Mini-Circuits
MMIC Amplifier Design
Agenda

1. MMIC Amplifier Technologies
2. Mini-Circuits MMIC Amplifier Strategy
3. Circuit Architectures
4. Design-In Quality and Reliability
5. Design, Test and Qualification
6. Advanced Packaging Technology
7. Mini-Circuits MMIC Amplifiers
8. Q&A
# MMIC Amplifier Technologies

## Overview of Semiconductor Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Si</th>
<th>SiGe</th>
<th>SiC</th>
<th>GaAs</th>
<th>GaN</th>
<th>InP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron Mobility</td>
<td>900 – 1,100</td>
<td>&gt; 2,000</td>
<td>500 – 1,000</td>
<td>5,500 – 7,000</td>
<td>400 – 1,600</td>
<td>10,000 – 12,000</td>
</tr>
<tr>
<td>(cm$^2$/Vs)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak Drift Velocity</td>
<td>0.3 - 0.7</td>
<td>0.1 – 1.0</td>
<td>0.15 – 0.2</td>
<td>1.6 – 2.3</td>
<td>1.2 – 2.0</td>
<td>2.5 – 3.5</td>
</tr>
<tr>
<td>(10$^7$ cm/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band Gap (eV)</td>
<td>1.1</td>
<td>&lt;1.1</td>
<td>2.2</td>
<td>1.4</td>
<td>3.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Frequency Range</td>
<td>&lt; 40</td>
<td>10 - 40</td>
<td>15 - 20</td>
<td>&gt; 75</td>
<td>20 - 30</td>
<td>&gt; 115</td>
</tr>
<tr>
<td>(GHz)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gain</td>
<td>Moderate</td>
<td>Better</td>
<td>Lower</td>
<td>Higher</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Noise Figure</td>
<td>Moderate</td>
<td>Good</td>
<td>Poor</td>
<td>Good</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Production Maturity</td>
<td>12” wafer</td>
<td>8” wafer</td>
<td>4” wafer</td>
<td>6” wafer</td>
<td>4” wafer</td>
<td>2” wafer</td>
</tr>
</tbody>
</table>
Why GaAs?

- High Electron Mobility
  - enable high frequencies and fast switching performance

- Intrinsic GaAs is Semi-Insulating
  - ideal substrate for stripline and high Q passives

- Large Band Gap 1.4eV
  - enable higher power operation

- Radiation hardness
  - well accepted for both Space and military applications

- Mass production and commercially ready in 6” diameter wafer

- Widely accepted as the superior technology for the production of high frequency, high power and low noise products
Mini-Circuits MMIC Amplifier Strategies

**GaAs pHEMT**
0.5/0.25/0.15 μm
E-mode and D-mode

**Products:**
- Low Noise Amplifiers
- High Linearity Gain Block
- Distributed Amplifiers
- mmWave Power Amplifiers

**Features:**
- High transition frequency ($F_t$)
- Low noise up to mmWave
- E-mode (single supply)
- High linearity
- High power density
- Great power and efficiency
- Low standby current
- May operate as low as 1.2V

**GaAs InGaP HBT**
2μm / 1μm

**Products:**
- High Linearity Gain Block
- Power Amplifiers <6GHz

**Features:**
- High current gain
- High power density
- High linearity and efficiency (PAE)
- Single supply
- Consistent product performance
- Proven technology for gain block and medium power amplifiers
Circuit Architectures

Darlington

Features:
- High current gain (β)
- Superior IP3 bandwidth
- Flat gain
- Great impedance match

Applications:
- IF gain block
- Multi purpose driver amplifier
Circuit Architecture

Cascode

Features:
• Improves input-output isolation
• Reduces the Miller effect
• Wide bandwidth
• High gain
• High output impedance
• High supply voltage
• High IP3

Applications:
• Low noise amplifiers
Circuit Architecture

**Features:**
- Deliver broadband performance
- Good impedance match
- Flat gain
- Excellent isolation

**Applications:**
- Radars
- Point to point radio
- Test instruments
Design-In Quality and Reliability

Active Biasing

- Amplifier’s performance changed when temperature changes
- Active biasing feature minimize performance variation across bias and temperature conditions.

Ideal Case (Fix biasing across temperature)
Passive Biasing
Active Biasing

Minimizing current drift across temperature.
Design-In Quality and Reliability

Protection Circuitry – ESD Protection Circuit

- Architecture: Diode string, Power-clamp circuit
- Provide alternate low resistance path for ESD
- Reduce current flow to critical circuit
- Improve ESD survivability and product reliability

Power Clamp Circuit

Diode String
Design-In Quality and Reliability

**Protection Circuitry – Transient Current Protection Circuit**

- Prevent circuits damage by transient voltage
- No degradation in RF performance

Voltage spike may cause permanent damage to MMIC amplifier

![Protection Circuit](image)

![Output to Ground voltage vs time](chart)
Design-In Quality and Reliability

MMIC Amplifier Junction Temperature Measurement

• Embedded Temperature Sensing Diode near transistor junction in production wafers

• Measure junction temperature and thermal resistance accurately on every new design and every production wafer lot

Temperature Sensing Diode near transistor junction
Design, Test and Qualification

Advanced Design Tools

- Advanced Design System Circuit Simulator
- Harmonic Balance Simulation
- Full wave 3D EM Simulation
- MMIC Layout Design
- Thermal Simulation
Design, Test and Qualification

Advanced RF Measurement Tools

State of the art RF instruments
- Agilent PNA-X Network Analyzer
- Signal Generator
- Signal Analyzer
- Noise Figure Analyzer
- Impedance Tuner

Comprehensive Test and Characterization
- S-parameter test
- Power test
- Noise Figure test
- IP3 test
- Load / Source pull test
# Design, Test and Qualification

## Stringent Qualification

<table>
<thead>
<tr>
<th>Test Item</th>
<th>Standard</th>
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</thead>
<tbody>
<tr>
<td>High Temperature Operating Life test HTOL</td>
<td>JEDEC Standard, JESD22A-108</td>
</tr>
<tr>
<td>Moisture Sensitivity Test (Level 1)</td>
<td>JEDEC Standard, J-STD-020</td>
</tr>
<tr>
<td>Temperature Cycle Test</td>
<td>MIL-STD-883, method 1010</td>
</tr>
<tr>
<td>Autoclave Test</td>
<td>JEDEC Standard, JESD22-A102</td>
</tr>
<tr>
<td>High Temperature Storage Test</td>
<td>JEDEC Standard, JESD22-A103</td>
</tr>
<tr>
<td>Scanning Acoustic Microscope Test</td>
<td>JEDEC Standard, J-Std-020C</td>
</tr>
<tr>
<td>Humidity Test</td>
<td>MIL-STD-202F method 103B</td>
</tr>
<tr>
<td>Solderability Test</td>
<td>JEDEC Standard, JESD22-B102</td>
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<tr>
<td>Lead Integrity Test</td>
<td>MIL-STD-883, method 2004</td>
</tr>
<tr>
<td>Whisker Growth Test</td>
<td>JEDEC Standard - JESD22A121</td>
</tr>
<tr>
<td>ESD Sensitivity Test</td>
<td>ANSI/ESD-STM5.1-2007 (HBM) STM5.2-1999 (MM)</td>
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</tbody>
</table>
Advanced Packaging Technology

Thermal Management

Package Design with Thermal Simulation and Optimization

Material Selection and Optimization

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal Conductivity (W/m° K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mold Compound</td>
<td>1.5</td>
</tr>
<tr>
<td>Competitors</td>
<td>0.88</td>
</tr>
<tr>
<td>Conductive Epoxy</td>
<td>45</td>
</tr>
<tr>
<td>Competitors</td>
<td>2.5</td>
</tr>
</tbody>
</table>

- Better product performance
- Extend product operating life
- Achieve long term thermal reliability
Advanced Packaging Technology

Moisture Sensitivity Level 1

- Proprietary package design eliminates risk of package delamination
- Long term product reliability under all operating and assembly conditions

Package without delamination under Scanning Acoustic Microscopy test

C-Scan Image

A-Scan Image

Signal of Good Unit
Mini-Circuits MMIC Amplifiers

GaAs HBT Darlington - Super Flat, Wideband Performance

Series: LEE

- DC – 8 GHz coverage
- 10 – 17 dBm typ. output power
- Internally matched to 50Ω
- Excellent package for heat dissipation
- Flat output power to 8 GHz
- Protected by US Patent 6,943,629

LEE-19+ P1dB vs. Frequency

- dBm vs. MHz graph showing performance of LEE-19+ amplifier.

Mini-Circuits Logo
Mini-Circuits MMIC Amplifiers

GaAs HBT with ½ Watt $P_{\text{out}}$

Series: GVA

- DC – 7 GHz coverage
- High power, up to 29 dBm
- High IP3 – up to 41 dBm
- Good return loss, better than 10 dB
- Excellent efficiency, up to 50%

GVA-91+, $P_{1\text{dB}}$ vs. Frequency

![GVA Amplifier](Image)
Mini-Circuits MMIC Amplifiers

0.5μm E-PHEMT - 75Ω w. Feedback and Optimized NF, IP3

Series: PGA

PGA-106-75+
Recommended Application Circuit

- 5 – 2150 MHz coverage
- Flat gain / high dyn. Range / low NF
- High IP3, 37 dBm typ. at 0.5 GHz.
- High IP2, 50 – 60 dBm
- Low noise figure, 3.1 dB at 0.5 GHz.
- Excellent CSO/CTB
  - CSO, -56 dBC
  - CTB, -72 dBC
Mini-Circuits MMIC Amplifiers

0.25µm Super Ultra Low Noise Figure EPHEMT

Series: PMA2

- 400 – 3000 MHz coverage
- 0.18 $F_{\text{min}}$ at gamma opt.
- Ultra low min. NF, 0.22 dBm @ 900 MHz.
- High gain, 19 dB @ 900 MHz.
- Excellent gain flatness, ±1 dB
- Small size
Mini-Circuits MMIC Amplifiers

0.15µm PHEMT- ½ Watt at 26 GHz

Series: AVM

- Wideband 13 – 26.5 GHz.
- Output power up to +27 dBm
- Excellent directivity, 35 dB typ @ 20 GHz.
- Unconditionally stable
- Excellent gain flatness, ±1 dB

AVM-273HP+, P1dB vs. Frequency

<table>
<thead>
<tr>
<th>MHz</th>
<th>dBm</th>
</tr>
</thead>
<tbody>
<tr>
<td>11000</td>
<td></td>
</tr>
<tr>
<td>15000</td>
<td></td>
</tr>
<tr>
<td>20000</td>
<td></td>
</tr>
<tr>
<td>25000</td>
<td></td>
</tr>
<tr>
<td>30000</td>
<td></td>
</tr>
</tbody>
</table>
Q & A
Thank You