MULTILAYER DIELECTRIC THICKNESS CALCULATION
by Tony Senese

Designing multilayer constructions involves several critical choices. One of the most difficult is that of determining the proper prepreg styles to use in order to yield critical dielectric thicknesses. To some this is a "black art" better left to experienced lamination supervisors. This usually involves a great deal of empirical testing or "first article" manufacturing techniques which are time consuming and expensive. This paper describes a simple mathematical model for predicting prepreg thickness yields which can bring the "black art" of multilayer construction into the light of day.

Critical Factors

The factors that determine prepreg dielectric thickness are:

1.) Circuit configuration
2.) Prepreg Parameters
  a.) Glass style
  b.) Resin content
  c.) Resin Flow

Each of these can be quantified mathematically within certain limitations. These limitations are dictated by normal process and raw material variations at both the prepreg supplier and the multilayer manufacturer. The effect of each type of variation will be taken into account here.

Circuit configuration

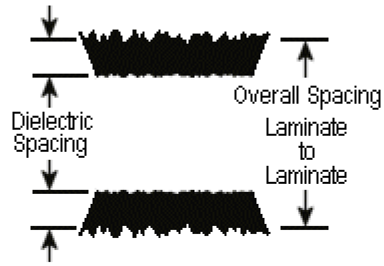
One of the most obvious, but most often left out, considerations in determining prepreg thickness yield is circuit configuration. Copper weight (and thus thickness) is only part of the picture.

Circuit contributions to overall MLB thickness can be determined by simply multiplying the copper thickness by the percentage of copper on each circuit pattern, as shown here.

copper weight = 1 ounce = .0013"
circuit pattern = signal = 20% copper
copper thickness contribution = .0013"x .20 = .00026"

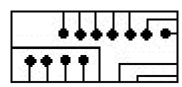
It is not so simple to calculate the circuit contribution to each individual dielectric space.

To some extent the location of the coupon and the border venting pattern play a role in predicting yields. In order to try to simplify this discussion we will assume that the border venting pattern contains the same amount of copper as the circuit area, and that coupons are at the edge of the multilayer panel. Normally, dielectric thickness measurements are made from the top of one circuit to the top of the next. It is therefore necessary to subtract out the copper thickness of each opposing circuit from the overall (laminate to laminate) thickness.



The equation for copper contribution to dielectric thickness then becomes:

copper weight = 1 ounce = .0013"



circuit pattern = signal = 20% copper

OA copper thickness contribution =
.0013"x .20 = **.00026"**

MINUS original copper thickness =
.00026" - .0013" **= -.00104**

This type of calculation may seem somewhat confusing because there is no such thing as "negative thickness" but this is the correct number to use for a circuits contribution to dielectric thickness since the circuit is encapsulated in the prepreg and thus reduces the spacing.

Thus we have calculated one of the two critical factors in determining our dielectric space. Before we go on to the more complicated task of calculating prepreg thickness lets look at the possible sources of variation in this calculation and their affect on spacing.

Improper estimation of circuit coverage

An error of 20% in the estimation of circuit coverage would yield the following error in calculating the dielectric spacing.

Actual circuit coverage = 10% on 1 oz. cu.

.10 x .0013" - .0013" = -.00117" actual

.30 x .0013" - .0013" = -.00091" estimate

Difference .00026"

This difference would be compounded by a factor of two since most dielectrics contain two opposing circuits. The total error is then .00052". M^2

Improper estimation of copper thickness

An error of .0002" in copper thickness would yield the following error in estimated spacing.

.10 x .0012" - .0012" = -.00108" actual

.10 x .0014" - .0014" = -.00126" estimate

Difference
.00018" x 2 (for both layers) = .00036"

Depending on which way each of these errors is made the compound error would be either:

.00036" + .00052" = .00088" or

.00052" - .00036" = .00016"

You can see it is important to be accurate with these engineering values as many times the entire tolerance for a given dielectric is only +/- .001".

Prepreg Parameters

Determining prepreg thickness yield can be very frustrating due to the number of factors involved. Unlike copper, prepreg thickness varies across the width of a panel. It is usually, thickest at the center and thinnest at the corners and edges. Prepreg thickness also varies within small areas on a panel due to copper configurations and prepreg nesting of multiple plies of similar glass styles. Fortunately, most of the variation can be accounted for if calculations are done for the thickest and thinnest possible outcome.

Glass style

The primary determinant of prepreg thickness is the glass style used. The chart below lists 5 of the most common glass styles used in our industry and their characteristics.

Glass Style	Density (g/cc)	Thickness (Mils)	Basis Weight (oz/sq.yd.)	Basis Weight (g/ M^2)
106	2.54	1.2 - 1.4	.70 - .74	23 - 26
1080	2.54	1.9 - 2.3	1.35 - 1.41	45 - 50
2313	2.54	3.0 - 3.5	2.20 - 2.50	77 - 84
2116	2.54	3.4 - 4.0	2.90 - 3.15	97 - 107
7628	2.54	6.4 - 7.2	5.70 - 6.35	197 - 212

As you can see each style occupies a natural thickness range. There is some overlap between styles, but for the most part each is unique.

Resin Content

For years the circuit board industry has specified resin content for prepreg. This is a simple percentage, based on weight, of resin to glass. The problem with this type of specification is that thickness varies with the volume percentage of the resin, not the weight. Laminators learned many years ago that they could more accurately predict thickness yields if they controlled the overall weight or "treated weight" of a prepreg and not the ratio of resin to glass. This is because thickness varies directly with volume. If glass basis weight goes up, the resin volume must be increased to maintain the same resin content. This increases the total thickness. If total weight is being controlled and the glass basis weight goes up, then the resin volume is decreased to maintain the same basis weight. This results in almost no change in total thickness. From resin density (1.35 g/cc), glass density (2.54 g/cc) and glass basis weight ranges above we can calculate the initial thickness range (Ho) for any given prepreg style using the following equation.

1.) To convert from weight % to initial thickness (Ho)

Wg = Unit glass basis weight in g/ M^2
RD = Resin Density (1.35 g/cc)
GD = Glass Density (2.54 g/cc)
RC = Weight % resin content

$$Ho = \frac{Wg}{(GD)(25.4)\left(1 - \frac{RC/RD}{RC/RD + (100-RC)/GD}\right)}$$

or paste this array into a spreadsheet:

50	Wg = Unit glass basis weight in g/M
1.35	RD = Resin Density (1.35 g/cc)
2.54	GD = Glass Density (2.54 g/cc)
65	RC = Weight % resin content
3.482996	Thickness in mils

EXAMPLE

2313 prepreg - 57-63% resin content total possible thickness range
(before resin flow)

Minimum
Basis weight 77g/M2, RC 57% = .00417"

Maximum
Basis weight 84g/M2, RC 63% = .00515"

Using this equation and typical resin content ranges, the initial thickness ranges for the five glass styles listed above are show in TABLE I.

TABLE I

Glass Style	Resin Content	Thickness* (Mils)
106	72-77	2.1-2.8
1080	61-67	2.8-3.4
2113	53-56	3.8-4.6
2116	51-57	4.6-5.4
7628	40-46	7.2-8.0

*This is the maximum possible thickness contribution.

These thickness yields would encompass the entire range for each style except for the inconvenience of resin flow during lamination. This makes our calculation of minimum thickness/ply much more difficult. We must subtract out resin lost due to flow and to fill in copper in order to determine absolute minimum and maximum prepreg dielectric spacing. Calculation of prepreg thickness lost due to copper fill was previously covered. (Remember the negative thickness number?) So all we have to worry about is resin lost due to flow. This is the most process dependent part of our equation.

Prepreg melt rheology, heat rise, kiss cycle time and full lamination pressure will all affect the amount of resin flow. Other minor factors are border venting design, panel size, and lamination tooling.

The easiest way to quantify this is to measure the center and edge thickness of several different board types. Calculate the percentage taper in thickness and subtract that same percentage from the numbers in Table I. The percentage must be calculated over prepreg thickness only. This is not to say that laminate thickness does not vary, but for most panel sizes laminate thickness does not contribute significantly to edge taper.

Part#	Thickness Center	Thickness Edge	Prepreg Thickness	% Taper
139850280	0.079	0.072	0.042	16.70%
238696219	0.064	0.058	0.03	13.30%
64967565	0.125	0.11	0.064	23.40%
89346750	0.095	0.088	0.044	15.90%
	Average Taper		17.3%	

TABLE II

Glass Style	Resin Content	Maximum Thickness (Mils)	Minimum* Thickness (Mils)	Nominal Thickness (Mils)
106	72-77	2.1-2.9	1.7-2.4	2.3
1080	62-67	2.8-3.7	2.3-3.1	3
2313	57-63	4.2-5.2	3.5-4.3	4.35
2116	54-60	4.8-6.3	4.0-5.2	5.15
7628	42-46	7.2-8.6	6.0-7.1	7.3

* 17.3% less than maximum thickness due to edge taper.

From TABLE II we can calculate the extremes of process and materials and determine the best construction for a given dielectric. Remember, this will be the thickness range from the center to the edge of the board under worse case variability.

The key to making this calculation work is to build as close to the nominal dielectric specification as possible. This will give the best overall results.

EXAMPLE

Dielectric spacing between layer 2 and 3 is .005" +/- .0015. Layer 2 and 3 are both one ounce copper with 20% circuit coverage.

STEP 1. -- Calculate copper thickness contribution.

(2 x .0012") x 20% - (2 x .0012") = -.00192"

Step 2. -- Calculate nominal dielectric of likely alternatives.

A) 2 plies of 1080

	MIN	MAX
1080	2.3	3.7
1080	2.3	3.7
Copper	-1.92	-1.92

2.68-5.48 or 4.08 +/- 1.4

B) 1 ply 106, 1 ply 2313

	MIN	MAX
106	1.7	2.9
2313	3.5	5.2
Copper	-1.92	-1.92

3.28-6.18 or 4.73 +/- 1.45

C) 1 ply 106, 1 ply 2116

	MIN	MAX
106	1.7	2.9
2116	4	6.3
Copper	-1.92	-1.92

3.78-7.28 or 5.53 +/- 1.75

D) 1 ply 1080, 1 ply 2313

	MIN	MAX
1080	2.3	3.7
2313	3.5	5.2
Copper	-1.92	-1.92

3.88-6.98 or 5.43 +/- 1.55

E) 3 plies of 106

	MIN	MAX
106	1.7	2.9
106	1.7	2.9
106	1.7	2.9
Copper	-1.92	-1.92

3.18-6.78 or 4.98 +/- 1.8

Alternative "B" is the closest of the four but does not quite meet the specification. This is not of great concern however. Our model takes into account the absolute worse case scenario. The extreme thicknesses will only occur if both glass styles used are at either the top or the bottom of their resin content specification at the same time. This is one reason to try to use at least two different glass styles in each dielectric opening. This practice also minimizes the amount of "nesting" that can occur and makes thickness predictions more reliable.

Conclusion

Accurate prediction of dielectric thickness in multilayer printed circuit boards is dependent on several critical factors. These factors can be measured and modeled using simple mathematics.

The benefits of this approach are:

The accuracy of the model is dependent on the accuracy of the data used to calculate resin flow and initial thickness, not a supervisor’s memory. Expensive, time consuming first article manufacturing techniques can be eliminated through the use of this approach to multilayer construction.

Standard layup configurations can be designed that will meet customer requirements more accurately and consistently.

Manufacturability and cost of a given design can be evaluated before the fact, not, after the scrap.