Balanced Amplifier in Package on Board

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Introduction

Demonstrate MMIC Balanced Amplifier design flow
• Linear and Non-Linear Design
• Amplifier incorporated into package
• System in packages and board

Evaluate System performance
• Non-linear circuit evaluation of Amplifiers
• Linear evaluation of Hybrid combiners
• Electromagnetic evaluation of packages on board
• Co-simulation of entire system
Agenda

Design Environment
• Design Technology and Management
• Designer Links
• HFSS – Solver on Demand

System details
• Balanced Amplifier overview
• MMIC Amplifier design
• Hybrid design

System on board design
• Amplifier in Package
• Entire design on board
Overview: Chip in Package
Overview: Package to Board
Design Environment
Ansoft Designer Overview

Design Technology

• Circuit & System Analysis
  – Time and Frequency Domain
• Electromagnetic Analysis
• Solver on Demand
  – HFSS, PlanarEM, Nexxim and HSPICE

Design Management

• Hierarchical Schematic and Layout (2D/3D)
• Design Exploration
  – Parameterization, Optimization, Sensitivity & Statistical
• Bi-directional Links to Field Solvers
  – HFSS, PlanarEM, SIwave, Q3D, 2D Extractor
• 3rd Party Links for Models and Geometry

High Performance Computing (Multi-core/GPU)
Ansoft Designer User Interface

- Design Management
- Design Entry
- Layout
- Post-Processing
- Simulation Management
- Property Management
Designer Links

Links for Cadence Allegro/APD/Virtuoso
• Run from either Cadence or Designer (Allegro/APD)
• Design cutouts and wirebonds for critical nets
• Tightly couples ECAD, Circuits and HFSS

Links for ODB++
• Common PCB Manufacturing format
• Translation path for Mentor, Zuken, Cadence, Altium, ...
Ansoft Designer HFSS - Solver on Demand

HFSS - Solver on Demand
• Intuitive PCB design entry alternative for HFSS
• Chips, packages, channels, modules, ...
• HFSS / PlanarEM engine selection at runtime

3D Full-wave FEM Technology
• Designer layouts simulated with HFSS
  – Boundaries handled automatically
  – Excitations with a mouse click
  – Finite dielectrics and ground supported

• Terminal Excitations (Wave and Lumped Gap Port)
  – Single ended and Differential
  – Vertical and Horizontal
  – Coaxial, CPW and Grounded CPW
System Design Details
What is a Balanced Amplifier?

- Two nearly identical amplifiers in parallel
- Amplifiers between two 90° hybrids
  - Reflections cancel at I/O ports through hybrid
Balanced Amplifier

Why used a Balanced Amplifier?

- Amplifiers optimized without concern of loading
  - Noise Figure, Flatness, etc.
- Linear range and Max power increase by 3dB
- Reflections absorbed by loads at isolation ports

\[
\frac{V_{\Gamma}}{2} \angle 0^\circ + \frac{V_{\Gamma}}{2} \angle 180^\circ = 0
\]

\[
\frac{VG}{\sqrt{2}} \angle 0^\circ
\]

\[
VG \angle 90^\circ
\]
Balanced Configuration Operation

\[ A \leq 0^\circ \]

\[ \frac{A}{\sqrt{2}} \]

\[ A \leq \theta - \phi \]

\[ \frac{A}{\sqrt{2}} \]

\[ \theta - 90^\circ \]

\[ \frac{A}{\sqrt{2}} \]

\[ \theta \leq 90^\circ \]

\[ \frac{A}{\sqrt{2}} \]

\[ \theta - 90^\circ \]

\[ \frac{A}{\sqrt{2}} \]

\[ \theta \leq \phi \]

\[ \frac{A}{\sqrt{2}} \]

\[ \phi - 90^\circ \]

\[ \frac{A}{\sqrt{2}} \]

\[ \theta - 90^\circ \]

\[ \frac{A}{\sqrt{2}} \]

\[ \theta \leq \phi \]

\[ \frac{A}{\sqrt{2}} \]

\[ \theta - 90^\circ \]
Design Description

- Balanced Amplifier
  - Combine two MMIC Amplifiers in parallel
  - Incorporate amplifiers in separate packages
  - Combine Amplifiers and 90° Hybrids on board
  - Include on-board biasing for amplifiers
MMIC Amplifier Design
MMIC Amplifier Details

Power Amplifier

- Modeled in Designer with UMS design kit
  - UMS pHEMT Process
- 10GHz center frequency
- Multiple Gain stages for increased output
  - Wilkinson dividers to distribute power
  - Compression determined by final stage
  - Linear region and compression level increased
- Reactive matching
- Transmission line sections designed for 10GHz
Amplifier Schematic

• Three Gain stages separated by Wilkinson dividers
Amplifier Response

- Three amplification stages produce 22dB of gain
- Input compression point around 11dBm

Gain = 22dB

F = 10GHz

Power = 30dBm
P1dB = 11dBm
Amplifier Layout
Branchline Hybrid Design
90° Hybrid Design Overview

- Hybrid Applications
- Power Splitter / Combiner
  - Load on one of the input / output ports, respectively
- Sum and Difference outputs
  - Two inputs to hybrid

- 90° Hybrid Features
- Power Splitter
  - Second input port is terminated
  - Quarter wavelength lines
    - Series lines have lower imedance
  - Output ports are 90° out of phase with each other

\[ Z = Z_0 / \sqrt{2} \]
\[ L = \frac{\lambda}{4} \]
90° Hybrid Design Overview

- Physical Modeling
- Implement with transmission lines
- Conserve space by bending series lines
- Parameterize lengths and widths
- Analyze electromagnetically to account for all effects
- Optimize and Tune to 10GHz
**90° Hybrid Design Overview**

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90° Hybrid Design Setup

- Hybrid Parameterization
- Wavelength, width and feed length

- HFSS – Solver on Demand
- HFSS analysis directly in Designer
- View mesh, airbox and parameterization
Hybrid Parameterized Analysis

- **Build Model from parametric solutions**
  - Coarse sweep over each parameter
  - Distributed solve for speed up

- **Circuit Model of HFSS solution**
  - Circuit simulation interpolates solution space
  - EM accuracy at circuit speeds
Hybrid Real Time EM Tuning

- Solved Parametrically
- Tuned in real time

Lambda/4 = 144mil
W35 = 6.7mil
Larm = 125mil

Curve Info
- dB(S(Port1,Port1))
- dB(S(Port1,Port2))
- dB(S(Port1,Port3))
- dB(S(Port1,Port4))

Lambda4='144mil' Larm='125mil' W35='6.7mil'

Test Hybrid Tuned Response
Include Package Transition Effects

• Additional effects
  • Wirebonds
  • Vias
  • Transitions
  • Package
• Include "partial package" in hybrid analysis
  • Vary arm lengths to tune hybrids
Package & Transition Parametric Sweep

- Parametric Analysis

![Setup Sweep Analysis screenshot](image)
Dual Hybrid Testing

• Check parallel operation
  • Validate balanced amp configuration
  • Amplifiers added in at final testing
  • Tune parametric model

• Demonstrates
  • Insertion and Return Loss
  • Isolation functionality
  • Design Integrity
Dual Hybrid

• “Design in Design” feature
  • Paste EM Designs into other EM Designs
  • Unlimited Hierarchy
  • Solve “full” model
  • Sub-Designs are fully parameterizable

Other Geometries
Dual Hybrid Electromagnetic Results

RF In

Iso

RF Out

S-Parameters Plot

F [GHz]
Via Transition
MMIC Amplifiers in Packages on Board
Chip in Package on Board

- **MMIC Amplifier in Package**
  - MMIC Chips in QFN Package
  - 2 packaged amplifiers on FR-4 multi-layered board
  - Multiple wire bonds and vias in package

- **Balanced Amplifier on Board**
  - Multiple SMT Components for bias
  - Branchline 90° hybrids in stripline layer
  - Vias, signal pads and interconnects

- **HFSS – Solver on Demand**
  - Board & package solved with HFSS in Designer
  - Combined with power amps and passives
Chip in Package on Board
Mesh View: HFSS in Designer

Without Bias For clarity
Mesh View: HFSS in Designer

With Bias
Chip in Package On Board: Schematic
Full Board and Package Layout
Full board Linear Performance

- System Gain very close to ideal: 21.9dB
Power Comparison

<table>
<thead>
<tr>
<th>Name</th>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>m1</td>
<td>13.0</td>
<td>30.5</td>
</tr>
<tr>
<td>m2</td>
<td>13.0</td>
<td>33.0</td>
</tr>
</tbody>
</table>

BLUE – Full Board
RED – Single Amplifier
Conclusion

- An integrated *Chip in Package on Board* Design flow has been presented
  - Balanced Amplifier
  - MMIC Amplifier
  - Branchline Hybrid

- Electromagnetics and Circuits combined for entire solution
  - Non-linear amplifier handled at circuit level
  - Hybrids, Packaging and Board handled with Electromagnetics
  - Designer Links automates geometry transfer and setup
  - HFSS – Solver on Demand integrates seamless with circuits

- Balanced Amplifier Benefits
  - Amplifier design optimized independent of loading effects
  - Increased linear dynamic range and maximum power