4x4 X-Band Butler Matrices

Introductory Package for
RIT Senior Design Project

December 5, 2008

Prepared By:
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Initial Timeline Draft

• Start Date: 12/01/08
• Design Review: 02/13/09
• Manufacturing Review: 02/20/09
• Delivery of Test Boards: 04/24/09
• Final Review: 05/08/09
Project Information

• Design of 2 types of Butler Matrices that can be used for antenna beamforming.
• Operating frequency range: 10 – 12 GHz (in X-Band)
4x4 Butler Matrices

Butler A

Butler B

S D

S D

0 2

-1 1
Necessary Components

• 180° Hybrid – Knöchel model
• 90° Hybrid – Branchline
• 45° Phase Shifter – Schiffman
• Connector Launch
Stackup options

61.5mil Stackup

- Rogers RO3003® 0.030"
- Arlon 6700 0.0015"
- ½ oz. Copper (0.0007”)

121.5mils Stackup

- Rogers RO3003® 0.060"
- Arlon 6700 0.0015"
- ½ oz. Copper (0.0007”)

Notes:  - One stackup should be chosen based on initial component designs.
         - Data sheets provided at the end of this package.
Example of Components

Phase Shifter - Schiffman

90° Hybrid - Multisection Branchline

180° Hybrid - Knochel Model

Notes:
- Example of components of the same type as will be designed.
- The high impedance lines of the Hybrids as well as the gaps of Schiffmans should receive special attention. Initially use a desired minimum desired linewidth and gap of 10 mils.
Example of Components

Vertical Connector Launch

GPPO Pin
Part #: Micromode MSSP-8476

GPPO Shroud
Part #: Micromode MSSP-8475

LaserVia
Diam=0.020"

Top Pad Diam=0.044"

Solder
AIR

GPPO Connector:
-connector pin
-connector shroud
RO3000® Series High Frequency Circuit Materials

Features and Benefits:
- Low dielectric loss for high frequency performance (RO3000). Laminates can be used in applications up to 30-40 GHz.
- Excellent mechanical properties versus temperature for reliable and dimensionally-stable multilayer board constructions.
- Uniform mechanical properties for a range of dielectric constants. Ideal for multilayer board designs with a range of dielectric constants. Suitable for use with epoxy glass multilayer board hybrid designs.
- Stable dielectric constant versus temperature and frequency for RO3003, ideal for board pass filters, microstrip patch antennas, and voltage controlled oscillators.
- Low in-plane expansion coefficient (matched to copper). Allows for more reliable surface mounted assemblies, ideal for applications sensitive to temperature change and excellent dimensional stability.
- Volume manufacturing process for economical laminate pricing.

Typical Applications:
- Automotive Collision Avoidance Systems
- Automotive Global Positioning Satellite Antennas
- Cellular and Fager Telecommunications Systems
- Patch Antennas for Wireless Communications
- Direct Broadcast Satellites
- DataLink on Cable Systems
- Remote Meter Readers
- Power Backplanes

RO3000® High Frequency Circuit Materials are ceramic-filled PTFE composites intended for use in commercial microwave and RF applications. This family of products was designed to offer exceptional electrical and mechanical stability at competitive prices.

RO3000® series laminates are PTFE-based circuit materials with mechanical properties that are constant regardless of the dielectric constant selected. This allows the designer to develop multilayer board designs that use different dielectric constant materials for individual layers, without encountering warpage or reliability problems.

The dielectric constant versus temperature of RO3000 series materials is very stable (Charts 1 and 2). These materials exhibit a coefficient of thermal expansion (CTE) in the X and Y axis of 17 ppm/°C. This expansion coefficient is matched to that of copper, which allows the material to exhibit excellent dimensional stability, with typical etch shrinkage (after etch and bake) of less than 0.5 mils per inch. The Z-axis CTE is 24 ppm/°C, which provides exceptional plated through-hole reliability, even in severe thermal environments.

RO3000® series laminates can be fabricated into printed circuit boards using standard PTFE circuit board processing techniques with minor modifications as described in the application note “Fabrication Guidelines for RO3000® Series High Frequency Circuit Materials.”

Available claddings are ¼, ½, or 1 oz./sq. ft. (17, 35, 70 μm thick) electro-deposited copper foil.

RO3000® laminates are manufactured under an ISO 9002 certified system.

The data in Charts 1, 2 and 3 was produced using a modified ASTM-526 test at 2.45 GHz. For additional information, contact Rogers.

T.R. 9134 and T.W. 4924.
### Data Sheet: Rogers 3003®

#### Typical Values

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>RO3003</th>
<th>RO3004</th>
<th>RO3010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric Constant</td>
<td>3.00 ± 0.04</td>
<td>3.00 ± 0.04</td>
<td>3.00 ± 0.04</td>
</tr>
<tr>
<td>Thermal Coefficient of α</td>
<td>-1.20 ± 0.26</td>
<td>-0.80 ± 0.26</td>
<td>-0.80 ± 0.26</td>
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<tr>
<td>Dimensional Stability</td>
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<td>0.5</td>
<td>0.5</td>
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<tr>
<td>Volume Resistivity</td>
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<td>10¹⁰</td>
<td>10¹⁰</td>
</tr>
<tr>
<td>Surface Resistivity</td>
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<td>10⁵</td>
<td>10⁵</td>
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<tr>
<td>Thermal Expansion</td>
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<td>17</td>
<td>17</td>
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<tr>
<td>Coefficient of Thermal Expansion</td>
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<td>Copper Flexibility</td>
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<td>100°C Tg</td>
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<td>180</td>
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<tr>
<td>Color</td>
<td>Tan</td>
<td>Tan</td>
<td>Off White</td>
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<tr>
<td>Density</td>
<td>2.8</td>
<td>2.8</td>
<td>2.8</td>
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<tr>
<td>Lead Form Process Capability</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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</tbody>
</table>

(1) References: Internal T.R. ± 1.20 ± 0.26. Tests of T.R. unless otherwise noted. Typical values should not be used for specification limits.

(2) The nominal dielectric constant of an 0.020" thick RO3004® laminate as measured by the IPC-TM-600, 2.6.8.8 will be 3.02, due to the elimination of aging caused by air gaps in the test fixture. For further information refer to section 2.6.8.8.

#### RO3000 Series High Frequency Laminates

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>RO3000</th>
<th>RO3004</th>
<th>RO3010</th>
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<td>Dielectric Constant</td>
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<tr>
<td>Thermal Coefficient of α</td>
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<tr>
<td>Dimensional Stability</td>
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<tr>
<td>Volume Resistivity</td>
<td>10¹⁰</td>
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<td>10¹⁰</td>
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<tr>
<td>Surface Resistivity</td>
<td>10⁵</td>
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<td>10⁵</td>
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<tr>
<td>Thermal Expansion</td>
<td>17</td>
<td>17</td>
<td>17</td>
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<tr>
<td>Coefficient of Thermal Expansion</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>100°C Tg</td>
<td>180</td>
<td>180</td>
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<tr>
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<td>Tan</td>
<td>Tan</td>
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<td>2.8</td>
<td>2.8</td>
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<tr>
<td>Lead Form Process Capability</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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</tbody>
</table>

#### Contact Information

- **USA**: Rogers Advanced Circuit Materials - ISO 9000:2000 certified
  - Tel: 400-8101-350
  - Fax: 400-8101-4553

- **Belgium**: Rogers NV - Bent ISO 9000:2000 certified
  - Tel: 34-90-2300-611
  - Fax: 34-90-2300-650

- **Japan**: Rogers Japan Inc.
  - Tel: 81-3-5230-2750
  - Fax: 81-3-5230-6571

- **Taiwan**: Rogers Taiwo Inc.
  - Tel: 886-2-8670-0764
  - Fax: 886-2-8670-0167

- **Korea**: Rogers Korea Inc.
  - Tel: 82-2-714-6112
  - Fax: 82-2-714-6008

- **Singapore**: Rogers Technologies Singapore Inc.
  - Tel: 65-747-5221
  - Fax: 65-747-7428

- **China**: Rogers (Shanghai) International Trading Co., Ltd
  - Tel: 86-21-6051-0088
  - Fax: 86-21-6051-0089

The information in this data sheet is intended to assist you in designing with Rogers' circuit material laminates. It is not intended to and does not create any warranties express or implied, including any warranty of merchantability or fitness for a particular purpose or that the results shown on this data sheet will be achieved by a user for a particular purpose. The user should determine the suitability of Rogers' circuit material laminates for each application.

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CuClad 6250 and 6700 Bonding Films

Features:
- Thermoplastic Bonding Films
- Similar Ok and Ef range to many PTFE laminates

Benefits:
- Can be reheated to remelt and reflow bonding film
- Excellent Electrical Properties

Typical Applications:
- Stripline Circuitry
- Multi-Layer Boards and Hybrid Con instructions for Microwave Applications
- Attachment of Circuit Boards to Heavy Plate Heat Sinks

CuClad 6250 and 6700 are low melting point bonding films that have been developed for lamination of stripline or other multilayer circuits fabricated from CuClad or other Arlon PTFE-based laminates. Dielectric constants of 6250 and 6700 Bonding Films fall in the midrange of CuClad and DIIClad Microwave Printed Circuit Board Substrates product lines and ensure uniform reproducibility of electrical performance.

Shelf Life and Storage: Maximum recommended shelf life for CuClad 6250 or 6700 is two years when material is stored away from direct sunlight and in the original sealed package at no greater than 25°C (77°F) and 70% relative humidity. The film rolls should be stored on edge (standing upright) or suspended by the roll cores to avoid creating creased areas or flat spots due to roll weight.

Typical Properties: CuClad 6250 and 6700

<table>
<thead>
<tr>
<th>Property</th>
<th>Units</th>
<th>Test Method</th>
<th>6250</th>
<th>6700</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric Constant @ 10 GHz</td>
<td>IPC TM-650</td>
<td>2.32</td>
<td>2.35</td>
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<tr>
<td>Dielectric Factor @ 10 GHz</td>
<td>IPC TM-650</td>
<td>0.0013</td>
<td>0.0025</td>
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<tr>
<td>Dielectric Strength</td>
<td>V/mil</td>
<td>ASTM D-149</td>
<td>1000 min</td>
<td>900</td>
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<tr>
<td>Volume Resistivity</td>
<td>Ohm-cm</td>
<td>ASTM D-257</td>
<td>10^9</td>
<td>10^8</td>
</tr>
<tr>
<td>Surface Resistivity</td>
<td>Ohms</td>
<td>ASTM D-257</td>
<td>10^9</td>
<td>10^8</td>
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<tr>
<td>Arc Resistance</td>
<td>sec</td>
<td>ASTM D-495</td>
<td>130-140</td>
<td></td>
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<tr>
<td>Water Absorption</td>
<td>%</td>
<td>ASTM D-570</td>
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<tr>
<td>Thermal Conductivity</td>
<td>W/m-K</td>
<td>0.17</td>
<td>0.17</td>
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<tr>
<td>Brittleness Temperature</td>
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<td>-80</td>
<td></td>
<td></td>
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<tr>
<td>Crystalline Melt Point</td>
<td>°F (°C)</td>
<td>Hot Stage</td>
<td>394 (199)</td>
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<tr>
<td>Continuous Use Temperature</td>
<td>°F (°C)</td>
<td>165 (75/110)</td>
<td>250 (125)</td>
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<tr>
<td>Density</td>
<td>g/cm³</td>
<td>ASTM D-1505</td>
<td>0.03</td>
<td>0.01</td>
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</tbody>
</table>

Material Availability:

<table>
<thead>
<tr>
<th>Available Width</th>
<th>CuClad 6250</th>
<th>CuClad 6700</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available Roll Lengths</td>
<td>30 ft or 150 ft</td>
<td>30 ft or 150 ft</td>
</tr>
<tr>
<td>Available Thicknesses</td>
<td>0.0015&quot;</td>
<td>0.0015&quot; or 0.003&quot;</td>
</tr>
</tbody>
</table>

Results listed above are typical properties; they are not to be used as specification limits. The above information contains no expressed or implied warranties. The properties of Arlon laminates may vary, depending on the design and application.
Processing Recommendations

Preparation of Surfaces to be Bonded

1. Etched copper circuitry or copper ground/power planes should be treated with a light microetch prior to lamination. Copper surfaces should not be mechanically scrubbed (rotating or oscillating brush) or pumice scrubbed.
2. Etched or PTFE surfaces should be dry and clean, free of all process chemical residues as well as dust, dirt, grease, oils, fingerprints, etc. Thorough rinsing with clean, deionized water followed by forson or air drying may be sufficient. A flush or dip in isopropyl alcohol (IPA) will aid in drying. Do not swab or wipe surfaces.
3. As-etched copper clad surfaces may not require treatment to promote bonding immediately after etching the copper, however, for unetched PTFE laminates or PTFE surfaces that have been welded, rubbed or handled carelessly prior to lamination, it is strongly recommended:
   - Sodium metal based chemical surface preparation, using Tetra-etch® Fluoropolymer Etchant (W.L. Gore) or Fluoroetch® Fluoropolymer Etchant (Acton Technologies), is recommended to maximize adhesion of bonding film to the PTFE surfaces.
   - Gas plasma cycles have also been shown as effective to promote adhesion to PTFE surfaces; this applies not only to plated through hole preparation, but also to multilayer lamination.
   - Panels should be stored in a clean, dry environment. Layup and lamination should be done as soon as possible, preferably within 24 hours of etching/surface preparation.
5. CuClad 6250 and 6700 bonding films come ready to use and require no preparation. Handling/cutting of material should take place in a clean, dust-free environment. The operator should use gloves to prevent transfer of oils and acids from hands to fingers.

Bonding Process

1. Lay the bonding film between the layers to be laminated. Be sure to use enough film to encapsulate the thickness of copper traces and patterns and to provide additional thickness as dielectric if required.
2. It is recommended that a thermocouple be placed into the laminate at the edge of the bond line (outside the working area of the MIL) to measure actual working temperature at the bonding interface.
3. Preheat the press to the approximate bonding temperature required:
   - For CuClad 6250 Bonding Film, a set temperature of 275°F is suggested (bonding will occur at temperatures between 250°F and 300°F).
   - For CuClad 6700 Bonding Film, a set temperature of 400°F is suggested (bonding will occur at temperatures between 350°F and 440°F).
4. Apply pressure at approximately 100 psi. Pressure as high as 200 psi may be used if lower pressure does not result in sufficient flow for more complex circuit fill. Sufficient flooding should be used to develop uniform pressure, or spotty bonds/blisters may occur.
5. Hold the press until the temperature at the bond interface reaches the critical point:
   - For CuClad 6250, this should be a minimum of 250°F (max. 300°F).
   - For CuClad 6700, this should be a minimum of 400°F (max. 475°F).
6. Hold at temperature for an additional 10 minutes (for 6250) or 15 minutes (for 6700). This step is critical. Insufficient time at temperature will result in a failed or spotty bond.
7. Cool under pressure at a maximum cool-down rate of 10°F/min.
   - For CuClad 6250, cool to under 125°F before removing from the press.
   - For CuClad 6700, cool to under 200°F before removing from the press.

Note: Transfer to a cooling press for cool down under pressure to maximize available hot press availability is acceptable. Transfer should be made, while still hot, and material should not be allowed to sit on cold surfaces during transfer. Cool down pressure should equal the hot pressure. Forced cooling greater than 10°F/min or without adequate pressure may result in partial debonding or board warpage.
8. Lamination Temperature Profiles
   - Curves shown on the accompanying charts illustrate typical cycles that can produce satisfactory bonding results.