Choosing the Right Stepper Motor Driver

Pete Millett

Staff Technical Marketing Engineer

September 2023

Pete Millett – Staff Technical Marketing Engineer

2014–Present

- MPS Staff Technical Marketing Engineer for motor driver ICs
- Responsible for new product definitions as well as application engineering

2005–2013

- Systems Engineer and Systems Manager at Texas Instruments
- Product definition and systems engineering for motor driver ICs (DRV8XXX)

1982–2005

- Board-level hardware design engineer at various computer and consumer electronics companies

Stepper Motor Back EMF

Stepper Motor Basics – Operational Review

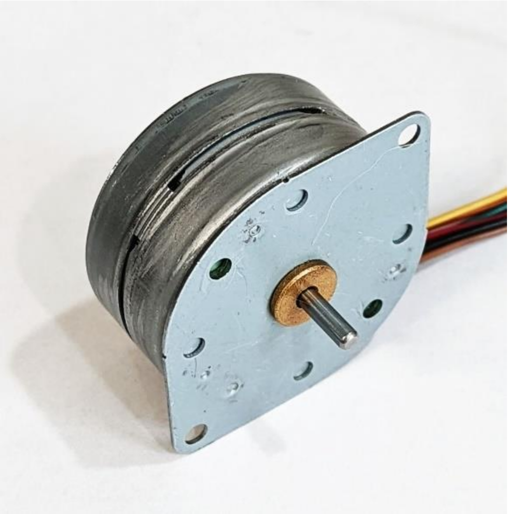
Stepper Motor Driver Datasheet Specs

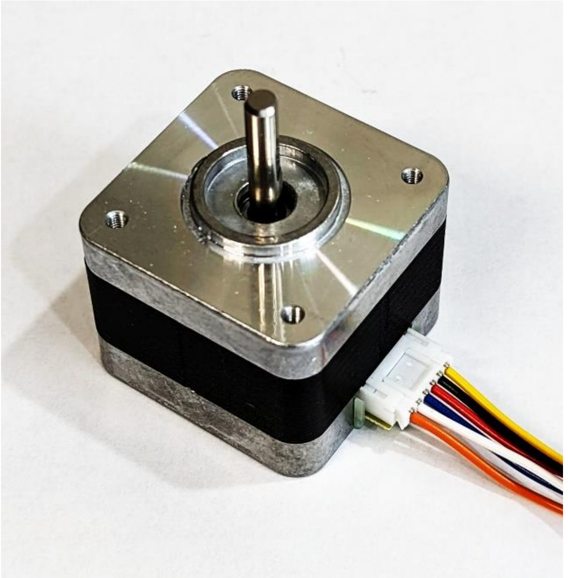
Finding the Right Stepper Motor Driver

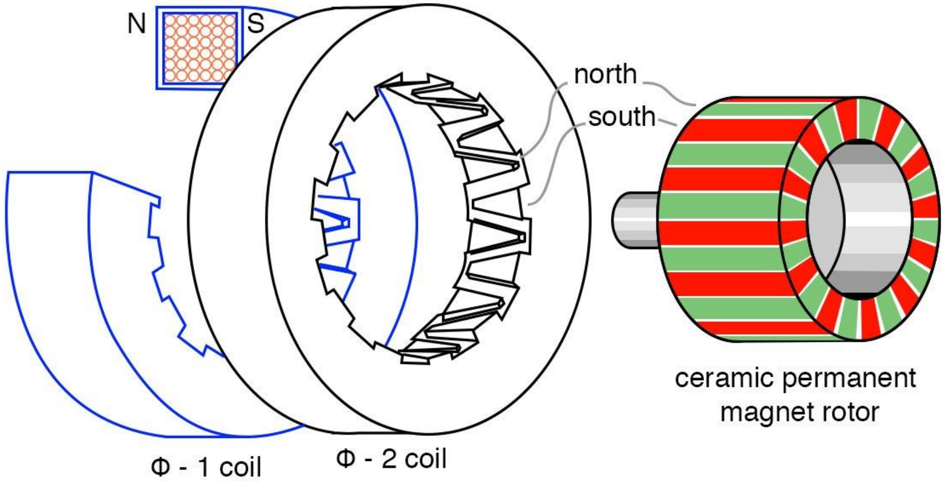
Summary / Q&A

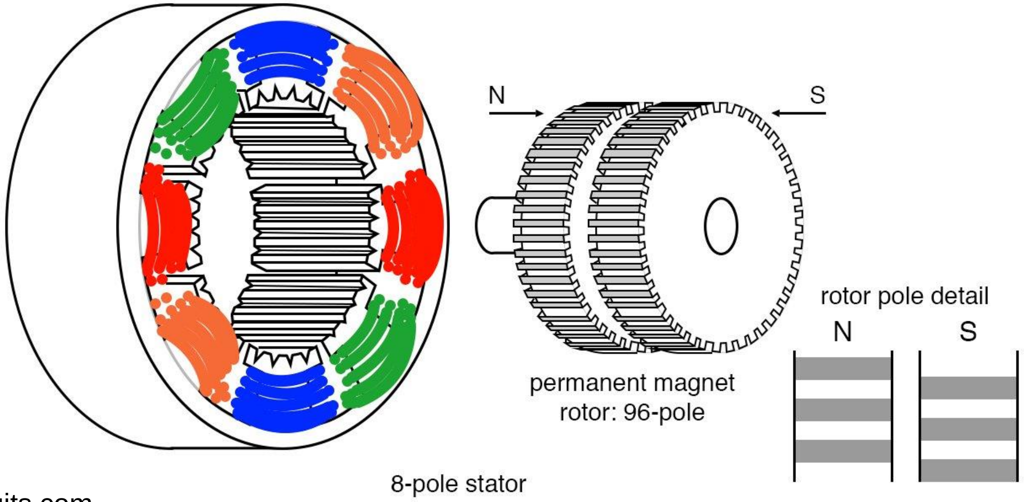
Stepper Motor Basics

Stepper Motor Construction







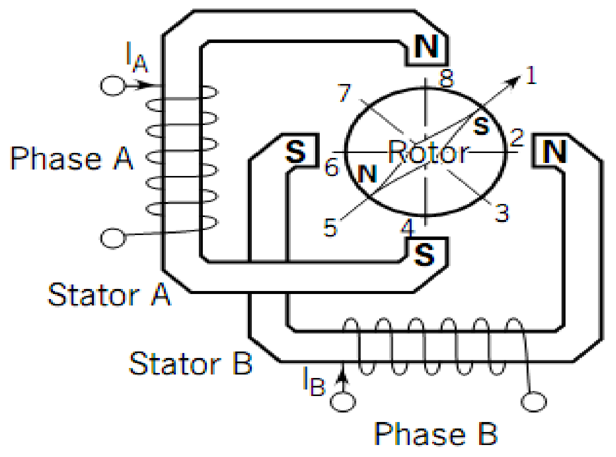


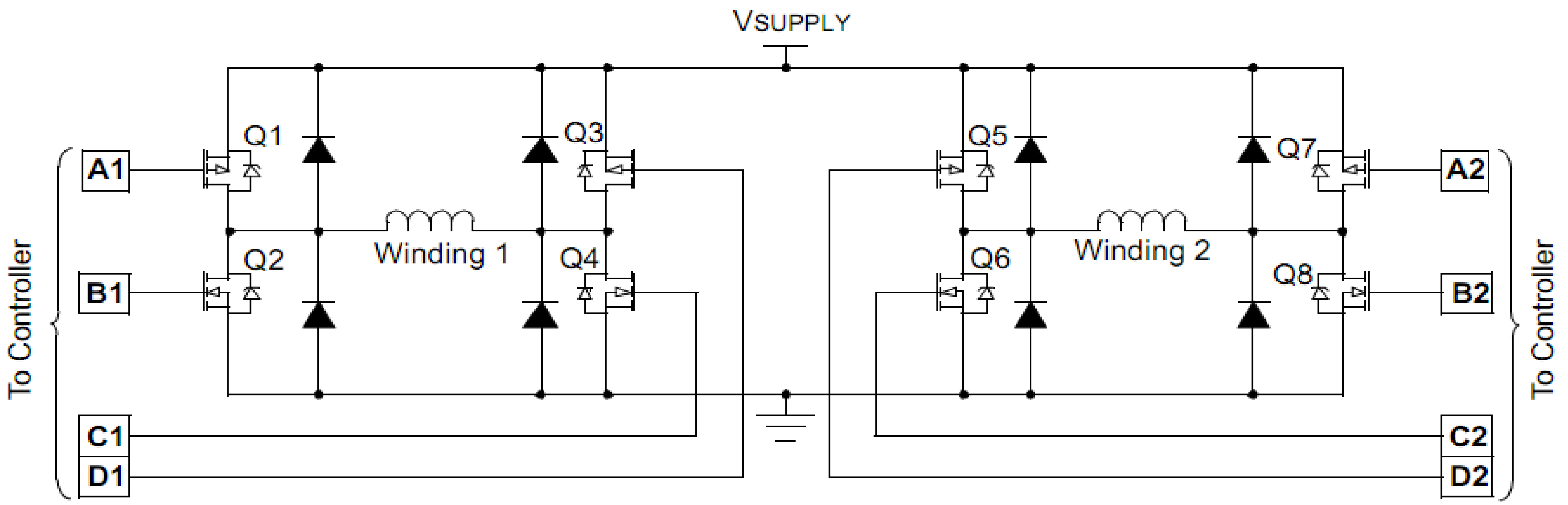
Images from www.allaboutcircuits.com

Permanent Magnet Stepper Motor

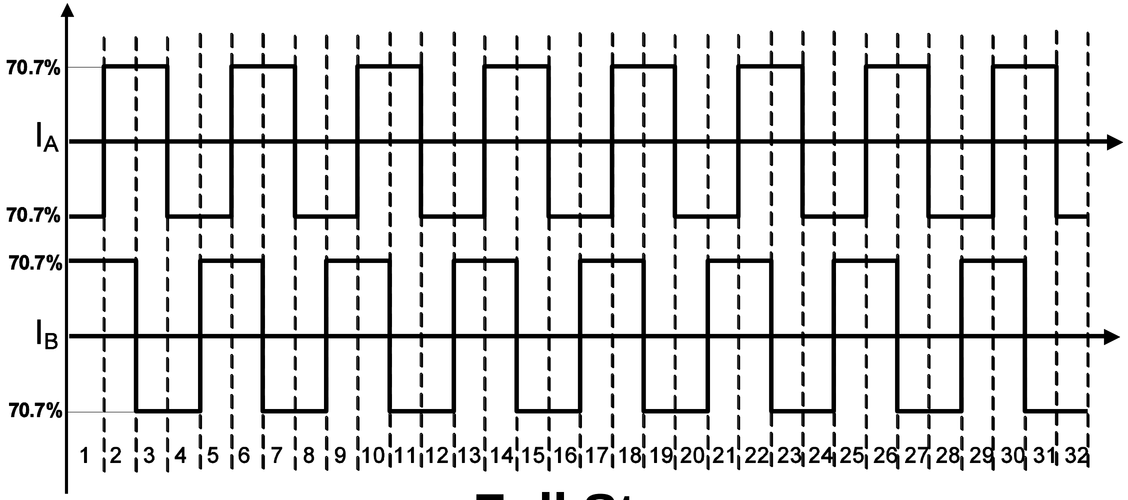
Hybrid Stepper Motor

Driving a Stepper Motor

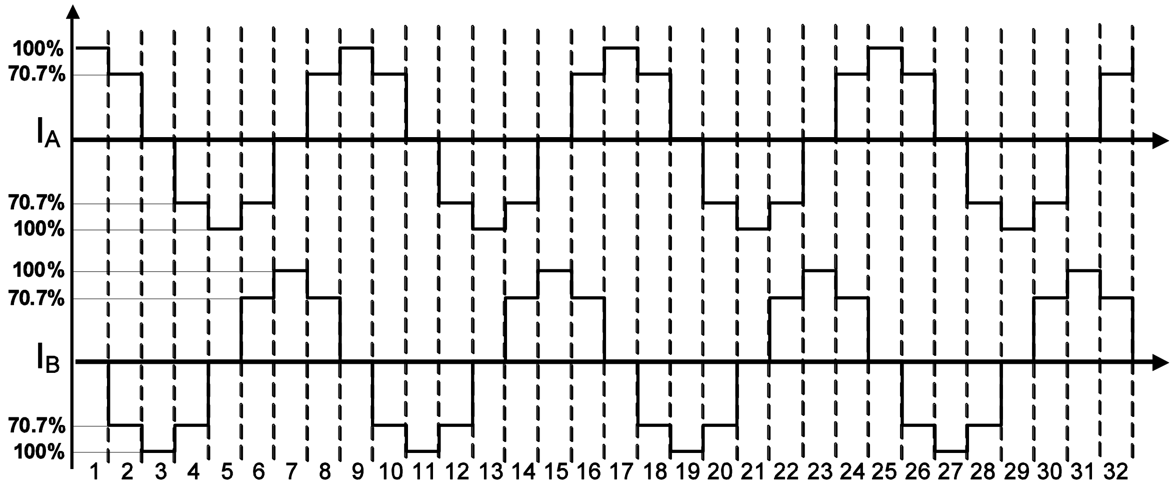




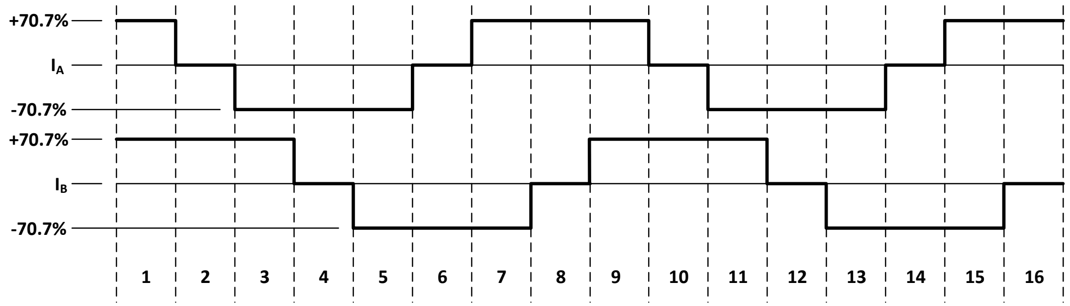
Step Modes and Microstepping



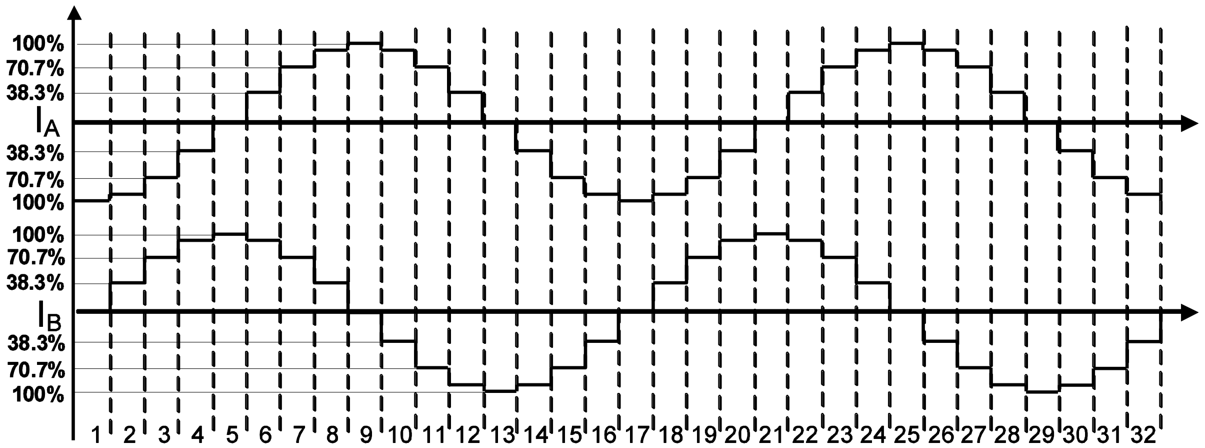
Full Step



Half-Step



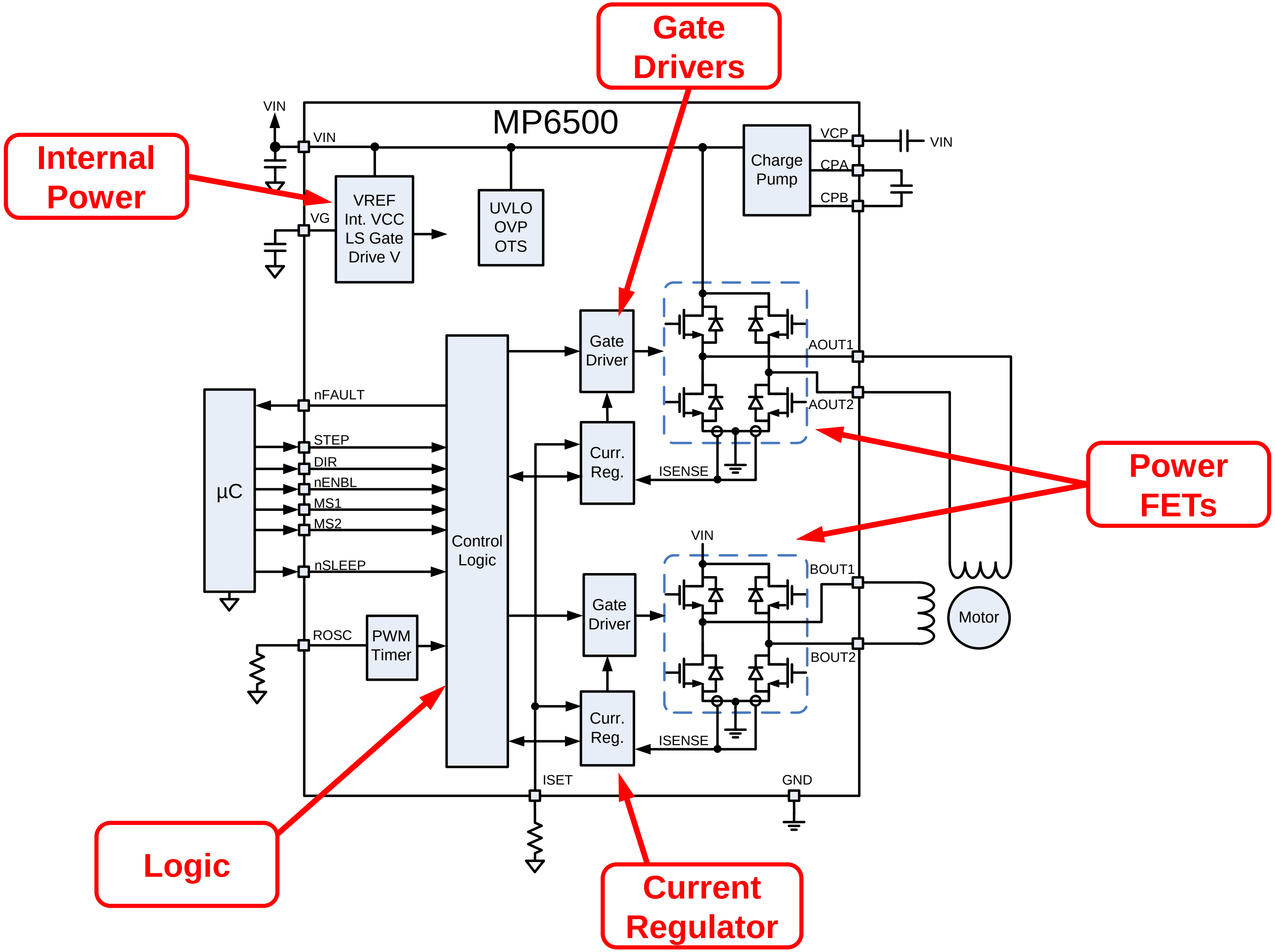
Non-Circular Half-Step (1-2 Phase)



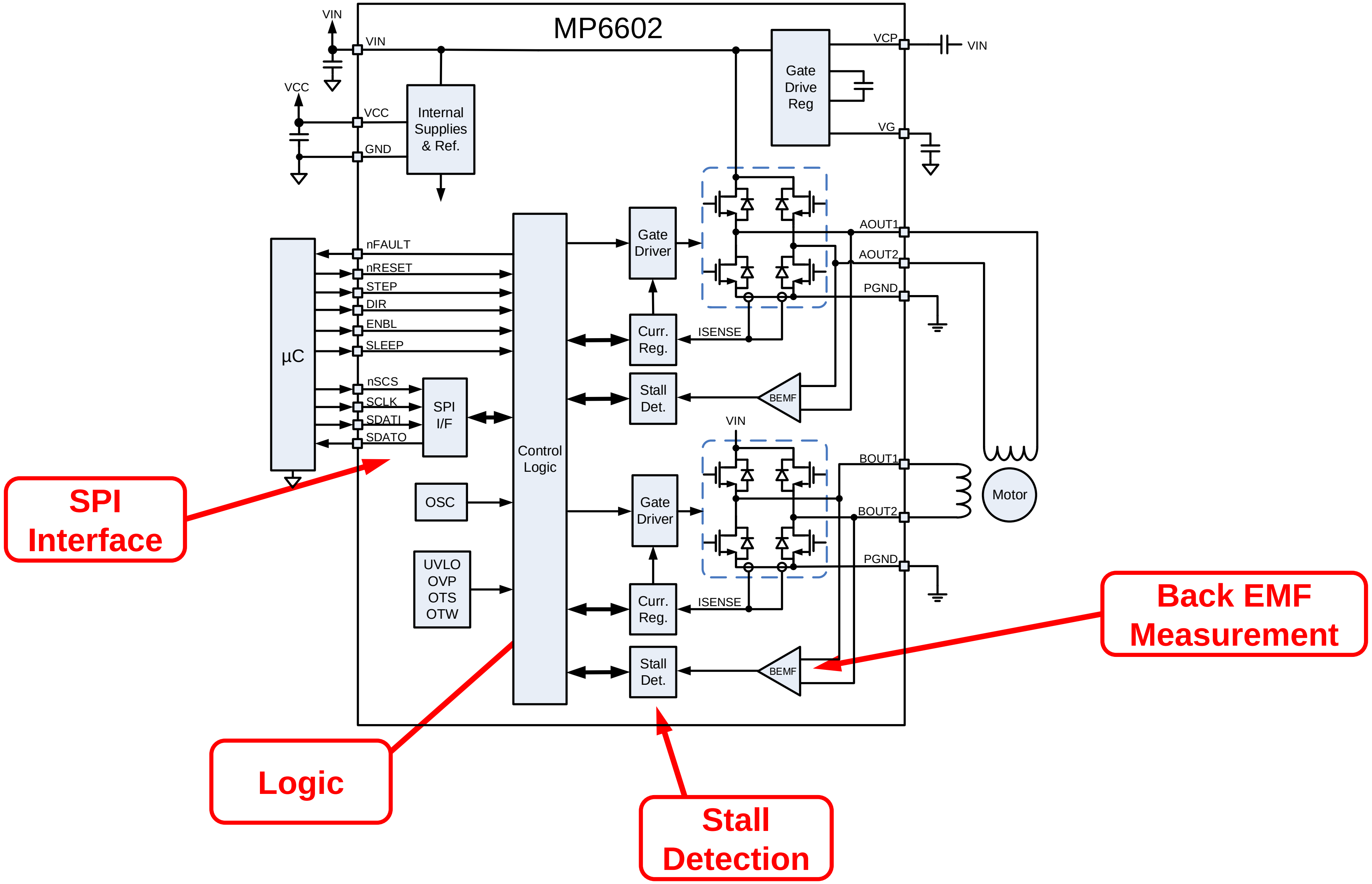
Quarter-Step

Stepper Motor Driver ICs

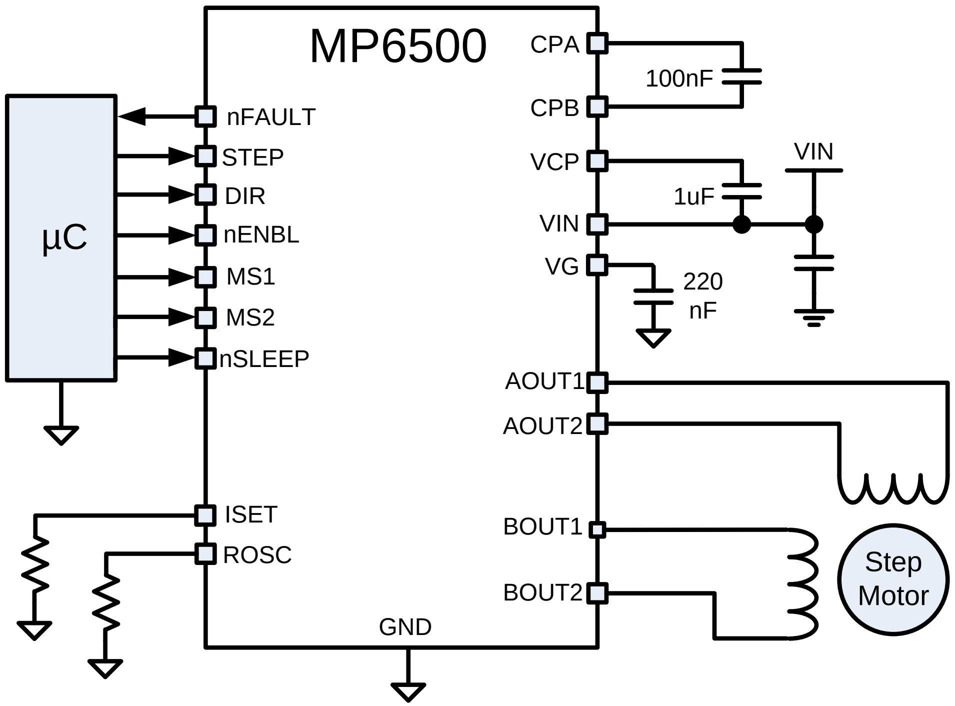
Stepper Driver ICs: What’s Inside (Simple)



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

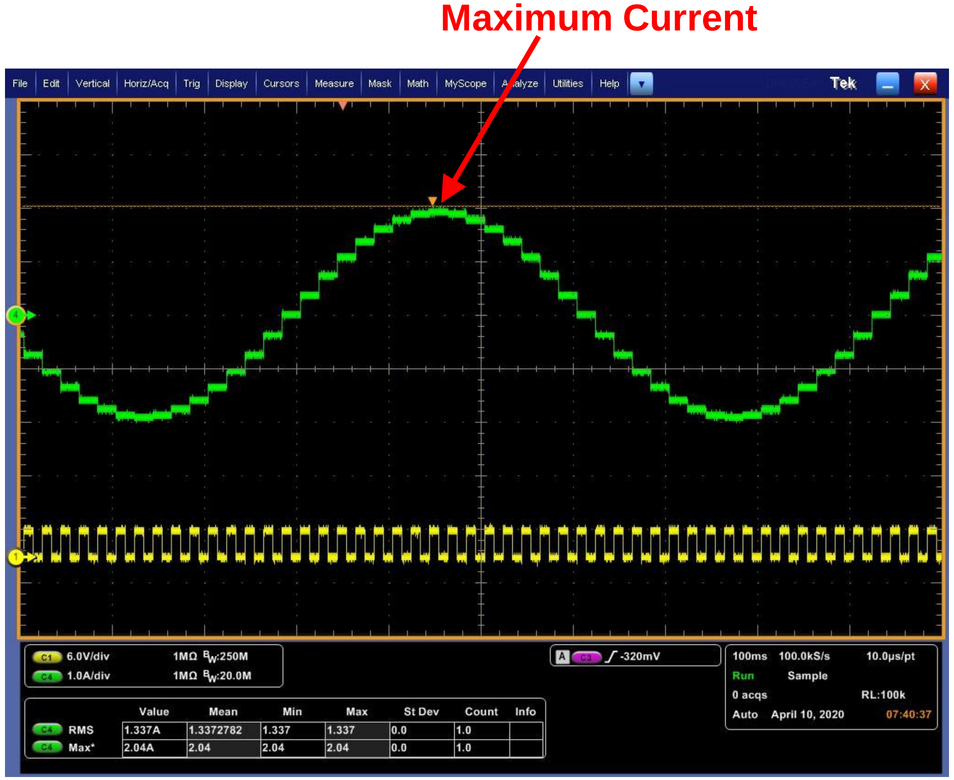
Voltage and Current Ratings

• 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.**

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.**

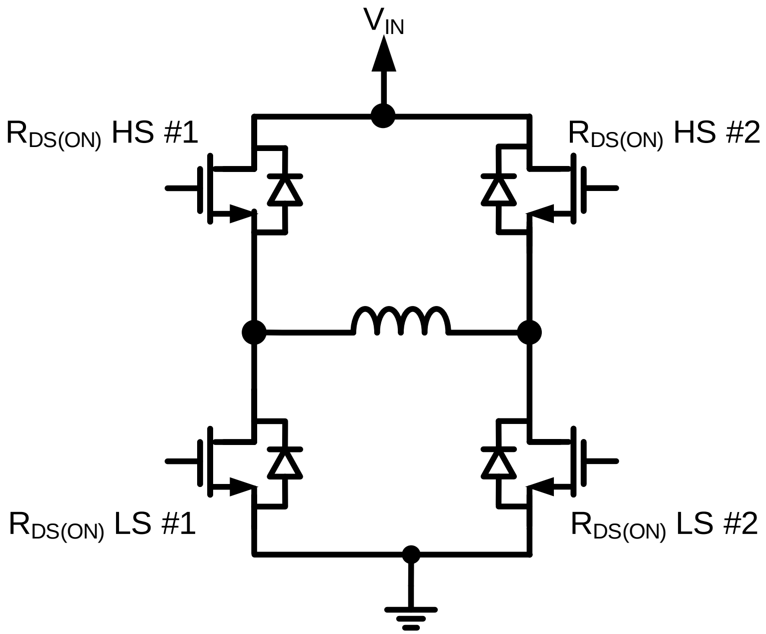
Stepper Driver Current Ratings



Peak	Highest permitted instantaneous current before OCP -or- highest normal winding current
Maximum	Highest normal winding current
Continuous	Highest continuous winding current -or- highest normal winding current
Average	Highest average winding current
RMS	Highest RMS winding current, usually- 0.707 times the peak or maximum current
Full scale	Highest normal winding current

Power Dissipation

$R_{DS(ON)}$ Specifications



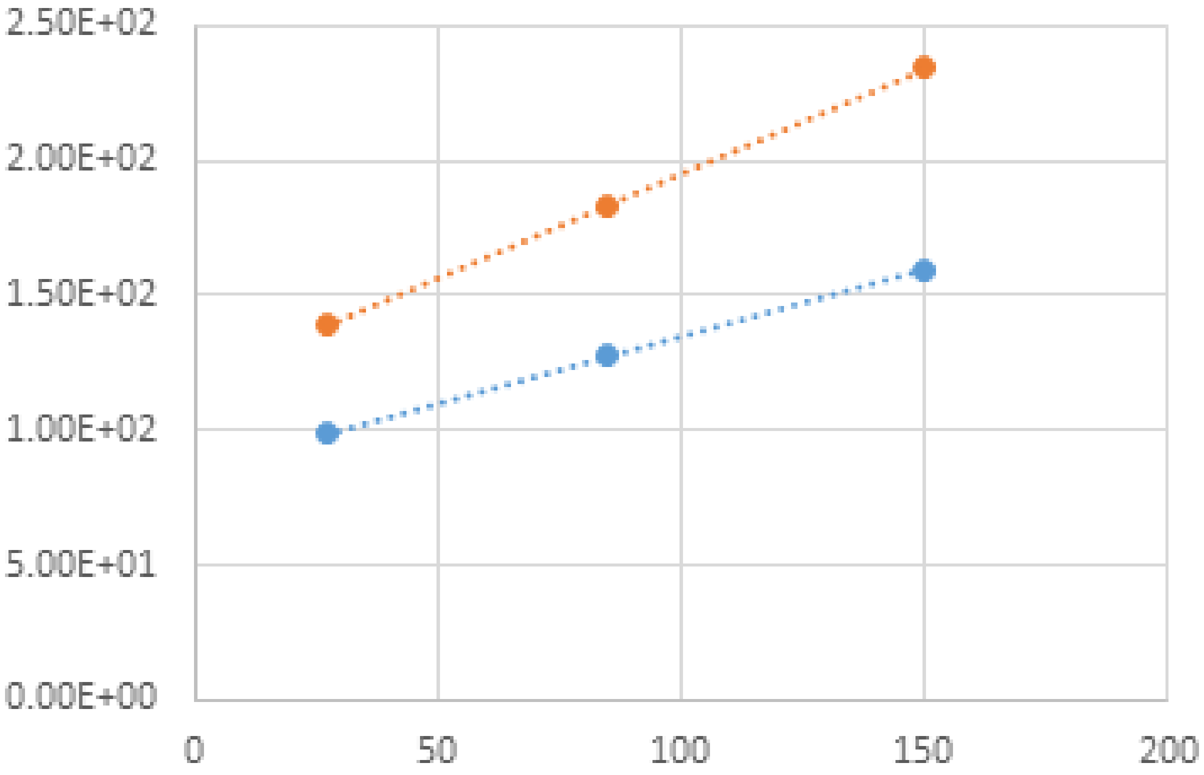
Internal MOSFETs						
Output on resistance	R_{HS}	VIN = 24V, I_{OUT} = 1A, T_J = 25°C		0.195	0.22	Ω
		VIN = 24V, I_{OUT} = 1A, T_J = 85°C		0.25		Ω
	R_{LS}	VIN = 24V, I_{OUT} = 1A, T_J = 25°C		0.17	0.21	Ω
		VIN = 24V, I_{OUT} = 1A, T_J = 85°C		0.25		Ω

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

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

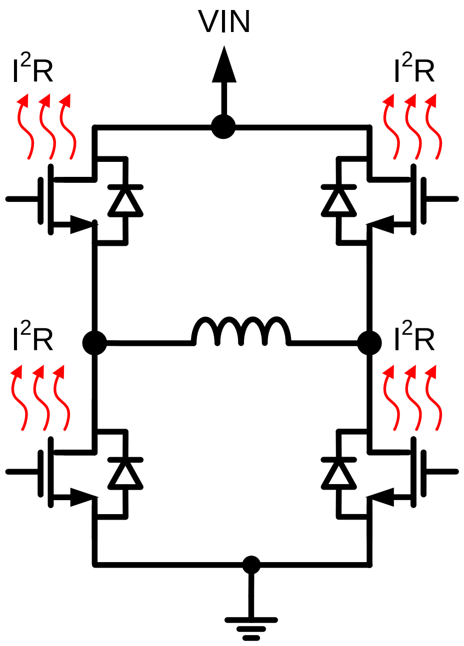


$R_{DS(ON)}$ vs. Temperature

Power Dissipation in Motor Drivers

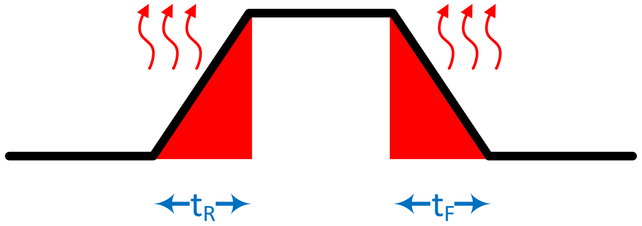
Resistive Losses

$P_R = I^2R$



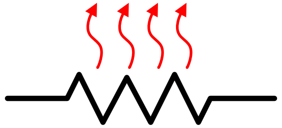
Switching Losses

$P_S \approx ½ \times V \times I \times f_{SW} \times t_R + ½ \times V \times I \times f_{SW} \times t_F$



Static Losses

$P_Q = V_{IN} \times I_Q$



Total Power

$P = P_R + P_S + P_Q$

MP6500 Total Power Dissipation Calculation

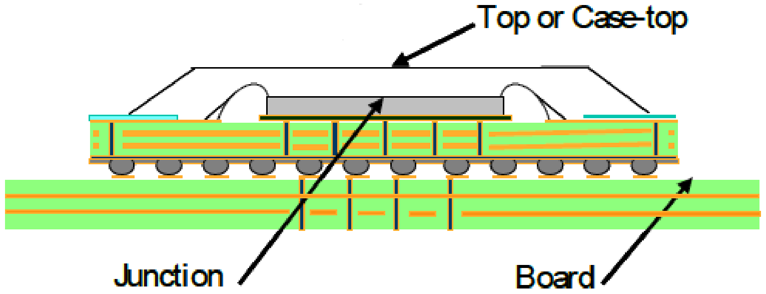
Input supply voltage	V_{IN}		4.5	24	35	V
Quiescent current	I_Q	VIN = 24V, nENBL = 0, nSLEEP = 1, with no load		1.5	5	mA
	I_{SLEEP}	VIN = 24V, nSLEEP = 0			1	μA

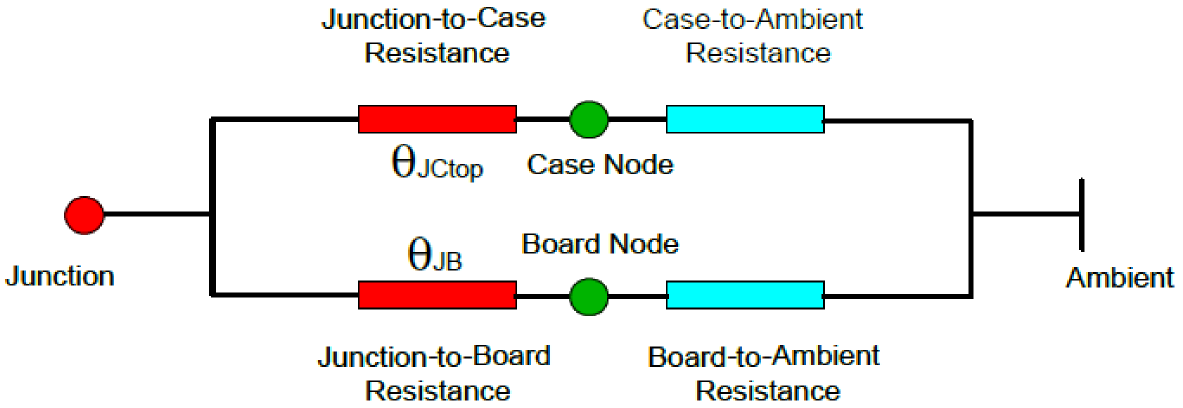
Output on resistance	R_{HS}	VIN = 24V, I_{OUT} = 1A, T_J = 25°C		0.195	0.22	Ω
		VIN = 24V, I_{OUT} = 1A, T_J = 85°C		0.25		Ω
	R_{LS}	VIN = 24V, I_{OUT} = 1A, T_J = 25°C		0.17	0.21	Ω
		VIN = 24V, I_{OUT} = 1A, T_J = 85°C		0.25		Ω

Resistive Losses: P_R = 1.41A^2 x 353mΩ = 705mW per H-bridge
Switching Losses: Estimated P_{SW} = ~70mW per H-bridge
Static Losses: P_Q = 24V x 1.5mA = 36mW

Total Power: 2 x 755mW + 2 x 70mW + 36mW = 1.58W

Thermal Resistance & Models





Simple Estimation:

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

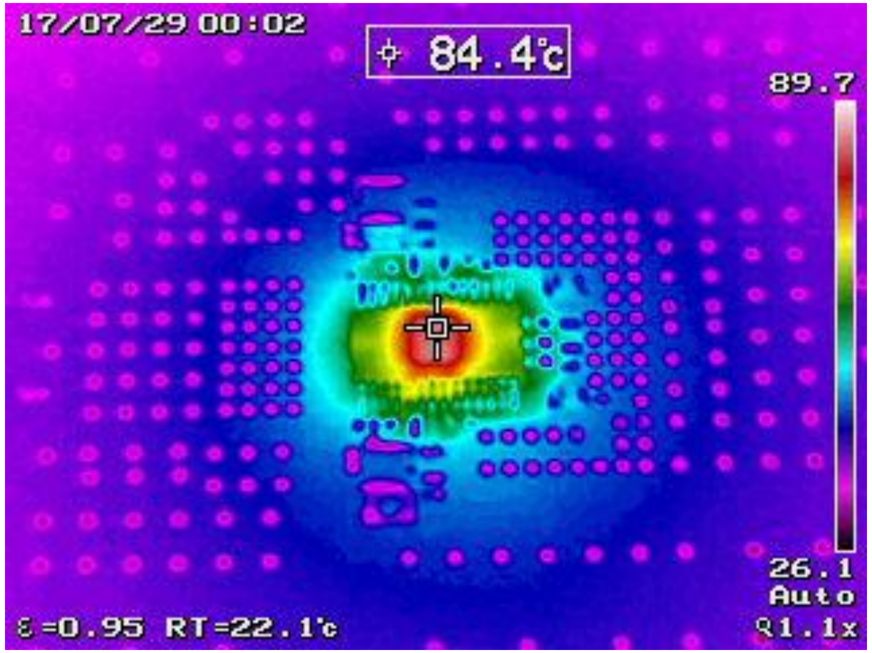
PCB Design for Power Dissipation

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

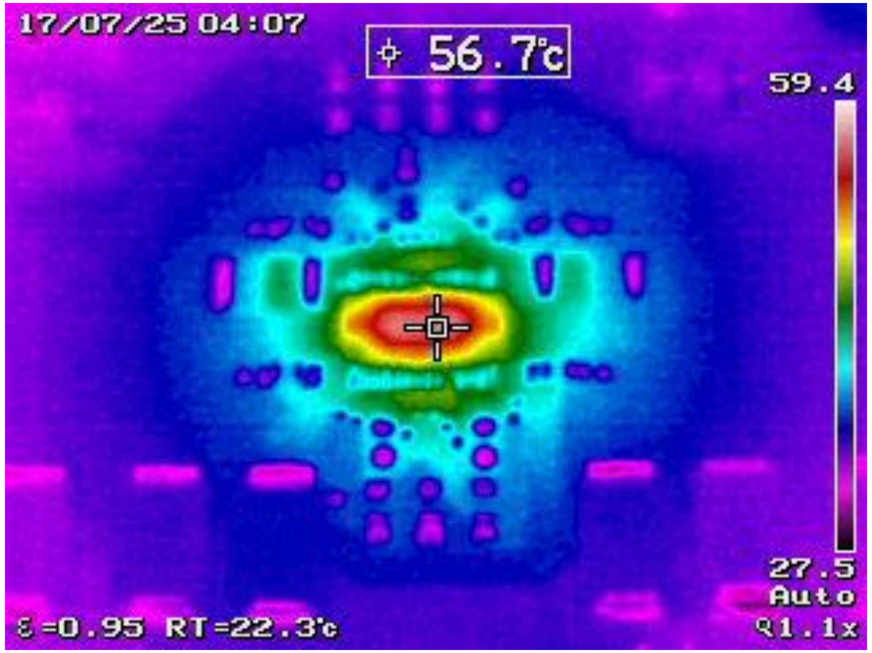
Dimension	Specification	User
Board Finish Thickness	1.60 mm ± 10%	
Board Dimension (pkg length < 27 mm)	76.2 mm x 114.3 mm	
Board Dimension (27 mm ≤ pkg length ≤ 48 mm)	101.6 mm x 114.3 mm	
Board material	FR-4	
Trace Copper Thickness	0.070 mm ± 20%	
Trace Width, Finished	0.25 mm ± 10% for ≥ 0.50 mm pin 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!

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

MP6500 – Current rating is "2.5A maximum"

Effective $R_{DS(ON)}$ is 380mΩ

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

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

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: $P_R = 1.41A^2 \times 900m\Omega = 1.79W$
Switching Losses: Estimated P_{SW} = ~70mW
Static Losses: $P_Q = 24V \times 5mA = 120mW$

Total Power: 2 x 1.79W + 2 x 70mW + 120mW = 3.83W

Temperature Rise

MP6500 (TSSOP) – 1.58W x 32°C/W = 51°C temperature rise
T_J = 150°C when T_A = 99°C

Competitor (TSSOP) – 3.83W x 30.9°C/W = 118°C temperature rise
T_J = 150°C when T_A = 32°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 = 1.4A RMS (2A peak)

At High Temperatures (85°C):

MP6500 (TSSOP) – Max Power = (85° - 25°) / 32°C/W = 2W
Maximum Current per Winding = 1.6A RMS (2.3A peak)

Competitor (TSSOP) – Max Power = (85° - 25°) / 30.9°C/W = 2.1W
Maximum Current per Winding = 1A RMS (1.4A peak)

…And It May Be Even Worse!

Datasheet Specifications

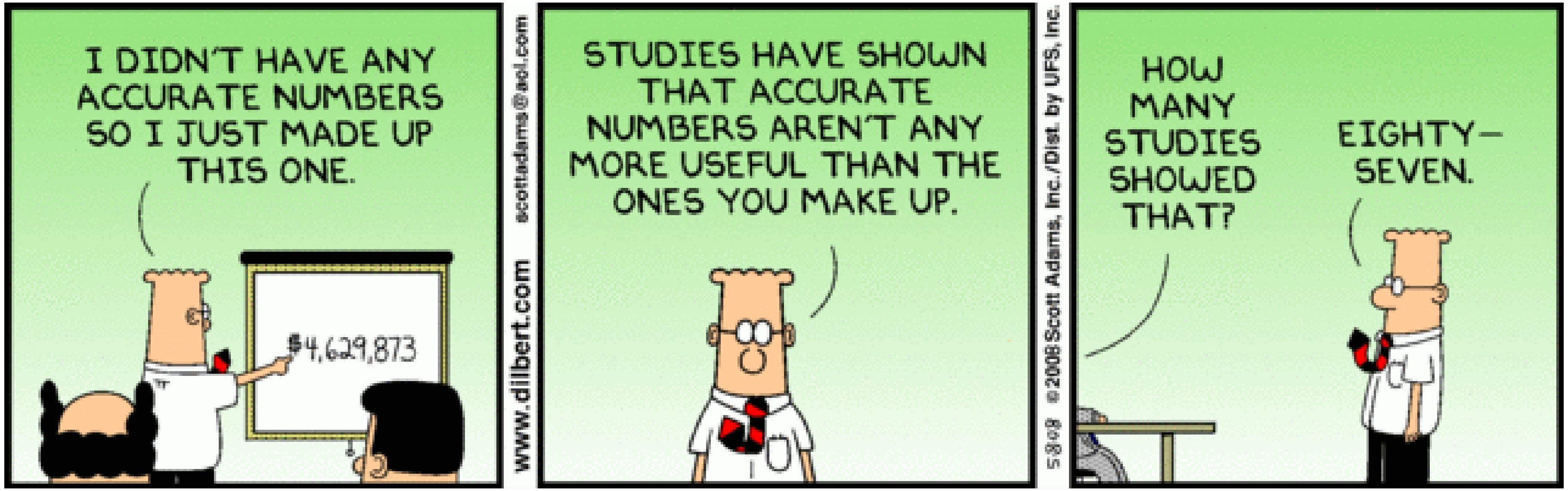


Image from www.dilbert.com

Summary

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

Q&A

Please submit questions through the “Q&A” menu option in the Zoom app

This webinar and others will be available for on-demand streaming at:

MonolithicPower.com/webinars