AN6025

Application note

Interaction of L99SP08 with single and dual channel hybrid eFuses

Introduction

This application note describes the functionality of standby-ON mode enabled by the interaction between the L99SP08 and the VNF9D1M5Q, but the same description can be extended to the listed hybrid STi^{2}Fuse products:

- VNF9D1M2Q (2-channel high-side drivers with R_{on} = 1.2 mΩ)
- VNF9D1M5Q (2-channel high-side drivers with R_{on} = 1.5 mΩ)
- VNF9D3Q (2-channel high-side drivers with R_{on} = 3.0 mΩ)

The L99SP08 is an 8-channel high-side driver designed to operate in combination with the STi^{2}Fuse product family.

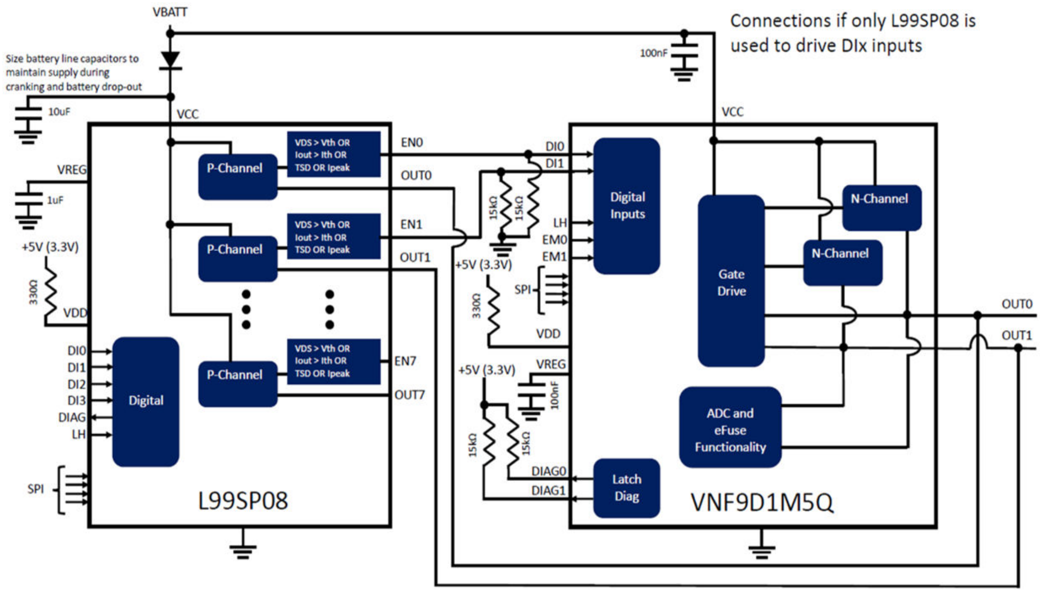
The hybrid STi^{2}Fuse products are single and dual channel high-side drivers for power distribution applications. They embed the ST proprietary I^2t functionality, which features intelligent circuit breaking to protect PCB traces, connectors, and wire harnesses from overheating, without impacting load transients such as inrush currents and capacitance charging. Normally, these STi^{2}Fuse products maintain the load connection to the battery during high current demand states of the application.

The standby-ON functionality aims to set the L99SP08 and STi^{2}Fuse products to a very low power consumption state, matching the low current requirements of the applications in specific cases, such as parking mode.

In fact, in low current demand states, the L99SP08 can control the loads, and the standby-ON function ensures a very low quiescent current from the battery.

1 General application schematic

Figure 1. General application schematic



In the figure above it is described the typical application schematic of one VNF9D1M5Q connected to one L99SP08, considering that the L99SP08 is an octal channels, so it can drive up to four VNF9D1M5Q.

The two devices are put in parallel between the V_{batt} and OUT_x, note that on the battery line of L99SP08 a diode has to be placed to sustain the application condition of reverse battery.

The interaction between the two devices is handled through EN_x pins on L99SP08 side, which have to be connected to DI_x of VNF9D1M5Q.

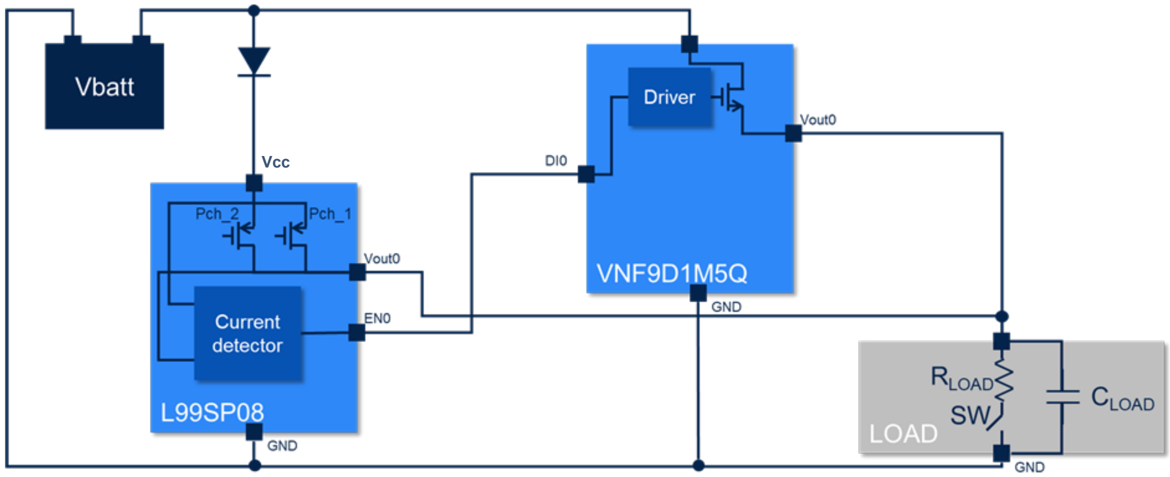
The EN_x pin is raised up if a fault occurs in the relative channel of L99SP08 thus the VNF9D1M5Q goes on, when the DI_x is raised up, it goes out from standby state moving to failsafe and switching ON the internal N-channel MOS; moreover, the EN_x pin could be driven also through RAM registers.

Both devices implement the SPI communication interface and the possibility to be driven in limp home mode through LH pins.

2 Application schematic of a test bench used to evaluate the cross-talking between L99SP08 and VNF9D1M5Q

The application circuit used for this trial involves only one channel, so EN_0 of L99SP08 is connected to DI_0 of VNF9D1M5Q, while the load includes: one capacitor, one resistor put in series to a switch used to connect the resistor on demand. Here below the application schematic:

Figure 2. Typical application circuit to weak-up the VNF9D1M5Q



For this test bench the signal probed was:

V_{cc} of L99SP08 (yellow probe).

EN_0 of L99SP08 → DI_0 of VNF9D1M5Q (orange probe).

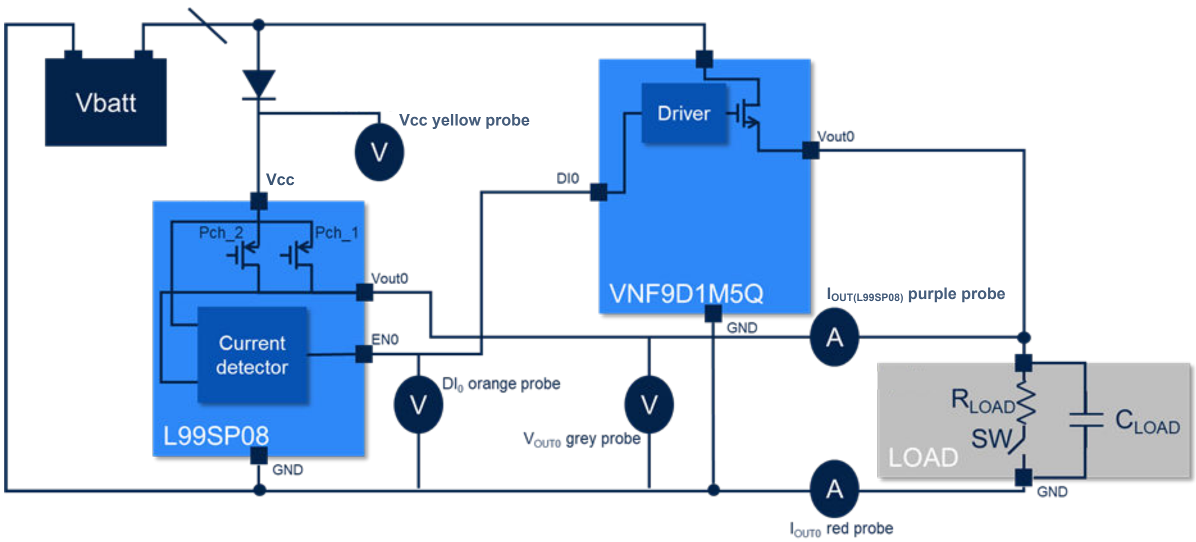
V_{out0} output of the load (grey probe).

Current flowing through the L99SP08 (purple probe).

Current flowing on the ground line which shows the current of the system (red probe).

The figure below shows how the probes are placed.

Figure 3. Probing of application circuit to weak-up the VNF9D1M5Q



3 Test bench analysis

The test bench to analyze the interaction between the L99SP08 (P-channel path) and VNF9D1M5Q (main eFuse FET) is composed of the following steps:

1. Analysis of current from the whole system in standby-ON condition.
2. Wake-up of VNF9D1M5Q from standby-ON through L99SP08.

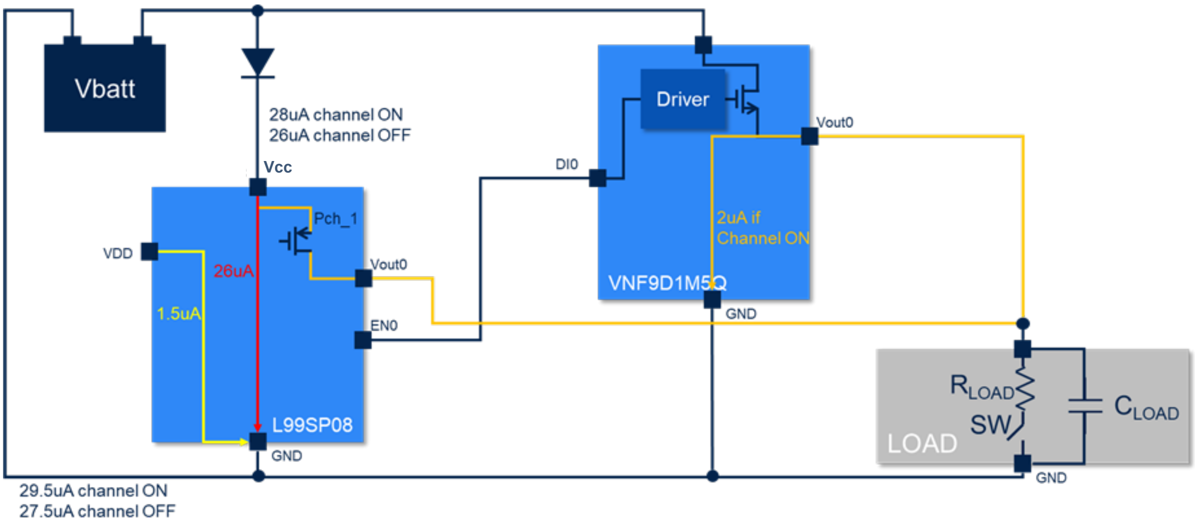
3.1 Analysis of current from the whole system in standby ON condition

The main purpose of companion mode (L99SP08 + VNF9D1M5Q) is to minimize the quiescent current in standby mode. The aim of this test is to check the current consumption from battery in standby state in both conditions: channels ON and channels OFF.

The total amount of current consumption from battery is ~26 μA with channel OFF, while if the P-channel is switched ON ~2 μA has to be added to the previous current, leading it to ~28 μA. The 2 μA is a leakage current on Vout pin of VNF9D1M5Q.

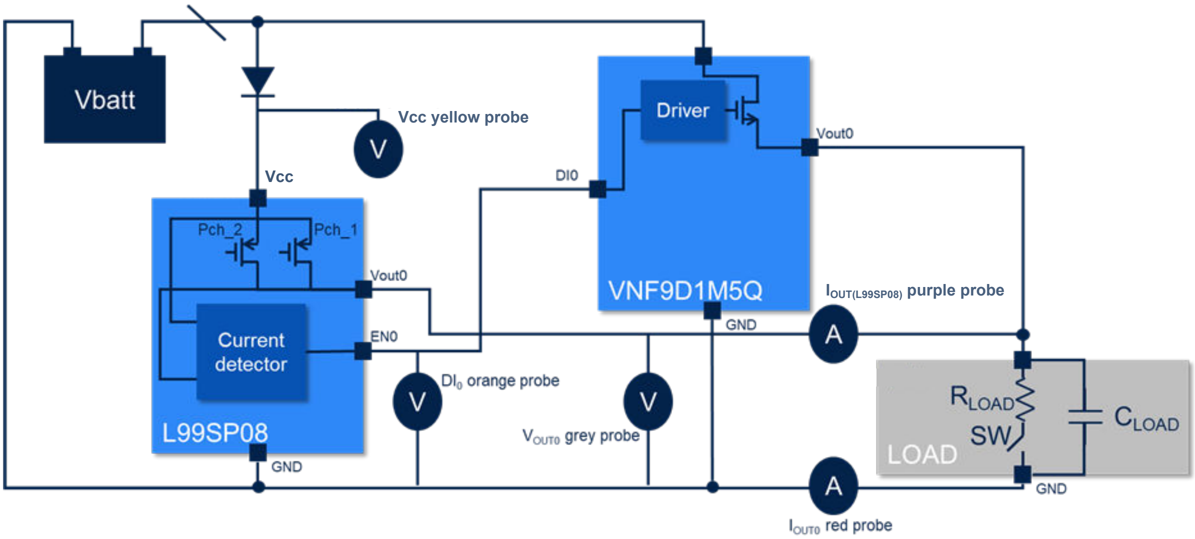
Switching ON all the 8 channels of L99SP08 the total amount of current becomes 26 μA (L99SP08 current) + 2 μA * 8 channels of VNF9D1M5Q, leading to 42 μA. It means that the current per channel in standby-ON condition with 8 channels ON is ~5 μA.

Figure 4. Current path of current consumption in companion mode standby ON state



3.2 Wake-up of VNF9D1M5Q from standby ON through L99SP08

Figure 5. **Application circuitry used for wake up VNF9D1M5Q from standby ON**



Application circuitry setup:

R_{LOAD}: 2.5 Ω, C_{LOAD}: 10 mF , V_{batt}: 13 V

This test is performed to analyze the behaviour of the companion mode.

The steps performed in this test to evaluate the wake up of VNF9D1M5Q through L99SP08 are:

1. L99SP08 standby channel OFF – VNF9D1M5Q standby.
2. L99SP08 standby channel OFF – VNF9D1M5Q normal mode CCM.
3. L99SP08 normal mode channel ON – VNF9D1M5Q normal mode channel ON.
4. L99SP08 normal mode channel ON – VNF9D1M5Q normal mode channel OFF.
5. L99SP08 standby channel ON – VNF9D1M5Q standby.
6. L99SP08 wakes-up VNF9D1M5Q through I_{peak}.

The steps from 1 to 5 are the steps needed to prepare the standby-ON: starting from the condition with both devices in standby and load discharged (step 1), moving to wake up the VNF9D1M5Q and charging the capacitive load through the function of capacitive charging mode (step 2), then the channel of L99SP08 is switched ON thus both channels concur to feed the load (step 3), therefore now the device is ready to go in standby-ON condition by switching off the channel of VNF9D1M5Q (step 4) and moving both devices in standby state (step 5).

Figure 6. L99SP08 state diagram

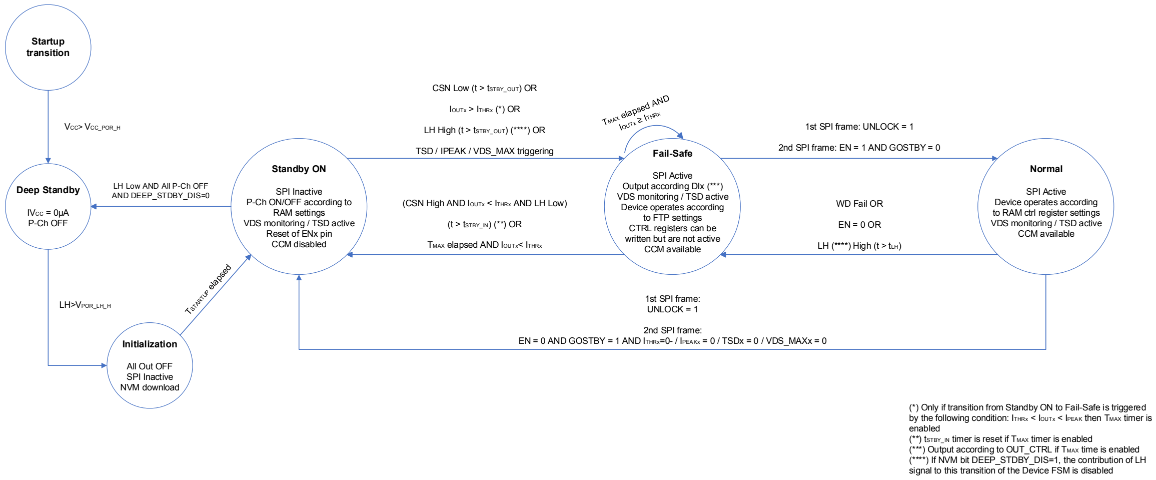
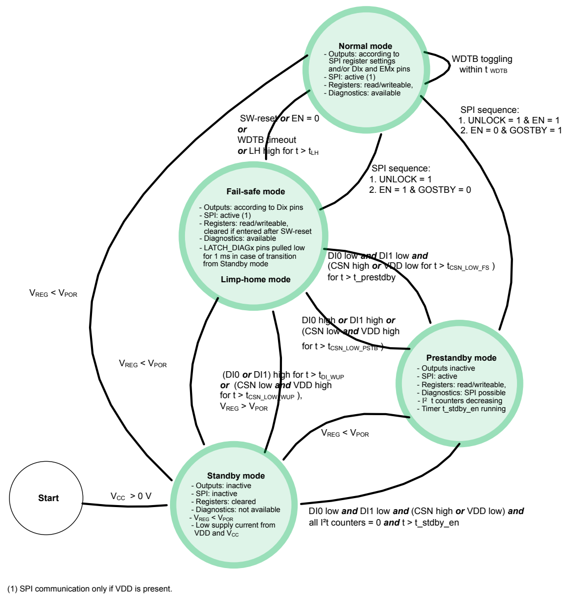
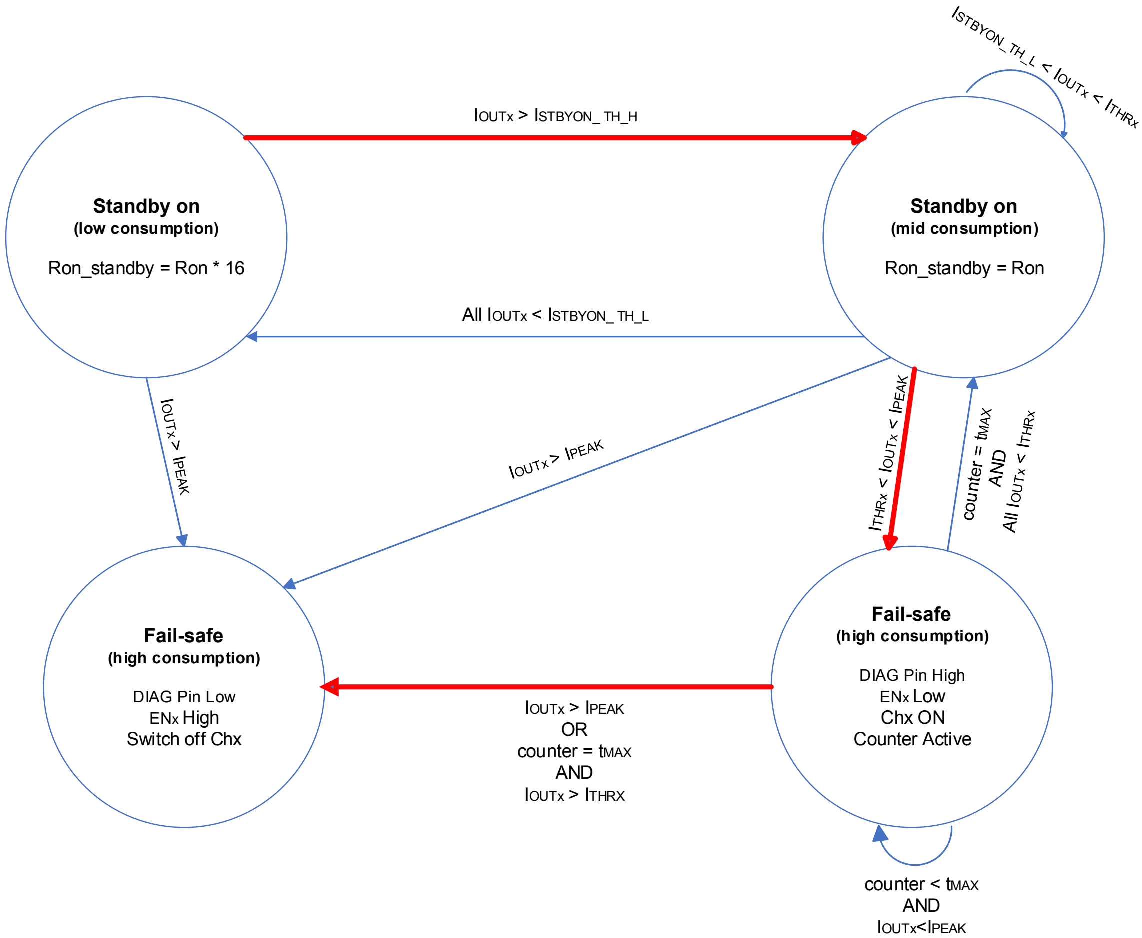


Figure 7. VNF9D1M5Q state diagram



In the step 6 the L99SP08 goes out from its standby-ON condition automatically following the state diagram described in the figure below. In this test the transitions marked in red are performed starting from standby-ON low consumption to go to failsafe with EN_X high to wake up the VNF9D1M5Q.

Figure 8. L99SP08 standby-ON exit strategy



The figure below describes the last step of our evaluation, it is further divided into 4 “regions”:

The first region describes the condition of the devices in the step 5, where both devices are in standby, and no current is required from the load.

Thus, the closing of switch SW (see Figure 5) is the start of the second region, it emulates a current required from the load, the L99SP08 starts to give the current following the equation:

$I_{OUT\_L99SP08} = \Delta V_{DS}/R_{ON\_STANDBY}$.

Where $R_{ON\_STANDBY}$ is 13 Ω typical, and ΔV_{DS} is:

$\Delta V_{DS} = V_{CC_{L99SP08}} - \mathrm{V_{LOAD}}$

The V_{LOAD} is the voltage across the capacitor, which in this region is sustaining the current required by the load decreasing its energy and consequently its voltage:

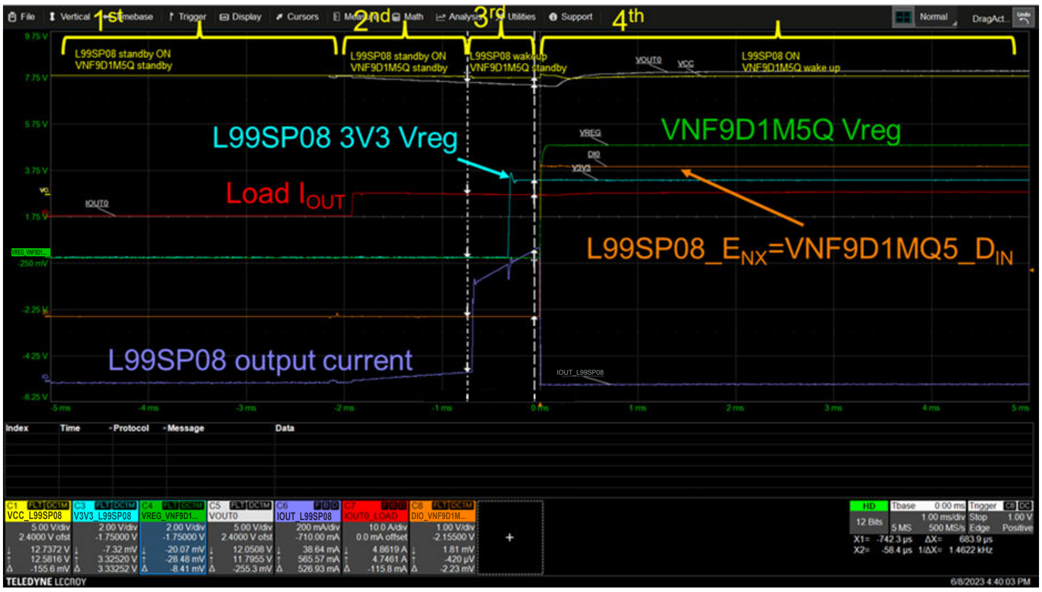
$$\Delta V_{LOAD} = \frac{I_{LOAD} * \Delta t}{C_{LOAD}}$$

So, after a certain time, the $I_{OUT\_L99SP08}$ overcomes the threshold $I_{STBYON\_TH\_H}$ (45 mA typical) and moves to standby-ON mid consumption state (see figure above) changing the Rds_{ON} of L99SP08 channel to 1 Ω typical.

Now the test is in the third region, where the L99SP08 is woken up as soon as the current overcomes the I_{THR} threshold (configured to 400 mA for this test), the L99SP08 wake-up is the time where V3V3 pin goes to 3.3 V . In the meantime, the current on L99SP08 is going to increase when reaching the I_{peak}.

When I_{peak} is reached the L99SP08 switches off the channel, rising the respectively EN pin and switching on the VNF9D1M5Q, which switches on its N-MOS supplying the load current required.

Figure 9. Wake-up of VNF9D1M5Q through Ipeak on L99SP08



4 Test bench to analyze the voltage output dropping and the time from L99SP08 overcurrent detection to VNF9D1M5Q wake-up

The purpose of this analysis is to understand the time window from the L99SP08 overcurrent detection to the VNF9D1M5Q channel switched ON. If the overcurrent event generates an I_{peak} flag, the L99SP08 turns off its channel for safety reasons so, during this event time window, the load is not supplied by either the L99SP08 or VNF9D1M5Q until it is woken-up. Thus, the load is supplied only by the load capacitor which discharges through the load generating a voltage dropping.

The schematic used for this test was described in Section 2.

The setup for this analysis is:

Table 1. Test setup

Parameter	Value
Setup V_{CC}	13.5 V – I_{LOAD}
#1 C_{LOAD}	0 mF
#2 C_{LOAD}	0.22 mF
#3 C_{LOAD}	0.47 mF
#4 C_{LOAD}	1 mF

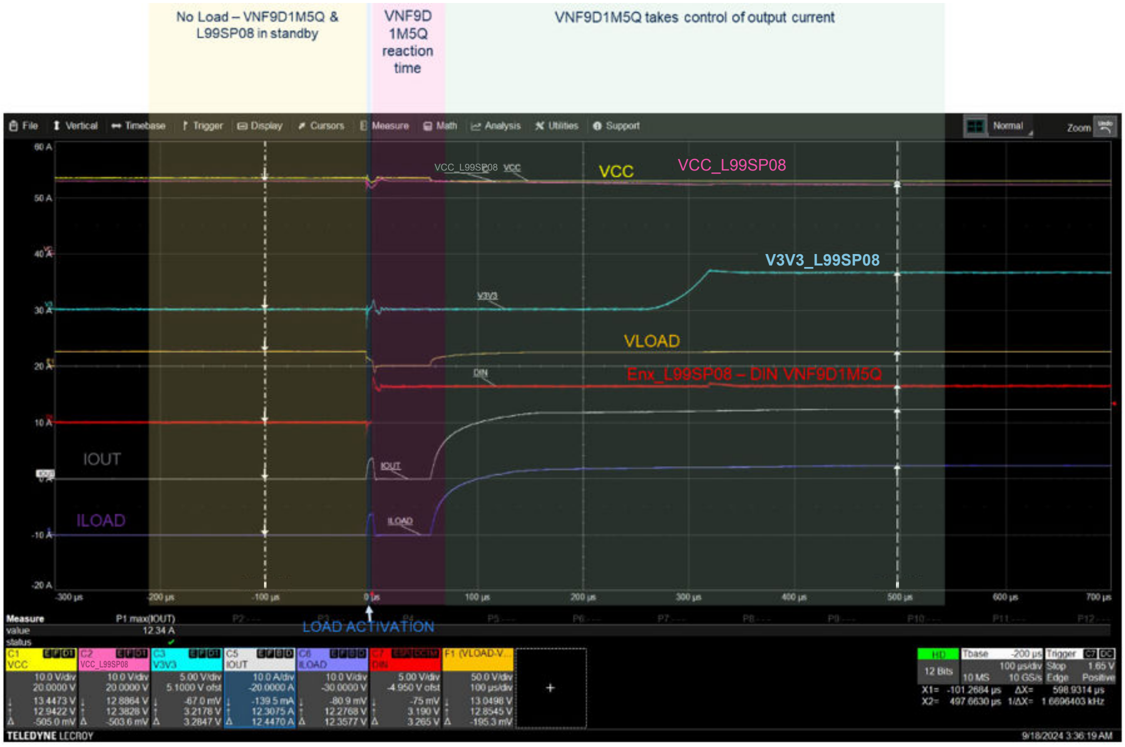
The steps to perform the test are the following:

1. L99SP08 standby channel OFF – VNF9D1M5Q standby
2. L99SP08 standby channel OFF – VNF9D1M5Q normal mode CCM
3. L99SP08 normal mode channel ON – VNF9D1M5Q normal mode channel ON
4. L99SP08 normal mode channel ON – VNF9D1M5Q normal mode channel OFF
5. L99SP08 standby channel ON – VNF9D1M5Q standby
6. L99SP08 wakes-up VNF9D1M5Q through I_{peak}

4.1 Test #1 C_{LOAD} 0 mF

Test 1 was performed without load capacitor, the expectation was that after the L99SP08 I_{peak} recognition, the output voltage decreases suddenly to ground.

Figure 10. Test #1 C_{LOAD} 0 mF



The outcomes of the trial are:

- Reaction time: ~60 µs (see Figure 11)
- Output voltage drop: 13.5 V (see Figure 12)

Figure 11. **Test #1 reaction time**

Figure 12. **Test #1 output voltage drop**

4.2 Test #2 C_{LOAD} 0.22 mF

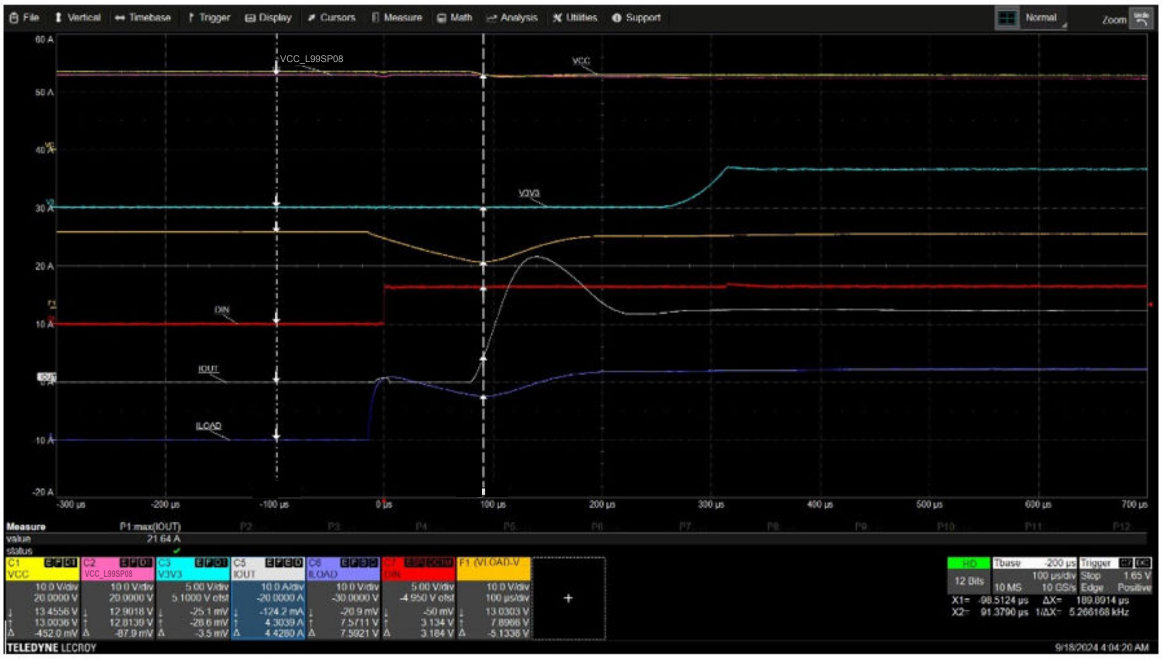
Test 2 was performed with 220 μF as output capacitor.

The outcomes of the trial are:

- Reaction time: ~93 μs (see Figure 13)
- Output voltage drop: 5.1 V (see Figure 14)

Figure 13. Test #2 reaction time

Figure 14. Test #2 output voltage drop



4.3 Test #3 C_{LOAD} 0.47 mF

Test 3 was performed with 470 μF as output capacitor.

The outcomes of the trial are:

- Reaction time: ~145 μs (see Figure 15)
- Output voltage drop: 4.1 V (see Figure 16)

Figure 15. Test #3 reaction time

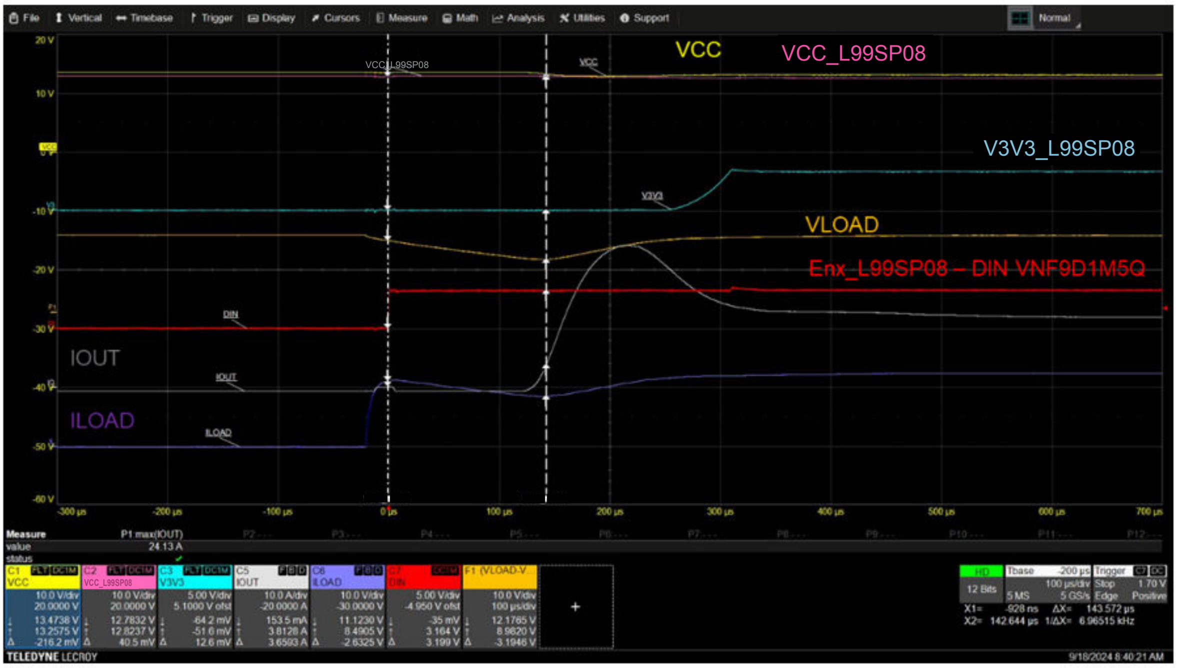
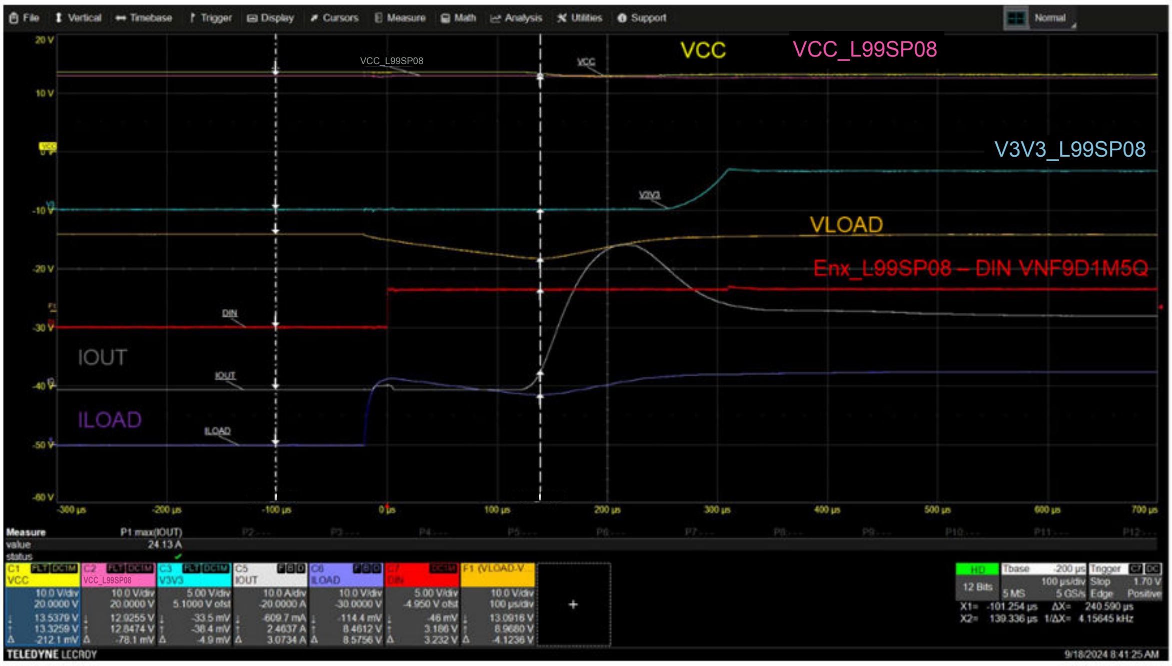


Figure 16. Test #3 output voltage drop



4.4 Test #4 C_{LOAD} 1mF

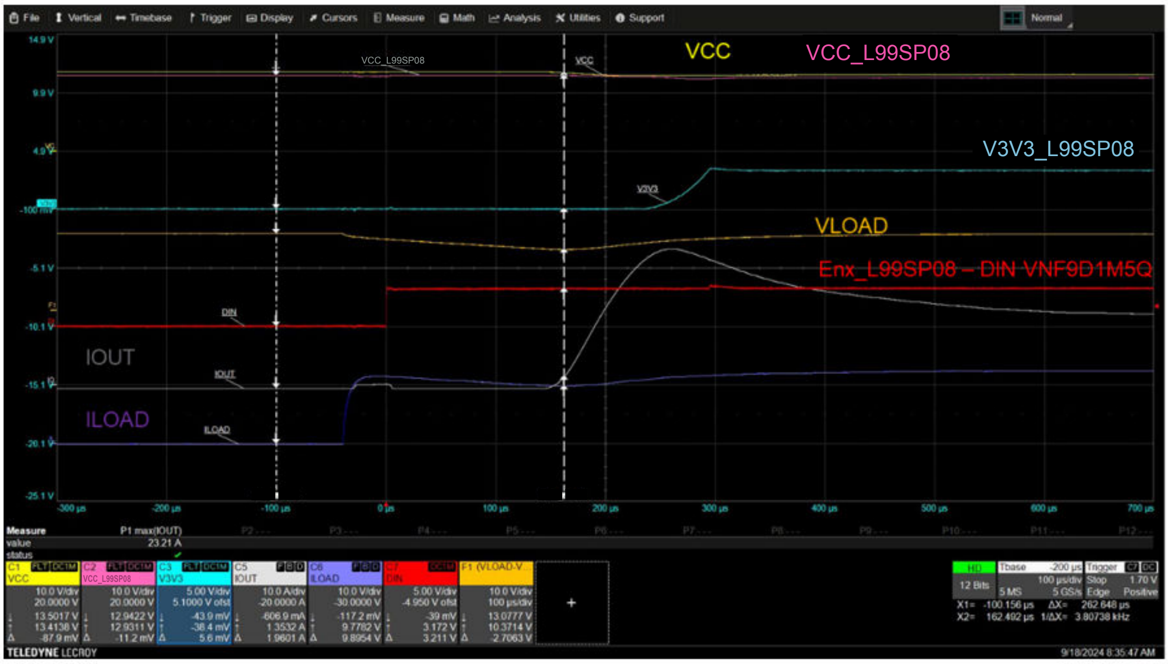
Test 4 was performed with 1 mF as output capacitor.

The outcomes of the trial are:

- Reaction time: ~169 µs (see Figure 17)
- Output voltage drop: 2.7 V (see Figure 18)

Figure 17. Test #4 reaction time

Figure 18. Test #4 output voltage drop



4.5 Outcomes

The following table summarizes all the test results.

Setup V_{CC}: 13.5 V – I_{LOAD} 13 A	Reaction time	Load voltage drop
#1 C_{LOAD}: 0 mF	60 µs	13.5 V

Setup V_{CC}: 13.5 V – I_{LOAD} 13 A	Reaction time	Load voltage drop
#2 C_{LOAD}: 0.22 mF	93 µs	5.1 V
#3 C_{LOAD}: 0.47 mF	145 µs	4.1 V
#4 C_{LOAD}: 1 mF	169 µs	2.7 V

Revision history

Table 2. **Document revision history**

Date	Revision	Changes
20-Nov-2023	1	First release.
07-Jun-2024	2	Updated *Figure 6. L99SP08 state diagram*.
20-Nov-2024	3	Added Section 4: Test bench to analyze the voltage output dropping and the time from L99SP08 overcurrent detection to VNF9D1M5Q wake-up.
17-Oct-2025	4	Reviewed Section Introduction to extend current notes to other hybrid STi^2Fuse products. Minor fixes for some typo errors.
25-Mar-2026	5	First public release

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