Choosing the Right Bypass Caps for Your RF Power Amplifier

By Brian Baxter, Posted Wed Apr 17 2024 20:07:00 GMT-0500 (Central Daylight Time)

Wireless communication is a ubiquitous part of modern life. We use it daily and without thought in the form of cellular phones, Wi-Fi hotspots, Bluetooth accessories, satellite radio and over-the-air digital TV. Just to name a few. The workhorse of these wireless systems is the RF power amplifier (RF PA). The RF PA is responsible for amplifying low power internal signals for radiation over the air using some type of antenna. Defining characteristics of these devices are their frequency response, gain, power efficiency, and power output capability. These characteristics are often at odds with each other and compromises are made in every system design. For instance, it's not possible to simultaneously have very high output power capability and very low power consumption. Physics doesn't allow us to get more power out than we put in. Thus, RF power amplifier designs are often pushed to the absolute limits of performance to provide system users with the best possible experience (i.e. long-range communication, good battery life and high data rates). Such designs, while desirable and necessary, become more vulnerable to external non-idealities such as noise, supply voltage transients and RF feedback. In the best case, these non-idealities will simply degrade performance of the system. In the worst case, they can produce powerful oscillations that either damage the PA or block other users from accessing the system. So, how can we defend against these external non-idealities?

This brings us to the topic of today's post: Bypass Capacitors.

Bypass capacitors are often misunderstood and viewed as an afterthought in the implementation of an RF system. This can lead to many of the problems listed above and result in unnecessary board spins and product delays. A better understanding of the purpose of, how to choose, and where to install bypass capacitors will help avoid trouble. The remainder of this article will explain these topics in more detail.

What's the purpose of bypass capacitors?

Bypass capacitors are installed between the DC supply line of the PA and the ground plane. They perform three main functions in the context of RF power amplifiers:

1. Noise Reduction
2. DC Supply Stability
3. RF Feedback Reduction

Let's look at each of these in a little more detail.

Noise Reduction

DC power supplies can be inherently noisy depending on the methods used to create the DC voltage. This high frequency noise ("switching noise") will be present on the DC supply line and can have a negative effect on the PA in multiple ways. Importantly, the noise can reduce the signal to noise ratio at the output of the PA which will reduce the capability of the entire system.

DC Supply Stability

Some RF systems can produce instantaneous high current demands on the DC power supply. In these instances, the DC power supply may not be able to supply the required current or that current may result in excessive IR drop from the source. In both cases, the DC voltage at the PA will momentarily droop causing variations in PA gain and output power. Both of which will affect the modulation quality at the output of the system. Bypass capacitors can serve as charge storage reservoirs nearby the PA and can provide nearly instantaneous current to the PA with minimal voltage drop.

RF Feedback Reduction

One of the main enemies of PA design is unwanted oscillations. In the worst case, this can manifest when the PA becomes an RF oscillator and produces an RF signal at the output (often a main frequency of oscillation along with multiple harmonics) without having an RF input applied. In order for PAs to become oscillators there must be a feedback loop with positive gain and the phase around that feedback loop must be approximately 360degrees. If we can break the feedback loop or alter its phase, we can prevent oscillation from occurring. Bypass capacitors reduce the chance of feedback loops developing by providing a low impedance path to ground for frequencies within the RF operating band of the PA.

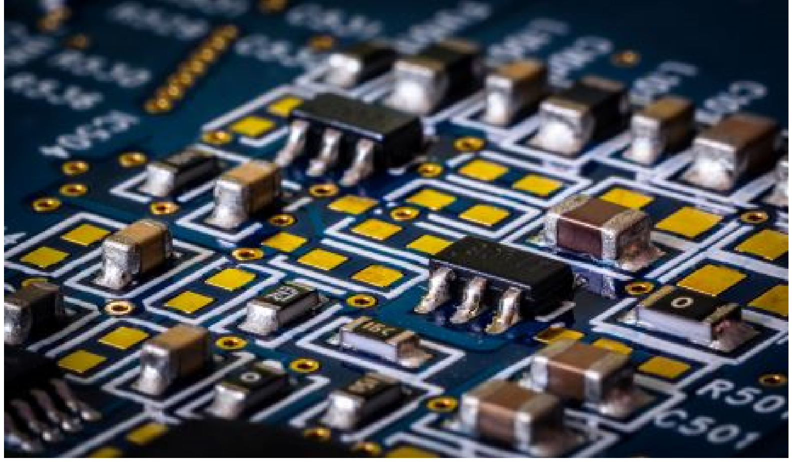
Now that we've explored how bypass capacitors can help improve system performance and reduce the chance of unwanted oscillations, lets discuss how to choose the right bypass capacitor for your application.

How do you choose the right bypass capacitor?

There are a number of things to consider when choosing a bypass capacitor for your application. These include things like the capacitance value, material type, voltage and temp ratings and the package type.

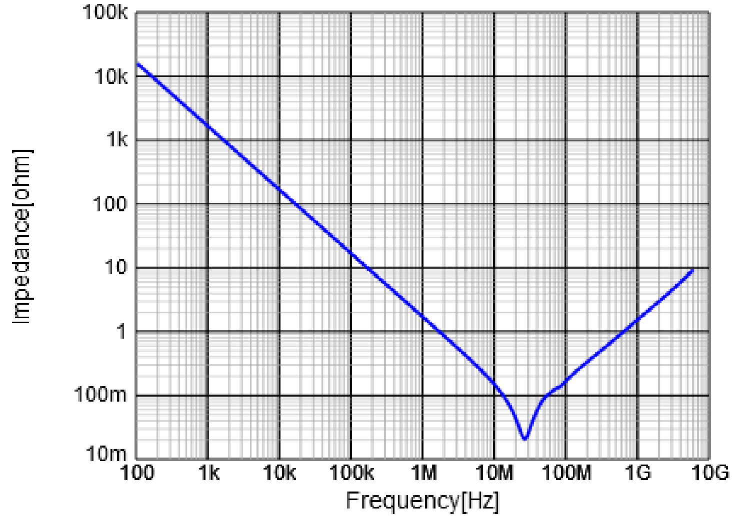
Package Type

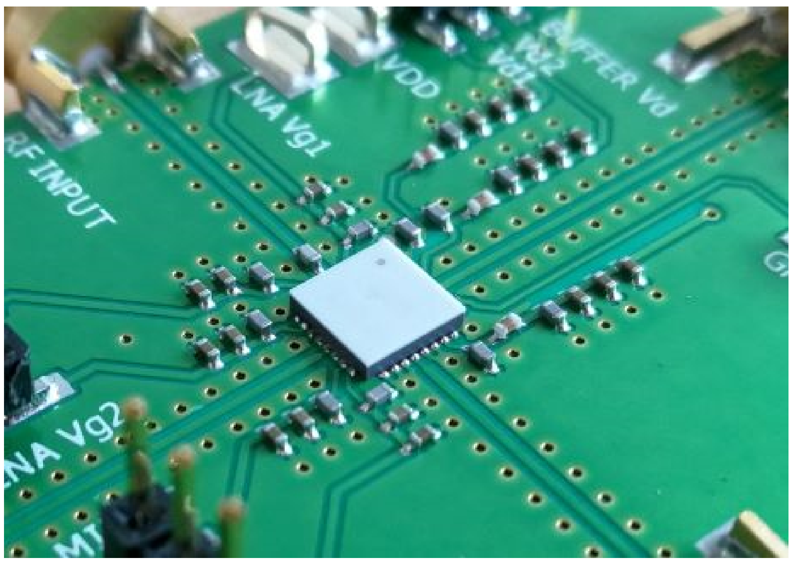
Capacitors come in many shapes and sizes. These include surface mount chip capacitors (SMD), through hole leaded (radial, axial and ceramic disc), film and electrolytic. The most common type used in high frequency RF bypassing is the SMD. SMD capacitors excel in high frequency applications due to their low ESR and low parasitic inductance. Additionally, they are available in a wide variety of capacitance values and compact sizes. Marki Microwave provides an extensive line of SMD amplifiers. Please visit our catalog at the following link for more details: Marki SMD Amplifier Product Catalog



Capacitor Value

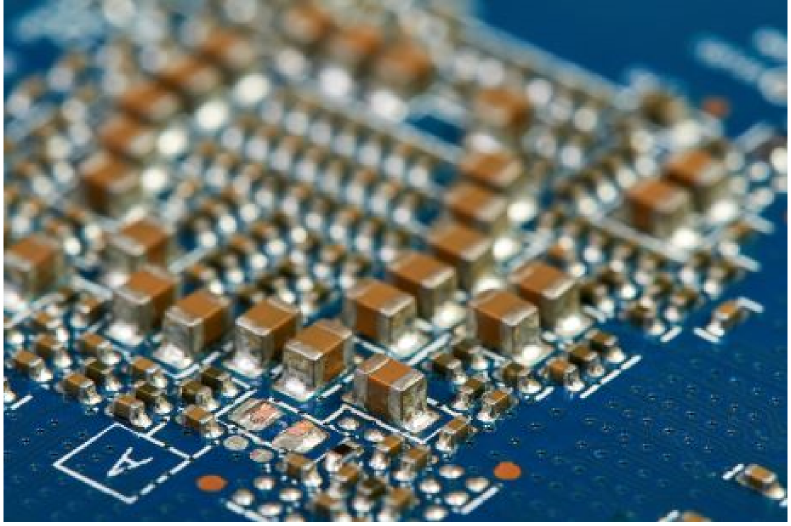
The value of capacitance you choose is directly related to the RF or Noise frequency you're interested in suppressing. The goal is to provide a low impedance path to ground for the un-desired frequencies. This is a straightforward process when dealing with a narrow-band noise or oscillation issue. Capacitor manufacturers will often publish impedance data for their capacitors online. Using this information, you can determine the capacitor that will provide the lowest impedance to ground in your application. Many manufacturers will also publish the self-resonant frequency (SRF) of their capacitors online. This will coincide with the lowest impedance point for that capacitor. If your manufacture doesn't provide the SRF, you can start with the familiar formula for capacitive reactance (Xc) to estimate a coarse value of capacitance that will provide an impedance of less than 100 mOhms. Then use the manufacturer's website to confirm low impedance at your frequency of interest. The above method works well for narrow band applications but can be more tricky for wideband applications. In these cases, you may need to use multiple capacitors on the line to provide a low impedance to ground for a wider range of frequencies. This is sometimes referred to as "stacking" capacitance and also results in lower total parasitic inductance when compared to using a single larger capacitor.





Capacitor Type

There are multiple different types of capacitors to choose from. RF bypass capacitors are usually in the surface mount device (SMD) form factor. SMD capacitors come in multiple material and construction types, each with its own unique characteristics and advantages. For bypassing applications where low impedance is a primary concern, its typical to see multilayer ceramic chip capacitors or MLCCs. This type of capacitor will generally have the highest value of capacitance offered in the smallest footprint with low equivalent series resistance (ESR) values. Some applications may benefit from tantalum capacitors due to their higher capacitance per volume, but this come with a tradeoff of higher ESR.

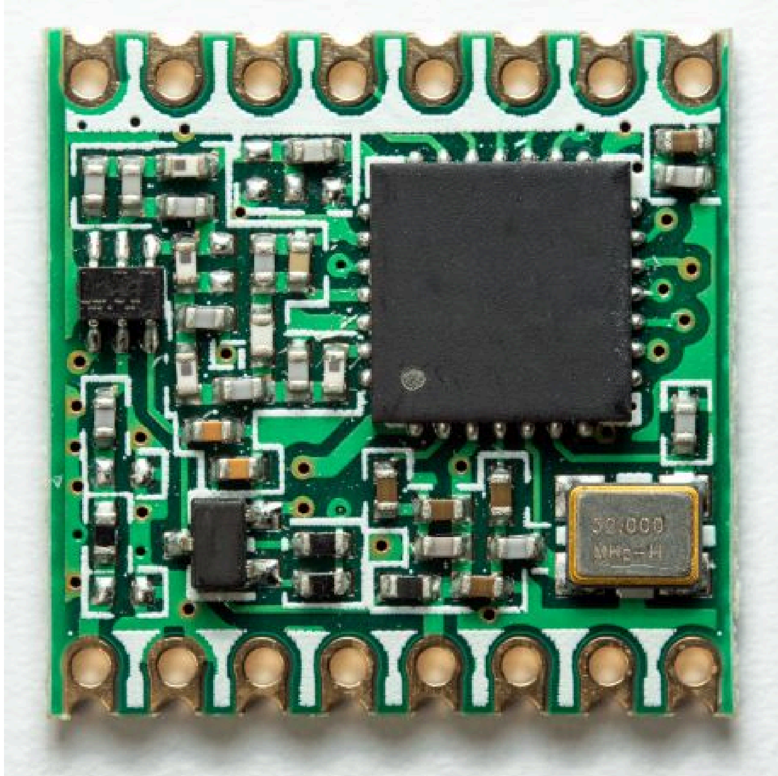


Capacitor Voltage and Temp Ratings

After choosing your capacitor form factor, value and type, it's important to consider the environment the capacitor will be operating in. Capacitors will have multiple different voltage ratings. These include DC, AC, Peak and Transient voltage ratings. Consult manufacturers documentation to understand the limitations of your particular capacitor. Capacitors will also have multiple temperature ratings including, operating, storage, temp coefficient and temp derating. Ensure your capacitor is designed to operate in the temperature environment of your application. Additionally, note the temperature coefficient and derating specs will effect both the effective value of capacitance vs temperature as well as its voltage handling capability.

Capacitor Placement

Its important to place bypass capacitors as close as possible to the RF device being protected. This minimizes the opportunity for noise and stray RF signals to couple onto the supply lines "inside" of the bypassing.



Conclusion

The design and operation of RF PAs in wireless communication systems is a necessary but complex task. Despite the inherent trade-offs in RF PA performance characteristics, RF PA designs are continuously pushed to their limits to meet user demands. However, these designs are vulnerable to external non-idealities, including noise, voltage transients, and RF feedback, which can degrade performance or lead to system failure. Bypass capacitors play a crucial role in mitigating these challenges by providing a low impedance path to ground, thereby reducing noise, stabilizing DC supply, and minimizing the risk of unwanted oscillations. Choosing the right bypass capacitor involves careful consideration of factors such as capacitance value, material type, voltage and temperature ratings, package type, and placement. A thorough understanding of these considerations is essential for optimizing RF PA performance and ensuring the seamless operation of wireless communication systems in our increasingly connected world.

Please see these other Marki Microwave Tech Notes related to RF amplifiers:

Microwave Amplifier Biasing Made Easy

An Introduction to Microwave Amplifiers Part 1

An Introduction to Microwave Amplifiers Part 2

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