21st ANNIVERSARY

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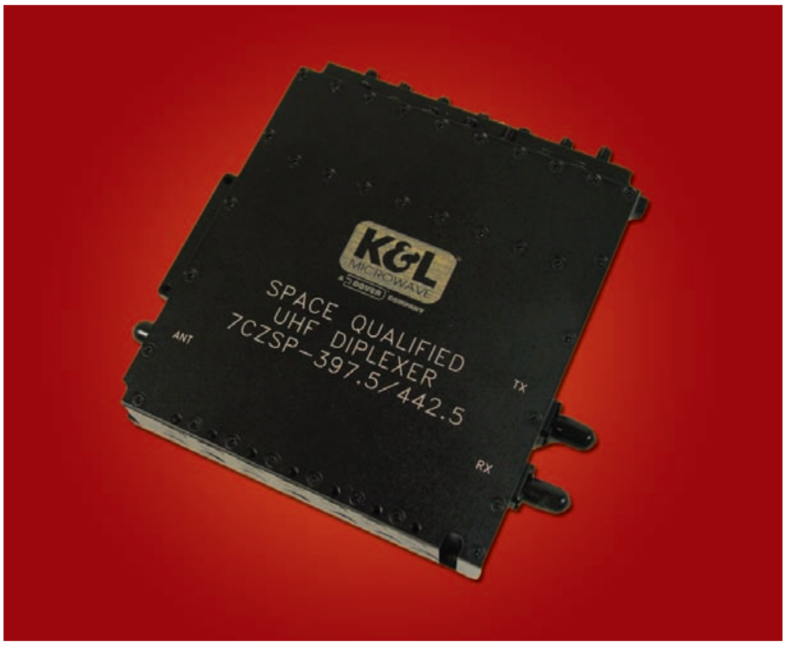
OCTOBER 2010



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In This Issue

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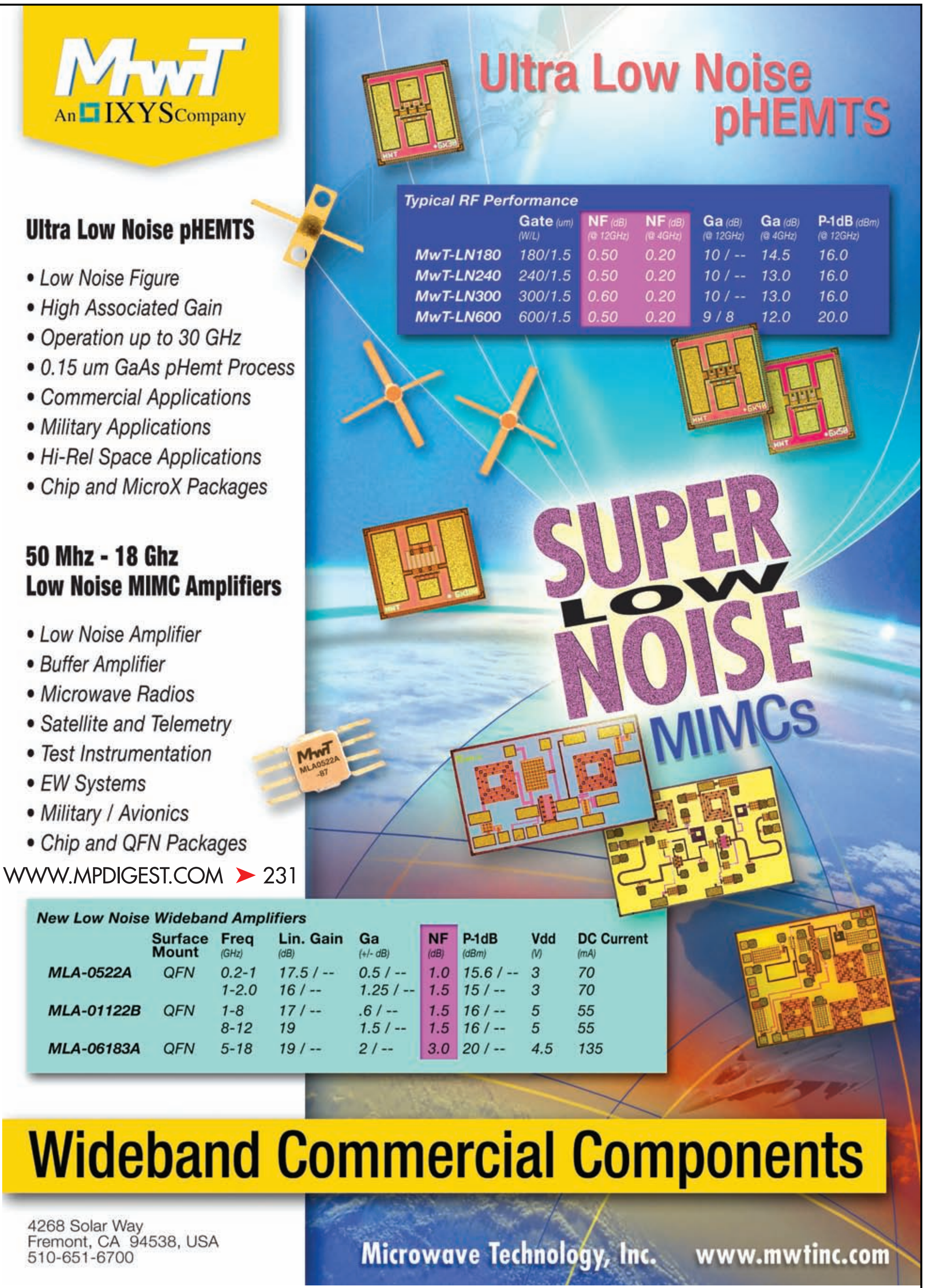
Miniaturize Microwave Power Amplifiers by Means of PCB Materials Selection

by John Coonrod, Rogers Corporation

Power amplifier specifiers continue to seek units with higher power levels in smaller packages for commercial, industrial, military, and even medical applications. Although the selection of power transistors and their matching networks is critical to the ultimate performance possible with a given amplifier design, the printed-circuit-board (PCB) material also plays a key role in determining the overall performance and even the size of the amplifier.

The dimensions of the transmission lines in a high frequency amplifier circuit are directly related to the wavelengths of the frequencies for which the amplifier is intended. As the frequencies increase, the wavelengths of those frequencies decrease, along with the dimensions of the transmission lines and other circuit structures on an amplifier PCB. A critical design step in any high frequency amplifier is determining the impedances necessary to transform the typically low impedance of an RF/microwave transistor to the characteristic impedance of the system in which the amplifier will be used, typically 50 or 75 Ω. The necessary matching impedances can be found by using a Smith Chart and scattering-parameter (S-parameter) values or performing simulation and calculations with a computer-aided-design (CAD) program.



In addition to wavelength, the dielectric constant of the PCB material can also determine the size of an amplifier's transmission lines and circuitry. Air, for example, has a dielectric constant of 1; practical PCB substrate materials have higher values. Materials with extremely low loss, such as polytetrafluoroethylene (PTFE), have values as low as 2.2. By using PCB materials with higher values, however, it is possible to design amplifier circuits for a given frequency range that are proportionally smaller than similar circuits designed on a lower-dielectric-constant material.

Although using a PCB substrate material with higher dielectric constant can reduce the size of high frequency circuit features, conductor widths must also be made narrower with a higher-dielectric-constant material to maintain desired impedance values. These shorter and narrower circuit dimensions can present challenges for some circuit fabrication processes. Fabricating circuits with finer features requires precise control of circuit-feature definition as well as excellent dimensional stability of the PCB substrate during the circuit fabrication process. In addition, as amplifier circuits are miniaturized, and power transistors more closely spaced, sound thermal-management practices must be followed to ensure the reliability of these more compact amplifier designs.

A variety of different dielectric substrate materials have been used for high frequency ampli-

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fier circuits, from low-cost FR-4 materials to higher-cost, higher-performance PTFE-based PCB substrates. One material that has delivered proven performance in a wide range of microwave power amplifier designs is RO4350B™ laminate from Rogers Corporation (www.rogerscorp.com). The low-loss copper-clad thermoset material exhibits a dielectric constant of 3.48, with low coefficient of thermal expansion (CTE) for good dimensional stability with temperature. Because it is not based on PTFE, it can be processed with the simple, low cost methods used for FR-4 substrates.

A PTFE laminate, with its lower dielectric constant (typically 2.2) and lower dissipation factor (loss) than RO4350B material, can ensure maximum gain from an amplifier with minimal generation of heat. But PTFE materials are also more expensive than RO4350B laminates, with a higher cost of circuit fabrication. To support tighter cost and loss budget requirements, additional PCB materials were developed to complement RO4350B laminates, using the same non-PTFE dielectric system but with a special copper laminate to minimize conductor losses. With dielectric constants ranging from 3.0 to 3.8, these newer RO4350B LoPro™ laminates feature a low-profile copper foil with low loss and excellent thermal characteristics for use in power amplifiers at microwave frequencies.

Figure 1 offers a comparison of the RO4350B and RO4350B LoPro PCB materials along with performance curves for low-cost FR-4. All three of these substrates are thermoset materials. The fourth curve is for a PTFE-based material, RO3035™ substrate from Rogers, a ceramic-filled PTFE system that supports ease of circuit fabrication compared to traditional PTFE substrates while maintaining the low-loss advantages of standard PTFE substrates. All four PCB materials have been used in power amplifier designs for a variety of different frequency bands and applications.

Designers seeking to miniaturize high frequency circuits have traditionally been limited to PTFE-based laminates when seeking materials with high dielectric constants. PTFE laminates have been available with dielectric constants of 10 and higher, allowing designers to achieve significant reductions in the size of their amplifier circuits. Typically, the PTFE materials used to design reduced-form-factor amplifiers have a dielectric constant around 6.

Unfortunately, PTFE is a soft material subject to dimensional changes over temperature, a problem that can cause unwanted changes in performance when the substrate materials are used in high power amplifier circuits. Because circuit features shrink when using higher-dielectric-constant PCB materials, the dimensional instabilities of PTFE substrates can pose problems for many high frequency designs, especially amplifiers. The low thermal conductivity of PTFE materials can also place limits on amplifier power levels as circuit size is reduced and heat-generating power transistors are more closely spaced.

For designers seeking to miniaturize their amplifier circuits, a practical alternative to high-dielectric-constant PTFE PCB materials is RO4360™ laminate recently introduced by Rogers. Its dielectric constant of 6.15 is comparable to that of the PTFE substrates used to design miniature power amplifier circuits. This non-PTFE,

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glass-reinforced thermoset material builds on the legacy of RO4350B laminates, although with increased thermal conductivity for handling higher output-power levels in amplifier circuits. Standard RO4350B materials have thermal conductivity that is considered quite respectable, at 0.62 W/m-K. The newer RO4360 laminates improve upon this value by about 22%, with thermal conductivity of 0.80 W/m-K. Since the RO4360 laminate is based on glass-reinforced thermoset dielectric rather than PTFE, its dimensional stability is quite good, and the material is well suited to standard, FR-4-type circuit fabrication processes.

How much miniaturization is possible by designing an amplifier with a higher-dielectric-constant PCB material? As an example, Figure 2 shows the difference in fabricating a microstrip edge-coupled filter using a laminate with dielectric constant of 3.48 (top) versus one with a dielectric constant of 6.15 (bottom). For the operating frequency of 2.4 GHz, a size reduction of about 29 percent was achieved with the higher-dielectric-constant material.

In selecting a PCB material for a power amplifier, laminates with minimal variations in thickness and dielectric constant generally deliver circuits also capable of minimal deviations in expected performance. As an example, Doherty amplifier configurations have become widely adopted in microwave amplifiers for wireless communications systems. The Doherty amplifier is capable of high efficiency with generous gain and output power. To achieve that efficiency, however, the amplifier requires quarter-wavelength impedance matching sections between several portions of the amplifier circuitry. The quarter-wavelength transformers are formed by printed conductors on the PCB. To achieve proper phase response, it is essential that the laminate material chosen for the transformer offers tightly controlled thickness and dielectric constant. When the multiple impedance matching sections of a high frequency power amplifier can be tightly controlled, with minimal reflected energy, the amplifier's efficiency can be optimized. The RO4360 laminates achieve a dielectric constant tolerance within ±2.4% of the nominal value (6.15), with a thickness tolerance that is within ±7.5% for a 20-mil-thick laminate, to ensure tight control of impedance transformation circuits.

Many high frequency power amplifier circuits are based on microstrip technology, although some newer designers are also using stripline. Each technology has its benefits and limitations in terms of bandwidth and dispersion, although circuit fabrication approaches differ for the two technologies. A microstrip PCB can be fabricated as a simple nonplated-through-hole (PTH) board, which requires a simple and inexpensive process. Stripline requires a multilayer construction in which PTHs are fabricated to connect different circuit layers. Fabrication of stripline circuits is more complex and costly than that of microstrip circuits.

Stripline circuits are typically formed using laminate and bonding layers of a substrate. Since the materials are different, a traditional problem has been in constructing a homogeneous stripline structure without involving complex fabrication processes. Fortunately, along with the release of the high-dielectric-constant RO4360 laminate material, Rogers also recently introduced its RO4460 prepreg bonding layer mate-

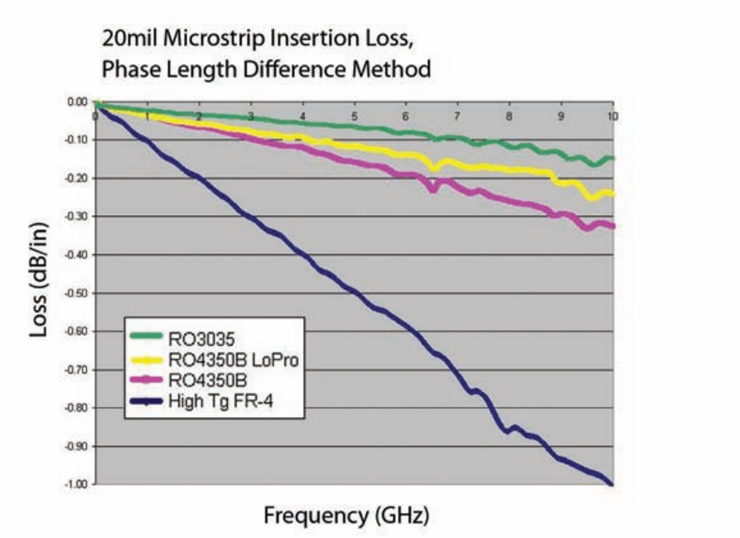

Figure 1: Microstrip insertion loss of different circuit materials used in power amplifiers

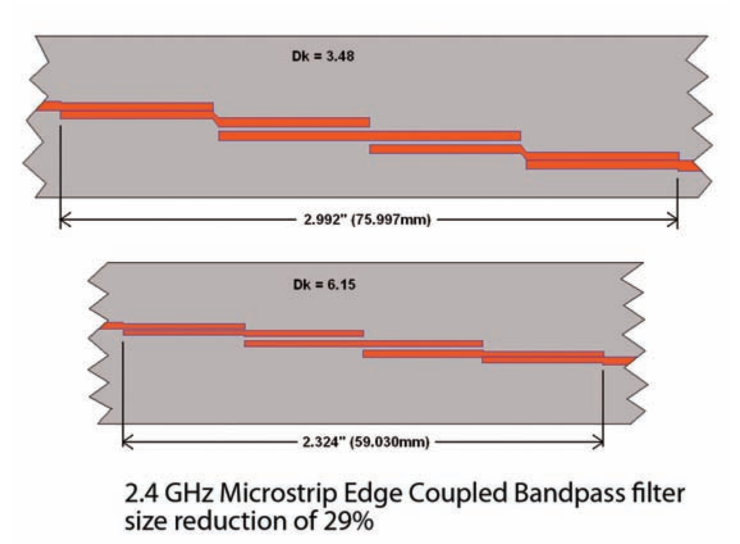

Figure 2: The same 2.4-GHz filter was fabricated on a laminate with dielectric constant of 3.48 (top) and dielectric of 6.15, with the higher-dielectric-material yielding a considerable saving in physical size.

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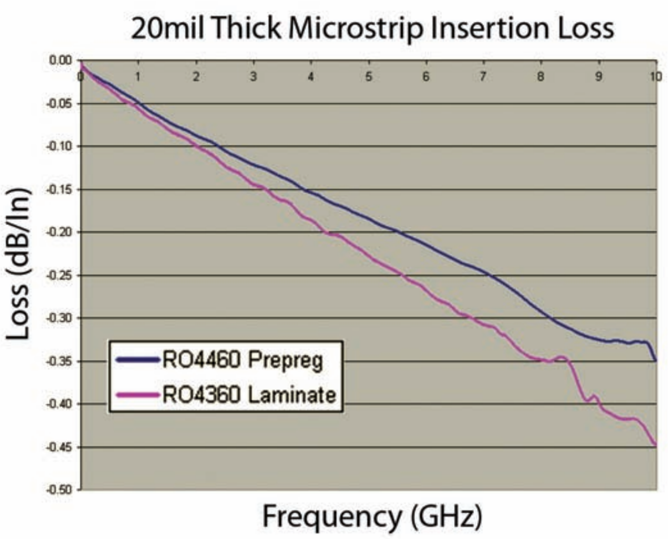

Figure 3: Measurements of microstrip fabricated on 20-mil-thick laminate and prepreg materials show extremely low loss with frequency of both materials. The materials are also suitable for multilayer stripline circuits.

rial with dielectric constant of 6.15 matched to that of the RO4360 laminate. The prepreg is a thermoset material with electrical and mechanical characteristics that are nearly identical to the RO4360 laminate, allowing the fabrication of homogeneous stripline. In addition, since neither the laminate nor the prepreg contains PTFE, standard, low cost fabrication processes can be used in forming stripline amplifier circuits.

Typically, prepregs developed for use with a particular substrate material will exhibit different dielectric properties. But the RO4460 prepregs were engineered to match the dielectric constant and loss characteristics of the RO4360 laminates; in fact, the prepreg's dissipation factor is the same or better than that of the laminate to ensure low-loss microstrip and stripline circuits fabricated with the laminate/prepreg system. As evidence, Figure 3 shows the results of microstrip circuits formed on the laminate and prepreg materials and tested for insertion loss. Although the loss characteristics track with increasing frequency, the prepreg shows consistently lower loss than the laminate material, even at higher frequencies.

For amplifier designers concerned with meeting environmental compliance or Underwriters' Laboratories (UL) requirements for safety, the 6.15 dielectric constant laminate and prepreg materials are RoHS-compliant and certified to UL 94 V-0 specifications. The materials have also been proven to be quite robust when used in lead-free soldering processes.

When miniaturization of a power amplifier circuit is an issue, the simplest solution is the use of a higher-dielectric-constant PCB material. A number of materials have been available for some time, although most of these are based on PTFE. While the material provides excellent low-loss performance, it offers limited dimensional stability as a function of temperature—a true concern for designers of high frequency, high-power amplifiers. As an alternative, recently developed non-PTFE laminates and prepreg materials, both with a dielectric constant of 6.15, feature excellent dimensional stability with temperature with low loss, consistent thickness, and consistent dielectric constant. This higher-dielectric-constant materials system supports smaller amplifiers using both microstrip and stripline technologies, and without the complex processing steps needed when using PTFE.

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