High Power Switched Filter Banks Raise the Temperature on Design Challenges
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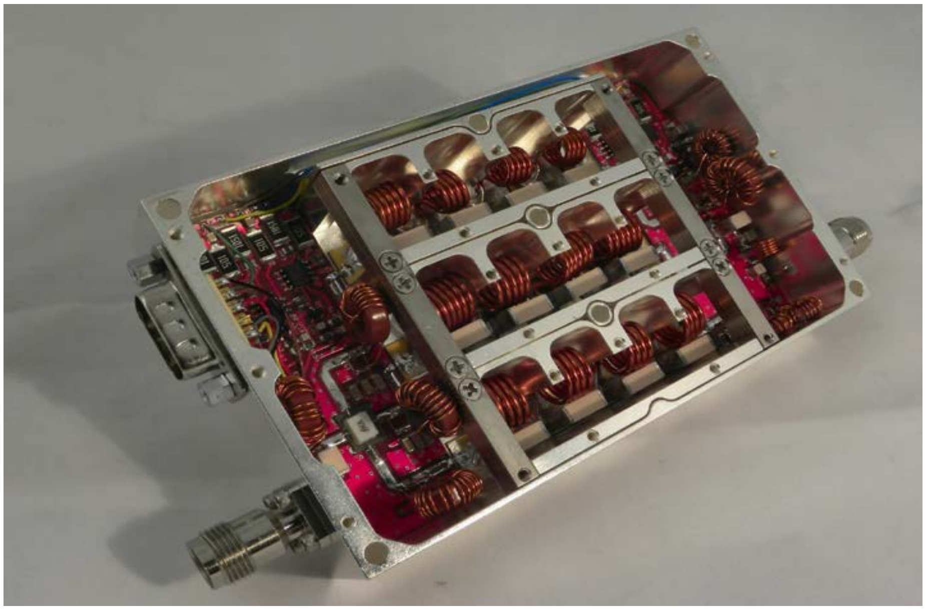
An application that has driven the early development of high power SFBs is communications band signal jamming in the VHF and UHF frequencies. These devices have predominantly been used to prevent communications band signals to remotely triggered explosives and to deny cellular service near secure governmental and military facilities. Nonetheless, technology that has initially been leveraged to mitigate communications may be a solution that enhances communications in modern and future trending applications.

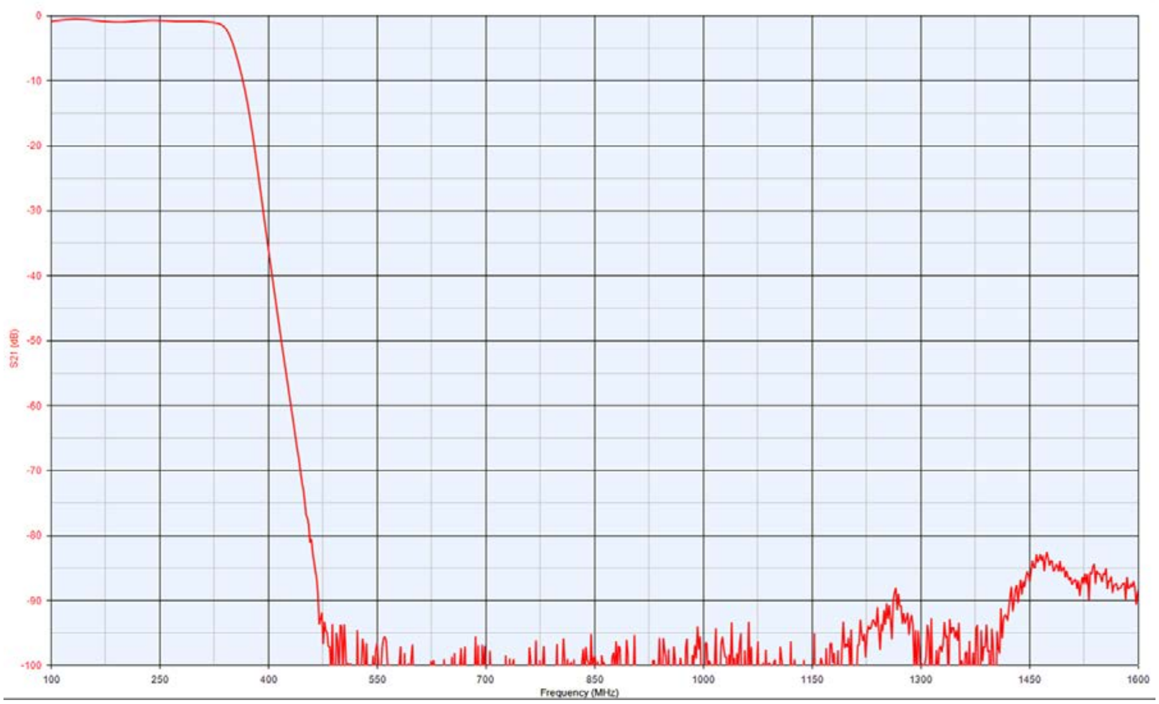


Assembly chassis for high power SFBs must be designed to incorporate design elements to optimize electrical, RF, and thermal performance.

The Difference Between High Power and Low Power SFBs

High power SFBs are generally judged by the same performance parameters as lower power SFBs. These parameters include size, weight and cost. Electrical considerations, such as passband, roll off, insertion loss, and out of band rejection are also as significant in high power SFBs. Achieving a lower insertion loss and higher out of band rejection may require more design effort for high power SFBs, as heat dissipation from a high insertion loss and attenuating high power harmonics are often key considerations.

The main differentiations between the low power and high power SFB requirements include high power SFBs' heat-dissipation characteristics and the high voltage handling needs. These two factors of high power operation induce greater voltage and thermal stresses on the switch elements and components directly in the signal chain. Additionally, higher voltages and power increase the impact of nonlinearities in system components. These factors demand a detailed analysis of each component's performance over a wide range of operational parameters.



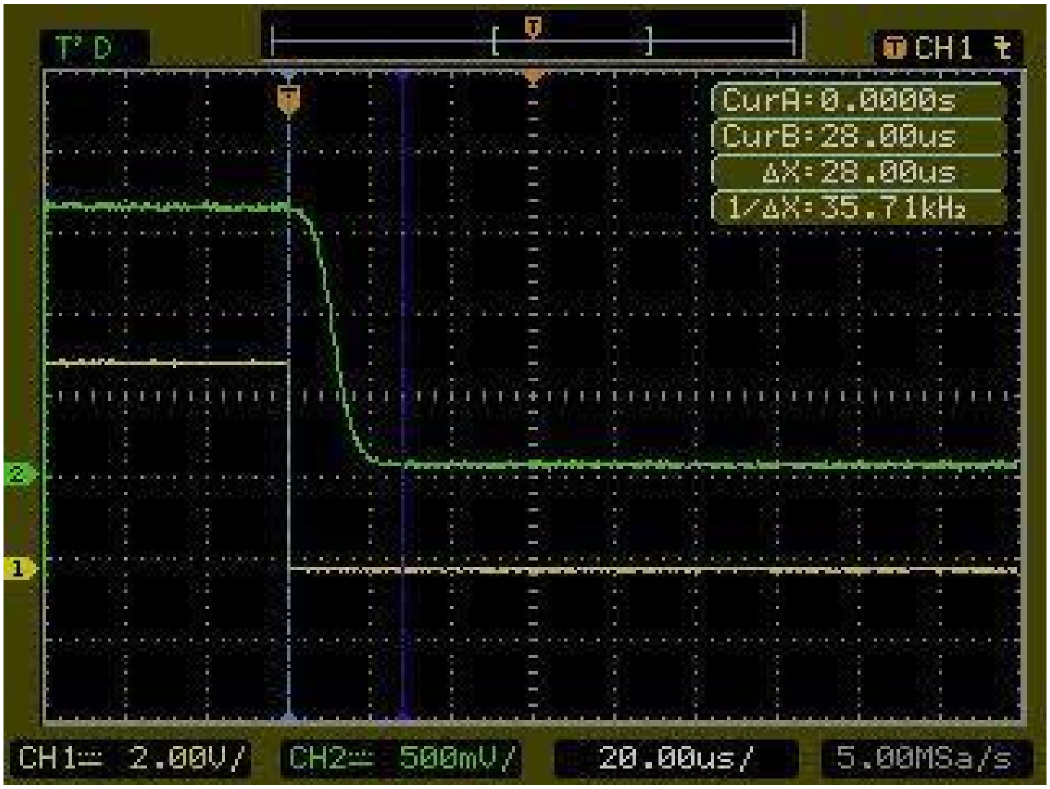
Both a flat passband with low insertion loss and steep drop off on high power SFB filters is critical to enable the 100s of watts of RF power that are passed and filtered by these devices.

High Power SFB Design Challenges

Often, the SFB is considered a less critical component compared with high power amplifier system. However, an assembly that wasn't designed upfront with the considerations of the SFB may lead to an underutilization of the amplifier module's capability or significant amounts of costly redesign.

The physical demands by the latest applications also encourage much lower size, weight, and reduced cost structure, without sacrificing functionality. This is hard to achieve without optimizing the physical and electrical design of the SFB section in an integrated assembly. The power and thermal factors also form a trade-off with frequency and bandwidth, as high frequency RF signals tend to generate greater thermal dissipation in signal chain components in much smaller dimensions.

Additionally, high power, voltage, current, and thermal stresses can exceed the maximum operating specifications for many components not designed specifically for high power operation. A complete understanding of the signal characteristics presented to the assembly establishes design requirements so that each component can be optimized to withstand the various stresses associated with the applied power. For example, various continuous and pulsed power conditions can dramatically influence the thermal consideration and transient voltage/current handling parameters of many signal chain components.

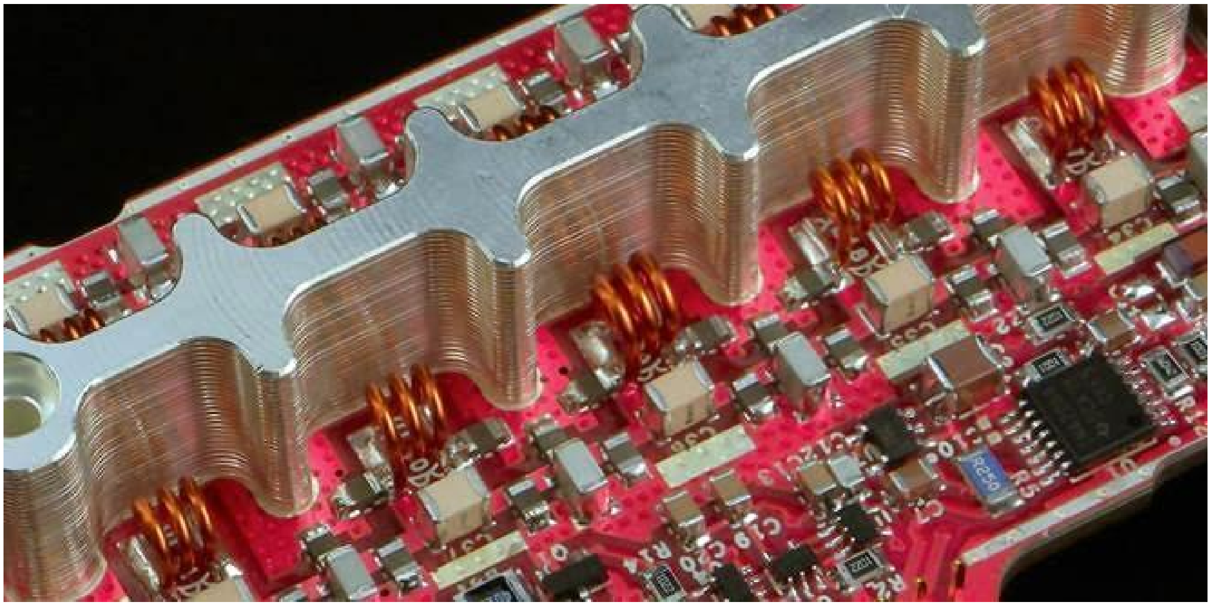


Hot switching in high power SFBs poses many challenges, as the impedance shift from on-state to off-state in PIN diode switches could induce undesired reflections and loading of the switch circuitry.

Another electrical consideration is the increased harmonics from nonlinear components whose harmonic products scale with input power. The active switching elements, such as PIN diode and FET switches, fall under this category, as well as any nonlinear driver and bias circuitry. Higher RF power also leads to increased reverse bias voltages that can affect diodes, drivers, resistors, and interconnect components. This in turn, increases the thermal stresses experienced by those components. The switching speed is also limited by the power and thermal stresses experienced during switching.

Component & Device Limitations and Considerations

Every component and device in the signal chain of a high power SFB also brings limiting factors, parasitics, and design challenges. For example, switches and inductors are critical to design performance. For inductors, the ability to carry high RF power requires an increase in wire thickness to minimize thermal concerns from resistive losses. An increase in wire diameter also increases the parasitic capacitances—interwinding capacitance and shunt capacitance to nearby grounds—and overall inductor size and inductance, which ultimately limits the diversity of filter topologies and quality factor of the filter stage.

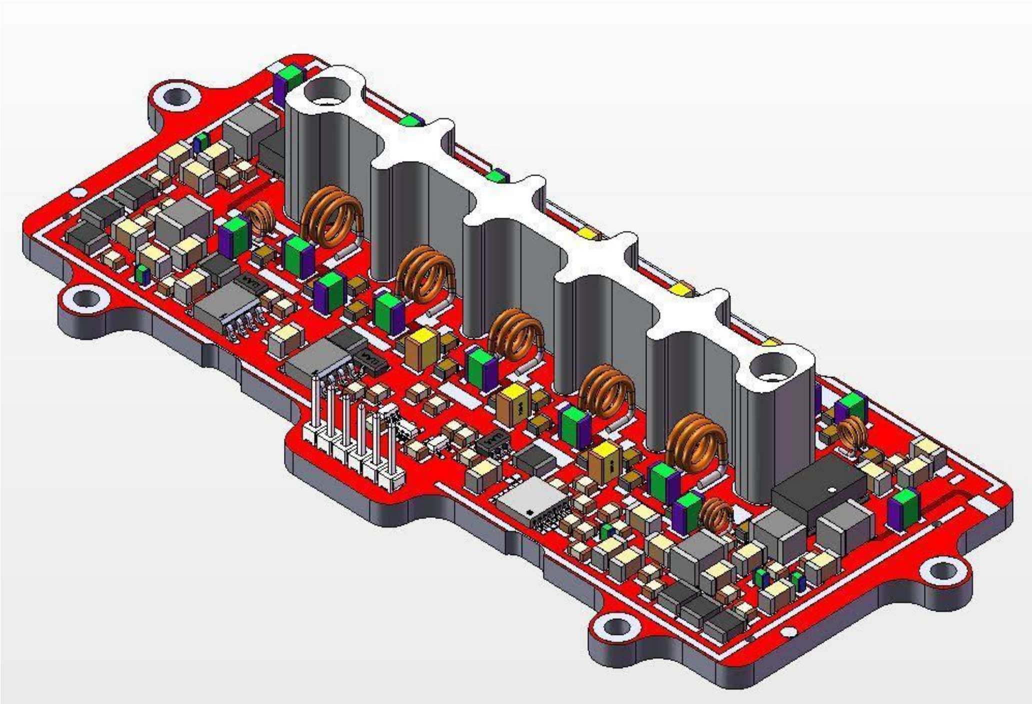

The latest 3D CAD tools enable more optimal component placement and more compact designs in a rapid design cycle.

The switches in a high power SFB are burdened with the task of both allowing and blocking hundreds of watts of RF power without exceeding power, voltage, current, and thermal operating parameters. For these reasons, it is generally infeasible to achieve the necessary device performance while enabling hot-switching capability. Hot switching would induce potentially significant transients that could easily exceed the switch device ratings, or even the PA and downstream components.

Specifically for PIN diode switches in a high power SFB, hot switching poses a hazard to itself and other components and devices. During a PIN diode on-state, the insertion loss through the switch is very low, and in the off-state, the PIN diode has a very high resistance and low leakage current. However, while a PIN diode is switching, the impedance during the transitional state can cause the switch to dissipate the bulk of the applied power resulting in failure of the diode. Thermal energy induced during hot-switching could also exceed the switch materials operating parameters and lead to accelerated aging or device failure.

The Big Thermal Challenge

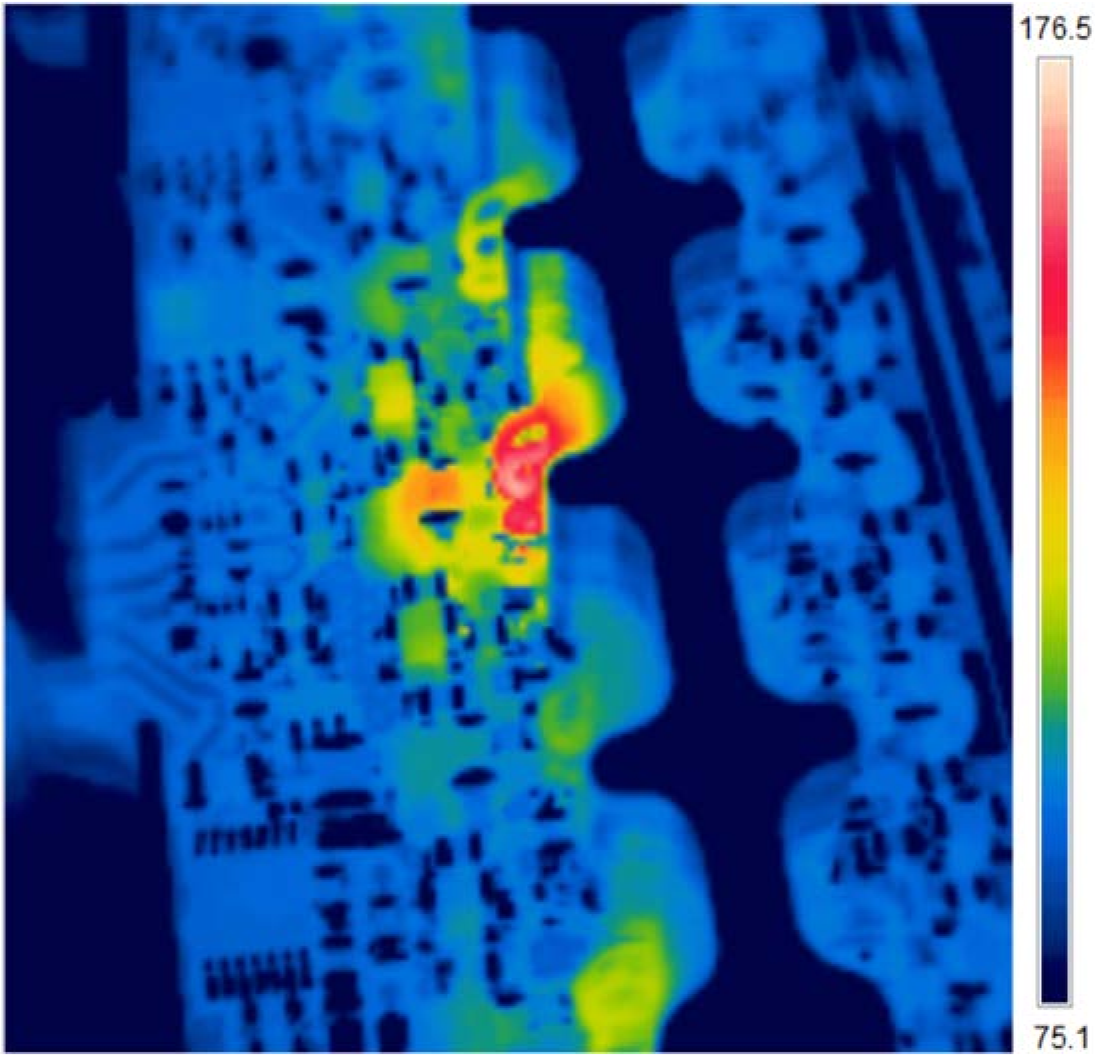
Though understanding the magnitude of RF energy converted to thermal energy in a high power signal chain is relatively straightforward physics, managing the thermal energy in such a way that prevents device/component failure and undesired operation is a far greater challenge. As sustained high temperatures can influence performance, accelerate aging, and even destroy components/devices, appropriately designing and testing a high power SFB assembly can ensure longevity and proper operation even under environmental extremes. In many cases, an assembly is tested under extreme temperature conditions to determine whole assembly survivability.



Thermal cameras aid in analyzing points of high thermal could lead to unpredicted failures and performance degradation if left unaddressed.

However, extreme temperatures may not occur or affect each component in an assembly in the same way. These factors may require rigorous and individual device and component testing while thermal cycling to discover failure modes and limitations. Understandably, this level of consideration applies to applications where failure of the assembly in the field is worth the added upfront expense of such rigorous performance analysis.

Other methods of optimizing a design with thermal considerations include using 3D CAD models in both EM simulators and thermal simulators to predict areas of thermal concern early in the design phase. With some details known of the high thermal stress areas in the design, changes to the thermal management system of the assembly can be made in early stages of the design cycle—where costs for modifications tend to be less expensive. Computer modeling and simulations have advanced significantly in the past few years. Nevertheless, these design tools cannot replace an engineer's design experience and understanding of the complex interactions between system components. Additionally, a trained eye is extremely valuable in interpreting the modeling and simulation data and converting that information into design solutions.



The placement and design parameters of each component in a high power SFB are critical for proper device behavior, and therefore, must be carefully considered in each state of the assembly design and integration.

The complex design challenges associated with providing reliable and high performance filtering for the latest high power applications has brought about many creative and unconventional solutions when compared to a traditional SFB. Producing drop-in SFB modules that leverage standard high volume assembly methods is one approach to reducing the size, cost, and manufacturing time of previous sophisticated custom made hardware. Future communications technology trends and increased commercial, industrial, and military demand for high power SFB technology will continue to require design and system engineers to push the boundaries of filter assembly design.