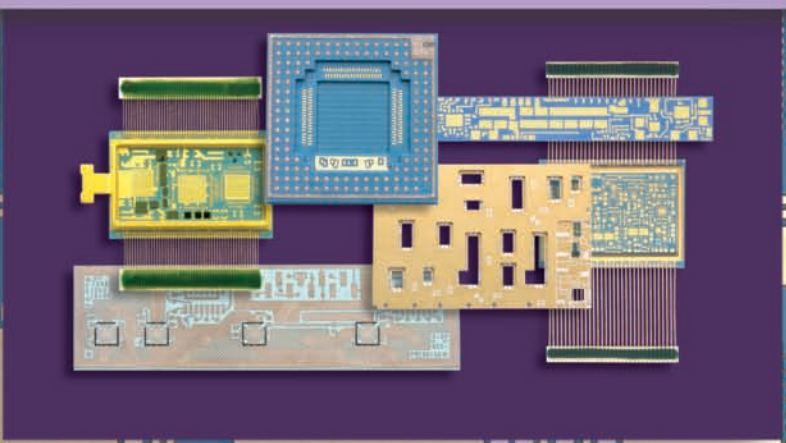
LTCC Design Guide



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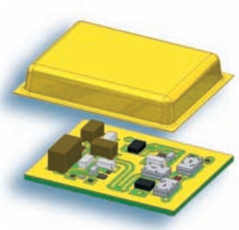
About this LTCC Design Guide



This LTCC Design Guide reflects the current LTCC capabilities of Anaren Ceramics' facility and experience. We've provided it to assist you in the initial evaluation of your design's compatibility with the LTCC technologies we offer – as well as to introduce you to methods, processes, and techniques that can minimize costs and cycle times.

This guide does not represent the full range of possibilities of our fast-expanding and continually improving technologies, nor does it replace the interaction between customers and Anaren Ceramics' engineers; this dialogue is welcome and needed to provide the most robust and cost-effective design.

About Us

Anaren Ceramics – Added to the Anaren team in 2001 and now a critical part of our Space & Defence Group, Anaren Ceramics is a leading manufacturer and innovator of quality ceramic technology. Our specialties include:

- **Custom and standard solutions.** Whether you require the high-performance and extreme tolerances of LTCC, the excellent performance and cost-competitiveness of a thick film solution, or one of hundreds of standard resistive components (including terminations, resistors, capacitors, inductors, and attenuators) – we're prepared to assist you. In all cases, you are assured of maximum design flexibility, a wide range of materials choices, and robust engineering support that sets us apart from ordinary built-to-print shops.
- **Vertical integration.** Need design assistance, ceramic machining, thick film screening, or LTCC manufacturing? How about etching, plating, laser trimming, and comprehensive product testing? Anaren Ceramics offers it all under one roof – for reduced costs, speedier turn times, and the advantages of shared information across disciplines.
- **Products for a diverse customer base.** At Anaren Ceramics, we work with customers in medical, wireless, optical, automotive, aerospace, aviation, and other industries. The varied and exacting demands of these sectors have made us proficient in developing all kinds of low-cost, quick-turn prototypes. They have also enabled us to compress our design-to-production cycle times; match our capacity to your low- or high-volume manufacturing needs; and develop a range of quality "stock" products, including microwave chip attenuators and the industry's smallest wire-bondable chip resistors (20 x 20 mils), to very high-performance specs.
- **The added confidence of Anaren engineering.** If your project calls for specialized microwave circuit design know-how in addition to Anaren Ceramics design capabilities, count on our sister company: Anaren Microwave, Inc. Results can include reduced costs and time-to-market.

So if you're thinking of solutions never before possible, think Anaren Ceramics! Start with this LTCC Design Guide for data, specifications, and drawings – then call us at 603-898-2883 when you need the expertise, experience, and capabilities to make those solutions real.

Product Quality Assurance

- ISO-9001:2000 registered
- Quality requirements MIL-Q-9858
- QPL listed chip resistors MIL-PRF-55342
- Test capabilities MIL-PRF-38534
- Test methods MIL-STD-883
- Other testing available by request

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LTCC Process

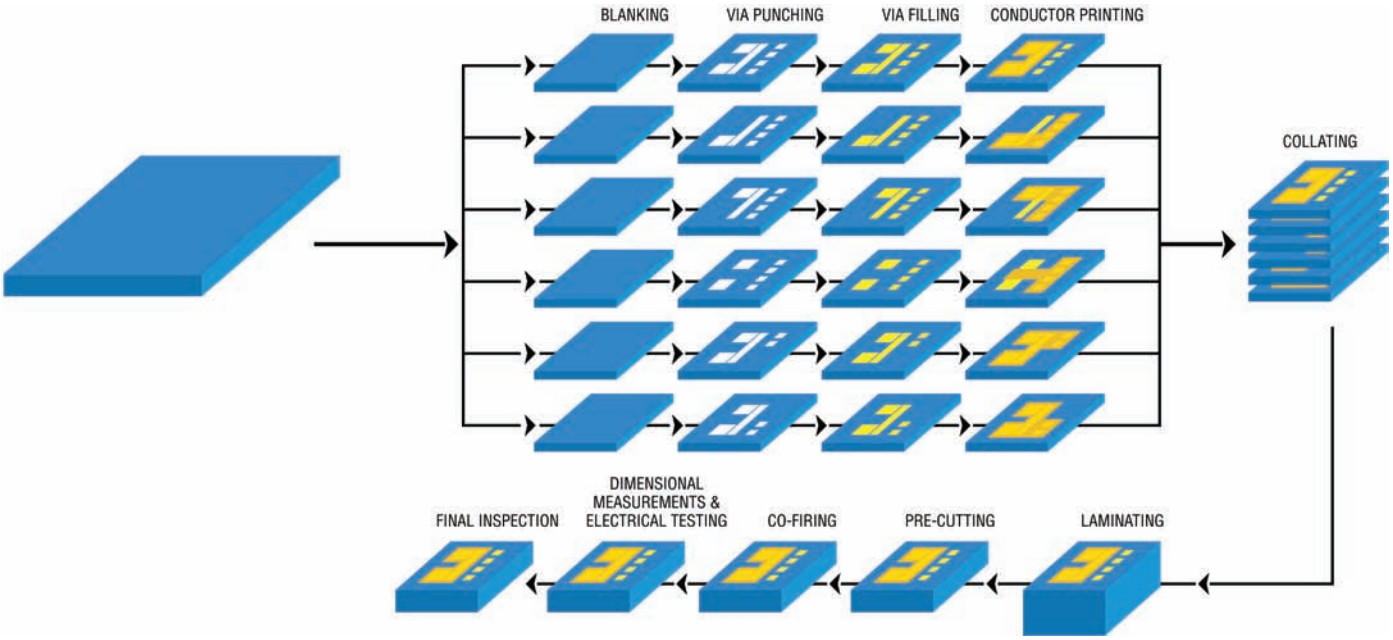


Figure 1.1.1: Typical Process for Fabricating an LTCC Structure
A series of steps are required for the production of LTCC structures. Performance, structure, and process capability of both ceramic and conductor are explained in the following pages.

Material Properties

Available Material Systems

Table: 2.1.1: Available Material Systems

Available Tape Systems	Available Metallization Systems
DuPont 951	All gold, all silver, mixed metal[1]
DuPont 9K7	All gold
DuPont 943	All gold, all silver
Heraeus CT702	All gold, all silver
Ferro A6M	All gold

Notes:
1. Mixed metal refers to a silver-gold combination – all inner conductors are silver for lower cost – outer conductors are gold for better wire bond ability.
2. Anaren Ceramics material processing capability is not limited to the materials called out here – please call Anaren Ceramics engineering department to discuss your special needs.

Material System Mechanical Properties

Table: 2.2.1: Material System Mechanical Properties

Parameter	DuPont 951	DuPont 943	Ferro A6M
Green sheet area (inches^2)	6.5 & 8.0	6.5 & 8.0	6.5
Usable green sheet area (inches)	4.6 & 6.2	4.6 & 6.2	4.5
XY shrinkage	12.92%	9.75%	14.85%
XY shrinkage tolerance	±0.3%	±0.3%	±0.3%
Green tape thickness (mils)	2, 4.5, 6.5, 10	2, 5, 10	5, 10
Fired tape thickness (mils)	1.7, 3.8, 5.5, 8.5	1.7, 4.25, 8.5	3.7, 7.4
Z shrinkage	15%	10.3%	25%
Z shrinkage tolerance	±0.5%	±0.5%	±0.5%
Patterning technology	Screen Print & Etch	Screen Print & Etch	Screen Print
Thermal Conductivity	3.3	4.4	2.0
Young's Modulus (GPa)	120	150	92
Poisson's Ratio	—	0.24	—
Flexural Strength (MPa)	320	230	170
Density (g/cm^3)	3.1	3.2	2.5

Note:
1. 951 & 943 mechanical data taken from DuPont website

Material System Electrical Properties

Table: 2.3.1: Material System Electrical Properties

Parameter	DuPont 951	DuPont 943	Ferro A6M
Dielectric Constant @3GHz	7.8	7.4	5.6
Dielectric Constant tolerance	±0.2	±0.2	—
Loss Tangent @3GHz	0.006	0.002	0.002
Breakdown voltage (V/25µm)	> 1000	> 1100	> 900

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

Conductor Parameters

Anaren Ceramics characterizes the cross sectional shape of a conductor embedded in an LTCC substrate 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)

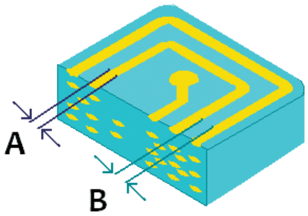


Figure 3.1.1: Line Width and Line to Line Spacing

Table 3.1.1: Line Width

	Absolute Minimum (mils)	Typical Minimum (mils)	Tolerance (mils)
(A)Printed	3.0	4.0	±1.0
(A)Etched	2.0	3.0	±0.5

Table 3.1.2: Line to Line Spacing

	Absolute Minimum (mils)	Typical Minimum (mils)	Tolerance (mils)
(B)Printed	3.0	4.5	±1.0
(B)Etched	2.0	3.0	±0.5

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. Etched parameters refer to Anaren Ceramics two etching processes:
   a. A green state etching process called Fodel which is applicable to DuPont material sets only;
   b. A post fired etching process.
5. Parameters are applicable to exposed and buried layers.

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

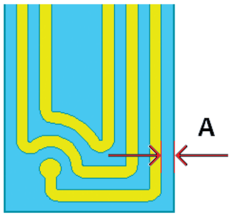


Figure 3.2.1: Conductor to Ceramic Edge

Table 3.2.1: Conductor to Ceramic Edge Parameters

	Absolute Minimum (mils)	Typical Minimum (mils)	Tolerance (mils)
(A)Printed	4.0	8.0	±1.0
(A)Etched	3.0	5.0	±0.5

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)

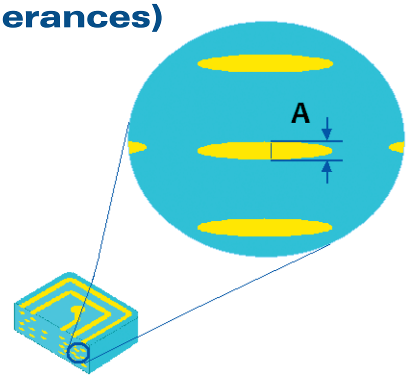


Figure 3.3.1: Conductor Thickness

Table 3.3.1: Conductor Thickness Parameters

	Absolute Minimum (mils)	Typical Minimum (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 Parameters

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

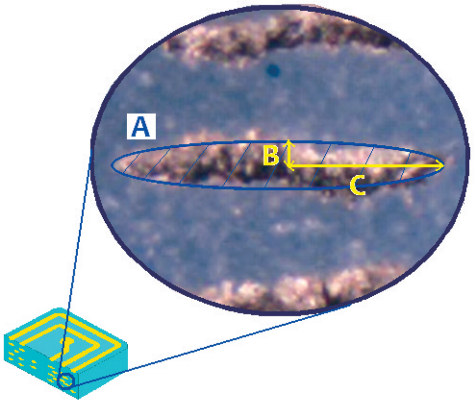


Figure 3.4.1: Cross-Section of a Conductor with a Traced Ellipse. The minor and major radius of the ellipse is shown. These radii define the thickness, width, and elliptical area of the conductor lines.

Table 3.4.1: 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 π serve as the formula for calculating the elliptical area. $A = B.C.\pi$
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.
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.

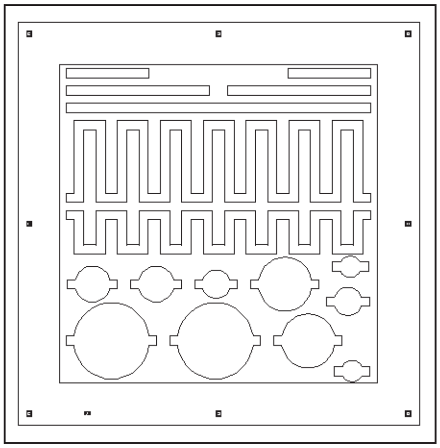


Figure 3.5.1: Buried Ground Plane, Metal Coverage <50%

- 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)

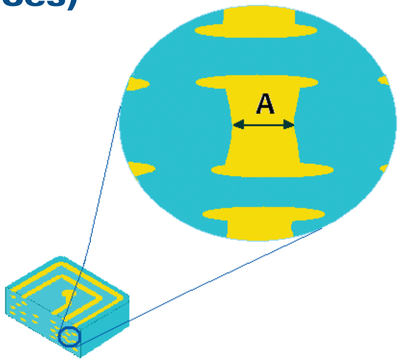


Figure 4.1.1: Diameter of Vias

Anaren defines via diameter as the narrowest point of the via transition form 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 4.1.1: 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.
2. See appendix B for further statistical data

Via Capture Pad (minimums, typical, and tolerances)

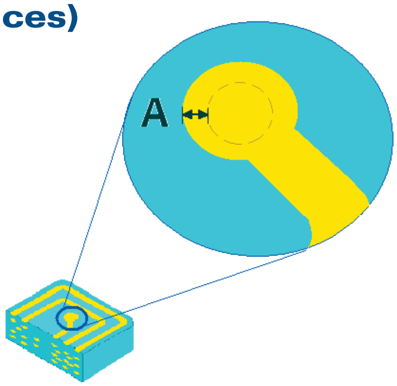


Figure 4.2.1: Via Capture Pad

Dashed line represents a via. Label (A) represents the distance from the via's edge to the edge of the capture pad.

Table 4.2.1: 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)

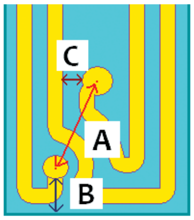


Figure 4.3.1: Via Spacing and Layout

Table 4.3.1: 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.

Multilayer Parameters

Tape Layer Thickness (minimum, typical, and tolerances)

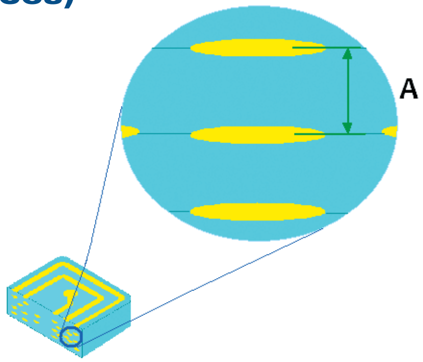


Figure 5.1.1: Ceramic Tape Layer Thickness

Table 5.1.1: Ceramic Tape Layer Thickness

Parameter	Minimum (mils)	Typical (mils)	Tolerance (mils)
(A) Tape thickness 2 mil	1.45	1.7	±0.25
(B) Tape thickness 4.5 mil	3.55	3.8	±0.25
(C) 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. Anaren Ceramics tape thicknesses are not limited to the tape thickness called out above. Please call Anaren Ceramics engineering department to discuss your special needs.

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

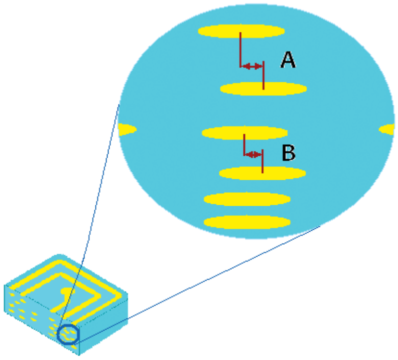


Figure 5.2.1: Layer to Layer Alignment

Table 5.2.1: Layer to Layer Alignment

Parameter	Typical (mils)	Tolerance (mils)
(A & B) Layer to layer alignment	0	±2.0

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 seperated 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 and DuPont 943 material sets. D_K is extracted from resonant frequency measurements using the following equations:

Table 6.1.1: 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 Anaren Ceramics. 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.

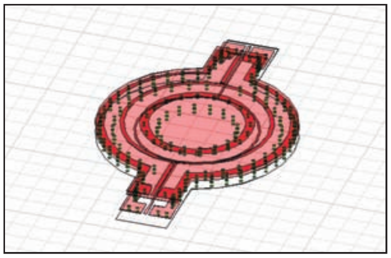


Figure 6.1.1: Dual Ring Resonator Structure

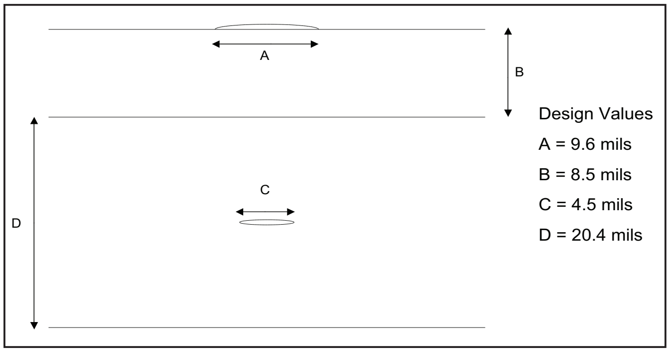


Figure 6.1.2: Transmission Line Dimensions – DuPont 951 & DuPont 943.

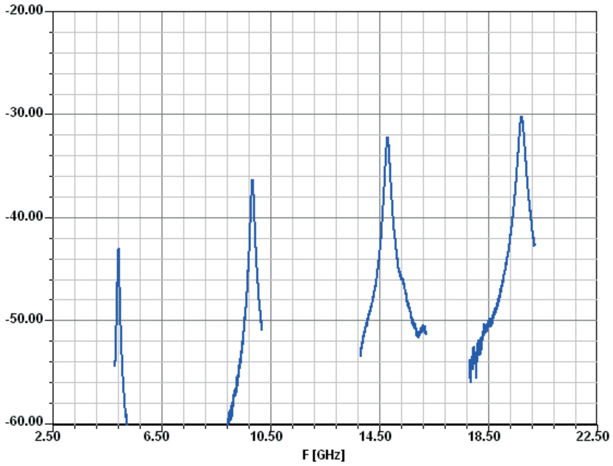


Figure 6.1.3: Typical Broadband 5GHz Ring Resonator Response showing resonances at the first/second/third and fourth harmonics.

RF & Microwave Parameters

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.

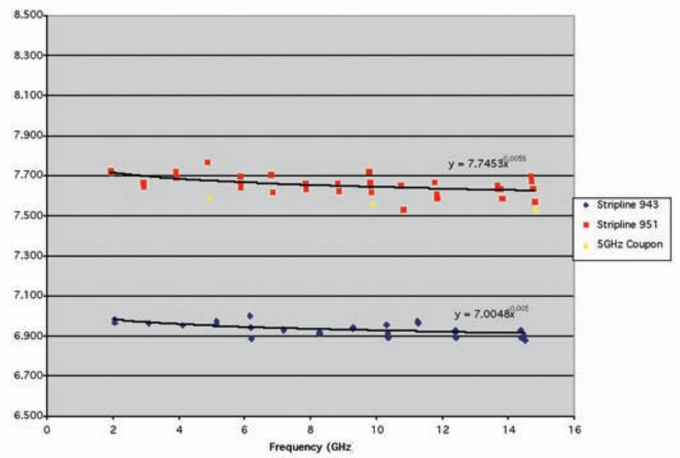


Figure 6.1.4: D_K Estimates for DuPont 943 and DuPont 951 from stripline ring resonator measurements

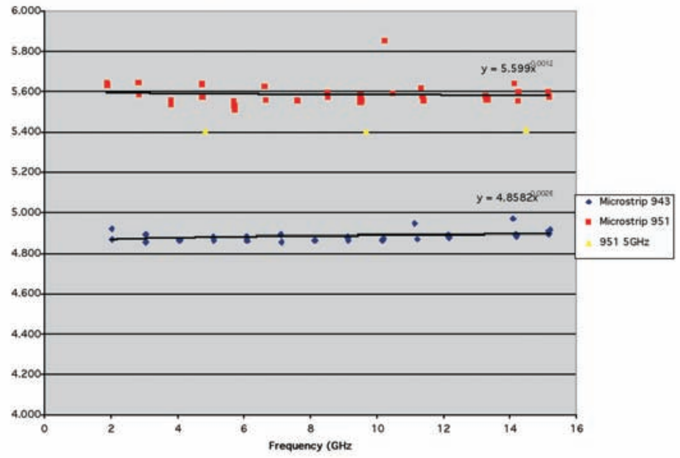


Figure 6.1.5: Effective D_K Estimates for DuPont 943 and DuPont 951 from microstrip

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 6.2.1: 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 6.2.2: Calculated attenuation/unit length for DuPont 951 and DuPont 943 stripline and microstrip transmission lines

	DuPont 951		DuPont 943	
Frequency (GHz)	Microstrip Attenuation /unit length (dB)	Stripline Attenuation /unit length (dB)	Microstrip Attenuation /unit length (dB)	Stripline Attenuation /unit length (dB)
2	-0.15	-0.24	-0.13	-0.20
3	-0.19	-0.29	-0.16	-0.23
4	-0.23	-0.35	-0.18	-0.26
5	-0.28	-0.40	-0.20	-0.29
6	-0.32	-0.46	-0.22	-0.31
7	-0.36	-0.52	-0.24	-0.34
8	-0.40	-0.57	-0.26	-0.37
9	-0.45	-0.63	-0.28	-0.39
10	-0.49	-0.68	-0.30	-0.42
11	-0.53	-0.74	-0.32	-0.45
12	-0.57	-0.80	-0.34	-0.47
13	-0.62	-0.85	-0.36	-0.50
14	-0.66	-0.91	-0.38	-0.53
15	-0.70	-0.96	-0.40	-0.55

RF & Microwave Parameters

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.

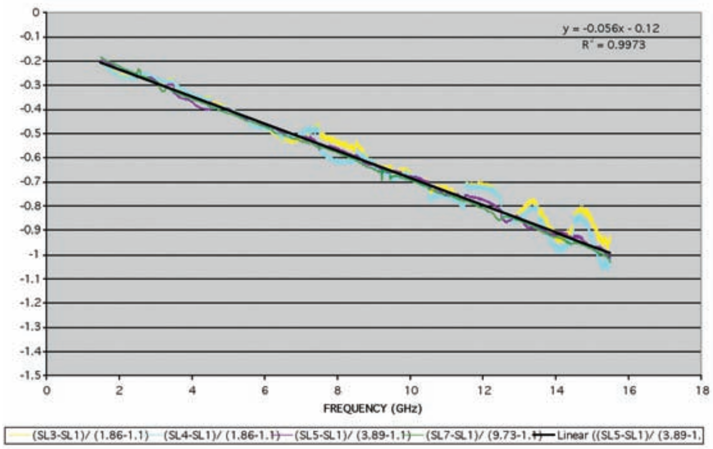


Figure 6.2.1: DuPont 951 Stripline Attenuation Lines – attenuation per unit length

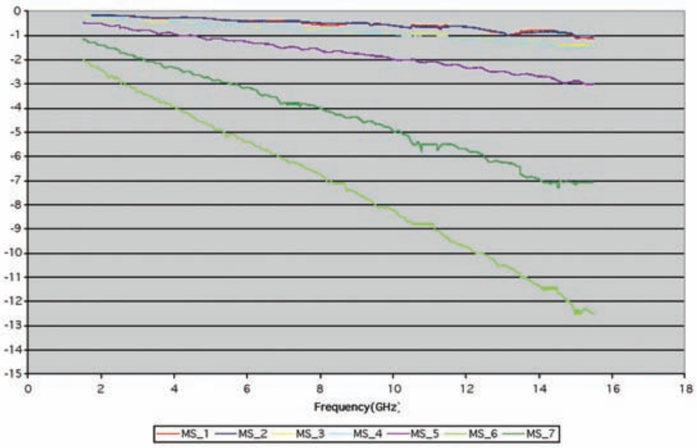
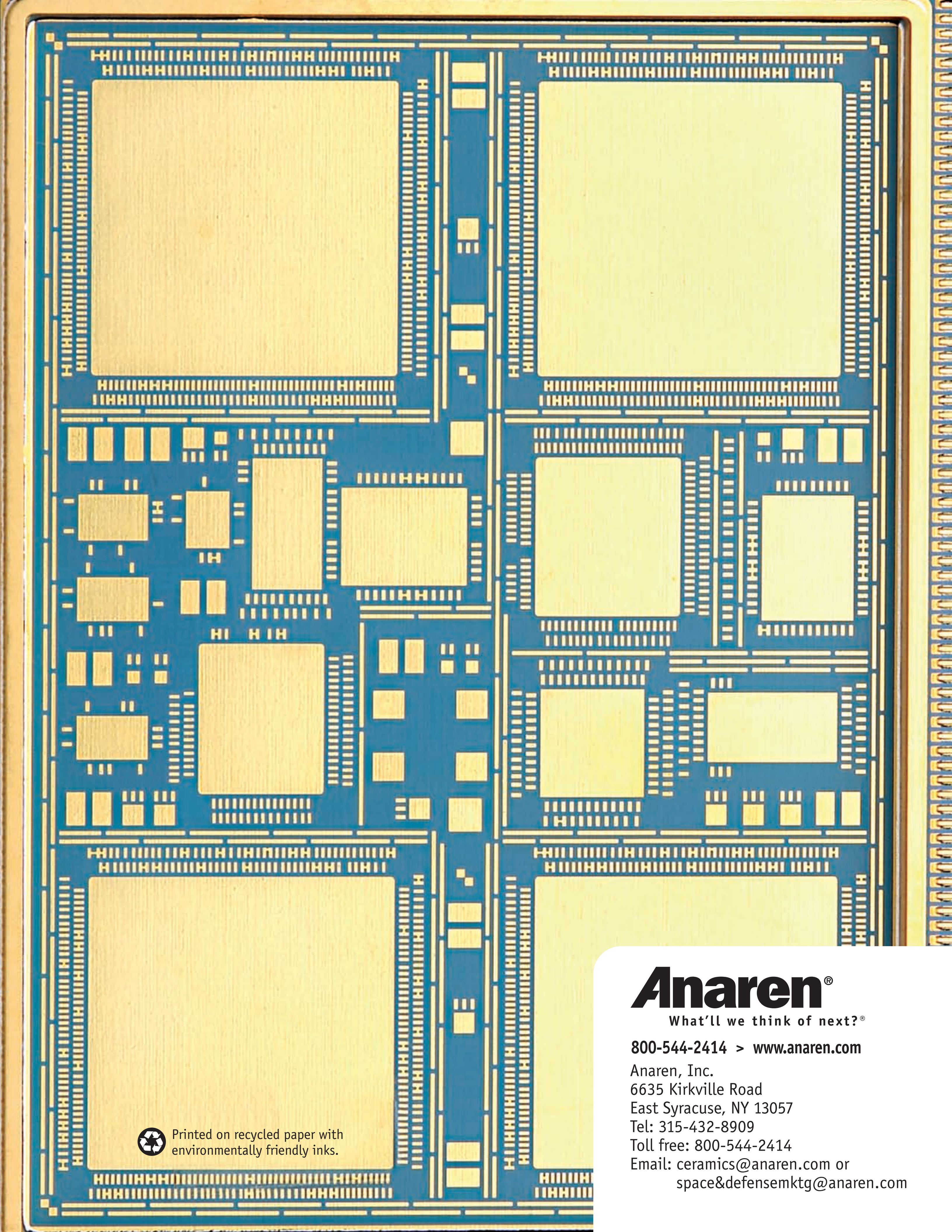


Figure 6.2.2: DuPont 951 Microstrip Attenuation Lines



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