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Impact of TIM Dielectric Constant on EMI Radiation

Common EMI sources in many systems are integrated circuits (ICs). ICs are also generators of thermal energy which must be efficiently removed via a heat sink. To enable efficient thermal energy flow a Thermal Interface Material (TIM) is used between the IC and a heat sink. Desirable qualities in a TIM are high thermal conductivity and softness to ensure good physical contact between the IC, heatsink and TIM. However it has been found that the electromagnetic properties of the TIM material can increase the EMI radiation leading to failure in regulatory compliance or deterioration in operating efficiency in the device. This has led many users to demand TIM material with a low dielectric constant (dk). This paper will investigate why the TIM dk could have an impact on EMI radiation.

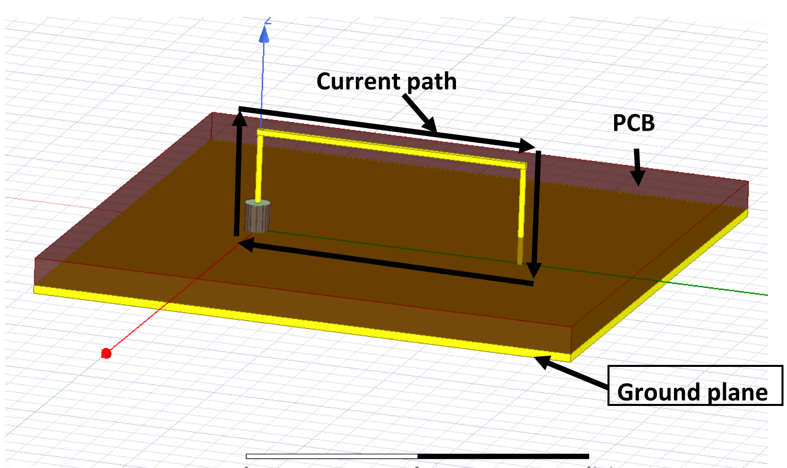
Radiation from an IC

Integrated circuits contain multiple current paths that will generate radiated electromagnetic energy. The inner workings of an actual IC are far too complicated to model in terms of EM radiation. Currents are not constant and will differ based on the ICs operating mode. Therefore to model the IC we need to make some simplifying assumptions.

Source types

A term for any object or component that radiates electromagnetic energy is an antenna. Depending on their size, shape, material properties, different antennas will radiate in different ways. Some will radiate very well, some not so well. For our purposes there are only two basic categories of antennas, linear and circular. In a linear antenna, the conductive portion is a straight line similar to the radio antenna on your car. The current is constrained by the ends of the antenna. In a circular antenna, the current is not constrained and freely propagates out from the energy source then returns to the energy source. We have found that the best model to represent radiation from an IC is a circular (loop) source mounted vertically on a printed circuit board (PCB). The analysis in this paper regarding the impact of the dielectric constant would be very similar for any type of source.

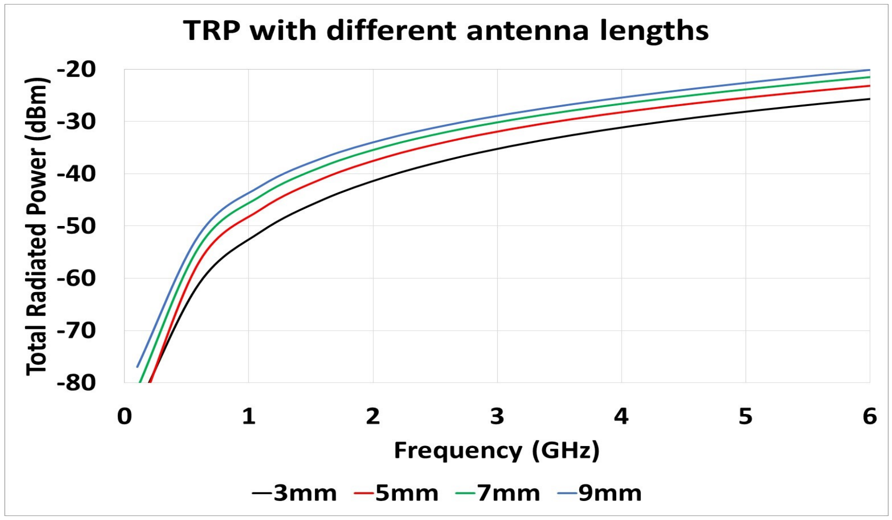
The model shown below represents a vertical loop source realized on a PCB, the current path goes from the source at left up one conductive post then across the horizontal conductive portion then down the second conductive post and returns to the source via the conductive ground plane. In our model the antenna height is 2mm and the antenna length (horizontal portion) will vary.



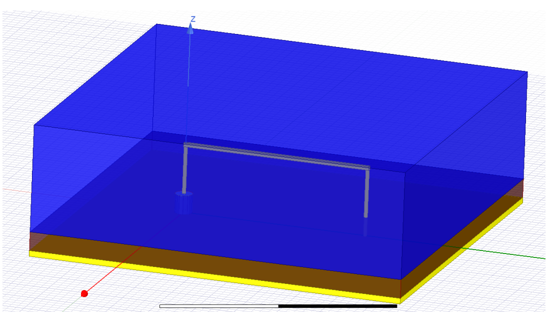
Model

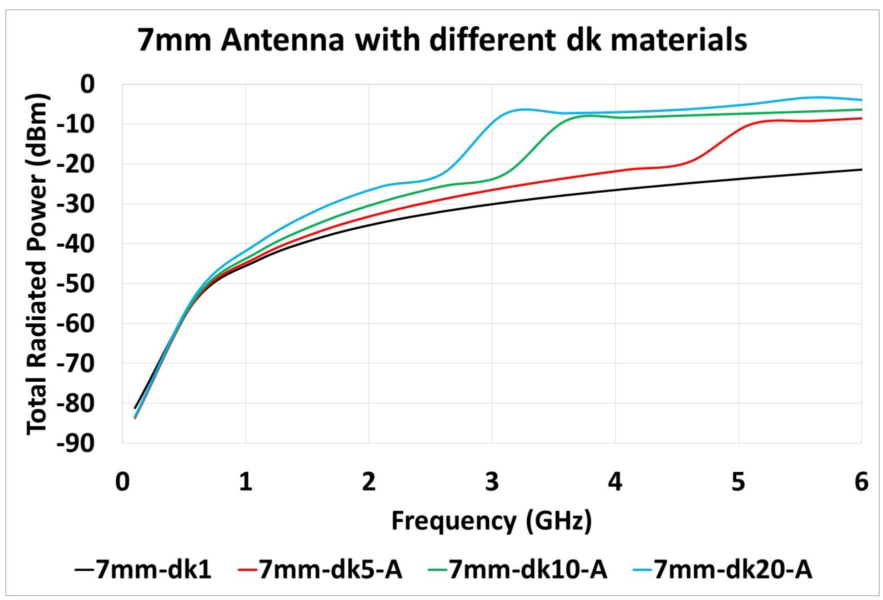
In our model we will inject energy at the source. We will then calculate Total Radiated Power (TRP) at each frequency of concern. TRP is calculated over a full 360 degree sphere. An efficient or 'good' antenna will radiate more energy than an inefficient or 'bad' antenna. First we will calculate the impact of the antenna length on the TRP. We used values for the length equal to 3, 5, 7, and 9mm. TRP is calculated in dBm which is milliwatts on a decibel scale. 0 dBm=1 milliwatt, -10 dBm=0.1 milliwatt, -20dBm =0.01 milliwatt etc.

As seen in the results at right, the larger the antenna, the greater the total radiated power. This is a general principle in microwave engineering that, all else equal, the efficiency of an antenna is directly proportional to its size.



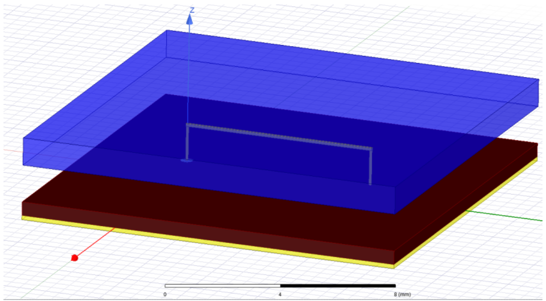
Now what happens if we embed the antenna inside a material with a dielectric constant? The model above has the antenna in free space (vacuum) where the dielectric constant equals 1. What if it was inside a material with dielectric constant equal to 5, 10, and 20?

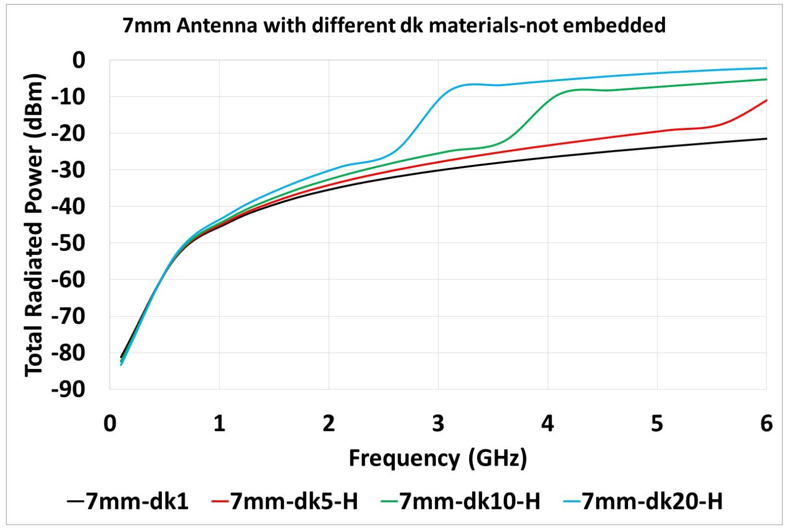




The TRP increases proportionally to the dielectric constant. Why would this be? The graph's x-axis is the frequency in GHz. As the frequency increases, the wavelength gets shorter (see end note Electromagnetic Radiation). The antenna length is constant. The wavelength will compress (become shorter) inside a material with a dielectric constant (see end note What is the 'Dielectric Constant'?). Due to this wavelength compression, embedding the antenna inside a material with a dielectric constant will make the antenna larger in terms of a wavelength. It will therefore radiate a larger amount of power.

But we're not embedding the IC/antenna into a TIM material. We are placing the TIM material on top of the IC. What would be the impact then?

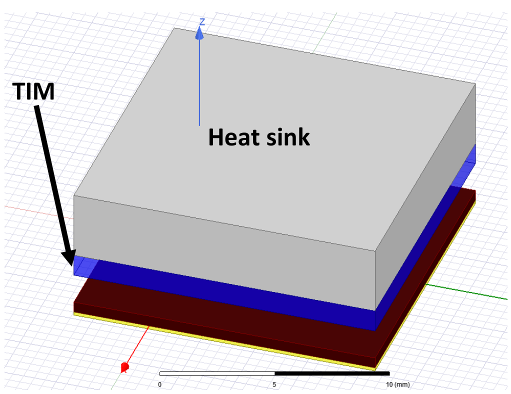


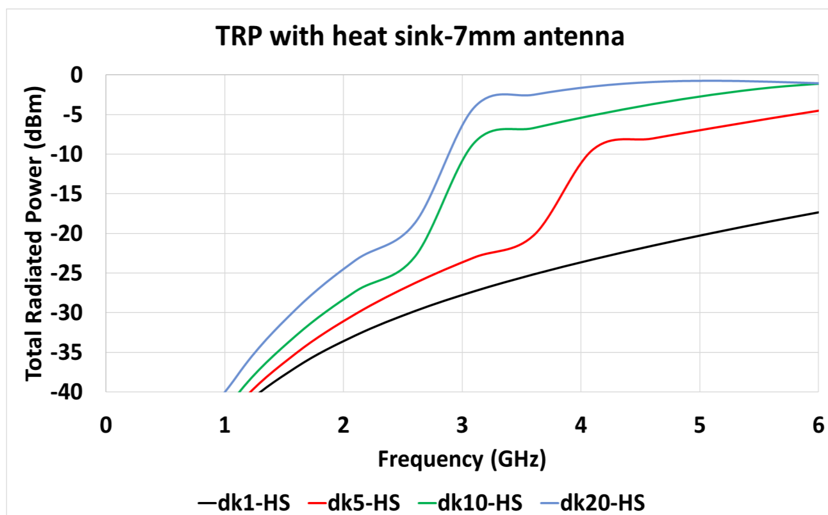


There is still a significant impact on the radiated power induced by a high dk TIM material.

What if we add a heat sink?

In an actual application the TIM will contact a heat sink. Heat sinks are generally made of metal so electromagnetically they can be treated as a perfect electrical conductor.

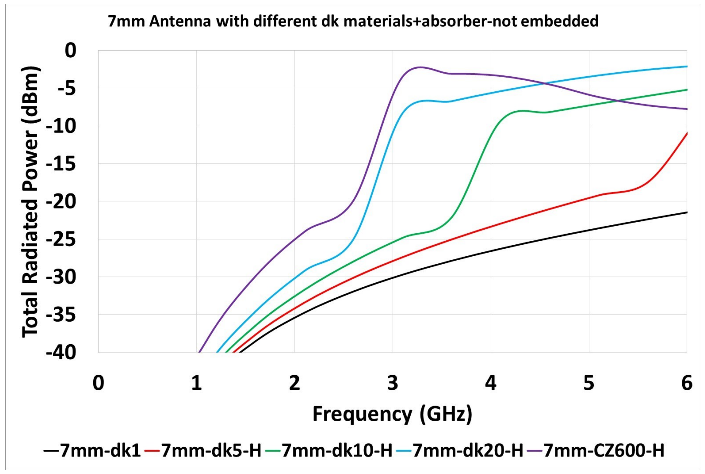




The same general conclusions apply when the heat sink is added to the model. A higher dk results in increased radiated emissions.

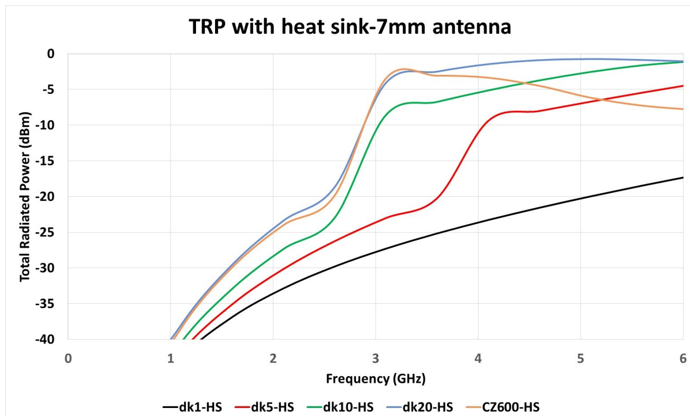
Can absorber help?

What if we replaced the TIM material with a Coolzorb type material. Coolzorb is designed to absorb electromagnetic radiation while maintaining the thermal conduction properties of a normal TIM. Could it absorb the excess energy? As with most questions about absorber, the answer is "it depends".



TRP with TIM material and Coolzorb Total Radiated Power

At right is the graph from above with the results of replacing the TIM with Coolzorb 600 (and re-scaled for clarity). The purple line represents Coolzorb. Note that below around 4.5 GHz, the Coolzorb actually increased the radiated power while above 4.5 GHz the radiated power decreased. There are two factors going on here that compete with each other. Absorbers like Coolzorb have very high material parameters (permittivity and permeability). As noted above, this property will tend to increase the radiated power from a source. Absorbers will also absorb the energy. This will tend to reduce the radiated power.



TRP with TIM material and Coolzorb+Heatsink

The attenuation of an absorber tends to increase with frequency (see end note Absorber Properties). For a constant physical volume of absorber, the amount of absorption will increase with frequency. In this model, at low frequencies, the increase in radiation due to high material parameters is greater than the decrease due to absorption so the radiated power increases. At higher frequencies the absorption outweighs the impact of high material parameters so the radiated power decreases.

Adding a heat sink changes the results a little more. Now the TRP of Coolzorb is roughly the same as a TIM with dk=20 up to around 3.5 GHz. Above 3.5 GHz, Coolzorb greatly reduces the TRP. This is likely due to the heat sink constraining the energy a bit inside the material where the absorptive properties of the Coolzorb could attenuate the energy.

Note that the results here are general tendencies. We should not take 3.5 GHz as the crossing point between Coolzorb and standard TIM material. A different quantitative result will occur with different antenna lengths, TIM size, thickness etc but the qualitative results will be the same. The reality is that an IC source will be composed of multiple current sources and loop sizes in addition to other configurations so in general the frequency point of improved Coolzorb performance will vary.

Conclusions

The electromagnetic radiation from an IC was modeled using a vertically oriented loop source. This type of source has been shown to best emulate the actual radiation from an IC. Embedding the source in a material with a dielectric constant (dk) greater than 1 increases the total radiated power (TRP) vs the TRP of the antenna in a vacuum. The TRP increases as the dk increases. This phenomonenon is still seen if the source is just below the material with dk>1 as it would be in a TIM application. This phenomenon is due to wavelength compression in the TIM material. This wavelength compression increases the effective size of the source in terms of a wavelength which increases the radiated power.

A TIM with absorptive properties (Coolzorb) could reduce the total radiated emissions however it has limited affect at lower frequencies due to the small physical volume in terms of a wavelength. At higher frequencies Coolzorb will give significantly improved performance in reducing radiated emissions.

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Laird Thermal Materials

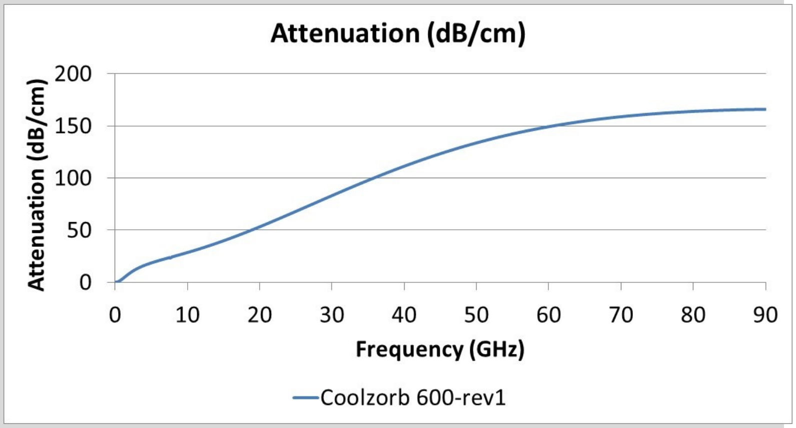
Lairds extensive experience with both thermal and EMI management allows for a unique system level approach and understanding of thermal and EMI interactions. We offer advanced system modeling and simulation as well as other multifunctional materials to help mitigate EMI and thermal design concerns.

If looking for a thermal material with a lower dielectric constant, Laird offers products across various thermal conductivities with low dielectric constant values when measured at higher frequencies. By selecting one of the materials below, design engineers can ensure the EMI radiation of the system will not increase with the addition of the thermal material. Materials with low dielectric constant are shown in the table below.

Material	Dielectric Constant (@10GHz)	Thermal Conductivity
Tpli 200	3.2	5.0 W/mK
Tflex SF600	3.5	3.0 W/mK
Tputty 502	3.6	3.0 W/mK
Tflex 600	4.0	3.0 W/mK
Tpcm 905c	4.2	0.7 W/mK
Tflex 300	4.5	1.2 W/mK

Absorber properties

As the name implies, absorbers will absorb or attenuate electromagnetic energy. Absorbers tend to have high values for their permittivity and permeability with high loss components (imaginary portion of permittivity/permeability). A common metric used to differentiate absorbers is called the attenuation which is calculated from the material parameters and is reported in units of dB/cm. This represents how much the wave is attenuated per distance of travel inside the material. A higher value means that more is absorbed.



The attenuation for Coolzorb 600 up to 90 GHz is shown at right. Note that the attenuation increases with frequency. At first glance you may infer that the material is becoming inherently more absorptive (higher values for loss factors of permittivity and permeability as frequency increases) but this is not true. In fact the inherent loss values actually decrease as the frequency increases. The increase in attenuation with frequency is entirely due to the wavelength becoming shorter as the frequency increases.

The loss factors for permittivity (electric) and permeability (magnetic) are an indication of loss per wavelength traveled. The attenuation is in terms of loss per centimeter traveled. If we cram more wavelengths into a shorter distance, the attenuation in dB/cm will increase.

Even though absorbers have very high loss factors at low (<3 GHz) frequencies, in a practical application there may not be enough physical volume of absorber material to give acceptable absorption. This becomes less of an issue as the frequency increases.

Electromagnetic Radiation

The sources of electromagnetic radiation are electric currents which are electrons moving due to an applied voltage or electric field. Electrons move very easily through conductive materials such as metals.

EM radiation arises from AC or alternating currents. Alternating currents occur when the direction of the electron flow switches direction (alternates) back and forth in a conductor. The number of times per second that the current switches direction is called the frequency. The frequencies of interest to us are in the MHz (Megahertz-millions of cycles/second) and GHz (Gigahertz-billions of cycles per second) so this current switching is quite fast.

EM radiation propagates at the speed of light in a vacuum. Light is actually a form of high frequency EM radiation. The frequency of visible light is approximately 500,000 GHz.

EM radiation propagates with an alternating electric (E) field and magnetic (H) field. The direction of the E and H field alternate in the form of a sine wave.

The wavelength of EM energy in a vacuum can be calculated by dividing the speed of propagation (speed of light) by the frequency. The speed of light is $3x10^{10}$ cm/sec. If the frequency is 1 GHz (or $1x10^9$ cycles/sec) the wavelength is

$$wavelength = \frac{3x10^{10} cm/sec}{1x10^9 cycles/sec} = 30cm$$

A handy formula to quickly calculate wavelength is

$$wavelength(cm) = \frac{30}{frequency(GHz)}$$

so the wavelength at 10 GHz is 3cm and the wavelength at 15 GHz is 2cm.

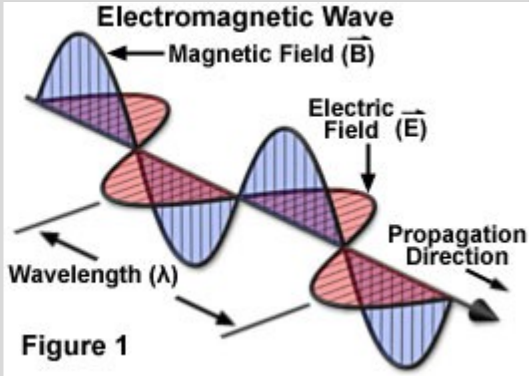


Figure 1

What is the 'dielectric constant'?

Electromagnetic energy consists of an electric field component and a magnetic field component. Both fields will be modified in the presence of matter. The measure of a material's impact on the electric field is called the permittivity. Permittivity is a 'complex' number which means it has two components called the 'real' and the 'imaginary' parts. The dielectric constant is the real part of the permittivity.

The primary impact of the dielectric constant is wavelength compression. Recall that the wavelength of an electromagnetic wave is given by the speed of the wave (speed of light) divided by the frequency. When the wave is inside a material it slows down. This results in the wavelength inside the material becoming shorter.

The imaginary part of the permittivity is a measure of loss or absorption of energy in the material. A good absorber will have a high value for the imaginary permittivity.

Note that there is an analogous material property denoting a material's affect on the magnetic field. This is called the permeability. Permeability also has a real (magnetic constant) and imaginary (loss or absorption) component.

A 'dielectric' absorber will have no affect on the magnetic field (permeability=1). It will attenuate or absorb the electric field. A 'magnetic' absorber will impact and attenuate both the electric and magnetic fields.