Design and Fabrication of Thinner, Higher Speed Flexible Circuits

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Abstract:
Modern flexible printed circuits demand improved signal integrity due to increasing data rate requirements for interconnects. At the same time, form factors available to designers are becoming smaller. All polyimide flexible circuit materials have been used in high-reliability applications for decades. [1, 2] There is a well-established infrastructure of fabricators skilled in manufacturing controlled impedance flexible circuits. Solutions to meet the challenge of thinner, higher speed controlled impedance circuits include improved materials, more disciplined manufacturing and more comprehensive, improved, electrical characterization data.

Historically, performance specifications for flexible circuits were driven by mechanical properties. Electrical considerations were secondary. Today, controlled impedance circuit tolerances are becoming tighter and higher frequency performance is an additional requirement. Since flexible circuit dielectrics are very thin, small differences in dielectric properties can have a large impact on impedance. These thinner dielectrics reduce form factor due to decreased volume, also thin layers can be folded into tighter bends than conventional printed wiring.

Designers and fabricators use software tools like Polar [3] to model circuit geometry to achieve the target impedance. Unfortunately, dielectric data available in typical data sheets is inadequate to successfully design and fabricate a controlled impedance flexible circuit. As a response to this reality, each fabrication shop and design house uses slightly different values for dielectric constant. This approach works OK if the impedance tolerance is relatively wide, but becomes unsustainable for tighter tolerances or higher frequencies.

This paper is divided into two parts:

Part 1 describes differential impedance test structures using adhesive/polyimide, all polyimide, and new high speed flexible circuit materials. Measured data is compared to Polar models with increasing degrees of complexity. The values of dielectric constant used will show agreement between measured and modeled results of 2.5% or better.

Part 2 summarizes the evaluation results of new high speed flexible circuit materials from the perspective of a leading flexible circuit fabricator. The ease and quality of processing will be compared to traditional adhesive/polyimide and all polyimide flex materials. Results will confirm that the high speed flexible circuit materials are fully compatible with standard flexible circuit processing without significant process modifications.

Introduction:
A successful controlled impedance circuit has a robust design that consistently falls within the defined specification limits. Whenever possible, the tolerance is designed as wide as possible to maximize yields and minimize cost. Typical impedance tolerance for a robust design is ±10% or ±15%. As speed demands go higher, typically designers need to tighten the impedance tolerance. Designs with impedance tolerance of ±5% are emerging

The physical reason for why impedance tolerance needs to be tightened as speed increases has to do with reflections due to impedance discontinuities. An ideal controlled impedance circuit will have constant impedance through the entire design range. Whenever there is a change in impedance over the transmission line, there is reflected signal. The larger the impedance change, the larger the reflection.

The main adjustment that fabricators can make to keep impedance constant is to control etching and plating so that line width stays as constant as possible. Designers can adjust more parameters in a circuit including dielectric thickness and types of dielectrics used. Critical for success of both designers and fabricators is well characterized materials. The most important material property for controlled impedance is dielectric constant. The focus of this work is to show “real world” controlled impedance structures. The output of this work is dielectric constant values that designers and fabricators can use for modeling of controlled impedance flexible circuitry.

Dielectric Constant Values:

Most values stated in product literature for dielectric constant are "bulk" values. In general, samples tested to determine "data sheet" dielectric constant values are much thicker >10 mils than samples used for flexible circuits. Dielectric constant values used in practice by flexible circuit designers are generally about 5 to 15% lower than the values stated in data sheets. Another distinguishing characteristic of dielectrics used in conventional flexible circuits is the fact that the adhesives have a different (usually lower) dielectric constant than the standard polyimide core material. Based on low frequency bulk measurements and feedback from various fabricators, DuPont has determined dielectric constant values of standard polyimide, Adhesives and all polyimide materials. Initial assumptions of new materials (fluoropolymer/polyimide composites) are also provided as summarized in Table 1.

Table 1

Material	Dielectric Constant
Stand PI	3.50
Stand Adhesive	2.95
Flame Resistant Adhesive	3.05
Adhesiveless PI	3.10
Flouropolymer PI (1:1 Ratio)	2.50
Flouropolymer PI (2:1 Ratio)	2.25

In cases where the dielectric constant needs to be determined for a composite structure (such as coverlay), a weighted average of the two dielectrics determined the dielectric constant used in a model.

Methodology:

An edge-coupled differential microstrip structure was chosen since this is one of the most common controlled impedance topologies utilized in flexible circuit applications. This structure has a two signal lines above a ground plane. The critical properties influencing impedance are dielectric constant (Er), dielectric thickness (H), conductor width (W), conductor thickness (T) and spacing between conductors (S).

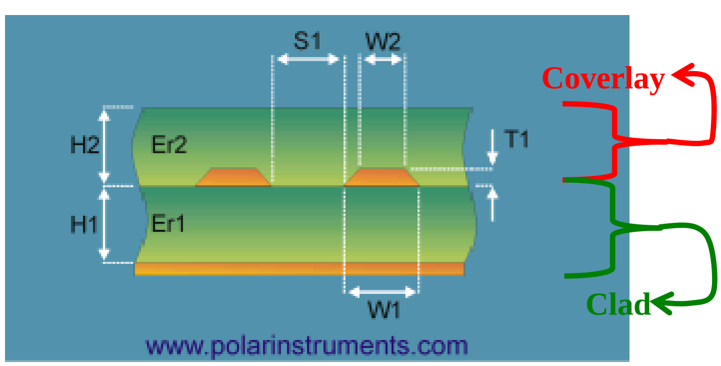


Figure 1 – Basic differential microstrip structure used.

Table 2

Case	Clad	Coverlay
A	2 mil thick adhesiveless polyimide clad to ½ oz Cu	1 mil standard adhesive on one side of 1 mil standard polyimide
B	2 mil standard polyimide with 1 mil standard adhesive on each side clad with ½ oz Cu	1 mil standard adhesive on one side of 1 mil standard polyimide
C	2 mil standard polyimide with 1 mil flame resistant adhesive on each side clad with ½ oz Cu	1 mil thick flame resistant adhesive on one side of 1 mil standard polyimide
D	2 mil fluoropolymer:polyimide composite combined at 1:1 ratio clad to ½ oz Cu	1 mil standard adhesive on one side of 1 mil standard polyimide
E	3 mil thick adhesiveless polyimide clad to ½ oz Cu	1 mil standard adhesive on one side of 1 mil standard polyimide
F	3 mil standard polyimide with 1 mil standard adhesive on each side clad with ½ oz Cu	1 mil standard adhesive on one side of 1 mil standard polyimide
G	3 mil standard polyimide with 1 mil flame resistant adhesive on each side clad with ½ oz Cu	1 mil thick flame resistant adhesive on one side of 1 mil standard polyimide
H	3 mil fluoropolymer:polyimide composite combined at 2:1 ratio clad to ½ oz Cu	1 mil standard adhesive on one side of 1 mil standard polyimide

A total of 24 samples were fabricated as part of this study. Three boards of eight different copper clad flexible circuits were manufactured. Compatible coverlay material was used in each case. Two impedance measurements were made on each board. The following table details the construction for the experiments performed.

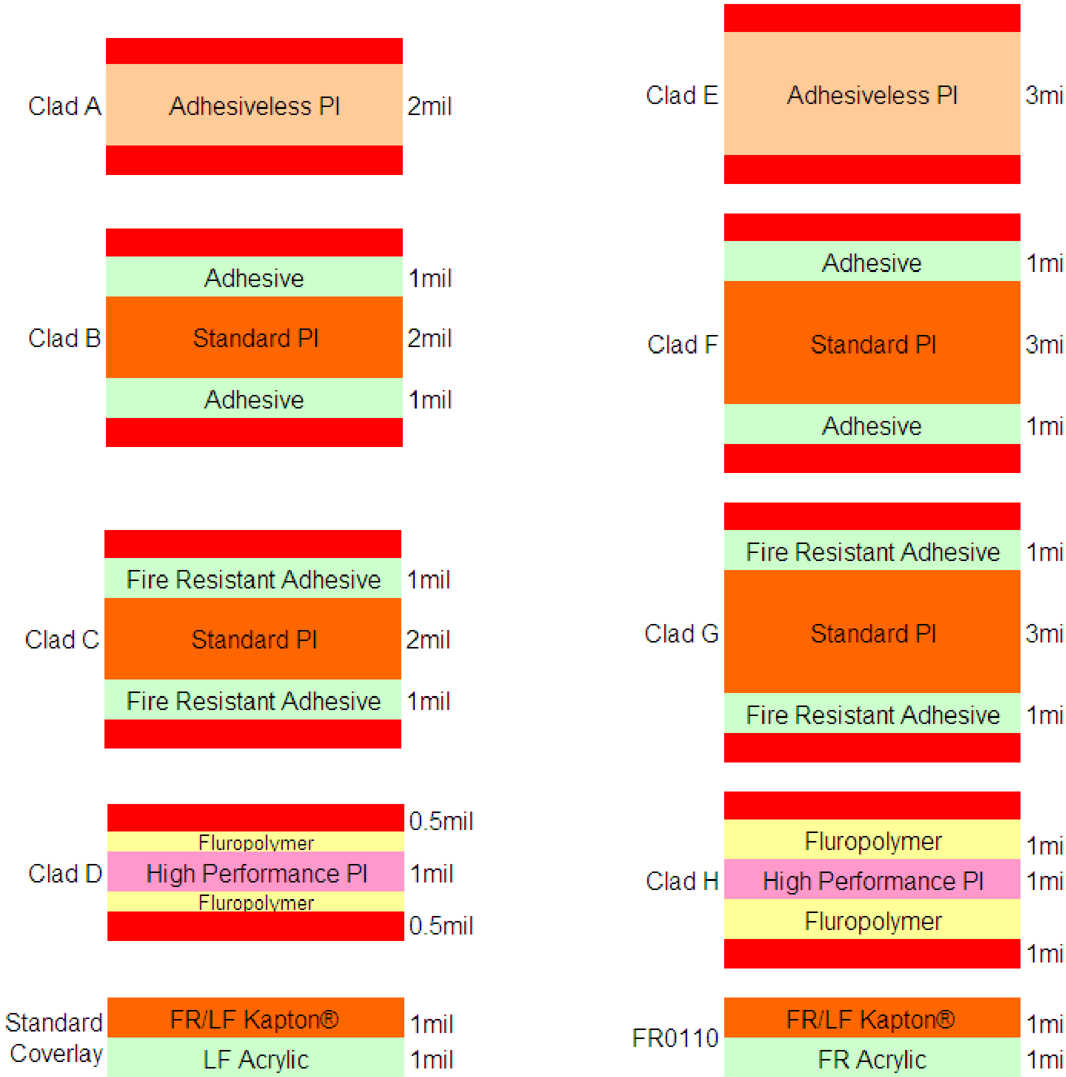


Figure 2 – Detailed descriptions of copper clad laminates and coverlays used in test

For the sake of consistency, the same pitch between signal lines was used for each differential pair. The nominal target coupon line widths were varied between 5.0 mil and 6.5 mil. As a result, target differential impedance varied between 70 ohms and 120 ohms due to the different thickness and dielectric constants of the materials.

After the test boards were fabricated and impedance measurements were recorded, a coupon from each board was cross-sectioned. Critical dimensions were recorded according to the Polar SI 9000 cross-section model. The differential impedance from the calculated model was compared to the measured values. The two results are compared to determine if either model calculates impedance values that more accurately meet the measured impedance. Model 1 considers both the clad and the coverlay as homogeneous. Model 2 considers the adhesive and the standard polyimide as having their distinct dielectric constant values.

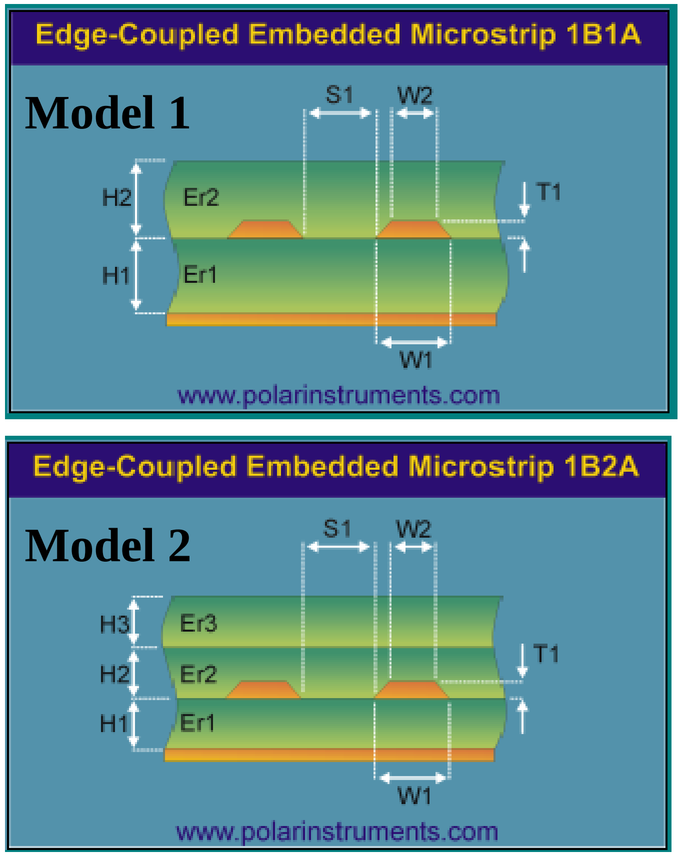


Figure 3 – Polar SI9000 models used to evaluate impedance.

Results:
Impedance measurements are shown in Table 3 (below) for each of the 24 boards. A typical cross section measurement is shown in Fig 4.

Table 3

Case	Board	Design (mils) W	Design (mils) S	Measured Zdiff (ohms)
A	1	6.0	7.0	72.2
	2	6.0	7.0	73.6
	3	6.0	7.0	71.7
B	1	5.5	7.5	105.8
	2	5.5	7.5	106.8
	3	5.5	7.5	104.8
C	1	5.5	7.5	109.1
	2	5.5	7.5	108.4
	3	5.5	7.5	110.6
D	1	5.5	7.5	79.9
	2	6.5	6.5	78.5
	3	6.0	7.0	77.4
E	1	6.0	7.0	88.1
	2	6.0	7.0	89.5
	3	5.5	7.5	90.0
F	1	5.0	8.0	122.0
	2	5.5	7.5	114.6
	3	5.5	7.5	113.4
G	1	5.5	7.5	113.0
	2	5.5	7.5	113.4
	3	5.0	8.0	113.4
H	1	6.0	7.0	99.5
	2	6.0	7.0	98.6
	3	5.5	7.5	101.4

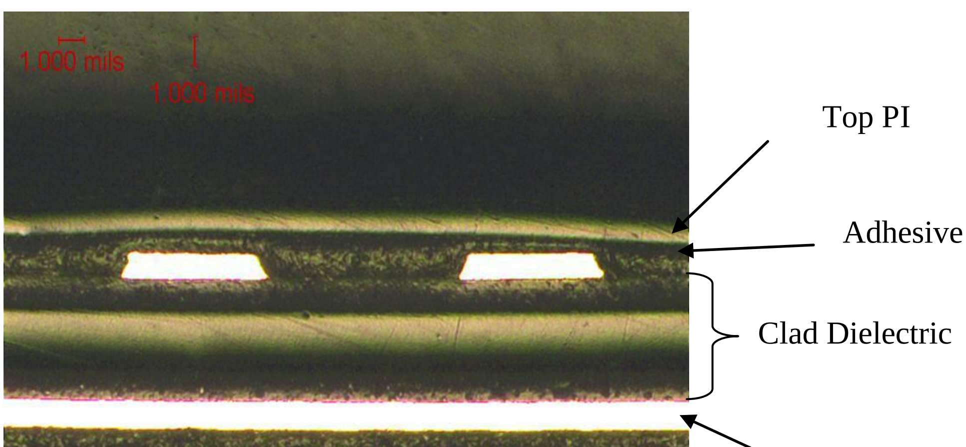


Figure 4 – Cross Section of a typical "Case B" coupon

Dimensions were measured based on those for a specific Polar model. A separate data table is shown for each model (Table 4 and Table 5).

Table 4

Model 1 Data		Measurements in mils					
Case	Board	H1	H2	W1	W2	S1	T1
A	1	1.90	2.72	5.84	5.32	7.24	0.80
	2	1.93	2.65	5.74	5.29	7.18	0.84
	3	1.90	2.52	6.10	5.46	6.75	0.81
B	1	3.95	2.33	5.45	4.65	7.21	0.79
	2	3.95	2.49	5.56	4.81	7.21	0.77
	3	4.05	2.49	5.77	4.93	6.98	0.85
C	1	4.28	2.26	5.56	4.81	7.24	0.80
	2	4.28	2.52	5.66	4.89	7.05	0.84
	3	4.25	2.42	5.35	4.75	7.57	0.81
D	1	1.90	2.29	5.97	5.19	6.95	0.82
	2	1.93	2.23	6.17	5.33	6.66	0.78
	3	1.96	2.29	6.53	5.43	6.23	0.85
E	1	2.91	3.08	6.22	5.43	6.43	0.74
	2	2.84	2.59	5.73	5.32	7.08	0.87
	3	2.85	2.85	5.97	5.27	6.92	0.82
F	1	4.93	2.48	4.73	4.27	7.93	0.78
	2	5.10	2.38	5.42	4.75	7.34	0.80
	3	4.97	2.62	5.48	4.88	7.34	0.82
G	1	4.74	2.39	5.50	4.99	7.24	0.83
	2	4.87	2.52	5.63	4.93	7.01	0.82
	3	4.87	2.59	5.38	4.88	7.37	0.80
H	1	2.84	2.49	6.22	5.38	6.62	0.83
	2	2.88	2.49	6.15	5.42	6.56	0.82
	3	2.91	2.72	5.99	5.46	6.92	0.81

Table 5

Model 2 Data		Dimensions in mils						
Case	Board	H1	H2	H3	W1	W2	S1	T1
A	1	1.90	1.80	0.92	5.84	5.32	7.24	0.80
	2	1.93	1.70	0.95	5.74	5.29	7.18	0.84
	3	1.90	1.57	0.95	6.10	5.46	6.75	0.81
B	1	3.95	1.44	0.89	5.45	4.65	7.21	0.79
	2	3.95	1.54	0.95	5.56	4.81	7.21	0.77
	3	4.05	1.54	0.95	5.77	4.93	6.98	0.85
C	1	4.28	1.37	0.89	5.56	4.81	7.24	0.80
	2	4.28	1.60	0.92	5.66	4.89	7.05	0.84
	3	4.25	1.44	0.98	5.35	4.75	7.57	0.81
D	1	1.90	1.34	0.95	5.97	5.19	6.95	0.82
	2	1.93	1.44	0.89	6.17	5.33	6.66	0.78
	3	1.96	1.40	0.89	6.53	5.43	6.23	0.85
E	1	2.91	2.16	0.92	6.22	5.43	6.43	0.74
	2	2.84	1.63	0.96	5.73	5.32	7.08	0.87
	3	2.85	1.99	0.86	5.97	5.27	6.92	0.82
F	1	4.93	1.50	0.98	4.73	4.27	7.93	0.78
	2	5.10	1.40	0.98	5.42	4.75	7.34	0.80
	3	4.97	1.57	1.05	5.48	4.88	7.34	0.82
G	1	4.74	1.47	0.92	5.50	4.99	7.24	0.83
	2	4.87	1.67	0.85	5.63	4.93	7.01	0.82
	3	4.87	1.70	0.89	5.38	4.88	7.37	0.80
H	1	2.84	1.47	1.02	6.22	5.38	6.62	0.83
	2	2.88	1.31	0.95	6.15	5.42	6.56	0.82
	3	2.91	1.83	0.89	5.99	5.46	6.92	0.81

Analysis:

Dielectric constant values from Table 1 and dimensions from cross sections (Tables 4 and 5) were applied to the Polar SI9000 analysis tool. The screen shots shown in Figure 5 and Figure 6 show the analysis results for Model 1 and Model 2 respectively. Specifically structure A, board 1 is shown in both examples.

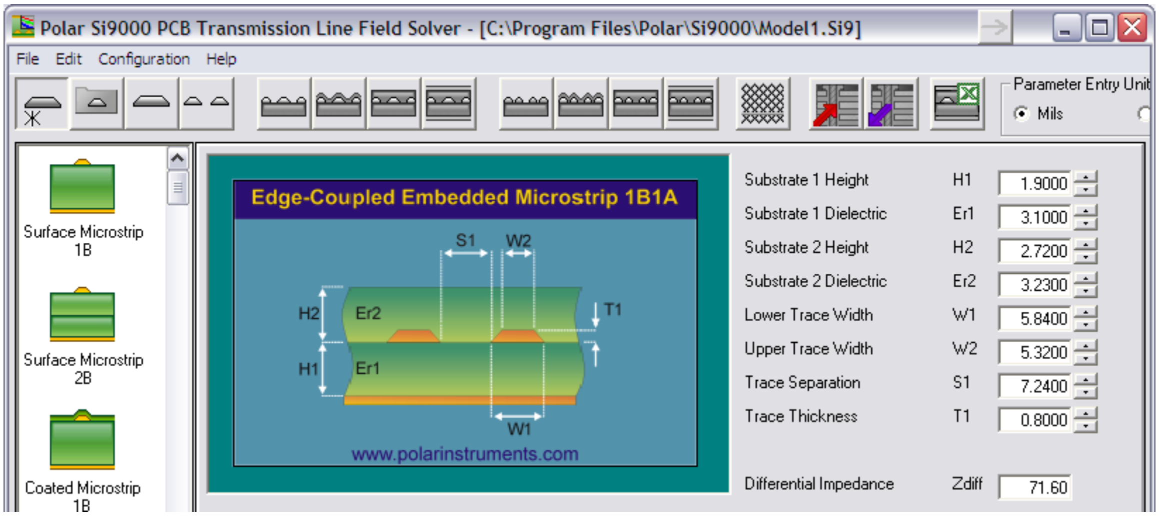


Figure 5 – Example of Analysis for Model 1

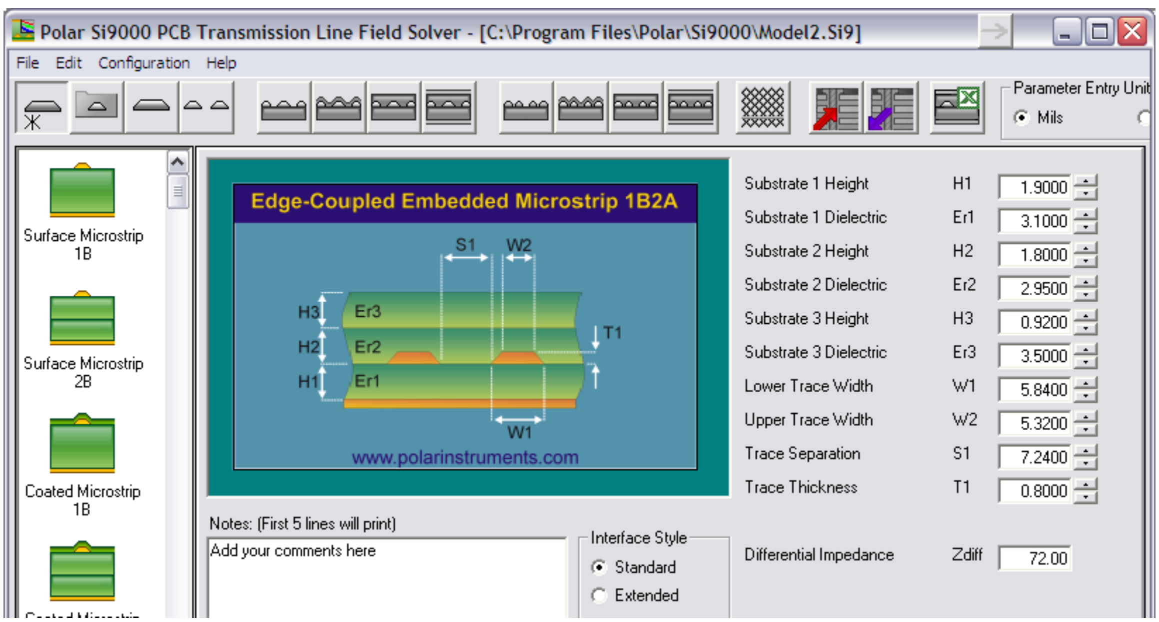


Figure 6 – Example of Analysis for Model 2

Ideally the modeled impedance and the measured impedance should be equal. For a model this simple, a difference of +/-5% is reasonable and a difference of +/-2.5% is considered excellent. Table 6 summarizes the Polar analysis calculations and compares each model to the measured result. Delta values in green indicate agreement within +/-2.5% while values in red indicate a deviation of more than +/-2.5%. Note that in all cases, the difference between measured and modeled impedance is within +/-5%.

Table 6

Case	Board	Differential Impedance (Ohms)			%Δ (Model-Meas)	
		Model 1	Model 2	Measured	Model 1	Model 2
A	1	71.6	72.0	72.2	-0.9%	-0.3%
	2	72.6	73.0	73.6	-1.3%	-0.7%
	3	69.9	70.9	71.7	-2.6%	-1.2%
B	1	106.2	106.6	105.8	0.4%	0.8%
	2	104.9	105.3	106.8	-1.8%	-1.4%
	3	103.2	103.6	104.8	-1.5%	-1.1%
C	1	109.4	109.9	109.1	0.3%	0.7%
	2	107.0	107.6	108.4	-1.3%	-0.8%
	3	110.6	111.1	110.6	0.1%	0.5%
D	1	77.2	77.5	79.9	-3.5%	-3.1%
	2	76.6	76.8	78.5	-2.5%	-2.2%
	3	74.3	74.6	77.4	-4.0%	-3.6%
E	1	86.3	87.2	88.1	-2.1%	-1.0%
	2	89.1	89.6	89.5	-0.4%	0.1%
	3	87.9	88.5	90.0	-2.3%	-1.6%
F	1	121.5	122.0	122.0	-0.5%	-0.1%
	2	115.8	116.1	114.6	1.0%	1.3%
	3	113.1	113.6	113.4	-0.3%	0.1%
G	1	111.9	112.4	113.0	-1.0%	-0.5%
	2	111.5	112.2	113.4	-1.7%	-1.1%
	3	114.3	114.6	113.4	0.8%	1.0%
H	1	96.0	96.4	99.5	-3.5%	-3.0%
	2	96.8	97.9	98.6	-1.9%	-0.8%
	3	98.1	98.9	101.4	-3.2%	-2.5%

Further Analysis:

All of the boards made from Acrylic based copper clad laminates (B, C, F and D) have excellent agreement between measured and modeled results. For the all polyimide non-acrylic based laminates (A,D, E and H), the agreement was good, but all were not within the +/-2.5% target. As a result, cross sections were analyzed more closely to determine if differences could be found between these two cases. Figure 8 shows typical examples of non-acrylic laminates (Board A) versus acrylic based laminates (Board B). Note that the signal lines for Board B are clearly fully encapsulated by the coverlay while Board A appears to have a small air gap, or at least incomplete encapsulation between the signal lines.

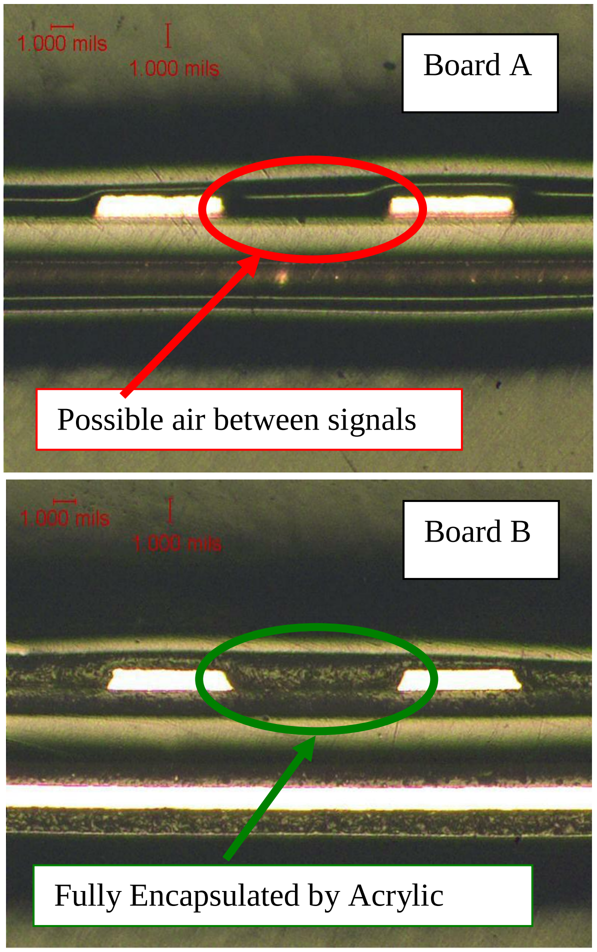
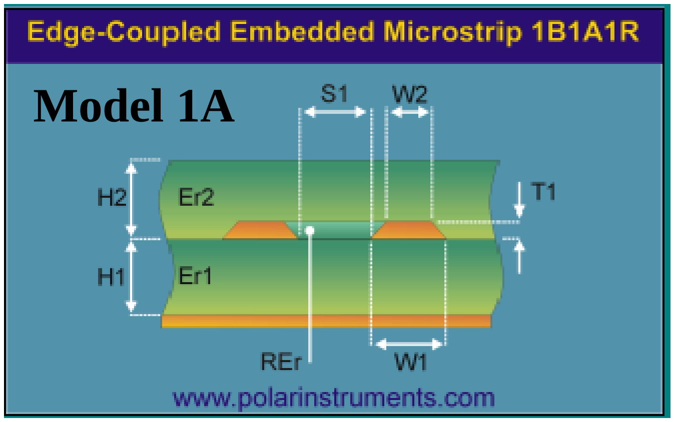


Figure 7 – Cross Section Comparison of All Polyimide versus Acrylic Based Laminates

Fortunately, Polar SI9000 has a model that takes this case into account. Figure 9 shows these models, which are essentially the same as Model 1 and Model 2 except they assume a different dielectric constant between the signal lines. Specifically, a REr value of 1.0 was used here. These alternate models (Model 1A and Model 2A) were applied using the same inputs as shown in Tables 4 and 5. As shown in Table 7, results of this revised analysis are excellent with this improved model.



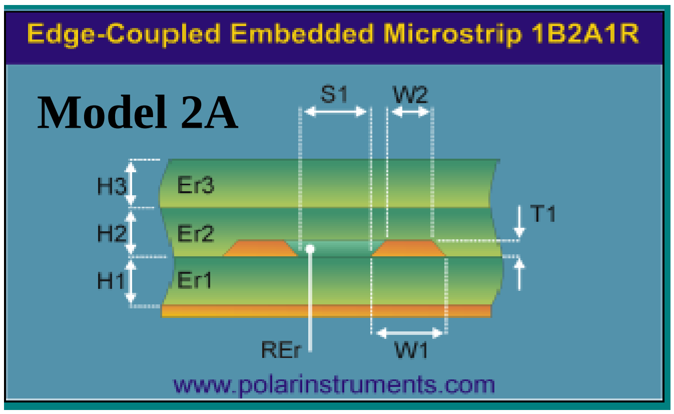


Figure 8 – Alternate Models for Boards Using Non-Acrylic Laminates

Table 7		Differential Impedance (Ohms)			%Δ (Model-Meas)	
Case	Board	Model 1A	Model 2A	Measured	Model 1	Model 2
A	1	73.1	73.3	72.2	1.2%	1.5%
	2	74.3	74.5	73.6	0.9%	1.2%
	3	71.3	71.5	71.7	-0.5%	-0.3%
D	1	79.0	79.2	79.9	-1.1%	-1.0%
	2	78.4	78.4	78.5	-0.2%	-0.2%
	3	76.2	76.3	77.4	-1.6%	-1.5%
E	1	88.6	89.0	88.1	0.5%	1.0%
	2	91.4	91.6	89.5	2.1%	2.3%
	3	90.0	90.4	90.0	0.1%	0.5%
H	1	98.8	98.9	99.5	-0.7%	-0.5%
	2	99.7	98.6	98.6	1.0%	-0.1%
	3	101.0	101.4	101.4	-0.4%	0.0%

Summary and Conclusions:

There are several material choices for designing controlled impedance flexible circuits. Acrylic based copper clad laminates offer consistent performance for the lowest cost. Applications requiring high reliability and flexible circuit life are best suited for the use of adhesiveless clad materials. Fluoropolymer/polyimide composite laminates have significantly lower dielectric constant compared to traditional flexible circuit materials. This enables thinner stack-ups or higher impedance options for designs.

Differential Impedance of flexible circuits can be modeled accurately based on analytical tools such as the Polar SI9000 software. The dielectric constant values are somewhat different for controlled impedance applications than the "bulk" values quoted in the typical data sheet. Considering the Kapton® and adhesive separately makes a design more accurate when using acrylic based materials. It is suggested that consideration be given to the effects of a slight incomplete encapsulation in the model when utilizing All polyimide or fluoropolymer/polyimide composite clad laminates in the stack-up.

This study was conducted on edge-coupled differential structures. For other structures such as stripline construction that are more complex, the agreement between modeled and measured results may not be as precise. This work provides a sound baseline for design and verification of controlled impedance flexible circuits. We welcome alternate designs and suggestions for future work.

References

[1] "High Speed Flex Design Considerations", www.samtec.com, December 2004, Available for download under Technical Library -> Presentations.

[2] "Flexible Electronics Handle Harsh Realm". www.mwrf.com/milelec May 2008, Military Electronics – Penton Media.

[3] Polar Instrument, Ltd. www.polarinstruments.com

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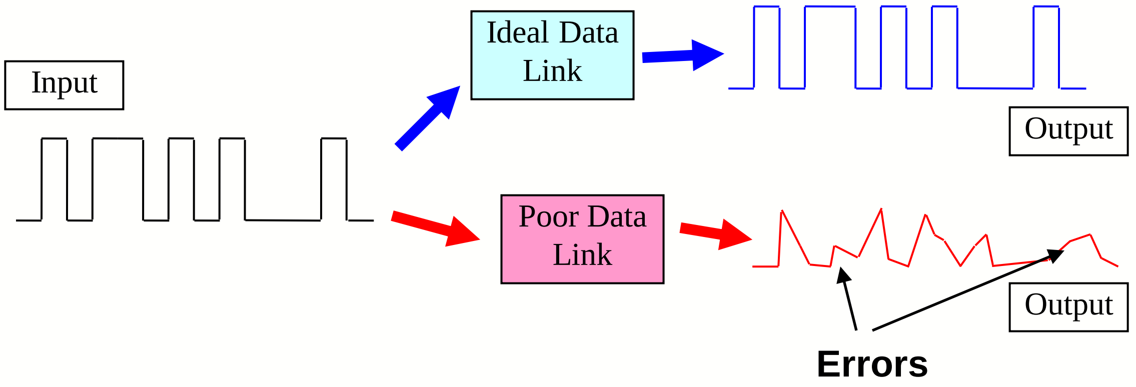
    - Cross Sections

Signal Integrity

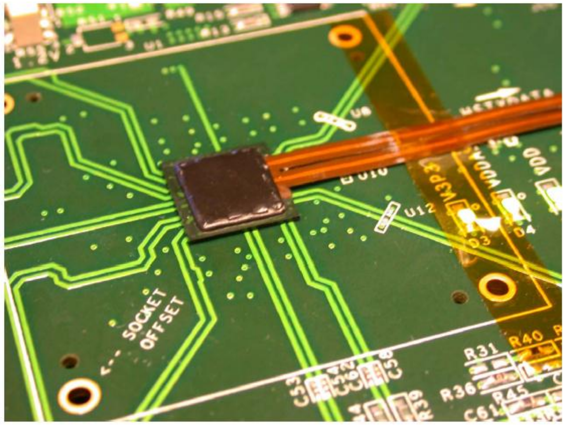
- A term associated with transmission of DIGITAL data.
- Need to get bits from input to output with no errors.
- The materials that link the input and output have an impact on signal integrity.



High Speed Applications

- Selected examples

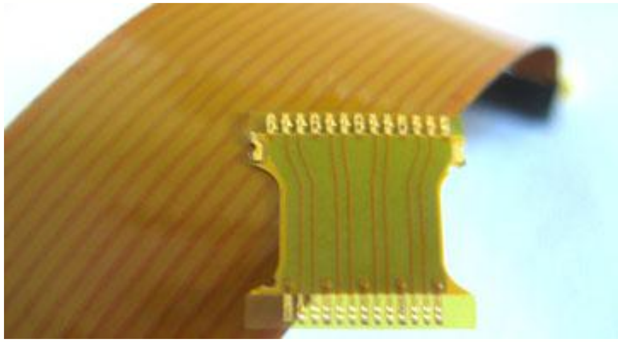
Connecting IC’s on Board
Courtesy of Silicon Pipe (www.siloconpipe.com)



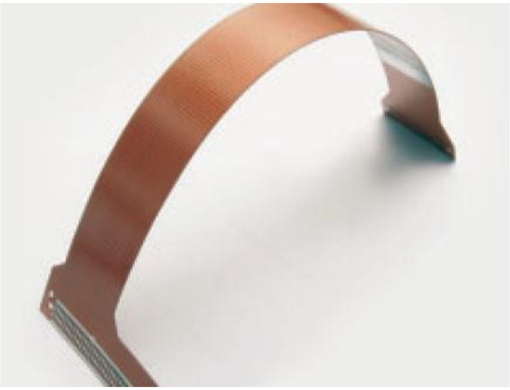
Assembly by NxGen Electronics

SiliconPipe

Flex Interconnect for Military Application
Courtesy of Vulcan Flex Circuits (www.vulcanelectric.com)



Flex for High Speed Network Switching Equipment
Courtesy of PFC Flexible Circuits (www.pfcflex.com)



Connecting Between Boards
Courtesy of Optiprint (www.optiprint.ch)

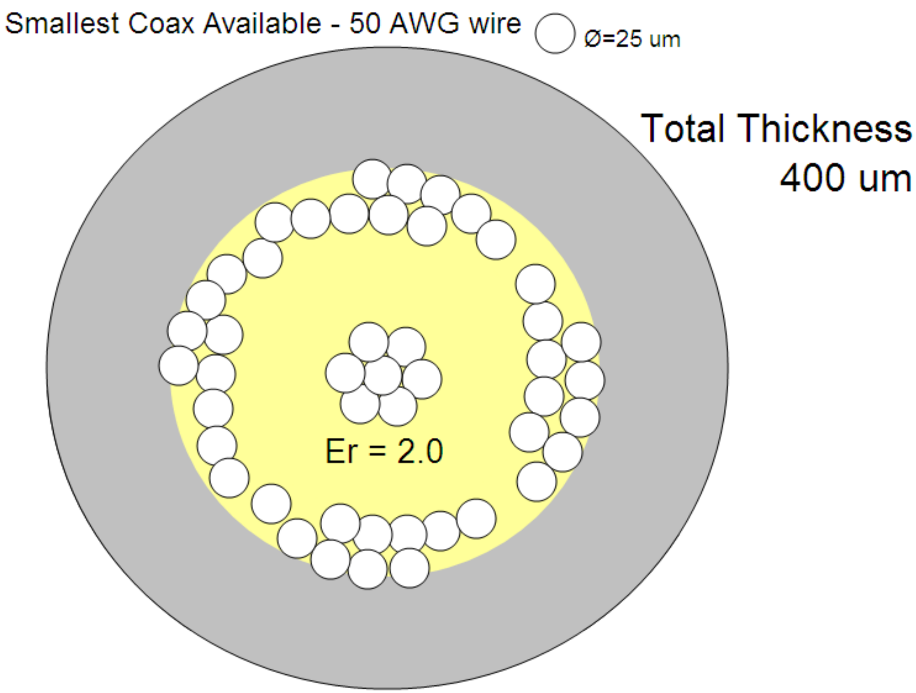
Differences at High Speed

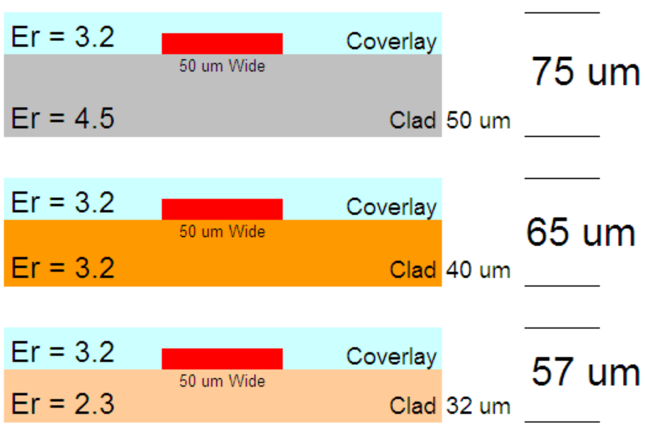
- <u>Low Frequency</u> – You do not have to get too precise with your lines (strings) or substrate (tub) to make bass notes. Do not need to worry about the signal quality.
  - A washtub bass shown:
    - Cost = $9.95 (not including dog)
    - Minimal expertise required

- <u>High Frequency</u> – The clarity and overtones need to be perfect. The substrate (wood in this case) matters a lot.
  - An antique violin
    - Cost = $2 Million
    - Extensive expertise required

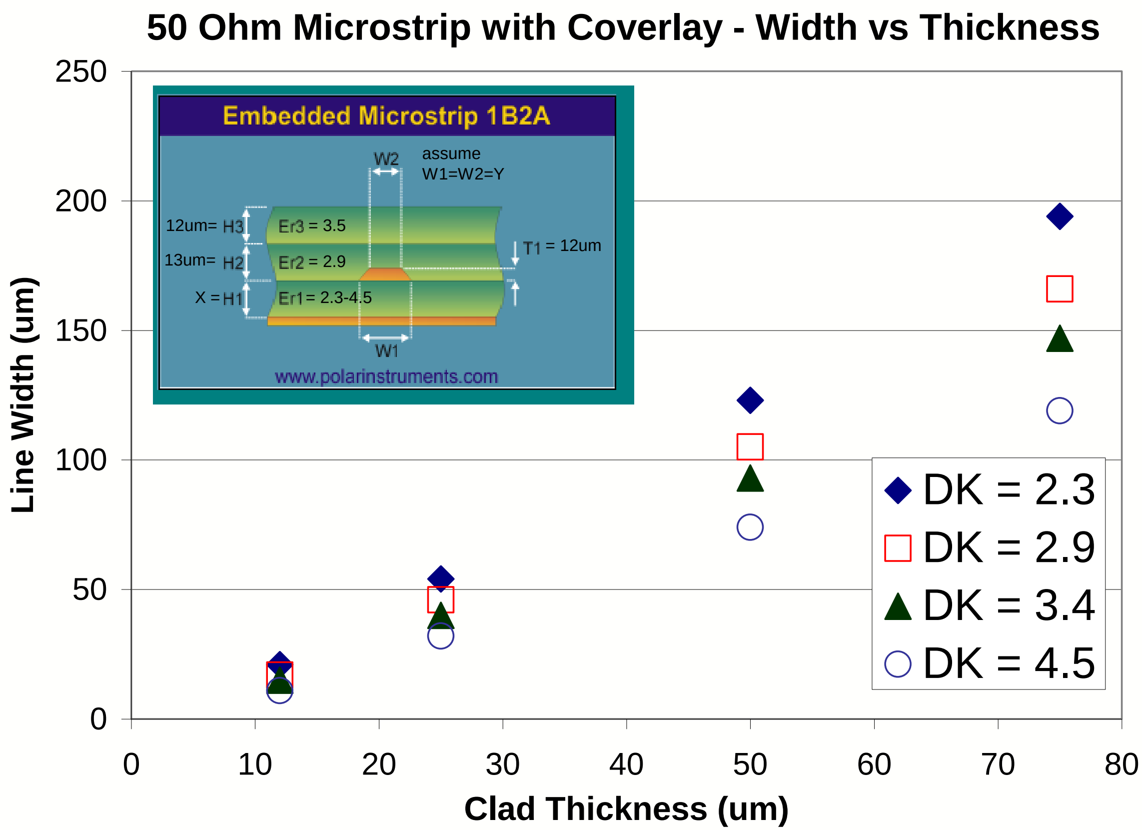
Why Flex?

- Thinner! – Scaled diagrams of the thinnest flex
- Coax is significantly thicker than flex
- Can design for differential or single-ended with flex, not coax.





Dielectric Constant (Er) is Important



Accurate values of DK are critical to design and fabrication

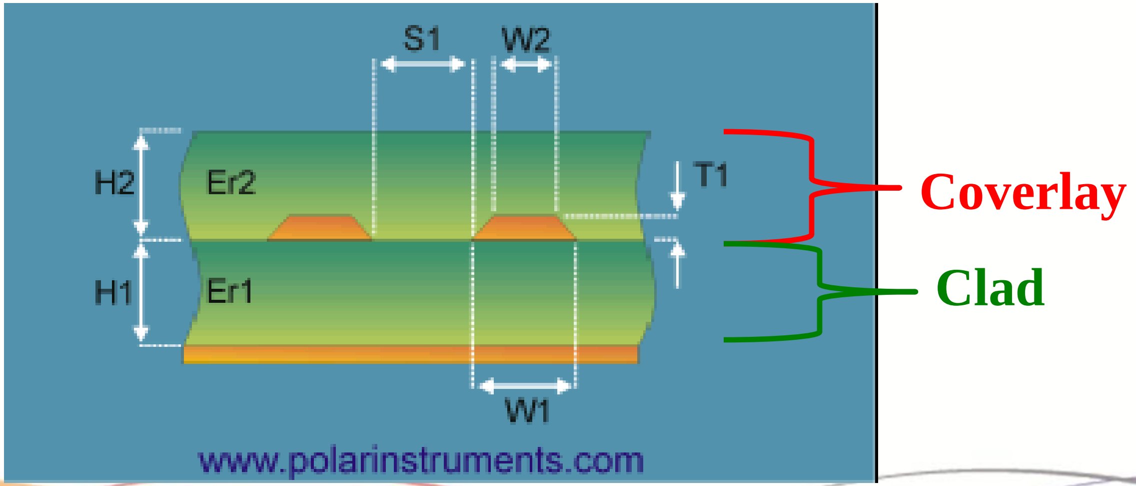
Dk Values for Flex Materials

- Laminate and coverlay material is usually very thin
- Material behaves a little differently than glass reinforced laminates
- DesignCon papers by author can provide more insight

Material	Dielectric Constant
Standard PI	3.50
Standard Adhesive	2.95
Flame Resistant Adhesive	3.05
Adhesiveless PI	3.10
Fluoropolymer:PI (1:1 Ratio)	2.50
Fluoropolymer:PI (2:1 Ratio)	2.25

Validation Experiment with Vulcan

- Differential Microstrip Structures
  - Z_{diff} about 70-125 ohms
- Modeled with Polar Instruments SI9000
- Circuits built and impedance (Z_{diff}) measured
- Measured values compared to model
- All panels manufactured at the same time by Vulcan Flex Circuit

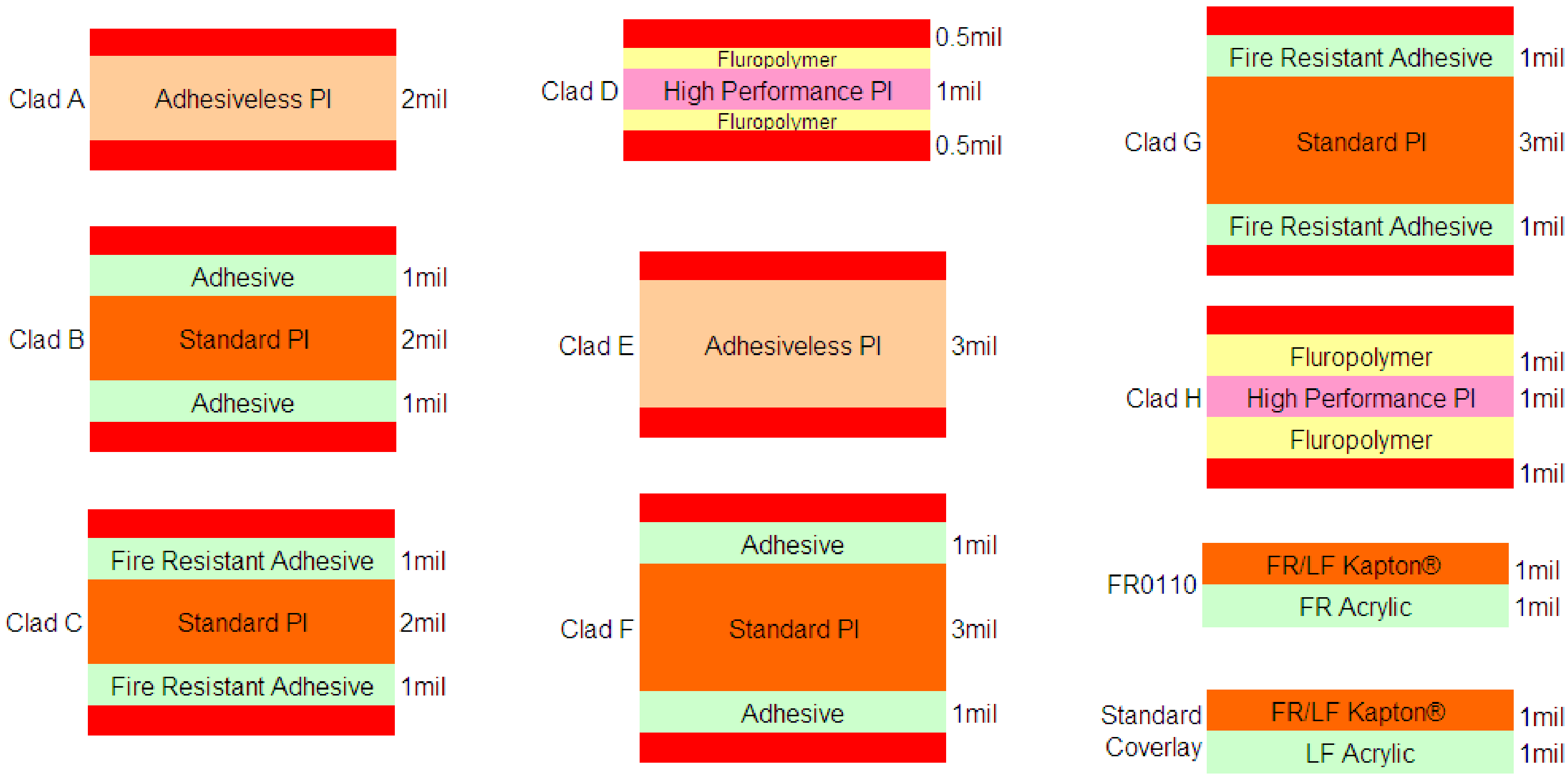


Materials Evaluated

- B, C, D and E PI with Acrylic Adhesive
- A and E Adhesiveless PI
- D and H Fluoropolymer PI Composites
- Standard Acrylic Coverlays Used for All

Case	Clad	Coverlay
A	2 mil thick adhesiveless polyimide clad to ½ oz Cu	1 mil standard adhesive on one side of 1 mil standard polyimide
B	2 mil standard polyimide with 1 mil standard adhesive on each side clad with ½ oz Cu	1 mil standard adhesive on one side of 1 mil standard polyimide
C	2 mil standard polyimide with 1 mil flame resistant adhesive on each side clad with ½ oz Cu	1 mil thick flame resistant adhesive on one side of 1 mil standard polyimide
D	2 mil fluoropolymer:polyimide composite combined at 1:1 ratio clad to ½ oz Cu	1 mil standard adhesive on one side of 1 mil standard polyimide
E	3 mil thick adhesiveless polyimide clad to ½ oz Cu	1 mil standard adhesive on one side of 1 mil standard polyimide
F	3 mil standard polyimide with 1 mil standard adhesive on each side clad with ½ oz Cu	1 mil standard adhesive on one side of 1 mil standard polyimide
G	3 mil standard polyimide with 1 mil flame resistant adhesive on each side clad with ½ oz Cu	1 mil thick flame resistant adhesive on one side of 1 mil standard polyimide
H	3 mil fluoropolymer:polyimide composite combined at 2:1 ratio clad to ½ oz Cu	1 mil standard adhesive on one side of 1 mil standard polyimide

Material Details



Structures Designed

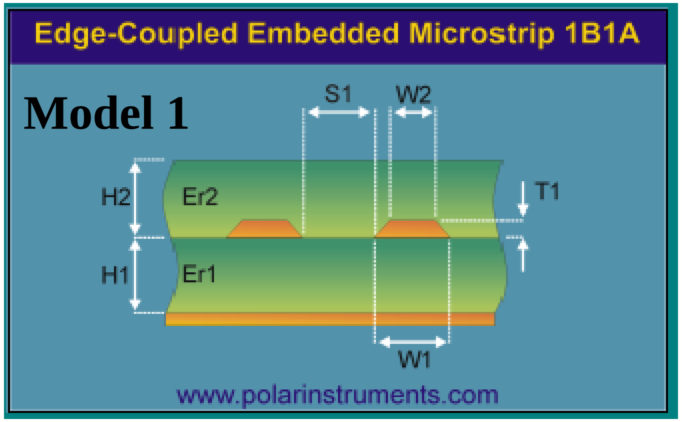
- Line Width
  - Target W = W1 in Polar model
  - Varied between 5.0-6.0 mils
- Line Spacing
  - Target S = space between W1
  - Varied between 6.5-8.0 mils
- Impedance Measurements
  - Performed at Vulcan Electric
  - Used Polar Instruments TDR

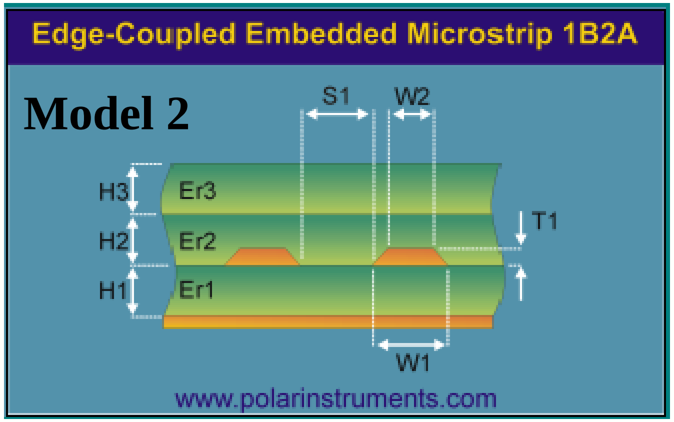
		Design (mils)		Measured
Case	Board	W	S	Zdiff (ohms)
A	1	6.0	7.0	72.2
	2	6.0	7.0	73.6
	3	6.0	7.0	71.7
B	1	5.5	7.5	105.8
	2	5.5	7.5	106.8
	3	5.5	7.5	104.8
C	1	5.5	7.5	109.1
	2	5.5	7.5	108.4
	3	5.5	7.5	110.6
D	1	5.5	7.5	79.9
	2	6.5	6.5	78.5
	3	6.0	7.0	77.4
E	1	6.0	7.0	88.1
	2	6.0	7.0	89.5
	3	5.5	7.5	90.0
F	1	5.0	8.0	122.0
	2	5.5	7.5	114.6
	3	5.5	7.5	113.4
G	1	5.5	7.5	113.0
	2	5.5	7.5	113.4
	3	5.0	8.0	113.4
H	1	6.0	7.0	99.5
	2	6.0	7.0	98.6
	3	5.5	7.5	101.4

Two Models Evaluated

- Model 1
  - Considers Coverlay as One Unit
  - DK of PI and Adhesive Averaged Together

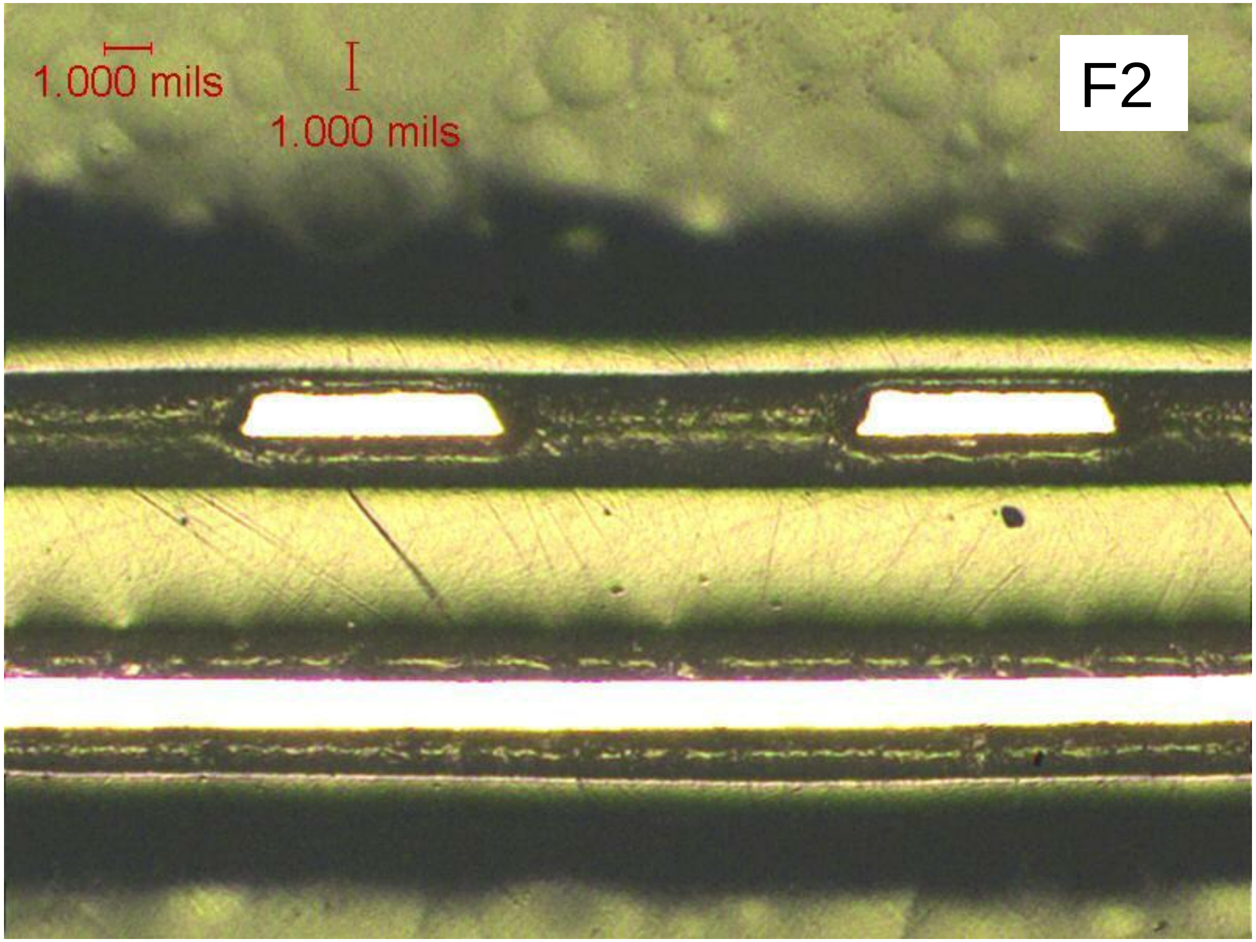
- Model 2
  - Considers PI and Adhesive Separately





Measure Cross Sections

- Take measurements for dimensions
- Model 1 measurements
- Model 2 measurements



X-Section Dimensions

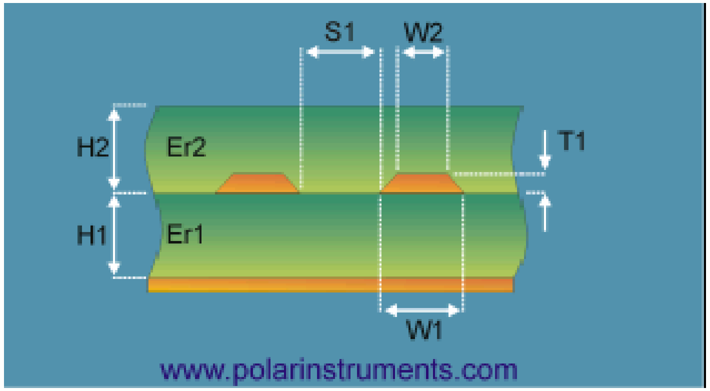
Case	Board	Design (mils) W	Design (mils) S
A	1	6.0	7.0
	2	6.0	7.0
	3	6.0	7.0
B	1	5.5	7.5
	2	5.5	7.5
	3	5.5	7.5
C	1	5.5	7.5
	2	5.5	7.5
	3	5.5	7.5
D	1	5.5	7.5
	2	6.5	6.5
	3	6.0	7.0
E	1	6.0	7.0
	2	6.0	7.0
	3	5.5	7.5
F	1	5.0	8.0
	2	5.5	7.5
	3	5.5	7.5
G	1	5.5	7.5
	2	5.5	7.5
	3	5.0	8.0
H	1	6.0	7.0
	2	6.0	7.0
	3	5.5	7.5

Design

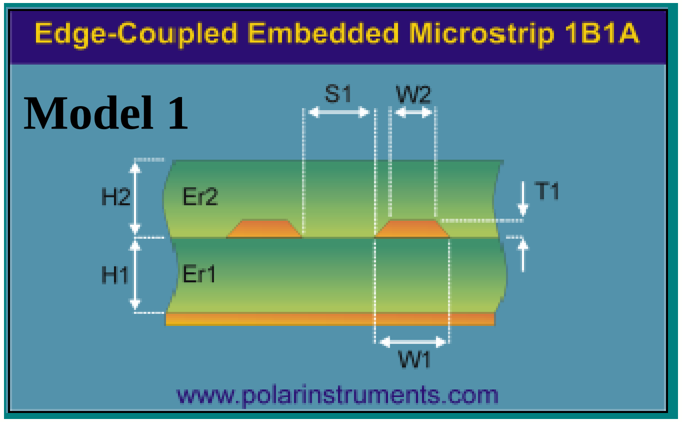
Versus

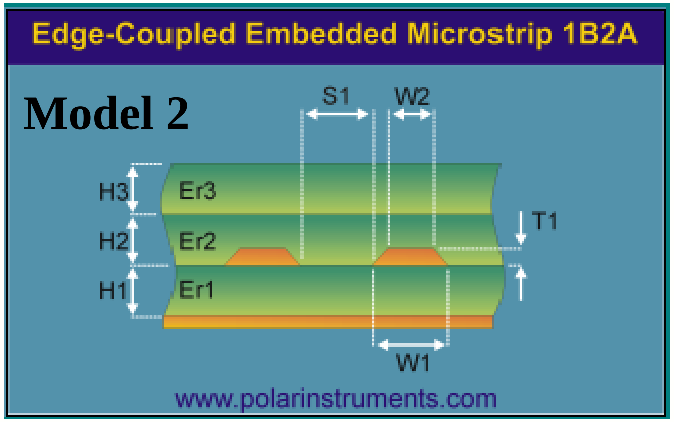
Measured

Case	Board	Measurements in mils W1	W2	S1	T1
A	1	5.84	5.32	7.24	0.80
	2	5.74	5.29	7.18	0.84
	3	6.10	5.46	6.75	0.81
B	1	5.45	4.65	7.21	0.79
	2	5.56	4.81	7.21	0.77
	3	5.77	4.93	6.98	0.85
C	1	5.56	4.81	7.24	0.80
	2	5.66	4.89	7.05	0.84
	3	5.35	4.75	7.57	0.81
D	1	5.97	5.19	6.95	0.82
	2	6.17	5.33	6.66	0.78
	3	6.53	5.43	6.23	0.85
E	1	6.22	5.43	6.43	0.74
	2	5.73	5.32	7.08	0.87
	3	5.97	5.27	6.92	0.82
F	1	4.73	4.27	7.93	0.78
	2	5.42	4.75	7.34	0.80
	3	5.48	4.88	7.34	0.82
G	1	5.50	4.99	7.24	0.83
	2	5.63	4.93	7.01	0.82
	3	5.38	4.88	7.37	0.80
H	1	6.22	5.38	6.62	0.83
	2	6.15	5.42	6.56	0.82
	3	5.99	5.46	6.92	0.81



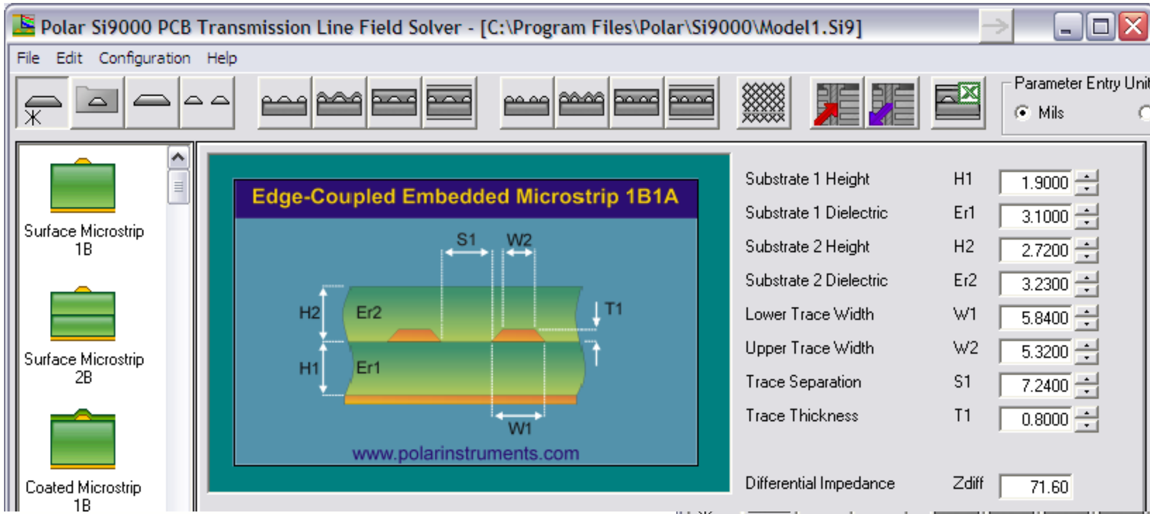
Dielectric X-Section Dimensions



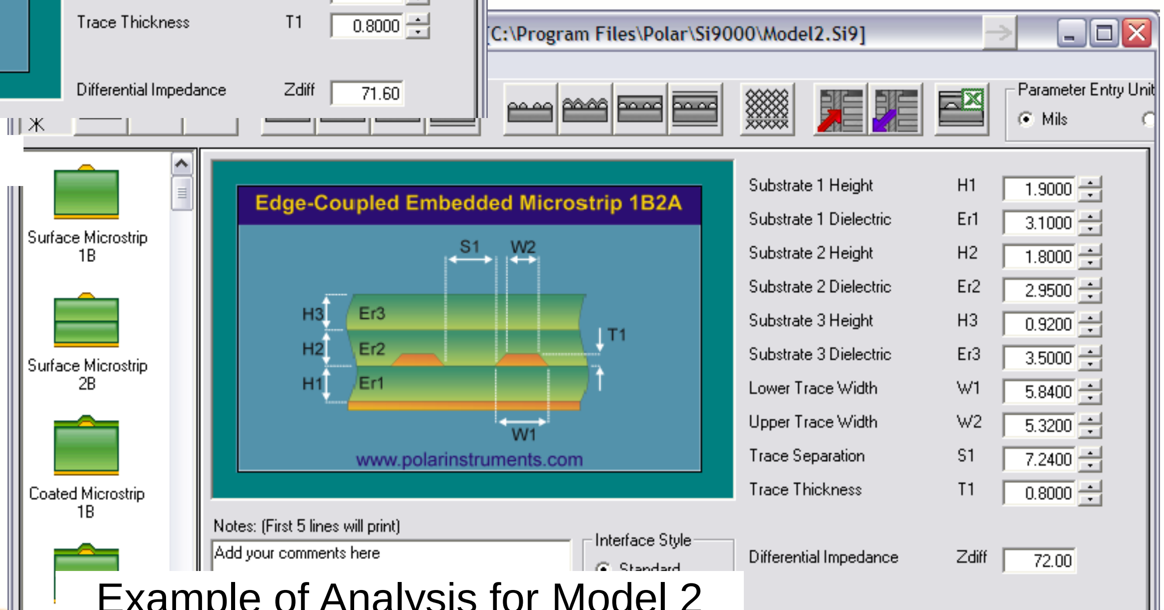


		Model 1		Model 2		
Case	Board	H1	H2	H1	H2	H3
A	1	1.90	2.72	1.90	1.80	0.92
	2	1.93	2.65	1.93	1.70	0.95
	3	1.90	2.52	1.90	1.57	0.95
B	1	3.95	2.33	3.95	1.44	0.89
	2	3.95	2.49	3.95	1.54	0.95
	3	4.05	2.49	4.05	1.54	0.95
C	1	4.28	2.26	4.28	1.37	0.89
	2	4.28	2.52	4.28	1.60	0.92
	3	4.25	2.42	4.25	1.44	0.98
D	1	1.90	2.29	1.90	1.34	0.95
	2	1.93	2.23	1.93	1.44	0.89
	3	1.96	2.29	1.96	1.40	0.89
E	1	2.91	3.08	2.91	2.16	0.92
	2	2.84	2.59	2.84	1.63	0.96
	3	2.85	2.85	2.85	1.99	0.86
F	1	4.93	2.48	4.93	1.50	0.98
	2	5.10	2.38	5.10	1.40	0.98
	3	4.97	2.62	4.97	1.57	1.05
G	1	4.74	2.39	4.74	1.47	0.92
	2	4.87	2.52	4.87	1.67	0.85
	3	4.87	2.59	4.87	1.70	0.89
H	1	2.84	2.49	2.84	1.47	1.02
	2	2.88	2.49	2.88	1.31	0.95
	3	2.91	2.72	2.91	1.83	0.89

Calculating Impedance



Example of Analysis for Model 1



Example of Analysis for Model 2

Analysis

- Comparison of Models to Measured
- All acrylic based materials within 2.5% of model
  - Acrlyic adhesive based materials B, C, F and G
  - Adhesiveless materials A, D, E, and H had slightly more variation
- Fluoropolymer/PI composites have higher measured Z_{diff} than model

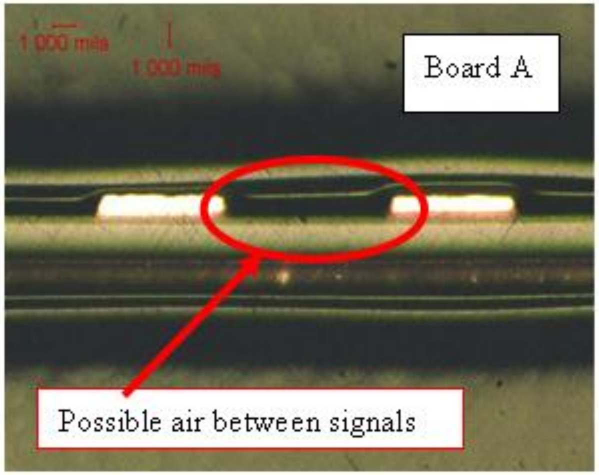
		Differential Impedance (Ohms)			%Δ (Model-Meas)	
Case	Board	Model 1	Model 2	Measured	Model 1	Model 2
A	1	71.6	72.0	72.2	-0.9%	-0.3%
	2	72.6	73.0	73.6	-1.3%	-0.7%
	3	69.9	70.9	71.7	-2.6%	-1.2%
B	1	106.2	106.6	105.8	0.4%	0.8%
	2	104.9	105.3	106.8	-1.8%	-1.4%
	3	103.2	103.6	104.8	-1.5%	-1.1%
C	1	109.4	109.9	109.1	0.3%	0.7%
	2	107.0	107.6	108.4	-1.3%	-0.8%
	3	110.6	111.1	110.6	0.1%	0.5%
D	1	77.2	77.5	79.9	-3.5%	-3.1%
	2	76.6	76.8	78.5	-2.5%	-2.2%
	3	74.3	74.6	77.4	-4.0%	-3.6%

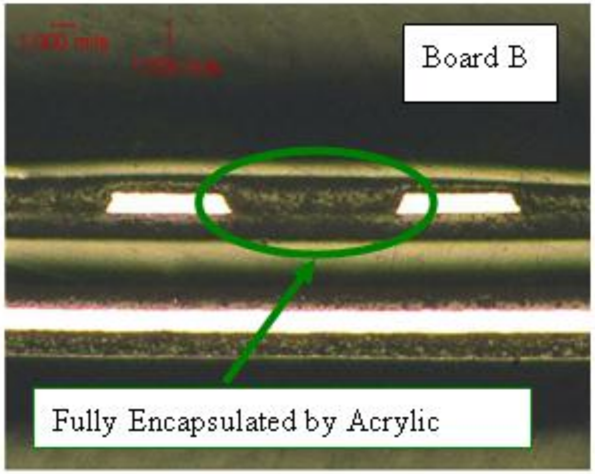
		Differential Impedance (Ohms)			%Δ (Model-Meas)	
Case	Board	Model 1	Model 2	Measured	Model 1	Model 2
E	1	86.3	87.2	88.1	-2.1%	-1.0%
	2	89.1	89.6	89.5	-0.4%	0.1%
	3	87.9	88.5	90.0	-2.3%	-1.6%
F	1	121.5	122.0	122.0	-0.5%	-0.1%
	2	115.8	116.1	114.6	1.0%	1.3%
	3	113.1	113.6	113.4	-0.3%	0.1%
G	1	111.9	112.4	113.0	-1.0%	-0.5%
	2	111.5	112.2	113.4	-1.7%	-1.1%
	3	114.3	114.6	113.4	0.8%	1.0%
H	1	96.0	96.4	99.5	-3.5%	-3.0%
	2	96.8	97.9	98.6	-1.9%	-0.8%
	3	98.1	98.9	101.4	-3.2%	-2.5%

Further Analysis

- Adhesiveless PI and Fluoropolymer/Polyimide Composites looked different in cross section.
  – Board A has acrylic adhesive bonding to adhesiveless polyimide
  – Board B has acrylic adhesive bonding to acrylic in clad

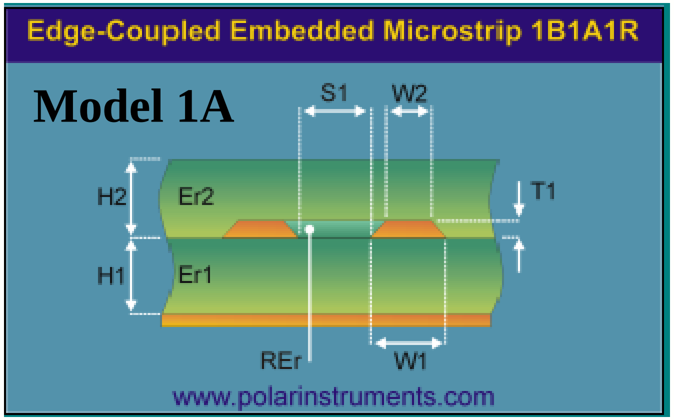
- Small amounts of air can be entrained in between signal lines without blistering (not enough to cause a delamination problem).

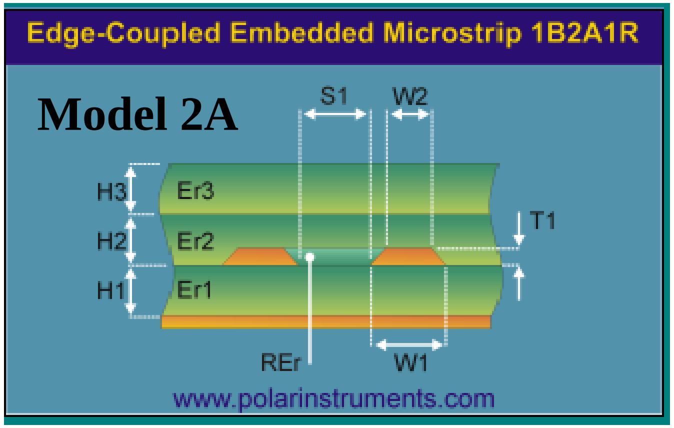




Slightly Modified Models

- Alternate models available in Polar
- The only difference is the assumption of a different Er between the differential lines.
- Assume REr = 1.0 (air)
- Applied only to adhesiveless PI and fluoropolymer/PI composites (A, D, E and H)





Results – Modified Models

- Modified models match the measured results more closely than the original models.

- All within 2.5%

Case	Board	Differential Impedance (Ohms) Model 1A	Model 2A	Measured	%Δ (Model-Meas) Model 1	Model 2
A	1	73.1	73.3	72.2	1.2%	1.5%
	2	74.3	74.5	73.6	0.9%	1.2%
	3	71.3	71.5	71.7	-0.5%	-0.3%
D	1	79.0	79.2	79.9	-1.1%	-1.0%
	2	78.4	78.4	78.5	-0.2%	-0.2%
	3	76.2	76.3	77.4	-1.6%	-1.5%
E	1	88.6	89.0	88.1	0.5%	1.0%
	2	91.4	91.6	89.5	2.1%	2.3%
	3	90.0	90.4	90.0	0.1%	0.5%
H	1	98.8	98.9	99.5	-0.7%	-0.5%
	2	99.7	98.6	98.6	1.0%	-0.1%
	3	101.0	101.4	101.4	-0.4%	0.0%

Conclusion

- This experiment shows that the correct values to us for dielectric constant are verified.
- Thinner or higher impedance designs are attainable using fluoropolymer/PI composites.

Material	Dielectric Constant
Standard PI	3.50
Standard Adhesive	2.95
Flame Resistant Adhesive	3.05
Adhesiveless PI	3.10
Fluoropolymer:PI (1:1 Ratio)	2.50
Fluoropolymer:PI (2:1 Ratio)	2.25

For More Info

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