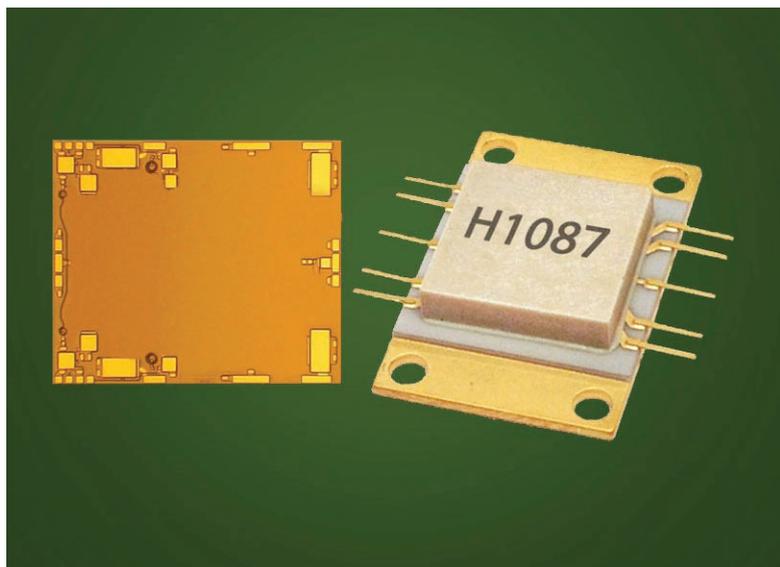


RF TO LIGHT

SEPTEMBER 2013



GaN MMIC Power Amplifiers

Four new GaN MMIC power amplifier products offer significant performance, size and durability advantages for communications, test instrumentation and radar systems operating in the 2 to 20 GHz frequency range. The die versions of the amplifiers feature compact die sizes, high output power capability and simplified biasing, which make them ideal for integration into high power density MCM and subsystem applications.

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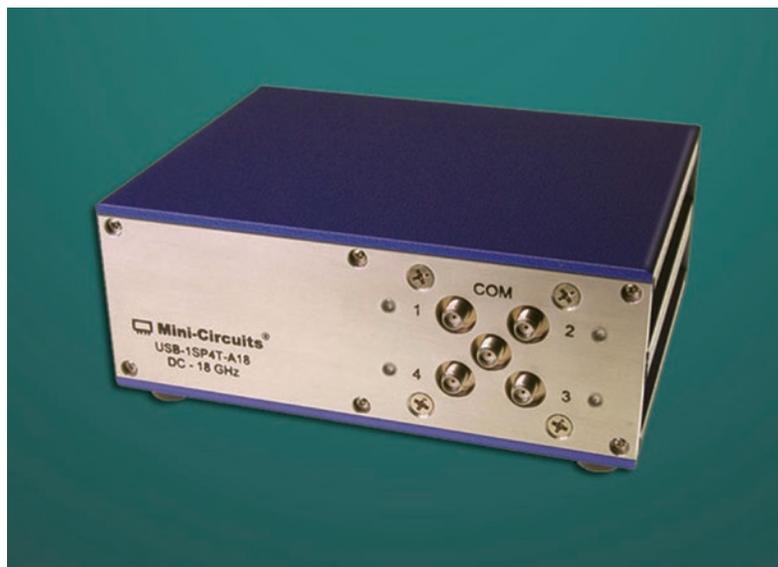
HITTITE MICROWAVE

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USB RF-SP4T Switch Matrix

Model USB-1SP4T-A18 is a general purpose USB controlled SP4T electro mechanical absorptive fail-safe RF switch constructed in break-before-make configuration and powered by +24V_{DC} with a switching time of 25 mSec typical. It is capable of 100 million cycles, has an easy to control USB interface, and boasts a wide frequency from DC to 18 GHz.

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Selecting Microwave Laminates for Antenna and Radar Applications

by John Coonrod, Market Development Engineer, Rogers Corporation, Advanced Circuit Materials Division

Radar and antenna applications require many different types of printed-circuit-board (PCB) materials. Each of these applications has a unique set of requirements, and having a wide choice of PCB materials affords more freedom of design. But having a selection of PCB materials with just a wide range of dielectric constant (ϵ_r or Dk) may not be sufficient. A number of different PCB material attributes can impact antenna and radar circuitry performance. For antennas (and other circuits, such as amplifiers), for example, passive intermodulation (PIM) performance is an important performance parameter that can be affected by the choice of PCB material, and understanding circuit-material-related issues for parameters such as PIM can help improve the PIM and general performance levels of antenna and radar applications.

When selecting PCB materials for antenna and radar applications, it is useful to understand a number of different attributes of circuit materials so that an optimum PCB material can be matched with a particular application. Some of the main PCB material properties to consider are dielectric constant (Dk) and dissipation factor (Df), but numerous other PCB material qualities can be critical to antenna and

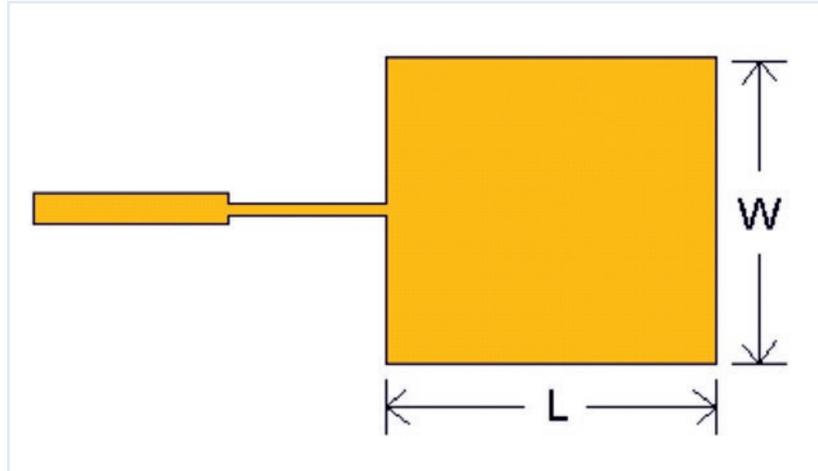


Figure 1: This drawing shows a radiating element for a patch antenna

radar applications, notably for thermal management and how a PCB material performs at elevated temperatures and power levels. For example, a PCB material's coefficient of thermal expansion (CTE) provides insight into the expansion and contraction of a circuit material over a range of temperatures, such as the elevated temperatures that occur at high power levels due to circuit losses. Another material parameter, the thermal coefficient of dielectric constant (TCDk) provides information on how a circuit material's Dk will change with temperature, and how such changes in Dk might potentially impact a circuit design that depends on maintaining Dk values within a certain range. Yet another thermal property of circuit materials is the thermal conductiv-

ity of a PCB material, and the material's capability for efficiently transferring heat away from a source on a circuit, such as a high-power amplifier, to a receptacle for the unwanted thermal energy, such as a heat sink. Good PCB material thermal conductivity can contribute a great deal to achieving stable performance and high reliability for circuit's fabricated on that PCB material.

The dielectric constant is a starting point for many PCB material selection processes. Although it can be measured in all three axes (length, width, and thickness, or x, y, and z directions) of a PCB material, the value of Dk in the z-direction at a particular test frequency, such as 10 GHz, is typically used when comparing PCB materials for use in high-frequency RF/microwave appli-

cations. PCB materials with z-axis Dk values ranging from about 2 to 10 at 10 GHz are most commonly used for RF/microwave circuit applications, with materials having the lowest Dk values most often used for PCB antenna applications.

Still, PCB materials with higher Dk values yield smaller circuit structures for a given wavelength/frequency, and a recent trend in antenna technology has been exploring the use of PCB materials with higher Dk values to create smaller PCB antennas. Patch antennas or arrays formed of patch antennas are commonly used for many antenna designs and radar systems. The radiating elements for such patch antennas are based on a physical size of approximately one-half wavelength at the frequency of interest. By switching to a PCB material with higher Dk value, the wavelength for a given frequency is effectively reduced, as is the required size of the patch antenna's radiating elements. Figure 1 shows a simple drawing for a patch antenna radiating element with the length, L, of the element approximately equal to one-half wavelength of the frequency of interest.

Reducing the size of an antenna element can benefit many applications, but it also brings some tradeoffs, such as a reduction in the width of the radiating element's feed line. The feed line transports energy from a source to the radiating element; a narrower feed line results in higher insertion loss and less energy received at the radiating element.

Table 1 shows relationships between several different Dk values, patch element size, potential area reduction, and the feed line conductor width.

The information in Table 1 assumes a microstrip patch antenna element, with

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Table 1: Comparison of patch radiating element size when using microwave circuit materials of different Dk values. The potential size reduction is shown as well as the impact on the feed line conductor width.

dK	Antenna radiator size			% Area Reduction	50 Ohm Conductor Width Feed Line (mils)
	Length (in.)	Width (in.)	Area(in. ²)		
3	1.342	0.835	1.12057	baseline	76
4	1.162	0.747	0.868014	23%	62
6	0.952	0.632	0.601664	46%	45
10	0.742	0.504	0.373968	67%	29

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microstrip fabricated on a 30-mil-thick laminate at a center frequency of 5 GHz. Table 1 shows the reduction in the size of the patch antenna radiating element as a function of Dk value. It also shows that the narrowing of the conductor width with increasing Dk value can be a concern because of the increase it brings to the insertion loss of the feed line.

Table 1 is based on PCB materials in a generic sense, calculating circuit dimensions based on Dk value, while Table 2 lists commercial RF/microwave circuit materials currently used in many antenna and radar circuit applications. Table 2 presents key properties for its list of RF/microwave PCB materials for antenna and radar applications, and the information will be used as a reference throughout the rest of this article.

Table 2 provides a range of PCB materials with different Dk values, enabling circuit designers to select a circuit material with higher Dk value to miniaturize antennas and other microwave circuitry. The Dk is just one circuit-material parameter; it is typically weighed with other PCB parameters, such as dissipation

Table 2: Common microwave circuit materials currently used in antenna and radar applications.

Material	Dk	Df	TCDk	CTE	Thermal Conductivity (W/m/K)
RO4725JXR™	2.55	0.0033	23	40	0.52
RO4730JXR™	3.00	0.0033	21	40	0.52
RT/duroid®6035HTC	3.60	0.0013	-66	39	1.44
RO3206™	6.60	0.0027	-212	34	0.63
RO4360G2™	6.40	0.0038	-120	26	0.80
TMM®6	6.30	0.0023	-11	20	0.72
RO3210™	10.80	0.0027	-459	34	0.81
TMM10	9.80	0.0022	-38	20	0.76
TMM10i	9.90	0.0020	-43	20	0.76
TMM13i	12.20	0.0019	-43	20	0.76

factor (Df), when selecting a PCB material for an application. The Df parameter, for example, provides an indicator of the dielectric loss associated with a particular circuit material. If a circuit material with higher Dk is used to miniaturize an antenna, the Df value for that material will provide insight into the expected insertion loss for the antenna's feed line. In other cases, such as when the antenna may be fed by a coaxial cable rather

Table 3: Shifts in center frequency calculated by commercial EM simulation software for a microstrip patch resonator element as defined in Table 1 using PCB material with Dk of 3.

Material TCDk (ppm/°C)	Center Freq. (GHz)	Frequency shift (MHz)
0	5.024	baseline
-78	5.048	24
21	5.017	7

than a PCB feed line, the PCB material's Df value will be less of a concern for that application. As a quick example, if RO3210™ circuit material was initially selected to miniaturize a patch antenna or patch array, but it was later discovered that the feed line insertion loss was important and had to be reduced, then the TMM10i circuit material would be a better choice, delivering both miniaturization and low feed line insertion loss.

A PCB material's TCDk can be very important for some applications and not for others. A circuit material's TCDk may be less of a concern for applications where circuitry may operate within a well-controlled environment, such as in a facility maintained at room temperature. But for applications with a heat source, such

as in tower-top antenna systems where transmit power amplifiers and other systems are contained within the same enclosure, the environmental operating temperatures can cover a wide range, and a PCB material's TCDk can be a very important property.

The impact of TCDk can be shown with a simple example. With data from Table 1 and assuming a patch antenna such as the one in Figure 1 on PCB material that is 30-mils thick with Dk value of 3.0 in the z-axis at 10 GHz, a commercial electromagnetic (EM) software simulation tool was used to predict the center frequencies of these antenna circuits based on the TCDk value of the PCB material and the operating temperature.

Table 3 shows the results of using an operating temperature

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Universal Module Power Amplifiers

- All modules are EAR99, no license required.
- All weigh 1.6oz (45g).
- All have size 1.5"(L)x1.2"(W)x0.58"(H)



Model #	Frequency	G _{SS}	P _{1dB}	P _{3dB}	η	V _{dd}	V _{g1,2}
AM072239UM-2H	0.7-2.2GHz	30dB	38dBm	39dBm	25%	28V	-0.94V
AM204437UM-3H	2.0-4.4GHz	30dB	36dBm	37dBm	25%	8V	-0.80V
AM264240UM-2H	2.6-4.2GHz	20dB	39dBm	40dBm	35%	14V	-0.95V
AM357037UM-2H	3.5-7.0GHz	25dB	36dBm	37dBm	28%	8V	-0.89V
AM357039UM-3H	3.5-7.0GHz	21dB	38dBm	38.5dBm	25%	14V	-0.89V
AM559538UM-3H	5.5-9.5GHz	24dB	37dBm	38dBm	25%	8V	-0.87V
AM08011034UM-3H	8.0-11GHz	25dB	31dBm	34dBm	20%	5V	-2.4V
AM08011036UM-3H	8.0-11GHz	28dB	32dBm	36dBm	25%	5V	-2.6V

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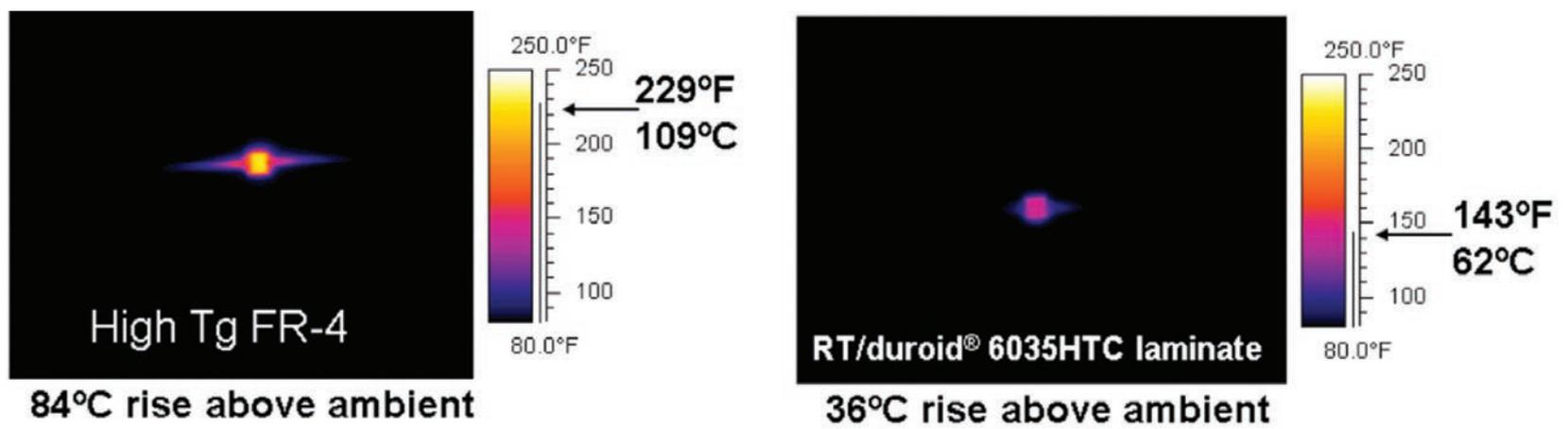


Figure 2: Thermal images of the same circuit and heat sink, with the same applied power, but using two different PCB materials of significantly different thermal conductivity

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range of +25 to +150°C and TCDk values of -78 and +21 ppm/°C based on commercial polytetrafluoroethylene (PTFE) woven glass circuit material and RO4730™ PCB material. The differences in center frequency as a result of the different TCDk material values are shown relative to an ideal, 0 ppm/°C baseline condition.

A laminate's CTE parameter can be an important consideration for multilayer microwave PCBs. As a general guideline, in a multilayer PCB construction the CTE should be less than 70 ppm/°C. To minimize mechanical stress with temperature in a multilayer PCB, the circuit material's CTE should be as close as possible as the CTE of copper, which is about 17 ppm/°C. A PCB based on material with relatively low CTE will suffer less internal stress during soldering operations and less stress as a result of long-term thermal cycling. As an example, a PCB with higher CTE values can experience mechanical shearing between the PCB and its mounting hardware as a result of long-term thermal cycling.

Power amplifiers built on microwave PCB materials are used extensively in radar applications. They are candidates for thermal management, to minimize temperature-induced mechanical stress within their circuits, but they are also sources of heat within a radar system, with their high-power active devices. These power

amplifier PCBs often include large heat sinks to help dissipate the heat produced by the amplifier devices or chips, and sometimes the devices or chips can even be mounted directly on the heat sink. In many cases, the amplifier devices or chips are mounted on the PCB material and the heat must flow through the circuit material to the heat sink. A PCB material with high thermal conductivity will be conducive to efficient flow of heat to the heat sink, with less heat generated around the amplifier's active devices or along the path to the heat sink for improved thermal management.

Most PCB materials are considered thermal insulators; most have thermal conductivity values ranging from 0.20 to 0.30 W/m/K. A PCB material with thermal conductivity of better than 0.50 W/m/K is considered good in terms of being able to conduct heat. Most of the laminates in Table 2 are in this range, since the fillers used to adjust the electrical properties of the PCB materials are also good thermal conductors. In particular, RT/duroid® 6035HTC laminate was formulated for high thermal conductivity. It is a popular PCB material choice for high power amplifiers and designers are increasingly considering it for antenna applications because of the combination of low Df and high thermal conductivity.

To better understand the thermal conductivity properties of microwave PCB materials, a

study was conducted using several microwave laminates with a surface-mount resistor soldered to each. A DC current was used to heat the resistor and thermal imaging was performed on the different laminates. The same circuit structure was used in all cases: a 20-mil-thick microstrip circuit on 1 oz. copper, attached to a heat sink, with the only difference in each case being the substrate. Materials with significantly different thermal conductivities were subjected to the same DC power levels and the thermal images of two of these circuits are shown in Figure 2.

As the thermal images of Figure 2 show, the temperatures of the resistors rise significantly above the ambient temperature. The high Tg FR-4 circuit material on the left, with the much higher rise in temperature, has a thermal conductivity of 0.30 W/m/K while the RT/duroid 6035HTC laminate on the right has a thermal conductivity of 1.44 W/m/K.

PIM has become a growing concern in high-frequency systems since it can degrade receiver sensitivity and distort digitally modulated signals. It is caused by a nonlinear interaction of two or more signals at some circuit junction, including through cables, connectors, and many passive microwave components. PIM can also limit the performance of PCB antennas and radar systems.

Microwave PCB materials can be guilty of enhancing or providing conditions for PIM generation, mainly due to PCB

substrate properties, the surface roughness of the PCB's copper cladding, and any treatments performed on the laminate's copper cladding. But a well-formulated PCB substrate with optimum copper foil can yield a microwave laminate with minimal PIM issues.

There is no standard procedure for PCB antenna PIM testing at this time, although much work has been done in this field. A couple of materials listed in Table 2 have had lengthy development periods and have been shown to exhibit good PIM performance: the RO4725JXR™ and RO4730JXR™ laminates. Good PIM performance is typically considered to be -140 dBc or better, with a value of -155 dBc considered very good. Both of these laminates typically achieve -155 dBc or better in PIM performance testing.

For any designer considering PCB materials for antenna and radar applications, knowing how a circuit material's parameters translate into thermal behavior and RF/microwave performance can help simplify the selection process. Material suppliers can also provide useful advice on the choice of different materials for different applications, based on the experiences of their customers.

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