TECH DAYS
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BLDC Motor Drivers: Integration Advantages and System Improvements

Motor Drives

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Training summary

BLDC Motor Drivers: Integration Advantages and System Improvements

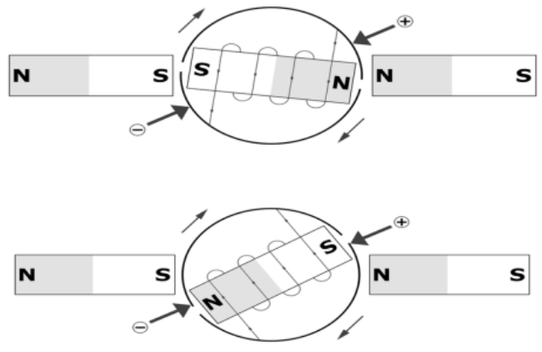
This presentation will help designers and engineering managers understand the key technologies used in BLDC motor drivers. The motor driver technologies that will be discussed are sensored, sensorless, single hall operation, adaptive drive angle advance, initial position detection and acoustic improvements. This background is useful for determining the improvement that can be made using TI's integrated motor driver solutions.

Agenda

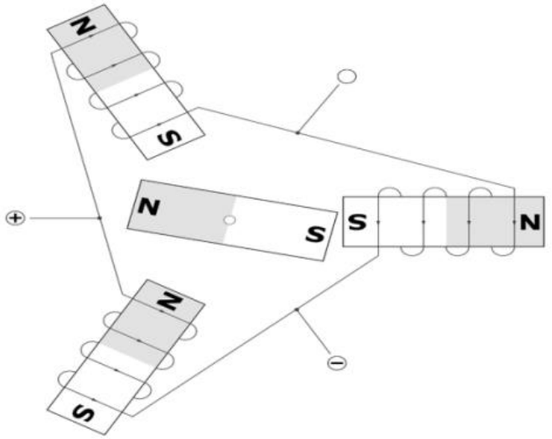
- BLDC Motor basics and operation
- BLDC Commutation Methods
- Advanced Algorithm
- DRV10x Devices Overview

The Brushless DC (BLDC) Motor

- A “normal” DC (brush) motor moves by reversing the current through the windings using switch contacts, comprised by the commutator (mounted on the armature) and brushes (fixed to the motor shell).
- A BLDC motor does not use brushes and a commutator – instead, commutation is performed electronically by switching the current with transistors/FETs.
- Rotor position is usually either sensed (“Hall-Effect” sensors) or measured or estimated .
- BLDC motors have several phases (coils). Most common motors are 3-phase motors (3 sets of windings. Example shown would be a 2-pole motor – the magnet has 2 poles (N and S) and 3 windings (phases).



Brushed motor



Brushless motor

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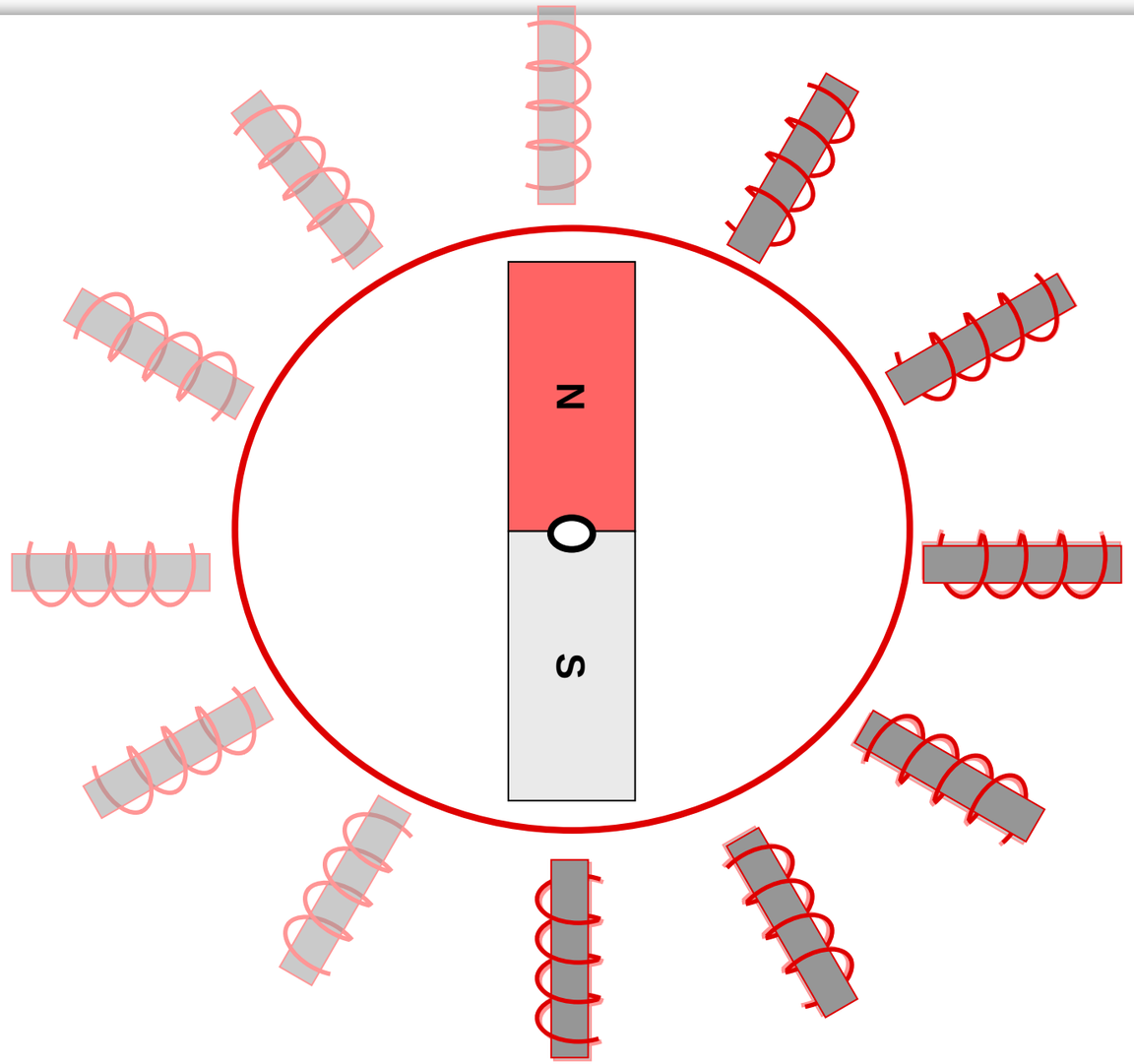
Easy model of BLDC Motor

Stationary electrical magnets are evenly distributed around the frame.

Successively inject current to each coil, generating moving magnet field.

This is the easy model of BLDC Motor.
It achieves the converting from
Electrical energy to Mechanical energy.



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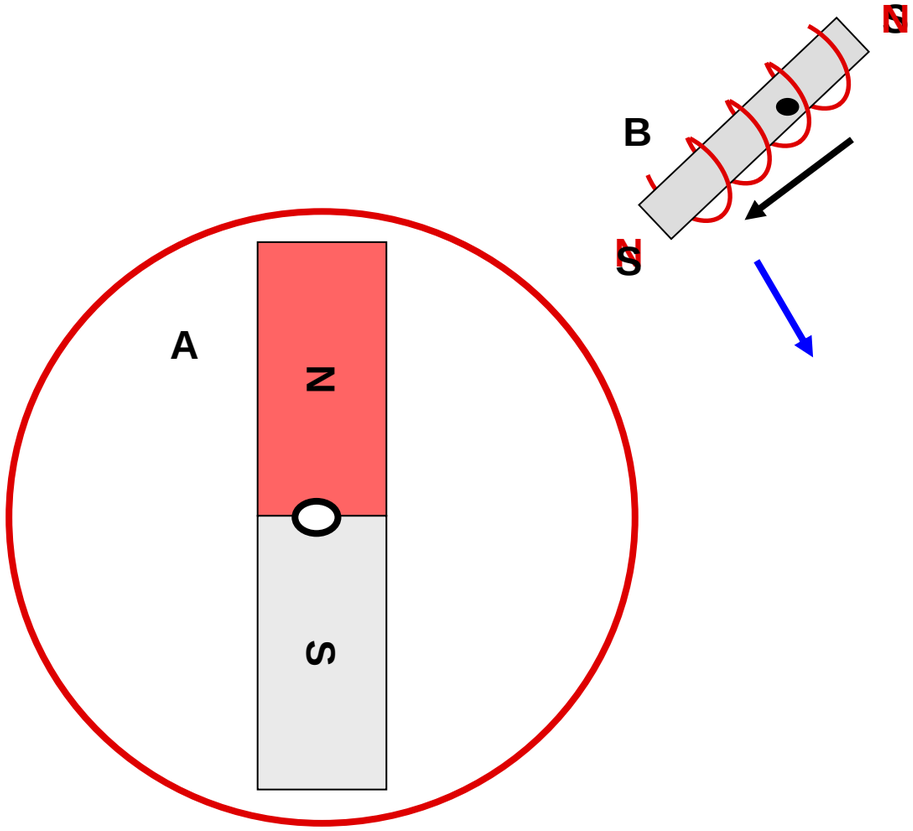
Electromagnetic Theory

Instead of permanent magnet, electro magnet can be used (Coil)



Furthermore there are several advantages.

1- Direction is changeable.

2 - Strength is changeable.

The magnet A is called Rotor. And B is called Stator. However in this figure B is not stationary.

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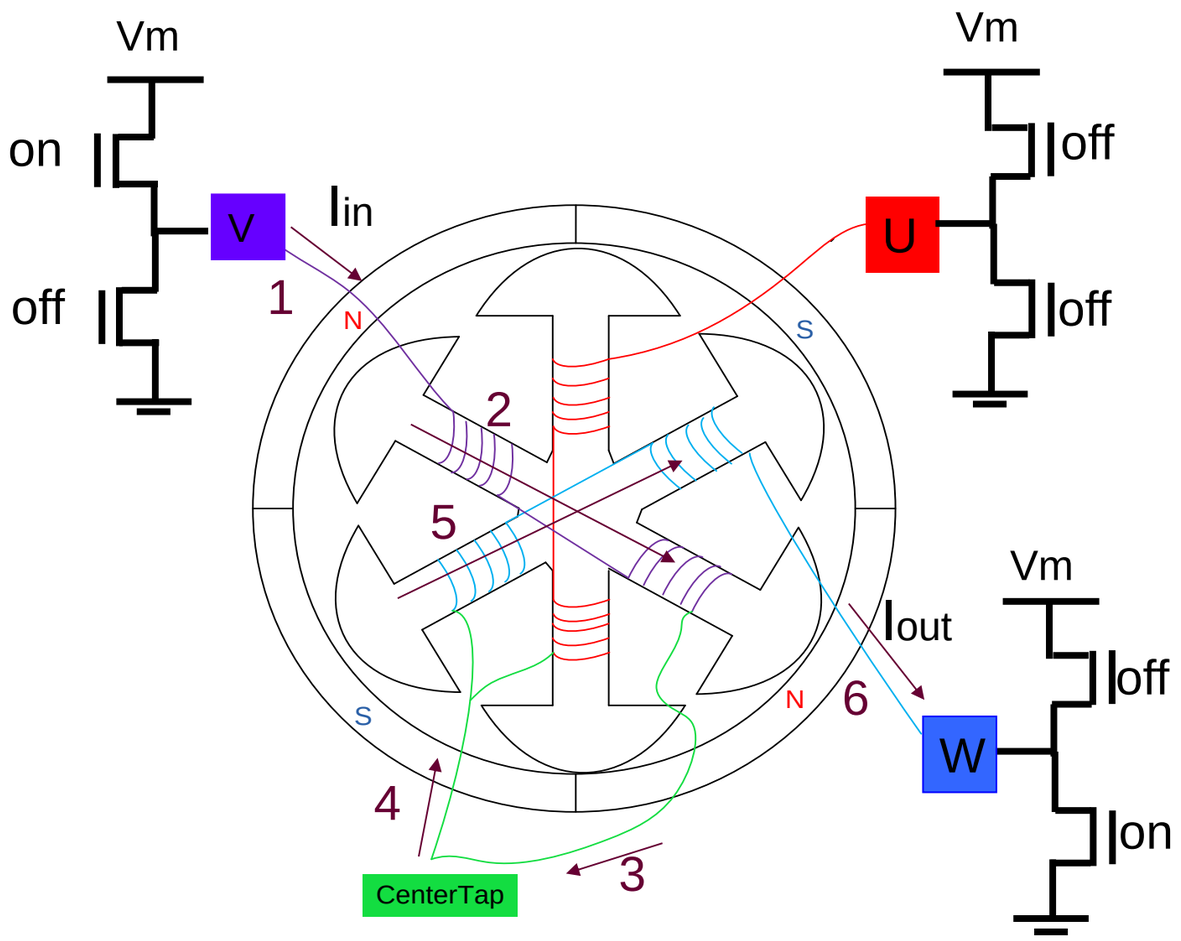
BLDC Motor Commutation Methods

BLDC Motor Operation



- 6 different commutation cycle (electrical cycle) to move rotor between 2 poles. (rotor position relative to stator is exactly same for every poles away)

- For 4 poles motor, commutation controller needs goes through 2 electrical period for one mechanical revolution.
  - 1 mechanical revolution = 2 electrical cycles
  - 2 electrical cycles = 12 commutation states

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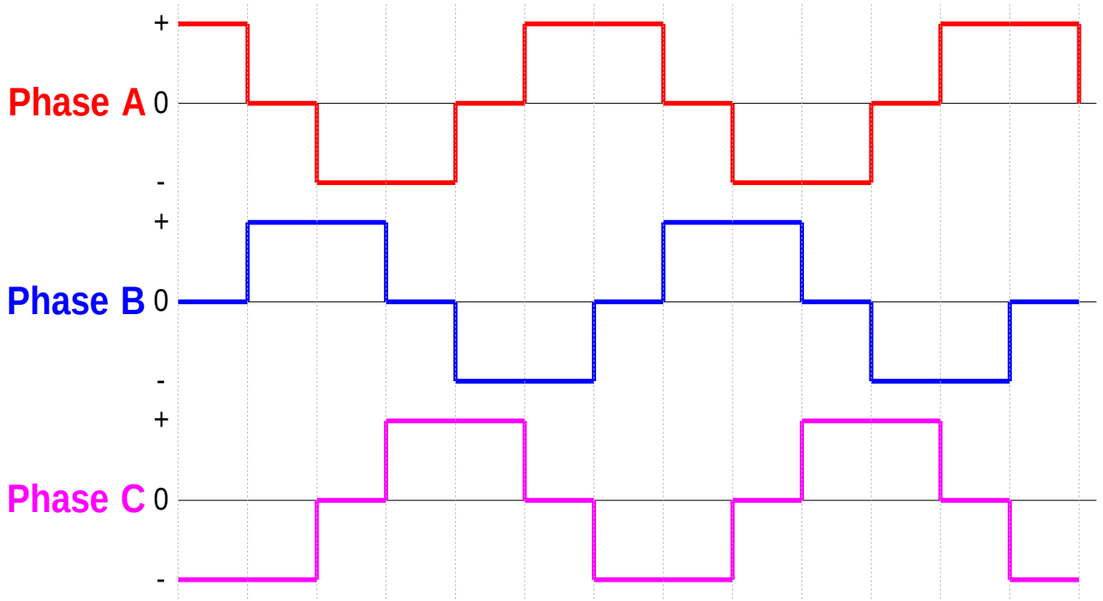
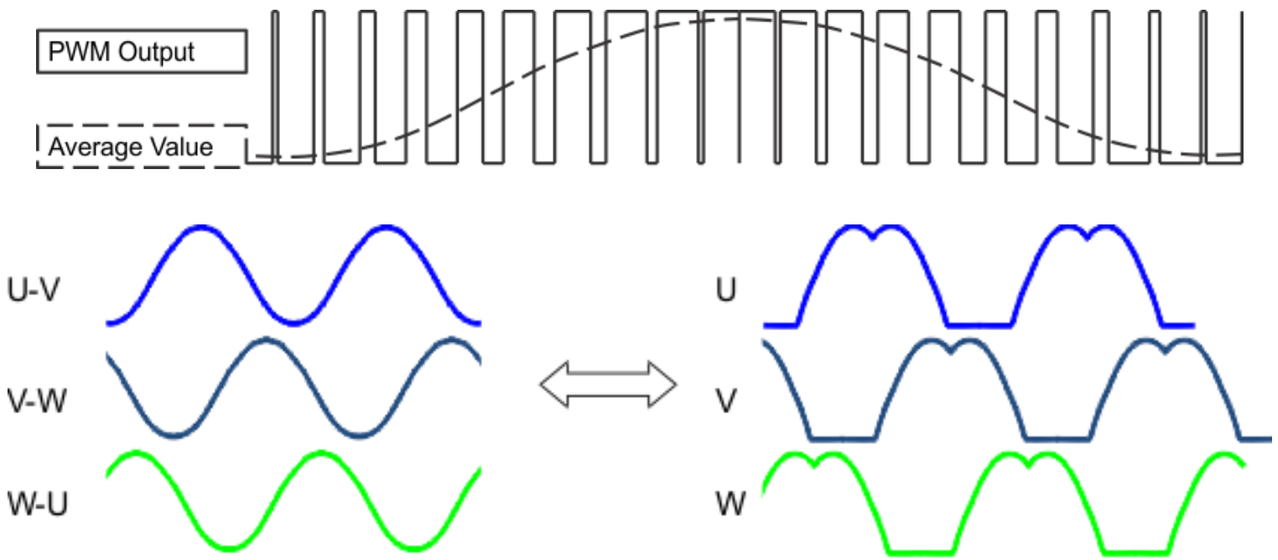
Trapezoidal commutation v/s Sinusoidal Commutation





6 Step Trapezoidal Control:
2x Phases always on / 1x Phase off

- **Easy control and requires less processing power**
- **Torque ripple is higher**

Sinsusoidal with third harmonics

- **Control can be complicated and requires more processing power**
- **Less torque ripple – Higher efficiency**

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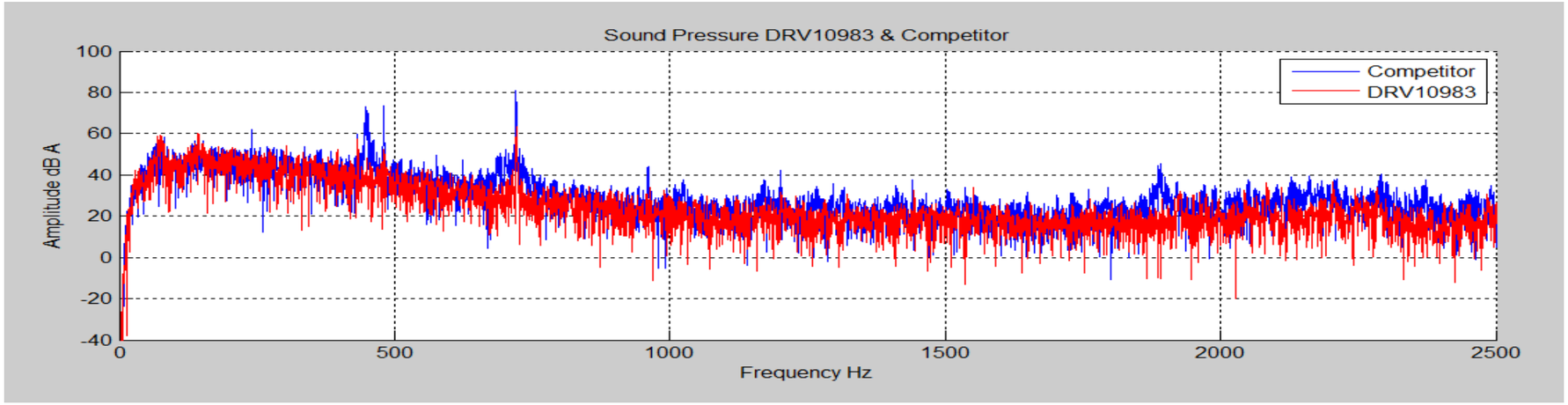
Trapezoidal commutation v/s Sinusoidal Commutation

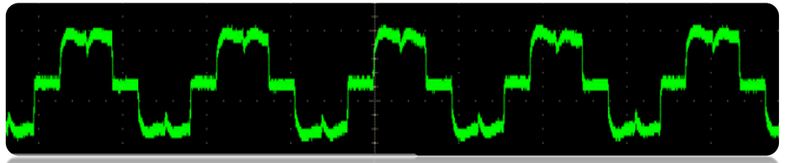


- More Acoustic noise
- Simpler algorithms
- Can operate at higher speed

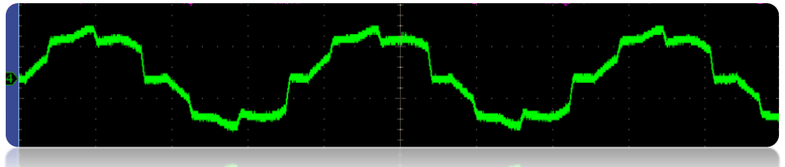
- Less Acoustic Noise
- Complicated algorithms like FOC, 180º sinusoidal
- Max speed is limited by PWM frequency

Performance: Driving Methods vs. Acoustics

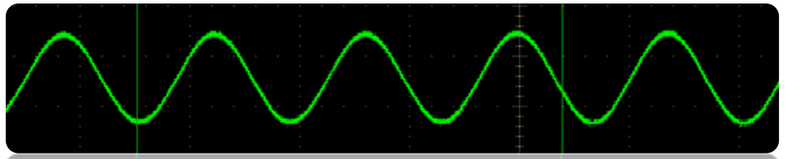
120° phase current

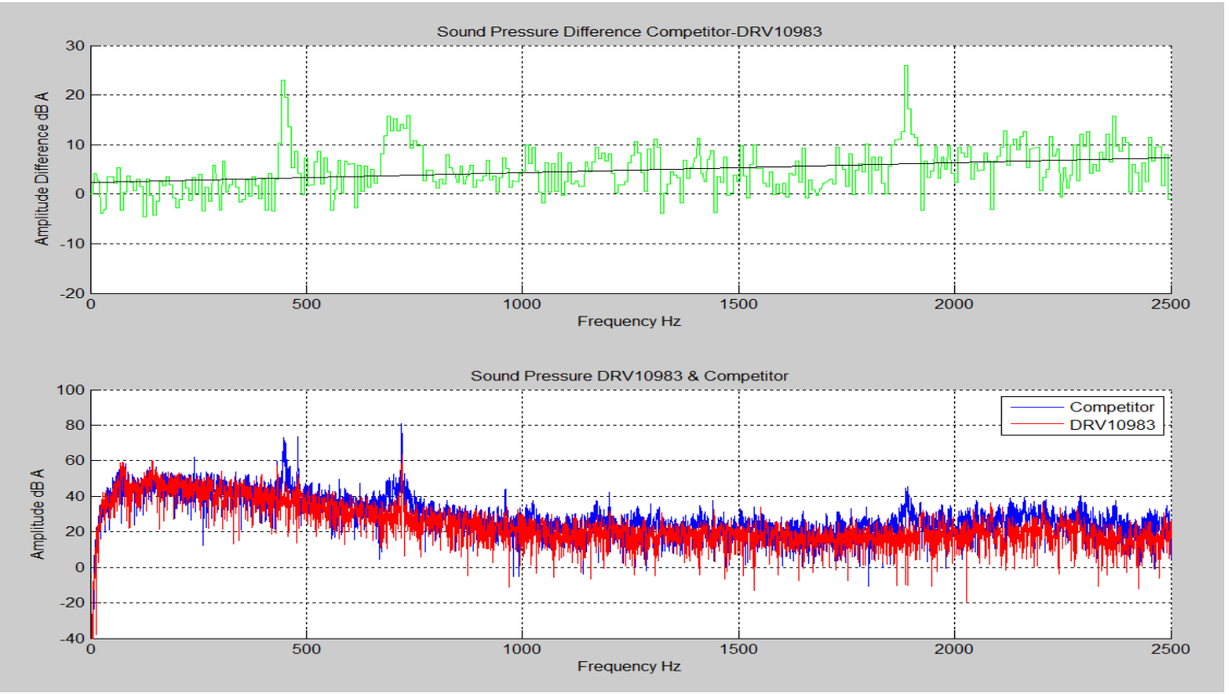


150° phase current



180° phase current sinusoidal



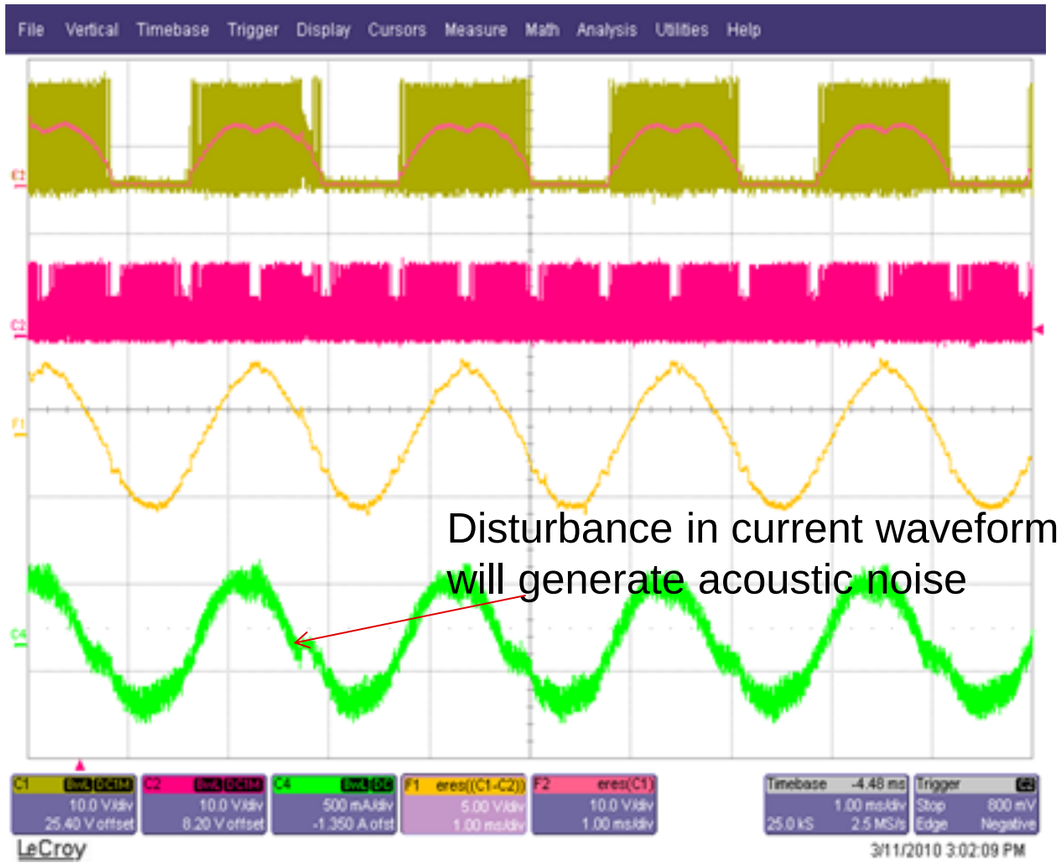


Various Drive Methods Are Available

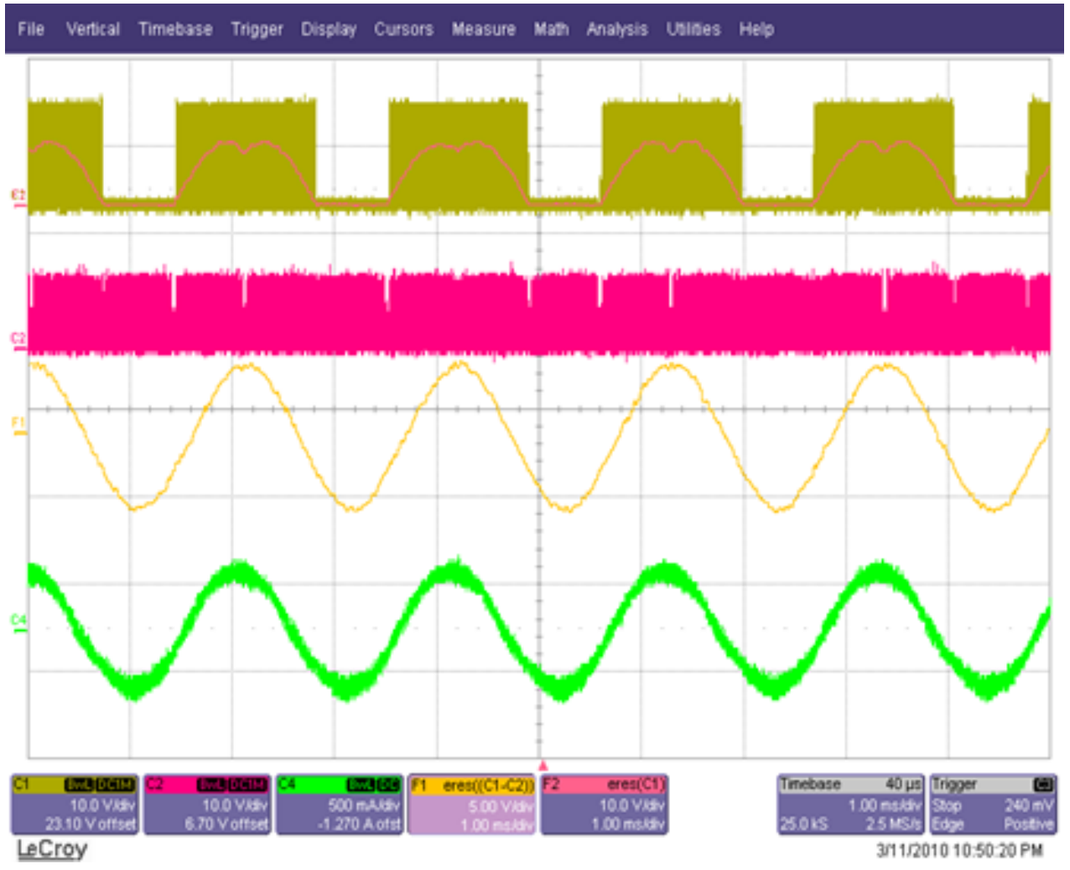
Pure Tone Acoustics Are Significantly Reduced When Using Sinusoidal Drive

170° versus 180° commutation

170° commutation



180° commutation



TI Information – NDA Restrictions

Commutation methods summary

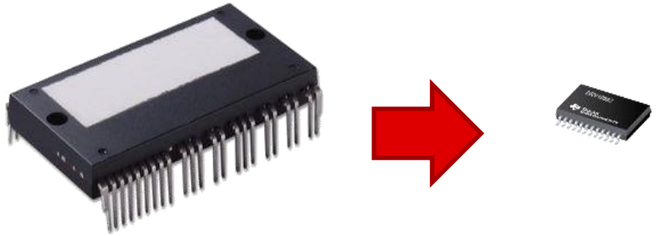
There are multiple commutation methods for driving a three phase BLDC motor.

- **Trapezoidal or 120° operation**
  - Simple
  - Good for very high speed applications
- **Pseudo sinusoidal like 150° or 170° operation**
  - Better acoustic performance
  - Better efficiency
  - More complicated implementation compared to trapezoidal
- **Sinusoidal or 180° operation**
  - Best acoustic performance
  - Best efficiency
  - Most complicated implementation

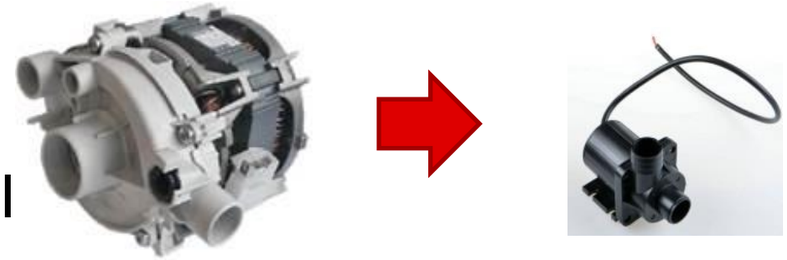
Advantages of Low Voltage BLDC Motors

- ***High Features Integration*:** Smaller package on board, Low RDSON Power MOSFETs, Current sense Amps, Temperature sensor, Integrated DC-DC, LDOs and even motor controller.

- ***Protection Features:*** Cycle by Cycle Over current protection, Over temperature protection, Stall detection, auto restart etc.,



- ***More Safety:*** due to low voltage operation.



- ***Easier Manufacturing:*** Requires lower process technol and saves cost. Smaller Motor size.

- ***Universal Voltage Operating Range***: As the motors are 24V rated, same solution can be used for 110V / 220V line voltage based products for across the globe requirements.

Sensored and Sensor-less BLDC motor design

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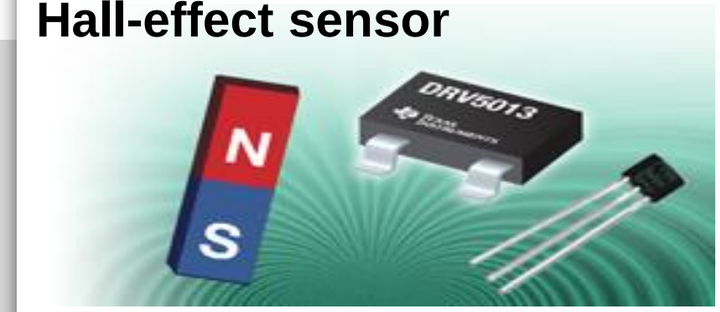
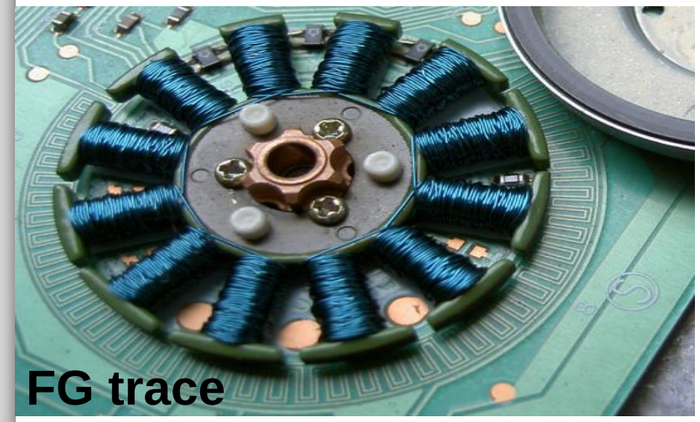
Sensored vs. sensorless detection

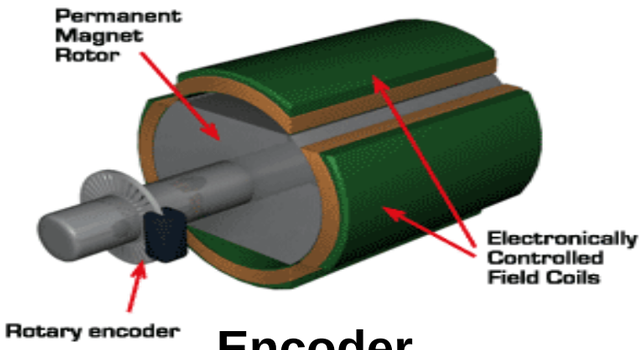
Sensored

Hall-effect sensor





FG trace

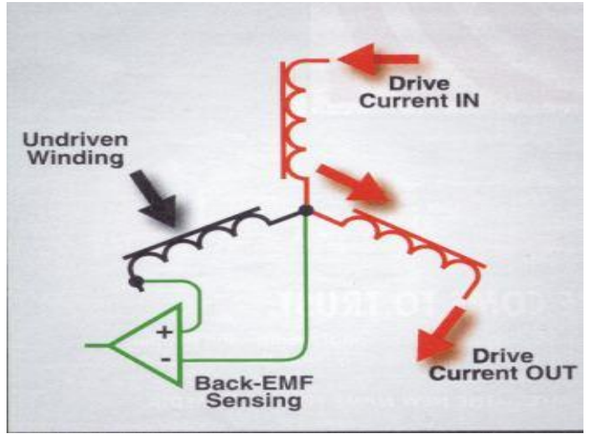


Encoder

Resolver

Sensorless

Motor flux



Back-EMF measurement / estimation

Sensored Control v/s Sensorless Control

- Motor commutation based on feedback from Resolver/Encoder/Hall sensors
- Motor can quickly respond to load changes
- Low speed of operation easier to control
- No backward rotation necessary to find initial position of motor

- Motor commutation based on either estimated/measured BEMF
- Least amount of board space used since no Hall sensors needed
- Easier to connect control circuitry to motor
- Most cost effective, compact solution

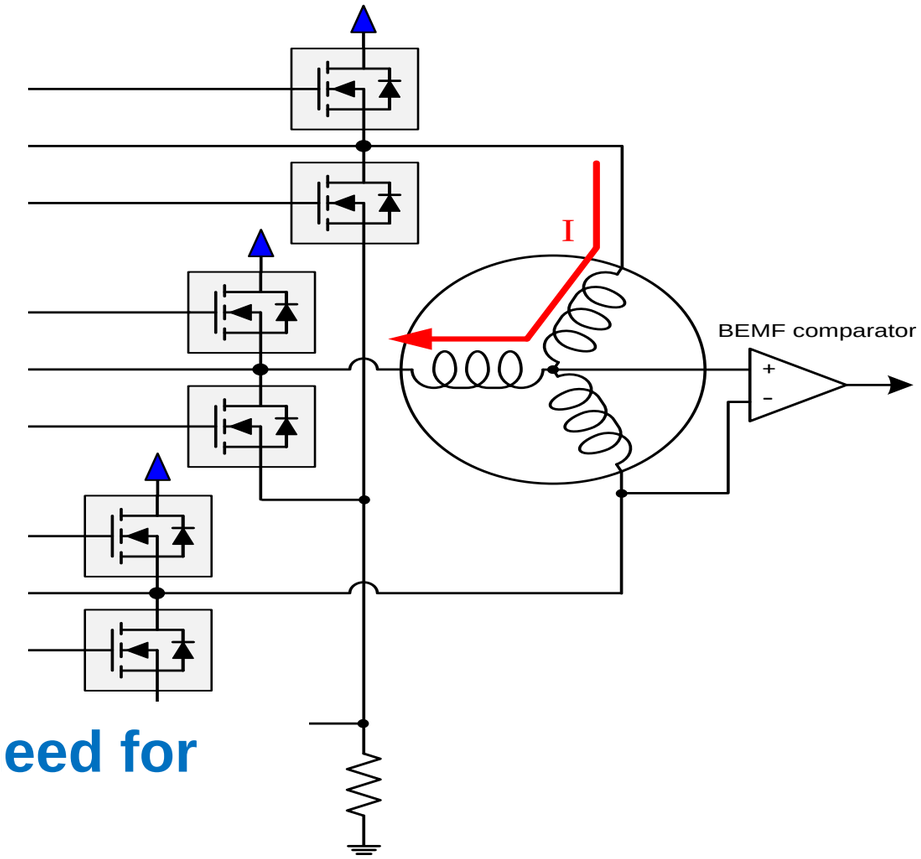
Sensor-less BEMF measurement

Measure the Back-EMF and look for the zero crossing

This gives us 6 transitions per electrical cycle!

This requires some window to measure the Back-EMF where one coil is not being driven

Trapezoidal or 120 ° commutation



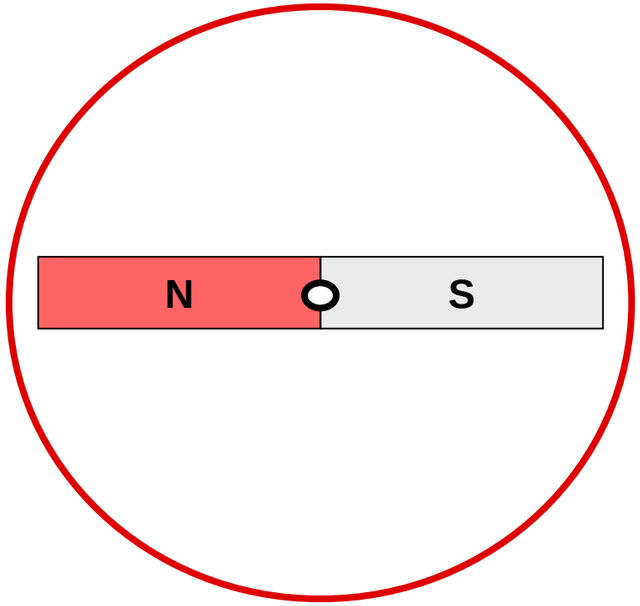
Alternatively, BEMF can be estimated without the need for BEMF zero-crossing detection

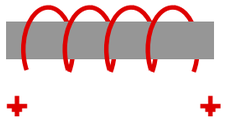
Sensor-less BEMF estimate

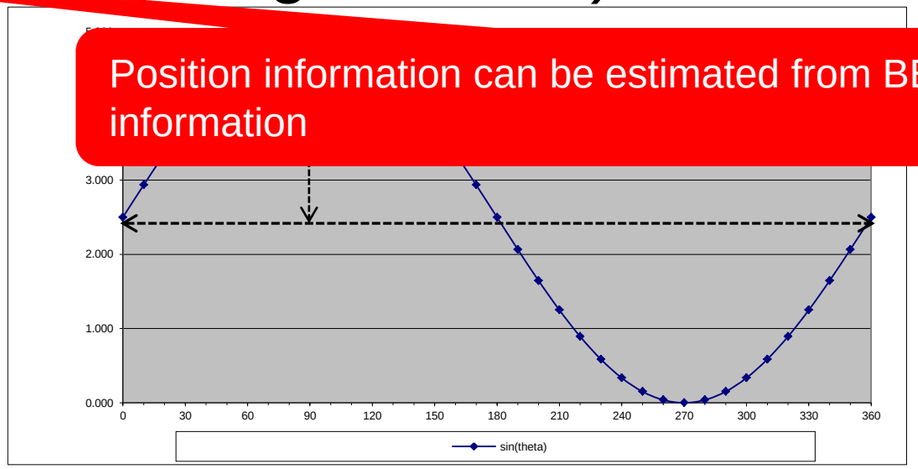
When a motor spins, the permanent magnetic rotor, moving across the stator coils induces a voltage (Back EMF)

BEMF ∝ magnetic Flux * speed.

Position = function(magnetic flux).







Position information can be estimated from BEMF information

Sensor-less BEMF estimate

You need some idea of the motor parameters, terminal voltages, and currents

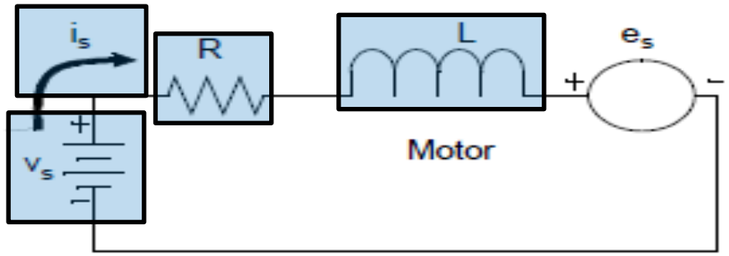
If you know the motor L and R, you can calculate the BEMF if you measure the V and I

In software this block is called a BEMF observer

Since BEMF is very small at low speeds, this method is not good for low Hz rotation

Keep monitoring and check when the zero crossing occurs

Motor model:



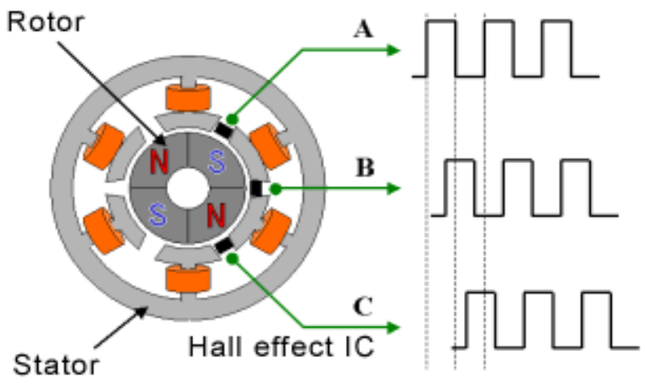
$$v_s = R i_s + L \frac{d}{dt} i_s + e_s$$

BEMF to be calculated

Vs – motor voltage
Is – motor current
R – motor resistance
L – motor inductance

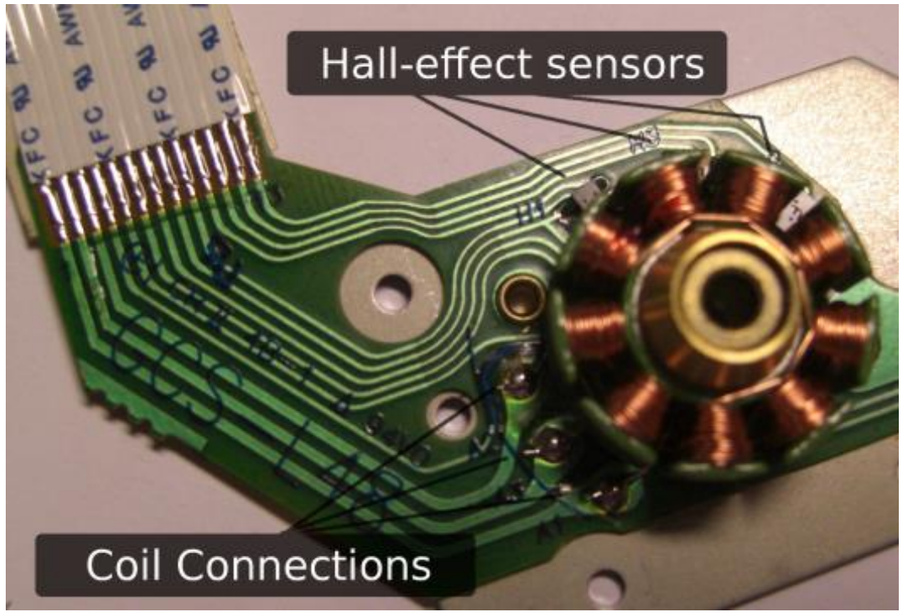
Hall effect sensor

The Hall-effect sensor is measuring the magnetic field produced by the permanent magnet on the rotor

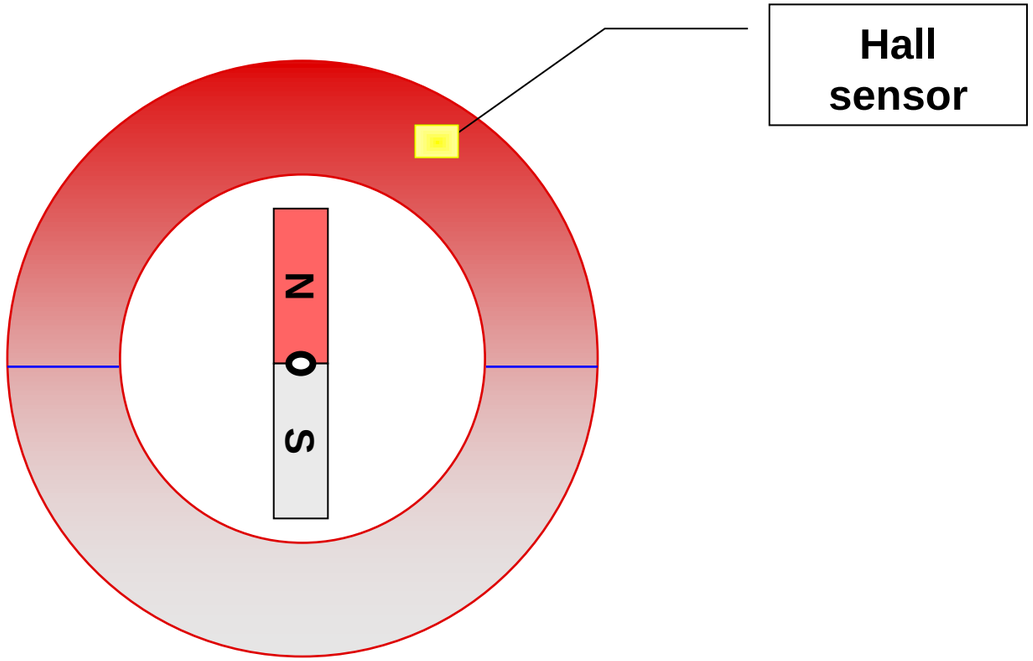


Requires three ICs, but some motors already have hall elements or sensors integrated

You can use one hall-effect sensor for constant speed applications, but all three are still needed for motor startup



How does a hall sensor work

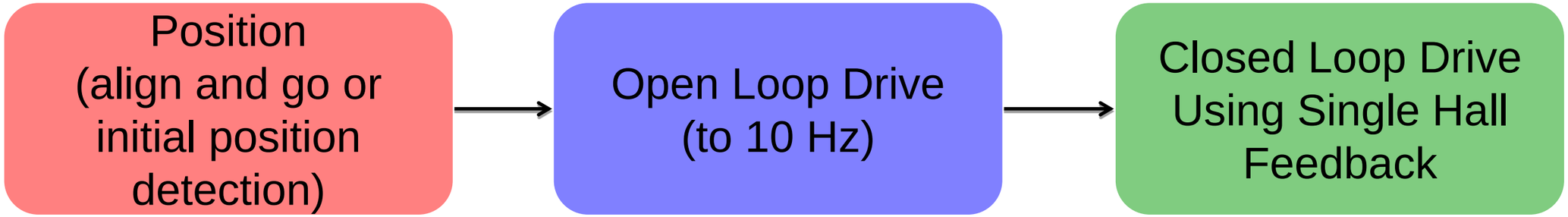


- Hall-effect sensor outputs the 0-1 signal indicating the polarity of magnetic field going throw its surface.
- Hall-effect sensor should be installed at specific location.
- One hall-effect sensor can distinguish the cycle into two parts.

Hall sensor output

Single hall operation

Single hall sensor + initial position algorithm



The system begins with an position detection

Open loop commutation spins the motor up to a hand off frequency

After a handoff frequency, the hall feedback is used to close the commutation control

Advantages: Only one hall 180° sinusoidal

Single hall operation

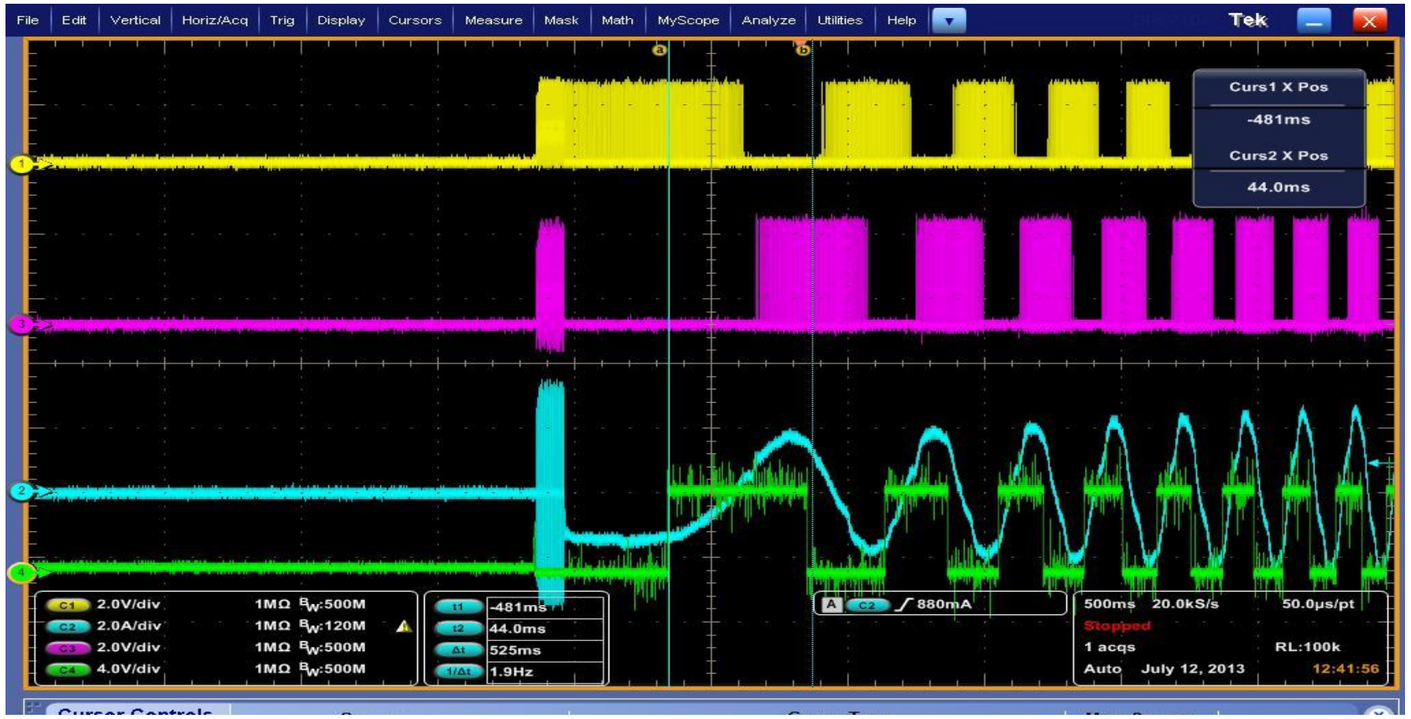
Position (align and go or initial position detection) → Open Loop Drive (to 10 Hz) → Closed Loop Drive Using Single Hall Feedback

U Voltage

V Voltage

Current

Hall Output



Summary of sensing techniques

Sensored Based

- Easy to implement
- Robust for start and run
- High cost
- Low reliability

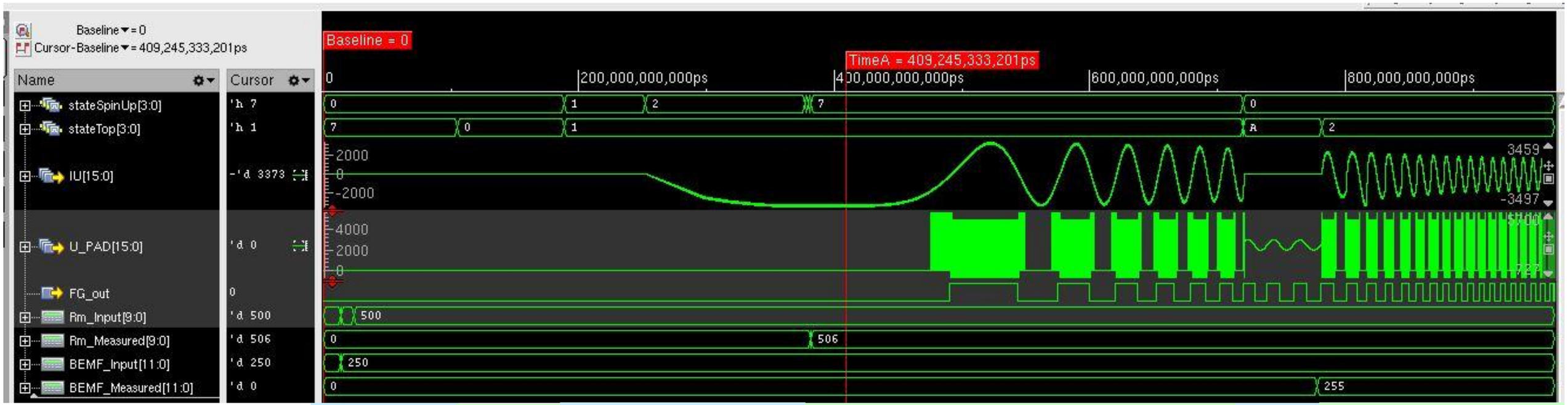
Sensor-less Based

- Low cost
- High reliability
- No physical space restrictions
- Good sealing of connections
- Good manufacturability
- Challenge to determine the initial position

Different Algorithm for BLDC motor

- **Motor Startup** : Initial position detection/Align
- **Acceleration/Deceleration** : Soft start (Open Loop), Anti voltage surge
- **Steady State** : Adaptive Drive Angle.

BLDC Operation



Warm-up	ISD	Position Detection	Open loop	BEMF	Closed loop

TI Information – NDA Restrictions

Startup method - Initial Position Detection(IPD)

Initial motor startup for sensorless algorithm

- BEMF based Sensorless observers needs sufficient level of BEMF to operate accurately
- Initial position is needed to start commutation in open loop

Two methods for initial startup – **Align:** Rotor is aligned to known position

Initial Position Detection: Position of rotor is determined

IPD Algorithm:

- IPD is used to detect initial position of rotor **without rotating it**
- **Benefits to customer:**
  - No reverse spin during startup **(performance)**

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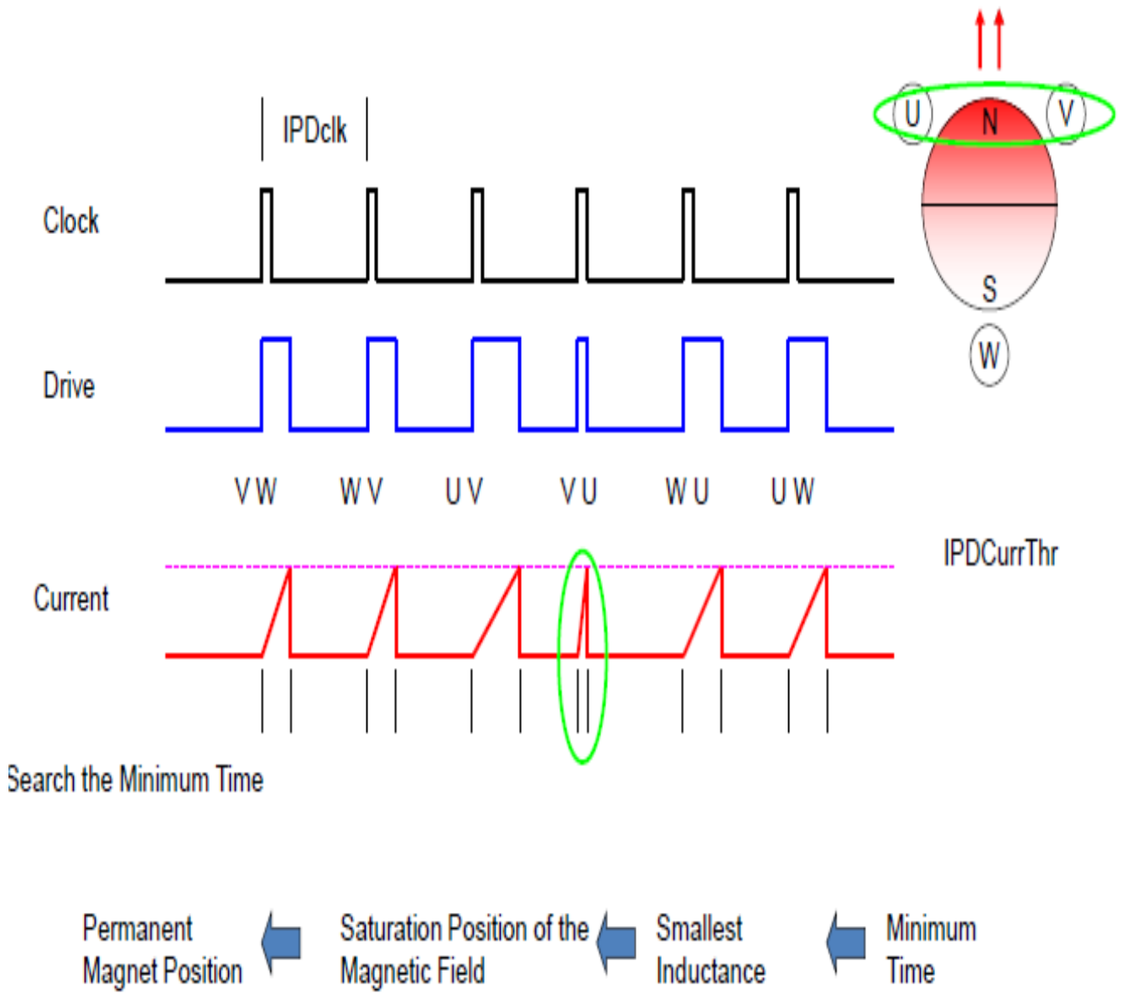
How IPD works

- Voltage application sequence: VW WV UV VU WU UW
- Time is measured until reached threshold
- Shortest time Minimum inductance
- Minimum inductance is because of the alignment of the north pole of the motor with this particular driving state



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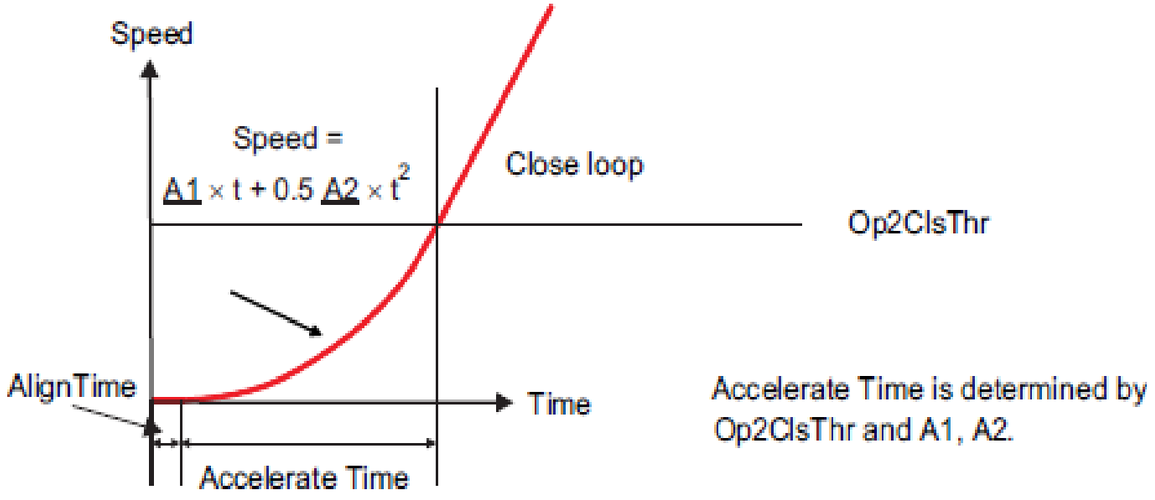
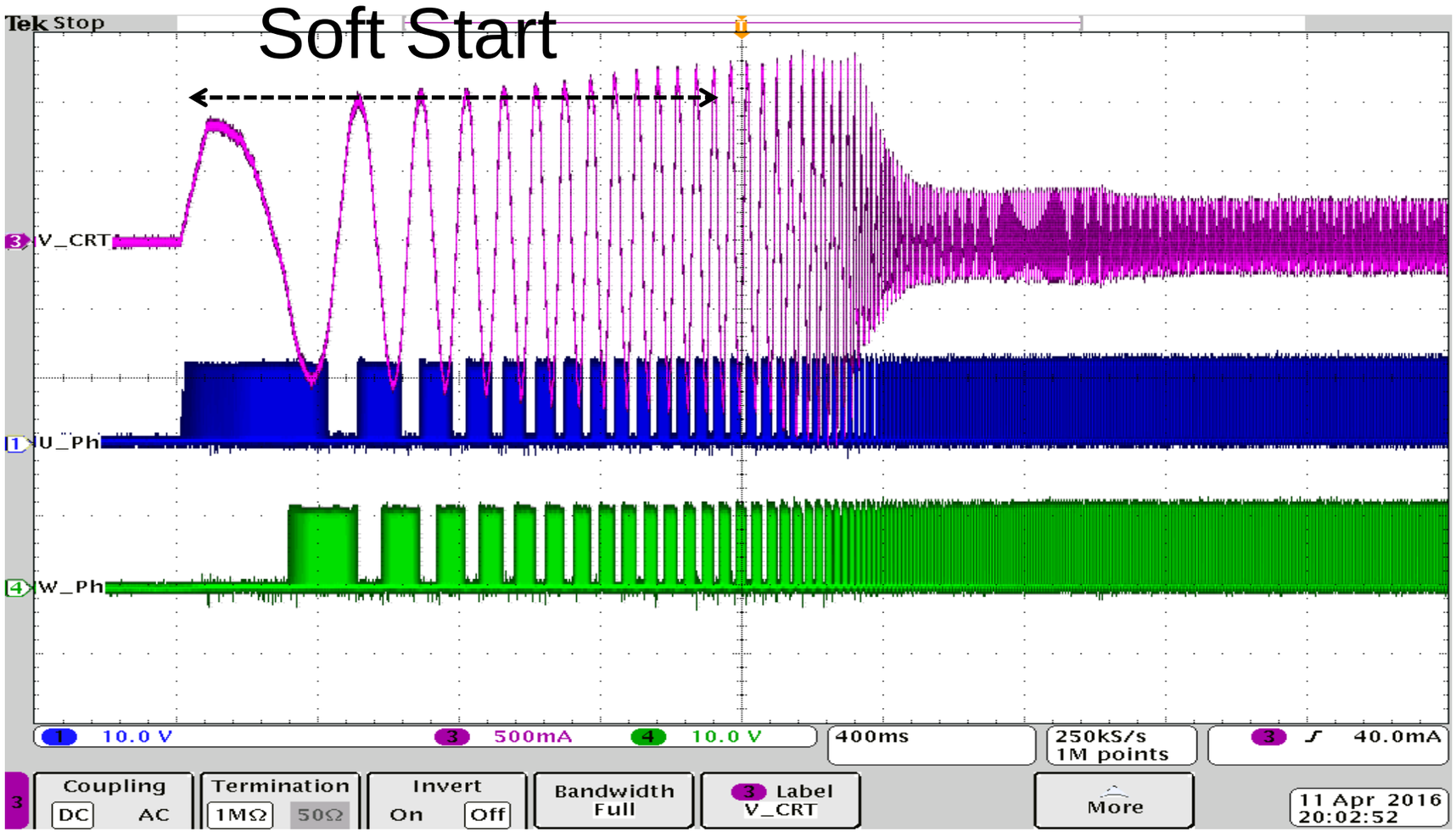
Soft Start – Open Loop Acceleration

- The motor is commutated blindly without information about rotor's position until it reaches sufficient speed so that driver can estimate BEMF accurately.
- Soft Start is achieved by starting motor from smaller speed and then accelerating based on first and second order acceleration rates

- **Benefits to customer:**
  - Avoid Startup Failures **(Reliability)**
  - Supports variety of loads and motors **(Adaptability)**



Soft Start – Open Loop Acceleration in Action



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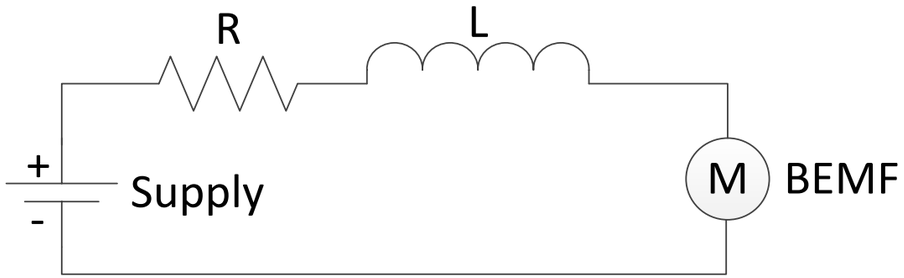
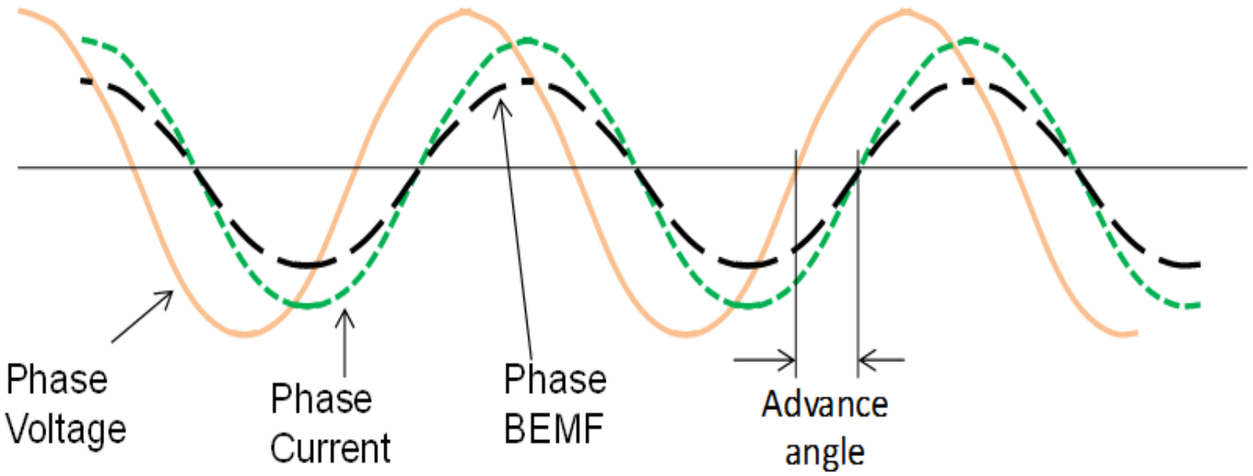
Drive Angle Adjust

Motor Model



Drive Angle/Advance Angle



- Phase current lags Phase voltage due to inductive effect of motor
- Optimal Efficiency can be achieved when Stator Flux is in quadrature with Rotor Flux
- Phase current needs to be in phase with BEMF

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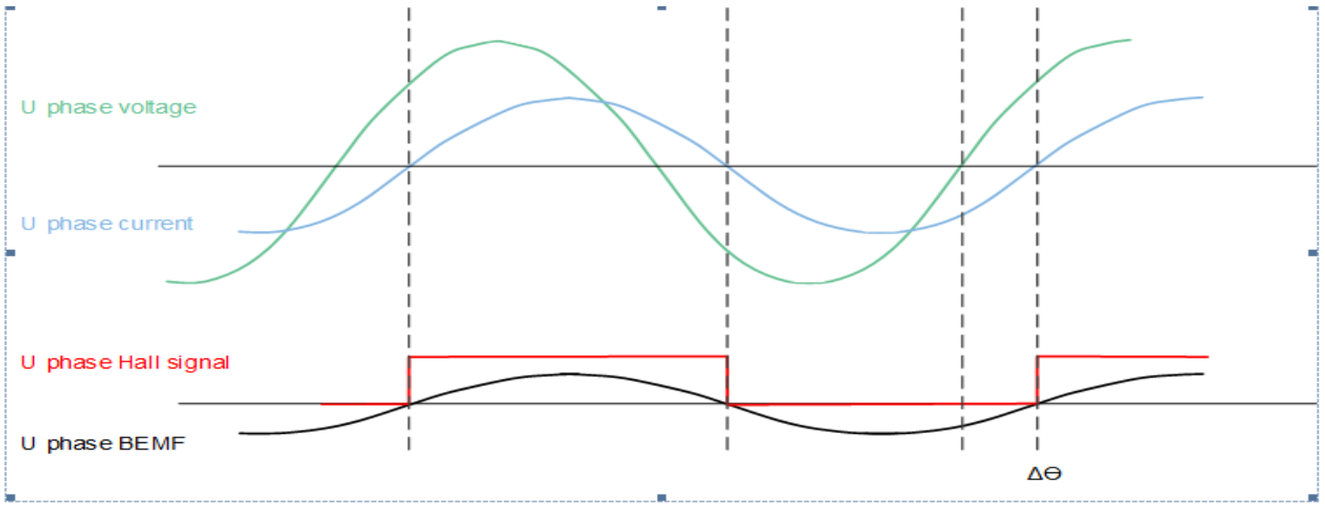
Adaptive Drive Angle Adjust

Problems with Fixed Drive Angle

- Requires manual adjustment everytime motor is changed
- Requires fine tuning with change in operating point (load/speed) to achieve optimal efficiency

How Adaptive Drive Angle Adjust Works



- Phase difference between Phase current and Hall signal/BEMF is measured
- Drive angle is adjusted to minimize phase difference

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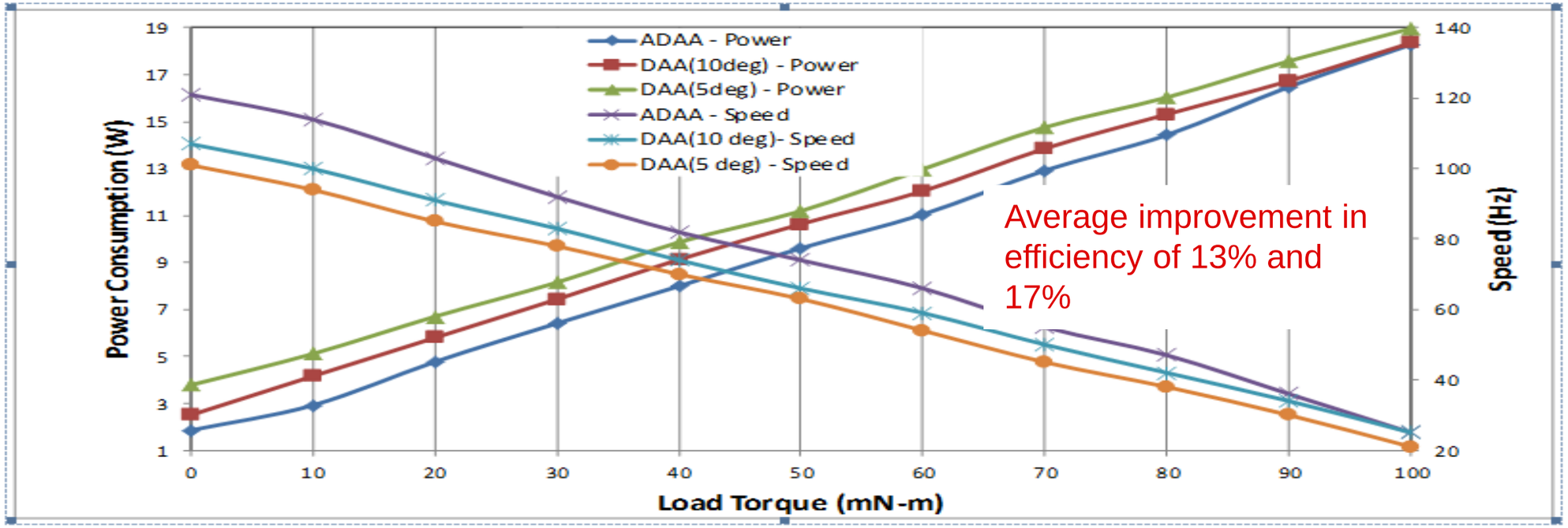
Adaptive Drive Angle Adjust in Action



The data shown in Figure was collected using a motor from Hurst (DMA0102024D2010).

- ***Benefits to customer:***
  - Higher Efficiency compared to fixed drive angle**(performance)**
  - Less tuning required **(ease of use)**

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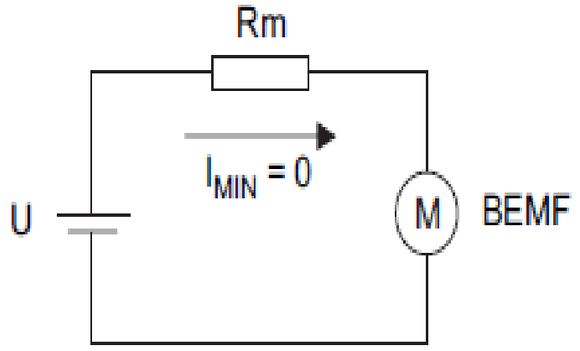
Anti-Voltage Surge(AVS)

- AVS prevents energy from been pumped to supply voltage and **protects** other devices connected to supply
- **Benefits to customer:**
  - Prevents VCC surge **(protection)**



$U_{MIN} = BEMF + I_{MIN} \times Rm = BEMF$

How AVS works

- Buffers the speed command value and limits the resulting output voltage
- It makes sure U_{MIN} will not be less than the motor's BEMF

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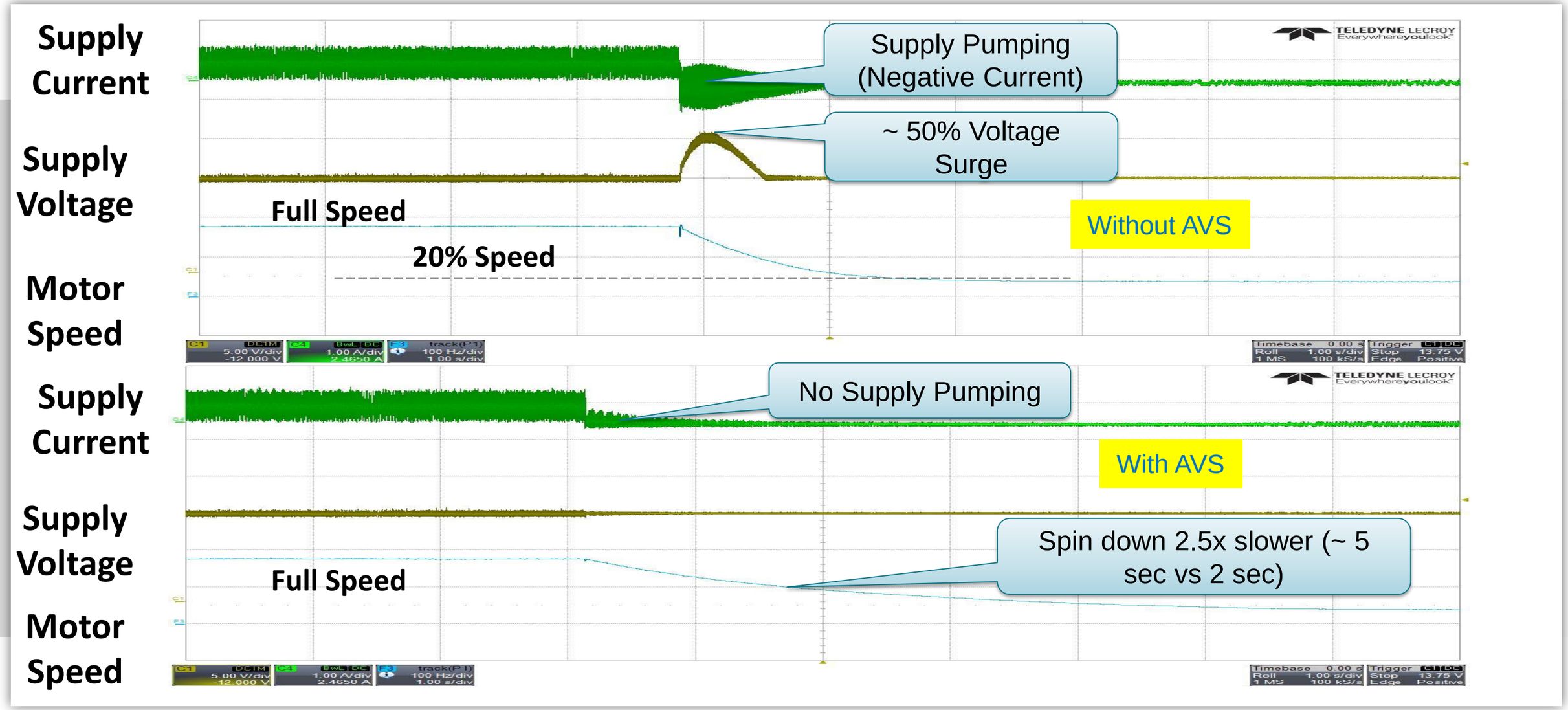
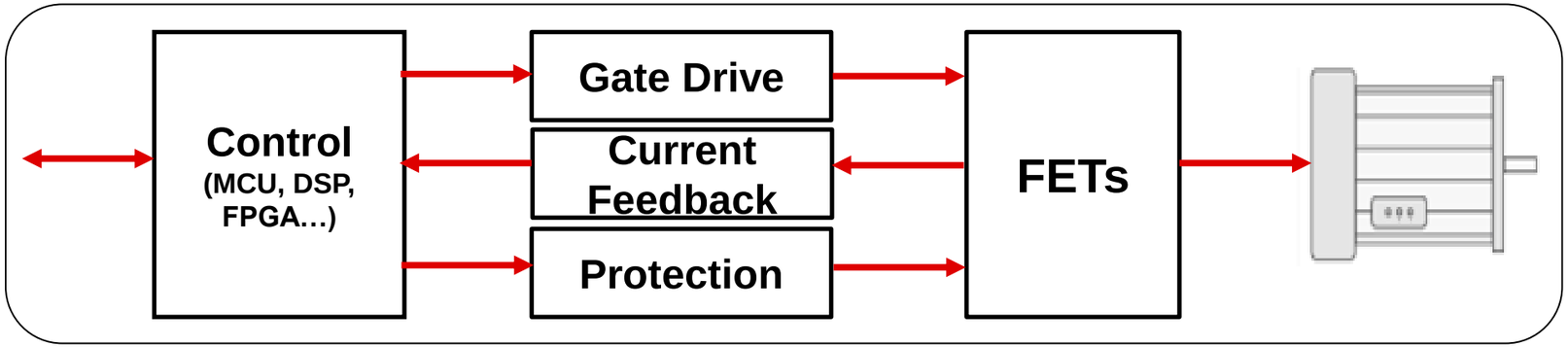
Anti-Voltage Surge(AVS) in Action



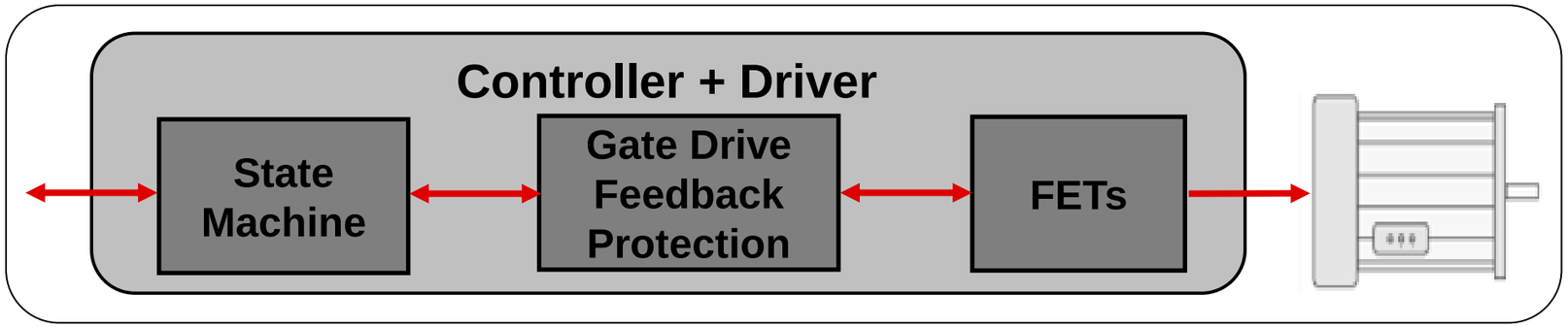
DRV10x Overview

Architectural Benefits

Discrete Solution
- Software and hardware design
- Significant board space
- Higher component count



DRV10x Fixed Function
- Single chip solution
- Smallest board space
- Code-free development

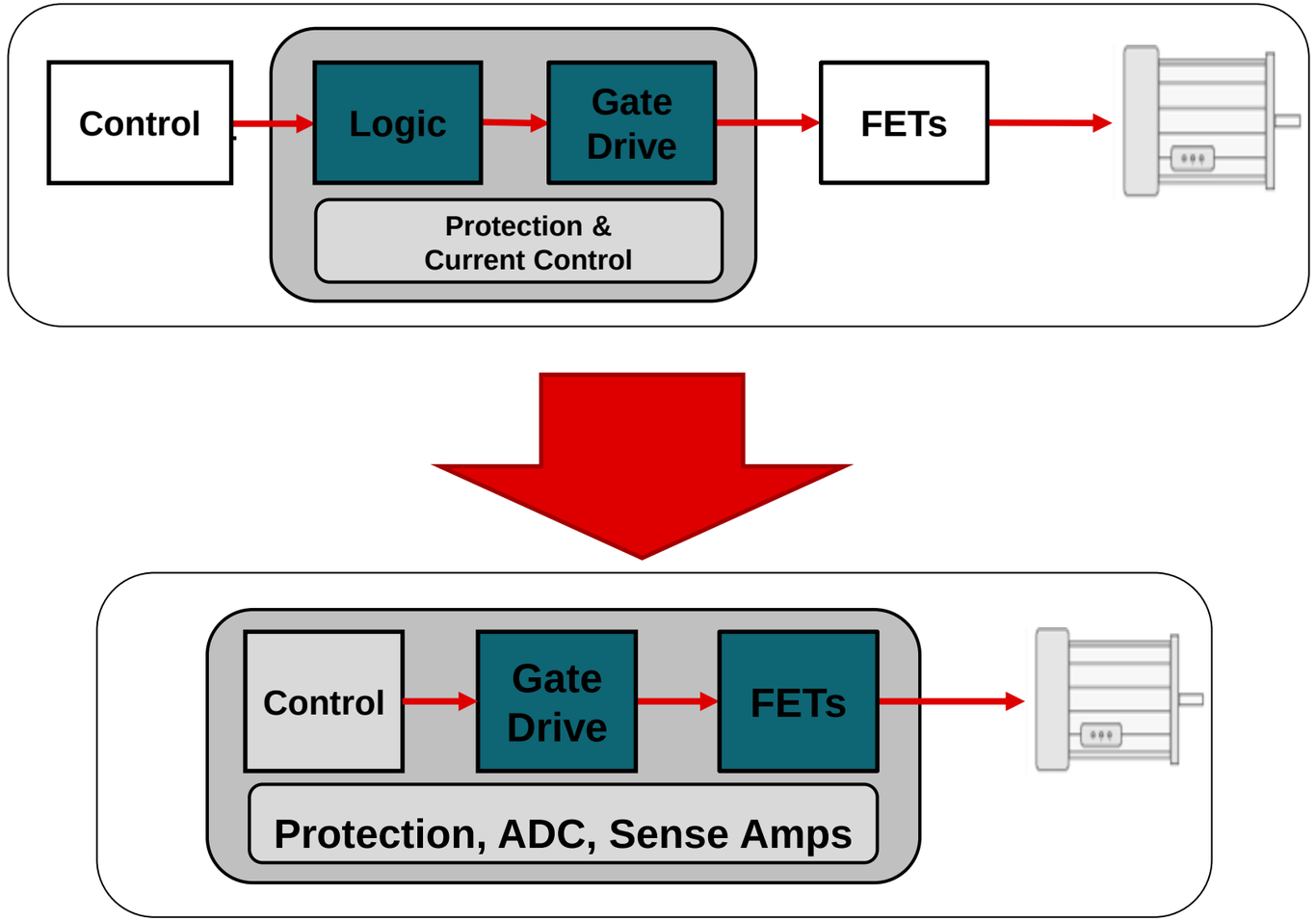


Ease of Use: High Integration

Integration/Cost
Cost effective motor solution in a single part

Code Free
No code required for low level motor control

Distribute Control
Focus on the system solution



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Ease of Use: Code-Free Development

Integration/Cost

Cost effective motor solution in a single part

Code Free

No code required for low level motor control

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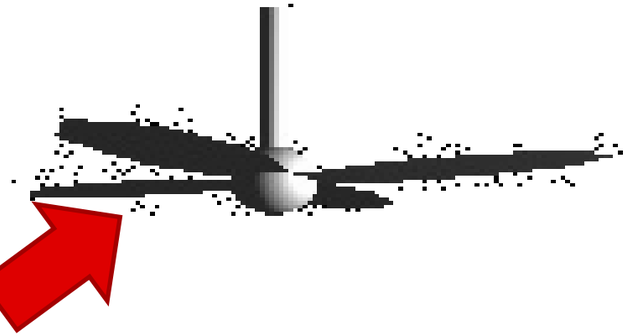
Focus on the system solution



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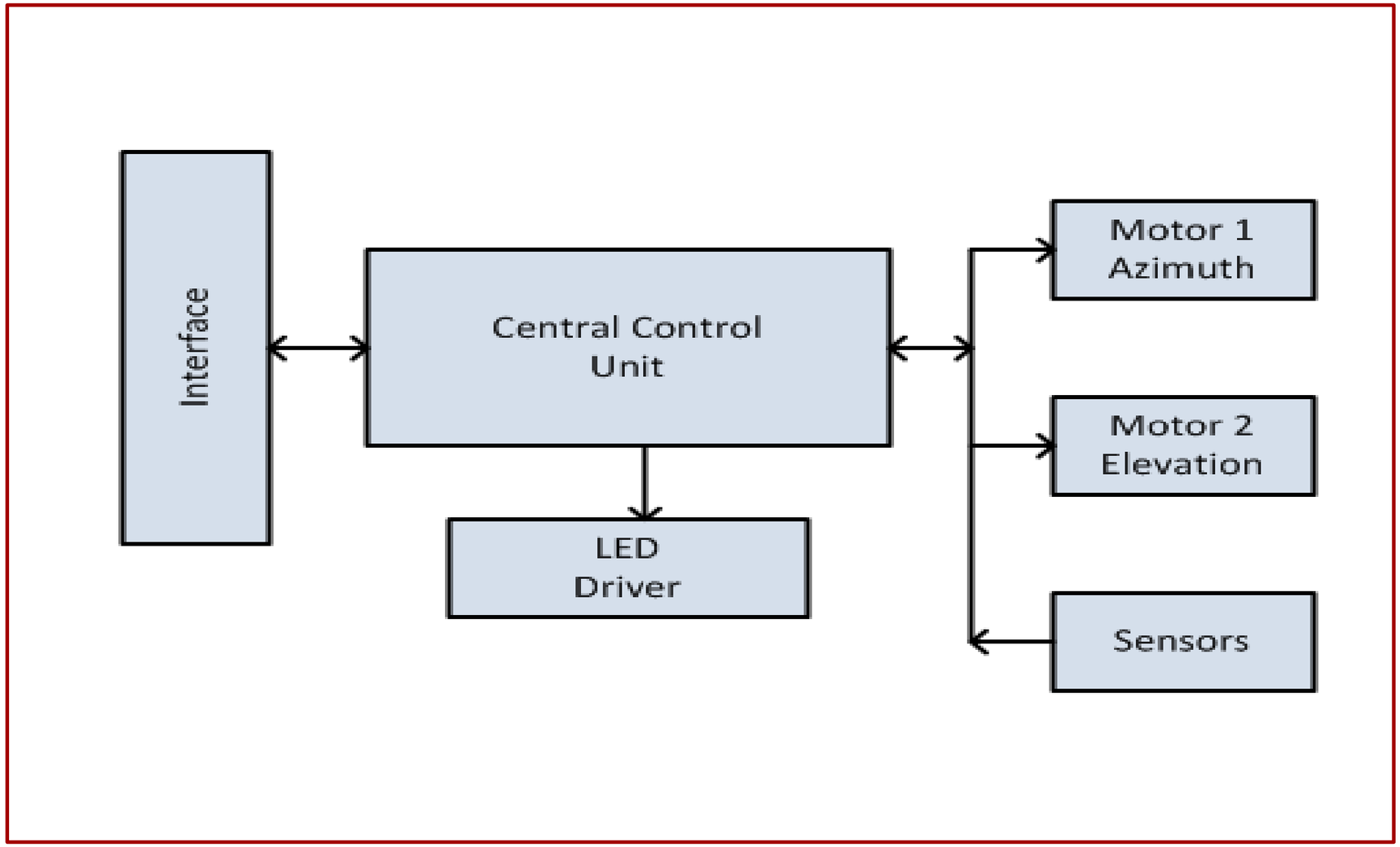
Ease of Use: Fast Time to Market

Integration/Cost
Cost effective motor solution in a single part

Code Free
No code required for low level motor control

Distribute Control
Focus on the system solution



DRV10x: Focus on Customer Needs

Challenge	Customer Expects	DRV10x Delivers
• **High performance**	• Low audible noise • Small vibration • High efficiency	• Sinusoidal control for ultra-quiet operation with small vibration and high efficiency
• **Ease of use**	• Fast time to market • No code development • Space efficient	• Single chip with control, gate drive, FETs and power mgmt • State-machine based control, no code development required
• **Dependable operation**	• Reliable start-up and spin across wide motor range	• Configure for different motors through registers with tuning guide
• **Protection**	• No system damage from fault conditions • No system failures from motor induced over-voltage • Stall detection and recovery	• Over-current, thermal, under-voltage, open load protection • Anti-Voltage Surge protects against supply pumping • Rotor stall report and restart

BLDC Motor Driver Application Examples:

Laptop Cooling

Power / Garden Tool

Ceiling / Pedestal / Exhaust Fan

Washer / Dishwasher

Refrigerator

Server Cooling

Floor Care

Drone

EV / HEV Battery Cooling

Climate Control Seat

Motorcycle Fuel Pump

Dependable Operation: Tune for Wide Range of Sensorless BLDC Motor System

Motor Parameters
R, Kt

Different Acceleration

Startup Current Limit

Spin-Up Profile
IPD vs. Align & Go
Acceleration Rates
Handoff Frequencies
Initial Condition Handling

PWM Frequency Options

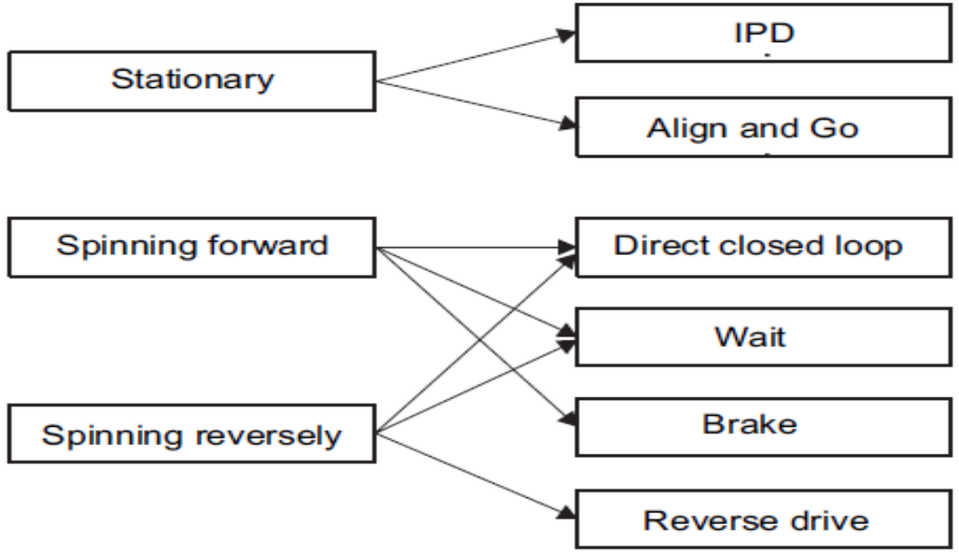
Drive Angle Adjustment

Motor Speed Feedback Options

Protection Options
Anti-Voltage Surge, Over-Current, Thermal Shutdown, UVLO

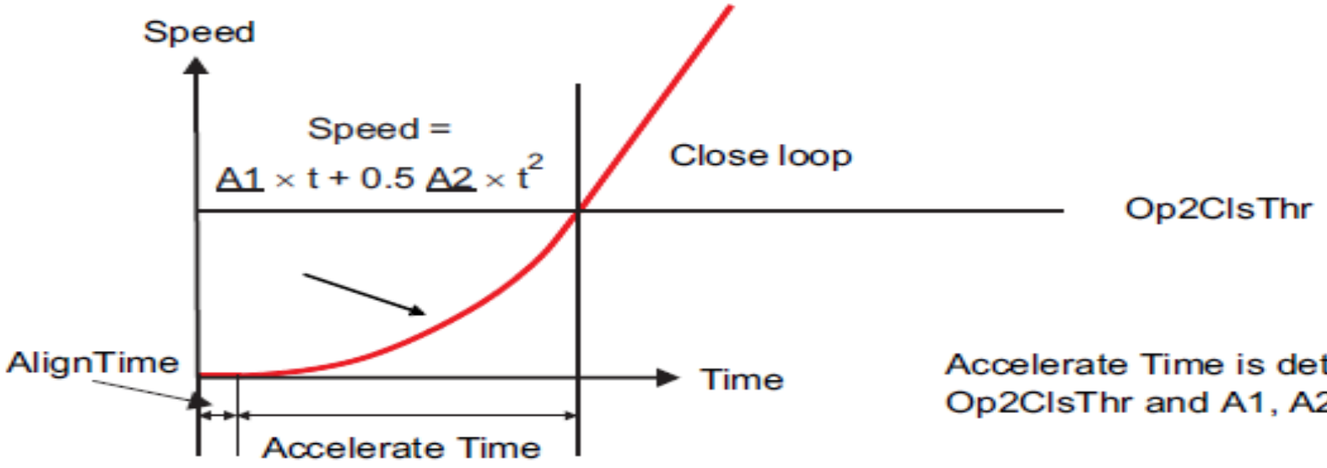
Configurable Power Management

Dependable Operation: Sensorless Motor Spin-Up



Need to be able to start reliably under a wide range of initial conditions

Configure motor start profile to work with a wide range of motors and loads



Accelerate Time is determined by Op2ClsThr and A1, A2.

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Dependable Operation: Tune for Wide Range of Sensored BLDC Motor System

Hall Placement Angle Options
0° vs. 30° Placement

1- or 3-Hall support

Drive Angle Adjustment

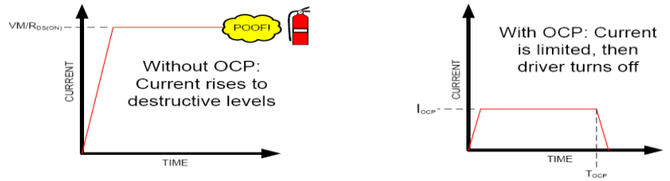
Retry Timing After Stall

Protection Options
Over-Current, Thermal Shutdown, UVLO

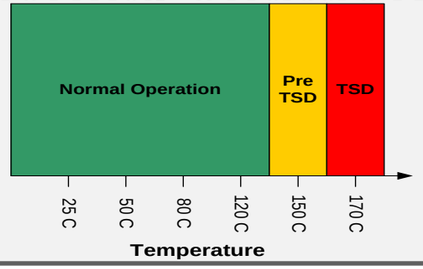
Motor Stop Options
Brake vs. Coast

Full Suite of On-Chip Protection

Over Current Protection

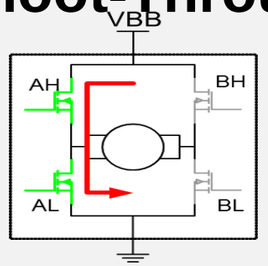


Thermal Shutdown



Under-Voltage Lock-Out (UVLO)

Shoot-Through



Stall Detect & Report

5-Statge Detect

Anti-Voltage Surge (AVS)

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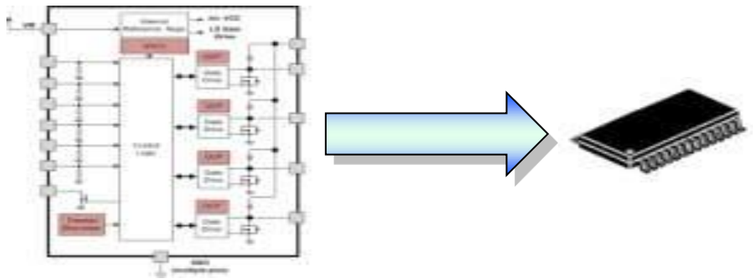
TI's Motor Driver Features

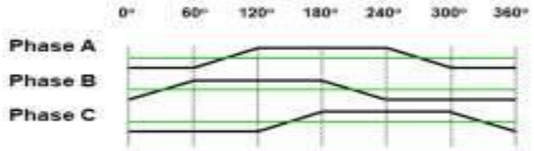
Fully Integrated Solutions

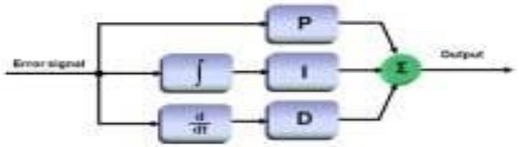
- Reduced Board Space / BOM
- Improved Reliability
- No discrete design experience needed. Just drop in and spin.



Embedded Intelligence

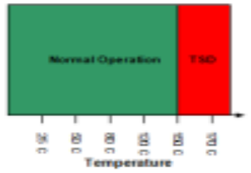
- Minimal MCU support required
- Basic to advanced commutation engines
- Sensored and sensorless support
- Digital control loops

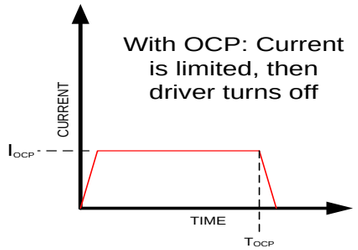




Robust, Reliable & Fully Protected

- Over current / Short circuit protection
- Thermal protection
- Under voltage lock out
- Shoot-through protection





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