5.1 Fully Integrated Isolated DC-to-DC Converter and Half Bridge Gate Driver with Integral Power Supply

1st International Workshop on Power Supply on Chip
Cork, Ireland

Baoxing Chen
Analog Devices, Inc.
804 Woburn St.
Wilmington, MA 01887
Outline

- Integrated Signal and Power Isolation Needs
- Power Converter Architecture
- Transformer Structure
- Converter Performance
- Half Bridge Gate Driver Architecture
- Summary
Isolation Applications

PLC
I/O and Communication

Power Supply

Instrumentation
Data Acquisition and Communication

Motor Control
Sensing and Gate Drive

Patient Monitoring
To/From Patient

Plasma TV
## Integrated Isolated Power Transfer Needs

- **Miniaturized, isolated dc-to-dc converter**
- **High frequency energy conversion with low frequency energy regulation**
- **Energy conversion optimized while regulation maintained through wide input and load ranges**

---

**Power Isolation**

**Signal Isolation**

- **SENSORS**
- **ACTUATORS**
- **SWITCHES**
- **COMMUNICATIONS**

- **CONTROLLERS**
- **PROCESSORS**
- **DISPLAYS**
- **USER INTERFACES**
Signal Transmission Operational Diagram

1. **Detect Data Edges**
2. **Encode as Pulses**
3. **Transfer Through Transformer**
4. **Decode Pulses**
5. **Reconstruct Data**

- **Rising Edge**
- **Falling Edge**
- **CMOS Top Metal**
- **Insulation**
DC-to-DC Converter Architecture
$V_1 = V_{DD} + V_1 \cos(\omega t)$.

Region I: $V_1 < V_t/2$ both saturated.
Region II: $V_t/2 < V_1 < V_{DD}$ one linear, and one saturated.
Region III: $V_{DD} - V_t < V_1$, one linear, and the other will be off.

We want region III! Power delivered to load, not MN1/MN2!!!
Transformer-Coupled Resonator

\[ \omega_{1,2}^{2 \text{ Transf}} = \frac{-(L_1C_1 + L_2C_2) \pm \sqrt{(L_2C_2 + L_1C_1)^2 + 4C_1C_2(M^2 - L_1L_2)}}{2C_1C_2(M^2 - L_1L_2)} \]

\[ \omega_1^{2 \text{ Transf}} = \frac{1}{(L + M)C} \quad \omega_2^{2 \text{ Transf}} = \frac{1}{(L - M)C} \]

\[ Z_{in}(\omega_1)_{\text{ Transf}} \approx \frac{L + M}{2rC} \quad Z_{in}(\omega_2)_{\text{ Transf}} \approx \frac{L - M}{2rC} \]

High Q Resonance

Low Q Resonance
Converter Stability

Modified PI Controller (K Factor Type II)

\[ G_c = k \frac{1 + s\tau}{s\tau} \frac{1}{1 + s\tau_p} \]

\[ k = \frac{R_2C_2}{R_1(C_1 + C_2)} \]

\[ \tau = R_2C_2 \]

\[ \tau_p = \frac{R_2C_1C_2}{C_1 + C_2} \]
Power Transformer Radiation Minimized Through Antiphase Center Tap

PCB Radiation Dominant-PCB Techniques Available
Transformer Structures

- **Primary**: Two Coils Connected in Center-Tapped
  - \( L = 8 \text{ nH}, \ R = 0.8 \ \Omega, \ Cs = 0.38 \ \text{pF}, \ Q = 19 \) at 300 MHz
  - Radius = 460 \( \mu \text{m} \), Turns = 3, Width = 60 \( \mu \text{m} \), Space = 7 \( \mu \text{m} \)

- **Secondary** (1:1 for 5 V output): Two Coils Connected in Center-Tapped
  - \( L = 8 \text{ nH}, \ R = 0.8 \ \Omega, \ Cs = 1.2 \ \text{pF}, \ Q = 13 \) at 300 MHz
  - Radius = 460 \( \mu \text{m} \), Turns = 3, Width = 60 \( \mu \text{m} \), Space = 7 \( \mu \text{m} \)

> 6 kV rms ISOLATION
Converter Waveforms

Ch. 1 is the 450 kHz PWM signal.
Ch. 2 is the input supply.
Ch. 3 is the isolated supply output.

ZOOM-IN

340 MHz Noise => 170 MHz Tank
Converter Performance: Saving Power Compared to Discrete Solution

Est. Total Power: 220 mW
Supply @ 20 mA Load: 205 mW
iCoupler Data: 15 mW

Est. Total Power: 490 mW
Supply @ 20 mA Load: 275 mW
Optocoupler Data: 220 mW
Isolated Gate Drive Integration Needs

Size Reduction, Ease of Use, and Elimination of Duty-Cycle Limitation
Half-Bridge Gate Driver Architecture

160MHz TANK

$V_{DD} = 5V$

$V_{DD} = 5V$

$GND$

$V_{OA}$

$V_{OB}$

$V_{ISO} = 15V$

$GND_A$

$V_B = 15V$

$GND_B$

$V_{IA}$

$V_{IB}$

PWM
500 mW DC-to-DC Converter and Half-Bridge Gate Driver in 16-Lead SOIC

4-Channel Isolation Integrated
Summary

- 500 mW, 33% efficient integrated isolated DC-to-DC converter architecture was reviewed.
- The integrated signal and power integration provide possibilities for total isolated system integration; reduces total system cost and complexity.

Acknowledgement of contribution and assistance from ADI iCoupler group members