ARIES: Using Annular-Ring Embedded Resistors to Set Capacitor ESR in Power Distribution Networks

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Outline

• Introduction
• Distributed Matched Bypassing
• Annular Buried Resistor
• ARIES
• Test board performance
• Implementation
• Conclusions
Dictionary

- DMB = Distributed \textit{M}atched \textit{B}ypassing
- ABR = \textit{A}nnular \textit{B}uried \textit{R}esistor
- ARIES = Annular \textit{R}esistive \textit{I}nterstitial \textit{E}lement, \textit{S}creened-in
Distributed Matched Bypassing (1)

\[ R_1 = R_2 = \sqrt{\frac{L_2}{C_1}} \]

\[ \log Z \]

\[ \log f \]

\[ (\omega C_1)^{-1} \]

\[ \omega L_2 \]

\[ f_{23} \]

\[ f_{12} \]

power source

first capacitor bank

second capacitor bank

DET

EAVP

AVP

St. Cyr, Novak, Biunno, Howard

EPEP, October 2001
Distributed Matched Bypassing (2)

- Elements:
  - Power-ground planes over (thin) laminate
  - A small number of \textit{SAME VALUE} capacitors (2.2UF IDC)
  - Few bulk capacitors
- Controlled-ESR capacitors
- Smooth impedance profile
- Suppresses plane resonances, and
- Avoids antiresonances among
  - Capacitors, and
  - Capacitors and planes
Distributed Matched Bypassing (3)

- **Conventional** designs use C, ESR and ESL. Resonances depend on all three:
  - Hard to simulate all combinations
  - ESR for present capacitors cannot be specified

- **DMB** relies on a user-defined series resistance (ABR) of bypass capacitors:
  - Lowest number of capacitors
  - Straightforward positioning
  - C and ESL variations matter much less
  - Fewer combinations -> more predictable result
  - Components are equal -> increased reliability

>> shared dissipation
ABR
Annular Buried Resistor
ARIES
Annular Resistive Interstitial Element, Screened-in

Eight-terminal capacitor

- Blind vias
- 130-180pH loop inductance

Top metal layer
GND layer
PWR layer

Printed resistors
Test Board

- 10”x5” outline
- 2 pairs of 2-mil cores
- 1” square grid test points (PTH)
- Offset 1” square grid for ARIES
Test Board Impedance Log-Log

Impedance magnitude [ohm]

- No-R
- With-R
- Bare

Self impedance
2”x2” from corner
Test Board Impedance Lin-Lin

Impedance magnitude [ohm]

Self impedance
2”x2” from corner
Implementation

<table>
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<tr>
<th>number of caps</th>
<th>304</th>
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<td>caps area [sq inch]</td>
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Conclusions

• Smooth, optimum impedance profile is achieved by DMB (AVP, EAVP, DET)
• DMB requires user-defined ESR
• ABR is used to add series resistance to (ceramic) capacitors
• ARIES implementation:
  • 130-180pH ESL
  • 1-1000MHz coverage
Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 100kHz

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Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 150kHz

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Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 200kHz
Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 300kHz

Istvan Novak, October 2001
Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 500kHz

Istvan Novak, October 2001
Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 750kHz
Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 1MHz
Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2μF capacitors with 0.72-ohm ARIES at 1.5MHz

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Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 2MHz

Istvan Novak, October 2001
Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 3MHz

Istvan Novak, October 2001
Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 5MHz

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Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 7.5MHz
Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 10MHz

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Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 15MHz

Istvan Novak, October 2001
Impedance profile in ohms of 10\"x5\" 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 20MHz

Istvan Novak, October 2001
Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 30MHz
Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 50MHz

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Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 75MHz

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Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 100MHz
Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 150MHz.
Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 200MHz
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Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 500MHz
Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 750MHz

Istvan Novak, October 2001
Impedance profile in ohms of 10”x5” 2x2-mil plane pairs with 26x2.2uF capacitors with 0.72-ohm ARIES at 1000MHz