Choosing blocking capacitors – it's more than just values

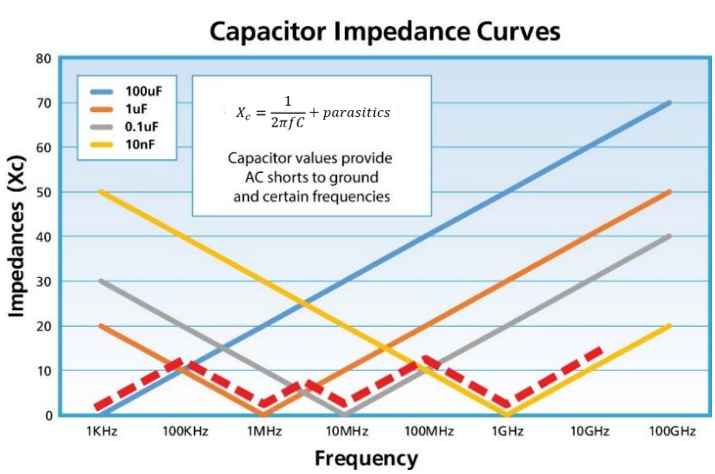
This article explores improving RF performance, but with less capacitors that, in their ideal form, block DC current and pass AC current. This makes capacitors a fundamental building block in Radio Frequency (RF) and microwave systems. They are often used to create filters, generate DC protection, and to create bypass networks. Often designers use rules of thumb or approximate equations to link capacitor values to final RF performance. As system requirements constantly require higher performance these assumptions are no longer valid. Here at Knowles Precision Devices DLI facility, we looked in detail at real world performance that can't be predicted by design theory, and then took measurements with common capacitor bypass networks to support our analysis.

In the case of bypass applications, capacitor values are carefully chosen to provide a low resistance ground path for unwanted noise signals generated by switching power supplies or high frequency noise coupled into the system. Using the ideal capacitor impedance:

Eq. 1 $X_c = \frac{1}{2\pi f C}$ (Where *f* is the operating frequency and *C* is the capacitance value in Farads)

an engineer or system designer can easily calculate the theoretical capacitor values needed to provide a low resistance path to ground at a given frequency.

Fig. 1 – Capacitor Impedance Curves



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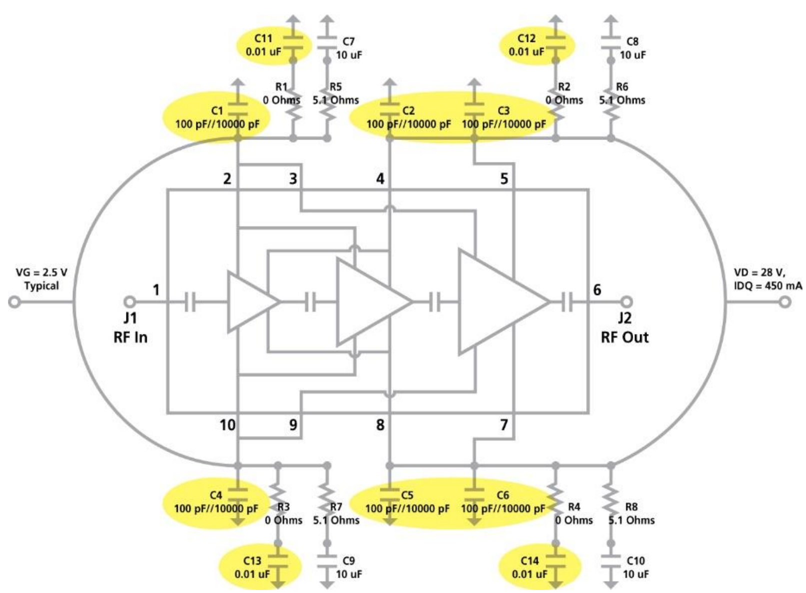
For designers looking to have broadband RF isolation, capacitors are the go-to components to complete the task. In practice, actual capacitors are modelled as a combination of capacitors, inductors, and resistors. At resonance the parasitic inductor and capacitor cancel out and an impedance low is realized. Above resonance the response of the inductor begins to dominate and cause the positive impedance slope as shown in Fig. 1. A common design rule is to consider 3 or 4 capacitors in shunt to ground, each with different values to provide broadband RF isolation. The end result becomes clear looking at the dashed red curve in Fig. 1. This shows four capacitors curves superimposed, providing a broader frequency range of low resistive paths to ground for unwanted noise signals.

Many designers go this route based on the recommendations made by the reference designs from the active device manufacture. Fig. 2 is borrowed from a major manufacturer of amplifiers and shows the approach they recommend. Bypass capacitors are identified with yellow bubbles.

In this case the manufacturer is recommending ten (10) capacitors per MMIC to provide adequate grounding for DC supply lines. When taking such an approach one needs to consider the RF performance of the system as a whole. Rather than looking at the capacitor in isolation and relying on the performance predicted in Fig. 1, we should ask if the RF performance of the capacitors in practice is optimal for a design.

Fig. 2 – Typical Bypass Capacitor Recommendations



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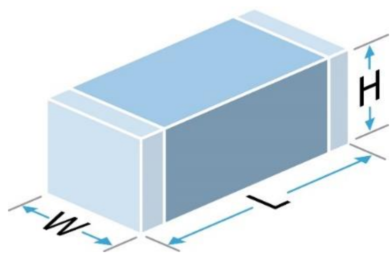
One aspect of capacitor RF performance is driven by parasitic inductance as discussed earlier in the article. The parasitic inductance causes the positive slope after resonance and drives real world capacitor performance away from what is predicted by the ideal values of eq. 1. A typical capacitor is shown below with dimensions of length (*L*), width (*W*), and height (*H*). The majority of unwanted inductance in the plots previously shown in Fig.1, arises from the contact pad geometries illustrated in Fig. 3.

Fig. 3 – General Capacitor



One can calculate approximate values if an assumed current (*I*) flows through the capacitor.

1. Under this assumption the flux is calculated with Ampere's law presented in eq. 2:
   $\oint_C B \cdot dl = \mu_0 I$
2. Where the magnetic flux density (*B*) around a closed path is equal to the current (*I*) times the free space permeability constant (μ_0). Once flux density is calculated the total flux through a surface (ie contact pad) is determined with eq. 3:
   $\Phi = \int_S B \cdot ds$
3. And inductance is then related to flux through eq. 4:
   $L = \Phi I$
4. Through the magic of math and some algebraic elbow grease one can arrive at an equation that shows inductance is inversely proportional to contact pad geometries.
   $L \propto \frac{\mu_0}{WH}$

In other words, if we can increase the contact pad size we can reduce the parasitic inductance. Using new manufacturing processes, DLI has managed to provide a larger pad area in equivalent capacitors footprints, without compromising on the voltage rating.

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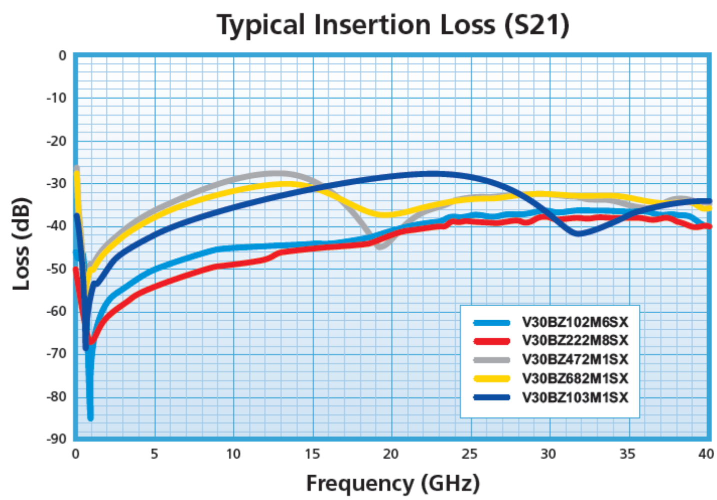
Equations and datasheet recommendations only get an engineer so far. At some point the "rubber must meet the road" as the saying goes. This is where DLI's state of the art RF and microwave test lab verifies RF performance through a series of RF measurements of the V-Series Capacitors and guarantees performance. Bench measurements show that by optimizing a blocking capacitor for RF performance, superior rejection can be achieved. Furthermore, that RF performance can be optimized for different system needs. Fig. 4 shows the S Parameter response of DLI's V-Series parts in shunt to ground from 100MHz to 40GHz. Operating in shunt mode the capacitors provide a broadband low impedance path to ground, acting as a filter for any unwanted noise providing typical suppression values of -35dB or 98.22% efficiency

Fig. 4 - Broadband RF Response of V Series Capacitors in shunt to ground



From Fig. 4 it also is interesting to note that RF performance of one V-Series capacitor provides broadband performance typically achieved by multiple capacitor networks.

Using Measured Bypass Network results, DLI took the investigation one step further to consider what the performance of these devices could achieve in minimizing recurring harmonics from a hypothetical tone. To block frequencies below 100 MHz, they compared a traditional capacitor bypass network pulled from an industry datasheet (consisting of 3 capacitors ranging from pF to nFs), V-Series Capacitors, and a DLI UX series capacitor in combination with the V series part. They then ran a few different tones through the devices to simulate noise sources and compared the results. The results from these discrete tone tests are in Fig. 5. Once again, it is interesting to note that RF performance was not necessarily correlated to the choice of capacitor's capacitance value, and verifying RF performance is the only way to guarantee performance.

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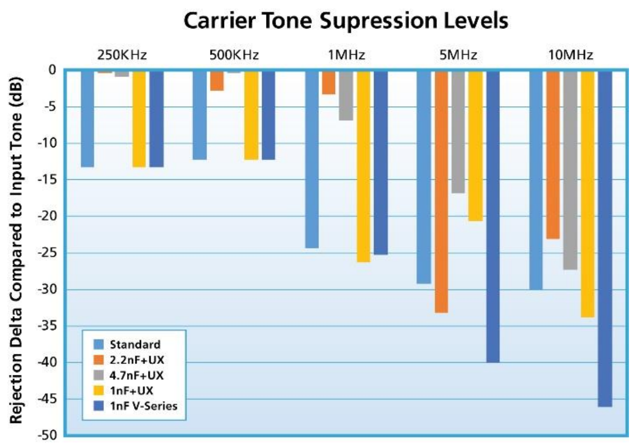
The other finding from this work is related to the space efficiency of this RF performance minded approach. In the sub 100MHz range one V-Series capacitors provided measured performance equal to or exceeded that of the standard multi-capacitor approach. This is an 82% reduction in footprint area without a compromise on performance. For designers whose costs rise substantially with increased footprints and component count, a solution with the V series capacitors can minimize components counts on bill of materials (BOM).

Fig. 5 - Tone rejection performance test results



In conclusion, when choosing the proper capacitor values one can use the ideal Eq. 1 for reference, but figs 4 and 5 show that calculated performance doesn't always equate to measured performance in the system. These initial findings show great promise in performance for a range of applications from RF blocking for GaN and GaAs amplifiers, blocking RF noise in switching circuits and A/D and D/A applications where isolation becomes critical, or providing higher isolation on DC busses. The V-series is a clear solution for all these applications by reducing part count on BOM, providing a small form factor, providing superior voltage handling, and excellent RF performance.

Ends

Note: Dielectric Laboratories (DLI), Novacap, Syfer Technology and Voltronics came together to form a single organisation, Knowles Precision Devices – they have now been joined by Johanson Manufacturing and Compex. This entity has a combined history exceeding 200 years and is a division of Knowles Corporation of USA, an independent publicly traded company.

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