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Research paper

Extending Battery Life using Boost Converter through Feedback Control

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Abstract

Battery life is an important factor in any portable device. All possible efforts are being made to prolong the usage time of a battery. Eventually when a battery has low charge, the output voltage deteriorates and eventually reaches a point which is not enough to drive the load. This paper proposes a way of boosting the output voltage in this situation to increase the life of a battery before next charge phase, thereby using energy from the battery which would otherwise be unused. The proposed technique uses a DC-DC Boost Converter in Continuous Conduction Mode. An error amplifier with a Type-3 Compensation circuit is used in the feedback path to stabilize the system. The PWM comparator circuit is used to generate the required PWM input signals for the Boost Converter with required Duty Cycle.

Keywords: *Boost Converter; Compensation; CCM; Error Amplifier; PWM Generator; Voltage Mode*

1. Introduction

When we discharge a battery by consuming the power stored in it, we will never be able to discharge it beyond a certain point. Because, beyond this, terminal voltage will fall. The maximum discharge level depends on the type and quality of the battery. A true deep cycle battery has a discharge capacity of up to 80%. Typical batteries have much less at around 50% [1]. For low-power devices powered by batteries, every microampere of current becomes critical for extending battery life and increasing the time between battery replacements. On the other hand, the need to keep the devices going on for longer periods of time is also increasing.

One of the techniques to extend the battery life is to adjust the energy consumption by controlling the voltage supplied to digital circuits to the extent of their usage. The drawback of this technique is that if the supply voltage is reduced, the energy consumption goes down, but the speed of operation also decreases. If the supply voltage is lowered excessively, the energy consumption increases because a much longer time is taken to do the same amount of work. This solution fails when the voltage falls below the required minimum output voltage.

In this paper, we propose an alternate approach, wherein we continuously monitor the battery voltage (V_{IN}) and check if it falls below a reference voltage (V_{REF}). This is achieved using an Error Amplifier (EA). As long as battery voltage is above the reference, the battery is connected directly to the load. Once the voltage falls below the reference voltage, boost converter takes over and it adjusts its duty cycle through PWM Generator such that required output voltage V_{OUT} is maintained. In this way we will be able to use the battery even when the voltage level falls below the reference level, thus extending the battery life or ampere hour rating.

2. System architecture

The overall architecture of the system is given in Fig.1. It contains mainly [3] components: Boost Converter, Error Amplifier (EA) and PWM generator (PWM).

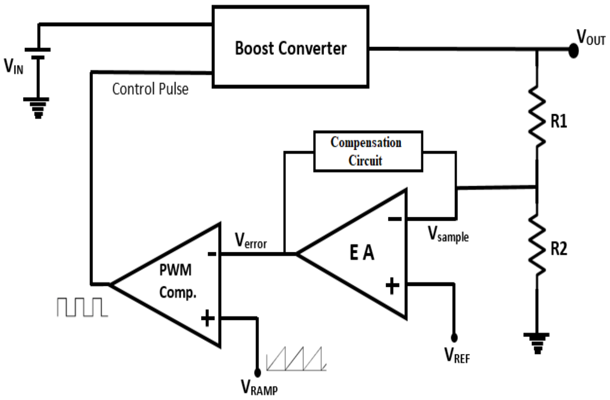

Fig. 1: System Architecture.

Boost Convereter, the heart of the system, is responsible to maintain the output voltage at a specified constant value. The system consists of boost converter in the forward path and an error amplifier with a PWM generator in the feedback path. Error Amplifier keeps sensing the output voltage and generates an error signal proportional to the difference between a constant V_{REF} and the sampled output voltage. The circuit is designed to to use Voltage Mode Control (VMC). PWM Generator generates PWM control pulses whose duty cycle is adjusted according to the error signal from Error Amplifier. To stabilize the circuit operation, Error Amplifier has been designed with a compensation circuit.

2.1. Boost converter

Boost Converters [2] are widely used in electronic circuits when a DC supply voltage available is not sufficient enough for the system being supplied. Here we designed an inductor-based, continuous conduction mode (CCM) [3], [4] DC-DC boost converter because of its best power conversion efficiency among all the other implementation methods.

The DC/DC boost converter shown in Fig. 2 only needs four external components: Inductor, 2 MOSFET switches, and output capacitor.

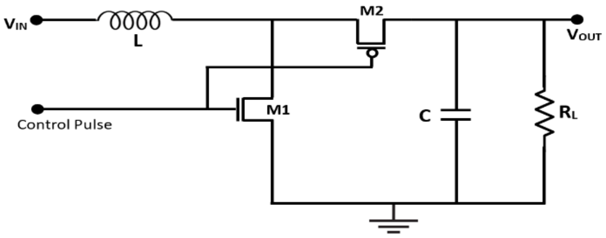

Fig. 2: Boost Converter Schematic.

The value of inductor and capacitor are determined from the formulae: [3], [5], and [6]

Inductor (to keep the boost converter in CCM):

$$L \geq \frac{D\,(1-D)^2\,R_{load}\,T}{2} \tag{1}$$

Capacitor (to keep output ripple within 1% of its peak value):

$$C \geq \frac{D\,T}{0.01 * R_{load}} \tag{2}$$

Where D is the duty cycle of control pulses

$$D = 1 - \frac{V_{IN}}{V_{OUT}} = \frac{T_{ON}}{T} \tag{3}$$

The circuit is designed for a switching frequency of 1 MH_Z. The sizes of the MOSFET switches are determined from the peak value of the inductor current and the acceptable voltage drops across the switches.

2.2. Error amplifier and PWM generator

Op-Amp with a gain of 60dB is used to implement both the Error Amplifier and PWM Comparator [7], [4] as shown in Fig. 3. Ideally a gain of 60dB is good enough. EA is fed with the sampled output voltage to the inverting terminal and a reference voltage in the non-inverting terminal to generate an error signal.

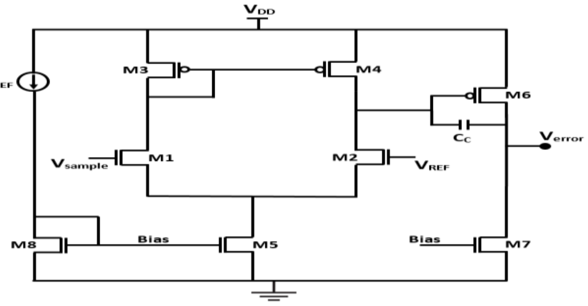

Fig. 3: Op-Amp used in EA and PWM Comparator.

The basic operating principle of the VMC is that the duty cycles of the drive signals to control the MOS switches are proportional to the "error voltage" which is actually the difference between the output voltage of the converter and the regulated (reference) voltage. Therein, the error amplifier (EA) is used to provide an error voltage V_{error} to the PWM Comparator (PWM). The PWM Comparator generates the PWM waveforms by comparing the error voltage (V_{error}) with a fixed voltage ramp (V_{RAMP}) generated from an extra clock.

3. Stability and compensation

A major problem faced by designers in the design of Boost Converters is the stability of the circuit due to the presence of feedback that too at high frequencies [8]. This can be resolved by having a feedback with compensation to stabilize the circuit. The Error amplifier used here uses an Op-Amp with Type-3 Compensation network as shown in Fig. 4a.

The condition for stability is that the poles of the circuit should be on the left half of s-plane. To ensure stability, the circuit should have a sufficiently high Gain Margin and Phase Margin. The Bode plot can be used to determine the Gain Margin and Phase Margin.

By properly designing the compensation network we can shape the loop gain such that it has enough phase and gain margins [9] so that the system is stable with good output regulation. The circuit consists of an integrator, a pole at origin, two other poles and two zeros as shown in the Fig. 4b. Fig. 5 shows the Error Amplifier Bode Plot.

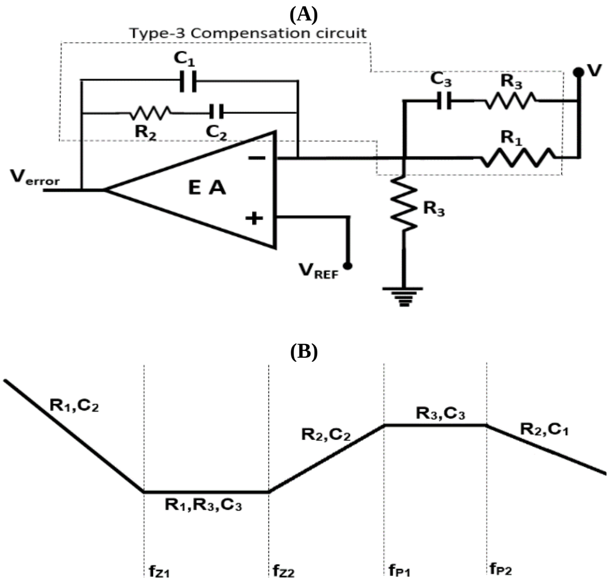

Fig. 4: Error Amplifier: A) with Compensation B) Poles and Zeros.

The approximate transfer function of the system is given by

$$H(s) = \frac{(sC3(R1+R3)+1)(sC2R2+1)}{(sC2R1)(sC3R3+1)(sC1R2+1)} \tag{4}$$

And the poles and zeros introduced by this circuitry are given by

$$fp0 = \frac{1}{2\pi R1C2} \quad fz1 = \frac{1}{2\pi(R1+R3)C3}$$

$$fp1 = \frac{1}{2\pi R3C3} \quad fz2 = \frac{1}{2\pi R2C2}$$

$$fp2 = \frac{1}{2\pi R2C1}$$

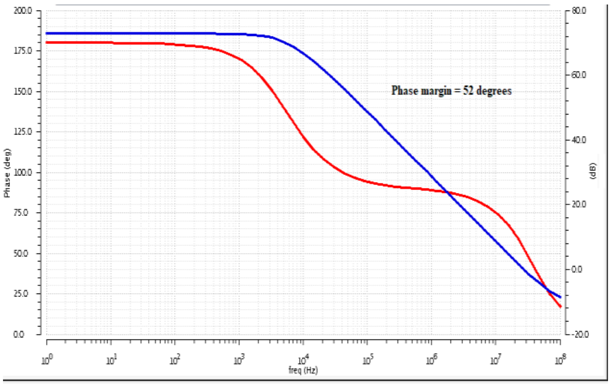

Fig. 5: Error Amplifier Bode Plot.

4. Results and waveforms

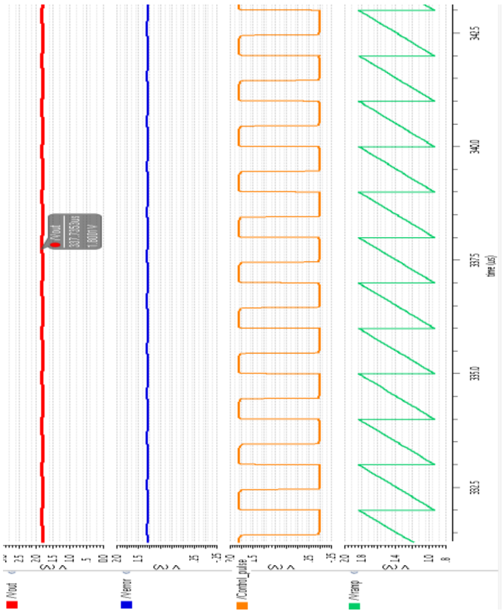

Fig. 6: System Waveforms for V_{IN} = 1.0V.

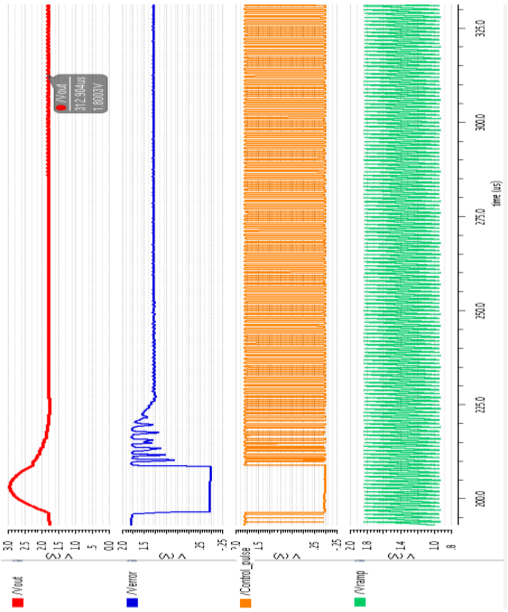

Fig. 7: Ramp Voltage, Control Pulse and Error Voltage Waveforms for V_{IN} = 1.0V.

5. Conclusion

Boost Converter with type 3 compensator is designed for an output voltage of 1.8 V and simulated in 180nm technology using Cadence Virtuoso spice simulator. The circuit is found to maintain a constant output voltage of 1.8V till the input is swept down to 0.6 V and starts oscillating below that. The output ripple is found to be 0.7% of its rated output voltage. Power dissipation of the entire system has been measured and is found to be 6.6□W.

References

[1] http://www.streetmusician.co.uk/batterycalculation/.

[2] Y. K. Teh, P. K. T. Mok, "Design Consideration of Recent Advanced Low-Voltage CMOS Boost Converter for Energy Harvesting," 22nd European Conference on Circuit Theory and Design, (ECCTD 2015), Trondheim, Norway, 24 - 26 Aug 2015.

[3] B. M Hasaneen; Adel A. Elbaset Mohammed, "Design and Simulation of DC/DC Boost Converters", 12th International Middle-East Power System Conference, MEPCON, 2008, pp: 335-340.

[4] Application Report Understanding Boost Power Stages in Switchmode Power Supplies, Literature Number SLVA061, and Texas Instruments Incorporated, March 1999.

[5] Nurul Arfah Che Mustapha, A.H.M. Zahirul Alam, Sheroz Khan, Amelia Wong Azman, "Boost Converter for Low Voltage Energy Harvesting Applications: Basic Component Selection", 2013 IEEE International Conference on Smart Instrumentation, Measurement and Applications (ICSIMA 2013), November 26-27, Kuala Lumpur, Malaysia.

[6] Brigitte Hauke, "Basic Calculation of a Boost Converter's Power Stage", Texas Instruments Application Report, SLVA372C–November 2009–Revised January 2014.

[7] Tsz Yin Man, Philip K. T. Mok, Mansun J. Chan, A 0.9-V Input Discontinuous-Conduction-Mode Boost Converter With CMOS-Control Rectifier, IEEE Journal of Solid-State Circuits, Vol. 43, No. 9, pp. 2036-2046, September 2008.

[8] Robert W. Erickson, Dragan Maksimovic, "Fundamentals of Power Electronics", 2nd Edition, Kluwer Academic Publishers, 2004.

[9] Lirong Zhu, Feng Quanyuan, "Design of PWM Controller for Monolithic Boost Converter", seventh IEEE International Conference on ASIC, 2007, pp. 660 – 663.