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A Steady State Model for the Continuous Conversion Ratio Charge Pump

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Introduction

In order to expand the efficient voltage conversion range of standard charge pump based dc-dc converters, the architecture in was proposed. However, as the architecture has recently been proposed, no models have yet been generated which account for the impact of finite switch resistance on the output current characteristic. The paper develops a model from first principles, and validates the model by comparison to simulation data.

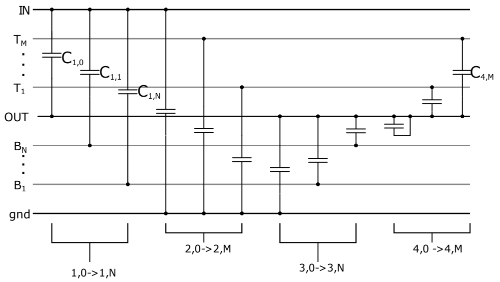

Fig. 1: Circuit diagram of the continuous conversion ratio charge pump.

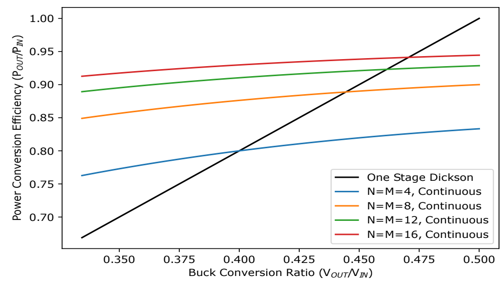

Fig. 2: Comparison of a single stage Dickson and Continuous Conversion charge pump without parasitics

Analysis

In order to incorporate the switch resistance, a first order approximation of the circuit is used. The circuit in Fig. 3 is an example of the flying capacitor states, which can be alternately represented as Fig. 4. From Fig. 4, the voltage across the flying capacitors can be expressed using a first order RC time constant. As this time constant is equivalent between the different states, a useful approximation of the exponential decay is, $A = 1 - \exp(-1/(f_{SW}C_{Fly}R_{ON}))$.

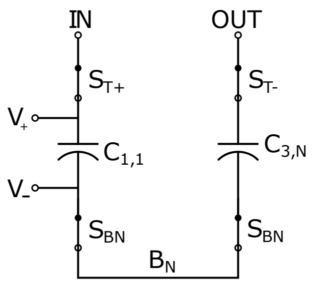

Fig. 3: Example of flying capacitors on steps, 1 and 3,N.

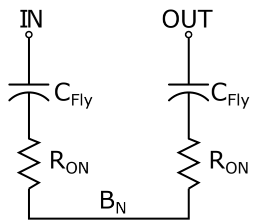

Fig. 4: RC circuit equivalent of Fig. 3.

Verification

From the analysis, equations for both the input and output power can be acquired, where

$$P_{IN} = V_{IN} f_{SW} C_{Fly} \frac{M A V_{OUT} + (2-A)V_{IN}}{A(M-1)+2},$$

and

$$P_{OUT} = V_{OUT} f_{SW} C_{Fly} \left(\frac{(2-A)(V_{IN}-V_{OUT})}{A(M-1)+2} + \frac{N A V_{OUT}}{A(N-1)+2} + (V_{IN} - V_{OUT}) \right).$$

These can then be verified with transient simulations using pspice. The pspice configuration results are then compared to the calculated results from the power equations.

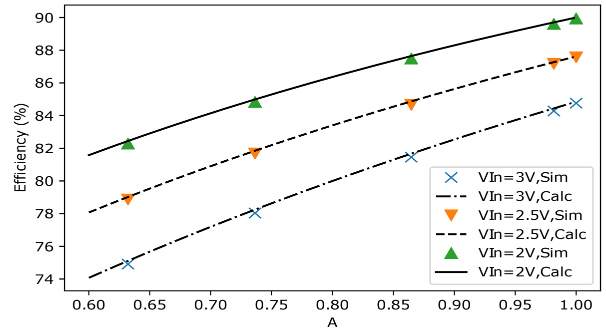

Fig. 5: Comparison of simulated and calculated efficiency for various values of V_{IN} and A.

The resulting comparison is graphed in Fig. 5, with an average error of <0.3% in both P_{IN} and P_{OUT}.

Future Work

There are a number of effects which the provided work does not take into account. The exact impact of leakage effects on the efficiency should be investigated, in addition to non-linearity in C_{Fly} with respect to voltage. There is also a need to generate a frequency domain model of the structure, in order to ensure stability and functionality.