Gnat-Power Sawtooth Oscillator Works on Low Supply Voltages

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Making basic analog circuit functions that operate from a low-voltage battery supply can be tricky. Lack of headroom and the need to minimize supply and leakage currents are usually the biggest challenges. Many of the usual tricks, such as diode signal clamps and stacked transistor connections, often fall apart when your goal is one-cell operation.

This sawtooth oscillator design idea, drawing less than 3.2µA and working at under one volt, is a useful building-block that fits the bill for extremely low power consumption and operation to low supply voltages. It could be used as the basis for a PWM control loop, a timer, a VCO, or as a capacitance-to-frequency converter. It's a nifty circuit because it a) uses an open-drain comparator output to make an accurate switched current source, and b) uses a latch function to make a simple comparator into a window comparator, while needing no extra components.

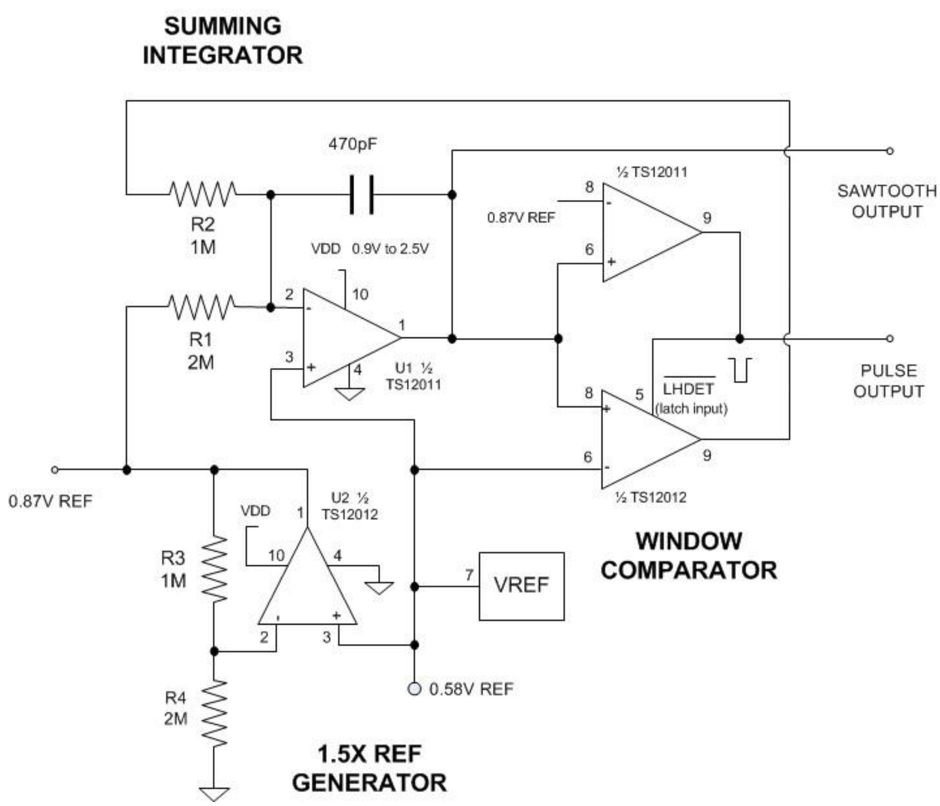

Figure 1. Low-Voltage Sawtooth Generator

The appeal in this circuit is found in the combination of tiny size, ridiculously low number of external components, low supply current, and ability to maintain a constant amplitude and frequency despite the variable battery voltage. Unlike the classic op-amp astable multivibrator, this design features comparator thresholds that are set by precision reference voltages rather than the output swing of the op amp in combination with resistor feedback. A ratiometric fixed-frequency design of this type usually results in a variable amplitude sawtooth waveform, which is undesirable in PWM control loops as it can affect the loop gain. As a side benefit, the up/down ramps can be independently controlled by scaling R1 and R2.

There are only seven components in this circuit: two ICs, four resistors, and a capacitor. The key bits are two Touchstone Semiconductor analog building-block ICs in $4mm^2$ TDFN packages (the TS12011 and the TS12012), that each contain an op amp, a comparator, and a reference. By leaning on their characteristics, the design can be kept terrifically tiny and simple.

Here's how the circuit works: A summing integrator feeding a window comparator generates the sawtooth wave. The integrator summing node is held at VREF by the feedback action of the amplifier. Thus, a fixed positive reference current set by R1 is balanced by a larger-amplitude switched negative current set by R2. The lower comparator block has an open-drain output; when its output is low, current is pulled from the summing node via R2:

$I_{R1} = (0.87V_{REF} – 0.58V_{REF})/R1$ and I_{R2} (switched) $= 0.58V_{REF}/R2$

If I_{R2} is set to 2 x I_{R1}, a symmetrical triangle wave results.

The frequency is set as follows:

$$F = \frac{1}{(1/I_{R1} + 1/I_{R2}) * C * V} = 850\text{Hz as shown.}$$

Where V is the difference between $0.87V_{REF}$ and $0.58V_{REF}$.

The window comparator employs a built-in latch function of the TS12012 to provide hysteresis. The latch function has a sly feature – when $\overline{\text{LHDET}}$ is pulled low, the comparator inputs are still active and sensing the input state, until the inputs cross. The comparator in U2 gets set when the ramp crosses the lower threshold at $0.58V_{REF}$, and reset when the ramp crosses $0.87V_{REF}$. The reset pulse is momentary, but puts the latch in a state where the comparator inputs crossing cause it to set and latch again (which happens due to the switched reference current causing the integrator to ramp negative). Net result: no glue logic needed.

The battery voltage ranges down to 0.9V with a miserly VDD current of 3.2µA. Maximum operating frequency is limited by the op amp slew rate and prop delays to about 3kHz. Disconnecting R1 and driving it with a voltage source greater than $0.58V_{REF}$ gives you a VCO function.

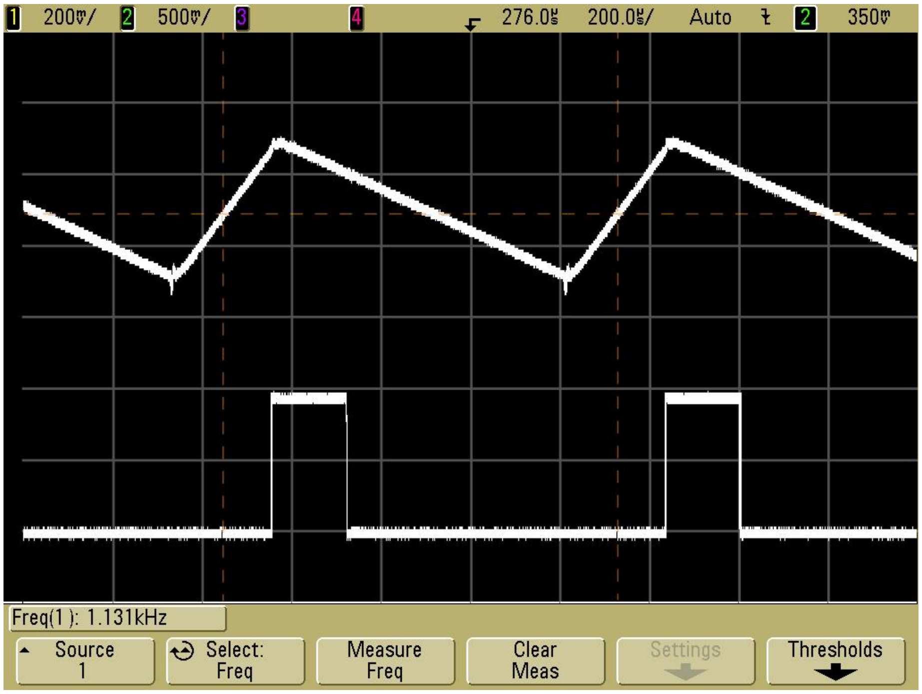

Figure 2. Scope photo: Sawtooth and pulse outputs. The pulse train is used to reset the latching comparator.

For additional information, please follow the links to the corresponding product pages:

- TS12011 Product Information
- TS12012 Product Information

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