Bang-bang photovoltaic regulator needs no magnetics

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Photovoltaic systems commonly include a means of energy storage – batteries or supercaps – to provide electricity to the load when sunlight is not available or during power transients. However, when feasible, storage-free systems are an environmentally-friendlier alternative with higher MTBF.

The **Design Idea** depicted in **Figure 1** is a photovoltaic voltage regulator that operates in a *bang-bang* style switching mode, achieving high efficiency. It is easily scalable and uses only discrete components.

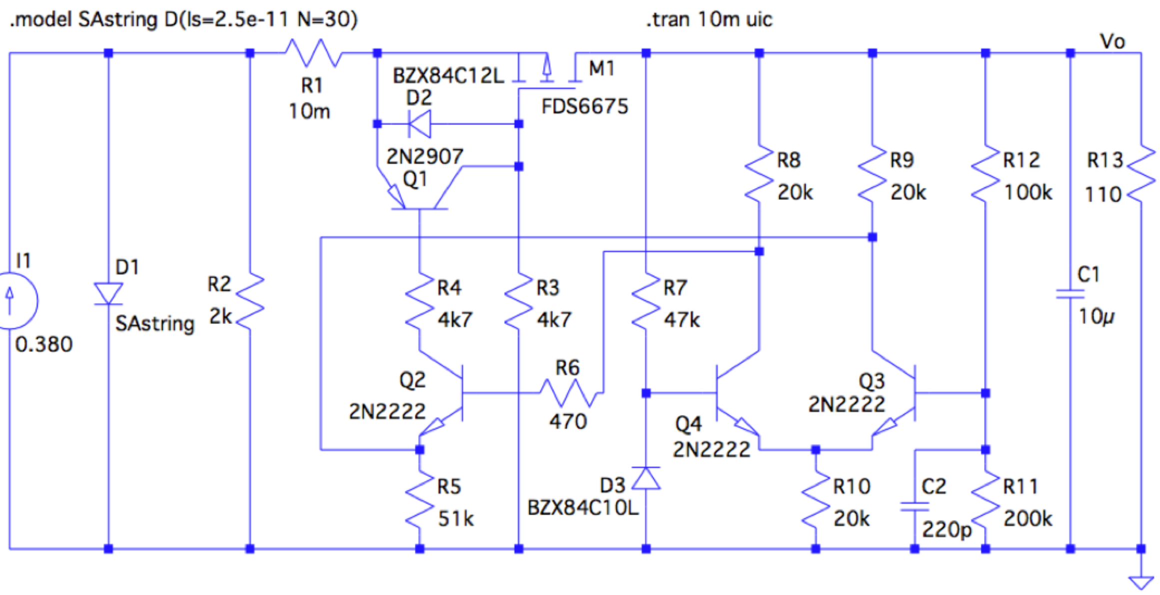

Figure 1 Simple free-running photovoltaic voltage regulator (note: D2 & D3 are Zeners).

PMOS transistor M1 turns on and off to charge output capacitor C1. When M1 is open, the photovoltaic source goes to its open-circuit voltage and C1 discharges into the load; when M1 is on, the photovoltaic source is clamped to the output voltage V_O, and C1 charges again.

A SPICE model for the photovoltaic source is given by I1-D1-R1-R2, which represents a string of 30 low power silicon solar cells in series.

Circuit operation is as follows: M1 switches on during start-up since R3 & Zener D2 set V_{GS} to 12V. As C1 charges, the voltage on Zener D3 rises until it reaches 10V, setting the voltage reference level. V_O continues rising until the output of the differential amplifier comprising Q3 & Q4 turns on Q2 and Q1, which turns off M1.

V_O then decreases until the output of the differential amplifier is not enough to keep Q2 on. The regulator remains in bang-bang mode indefinitely and the output voltage is given by:

$$Vo = V_{Z_{D3}} \frac{R_{12} + R_{11}}{R_{11}} \tag{1}$$

Output voltage ripple and switching frequency can be adjusted by the output capacitor C1 and the feedback network capacitor C2. Increasing C2 value slows down the voltage sensing, which could be necessary for stability purposes but also increases the output ripple. A balance between switching frequency and output voltage ripple is recommended depending on the application.

Waveforms from the prototype are shown in **Figure 2**. Ripple is less than 0.5 V_{P-P} on a 15V output, and the switching frequency is a bit over 25 kHz.

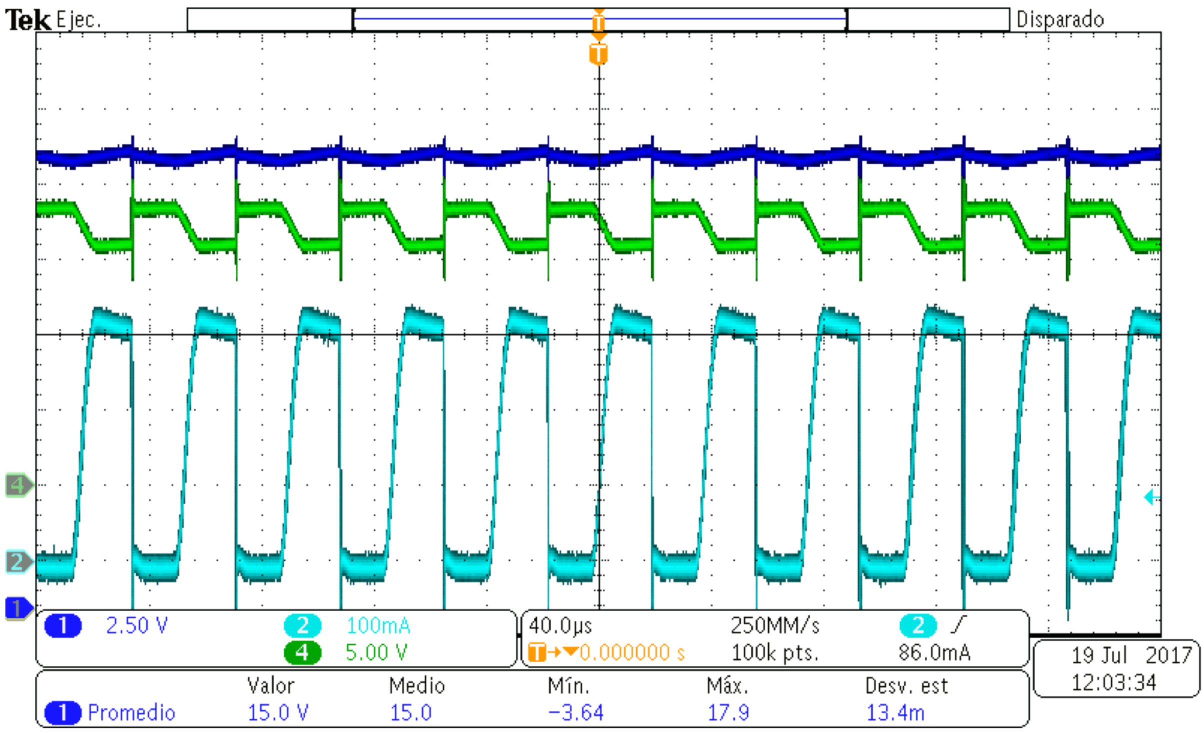

Figure 2 Voltage regulator waveforms. Blue: output voltage; green: input voltage; cyan: M1 current.

To conclude, this circuit is a simple yet robust and versatile solution to obtain regulated voltage from photovoltaic sources. The design is easily adaptable to other voltage or current needs.

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