Monolithic 4-20 mA Isolating Current Replicator Using GMR Resistors

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Outline

• Review of Isolation Methods
• Description of GMR Isolation Technique
• Characteristics of GMR Resistors
• Detailed Circuit Description
• Experimental Results
• Summary
Applications of Isolation Devices

• Long Distance Wired Communications
  – Analog
    • 4-20mA Current Loop (Instrumentation)
  – Digital
    • 4-20mA Current Loop (‘0’ ≤ 4 mA, ‘1’ ≥ 12 mA)
    • High Speed Networks (IEEE 802.3, 802.14,1394)

• Power Controllers

• Medical Instrumentation
Conventional Isolation Techniques

• Optical Isolator
  – Discrete Components
  – Nonlinear
  – Slow

• Transformer or Capacitor Coupling
  – Discrete or Multi-Chip
  – AC Only (modulator/demodulator for DC)
Magnetic Field Sensing Isolation with GMR Resistor

- Silicon Compatible
- High Speed (~1nsec.)
- Good Linearity
Giant-Magneto-Resistance Effect

\[ \rho \approx \rho_0 - \frac{\Delta \rho_{\text{max}}}{2} \cos \phi \]

(\(\phi\) is function of applied field)
Isolated Current Loop & GMR Resistors

Aluminum Coil

GMR Resistors

High Voltage Addition

2.5um Thick Si₃N₄

SiO₂

Standard Process

Si Substrate
GMR Resistance vs. Isolated Loop Current

$I_{loop}$  $R$

Operating Range

Resistence (Ohm)

Loop Current (mA)
Isolated GMR Current Replicator

- Typical Applications
  - Isolated 4 - 20 mA Receiver
  - Isolation Amp (with V to I)
  - Opto-isolator Equivalent

[Diagram showing GMR Current Sensor, Isolated Voltage Barrier, I_in, I_out, V_sense]
Complete Current Replicator

- **Amplifier Requirements**
  - High Gm
  - Limited CM Range
  - Limited Output Voltage Swing

- **GMR Linearity Requirements**
  - Reduced by Matching

- **Effect of Bridge Offset**
  - Input Current Offset
  - Small Nonlinearity
Amplifier Schematic

- Standard Bipolar Process
  - 4 µm Minimum Feature
  - 20 V $B_{v_{ceo}}$
- Hi Gm (~150 S @10 mA)
- CM Feedback
- Supply Independent Biasing
Die Photo

Amplifier  Feedback Loop  Input Loop

GMR Resistors
Current Ramp Response

Output: 5 mA/div

Input: 5 mA/div

20 µs/div
Isolator Transfer Characteristic

![Graph showing the relationship between input current and output current with % nonlinearity relative to full scale.](image)

- **Input Current (mA):** 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22
- **Output Current (mA):** 0 to 25
- **% Nonlinearity Relative to F.S.:** -1 to 1
Step Response

Output: 5 mA/div

Input: 5 mA/div

1 μs/div
CMR Performance

$(I_{in} = 10 \text{ mA DC})$

Output: 100 $\mu$A/div

Input: 20 V/div

2 ms/div
## Isolator Characteristics Summary

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
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<tbody>
<tr>
<td>Power Dissipation (I_{out} = 4 mA)</td>
<td>53 mW</td>
</tr>
<tr>
<td>Error from best-fit line after single point offset trim (4-20 mA range)</td>
<td>&lt; .5 % of full scale</td>
</tr>
<tr>
<td>Untrimmed Equiv. Offset</td>
<td>5 mA</td>
</tr>
<tr>
<td>- 3 dB Bandwidth</td>
<td>DC - 400 kHz</td>
</tr>
<tr>
<td>Maximum Slew Rate (100 Ω Load)</td>
<td>20 mA/usec.</td>
</tr>
<tr>
<td>± 10 mA Settling Time (.1%)</td>
<td>&lt; 2 µsec.</td>
</tr>
<tr>
<td>Equiv. Input &amp; Output Noise</td>
<td>7.4 µA_{rms} (BW =1MHz)</td>
</tr>
<tr>
<td>Isolation Voltage (8 pin DIP)</td>
<td>&gt; 1500 Volts</td>
</tr>
<tr>
<td>Die Size</td>
<td>.72 x 1.5 mm</td>
</tr>
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Summary

• Monolithic Si Compatible Isolation Method
  – Simple GMR & Si$_3$N$_4$ Addition to Standard Process
  – May be Used with Multiple Isolated Inputs

• 4-20 mA Isolating Replicator Demonstrated
  – 4 µm Standard Linear Bipolar Process
  – > 1500 V Isolation (8 pin DIP)
GMR Bridge Characteristics

Loop A Current

5V

Loop B Current

Bridge Output vs Loop Currents

Bridge Output (mV)

0 5 10 15 20

Loop A Current (mA)

Loop B Current (mA)

0 5 10 15 20