Part 3: What is smart gate drive and what does it mean for me?

- Smart Gate Drive and its benefits
- Stepper smart tune and its benefits
- Sine (180°) commutation
- Current sensing and current regulation
Smart gate drive

- Space saving
- Protection
- Easy-to-use

Texas Instruments – Motor Drives
Examining the motor drive system

Competitor gate driver

Discrete solution

Smart Gate Driver

To Load

V_S SUPPLY

+ —

V_G ATE

V_B ST

V_D S Monitor

OC Detect

INL

INH

R_S OURCE

R_SINK D_SINK

R_PD

C_B ST

V_S SUPPLY

+ —

VG ATE

V_D S Monitor

OC Detect

V_DS Monitor

To Load

V_SUPPLY

+ —
Smart gate drive technology - benefits

- Gate drive strength adjustability
- dV/dt protection, strong pull down
- Gate drive fault protection
- Closed-loop dead time
- Passive gate pull-down

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**Switch 1**

- Source: OFF
- Sink: 10 mA

**Switch 2**

- Source: OFF
- Sink: 20 mA

... (for Switches)

**Switch N**

- Source: OFF
- Sink: 120 mA

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MOSFET (External)

**Gate Drive (Internal)**

- V_{GATE} = 20 mA
- V_{GATE} = 110 mA
- V_{GATE} = 250 mA
- V_{GATE} = 560 mA

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**ISOURCE**

- OFF

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TI Information – Selective Disclosure
Smart gate drive technology - benefits

- Gate drive strength adjustability
- $dV/dt$ protection, strong pull down
- Smart fault response
- Closed-loop dead time
- Passive gate pull-down
Smart gate drive technology - benefits

- Gate drive strength adjustability
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Persistence capture of slew rate with different gate drive settings
Smart gate drive technology - benefits

- Gate drive strength adjustability
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**DRV832x & DRV835x**: Family of 60V/100V three phase smart gate driver with buck regulator and three current shunt amplifiers

Key applications that benefit from smart gate drive
- **Power Tools** - TIDA-01516
- **Brushless-DC Motor Drives** - TIDA-01619
- **Electric Bikes and Scooters** - TIDA-00774
- **Electronic Speed Control (ESC)** - TIDA-00643

TI Information – Selective Disclosure
Smart gate drive technology - benefits

- Gate drive strength adjustability
- \( \frac{dV}{dt} \) protection, strong pull down
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Implementation of Miller Clamp

Smart Gate Driver

\( V_{\text{SUPPLY}} \)

\( C_{GD} \)

\( V_{DS} \)

\( V_{GS} \)

\( I_{\text{SOURCE}} \)

\( I_{\text{STRONG}} \)

Strong Pull Down

TI Information – Selective Disclosure
Smart gate drive technology - benefits

- Gate drive strength adjustability
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Continuous gate monitor:
- Intelligently detect a FET gate short
- Protects against low gate drive settings
- Prevents shoot through during faults
- $I_{HOLD}$ to protect gates after switching
Smart gate drive technology - benefits

- Gate drive strength adjustability
- $dV/dt$ protection, strong pull down
- Gate drive fault protection
- Closed-loop dead time
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**Traditional**: Dead time on the input

**Smart Gate Drive**: Dead time on the output
Smart gate drive technology - benefits

- Gate drive strength adjustability
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- Gate drive fault protection
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- Passive gate pull-down

**Traditional**: Use external passives to keep the FETs off

**Smart Gate Drive**: Integrated pulldown resistor in sleep mode or power off

TI Information – Selective Disclosure
Smart tune
Automatic decay mode for stepper motors

Texas Instruments – Motor Drives
Why do decay modes matter in stepper motors?

Keeping current in regulation ensures that the motor operates smoothly, quietly, and efficiently.

Engineers traditionally spend weeks to months tuning stepper motor drivers to choose the best decay mode over their operating conditions.

The best decay mode will depend on several factors:

- Supply voltage
- Motor resistance and inductance
- Motor rotation speed (Back-EMF)
- Inductor saturation
Regulate current with decay modes

Fixed mixed decay

- Begins as fast decay
- After TDECAY, switches to slow decay

![Graph showing I (A) vs. t (us)]

Drives decay modes: Fast and Slow decay

**ITRIP**
Optimizing stepper performance

Current distortion
At high speed, motor BEMF operates differently in quadrants I and II

**Slow speed**

Quadrant I: BEMF is out of phase with the current
- May only need slow decay at speed

Quadrant II: BEMF is in phase with the current
- Need a more aggressive decay at speed

**Fast speed**
Smart tune in action

- **Slow speed (3 kHz)**
- **Fast speed (10 kHz)**

**Fixed 30% mixed decay**:
- Smart tune applied
- Loss of current regulation
How smart tune technology works

Optimize decay mode iteratively for a given current step: cycle-by-cycle changes on the decay mode if needed

- Overshoot $\rightarrow$ needs to be more aggressive (prevents regulation loss)
- Long drive time $\rightarrow$ needs to be less aggressive (operates more efficiently)
Smart tune in action

2 µs fixed mixed decay versus smart tune

Smart tune runs 5-12 degrees cooler at load!
Smart tune technology for stepper motors

- Available on DRV8846, DRV8880, DRV8881E, and DRV8886AT. More to come!

- These drivers automatically configure the decay mode on-the-fly to operate at the best setting for motor operation

- Key benefits of smart tune technology:
  - Don’t need to spend weeks/months tuning the motor (development cost)
  - Motor runs more efficiently than fixed decay modes (power budget)
  - Motor runs quietly without losing regulation (performance)
  - Adjusts to motor parameter changes over lifetime (reliability)
  - You can source multiple motor vendors (production risk management)
BLDC motor commutation

Texas Instruments: BLDC Motor Drivers
BLDC commutation
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
Electrical cycle and mechanical cycle

• Mechanical cycle:
  Time for the motor to travel One full revolution
  Mechanical angle corresponding to the Mechanical cycle.

• Electrical cycle:
  Time for the rotor to pass a pair of Poles.
  Electrical angle corresponding to the Electrical cycle.
Speed vs torque

- Current is directly proportional to Torque

- When torque increases, so does the current. As a result:
  - Voltage drop on the motor resistor increases
  - Speed decreases because $\text{VBEMF} = \text{VS} - \text{VR} - \frac{\text{Ldi}}{\text{dt}}$

Motor rotation creates the BEMF. Higher the speed of motor higher is amplitude of generated BEMF. This generated BEMF offsets the applied voltage.
Trapezoidal commutation v/s sinusoidal commutation

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

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

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

Sinsusoidal with third harmonics
Performance: **Driving methods vs. acoustics**

Various drive methods are available

Pure tone acoustics are significantly reduced when using sinusoidal drive
Sinusoidal commutation

How could the control system know, the rotor position?

Two ways to determine rotor position:
- Sensors
- Estimation (sensor-less)
Motor position and speed sensors

- **Resolver**
  - High resolution, AD input.
  - High cost

- **Optical Encoder**
  - High resolution
  - Calculation
  - Low reliability

- **Hall Effect**
  - Low resolution
  - Low cost
How does 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.
Commutation – sine drive

180° sine commutation (DIR = 0)

- State
- Hall U
- Hall V
- Hall W
- Phase U HS
- Phase U LS
- Phase V HS
- Phase V LS
- Phase W HS
- Phase W LS

(1) Low for asynch rectification, inverted HS signal for sync rectification
Position-estimation back-EMF

• EMF:
  Electromotive Force, the origin of voltage in electrical devices.

• Faraday's law:
  The EMF generated when a wire moves across magnetic field.
Position-estimation back-EMF

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

\[ \text{BEMF} \propto \text{Magnetic Flux} \times \text{Speed}. \]

Position = Function( Magnetic Flux).

Position information can be estimated from BEMF information.
Position-estimation back-EMF

**Motor Model**

\[ V_{BEMF} = U - I \times R - L \frac{di}{dt} \]

- BEMF can be estimated using motor parameters, voltage and current information.
- \( U \) is applied voltage to motor phase.
- For any given system current is measured using shunt or current sensor.
- \( R \) is motor resistance
- \( L \) is motor inductance
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<th>Sensored control</th>
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<th>Sensorless control</th>
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<tr>
<td>Motor commutation based on feedback from Resolver/Encoder/Hall sensors</td>
<td>• Motor commutation based on either estimated/measured BEMF</td>
<td></td>
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<tr>
<td>Motor can quickly respond to load changes</td>
<td>• Least amount of board space used since no Hall sensors needed</td>
<td></td>
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<tr>
<td>Low speed of operation easier to control</td>
<td>• Easier to connect control circuitry to motor</td>
<td></td>
</tr>
<tr>
<td>No backward rotation necessary to find initial position of motor</td>
<td>• Most cost effective, compact solution</td>
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Speed command: Analog, Digital and PWM

There are different ways in which the control signals for changing speed of the motor is applied:

- Pulse Width Modulated signal (PWM)
- Variable DC voltage (Analog)
- I2C communication (Digital)

Based on calculated PWM, the output of driver is adjusted.
Integrated current sensing technology

Texas Instruments: Brushed-DC and Stepper Motor Drivers
Why do I need to sense the current?

Brushed-DC Motor

Inrush Current Limiting
Torque Control

Stepper Motor

Stepping and Microstepping
Current Regulation and Current Control
Current sensing resistor – Brushed-DC

1206 or larger

**DRV8870:**
3.6A Brushed-DC driver, “traditional” current sensing

0402 or smaller

**DRV8876:**
37V, 3.6A Brushed-DC driver with *integrated current sensing* and current sense output
**Current sensing resistor – stepper**

**DRV8880**: 2A Stepper driver with smart tune, “traditional” current sensing

**DRV8886AT**: 2A Stepper driver with smart tune and integrated current sensing

1206 or larger

0402 or smaller
Current sensing resistor – stepper

DRV10970: 3-phase sensored BLDC driver with single/3 Hall support and integrated current sensing
DRV888x – current sense accuracy

Traditional Stepper:

- LDO: ±2%
- Driver:
  - STEP: ±6.25%
  - DIR: ±8%
- VREF Divider:
  - VREF: ±1%
- MCU

DRV888x family:

- LDO: ±1%
- Driver:
  - STEP: ±1%
  - DIR: ±1%
- VREF Divider:
  - VREF: ±1%
- MCU

Already includes ±1% from RREF Resistor

TI Information – Selective Disclosure
Integrated current sensing technology

• Available on **DRV8871, DRV8876** (Brushed-DC) and **DRV8884/5/6/6AT** (Stepper)

• Eliminates all current sense resistors while providing accurate current regulation

• **Key Benefits from integrated current sensing:**
  – Removed sense resistors and reduced board size *(system cost)*
  – No power loss over the sense resistor *(power budget)*
  – Fewer components on the board *(manufacturability)*
  – Easy device layout with no sense routing *(development)*

• **To find out more visit**