LTCC Design Guide

Offering innovative precision ceramic substrate solutions:

> Low Temperature Co-fired Ceramics
> Lower-cost Microwave Circuits

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Salem, NH 03079

TTM Technologies

Inspiring Innovation

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LTCC Process

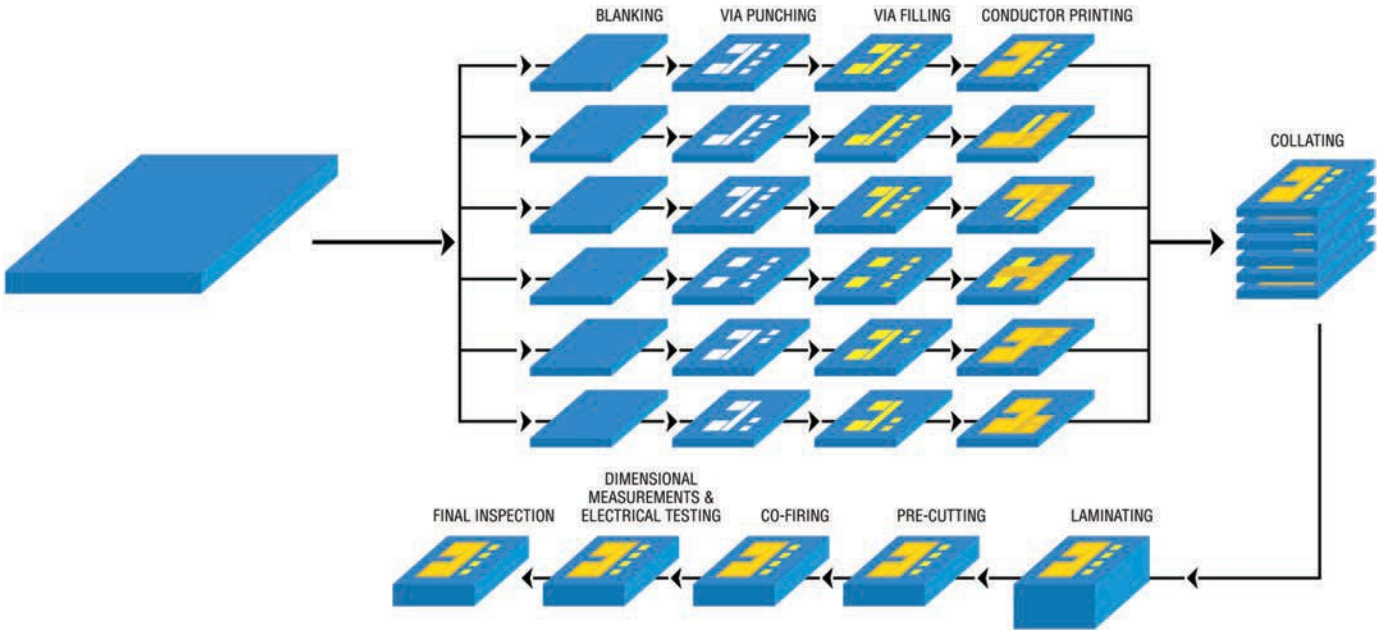

Figure 6.1.1: Typical Process for Fabricating an LTCC Structure
A series of steps are required for the production of LTCC structures. Performance, structure, and process capability of both ceramic and conductor are explained in the following pages.

Material Properties

Available Material Systems

Available Tape Systems	Available Metallization Systems
DuPont 951	All gold, all silver, ENiG
Ferro A6M	All gold

Table: 7.2.1: Material System Mechanical Properties

Parameter	DuPont 951	Ferro A6M
Green sheet area (inches^2)	6.5 & 8.0	6.5
Usable green sheet area (inches)	4.6 & 6.2	4.5
XY shrinkage	12.92%	14.85%
XY shrinkage tolerance	±0.3%	±0.3%
Green tape thickness (mils)	2, 4.5, 6.5, 10	5, 10
Fired tape thickness (mils)	1.7, 3.8, 5.5, 8.5	3.7, 7.4
Z shrinkage	15%	25%
Z shrinkage tolerance	±0.5%	±0.5%
Patterning technology	Screen Print & Etch	Screen Print
Thermal Conductivity	3.3	2.0
Young's Modulus (GPa)	120	92
Poisson's Ratio	—	—
Flexural Strength (MPa)	320	170
Density (g/cm^3)	3.1	2.5

Note:
1. 951 mechanical data taken from DuPont website

Table: 7.3.1: Material System Electrical Properties

Parameter	DuPont 951	Ferro A6M
Dielectric Constant @3GHz	7.8	5.6
Dielectric Constant tolerance	±0.2	—
Loss Tangent @3GHz	0.006	0.002
Breakdown voltage (V/25µm)	> 1000	> 900

Note:
1. Typical values are shown in this table.

Table: 7.4.1: Materials Options Preferred Material System

Manufacturer	DuPont	Ferro
Process	**951**	**A6M**
Inner Layer Au	TC502	30-025
Via Fill Au	TC501	30-078
Wirebond Co-Fire Au	5742 (Al wire) 5734 (Au wire)	30-065 (Al wire) 30-025 (Au wire)
Wirebond Post-Fire Au	5743 (Al wire) 5715 (Au wire)	30-068 (Al wire)
Solderable Au	5739 (Pt/Au)	36-020 (Pt/Au)
Brazing Material (AuSn, AuGe Braze)	5062/5063	4007
Inner Layer Ag	6142 (Signal) 6148 (Power, Gnd)	33-398
Via Fill Ag	6141 (Ag) 6138 (Pd/Ag)	33-343 (Ag) 39-005 (Pd/Ag)
Solderable Co-Fired Ag	6146 (Pd/Ag)	33-391
Solderable Post-Fired Ag	6135 (Pd/Ag)	3350
Co-Fired Resistors	CF Series	87 Series
Post-Fired Resistors	7200 Series	82 Series
Co-Fired Dielectric	9615	10-088
Post-Fired Overglaze	QQ550	NCA[a]

Note: a) NCA – Not currently available

Conductor Parameters

The cross sectional shape of a conductor embedded in an LTCC substrate is characterized as an ellipse. Cross-sectional views of the conductors depict shapes that are not rectangular, but shapes with thicker mid-sections and tapered edges. Ellipses are traced around the conductor's outer edges and parameters such as width, thickness, and area is defined and based on the major and minor radii of the ellipses.

Conductor Line Widths and Spacings (minimums, typical, and tolerances)

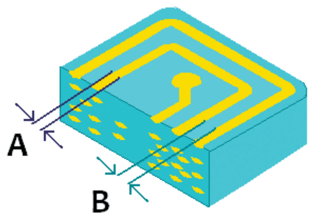

Figure 8.1.1: Line Width and Line to Line Spacing

Table 8.1.1: Line Width

	Minimum (mils)	Typical (mils)	Tolerance (mils)
(A)Printed	3.0	4.0	±1.0

Table 8.1.2: Line to Line Spacing

	Minimum (mils)	Typical (mils)	Tolerance (mils)
(B)Printed	3.0	4.5	±1.0

Notes:
1. Cross-sectional views of the conductors depict an elliptical shape – therefore conductor width is defined as the major diameter of a traced ellipse.
2. Printed parameters characterized in DuPont 951 all silver conductor system.
3. Printed parameters refer to a screen printing process.
4. Parameters are applicable to exposed and buried layers.

Conductor to Ceramic Edge (minimums, typical, and tolerances)

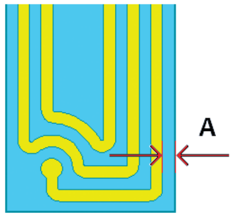

Figure 8.2.1: Conductor to Ceramic Edge

Table 8.2.1: Conductor to Ceramic Edge Parameters

	Minimum (mils)	Typical (mils)	Tolerance (mils)
(A)Printed	4.0	8.0	±1.0

Note:
Conductor thickness is defined as the minor radius of an ellipse at the center of the conductor.

Conductor Line Thickness and Shape (minimum, typical, and tolerances)

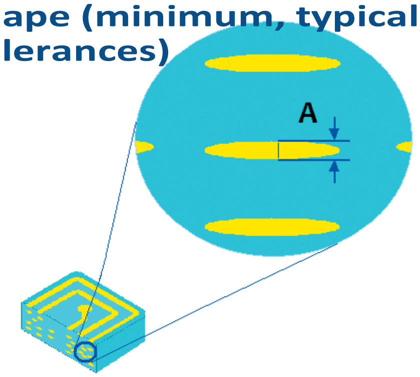

Figure 8.3.1: Conductor Thickness

Table 8.3.1: Conductor Thickness Parameters

	Minimum (mils)	Typical (mils)	Tolerance (mils)
(A)	0.4	0.5	±0.2

Note:
Conductor thickness is defined as the minor radius of an ellipse at the center of the conductor.

Conductor Cross-Sectional Area and Elliptical Dimensions (minimum, typical, and tolerances)

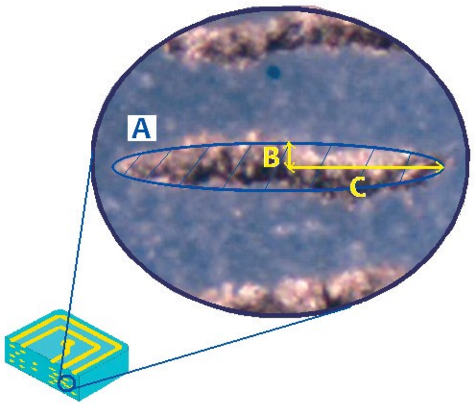

Figure 8.4.1: Cross-Section of a Conductor with a Traced Ellipse. The minor and major radius of the ellipse is shown. These radii define the thickness, width, and elliptical area of the conductor lines.

Table 8.4.1: Elliptical Parameters

	Minimum	Typical	Tolerance
(A) Elliptical Area (mils^2)	0.9	1.80	—
(B) Minor Radius (mils)	0.2	0.25	±0.1
(C) Major Radius (mils)	1.5	2.25	±0.5

Notes:
1. Cross-sectional views of the conductors depict an elliptical shape – therefore the elliptical area served as an accurate measurement for its area.
2. The product of the major radius, minor radius, and - serve as the formula for calculating the elliptical area. A = B.C. –
3. The major and minor radius also serve as a mathematical model to define the cross-sectional shape of the conductors.

Conductor Layout Recommendations

The following are some general recommendations when laying out a multilayer circuit in LTCC.

1. Ground and power plane layout recommendations – keep metallization to <50% of ceramic area for better adhesion of ceramic layer to ceramic layer and for better consistency of shrinkage through a panel; for buried metal layers, see example in Figure 3.5.1. For best practices, use a hatched ground plane where possible.
2. Full metal coverage can be printed on exposed surfaces post firing.
3. Relative even distribution of metal on any tape layer is recommended for consistent ceramic shrinkage during firing.

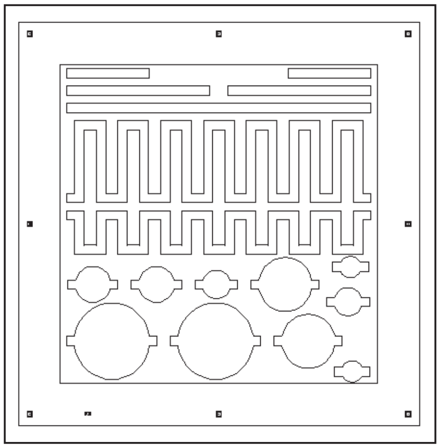

Figure 8.5.1: Buried Ground Plane, Metal Coverage <50%

> Shows solid ground plane in buried layer – % coverage in active area <50%.

> Metal is spread relatively evenly through the panel active area allowing even shrinkage.

Via Parameters

Via Diameter (minimums, typical, and tolerances)

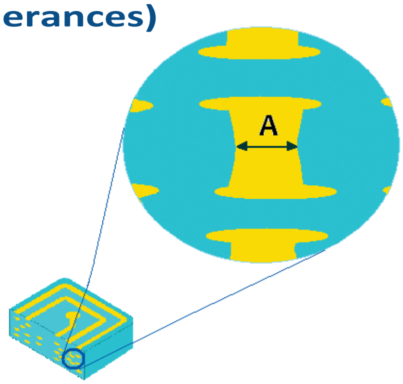

Figure 9.1.1: Diameter of Vias
Via diameter is defined as the narrowest point of the via transition from layer to layer. Typically there is a via capture pad on the interconnected layers. The via capture pad is larger in diameter than the via leading to the cross sectional pedestal shape shown.

Table 9.1.1: Via Diameter

	Minimum	Typical	Tolerance
(A) 2 mil Tape Thickness	3.4	4.5	±1
(A) 5 mil Tape Thickness	3.4	4.5	±1
(A) 10 mil Tape Thickness	6.8	8.5	±1

Notes:
1. Via diameter must be less than 80% tape thickness.

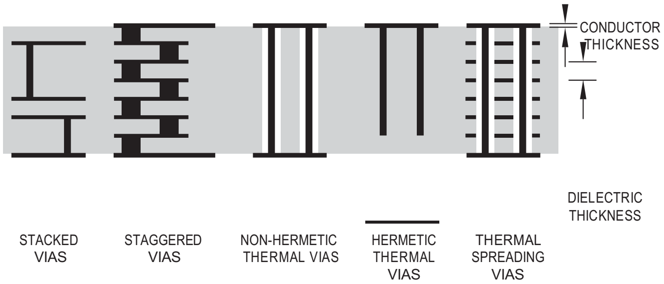

Figure 9.2.1: Vias Definition, Cross Section

Via Capture Pad (minimums, typical, and tolerances)

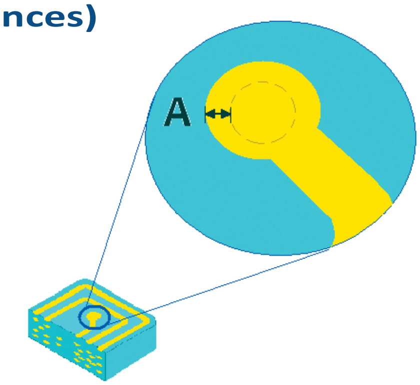

Figure 9.3.1: Via Capture Pad
Dashed line represents a via. Label (A) represents the distance from the via's edge to the edge of the capture pad.

Table 9.2.1: Via Capture Pads

Parameter	Minimum (mils)	Typical (mils)	Tolerance (mils)
(A) Via Capture Pad	2	3.5	±1.5

Notes:
1. No capture pad is needed unless a trace is connected to the via.
2. In some cases, capture pads are omitted by design – i.e. a trace that is less than the via diameter can run over the via as a means of connection.

Via Spacing and Layout (minimums, typical, and tolerances)

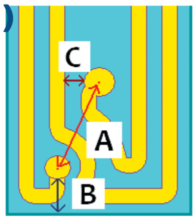

Figure 9.4.1: Via Spacing and Layout

Table 9.3.1: Via spacing and layout recommendations

Parameter	Minimum (mils)	Typical (mils)	Tolerance (mils)
(A) Via to Via Spacing	(1.5 x D) + D	—	±1
(B) Via to Conductor Edge	3	4	±1
(C) Via to Ceramic Edge	3	4	±1

Note:
1. Where "D" is via diameter.

Table: 9.4.1: Design Guidelines Summary

Design Feature	Standard Guides	Premium Guides
Tape Layer Count	8-20 Layers	Up to 30 Layers[b]
Max. Substrate Size, Fired[a]	100 mm x 100 mm	100 mm x 100 mm
Thermal Vias, 95 µm Tape	250 µm Ø 10 mil	125 µm Ø 5 mil 250 µm pitch 10 mil
Thermal Vias, 215 µm Tape	250 µm Ø 10 mil	180 µm Ø 300 µm pitch
Distance, Conductor to Edge	250 µm min. 10 mil	175 µm min.
Internal Ground/ Power Plane Coverage	Grid: 50% Metal Localized: 100%	Grid: 50% Metal Localized: 100%
Minimum Tape Layer Count or Minimum Thickness	8 Layers or 1 mm, Whichever is More	8 Layers or 1 mm. Whichever is More

Notes: a) Typical with current tooling. Custom tooling will allow a maximum fired size of 160 x 160 mm. More complex size and shape designs can be addressed on an individual basis.
b) Up to 60 layers are possible with alternative processing techniques.

Cavities

> Cavities are defined as openings or through-holes in the LTCC design that are introduced into the green state structure prior to firing. Post-machined operations (CO_2 laser drilling) are not included in the recommendations below.

> Minimum distance of 100 mils must be maintained between adjacent cavities or through-holes, or between cavity walls or through-holes and the part.

> Minimum cavity length and width are 100 mils. Maximum ratio of cavity depth to minimum XY dimension is 1:1. Preferred ratio is 1:2. Minimum radius on any corner of a cavity is 20 mils.

> Cavities with floors must have a minimum floor thickness of 20 mils. Via and conductor limitations related to cavity walls or cavity shelves are the same as those listed in Table 9.4.1. Vias are listed in Table 8.2.1.

> Cavities may have one or more intermediate, stepped shelves. Minimum shelf thickness is 20 mils. Minimum shelf width is 50 mils.

> Maximum combined surface area of cavity opening to total part surface area is 60%. Preferred maximum is 40%.

Electroless Plating

> As a vertically integrated facility, TTM offers electroplating (Ni/Au and Ni/Pb-Sn), and electroless plating (Ni/Au).

Singulation

> Primary methods for component singulation are: laser machining and diamond saw, which may be used in combination.

> Singulation typically requires 60 mils of non-active area surrounding the final circuit. For complex shapes, CO_2 machining offers routing capability for the LTCC substrate.

> Products with wider mechanical tolerances can be green state singulation for cost reduction.

> Diamond saw dicing offers minimal dimensional deviation for standard, rectangular shapes.

Brazing

> Conductors for successful brazing to LTCC are available for the primary tape systems. Please refer to Table 2.4.1 for the specific material choices.

> To meet MIL Specification Visual Inspection Criteria, it is recommended that the brazing pad be 30-40 mils larger than the lead or seal ring component.

> Gold-tin or gold-germanium soldering is recommended for most applications.

Testing

> DC electrical testing can be achieved with either an electrical Net test (opens and shorts) or capacitor test. It is required that the customer supply an ASCII Netlist per 356D.

Passive Elements

> Inductors, resistors, and capacitors may all be integrated into a standard LTCC structure. Electrical characteristics are achieved through a combination of design (e.g., surface real estate, one or more layers), inherent properties of the green tape, and the material system chosen.

> Depending upon the material system, enhancement materials exist to locally increase the dielectric constant for some capacitor ranges. Specifics must be reviewed on a design-by-design basis.

> Buried resistors will exhibit a tolerance of ±30%. Surface resistors may typically be laser trimmed using a Nd:YAG laser to ±2% to ±5%. Tighter tolerance requirements must be reviewed on a design-by-design basis. Resistor values are limited by design and material availability, but typically run between 10 Ω and 1 kΩ for buried resistors, and 1 Ω to 100 MΩ for surface resistors. Minimum buried resistor size is 30 x 30 mils; minimum surface resistor size is 20 x 20 mils.

> Overcoat and solder-blocking materials are available as post-fired operations.

Multilayer Parameters

Tape Layer Thickness (minimum, typical, and tolerances)

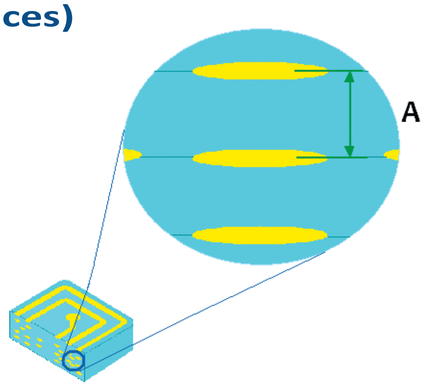

Figure 10.1.1: Ceramic Tape Layer Thickness

Table 10.1.1: Ceramic Tape Layer Thickness

Parameter	Minimum (mils)	Typical (mils)	Tolerance (mils)
(A) Tape thickness 2 mil	1.45	1.7	±0.25
(A) Tape thickness 4.5 mil	3.55	3.8	±0.25
(A) Tape thickness 10 mil	8.25	8.5	±0.25

Notes:
1. Tape thickness is defined as the distance between the centers of conductors in a successive layer.
2. Combinations of tape may be used to achieve alternative desired thickness.

Conductor and Tape Collation/ Layer to Layer Alignment (tolerance)

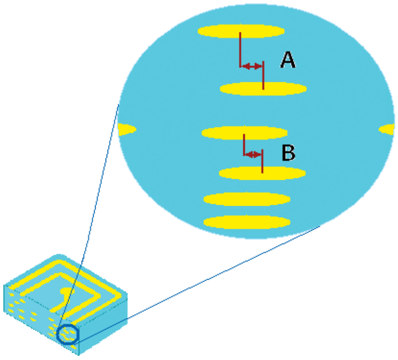

Figure 10.2.1: Layer to Layer Alignment

Table 10.2.1: Layer to Layer Alignment

Parameter	Tolerance (mils)
(A & B) Layer to layer alignment	±2.0

RF & Microwave Parameters

Dielectric Constant Measurements

Ring Resonators are used to measure the dielectric constant of available material sets. A ring resonator is a simple structure that is a 50Ω transmission line, one wavelength long at a fundamental frequency. The single wavelength transmission line ring has no discontinuity effects resulting in a standing wave pattern that resonates at every harmonic of the fundamental frequency. There is no reflection characteristic on the ring structure resulting in full wavelength resonances only. Energy is coupled onto and off the ring through two identical transmission lines that are separated from the ring by a 4 mil gap, resulting in a capacitive coupling effect. The dielectric constant information is extracted from the frequency of resonance at each harmonic allowing multiple D_K (dielectric constant) estimates per structure. This information is somewhat independent of the quality of the transmission line print allowing a very accurate estimate of the material D_K.

Microstrip and Stripline ring resonators have been designed, fabricated and measured yielding D_K data for DuPont 951 material sets. D_K is extracted from resonant frequency measurements using the following equations:

Table 11.1.1: D_K and effective D_K:

STRIPLINE RING RESONATORS	Material $D_K = (c*n/(f_c*l))^2$
MICROSTRIP RING RESONATORS	Effective $D_K = (c*n/(f_c*l))^2$
PARAMETERS	$c = 3.0*10^8$ (m/s)
	n = Harmonic number
	f_c = Measured harmonic resonant frequency (Hz)
	l = Resonator length (m)

Dual ring resonator coupons designed to resonate at fundamental frequencies of 2, 3, 5, 7 and 11 GHz have been manufactured and RF tested at TTM-Salem. The resonator coupon contains a microstrip structure and a stripline structure, forming two ring resonators in one block of ceramic. Figure 6.1.1 shows a single dual resonator coupon; figure 6.1.2 shows a cross section of the dual resonator structure. Figure 6.1.3 shows a typical broadband 5GHz ring resonator response.

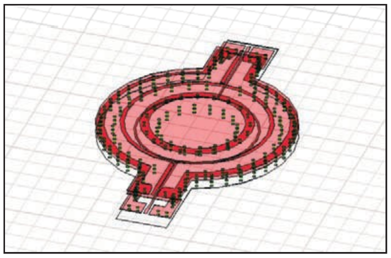

Figure 11.1.1: Dual Ring Resonator Structure

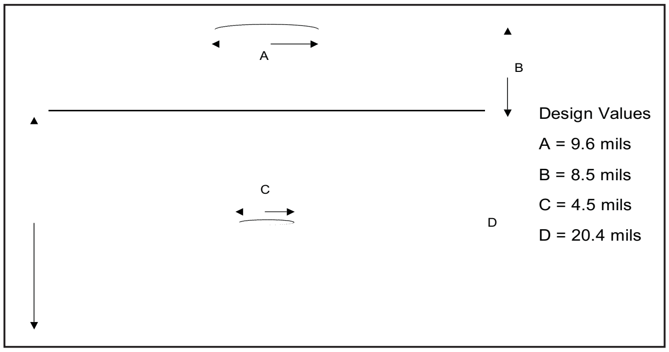

Figure 11.1.2: Transmission Line Dimensions – DuPont 951.

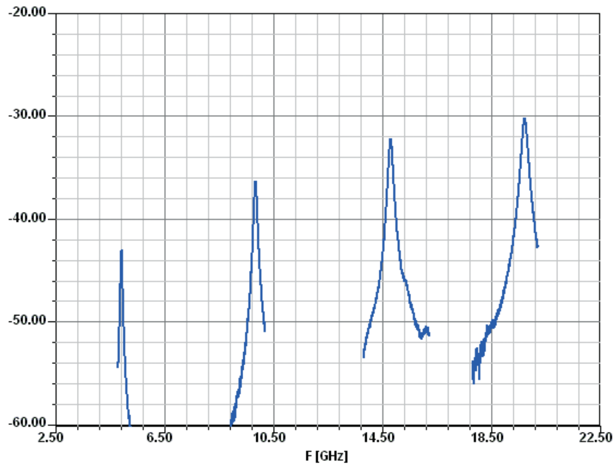

Figure 11.1.3: Typical Broadband 5GHz Ring Resonator Response showing resonances at the first/second/third and fourth harmonics.

RF & Microwave Parameters *(continued)*

The ring resonator coupons can be used to estimate lot to lot material dielectric constant (D_k) and effective D_k at multiple frequencies; the 5GHz resonator has recently been used as a means of comparing process variation between firing processes in a box oven and on a belt furnace.

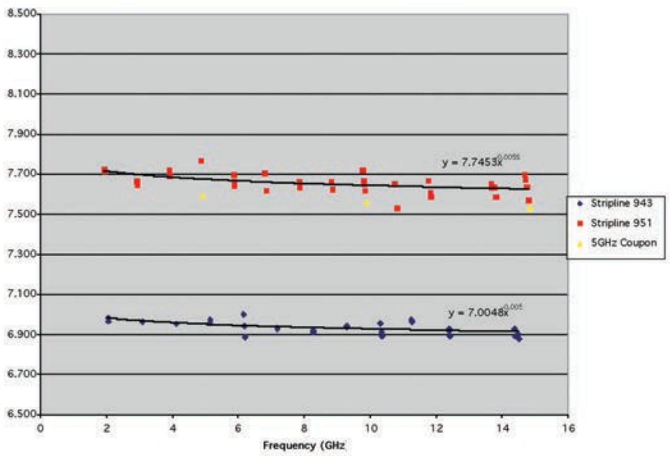

Figure 11.1.4: D_k Estimates for DuPont 943 and DuPont 951 from stripline ring resonator measurements

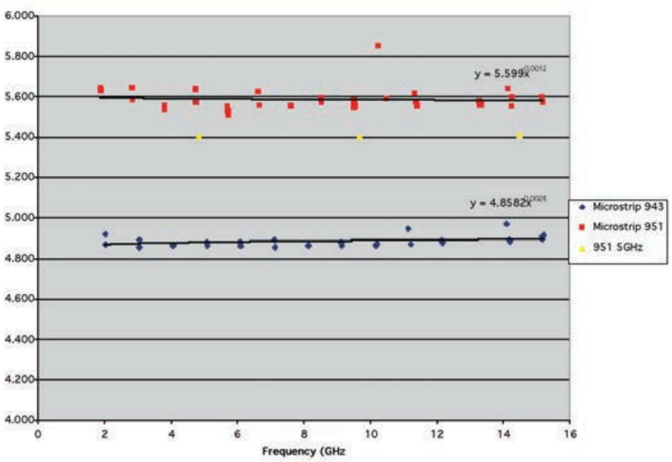

Figure 11.1.5: Effective D_k Estimates for DuPont 943 and DuPont 951 from microstrip

Attenuation Per Unit Length vs. Frequency Measurements

Attenuation Lines: 50Ω Microstrip and Stripline transmission lines are used to measure attenuation vs. frequency. Lines of varying lengths are measured up to 20GHz and compared to each other. All attenuation line data is normalized to a unit length of one inch.

Table 11.2.1: Attenuation line lengths

	Microstrip Line Length (inches)	Stripline Line Length (inches)
Line 1	1.0	1.1
Line 2	1.0	1.1
Line 3	1.76	1.86
Line 4	1.76	1.86
Line 5	3.79	3.89
Line 6	16.35	16.45
Line 7	9.63	9.73

Table 11.2.2: Calculated attenuation/unit length for DuPont 951 stripline and microstrip transmission lines

Frequency (GHz)	Microstrip Attenuation/unit length (dB)	Stripline Attenuation/unit length (dB)
2	-0.15	-0.24
3	-0.19	-0.29
4	-0.23	-0.35
5	-0.28	-0.40
6	-0.32	-0.46
7	-0.36	-0.52
8	-0.40	-0.57
9	-0.45	-0.63
10	-0.49	-0.68
11	-0.53	-0.74
12	-0.57	-0.80
13	-0.62	-0.85
14	-0.66	-0.91
15	-0.70	-0.96

Attenuation per unit length is an average of six line measurements – lines having differing lengths. Microstrip transmission lines are ~9mils in width and 0.5mils in thickness; stripline transmission lines are ~4.5mils in line width and 0.5mils in thickness.

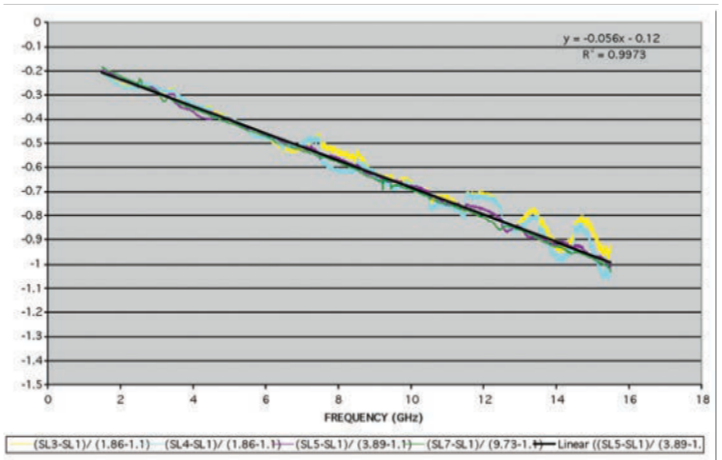

Figure 11.2.1: DuPont 951 Stripline Attenuation Lines – attenuation per unit length

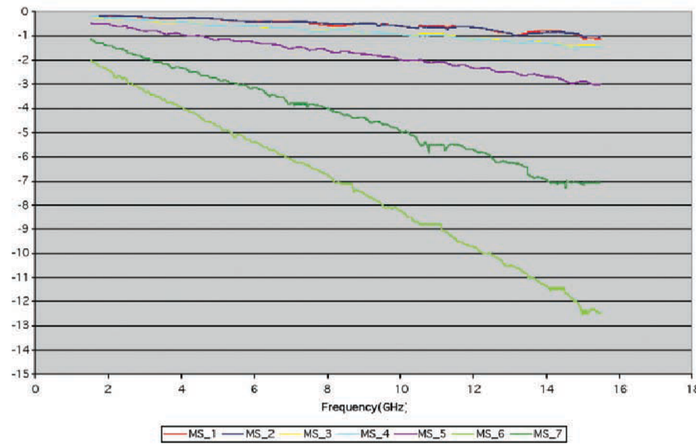

Figure 11.2.2: DuPont 951 Microstrip Attenuation Lines – attenuation per unit length