DESIGN SOLUTION 7203

VERY LOW INPUT-VOLTAGE BOOST CONVERTER ENABLES DIRECT METHANOL FUEL CELL HEARING AIDS

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Abstract:

Learn how a very low input-voltage boost converter enables direct methanol fuel cells (DMFC) power hearing aids for a full day on a single, fast refill.

Introduction

When we think about wearable technology today, the first thing that comes to mind is fashionable ear buds, smart watches, smart glasses, and fitness trackers. The venerable hearing aid is finally being joined and perhaps soon integrated into this plethora of wearables. It appears in fact, that hearing aids are again poised to be first in adopting the new technology of direct methanol fuel cells (DMFC), leaving behind conventional batteries for this new efficient power source. Today, battery-powered hearing aids typically need 4 to 5 hours to recharge. That's a pretty high and inconvenient downtime, unless perhaps it's at bedtime. But what if your hearing aids need to go back online in 30 seconds? That is the promise of DMFC technology! Goodbye long recharge, welcome quicker power refill.

This design solution reviews the challenges of powering a hearing aid (**Figure 1**) with a fuel cell and the energy it requires operating for a full day on a single refill.

The 400mV cell voltage is too low to power the electronics downstream. A step-up voltage regulator can solve the problem but there aren't many voltage regulators out there that can operate off 400mV. In this design solution, we present a novel boost converter that can operate from a very low input voltage with very high efficiency and very low quiescent current. The low input voltage operation enables the application of fuel cell technology to the hearing aids, while its low quiescent current and high efficiency maximizes the operation off a single refill.

Figure 1. Patient wearing a hearing aid.

Fuel Cell Operation

Direct methanol fuel cells are a type of proton-exchange fuel cells in which methanol and air are used as the fuel. Their main advantage is the ease with which they handle methanol, an energy-dense and stable liquid at all environmental conditions. The DMFCs consist of a central proton conductive membrane, or polymer electrolyte membrane (PEM), surrounded by an anode on the fuel side and a cathode on the air side. The methanol fuel is oxidized catalytically at the anode, providing the electrons that sustain an electric current. The protons are led through the membrane to the cathode, where they combine with oxygen and electrons to form vaporized water and a negligible amount of carbon dioxide.

With an energy density of 4466Wh/l, 270µl methanol has an energy content E of:

$$E = 4466 \times 270\mu = 1.2\text{Wh}$$

Assuming a fuel-cell efficiency of 10%, we have a useful energy of 120mW. With a cell voltage of 0.4V, we have an equivalent stored charge of:

$$Q = \frac{1.2\text{Wh}}{0.4\text{V}} = 300\text{mAh}$$

Hearing Aid Block Diagram

Figure 2 shows a typical hearing aid block diagram. A methanol fuel cell supplies a charge of up to 300mAh to power the on-board DSP, microphone, speaker, ADC, DAC, and amplifiers through a DC-DC step-up regulator.

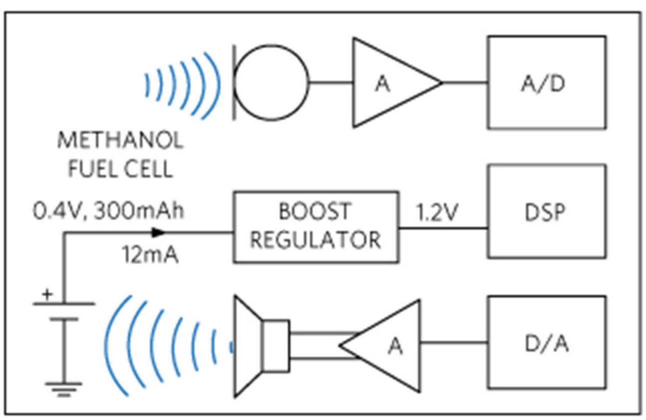

Figure 2. Methanol-powered hearing aid block diagram.

In a typical case, a system that consumes an average current of 12mA will last a bit more than a day:

$$\text{DURATION} = \frac{300\text{mAh}}{12\text{mA}} = 25\text{h}$$

The Challenges

The boost converter's low input voltage operation is essential for a DMFC-based system. Small size is a must in small wearables like hearing aids. High efficiency and low quiescent current are also important for both the best energy utilization and the longest operation between refills. But these are conflicting requirements. Increasing the frequency of operation of the voltage regulator will reduce the size of passives but increase losses, thereby reducing its efficiency.

The offering of differentiated hearing aid products also creates a need for multiple customized versions of voltage regulators, especially with respect to input/output voltage and current specifications. Accordingly, a hearing aid manufacturer may be forced to maintain a sizeable and costly inventory of different regulators and passives required to support them.

A State-of-the-Art Solution

As an example, the MAX17220 nanoPower synchronous boost converter (**Figure 3**) offers very high efficiency, a 400mV to 5.5V input range, a 225mA peak inductor current limit, and an output voltage that is selectable using a single standard 1% resistor. A novel True Shutdown™ mode yields leakage currents in the nanoampere range, making this a truly nanopower device.

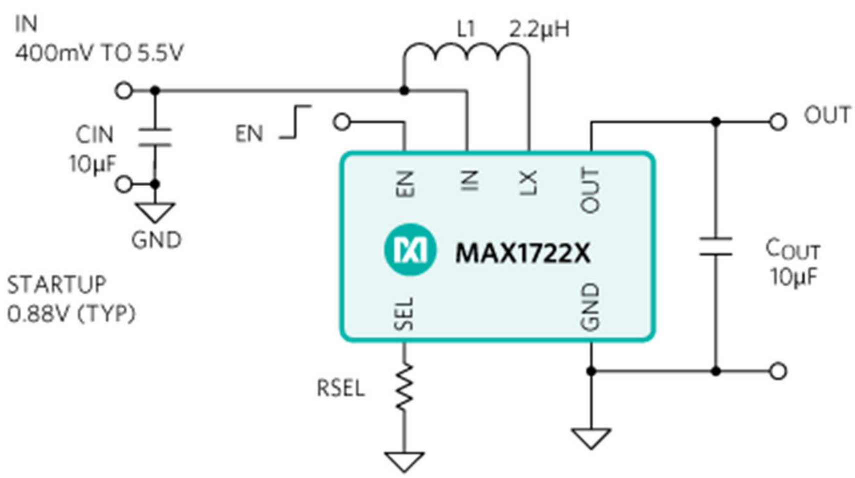

Figure 3. Boost converter application diagram.

Small Size

Every detail of the MAX17220, MAX17221, MAX17222, MAX17223, MAX17224, MAX17225 family of boost converters was carefully chosen to allow for the lowest power and smallest solution size. Such details as switching frequencies up to 2.5MHz, tiny package options, single-output setting resistor, 300ns fixed turn-on time, as well as three current-limit options, allow the user to minimize total solution size.

The ICs are offered in two tiny package options, a 2mm x 2mm 6-pin µDFN and a 0.88mm x 1.4mm 6-bump WLP (2 x 3, 0.4mm Pitch).

Low Input Voltage and Ultra-Low Quiescent Current

The nanoPower boost converter has ultra-low quiescent current and is designed to operate at low input voltages by bootstrapping itself from its output by drawing current from the output. Referring to **Figure 4**, the input quiescent current (I_{QINT}) for the IC is 0.5nA (enable open after startup) and the output quiescent current (I_{QOUT}) is 300nA.

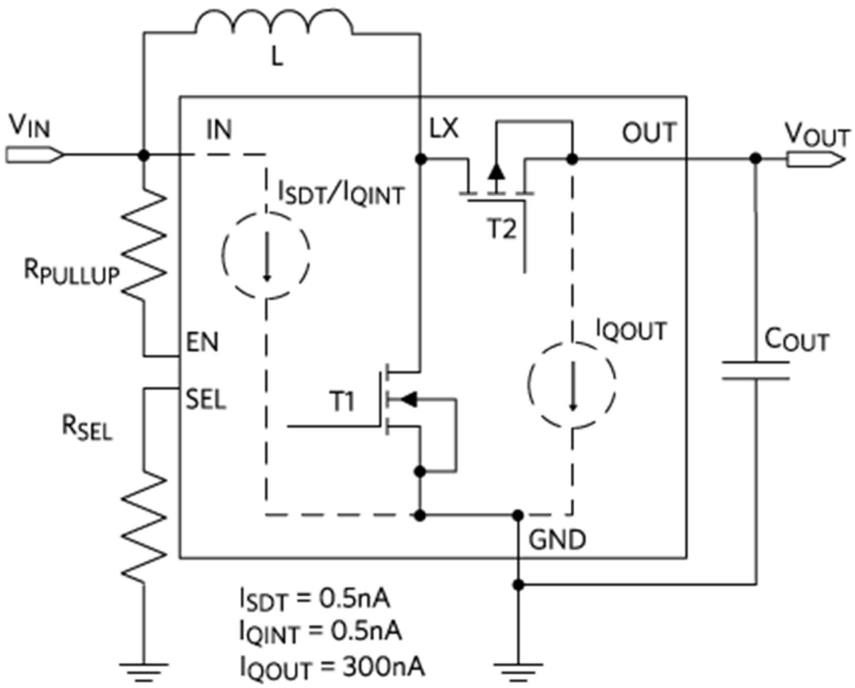

Figure 4. Boost converter with lower shutdown and quiescent currents.

To calculate the total input quiescent current, the additional input current needed to feed the output current (I_{QOUT_IN}) must be added to I_{QINT}. Since the output power is related to the input power by the efficiency ($P_{OUT} = P_{IN} \times \eta$), it follows that:

$$I_{QOUT\_IN} = I_{QOUT} \times (V_{OUT}/V_{IN})/\eta$$

If V_{IN} = 1.4V, V_{OUT} = 3.3V, and efficiency η = 88% at low current, we have:

$$I_{QOUT\_IN} = 300nA \times (3.3/1.4)/0.88 = 803.5nA$$

Adding the 803.5nA to the input current of 0.5nA yields a grand total input quiescent current of 804nA (I_{QINGT}). This quiescent current is 12 times lower than the 10µA of a typical step-up voltage regulator, as discussed in the previous case.

High Efficiency

The boost converter IC features low-R_{DSON}, on-board powertrain MOSFET transistors that yield excellent efficiency even when operating at frequencies high enough to warrant a small overall PCB size (**Figure 5**).

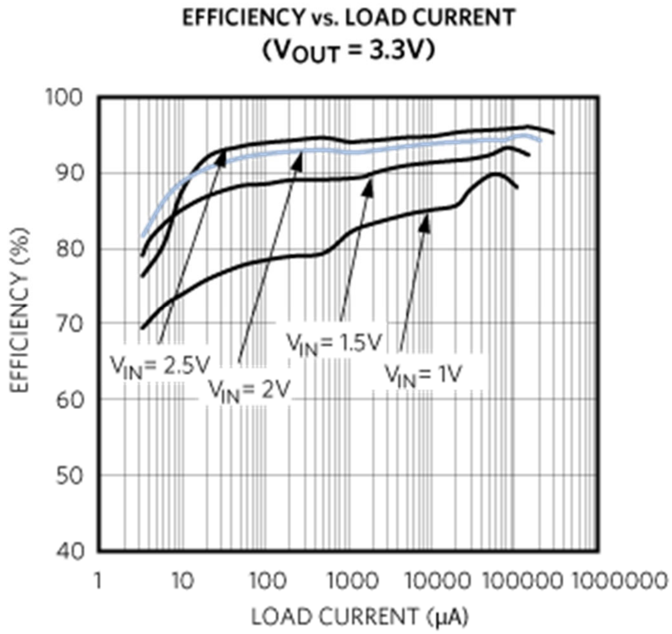

Figure 5. High-efficiency boost converter with low-on-resistance, on-board powertrain MOSFET transistors.

Enable Transient Protection Mode

The boost converter also includes an option for enable transient protection (ETP) mode. When activated by the presence of a pullup resistor, extra on-chip circuitry powered by the output capacitor assures that EN stays high during short transient disturbances at the input. In this case, the quiescent current calculated above increases by a few tens of nanoamps.

BOM Advantage and Smart V_{OUT} Selection

The MAX17224 eliminates the traditional resistor-divider that is used to set the output-voltage value in favor of a single-output selection resistor (R_{SEL}), as shown in Figure 4. The IC uses a proprietary scheme to read the R_{SEL} value that consumes up to 200µA at startup only. A single standard 1% resistor sets one of the 33 different output voltages, separated by 100mV increments between 1.8V and 5V. The result is a small reduction in BOM (one less resistor), simplified inventory (a single regulator for multiple applications), and lower quiescent current.

Conclusion

Direct methanol fuel-cell technology promises to solve a big shortcoming of battery-powered wearables, namely the long time required to recharge the battery. By utilizing methanol as the energy source, this type of fuel cell eliminates battery recharge in favor of a fuel-cell tank refill, reducing hours of charging to mere seconds of refilling. But the low voltage generated by the fuel cell can potentially pose a problem in its wide adoption. We introduced a very low input-voltage, ultra-low quiescent-current, high-efficiency boost converter that can bridge the gap between the DMFC’s low input voltage and the hearing aid’s high-voltage electronics, enabling seamless operation for a full day on a single refill.

A similar version of this design solution originally appeared in EE Power on March 26, 2020.