TECHNICAL PAPER

Passive Components for GaN Based Devices

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Abstract

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GaN based power and RF (Radio Frequency) devices are now available from multiple manufacturers at affordable prices due to those intensive efforts.

Multiple sources have documented GaN based semiconductor performance advantages of faster speed, lower loss, and higher frequency-voltage-temperature operation. Those advantages are, in turn, enabling end systems that have enhanced performance on lower power consumption levels in smaller and lighter packages, which are more reliable.

GaN devices have needs for high performance passive components and create a need for whole new families of passive devices.

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PASSIVE COMPONENTS FOR GaN BASED DEVICES

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INTRODUCTION

Abstract

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Multiple sources have documented GaN based semiconductor performance advantages of faster speed, lower loss, and higher frequency-voltage-temperature operation. Those advantages are, in turn, enabling end systems that have enhanced performance on lower power consumption levels in smaller and lighter packages, which are more reliable.

Less documented are the passive component options for designers to choose from when designing GaN based systems. The correct passive component selection is more critical than ever, given the possibility that the passive components surrounding GaN devices can potentially contribute more to total system power loss than the active components. In situations where passives contribute less to system loss, they still can potentially limit the ability of GaN to operate at the high end of its operational window.

This paper outlines passive components that pair well with GaN RF and power semiconductors.

Introduction

Regardless if the GaN semiconductor is RF or power in end use design, GaN devices show significant advantages over similar silicon devices in terms of efficiency, speed, operating frequency, power levels and temperature. Equivalent sized GaN to Silicon die comparisons show massive current, voltage, power, and switching speed advantages, consistently favoring GaN.

Alternatively, a GaN based semiconductor could be dramatically smaller than its Si counterpart if equivalent performance is the goal.

Regardless of the route taken – GaN has the potential to change both RF and power electronics design tremendously because of significantly reduced conduction losses (lower RDS-ON) and faster switching capacity due to reduced material capacitance and enhanced electron mobility. This upheaval will create a whole new set of design issues from scenarios never encountered until now.

PASSIVE COMPONENTS FOR GaN BASED DEVICES

INTRODUCTION

Two examples follow:
The first example is that of RF in nature and highlights the impact of GaNs power capability. Sturdivant[1] reports that heat flux on high power GaN MMICs (Monolithic Microwave Integrated Circuit) supporting multi-phased antenna arrays can approach 2.5kW/cm². To put this in perspective, this heat density level exceeds the power level of a home clothing iron. The natural concern is to interpret this condition as a need for high-temperature passive components – which is correct. However, beyond that, passives will need to handle faster voltage transitions, exhibit lower internal losses, and introduce minimal parasitic loading into the circuit.

The second example is that of the lower level power chargers – the type each of us uses in our daily lives. In this example, GaNs impact is one of dramatic end unit size reductions. Assuming approximately the same package size, GaN based power converters can utilize increased switching frequency that results in smaller capacitor and inductor values used in designs. As a result, a typical low power switching supply can reduce its size by more than half, increasing the power density from 5.3 W/in³ to 11.4 W/in³ and dropping weight from 820g to 560g (~ 32% reduction)[2]. These designs will require low inductance power MLCCs (Multi-Layer Ceramic Capacitor).

These examples show the multiple scenarios GaN designs will push passive components in many directions.

RF GaN PASSIVE COMPONENT NEEDS

The discussion for passive components supporting RF GaN is broken into four areas to illustrate the differing requirements GaN places on passives.

Those four areas are: Miniaturization/High Frequency, Filtering, V_{DD} Supply, Thermal Control

Miniaturization/High Frequency

Single layer capacitors (SLC) can be used inside GaN packages as a pre-match network between the lead frame and gate of the GaN device. This configuration creates a broadband impedance match on the input of the GaN device. SLCs are also used externally to the package as impedance matching for packaged GaN devices, as front-end DC blocking and broadband bypass. As the name implies, single layer capacitors are comprised of a single ceramic dielectric layer and have terminations that are epoxy attachment capable, and wire bondable. Standard terminations are Ti/W-Au and Ti/W-Ni-Au. All terminations are sputtered and provide excellent surfaces for wire bonding and exceptional adhesion characteristics.

Termination integrity is essential because temperature cycling may be severe in and around high-power RF GaN devices.

SLC terminations can be 'bordered' or non-bordered.

Bordered terminations refer to termination metallization not extending to the edge of the capacitor. Bordered devices have proven effective in reducing susceptibility to conductive epoxy electrode bridging due to excess conductive epoxy laydown. Though border capacitors can be used in source bypass, standard SLCs are preferred since this will reduce the bond length to the active device by reducing the distance of the top termination bond length to the active device target.

RF GaN PASSIVE COMPONENT NEEDS

SLCs can also take the form of single or multiple capacitors on a single 'substrate.' Regardless of the specific configuration – Single layer capacitors, Dual-Caps, or Multi-Cap Arrays – all devices can be used in impedance pre-matching, impedance matching, bypass & DC blocking through 40 GHz.

Since temperatures and temperature excursions can be extreme, dielectric stability is of great importance. AVX offers SiO2 dielectric and NP0 SLC capacitors with temperature stability of 30ppm/°C for matching applications where stability is critical.

AVX has pioneered a grain boundary barrier layer (GBBL) system developed as a replacement for conventional Z5U/Y5V dielectrics in applications where more bulk capacitance is a concern. The AVX GBBL material system has X7S temperature characteristics and offers measurable temperature stability versus less stable dielectrics like Z5U and Y5V. An example is shown in figure 1.

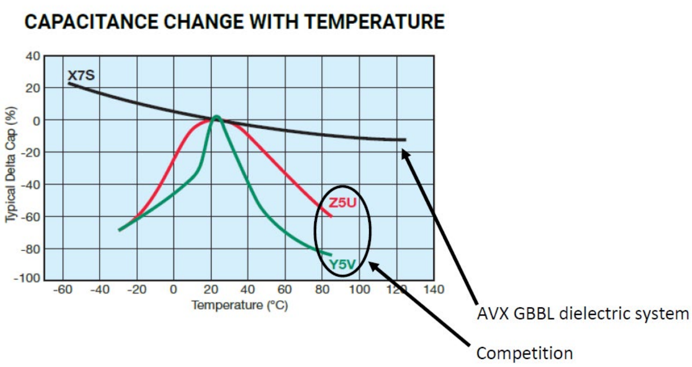


Figure 1: Comparison of AVX GBBL SLC Stability vs. Z5U/Y5V Competition

MIM (Metal-Insulator-Metal) capacitors are ideal for very high frequency early/relatively low power RF transmit & receive stages because of their low loss and small size, resulting from the parts transmission line wire bond pad structure with backside ground. MIMs are ideal in DC blocking applications and allow easy simulation of inductance effects of wire bond attachments. Typical capacitance values are 0.3 to 15pF at voltages < 100V and 20% tolerance. MIMs exhibit 60ppm/°C and can be custom designed based upon a capacitance/area of 50 to 100pF/mm2.

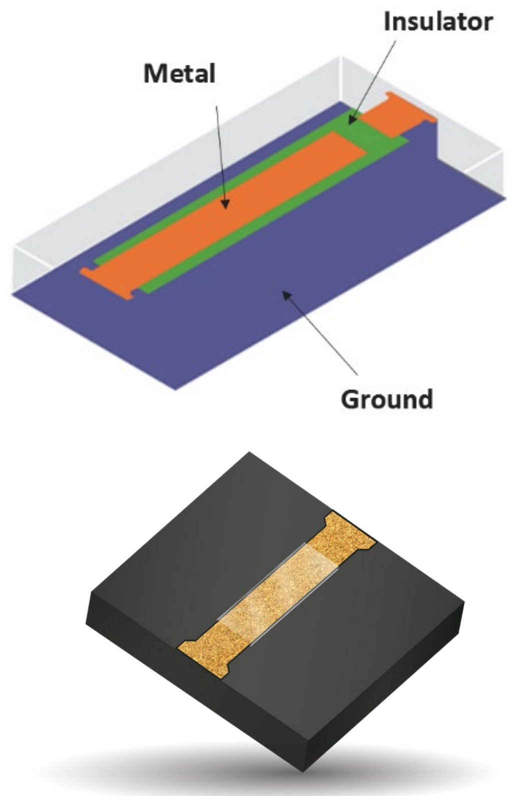


Figure 2: Depiction of MIM Capacitor

The transmission line MIM capacitors offer quartz, alumina, glass, and other substrates to minimize losses. Copper traces provide optimal conductivity. Front and backside gold metallization make this device suitable for epoxy, gold wire/ribbon bond attachments.

RF GaN PASSIVE COMPONENT NEEDS

VDD Supply Voltage Filtering

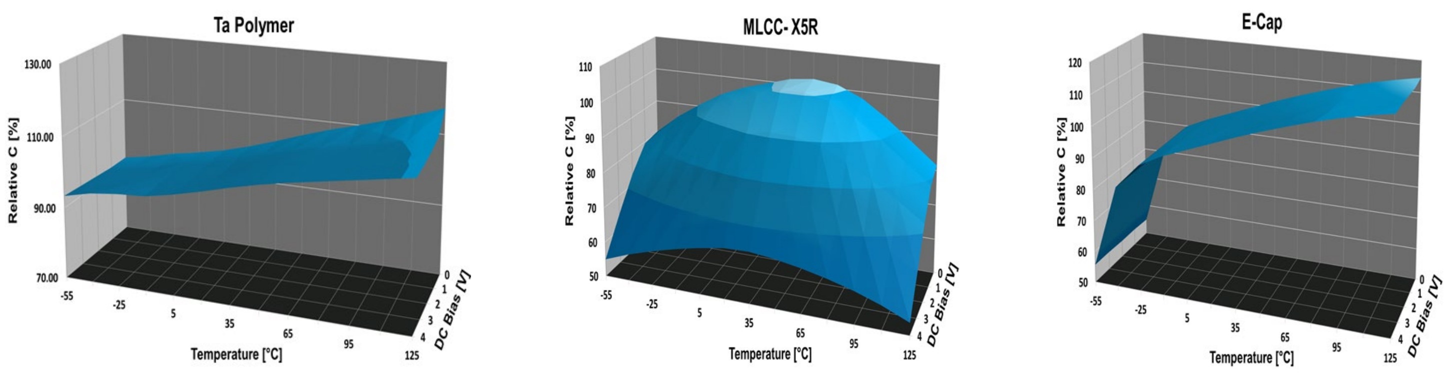
GaN exhibits substantial amounts of low-frequency gain. Proper VDD power quality is required to isolate the drain-source to prevent oscillations. Luckily, Tantalum and Tantalum polymer capacitors can provide large amounts of capacitance in a small case size at a high self-resonant frequency with zero DC bias effects, no piezoelectric noise, zero aging, and high reliability. In short – Tantalum and Tantalum polymer capacitors, in particular, are an ideal choice for these applications, whether consumer, industrial, military, or space.

Since the characteristics of Tantalum capacitors are well known, a discussion on Tantalum Polymer (TaPoly) capacitors follows.

Tantalum polymer advances have extended the voltage ratings of miniature SMT capacitors to 125V. There is a recommended 20% derating of Tantalum polymer voltage ratings, but even with this derating – Tantalum polymer capacitors offer a more competitive voltage rating than Aluminum electrolytic (Al-El) capacitors.

The capacitance range offered in Tantalum polymer capacitors varies by case size and voltage rating, but the overall range of capacitance offered to designers ranges from sub µF to 1500µF. Further, Tantalum polymer capacitors exhibit zero piezoelectric noise, zero DC bias effects, and virtually zero aging. A comparison graph of TaPoly DC bias voltage stability to high CV (Capacitance/ Unit Volume) MLCCs and Aluminum electrolytics is shown in figure 3.

As shown in figure 3, MLCCs suffer from devastating capacitance DC bias instability that varies between manufacturers and has other degradation effects such as aging, which can add further capacitance loss of 2% per decade. Aluminum electrolytics offer better capacitance stability than MLCCs, but that comes at a price of increased size, weight, and potentially much less reliability.



Tantalum Polymer *High CV MLCC* *Aluminum Electrolytic*

Figure 3: Capacitance Stability vs. DC Bias vs. Temperature

RF GaN PASSIVE COMPONENT NEEDS

Description	Capacitance (µF)	V. Rating (V)	Length (mm)	Width (mm)	Height (mm)	Vol. (mm^3)	Mass (g)	ESR (mΩ) @ 100kHz	Irms (A) @ 100kHz	Irms (A) @ 120Hz
SMD, TaPoly, Case Size E	10	63	7.3	4.3	4.3	134.9	0.472	100	1.69	0.324
SMD, Al-El, Radial Can	10	63	6.6	6.6	7.7	335.4	-	2000	0.06	0.04
SMD, TaPoly, Case Size E	22	50	7.3	4.3	4.3	134.9	0.472	150	1.3	-
SMD, Al-El, Radial Can	22	50	5.3	5.3	6.1	171.3	-	880	0.165	0.107
SMD, TaPoly, Case Size Y	47	35	7.3	4.3	2	62.8	0.215	100	1.36	0.599
SMD, Al-El, Radial Can	47	35	8.3	8.3	10.3	709.6	-	150	0.35	0.14
SMD, TaPoly, Case Size U	220	20	7.3	6.1	4.3	191.5	0.642	193.6 @ 120Hz	3.32 @ 40kHz	1.4
Thru-hole, Al-El, Radial	220	20	-	10 (dia.)	14.3	1123.1	-	1472 @ 120Hz	0.331 @ 40kHz	0.266
SMD, TaPoly, Case Size T	10	16	3.5	2.8	1.2	11.76	0.039	100	1.34	0.169
SMD, Al-El, Radial Can	10	16	4.3	5.5	6.1	144.27	-	1350	0.09	0.068

Figure 4: Electrical and physical characteristics comparison of five Al-El and TaPoly capacitors

Tantalum devices offer an average capacitance of 0.6uF/mm^3 (33.4µF/g). Miniature aluminum electrolytics have a capacitance to volume average of 0.1uF/mm^3. Tantalum Polymer capacitors excel in offering multiple case sizes, which allow designers to 'exactly fit' bulk capacitors into their design. The different capacitance case sizes and novel lead frame packages enable tantalum polymers to offer dramatically lower inductance than Aluminum Electrolytic devices. A table of TaPoly inductance by case size is shown in figure 5, along with the various lead frame options offered in Tantalum Polymer.

Case Size	Typical Self Inductance value (nH)	Case Size	Typical Self Inductance value (nH)	Case Size	Typical Self Inductance value (nH)
A	1.8	H	1.8	U	2.4
B	1.8	K	1.8	V	2.4
C	2.2	N	1.4	W	2.2
D	2.4	P	1.4	X	2.4
E	2.5	R	1.4	Y	2.4
F	2.2	S	1.8	5	2.4
G	1.8	T	1.8		

Standard Devices

Case Size	Typical Self Inductance value (nH)
D	1.0
E	2.5
U	2.4
V	2.4
Y	1.0

Multi-Anode Devices

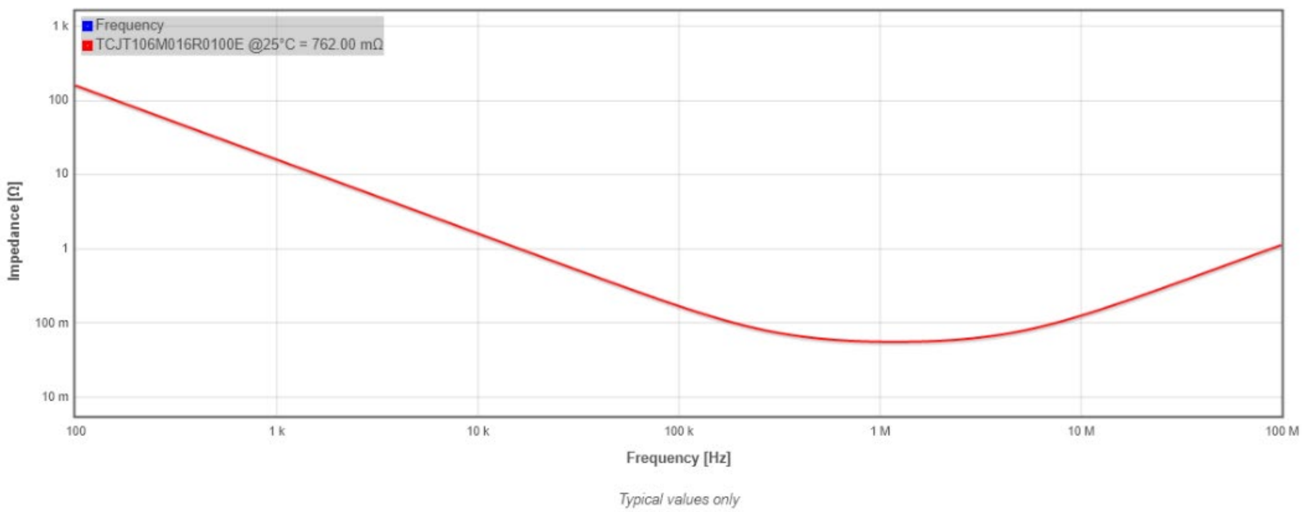
Case Size	Typical Self Inductance value (nH)
K	1.0
L	1.0
M	1.3
N	1.3
O	1.0
S	1.0
T	1.0
X	1.8
Z	1.8
3	2.0
4	2.2
6	2.5
8	2.2

Low Profile Devices

Figure 5: Tantalum inductance and package/termination options

RF GaN PASSIVE COMPONENT NEEDS

Tantalum polymer's capacitance density and low inductance result in attractive broadband low-frequency filtering and sizeable current ratings, as shown in figure 6.



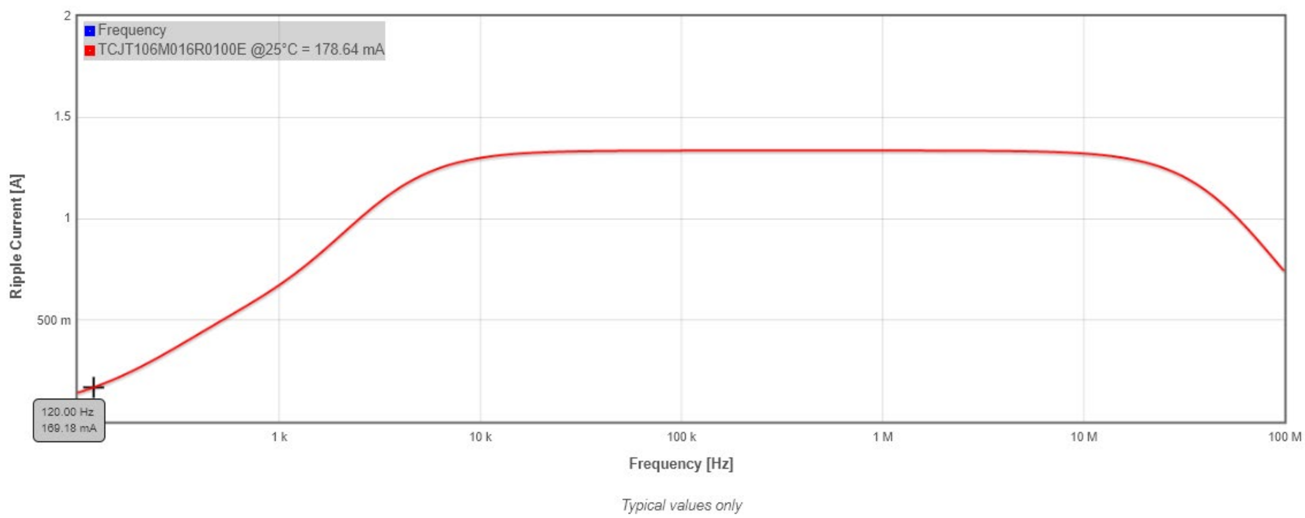


Figure 6: Impedance and ripple current vs. frequency of a 10µF, 16V TaPoly

In closing, it is important to note that high-temperature polymers exist and offer an operating temperature range of up to 230°C.

RF GaN PASSIVE COMPONENT NEEDS

Filtering

Although there are numerous filtering options, only a high-level overview of thick & thin film capacitors, thin film & laminate filters, and thin film & laminate inductors will be presented to account for the majority of passive component technologies used in typical solutions.

Thin Film vs. Thick Film Capacitors

Thin Film

Thin film capacitors are made by sputtering Aluminum on an Alumina substrate. The resulting capacitor has close to ideal capacitor characteristics of high Q, high Insulation Resistance, and ultra-low ESR. Thin film capacitors are available in 01005 to 1210 case sizes at voltage ratings up to 200 volts and tolerances as low as 0.01pF or 0.1%. They offer tight temperature stability (+/-30ppm/°C), zero aging, and exceptional tolerance capability.

Further, thin film capacitors can be made in any capacitance value and exhibit the tightest capacitance tolerance commercially on a lot-to-lot basis since they are manufactured in essentially a semiconductor lithographic based process. Values range from 0.1pF to 47pF. Thin film capacitors have a useful frequency range of up to 40 GHz. A comparison of thick film versus thin film capacitors was reported on by Smith[3] and shown in figure 7.

Capacitor	Thermal Exchange in Degrees Celsius per Watt	Power Rating @ 20°C Rise above an ambient of 25°C
Thin Film Alumina Substrate 1210	59° C/Watt	.34 Watts
Thin Film Alumina Substrate 0805	83.3° C/Watt	.24 Watts
Thin Film Alumina Substrate 0603	106° C/Watt	.186 Watts
Thin Film Alumina Substrate 0402	158° C/Watt	.127 Watts
Procelain 0505	126° C/Watt	.158 Watts
Procelain 1111	67.7° C/Watt	.295 Watts
Ceramic 1210	70.9° C/Watt	.282 Watts
Ceramic 0805	113° C/Watt	.177 Watts
Ceramic 0603	145° C/Watt	.139 Watts
Ceramic 0402	219° C/Watt	.091 Watts

Figure 7: Power comparison of thick film vs. thin film capacitors

Thin film processes also produce thin film inductors, which are available in 0201 to 0603 case sizes. Inductance values range from 0.33nH to 22nH and tolerances from 0.1nH to 5%.

Thick Film Capacitors

Thick film capacitors come in a variety of dielectrics ranging from NP0, porcelain to BX and X7R. Their internal electrode systems are based upon high conductivity metals such as copper, silver, nickel, and palladium. Case sizes range from 01005 up to 0.380in x 0.380in square, with the larger case sizes dominating high power –current-voltage applications – up to 7200V rated. The devices' useful frequency range depends on material systems, case size, and capacitance values but generally can be said to be > 40GHz. Distributed filters of all types can be easily built based upon the broad range of thick film RF capacitors.

Thin Film vs. MLO Filter

Multilayer Organic (MLO) Filters

MLO technology is essentially a 3D micro-stack of low loss dielectrics with laser direct imaged copper traces that form inductors and capacitors. These inductors and capacitors are typically very high Q and very tight tolerance. The inductors and capacitors can take the form of small case size, low profile height discrete SMT packages with castellated terminations (0402, 0603), or they can take the form of larger RF modules.

MLO inductors come in 0402 case size and offer high Q in small thin packages. Tolerance and lot-to-lot repeatability rival that of thin film inductors. MLO inductors are available in tolerances as low as 0.02nH to 2% and values up to 32nH.

Complex filters are formed by the individual capacitor & inductor layers being stacked vertically. Options for vertical stack connections are copper-based vias and blind vias. The resulting 3D stack can form potentially very complex RF filters in small thin packages – see figure 8.

RF GaN PASSIVE COMPONENT NEEDS

Multilayer Organic (MLO) Filters Continued
MLO components can be a viable alternative to LTCC (Low-Temperature Co-fired Ceramic) since they are inherently low loss (because of thick copper traces and low loss dielectrics), much smaller physical sizes, and similar coefficient of thermal expansion (CTE) to most substrates. MLO devices are capable of use in the total spectrum of GaN RF device frequencies. MLO structures can potentially have a high pinout count – whether for signals or heat conduction, and termination types are NiAu, ENIG (Electroless Nickel Immersion Gold), and ENEPIG (Electroless Nickel Electroless Palladium Immersion Gold).

MLO low pass filter frequencies range from 54MHz to 6.1GHz in 2616 to 5021 EIA packages with 4W RF power handling capability. Band pass filters can be constructed in the same sizes but within a tighter frequency range (0.8-4.7GHz) and considerably less power (1W) because these are incredibly complex devices with the highest density and integration of capacitive and inductive elements. Again, in the same package sizes, high pass filters can be designed from 0.7 to 6.5GHz, all at 2W handling capability afforded by the reduced complexity when compared to band pass filters.

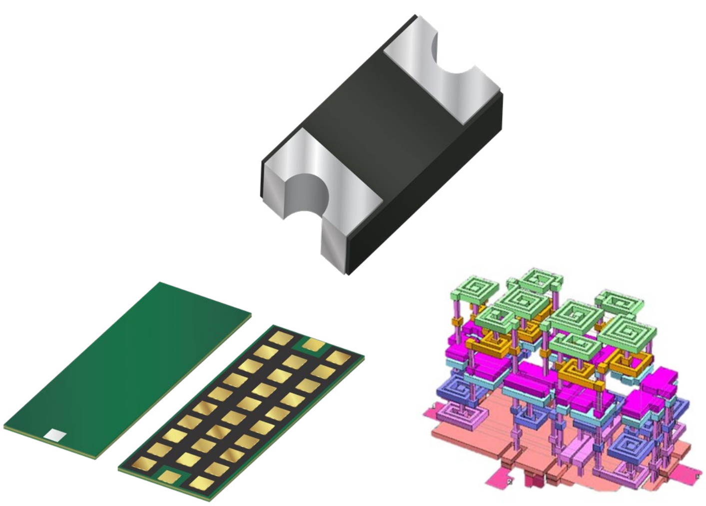


Figure 8: Discrete MLO device (top), complex filter (bottom left), and 3D model of capacitive/ inductive elements (bottom right)

Thin Film Filters
Thin-film multilayer technology creates low pass and band pass filters in small packages. One example of this technology is 5W band pass filters in packages as small as an 0805 case size with a frequency range of 1 GHz to 10 GHz. Larger case size 1206 filters have 8 watt power ratings and frequency ranges approaching 7 GHz.

Thin film low pass filters can range from 3 to 15 watt capability in 0402 to 2816 EIA case size packages. The frequency range offered is from 512MHz to 6GHz.

Thermal Control
As pointed out earlier, GaN has the potential to create massive heat flux through its high-power/ small-package signature. High power in small packages requires novel methods in heat control, which boil down to remove, spread, and couple excess heat from the active device/source. Traditional heat control methods are well known, but miniature heat pipes are an attractive, cost-effective method to provide heat flow out of any active device's pins.

Traditional heat pipes exhibit potential reliability issues such as heat pipe degradation from leaks between the inside/outside of the heat pipe and gas generation within the heat pipe envelope. (Gas generation results from chemical reactions caused by either an incompatible fluid/material system or contaminants from improper cleaning and processing).

Even tiny leaks in the envelope material, at a joint, or the fill tube's seal, may cause degradation over time. Small power heat pipes can still be potentially large, and that size will cause limitations on maximum shock, vibration, and acceleration. Plus, efficiency varies by the structure's position relative to gravity. Heat pipes provide tremendous performance but cannot be used on active pins of semiconductors.

RF GaN PASSIVE COMPONENT NEEDS

Thermal Control Continued

Unlike traditional heat pipes, Q Bridges are thermally conductive and exhibit a low parasitic capacitance load, high insulation resistance, and high breakdown voltage in a miniature SMT case size. Specific numbers vary by case size, but typical parasitic capacitance is 0.04pF to 0.13pF in standard EIA case sizes of 0402, 0603, 0805. Thermal conductivity ranges from 40 to >500mW/°C. Termination options are Sn/Ni/Pt; AgPt; Ag/non-magnetic layer. Q Bridges are easily customizable for specific heat flow optimizations around MMICs, and other high-power structures and proven custom designs of 0302 to 3737 have helped optimize high power circuitry. Applications range from GaN PA (Power Amplifier) to LNA (Low Noise Amplifier), optics, and hypersonic platform heat control. An example of heat reduction in an ultra-miniature MMIC can be found in figure 9. This experiment was based upon a high-performance ultra-miniature 100W MMIC ran at CW (Continuous Wave) for 20 seconds. Infrared (IR) measurements were taken with and without Q Bridge heat pipes. The figure on the top shows a typical heat of ~80°C was reduced to approximately 38°C in the 3 areas where the Q Bridges were placed on the bottom picture.

It should be noted that the MMIC and its associated layout was not optimally laid out for Q bridge heat pipes. Even more favorable heat reduction could occur when custom Q bridge devices are designed into early revisions of PA design.

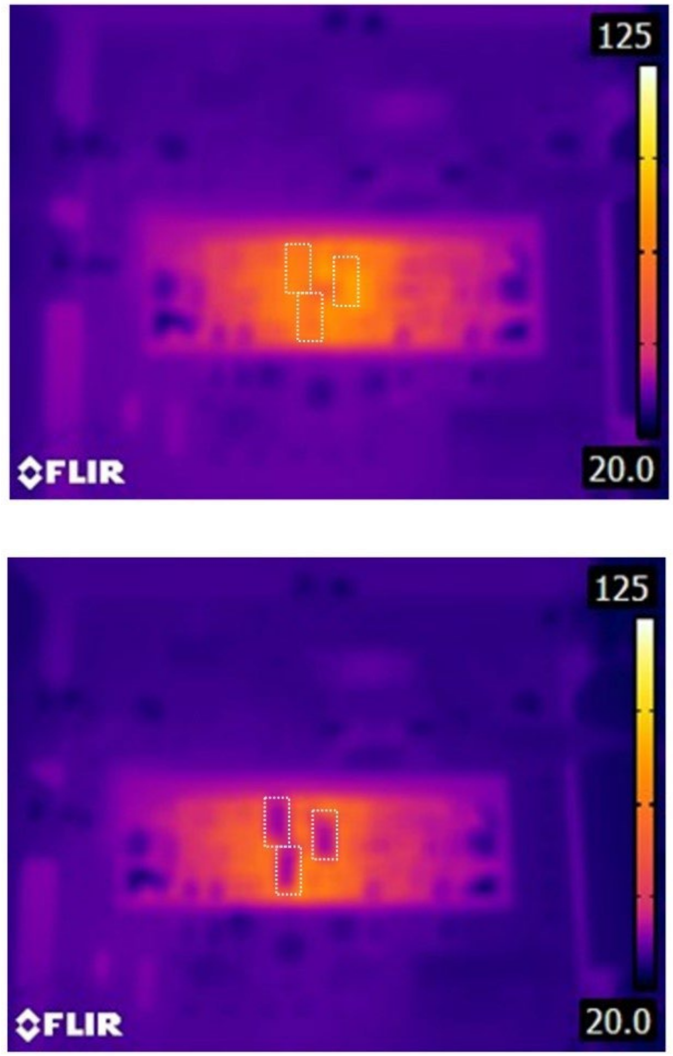
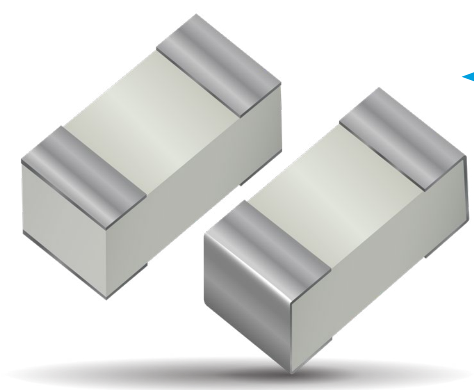


Figure 9: IR image of 100W MMIC without Q bridge (top), IR image of 100W MMIC with Q Bridge (bottom)



Depiction of Q Bridge SMT Thermal Conductor. Non-Edge Wrap Termination (Left), Edge Wrap Termination (Right)

PASSIVE COMPONENTS FOR GaN BASED DEVICES

POWER ELECTRONICS AND GaN PASSIVE COMPONENT NEEDS

GaNs impact on power electronics and the resulting demand for passive components is just as significant and challenging as the examples shown in RF designs. Power GaN semiconductors exhibit lower switching losses and switch at higher frequencies with better on/off performance. GaN will generate more heat and operate at higher temperatures reliably.

The resulting impact on passive components is a need for low Equivalent Series Resistance (ESR) and lower Equivalent Series Inductance (ESL) components. Further, these devices must operate at higher temperatures, voltages, and currents. Our discussions will concentrate on capacitors and their progress in higher voltage & temperature operation in smaller packages with lower parasitic loss.

We will provide discussions on capacitors used in low power, medium power and high power designs. Generally speaking, these power groupings correspond to:

100W with frequencies up to 1MHz –
typical of Auto in cabin wireless charging, Industrial, IT and high-end consumer applications

10kW with frequencies of 50 to 1MHz –
typical general purpose to high end switch mode power conversion

>10kW from low multi-kHz to 100kHz –
typical of IGBT power drives, solar inverters & fast chargers

From a small signal point of view – reduced inductance bulk capacitors are already being used in GaN power electronics. Reduced inductance capacitors range from previously discussed Tantalum Polymer capacitors (used to improve V_{DD} bias quality at low frequencies) to low inductance MLCCs and low inductance MLCC stacks.

Tantalum polymer capacitors hold great promise (as in GaN RF designs) based upon their stable capacitance over temperature, bias and age. TaPoly capacitors offer an ESR ~1/8th that of traditional tantalum capacitors at voltages up to 125 volts. Under-Tab termination styles, and 0402 case sizes have driven TaPoly inductances down to <1nH with a maximum capacitance of 100µF. If DC bias effects were considered, the TaPoly device performs equivalent to approximately to the level of a 275µF high CV MLCC counterpart. Further, TaPoly capacitors are available in larger case sizes and values up to 1500µF in 7.3mm x 6.1mm x < 2mm dimensions.

Operating voltages drop in large case sizes, and these low ESL (2.2nH) devices are capable of quickly delivering charge in hold-up and pulsed applications.

To summarize – Tantalum & Tantalum Polymer capacitors provide much higher reliability and, in many cases, much-improved ESL, C/V, and voltage ratings than other bulk capacitor types. For that reason, low power conversion circuitry is expanding their use in high-efficiency GaN based power conversion.

POWER ELECTRONICS AND GaN PASSIVE COMPONENT NEEDS

Low Inductance MLCCs

Low inductance MLCCs are created by reducing the current loop between terminations - see figure 10.

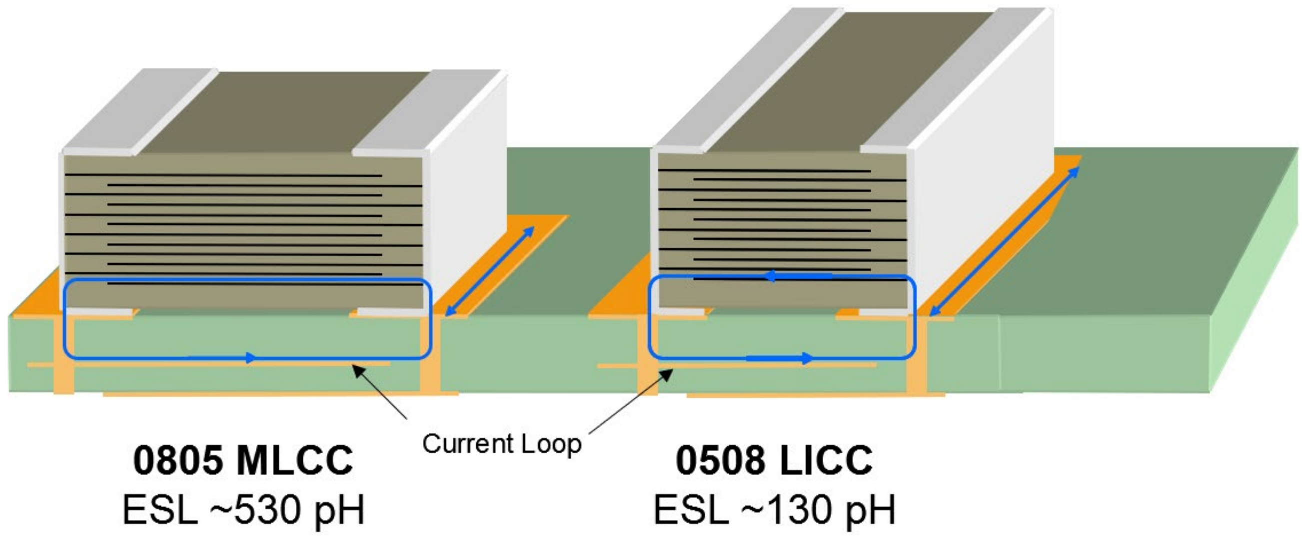


Figure 10. Cross-section view of electrode and termination geometries contributing to current loop.

As shown in the figure, a traditional 0805 case size MLCCs inductance is ~ 530 pH. If the current loop is reduced by rotating the terminations 90 degrees and reducing the current loop, the inductance drops to approximately 130pH.

Reduced ESL MLCCs are available in voltages up to 50 volts in 0508 and 0612 case sizes with parasitic loading as low as 130pH and 3 mΩ ESR.

As higher capacitance values are needed, reduced inductance stacks have been created.

Stacked MLCCs

Stacked MLCCs are an alternative to Aluminum electrolytic capacitors. Stacked MLCCs offer reduced ESR & ESL over Aluminum electrolytic capacitors plus enhanced reliability and operating temperatures up to 200°C. Reduced ESR & ESL means that stacked MLCCs can handle more current and act as a capacitor across a wider frequency range than other higher parasitic loss capacitors (Aluminum Electrolytic). Stacked capacitors also have physical advantages over Aluminum electrolytics - The DIP (Dual In-line Package) leads in either thru-hole or surface mount configurations offer superior stress relief to the ceramic elements. The leads effectively decouple the parts from the board and minimize thermally or mechanically induced stresses encountered during assembly, temperature cycling, or other environmental conditions.

POWER ELECTRONICS AND GaN PASSIVE COMPONENT NEEDS

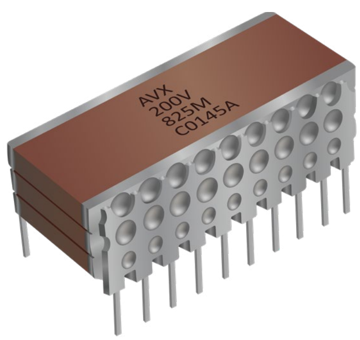
Stacked MLCCs Continued

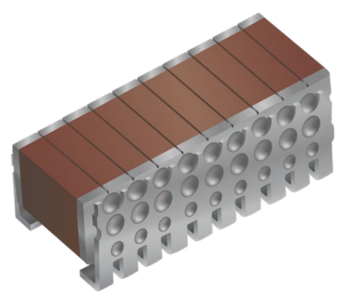
A comparison of the advantages of stacked MLCCs vs. Al-El is in figure 11 below:

Typical ESR Performance (mΩ)			
	Aluminum Electrolytic 100uF, 50V	Aluminum Electrolytic 100uF, 16V	Stacked MLCC 100uF, 50V
ESR @ 10kHz	300	29	3
ESR @ 50kHz	285	22	2
ESR @ 100kHz	280	20	2.5
ESR @ 500kHz	265	18	4
ESR @ 1MHz	265	17	7
ESR @ 5MHz	335	17	12.5
ESR @ 10MHz	560	22	20

Figure 11: ESR vs. Frequency of Stacked MLCCs and Al-Els in various CV values

MLCCs can be stacked either vertically or horizontally:





	Horizontal Stack		Vertical Stack	
	Minimum	Maximum	Minimum	Maximum
Dimensions (mm) (L x W x H)	6.35 x 6.35 x 7.62	31.8 x 52.1 x 34.3	5.08 x 10.8 x 5.21	6.35 x 27.3 x 7.24
Capacitance (µF)	0.01	390	8.2	220
Voltage (V)	50	500	25	100

Figure 12: Comparison of horizontal and vertical stack MLCCs

POWER ELECTRONICS AND GaN PASSIVE COMPONENT NEEDS

Stacked MLCCs Continued

Stacked capacitors offer very high capacitance in a small volume with low loss. Stacking can be done horizontally, i.e. the electrodes/chips are horizontal with the mounting surface – with capacitors placed on top of one another, see figure 12. This takes advantage of the vertical dimension and reduces the XY board area, and utilizes available height. Lead frames can be thru-hole, J or L lead termination styles. These devices have MIL-PRF-49470 qualification and come in multiple dielectrics, case sizes, and include values up to 390µF and ratings up to 500V.

Vertically stacked ceramic elements, i.e. electrodes/chips orthogonal to the board, offer a lower height but utilize more board surface area, see figure 12. Vertically stacked MLCCs come in 3 case sizes and have capacitance values up to 220µF and voltage ratings up to 100V.

Capacitor elements stacked both horizontally & vertically also has been created – mini TurboCaps. These devices offer a unique small area, small height package with capacitance values up to 82µF and voltages up to 100V, depicted in figure 13.

Figure 14 provides a comparison of impedance, ESR, and current performance across frequency for a horizontal, vertical, and mini TurboCap. Three 18µF, 50V rated devices were selected because this is one of the very few shared ratings across the three stacking technologies.

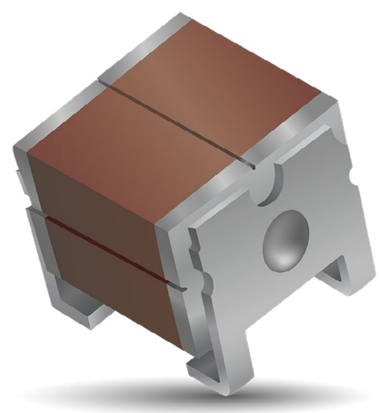
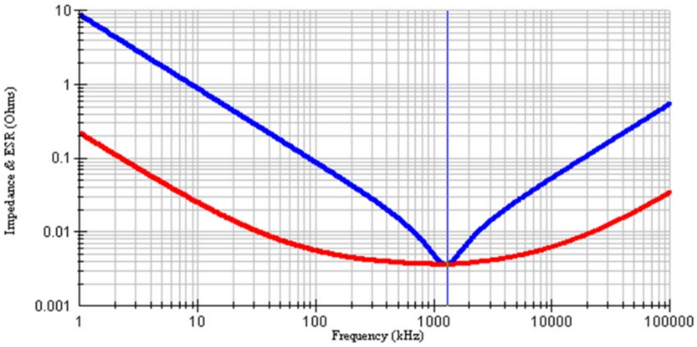
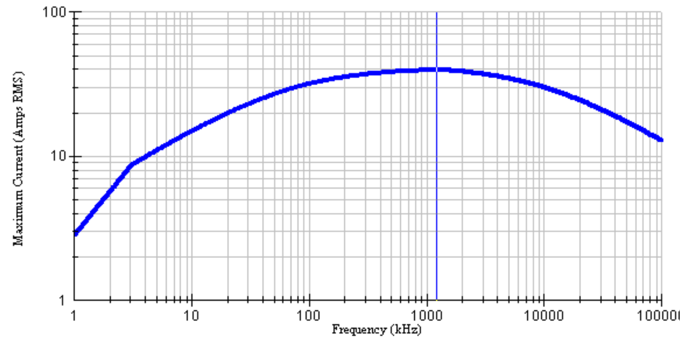


Figure 13: Image of miniature TurboCap with both horizontal and vertical stacked MLCCs

POWER ELECTRONICS AND GaN PASSIVE COMPONENT NEEDS

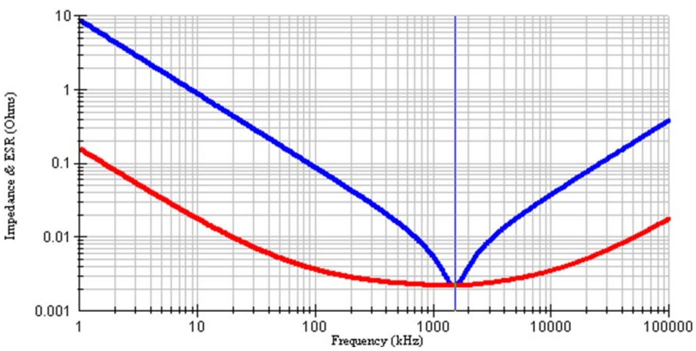


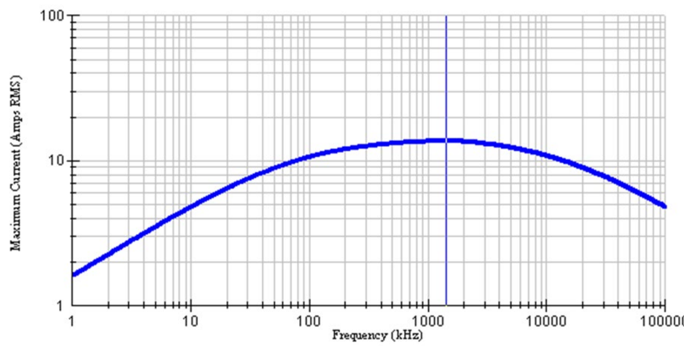


Z(blue)/ESR(red) vs. Frequency

Maximum Current vs. Frequency

Horizontal MLCC Stack, 18uF, 50V, ESL = 1.4nH, 913.1mm³

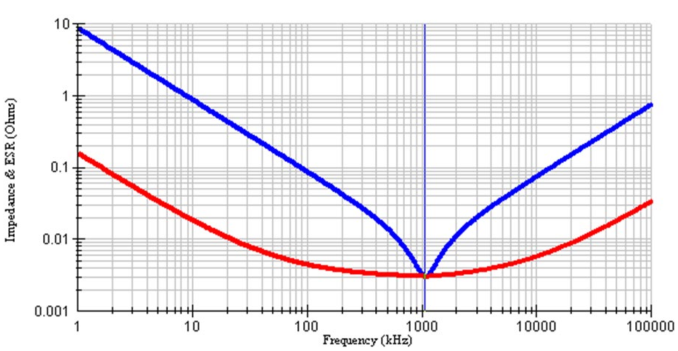


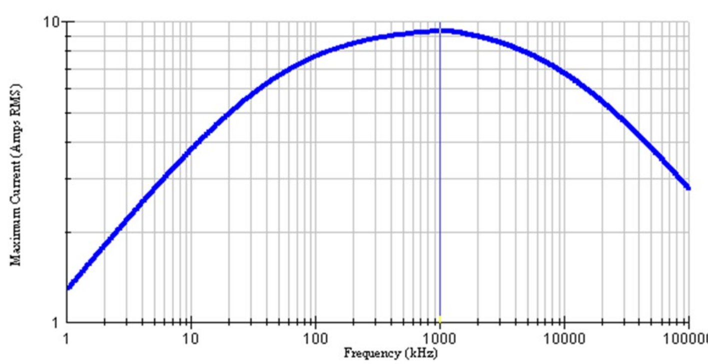


Z(blue)/ESR(red) vs. Frequency

Maximum Current vs. Frequency

Vertical MLCC Stack, 18uF, 50V, ESL = 0.6nH, 285.9mm³





Z(blue)/ESR(red) vs. Frequency

Maximum Current vs. Frequency

Mini-TurboCap MLCC Stack, 18uF, 50V, ESL = 1.2nH, 142.2mm³

Figure 14. Characteristics of Horizontal (top), vertical (middle), and combined stacks (bottom)

POWER ELECTRONICS AND GaN PASSIVE COMPONENT NEEDS

High Voltage MLCCs

High voltage MLCCs play an essential role in GaN power conversion from snubbers to filters and resonant elements.

High voltage MLCCs can take the form of SMT devices, Radial devices, stacked MLCCs, or custom figurations. An example of low loss low ESL/ESR high voltage stacked MLCCs is shown below in figure 15.

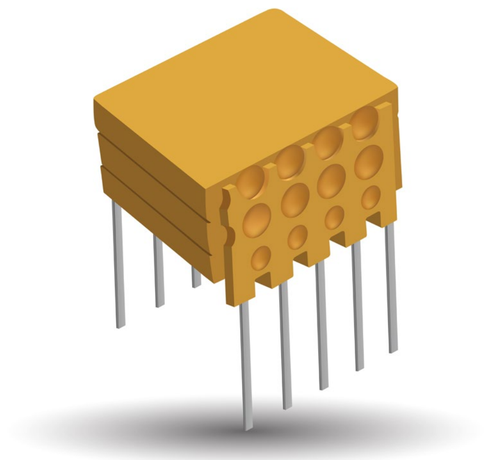


Figure 15: Epoxy coated space-grade high voltage horizontal stack MLCC

High voltage stacked capacitors are available in multiple dielectrics and offer rated voltages to 5kV and capacitances up to 15μF.

High Power Film Capacitors

GaNs impact on high power circuitry is as equally impressive as its impact on RF & low power conversion applications. Whole new end uses suddenly become possible and will require capacitors for DC filtering, protection discharge, and tuning.

Film capacitors have made significant improvements in capacitance per unit volume, reduced losses that increase ripple current capability across a wider frequency range, improved reliability, and reduced weight.

These improvements were achieved using optimized materials and different segmentations of the metallization on the film dielectric to optimize self-healing. At this point, applications operating in voltage ranges between 600 VDC and 1200 VDC can be more economically covered by film capacitors than electrolytic. Films are also used in applications with voltage requirements > 1200 VDC, and these devices utilize improved corona breakdown measures of the film surrounded by a non-toxic (vegetable) oil. Power Film capacitor advantages are so compelling that the trend for power conversion is to replace electrolytic capacitors with film capacitors.

This trend is generated by many advantages that film technology offers. Among them are:

- High current capabilities; up to 1_{ARMS} per μF
- Handle voltage reversal
- High peak current capabilities
- No acid inside
- Long lifetime
- No storage problems
- Self-healing
- Overvoltage withstanding up to 2 times rated voltage

Film offers a unique ability to self-heal without catastrophic failure; instead, only a marginal decrease of capacitance is observed. This feature is a greatly desired property when working in kilowatt to multiple tens of kilowatt designs (or larger). In addition to the high levels of safety inherent with power film capacitors, thermal and electromagnetic models (see figure 16) can be used to analyze hot spots for accurate prediction and control of operating life to electrically and economically optimize designs given the custom nature of high power film capacitor use.

POWER ELECTRONICS AND GaN PASSIVE COMPONENT NEEDS

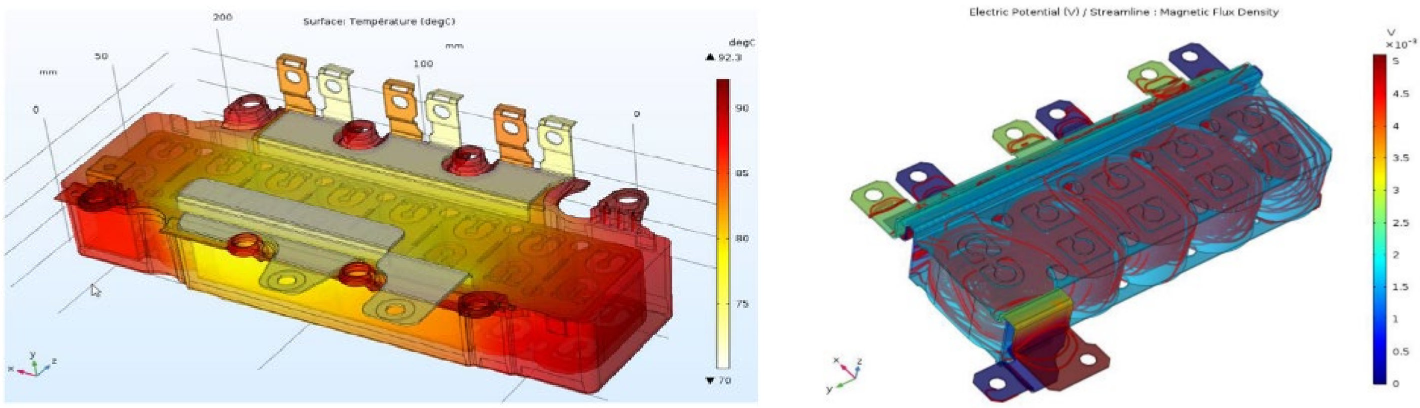


Figure 16: Thermal model (left) and electromagnetic model (right) of a power film capacitor

Film capacitors come in many configurations and styles, but all are based upon a metallized film that is wound or, in some cases, layered. Individual chips or windings (called pucks) are configured in various connections to create higher voltage and larger capacitance stacks.

Examples of three film based power devices are shown below in figure 17.

Parameter Range	FFVS	FSB	FHC
Capacitance(μF)	22 - 200	.01 - 5.6	100 - 1500
Voltage (DC)	600 - 1900	700 - 2000	300 - 1400
Current (A_{RMS})	57 - 87	3 - 39	70 - 190
Inductance (nH)	8 - 16	≤ 25	≤ 70

Figure 17: Comparison of three film capacitors

The range of Film capacitors shown is only a small look into the many ways that film capacitors can be configured for optimal performance with GaN devices.

PASSIVE COMPONENTS FOR GaN BASED DEVICES

Summary

GaN has created a need for low loss passive components in both RF and power circuitry. New material systems with optimized terminations such as Tantalum Polymer capacitors and MLO filters are ideal ways to shrink the supporting passive components size surrounding active devices while optimizing RF performance. Traditional capacitors with unique termination layouts (as shown in stacked capacitors) are ideal in providing low parasitic loss across more comprehensivefrequencies in smaller, more reliable packages.

Self-healing passives offer high power GaN devices a fail-safe capacitor to increase system reliability/up-time. Finally, new families of devices such as Q bridge have been created to address the heat flow problems associated with GaN active devices. Other recent high-temperature, low loss dielectrics, metallizations, and configurations exist and are being expanded upon to keep up with GaNs ever-increasing frequency of operation and power capabilities.

1. Sturdivant, 5G/6G Phased Array Packaging Challenges and Opportunities, IMAPS NE Nov. 2020

2. CUI Blog, SDI 200G-U Series Blog, www.cui.com

3. Smith, Energy and Power Handling Capabilities of Thin Film and Ceramic Capacitors, www.avx.com

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