Part 1: What is the right motor for my application?

• Brushed, stepper and brushless-DC motors
• Common uses for each motor type
• Compare motors based on performance and use cases
Electric motor control system overview

Motor control
- Microcontroller
- Manages the control system, motor commutation, driver settings, fault handling

Gate driver
- MOSFET or IGBT gate driver
- Level shifts logic control signals
- Power stage fault detection and handling

Power stage
- Power MOSFET or IGBT
- Interface main power rail to electric motor
- Often in half-bridge, H-bridge, or inverter configuration

Feedback
- Signals from motor
- Position, torque, voltage, current

Motor driver technology
Advance your next system with TI's motor driver technology
Motor types

**Brushed-DC motor**
+ Low cost
+ Easy to design
- Brushes wear out
- Inefficient

**Brushless-DC motor**
+ Very efficient
+ Long life / reliable
- Expensive
- Complex design

**Stepper motor**
+ Open loop position / speed control
+ Simple control
- Resonance
- Noise

Application Reference Designs
Smart Meters, Video Surveillance, Small and Large Appliances, Electronic Locks,

Application Reference Designs
Garden and Power Tools, Appliance Pumps and Fans, E-Mobility, Factory Automation & Logistics

Application Reference Designs
Printers, Refrigerator & Freezer, Mobile EPOS Printers, Stage Lighting

Drive performance with Brushed DC (BDC) motor drivers

Integrated FET and Smart Gate Drive solutions for Brushed DC motor control

Brushed-DC Motors

Texas Instruments – Motor Drives
Brushed – DC motor construction

- Permanent magnet
- Motor winding
- Commutator
- Brushes
Brushed – DC motor commutation

Bidirectional brushed motor driver

Forward Drive
Reverse Drive

Brushed – DC motor commutation

Texas Instruments
Brushed – DC motor: H-Bridge states

### H-Bridge States

<table>
<thead>
<tr>
<th>Mode</th>
<th>HS1</th>
<th>LS1</th>
<th>HS2</th>
<th>LS2</th>
<th>OUT1</th>
<th>OUT2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coast</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>Z</td>
<td>Z</td>
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<tr>
<td></td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
<td>H</td>
<td>L</td>
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<tr>
<td></td>
<td>OFF</td>
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<td>ON</td>
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<td>L</td>
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<tr>
<td></td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>ON</td>
<td>L</td>
<td>L</td>
</tr>
</tbody>
</table>

- **Coast** – current will flow through the body diodes into VM
- **Forward** – current flows from OUT1 to OUT2
- **Reverse** – current flows from OUT2 to OUT1
- **Brake** – current recirculates through the low side FETs
Brushed – DC motor: Protection

Integrated Brushed-DC drivers, like [DRV8837](https://www.ti.com/lit/ds/symlink/drv8837.pdf), offer increased protection over discrete components.

- **No fuse, no protection!**
- **No thermal protection!**
- **No UVLO protection!**
- **No on-chip shoot through protection**
DRV8x Bushed DC Drivers

- **Smaller board space**
  Enables small and simple design

- **Embedded intelligence**
  Reduces software design; allows lower-end MCU

- **Complete protection**
  Improves robustness and reliability

- **Ease of use**
  Accelerates design / ramping; simplifies assembly

**Example:** In an e-lock system, TI’s DRV8837 replaced various discrete components, including the fuse, due to its small form factor and ease of design

Common applications with size constraints:
- IP Network Cameras
- Power Tools
- Vacuum Robots

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DRV8837

drv8701

Texas Instruments
Bushed-DC Motor Applications

- Power Tools: DRV8701
- E-Locks: DRV8837
- Toys: DRV8837C
- Currency Counter: DRV8842, DRV8871
- Smart Meters: DRV8837, DRV8837C
- Coffee Machine: DRV8847, DRV8870
- Vacuum Robots: DRV8701, DRV8870
- IP Network Cameras: DRV8837, DRV8835
Brushless DC (BLDC) Motor Drivers

Smart gate drivers and integrated motor drivers for BLDC motor control

Brushless-DC Motors

Texas Instruments – Motor Drives


**Brushed-DC versus brushless-DC**

**Brushed-DC**
- Less torque per weight
- Less torque per watt
- More audible noise
- Shorter lifetime
- Lower reliability
- Commutator sparking
- More EMI radiation
- May need airflow to cool rotor
- Lower RPM
- ...
- Easy to drive

**Brushless-DC**
- More torque per weight
- More torque per watt
- Less audible noise
- Longer lifetime
- Higher reliability
- No sparking
- Less EMI radiation
- Can be completely enclosed
- Higher RPM
- ...
- Hard to drive ($$$)
Brushless-DC motor construction

**Brushed DC Motor**
- Permanent magnets on stator
- Coils on rotor
- Bad dissipation because the heat is confined to the small rotor

**Brushless DC motor**
- Permanent magnets on rotor
- Coils on stator
- Good dissipation because the heat is generated on the stator
Brushless-DC motor construction

Inner Rotor (Conventional)
- Smaller construction (compact)
- Better heat dissipation
- Lower rotor inertia
- Quick speed change applications
  - High torque and speed
  - High cogging torque
  - Harder to wind the coils
  - High performance magnets
- Servos, actuators, pumps

Outer Rotor (Outrunner)
- Larger construction
- Worse heat dissipation
- Higher rotor inertia
- Constant speed applications
  - Higher torque at low rpm
  - Low cogging torque
  - Easier to wind the coils
  - Lower performance magnets
- Fans, hard disk, printers
Both are driven the same way

**Wye (Y) Winding**
- Star connection
- Normally more efficient
- Less resistive losses
- Immune to parasitic currents
- Higher torque at low speed
- Lower top speed

**Delta (Δ) Winding**
- Normally less efficient
- More resistive losses
- Parasitic currents can circulate
- Lower torque at low speed
- Higher top speed

**Most common**

**Brushless-DC motor winding connections**

**Texas Instruments**
Detecting rotor position

Sensored

- Hall-effect sensor
- Encoder
- FG trace

Definite rotor position
Easier to start
Simple processing
More components
Better jitter performance

Sensorless

- Motor flux
- Back-EMF measurement

Have to estimate rotor position
More difficult to start
More complicated calculations
Fewer components
Worse jitter performance
**Brushless-DC motor applications**

**PC & Notebooks**
Her0 Device: DRV10964

**Drones**
Her0 Device: DRV832x

**Residential and Living fans**
Her0 Device: DRV10983/DRV832x

**Automotive Overview**
Her0 Devices: DRV10983-Q1/ DRV8320-Q1 / DRV3205-Q1

**Power Tools**
Her0 Device: DRV832x

**Vacuum Robots**
Her0 Device: DRV10983/DRV8320

**Refrigerators & washers**
Her0 Device: DRV10987/DRV832x
Step into simple speed and position control

Highly accurate & smooth motion that is easy to design

Stepper Motors

Texas Instruments – Motor Drives
Stepper motor construction

H-bridges A and B drive motor phases

Motor winding on stator

Rotor with permanent magnet
Bipolar stepper motor construction
Bipolar stepper motor control

Full Stepping – option #1 “wave drive”
Bipolar stepper motor control

Standard half stepping

Current regulation needed
Regulating current in stepper motors

PWM current chopping used to regulate current

At each current step, current is driven until it hits $I_{\text{TRIP}}$, then the bridge enters a decay mode for a period of time

Decay Modes: Slow, fast, mixed decay

Timers: Fixed frequency and fixed time-off

TERMS:

$I_{\text{TRIP}}$ – Current trip level
$t_{\text{DRIVE}}$ – Drive time
$t_{\text{OFF}}$ – Decay mode time
$t_{\text{DECAY}}$ – Fast decay time during mixed decay
$t_{\text{BLANK}}$ – Minimum drive time
Regulate current with decay modes

Slow decay
- Winding current is recirculated in both low-side FETs
- Smallest ripple
Regulate current with decay modes

**Fast decay**
- H-bridge reverses state to allow current to flow in reverse
- H-bridge disabled when current decays to zero to prevent reverse current
- Largest ripple

This is only an example.
Motor current may not decay to zero!
Regulate current with decay modes

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

- Attend Webinar 3 where we will discuss Smart Tune – automatically decay mode based on dynamic decay and ripple control technology

![Graph showing mixed decay modes](image)
Stepper Motor Applications

Stage Lighting
DRV8881, DRV8841

Security Camera
DRV8835

Antenna Positioning
DRV8824

ATMs
DRV8886AT, DRV8880

Retail & POS Printers
DRV8833C, DRV8847

Refrigerator
DRV8847, DRV8812

Textile Equipment
DRV8818, DRV8886AT

Printers
DRV8886AT, DRV8885
## Comparison between motor types

<table>
<thead>
<tr>
<th></th>
<th>Brushed-DC</th>
<th>Brushless-DC</th>
<th>Stepper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low cost</td>
<td>$</td>
<td>$$$</td>
<td>$$</td>
</tr>
<tr>
<td>Current control required?</td>
<td>X</td>
<td>X</td>
<td>Needed*</td>
</tr>
<tr>
<td>Long motor life</td>
<td>Worst</td>
<td>Best</td>
<td>Better</td>
</tr>
<tr>
<td>Open loop position control</td>
<td>X</td>
<td>X</td>
<td>Yes</td>
</tr>
<tr>
<td>High efficiency</td>
<td>Worst</td>
<td>Best</td>
<td>Bad</td>
</tr>
<tr>
<td>Low noise</td>
<td>Worst</td>
<td>Best</td>
<td>Better**</td>
</tr>
<tr>
<td>High RPM</td>
<td>Limited by voltage</td>
<td>Best</td>
<td>Limited by step frequency</td>
</tr>
<tr>
<td># of FETs for bidirectional control</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
</tbody>
</table>

* Current control needed for microstepping. Not needed if full stepping only
** Stepper motors can have low noise, but only if decay modes are tuned properly!!!