ISO6.4: The Past, Present, and Future of Current Sensing

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Presentation Outline

The task of sensing current
Existing methods of current sensing and their benefits and challenges:
• Shunt resistors
• Current sense transformers
• Hall-effect
• AMR

New proposed method- Integrated “GaNSense”
Impacts of optimized sensing and where it could go next
The task of sensing voltage and current

- Voltage and current are critical signals required to operate and control electronic systems.
- Voltage can be sensed as high impedance *without* "disturbing" the system.
- Current sensing often requires breaking the circuit design to insert an additional current sense element.
Power Converters: To control you must sense

What component doesn’t belong here if we are trying to design a **high-efficiency** power converter?
Motor Drives: To control you must sense

What components do NOT belong here if we are trying to design a **high-efficiency** motor drive?
Sensing current with shunt resistors

**Benefits:** Accurate, can sense low-value currents, can sense DC currents

**Drawbacks:**
- Lossy - adding shunt loss element only to create voltage representation of current. Creates thermal challenges. Added source inductance slows turn on/off of switching elements. Tradeoff of accuracy vs. efficiency.
- Complicated - requires additional components, could require isolation, careful design. Can’t easily sense bi-directional current.
- Slow - need to sense, condition signal, convert to digital, process, convert back to analog, act in some cases
- Large, expensive current shunts are needed. May require dedicated bias supplies and additional ICs.
Sensing with current-sense transformers (CTs)

**Benefits:** Already isolated; can be used for high-side or low side sensing easily, lower power loss for high-current sensing, achieves signal gain with simple turns-ratio, no dedicated bias supply needed, naturally senses bi-directional current

**Drawbacks:**
- Can’t sense DC current
- Duty-cycle limitations to prevent transformer saturation
- Large components; usually toroids
Sensing current with Hall-effect sensors

**Benefits:** Nearly "lossless", can measure DC currents

**Drawbacks:**
- Inaccurate at low current values. Sometimes requires zero-current offset design
- Distorted by external magnetic fields or specific mechanical orientations
- Requires dedicated hall sensor ICs and bias supplies and supporting circuitry
- Usually accurate for only a narrow current range of interest
- Relatively low bandwidth (<100 kHz)
- Comparatively more $ than previous solutions listed
Anisotropic Magneto-Resistive (AMR) Sensing

**Benefits:** High Bandwidth (1.5MHz+), can measure AC and DC signals, small, resistant to external fields and noise, low offset error

**Drawbacks:**
- Dedicated IC required
- Bias supply needed
- New technology, limited vendors
- Comparatively more $ than previous solutions listed

*courtesy of Aceinna*
The future of current sensing and the power electronics building block

- Integrated “lossless current sensing” built in with the power FET device
- Removes shunt current resistor, hotspot, and parasitic inductance in FET source path
- Removes extra resistance, increases efficiency (Ex. +0.5% for 65 W QR Flyback)
- Localized and accurate; immune to noise/fields/ground-bounce
- Adjustable current limit through external $R_{SET}$ outside power path
- Doesn’t require any additional components or ICs or dedicated bias power
Proven technique reimagined: Current-Mirror

Benefits:

• Small “current-mirror” built in parallel monolithically with main power GaN FET, so-called “GaNSense”
• Negligible size/cost adder
• Well-matched devices. $R_{DS(ON)}$ and temperature effects cancelled out naturally
• Sensing “mirror” FET $R_{DS(ON)} \sim 1000-1500$ times larger than main power FET. Negligible power loss.
• $I_{SENSE}$ then becomes ratio of $I_{SOURCE}$ based on $R_{DS(ON)}$. 
Higher Efficiency and less heat

Efficiency (60W HFQR, 20V/3A)

- NV6125
  - $R_{DS(ON)} = 170 \text{ m}\Omega$
  - $R_{CS} = 170 \text{ m}\Omega$
  - $R_{ON(TOT)} = 340 \text{ m}\Omega$

- NV6136
  - $R_{DS(ON)} = 170 \text{ m}\Omega$
  - $R_{CS} = 0 \text{ m}\Omega$
  - $R_{ON(TOT)} = 170 \text{ m}\Omega$

Efficiency $+0.5\%$

- $R_{CS}$ HOT-SPOT $= 85^\circ\text{C}$!
- NO HOT-SPOT
- $T_{GaN}$ 10$^\circ\text{C}$ Cooler
Higher reliability and speed

Benefits:

• Localized sense+protection; higher reliability
• Faster; capable to operate at higher frequency
# Comparison of current sensing methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Bandwidth</th>
<th>Response time</th>
<th>Accuracy</th>
<th>Requires bias supply</th>
<th>Current Range</th>
<th>Power Loss</th>
<th>Relative Size</th>
<th>Sensing cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shunt Resistor + OpAmp</td>
<td>kHz-10 MHz</td>
<td>300 ns-1 ms</td>
<td>1-5%</td>
<td>Yes</td>
<td>mA-A</td>
<td>mW-W</td>
<td>Medium</td>
<td>$$</td>
</tr>
<tr>
<td>Current Transformer</td>
<td>60 Hz-1 MHz</td>
<td>300 ns-1 ms</td>
<td>3-5%</td>
<td>No</td>
<td>mA-kA</td>
<td>mW</td>
<td>Medium-Large</td>
<td>$$</td>
</tr>
<tr>
<td>Hall Effect</td>
<td>kHz-100 kHz</td>
<td>10 us-1 ms</td>
<td>5-10%</td>
<td>Yes</td>
<td>A-kA</td>
<td>mW</td>
<td>Large</td>
<td>$$$</td>
</tr>
<tr>
<td>AMR</td>
<td>Hz-1.5 MHz</td>
<td>&lt;300 ns</td>
<td>0.6%-3%</td>
<td>Yes</td>
<td>mA-A</td>
<td>&lt;40mW</td>
<td>Medium</td>
<td>$$$</td>
</tr>
<tr>
<td>GaNSense Lossless Current Sensing</td>
<td>Hz-8 MHz</td>
<td>30-100 ns</td>
<td>2%</td>
<td>No</td>
<td>mA-A</td>
<td>&lt;10mW</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Where to next in current sensing?

- Higher Levels of integration in 1-switch and 2-switch power converters and motor drives
- Pushing the limits of accuracy/bandwidth/robustness as demands for efficiency and power density continue to increase
- New circuit topologies with high performance WBG power switches demands new current sensing
Thank you for your interest.

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