



# An Interface Circuit for Energy Transducers\*

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## Abstract

This paper presents an efficient self-startup interface circuit for ambient energy sources. The proposed circuit consists of a charge pump, a boost converter, a charge transfer control circuit and some passive components. The charge pump boosts the low voltage at the output of the energy source to store the charge into a super capacitor. Once enough charge is stored into the super capacitor, the charge transfer control circuit has been active (i.e. being on) to bridge the super capacitor to the boost converter. Thus, the load receives power supply in a short period of time i.e., operates in the burst mode since the generated power at the energy source is lower than the power required by the load. The boost converter is used for providing a constant voltage level (e.g. 3.3 V) to the load. The proposed circuit has been evaluated using off-the-shelf components and connects to emulate the energy source. A voltage source in series with a resistor can be modeled to emulate the energy source. The proposed circuit can start the operation as low as 0.3 V input voltage and up-convert to 3.3 V. The proposed interface circuit has been tested for various loads in order to indicate the effectiveness of the circuit. The proposed circuit has a peak overall efficiency of 11.56 %, which is higher than the conventional interface circuit achieves. As compared to conventional interface circuit, the proposed circuit enhances the efficiency by 1.8 X. The measured results indicate that the proposed circuit achieves a high efficiency without the need of external supply.

**Keywords:** Energy harvesting, Boost converter, Charge pump.

## Enerji Dönüştürücüler için Ara Devresi

### Öz

Bu makale, ortam enerji kaynakları için kendiliğinde başlayan bir ara devresi sunmaktadır. Önerilen devre bir voltaj katlayıcı, bir boost dönüştürücü, bir yük aktarım kontrol devresi ve bazı pasif devre elemanlarından oluşur. Voltaj katlayıcı, enerji kaynağının çıkışındaki düşük voltajı artırarak, bir çift katmanlı kapasitörde saklar. Çift katmanlı kapasitöre yeterli elektriksel yük depolandıktan sonra, yük aktarım devresi aktif hale gelerek çift katmanlı kapasitör ile boost dönüştürücü arasında bir bağlantı kurar. Böylece, yüke kısa bir süreliğine güç sağlanır, yani enerji kaynağında üretilen güç, yükün gerektirdiği güçten daha düşük olduğu için yük burst modda çalışır. Boost dönüştürücü, yüke sabit bir voltaj seviyesi (örneğin 3.3 V) sağlamak için kullanılır. Önerilen devre, piyasadaki hazır cipler kullanılarak test edildi ve taklit edilen enerji kaynağına bağlandı. Enerji kaynağını taklit etmek için bir voltaj kaynağına seri bir direnç bağlanarak modellenilebilir. Önerilen devre, en az 0.3 V giriş voltajında çalışmaya başlatılabilir ve 3.3 V'a yükseltebilir. Önerilen ara devresinin etkin bir şekilde çalıştığını göstermek için çeşitli yükler altında test edilmiştir. Önerilen ara devre, %11.56'lık bir verime sahiptir ve bu verim, önceki çalışmadaki ara devrenin veriminden daha yüksektir. Önceki çalışmadaki ara devresi ile karşılaştırıldığında, önerilen devre verimi 1.8 kat artırır. Ölçülen sonuçlar, önerilen devrenin harici beslemeye ihtiyaç duymadan yüksek bir verim elde ettiğini gösterir.

**Anahtar Kelimeler:** Enerji hasadı, Boost dönüştürücü, Voltaj katlayıcı.

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## 1. Introduction

There are many electronic devices (e.g. sensors) utilized in the environment in order to increase awareness on protecting and controlling the environment. The most deployed energy sources for these applications are batteries. However, there are some issues related to batteries utilized for these applications; limited life time, so required frequent replacement. The realization of power supply for these applications is a critical issue that essentially confronts to achieve the performance and usability. Therefore, power supply for these applications should be placed around them and self-sustainable. As a result, energy harvesting with ambient sources is a promising alternative energy sources.

Various types of ambient energy sources have been introduced such as photovoltaic cells, thermoelectric generators (TEGs), piezoelectric, radio frequency (RF), microbial fuel cells (MFCs). However, these energy sources generate low voltage and power at their outputs which are insufficient to provide power supply for applications. Therefore, there is a need for boosting the low voltage at the output of the energy source to a voltage level demanded by the load. Also, the energy produced by the energy source should be accumulated over time into a temporary storage element and periodically transported to the load i.e. burst mode operation for the load. These can be achieved by an interface circuit that bridges between the energy source and the load.

Prior work (Wang, 2013) proposed an interface circuit for thermoelectric generator, but it has low efficiency. Thus, there is a need for an efficient interface circuit for ambient energy sources.

This paper presents an efficient self-sustainable interface circuit for energy transducers. The proposed circuit has been evaluated with off-the-shelf components including a charge pump, a boost converter, a charge transfer control circuit and some passive components. Experimental results indicate that the proposed circuit accomplishes the peak end-to-end efficiency of 11.56%. The circuit starts the operation as low as 0.3V, and provides the voltage of 3.3V at the output.

## 2. Material and Methods

### 2.1. Prior Work

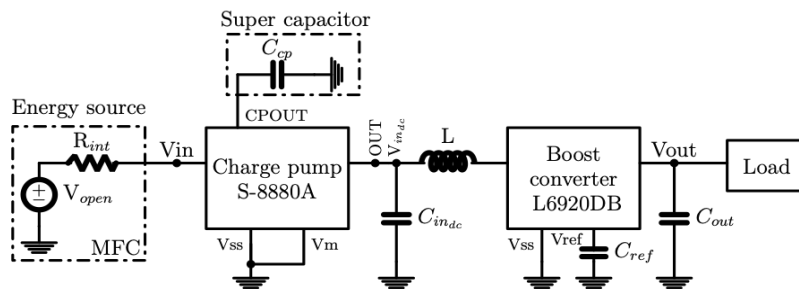


Fig. 1 Conventional interface circuit.

The existing energy harvesting circuit with thermoelectric generator has been introduced in (Wang, 2013). The circuit consists of a charge pump, two boost converters and some passive components. The charge pump (S-8880A manufactured by Ablic Inc.) is directly connected to the energy source, and its output is directly connected to the one of boost converters. The connection of the charge pump to the boost converter through the output of the charge pump causes efficiency degradation due to large energy dissipation at circuitry placed inside of the charge pump output.

In order to emulate the existing work and compare with the proposed circuit, a conventional circuit is shown in Fig. 1. This circuit is exactly similar to the prior work (Wang, 2013), but has a dissimilarity such as the connected boost converter. Nevertheless, this conventional circuit is good at showing the efficiency degradation once the output of the charge pump directly connects to a boost converter.

Once the supercapacitor starts discharging through the out pin of the charge pump (see Fig. 1), the stored energy at the supercapacitor is transferred to the boost converter, as shown in Fig. 2. It can be seen that the supercapacitor is discharging when  $R_M$  PMOS transistor turns on. Thus, there is a conduction loss on the PMOS transistor. The discharge control switch ( $R_M$  PMOS transistor) resistance is typically  $30\Omega$  (ABLIC Inc.), which causes a large power dissipation at the overall circuit. The resistance should be small in order to minimize the efficiency degradation.

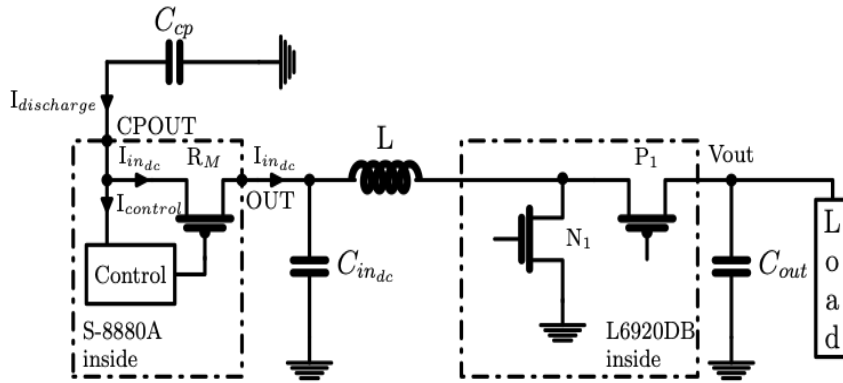


Fig. 2 The supercapacitor discharging scenario for conventional interface circuit.

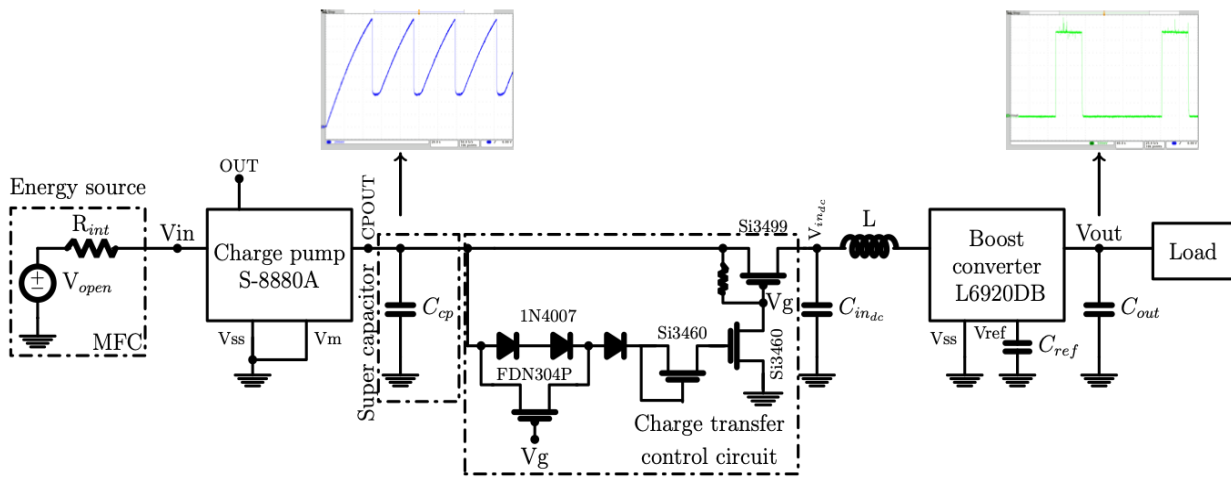


Fig. 3 The proposed interface circuit.

## 2.2. Proposed Interface Circuit

Fig. 3 shows the circuit implementation of the proposed interface circuit that consists of a charge pump, a charge transfer control circuit and a boost converter. The charge transfer control circuit is used for managing the stored energy at the super capacitor and providing power supply to the load. Unlike the conventional circuit, the proposed circuit achieves the charge transfer to the load through the boost converter by adding the charge transfer control circuit that bridges between the super capacitor and the boost converter. This scheme leads the discharging of the super capacitor through a small resistance discharge control switch (Si3499DV manufactured by Vishay semiconductor) whose resistance is  $36\text{m}\Omega$  (Vishay Siliconix). However, the resistance of the discharge control switch in the conventional interface circuit has a value of  $30\Omega$  (ABLIC Inc.), which is 833x greater than the proposed circuit has. The discharging scenario for the proposed circuit is shown in Fig. 4.

Due to low resistance value at the charge transfer control circuit, the power dissipation at the switch will be small. This results in increasing in the overall efficiency.

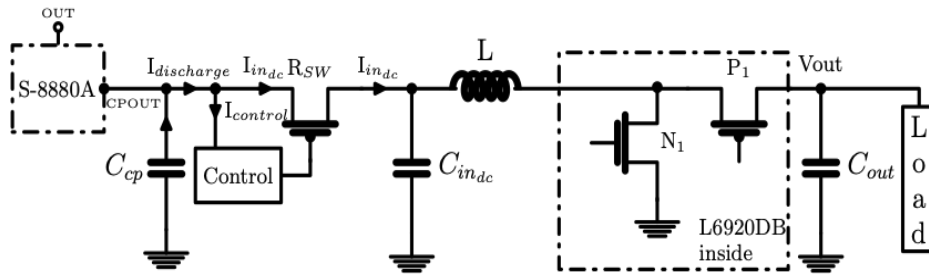
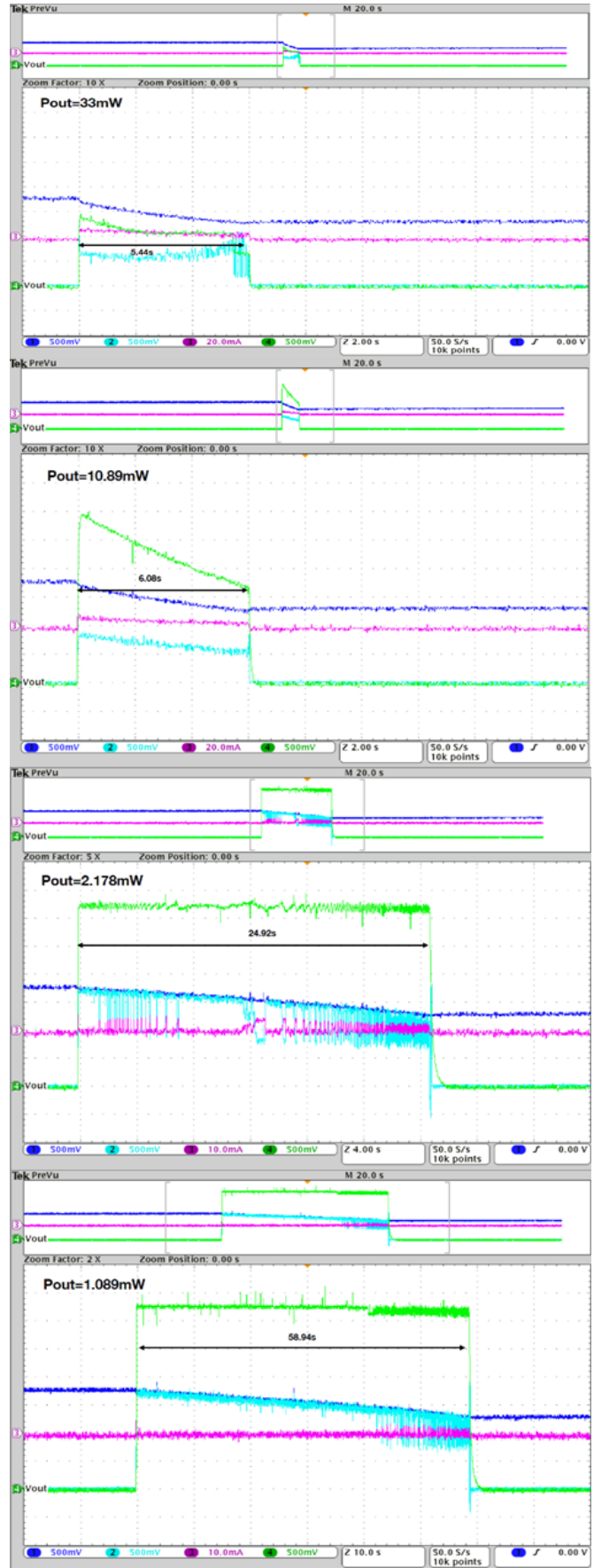
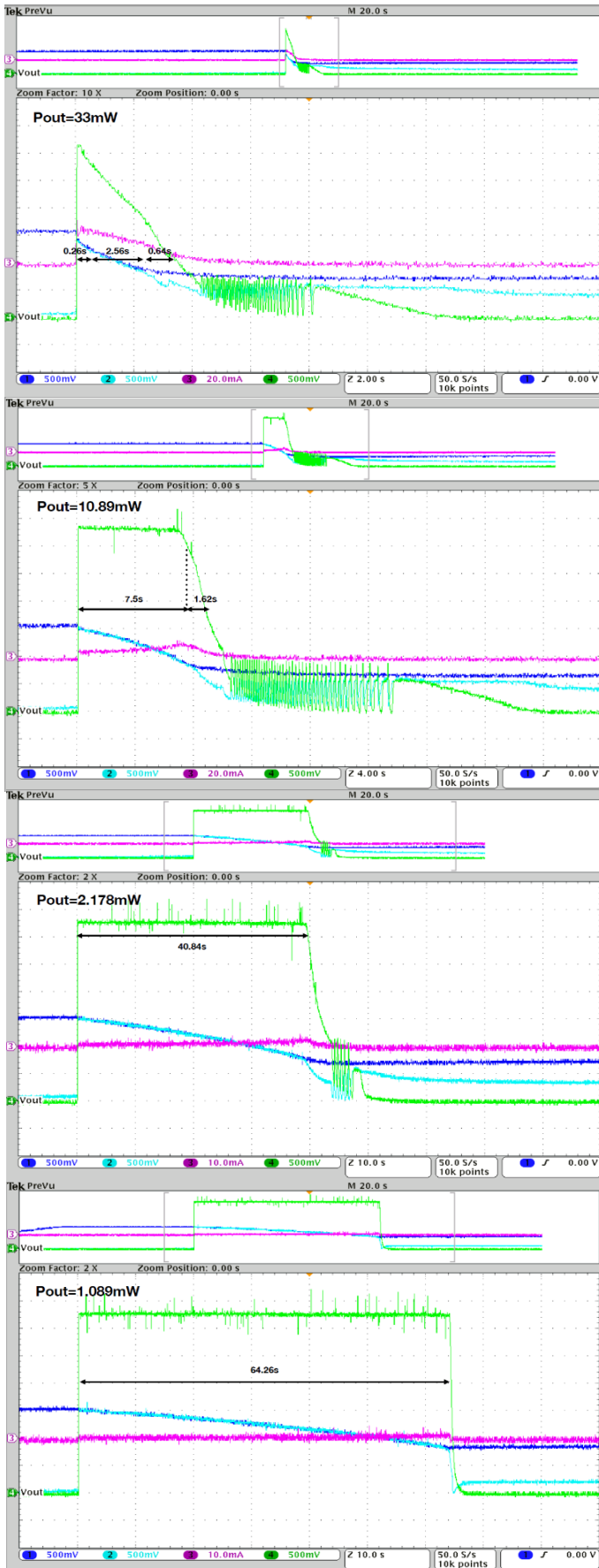


Fig. 4 The supercapacitor discharging scenario for the proposed interface circuit.

### 3. Results and Discussion

To evaluate the proposed and the conventional interface circuits, test circuits deployed discrete components were constructed. These circuits are connected to an energy source which is emulated as a voltage source ( $V_{open}$ ) of 800 mV in series with a resistor ( $R_{int}$ ) of 100  $\Omega$ . The parameters are used in the circuits as follow: a 235mF supercapacitor, a 1mH inductor, a 470 $\mu$ F input capacitor  $C_{indc}$  and a 47 $\mu$ F output capacitor  $C_{out}$ .

Fig. 5 shows voltage waveforms for the output voltage of the circuit  $V_{out}$ , the input voltage of the boost converter  $V_{indc}$  and the voltage at node CPOUT. It can be seen that the proposed interface circuit can up-convert the output voltage to above 3V for load ranging from 1.089mW to 33mW while the conventional circuit can boost to below 3V for some load ranging (e.g., 33mW and 10.89mW). Also, time duration for the load being active (i.e., the load receives power supply) is variable for two circuits; the proposed circuit has a longer time to keep the load receiving power supply. This is because the power dissipation at the discharge control switch in the proposed circuit is minimized by deploying the charge transfer control circuit.



Conventional

Fig. 5 Voltage waveforms at  $V_{out}$  (green color),  $V_{indc}$  (turquoise color) and  $CPOUT$  (blue color).

The end-to-end efficiency for these circuit is expressed as

$$\eta_{end} = \frac{P_{out} \times t_{discharge}}{P_{max} \times t_{charge}} \quad (1)$$

where  $P_{out}$  is the power obtained at the output of the circuit.  $t_{discharge}$  is the time duration that load receives power supply.  $t_{charge}$  is the time period between two power cycles received by the load.  $P_{max}$  is the maximum power available from the energy source which is given by

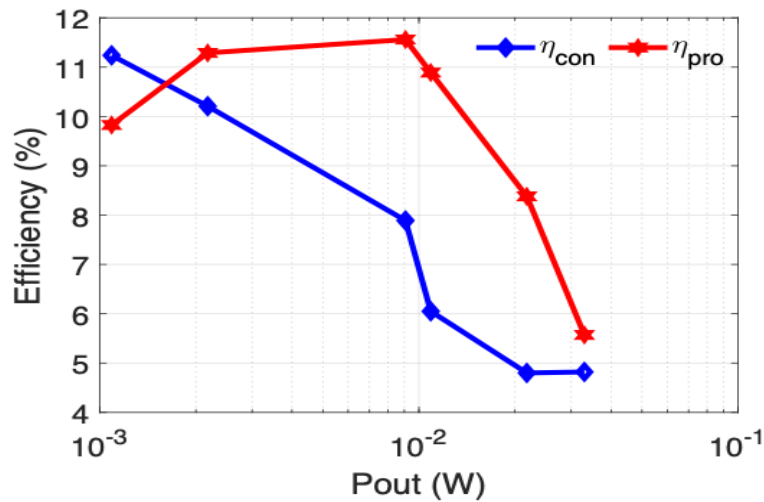
$$P_{max} = \frac{V_{open}^2}{4 \times R_{int}} \quad (2)$$

The end-to-end efficiencies for the conventional ( $\eta_{con}$ ) and the proposed ( $\eta_{pro}$ ) interface circuits under various loads are shown in Fig. 6. The peak end-to-end efficiency of the proposed circuit is 11.56%. It can be seen that the proposed circuit generally has higher efficiencies than the conventional circuit has. With the proposed circuit, the efficiency is improved by 1.8x.

Fig. 6 Measured end-to-end efficiencies for circuits under various loads.

#### 4. Conclusion

This paper presents an interface circuit for energy sources. It consists of a charge pump, a charge transfer control circuit and a boost converter. A test circuit is constructed by using off-the-shelf components. Measured results show that the proposed interface



circuit is superior to the conventional circuit in terms of power dissipation and efficiency. The proposed circuit achieves a peak end-to-end efficiency of 11.56%. The proposed circuit needs the input voltage as low as 0.3V, and can step-up to 3.3V.

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