

Industry Session 15: Energy Harvesting



MicroWatts AC-DC Conversion IC Design for Vibration and RF Energy Harvesting

Presented by

Mike Hayes for Wensi Wang, Jiaqi Yu

Beijing University of Technology

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1 . *Research Background*

2 . *Purpose And Significance*

3 . *Circuits Implementation*

4 . *Simulation Results*

5 . *Conclusion*



Research Background

Solar energy, thermal energy and vibration energy are the main sources of today's energy harvesting technology. For vibrational energy, there are many forms of ambient source, such as :



Human Walking
(Sport)



Vehicle Movement
(Engine)

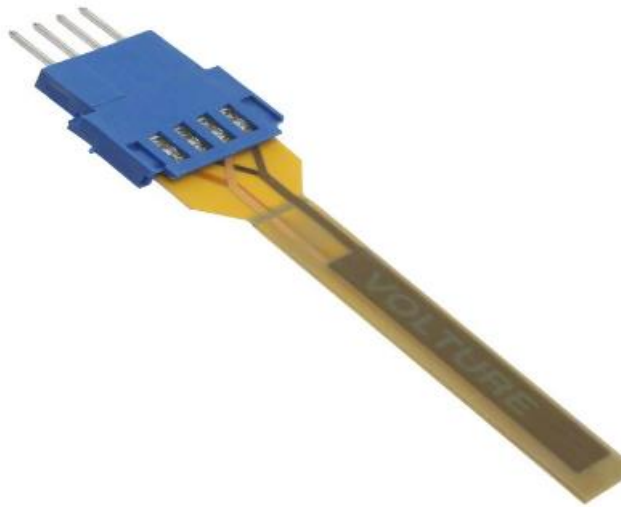


Train Vibration
(Track)

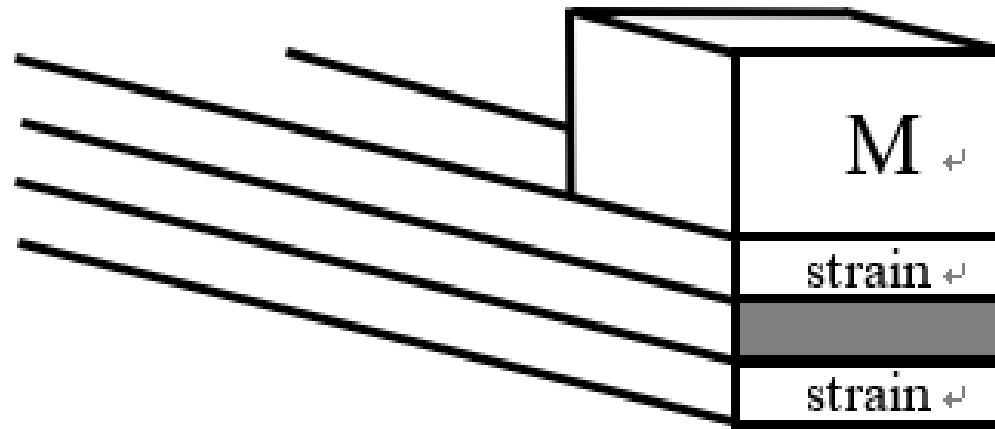


Research Background

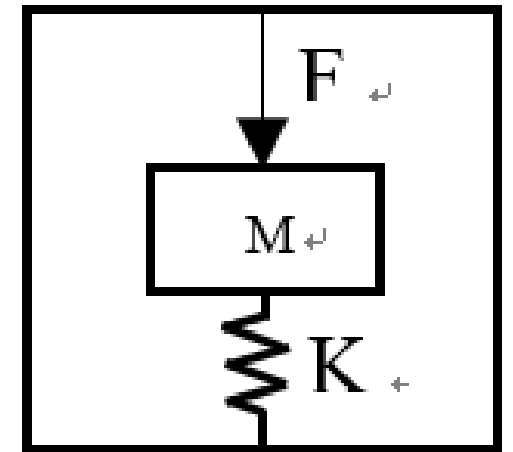
Typical vibration energy harvesters are mainly divided into three types: electromagnetic, capacitive and piezoelectric. The piezoelectric energy harvester (PEH) is usually formed in a cantilever-beam structure.



MIDE V22B
(The PEH)



Cantilever-beam Structure



Equivalent Mechanical Model

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Purpose And Significance

In this paper, the PEH is used as the input excitation source. So we design a Power Management IC based on Parallel-SSHI (synchronized switch harvesting on inductor) technique in a 0.18- μm CMOS process.

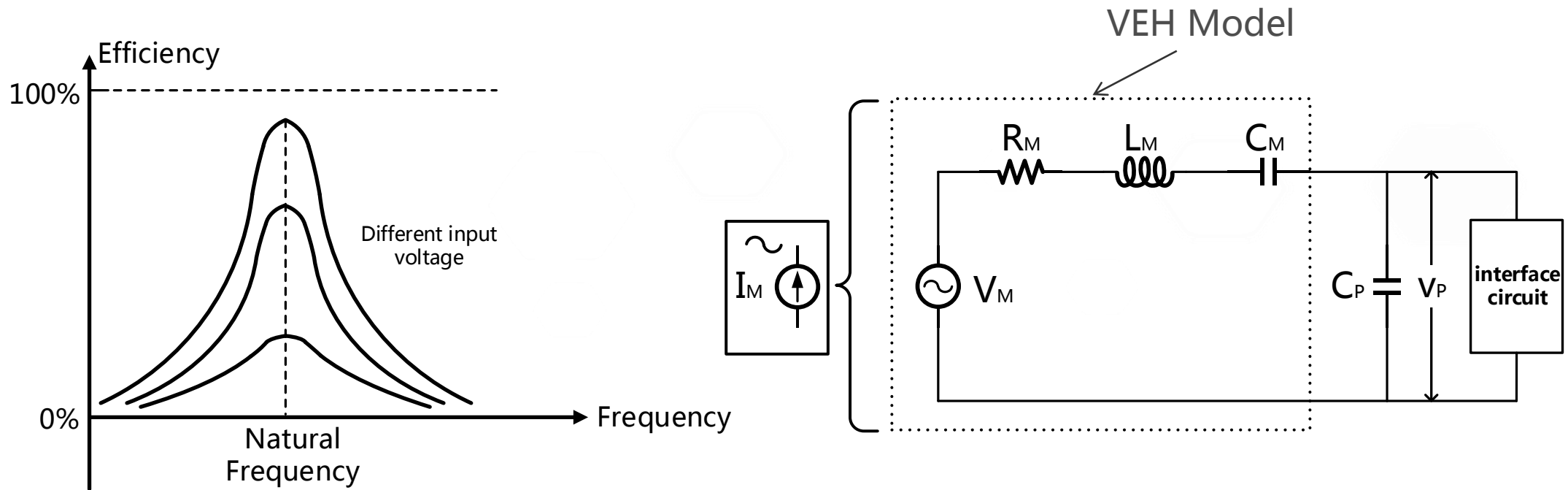
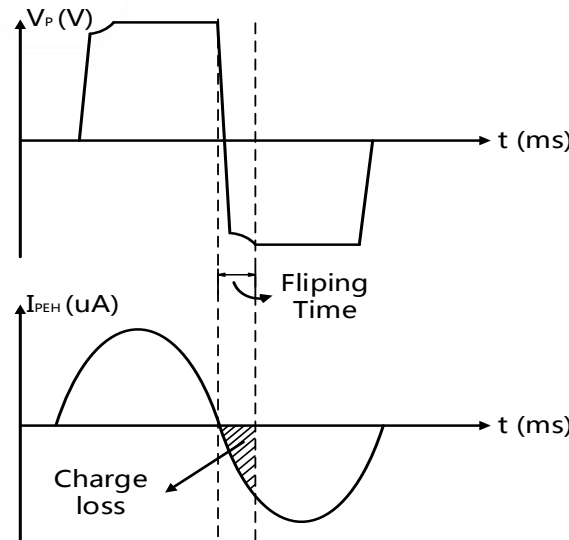
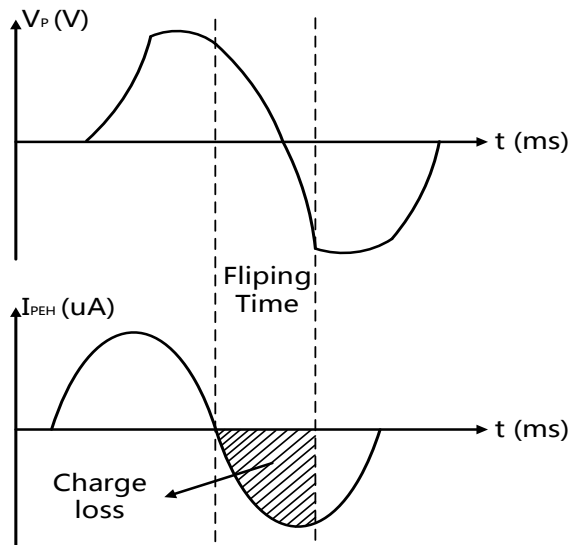
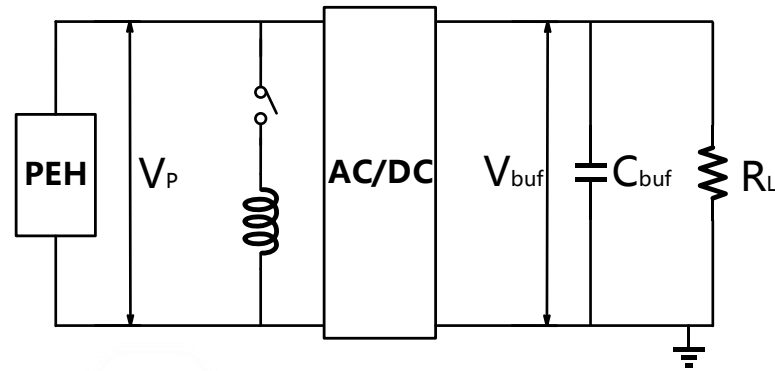
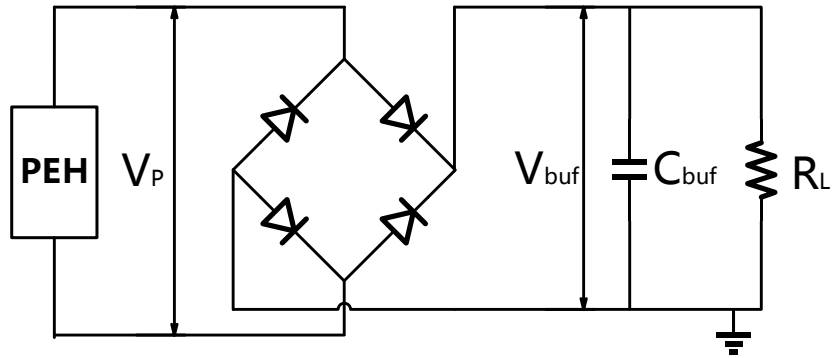


Diagram of efficiency changing with frequency for different input voltage

Equivalent Electrical Model



Purpose And Significance



Comparing with the FBR*,
Parallel-SSHI technique:

- shortens the flipping time
- prolongs the charging time at high potential
- reduces the loss of charge
- enables a high voltage change rate to the inductor.

Schematics of FBR (left) and P-SSHI (right) connected to a PEH and its operation waveform

* FBR= full bridge rectifier

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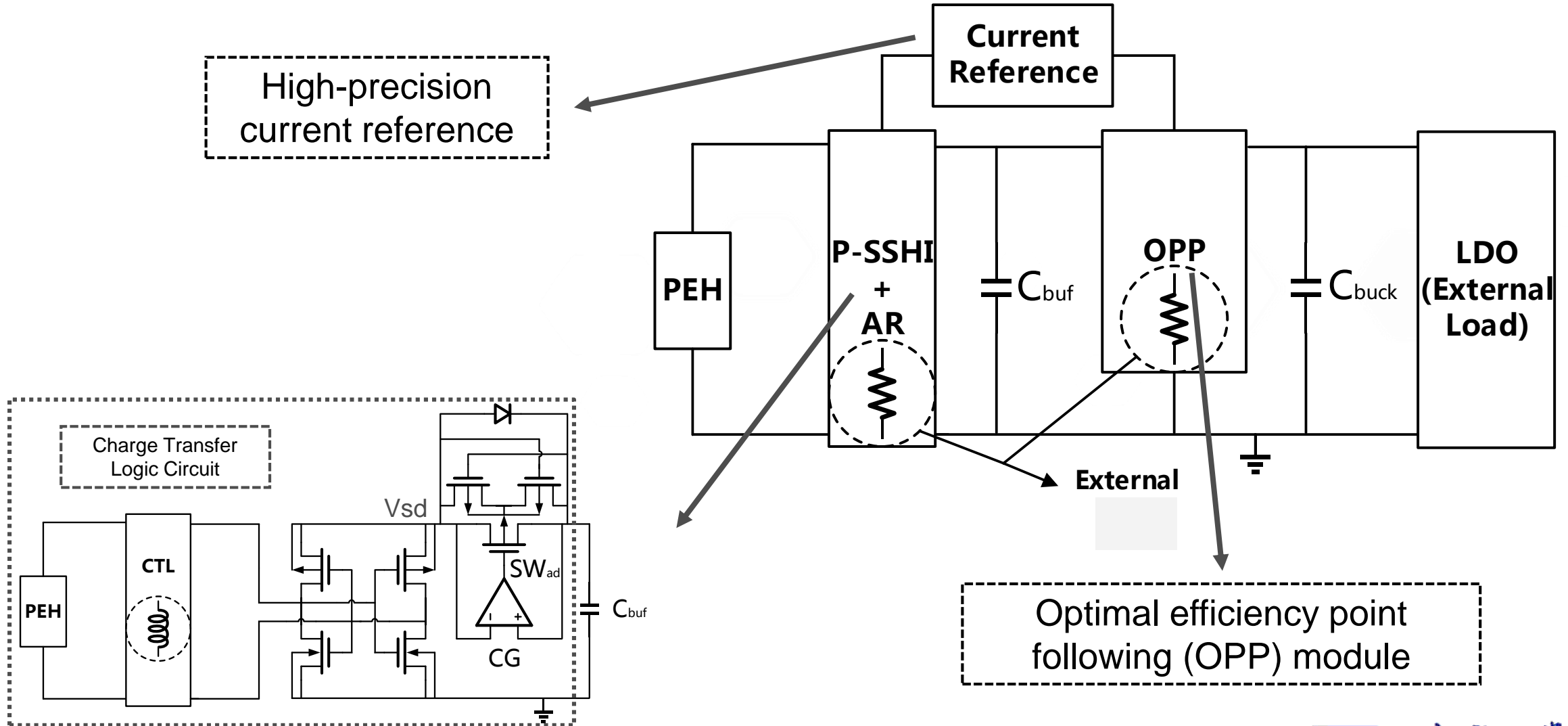
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Circuits Implementation

A. System Architecture

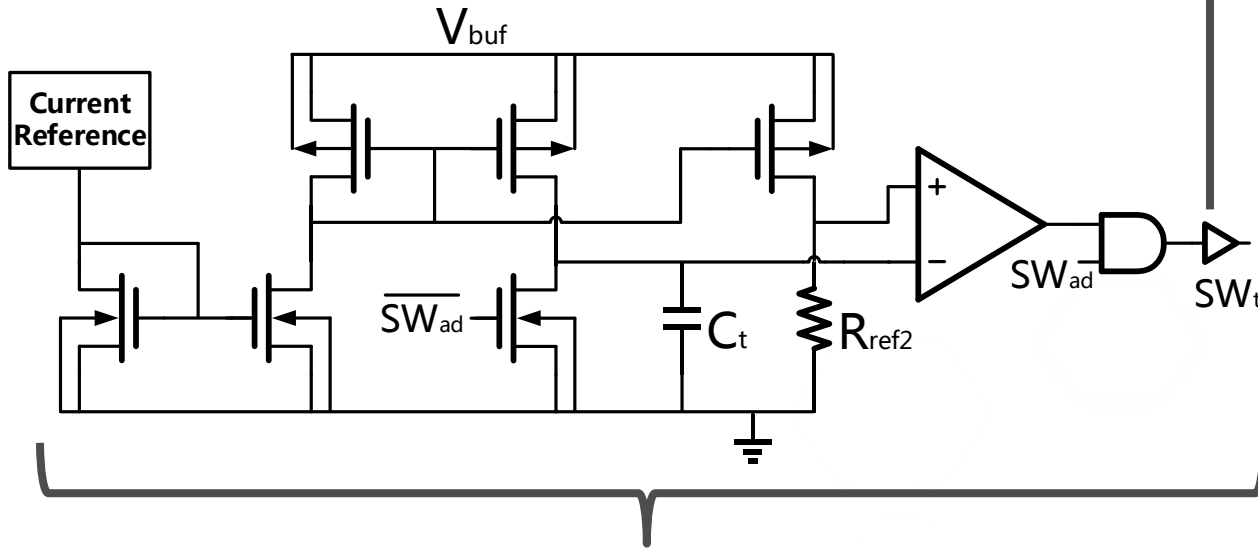


External resistors to adjust max power point



Circuits Implementation

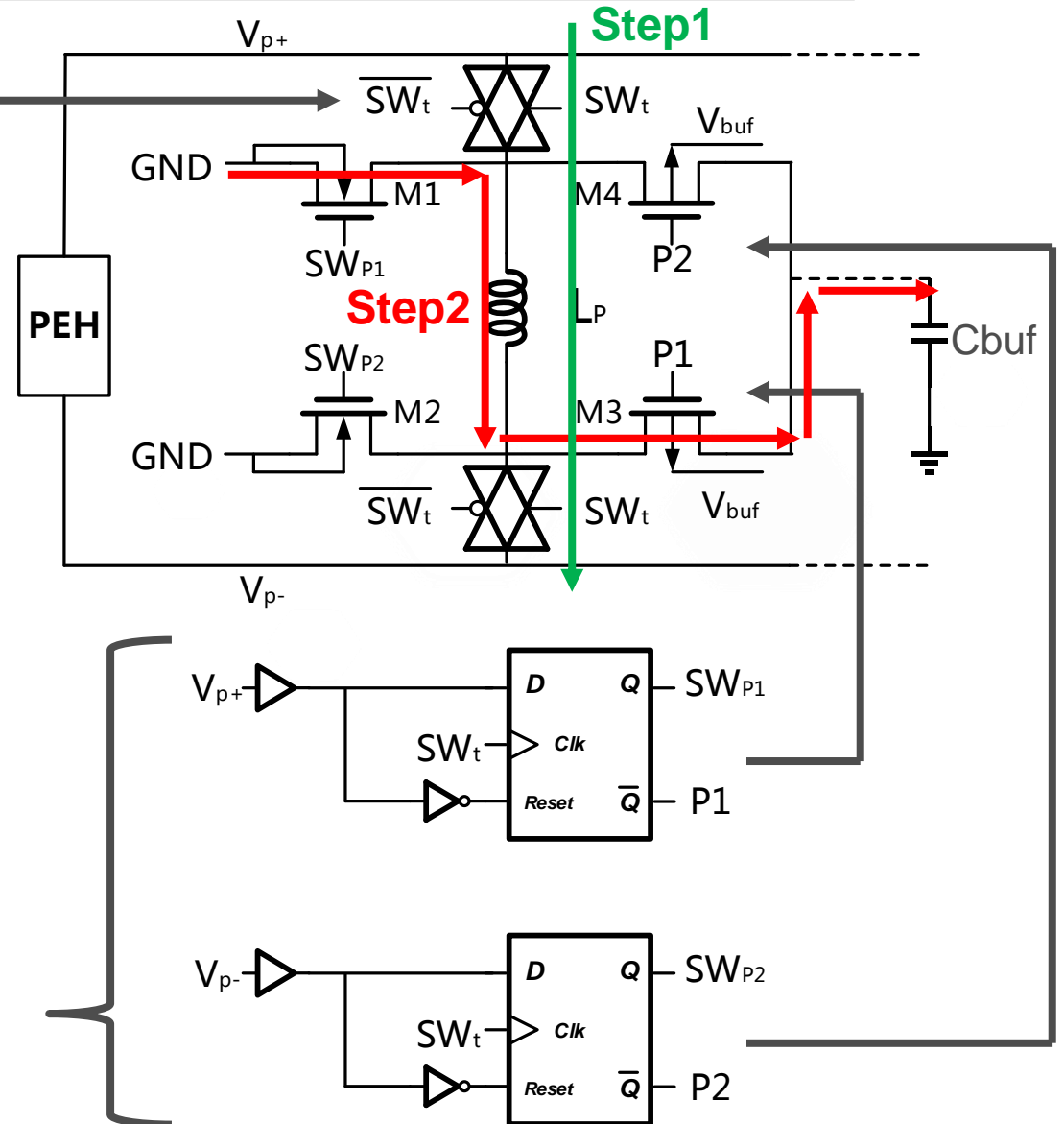
B. Charge Transfer Logic Circuit (CTL)



Step1. The charge switch control circuit is running. It charges the inductor in the flipping time by controlling the transmission gate.

Step2. The transmission gate is open. The discharge switch control circuit is running. It transfers the charge stored in L_P to the output capacitor C_{buf} .

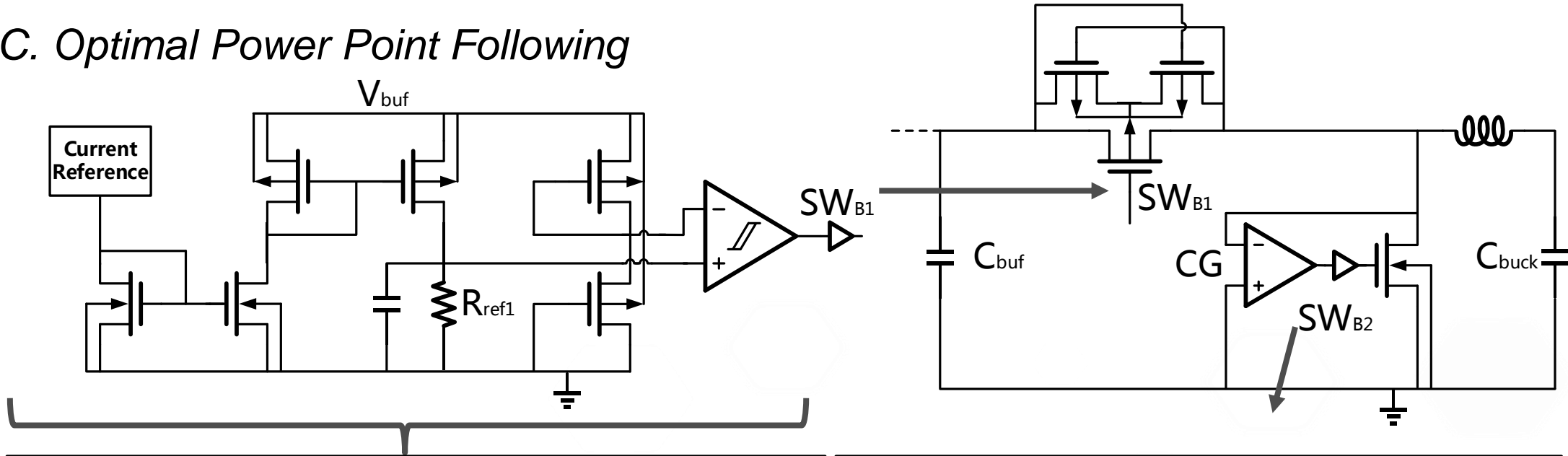
* The red line and green line are the current paths.





Circuits Implementation

C. Optimal Power Point Following



Step1. Its role is to maintain the V_{buf} at the voltage of optimal power point ($V_{buf,op}$). $V_{buf,op}$ is calculated using the **harmonic balance method**

Step2. It is used to control the switch SW_{B2} , so that the reverse current is released to form a new current path to prevent the output voltage from falling.

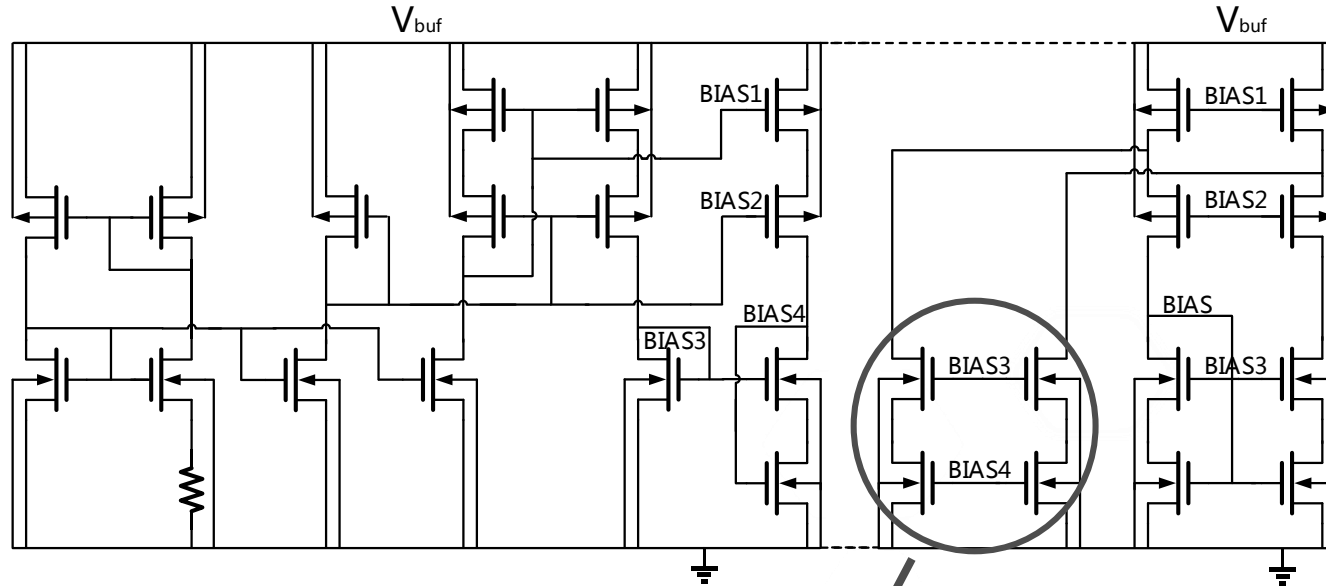
harmonic balance method: This theory describes the mathematical relationship between the vibration input source and the optimal power point.

$$V_{buf,op} = \frac{\pi V_M}{8 \left(1 - \frac{\pi^2}{4} (1 - \eta_F) f C_P \right)}$$

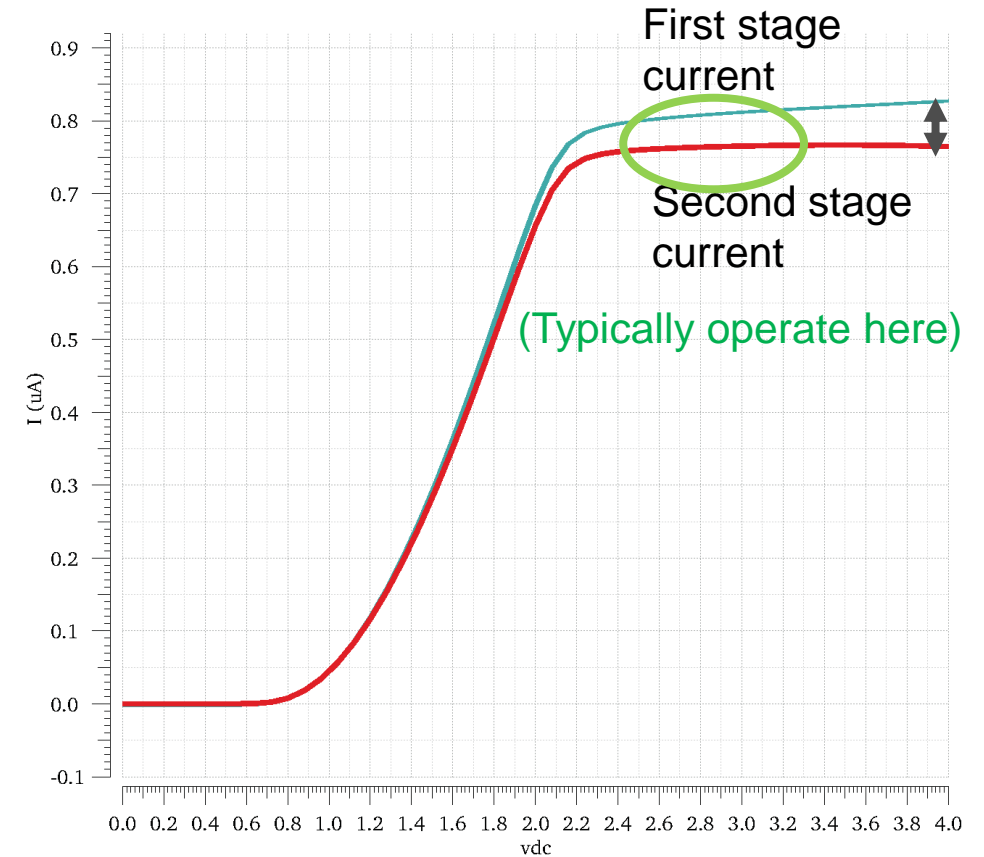


Circuits Implementation

D. High-precision Current Reference



The differential current of the first stage bias current and the desired high-precision current is diverted to the BIAS3 and BIAS4 branches.



Simulation waveform of first stage bias current (green, above) and desired high-precision current (red, below).

Needed to generate high precision V into CTL circuit to optimise operating point and minimise flip losses

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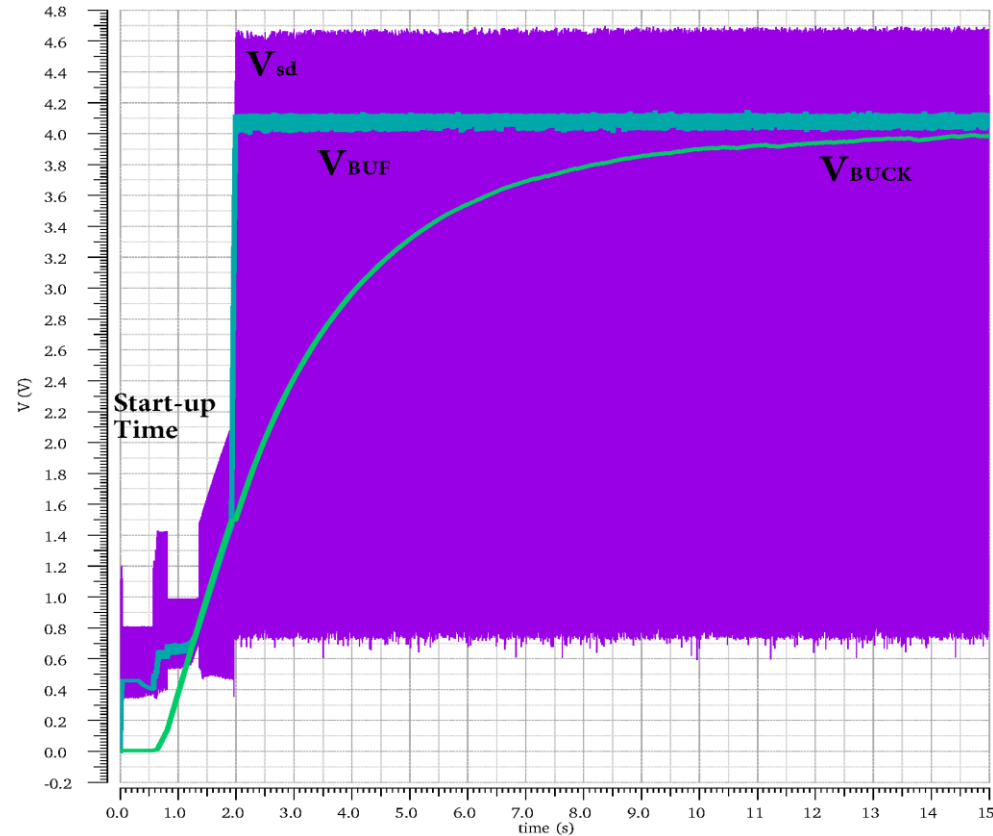
3 . *Circuits Implementation*

4 . *Simulation Results*

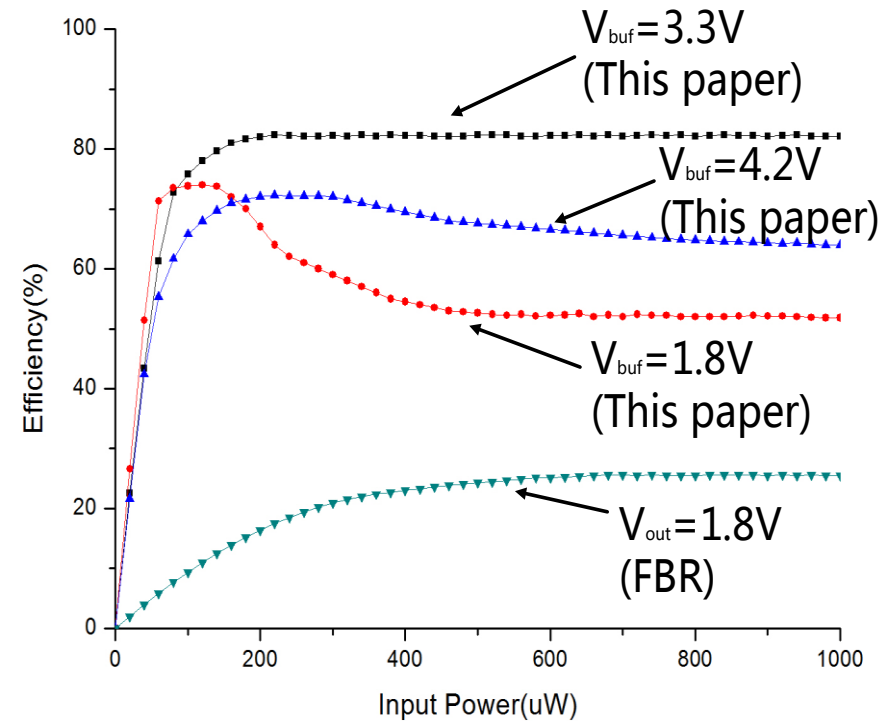
5 . *Conclusion*



Simulation Results



Simulation waveform of system. The PEH model parameters were set up: $R_M = 64.1k\Omega$, $C_M = 58.6pF$, $L_M = 8.2kH$, $C_P = 20nF$. V_{buf} reached 4.1V at stable time.



Efficiency waveforms for different V_{buf} peak efficiency can reach 83.2% in 3.3V (this paper).

Typically operated a few volts up to 5V max

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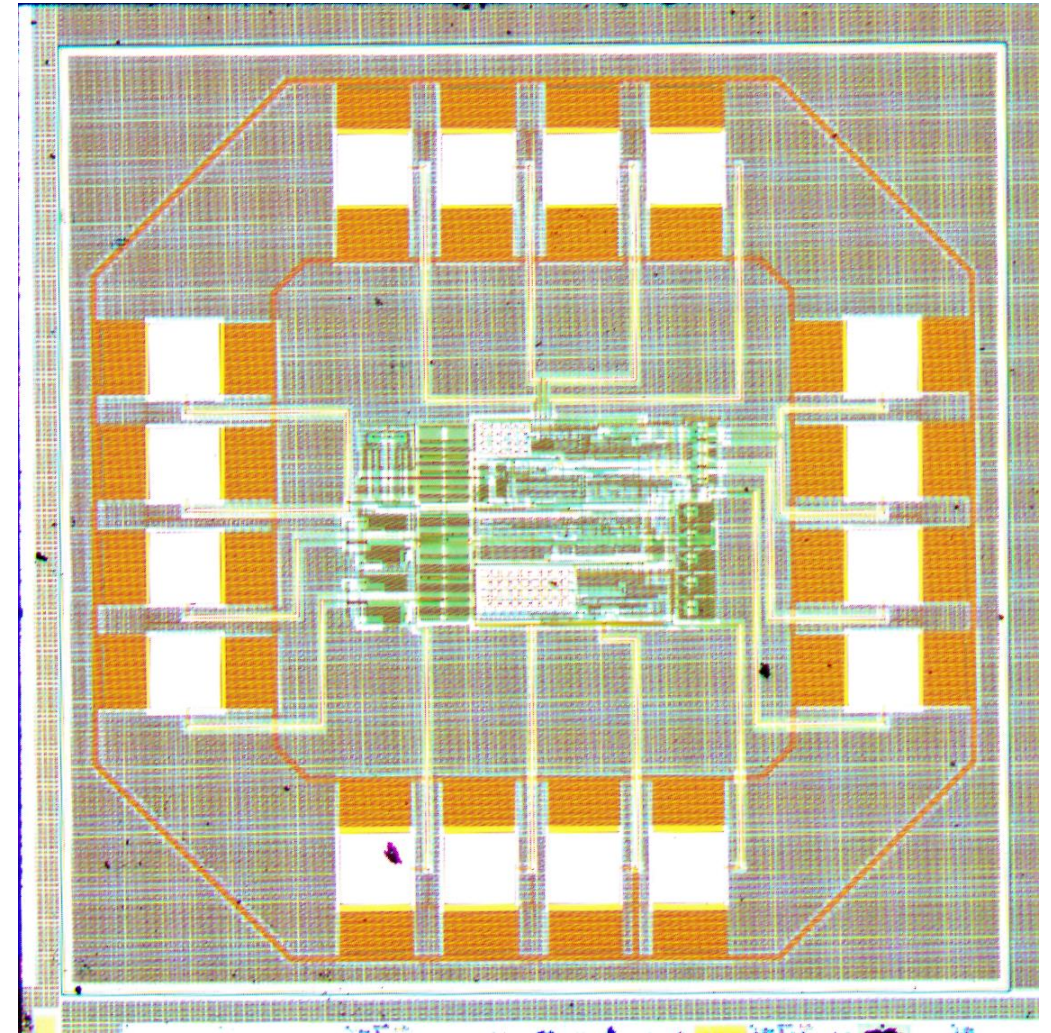
4 . *Simulation Results*

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Conclusion

- A system using a parallel-SSHI interface with power management has been designed and fabricated in a 0.18- μm CMOS process.
- Through the OPP, this system can be operated in the most efficient state.
- The CTL module uses a **small scale logic circuit** to achieve charge transfer.
- High-precision current reference enables the external load to provide **a more stable reference voltage and improve system flexibility**.
- Compared with the low efficiency of FBR structure, the **peak efficiency can reach 83.2%** in this paper.



Die micrograph



Contact Info:

wensi.wang@bjut.edu.cn