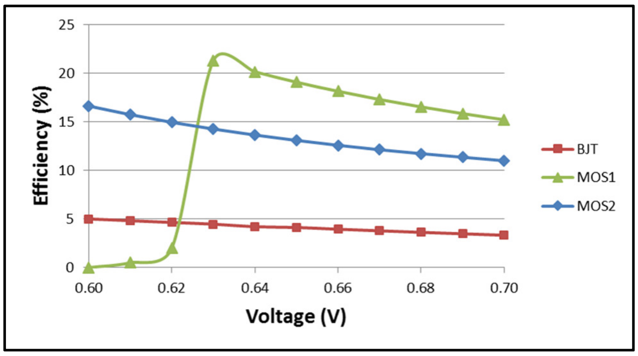


Fig 7. Efficiency as a function of the supply voltage for the oscillator with full wave rectifier.

IV. Impact of the Threshold Voltage in the Efficiency

Vto (parameter connected to the threshold voltage) of MOS2 was modified in order to observe the influence of this parameter in the circuit. Circuits with half wave and full wave rectifiers were simulated.

The graph with the performance of both circuits as a function of Vto is illustrated in Fig. 8. The supply voltage is 0.50 V and the load resistance is 10 kΩ. It is clear that there is no significant difference between the performance of the circuit with half wave rectifier and full wave. The best performance is obtained with the minimum resistance to the occurrence of oscillation. When using the full wave rectifier, the circuit stops oscillating with a Vto of 0.75 V.

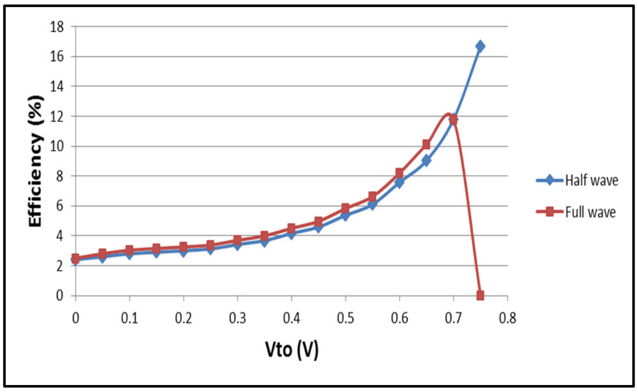


Fig 8. Efficiency of the oscillator as a function of Vto.

V. Conclusions and Future Works

The circuit performed better with MOSFETs. Both in the use of the half-wave and full-wave rectifiers, the PMDXB550UNE transistor was able to operate over the entire voltage range, which did not happen with the BSH103 transistor.

It is believed that the difference in operating voltage range of the circuit with a half-wave rectifier and that with a full-wave rectifier is due to the unbalanced behavior of the first. Thus, one transistor would be in charge of maintaining the oscillation and the other would supply the load in the circuit. In the case of using the full-wave rectifier, the load affects both transistors, making a higher voltage necessary to oscillate.

The best configuration found was the one that uses of the PMDXB550UNE transistor and half-wave rectifier. Even so, the expected performance (minimum of 50%) was not achieved.

The modification of Vto did not bring any advantage with the circuit supplying a fixed load. The condition of variable load still should be investigated. It is also necessary to verify also if the circuit does not have a greater power capacity with the modification of the Vto.

Acknowledgment

The authors would like to thank CNPq for the scholarship of E. C. Bento.

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