Microwave Multi-layer Printed Circuit Boards

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Abstract

Over the last 30 years we have seen a lot of different designs on microwave printed circuit boards. The one area of microwave board design that has changed is the design and use of multi-layer printed circuits boards. Traditionally multi-layer boards for microwave applications have been made with etching off the copper on a piece of microwave material and using a 1.5 mil thick bonding film, bonding it to another dielectric layer. With the introduction of new low loss prepregs, engineers can now design multi-layer microwave boards which use more traditional printed circuit board manufacturing processes. This paper will look at the history of multi-layer microwave boards from clamping to bonding films and to today's use of microwave prepregs. The paper will finish up with a material cost comparison of the construction types using bonding films, prepregs and foil lam constructions.

History

High performance printed circuit boards or what we would call high frequency printed circuit boards were manufactured for years as microstrip designs. See figure 1.

Figure 1. Microstrip Circuit

Military applications for triplate or what we call stripline designs started back in the early 1970's. The earliest design was reported to be on the Shrike missile design. There were no good bonding films or bonding techniques available at the time so the engineers designed the boards and actually clamped them together with screws between two metal plates. These early devices were called Unitized Microwave Devices or UMD's. See figure 2.

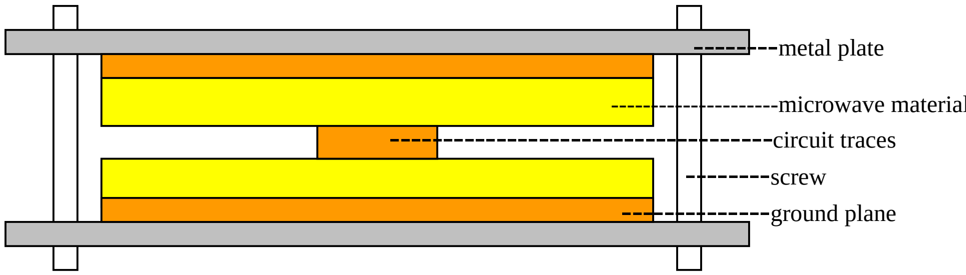

Figure 2. Unitized Microwave Device

The boards were etched and then tuned and clamped at some specified pressure between metal plates. In the actual application, the designs proved to have a fundamental flaw. The PTFE that was clamped between the plates would cold flow under the clamping forces. This lower pressure would allow additional air to enter along the bond line of the UMD. The additional air would in essence change the effective dielectric constant of the design and the UMD would be out of tune. The engineers would routinely remove the boards from the missile and retune the UMD by retorquing the screws, increasing the pressure. But the never ending cold flow characteristics of PTFE caused the UMD to detune again and again over time. Thus the military retired the UMD on the Shrike program and the industry retired the UMD not too long after.

Bonding Films

It wasn’t until later in the 1970’s that bonding films were introduced and the stripline printed circuit board was once again looked at as a design alternative. 3M introduced the 6700 bonding film in the mid 1970’s. This was a copolymer including chlorotrifluorethylene material with good electrical properties. The individual board layers were etched and this 1.5 mil film was placed in between the layers and the assembly was put in a press and the bonding film would melt, flow around the etched traces and bond the dielectric layers together. In the mid 1980’s 3M sold its product line to Arlon but the 6700 bonding film is still sold by Arlon today. Both Rogers, with their RO 3001 bonding film, and Taconic, with their HT1.5 bonding film sell a similar product to the 6700 bonding film. A little known fact is that all three suppliers buy and resell an Allied Signal Aclar film and repackage it under their own names. The 6700 bonding film was the workhorse of the bonded stripline industry for years. If it has any real drawback it is that its melt point is between 200 and 205°C. Applications requiring sequential lamination could or would experience some delamination as the 6700 bonding film would remelt on subsequent laminations. Dupont introduced an FEP (fluorinated ethylenepropylene copoloymer) bonding film in the late 1970’s which melted at a temperature of 260°C. This film is available in thicknesses of 0.5, 1, 1.5 and 2 mil. The higher temperature allowed designers to design boards that would need sequential lamination or boards that would require higher processing temperatures with high temp solders or lead free solders. The FEP also presented some challenges as not every printed circuit board shop has the capability of running their presses at the 260°C required to process the FEP. See Table 1 for various bonding film properties.

Film	FEP	HT 1.5	6700	3001
Distributor	Dupont	Taconic	Arlon	Rogers
Description	Fluorinated ethylenepropylene copolymer	Copolymer with chlorotri-fluoroethylene	Copolymer with chlorotri-fluorethylene	Copolymer with chlorotri-fluorethylene
Dielectric Constant	2.1	2.35	2.35	2.28
Dissipation Factor	0.0003	0.003	0.003	0.003
Melt temperature	260°C	200-205°C	200-205°C	200-205°C
Process Temp	280°C	220°C	220°C	220°C
Pressure	200 psi	50 to 200 psi	50 to 200 psi	50 to 200 psi

Table 1. Properties of various bonding films.

Overall the stripline design would use two dielectric layers and one of the sides of the dielectric layer would be etched clean of copper and the bonding film would be used to bond the layers together. See figure 3.

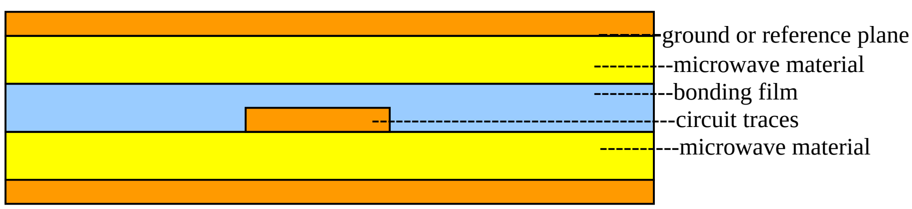

Figure 3. Stripline Circuit.

If a multi layer board of more than three copper layers was designed then the designer would etch off all the copper on every other layer and bond the layers together with FEP or 6700 bonding film.

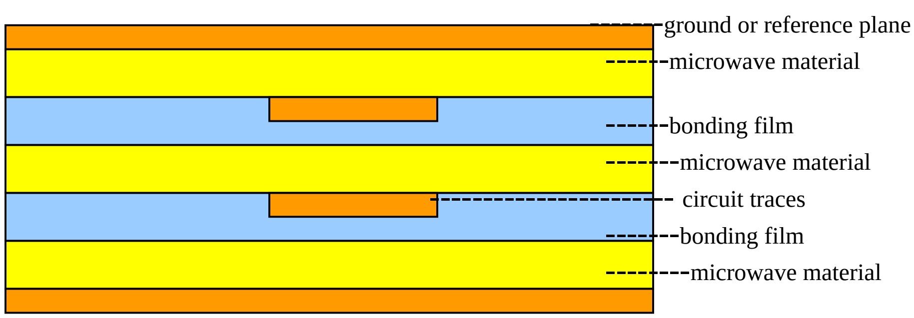

Figure 4. Multi-layer with one side etched off of each layer

Or copper could be etched off both sides of the inner layers and bonding film would be used. See figure 5.

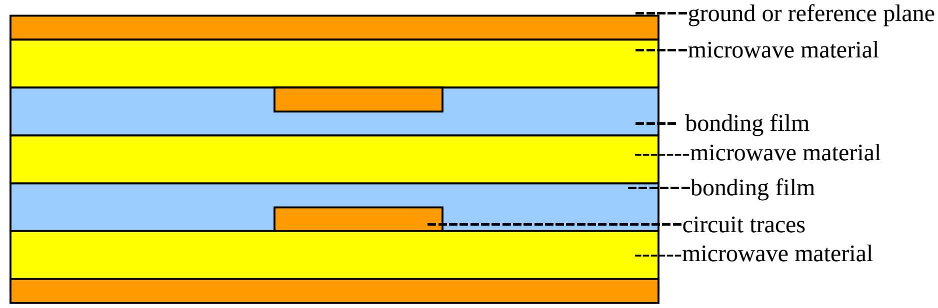

Figure 5.   Multi layer with inner layer etched free on both sides.

Hybrid Constructions

During the last few years, more designers have gone with designs that use what some call hybrid constructions. These designs use high frequency materials as the top dielectric layer and the other dielectric layers are usually FR 4 or another lower frequency performance material. Throughout the rest of this paper I will be talking about multi-layer boards and will use FR4 as the typical low frequency material but these designs could also be BT epoxy, polyimide glass or other low frequency performance materials.   See figure 6.

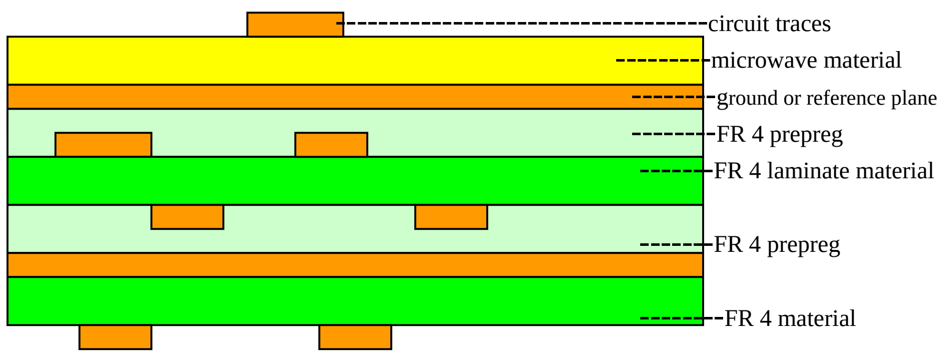

Figure 6   Hybrid design with high frequency microstrip on top layer

As designers have gotten more comfortable in mixing dielectric materials in designs, they have also gone to stripline or even multi-layer high frequency dielectric layers in conjunction with FR4 materials. These designs have led to the development of high frequency prepregs that can be used in applications similar to the FR 4 prepregs. Prepreg materials like Taconic's TacLam and Rogers RO 4450 or Gores Speedboard™ C have been introduced and are being used in multi- layer high frequency printed circuit board designs. See Figure 7.

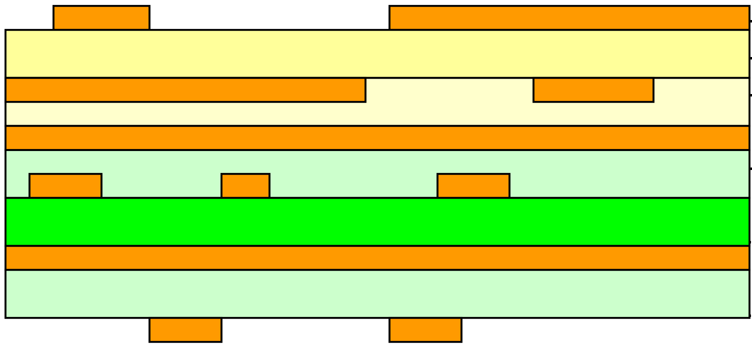

Figure 7.   Hybrid design with stripline on top of FR 4 multi layer using high frequency prepreg.

High Frequency Prepregs

Although engineers have used every type of prepreg or bonding film on designs, this paper will concentrate on only those prepregs that have specific properties that make them electrically compatible with high frequency, high performance materials. In particular the author will cover the TacPreg system from Taconic, RO 4000 system from Rogers, the 25 series from Arlon and Speedboard™ C from WL Gore. See Table 2 for a comparative listing of microwave grade prepregs.

Taconic TacPreg®

TacPreg from Taconic is the newest addition to the short list of high frequency prepreg materials. TacPreg is a composite material made up primarily of a fluorocarbon resin. The center core is a fluorocarbon, PTFE, which is mixed with ceramic fillers and coated onto a glass fabric. This center core is then coated with a thin coating, top and bottom, of a BT epoxy resin system. The TacPreg TP-32 and TacPreg TP-35 have a very small amount of bromines in the BT epoxy layer. Taconic will be introducing a new TacPreg which will be a "green" version where the small amount of bromine will be removed from the product. The advantage of this system is that the board fabricator can use a lamination cycle that is the same as BT epoxy system. The materials are offered with a 1080 glass fabric core for ease in drilling. Thicknesses are available at 4.5 and 5.0 mils. Additional thicknesses in the 6 mil and 10 mil are in the works. Adhesion of copper to the TacPreg system is excellent. This will allow engineers to go to smoother coppers like reverse treated or very low profile coppers for better performance at higher frequencies.

Material	TacPreg TP-32	TacPreg TP-35	TacPreg TP-34	RO 4403	RO 4450	25N	25FR	Speedboard C
Composition	Ceramic filled PTFE coated on 1080 Glass with BT epoxy coating	Ceramic filled PTFE coated on 1080 Glass with BT epoxy coating	Ceramic filled PTFE coated on 1080 Glass with BT epoxy coating	Ceramic filled thermoset resin coated on 1080 glass	Ceramic filled thermoset resin coated on 1080 glass	Ceramic filled thermoset resin coated on 1080 or 2112 glass	Ceramic filled thermoset resin coated on 1080 or 2112 glass	Matrix of BT epoxy and expanded PTFE
Manufacturer	Taconic	Taconic	Taconic	Rogers	Rogers	Arlon	Arlon	Gore
Dielectric Constant	3.19	3.5	3.34	3.17	3.54	3.38	3.58	2.6
Dissipation Factor	.004	.005	.004	.005	.004	.0025	.0035	.004
UL	94 V0	94 V0	94 V0	No	94 V0	No	94 V0	94 V0
Bromine Free	No	No	Yes	Yes	No	Yes	No	Yes
Process temp.	392 F	392 F	392 F	350 F	350 F	375 F	375 F	360 to 428 F
Process Pressure	450 psi	450 psi	450 psi	400 psi	400 psi	300-350 psi	300-350 psi	290-435 psi
Cycle time	150 mins.	150 mins	150 mins	255 mins	120 mins	150 mins	150 mins	150 minutes

Table 2. Comparison of the various high frequency prepregs available.

Rogers 4000 and Arlon 25.

Rogers 4000 series prepregs and Arlons 25 series prepregs represent efforts by materials suppliers to supply low cost material solutions with properties similar or close to those of PTFE. Both suppliers make a ceramic filled glass cloth reinforced thermoset material. Both suppliers have a lower loss prepreg and a higher loss prepreg. Rogers' 4403 and Arlon's 25N are both non-flame retardant materials. The base resin system used in these prepregs is a hydrocarbon material. In order to make the materials non-flammable, masses of bromine fillers have to be added to the material. These bromines don't do anything to help the material other than make them non-flammable. This addition of fillers increases the dielectric constant and the dissipation factor as well. Rogers has RO 4450 prepreg material and Arlon has the 25FR prepreg. Both companies offer a 1080 glass fabric based prepreg at about 4 mils thickness. Arlon also offers a 2112 glass fabric based prepreg for applications up to 6 mils thickness. The inherent disadvantages of these material systems are excessive drill wear because of the ceramic fillers used in the material system. Higher drill bit costs may be expected when using these materials. Also these materials have been known to have poor adhesion to copper surfaces. This presents a limitation when engineers design a lower cost foil lamination board. Specific foils from specified manufacturers may be recommended to achieve adequate peel strength on foil lamination builds.

Gore Speedboard™ C

All of the prepreg materials covered so far are glass reinforced resins. WL Gore Speedboard C uses a different approach to making a low loss prepreg system. They use a PTFE (Teflon®) matrix with a BT epoxy resin. This combination of resins creates a material with the lowest dielectric constant of any prepreg system. But this resin system comes with a cost differentiation that is two to three times the price of the Taconic, Rogers or Arlon prepregs. Speedboard C comes in a variety of thicknesses, i.e. 1.5 mils, 2.0 mils, 2.5 mils and 3.4 mils. Copper has excellent adhesion to this prepreg. Drilling is a concern as the resin matrix being Teflon material will tend to smear. Fabricators should follow recommended drilling parameters to yield good boards. The biggest advantage that Speedboard C has over the other prepregs mentioned is laser processing. Because the matrix is not woven glass reinforced, the material will laser ablate nicely. This could be a big plus in foil lamination constructions with micro vias.

Foil Lamination Constructions.

Now that we have looked at the various prepregs available, we should look at another type of construction that microwave design engineers are looking at for lower cost constructions; the foil lamination constructions or foil lams as they are commonly known. What do we mean when we say foil lam builds? A design typically uses copper clad laminates and prepregs are used as dielectric layers on the inside of the board. What if you could replace the external laminate layers on the outsides of the board with a prepreg and laminate a piece of copper to that prepreg layer. You would eliminate a costly copper clad laminate and replace it with a low cost prepreg. Speedboard C has been used on foil lam constructions but only in applications where micro via technology was needed. The high cost of the Speedboard C made it an unattractive choice for low cost applications. Both prepregs from Rogers and Arlon present challenges for foil lam constructions because of low adhesion to copper foils. Special care and the recommendation to use special coppers make this a costly design. The TacPreg from Taconic offers the designer a choice to design with a foil lam build. TacPreg has excellent adhesion to copper foils and is the right material for lower cost foil lam constructions. The following design shows the effectiveness of using a foil lam construction. Figure 8 shows a design with three copper clad dielectric layers and two prepreg layers. Figure 9 shows the same design but using only two layers of copper clad laminate and three areas of prepreg.

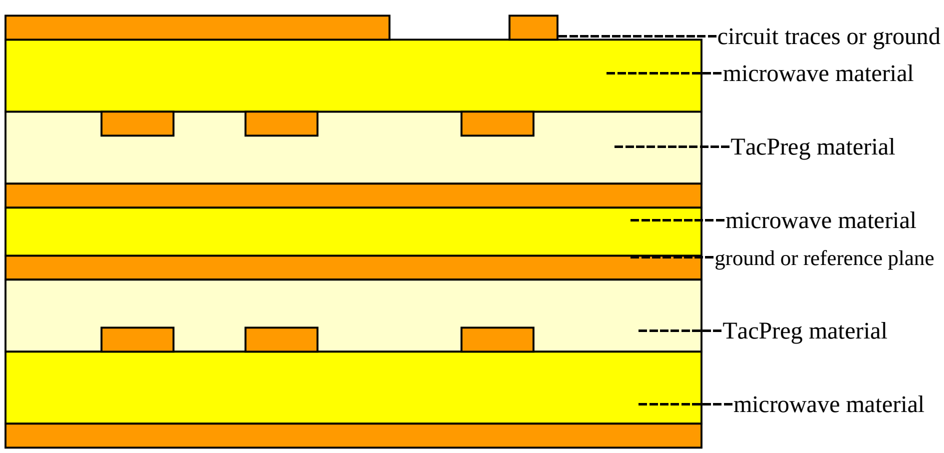

Figure 8. All microwave materials with three dielectric layers and two layers of prepreg.

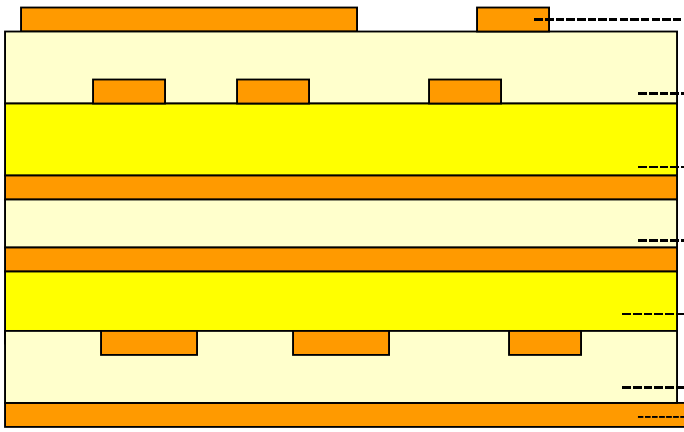

Figure 9. Similar design as in figure 8. but using two layers of laminate and three areas of microwave prepreg material.

Cost Comparison of Different Manufacturing Techniques

Let’s look at the cost of the various material stack ups. We will take a design similar to the design in Figure 8 and compare the cost of material on that design using three different manufacturing techniques.

1. Laminate layers and bonding films using Taconic HT 1.5 layers with Taconic RF-35 microwave material. This design would use five layers of RF-35 and 4 layers of HT 1.5 bonding film.
2. Using Taconic RF-35 in conjunction with Taconic TacPreg as shown in Figure 8. This will use three layers of Taconic RF-35 and two areas of TacPreg prepreg
3. Using Taconic RF-35 in conjunction with Taconic TacPreg as shown in Figure 9. This will use two layers of Taconic RF-35 and three areas of TacPreg. This will also require two sheets of copper foil supplied by the printed circuit board shop.

For the sake of comparison we will look at all the layers being 20 mil layers. We also assume the same type of coppers would be used on all layers. Also for comparative purposes we will assume a manufactured panel of 18” x 24”.

	Design 1		Design 2		Design 3	
Layers of RF-35 0.020" laminate	5 dielectric layers	5 x $30.00 = $150.00	3 dielectric layers.	3 x $30.00 = $90.00	2 dielectric layers	2 x $30.00 = $60.00
Layers of bonding film 1.5 mils thick	4 plies of .0015". 1 ply between each layer of laminate	4 x $4.50 = $18.00				
Layers of 0.010" TacPreg			2 plies for each 20 mil spacing. Total 4 sheets	4 times $13.50 $54.00	2 plies for each 20 mil spacing. Total 6 sheets.	6 times $13.50 $71.00
Layers of copper foil laminated.					2 pieces of copper foil.	$3.00
Material Cost		$168.00		$144.00		$134.00

Table 3 - Comparing material cost of designs with bonding films, prepregs and foil lamination constructions.

The cost of using foil lamination construction is the lowest material cost of the three similar designs. This paper does not cover the differences in manufacturing cost of the printed circuits board at the board shop. When one considers additional cost of baking dielectric layers, extra precautions during lamination to prevent bow, twist and warp, processing steps to achieve etch tolerances and dimensional stability, etc. the cost differences in the finished board could be 15% to 20% lower on the foil lam board build versus the traditional prepreg builds. Those factors are beyond the scope of this paper.

Conclusion

Regarding microwave printed circuit boards, the trend has been to go to higher performance and to combine more functions on the boards. Thus the trend is going to more layers. While the trend is higher performance and more layers the push has been towards lower cost constructions. Prepregs like TacPreg offered from Taconic offer the design engineer a practical solution---higher performance boards with a microwave grade prepreg and lower cost boards.