AN6002

Application note

Performance analysis of STSPIN9x8 devices at different output slew rates

Introduction

High efficiency and low power dissipation are two key-drivers for the selection of a device for motor control applications. Increasing the output dV/dt (slew rate) improves the dynamic performance of the control (shorter pulses and more precise PWM) and reduces the losses.

However, a high slew rate value does not only have benefits, it may also have disadvantages: a worsening of the radiated EMI and a reduced robustness to voltage overshoots/undershoots of the board.

STSPIN9x8 devices are featured with selectable output slew rates among four different values (0.3 V/ns, 0.6 V/ns, 1.2 V/ns, and 2 V/ns) allowing the user to identify the one that best suits its application.

This document guides the users to the selection of the slew rate value describing the pros and cons and showing the characterization of the STSPIN9x8 performances vs slew rate.

1 Basics

1.1 List of acronyms and abbreviations

The following is a list of the acronyms and abbreviations used in the document with their meanings.

Table 1. List of acronyms, abbreviations, and symbols

	Description
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
PWM	Pulse Width Modulation

2 Overview

STSPIN9x8 devices are designed with an adjustable slew rate among four predefined values connecting the proper resistor value between the SR pin and ground as listed in Table 2

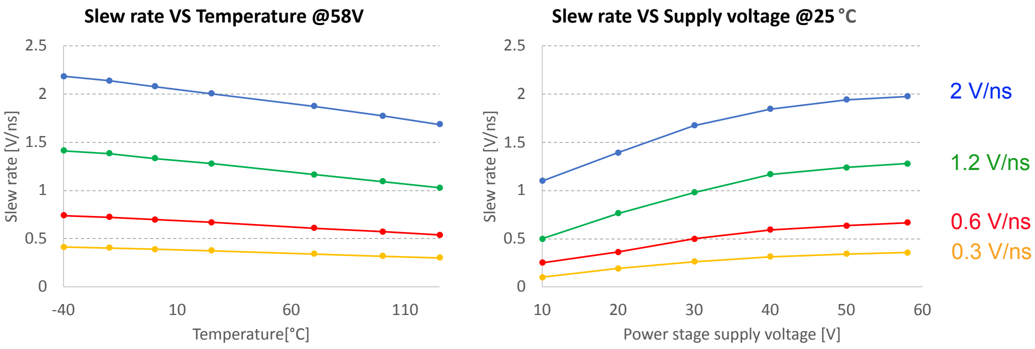
Table 2. **STSPIN9x8 slew rate selection**

Slew rate	SR resistor value
0.3 V/ns	10 kΩ
0.6 V/ns	5.6 kΩ
1.2 V/ns	2.2 kΩ
2 V/ns	1 kΩ

The slew rate value is calculated as the change of voltage per unit of time between 10% and 90% of the voltage supply. It should be considered that since its value depends on both temperature and supply voltage, it is defined at the maximum operating voltage and at 25°C ambient temperature.

The Figure 1 shows the variation of the slew rate vs temperature and voltage supply of the STSPIN9x8 devices.

Figure 1. **Slew rate characterization**



The selection of the slew rate implicitly involves the selection of important parameters that affect the dynamic response of the driver, such as the rise/fall times (directly linked to the slew rate) and the dead time.

The MOSFETs output rise and fall times are inversely proportional to the slew rate and influence the switching losses, hence the efficiency of the driver. Besides this, the dead time is also automatically changed with the slew rate selection. It avoids that the high-side and low-side MOSFETs are switched on at the same time preventing cross-conduction. The dead time is inversely proportional to the slew rate and it affects the power that needs to be dissipated on the body-diode due to the current flowing in it while the MOSFETs are off.

Additionally, higher dV/dt generates higher voltage spikes in the PCB traces and cables and consequent strong current bursts originating undesired radiated electromagnetic noise.

In conclusion, all the following pros and cons need to be taken into account as consequences of the selection of a high output slew rate.

Pros

- Better dynamic performance (reduced rise/fall time, shorter dead time, shorter output pulses)
- Lower losses
- Reduced heating

Cons

- Higher radiated electromagnetic noise
- Need for accurate printed circuit board layout

3 STSPIN9x8 performance analysis vs slew rate

In the following paragraphs, there is an extensive analysis of the advantages and disadvantages of different slew rate values, and the results of the measurements for the STSPIN9x8 devices are presented.

3.1 Dynamic performance

The selection of a high output dV/dt intuitively involves better dynamic performance. In particular, three parameters are greatly impacted: the minimum transmitted pulses, the dead time (output disabling time between PWM commutations to avoid cross-conduction), and the rise/fall times.

The minimum transmitted pulse corresponds to the minimum PWM duty cycle that, at a certain frequency, the device is able to transmit to the output (see Figure 2).

Figure 2. **Output minimum pulse**

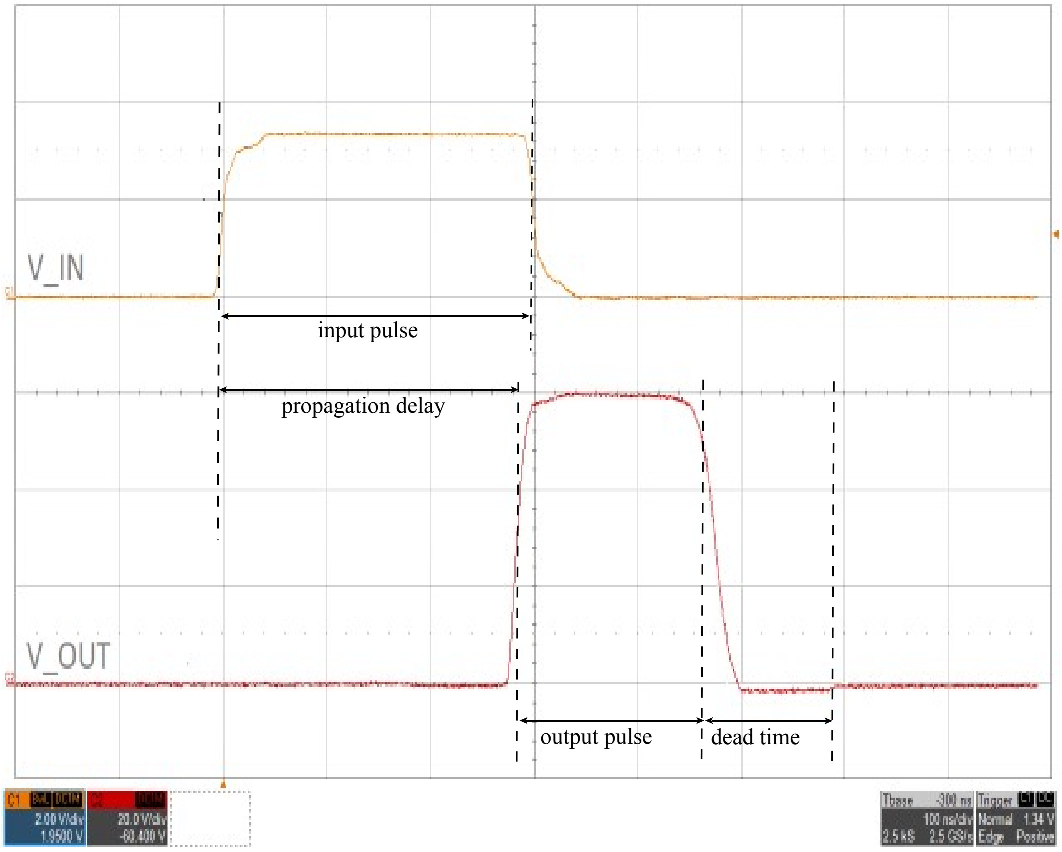
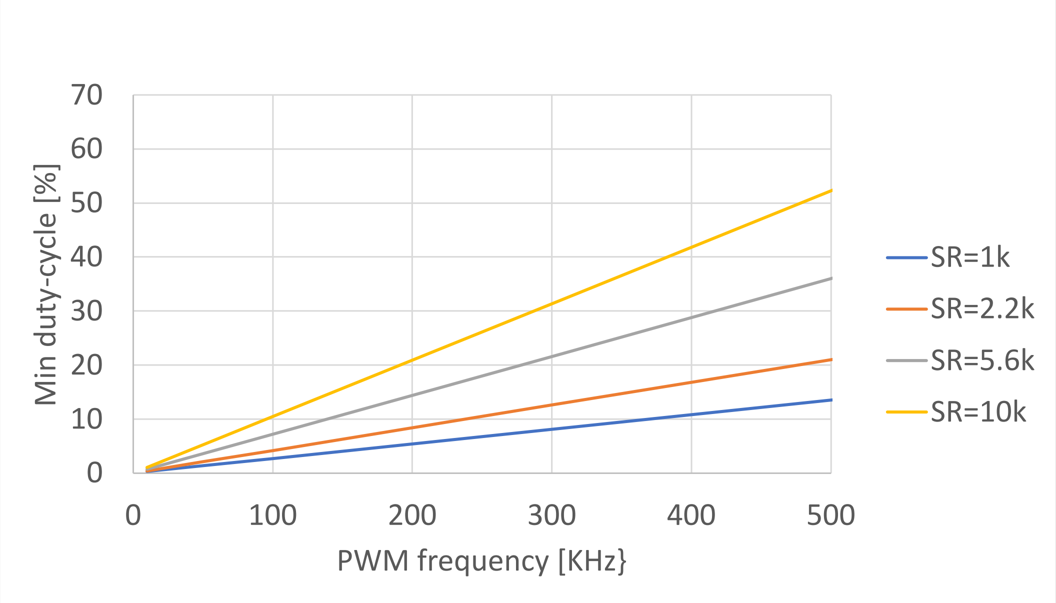


Table 3. **STSPIN9x8 minimum transmitted pulse**

Slew rate	Minimum transmitted pulse
0.3 V/ns	1050 ns
0.6 V/ns	720 ns
1.2 V/ns	420 ns
2 V/ns	280 ns

This may become a limiting factor especially when driving the device at high frequencies since there is a minimum PMW on-time requirement to properly drive the load (see Figure 3).

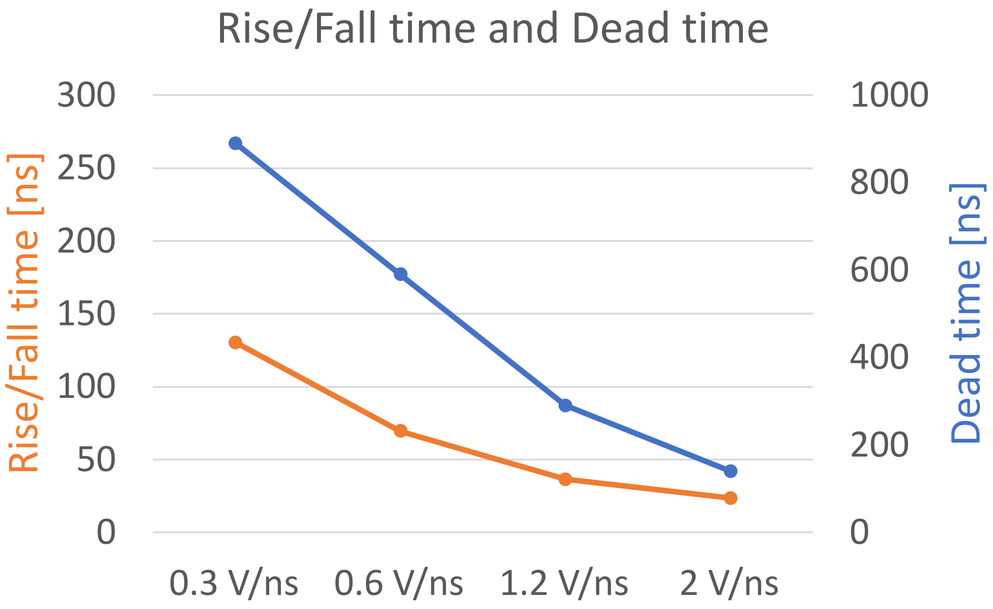
Figure 3. Output minimum duty-cycle



It should be noted that the minimum transmitted input pulse does not correspond to the minimum output pulse. In fact, as shown in Figure 2, the input off-state determines the switching on of the low-side MOSFET (with a delay, i.e. the propagation time) that occurs after a period of time (dead time) after the switching off of the high-side MOSFET. So, the minimum pulse actually seen at the output is the input minimum pulse minus the dead time.

The dead time, as well as the rise/fall times, changes with the slew rate. The device automatically varies these parameters according to Figure 4, so that cross-conduction between high-side and low-side MOSFETs is prevented during each PWM commutation.

Figure 4. Dead time and rise/fall time



3.2 Losses

MOSFET losses are by conduction, switching, and body diode's drop. While conduction losses depend on the $R_{DS,on}$ of the device, independently from the slew rate, both switching and body diode's drop losses are impacted by the slew rate change.

Switching losses are associated with the gate charging during the turning on and off of the MOSFET. They can be calculated with the following simplified formula:

$$P_{sw} = E_{sw} \cdot f = \frac{V_S \cdot I_L \cdot t_v}{2} \cdot f \tag{1}$$

where

E_{sw} is the energy dissipated during one commutation

V_s is the supply voltage of the power stage

I_L is the RMS value of the output current

t_v Miller plateau duration

f is the switching frequency of the half-bridge

In the equation, the t_v, the duration of the Miller plateau, is the time needed to toggle the output voltage (i.e. the rise/fall time). The higher the slew rate is, the lower the rise/fall time (see Section 3.1), therefore, the switching losses are lower. On the contrary, with a lower dV/dt, the switching losses increase.

As explained in the previous paragraphs, during each commutation, the output is kept in high impedance for a determined time (dead time). During dead time the output current flows through the body diode of one MOSFET (low-side when the current is sourced by the half-bridge and high-side in the opposite case) generating additional losses. Half-bridge power losses for dead time can be approximated by the following equation:

$$P_{DT} = V_D \cdot I_L \cdot t_{DT} \cdot f \tag{2}$$

where

V_D is the diode forward voltage

I_L is the RMS value of the output current

t_{DT} is the dead time

f is the switching frequency

In the equation, the t_{DT} is the time the current circulates in the body diode. The higher the slew rate is, the lower the dead time (see Section 3.1), therefore the diode losses are lower. On the contrary, with lower dV/dt, diode losses increase.

3.3 Power dissipation and device temperature

As seen in the previous paragraph, the slew rate selection greatly affects the power dissipation of the device, due to the increased switching and body diode's drop losses. This leads to an increased heating with lower slew rate values.

As an example, the Figure 5 shows the results of a test carried out on the evaluation board EVSPIN958 in full bridge mode in the following conditions:

- PWM frequency (f): 20 kHz
- Supply voltage (V_S): 58 V
- Load current (I_L): 2.4 A_{peak} (1.72 A_{RMS})
- Ambient temperature: 25 °C
- Planar orientation of the board
- Natural convection only

The additional heating due to the increased power losses with minimum slew rate can be appreciated. Analytically it corresponds to:

$$\Delta T = R_{thJA} \cdot (\Delta P_{sw} + \Delta P_{DT}) \tag{3}$$

where

R_{thJA} is the junction to ambient thermal resistance

ΔP_{sw} is the difference of the switching losses

ΔP_{DT} is the difference of the body diode losses

Hence, calculating from equation (1) the total delta switching losses for both rise time and fall time (for the sake of simplicity, t_{RISE} and t_{FALL} was used at 85 °C for both slew rate values):

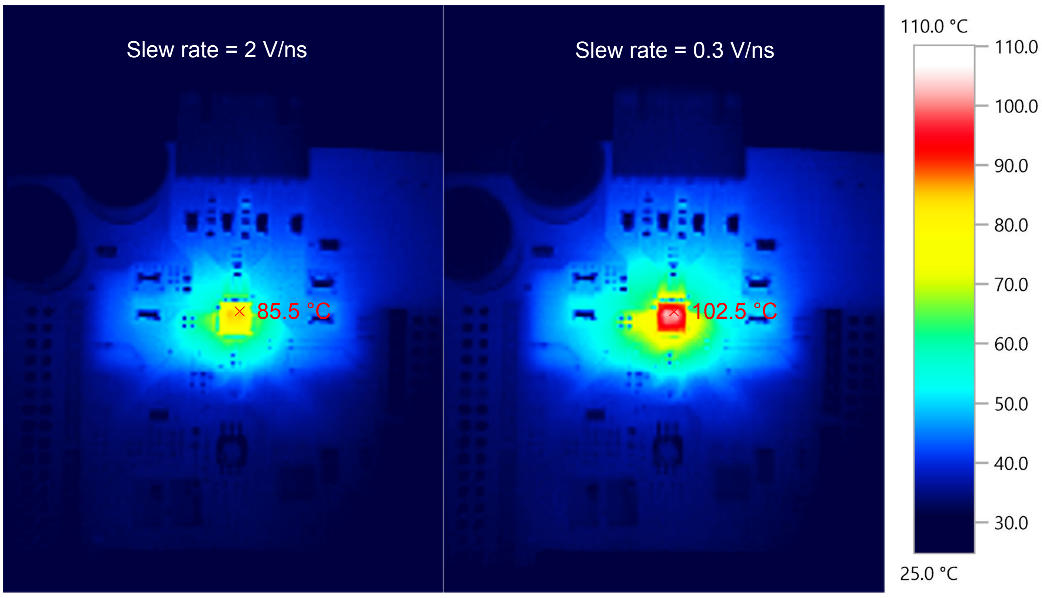
$$\Delta P_{sw} = \frac{V_S \cdot I_L \cdot (\Delta t_{RISE} + \Delta t_{FALL})}{2} \cdot f = \frac{58V \cdot 1.72A \cdot [(240ns - 35ns) + (240ns - 35ns)]}{2} \cdot 20KHz = 409 \text{ mW}$$

and from equation (2), twice the delta diode losses (turning on and off the bridge):

$$\Delta P_{DT} = 2 \cdot V_D \cdot I_L \cdot \Delta t_{DT} \cdot f = 2 \cdot 1V \cdot 1.72A \cdot (890ns - 140ns) \cdot 20KHz = 52 \text{ mW}$$

and considering a thermal resistance of 36 °C/W, we obtain from equation (3) a ΔT = 16.6 °C that is in good agreement with the measurement (Figure 5).

Figure 5. **Device heating**



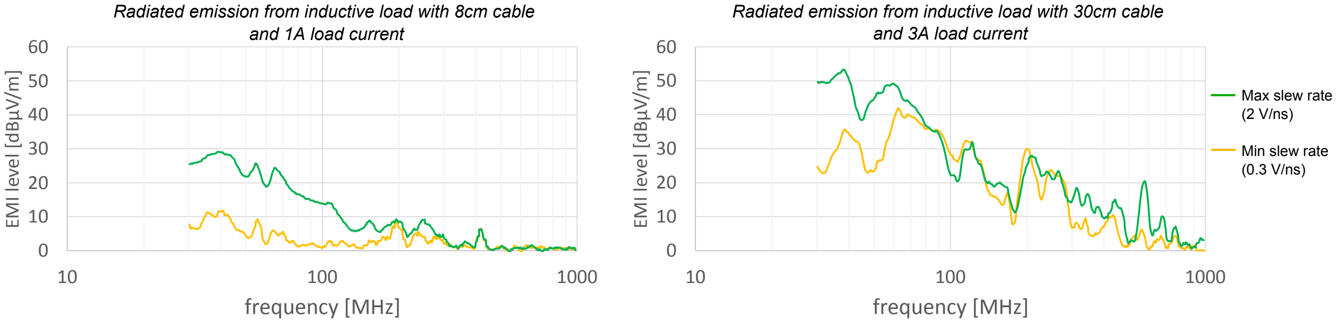
3.4 Radiated electromagnetic noise

The switching MOSFETs draw a burst of current, which generates a magnetic field at the switching frequency, as well as at higher harmonics. These fields can induce a signal in nearby traces on a PCB, and interfere with signals with low EMI immunity.

At maximum slew rate, integrated MOSFETs in STSPIN948 typically take ~30 ns to switch between the OFF and ON states at maximum supply voltage operating condition outputting up to 4.5 A that may induce unwanted voltage spikes in the parasitic inductance of the traces and the cables.

To better evaluate the worsening of the electromagnetic interference, a test was carried out with the evaluation board EVSPIN948 varying the load current and the slew rate, and driving a load with 8 cm or 30 cm cable length. The results were collected in an EMC test chamber with an EMI receiver (Figure 6).

Figure 6. EVSPIN948 radiated noise



As shown, the radiated noise strongly depends on the application topology (i.e. cables, connectors) and it increases with the load current. However, the comparison between tests performed with maximum and minimum slew rate values, highlights how electromagnetic emissions can be minimized especially in the frequency range up to 1 GHz.

4 Conclusions

STSPIN9x8 devices allow the user to select proper output slew rate settings according to their application needs.

The parameters should be chosen evaluating pros and cons, trading off between improving device dynamic performance, efficiency, power dissipation, and emitted electromagnetic radiation. In fact, on one hand, increasing output dV/dt allows for more precise duty-cycles to be reached with reduced dead time and rise/fall times, and it improves efficiency and reduces switching losses and body diode’s drop, hence device heating. On the other hand, it has an impact on the radiated electromagnetic noise.

Moreover, attention should be paid to PCB layout when quickly switching at high currents, in order to avoid unwanted overshoot and below ground spikes due to parasitic inductance of the traces and exceeding the absolute maximum ratings of the device.

Revision history

Table 4. **Document revision history**

Date	Version	Changes
08-Sep-2023	1	Initial release.

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