Build a charge pump with ultralow quiescent current

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PORTABLE BATTERY-powered devices often spend most of their life in standby mode, in which the quiescent current of an internal boost converter continuously bleeds the battery. The quiescent current during standby can be larger than the actual load current. Though several inductor-based converters offer maximum quiescent current of less than 10 µA, designers usually prefer or require a regulated charge pump for cost-sensitive designs that must be intrinsically safe. Off-the-shelf regulated charge pumps with output-current capabilities of at least 10 mA have typical minimum quiescent currents of 50 to 100 µA. If that level of quiescent current is unacceptable, you can reduce the overall average by adding circuitry that remotely monitors the regulated voltage and toggles the charge pump into and out of shutdown. That approach, however, may not achieve the desirable quiescent-current level of less than 10 µA. The advent of low-on-resistance analog switches and ultralow-current comparators and references makes possible a charge-pump circuit whose maximum quiescent current is approximately 7 µA (**Figure 1**).

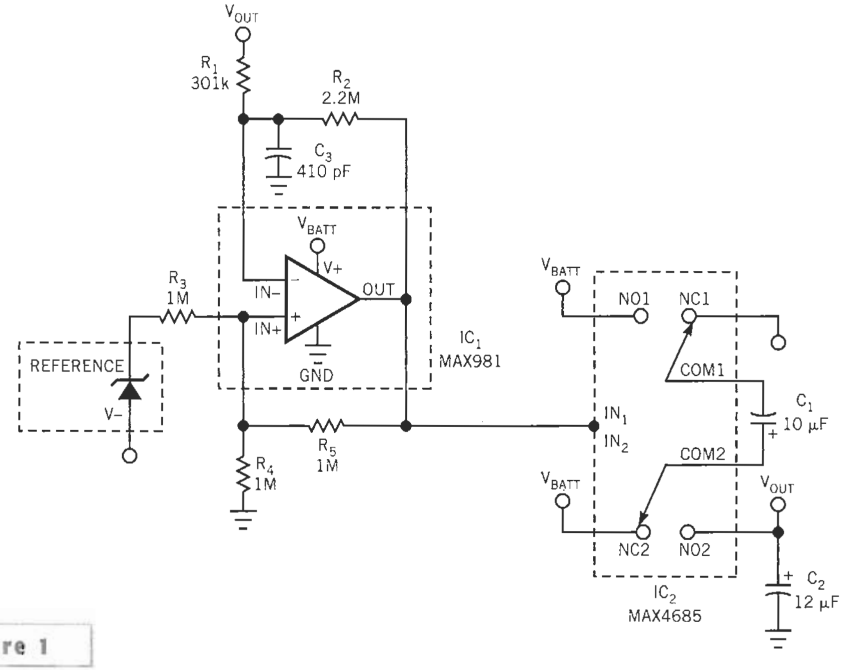

Figure 1

This charge-pump circuit uses analog switches to achieve ultralow quiescent current.

Charge pumps use an ac-coupling technique to transfer energy from a transfer capacitor to a storage capacitor. The transfer capacitor first charges via analog switches to the level of V_{BATT}, and then other analog switches transfer the energy to a storage capacitor tied to V_{OUT}. The transfer capacitor then charges again, and the cycle repeats. With ideal analog switches exhibiting zero loss, the V_{OUT} level equals two times V_{BATT}. As expected, however, the analog switches' finite on-resistance produces an output level that drops in proportion to the load current. The basic regulated charge pump in **Figure 1** includes an oscillator, several analog switches, a voltage reference, and a comparator. The comparator serves as a voltage monitor and an oscillator. When the circuit is in regulation, the comparator output is low, which closes the NC (normally closed) switches and allows C_1 to charge to V_{BATT}. When the voltage at V_{OUT} dips below the output-regulation threshold—3.3V in this case—the comparator output goes high. The NO (normally open) switches close, transferring C_1's charge to C_2. This cycle repeats until V_{OUT} regains regulation.

Resistors R_3 to R_5 provide the hysteresis necessary for oscillation. Their value, 1 MΩ, creates a notable level of hysteresis and minimizes V_{BATT} loading. As the comparator output changes state, feedback resistor R_5 creates hysteresis by moving the threshold you apply to the comparator's positive input. For the resistor values shown, reference value nominal for IC_1 (1.182V), and V_{BATT}=3V, the V_{IN}+threshold swings between approximate values of V_{IN}+(low)=0.39V and V_{IN}+(high)=1.39V. When the circuit is in regulation, $V_{IN}-$ slightly exceeds $V_{IN}+$, the comparator output is low, the R_1-R_2 divider senses the voltage at V_{OUT}, and the threshold at $V_{IN}+$ is low (0.39V). With $V_{IN}+$ at 0.39V, you can calculate the R_1 and R_2 values from the equation $V_{IN}+=V_{OUT}[R_2/(R_1+R_2)]$. The resistance of R_1+R_2 should be greater than 1 MΩ to minimize V_{BATT} loading. If V_{OUT}=3.3V and R_2 is 2.2 MΩ, R_1 calculates to 301 kΩ. Capacitor C_3 connects to the comparator's $V_{IN}-$ input. Along with R_1 and R_2, C_3 sets the oscillation frequency according to the following simplified relationships: $t_{DISCHARGE}=t_{LOW}=-(R_2C_3)\ln[(V_{IN}+(LOW))/(V_{IN}+HIGH))]$; $t_{CHARGE}=t_{HIGH}=-(R_2C_3)\ln[1-(V_{IN}+(HIGH)-V_{IN}+(LOW))/(V_{BATT}-V_{IN}+(LOW)]$; and $f_{OSC}=1/t_{PERIOD}$, where $t_{PERIOD}=t_{LOW}+t_{HIGH}$.

To maximize efficiency and reduce the effects of comparator slew rate, you should set a relatively low frequency. Choosing C_3=470 pF yields the following: t_{LOW}=178 μsec, and t_{HIGH}=68 μsec; thus, f_{OSC}=4 kHz.

Select the values of C_1 and C_2 to achieve the desired load current and ripple. For this application (I_{LOAD}=10 mA), C_1=10 μF. To calculate the value of C_2, make an approximation based on the desired ripple voltage: $C_2=(I_{LOAD}\times t_{LOW})/V_{RIPPLE}$. With I_{LOAD}=10 mA and V_{RIPPLE}=150 mV, C_2=12 μF.

With these component values, the circuit draws a maximum quiescent current of 6.9 μA and offers a considerable improvement over off-the-shelf charge pumps. You can further lower the quiescent current by increasing the resistor values, but that effect is minimal because IC_2's maximum quiescent current of 3.8 μA dominates the total. This circuit lets you implement an ultralow-quiescent-current-regulated charge pump. Until off-the-shelf options are available, it provides an alternative for designers seeking to implement a low-cost design without the use of inductors.□