Improved Nagata Current Source Insensitive to Temperature and Power Supply Voltage


Gunma University
ASO Corp.
Outline

- Research Background and Objective
- Original Nagata Current Source
- Improvement to Supply Voltage Insensitivity
- Improvement to Temperature Insensitivity
- Simulation Verification
- Conclusion
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Research Background

Analog ICs require

**Reference current / voltage source**

Stable against PVT variation

P: Process  
V: Supply voltage  
T: Temperature

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**Bandgap reference circuit**

- Complicated
- Large chip area

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**Nagata current source**

- Simple, No start-up circuit
- Insensitive to supply voltage
Research Objective

Improvement of Nagata current source insensitive to temperature as well as supply voltage

Graph showing $I_{OUT}$ versus $V_{DD}$ with an indication of temperature change.
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**Original Nagata Current Source**

Nagata current source


**Simple** \[\rightarrow\] **Widely used.** Ex: in DC-DC converter IC

At peak vicinity

Small $I_{OUT}$ change against $V_{DD}$ change
Reason for having a peak (1)

\[ I_{IN} : \text{small} \]

\[ R I_{IN} : \text{small} \]

\[ I_{IN} = I_{OUT} \]
Reason for having a peak (2)

\[ I_{IN}: \text{large} \]
\[ R I_{IN}: \text{large} \]
\[ V_{GS2} \text{ becomes smaller} \]
Improvement to Widen Flat Range

Point
Peak vicinity is narrow → Wider

Our Approach
Use multiple current peaks and their sum.
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Using multiple current peaks and their sum

Measurements of Supply Voltage Sensitivity

Total output current is constant against $V_{DD}$ variation

Measurements of Temperature Sensitivity

Use Hair dryer

Problem!

Need for improvement
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MOSFET Temperature Characteristics

Utilize for temperature-insensitive reference current source
Proposed Reference Current Source

Use multiple Nagata current mirrors with appropriately designed parameter values

Output a constant current insensitive to temperature and power supply voltage

Use as a reference current source
Comparison

Insensitive to supply voltage as well as supply voltage

Careful design of W/L, R values

Basically, the same circuit topology
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SPICE Simulation Circuit

W/L, R values are designed to make $I_{OUT}$ temperature-, supply voltage-insensitive.

**LTspice**
TSMC 0.18μm MOS model
Total output current is constant over wide range of supply voltage
Simulation Result for Temperature

Insensitive to temperature!
Analysis: M2 drain current

Negative temperature characteristics
Analysis: **M3 drain current**

$\text{Analysis: M3 drain current}$

$V_{DD}$

$\text{Negative temperature characteristics}$
Analysis: **M4 drain current**

**Positive temperature characteristics**
Analysis: **M5 drain current**

**Positive temperature characteristics**
Reason for Temperature Insensitivity

Negative temperature characteristics

Positive temperature characteristics

Cancel temperature characteristics
Resistor Temperature Coefficient

Temperature coefficient of resistors can be positive or negative.

W/L, R values can be designed to make $I_{OUT}$ temperature-, supply voltage-insensitive.

Big advantage of our circuit
Point of Our Temperature Compensation

**Conventional circuit**

- Rely on **positive** temperature coefficient of R

**Proposed circuit**

- Can be **positive**, **negative**, or **zero**

Diagram:

```
     VDD
       |
       I_IN
       |
       R
       |
       |
       a
       |
       |
       |
       b
       |
M1      |
       |
       |
VGS1    |
       |
       |
       |
       |
       |
       |
M2      |
       |
       |
VGS2    |
```
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Conclusion

- Proposal of MOS reference current sources
- Temperature insensitivity has been improved.
- Comparison

<table>
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<tr>
<th>Circuit</th>
<th>Current constant range</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original Nagata current source</td>
<td>Fair</td>
<td>Fair</td>
</tr>
<tr>
<td>Previously improved circuit</td>
<td>Excellent</td>
<td>Fair</td>
</tr>
<tr>
<td>Proposed circuit today</td>
<td>Excellent</td>
<td>Good</td>
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