Choosing the Right Stepper Motor Driver

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November 2023
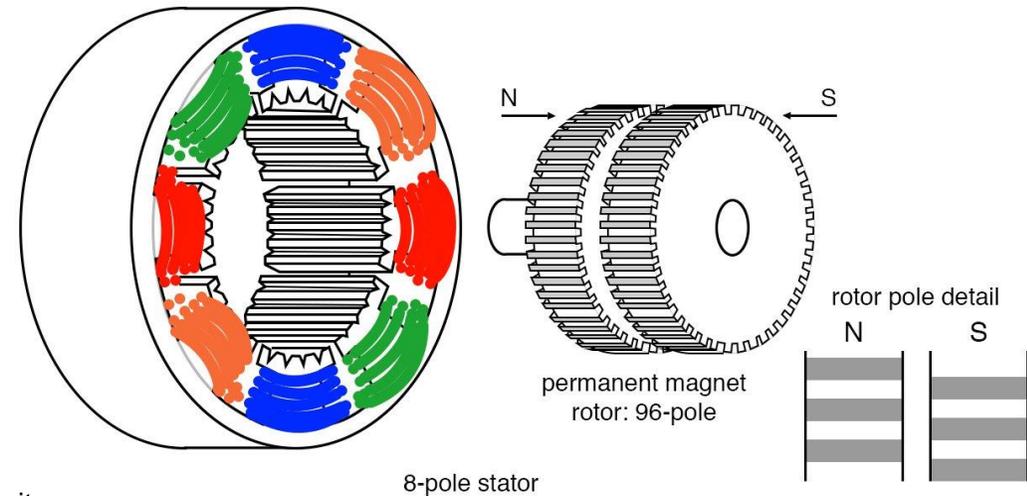
MPS

Agenda

Stepper Motor Basics – Operational Review
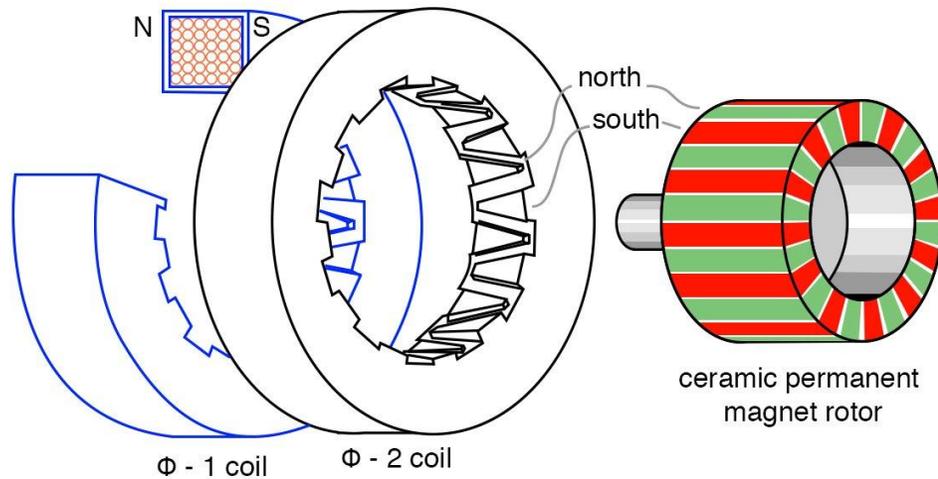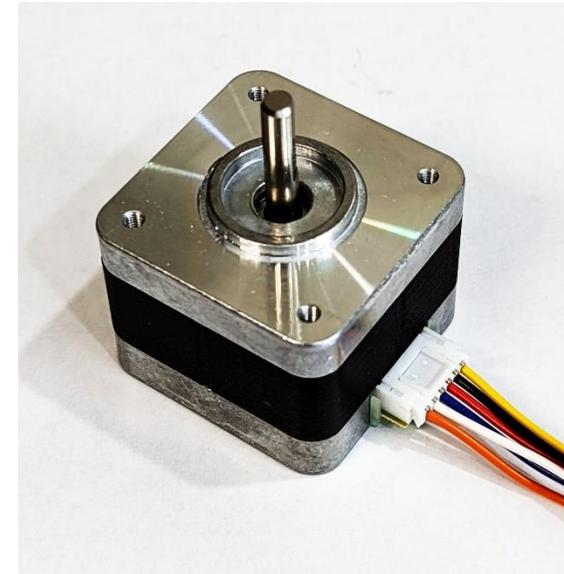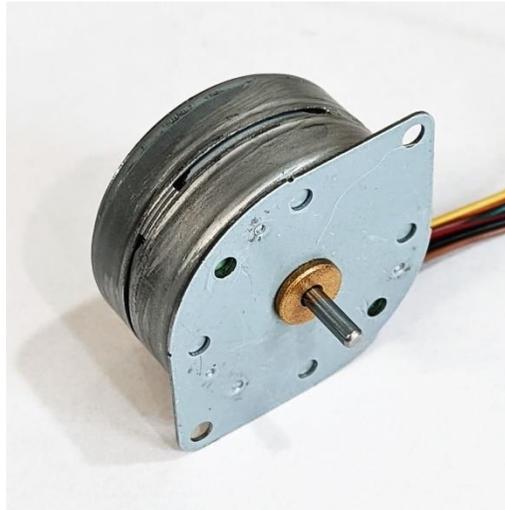
Stepper Motor Driver Datasheet Specs

Finding the Right Stepper Motor Driver

Summary / Q&A

Stepper Motor Basics

Stepper Motor Construction

N | S

north
south

Φ - 1 coil   Φ - 2 coil

ceramic permanent
magnet rotor

permanent magnet
rotor: 96-pole

rotor pole detail
N   S

8-pole stator

N   S

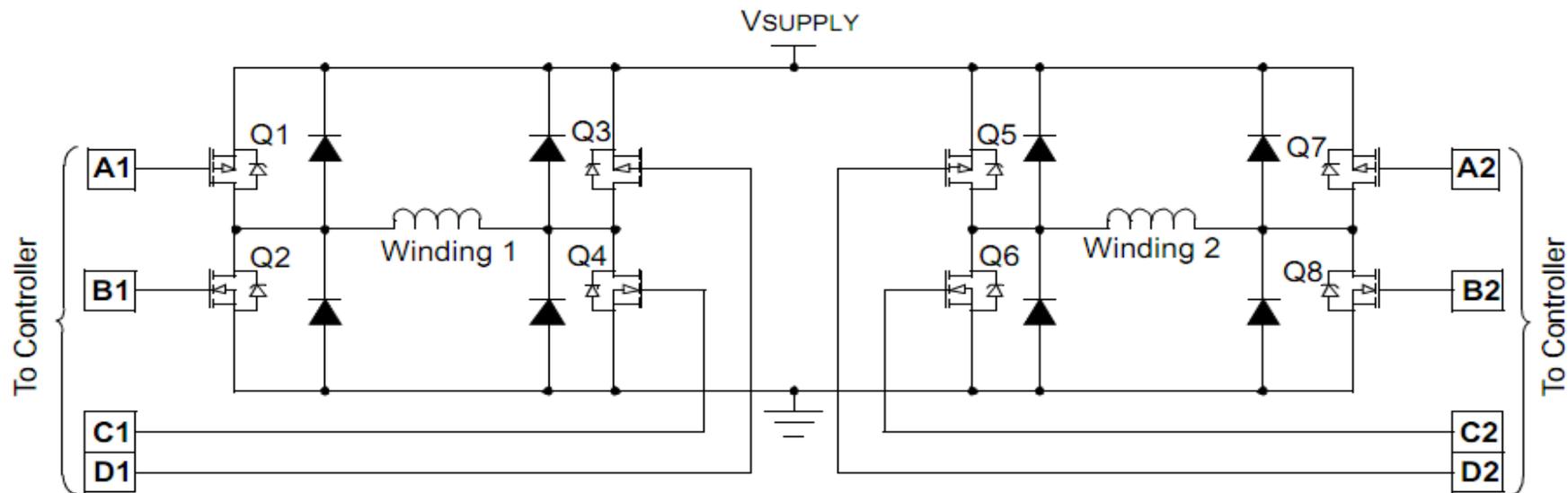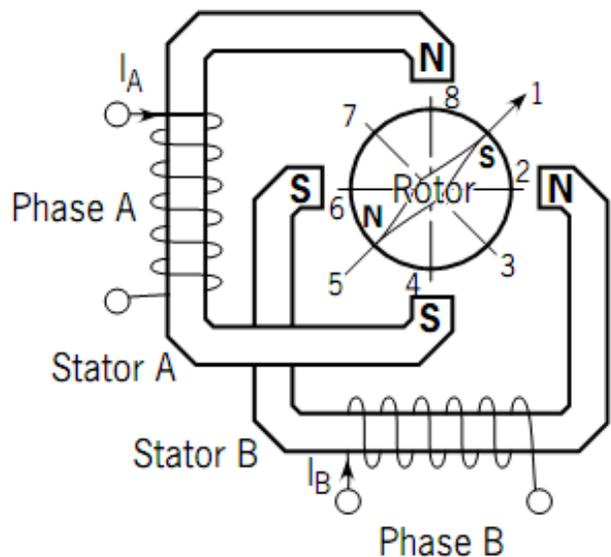Images from www.allaboutcircuits.com

Permanent Magnet Stepper Motor

Hybrid Stepper Motor

Driving a Stepper Motor

步进模式	通电顺序	电气角位置
单相励磁整步模式	A → B → A̲ → B̲	8 → 2 → 4 → 6
双向励磁整部模式	AB → A̲B → A̲B̲ → AB̲	1 → 3 → 5 → 7

Step Modes and Microstepping

步进模式	通电顺序	一个周期内电气角数量
单相励磁整步模式	A → B → A → B	4
双向励磁整步模式	AB→ AB → AB → AB	4
半步模式	AB→ B→ AB → A → AB → B → AB →A	8

Channel A current ratio

100.0%
83.15%
66.7%
33.3%

33.3% 55.56% 66.7% 100.0%

Channel B current ratio
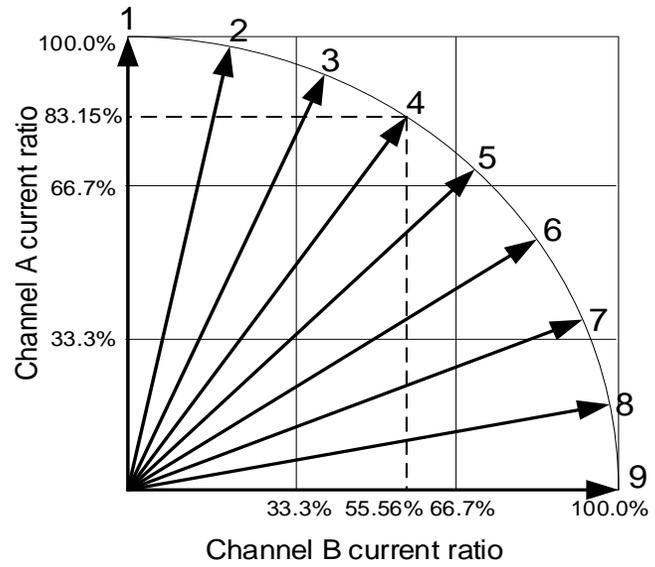
Relative Current Level Sequence(%)		Full Step	1/2 Step	1/4 Step	1/8 Step
Channel A	Channel B				
100	0	1	1	1	1
98.08	19.51				2
92.39	38.27			3	3
83.15	55.56				4
70.71	70.71		5	5	5
55.56	83.15				6
38.27	92.39			7	7
19.51	98.08				8
0	100	9	9	9	9

Step Modes and Microstepping
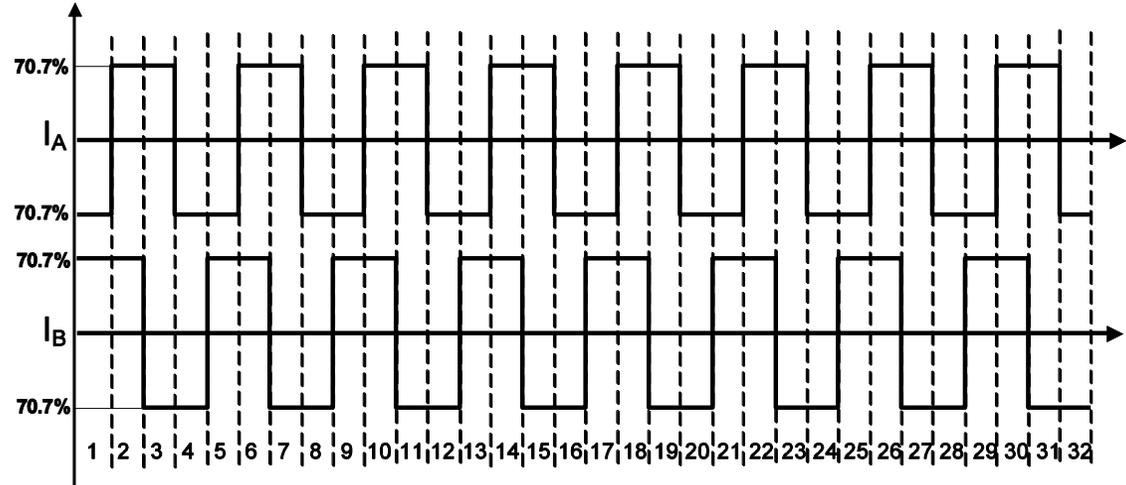
Full Step
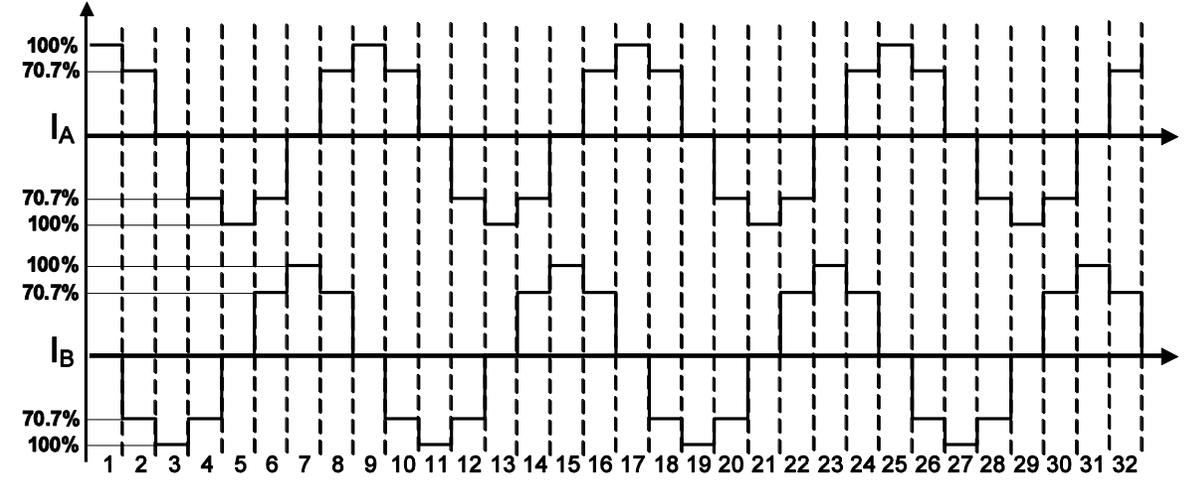
Half-Step

Quarter-Step

Eighth-Step

Stepper Motor Driver ICs

Stepper Driver ICs: What's Inside (Simple)
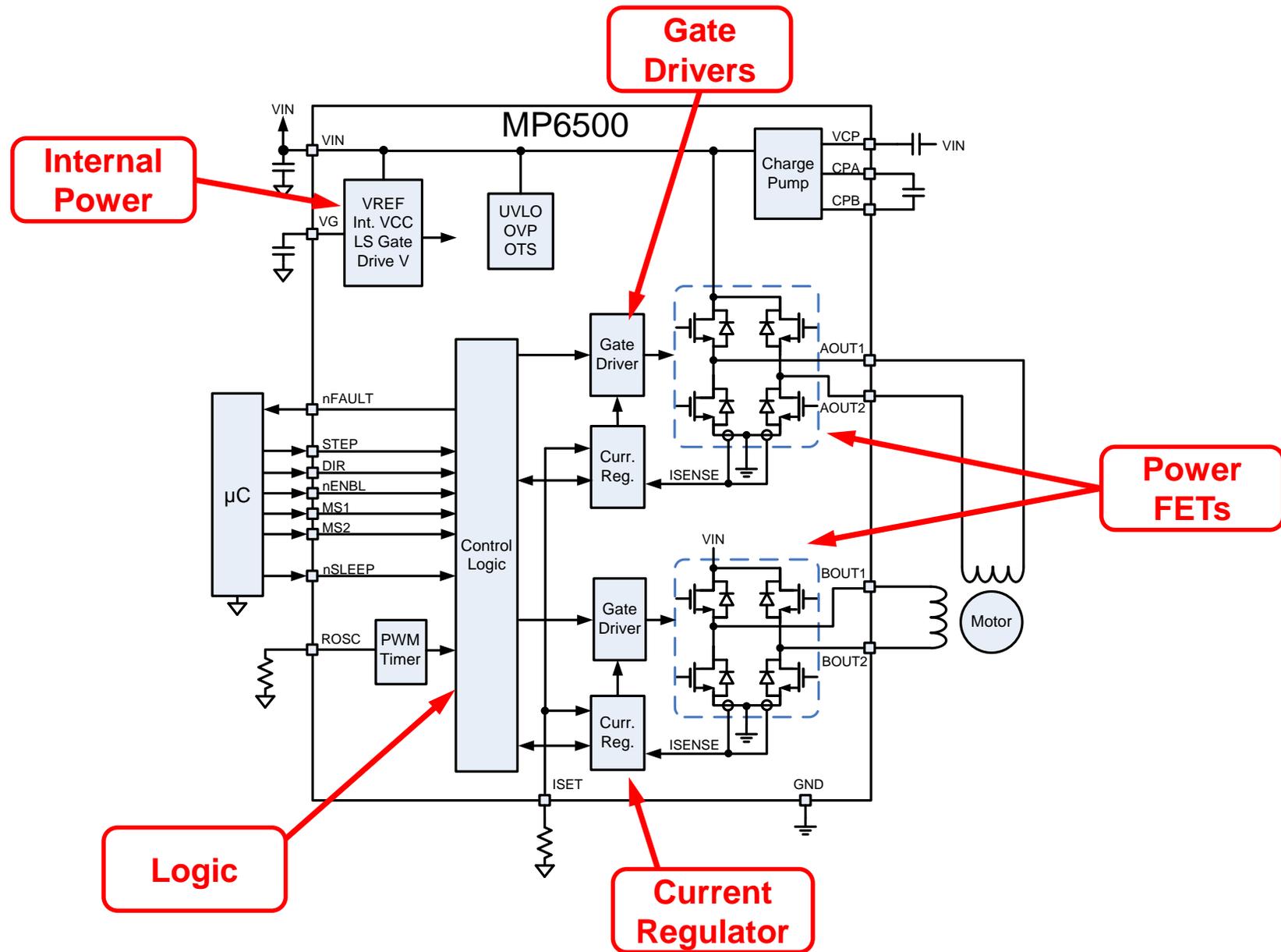
Stepper Driver ICs: What's Inside (Advanced)
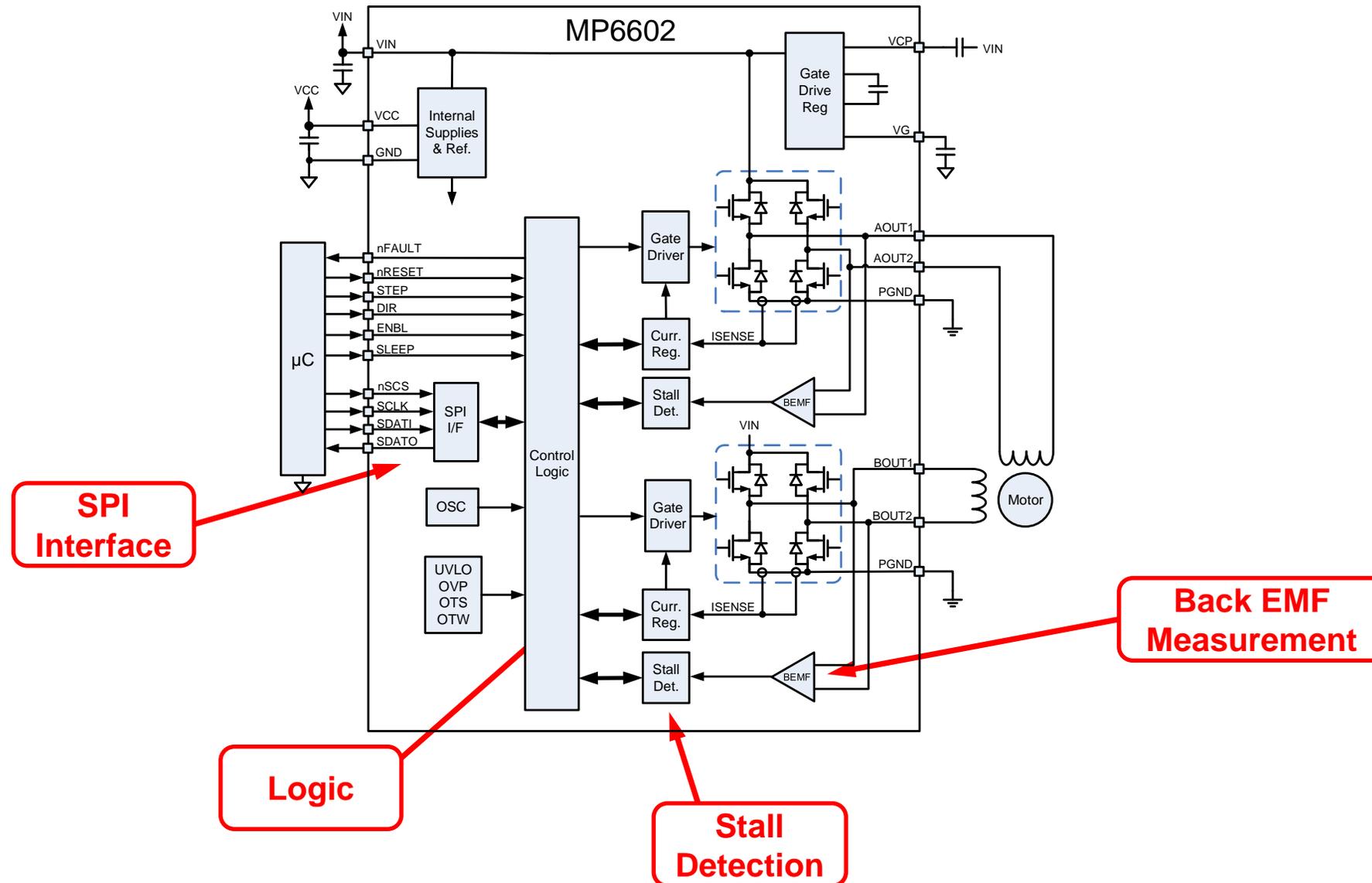
Stepper Driver ICs: Basic Features
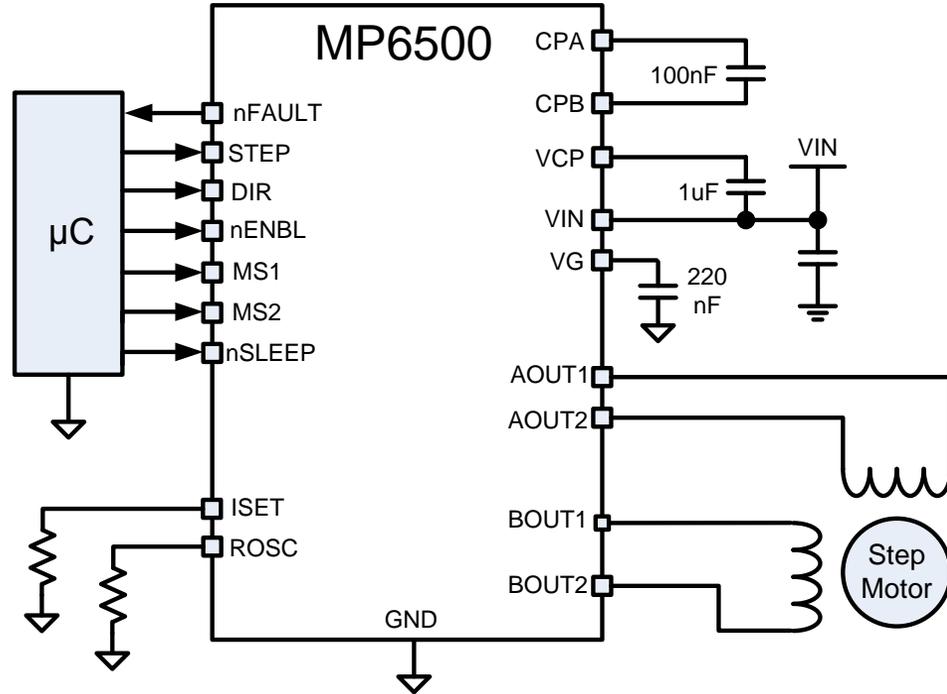
FEATURES

- Wide 4.5V to 35V Input Voltage Range
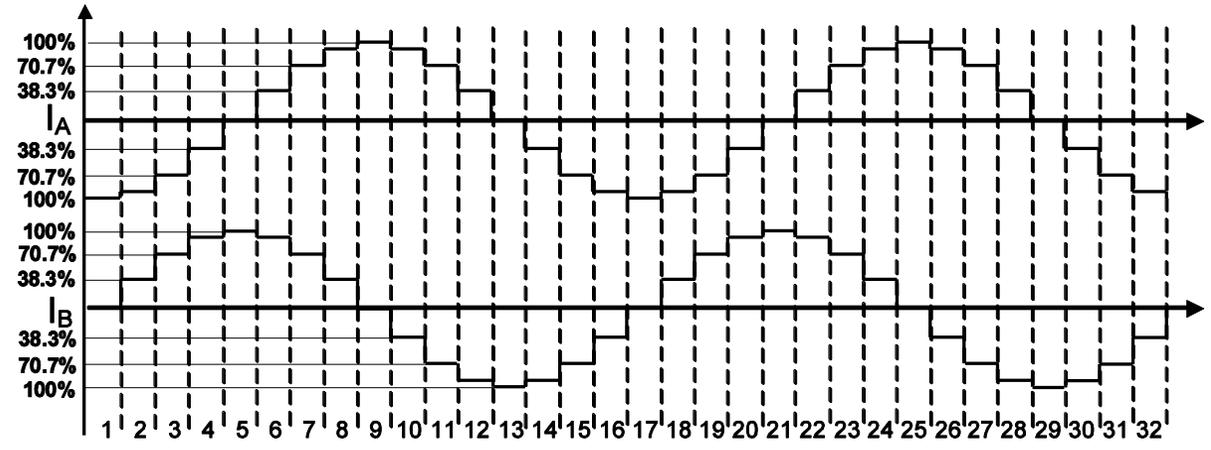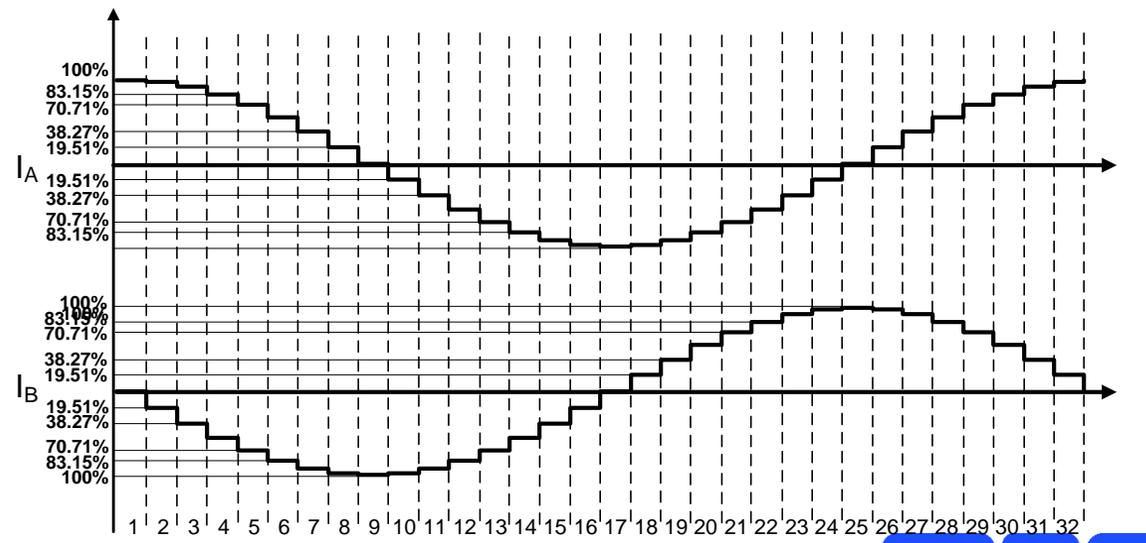- Two Internal Full-Bridge Drivers
- Internal Current Sensing and Regulation
- Low On Resistance (HS: 195mΩ, LS: 170mΩ)
- No Control Power Supply Required
- Simple Logic Interface
- 3.3V and 5V Compatible Logic Supply
- Step Modes from Full-Step to Eighth-Step
- 2.5A Output Current
- Automatic Current Decay
- Over-Current Protection (OCP)
- Input Over-Voltage Protection (OVP)
- Thermal Shutdown and Under-Voltage Lockout (UVLO) Protection
- Fault Indication Output
- Available in QFN-24 (5mmx5mm) and Thermally Enhanced TSSOP-28 Packages

Voltage and Current Ratings

- Wide 4.5V to 35V Input Voltage Range

    This is the input power supply voltage range that drives the motor.

- 2.5A Output Current

    This current rating is the amount of current that the driver is capable of driving into the windings. It can be very misleading!

- Low On Resistance (HS: 195mΩ, LS: 170mΩ)

    This is the internal resistance of the MOSFETs in the H-bridge. It is usually a typical number at room temperature.

- 3.3V and 5V Compatible Logic Supply
- No Control Power Supply Required

    The logic input pins may be compatible with different logic levels, and the part may or may not have a separate logic supply input.

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Driver Features

- Internal Current Sensing and Regulation

Older stepper motor drivers use an external shunt to regulate current.

- Step Modes from Full-Step to Eighth-Step

Different drivers support different step modes or degrees of microstepping.

https://www.monolithicpower.com/en/why-microstepping-isnt-as-good-as-you-think

- Automatic Current Decay

Accurate current control requires consideration of current decay.

https://media.monolithicpower.com/document/AN120_Understanding_MP6500.pdf

- Over-Current Protection (OCP)
- Input Over-Voltage Protection (OVP)
- Thermal Shutdown and Under-Voltage Lockout (UVLO) Protection
- Fault Indication Output

Various protection features are available.

- Available in QFN-24 (5mmx5mm) and Thermally Enhanced TSSOP-28 Packages

Package size may be important in your PCB design.

Stepper Driver Current Ratings

Maximum Current, peak current, full-scale current
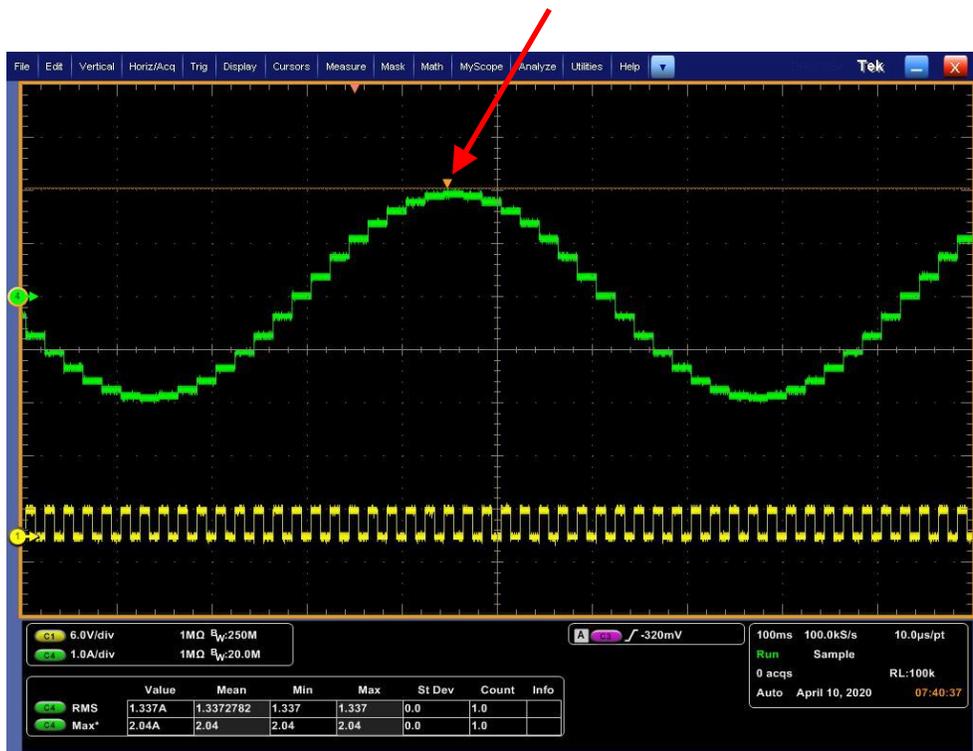
Peak 峰值电流 - 触发OCP之前允许的最大瞬时电流

Maximum 周期内最大输出电流

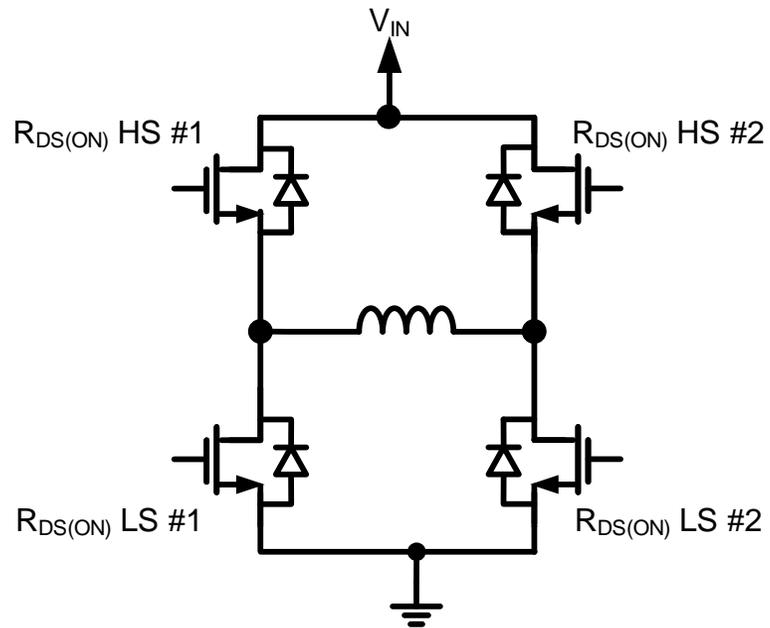**Continuous** 持续输出电流

Average 算数平均电流

RMS 均方根电流 - 正弦/余弦电流调制时，该电流是最大输出电流的70.7%

Full scale 满量程电流

Power Dissipation

R_{DS(ON)} Specifications

$R_{DS(ON)}$ Specifications

$$\text{Effective } R_{DS(ON)} = R_{LS} + (R_{HS} + R_{LS}) / 2$$

| Internal MOSFETs						
Output on resistance	R_{HS}	VIN = 24V, I_{OUT} = 1A, T_J = 25°C		0.195	0.22	Ω
		VIN = 24V, I_{OUT} = 1A, T_J = 85°C		0.25		Ω
	R_{LS}	VIN = 24V, I_{OUT} = 1A, T_J = 25°C		0.17	0.21	Ω
		VIN = 24V, I_{OUT} = 1A, T_J = 85°C		0.25		Ω

MP6500: Total Effective Resistance = ~353mΩ

MOTOR DRIVER OUTPUTS (AOUT1, AOUT2, BOUT1, BOUT2)					
$R_{DS(ONH)}$	High-side FET on resistance	T_J = 25°C, I_O = -1 A		450	550	mΩ
		T_J = 125°C, I_O = -1 A		700	850	mΩ
		T_J = 150°C, I_O = -1 A		780	950	mΩ
$R_{DS(ONL)}$	Low-side FET on resistance	T_J = 25°C, I_O = 1 A		450	550	mΩ
		T_J = 125°C, I_O = 1 A		700	850	mΩ
		T_J = 150°C, I_O = 1 A		780	950	mΩ

Competitor: Total Effective Resistance = ~900mΩ

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A Problem: $R_{DS(ON)}$ vs. Temperature
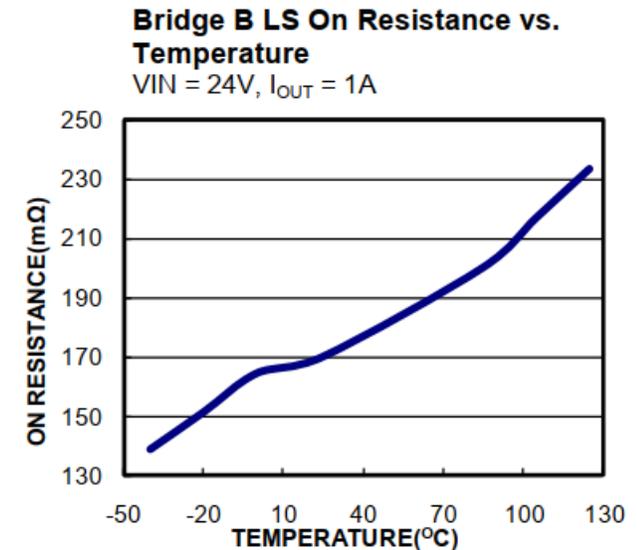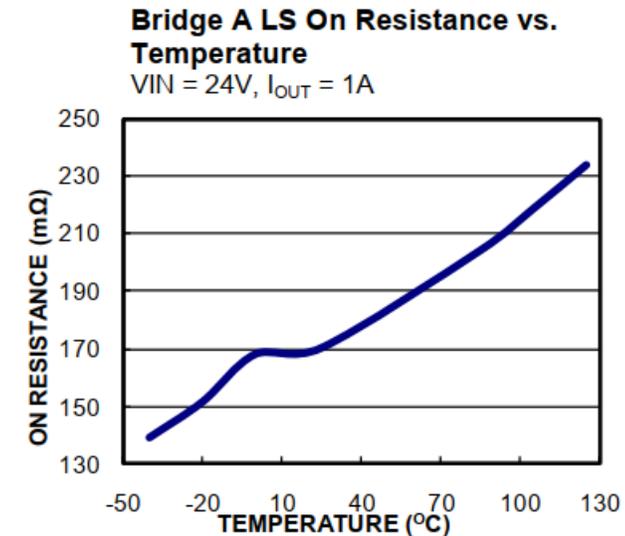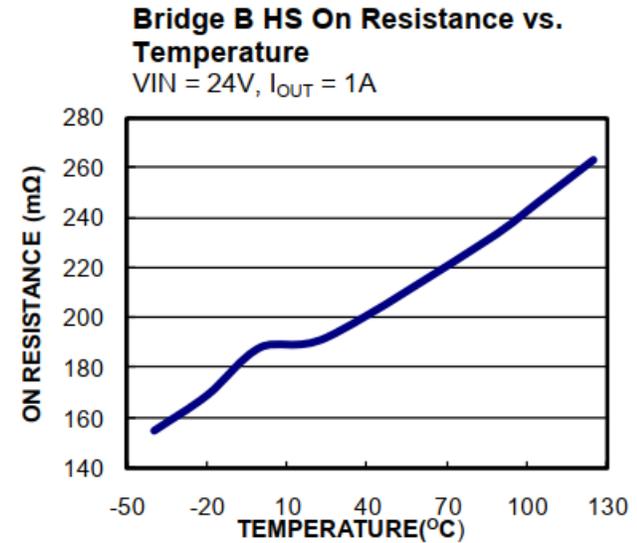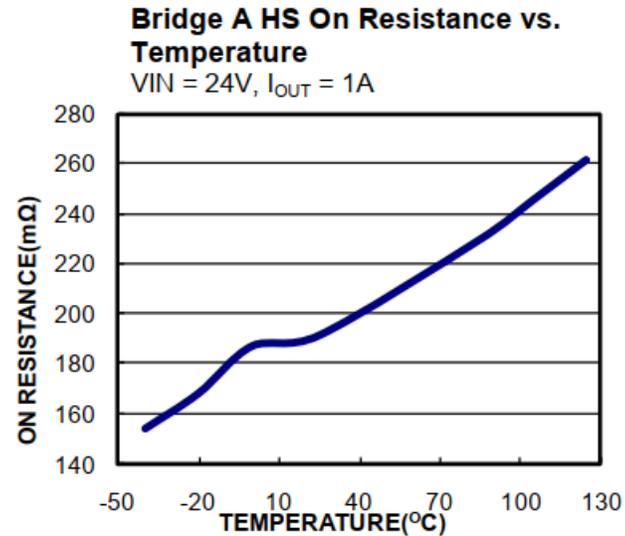
$R_{DS(ON)}$ vs. Temperature

Power Dissipation in Motor Drivers

Resistive Losses
$$P_R = I_{RMS}^2 \times R_{DS(ON)}$$

Switching Losses
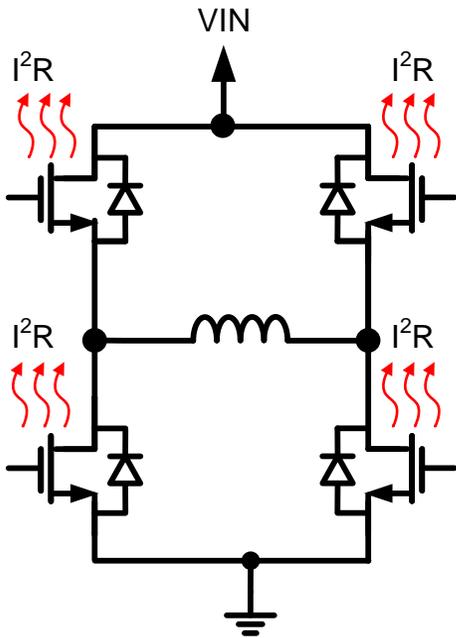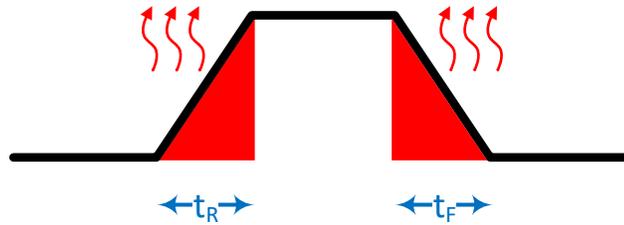$$P_S \approx \tfrac{1}{2} \times V_{IN} \times I_{RMS} \times f_{sw} \times t_R$$
$$+ \tfrac{1}{2} \times V_{IN} \times I_{RMS} \times f_{sw} \times t_F$$

Static Losses
$$P_Q = V_{IN} \times I_Q$$

Total Power
$$P = P_R + P_S + P_Q$$

MP6500 Total Power Dissipation Calculation

Input supply voltage	V_{IN}		4.5	24	35	V
Quiescent current	I_Q	VIN = 24V, nENBL = 0, nSLEEP = 1, with no load		1.5	5	mA
	I_{SLEEP}	VIN = 24V, nSLEEP = 0			1	μA

Output on resistance	R_{HS}	VIN = 24V, I_{OUT} = 1A, T_J = 25°C		0.195	0.22	Ω
		VIN = 24V, I_{OUT} = 1A, T_J = 85°C		0.25		Ω
	R_{LS}	VIN = 24V, I_{OUT} = 1A, T_J = 25°C		0.17	0.21	Ω
		VIN = 24V, I_{OUT} = 1A, T_J = 85°C		0.25		Ω

Resistive Losses: P_R = 1.414A² x 353mΩ = 706mW per H-bridge

Switching Losses: P_{SW} = 1/2 x 24V x 1.414A x 20kHz x 100nS x 2 = 68mW per H-bridge

Static Losses: P_Q = 24V x 1.5mA = 36mW

Total Power: 2 x 705mW + 2 x 68mW + 36mW = 1.58W

Thermal Resistance & Models
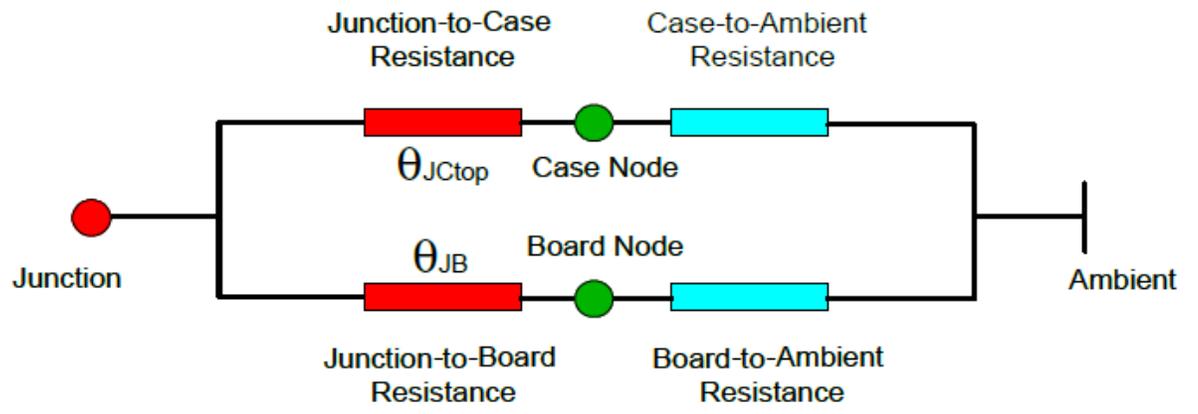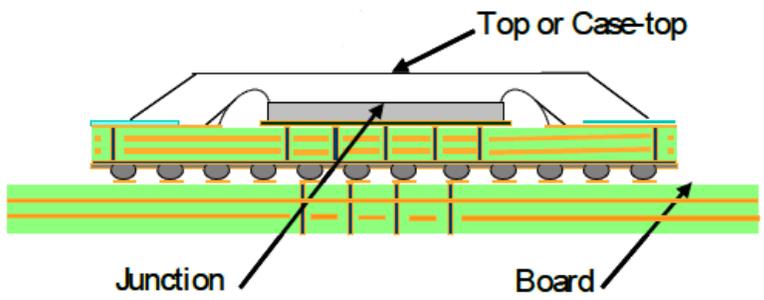
Simple Estimation:

Die Temperature = Ambient Temperature + (P x Θ_{JA})

PCB Design for Power Dissipation

Table 7 — JESD51-7 High Thermal Conductivity Leaded SMT Test Board Parameters [8]

Dimension	Specification	User
Board Finish Thickness	1.60 mm ± 10%	
Board Dimension (pkg length < 27 mm)	76.2 mm x 114.3 mm	
Board Dimension (27 mm ≤ pkg length ≤ 48 mm)	101.6 mm x 114.3 mm	
Board material	FR-4	
Trace Copper Thickness	0.070 mm ± 20%	
Trace Width, Finished	0.25 mm ± 10% for ≥ 0.50 mm pin pitch Lead width for < 0.50 mm pin pitch	
Trace Coverage Area (Total)		
Power/Ground Thickness	35 µm (1oz) copper +0/-20%	

Effect of Layer Count & Planes

MP6500 Driving a 2A Peak Stepper Motor
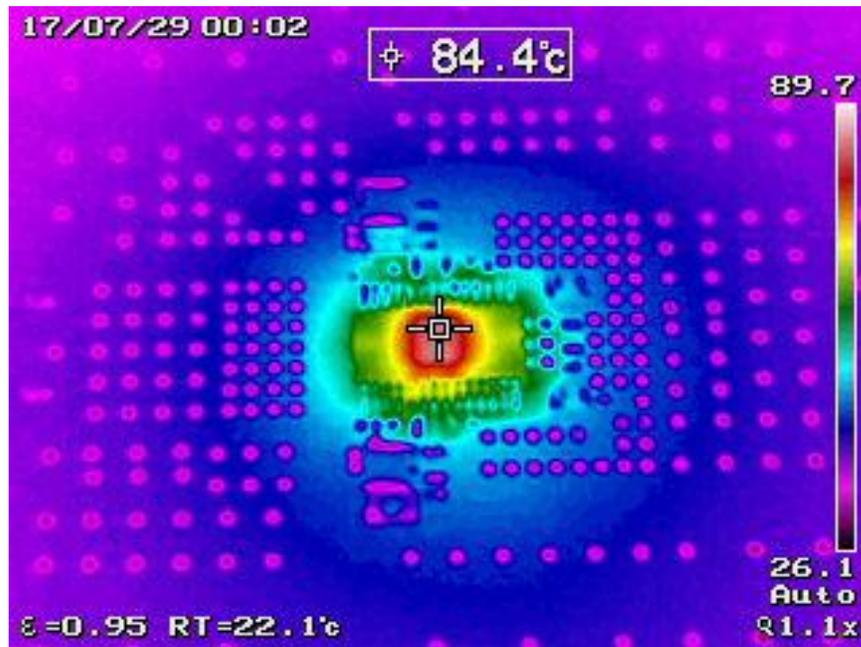
2 Layers
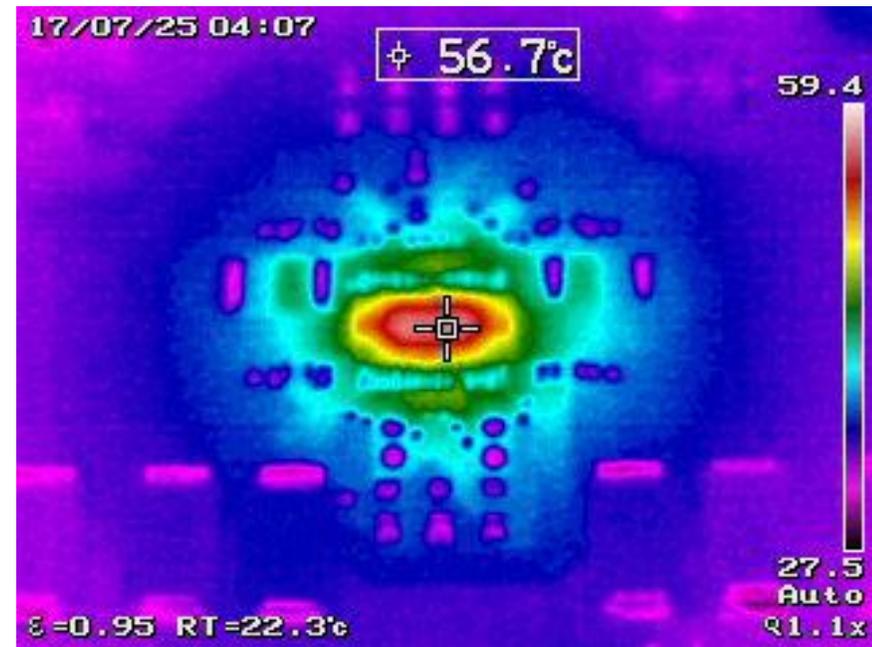
4 Layers (2 Planes)

Current Ratings Revisited

Datasheet Current Ratings Are Almost Meaningless!

MP6500 – **Current rating is "2.5A maximum"**

Thermal Resistance [4] θ_{JA} θ_{JC}
QFN-25 (5mmx5mm) .... 36 .... 8 .... °C/W
TSSOP-28 EP .... 32 .... 6 .... °C/W

Effective $R_{DS(ON)}$ is 380mΩ

Competitor – **Current rating is "2.4A peak, 1.5A full scale"**

THERMAL METRIC 1		PWP (HTSSOP)	RGE (VQFN)	UNIT
		24 PINS	24 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	30.9	40.7	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	25.2	31.1	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	11.3	17.9	°C/W
Ψ_{JT}	Junction-to-top characterization parameter	0.4	0.6	°C/W
Ψ_{JB}	Junction-to-board characterization parameter	11.3	17.8	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	3.1	4.3	°C/W

Effective $R_{DS(ON)}$ is 900mΩ

Competitor Total Power Dissipation Calculation

I_{VM}	VM operating supply current	DRVOFF = 0, nSLEEP = 1, No output		5	7	mA

MOTOR DRIVER OUTPUTS (AOUT1, AOUT2, BOUT1, BOUT2)						
$R_{DS(ONH)}$	High-side FET on resistance	$T_J = 25°C, I_O = -1 A$		450	550	mΩ
		$T_J = 125°C, I_O = -1 A$		700	850	mΩ
		$T_J = 150°C, I_O = -1 A$		780	950	mΩ
$R_{DS(ONL)}$	Low-side FET on resistance	$T_J = 25°C, I_O = 1 A$		450	550	mΩ
		$T_J = 125°C, I_O = 1 A$		700	850	mΩ
		$T_J = 150°C, I_O = 1 A$		780	950	mΩ

Resistive Losses: $P_R = 1.414A^2 \times 900mΩ = 1.8W$

Switching Losses: Estimated $P_{SW} = \sim70mW$

Static Losses: $P_Q = 24V \times 5mA = 120mW$

Total Power: 2 x 1.8W + 2 x 70mW + 120mW = 3.86W

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Temperature Rise

Based on JESD51-7

MP6500 (TSSOP)

ΔT = 1.58W x 32°C/W = 50°C

$T_J = T_A + \Delta T$ = 25°C + 50°C = 75°C

Competitor (TSSOP)

ΔT = 3.86W x 30.9°C/W = 120°C

$T_J = T_A + \Delta T$ = 25°C + 120°C = 145°C

Based on 2-layer evaluation board

MP6500 (TSSOP)

ΔT = 60°C, T_J = 85°C

Competitor (TSSOP)

$$\Delta T = \frac{60^oC}{41\%} \times \frac{30.9^oC/W}{32^oC/W} = 141^oC, \; T_J = 166°C$$

How Much Current Can These Parts Really Drive?

At Room Temperature (25°C):

MP6500 (TSSOP):
Max Power = (150° - 25°) / 32°C/W = 3.9W
Maximum Current per Winding = 2.3A RMS (3.2A peak)

Competitor (TSSOP)
Max Power = (150° - 25°) / 30.9°C/W = 4W
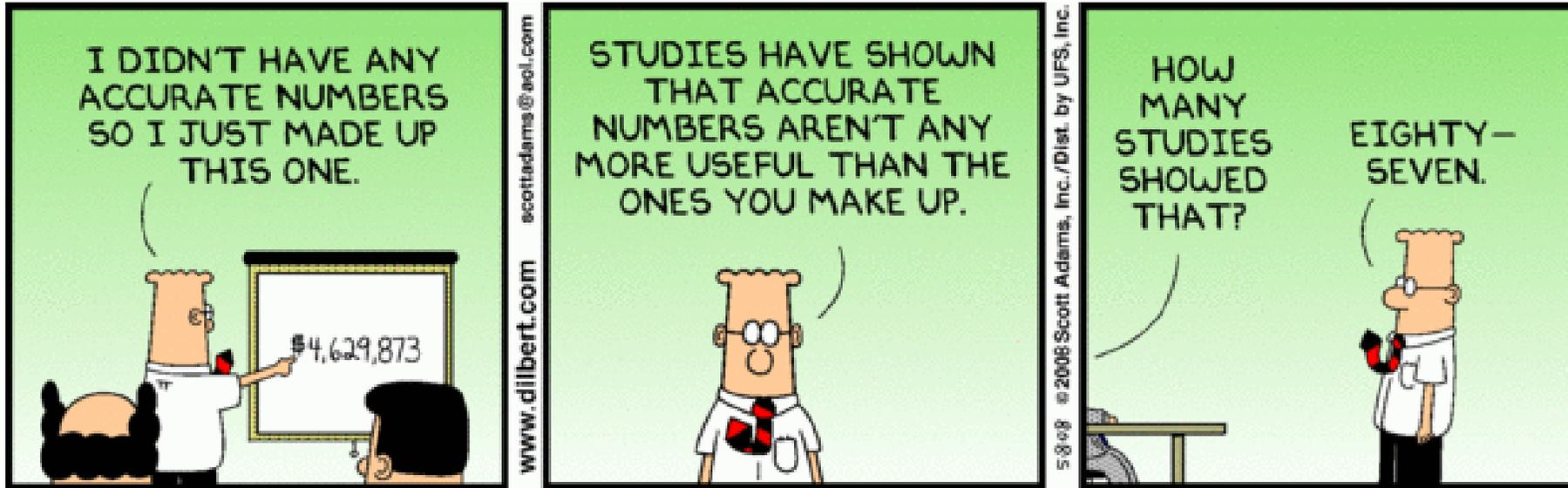Maximum Current per Winding = 1.5A RMS (2.1A peak)

Datasheet Specifications

Image from www.dilbert.com

Suggestion and Summary

- Don't take all the information on a stepper driver datasheet at face value!
- Do your own calculations when it comes to the current rating needed.
- Take into account PCB construction and ambient temperature.

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