INCREASING POWER DENSITY FOR MOTOR DRIVES WITH SILICON CARBIDE

Broderick Krager, Associate Fellow

APEX
MICROTECHNOLOGY
PRECISION • POWER • ANALOG

TODAY'S CONTENTS

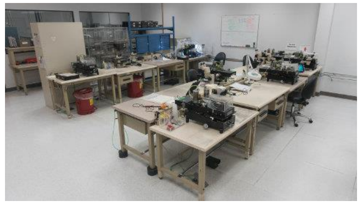
1. Introduction to Apex Motor Drive Options
2. SiC vs GaN vs Silicon
3. Benefits of SiC in a Hybrid Architecture
4. How to Control Apex SiC Products
5. Commutation Schemes for Maximizing Motor Efficiency

INTRODUCTION TO APEX MOTOR DRIVE OPTIONS

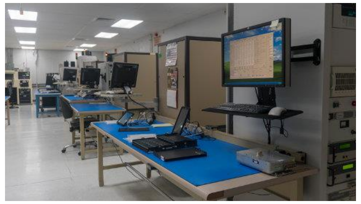
WHO IS APEX MICROTECHNOLOGY?

- Industry leader in high power analog devices since 1980
- Vertically integrated design and production facility located in Tucson, Arizona (USA)
- Subsidiary of HEICO, a successful and technology-driven aerospace, industrial, defense, and electronics company.
- ISO9001 & MIL-PRF-38534 Certified

Assembly



Thick Film



Test

Reflow

WHAT DOES APEX DO IN MOTOR DRIVE?

DC Brushed Motors (H-bridge)

SA160
10A, 80V

MSA260 IGBT
20A, 450V

SA50
5A, 80V

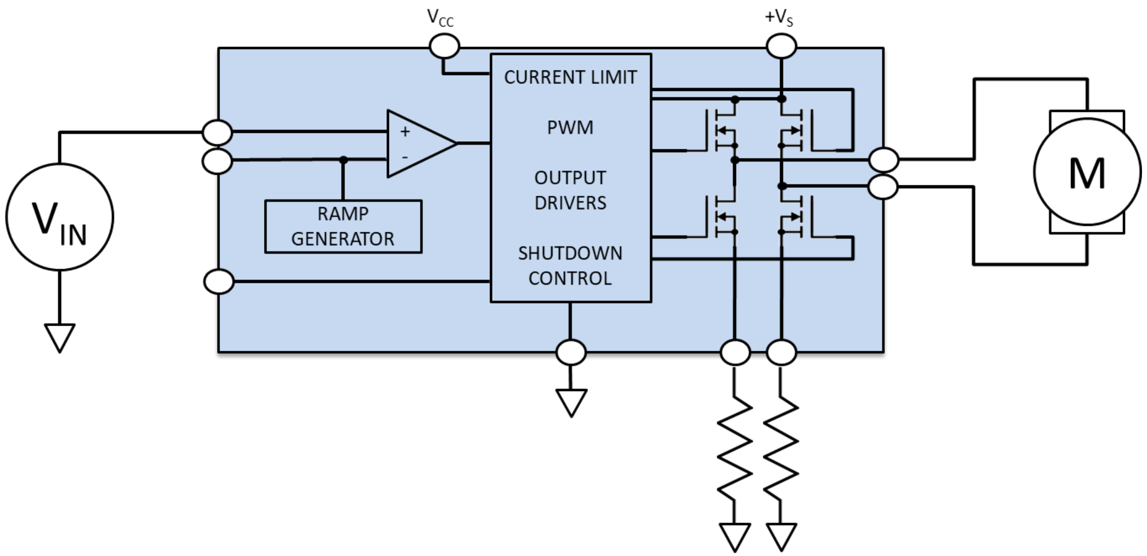
DC Brushless Motors (3-phase)

SA306
8A, 60V

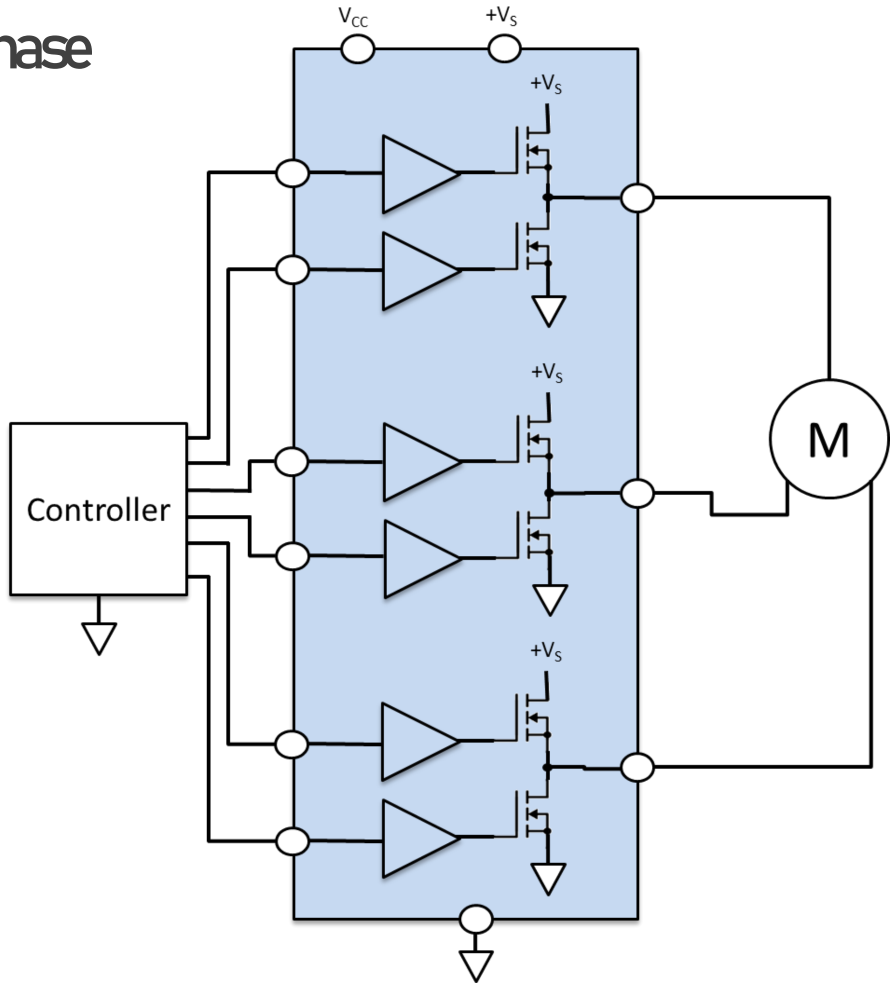
SA310 NEW SiC
30A, 650V

APEX MOTOR DRIVE CIRCUITS – UNDER THE HOOD

H-bridge



3-Phase

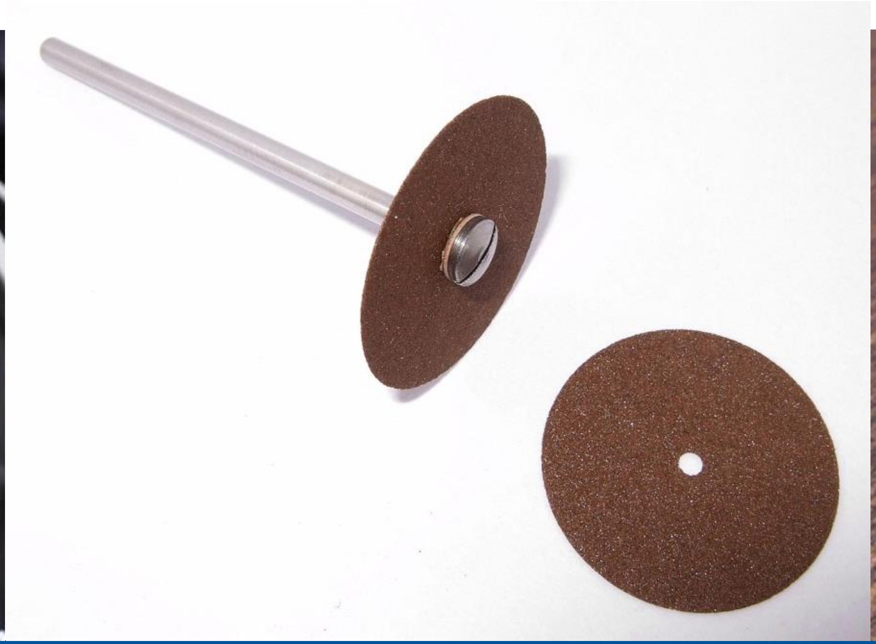


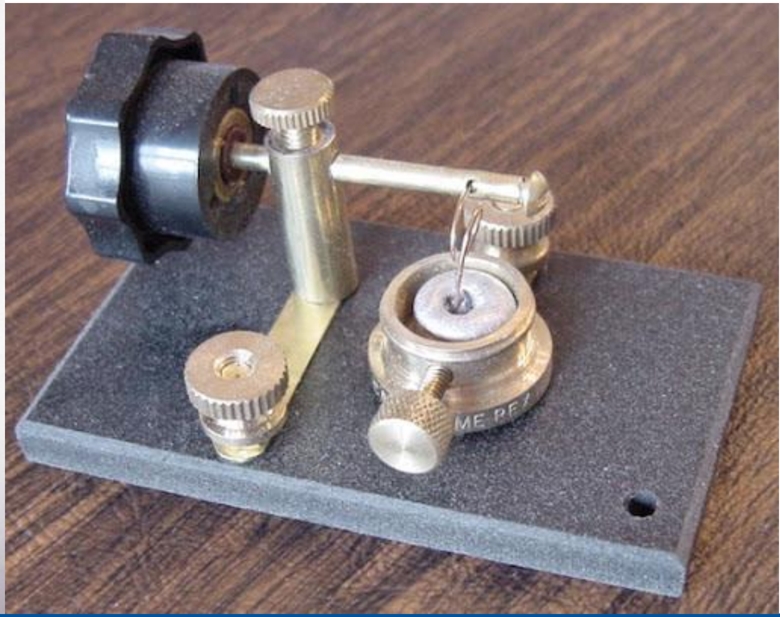
SiC VS. GaN VS. Silicon

A comparison of switch technologies across applications

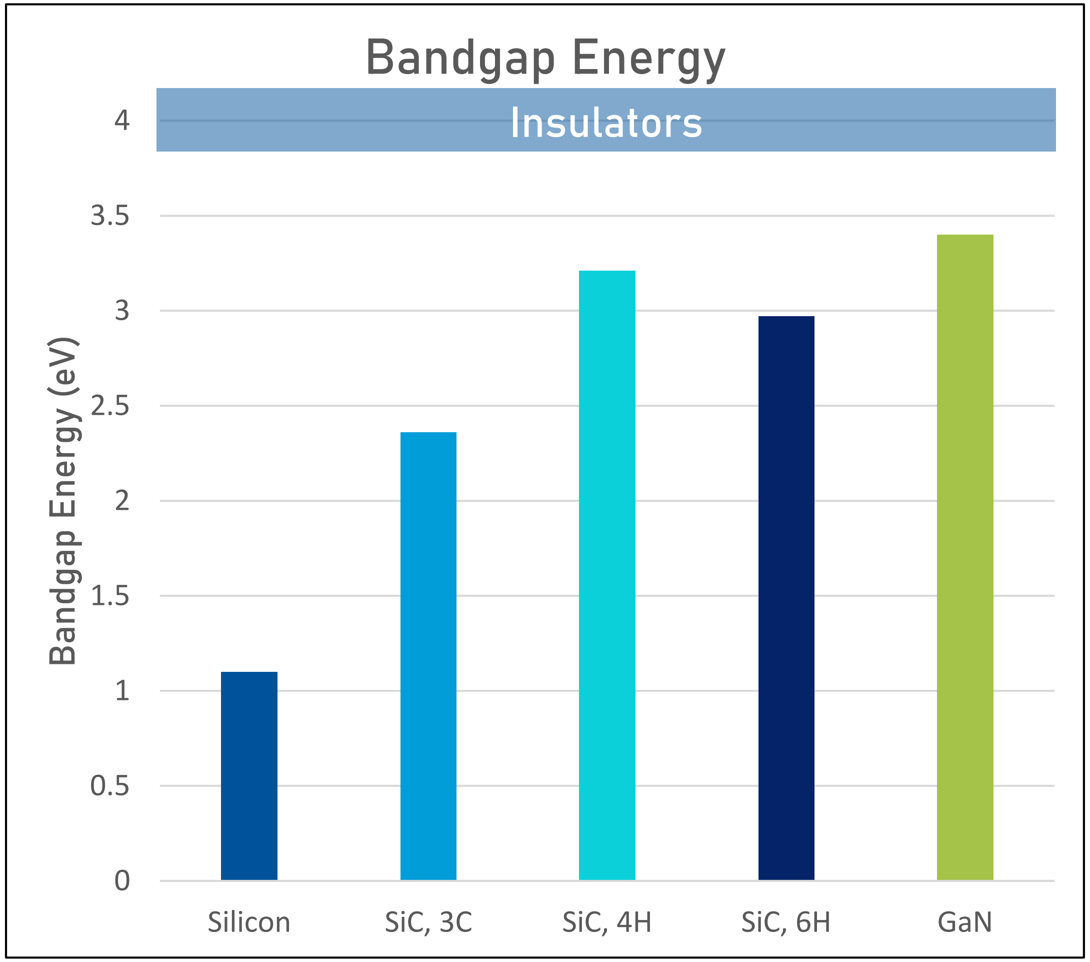
WHAT IS SILICON CARBIDE?

- First used as a commercial semiconductor in 1906
  - Same year as Silicon
- Made by passing current through molten Silica/Carbon mixture
- Incredibly hard material, commonly used in abrasive tools, disc brakes



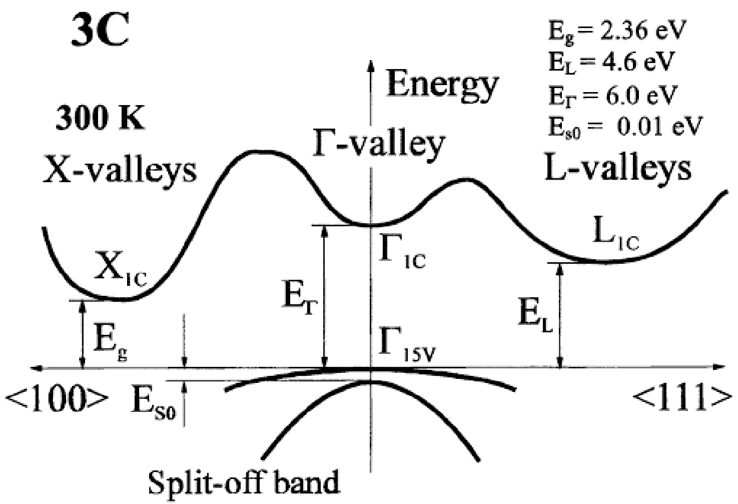


BANDGAP ENERGY

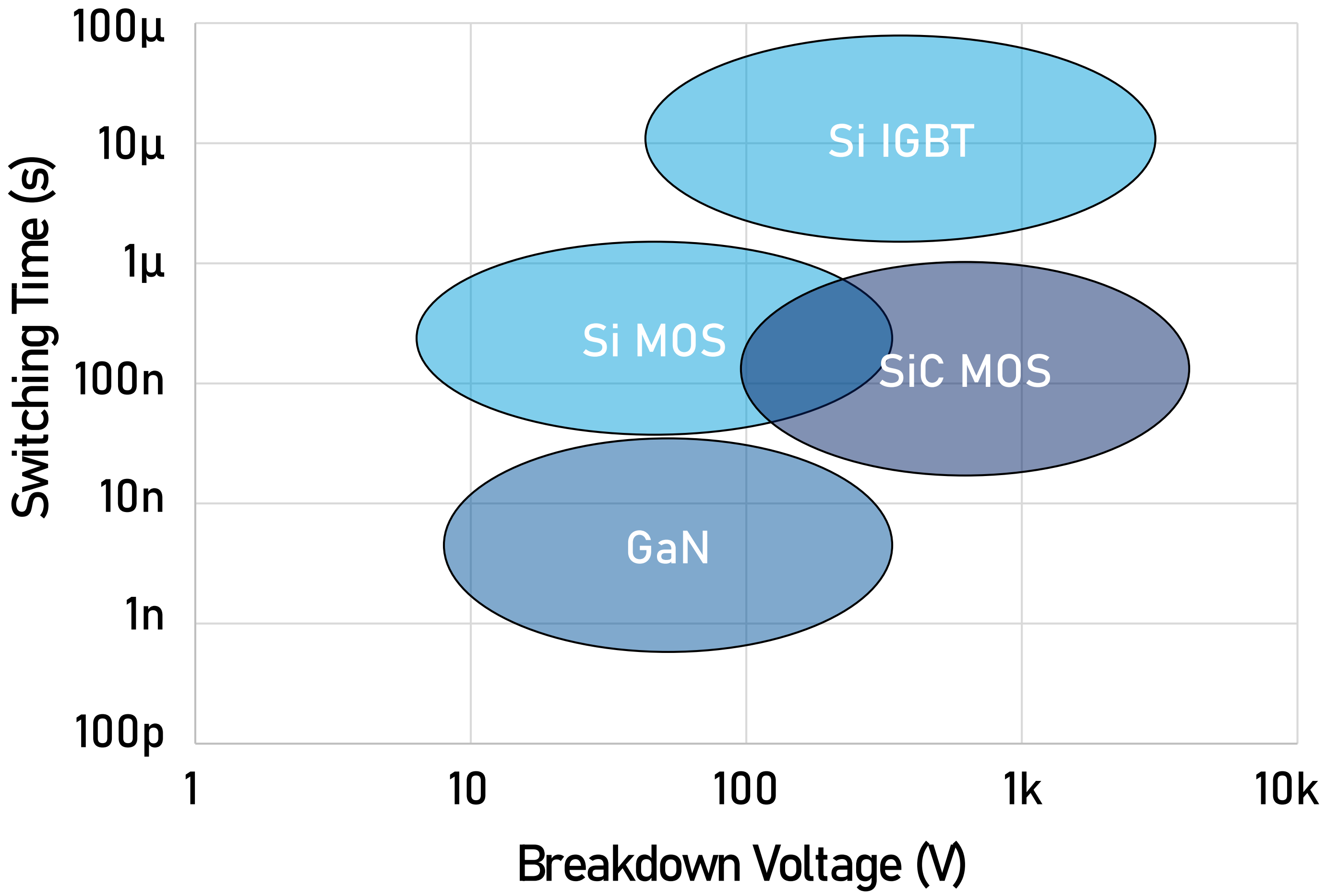


SiC has up to 3 times higher bandgap energy than Silicon

- 10 times higher breakdown voltage
- Operation up to 1000°C



TECHNOLOGY COMPARISON



SILICON CARBIDE

Si 60V 120A 10mΩ 83ns

SiC 600V 120A 10mΩ 83ns

SiC offers higher voltage and temperature than equivalent Silicon FETs

- OR -

SiC offers HV FETs with LV specs (superior switching times and $R_{DS(ON)}$)

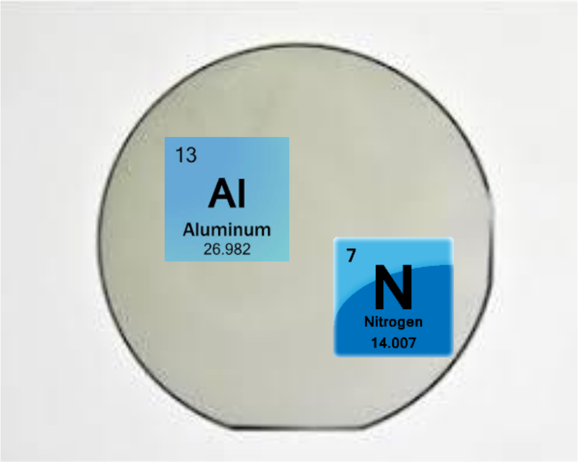
Si 650V 10A 1Ω 85ns

SiC 650V 100A 30mΩ 40ns

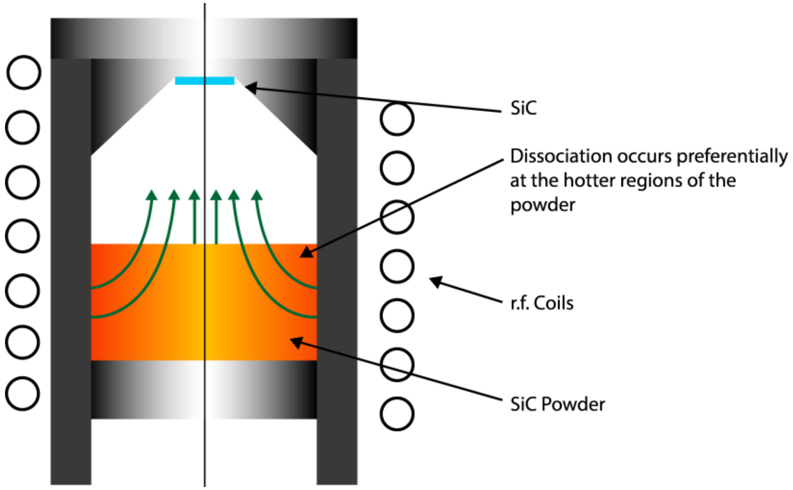
Most processing is identical to that of Silicon except:

- Crystal Growth - Physical Vapor Transport vs Float-Zone
- Wafering & polishing - very hard material
- Epitaxy - different dopants than Si

Epitaxy Materials



PVT Process

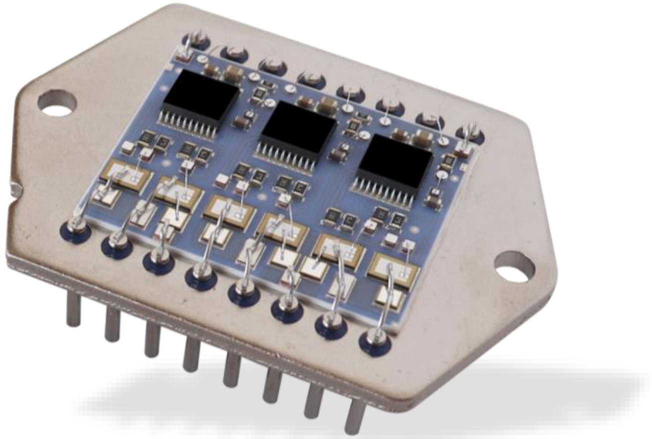


Polished Wafers

BENEFITS OF SiC IN A HYBRID ARCHITECTURE

WHAT IS A HYBRID CIRCUIT?

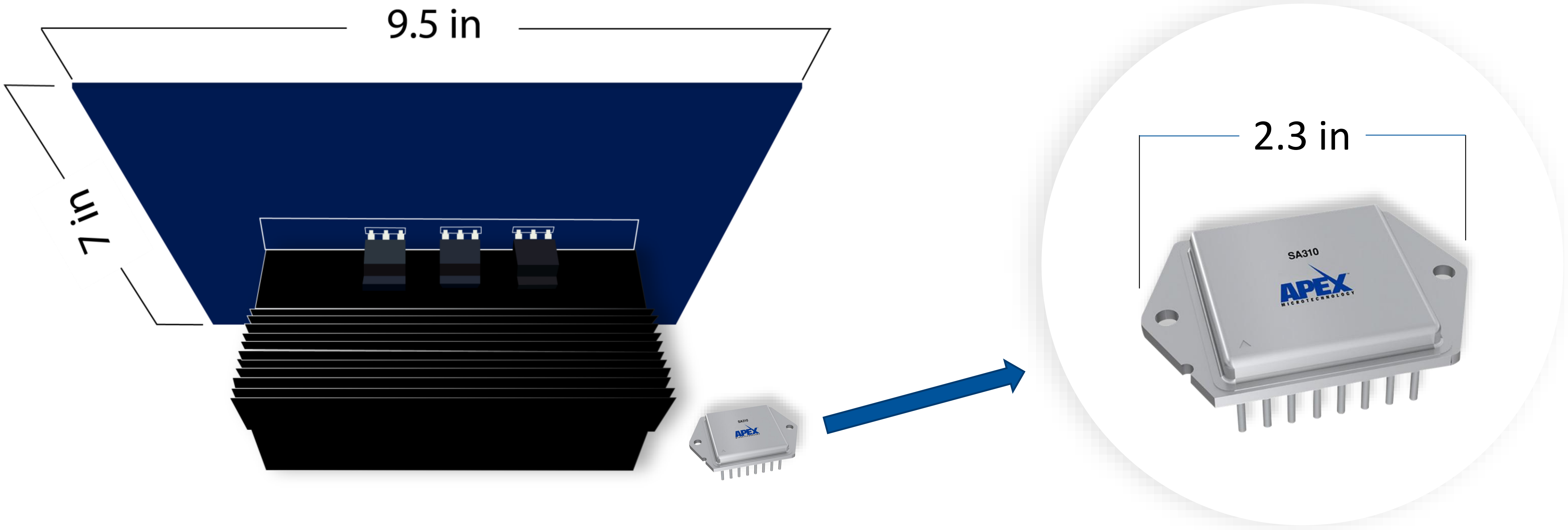
"electronic subassemblies [...] that can be fabricated as a separate module." - Motorola



Hybrids typically include:

- Ceramic substrate
- Bare-Die components
- Wirebonds
- Thickfilm-printed conductors, resistors, and insulators

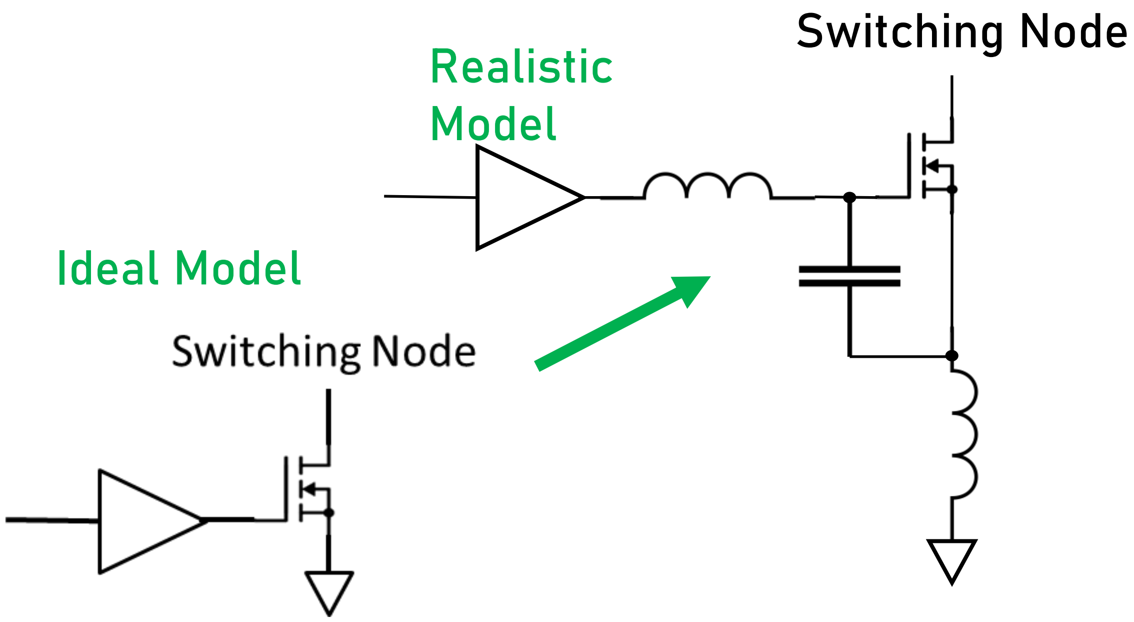
ADVANTAGES OF HYBRID TECHNOLOGY

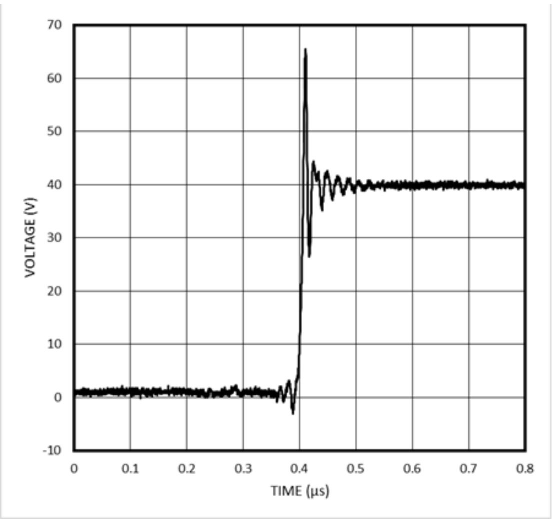


Bare Die allow for more dense circuit construction

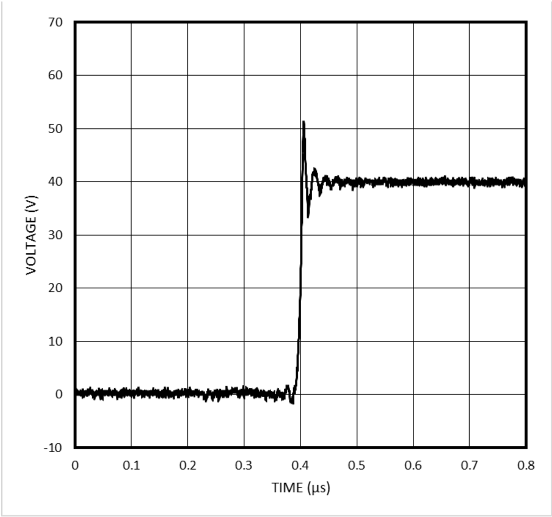
Parasitics

Parasitic inductance in the gate-source loop is optimized over a discrete design.





Non-Integrated SiC Module



Apex Integrated SiC Module

ADVANTAGES OF HYBRID TECHNOLOGY

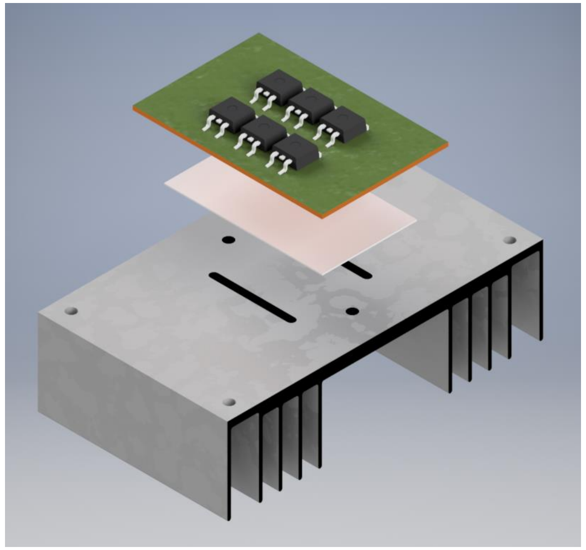
Power Density

- Substrate choices make it easier to get the heat out
- Higher Thermal Conductivity leads to:
  - Lower temperature rise per Watt
  - More Watts per Cubic Centimeter

Material	Thermal Conductivity (W/m-K)
Copper	400
Beryllium Oxide	290
Aluminum	170
Aluminum Nitride	170
Aluminum Oxide	30
Silicon Nitride	30
FR-4 with Thermal Vias	16
FR-4	0.29

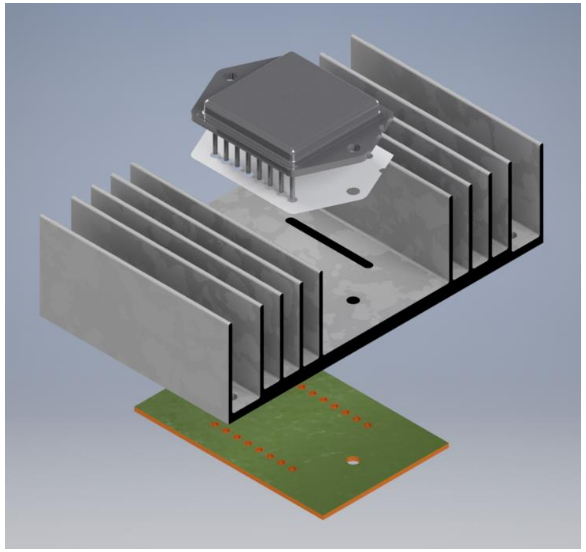
Blue = Ceramic Material

DESIGN EXAMPLE – 650V SiC 30mΩ 3-PHASE MODULE



Discrete D²PAK Design

$R_{\theta JA}$ = 3.81 °C/W
$T_{Junction}$ = 175 °C
$P_{delivered}$ = 8.2 kW



Hybrid

$R_{\theta JA}$ = 2.38 °C/W
$T_{Junction}$ = 175 °C
$P_{delivered}$ = 11.2 kW

37% More Power Output!

SILICON CARBIDE IN HYBRID ASSEMBLY- SUMMARY

- All else being equal, Hybrids offer the exact same advantages as Silicon Carbide
- Combining these technologies leads to compound benefits

	HYBRID	DISCRETE
Power Output	Higher	Lower
Power Density	Higher	Lower
Circuit Size	Smaller	Larger
Heatsink Size	Smaller	Larger
Switching Losses	Lower	Higher

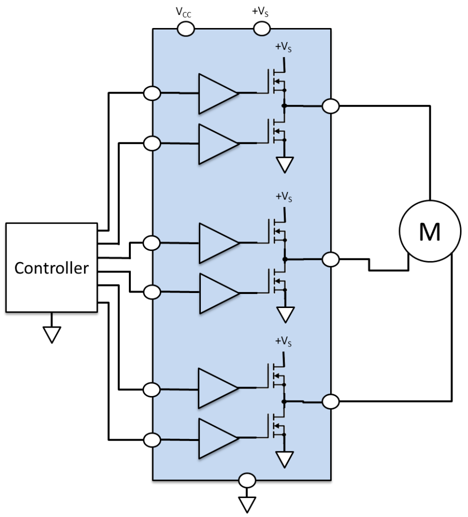
HOW TO CONTROL APEX SiC PRODUCTS

Interfacing with an integrated Motor Drive module

TYPES OF APEX MOTOR DRIVE MODULES

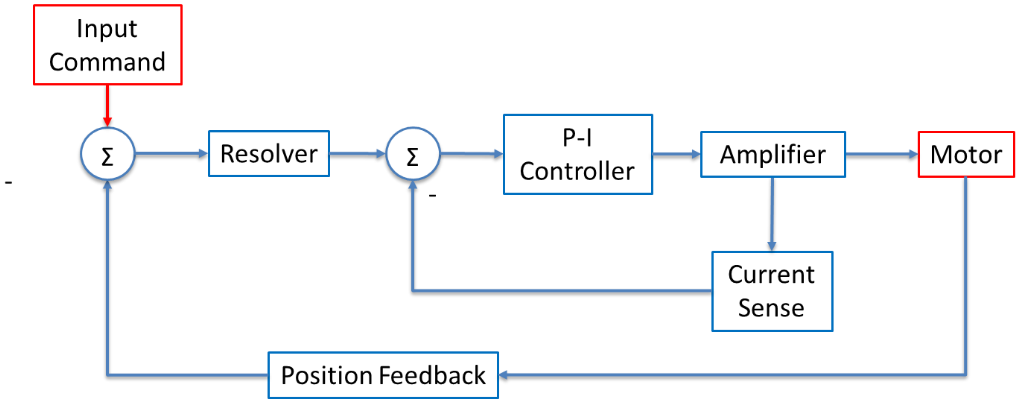
Standard Modules

- User sends signals to turn each switch on/off.
- Closed-loop control created externally



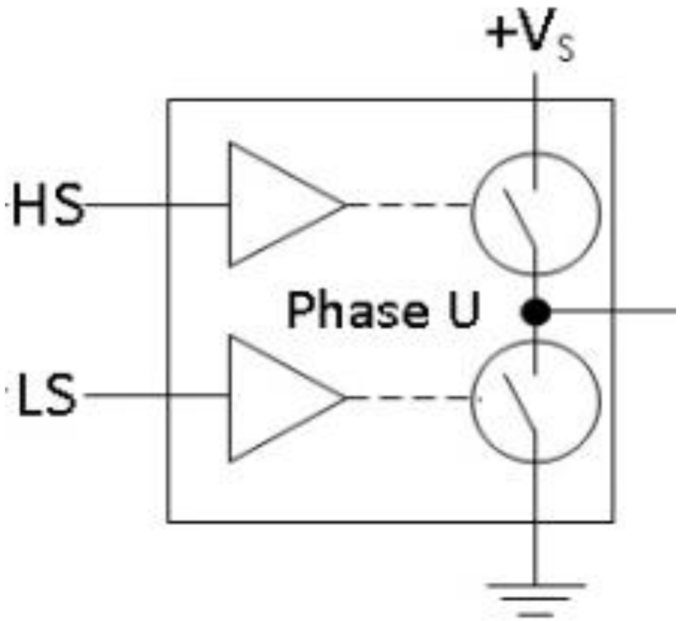
Mixed Modules

- User sends commands to activate several functions
- Closed-loop control managed by the module



OUTPUT STATES

Truth table for controlling the output state



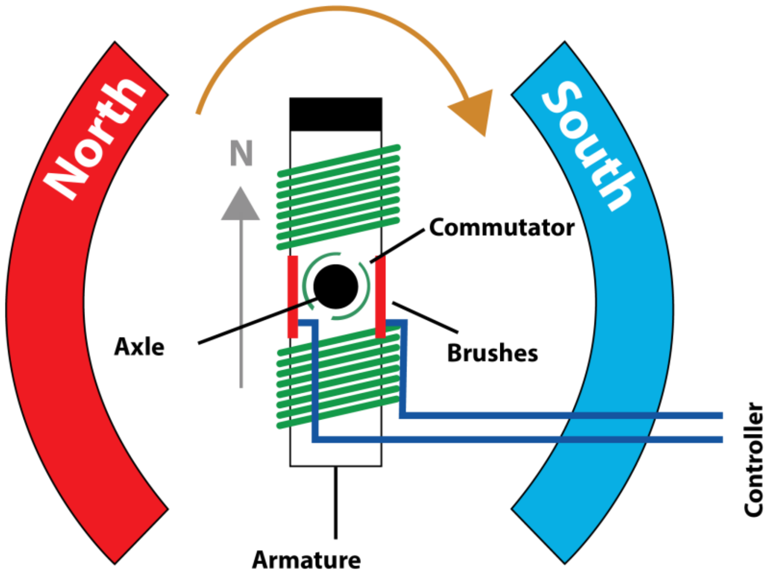
HS input	LS input	Output State
0	0	High-Impedance (HZ)
0	1	Ground (0)
1	0	High-Voltage (1)
1	1	Do not use

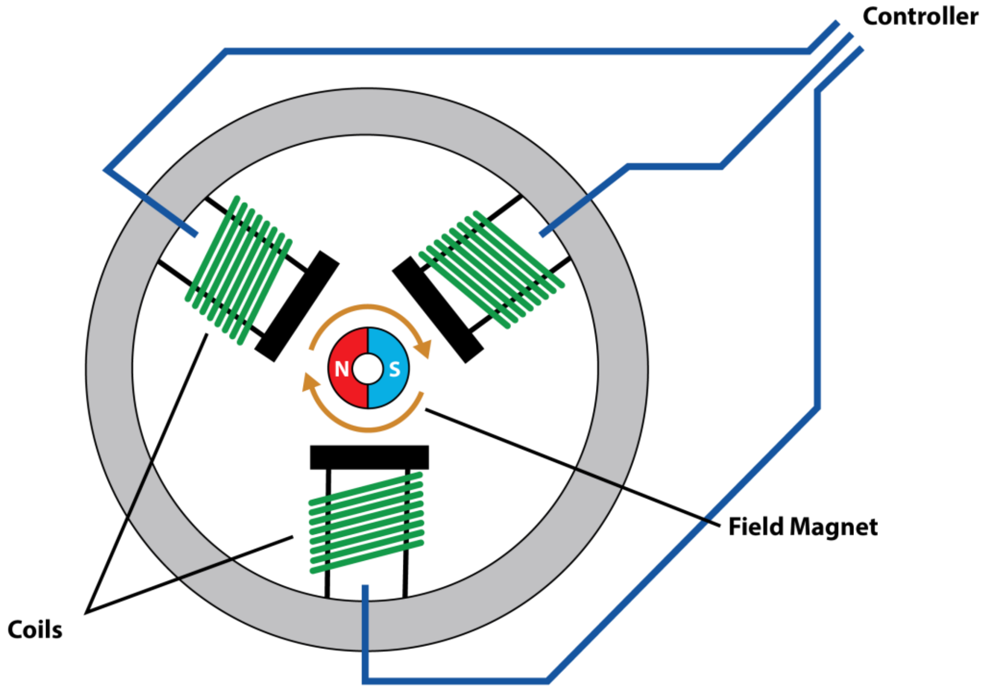
COMMUTATION SCHEMES FOR MAXIMIZING MOTOR EFFICIENCY

Sequencing the output states for various applications

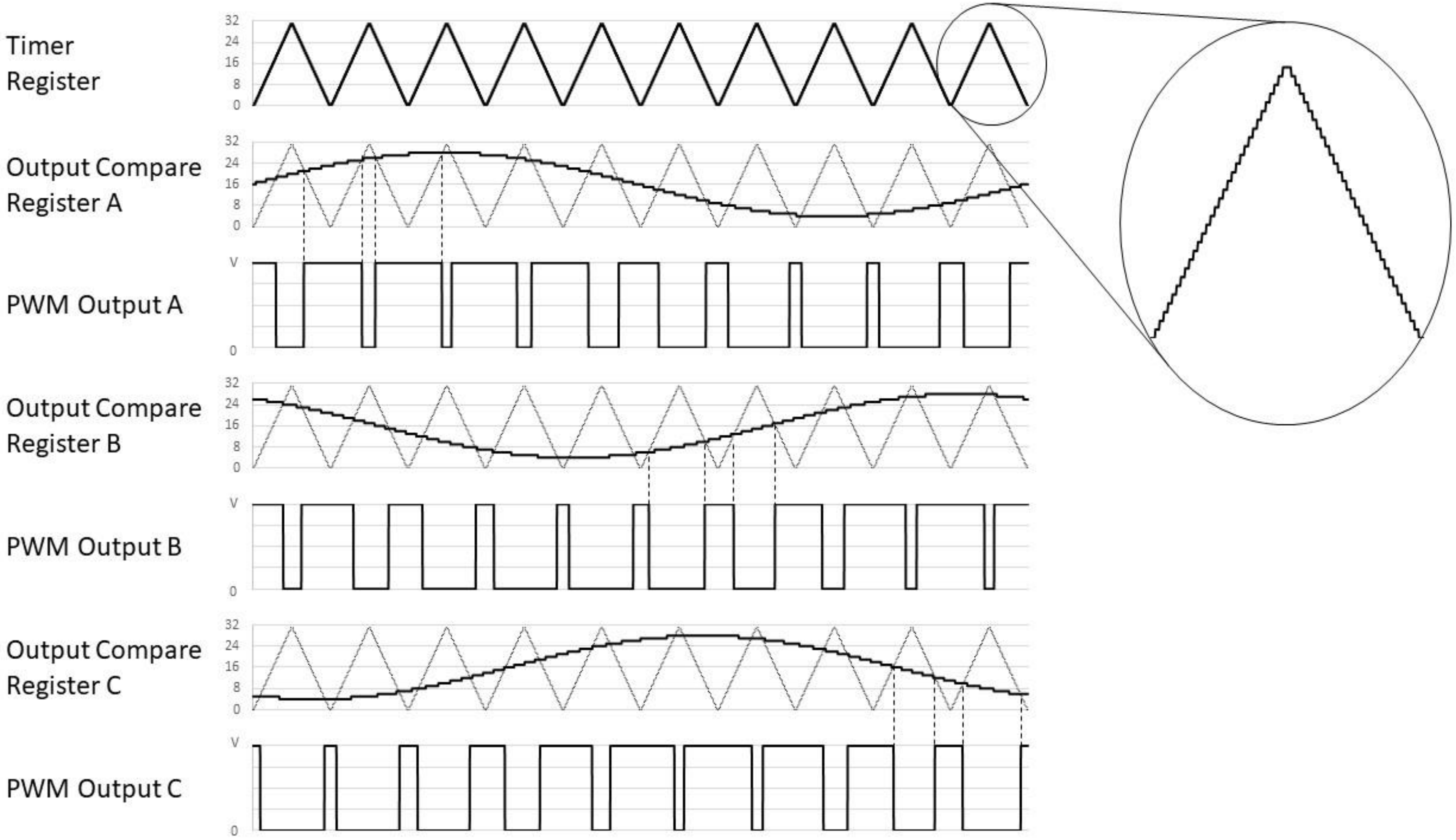
BRUSHED VS. BRUSHLESS

Brushed DC Motor	Brushless DC Motor
Mechanically Commutated	Electrically Commutated





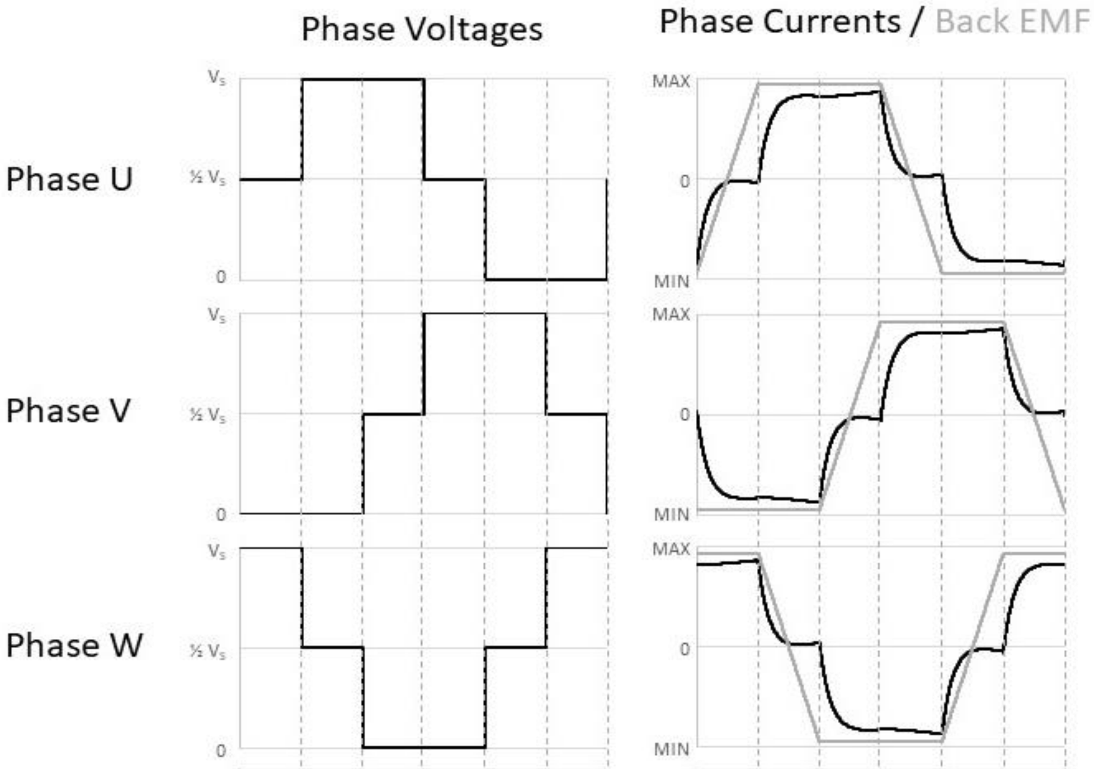
SINUSOIDAL COMMUTATION



- Requires Most Complicated Controller Hardware.
- Recommended for PMSMs.
- Low Torque Ripple.
- Limited to Low RPMs.
- Requires Encoder

TRAPEZOIDAL COMMUTATION

- Simplest Method – no dead-time required.
- Recommended for most BLDC motors.
- Low-speed torque is a challenge – use for high RPM applications
- Pairs well with Hall-effect sensors

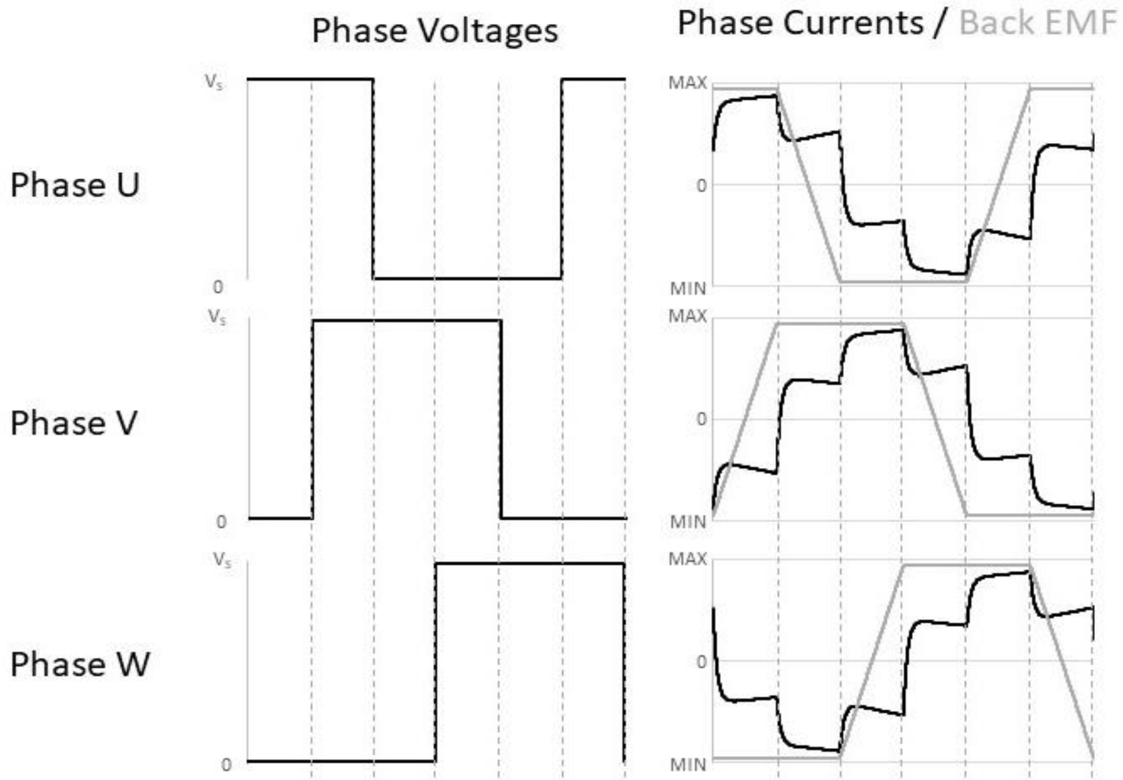


Phase U	HZ	1	1	HZ	0	0
Phase V	0	0	HZ	1	1	HZ
Phase W	1	HZ	0	0	HZ	1

HZ	1	1	HZ	0	0
0	0	HZ	1	1	HZ
1	HZ	0	0	HZ	1

SIX-STEP COMMUTATION

- Simple, but does require dead-time
- Good option for BLDC motors
- Offers smoother torque than trapezoidal – energizes more phases.
- Pairs well with Hall-effect sensors



Phase U	1	1	0	0	0	1	1	1	0	0	0	1
Phase V	0	1	1	1	0	0	0	1	1	1	0	0
Phase W	0	0	0	1	1	1	0	0	0	1	1	1

APEX
MICROTECHNOLOGY
PRECISION • POWER • ANALOG