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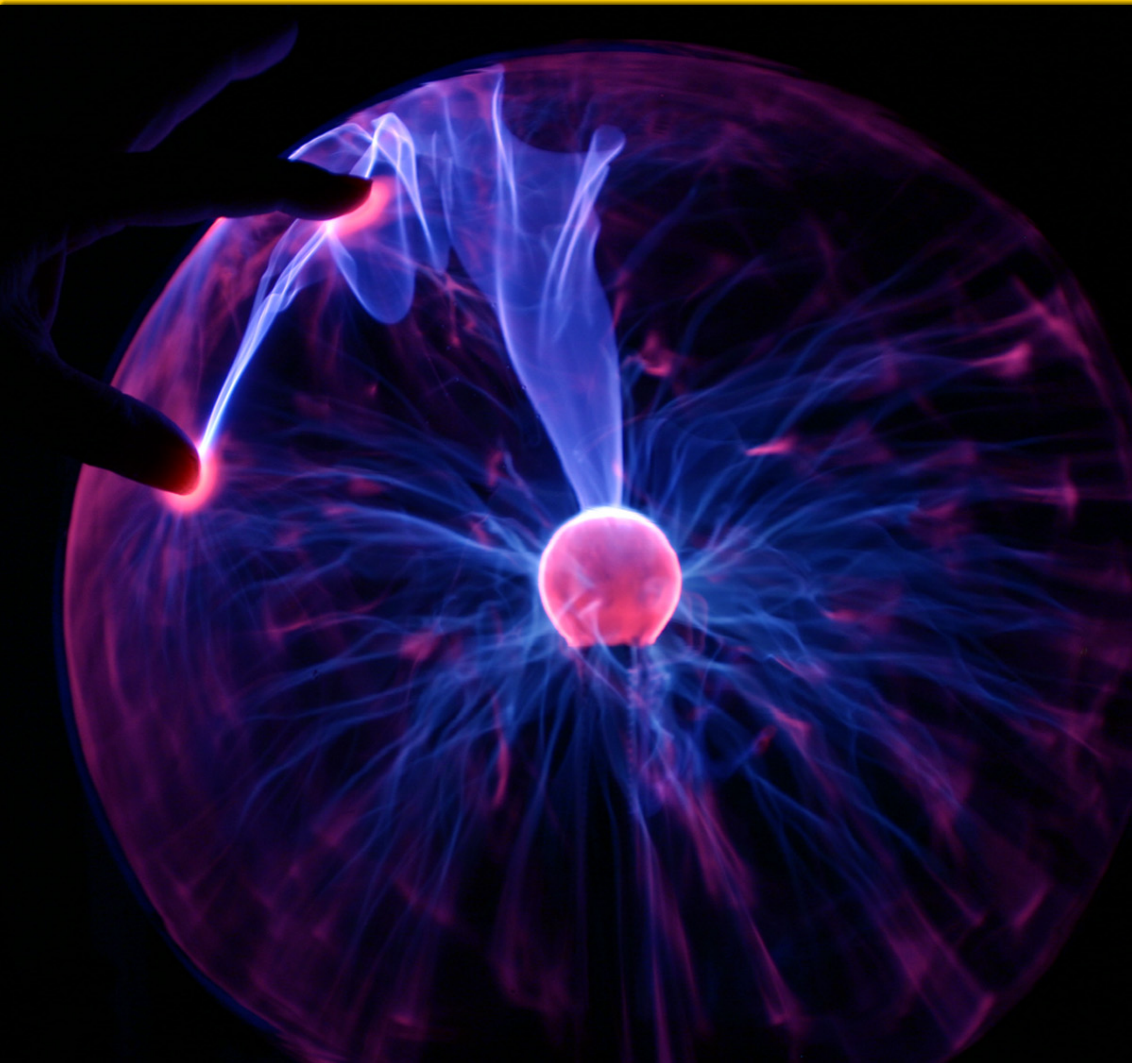

Microwave Radiation Loss Concerns in PCBs

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SUMMARY: A general definition of radiation loss is the energy on the circuit that is lost by radiating away from the circuit and into the surrounding environment. The lost energy has to go somewhere, and this can be a source of EMI issues. These losses become more prevalent at high frequencies, and designers must be aware of potential interactions between design techniques and circuit materials.

Circuits used at high frequencies, such as microwave frequencies, are prone to radiation losses. There are typically circuit design dependencies, but the circuit material may have an effect as well, and designers should be aware of potential interactions between the design techniques and circuit materials.

A typical PCB used at microwave frequencies experiences total loss, or insertion loss, made up of four different loss components: conductor, dielectric, leakage, and radiation losses. RF leakage losses at microwave frequencies are generally not an issue when using PCB materials; however, conductor losses and dielectric losses are definitely an issue. Radiation losses depend on the circuit configuration, design, material thickness, dielectric constant and frequency.

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Impedance mismatches can be a significant source of radiation loss. Normally the designer will try to match impedances, but some scenarios in microwave design require different impedance levels. Another issue, which is sometimes related to impedance mismatch, is radiation loss due to signal launch. Signal launch happens where the connector meets the circuit board. In this area, the signal energy has to transition from the coaxial wave propagation mode of the connector to the planar mode of the PCB. The signal launch areas can have significant radiation loss and the microwave designer will typically put a lot of effort into trying to quiet that transition.

Circuit losses due to radiation are generally not an issue with stripline configurations, and can be much less of a concern with grounded coplanar constructions. The single-ended microstrip transmission line is more prone to radiation loss and there are several issues which

50 ohm microstrip, Dk=3.66, Df=0.0037, thickness=6.6mil

Freq (GHz)	Dielectric Loss (dB/in)	Conductor Loss (dB/in)	Radiation Loss (dB/in)	Total Loss (dB/in)
1	-0.012	-0.114	0.000	-0.127
5	-0.063	-0.284	-0.001	-0.349
10	-0.127	-0.408	-0.005	-0.540
15	-0.191	-0.503	-0.011	-0.705
20	-0.255	-0.583	-0.020	-0.859
25	-0.321	-0.654	-0.031	-1.007
30	-0.386	-0.718	-0.045	-1.151

50 ohm microstrip, Dk=3.66, Df=0.0037, thickness=20mil

Freq (GHz)	Dielectric Loss (dB/in)	Conductor Loss (dB/in)	Radiation Loss (dB/in)	Total Loss (dB/in)
1	-0.012	-0.037	0.000	-0.051
5	-0.064	-0.094	-0.011	-0.170
10	-0.130	-0.136	-0.046	-0.313
15	-0.198	-0.168	-0.103	-0.470
20	-0.268	-0.196	-0.183	-0.647
25	-0.339	-0.221	-0.284	-0.845
30	-0.413	-0.244	-0.407	-1.064

Figure 1: Comparison of losses for microstrip transmisison line circuits, of different thickness while using the same substrate material.

can vary the amount of loss. As general statements, a thicker circuit will have more radiation loss than a thinner circuit. A circuit with a low dielectric constant will have more radiation loss than a circuit with high dielectric constant. Applications operating at lower frequencies will have less radiation as compared to those at higher frequencies. Finally, there are interactions between all of these conditions, which can complicate the understanding of radiation loss in circuit designs.

To demonstrate some different scenarios, several examples will be given regarding radiation loss. The software modeling tool that will be utilized is MWI-2010, which is free to download here. This software can predict insertion loss of a microstrip circuit and show the different components of this loss.

The first example shows differences in radiation loss when using the same substrate, but at different thicknesses. Figure 1 illustrates a comparison in losses of two 50 ohm microstrip transmission line circuits built on the same high-frequency laminate. The first circuit is using a laminate of 6.6 mils thickness, and the second circuit's laminate is 20 mils thick. The laminate has a dielectric constant of 3.66, dissipation factor of 0.0037 and is commonly used in high-frequency applications.

It can be seen in Figure 1 that the table on the left for the thinner circuit has much lower radiation losses than the table on the right for the thicker circuit. It is also obvious that the radiation losses are frequency dependent and the higher frequencies have the higher radiation loss values.

The next example demonstrates the differences in radiation losses for circuits using the same thickness of matieral, but with different dielectric constants. Figure 2 shows a comparison of 50 ohm microstrip transmission lines using high-frequency laminates of 20 mil thickness, with a dielectric constant of 2.20 and 4.50.

50 ohm microstrip, Dk=2.20, Df=0.0009, thickness=20mil

Freq (GHz)	Dielectric Loss (dB/in)	Conductor Loss (dB/in)	Radiation Loss (dB/in)	Total Loss (dB/in)
1	-0.002	-0.016	0.000	-0.019
5	-0.012	-0.039	-0.014	-0.066
10	-0.024	-0.060	-0.056	-0.142
15	-0.037	-0.079	-0.127	-0.244
20	-0.050	-0.097	-0.225	-0.373
25	-0.063	-0.115	-0.350	-0.529
30	-0.077	-0.131	-0.502	-0.711

50 ohm microstrip, Dk=4.50, Df=0.002, thickness=20mil

Freq (GHz)	Dielectric Loss (dB/in)	Conductor Loss (dB/in)	Radiation Loss (dB/in)	Total Loss (dB/in)
1	-0.007	-0.036	0.000	-0.045
5	-0.038	-0.103	-0.010	-0.152
10	-0.078	-0.151	-0.042	-0.272
15	-0.118	-0.189	-0.095	-0.403
20	-0.160	-0.221	-0.168	-0.550
25	-0.203	-0.250	-0.261	-0.714
30	-0.247	-0.276	-0.373	-0.897

Figure 2: Comparison of losses for microstrip transmisison line circuits, with different dielectric constant, using the same substrate thickness.

Figure 2 illustrates how a microstrip circuit with the same laminate thickness will have different radiation losses when using substrates with a different dielectric constant. The table on the left has much more radiation loss when using material with a dielectric constant of 2.20 than the table on the right with a circuit that features material with a dielectric constant of 4.50.

It can also be seen in Figure 2 that the dissipation factor (Df) is very different between these two materials. The Df mainly affects dielectric losses. The conductor losses are mostly dominated by copper properties, conductor width and surface roughness. Even though the material with a higher dielectric constant will have less radiation loss, it is necessary to have a narrower conductor width to maintain a 50 ohm trace, so the conductor losses will be higher than a circuit with a lower diectric constant. This is one of many tradeoffs that are to be expected when considering the proper material for an application.

Radiation loss can be problematic for microwave PCB performance, however, it can also cause issues by radiating energy to neighboring conductors and components on the PCB. A thorough understanding of radiation loss can help to minizize EMI issues as well as optimizing the circuit for higher-frequency performance. **PCBDESIGN**

John Coonrod is a market development engineer for Rogers Corporation, Advanced Circuit Materials Division. About half of his 25 years of professional experience has been spent in the flexible PCB industry doing circuit design, applications, processing, and materials engineering. Coonrod has also supported the high-frequency, rigid PCB materials made by Rogers for the past 10 years. Reach Coonrod here.