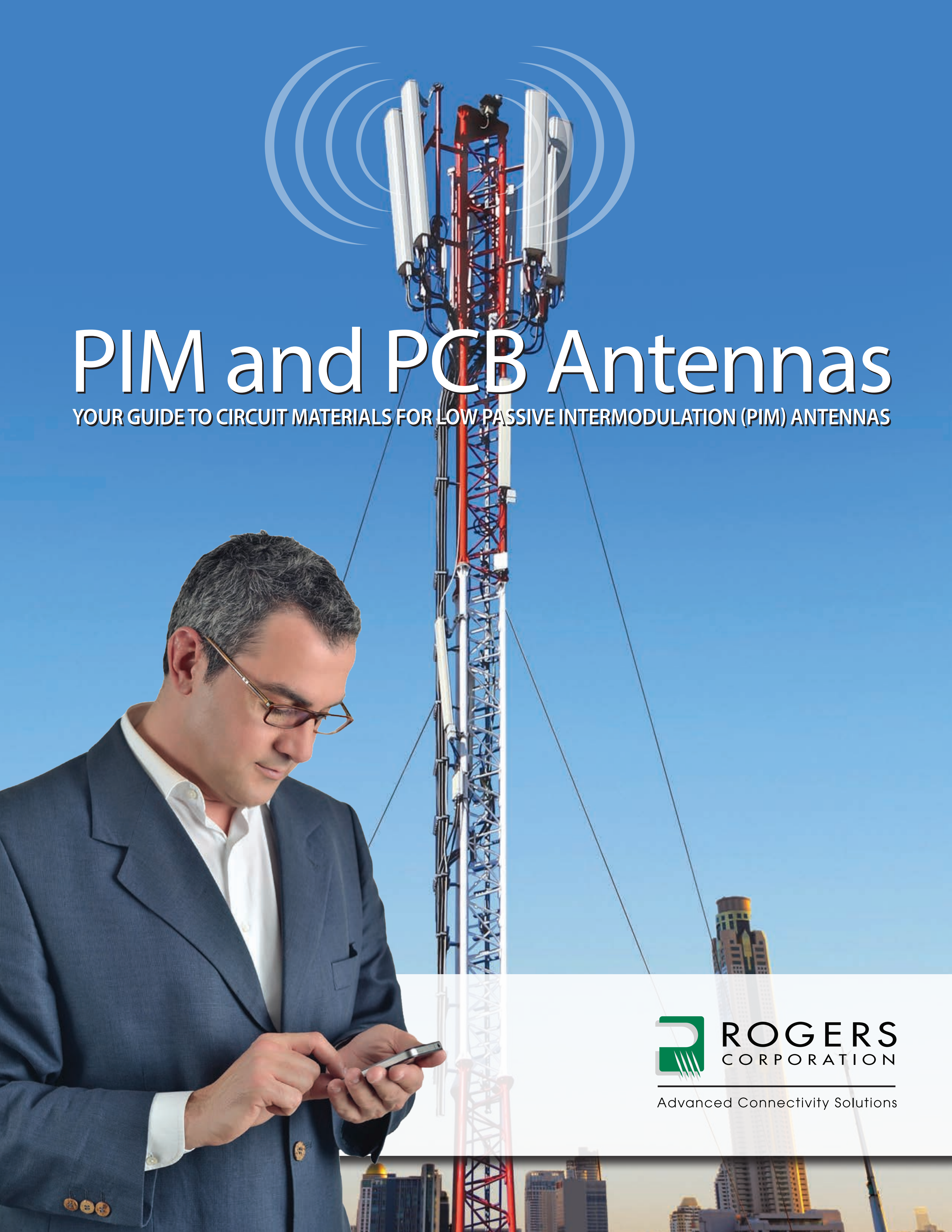
PIM and PCB Antennas

YOUR GUIDE TO CIRCUIT MATERIALS FOR LOW PASSIVE INTERMODULATION (PIM) ANTENNAS



ROGERS CORPORATION

Advanced Connectivity Solutions

PIM

Passive Intermodulation (PIM) has been a concern in wireless transmission systems since the 1970s. PIM affects systems that use a single antenna for both transmitting and receiving signals on multiple carrier frequencies. Slight non-linearities in the input/output relationship in the system can generate additional signals that are in-band at very low power levels that can increase the noise-floor. Increased noise degrades system performance. Its effects are becoming more noticeable with each new generation of wireless communication technologies. To suit a growing consumer appetite for "always-on" wireless communications, modern cellular communications technologies such as Fourth Generation (4G) Long Term Evolution (LTE) networks rely on advanced modulation techniques for reliable voice, video, and high-speed data communications. Such systems depend on minimal interference and low levels of PIM to function at optimum levels. Minimizing PIM usually involves evaluating the antennas in a cell site or other form of wireless basestation. And low-PIM antennas start with printed-circuit-board (PCB) laminates that can hold their own against PIM, by means of carefully selected materials, processing, and advanced test techniques. With good design practices and proper understanding, control, and monitoring of the PCB laminate properties, excellent system PIM can be achieved.

In a perfectly linear electrical system with multiple carrier frequencies, though "linear distortion" of power levels may occur, no additional frequencies can be generated. However, when the system exhibits non-linearity such as an amplifier approaching its saturation power level, additional frequencies that are linear combinations of the input carrier frequencies may be generated. Let us consider two closely spaced frequencies, f1 and f2, operating in the same band (Fig. 1). "Second order" IM products are 2f1, 2f2, and f2 – f1. All second order products generated are at frequencies far from the operating band, as do all even-order IM products. Third order products include 3f1, 3f2, 2f1+f2, 2f1-f2, 2f2+f1, and 2f2-f1. While some third order products are at frequencies far from the operating band, others (2f1-f2 and 2f2-f1) can fall in band, as shown in figure 1. Some of the higher odd-order IM products (5th, 7th, 9th, etc.) may also fall in-band, though at power levels significantly lower than the 3rd order products.

PIM is intermodulation that is generated in a passive system. The PIM power levels are generally very low compared to the transmitted signals that generate them. A PIM level of -153 dBc indicates a power level relative to the transmitted signal of 5 x 10-16. However, since the power of the received signals is very low, PIM can increase the noise floor and lead to operational problems.

Testing for Tomorrow

A number of factors can affect PIM in the transmitting side of a base station. The presence of ferrous metals or other magnetic materials in the electromagnetic field near the antenna can significantly increase PIM. Imperfect connections, such as conductive particles or chipped plating on the mating surfaces of conductors are a frequent cause.

When designing and utilizing PCB antennas it is important to remember that PIM is not a basic laminate property. Just like insertion loss, gain, directivity, and many other important electrical variables, PIM is a system property that depends highly on the system design. However, through extensive research at Rogers Corporation, we have determined the laminate properties that can help contribute to low PIM variables.

It is well known by antenna designers that minimizing current density is key to achieving a low PIM system. On the laminate side, Rogers determined that high

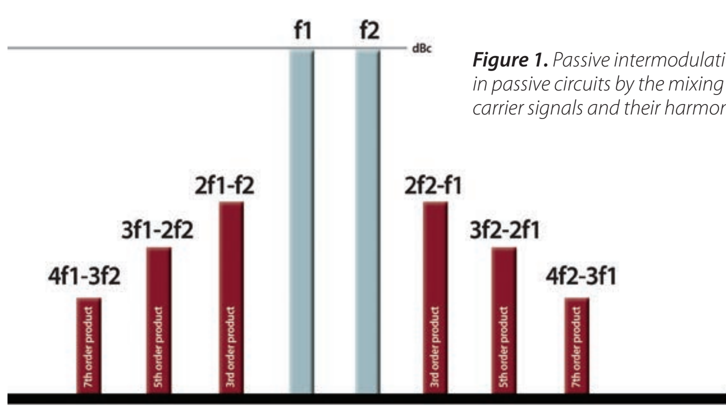


Figure 1. *Passive intermodulation (PIM) is produced in passive circuits by the mixing of two or more carrier signals and their harmonics.*

Figure 2. *A high-performance test set with PIM analyzer provides measurement results on the PIM levels from different circuit laminates.*

conductor purity and low conductor profile, dielectric formulation and physical properties, as well as control of the conductor – dielectric interface can be controlled properly to minimize PIM generation.

Rogers Corporation has regularly been testing PIM in-house since 2002 and developed a data and knowledge base unparalleled in the laminate industry. Our first PIM testing unit, a Summitek 1900b was installed in our R&D labs and used during development and periodic materials verification. Early in 2015, we added two additional Kaelus iQA-1921c (Fig. 2) units at our manufacturing facilities producing antenna grade materials. We now routinely monitor PIM as part of our standard production process.

Rogers Corporation's routine PIM test sample is a 305 mm (12") 50 ohm transmission line on 1.5 mm (0.060") dielectric material in the 1900 MHz band using two 43 dBm (20 watt) tones. Reflected PIM (also called reverse) is measured with port 1 of the sample connected to the PIM analyzer and port 2 connected to a low PIM load. Four lines are etched on a 12"x18" laminate and the circuit is backed by a 1.5 mm FR-4 stiffener. The connection is made to the board through 0.141" solder-plated braided low PIM cables and soldered lightweight coax to microstrip connectors. The circuits are gently manipulated, with attention to reducing the stress on the solder connection until the lowest stable PIM value is achieved and recorded. The recorded laminate value is the average of the recorded stable PIM value for each of the four lines.

When trying to differentiate between "good" PIM (perhaps in the range of -153 dBc) and "great" PIM (perhaps < -160 dBc), variation in the test results itself is relatively high since it is not far from the noise floor. Thus, repeated testing is very important to developing an understanding of relative PIM.

The following example demonstrates the importance in circuit design and current density in measured PIM. The 50 ohm transmission line on 0.030" Rogers RO4534™ laminate typically exhibits PIM of about -153 dBc. A customer routinely builds filters on this laminate that consistently exhibit PIM better than -160 dBc due to the difference in current density.

Making A Difference

These measurements and research studies are ongoing processes within different facilities at Rogers Coprporation. Testing revealed a great deal about the PIM performance of the company's PCB laminates, and led the way to the development of different types of circuit laminates well suited for low-PIM antennas, including the RO4500™ series thermoset laminates (see Table 1) and the AD series™ woven-glass, polytetrafluoroethylene (PTFE)/ceramic antenna circuit materials (see Table 2).

Table 1: Rogers Corporation's thermoset antenna laminates

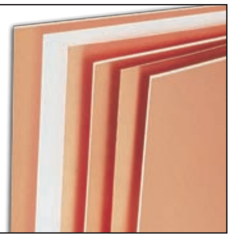
Laminate	Dielectric Constant (at 10 GHz, z-axis)	Dissipation factor at 10 GHz	Thermal Conductivity (W/m/K)	PIM (dBc)
RO4533™	3.30	0.0025	> 0.60	<-157
RO4534™	3.40	0.0027	> 0.60	<-157
RO4535™	3.50	0.0037	> 0.60	<-157
RO4725JXR™	2.55	0.0026	> 0.40	<-160
RO4730G3™	3.00	0.0029	> 0.40	<-160

All materials were tested with a 12 in. long microstrip transmission line test circuit on 0.060-in. (1.5 mm) thick laminate

Table 2: Rogers Corporation's WG PTFE/ceramic antenna materials

Laminate	Dielectric Constant (at 10 GHz, z-axis)	Dissipation factor at 10 GHz	Thermal Conductivity (W/m/K)	PIM (dBc)
AD250C™	2.50	0.0014	> 0.30	<-157
AD255C™	2.55	0.0014	> 0.30	<-157
AD300C™	2.97	0.0020	> 0.50	<-157

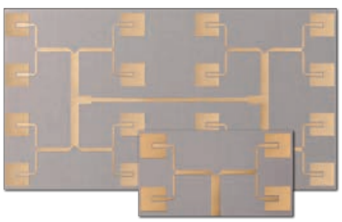
RO4500 series antenna-grade laminates include the RO4533, RO4534, and RO4535 circuit materials. They are ceramic-filled, glass-reinforced thermoset resin materials with excellent dimensional stability and uniform mechanical properties to help limit PIM.



The RO4500 series antenna-grade laminates are ceramic-filled, glass-reinforced thermoset resin materials with low PIM

They are available with values of dielectric constant (Dk) ranging from 3.3 to 3.5 at 10 GHz in the z direction and low loss, with loss tangent or dissipation factor (Df) from 0.0025 to 0.0037 at 10 GHz. All three circuit materials can handle the heat of high power levels, with excellent thermal conductivity values. When tested with Rogers' test fixture and microstrip transmission-line test circuit, all three materials exhibited low PIM levels of better than -157 dBc with two +43-dBm test tones.

AD Series antenna -grade materials include the AD250C™, AD255C™, and AD300C™ laminates. The circuit materials are formed of low-loss PTFE resin with carefully selected fillers and fiberglass reinforcement to achieveexcellent mechanical stability with low loss and tight control of dielectric constant across the material. In fact, the dielectric constant is controlled within ±0.05 for all three materials, for Dk values ranging from 2.50 to 2.97 measured in the z-direction at 10 GHz. As with the RO4500 Series materials, the AD Series laminates feature excellent thermal conductivity and low coefficient of thermal expansion (CTE) in the z axis for excellent stability when forming plated through holes (PTHs). And, like the RO4500 Series materials, the AD Series laminates feature low values of PIM, better than -157 dBc when measured with the Rogers' test fixture and test circuit.



The AD Series antenna-grade laminates incorporate PTFE resin with special fillers and fiberglass reinforcement for low PIM.

Both families of circuit materials contribute very little to an antenna's PIM levels. But, by applying lessons learned from the extensive testing and research, Rogers' has managed to exceed even this low level of PIM, with its RO4725JXR, and RO4730G3 antenna-grade circuit materials. These thermoset laminates feature Dk values of 2.55 and 3.0, respectively, with loss tangents of 0.0026 and 0.0027, respectively. For antenna designers (or designers of passive components concerned with PIM), the PIM levels when measured with the standard test circuit and measurement setup were exceedingly low: <-160 dBc, both for measurements on 0.060-in. (1.5 mm) thick laminates.

These three materials exhibit almost unmeasurable PIM levels and, along with the RO4500 and AD Series laminates, provide excellent foundations for antennas and other passive circuits where PIM must be minimized. PIM can result from many factors in a circuit or system, and even the thickness and dielectric constant of a laminate can affect PIM by contributing to the physical dimensions of transmission lines leading to higher current densities in densely spaced circuits. However, with these circuit laminates as starting points, antenna designers can be assured of having an opportunity to create an antenna design with the lowest PIM possible.

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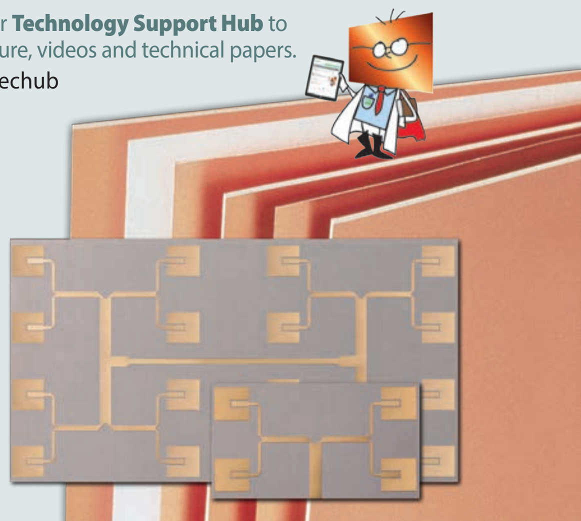

RO4534, AD Series, RO4500, AD250C, AD255C, AD300C, RO4533, RO4535, RO4725JXR, RO4730G3, the Rogers' logo and Helping power, protect, connect our word are trademarks of Rogers Corporation or one of its subsidiaries. Publication # 92-603. Revised 1481 071620