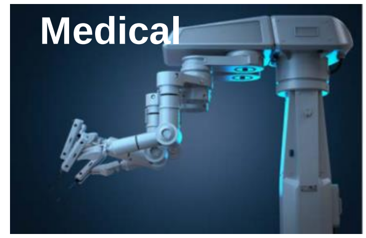
In this Why GaN webinar, we discuss why GaN makes a great solution for multiple applications used in robotics and drones.

Agenda

- GaN applications in robotics and drones
  - Motor drives
  - Machine vision: Time of Flight(ToF)/Lidar
  - DC-DC power supplies
- Why GaN?
- eGaN portfolio for robotics and drones

Today we will discuss the multiple applications where GaN has a significant benefit within robotic and drone systems. These include (build 1) motor drives, (build 2) machine vision, and (build 3) the DC-DC power supplies. (build 4) We will then examine why GaN is such an ideal solution for these systems. (Build 5) and finally we will review the discrete and integrated product portfolio that is available to support these systems.

Robotics and Drones



GaN Applications

Motor Drives

ToF/Lidar

DC-DC Power Supply

There are three major applications within robotics and drones that we will discuss today. (Build 1) motor drives (Build 2) time-of-flight/lidar systems for machine vision and (Build 3) the DC-DC power supply.

Motor Drives

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First, let’s look at motor drives

Why BLDC Motors?

<u>BLDC Motors are popular:</u>

- High torque and power density
- Wide speed range capability
- High efficiency
- Brushless ensures low EMI

<u>Application focus:</u>

- Robotics – Precision control
- Drones – Lightweight
- eBikes – small size, lightweight

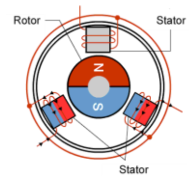


Image courtesy of: Renesas

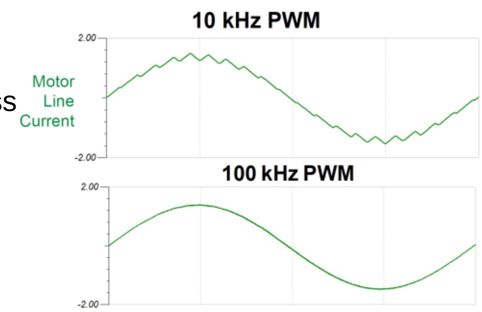
Image courtesy of: https://electricbikereport.com/

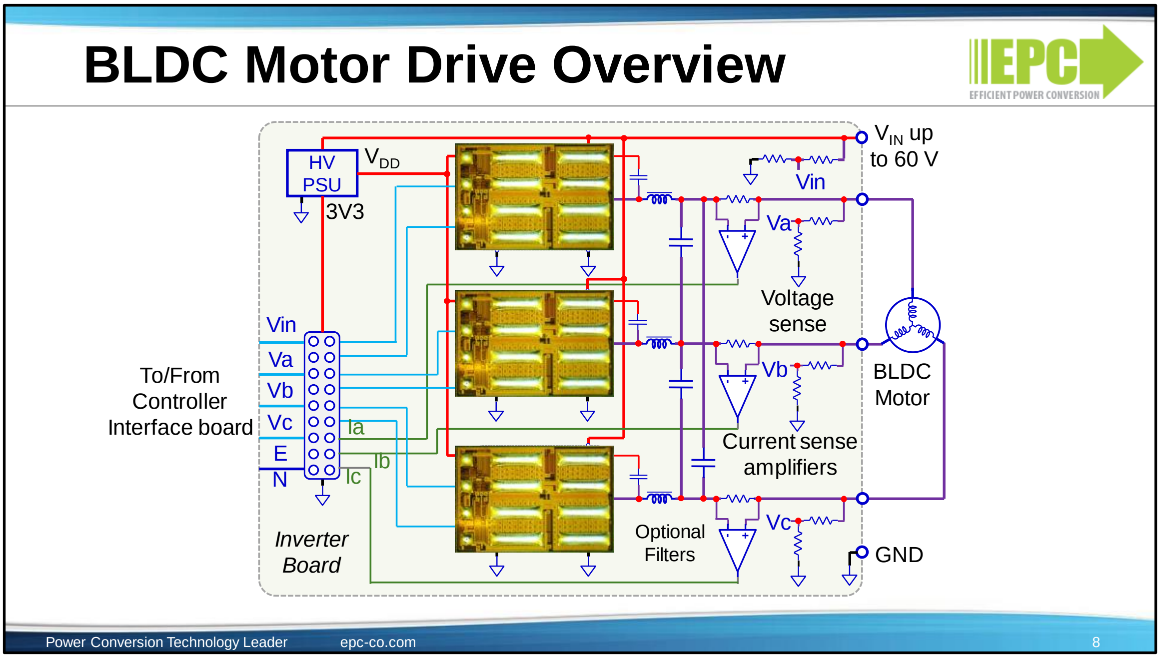
GaN Benefits in Motor Drives

GaN FET/ICs switch fast with no $Q_{RR} = 0$

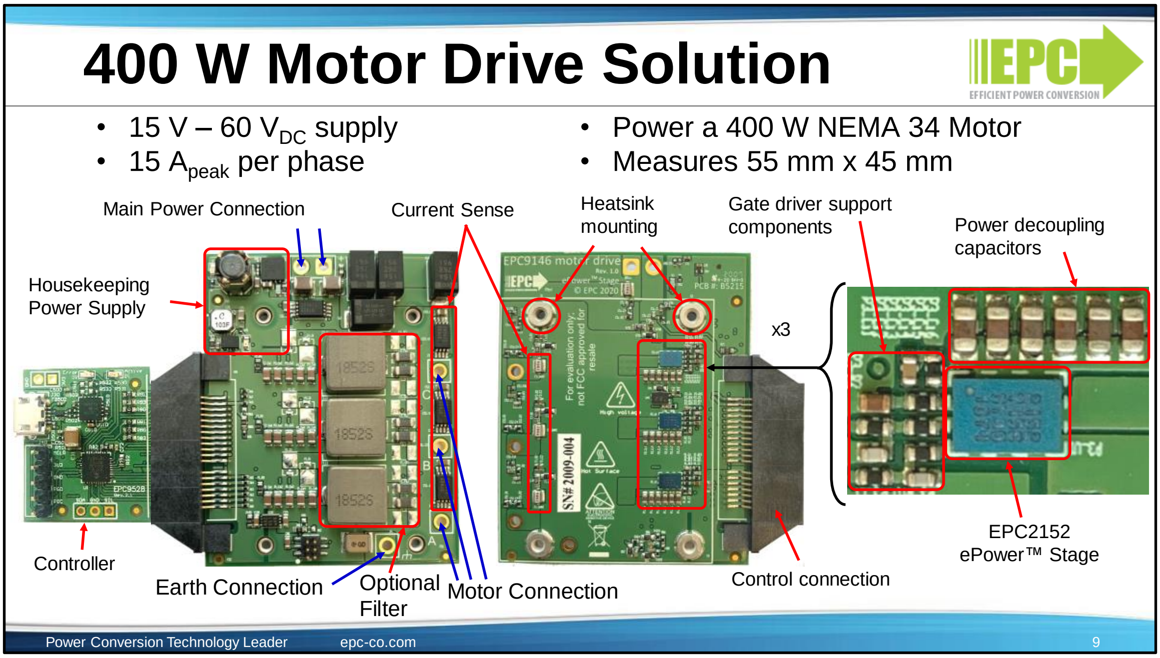
higher switching frequency | lower dead time

- Lower distortion → lower acoustic noise
- Lower current ripple → reduced magnetic loss
- Lower torque ripple → improved precision
- Lower filtering → lower cost, weight & size
- Supports low inductance motors





Here is the EPC2146 high-performance BLDC motor drive available as a demonstration system from EPC. (build 1) Each of the half-bridge power stages use one EPC2152 ePower Stage and requires only a few support capacitors.



The EPC2146 3-phase BLDC motor drive was designed and built to operate from a 15 V through 60 V main DC supply and deliver a peak current of 15 A into each phase of the motor. The drive can power a 400 W NEMA 34 size BLDC motor and measures just 55 by 45 mm. The drive includes the following features

(Build 1)
A main DC supply connection and a housekeeping power supply that operates off the main supply to provide 12 V for the ePower stage and 3.3 V for the controller

(Build 2)
A motor connection including an earth

(Build 3)
A current sense for each of the phases

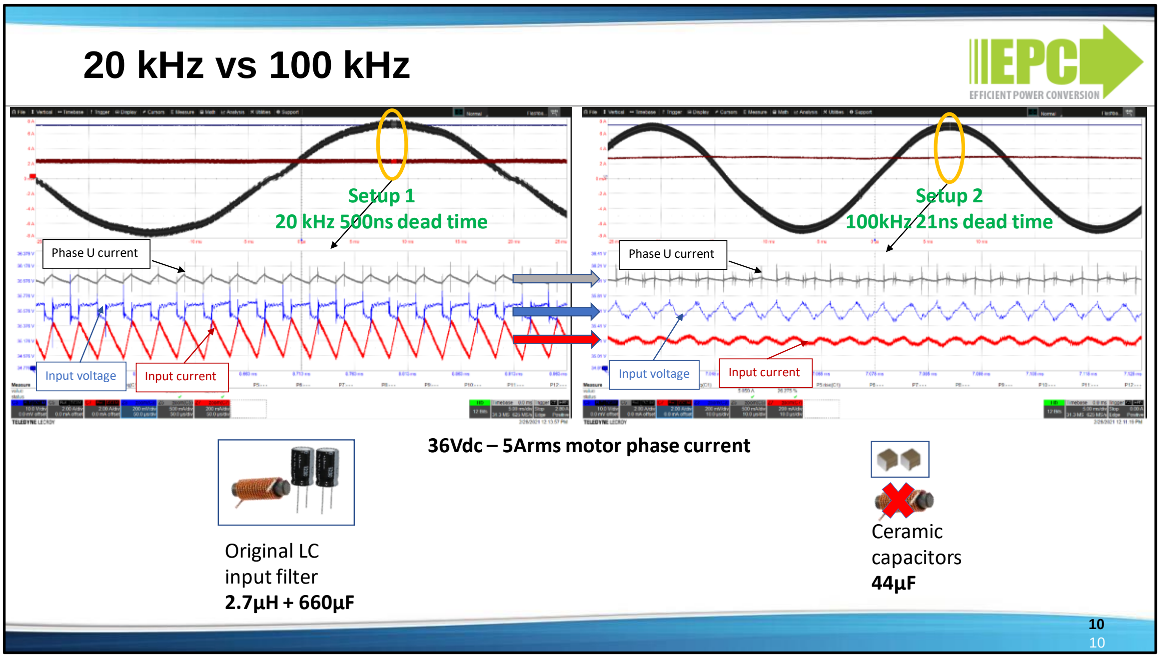
(Build 4)
An optional Filter to reduce dv/dt on the motor windings

(Build 5)
A heatsink mounting option

(Build 6)
The ePower stages showing the zoomed in portion for one of the phases and The EPC2152 ePower stage that can operate from 20 kHz through 1 MHz switching frequency

(Build 7)
The power stage decoupling capacitors and the gate driver support components

(Build 8)
And finally the controller and controller connection



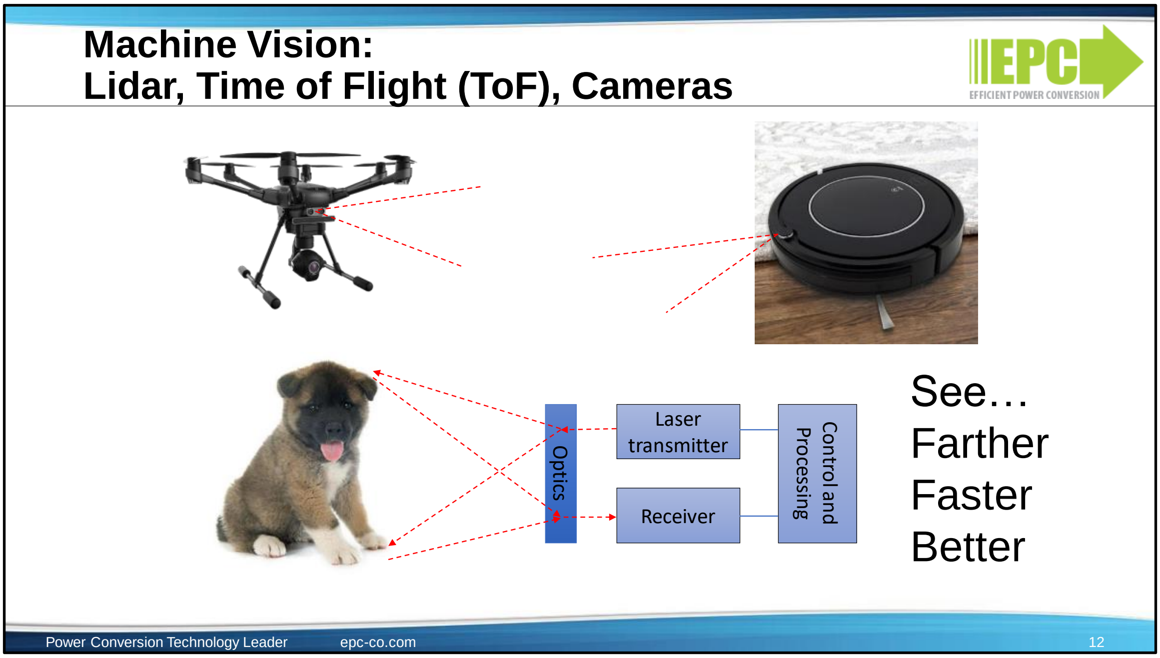
Here are the experimental results of the comparison between two setups in the same conditions other than PWM frequency and input filters. (Build 1) The system on the left is designed for 20 kHz and has the input filter designed accordingly. In this case with a 2.7 uH inductor and 660 uF electrolytic capacitors. It is running at 36Vdc 5Arms motor phase current

On the oscillogram is superimposed a zoom image at the positive peak of the motor phase current. The blue curve that shows a ripple at double of the PWM frequency is the input voltage ripple of 200mV peak to peak. The red curve is the input current ripple of 500mA peak to peak. The grey curve is the motor phase current ripple at 100mA peak to peak.

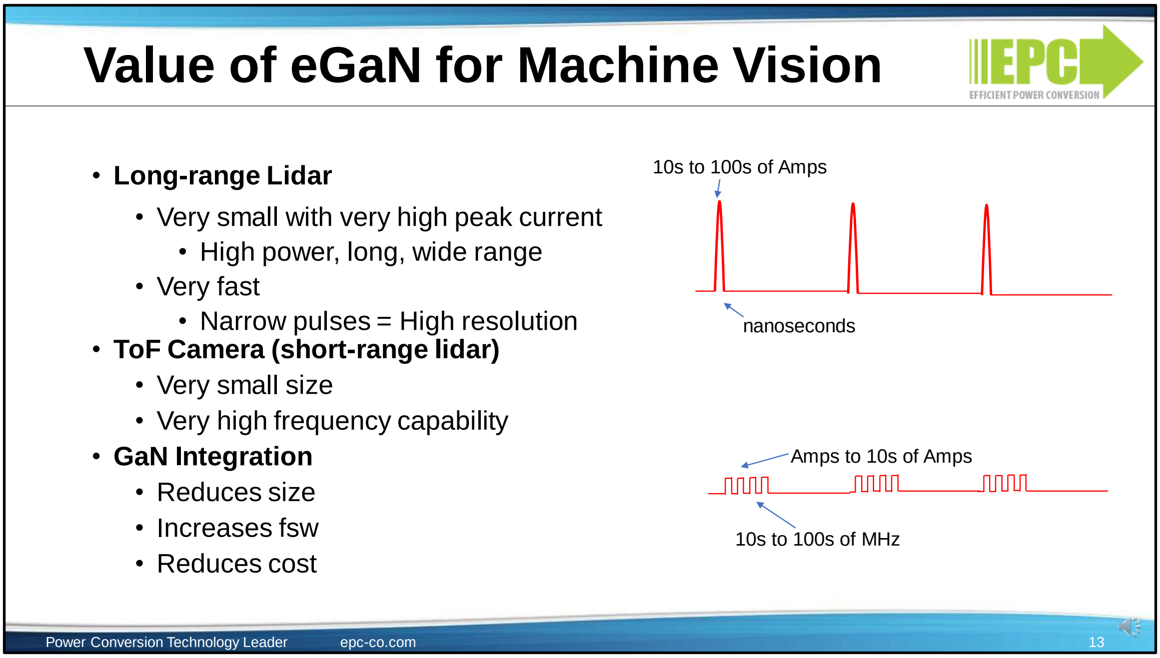
(Build 2) The system on the right is designed for 100 kHz operation and the input filter has been sized accordingly with on 44 uF ceramic capacitors and no input inductor. When comparing the 20 kHz system to the 100 kHz system, it is clear that the ripple from input voltage, input current and output current are each smaller than the ripple in the 100 kHz system. (Build 3) Aside from being much smaller and lighter due to the input filter improvements, and if the setup 1 passes EMI tests with LC input filter, then setup 2 is likely to pass the same tests with just 44uF ceramic capacitors.

Machine Vision: Time of Flight(ToF)/Lidar

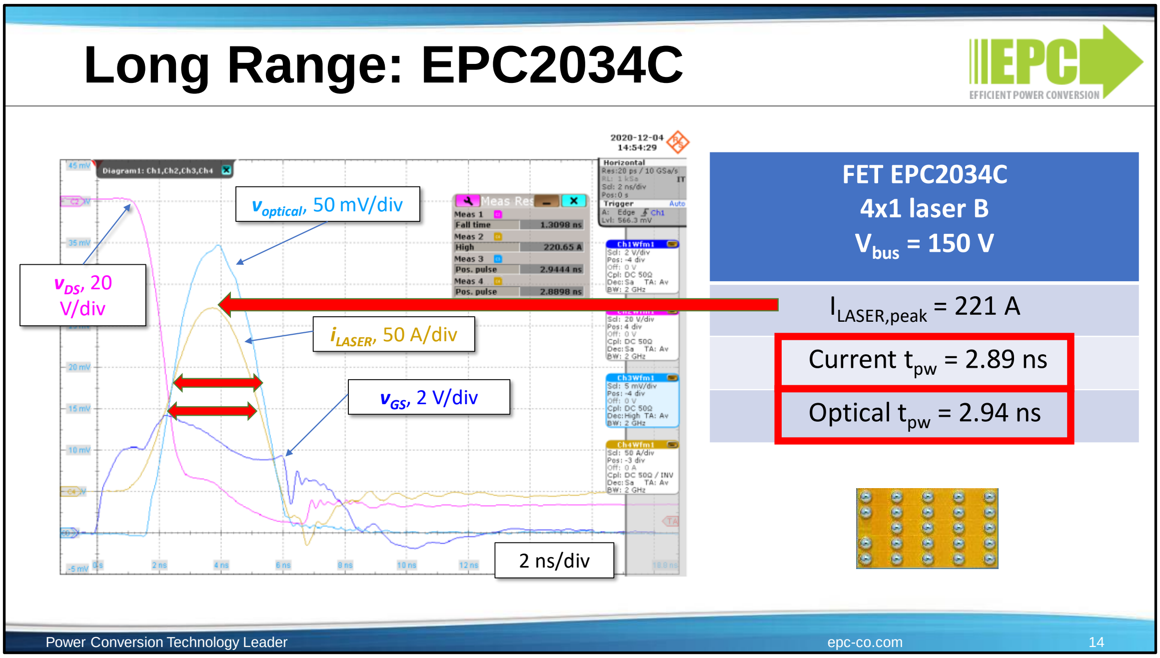
The next application for eGaN technology in robotics is machine vision…



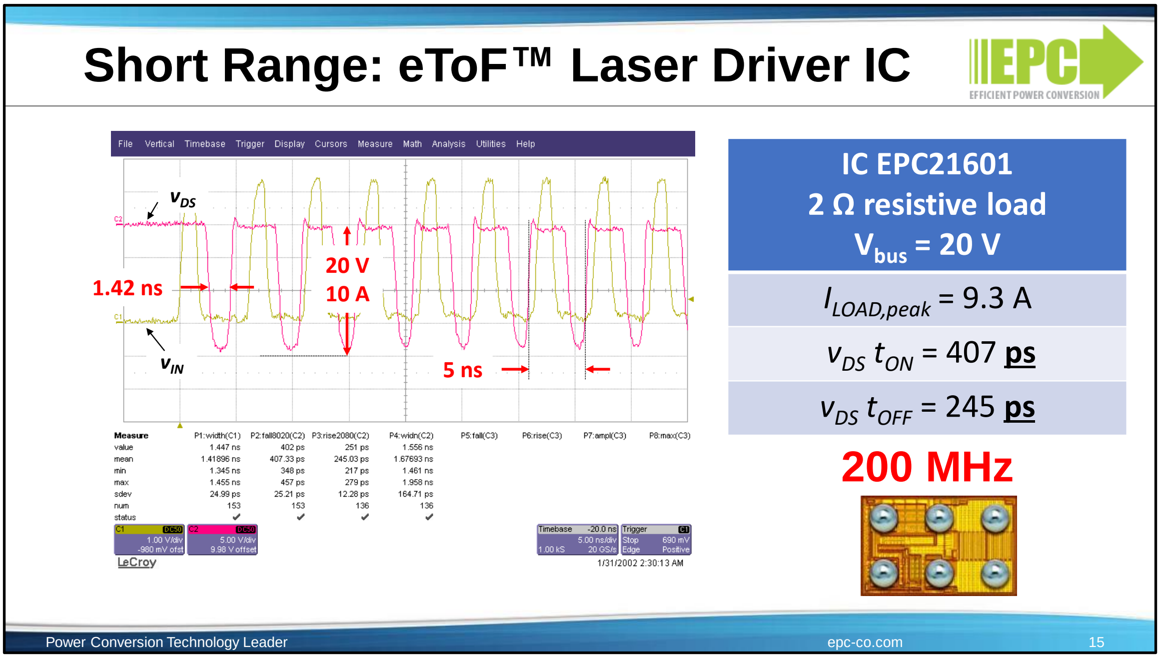
Lidar and Time of Flight (or ToF), give vision to robotics
eGaN devices are leading this application and support both Lidar for navigation and Time of Flight for collision avoidance.
With eGaN devices drones can (build 1) see farther, faster and better.



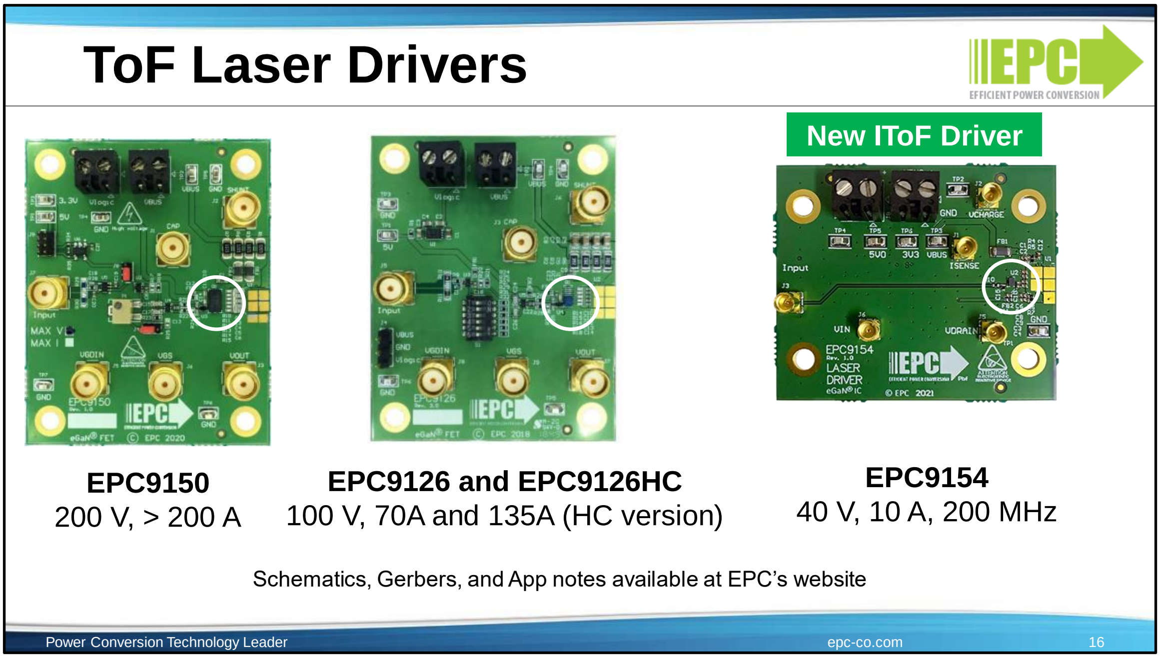
GaN devices have benefits for both long range and short-range solutions.
(build 1) Long range lidar is used for navigation and can see targets up to hundreds of meters. These systems require very short pulses, in the nanosecond range, with very high peak currents, up to hundreds of amps. This allows long and wide range and high resolution. Finally, size is very small.
(build 2) eGaN devices enable Lidar shorter pulses, because the rise time plus the fall time is almost 100 times smaller than Si MOSFETs. Additionally, tiny eGaN FETs deliver very high pulsed current. This makes eGaN FETs THE Lidar solution, as proven by their dominance in Lidar applications at all the major players.
(build 3) Time of flight (TOF) cameras, or short range lidar, need to be very small, and tiny TOF modules have excellent range and accuracy. Pulse currents are smaller than long range lidar, typically less than 10 A, (build 4) but the pulse frequency needs to be very high, tens or hundreds of MHz, to guarantee high resolution at short distances.
(build 5) eGaN devices are very small and monolithic integration (build 5) can further reduce size, increase frequency, and reduce cost.



So here's a real-world example using the EPC2034C. It's 200 volt rated, eGaN FET and it can conduct about 250 amperes in a pulse. But it's only 12 square mm in size, so it's pretty tiny. You have a 221 ampere laser pulse peak. And it's only 2.9 nanoseconds wide. So, it's under that three nanoseconds that we're talking about. And of course, you can look at the optical power, we're measuring the return signal. And it's also under three nanoseconds. This is state-of-the-art today. And as you can see, it is hard to achieve because you need very low power loop inductance and very, very low common source.



Now let’s go to very high frequency. So here we're delivering ten ampere pulses for a short range system. But in this case, the pulse width is down to 1.4 nanoseconds. Still delivering 10 amperes but it’s a five-nanosecond repetition which is 200 megahertz, so this will give you a high resolution in short distances, better than anything out there today.



We also have demonstration boards to support ToF/lidar designs. The EPC9150 is the one that I showed you earlier with the 220-ampere pulse. It uses the EPC2034C, 200 V device. We also have the EPC9126 and 9126HC for high current, which can go up to 135 amperes. And our new board, the EPC9154, which uses the new eToF laser driver integrated circuit and it can run up to 200 Megahertz, delivering 10 amps and 40 volts.

Of course, like all EPC products, schematics, gerbers, and app notes are available on our website.

DC-DC Power Supply

The final application for robotics and drones are the DC-DC power supplies…

Value of eGaN for DC-DC in Robotics

EPC EFFICIENT POWER CONVERSION

- Higher Power Density
- Smaller and Lighter
  - Half the solution size and weight to deliver the same power vs. Si MOSFETs
- Enable higher frequency to further reduce size
- High Efficiency

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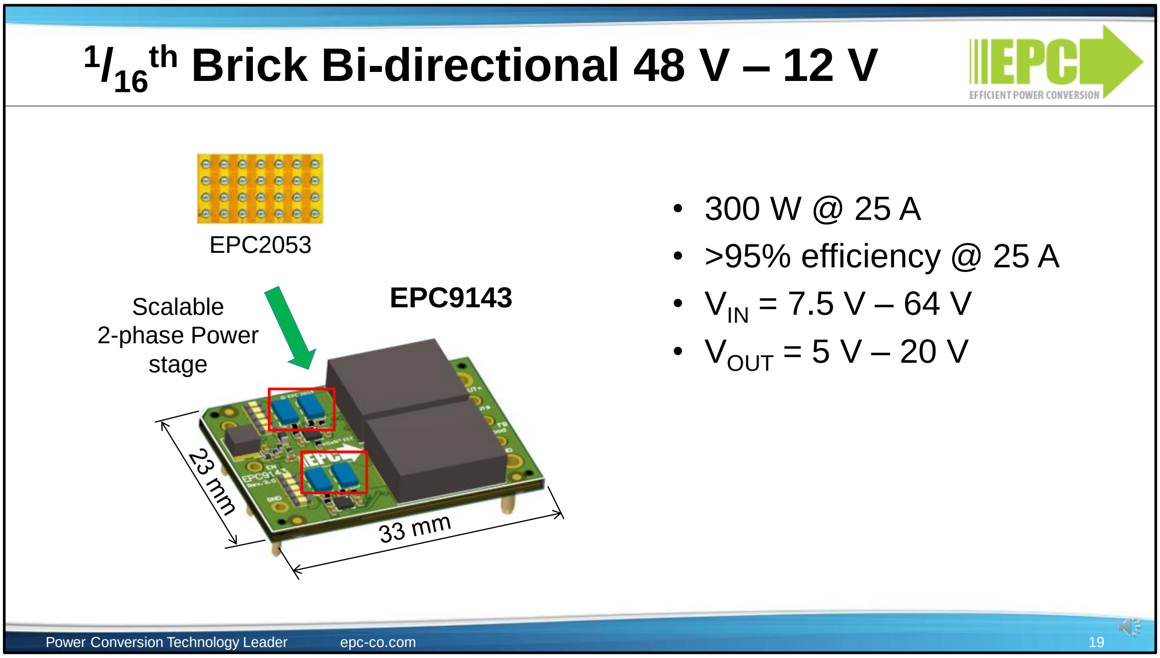
(Build 1) For the 48V DCDC, the fact that eGaN 100V FETs have the Best Figure of Merit for hard switching applications results in higher power density & efficiency vs Si MOSFET.
The DCDC is (build 2) smaller & lighter, (build 3)half of the solution size and weight to deliver the same power vs Si MOSFETs. This is due to 5 times smaller RDSon form factor & better FOM at 100 V.
(build 4) The lower switching losses of eGaN devices enable higher frequency to further reduce size. And finally, (build 5) eGaN devices allow higher battery efficiency that results in longer battery life and autonomy.



DC-DC in smaller robotics and drones generally operate from 48V, that is 4x 12V battery packs in series. Vout is generally 12V. Size is very critical and generally limited to < 1000mm2. Bi- directional buck – boost design is often required to recharge the battery for more autonomy.

A reference design for a bi-directional 48V to 12V 300W converter is available, the PN is EPC9143 and the application note is available.

The design delivers 25A and 300 W power with 96% efficiency. This represents 33% higher efficiency compared to silicon solutions

The design features an enhanced microcontroller that will enable users to configure the design for a 300W buck, or modify for a 300W boost or a bidirectional buck boost.

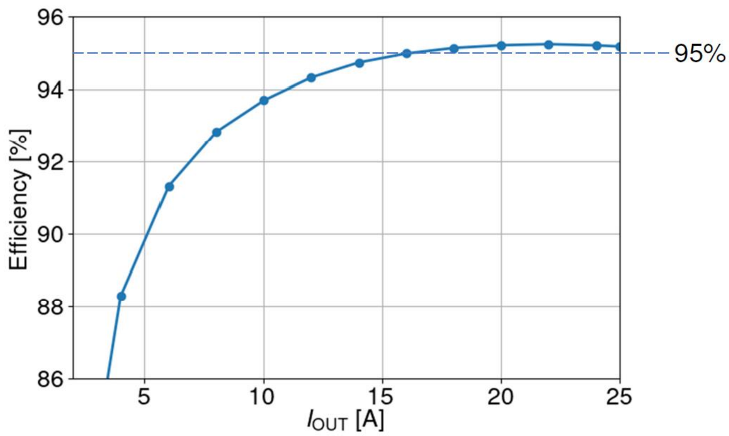
The default setting is a buck 300W to 12V regulated output. However, Vout could be set from 5V to 20V and Vin could vary from 7.5V to 64V.

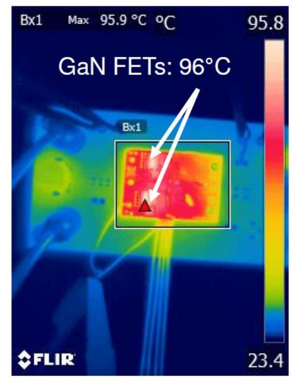
The switching frequency is 500 KHz that allows 300 W in the very small 1/16th brick format, which is just 33x23 mm2. This results in a power density greater than 610 W/in3.

The design is scalable and more phases can be added for higher power.

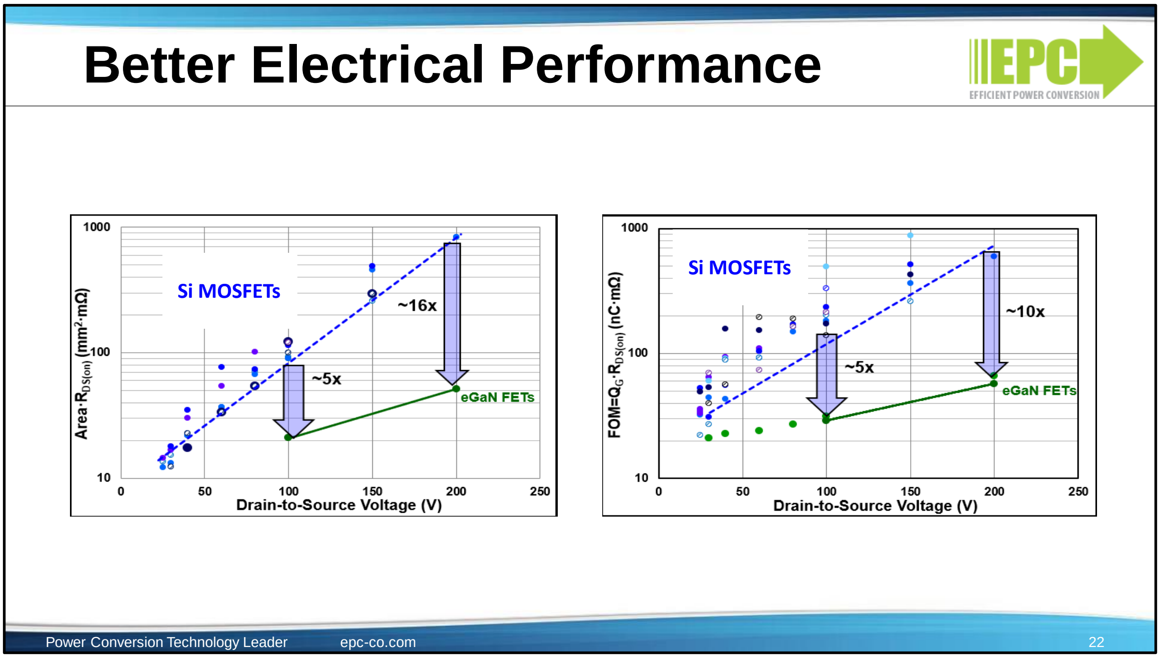
Performance Results

48 V input, 12 V output, 1700 LFM airflow





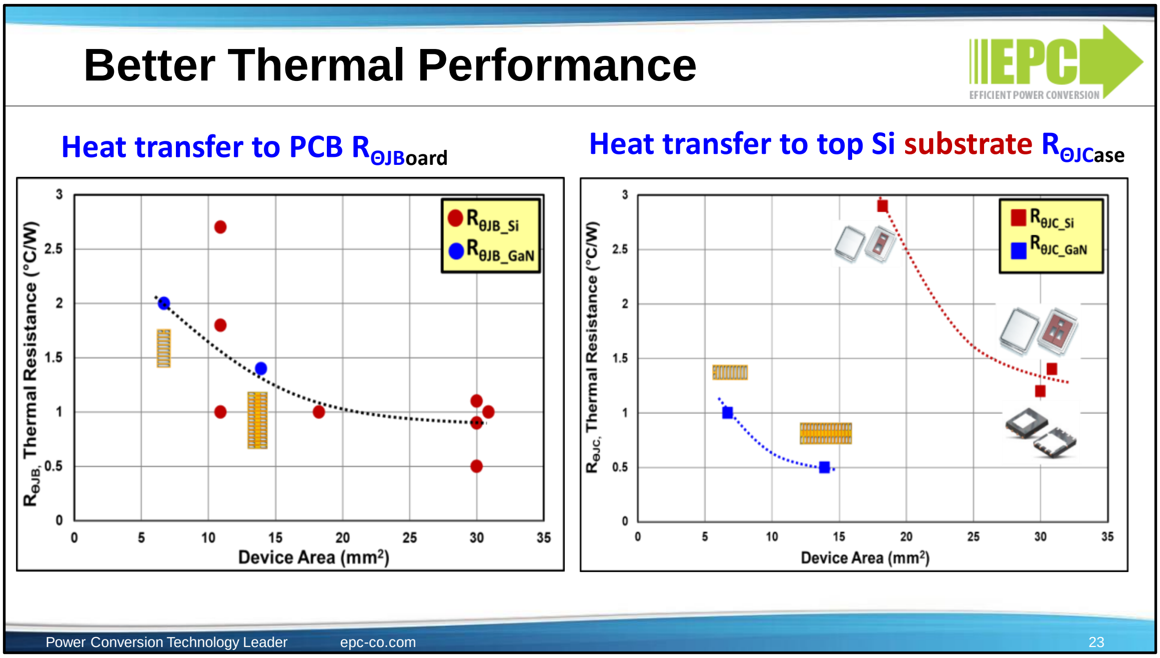
Why GaN?



In comparison to silicon MOSFETs, eGan transistors improve the key figure of merit, area x rdson, by 5 times at 100V. That improvement results in smaller size and lower cost or lower RDSon in the same size.

Additionally, the Figure of merit, RDSon x Qg, is also 5 times better than silicon, resulting in lower losses.

Finally, zero reverse recovery and less switching losses allow an increase in frequency for higher power density.

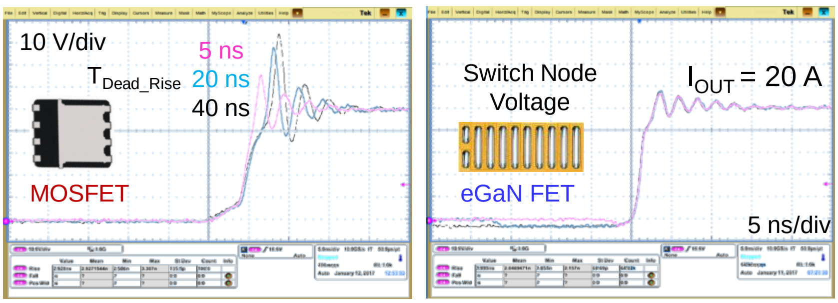


Even though our devices are very small, thermal is not a concern due to the excellent thermal properties of our eGaN dies. On the left you can see that the thermal resistance to pcb is similar to FETs.

However, on the right we are comparing thermal resistance to case against the absolute best thermal package available for MOSFETs – the Direct FET. The eGaN devices are 6 times better than the best-in-class DirectFET because eGaN dies can dissipate heat through the pcb, top, AND the lateral sides.

Better EMI

- Lower parasitic inductance
- Fast rise/ fall time moves noise to higher frequency for easier filtering
- Zero reverse recovery



Now this next topic is a question we get all the time due to the super fast switching speed of eGaN devices…what about EMI?

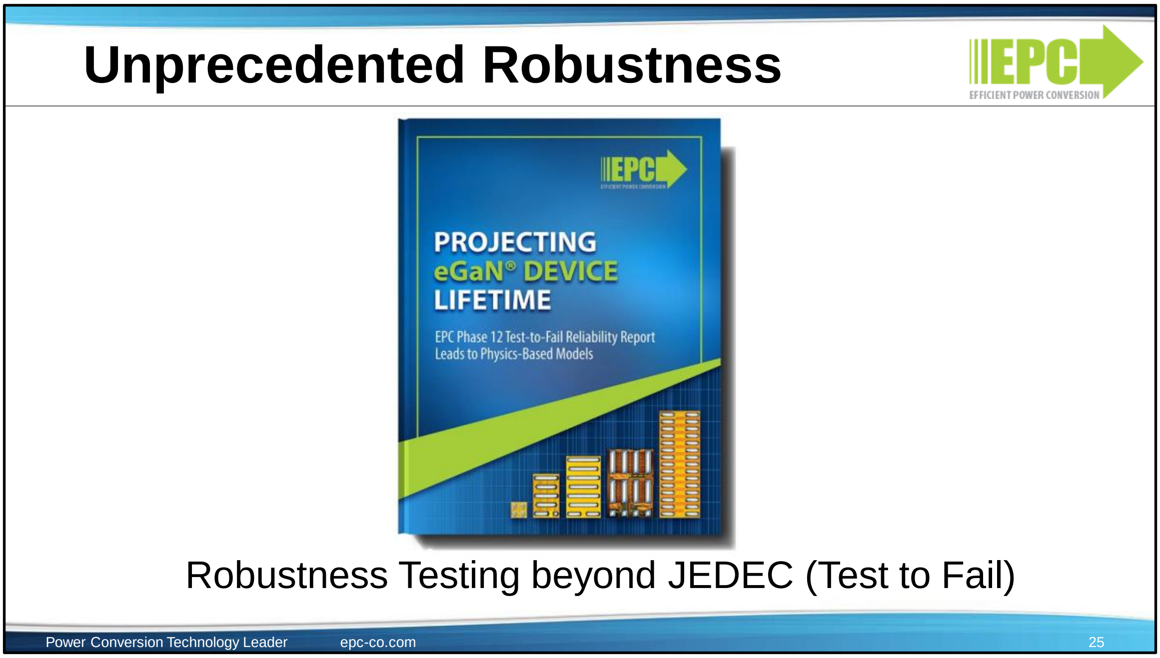
Gan Devices ***improve*** EMI and there are several reasons for that…

(1)Lower parasitic inductance reduces ringing energy. By adopting simple layout techniques, one can ensure significant reduction in EMI generation that adds zero cost to EMI mitigation.

(2) Fast Rise/ Fall Time moves noise spectrum to higher frequency for easier filtering. At higher frequencies, EMI reduction techniques are more effective ensuring lower cost to implement.

(3) Finally, eGaN FETs and ICs have zero reverse recovery and thus inherently generate less EMI energy in hard-switching converters.

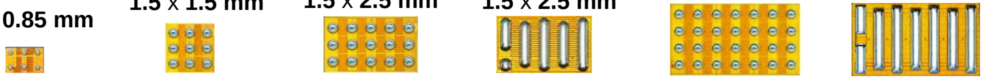
For more information on EMI view the How to GaN video on this topic.\\In summary, eGaN FETs and ICs are EMI compatible.



Another important feature is the unprecedent robustness of eGaN devices.
With a “test to Fail” approach to reliability testing, EPC tests devices well beyond JEDEC to improve robustness generation after generation. The test to fail report, Phase 12, is available on the EPC website.
This report details how by employing a test to fail methodology, intrinsic failure mechanisms can be identified and used to develop physics-based models to accurately project the safe operating life of a product over a more general set of operating conditions. This methodology is also employed to consistently produce more robust, higher performance, and lower cost products for power conversion applications.

eGaN® Portfolio for Robotics and Drones

100 V Products



	1.3 x 0.85 mm	1.5 x 1.5 mm	1.5 x 2.5 mm	1.5 x 2.5 mm	2 x 3.5 mm	2 x 3.5 mm
Parameter	**EPC2051** (@ 5 V_{GS})	**EPC2052** (@ 5 V_{GS})	**EPC2045** (@ 5 V_{GS})	**EPC2204** (@ 5 V_{GS})	**EPC2053** (@ 5 V_{GS})	**EPC2218** (@ 5 V_{GS})
$R_{DS(on)}$ typ	**20 mΩ**	**10 mΩ**	**5.6 mΩ**	**4.5 mΩ**	**3.2 mΩ**	**2.5 mΩ**
$R_{DS(on)}$ max	25 mΩ	12.5 mΩ	7 mΩ	5.6 mΩ	3.8 mΩ	3.2 mΩ
Q_G typ	1.7 nC	3.7 nC	5.9 nC	6.4 nC	12 nC	11.8 nC
Q_{GD} typ (1)	**0.3 nC**	**0.5 nC**	**0.8 nC**	**0.9 nC**	**1.5 nC**	**1.6 nC**
Q_{OSS} typ(1)	7.3 nC	13 nC	25 nC	25 nC	45 nC	46 nC
Q_{RR} typ	0 nC	0 nC	0 nC	0 nC	0 nC	0 nC
Area	**1.11 mm²**	**2.25 mm²**	**3.75 mm²**	**3.75 mm²**	**7 mm²**	**7 mm²**

(1) at V_{DS} = 50 V

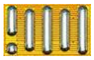
Here you see a full range of 100 V FETs from EPC with RDSon ranging from 20 mOhm to 2.5 mOhm (build 1). Gate charge is very small, (build 2) from 1.7 nC to 11.8 nC, Qgd is also very small, for very low switching losses, and Qrr is 0. The device area is ultra-small (build 3), from 1mm2 to 7mm2.

EPC 100 V vs. Si 80 V Devices

3.3 mm x 3.3 mm

(MOSFET Benchmark)

1.5 mm x 2.5 mm



(eGaN FET)

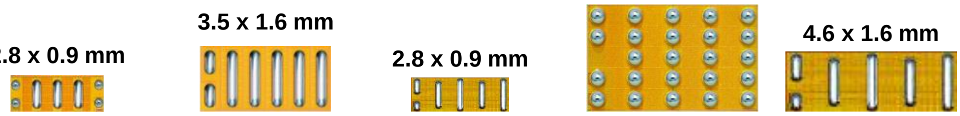
Parameter	BSZ070N08LS5 10 V_{GS}	EPC2204 5 V_{GS}	EPC GaN FET Improvement
$R_{DS(on)}$ typ	**7.2 mΩ**	**4.5 mΩ**	**38%**
$R_{DS(on)}$ max	9.2 mΩ	5.6 mΩ	**64%**
Q_G typ	15 nC	6.4 nC	**57%**
Q_{GD} typ	**5 nC @ 40 V_{DS}**	**0.9 nC @ 50 V_{DS}**	**82%**
Q_{OSS} typ	29 nC @ 40 V_{DS}	25 nC @ 50 V_{DS}	**14%**
Q_{RR} typ	**29 nC @ 40V Vr**	**0 nC**	**Infinitely**
Device Size	**10.9 mm^2**	**3.75 mm^2**	**66%**

Three times smaller, less losses, no reverse recovery, higher f_{SW}

If we compare the performance of eGaN FET vs the benchmark silicon MOSFET, the (build 1) RDSon of the GaN device is 38% smaller despite the higher voltage rating of the eGaN device, (build 2) Qg is 57% smaller, Qgd 82% smaller, and (build 3) Qrr is 0. Additionally, the eGaN FET (build 4) is 1/3 of the size. Overall, eGaN devices are 3 times smaller, have less losses and no reverse recovery and enable higher switching frequency.

200 V Products

2.8 x 0.9 mm | 3.5 x 1.6 mm | 2.8 x 0.9 mm | 4.6 x 2.6 mm | 4.6 x 1.6 mm



Parameter	EPC2019 (@ 5V Vgs)	EPC2010C (@ 5V Vgs)	EPC2207 (@ 5V Vgs)	EPC2034C (@ 5V Vgs)	EPC2215 (@ 5V Vgs)
$R_{DS(on)}$ typ	36 mΩ	18 mΩ	16 mΩ	6 mΩ	6 mΩ
$R_{DS(on)}$ max	50 mΩ	25 mΩ	22 mΩ	8 mΩ	8 mΩ
Q_G typ	1.8nC	3.7 nC	2.9 nC	11.1 nC	10 nC
Q_{GD} typ (1)	0.4nC	0.7 nC	0.6 nC	2 nC	1.6 nC
Q_{OSS} typ (1)	18nC	40 nC	22 nC	96 nC	68 nC
Q_{RR} typ	0nC	0 nC	0 nC	0nC	0 nC
Device Size	2.6mm^2	5.8mm^2	2.6 mm^2	12mm^2	7.36 mm^2

(1) at V_{DS} = 100 V

Here you see a full range of 200 V FETs from EPC with RDSon ranging from 36 mOhm to 6 mOhm (build 1). Gate charge is very small, (build 2) from 1.8 nC to 10 nC, Qgd is also very small, for very low switching losses, and Qrr is 0. The device area is ultra-small (build 3), from 2.6mm2 to 7.4mm2.

EPC 200 V vs. Si Devices

EPC EFFICIENT POWER CONVERSION

Si MOSFET Benchmark

eGaN FET

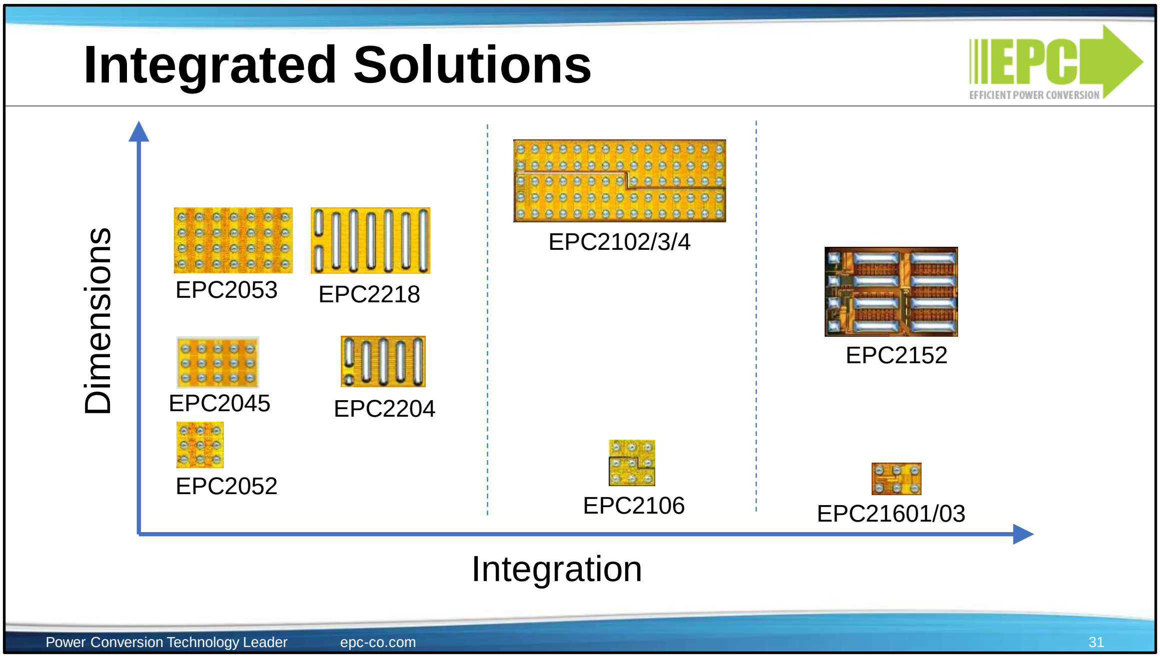
9.9 mm x 11.7 mm

4.6 mm x 1.6 mm

Parameter	IPT111N20NFD (@ 10 V_{GS})	EPC2215 (@ 5 V_{GS})	EPC GaN FET Improvement
$R_{DS(on)}$ typ	**9 mΩ**	**6 mΩ**	**33% lower**
$R_{DS(on)}$ max	11.1 mΩ	8 mΩ	**28% lower**
Q_G typ	**65 nC**	**10 nC**	**6x lower**
Q_{GD} typ	8 nC @100V Vds	1.6 nC	**80% lower**
Q_{OSS} typ	162 nC @ 100V Vds	68 nC	**58% lower**
Q_{RR} typ	309 nC	0 nC	**Infinitely lower**
Device Size	**115.83 mm^2**	**7.36 mm^2**	**15x smaller**

15 times smaller, less losses, no reverse recovery, higher f_{SW}

If we compare the performance of eGaN FET vs the benchmark silicon mosfet, the (build 1) RDSon of the GaN device is 33% smaller, (build 2) Qg is 6 times lower, Qd 80% lower, and (build 3) Qrr is 0. Additionally, the eGaN FET (build 4) is 15 times smaller. Overall, eGaN devices are 15 times smaller, have less losses and no reverse recovery, and enable higher switching frequency

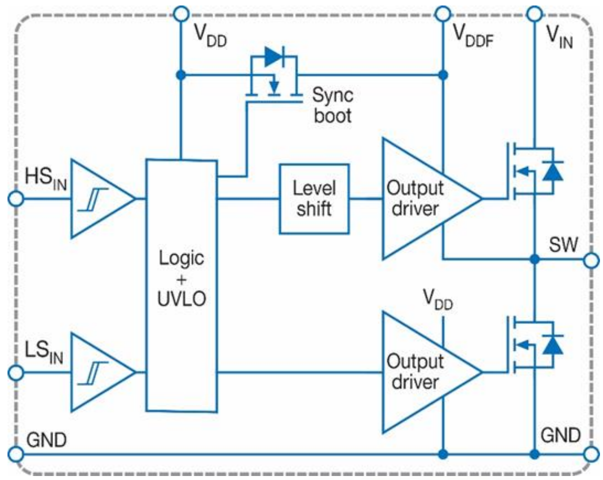


EPC also offers a flexible portfolio for motor drives application. Customers can select (build 1) discrete FETs, (build 2) integrated half bridges, or (build 3) our new integrated solutions

The Integrated Power Stage

EPC2152

- 80 V_{IN} max
- 15 A @ 100 kHz
- 10 mΩ
- 10 mm^2



The ePower Stage digital In and Power Out family simplifies design and will further reduce size. The devices is very small, only 10 mm2, and integrates drivers, level shifter, half bridge FETs and bootstrap. The maximum input voltage is 80V and the maximum current at 100 KHz is 15A.

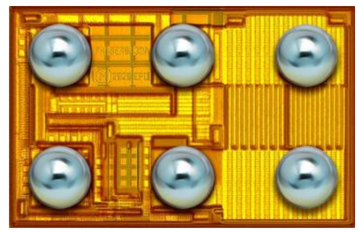
eToF™ Laser Driver IC

Integration

- Reduce CSI to a few pH
- Replace several parts with a single part
- Enhanced reliability
- Reduced driver area
- Reduced cost

Laser Driver IC

- 40 V, 10 A FET with integrated gate driver
- EPC21601: 3.3V logic level input
- EPC21603: LVDS logic level input



1.0 mm x 1.5 mm

A new laser driver IC family includes both the driver and the integrated circuit in the same chip. It's an integrated circuit that takes those two components and combines it into one eliminating virtually all of the inductance in the gate loop. The common source inductance is reduced to just a few picohenries. You could replace several parts with a single part. Of course, it's enhanced in reliability because it's just one chip instead of many. You have much smaller area and this chip it's selling for less than $1 in quantities of half a million or more. It is a 3.3 volt logic level input and is capable of outputting 10 amperes in teeny tiny 1 mm by 1.5 milliliter format.

Summary

- EPC devices enable smaller, lighter, higher precision robotics
  - Motor drives: smaller, lighter and more accurate
  - Machine vision: sees farther, faster, better
  - DC-DC power supplies: smaller and more efficient
- Given same $R_{DS(on)}$, EPC eGaN devices
  - Are smaller
  - Have lower switching losses
  - Have zero reverse recovery
  - Are more robust than silicon
- Integrated solutions simplify design and further reduce size and cost

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In summary, (build 1) EPC devices enable smaller, lighter, and higher precision robotics and drones. The motor drivers are smaller, lighter and more accurate. The lidar systems see farther, faster, and better and the power supplies are smaller and more efficient for longer battery life and range.
(Build 2) Given the same on-resistance, EPC eGaN devices are smaller, have lower switching dissipation, do not have no reverse recovery, and are more robust that silicon MOSFETs.
Lastly, (build 3) GaN integrated solutions simplify design and further reduce size and cost for all of these applications.

For more detailed information about GaN FETs and ICs, please see the 3rd edition textbook, GaN Transistors for Efficient Power Conversion or view more videos in the How2GaN series.
And for more information on eGaN FETs and IC products and evaluation kits, go to epc-co.com