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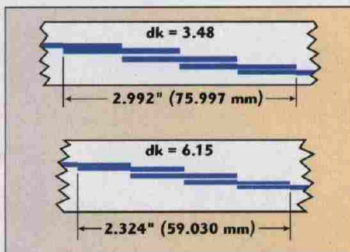
NEW HIGH FREQUENCY PCB MATERIALS FOR THE POWER AMPLIFIER INDUSTRY

It is obvious that the selection of the transistor for a power amplifier circuit is critical. However, it is often less obvious how the properties of the printed circuit board (PCB) can impact overall performance. The materials used to make the PCB can have an influence on a power amplifier's stability, gain and possible maximum output power.

With the trend to more compact designs, a PCB material with a higher Dk (dielectric constant, relative permittivity, ε_r) can help to enable this technology. Some of these materials have been on the market for several years now, all of which have trade-offs between electrical performance and other issues. Rogers Corp. recently released a laminate with the proven performance of the RO4000® product family, which is formulated specifically for the demands of new power amplifier applications. The product is the RO4360™ laminate.

The RO4360 substrate has a Dk of 6.15 and a Df (dissipation factor, loss tangent, tan δ) of 0.003 when tested at 2.5 GHz. Other substrates on the market with this higher Dk prior to the release of this product were primarily polytetrafluoroethylene (PTFE)-based. PTFE materials offer good electrical performance; however, there can be issues with PCB fabrication and plated thru-hole reliability. In addition, the overall cost of PTFE circuit fabrication is typically higher than a thermoset substrate. The RO4000 products have been proven to be easy for circuit fabrication and have demonstrated high plated thru-hole reliability.



▲ *Fig. 1 2.4 GHz microstrip edge coupled bandpass filter size reduction of 29%.*

The higher Dk offers the circuit designer the ability to reduce the size of the circuit. An example of how much a microstrip bandpass filter segment of a PCB can be reduced is shown in ***Figure 1***. In order to maintain a 50 Ω transmission line, the conductor width needs to be reduced. With a reduced conductor width, some concern may be related to thermal management. However, this is offset by the thermal conductivity of the RO4360 material, which is 25 percent higher than the proven legacy RO4350B™ laminate. Considering that PCB power handling capability is usually a function of the conductor width, ground plane spacing and the Df of the material, the low Df of the RO4360 laminate is also advantageous. The low loss also ensures maximum gain from the amplifier design. An insertion loss graph is shown in ***Figure 2*** for a 20 mil thick laminate and tested as a microstrip transmission line.

Another material property associated with temperature change is the coefficient of thermal expansion (CTE). The RO4360 laminate has a CTE that is very closely matched to copper in the x-y plane, which is about 16 ppm/°C. This is very important for several reasons. During the assembly stage of the process, having the PCB substrate expand the same amount as the copper will develop much

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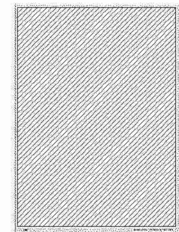

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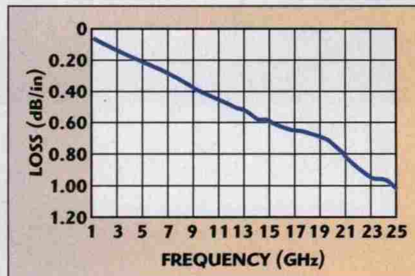
less stress and yield a more reliable circuit assembly. When the x-y plane CTE is significantly higher than the copper, the substrate will expand at a different rate than the copper during soldering; this can shear the copper pads off of the circuit. If this extreme situation does not occur, there will be a "locked-in" stress in the solder joints. This induced stress can cause a field issue as the circuit cycles through temperatures during its normal use.

The matched CTE in the x-y plane of the RO4360 laminate eliminates this potential issue. One more concern associated with CTE is the plated through hole (pth) reliability. It is very common for PCB laminates to have a CTE much higher in the z-axis (laminate thickness axis) than the x-y plane. Since this will be higher than the CTE of the copper that is plated in the through hole, this too can cause reliability issues. It is typically understood that a CTE that is less than 70 ppm/°C in the z-axis will yield



▲ *Fig. 2 Microstrip insertion loss for 20 mil thick RO4360 laminate.*

a circuit of good reliability. The CTE of the RO4360 substrate in the z-axis is 30 ppm/°C, making it a very reliable material for pth issues.

Lastly, the T_g (glass transition) of the material can also be important for a reliable circuit assembly. The T_g is the temperature where the material has a transition in the CTE or modulus vs. temperature slope. Most PCB laminates have a T_g that is below the soldering temperature experienced in assembly. This has been known to cause assembly reliability issues and is typically accepted as the "nature of the beast". What could exaggerate this issue are the newer designs using lead free soldering, which is done at a higher temperature. Typically, lead-free soldering reflow temperatures are around 260°C; most PCB laminates are well beyond their T_g at that temperature. The T_g of the RO4360 laminate is greater than 280°C, well above the maximum exposure temperature during lead-free soldering.

Moisture absorption is another material property that needs to be well controlled for a good power amplifier circuit. It is not uncommon for some PCB laminates to have a moisture absorption value as high as 2 percent. This absorbed water usually comes in the way of absorption from the environment by way of humidity. Since water has a Dk of about 73, the humidity can change the Dk value of the substrate, which can cause the circuit to perform poorly. Besides the change in impedance due to the absorbed moisture and the reflections caused by this change, the Df value of the PCB can also increase as well. A power amplifier design could have much worse performance than expected in a humid environment when using a PCB material that absorbs significant moisture. The RO4360 laminate has a very low moisture absorption property of 0.13 percent even when it is tested for 48 hours in warm water submersion.

As power amplifier designs evolve, the need for more complex PCBs increases. It is common to have a high frequency material, such as the Rogers RO4000 family of products, combined with other materials to build a hybrid PCB. This is typically done by using a low cost FR-4 material in the circuit design layers where the high performance capabilities of the RO4000 materials are not needed. However, when stripline structures are needed, which are becoming more prevalent in new power amplifier designs, then a high performance prepreg (bonding layer) is necessary. Until now the prepreg layer would be a lower Dk material and a non-homogeneous stripline would be necessary. The Dk difference between the laminate and prepreg layers will influence the effective

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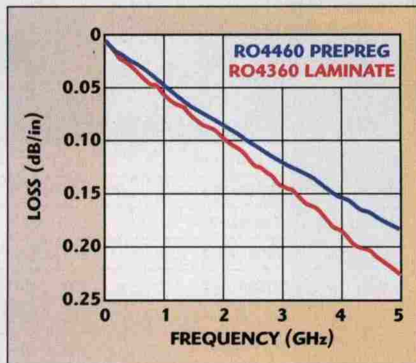
Dk value and some dispersion issues could result. Having a prepreg of the same Dk for the stripline structure is extremely advantageous. Rogers will soon release a prepreg to join the



▲ *Fig. 3 Microstrip insertion loss for 20 mil thick RO4460 prepreg and RO4360 laminate.*

RO4400™ family of products that will closely match the Dk of the RO4360 laminate. The prepreg will also match the other critical properties of the laminate as well. This is the first thermoset prepreg that has a higher Dk, making it very friendly to the PCB fabrication process. It also has excellent high frequency capabilities.

Of the several different properties previously discussed about the RO4360 laminate, in general, similar values for these properties apply to the laminated RO4460™ prepreg. As an added benefit to the PCB fabrication process, the resin flow properties have been improved over the capabilities of the other Rogers RO4400 prepregs.

The RO4460 prepreg has a Dk and Df closely matched to the RO4360 laminate. Insertion loss testing was done on microstrip circuits made with this prepreg and compared to the laminate. This comparison is shown in ***Figure 3***. As an added interest to power amplifier designers, the RO4360 laminate and RO4460 prepreg utilize RoHS-compliant, flame-retardant technology for applications requiring UL 94V-0 certification.

There can be many interactions between any substrate and the circuit fabrication, assembly processes and end-user application. Such interactions are difficult to predict. Rogers therefore strongly recommends that the customer evaluates each material and design combination to determine fitness for use over the entire life of the end product.

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