LOW VOLTAGE CONVERTER FOR ORGANIC TRANDUCERS IN ENERGY HARVESTING

Laila Znbill

Doctoral Degree Programme (2), FEEC BUT

E-mail: xznbil01@stud.feec.vutbr.cz

Supervised by: Jaroslav Boušek

E-mail: bousek@feec.vutbr.cz

Abstract: The paper describes the possibilities of energy harvesting using organic semiconductors. It is shown that organic semiconductors enable a large variability and some of their properties may be better than by inorganic semiconductor materials. Simple and reliable JFET driven DC to DC converter was designed for low voltage applications as thermoelectric generators and single-cell solar panels. It is able to operate from the voltage of few tenths of Volt and the output voltage could be in the level of several Volts. The efficiency was found close to 50%. Material and production costs are significantly lower than in case of standard low power integrated circuits.

Keywords: Organic semiconductors, Energy harvester, low power DC/DC converter.

1. INTRODUCTION

Energy harvesting is becoming more feasible today because of the increased efficiency of devices used to capture, store, and produce electrical energy. Nevertheless, many energy harvesting transducers provide a low output voltage not sufficient for electronic devices. For DC sources, like solar cells and thermal generators, there is therefore a need to slowly boost the voltage to a level sufficient for opera- tion of regular converters or low voltage circuits.

2. ORGANIC TRANSDUCERS FOR ENERGY HARVESTING

For electronic properties of organic materials there is crucial the existence of conjugated bond system where carbon atoms covalently bond with alternating single and double bonds. Hydrocarbon electrons delocalize and form a delocalized bonding π orbital with a π* antibonding orbital [1].

The delocalized π orbital is the highest occupied molecular orbital (HOMO), and the π* orbital is the lowest unoccupied molecular orbital (LUMO). In organic semiconductor physics, the HOMO takes the role of the valence band while the LUMO serves as the conduction band. The energy separation be- tween the HOMO and LUMO energy levels is considered the band gap of organic electronic materials and is typically in the range of 1eV to 4 eV [2].

2.1. ORGANIC PHOTOVOLTAIC CELLS

When organic material absorbs a photon, an excited state is created and confined to a molecule or to a region of polymer chain. The excited state can be then regarded as an exciton, or an electron-hole pair bound together by electrostatic interactions.

In organic solar cells (OSC) excitons are broken up into free electron-hole pairs by effective fields. The effective fields are set up by creating a heterojunction between two dissimilar materials. In this process the electron falls from the conduction band of the absorber to the conduction band of the acceptor material. It is necessary that the acceptor material has conduction band edge that is lower than that of the absorber material [3].

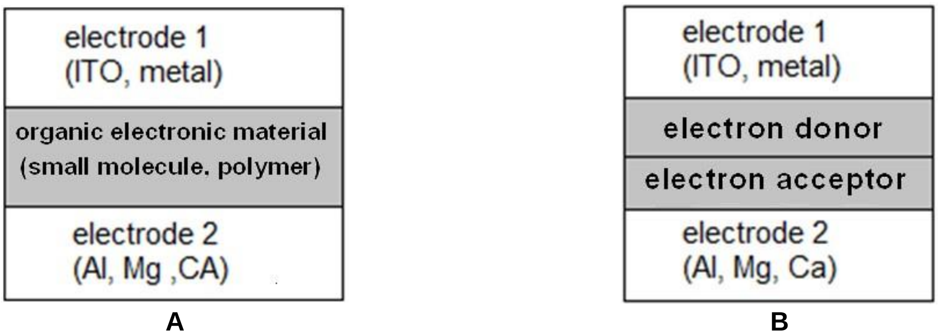


Figure 1: A) Single layer organic photovoltaic cell; B) Bilayer organic photovoltaic cell.

Single layer OSC. Single layer organic photovoltaic cells are the simplest form. These cells are made by sandwiching a layer of organic electronic materials between two metallic conductors, typically a layer of indium tin oxide (ITO) with high work function and layer with low work function metal such as Aluminum, Magnesium or Calcium. The difference of work function between the two conductors sets up an electric field in the organic layer. When the organic layer absorbs light, electrons will be excited to the LUMO and leave holes in the HOMO, thereby forming excitons. The potential created by the different work functions helps to split the exciton pairs, pulling electrons to the positive electrode and holes to the negative electrode. See Figure. 1A).

Bilayer OSC. Bilayer organic solar cells contain two layers in between the conductive electrodes. The two layers have different electron affinity and ionization energies, therefore electrostatic forces are generated at the interface between these two layers. The materials are chosen to make the potential differences large enough to split excitons much more efficiently than in case of single layer photovoltaic cells. The layer with higher electron affinity and ionization potential is the electron acceptor, and the other layer is the electron donor. This structure is also called a planar donor-acceptor heterojunction. See Figure. 1B).

2.2. ORGANIC THERMOGENERATORS

Thermoelectric modules work on two basic principles which are related one to another:

Seebeck effect. This effect creates potential difference across the connection of two materials module by heating one side of the module and cooling the opposite.

Peltier effect. When current passes through the junction of different materials one side is cooling and the other side is heating. Peltier cells are to time routinely used for cooling. Consequently, when we will deliver thermal energy to this junction we may produce electricity.

2.2.1. Thermoelectric power conversion

There are two critical factors for efficient thermoelectric power conversion. Firstly, the amount of heat flux must be successfully moved to the module. Secondly, the thermal conductivity of module material between hot and cold side must be as low as possible. Low thermal conductivity is a problem by almost all inorganic semi-conductive materials. Organic semiconductors could have the thermal conductivity almost one order lower. In any case the basic parameters there are the difference in work functions and Seebeck and Peltier coefficients [4]. See the Figure 2 for reference.

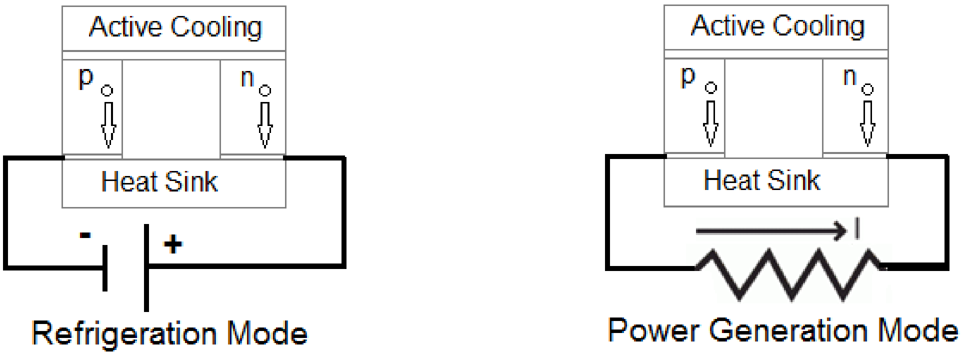


Figure 2: Peltier cell in power generation and thermoelectric cooling

2.3. LOW VOLTAGE CONVERTERS AVAILABLE AT THE MARKET

For utilization of organic thermo-generators it is necessary to consider that the output voltage of one thermoelectric element is very small. Even with the integration of many thermoelectric elements in series is not possible to increase the voltage to a level applicable for powering conventional electronic circuits. A similar situation can occur with single-cell solar panels applications. For optimal use of energy harvesters is therefore necessary to use a voltage converter with extremely low power supply voltage. Low voltage converters therefore implement boost converter that requires only microwatts of power to begin the operation.

The boost converter implemented in integrated circuit BQ25504 from Texas Instruments can start with input voltage as low as 330 mV. Once started, it can operate down to input voltage 80 mV.

Other types for example LTC3107, LTC3108 and LTC3109 from Linear technology, or MAX17710 from Maxim take power supply from output voltage. Therefore, to start up they usually need the external battery. Advantage of this design is that the input voltage could be extremely low. Basic properties of these circuits are listed in Table 1.

TYPE	Start Voltage	Lowest Voltage	Need power supply	Efficiency / Standby	
BQ25504	330 mV	80 mV	NO	> 50%	0,33 μA
LTC3108	-	20 mV	YES	> 50%	6 μA
MAX17710	-	750 mV	YES	> 50%	1,3 μA

Table 1: The overview of low voltage converters on the market

3. DESIGN OF J-FET LOW VOLTAGE CONVERTER

The biggest advantage of Organic Energy Harvesters (OEH) is their low price. The price of the necessary DC/DC converter may then be higher than the price of OEH alone.

The unit price of low voltage integrated circuits is around 50 CZK (US $ 2) and the price of other components included SMT PCB can be estimated at around 25 CZK (US $ 1). Simple and reliable JFET driven converter suggested here has material and production costs significantly lower.

3.1. PRINCIPLE OPERATION

Block diagram of converter is on Figure 3. The transformer (2) is used to increase the voltage at the inverter output. This transformer is also used to control the switching element (1). The output voltage is taken between the capacitors (3) and (4). The energy harvester (5) supplies a voltage less than 1 V. The voltage level to operate the device (6) at the inverter output is several volts.

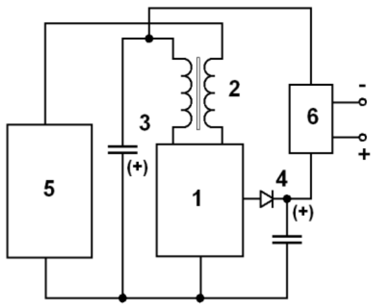
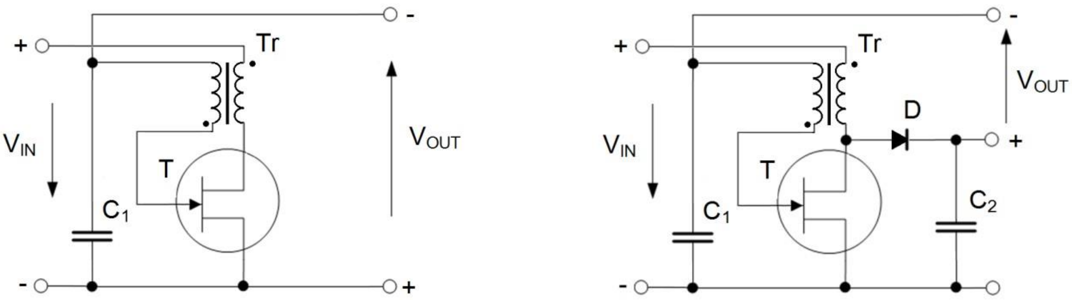


Figure 3: Block diagram of converter

Fundamental scheme of the inverter is shown in Figure 4 A). The transistor JFET operates as a switching element. As soon as the transistor turns on the secondary winding generates a voltage pulse. Capacitor C_1 is being charged by means of this pulse. The junction between the Gate electrode and Source of the transistor in this case operates as a rectifying diode. Because in this state the GateSource junction of JFET is in forward polarization the width of this junction is very small and there is very high conductivity across the transistor – it means between the electrodes S and D. Once the transformer core becomes saturated the voltage on the secondary winding starts to drop. Due to the positive feedback given with actual polarity of primary and secondary windings the transistor closes. With a negative voltage on the capacitor C_1, JFET is maintained in a closed state until the next part of the cycle where it passes into the on-state and consequently the whole process is repeated. The voltage on the capacitor C1 is at the same time output voltage of the converter as a whole.



A **B**

Figure 4: A) Basic scheme of the converter B) Converter with increased output voltage

The modified circuit shown in Figure 4 B) utilizes the energy stored in the transformer during the switch-on state. As soon as the switch-off starts a voltage pulse appears on the primary winding, which charges the capacitor C_2. This is due to the drop of magnetizing current and subsequent collapse of the magnetic field in the transformer core.

With optimal settings of the circuit the positive voltage on capacitor C_2 has approximately the same size as negative voltage on capacitor C_1. The output voltage can therefore be approximately twice as large. At the same time, there will be a slight increase in efficiency. At high current consumption, however, the output voltage decreases rapidly.

It was verified that the circuit can operate in a large range of frequencies. The working frequency of the circuit is determined by the transformer. To ensure high efficiency, it is necessary that the trans- former should minimize leakage inductance.

At low frequencies, the switching losses are small but the transformer is bulky and it is a problem to achieve a small leakage inductance. When using a toroidal transformer with a diameter of 8 mm the operating frequency of the circuit was 700 kHz. In this case, the efficiency has been limited by dynamic losses on the switch (JFET) and on the diode D.

4. RESULTS AND DISCUSSION

In Table 1 there are results of testing of inverter operated at frequency 700 kHz for both modifications of the inverter according to Figure 4. The threshold voltage V_T of JFET was $V_T = 2$ V. The transformer secondary to primary ratio was $N_S:N_P = 6:1$. For the converter, which utilizes energy stored in the transformer core, the efficiency is slightly higher. The output voltage is here greater however the cur- rent capacity is smaller.

MOD	Start Voltage	Stop Voltage	Output Current / Voltage	Power / Efficiency	
A	0,5 V	0,3 V	3V / 100 μA	300 μW	45 %
B	0,6 V	0,3 V	4 V/ 80 μA	320 μW	50 %

Table 1: Modifications of the circuit A) B); measured parameters.

4.1. CIRCUIT EFFICIENCY AND POSSIBILITIES OF FURTHER IMPROVING

To ensure high efficiency the transformer must have minimal leakage inductance. To limit the impact of dynamic losses the operating frequency of 100 kHz should not be exceeded. Here it is necessary to find a compromise between the size of the inverter and its effectiveness. Start up voltage could be much lower by higher transformer ratio and/or when using the transistor with lower threshold voltage. In both cases however the energetic efficiency of the circuit drops.

5. CONCLUSION

The paper describes the possibilities of organic energy harvesters. It is shown that organic semiconductors enable a large variability of properties and some of their properties may be better than by standard semiconductor materials. This applies especially for organic semiconductors for use in thermo-generators. To achieve long-term reliability of such devices, however, further development is needed.

DC to DC converter was designed for low voltage applications as thermoelectric generators and single-cell solar panels. It is able to operate from the voltage of few tenths of Volt and the output voltage could be in the level of several Volts. Achieved efficiency of the apparatus is approximately 50%, but it could be possible to increase it in further optimization, particularly in the design of the transformer.

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