Introduction to MMIC Technology

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Presentation Outline

- Introduction to MMICs
- MMIC applications
- State-of-the-art MMIC technologies
- New business challenges
- Conclusion and future trends
History of the MMIC

- Jack Kilby built the first IC at TI in 1958 for which he got the Nobel Prize in Physics in 2000
- Jean A. Hoerni at Fairchild invented the Planar process on Silicon in 1958
- In 1975 Ray Pengelly and James Turner at Plessey built the first MMIC at X-Band: "Monolithic Broadband GaAs F.E.T. Amplifiers"
- In 1987 H. Hung et al at COMSAT built the 1st mm-wave MMIC at 20GHz "Ka-Band monolithic GaAs power FET amplifiers"
- MMIC stands for Monolithic Microwave Integrated Circuits
MIC versus MMIC Solution?

• MIC Advantages:
  – Fast & Low Cost Development
  – Better Performance such as: NF, Efficiency, $P_{1dB}$
  – Variety of Dielectric Materials
  – Integration of Different Semiconductor Technologies: MESFETs, Bipolar, Pin Diodes, Digital…etc
  – Higher Levels of Integration is possible

• MMIC Advantages:
  – Low unit Cost
  – Performance Uniformity from Unit to Unit
  – Very Small Size & Weight
  – Very Broadband Performance due to few parasitic effects
  – Simple Assembly Procedure
3 Generations of a 10W PA
MMIC Applications

- Switches: SPDT, SPNT, NPMT, ..etc
- Amplifiers: LNAs, PAs, Drivers
- Attenuators: Fixed, variable, digital
- Phase Shifters: Fixed, variable, digital
- Mixers
- Frequency Multipliers
- VCOs
- Phase Detectors
- MMIC World market is around $5billion versus a total of $1Trillion electronics market
GaAs Market 1999 – 2011

MMICs for Wireless Applications

RF Front End for ETC Applications

MMIC PA for 802.11b
Power Amplifier MMICs

4W 0.03 to 3GHz MMIC
Die Size 2.2x1.8mm

250mW 2 – 25GHz Millimeter-wave PA
Passive MMICs

DC – 40GHz SPDT Switch  44GHz 4-bit Phase Shifter MMIC
MMIC Integration

Bias & Control Pins
Trends For Commercial Applications

- Multi-Function, Multi-Frequency Band MMIC: Combine switch, LNA, PA, Mixer on one chip (HBT, Enhancement-mode PHEMT, and depletion-mode PHEMT on one chip)
- SOC (System on One Chip): Including Baseband, IF and RF on one chip.
- MMIC for 4G (Smart Phone) growing market:
  - WiMAX (Worldwide Interoperability for Microwave Access): 1-20Mb/s
  - LTE (Long-Term Evolution): 5-12 Mb/S
Trends for Government Applications

• Applications:
  - Software radio broadband communications
  - High power broadband jammers
  - Phase Array Radars
  - mm-Wave

• Novel MMIC technologies:
  - GaN HEMT
  - HIFET
## Semiconductor Materials for MMICs

<table>
<thead>
<tr>
<th>MMIC Semiconductors</th>
<th>Electron Mobility</th>
<th>$\varepsilon_r$</th>
<th>RF loss</th>
<th>Thermal</th>
<th>Active Device Technology</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gallium Arsenide (GaAs)</td>
<td>0.85m²/V/s</td>
<td>12.9</td>
<td>Low</td>
<td>46 W/°C/m</td>
<td>MESFET, HEMT, pHEMT, HBT, mHEMT</td>
<td>PA, LNA, mixers, attenuators, switches, …etc</td>
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<tr>
<td>Silicon (Si)</td>
<td>0.14m²/V/s</td>
<td>11.7</td>
<td>High</td>
<td>145 W/°C/m</td>
<td>LDMOS, RF CMOS, SiGe HBT (BiCMOS)</td>
<td>Mature for low power mixed signal applications</td>
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<tr>
<td>Silicon Carbide (SiC)</td>
<td>0.05m²/V/s</td>
<td>10</td>
<td>Low</td>
<td>430 W/°C/m</td>
<td>MESFET</td>
<td>Very high power below 5GHz</td>
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<tr>
<td>Indium Phosphide (InP)</td>
<td>0.60m²/V/s</td>
<td>14</td>
<td>Low</td>
<td>68 W/°C/m</td>
<td>MESFET, HEMT</td>
<td>mm-wave</td>
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<tr>
<td>Gallium Nitride (GaN)</td>
<td>0.08m²/V/s</td>
<td>8.9</td>
<td>Low</td>
<td>130 W/°C/m</td>
<td>HEMT</td>
<td>High power, limited availability</td>
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<td>Application</td>
<td>Frequency</td>
<td>Device Process</td>
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<td>Low Noise Amplifiers</td>
<td>1-10GHz</td>
<td>GaAs Mesfet</td>
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<td></td>
<td>10 –100Ghz</td>
<td>GaAs pHEMT</td>
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<td></td>
<td>&gt; 100GHz</td>
<td>InP</td>
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<tr>
<td>Medium Power (&lt; 10W)</td>
<td>1 -10GHz</td>
<td>GaAs HBT, GaAs Mesfet</td>
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<td></td>
<td>10 – 100GHz</td>
<td>pHEMT</td>
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<tr>
<td>High Power (&gt; 100W)</td>
<td>1 - 10GHz</td>
<td>GaAs Mesfet, GaN, SiC</td>
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<td></td>
<td>10 – 30GHz</td>
<td>GaN</td>
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<tr>
<td>Switches for digital attenuators and</td>
<td>0.1 – 20GHz</td>
<td>Mesfet</td>
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<td>phase shifters</td>
<td>20–100GHz</td>
<td>pHEMT</td>
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<td>Low Power Mixed Signal</td>
<td>1 – 50GHz</td>
<td>SiGe BiCMOS</td>
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<tr>
<td>VCO</td>
<td>1 -100GHz</td>
<td>GaAs HBT</td>
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MMIC Packaging

a) Ceramic Drop-in

b) SMT Ceramic

c) SMT Plastic

d) Finished Products
New Business Challenges

- Starting a business is risky but challenging
  - Less than 5% of new startups are successful
  - Idea, market and team players
  - Convincing business plan
- Minimum capital to start a Fabless semiconductor facility is around $10,000,000
- Maintaining cash balance for 3 – 6 months operations
- Need State-of-The-Art Testing and Assembly equipment
- High Cost of development
  - New MMIC Mask & wafer costs: $50,000 - $150,000
  - Design mistakes are expensive
  - Extended manufacturing schedule: 6 – 9 months
- Rapid technological developments
Conclusion and Future Trends

- GaAs MMICs dominate power, low noise and passive applications at microwave and will continue to do so in the foreseeable future
- BiCMOS & SiGe MMICs is maturing for SOC and RF front end applications
- GaN MMICs are expected to mature in few years and may fulfill the need for 10W to 100W power levels up to mm-waves
- SiC and LDMOS Silicon MMIC will continue to serve applications for >10W below 5GHz
- 3-D MMICs will mature for mm-waves and higher level of integration in Silicon