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# Does Dk matter for power distribution?

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We know that in signal integrity, the relative dielectric constant (Dk) of the laminate is important. Dk sets the delay of traces, the characteristic impedance of interconnects and also scales the static capacitance of structures. Is the same true for power distribution? The answer is yes, but for power distribution all this matters much less.

Not long ago a friend of mine wrote: “I have a question about high Dk and embedded capacitance. (A well-known expert in EMC) said recently that the high Dk effects propagation delay and this essentially offsets the benefit: makes the useful area smaller. This seems logical, but seems opposed to all the published test data that shows better performance from the higher Dk buried capacitance options.”

Here is what my answer was: “There are two statements here, with an implied logical connection between them. Technically the first part (high Dk effects prop delay) is correct. The second part is also correct in its observation, namely that this makes the 'useful area' or 'service area' smaller. Whether this offsets the benefits or not, is up to interpretation. On the one hand, this is in line with my generic assessment about higher-Dk laminates when I say that for me the thin nature is more useful then higher Dk. At the same time it is true that *below the first series resonance frequency* higher Dk provides lower impedance, which could be valuable for some designs. So I think what is confusing here is that by changing Dk, the low-frequency and high-frequency characteristics change differently: while there is no difference in the laminate's impedance at high frequencies (when someone says that higher Dk has no benefits, this could be the basis for the statement), there is however improvement at low frequencies.

To illustrate the statement (“high Dk effects propagation delay and this essentially offsets the benefit”), lets look at the sketch of *Figure 1*.

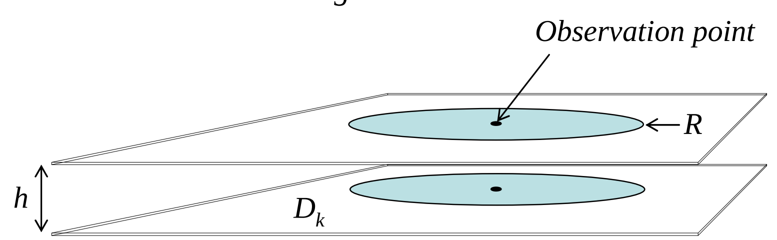


***Figure 1****: Definition of service radius. With higher $D_k$ R becomes smaller.*

The figure shows what some people call the service area or service radius of a plane pair. We draw a circle around an observation point with a radius of *R*, which equals the distance that a wave could travel in the particular dielectric within a unity amount of time. The unity amount of time is often selected such that it equals the $t_r$ rise time of our anticipated signal or noise excitation. As the popular argument goes, during a current transient occurring at the observation point, this service area holds all the charge, which can reach the observation point within $t_r$ time. The capacitance of the service area is:

$$C = \varepsilon_0 \varepsilon_r \frac{R^2 \pi}{h}, \quad C = \varepsilon_0 D_k \frac{R^2 \pi}{h} \tag{1}$$

In physics we usually denote the relative dielectric constant with $\varepsilon_r$; in engineering the customary notation for the same parameter is $D_k$. We also know that the propagation time equals distance divided by the speed of wave. In our case chose the propagation time to be $t_r$. Distance is $R$ and the speed of wave is speed of light ($c$) divided by the square-root of relative dielectric constant.

$$t_r = \frac{R}{\frac{c}{\sqrt{D_k}}} = \sqrt{D_k} \frac{R}{c} \tag{2}$$

We can rearrange *Eq. (2)* for $R$:

$$R = t_r \frac{c}{\sqrt{D_k}} \tag{3}$$

With Eq. (3) the capacitance of the service area becomes:

$$C = \varepsilon_0 t_r^2 c^2 \frac{\pi}{h} \approx \frac{t_r^2}{h} \tag{4}$$

The second form of *Eq. (4)* shows that with the speed of light ($c$), the dielectric constant of vacuum ($\varepsilon_0$) and PI ($\pi$) being constants, the capacitance becomes proportional to the square of rise time divided by the plane separation. Note that the capacitance expressed with this service radius concept does not depend on the relative dielectric constant; higher dielectric constant laminates store more charge in a given volume, but the wave propagates slower and therefore the service area becomes smaller; however, this smaller area contains the same amount of charge. The only way to get more capacitance available is to make the dielectric thinner (lowering $h$).

To illustrate the point that the low-frequency and high-frequency electrical characteristics change differently as we change $D_k$, lets look at *Figure 2*. The figure shows the self-impedance magnitude of a pair of square metal planes with a 4-mil (0.1 mm) dielectric separation. Two different $D_k$ values are assumed: 4, which is representative of the typical glass-reinforced laminates, and 16, which is representative of ceramic-filled laminates. The simulation was done with full causal plane and dielectric models: the proper skin depth and the corresponding change of inductance, as well as the frequency dependent $D_k$ and dielectric loss tangent ($D_f$) values were included. This full-causal simulation was done with a combination of Excel and the free Berkeley SPICE engine (how it was done, will the subject of a future column).

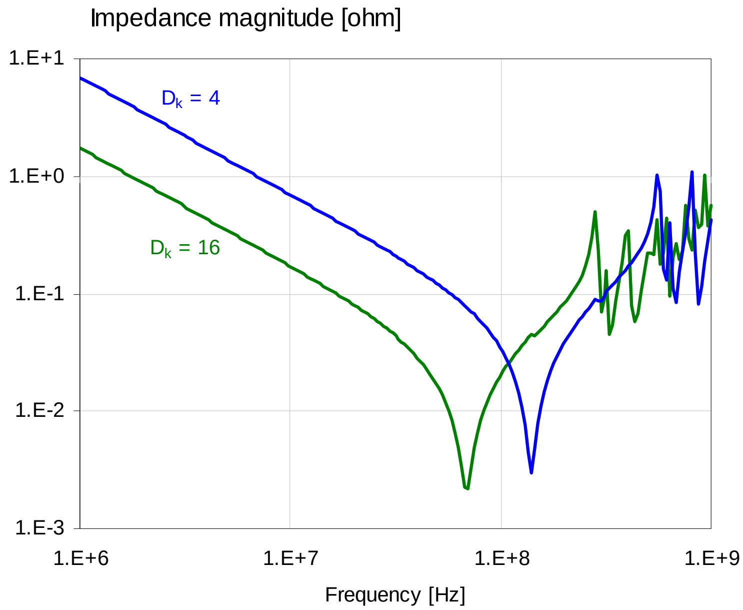


***Figure 2:*** *Simulated self-impedance magnitude of a 10 x 10 inch plane pair with $D_k$=4 (blue), and $D_k$=16 (green). $D_f$ was 1%, the plane was probed at the center, and the dielectric thickness was 4 mils (0.1 mm).*

At 1 MHz the curves start at 6.7 ohms and 1.68 ohms values, corresponding to 22 nF and 88 nF static plane capacitance values. Below the first series resonance frequency both curves appear to be straight lines sloping down as frequency increases. The first series resonance frequency is at 140 MHz with $D_k$ = 4, and at 70 MHz with $D_k$ = 16. Below the series resonance frequency there is one clear advantage of the higher $D_k$ value: the impedance is proportionally lower and the PDN design has more plane capacitance to work with. With typical board dimensions, however, the frequency range for having this benefit is limited to relatively low frequencies, where most PDN designs must complement the static plane capacitance with bypass capacitors anyway to bring the PDN impedance to sufficiently low levels.

When we look at the high-frequency portion of *Figure 2*, the picture is different: not considering the peaks and valleys, the average trends of the two impedance curves look very similar; both are rising and these average lines run very close to each other. This can be double checked by calculating the first-order plane inductances from the static capacitance values and series resonance frequencies. If we model the planes with a series $L_p$-$C_p$ network, $C_p$ being the static capacitance and $L_p$ being the plane inductance around the series resonance frequency, we can calculate their resonance frequencies:

$$f_{res} = \frac{1}{2\pi\sqrt{L_p C_p}} \qquad (5)$$

We can rearrange Eq. (5) to calculate the $L_p$ equivalent plane inductance; for both $D_k$ = 4 and 16 we get the same 60 pH value. This tells us that at high frequencies, where inductance dominates the self-impedance behavior, laminate $D_k$ matters very little.