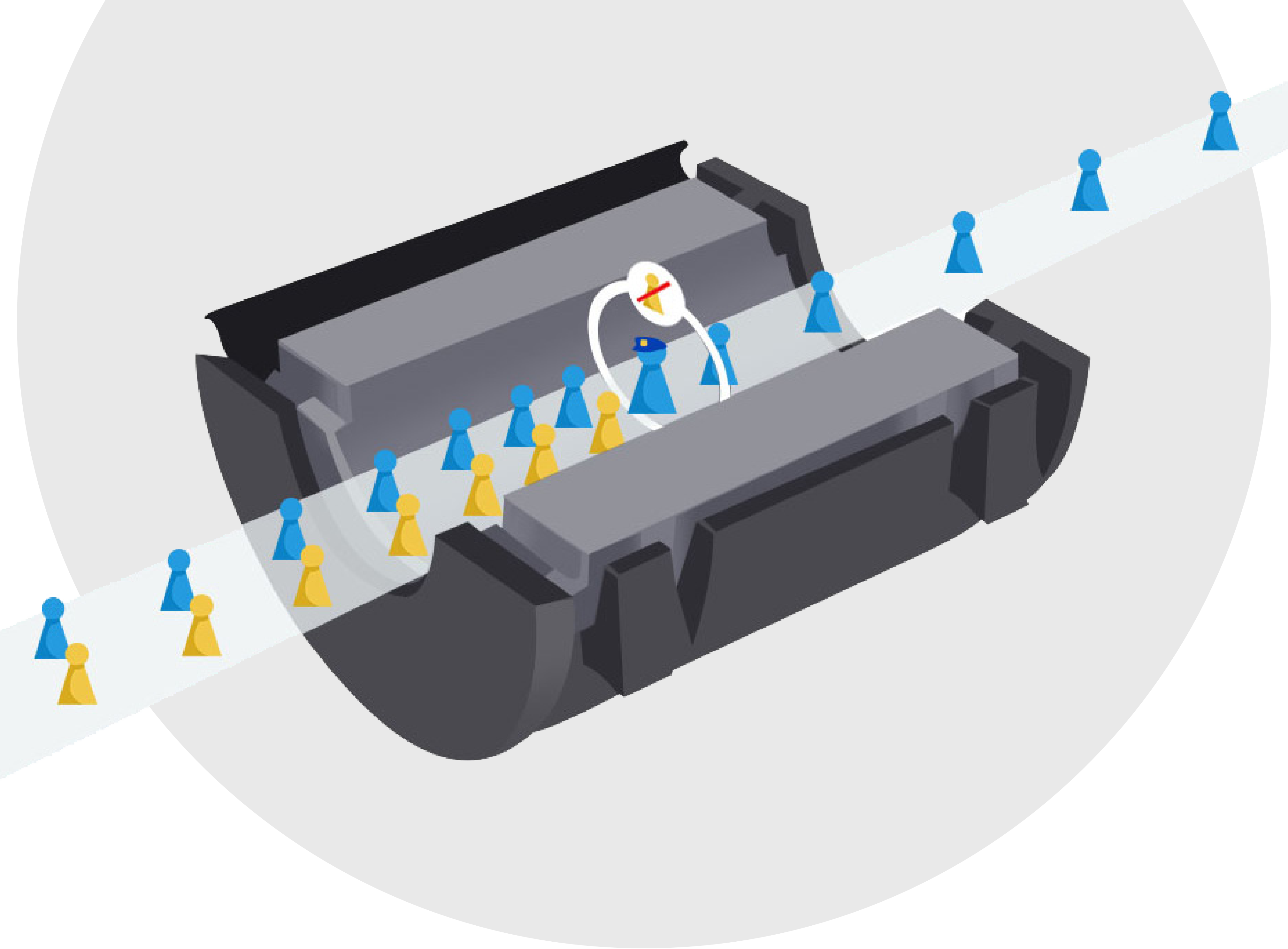

Guide to Using Ferrite Beads in a PCB

Utilizing Ferrite Beads and Other Magnetics

Altium®

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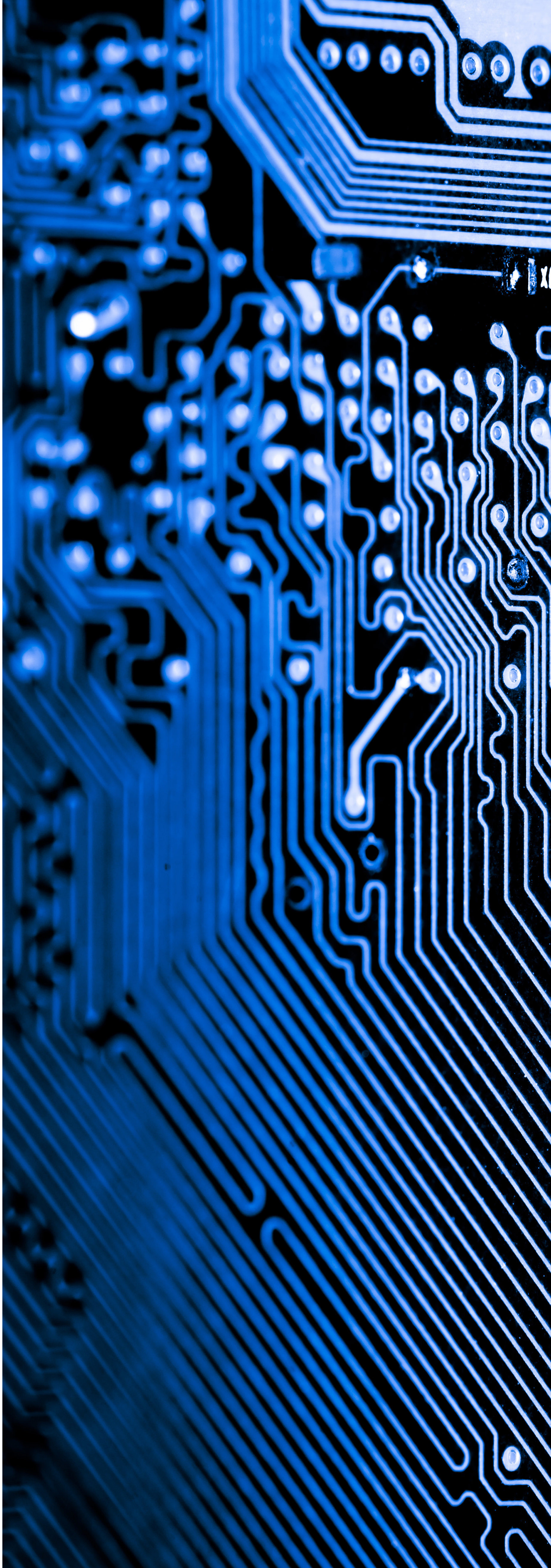
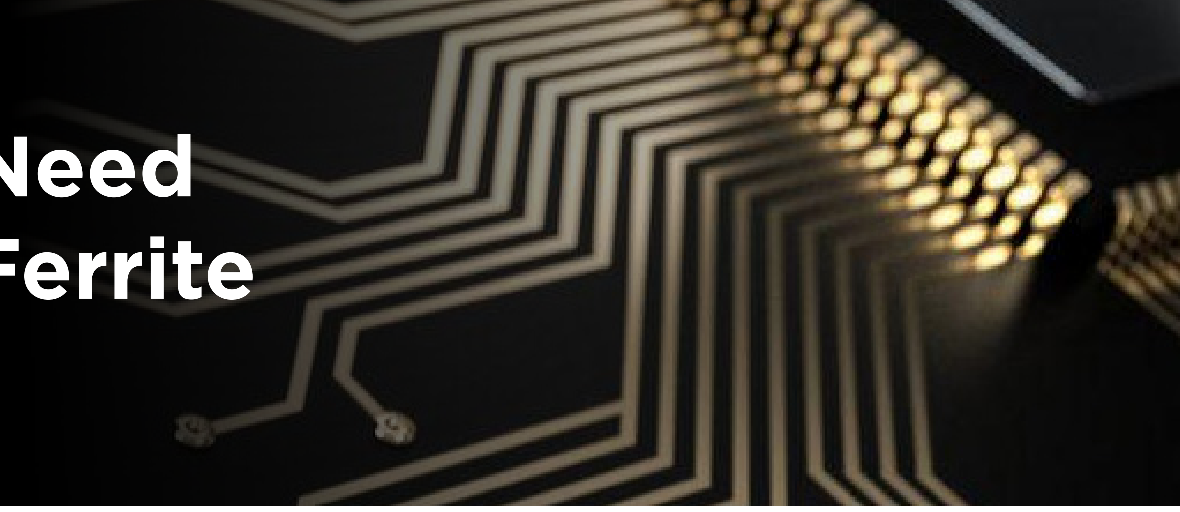


Everything You Need to Know About Ferrite Beads



As noted in my previous blog regarding PDS design, the whole power supply conundrum is one that has been plagued over the years with a number of erroneous rules-of-thumb; “black magic” design rules and confusion as to what does or doesn’t work.

One of the most controversial topic areas focuses on the use of ferrite beads as a means of controlling and containing EMI. There is conflicting information concerning the use of ferrite beads and it is difficult to ascertain which information is valid and which is not. The real challenge is that the erroneous information looks to be valid because of the large amounts of data associated with it. To add to the confusion, in the application notes of some ICs, the component vendors will recommend using ferrite beads as a means of eliminating EMI.

Microvias in Your CAD Software

Defining microvias starts in the PCB stackup editor, where layer pairs are defined and materials are selected. Note that you need to choose an appropriate laminate that can support the fabrication process you want to use. After building a proposed stackup, I always advise sending it to your fabricator for a review and getting their input as to manufacturability with microvias.

- What are the origins of ferrite beads?
- What is the history of their use?
- Why has it been assumed that the use of ferrite beads constitutes a valid design rule?
- What actually happens when a ferrite bead is put in series with the power lead of an IC?
- What do you do when an IC vendor specifies the use of ferrite beads?

As a result of the discussion presented here, it will be demonstrated how the use of ferrite beads in series with a power lead of an IC does not eliminate or contain EMI but, in fact, degrades the performance of the PDS.

The Origins of Ferrite Beads

To address the first point of confusion, ferrite beads are not beads. They are little inductors. The thing that people refer to as a bead is actually a toroid. (A toroid is a coil of insulated or enameled wire wound on a donut-shaped form made of powdered iron. It is used as an inductor in electronic circuits especially at low frequencies where comparatively large inductances are necessary. They have been used forever as the cores of transformers). To maintain consistency, ferrite inductors will be referred to as they are in the rest of the industry—ferrite beads.

Ferrite beads are surface mount components much like other components such as resistors and capacitors. And, they are available in the same sizes as these other components. A typical ferrite bead package is illustrated in Figure 1. Notice that the word bead is surrounded by quotation marks as this part is not, in fact, a bead.

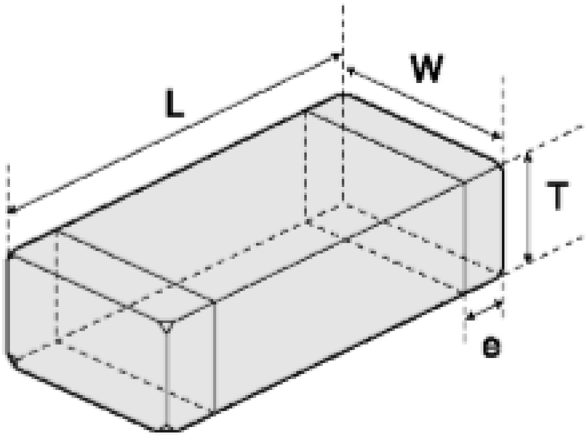


Figure 1. Typical Ferrite "Bead" Package

In terms of composition, ferrite beads are made from a ferrimagnetic material commonly referred to as a ferrite. This material behaves like an inductor made from a coil of wire. The attractiveness of this component is that it has a relatively high inductance in a small form factor. Typically, these components are not specified by the amount of inductance they have, but rather by their impedance at a particular frequency. As shown in Figure 2, the impedance of a ferrite bead is a function of frequency much like an inductor with the impedance being quite low at low frequencies, rising to a high point and then dropping off.

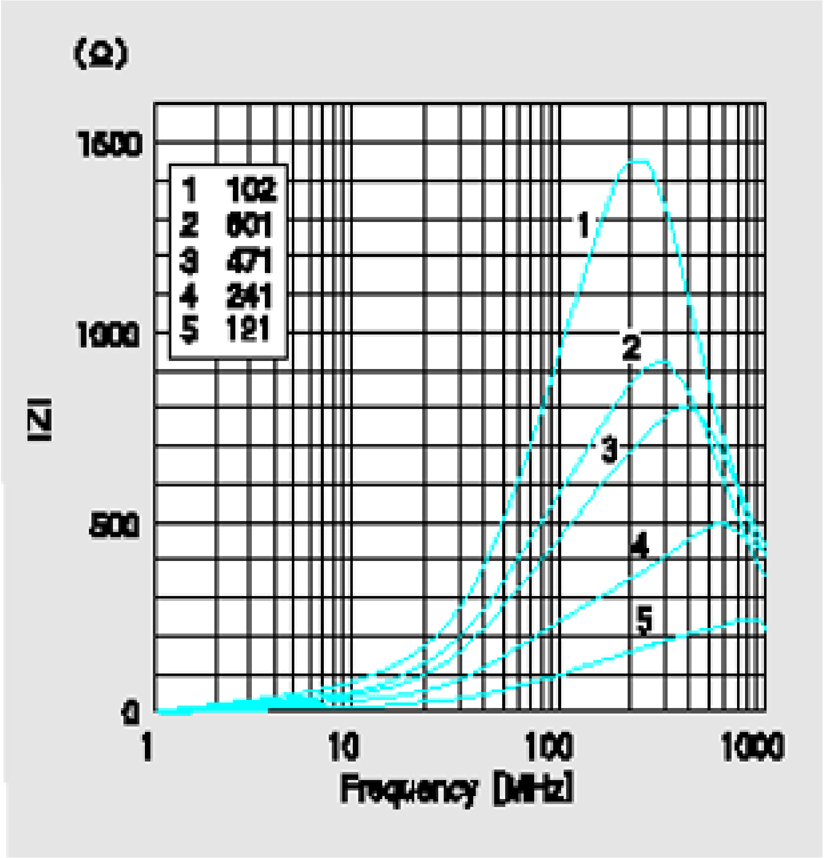


Figure 2. Typical Ferrite Bead Impedance vs. Frequency

The History of the Use of Ferrite Beads

The origins of the use of ferrite beads in PCB designs harkens back to the late 1980s when custom CMOS devices finally switched fast enough that they created frequencies in the EMI band. EMI technicians stuck the ferrite beads in the power leads of the devices and the EMI went away because the part could no longer switch fast enough to create the frequencies that were in the EMI band. Thus, the ferrite bead was a band aid. It worked and it stopped the part from making the noise but it also prevented the part from working at speed (i.e. switching fast). When ferrite beads were first utilized, speed, in terms of fast edges, was not an imperative so that is how the use of ferrite beads got its start.

To further illustrate this, when a ferrite bead was placed in series with the power lead of an IC, a circuit, such as the one depicted in Figure 3, was created.

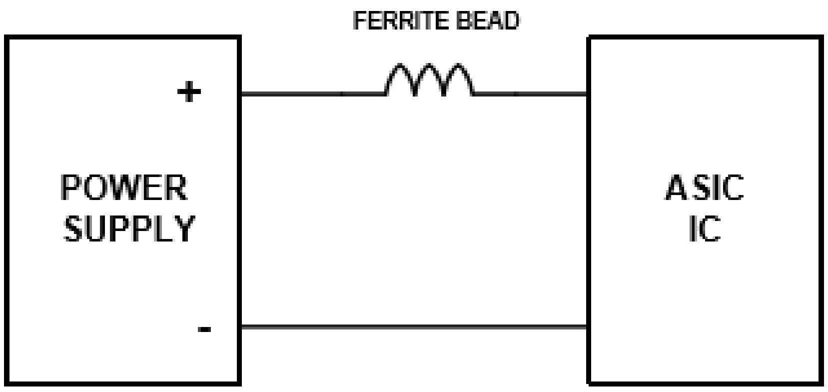


Figure 3. IC with Ferrite Bead in Power Lead

What Do Ferrite Beads Really Do?

What actually happens when you place a ferrite bead in series with the power lead of an IC is that the performance of the PDS is degraded as seen by the device increasing its output impedance. It's important to remember that a power supply is expected to be a voltage source, meaning that no matter how much current is drawn from it, the output voltage remains the same. In other words, power sources are expected to have zero or very low output impedance at all frequencies in order to properly do their job. As noted above, eventually, the speed of ICs increased to the point that inserting a ferrite bead prevented them from operating as they should. The reason was that the PDS output impedance was too high. The proposed solution was to add a capacitor after the inductor as shown in Figure 4.

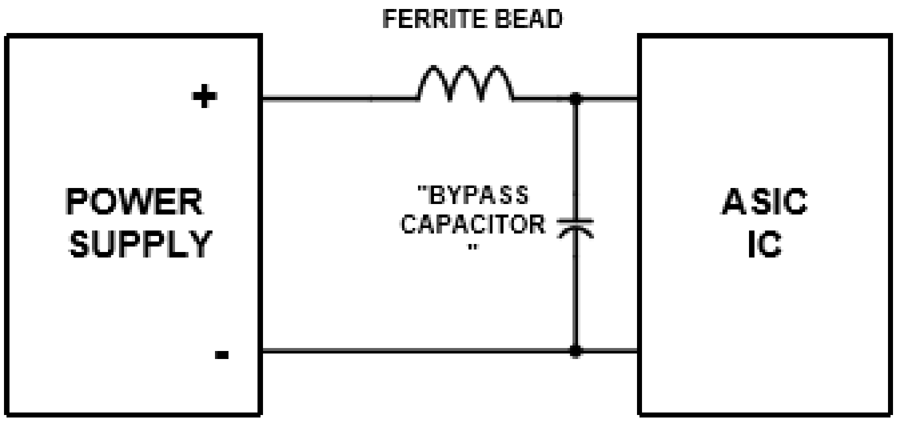


Figure 3. IC with Ferrite Bead in Power Lead

This solved the operating problem but brought back the EMI problem. Then, the method recommended for implementing this circuit was to cut an island in the Vdd plane. This is not a valid alternative either (see Reference 1 at the end of this blog).

Notice that in Figure 4, the capacitor is called a “bypass capacitor” with quotes around it. The reason for the quotes is to call attention to the fact that this capacitor is not bypassing noise, rather it is serving as a source of high frequency charge so that the ASIC can again switch rapidly. A much better name for these capacitors is “coulomb buckets” as they are functioning as local storage devices (see my previous blog POWER PLAY—SUCCESSFULLY DESIGNING POWER DELIVERY SYSTEMS, for further information on Coulomb buckets).

Why Is The Use of Ferrite Beads Put into Application Notes?

It should be noted that in a high speed ASIC, the inductor and the capacitor form a low pass filter preventing high frequency noise from getting to the component from the power subsystem side of the system. This is the reason given in most application notes for placing ferrite beads in series with the power leads of PLL (phase locked loop) devices and other “analog” type circuits including a high speed Serializer/Deserializer (SERDES).

IC vendors have typically recommended the use of ferrite beads in their applications notes for a couple of reasons. First, the author of the applications note will say, “We’ve always done it this way and if you don’t follow our application note, we won’t guarantee that the circuit will work properly.” If such a statement is made, it’s reasonable to ask if the application note is followed exactly, will the vendor guarantee the circuit will work. Often times, the answer is “no.” This certainly doesn’t leave you with much of a comfort zone in using your particular selected IC.

The second reason a vendor will give for specifying the use of a ferrite bead is that the bead is there to block noise in the power subsystem from getting into the sensitive circuit. At Speeding Edge, we have seen examples of this in actual test circuits. The noise is indeed blocked but the circuit performance is likely to be degraded due to poor power delivery to the circuit being protected.

Figure 5 shows the output waveform of a 3.125 GB/S serial link with a ferrite bead in the power lead of the output stage.

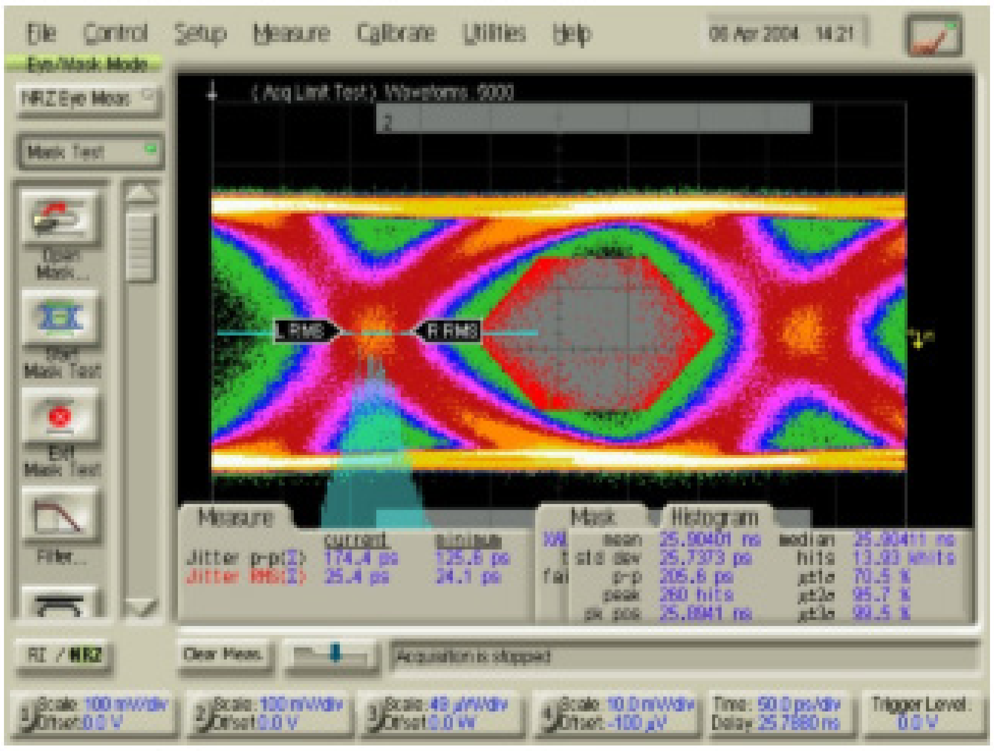


Figure 5. 3.125 Gb/S Serdes Output with Ferrite Bead in Power Lead

Figure 6 is the same output with the ferrite bead removed and the power lead connected directly to Vdd. As can be seen, inserting the ferrite bead actually made the circuit perform worse than with no ferrite bead.

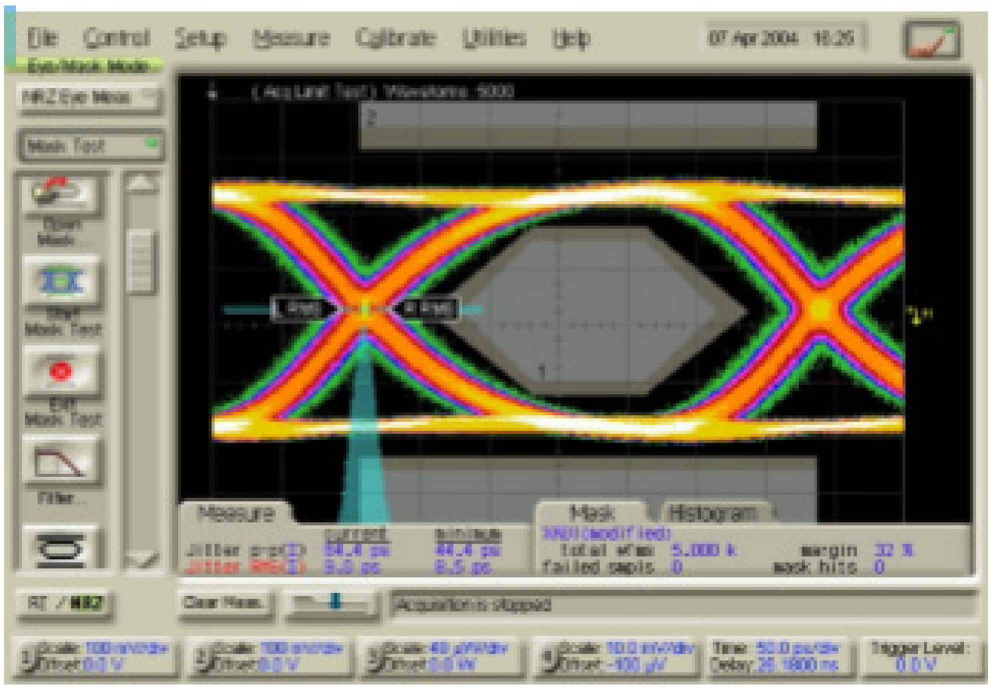


Figure 6. 3.125 Gb/S Serdes Output with Ferrite Bead Removed from Power Lead

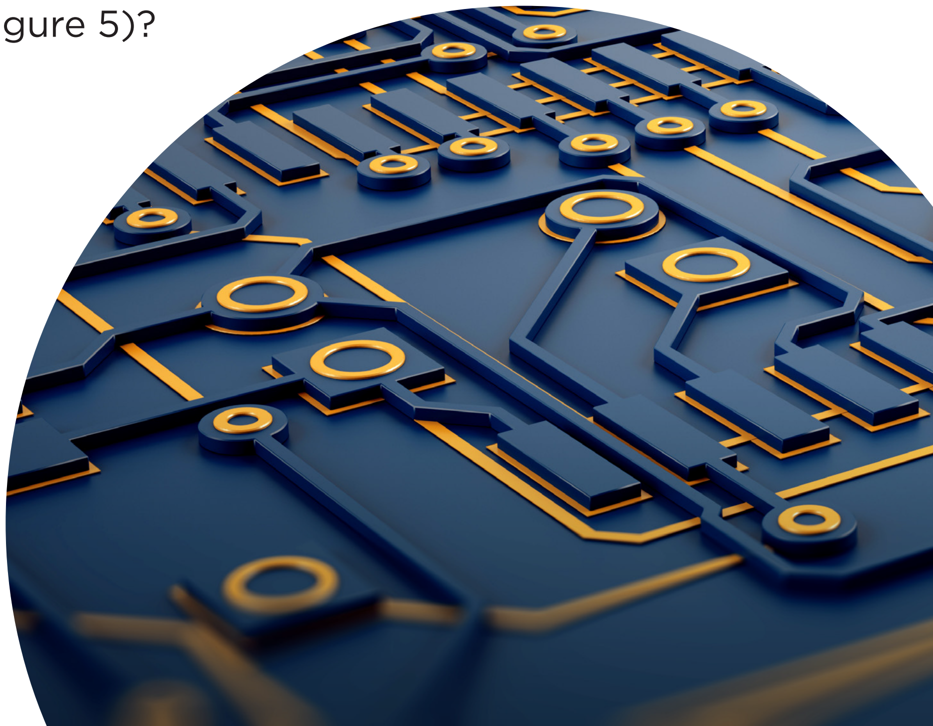
The circuit for Figure 5 was recommended by the supplier of the part, without first checking to see if the advice was sound. The waveforms shown were actually taken from an evaluation board supplied by the vendor. In terms of blocking noise from the power subsystem, this became treating the symptom rather than solving the problem. The problem was that there was noise in the power subsystem because it was not designed correctly.

The key thing for an IC vendor to understand is the power delivery needs of an IC. This includes the maximum delta I that the circuit may demand of the power delivery system as well as at what frequencies, and the maximum allowable delta V (ripple). Without this information, it is impossible to design a working, reliable PDS.

In reading the specifications for a component, such as an operational amplifier, one of the specifications is the power supply rejection ratio. This is a measure of the amount that variations on voltage of the power supply voltage affect the output of the device. It is possible to make such measurements for digital ICs and PLLs. The idea that ICs are just “logic” and don’t need this level of characterization is left over from the days of TTL when there was such high tolerance for Vcc variations that it was not necessary to account for them.

In actuality, an IC vendor needs to be able to advise users on how to create a functional power system. Any time there is a recommendation to add a ferrite bead in the power lead of a device, four questions must be asked of the IC vendor:

1. Is there a problem that can be solved by adding a ferrite bead?
2. Does the ferrite bead actually solve the problem?
3. Can I be sure that the addition of the ferrite bead does not create a new problem (such as that shown in Figure 5)?
4. Is using a ferrite bead the best way to solve the problem?



Our experience has been that after answering questions one and two, ferrite beads are eliminated from the design. Whenever we have encountered an applications note that recommends the use of ferrite beads, we have called the IC vendor/author and asked the above four questions. In no instance have we found that answering these questions results in the agreement that the addition of a ferrite bead is a good idea.

If after the foregoing process the vendor still insists on the use of ferrite beads, it’s imperative to insist on seeing a test circuit in which the component is used exactly the way it is intended to be used in the new design. If no test circuit exists, it is good to be suspicious. In one instance, when we were having trouble in getting a microprocessor to work properly, we asked to see the test circuit used to arrive at the applications note and the specifications for the part. We were told there wasn’t a test circuit and never had been one. When we asked, “how do you find out if the part works correctly?” The response was, “we give them to our customers and they tell us if they work!”

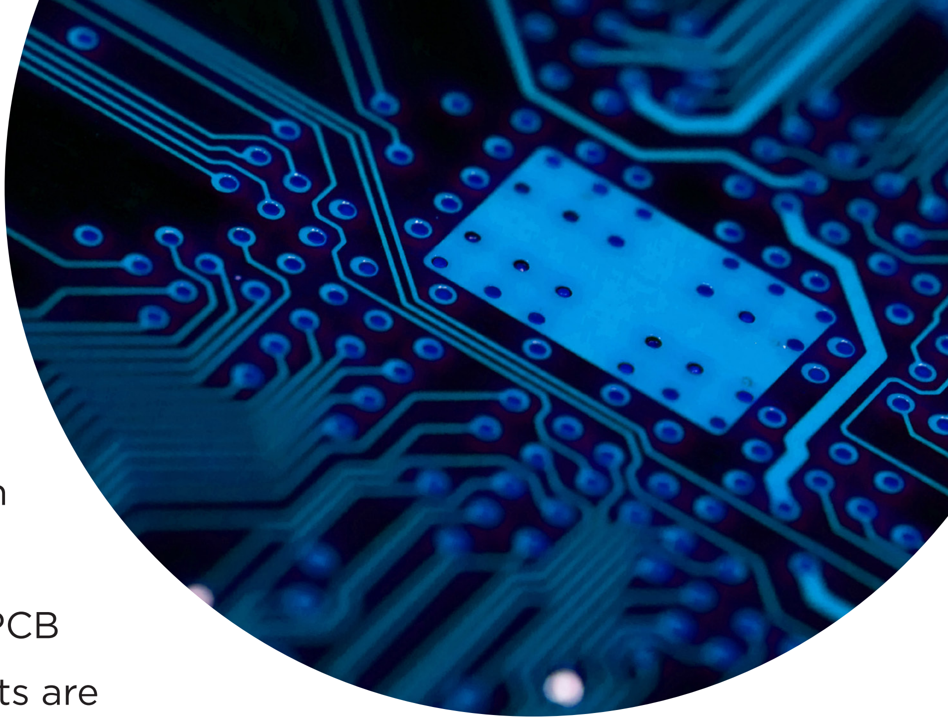
Summary

At Speeding Edge, our experience has been that the use of ferrite beads has been the result of a knee- jerk reaction, a band-aid or a case of holding onto bad practices rather than doing good engineering. As Lee Ritchey, President of Speeding Edge notes, “In the 40+ years of designing high-speed computer systems and networking products, I have never used a ferrite bead in the power lead of a device whether it is a PLL or an analog circuit—all of which have functioned to their specifications and passed appropriate EMI and ESD tests. Instead, I have determined what the ‘ripple’ requirements of a circuit are and designed the power delivery system to meet those requirements.”

References:

Ritchey, Lee W. and Zasio, John J., “Right The First Time, A Practical Handbook on High-Speed PCB and System Design, Volumes 1 and 2.”

How to Use a Ferrite Bead in Your Design to Reduce EMI



EMI and EMC can be a tricky subjects, and it's often tempting to mis-apply design guidelines to try and reduce EMI. One of these areas relating to EMC in PCB design is the use of ferrite beads. These components are basically filters, and they do perform a useful function on power cords in many electronics. You're probably reading this article on a laptop that uses a ferrite to filter out conducted EMI from the supply line.

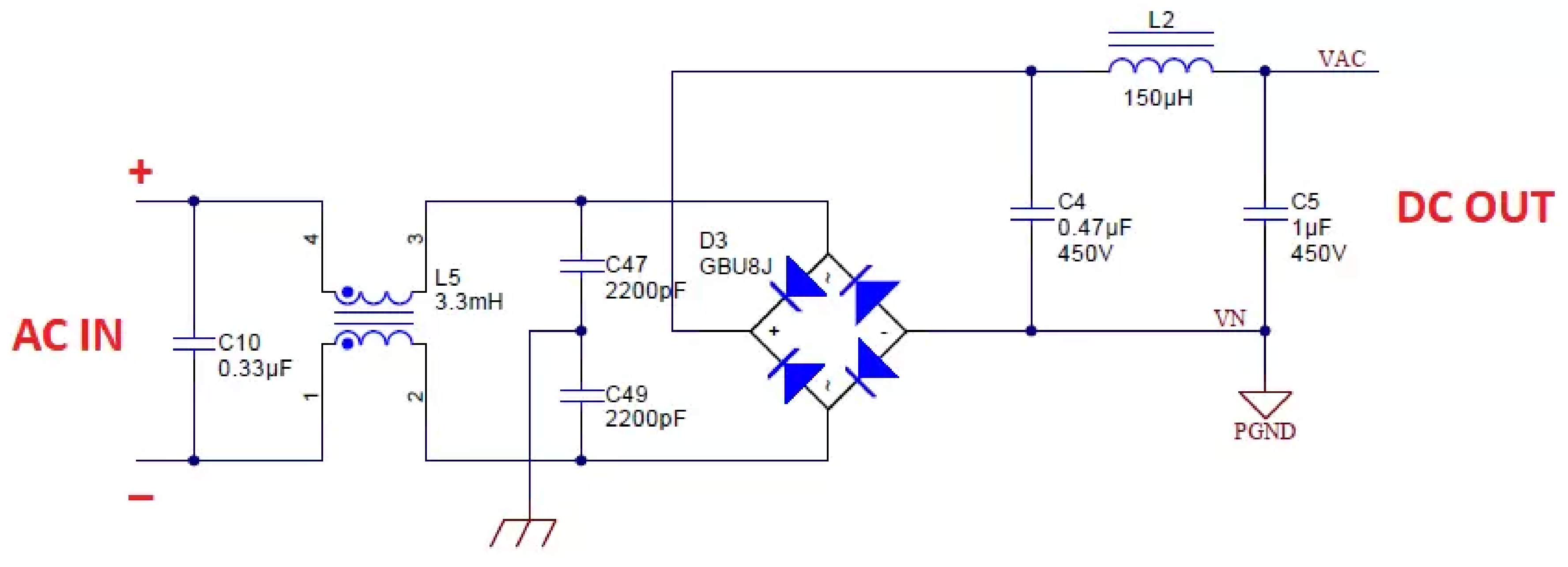
A problem begins to arise when you try to apply the same logic to other areas of a PCB. Ferrite beads are sometimes applied for EMI in two ways in attempts to minimize EMI, but the designer ends up creating a new EMI problem if these components are not used correctly. In this article, we'll go over some of the ways ferrites should not be used in a PCB, as well as how they actually operate in terms of their filtering behavior. As we'll see, the same logic that applies to ferrite cores on the input of a bridge rectifier stage in a power system does not apply to the power connection between a regulator and an integrated circuit.

Filtering With Ferrite Beads and Other Inductive Components

Ferrite beads are magnetic components, so it is tempting to think of ferrite beads as inductors that provide low pass filtering functions. They do block high frequencies, but only in a specific band; their impedance tends to maximize around 100 MHz to 1 GHz. Above that band their inherent capacitance takes over and their impedance begins to drop again, eventually providing high pass filtering functions. In this way, they aren't the perfect filters. However, these components can be used with other ferrites to address specific types of noise on the input power section. In fact, that's their most common usage.

While a bead by itself can't make a low pass filter, they can be used for more effective low-pass filtering at lower frequencies (e.g., 60 Hz AC or 120 Hz rectified DC ripple) when combined with shunt capacitors. Then you get what is essentially an LC filter that can provide low-pass filtering functions at sufficiently low frequencies. These are sometimes used on the AC power stage of a system to provide differential-mode noise filtering to ground, i.e., as a Pi filter. In higher power systems, this same circuit design is used with inductor coils as these can generally handle several amps of current. You would then follow this with a common-mode choke and further filtering on the output from your rectifier stage to produce DC power with low ripple.

An example showing these filtering elements an AC input is shown below. Note that L2 is typically a ferritic component (either a ferrite core inductor in high current systems, or a ferrite bead in low current systems).



This example circuit shows the rectifier stage in a power system used to convert AC to DC. Note that L2 could be a ferrite bead, depending on the current being drawn into this system.

Why should we worry about current? The reason has to do with saturation. When high DC current is being pulled into the system, the bead can saturate and lose inductance, similar to what happens in a transformer core at high current. In the most basic application, we would have the following set of inductive components involved in filtering noise on the input power stage as shown above:

- A ferrite clamp or choke on the input power line (see below)
- A ferrite bead within a voltage regulator to provide some switching noise compensation
- Inductors to provide low-pass filtering of input EMI
- Coupled choke coils specifically targeting common-mode or differential mode noise

Ferrite clamps used to filter noise on input power lines.

Placing these components on the input section of a power stage is much more effective than placing them on the output side. If you do use ferrites for filtering on the output side of a power converter, the acceptable use of these components depends on what you need them to do.

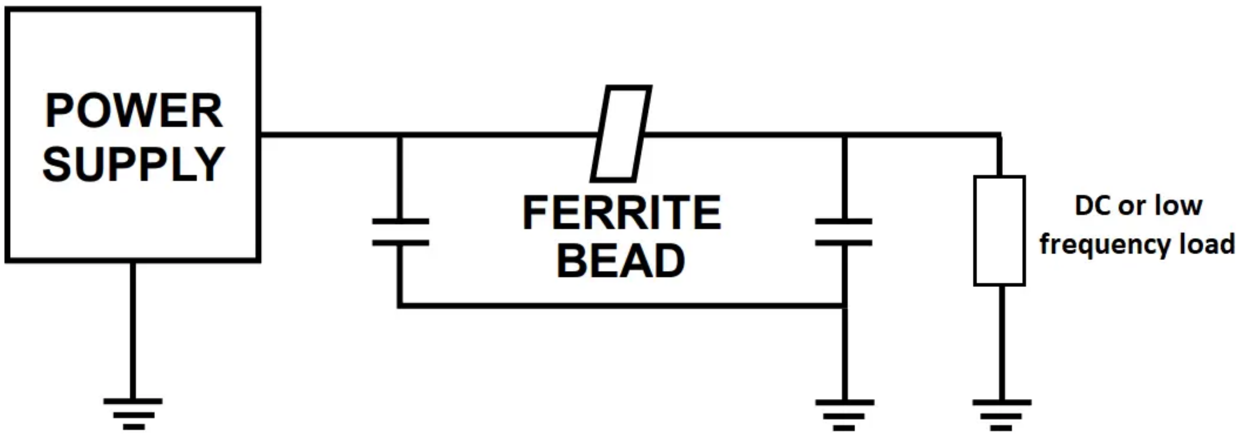
Ferrite Beads Should Not Be Used to Prevent Power Rail Ripple

When placed between a power regulator circuit output and the bypass capacitor on input power pins for a digital component, you have basically formed a Pi filter. Therefore, it would be reasonable to expect low-pass behavior at switching converter frequencies. This should not be done with high speed digital components as it will create new noise problems and will not function effectively as a low pass filter.

Why is this the case? There are a few reasons for this. My thought is that the typical recommended uses of ferrite beads are being applied in areas where they are no longer effective, or where they create new problems:

1. **At DC or low frequencies -** At very low frequencies used in switching regulators used to power other low frequency systems, a ferrite bead on the output in a Pi circuit will likely work fine and can reduce differential-mode conducted currents. Common-mode chokes can also be used for common-mode currents in the same way.
2. **Targeting switching frequencies -** This is also an acceptable strategy to specifically target a particular noise source with an inductive component, but only under the conditions in point #1. In effect, the ferrite bead is playing the same role as an LDO and by attempting to pass only the DC portion of the power to the load components in the system.
3. **For digital components -** When used with digital components, the ferrite bead is now presenting high impedance to large current transients with broad bandwidth, which creates strong ripple at the power pins of a digital component. In older TTL components, this was not a problem because they were slower and they could tolerate some level of VCC fluctuation. Today's CMOS components can experience ripple-induced jitter on the output lines due to fluctuations on the power rail.

An implementation for points #1 and #2 is shown below. This implementation is fine in #1 and #2 as it targets conducted EMI while allowing DC to pass. It will not function properly for point #3.

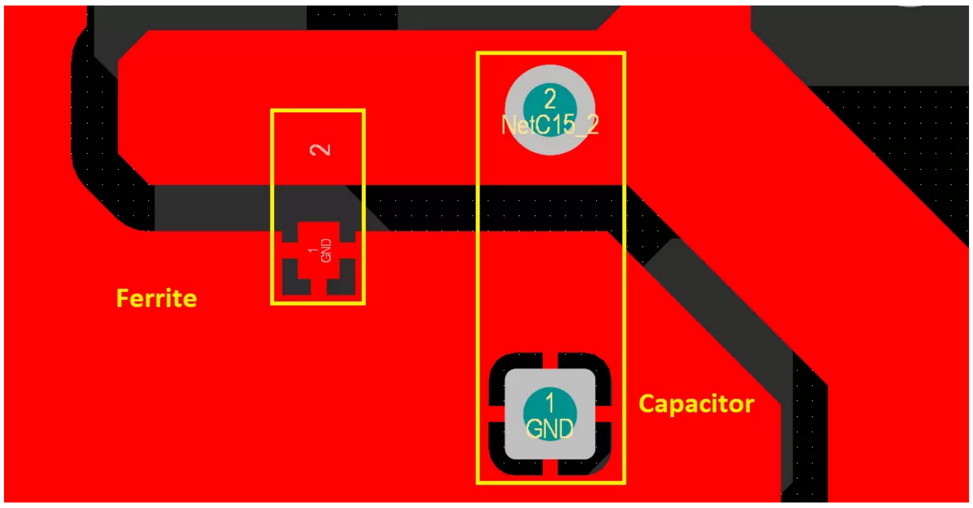


As we can see from points #1 and #2 above, there are some times where a ferrite on the output of a power regulator is acceptable. In fact, the image shown above is the typical way to use a ferrite bead for filtering power supply noise from reaching a static impedance. Using it to suppress noise from affecting a large digital IC as in point #3 is not one of them as you will create a new source of EMI due to ripple on the power rail. This is why we add capacitance to the power rail through the use of decoupling/bypass capacitors as this reduces the PDN impedance at the high frequencies associated with digital signal bandwidths. This will help suppress other noise phenomena in the design, particularly ground bounce.

Use Complete Ground Planes Instead of Bridging With Ferrites

One of the primary ways that is sometimes cited as a method to reduce EMI and interference between two sections of ground is to split the plane into two physically disconnected sections, and then bridge them with a ferrite bead. The idea is that the ferrite will provide a return path for any digital or analog signals crossing the gap while also setting the two sections to the same potential.

This is probably the worst EMI suppression guideline I’ve ever seen, especially because it encourages such bad routing practices. I’ve been asked to rework boards from other designers that have implemented this strategy and the design ended up failing EMC testing. Once the ferrite is removed and a complete ground plane is used to support routing, then the design ends up passing EMC testing.



This ferrite bead and capacitor create a resonant tank circuit with low damping.
This is not the proper way to use a ferrite bead as it will create a new EMI problem.

To make matters even worse, I've seen designers do this and then add a capacitor in parallel with the ferrite! This makes a resonant tank circuit that resonates strongly. Just about any portion of digital signal's power spectrum will excite the LC resonance in that circuit after it crosses the gap across a ground plane, leading to strongly underdamped modulation with very little damping.

Why is this such a bad idea? Here's why you should never try to split planes and connect them with a ferrite or a parallel LC circuit:

1. **Splitting ground planes is almost always unnecessary -** In mixed signal systems, split ground planes can create more problems than it solves, particularly in systems that use a mix of digital and high frequency analog. In short, it isn't needed except in specialty cases with low frequency analog. Read more about this here.
2. **It encourages bad routing -** Placing a ferrite bead does eliminate DC offset between the two regions, but it does not function as an effective low-impedance return path between the two sections. Therefore, routing across the gap alongside a ferrite creates a big loop inductance antenna that emits and receives EMI.
3. **A ferrite alone can still create a resonance -** If a ferrite is used to bridge two ground plane regions, it can still create a resonance even if no cap is present. There is some parasitic fringing capacitance between the two plane regions that will still create a lumped LC resonance with high natural frequency and moderate damping, so a stray pulse received in the inductive loop created by the ferrite could still excite this resonance.

Instead of trying to provide isolation with split planes, practice proper layout and routing practices. This is the best strategy to provide isolation.

General Noise Filtering

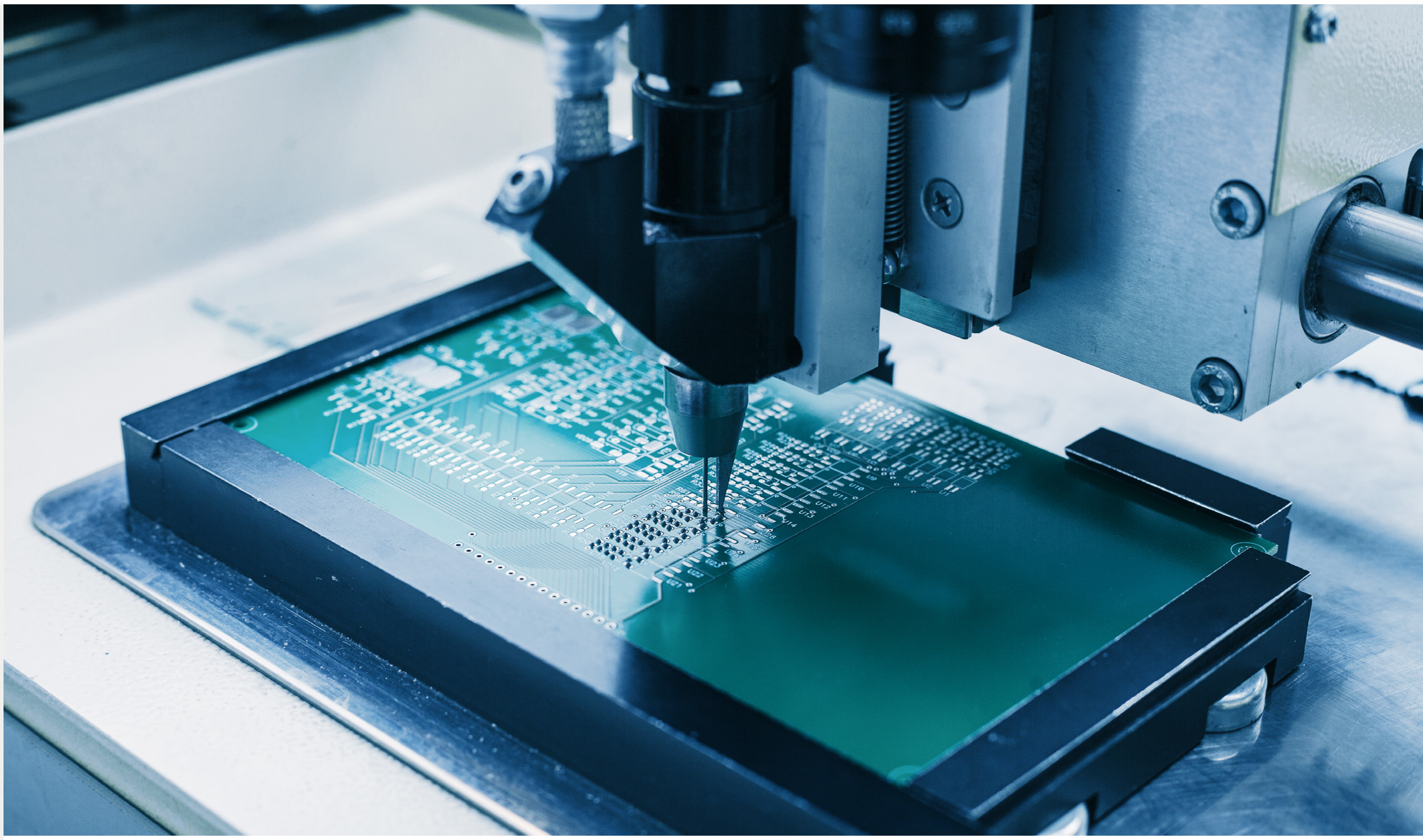
AC power connections aren't the place where ferrite beads can be used. Ferrite beads can help filter out low-level noise at low frequencies in many portions of a circuit as long as the desired signal sits within the relevant filtering band for the ferrite and any resonance in the filtering circuit is sufficiently damped. Make sure to check the impedance curve in your ferrite's datasheet and verify that you are using it to target the relevant noise frequency with a high impedance series element. The typical method for using a ferrite as a filter is to pair it with a small resistor in series, or to pair it with capacitors as a T or Pi filter circuit.

Once you have your capacitor and ferrite material in place, you can start filtering out high frequencies. While ferrite beads do have some parasitic resistance that creates damping, LC resonance can still occur, particularly when using smaller capacitors. If you really want to use a large capacitor, that risk can be mitigated by adding additional damping or limiting resonance through impedance matching or by simply adding a small amount of series resistance. If resonance does occur, it can lead to a gain of up to 10 dB, so take care to design your filter to avoid resonance if you're working in a bandwidth where this is a risk.

Summary

We often discuss the importance and function of ferrite beads. If you'd like to see an example of how ferrite beads can interfere with high speed digital components and how they should not be used, check out Everything You Need To Know About Ferrite Beads by industry expert Kella Knack.

Now that you know the proper use of ferrite beads to reduce EMI in your circuit, it's time to design your board. Great PCB design software like Altium Designer will give you all the tools you need to create your circuits, layout your PCB, and prepare your manufacturing deliverables. When you've finished your design, and you want to release files to your manufacturer, the Altium 365™ platform makes it easy to collaborate and share your projects.



Ferrite Beads and Transfer Impedance in a PDN Simulation

The use of ferrites in a PDN is one design recommendation that is fraught with unclear guidance and over-generalized recommendations. If you see an application note or a reference design that recommends placing a ferrite in a PDN, should you follow this in your specific design, or should you ignore this and focus on adding capacitance? What if you're using the ferrite to isolate two rails?

These are two questions we want to answer in this article. There may be two typical uses of ferrites in a PDN: as a supposed filtering element connected directly to a VDD pin, or as a blocking element between two different rails. The first one case should be avoided, yet the 2nd case has shown some promise if the ferrite is chosen correctly and if used on the appropriate rail. This is something you can examine in a SPICE simulation in an intermediate frequency range (up to about 1 GHz), and it's what I'll look at in this article.

Ferrite Beads in a PDN: Filtering or Isolation?

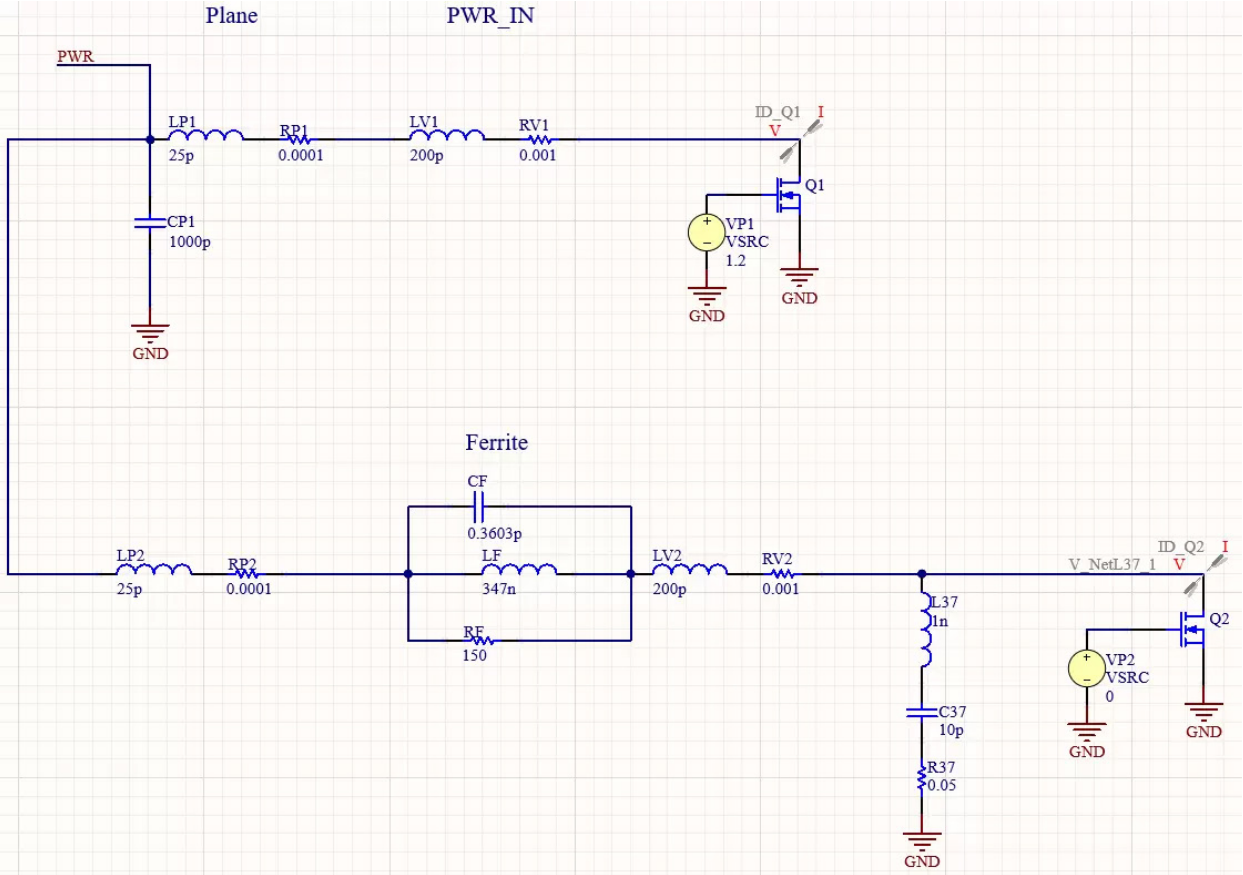
I've stated many times, and other designers will agree, that placing a ferrite in a PDN will add inductance to a PDN at intermediate frequencies, which is generally a bad idea if the PDN needs to support components that switch at fast edge rates (about 1 ns or less). Plenty of data backs up this assertion, particularly when the ferrite is connected to a rail that supplies power to high speed I/Os. Still, this is something seen in application notes on power regulators generally, and the use of ferrites sometimes gets taken out of context or implemented where it doesn't make sense.

That being said, I've designed boards without including a ferrite for isolation, even if the ferrite was recommended as part of the reference design or included in an application note. Another author on this blog backs up this assertion. This includes omitting the ferrite as an element to isolate one rail from another, such as the VDD input and a PLL power rail.

This case of using a ferrite as an isolating element between two rails on a PDN is what we want to look at in a SPICE simulation in this article. Essentially, we want to simulate the transfer impedance between two rails on a PDN. Read this article to learn more about transfer impedance before proceeding further, as well as this article looking at our basic PDN simulation with multiple caps. I'll continue with the basic PDN simulation model by adding a rail and attempting to isolate it with a ferrite.

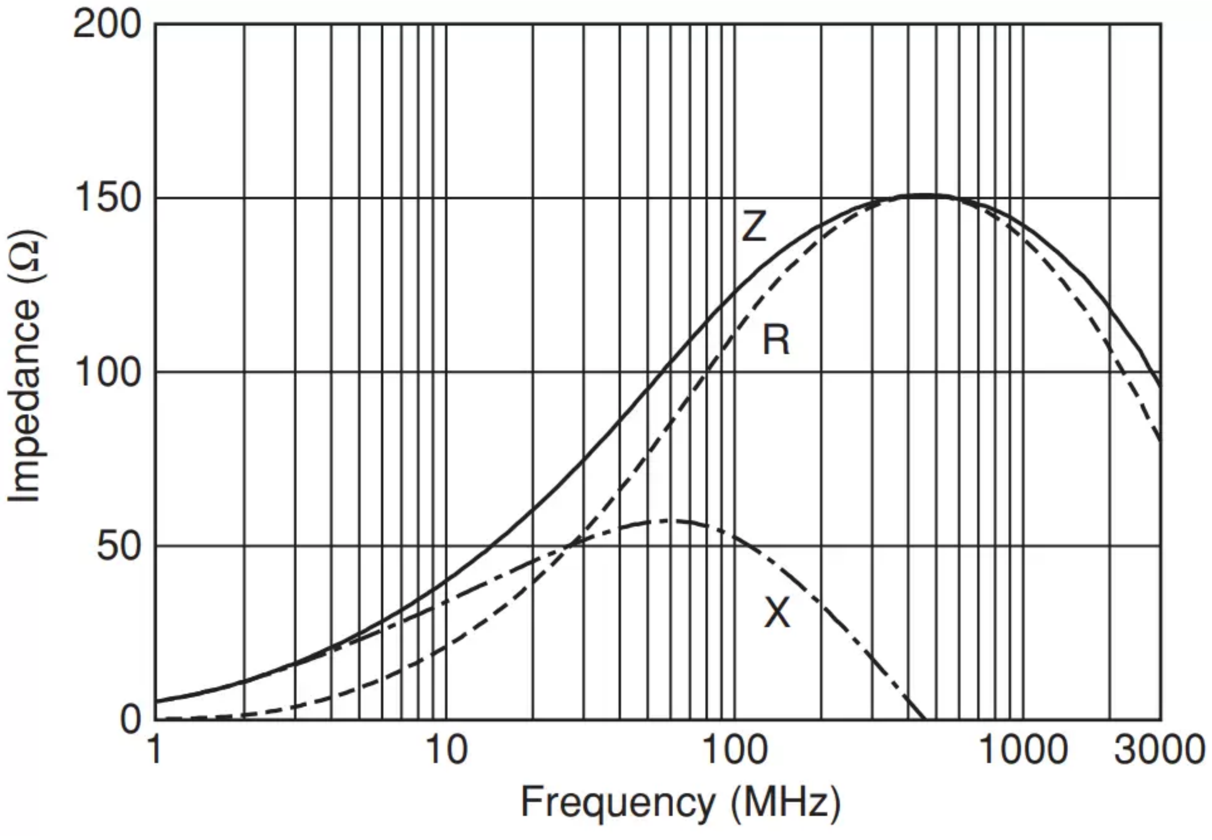
Simulation Model With a Ferrite Bead

The simulation model for our PDN with a ferrite includes two rails: a supply rail for I/Os, and an additional rail modeling a slower switching element such as a PLL. The PLL rail is being isolated from the I/O rail using a ferrite bead (sometimes called a ferrite chip). The goal of our simulation is to examine the effectiveness of a typical ferrite as an isolating element between these two rails.



The decoupling capacitor bank consists of 36 caps with various self resonant frequency (SRF) values as shown in a previous PDN simulation article.

The ferrite used in the simulation is part number BLM18PG121SN1 from Murata. This was modeled using a parallel RLC circuit as is typically used in SPICE simulations to represent ferrites. Using the bandwidth, the resistance at resonance, and the resonant frequency, the ferrite can be modeled by taking R = 150 Ohms, L = 347 nH, and 0.3603 pF. Note that this is not a perfect representation of the ferrite, but it is the best that can be done without a precise simulation model for this part.



During the simulation, we'll modulate the R value of the ferrite just to see its effects on noise transfer between the two rails in the simulation model. With the earlier decap simulation model and the above model for the isolating ferrite on the PLL rail, we now have what we need to perform a simulation. We'll examine a few cases to distinguish between different noise sources:

- The voltage at the PLL rail when only the I/O rail is switching
- The voltage at the PLL rail when the PLL is switching and the I/O is switching

Both cases allow us to calculate the PDN's entire impedance matrix if we like. Since we have 2 rails, this would be a 2x2 matrix relating the current draw at port n to the voltage measured at port m:

$$\begin{bmatrix} V_1(\omega) \\ V_2(\omega) \end{bmatrix} = \begin{bmatrix} Z_{11}(\omega) & Z_{12}(\omega) \\ Z_{21}(\omega) & Z_{22}(\omega) \end{bmatrix} \begin{bmatrix} I_1(\omega) \\ I_2(\omega) \end{bmatrix}$$

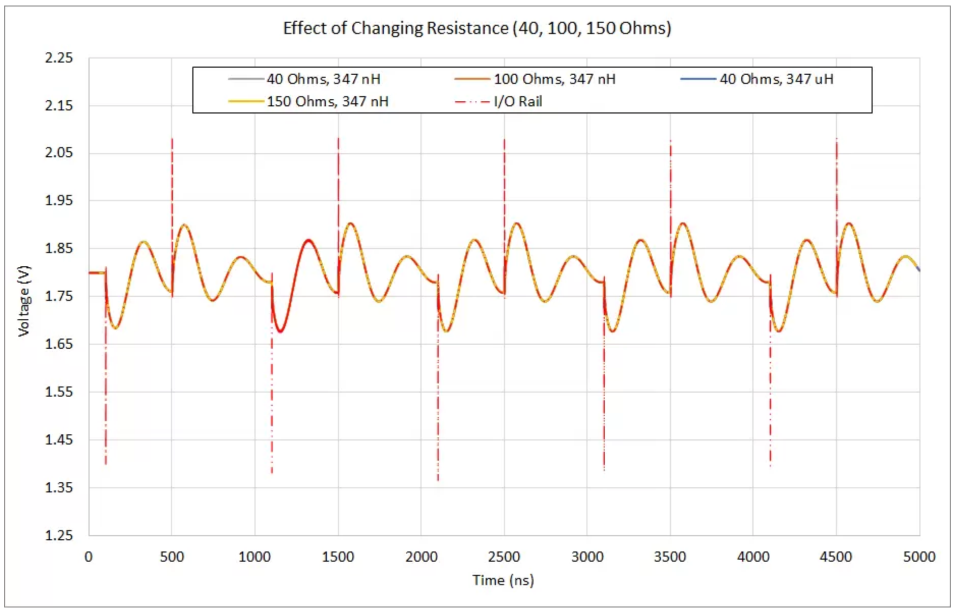
Impedance parameter matrix definition for the 2-port PDN in this simulation.

Goal #1 above amounts to calculating Z21 in the impedance matrix. We'll use this to help explain the results seen in the simulation. To examine noise propagation into the PLL rail, we'll compare the PLL rail voltage waveform with the I/O rail voltage waveform.

Results: I/O Rail Switching, PLL Quiet

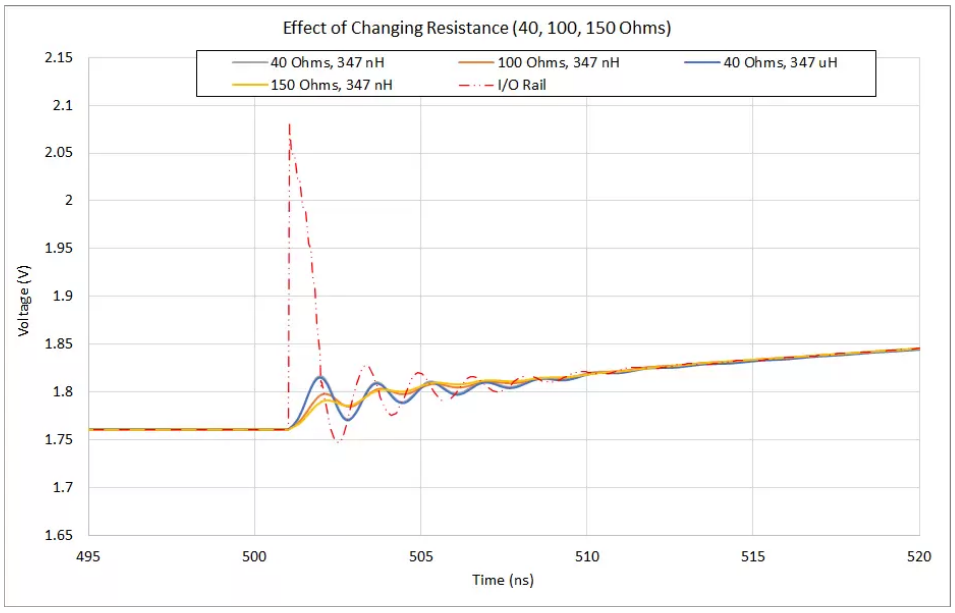
The initial results comparing the voltage on the I/O rail with the voltage on the PLL rail are shown below. The I/O rail is switching with 1 ns rise time at 1 MHz frequency, while the PLL rail is not switching.

The time-domain waveforms below seem to suggest the ferrite has no effect on noise isolation, regardless of the ferrite's effective parallel resistance and inductance. In fact, increasing the ferrite's inductance by a factor 1000 appears to have no effect on noise isolation.



Voltage on the I/O power rail and PDN power rail for various ferrite parameters.

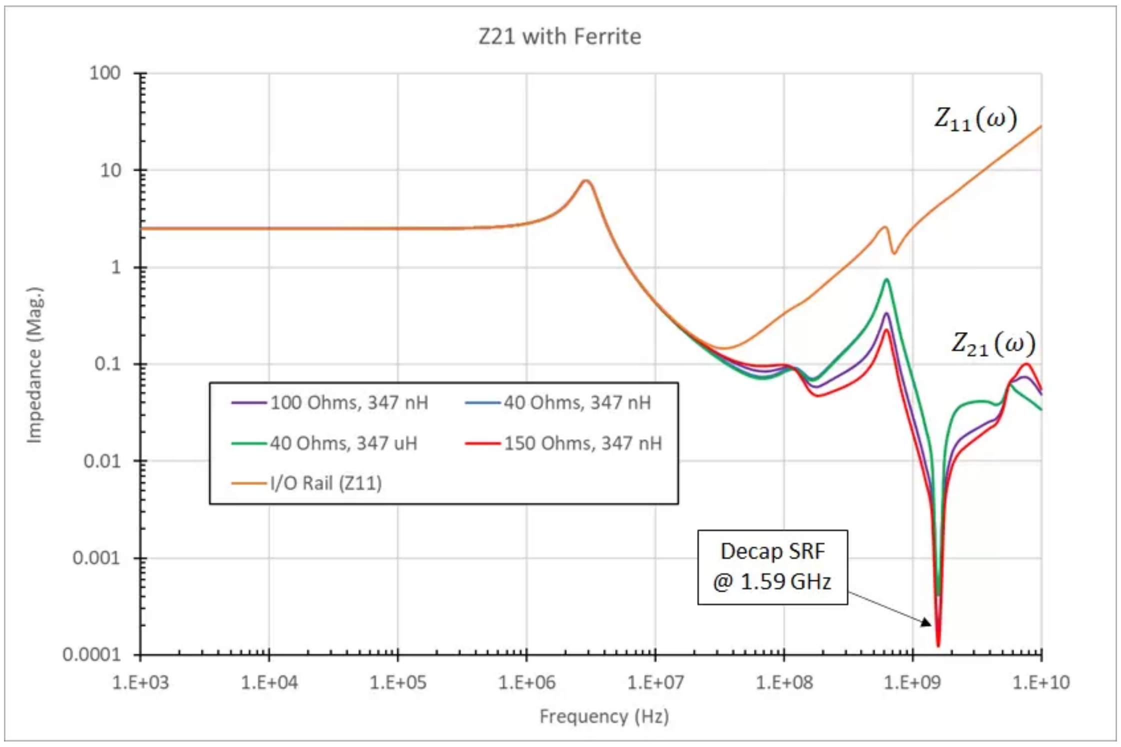
While it is not obvious, there is a very sharp transition right on the rising edge of the I/O voltage waveform. If we zoom in, we can see that this rising edge is not an artifact, but rather it is associated with a high-frequency pole in the I/O rail's impedance (in the Z11 parameter).



Zoomed in result comparing I/O power rail and PDN power rail for various ferrite parameters
Note that the blue and grey curves overlap.

Now we can see the effect of the ferrite; there is high-frequency noise generated on the I/O rail due to a pole in the Z11 parameter located at 631 MHz. This same pole exists in the transfer impedance spectrum (Z21), but it happens to be at much lower impedance. However, the high-frequency portion of the transient response, as shown above, experiences greater damping thanks to the placement of the ferrite. It's clear that the standard R/L value in the ferrite model is the factor that determines damping in the transient response, just as is the case in any other RLC circuit. In other words, we would prefer a large resistance and a low inductance, which runs counter to the justification for using a ferrite in a PDN.

In contrast, the low-frequency noise appears to be totally unaffected by the ferrite. The low-frequency noise at 2.81 MHz is nearly identical on both rails, so we would expect the Z-parameters for these rails and the Z21 spectrum to have the same poles at 2.81 MHz. Indeed, this is what we see in the Z-parameter spectra shown.

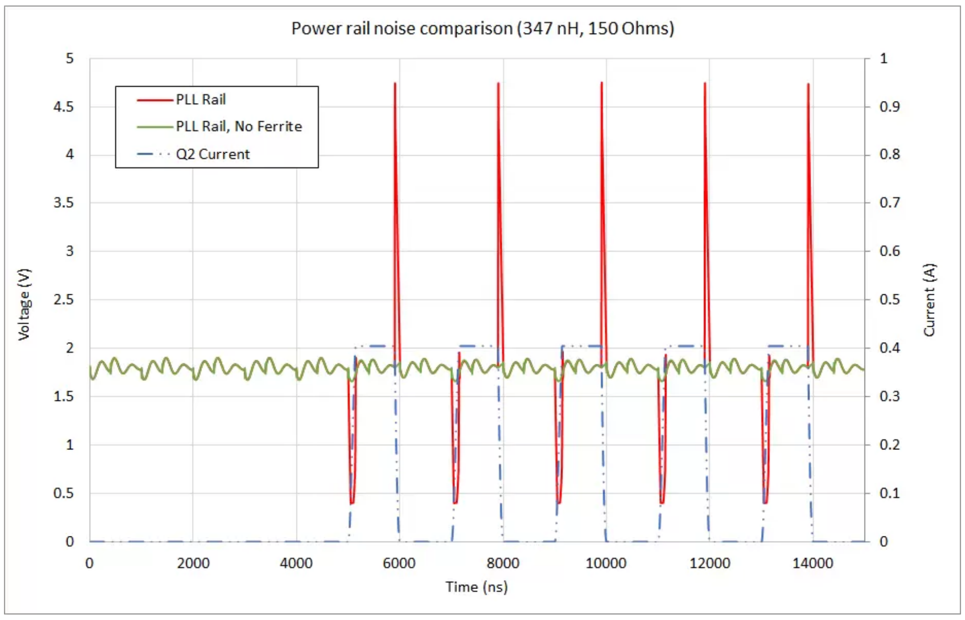


Zoomed in result comparing I/O power rail and PDN power rail for various ferrite parameters.

From comparing the self-impedance of the I/O rail (Z11) with the transfer impedance spectra (Z21), it's very clear that there is only marginal benefit at the 631 MHz pole and no benefit at the 2.81 MHz pole (this is the main pole that matters). While it might appear that the ferrite on the PLL rail is responsible for reducing the noise, the bypass capacitor also reduces the noise thanks to its SRF value at 1.59 GHz. The two together act similar to a controlled ESR capacitor, providing high damping and reduced noise.

Results: PLL Rail Switching, I/O Switching

Now we can investigate how switching on the PLL rail will be affected by the presence of the ferrite. The transient analysis results below clearly show how the switching action in the PLL creates huge glitches in the PLL rail voltage. The red and green curves show the PLL rail voltage with and without a ferrite, respectively. As soon as the PLL switches on after 5 us (blue dashed curve), we see that the PLL rail with the ferrite exhibits huge voltage spikes. These spikes are not seen on the same PLL rail with the ferrite removed.



Significant glitches are seen when the PLL switches due to the presence of the ferrite. When the ferrite is removed, the large glitches are eliminated.

We can clearly see that the PLL rail is clean again once we remove the ferrite (see the green curve above). In fact, we don't even see the noise from the I/O section! This should be the nail in the coffin for the ferrite in this design; the bypass capacitor is the big reducer of noise, not the ferrite. The results confirm that more capacitance is a favorable design change rather than adding inductance. This also illustrates the required design change on the I/O rail: add some small capacitors that directly target the 631 MHz peak in the PDN impedance spectrum.

Summary

What have we learned from this exercise? The results seem mixed, giving minimally acceptable results for the high-frequency pole and no results for the more problematic low-frequency pole. There are four important points:

1. The ferrite blocked some high-frequency noise from the I/O rail from reaching the PLL rail. This was achieved because the pole was located in the ferrite's resistive band, which can be seen by comparing the I/O noise measured on the I/O rail vs. the I/O noise measured on the PLL rail.
2. The bypass capacitor on the PLL rail greatly aids isolation as long as this capacitor is chosen properly (such that its SRF is close to the high-frequency pole).
3. The ferrite did absolutely nothing to reduce the low-frequency noise from the I/O rail from reaching the PLL rail. If the PLL were running as low as 0.9 V, the low frequency noise would create significant interference.
4. When the simulated slow-edge PLL element was switching, the inductance of the ferrite caused very large spikes on the PLL rail.

Overall, it looks like the ferrite was not much help where it was needed. We can deduce that adding dutifully chosen capacitors would provide the same benefits as the ferrite without the additional problems that come with the ferrite. From the bead's impedance curve, we can see that the bead provides practically zero additional damping at low frequency, so we would not expect the low-frequency noise to be attenuated. The low-frequency noise can instead be addressed by targeting it with a large capacitor that has SRF = 2.81 MHz on both rails.

So, should you use a ferrite for isolation in your PDN? Be careful with this as it depends on the range of frequencies you need to isolate against. In addition, you should check that the ferrite does not create a new noise problem on the isolated rail. If you think you need to use a ferrite for rail isolation in your PDN, make sure you simulate this first to ensure the ferrite accomplishes the intended purpose.

Whether you need to perform a PDN simulation with a ferrite, or you need to model more complex power and signal behavior, you can evaluate your design with the built-in SPICE package in Altium Designer®. You and your team will be able to stay productive and collaborate efficiently on advanced electronics designs through the Altium 365™ platform. Everything you need to design and produce advanced electronics can be found in one software package.

How to Use Ferrite Beads, Chips, Cores, and Plates

Mention the word ferrite around some circuit designers, and the mind probably jumps to "ferrite bead". These components are usually put into a design with a simple intent: block everything except for DC current. Very simply, ferrite beads, no matter their form factor, are intended to be a simple low-pass circuit. But what about other types of ferrites? How does their electrical functionality compare to a simple ferrite bead?

There are several types of ferrites to consider using in your design. While they all obey the same laws of physics, they can provide different functions in your design depending on their form factor and placement. In particular, there are some problems an alternative ferrite can solve that can't be approached with a ferrite bead.

Different Ferrites, Different Applications

Start looking at some component manufacturer websites, and you'll find some mixed terminology around ferrite beads. Some companies will use the correct name of a product when describing ferrites, while other product guides will just call everything a ferrite bead. Then there are ferrite plates, which are not provided by every ferrite bead manufacturer. Some EMI guidelines will also refer to the blanket "ferrite bead" when stating which component is your magic EMI solution, and typically without stating how or where to put the component.

The point of using a ferrite is to take advantage of the high magnetic susceptibility of ferrimagnetic materials to suppress noise and radiation. These materials have a high Q value in the standard inductance equation. When used as inductors, the high Q value is what gives you a large inductance for a physically small package. To break through all the confusion, let's look at each of these ferrite options to see which is the best option for your system.

Ferrite Core

This is the most common reference to a ferrite bead you'll find on forums, in guides, and elsewhere. We often do a bad job of differentiating this from an inductor, board-mounted ferrite chip bead, and common-mode choke for reasons we'll see momentarily. Some ferrite manufacturers will call this a ferrite choke or ferrite clamp rather than a ferrite core, and it gets confusing because some manufacturers will interchangeably use these terms for something else (either common-mode or differential-mode chokes, or chip ferrites). Be mindful of this when considering the use of toroidal ferrites for clamping power cords, and when looking at products on a manufacturer's website.

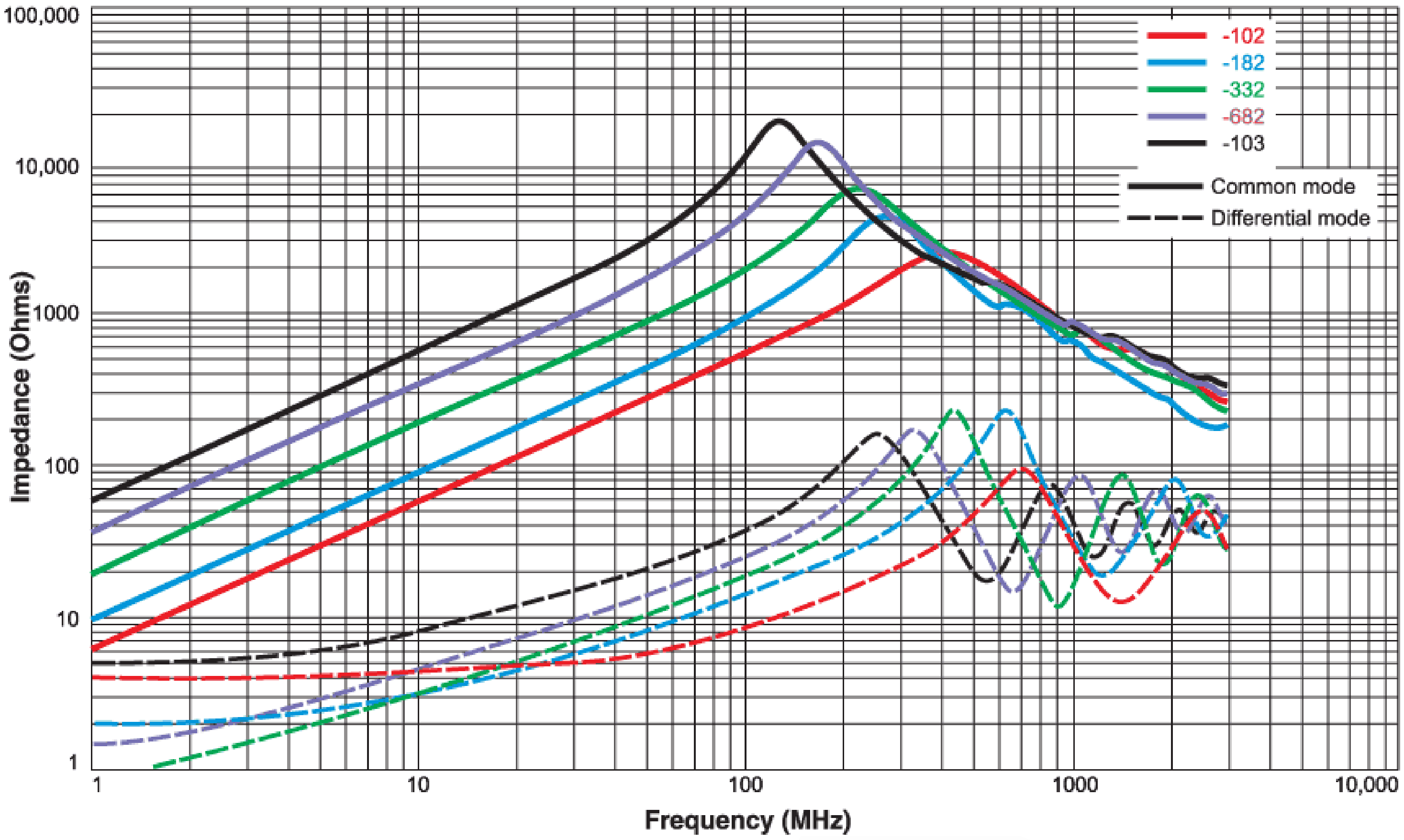
No matter the term used to refer to this component, it is intended to be placed on a power cord coming into the system with the idea of suppressing conducted common-mode noise coming from the grid. You'll sometimes see this as a toroidal core wrapping around the output cord from your DC power plug. If you're reading this on your laptop, there's probably a ferrite core on the power cord.

Chip Ferrites

These components are basically meant to be inductors with a ferrite core in a small SMD package with standardized land pattern. These are also often called "chip ferrite beads", so there is an important distinction with a standard ferrite core found on a power cord. The point of these components is to provide high inductance in a physically small package, much smaller than what you would see for a typical air-core inductor coil.

This chip is the SMD version of a ferrite core you'll find on a DC power cord.

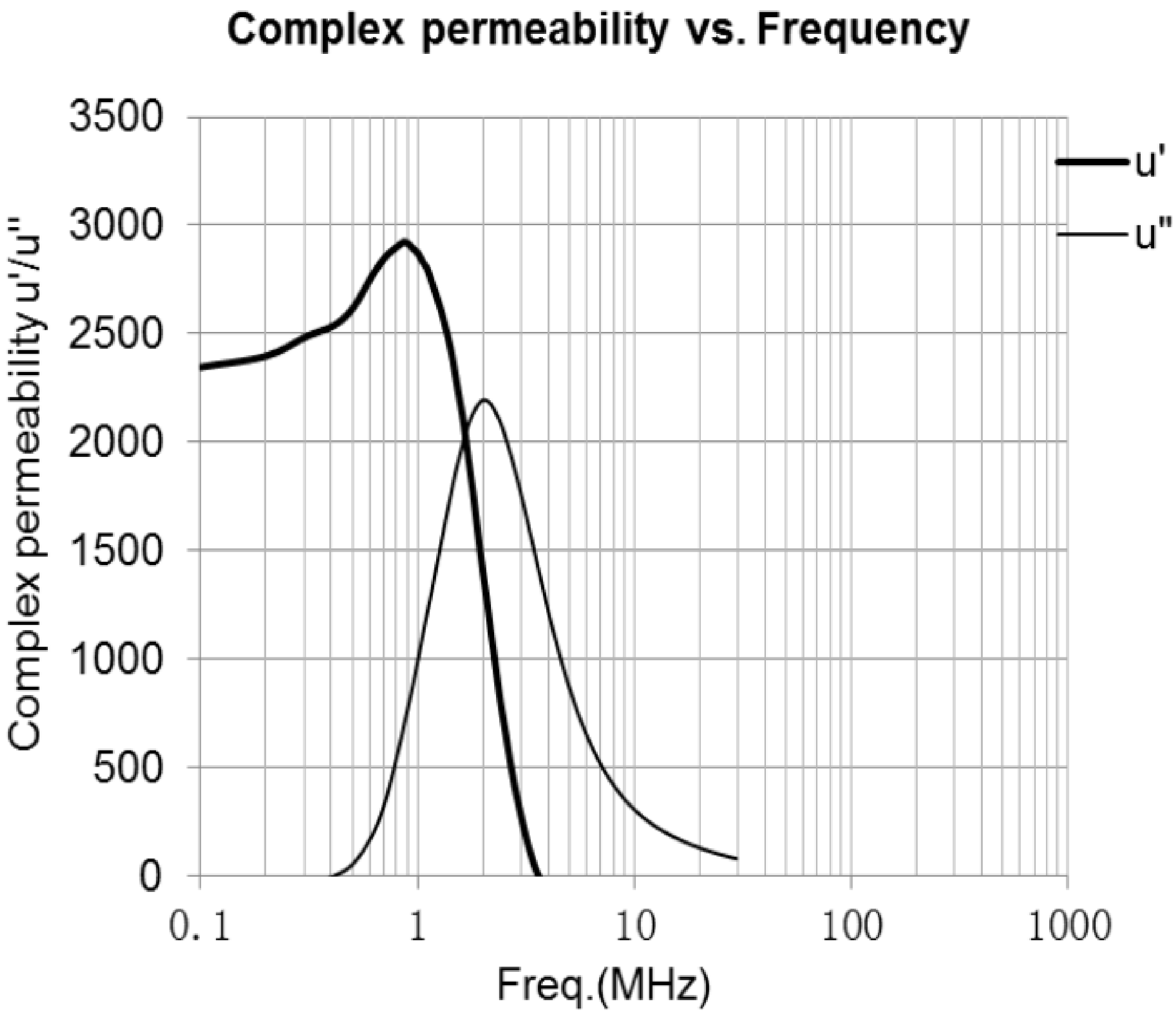
Chip ferrites can also come packaged as low-profile chip components that provide common-mode or differential-mode noise filtering. Cutoff frequencies for these components can reach hundreds of MHz. It's important to note that the impedance values will be different for differential-mode noise vs. common-mode noise. For example, take a look at the impedance curve for a chip ferrite bead below. The common-mode impedance shows the typical behavior of a single-ended inductor, but the differential-mode component still has high impedance, limiting the use of this type of component as a differential-mode filter unless you're worried about filtering up to ~GHz frequencies.



Common-mode and differential-mode noise impedance values in a two-terminal ferrite chip.

Ferrite Plates

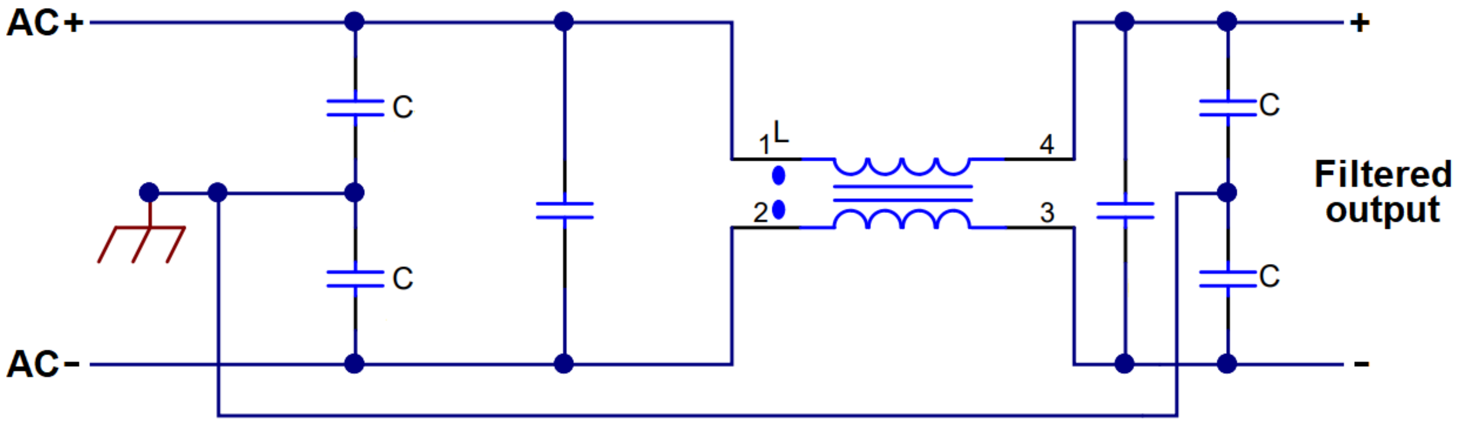
These components are literally plates or disks of a ferrimagnetic material, and they are placed in an enclosure near an offending component. A common application is in power electronics to counteract switching noise without adding a filter circuit to a layout. These materials can provide shielding against inductively coupled noise originating from a high dI/dt source, such as you would get in a high current switching power regulator. They also provide suppression of radiated EMI, acting as a standard shielding material. However, make sure to check the value of Q vs. frequency for these materials to determine shielding effectiveness.



Example complex permeability vs. frequency spectrum. This type of curve is typical for many ferrites.

Common-mode Chokes

Most often referred to as a pair of coupled inductors, these components include a cylindrical ferrite core with a wound wire to provide either common-mode noise filtering, although reversing the winding on one of these components will provide differential mode filtering. These components can be used with other reactive components to provide mixed-mode filtering at 2nd order and higher. A typical circuit that provides common-mode and differential-mode noise filtering with 12 dB/octave rolloff is shown below.



Example 2nd order EMI filter circuit with a common-mode choke (L) and differential-mode filtering provided by shunt capacitors. You can read more about this and other EMI filter circuits in this article.

Summary

The point of using ferrite beads is sometimes poorly communicated, although it's generally agreed that the point is to suppress EMI. In reality, ferrite beads are not a cure-all for every EMI problem, and in some cases placing them in a circuit will create a new EMI problem due to the bandstop behavior of real ferrite beads. Suppressing EMI is more complex than just placing a ferrite bead on a power cord or on the power lead of an IC, as Kella Knack describes in a recent article. Typically, you will need more than one solution that targets different frequency ranges, but only after you've followed some best layout practices for low EMI.

If you find that you do need to place a ferrite bead, core, plate, or SMD ferrite on your PCB, use the CAD tools in Altium Designer® to place and route components in your PCB layout. When you need to compare the effectiveness of your system with and without ferrites on the board, you can use the EDB Exporter extension to import a design into Ansys field solvers and perform a range of SI/PI simulations. When you've finished your design, and you want to release files to your manufacturer, the Altium 365™ platform makes it easy to collaborate and share your projects.

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