Open load detection with STSPIN220 stepper driver

Introduction

The STSPIN220 is a stepper motor driver designed for battery powered applications. The device has an integrated power stage with a complete set of protection features including overcurrent, overtemperature and short-circuit protection.

Some applications can be required to detect whether one or both phases of the motor are disconnected from the driver.

This document describes how to implement an external circuitry, in order to detect the open load condition.

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1 STSPIN220 basic operation

The STSPIN220 power stage is composed of two full-bridges, one for each phase of the stepper motor. Each full-bridge is driven by the internal logic in order to implement an independent PWM current control. When the current in the motor phase reaches the target level, a decay sequence is performed (slow decay and then fast decay). During normal operation, with a load connected, the output pins switch according to the PWM sequence: T_{ON}, slow decay and fast decay (see Figure 1). In an open load condition instead, one high-side MOSFET and the opposite low-side MOSFET are steady turned on: the absence of the load avoids the current flow, so the PWM controller does not switch (Figure 2).

Figure 1. Output voltages in a normal operating condition (load connected)
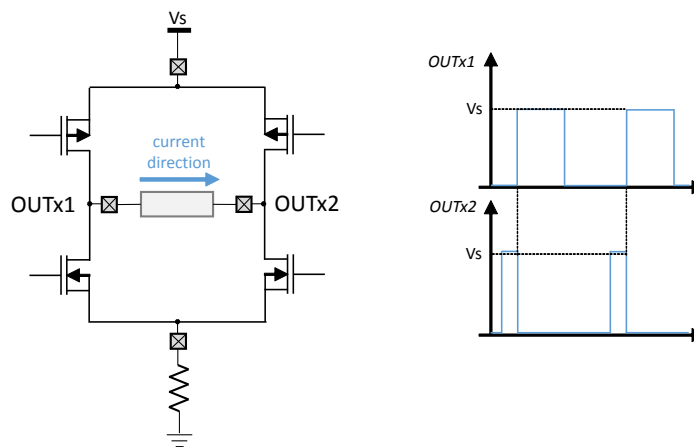

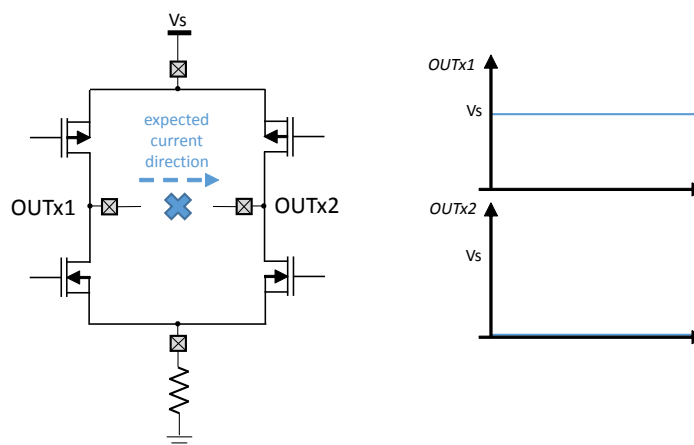**Figure 2. Output voltages in an open load condition (load unconnected)**

Figure 1 and Figure 2 show just one full-bridge: for this reason the out pins are generically indicated as OUTx1 and OUTx2, where x can refer to phase A or phase B. The figures depict the voltage for a given direction of the current. Changing the direction of the current results in a swap between voltage on OUTx1 and OUTx2.

1.1 Open load detector circuit

The open load detector checks when the condition represented in Figure 2 occurs. Since the circuit must work for both the current directions, it is best to not consider OUTx1 and OUTx2 separately, but acquire the sum of the two signals; if this resulting signal is steady at the Vs supply for a certain amount of time, an open load condition has occurred. A simple way to implement the circuit is represented in Figure 3.

Figure 3. Basic open load detector filter
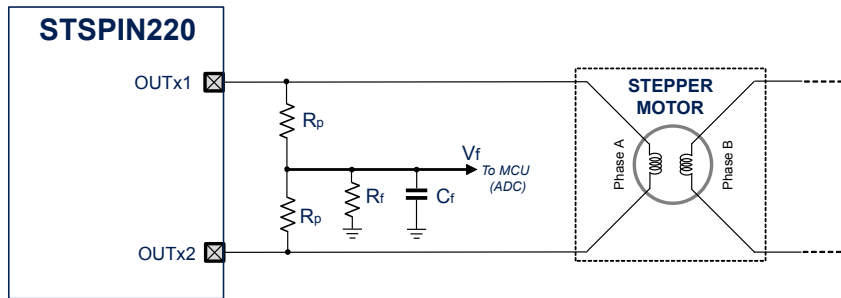
The partition introduced by the resistors net, makes the signal suitable for a microcontroller, which in many cases works at lower voltages than the STSPIN220 voltage supply. The capacitor C_f implements a low-pass filter, so the signal V_f is proportional to the duty cycle of the sum of the PWM on the outputs. When the signal V_f reaches the voltage corresponding to the 100% duty cycle, it means that the open load condition has occurred. Sampling the V_f signal (for example with an ADC line of the microcontroller) it is possible to detect when the open load condition occurs.

The capacitor C_f is mandatory, otherwise the open load detection is continuously triggered at each PWM cycle.

The circuit in Figure 3 represents the filter for one phase of the stepper motor. The same circuit must be replicated on the other phase; as a matter of fact, the open load condition can occur on phase A, phase B or both, and must be detected in all these cases.

1.2 Filter limitations and remarks

When using the circuit proposed in Figure 3, some points should be considered. The first regards the resistors used, which should be tens of kΩ, in order to reduce the bias currents flowing through them. The resistors are used to decouple the signal coming from the outputs and reduce it to a value suitable for the microcontroller or the digital logic.

The proper operation of the filter is based on the integrated PWM current control, which must be active. Therefore, the filter does not detect the open load condition when:

1. the power stage is disabled (i.e. EN/FAULT is set low by the external microcontroller)
2. the device is in STBY mode
3. one phase is in high impedance, during the zero-current microstep (open load is not detected on the phase in high impedance)

Although in the above cases the "open load" is not detected, this is not actually an issue. Indeed, the behavior of the system is the same, whether the load is connected or not. When the outputs of the STSPIN220 are in high impedance, the capacitor is discharged and kept low by the resistor R_f.

In some other conditions, there may be a false detection: even if the load is connected, the filter is triggered and signals an "open load". A false detection occurs when:

1. A wrong detection voltage threshold is selected for the V_f signal

2. The PWM current control works with very high duty cycles, close to 100%. This can happen if the target current is too high with respect to the voltage supply Vs, in relation to the electrical and mechanical parameters of the motor.

These situations should be avoided by properly sizing the components and the voltages in the system.

1.3 Filter sizing and configuration

According to the schematic reported in Figure 3, the voltage V_f corresponding to an open load condition is:

Equation 1

(1)

$$V_{f,open} = V_s \cdot \frac{R_f}{R_p + 2R_f}$$

where v_s is the voltage supply of the STSPIN220.

The R_p and R_f resistors can be chosen in order to have the voltage $V_{f,open}$ compatible with the maximum input voltage of the ADC.

If the open load condition occurs, the V_f reaches the $V_{f,open}$ value after a transient, which is determined by the time constant τ_f given by the C_f and the equivalent resistance of the filter. So the maximum time required to detect the open load condition can be defined as:

Equation 2

(2)

$$t_{DET} \approx \tau_f = 3 \cdot \left(\frac{R_p}{2} \parallel R_f \right) \cdot C_f = \frac{3R_p R_f C_f}{R_p + 2R_f}$$

The C_f capacitor can be sized according to the detection time required by the target application. The detection time must be greater than the maximum PWM period, otherwise the ripple on the V_f introduced by the PWM can lead to a false detection. As a rule of thumb, we can compare the time constant of the filter τ_f and the electrical time constant of the stepper motor τ_m, checking that:

Equation 3

(3)

$$\tau_f < \tau_m \Rightarrow \frac{R_P R_f C_f}{R_p + 2R_f} > \frac{L_m}{R_m}$$

where L_m is the phase inductance and R_m is the phase resistance of the stepper motor.

Anyway, the best way to optimize the trade-off between intervention time of the detector t_{DET} and V_f signal filtering is doing some specific bench test on the application.

Last parameter to be set is the threshold which triggers the detector. During normal operation the voltage V_f will follow the envelope of the PWM duty cycle: it reaches the maximum value V_{f,PWM_max} in correspondence with the maximum duty cycle. During open load condition instead, the voltage V_f increases up to its maximum value $V_{f,open}$ stated in Eq. (1).

The detection threshold $V_{f,th}$ must be chosen in between V_{f,PWM_max} and $V_{f,open}$; refer to Figure 4 in Section 2.1 for further explanations related to signals and waveforms involved.

2 Implementation and examples

As described in the previous section, the implementation of the open load detector is composed of two identical circuits, one for each phase, with a total components' count of 6 resistors and 2 capacitors; moreover, 2 ADC channels are required to detect the voltage threshold $V_{f,th}$, which triggers the open load condition.

2.1 Application example and waveform acquisition

To provide a typical example, let's consider an application with the following parameters:

- Voltage Supply V_S = 5V
- Microcontroller voltage V_{MCU} = 3.3V
- Motor phase parameters L_m = 4mH and R_m = 7Ω

According to this data, it is possible to select $R_p = R_f = 12kΩ$: the $V_{f,open}$ is 1.67V as stated in Eq. (1).

Assuming a maximum intervention time of about 1.8ms, Eq. (2) provides the value of C_f, that is 150nF, besides respecting what Eq. (3) states.

Testing this solution at bench results in the waveform reported in Figure 4. The driver works in the 32 microstepping mode: during normal operation, the current is a sinewave and the filtered voltage V_f has a rectified sinewave envelope, with a maximum value V_{f,PWM_max}. In this example only phase A is represented and it is disconnected "on the fly" in order to analyze the dynamic behavior of the filter. At load disconnection, the phase current falls to zero, meanwhile the V_f voltage increases at the expected value of 1.67V. Since the measured value V_{f,PWM_max} during normal operation is around 1.4V, the threshold $V_{f,th}$ can be set at 1.55V.

Figure 4. Waveform acquisition for a dynamic open load condition
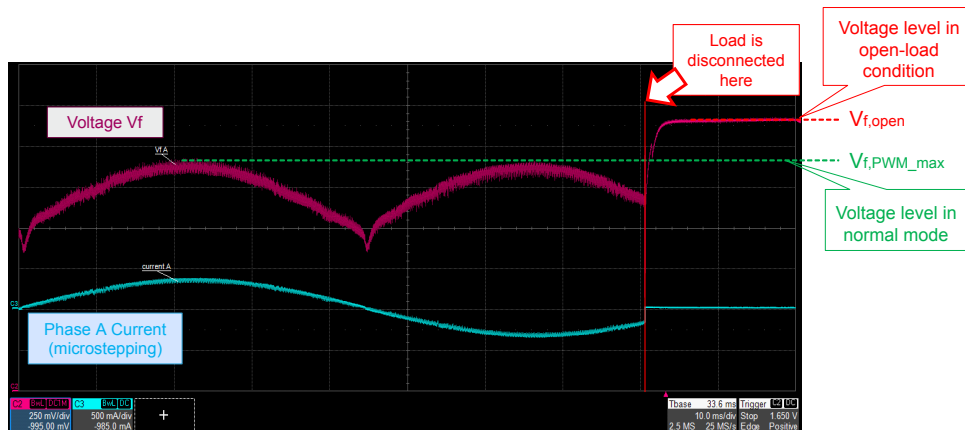
2.2 Implementation without additional MCU resources

If no ADC lines are available in the microcontroller, or in general no more microcontroller GPIOs are available in the system, a modified circuit represented in Figure 5 can be used. The open load threshold $V_{f,th}$ (set by R_1 and R_2 partition) is now detected by two comparators, one for each phase.

A single component can be used, such as the dual comparator LM193 or similar. The chosen comparators should have open-drain output, so they can be connected all together with the EN/FAULT pin of the STSPIN220. In this way it is possible to use the EN/FAULT line to detect the open load condition, without using another digital GPIO line of the microcontroller.

Note: *We are assuming that the EN/FAULT is already connected to the microcontroller, in order to manage the other failure conditions such as overtemperature and overcurrent*

When an open load is detected, the EN/FAULT pin goes low and the power stage is disabled for a time given by $R_{EN}C_{EN}$ time constant. Then, the open load filter discharges and consequently the EN/FAULT pin is released. At the end of the disable time, the power stage turns on and the open load condition is triggered again. Therefore, the EN/FAULT pin toggles continuously as long as the load is disconnected. The microcontroller firmware should manage the failure condition with a dedicated interrupt routine when the FAULT signal goes low.

The component sizing of this circuit should follow the rules already described previously: referring to the example explained in Section 2.1, we have the same values for R_p and R_f (both 12kΩ) and C_f (150nF). Since the selected threshold is $V_{f,th}$ around 1.55V, we can select R_1 = 68 kΩ and R_2 = 30 kΩ.

Figure 5. Open load circuit using comparators
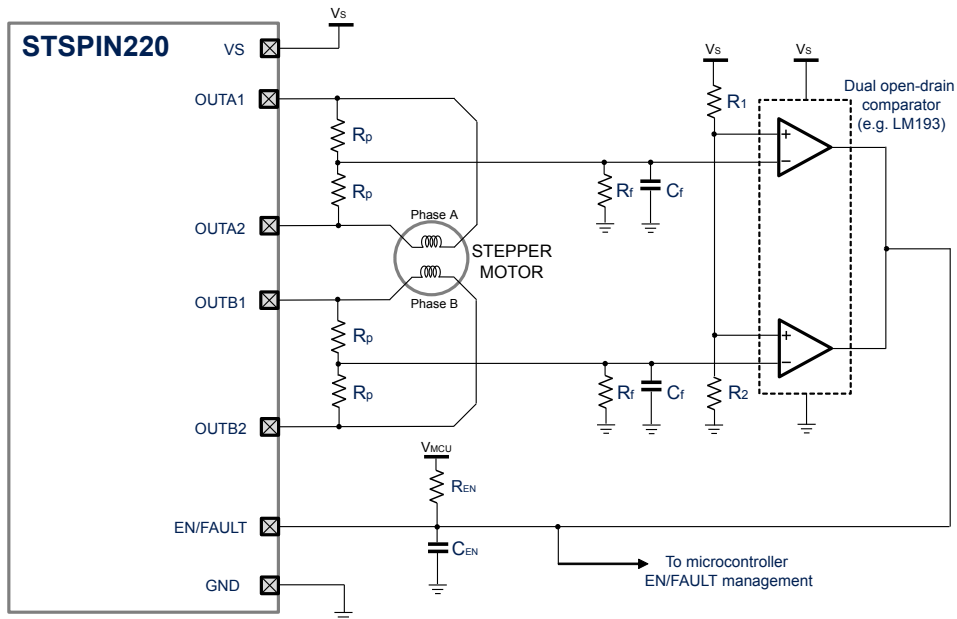
Revision history

Table 1. Document revision history

Date	Version	Changes
17-Sep-2019	1	Initial release.

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