ATE Loadboard Layout for High Density RF Applications

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Abstract

The current success of smart-phones and the relentless trend to reduce cost and add capabilities every year are key drivers in the wireless semiconductor business. Combining various RF technologies into one device along with the desire for multi-site testing can easily increase the RF ATE test fixture port count to a range of 48 and beyond. While a few ATE vendors provide test equipment for this requirement, the question remains on how to manage the interfacing and the test fixture design for high density RF without losing performance.

The current interfacing and layout paradigm will undergo a significant change. The RF connectors are moved further away from the DUT to allow easier assembly and debugging, but with higher risk of performance degradation due to loss, crosstalk and interference. The increase in the number of matching networks makes hand tuning a significant bottleneck in delivery of a working loadboard. This paper evaluates new hardware and layout techniques to address both mechanical and electrical performance for high density RF ATE test fixtures and applies this knowledge to measurement based modeling techniques to minimize hand tuning of RF matching networks.
Outline

1. Motivation and Concept
2. RF Cables
3. RF Connectors and Mounting Options
4. London Bridge (RF Interface)
5. Trace Design
6. Impact on RF Matching Networks
7. Summary
1. Motivation and Concept
RF Port Count Continues to Increase with Integration of Multiple Wireless Standards

Limited Component Space

Past

Present - Future

Front End Module

Power Amps

Band Pass Filter (BPF) Switch

Increase RF Ports (connectors / cables)

Longer Traces

DUT Access

Crosstalk

Tuning

Performance Degradation

Symmetric Device Layout
Market Reality and Test Implications

High End Handset
- Number of RF ports increasing
  - Multi-band
  - Receive diversity
  - Additional radio interfaces (WLAN, BT, GPS, FM Tx/Rx)
- Smart phone penetration accelerating
- Driving increase in RF port count for smart and high end feature phones
- World phone (3-4 bands) devices will drive multi-site RF port count requirements above 24

Ultra Low Cost Handset
- 1.8B new subscribers from 2008 to 2012, 93% from developing countries
- ULC Handset ($20 BOM) driving single chip SOC devices for entry level phones
- Limited RF port count required (<24)
- Cost goals driving increase in multi-site (X4 → X8)
2. RF Cables
High Density RTK-047 Tempflex Cable

- Small: 1.42mm Diameter vs. 1.8mm for Gore 53
- Low Loss Dielectric: dK=1.25
- Flexible: 6.4mm Bend Radius vs. 10.2mm for Gore 53
- Different lengths: 15cm / 20cm / 25cm
- Robust: Ganged housing with strain relief
- Less space:
  - Increases routing flexibility
  - Enables smooth operation with RF interface ring

![3” Gore Mini-SMP](image1)

![6” Ganged x6 Mini-Coax](image2)

![Gore 53 and RTK-047 Cable Loss](image3)
Measured Cable Performance

Full S-Parameter data includes cable loss and connectors

Properties of cables:
- RTK-47 7.5cm*
- Gore 53 7.5cm
- RTK-47 15cm
- RTK-47 20cm*
- RTK-47 Right Angle 20cm
- RTK-47 30cm

*Calculated based on 30cm and 15cm measured cable data.

Minimal difference between Gore 53 and RTK-047 for short cable lengths.
3. RF Connectors and Mounting Options
High Density Ganged Mini-Coax Connector

- 6x Ganged
- Share mechanical structure:
  - Reduces the size by 30%
- Increased mechanical robustness
- Individually replaceable cable by removing from housing
- Disengagement force < 24 N
  vs. single Mini-SMP full detent connector < 29 N
- Engagement force < 12.5 N
  vs. single smooth bore Mini-SMP < 11 N
- Mating cycles > 500 vs.
  - 500 cycles SMA connectors.
  - 100 cycles Mini-SMP connectors
## Mounting Options

<table>
<thead>
<tr>
<th>Standard Mount topology</th>
<th>Reverse Mount topology</th>
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</thead>
<tbody>
<tr>
<td>Signal pin to bottom layer microstrip</td>
<td>Signal pin to top layer microstrip</td>
</tr>
<tr>
<td>Vias required to connect to an inner or to the Top layer Microstrip</td>
<td>No Via required for Top layer Microstrip</td>
</tr>
<tr>
<td>Blind vias under the connector body can completely open up the space for digital routing layers.</td>
<td>Through hole slot completely blocks routing on all layers</td>
</tr>
<tr>
<td>Cable connection on bottom side of PCB</td>
<td>Cable connection on bottom side of PCB</td>
</tr>
</tbody>
</table>

### Top Side

![Top Side Image]

### Bottom Side

![Bottom Side Image]
Reverse Mount RF Performance

Full S-Parameter Data for Mini-Coax Connector to PCB Transition

23C11A x6 Reverse Mount to Top 12mil Microstrip (Fixture De-Embedded)

Return Loss -20dB @ 5GHz

PCB footprint experiments to compare mechanical and electrical signal pin trade-offs.

Simulations

Return Loss -26dB @ 5GHz

PCB footprints in dxf and Gerber format

V0015_Rosenberger_23C11A_40M MiniCoax_x6_Reverse_Top_SMT.zip
Standard Mount RF Performance

Full S-Parameter Data for Mini-Coax Connector to PCB Transition Simulations

Return Loss -25dB @ 4GHz

PCB footprint experiments to compare mechanical and electrical signal pin trade-offs.

PCB footprints in dxf and Gerber format

V0016_Rosenberger_23C11A_40M_MiniCoax_x6_Bot_SMT.zip
Ganged Connector Isolation

Standard Mount with vias to topside and reverse mount with no vias show similar performance for isolation.

Stripline routing on different layers but adjacent connector pins improves isolation by >10 dB.
4. RF Interface: London Bridge
London Bridge RF Interface Ring (1/2)

• Access to component area:
  - can be opened in the middle
  - can be lifted on either side and completely disengaged

• RF cables can be shorter for lower loss and less cable congestion

• Divided into 8 segments with 12 RF connections each. Easier assembly and better cable arrangement.

• Additional cavities in the ring frame allow unthreading the segment together with the cables.
London Bridge RF Interface Ring (2/2)

- New metal inlay frame with increased application routing area by 30%.
5. Trace Design Experiments

✓ Vias
✓ PCB Materials
✓ Isolation for Striplines and Microstrip Routing
Importance of Backdrilled Vias

PCB Via
4 Ground Topology
50 Ohms

Return Loss vs Stub Length

Via Impedance vs Stub Length

![Graphs showing return loss and via impedance vs stub length.](image)
Signal Path with 2 Optimized 50 Ohm Vias

TRL Calibration Thru-Line with Southwest Microwave 2.4 mm edge launch and optimized 50 ohm Vias.

- **R4350 Stripline (18mil)** in red and orange
- **Nelco 4000-13SI Stripline (19mil)** in blue and green

Return Loss -20dB @ 5GHz

4-ground vias on the optimized via provide better isolation and robust implementation.
Outline (5. Trace Design Experiments)

✓ Vias
✓ PCB Materials
✓ Isolation for Striplines and Microstrip Routing
PCB Materials for Longer High Density Routing

Fixture Removed, Loss Per Centimeter Data

![Graph showing loss per centimeter data for various PCB materials](image)

- **FR408 Microstrip 12mil**
- **R4350 Microstrip 20mil**
- **R4350 Stripline 18mil**
- **Nelco4000-13 Stripline 10mil**
- **R4350 Microstrip 12mil**
- **R4350 Stripline 9mil**
- **Nelco4000-13 Stripline 10mil**

TempFlex RTK Coax for Comparison

1.1 dB/ft @ 10 GHz
Outline (5. Trace Design Experiments)

- Vias
- PCB Materials
- Isolation for Striplines and Microstrip Routing
Ground Via Stitching to Fence Off X-Talk

Isolation by separation (no via stitching)

Isolation by Guard Trace

Isolation by Via Stitching
Outline

6. Impact on RF Matching Networks
Simple Matching Network Example

Lumped Model Design for 2 GHz Match

1.6pF 8nH

Load impedance= 100 Ohm
Source impedance= 50 Ohm

Term Term1 C
Z=50 Ohm C1
Num=1

Term L1 L=
Z=100 Ohm {t}
Num=2

T-Line Affects on the Matching Network

The real load is complex 98-J10.9

Rotation by Transmission-Line distances places the load on the other side of the SMITH Chart making it impossible to get a good match with the Series C followed by Parallel L Network.

Simulations need accurate load measurements and flexibility in matching network design to allow for phase rotation of the load to the matching network.

Measurement of Lumped Model Design for 2 GHz Match

3.3 GHz Minimum S11

Load Impedance

Load Impedance at the Matching Network
Measurement Based RF Tuning Approach

Verification of Measurement Based Model with Measured Data

Measured S-Parameters of connectors and PCB Routing

Measurement

Simulation

Simulation

Verification of Measurement Based Model with Measured Data

Measured S-Parameters of connectors and PCB Routing
New Matching Network Topology for Rotated Load Impedance

Impedance matching on the Smith Chart:

→correct topology!
Prediction vs. Measurement for the Tuned Matching Network

Inductor is now located before the capacitor on the source side

Optimized Prediction for 2 GHz Match

L=10nH, C=27pF

Simulated Match

Measured Data, M1=2.00 GHz

L=10nH, C=27pF

Matching Network Measurement
7. Summary

- Higher density Mini-Coax connector topology maintains electrical and improves mechanical performance.
- Optimized 50 ohm vias and stripline routing have the potential to significantly improve isolation and routing densities.
- RF matching networks are already affected by T-Line affects at 2GHz, so moving them further out for high density applications will not change the difficulty of tuning.
- The key to RF tuning is flexible matching network design and accurate measurement techniques for signal path and DUT S-Parameters.
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