Creating a Low-Leakage Rectifier

using a self-powered op amp

By Martin Tomasz, Senior Scientist, Touchstone Semiconductor, Inc.

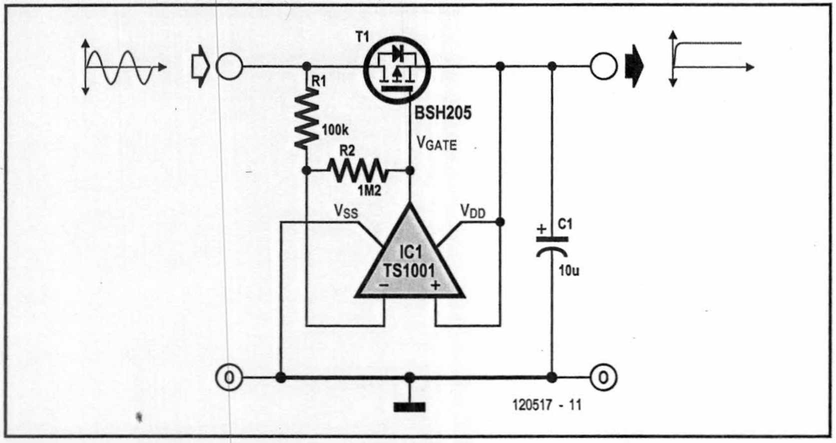


Figure 1.
This circuit emulates a rectifier, but it has forward-voltage drop of 40 mV or less. The circuit has less reverse leakage than a Schottky diode.

A nanopower op amp, a low-threshold P-channel MOSFET, and two feedback resistors are combined to make a rectifier circuit with less forward drop than a diode (**Figure 1**). Since the rectified output voltage powers the active circuitry, no additional power supply is necessary, and the circuit's quiescent current is lower than most Schottky diodes' reverse-leakage current.

This circuit provides active rectification at voltage drops as low as 0.8 V. At lower voltages, the MOSFET's body diode takes over as an ordinary diode.

When a forward voltage develops between the input and output voltages, the op amp circuit turns on the MOSFET, according to the following equation:

$$V_{GATE} = V_{OUT} - (R_2 / R_1) \times (V_{IN} - V_{OUT})$$

where V_{GATE} is the MOSFET's gate drive, V_{IN} is the input voltage, and V_{OUT} is the output voltage. The input and the output voltages to the MOSFET's drain-to-source and gate-to-source voltages are described by the following equations:

$$V_{DS} = V_{IN} - V_{OUT} \text{ and } V_{GS} = V_{GATE} - V_{OUT}$$

where V_{DS} is the drain-to-source voltage and V_{GS} is the gate-to-source voltage. Algebraically, these equations relate to the MOSFET's gate drive to a function of the drain-to-source voltage:

$$V_{GS} = -(R_2 / R_1) \times V_{DS}$$

A good design choice is to make R_2 12 times larger in value than R_1, resulting in a 40-mV voltage drop across the MOSFET's drain-to-source voltage, sufficient to turn on the MOSFET at low drain currents (**Figure 2**). A higher ratio further reduces the voltage drop within the limits of the op amp's worst-case input-offset voltage of 6 mV. Power for the op amp (the Touchstone Semiconductor TS1001) comes from the circuit's output-the output-reservoir capacitor C_1. Since he amplifier has rail-to-rail inputs and outputs and no phase inversion when operating near the rails, connecting its supply rails to the output works well. Additionally, since the amplifier operates at power-supply voltages as low as 0.8 V, the circuit's rectifying action works to this low voltage. The op amp's non-inverting input is connected to the V_{DD} rail and the amp's output to the gate of the MOSFET. The circuit consumes slightly more than 1 µA when actively rectifying a 100-Hz sine wave, less current leakage than that of most Schottky diodes. The BSH205's threshold is low enough to support milliamp-level currents at a gate-to-source voltage of 0.8 V.

About the author

Martin Tomasz is a seasoned analogue, radio, and mixed-signal engineer with 22 years' experience in circuit and systems design. As senior scientist at Touchstone Semiconductor, Martin has 17 patents to his credit. Prior to joining Touchstone Semiconductor, Martin spent two seasons in Antarctica working for the US Antarctic Program, working with scientific monitoring devices designed to work in extreme environments.

The op amp's bandwidth does limit the circuit to lower-frequency signals; at bandwidths higher than 500 Hz, the amplifier's gain begins to decline. However, as the signal frequency increases, the body diode of the MOSFET takes over the rectification function while the MOSFET remains off. Fast fall time input signals could potentially drag the output with reverse current through the MOSFET, before the op amp has a chance to turn the MOSFET off. However, for small currents, the MOSFET operates in its sub-threshold range. On the other hand, the amplifier quickly turns off due to the exponential relationship of the gate-to-source voltage to the drain-to-source current in the sub-threshold range. Ultimately, the amplifier's slew rate of 1.5 V/ms is the limiting factor. As long as the circuit's load is light enough to keep the MOSFET from operating in its linear range, reverse currents won't exceed forward currents.

A micropower solar-harvesting application is shown in **Figure 3**. The BPW34 cells generate 10 to 30 µA at 0.8 to 1.5 V, depending on the light. This circuit rectifies the peak harvested voltage in conditions of rapidly changing light and minimizes reverse leakage to the cells at low light conditions.

(120517)

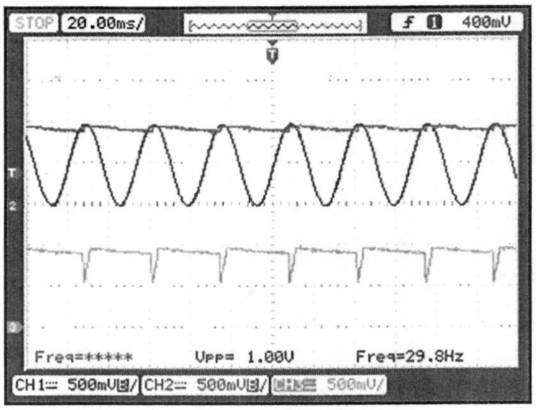


Figure 2.
The output of the circuit (green) with a sinewave input (yellow) shows that the FET's gate voltage (blue) drops out only when the input-to-output differential is less than 40 mV.

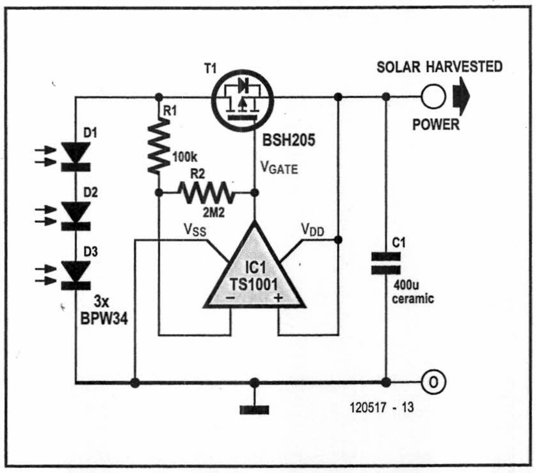
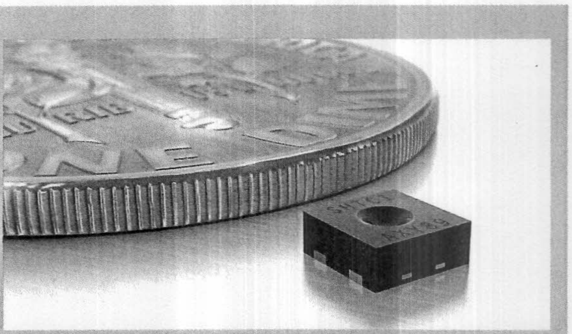


Figure 3.
You can use the active-rectifier circuit to charge a capacitor from solar cells. The rectifier has a low voltage drop and protects the cells from reverse current when there is no light.

World's smallest humidity and temperature sensor



Sensirion's tiny SHTC1 humidity and temperature sensor is specifically designed for mobile devices where size is a critical factor. Sensirion has rigorously followed the maxim "smaller is better" and developed the world's smallest sensor in its class, measuring a mere 2 x 2 x 0.8 mm. The sensor is based on the proven CMOSens® Technology, which allows the sensor and the signal processing electronics to be combined on a single silicon chip to achieve small device size. Production is targeted at high volume to allow low unit prices to be achieved by economy of scale. The supply voltage of 1.8 V is also fully in line with the needs of the target industry. The specifications of the new sensor show that the size, power consumption and price reductions do not have any impact on performance. It measures relative humidity over a range of 0 to 100 %RH with a typical accuracy of ±3 %RH. The temperature measuring range is -30 to +100 °C with a typical accuracy of ±0.3 °C. The sensor is fully calibrated, has a digital I²C interface, and is suitable for reflow soldering. This makes it compatible with standard industrial mass production processes for electronic modules. To ensure effective integration of the sensor in complex applications, Sensirion draws on its many years of experience with sensor products deployed in the millions and supports customers with corresponding application expertise. The new SHTC1 humidity and temperature sensor combines extreme miniaturization with top performance, and with Sensirion's implementation support it is doubtless a decisive step ahead of the competition.

www.sensiron.com/shtc1 **(120663-II)**