



Capacitive Charging Mode (CCM) for Hybrid STi²Fuse

Introduction

The purpose of this document is to demonstrate the functionality of the Capacitive Charging Mode (CCM) feature in an application environment using the evaluation boards for Hybrid STi²Fuse devices.

All application examples refer to [VNF9D1M5Q](#) and [VNF9D3Q](#) (dual-channel high-side driver with STi²Fuse protection for automotive power distribution applications), but they can be easily extended to the rest of the device family.

All tests were conducted on a typical sample representative of the standard populations.

1 Capacitive Charging Mode (CCM) for Hybrid STi²Fuse

The Hybrid STi²Fuse HSD Family integrates an M0-9 controller and M0-S11 power in the same package. This product family implements the CCM feature aimed at addressing the driving of capacitive loads for the power distribution domain.

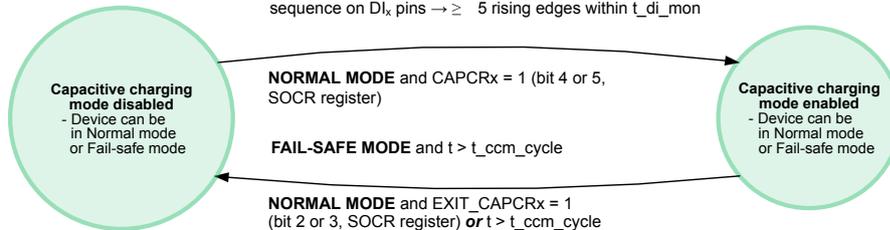
STi²Fuse HSD features an operative condition called Capacitive Charging Mode (CCM), which is available in both Fail-safe and Normal device states, and with channels configured in bulb mode. The CCM is not a device operating mode, but a channel-specific state.

When the channel is set to this mode, a specific procedure, allowing auto-restart after I_{PEAK} detection, allows a capacitive load to be charged within the maximum required time (t_{ccm_cycle}), see the related channel state diagram in Figure 1.

Figure 1. Channel state diagram

After **POR event**, CAPFSSRx bits (bit 5, Output Status registers, one bit per channel) are loaded from OTP (see UM3275, CAPCMx bits).
If CAPFSSRx = 1 the channel x has automatically gone to capacitive charging mode after transition from Standby mode to Fail-safe

FAIL-SAFE MODE and specific toggling sequence on DI_x pins → ≥ 5 rising edges within t_{di_mon}



2 Activation Details

The device enters this specific channel mode under the following conditions:

- **In Normal mode**
 - if a specific SPI frame is sent: set the CAPCR_x bit located in the SOCR register (bits 4 and 5 as highlighted in Figure 2) to a high value, the bit is automatically reset and acts as a trigger.
- **In Fail-safe mode**
 - after POR, if the bit CAPFSSR_x (loaded from OTP) is set
 - if a specific toggling sequence to DI_x pins is applied: at least 5 rising edges on DI_x pins within $t < t_{di_mon}$ (typ. 300 μ s)

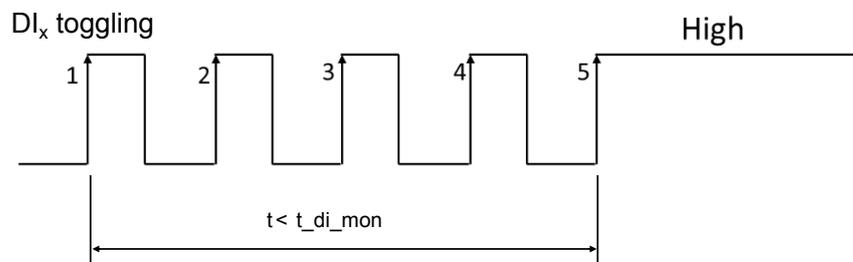
The device exits this specific channel mode under the following conditions:

- **In Normal mode**
 - if a specific SPI frame is sent: set to 1 the EXIT_CAPCR_x bit in the SOCR register (position 2 and 3 as highlighted in Figure 2)
 - if t_{ccm_cycle} (typ. 250 ms) has elapsed
- **In Fail-safe mode**
 - if t_{ccm_cycle} has elapsed

Figure 2. CAPCR_x bit at 1 triggers CCM of channel_x while EXIT_CAPCR_x bit at 1 exits CCM of channel_x in Normal mode



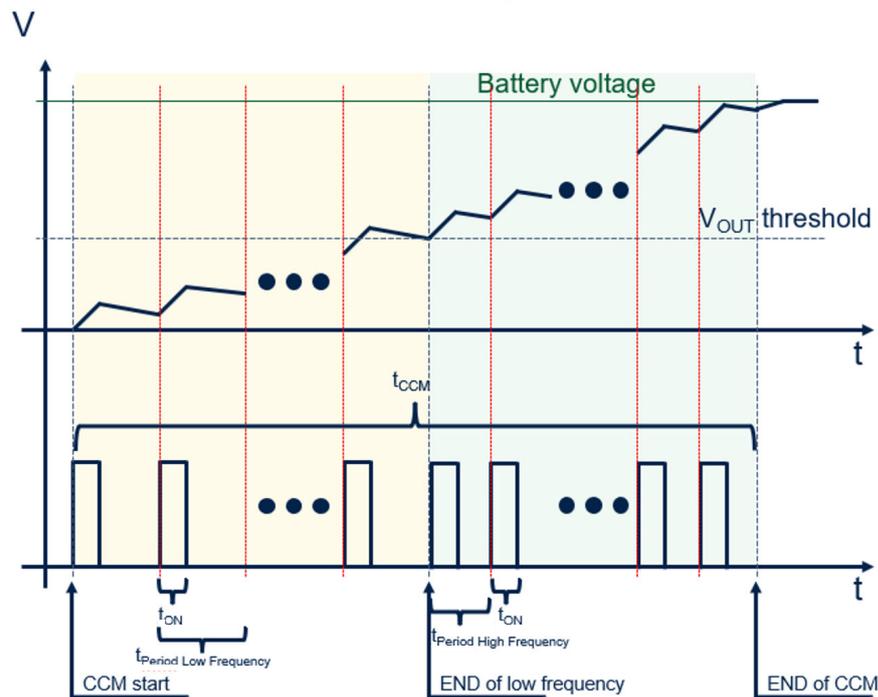
Figure 3. Example of DI_x toggling to activate CCM in Fail-safe mode



The capacitive charging mode charges output capacitors with a burst of low-frequency pulses with I_{PEAK} amplitude, provided that the total impedance is low enough to reach I_{PEAK} when charging the capacitor. If I_{PEAK} is not reached, the capacitor is charged with a single continuous charging pulse. In this specific channel operating mode, the device can distinguish a capacitor load from a short-circuit.

When a channel is set to capacitive charging mode and the output stage is turned on, an auto-restart procedure is started first in a low-frequency mode. If the ESR of the connected capacitor and the total output line impedance is low enough to let the channel reach its I_{PEAK} value, the channel will turn off after t_{filter_ipeak} filter time elapses and remain off for a t_{LF} low-frequency period (see Figure 4).

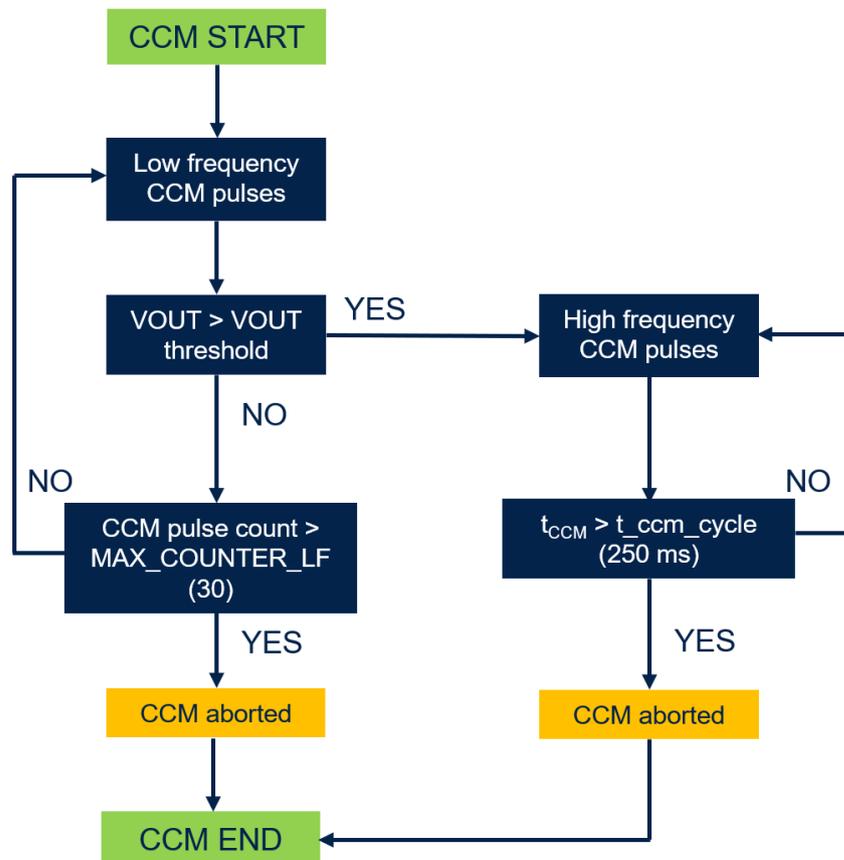
Figure 4. CCM switching evolution



At the end of the t_{FL} period, the device samples the output voltage of the channel in capacitive charging mode. As long as the output voltage remains below V_{OUT_THR} and the number of low-frequency charging cycles remains below the $MAX_COUNTER_LF$ threshold, the device remains in low-frequency mode and will turn on its output again. The channel exits the low frequency charging mode as soon as the V_{OUT_THR} threshold is exceeded or $MAX_COUNTER_LF$ is reached.

In the latter case, the channel will latch off for short-circuit detection and the status flag $IPEAKLSR_x$ in $OUTSR_x$ register – Channel Feedback Status bit and in the Global Status Byte will be set.

Otherwise, the channel enters a high-frequency charging mode (with a period equal to t_{HF}) and continues to charge the capacitor with a burst of I_{PEAK} pulses, provided that the line impedance is still low enough to let the channel reach I_{PEAK} . After each I_{PEAK} pulse, the channel will turn off after t_{filter_ipeak} filter time has elapsed and remains off for a t_{HF} period. The process will continue until the threshold $MAX_COUNTER_LF$ is reached, t_{ccm_cycle} has elapsed, or CCM is aborted through an SPI command.

Figure 5. CCM flow chart


The end user must consider that:

- The CCM is aborted if V_{OUT} threshold ($V_{OUT_THR} = 3\text{ V}$, typ.) is not reached during low-frequency pulses after a PWM max pulses number (30). Please refer to trials 14-17-21-23 reported in the next chapter as examples.
- After low-frequency inside high-frequency region, the pulses continue:
 - until CCM END, if $t_{CCM} < t_{ccm_cycle}$ (typ. 250 ms)
 - if $t_{CCM} > t_{ccm_cycle}$, then CCM is aborted
- Capacitor charging mode is compatible with capacitors up to C_{MAX} , even in high ambient temperature conditions.

Table 1 below summarizes various parameters related to CCM and extracted from device specifications.

Table 1. CCM parameters

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
t_{ccm_cycle}	Time to exit CCM		200	250	300	ms
t_{di_mon}	Time window to enter CCM in Fail-safe		198	300	402	μs
V_{OUT_THR}	V_{OUT} threshold for CCM		-9%	3	+9%	V
C_{MAX}	Max. capacitive load (depends on product)	$V_{CC}=16\text{ V}$, $T_J=85^\circ\text{C}$, $t_{C_{MAX}} = t_{ccm_cycle}$		4.7 (VNF9D3Q) 10 (VNF9D1M5Q and VNF9D1M2Q)		mF
t_{filter_ipeak}	Filtering time of Ipeak detection		0.95	1.2	1.45	μs

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
tLF	Period for low-frequency charging mode		3.4	4	4.6	ms
tHF	Period for high-frequency charging mode		0.85	1	1.15	ms
MAX_COUNTER_LF	Max. number of autorestart pulses allowed in short-circuit				30	

3 Capacitive charging examples

As explained in the previous chapter, a defined capacitive load is charged within 250 ms (the maximum allowed charging time) depending on the following variables:

- V_{CC} battery supply voltage of the entire application circuit. Higher values require longer t_{CHARGE}
- C_{LOAD} . Greater capacitances require a longer t_{CHARGE} . Also, ESR of the capacitor and connection cables might impact the charging feature.
- Selected device of the family. Products with a higher I_{PEAK} require a shorter t_{CHARGE}
- Ambient temperature. Higher starting temperatures require to complete the charging in a shorter t_{CHARGE}
- I_{NOM} setting (via bits INOMSR2x, INOMSR1x and INOMSR0x in register ITCFGCRx, where x stands for the channel 0 or 1). Higher I_{NOM} requires a shorter t_{CHARGE}
- t_{NOM} setting (via bits TNOMSR2x, TNOMSR1x and TNOMSR0x in register ITCFGCRx, where x stands for the channel 0 or 1).

Below [Table 2](#) and [Table 3](#) summarize the results of CCM verifications, performed under different setups, resulting in different C_{LOAD} charge times.

The tables are related to [VNF9D1M5Q](#) and [VNF9D3Q](#) respectively.

All results are detailed in the following chapters.

Table 2. Overall results obtained in CCM trials performed for the VNF9D1M5Q

Trial	DUT state	Temp ⁽¹⁾ (⁽²⁾)	VCC (V)	I_{NOM} (A)	t_{NOM} (s)	VCC cable length	C_{LOAD} cable length	C_{LOAD} (mF)	OUT	t_{CHARGE} (ms)	LF pulses	LF duration (ms)	HF duration (ms)
1	Normal	room	13.5	8	300	20 cm	20 cm	14.7	0	47	9	36.5	10.5
2	Fail-safe	room	13.5	8 (by default OTP)	300 (by default OTP)	20 cm	20 cm	14.7	0	44	8	32.5	11.5
3	Normal	room	13.5	8	300	20 cm	20 cm	10	0	28	5	20.5	7.5
4	Normal	room	10	8	300	20 cm	20 cm	10	0	4	1 (no peak)	NA	NA
5	Normal	room	18	8	300	20 cm	20 cm	10	0	50	8	31.3	18.7
6	Normal	room	13.5	8	300	20 cm	20 cm	14.7	1	47.5	9	36.5	11
7	Normal	room	13.5	8	300	20 cm	20 cm	4.7	0	10.5	3	10.5	NA
8	Normal	room	13.5	8	300	20 cm	5 μ H / 10 m Ω cable	14.7	0	15.5	3	15.5	NA
9	Normal	room	13.5	8	300	5 μ H / 10 m Ω cable	5 μ H / 10 m Ω cable	14.7	0	6	1 (no peak)	NA	NA
10	Normal	room	13.5	8	300	5 μ H / 10 m Ω cable	20 cm	14.7	0	6	1 (no peak)	NA	NA
11	Normal	room	13.5	8	1	20 cm	20 cm	14.7	0	56	9	36.5	19.5
12	Normal	room	13.5	27	1	20 cm	20 cm	14.7	0	47	9	36.5	10.5
13	Normal	room	13.5	27	300	20 cm	20 cm	14.7	0	47	9	36.5	10.5
14	Normal	room	13.5	27	300	20 cm	20 cm	short	0	NA: aborted	30	120	NA
15	Normal	room	13.5	8	300	20 cm	20 cm	14.7	0	49.5	9	36.5	13
							20 cm	4.7	1	14.5	4	14.5	NA
16	Normal	hot	13.5	8	300	20 cm	20 cm	14.7	0	42	8	32.5	10.5

Note: (1) room, $T_{case} \sim 35^{\circ}C$

Note: (2) hot, $T_{case} \sim 95^{\circ}C$

Table 3. Overall results obtained in CCM trials performed for the VNF9D3Q

Trial	DUT state	Temp ⁽¹⁾	VCC (V)	I _{NOM} (A)	t _{NOM} (s)	VCC cable length	C _{LOAD} cable length	C _{LOAD} (mF)	OUT	t _{CHARGE} (ms)	LF pulses	LF duration (ms)	HF duration (ms)
17	Normal	room	13.5	2	300	20 cm	20 cm	14.7	0	NA: aborted	30	120	NA
18	Normal	room	13.5	2	300	20 cm	20 cm	10	0	124	21	84	40
19	Normal	room	18.0	2	300	20 cm	20 cm	10	0	195	27	107	88
20	Normal	room	18.0	2	1	20 cm	20 cm	10	0	206	27	107	99
21	Normal	room	15.0	2	1	20 cm	20 cm	13.3	0	NA: aborted	30	120	NA
22	Normal	room	14.75	2	1	20 cm	20 cm	13.3	0	NA: aborted	30	120	NA
23	Normal	room	14.75	2	1	20 cm	20 cm	13.3	0	195	30	120	75

Note: ⁽¹⁾ room, T_{case} ~35°C

3.1 Example of 14.7 mF C_{LOAD} charged in Normal mode

The conditions and results acquired in **Trial 1** are reported below.

Setup 1:

- V_B = 13.5 V
- T_{AMB} = room
- **Load0 = 14.7 mF**
- Load1 = 23.5 Ω
- I_{NOMx} = 8 A
- t_{NOMx} = 300 s
- Cable from supply to VCC = 20 cm
- Cable from OUT_x to Load_x = 20 cm
- WD refresh time = 50 ms
- VNF9D1M5Q DUT in Normal mode

Execution:

- Turn ON CH1 on R_{LOAD} by SOCR1 = 1
- Set CAPCR0 = 1
- Turn ON CH0 by SOCR0 = 1 enabling CCM on CH0

Results:

- 14.7 mF is charged in ~47 ms (9 pulses at low frequency for ~36.5 ms followed by 4 pulses at high frequency)
- LATCH_DIAG0 goes low during CCM
- OUT1 remains stable ON sustaining 570 mA

Figure 6. Waveforms acquired during Trial 1

Low frequency phase in which each pulse achieves I_{PEAK} with a period of 4 ms (t_{LF}) until V_{OUT_THR} is reached

High frequency phase in which each pulse achieves I_{PEAK} or with a period of 1 ms (t_{HF}) until V_{OUT} reaches V_{CC} value



Figure 7. Zoomed image of previous capture focusing on last portion of low frequency and highlighting different periods between LF and HF portions



Figure 8. Zoom on 1st CCM pulse showing that I_{PEAK} is achieved



3.2 Example of 14.7 mF C_{LOAD} charged in Fail-safe mode

The conditions and results acquired in **Trial 2** are reported below.

Setup 2:

- $V_B = 13.5\text{ V}$
- $T_{AMB} = \text{room}$
- **Load0 = 14.7 mF**
- Load1 = 23.5 Ω
- $I_{NOMx} = 8\text{ A}$
- $t_{NOMx} = 300\text{ s}$
- Cable from supply to VCC = 20 cm
- Cable from OUT_x to Load_x = 20 cm
- **WD refresh time = 10 ms to maintain device in Fail-safe state {DIx low AND [CSN high for $t > t_{CSN_LOW_FS}$ (typ. 1 us)] for $t > t_{prestdby}$ (typ.14 ms)}**
- VNF9D1M5Q DUT in **Fail-safe** mode

Execution:

- Turn ON CH1 on R_{LOAD} by DI1 set high
- Turn ON CH0 by 5 pulses on DI0
- DI_x are set low after 1 s

Results:

- 14.7 mF is charged in 44 ms (8 pulses at low frequency for 32.5 ms followed by 5 pulses at high frequency)
- LATCH_DIAG0 goes low during CCM
- OUT1 remains stable ON sustaining 570 mA
- The different charge time in Trial 2 vs Trial 1 is due to the lower number of pulses needed in the low-frequency phase to reach V_{OUT_THR}.

Figure 9. Waveforms acquired during Trial 2

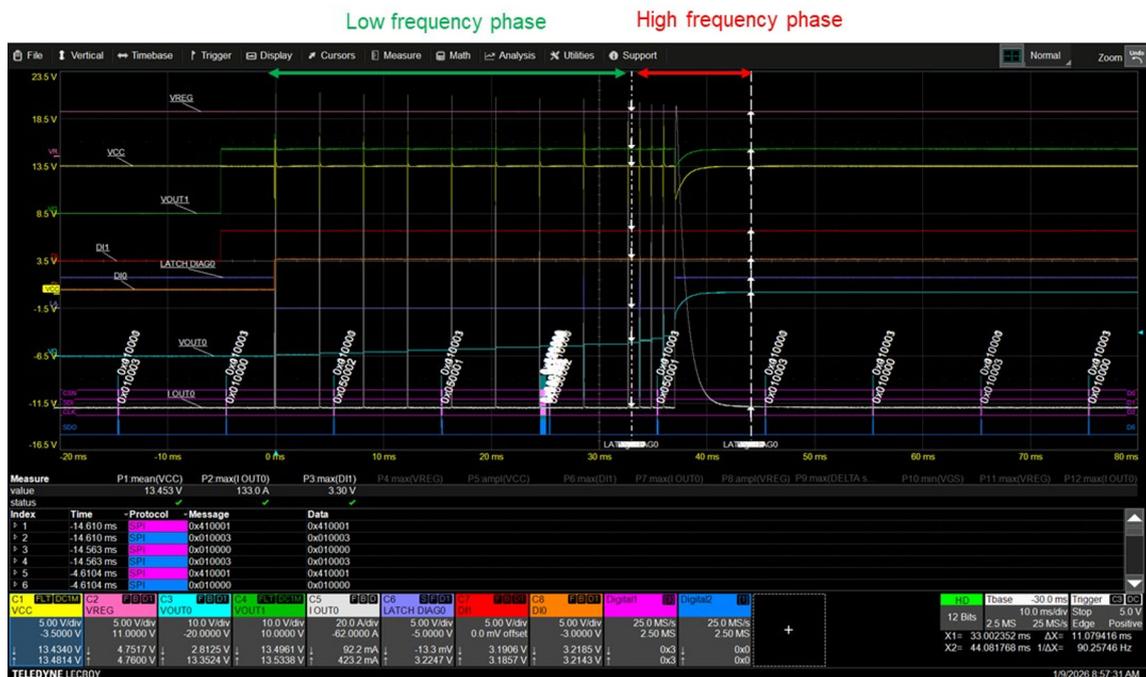
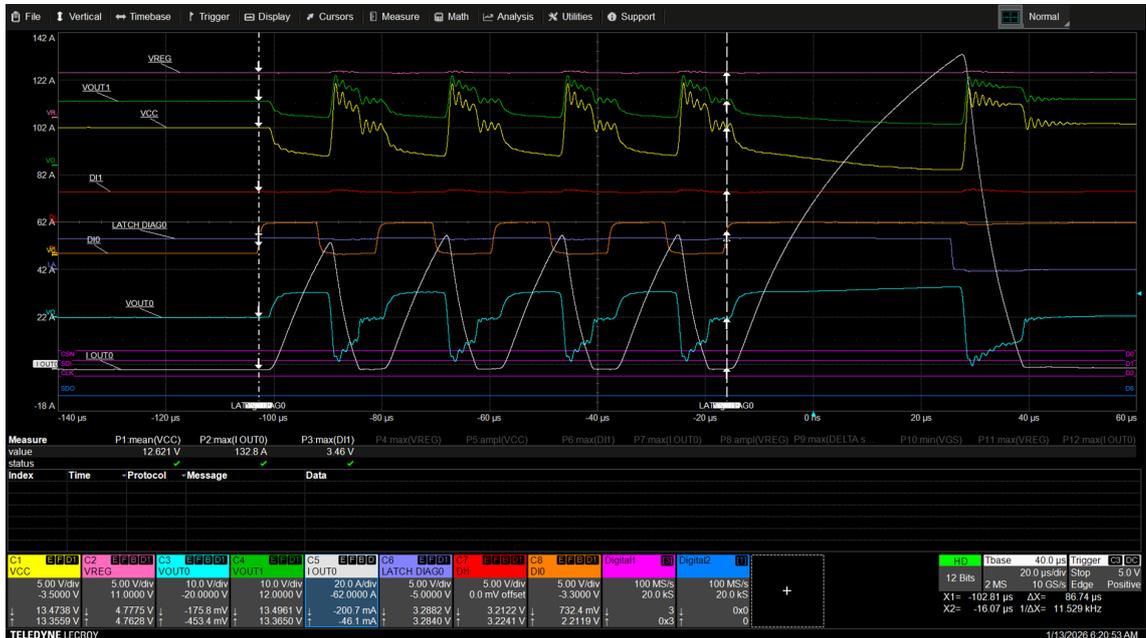


Figure 10. Zoomed image of previous capture focusing on last portion of low frequency and highlighting different periods between LF and HF portions



Figure 11. Zoomed image on pulses on DI1 pin to activate CCM in Fail-safe mode. The CCM started after few us of 5th pulse if the $t < t_{di_mon}$ (87 μ s in this example)



The Trial 2 was repeated, modifying the applied t_{di_mon} to highlight the value at which CCM can start on the used sample.

Table 4 below summarizes the results, confirming that the used sample is fully within specification (typ. t_{di_mon} = 300 μ s).

Table 4. CCM starts based on t_{di_mon}

Trial case	Applied t_{di_mon} (μ s)	CCM	Reference figure
2 A	87	Started	9-10-11
2 B	421	Not started	12-13
2 C	313	Not started	14
2 D	292	Started	16

Figure 12. Waveforms acquired during Trial 2 B



Figure 13. Zoomed image on pulses on DI1 pin on Trial 2 B. The CCM is not started after a few μ s since 5th pulse if the $t > t_{di_mon}$ (421 μ s in this example)



Figure 14. Zoomed image on pulses on DI1 pin. The CCM is not started after a few μ s since 5th pulse if the $t > t_{di_mon}$ (313 μ s in this example)

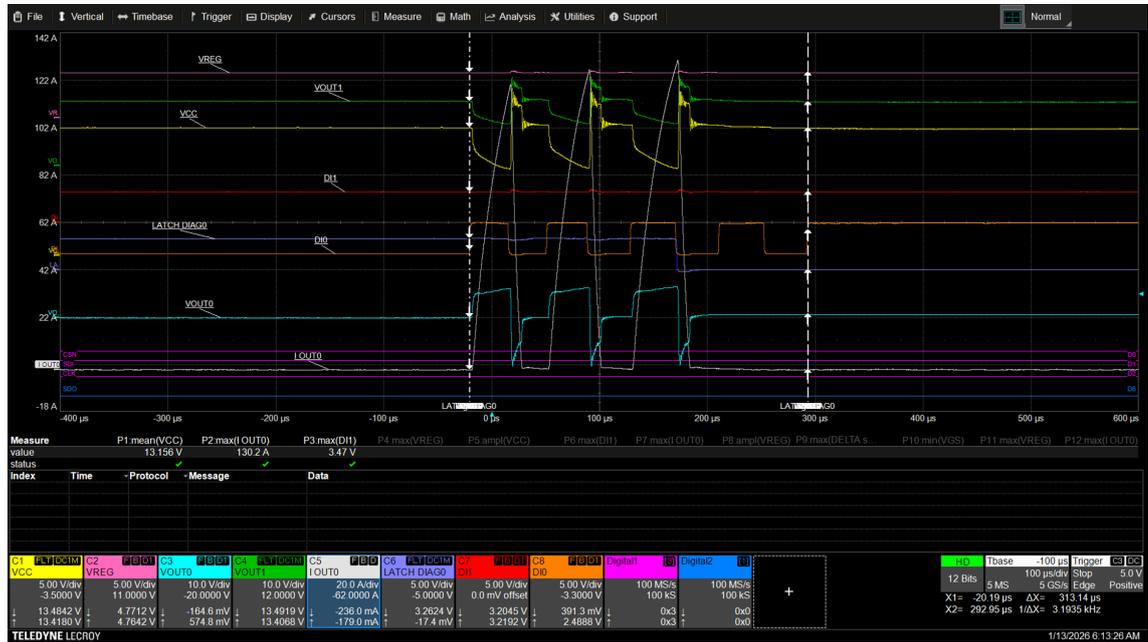


Figure 15. GUI image collected after Trial 2 B and 2 C highlighting that the CH1 is latched OFF

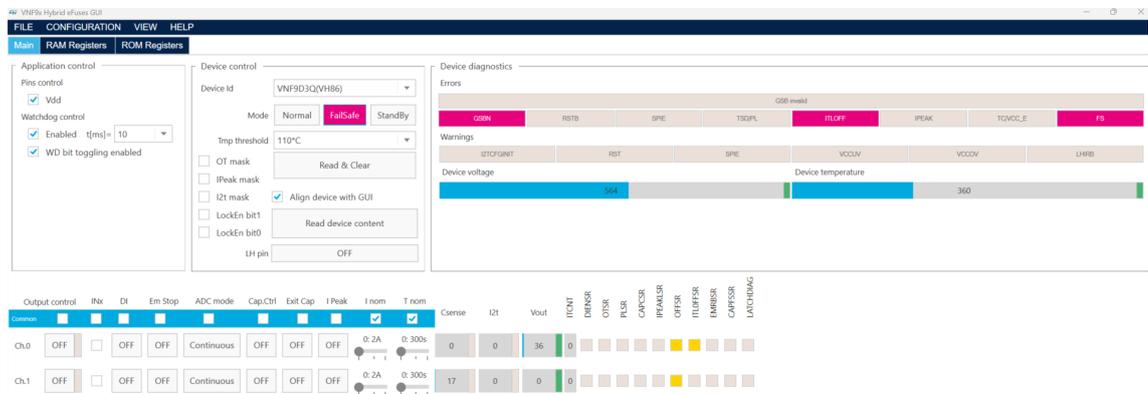


Figure 16. Zoomed image on pulses on DI1 pin. The CCM is not started after a few μs since 5th pulse if the $t > t_{di_mon}$ (292 μs in this example)



3.3 Example of 10 mF C_{LOAD} charged in Normal mode using different V_{CC} values

The aim of this paragraph is to show the impact of different V_{CC} values on the t_{CHARGE} of a defined capacitance. Table 5 below summarizes the collected results.

Table 5. t_{CHARGE} vs applied V_{CC}

Trial	Applied V _{CC} (V)	t _{CHARGE} (ms)	Reference figure
3	13.5	28	17
4	10	4 (with only 1 pulse not achieving I _{PEAK})	18
5	18	50	21

The conditions and results acquired in **Trial 5** in which V_{CC} is set at 13.5 V are reported below.

Setup 3:

- **V_B = 13.5 V**
- T_{AMB} = room
- **Load0 = 10 mF**
- Load1 = 23.5 Ω
- I_{NOMx} = 8 A
- t_{NOMx} = 300 s
- Cable from supply to V_{CC} = 20 cm
- Cable from OUT_x to Load_x = 20 cm
- WD refresh time = 50 ms
- **VNF9D1M5Q** DUT in Normal mode

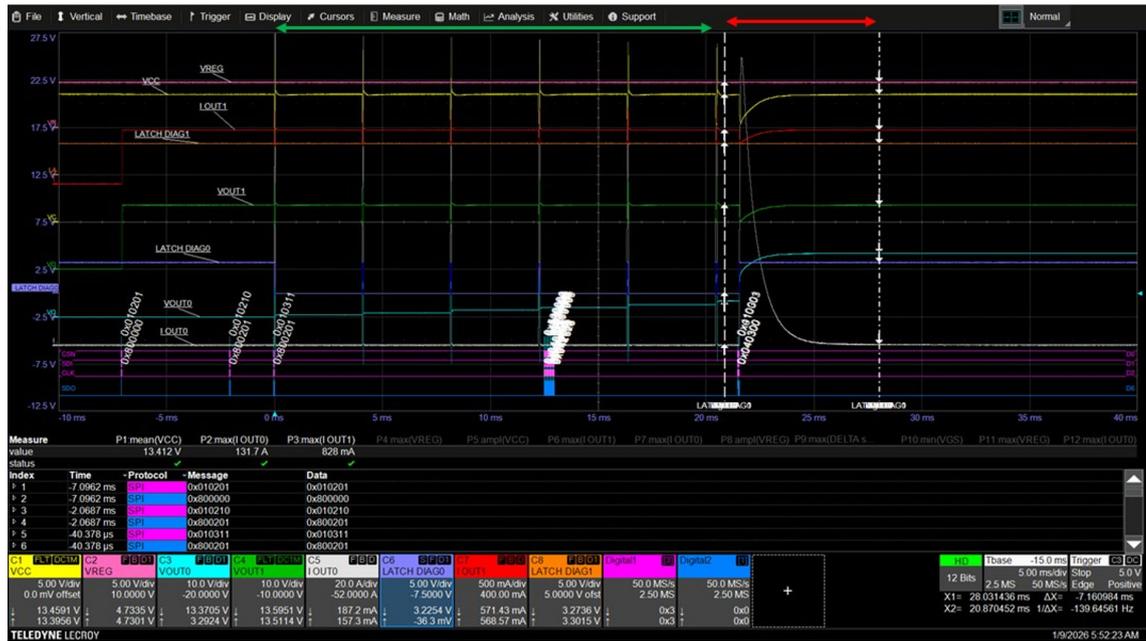
Execution:

- Turn ON CH1 on R_{LOAD} by SOCR1 = 1
- Set CAPCR0 = 1
- Turn ON CH0 by SOCR0 = 1 enabling CCM on CH0

Results:

- 10 mF is charged in ~28 ms (5 pulses at low frequency for ~20.5 ms followed by 2 pulses at high frequency)
- LATCH_DIAG0 goes low during CCM
- OUT1 remains stable ON sustaining ~570 mA

Figure 17. Waveforms acquired during Trial 3



The conditions and results acquired in **Trial 4** in which V_{CC} is decreased to 10 V are reported. A lower V_{CC} involves a shorter t_{CHARGE} due to a lower V_{OUT} to be achieved to charge the capacitor.

Setup 4:

- $V_B = 10 V$
- $T_{AMB} = \text{room}$
- **Load0 = 10 mF**
- Load1 = 23.5 Ω
- $I_{NOMx} = 8 A$
- $t_{NOMx} = 300 s$
- Cable from supply to $V_{CC} = 20 cm$
- Cable from OUT_x to $Load_x = 20 cm$
- WD refresh time = 50 ms
- VNF9D1M5Q DUT in Normal mode

Execution:

- Turn ON CH1 on R_{LOAD} by $SOCR1 = 1$
- Set $CAPCR0 = 1$
- Turn ON CH0 by $SOCR0 = 1$ enabling CCM on CH0

Results:

- 10 mF is charged with 1 pulse without reaching I_{PEAK} so that LATCH_DIAG0 does not go low (4 ms).
- The value of V_{OUT0} after 4 ms is 9.82 V and it is very close to $V_{CC} = 9.88 V$
- OUT1 remains stably ON sustaining 430 mA
- I_{PEAK} is not reached, the capacitor is charged with a single continuous charging pulse. In this specific channel operating mode, the device can distinguish a capacitor load from a short-circuit.

Figure 18. Waveforms acquired during Trial 4



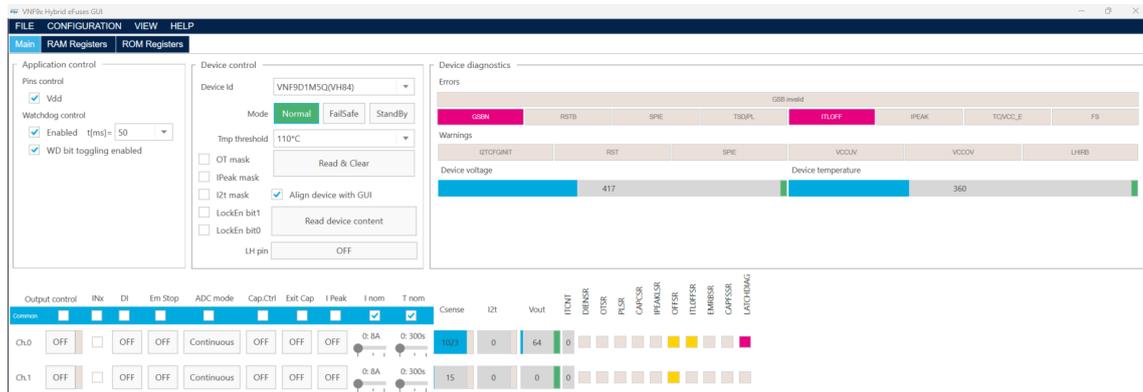
Even if this capacitance is loaded with 1 single pulse in CCM, the end user must consider that in case no CCM is enabled, it is not possible to charge the 10 mF due to Latch off protection intervention as visible in Figure 19 below), in which OUT0 is turned ON by SOCR0 = 0 with CAPCR0 = 0.

In this case, after the pulse limited by I²t protection, V_{OUT0} reaches 1.45 V and the OUT0 is latched OFF, with LATCH_DIAG0 moving and remaining stable low.

Figure 19. Waveforms acquired during Trial 4 without activating CCM



Figure 20. GUI image acquired after Trial 4 without activating CCM



The conditions and results acquired in **Trial 5** in which V_{CC} is increased to 18 V are reported. A higher V_{CC} involves a longer t_{CHARGE} due to a higher V_{OUT} to be achieved to charge the capacitor.

Setup 5:

- $V_B = 18 V$
- $T_{AMB} = \text{room}$
- **Load0 = 10 mF**
- Load1 = 23.5 Ω
- $I_{NOMx} = 8 A$
- $t_{NOMx} = 300 s$
- Cable from supply to $V_{CC} = 20 cm$
- Cable from OUT_x to $Load_x = 20 cm$
- WD refresh time = 50 ms
- VNF9D1M5Q DUT in Normal mode

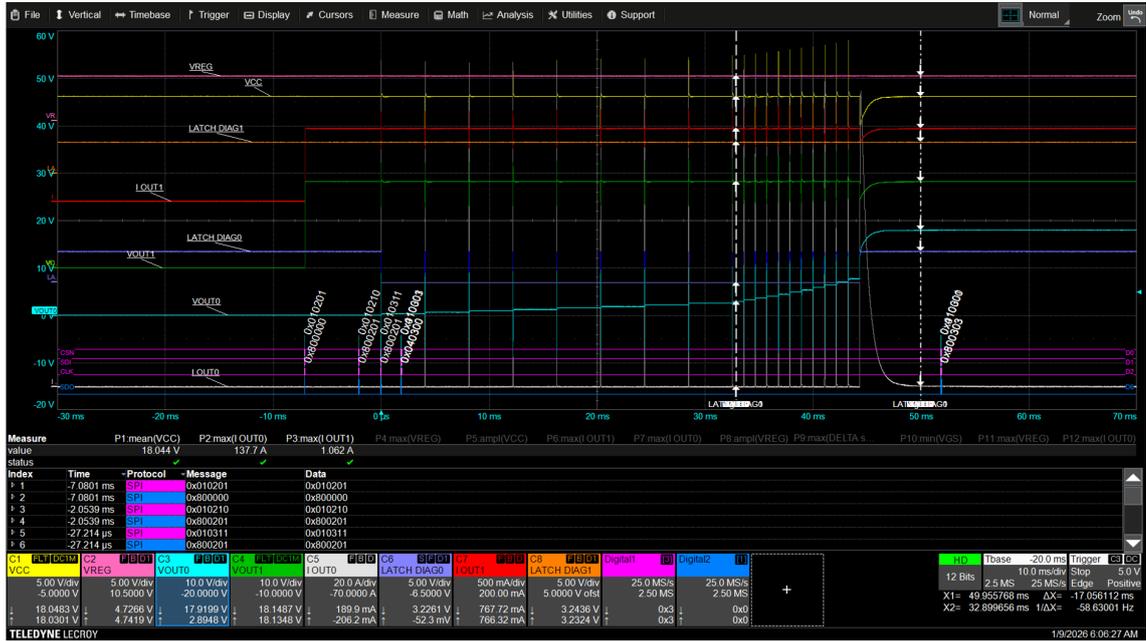
Execution:

- Turn ON CH1 on R_{LOAD} by $SOCR1 = 1$
- Set $CAPCR0 = 1$
- Turn ON CH0 by $SOCR0 = 1$ enabling CCM on CH0

Results:

- 10 mF is charged in 50 ms (8 pulses at low frequency for 31.3 ms followed by 12 pulses at high frequency)
- OUT1 remains stably ON sustaining 760 mA

Figure 21. Waveforms acquired during trial 5



3.4 Examples of C_{LOAD} charged in Normal mode using different values of capacitance

The aim of this paragraph is to show the impact of different C_{LOAD} values on the t_{CHARGE} , fixing all other parameters.

Table 6 below summarizes the collected results.

Table 6. t_{CHARGE} vs applied C_{LOAD}

Trial	C_{LOAD} (mF nominal)	t_{CHARGE} (ms)	Reference figure
3	10	28	17
6	14.7	47.5	22
7	4.7	10.5	23

The conditions and results acquired in **Trial 6** in which V_{CC} is set to 13.5 V and $C_{LOAD} = 14.7$ mF are reported. Greater capacitance involves longer t_{CHARGE} .

Setup 6:

- **$V_B = 13.5$ V**
- $T_{AMB} = \text{room}$
- Load0 = 23.5 Ω
- **Load1 = 14.7 mF**
- $I_{NOMx} = 8$ A
- $t_{NOMx} = 300$ s
- Cable from supply to $V_{CC} = 20$ cm
- Cable from OUT_x to $Load_x = 20$ cm
- WD refresh time = 50 ms
- [VNF9D1M5Q](#) DUT in Normal mode

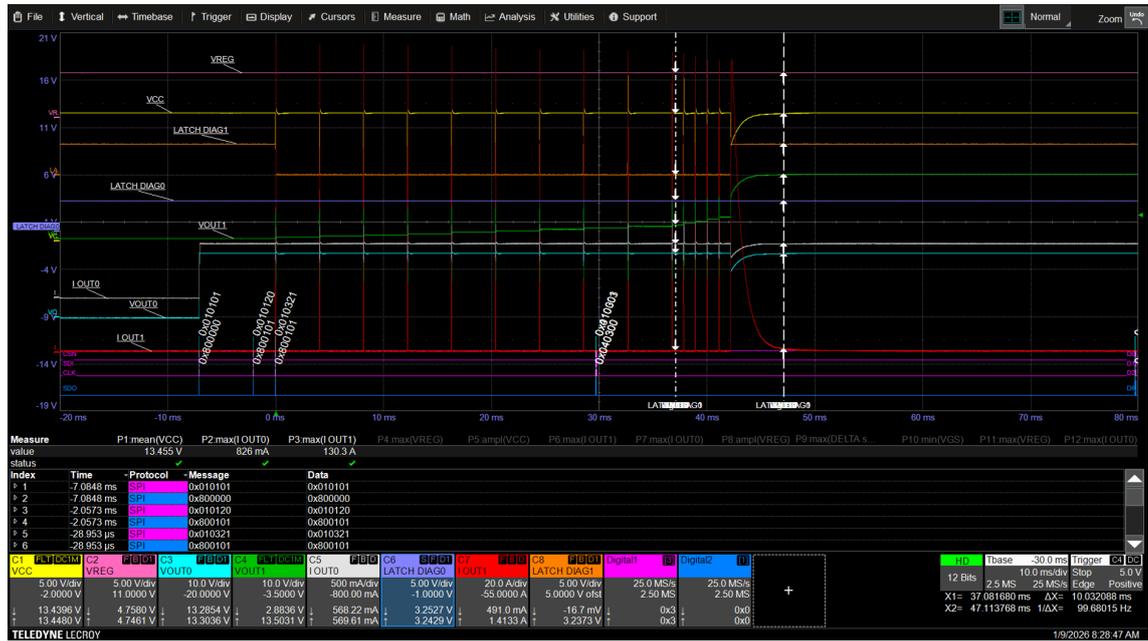
Execution:

- Turn ON CH0 on R_{LOAD} by $SOCR0 = 1$
- Set $CAPCR1 = 1$
- Turn ON CH1 by $SOCR1 = 1$ enabling CCM on CH1

Results:

- 14.7 mF is charged in ~47.5 ms (9 pulses at low frequency for ~36.5 ms followed by 6 pulses at high frequency)
- LATCH_DIAG1 goes low during CCM
- OUT0 remains stable ON sustaining ~570 mA
- The t_{CHARGE} of 14.7 mF is very similar moving from OUT0 (Trial 1) to OUT1 (Trial 6) confirming a negligible difference between the two output channels

Figure 22. Waveforms acquired during Trial 6



The conditions and results acquired in **Trial 7** in which V_{CC} is set to 13.5 V and $C_{load} = 4.7$ mF are reported. Smaller capacitances involve shorter t_{CHARGE} .

Setup 7:

- $V_b = 13.5$ V
- $T_{amb} = \text{room}$
- **Load0 = 4.7 mF**
- Load1 = 23.5 Ω
- $I_{NOMx} = 8$ A
- $t_{NOMx} = 300$ s
- Cable from supply to VCC = 20 cm
- Cable from OUT_x to $Load_x = 20$ cm
- WD refresh time = 50 ms
- VNF9D1M5Q DUT in Normal mode

Execution:

- Turn ON CH1 on R_{LOAD} by $SOCR1 = 1$
- Set $CAPCR0 = 1$
- Turn ON CH0 by $SOCR0 = 1$ enabling CCM on CH0

Results:

- 4.7 mF is charged in ~10.5 ms (3 pulses at low frequency for ~8.1 ms. The last pulse does not reach I_{PEAK})
- LATCH_DIAG0 goes low during CCM
- OUT1 remains stably ON sustaining ~570 mA

Figure 23. Waveforms acquired during Trial 7



3.5 Examples of CCM depending on cables used to connect VCC and or C_{LOAD}

The aim of this paragraph is to show the impact of cables to connect VCC to supply (fixed at 13.5 V) and/or C_{LOAD} (fixed at 14.7 mF) to OUT_x on the t_{CHARGE}, fixing all other parameters.

Previous trials were conducted using short connections on VCC and OUT_x introducing low stray resistance and inductance. Longer connections affect the t_{CHARGE}.

Table 7 below summarizes the collected results.

Table 7. t_{CHARGE} vs cables used on VCC and/or OUT_x

Trial	Cable on VCC	Cable on C _{LOAD}	t _{CHARGE} (ms)	Reference figure
1	20 cm	20 cm	47	6
8	20 cm	5 μH / 10 mΩ simulating 5 m cable	15.5	23
9	5 μH / 10 mΩ simulating 5 m cable	5 μH / 10 mΩ simulating 5 m cable	6	24
10	5 μH / 10 mΩ simulating 5 m cable	20 cm	6	25

The conditions and results acquired in **Trial 8** in which OUT0 is connected to C_{LOAD} = 14.7 mF by means of a 5 m cable are reported below. The impact of the cable features is a reduction in t_{CHARGE}.

Setup 8:

- V_B = 13.5 V
- T_{AMB} = room
- Load0 = 14.7 mF
- Load1 = 23.5 Ω
- I_{NOMx} = 8 A
- t_{NOMx} = 300 s
- Cable from supply to VCC = 20 cm
- **Cable from OUT0 to Load0 = 5 μH / 10 mΩ simulating 5 m wire**
- Cable from OUT1 to Load1 = 20 cm
- WD refresh time = 50 ms
- VNF9D1M5Q DUT in Normal mode

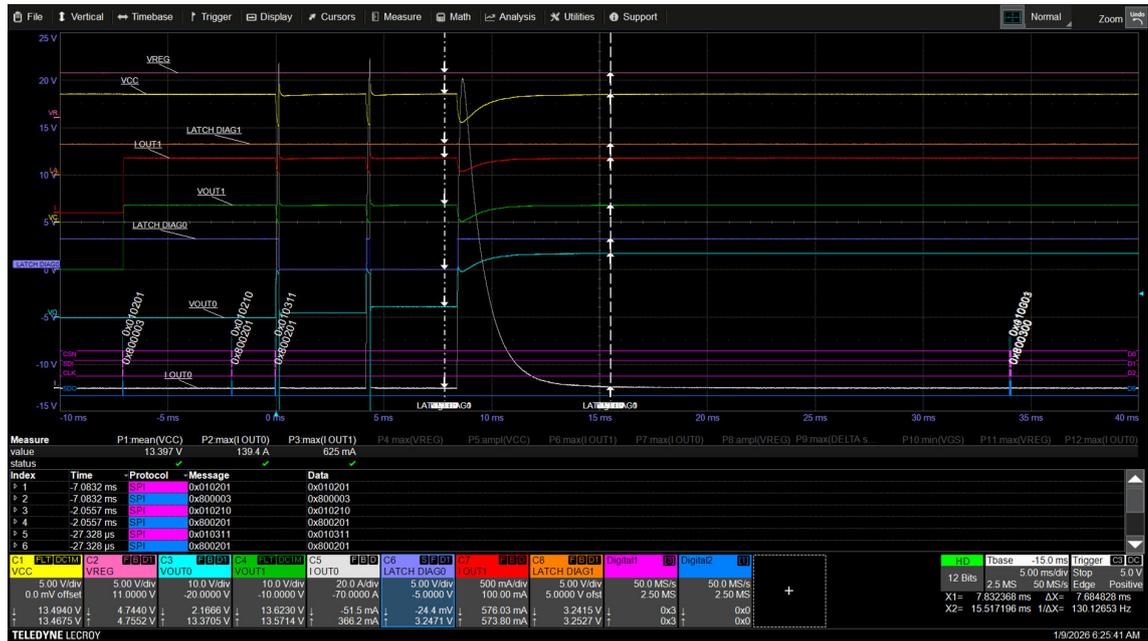
Execution:

- Turn ON CH1 on R_{LOAD} by SOCR1 = 1
- Set CAPCR0 = 1
- Turn ON CH0 by SOCR0 = 1 enabling CCM on CH0

Results:

- 14.7 mF is charged in ~15.5 ms (3 pulses at low frequency for ~8.1 ms. Last pulse does not reach I_{PEAK})
- OUT1 remains stable ON sustaining ~570 mA

Figure 24. Waveforms acquired during Trial 8



The conditions and results acquired in **Trial 9** in which both OUT0 and VCC are connected by means of 5 m cable are reported. The impact of cables features is a strong reduction in t_{CHARGE} .

Setup 9:

- $V_B = 13.5 V$
- $T_{AMB} = \text{room}$
- Load0 = 14.7mF
- Load1 = 23.5 Ω
- $I_{NOMx} = 8 A$
- $t_{NOMx} = 300 s$
- Cable from supply to VCC = 5 μH / 10 m Ω simulating 5 m wire
- Cable from OUT0 to Load0 = 5 μH / 10 m Ω simulating 5 m wire
- Cable from OUT1 to Load1 = 20 cm
- WD refresh time = 50 ms
- VNF9D1M5Q DUT in Normal mode

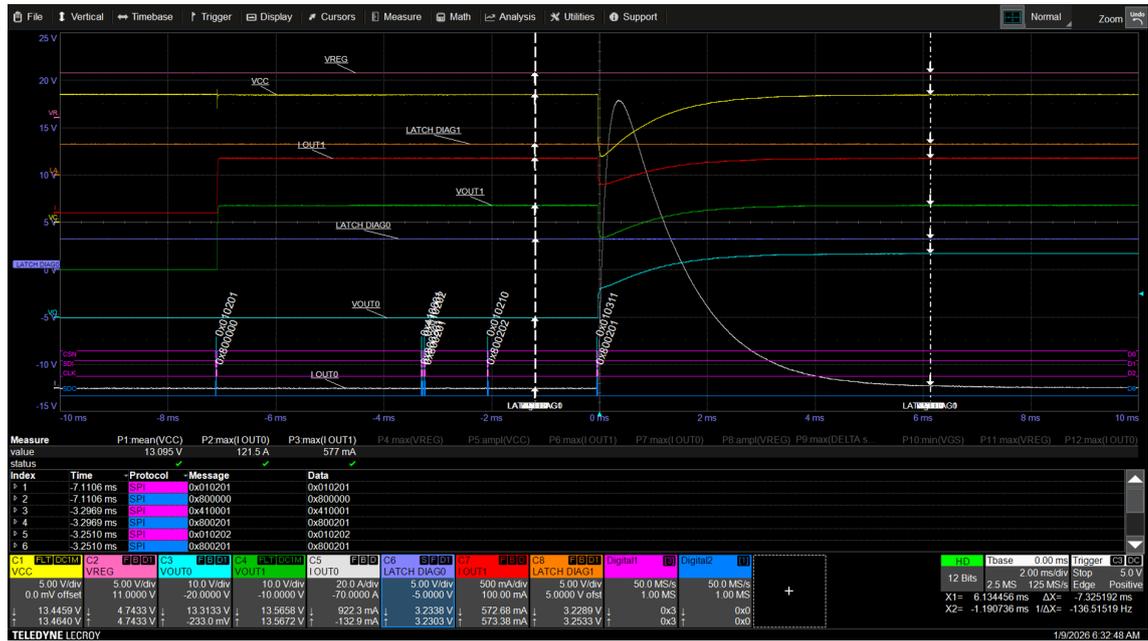
Execution:

- Turn ON CH1 on R_{LOAD} by SOCR1 = 1
- Set CAPCR0 = 1
- Turn ON CH0 by SOCR0 = 1 enabling CCM on CH0

Results:

- 14.7 mF is charged in 1 pulse without reaching I_{PEAK} so that LATCH_DIAG0 remains high
- OUT1 remains stable ON sustaining ~570 mA

Figure 25. Waveforms acquired during Trial 9



The conditions and results acquired in **Trial 10** in which VCC is connected to supply by means of 5m cable are reported. The impact of cables features is a reduction in t_{CHARGE} .

Setup 10:

- $V_B = 13.5 V$
- $T_{AMB} = \text{room}$
- Load0 = 14.7 mF
- Load1 = 23.5 Ω
- $I_{NOMx} = 8 A$
- $t_{NOMx} = 300 s$
- **Cable from supply to VCC = 5 μ H / 10 m Ω simulating 5 m wire**
- Cable from OUT_x to Load_x = 20 cm
- WD refresh time = 50 ms
- VNF9D1M5Q DUT in Normal mode

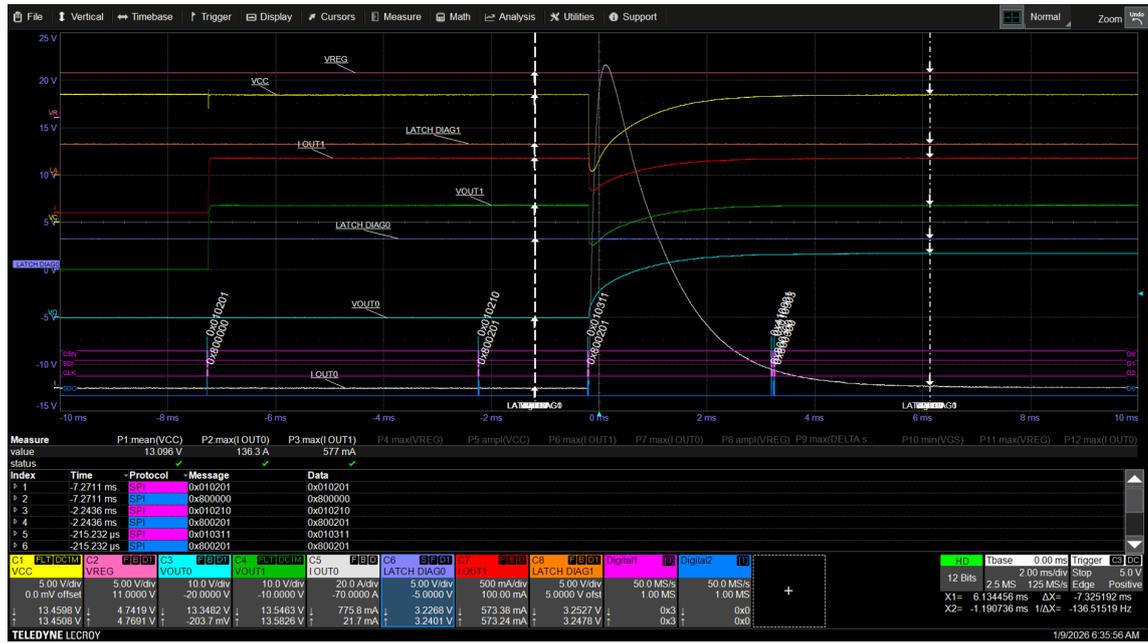
Execution:

- Turn ON CH1 on R_{LOAD} by SOCR1 = 1
- Set CAPCR0 = 1
- Turn ON CH0 by SOCR0 = 1 enabling CCM on CH0

Results:

- 14.7 mF is charged in 1 pulse without reaching I_{PEAK} so that LATCH_DIAG0 remains high
- OUT1 remains stable ON sustaining ~570 mA

Figure 26. Waveforms acquired during Trial 10



3.6 Examples of CCM varying I_{NOM} and t_{NOM}

The aim of this paragraph is to show the impact of I_{NOM} and t_{NOM} on the t_{CHARGE} fixing all other parameters ($V_{CC} = 13.5\text{ V}$ and $C_{LOAD} = 14.7\text{ mF}$).

Previous trials were conducted using default values of I_{NOM} (8 A) and t_{NOM} (300 s).

Table 8 below summarizes the collected results.

Table 8. t_{CHARGE} vs applied I_{NOM} and t_{NOM}

Trial	I_{NOM} (A)	t_{NOM} (s)	t_{CHARGE} (ms)	Reference figure
1	8	300	47	6
11	8	1	56	27-28
12	27	1	47	29-30
13	27	300	47	31-32

The conditions and results acquired in **Trial 11** in which t_{NOM} was reduced from 300 s to 1 s are reported. The impact of lower t_{NOM} is an increase in t_{CHARGE} due to the shorter duration of pulses in the last portion of charge at high frequency, in which the pulses are limited by I^2t protection.

Setup 11:

- $V_B = 13.5\text{ V}$
- $T_{AMB} = \text{room}$
- Load0 = 14.7 mF
- Load1 = 23.5 Ω
- $I_{NOMx} = 8\text{ A}$
- **$t_{NOMx} = 1\text{ s}$**
- Cable from supply to VCC = 20 cm
- Cable from OUT_x to Load_x = 20 cm
- WD refresh time = 50 ms
- VNF9D1M5Q DUT in Normal mode

Execution:

- Turn ON CH1 on R_{LOAD} by SOCR1 = 1
- Set CAPCR0 = 1
- Turn ON CH0 by SOCR0 = 1 enabling CCM on CH0

Results:

- 14.7 mF is charged in ~56 ms (9 pulses in low frequency phase for ~36.5 ms followed by 12 pulses in high frequency)
- LATCH_DIAG0 goes low during CCM when I_{PEAK} is achieved
- Last 8 pulses in low frequency do not achieve I_{PEAK}
- OUT1 remains stable ON sustaining ~570 mA
- Adopting $t_{NOM} = 1\text{ s}$ vs 300 s involves a longer t_{CHARGE} due to the impact on I^2t protection in the high-frequency phase.

Figure 27. Waveforms acquired during Trial 11

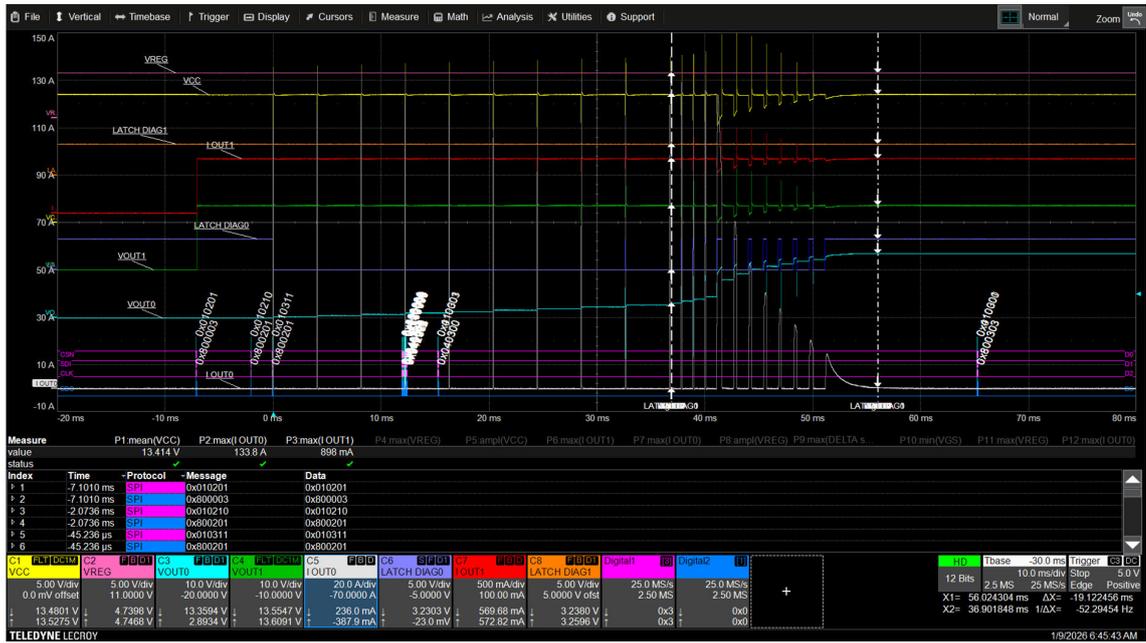


Figure 28. Zoomed view of CCM portion in high frequency acquired during Trial 11

The first 4 pulses in high frequency phase are able to achieve I_{PEAK}

Next 8 pulses in high frequency phase are not able to achieve I_{PEAK} , and their duration is limited by the triggering of I^2t protection. In any case the period remain always $1\text{ms} = t_{HF}$. Last pulse is able to complete the charge without triggering any protection



The conditions and results acquired in Trial 12 in which t_{NOM} is set at the min. value of 1 s and I_{NOM} at the max. value of 27 A are reported below. Higher I_{NOM} involves faster t_{CHARGE} .

Setup 12:

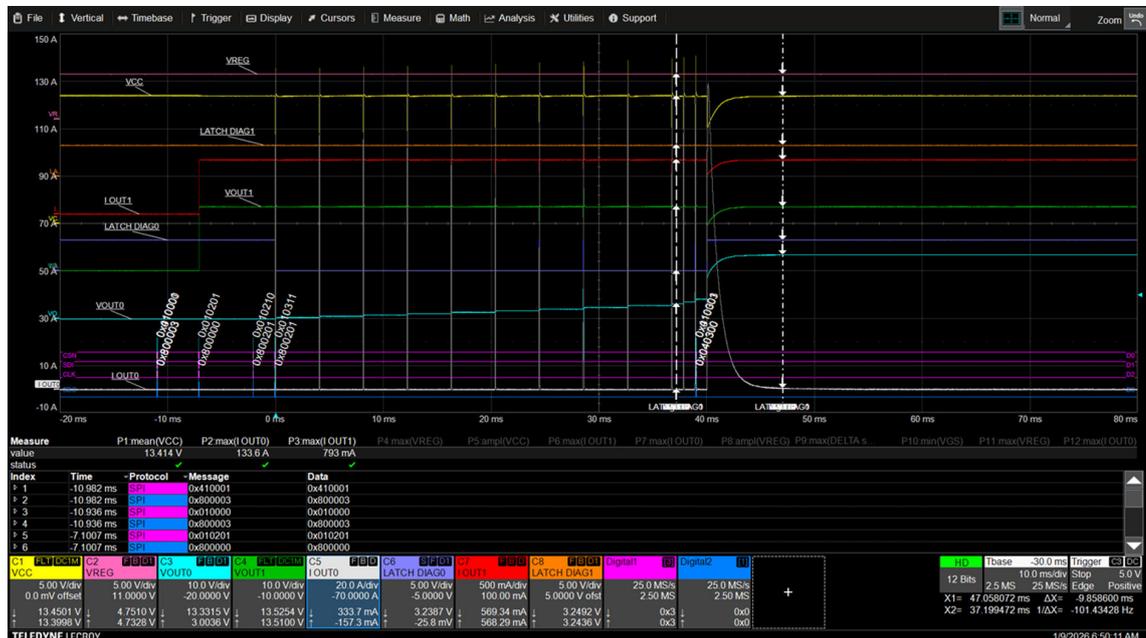
- $V_B = 13.5\text{ V}$
- $T_{AMB} = \text{room}$
- Load0 = 14.7 mF
- Load1 = 23.5 Ω
- $I_{NOMx} = 27\text{ A}$
- $t_{NOMx} = 1\text{ s}$
- Cable from supply to VCC = 20 cm
- Cable from OUT_x to Load_x = 20 cm
- WD refresh time = 50 ms
- VNF9D1M5Q DUT in Normal mode

Execution:

- Turn ON CH1 on R_{LOAD} by SOCR1 = 1
- Set CAPCR0 = 1
- Turn ON CH0 by SOCR0 = 1 enabling CCM on CH0

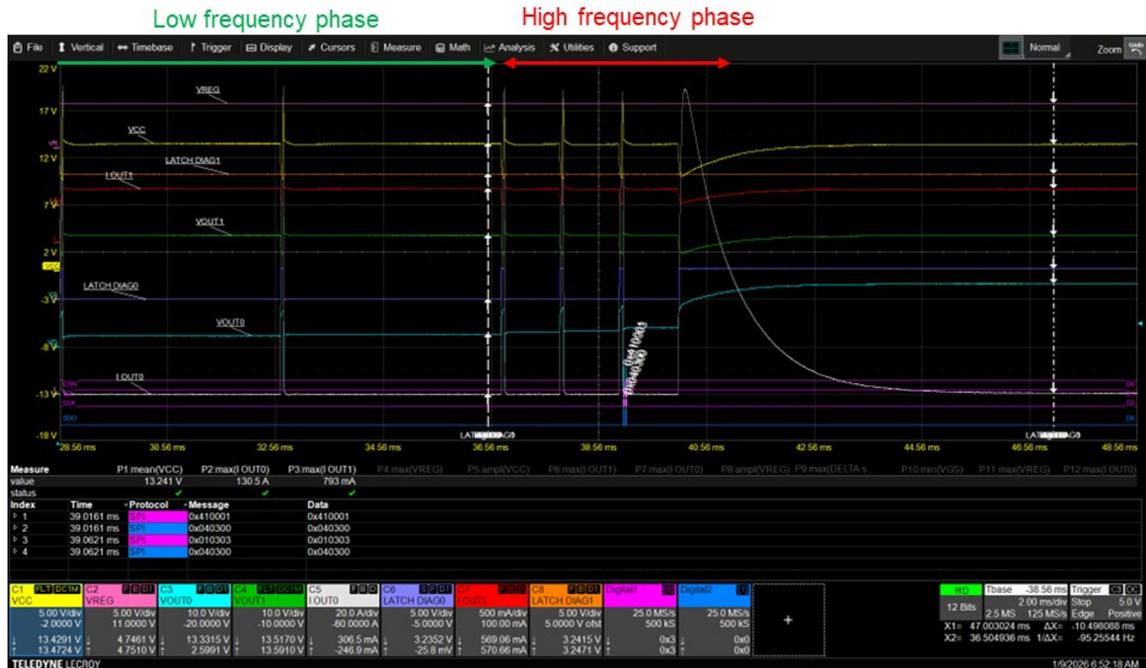
Results:

- 14.7 mF is charged in ~47 ms (9 pulses in low frequency for ~36.5 ms followed by 4 pulses in high frequency)
- OUT1 remains stable ON sustaining ~570 mA
- The ~9 ms difference in t_{CHARGE} of Trial 11 vs 12 is due to the different used I_{NOM} of 27 A vs 8 A (max vs min)

Figure 29. Waveforms acquired during Trial 12


As visible from the zoomed [Figure 30](#) below, the different high-frequency phase durations on Trial 11 vs 12 are due to the I_{NOM} value affecting the portion of the high-frequency phase in which the “on-time” is limited by I^2t protection:

- In **Trial 11** with $t_{NOM} = 1\text{ s}$ and $I_{NOM} = 8\text{ A}$, the high-frequency phase has a duration of ~19.5 ms due to 12 pulses (first 4 pulses reaching I_{PEAK} for 4 ms followed by 8 pulses triggered by I^2t protection)
- In **Trial 12** with $t_{NOM} = 1\text{ s}$ and $I_{NOM} = 27\text{ A}$, the high-frequency phase has a duration of ~9.5 ms due to 4 pulses (first 3 pulses reaching I_{PEAK} for 3 ms followed by 1 final pulse not triggered by I^2t protection)

Figure 30. Zoomed view of CCM portion in high frequency acquired during Trial 12


The conditions and results acquired in **Trial 13** in which both t_{NOM} and I_{NOM} are set at max. values are reported.

Setup 13:

- $V_B = 13.5\text{ V}$
- $T_{AMB} = \text{room}$
- Load0 = 14.7 mF
- Load1 = 23.5 ohm
- $I_{NOMx} = 27\text{ A}$
- $t_{NOMx} = 300\text{ s}$
- Cable from supply to VCC = 20 cm
- Cable from OUT_x to Load_x = 20 cm
- WD refresh time = 50 ms
- VNF9D1M5Q DUT in Normal mode

Execution:

- Turn ON CH1 on RLOAD by SOCR1 = 1
- Set CAPCR0 = 1
- Turn ON CH0 by SOCR0 = 1 enabling CCM on CH0

Results:

- 14.7 mF is charged in ~47 ms (9 pulses in low frequency for ~36.5 ms followed by 4 pulses in high frequency)
- OUT1 remains stable ON sustaining ~570 mA
- In this case, the duration of the high-frequency phase is the same as the one observed in setup 1, because in both cases, the last pulse is able to complete the charge without triggering I²t protection.

Figure 31. Waveforms acquired during Trial 13

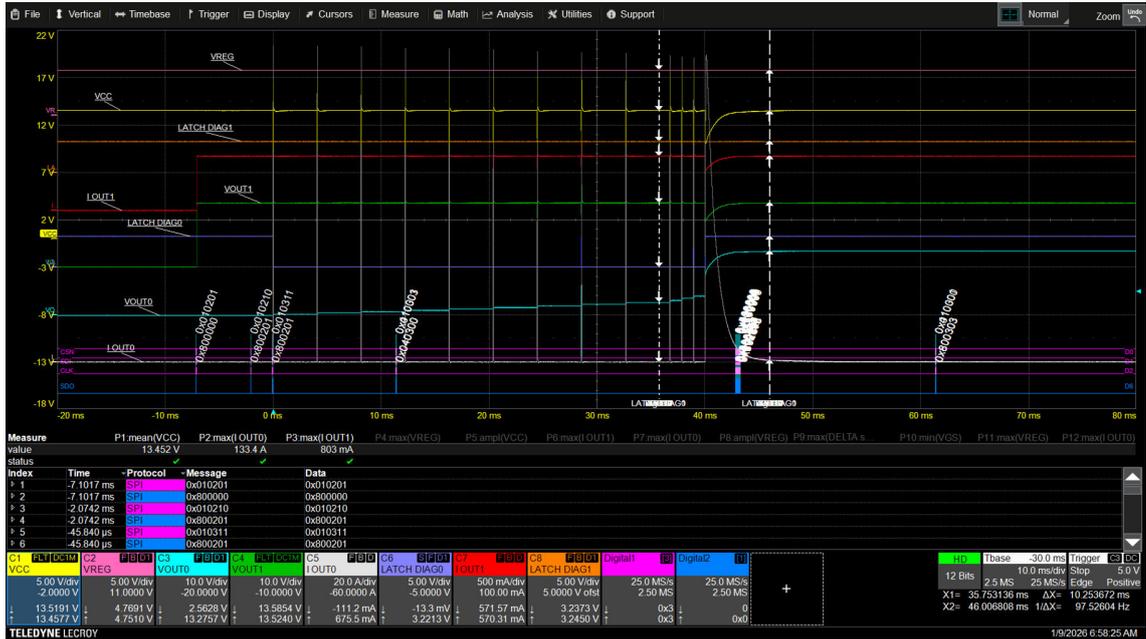


Figure 32. Zoomed view of CCM portion in high frequency acquired during Trial 13



3.7 Examples of CCM launched on a short circuit to GND

The aim of this paragraph is to show the behavior of the device in case CCM is launched on a short-circuit to GND instead of a C_{LOAD} .

The conditions and results acquired in **Trial 14** are reported below.

Setup 14:

- $V_B = 13.5\text{ V}$
- $T_{AMB} = \text{room}$
- **Load0 = short to GND**
- Load1 = $23.5\ \Omega$
- $I_{NOMx} = 8\text{ A}$
- $t_{NOMx} = 300\text{ s}$
- Cable from supply to VCC = 20 cm
- Cable from OUT_x to Load $_x$ = 20 cm
- WD refresh time = 50 ms
- VNF9D1M5Q DUT in Normal mode

Execution:

- Turn ON CH1 on R_{LOAD} by SOCR1 = 1
- Set CAPCR0 = 1
- Turn ON CH0 by SOCR0 = 1 enabling CCM on CH0

Results:

- After 30 pulses, the CCM is aborted because MAX_COUNTER_LF is reached
- LATCH_DIAG0 goes and remains low during and after CCM exit ITLOFF and IPEAK_DETECT are flagged in the GSB.
- OUT1 remains stable ON sustaining ~570 mA

Figure 33. Waveforms acquired during Trial 14

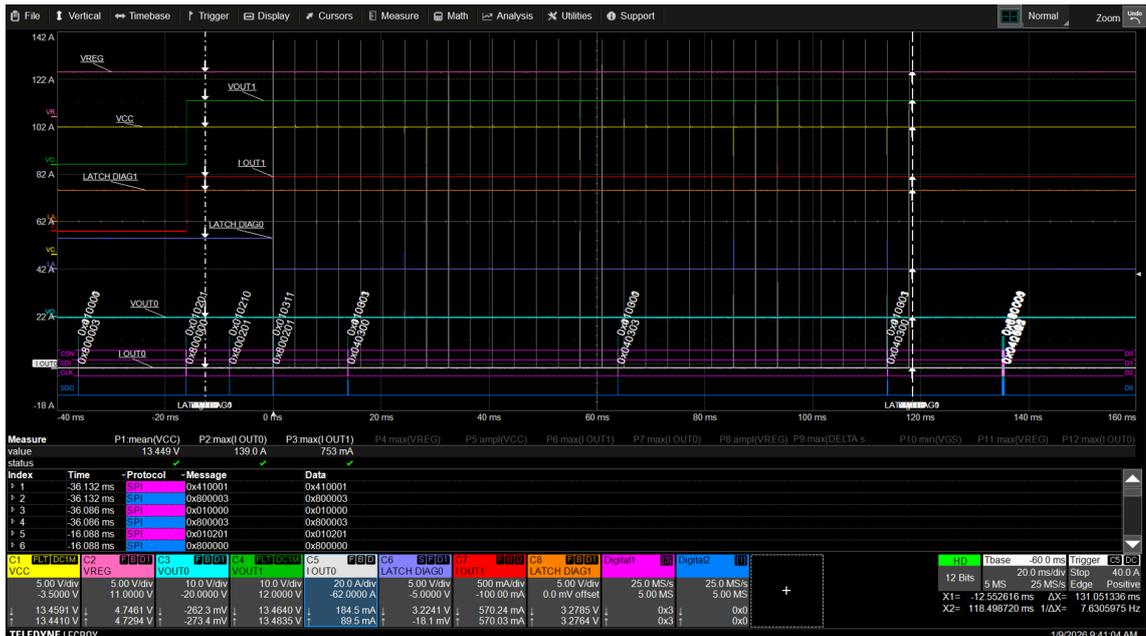
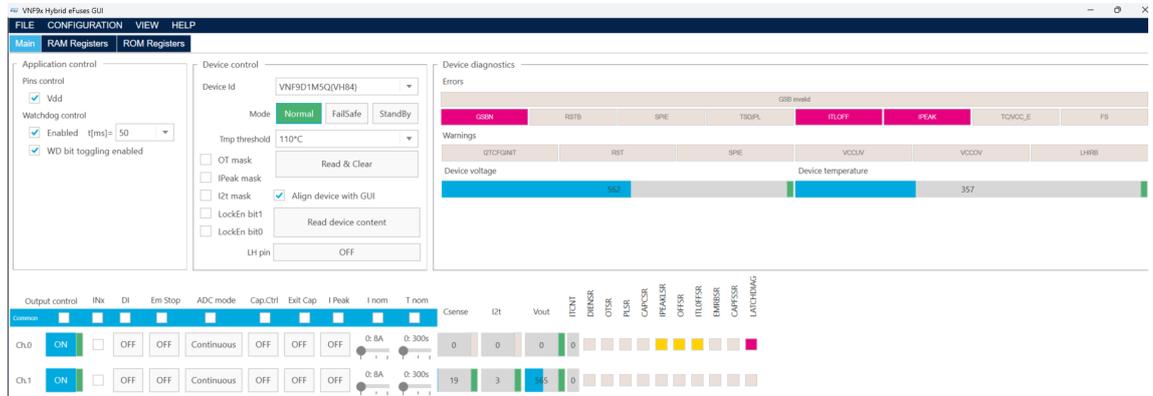


Figure 34. GUI image acquired after Trial 14 in which CCM is aborted due to MAX_COUNTER_LF achievement



3.8 Examples of CCM launched on both CH_x

The aim of this paragraph is to show the behavior of the device in case CCM is launched on both output channels on 2 different C_{LOAD}.

The conditions and results acquired in **Trial 15** are reported below.

Setup 15:

- V_B = 13.5 V
- T_{AMB} = room
- **Load0 = 14.7 mF**
- **Load1 = 4.7 mF**
- I_{NOMx} = 8 A
- t_{NOMx} = 300 s
- Cable from supply to VCC = 20 cm
- Cable from OUT_x to Load_x = 20 cm
- WD refresh time = 50 ms
- VNF9D1M5Q DUT in Normal mode

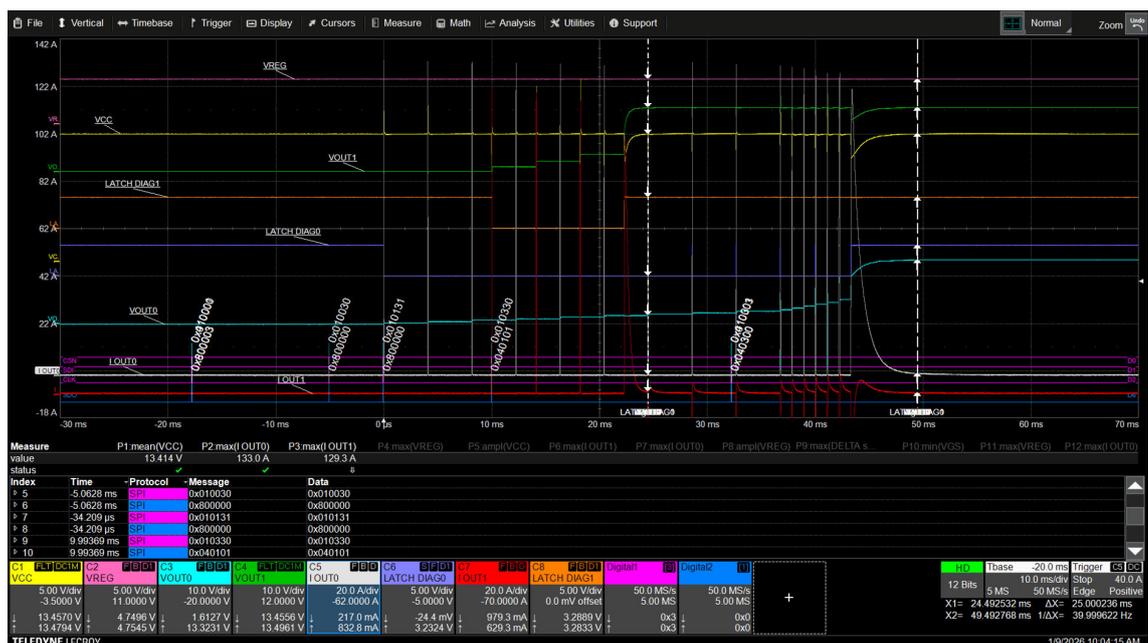
Execution:

- Set CAPCR0 = CAPCR1 = 1
- Turn ON CH0 by SOCR0 = 1 enabling CCM on CH0
- Turn ON CH1 by SOCR1 = 1 enabling CCM on CH1

Results:

- 14.7 mF is charged in ~49.5 ms (9 pulses in low frequency phase for ~36.5 ms followed by 7 pulses in high frequency)
- 4.7 mF is charged in ~14.5 ms (4 pulses in low frequency)
- LATCH_DIAG0 and LATCH_DIAG1 go low during CCM
- The 2 OUTs work independently

Figure 35. Waveforms acquired during Trial 15



3.9 Examples of CCM launched at hot temperatures

The aim of this paragraph is to show the impact of the ambient temperature on t_{CHARGE} .

Fixing all other parameters, a higher temperature decreases t_{CHARGE} .

Table 9 below summarizes the collected results.

Table 9. t_{CHARGE} vs cables used on VCC and/or OUT_x

Trial	T_{case} (°C)	t_{CHARGE} (ms)	Reference figure
1	35	47	6
16	95	42	36

The conditions and results acquired in **Trial 16** are listed below.

Setup 16:

- $V_B = 13.5 \text{ V}$
- $T_{\text{AMB}} = \text{hot}$ ($T_{\text{case}} \sim 95^\circ\text{C}$)
- Load0 = 14.7 mF
- Load1 = 23.5 Ω
- $I_{\text{NOM}x} = 8 \text{ A}$
- $t_{\text{NOM}x} = 300 \text{ s}$
- Cable from supply to VCC = 20 cm
- Cable from OUT_x to Load $_x$ = 20 cm
- WD refresh time = 50 ms
- [VNF9D1M5Q](#) DUT in Normal mode

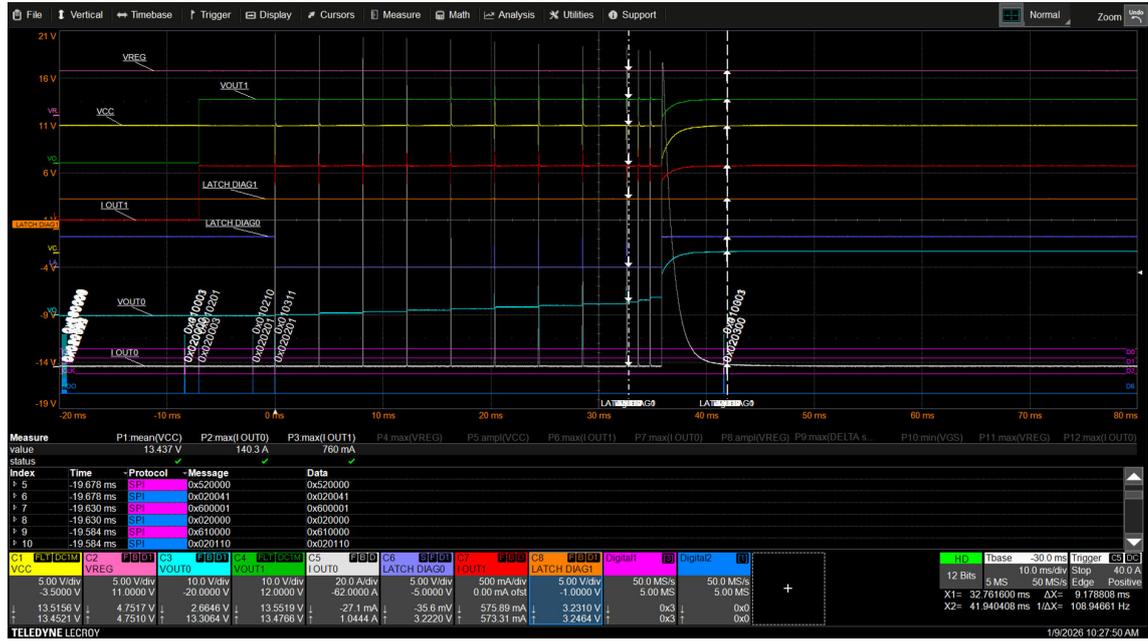
Execution:

- Turn ON CH1 on R_{LOAD} by $\text{SOCR1} = 1$
- Set $\text{CAPCR0} = 1$
- Turn ON CH0 by $\text{SOCR0} = 1$ enabling CCM on CH0

Results:

- 14.7 mF is charged in ~42 ms (8 pulses in low frequency phase for ~32.5 ms followed by 4 pulses in high frequency phase)
- OUT1 remains stable ON sustaining ~570 mA

Figure 36. Waveforms acquired during Trial 16



3.10 Examples of CCM launched on different e-fuse products with different $R_{DS(ON)}$ and I_{PEAK}

The aim of this paragraph is to show the impact of the $R_{DS(ON)}$ and I_{PEAK} of e-fuse products belonging to the same family as the VNF9DxxQ on t_{CHARGE} .

Fixing all other parameters, a product with a higher I_{PEAK} is able to charge the same C_{LOAD} in a shorter time.

Table 10 below summarizes the collected results.

Table 10. t_{CHARGE} vs e-fuse product using 14.7 mF

Trial	Selected product	$R_{DS(ON)}$ typ. (m Ω)	I_{PEAK} typ. (A)	t_{CHARGE} (ms)	Reference figure
1	VNF9D1M5Q	1.5	120	47	6
17	VNF9D3Q	2	87	Aborted due to MAX_COUNTER_ LF	37

The conditions and results acquired in **Trial 17** are listed below.

Setup 17:

- $V_B = 13.5$ V
- $T_{AMB} = \text{room}$
- Load0 = 14.7 mF
- Load1 = 23.5 Ω
- $I_{NOMx} = 2$ A
- $t_{NOMx} = 300$ s
- Cable from supply to VCC = 20 cm
- Cable from OUT_x to Load_x = 20 cm
- WD refresh time = 50 ms
- **VNF9D3Q DUT in Normal mode**

Execution:

- Turn ON CH1 on R_{LOAD} by SOCR1 = 1
- Set CAPCR0 = 1
- Turn ON CH0 by SOCR0 = 1 enabling CCM on CH0

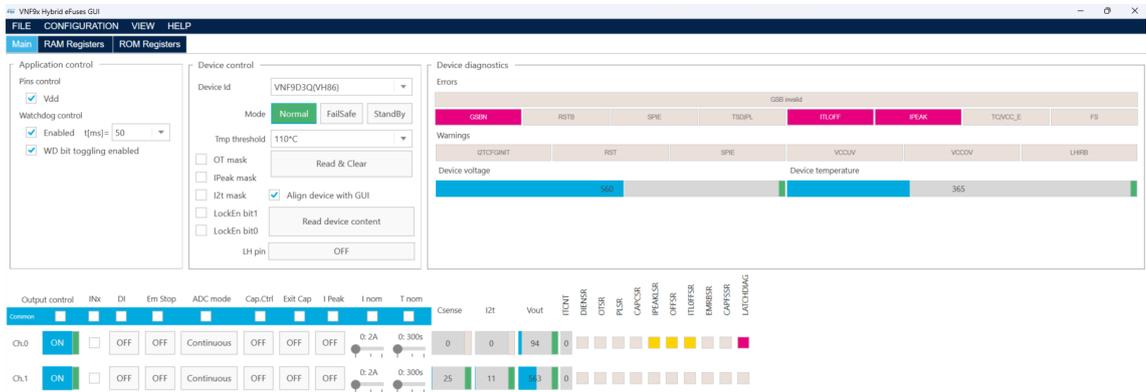
Results:

- 14.7 mF are not charged after 30 pulses so CCM is aborted due to MAX_COUNTER_LF achievement with V_{OUT} reaching ~2.1 V (below $V_{OUT_THR} = 3$ V) after 120 ms
- LATCH_DIAG0 remains low after CCM exit CCM
- OUT1 remains stable ON sustaining ~570 mA

Figure 37. Waveforms acquired during Trial 17



Figure 38. GUI image acquired at the end of Trial 17 in which CCM is aborted due to MAX_COUNTER_LF achievement



The VNF9D3Q device is not able to charge 14.7 mF while it is able to successfully complete the charge of 10 mF as visible in Trial 18 below.

Table 11 below summarizes the collected results using 10 mF and $V_{CC} = 13.5 V$.

Table 11. t_{CHARGE} vs e-fuse product using 10 mF and $V_{CC} = 13.5 V$

Trial	Selected product	$R_{DS(ON)}$ typ. (m Ω)	I_{PEAK} typ. (A)	t_{CHARGE} (ms)	Reference figure
3	VNF9D1M5Q	1.5	120	28	17
18	VNF9D3Q	2	87	124	39

The conditions and results acquired in Trial 18 are listed below.

Setup 18:

- $V_B = 13.5\text{ V}$
- $T_{AMB} = \text{room}$
- **Load0 = 10 mF**
- Load1 = 23.5 Ω
- $I_{NOMx} = 2\text{ A}$
- $t_{NOMx} = 300\text{ s}$
- Cable from supply to VCC = 20 cm
- Cable from OUT_x to Load_x = 20 cm
- WD refresh time = 50 ms
- **VNF9D3Q DUT in Normal mode**

Execution:

- Turn ON CH1 on Rload by SOCR1 = 1
- Set CAPCR0 = 1
- Turn ON CH0 by SOCR0 = 1 enabling CCM on CH0

Results:

- 10 mF is charged after ~124 ms (with 21 pulses in low frequency phase followed by 30 pulses in high frequency phase)
- OUT1 remains stably ON sustaining ~570 mA
- The longer t_{CHARGE} of 10 mF on VNF9D3Q vs VNF9D1M5Q is due to lower I_{PEAK} (I_{max} reached ~79 A vs 134 A on 2 different Trials, 3 vs 18) affecting both low and high frequency phases

Figure 39. Waveforms acquired during Trial 18



Table 12 below summarizes the collected results using 10 mF and Vcc = 18 V.

Table 12. t_{CHARGE} vs e-fuse product using 10 mF and V_{CC} = 13.5 V

Trial	Selected product	R _{DS(ON)} typ. (mΩ)	I _{PEAK} typ. (A)	I _{NOM} (A)	t _{NOM} (s)	t _{CHARGE} (ms)	Reference figure
5	VNF9D1M5Q	1.5	120	8	300	50	21
19	VNF9D3Q	2	87	2	300	195	40

The conditions and results acquired in **Trial 19** are reported below.

Setup 19:

- **V_B = 18 V**
- T_{AMB} = room
- **Load0 = 10 mF**
- Load1 = 23.5 Ω
- I_{NOMx} = 2 A
- t_{NOMx} = 300 s
- Cable from supply to VCC = 20 cm
- Cable from OUT_x to Load_x = 20 cm
- WD refresh time = 50 ms
- **VNF9D3Q DUT in Normal mode**

Execution:

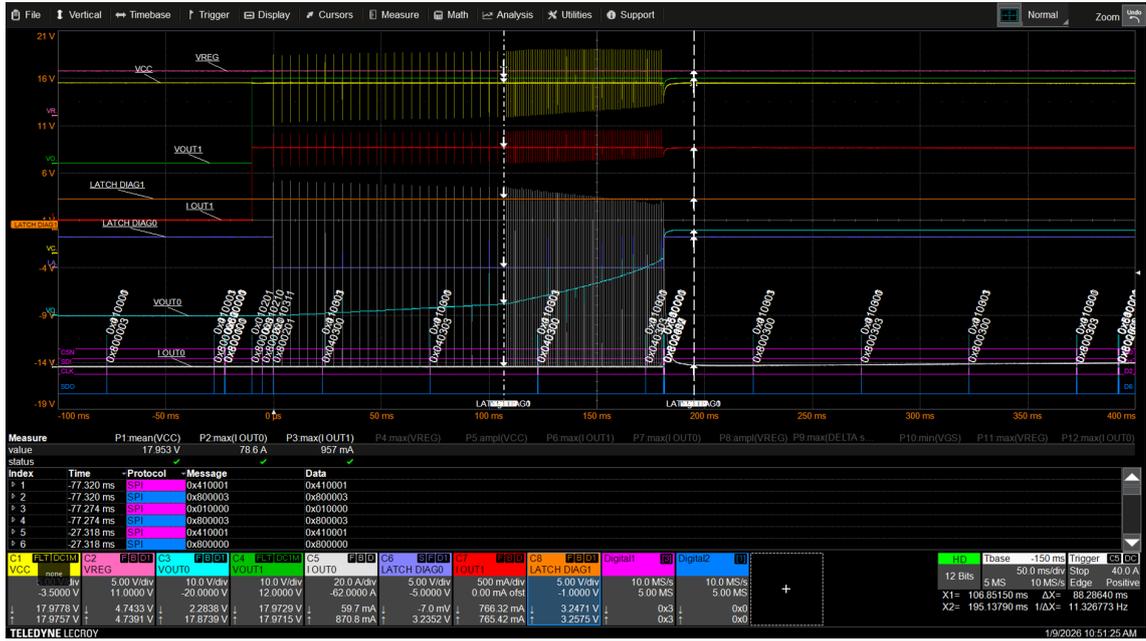
- Turn ON CH1 on R_{LOAD} by SOCR1 = 1
- Set CAPCR0 = 1
- Turn ON CH0 by SOCR0 = 1 enabling CCM on CH0

Results:

- 10 mF is charged after ~195 ms (with 27 pulses in low frequency phase very close to the MAX_COUNTER_LF for ~107 ms followed by 72 pulses in high frequency phase)
- OUT1 remains stable ON sustaining 760 mA

The longer t_{CHARGE} of 10 mF on VNF9D3Q vs VNF9D1M5Q is due to lower I_{PEAK} (I_{max} reached ~79 A on VNF9D3Q vs ~134 A on VNF9D1M5Q) affecting both low and high frequency phases.

Figure 40. Waveforms acquired during Trial 19



3.11 Examples of CCM interruptions

The aim of this paragraph is to show how CCM can be interrupted.

The various examples were verified using a **VNF9D3Q** device under various conditions, achieving different V_{OUT} values as summarized in **Table 13** below.

Table 13. t_{CHARGE} vs e-fuse product using 14.7 mF

Trial	DUT state	Methodology	Time after CCM launch (ms)	V_{OUT} value reached (V)	Reference figure
18 B	Normal	By setting $SOCR_x=0$	50	1.3	41
18 C	Normal	By setting $SOCR_x=0$	100	5.5	43
18 D	Normal	by setting $CAPCR_x = 0$ and $EXIT_CAPCR_x = 1$	40	1	44
18 E	Normal	by setting $CAPCR_x = 0$ and $EXIT_CAPCR_x = 1$	90	5.7	45
18 F	Fail-safe	Setting DI_x low	60	1.8	46
18 G	Fail-safe	Setting DI_x low	80	2.9	48

The conditions and results acquired in **Trial 18 B** are reported below.

Setup 18 B:

- $V_B = 13.5$ V
- $T_{AMB} = \text{room}$
- Load0 = 10 mF
- Load1 = 23.5 Ω
- $I_{NOMx} = 2$ A
- $t_{NOMx} = 300$ s
- Cable from supply to VCC = 20 cm
- Cable from OUT_x to Load $_x$ = 20 cm
- WD refresh time = 50 ms
- **VNF9D3Q DUT in Normal mode**

Execution:

- Turn ON CH1 on R_{LOAD} by $SOCR1 = 1$
- Set $CAPCR0 = 1$
- Turn ON CH0 by $SOCR0 = 1$ enabling CCM on CH0
- **After 50 ms, set $SOCR0 = 0$**
- CH1 is turned OFF after 300 ms by $SOCR1 = 0$

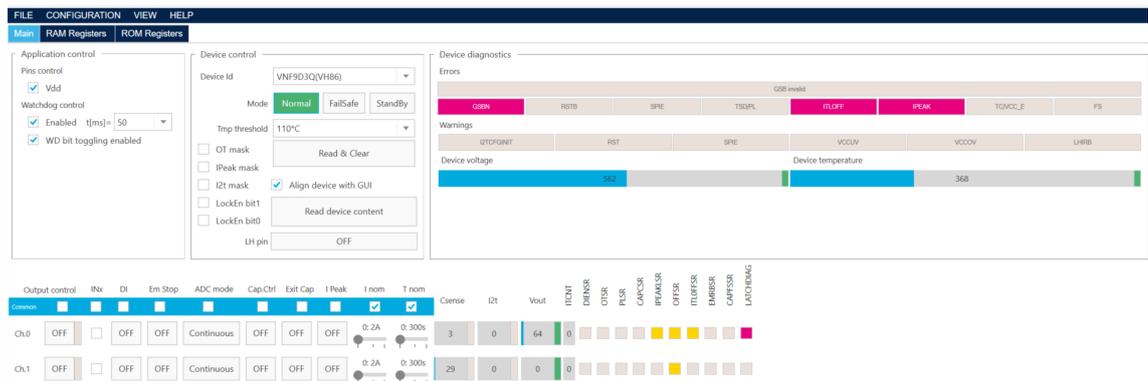
Results:

- 10 mF charge is interrupted during CCM low frequency phase after 50 ms and 13 pulses with V_{OUT} reaching ~1.3 V
- ITLOFF and IPEAK_DETECT are flagged
- OUT1 remains stable ON sustaining ~760 mA

Figure 41. Waveforms acquired during Trial 18 C with CCM interruption after 100 ms from start



Figure 42. GUI image acquired at the end of Trial 18 B highlighting I_{TLOFF} and I_{PEAK} flags



The conditions and results acquired in **Trial 18 C** are reported below.

Setup 18 C:

- $V_B = 13.5\text{ V}$
- $T_{AMB} = \text{room}$
- Load0 = 10 mF
- Load1 = 23.5 μF
- $I_{NOMx} = 2\text{ A}$
- $t_{NOMx} = 300\text{ s}$
- Cable from supply to VCC = 20 cm
- Cable from OUT_x to Load_x = 20 cm
- WD refresh time = 50 ms
- **VNF9D3Q DUT in Normal mode**

Execution:

- Turn ON CH1 on R_{LOAD} by SOCR1 = 1
- Set CAPCR0 = 1
- Turn ON CH0 by SOCR0 = 1 enabling CCM on CH0
- **After 100 ms, set SOCR0 = 0**
- CH1 is turned OFF after 300 ms by SOCR1 = 0

Results:

- 10 mF charge is interrupted during the CCM high-frequency phase after 100 ms and 13 pulses with V_{OUT} reaching ~5.5 V
- ITLOFF and IPEAK_DETECT are flagged
- OUT1 remains stable ON sustaining ~760 mA

Figure 43. Waveforms acquired during Trial 18 C with CCM interruption after 100 ms from start



The conditions and results acquired in **Trial 18 D** are listed below.

Setup 18 D:

- V_B = 13.5 V
- T_{AMB} = room
- Load0 = 10 mF
- Load1 = 23.5 Ω
- I_{NOMx} = 2 A
- t_{NOMx} = 300 s
- Cable from supply to VCC = 20 cm
- Cable from OUT_x to Load_x = 20 cm
- WD refresh time = 50 ms
- **VNF9D3Q DUT in Normal mode**

Execution:

- Turn ON CH1 on R_{LOAD} by $SOCR1 = 1$
- Set $CAPCR0 = 1$
- Turn ON CH0 by $SOCR0 = 1$ enabling CCM on CH0
- **After 40 ms, set $CAPCR0 = 0$ AND $EXIT_CAPCR0 = 1$**
- CH1 is turned OFF after 300 ms by $SOCR1 = 0$

Results:

- 10 mF charge is interrupted during the CCM low-frequency phase after 40 ms leaving CCM and V_{OUT} reaching ~ 1 V
- $ITLOFF$ and $IPEAK_DETECT$ are flagged
- $OUT1$ remains stable ON sustaining ~ 760 mA

Figure 44. Waveforms acquired during Trial 18 D with CCM interruption and exit after 40 ms from start


The conditions and results acquired in **Trial 18 E** are reported below.

Setup 18 E:

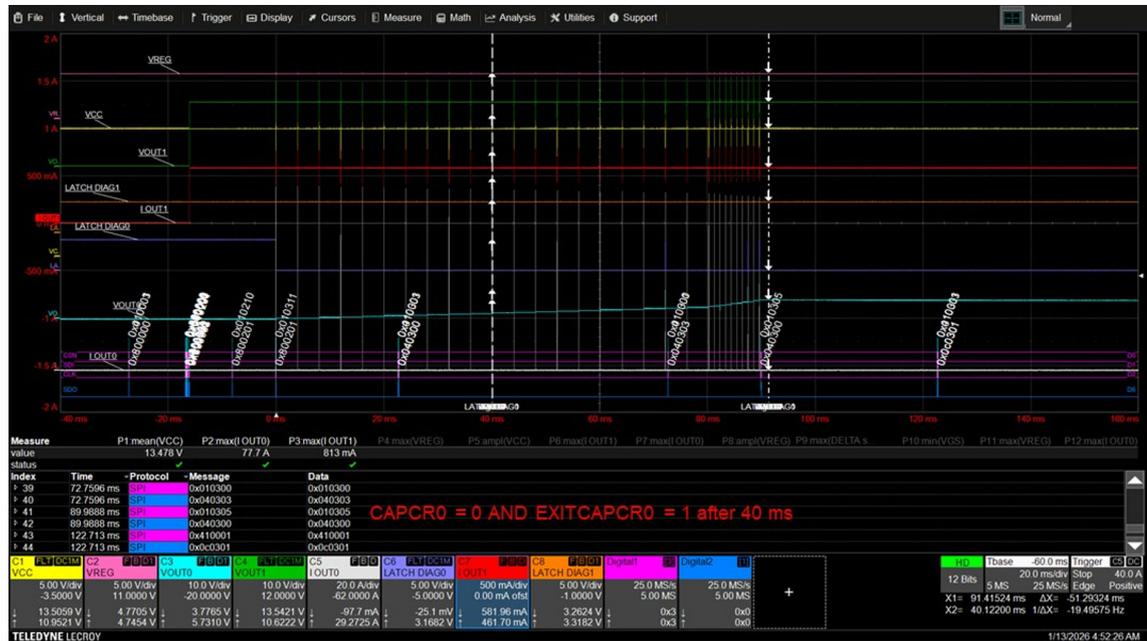
- $V_B = 13.5$ V
- $T_{AMB} = \text{room}$
- Load0 = 10 mF
- Load1 = 23.5 Ω
- $I_{NOMx} = 2$ A
- $t_{NOMx} = 300$ s
- Cable from supply to $V_{CC} = 20$ cm
- Cable from OUT_x to $Load_x = 20$ cm
- WD refresh time = 50 ms
- **VNF9D3Q DUT in Normal mode**

Execution:

- Turn ON CH1 on R_{LOAD} by $SOCR1 = 1$
- Set $CAPCR0 = 1$
- Turn ON CH0 by $SOCR0 = 1$ enabling CCM on CH0
- **After 90 ms, set $CAPCR0 = 0$ AND $EXIT_CAPCR0 = 1$**
- CH1 is turned OFF after 300 ms by $SOCR1 = 0$

Results:

- 10 mF charge is interrupted during the CCM high-frequency phase after 90 ms leaving CCM and V_{OUT} reaching ~ 5.7 V
- ITLOFF and IPEAK_DETECT are flagged
- OUT1 remains stable ON sustaining ~ 760 mA

Figure 45. Waveforms acquired during Trial 18 E with CCM interruption and exit after 90 ms from start


The conditions and results acquired in **Trial 18 F** are listed below.

Setup 18 F:

- $V_B = 13.5$ V
- $T_{AMB} = \text{room}$
- Load0 = 10 mF
- Load1 = 23.5 Ω
- $I_{NOMx} = 2$ A
- $t_{NOMx} = 300$ s
- Cable from supply to VCC = 20 cm
- Cable from OUT_x to Load $_x$ = 20 cm
- WD refresh time = 50 ms
- **VNF9D3Q DUT in Fail-safe mode**

Execution:

- Turn ON CH1 on R_{LOAD} by DI1 = 1
- Turn ON CH0 in CCM by 5 pulses on DI0 with $t < t_{di_mon}$
- After 60 ms set DI0 = 1
- After an additional 50 ms set DI1 = 0

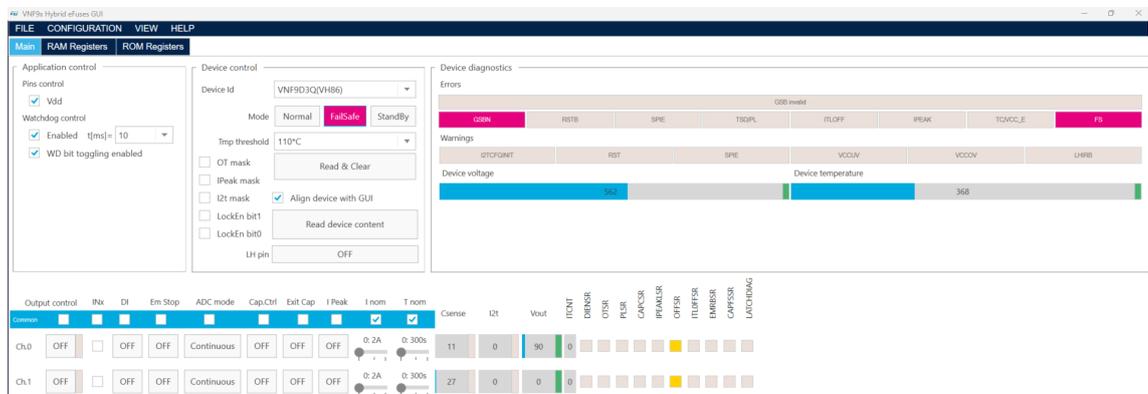
Results:

- 10 mF charge is aborted during the CCM low-frequency phase after 60 ms with V_{OUT} reaching ~1.8 V
- ITLOFF and IPEAK_DETECT are not flagged
- OUT1 remains stable ON sustaining ~760 mA

Figure 46. Waveforms acquired during Trial 18 F with CCM aborted after 60 ms from start in Fail-safe mode



Figure 47. GUI image acquired at the end of Trial 18 F highlighting no faults. The reading of ADCVSR0 at 90d indicates V_{OUT0} @ 2.2 V from ADC



The conditions and results acquired in **Trial 18 G** are listed below.

Setup 18 G:

- $V_B = 13.5\text{ V}$
- $T_{AMB} = \text{room}$
- Load0 = 10 mF
- Load1 = 23.5 Ω
- $I_{NOMx} = 2\text{ A}$
- $t_{NOMx} = 300\text{ s}$
- Cable from supply to VCC = 20 cm
- Cable from OUT_x to Load_x = 20 cm
- WD refresh time = 50 ms
- **VNF9D3Q DUT in Fail-safe mode**

Execution:

- Turn ON CH1 on R_{LOAD} by DI1 = 1
- Turn ON CH0 in CCM by 5 pulses on DI0 with $t < t_{di_mon}$
- After 80 ms set DI0 = 1
- After an additional 50 ms set DI1 = 0

Results:

- 10 mF charge is aborted after 80 ms with V_{OUT} reaching ~2.9 V
- ITLOFF and IPEAK_DETECT are not flagged
- OUT1 remains stable ON sustaining ~760 mA

Figure 48. Waveforms acquired during Trial 18 G with CCM aborted after 80 ms from start in Fail-safe mode



3.12 Examples of CCM trial with t_{CHARGE} close to $t_{\text{ccm_cycle}}$

The aim of this paragraph is to show examples of a charge close to $t_{\text{ccm_cycle}}$, varying V_{CC} , C_{LOAD} , t_{NOM} . The various examples were verified using a **VNF9D3Q** device in Normal mode and under various conditions, and are summarized in [Table 14](#) below.

Table 14. Various examples of CCM on VNF9D3Q in Normal mode with $I_{\text{NOMx}} = 2 \text{ A}$

Trial	V_{CC} (V)	C_{LOAD} (mF)	t_{NOM} (s)	t_{CHARGE} (ms)	Reference figure
19	18	10	300	195	40
20	18	10	1	206	49
21	15	13.3	1	Aborted due to MAX_COUNTER_LF	50
22	14.75	13.3	1	Aborted due to MAX_COUNTER_LF	51
23	14.5	13.3	1	195	53

The conditions and results acquired in **Trial 20** are listed below.

Setup 20:

- $V_{\text{B}} = 18 \text{ V}$
- $T_{\text{AMB}} = \text{room}$
- **Load0 = 10 mF**
- Load1 = 23.5 Ω
- $I_{\text{NOMx}} = 2 \text{ A}$
- **$t_{\text{NOMx}} = 1 \text{ s}$**
- Cable from supply to $V_{\text{CC}} = 20 \text{ cm}$
- Cable from OUT_x to $\text{Load}_x = 20 \text{ cm}$
- WD refresh time = 50 ms
- **VNF9D3Q DUT in Normal mode**

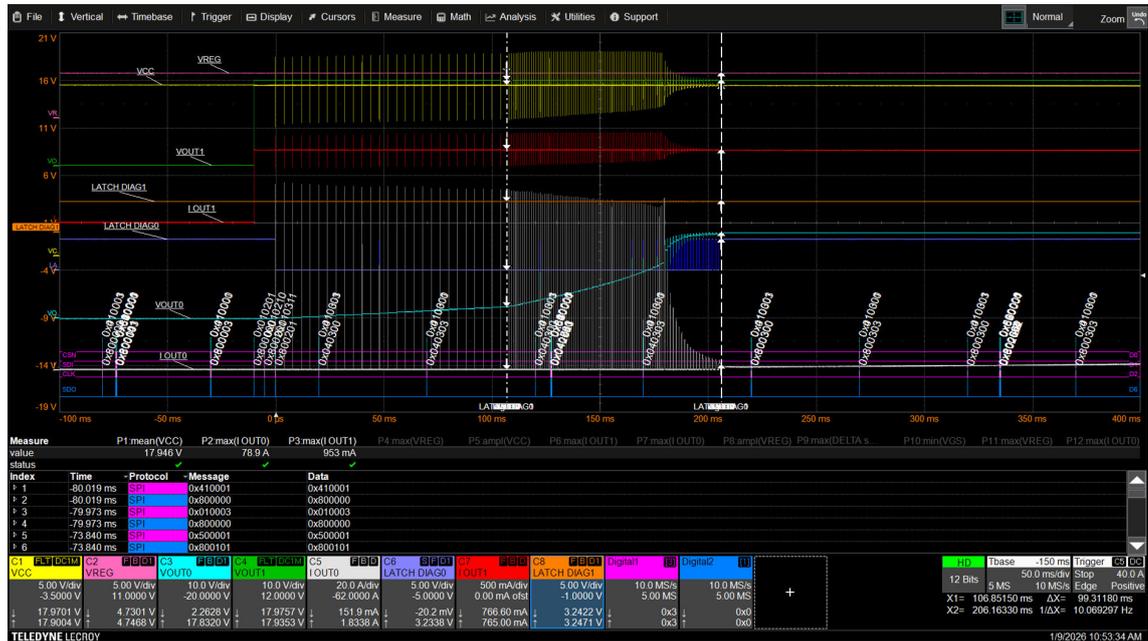
Execution:

- Turn ON CH1 on R_{LOAD} by $\text{SOCR1} = 1$
- Set $\text{CAPCR0} = 1$
- Turn ON CH0 by $\text{SOCR0} = 1$ enabling CCM on CH0

Results:

- 10 mF is charged after 206 ms (with 27 pulses in the low-frequency phase very close to the MAX_COUNTER_LF for 107 ms followed by ~100 pulses in the high-frequency phase)
- OUT1 remains stable ON sustaining 760 mA
- The longer t_{CHARGE} of 10 mF in Setup 20 vs 19 is due to the longer duration of the high-frequency phase in which the "on-time" is limited by I^2t protection

Figure 49. Waveforms acquired during Trial 20



The conditions and results acquired in **Trial 21** are reported below.

Setup 21:

- $V_B = 15\text{ V}$
- $T_{AMB} = \text{room}$
- **Load0 = 13.3 mF**
- Load1 = 23.5 Ω
- $I_{NOMx} = 2\text{ A}$
- $t_{NOMx} = 1\text{ s}$
- Cable from supply to VCC = 20 cm
- Cable from OUT_x to Load_x = 20 cm
- WD refresh time = 50 ms
- **VNF9D3Q DUT in Normal mode**

Execution:

- Turn ON CH1 on R_{LOAD} by SOCR1 = 1
- Set CAPCR0 = 1
- Turn ON CH0 by SOCR0 = 1 enabling CCM on CH0

Results:

- 13.3 mF are not charged after ~120 ms (with 30 pulses in the low-frequency phase, the MAX_COUNTER_LF is achieved with V_{OUT} ~2.18 V below V_{OUT_THR}, so CCM is aborted)
- OUT1 remains stably ON sustaining ~640 mA

Figure 50. Waveforms acquired during Trial 21



The conditions and results acquired in **Trial 22** are listed below.

Setup 22:

- $V_B = 14.75\text{ V}$
- $T_{AMB} = \text{room}$
- **Load0 = 13.3 mF**
- Load1 = 23.5 Ω
- $I_{NOMx} = 2\text{ A}$
- $t_{NOMx} = 1\text{ s}$
- Cable from supply to VCC = 20 cm
- Cable from OUT_x to Load_x = 20 cm
- WD refresh time = 50 ms
- **VNF9D3Q DUT in Normal mode**

Execution:

- Turn ON CH1 on R_{LOAD} by SOCR1 = 1
- Set CAPCR0 = 1
- Turn ON CH0 by SOCR0 = 1 enabling CCM on CH0

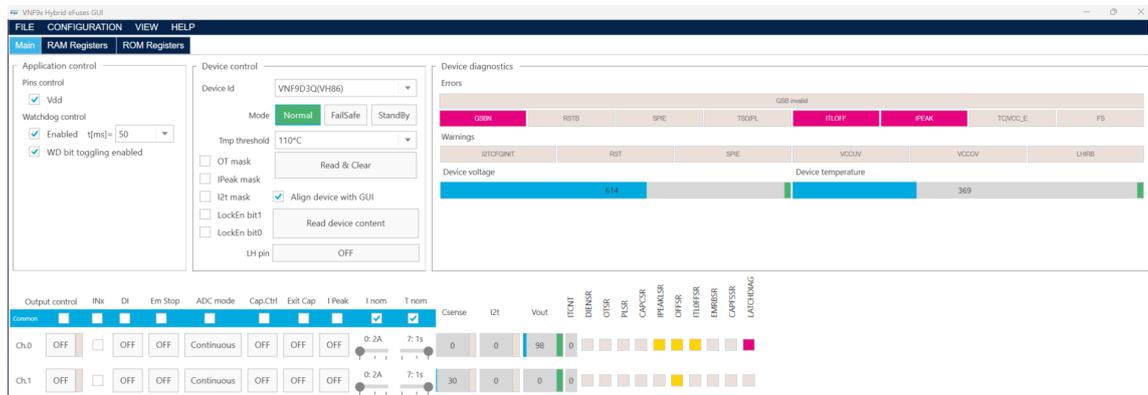
Results:

- 13.3 mF are not charged after 120 ms (with 30 pulses in the low-frequency phase, the MAX_COUNTER_LF is achieved with V_{OUT} < V_{OUT_THR} at ~2.22 V, so CCM is aborted)
- OUT1 remains stably ON sustaining ~630 mA

Figure 51. Waveforms acquired during Trial 22



Figure 52. GUI image acquired at the end of Trial 18 F highlighting no faults. The reading of ADCVSR0 at 98d indicates V_{OUT0} @ 2.4 V from ADC



The conditions and results acquired in **Trial 23** are listed below.

Setup 23:

- **V_B = 14.5 V**
- **T_{AMB} = room**
- **Load0 = 13.3 mF**
- **Load1 = 23.5 Ω**
- **I_{NOMx} = 2 A**
- **t_{NOMx} = 1 s**
- Cable from supply to VCC = 20 cm
- Cable from OUT_x to Load_x = 20 cm
- WD refresh time = 50 ms
- **VNF9D3Q DUT in Normal mode**

Execution:

- Turn ON CH1 on R_{LOAD} by $SOCR1 = 1$
- Set $CAPCR0 = 1$
- Turn ON CH0 by $SOCR0 = 1$ enabling CCM on CH0

Results:

- 13.3 mF is charged after ~195 ms (with 30 pulses in the low-frequency phase equal to the $MAX_COUNTER_LF$ for 120 ms reaching $V_{OUT} > V_{OUT_THR}$ at ~2.7 V, followed by ~67 pulses in the high-frequency phase)
- OUT1 remains stably ON sustaining ~620 mA
- This example shows the max. V_{CC} allowed to successfully charge 13.3 mF with the mentioned setup.

Figure 53. Waveforms acquired during Trial 23


In general, using a bench test in static fixed conditions, if a VNF9DxxQ device at a defined V_{CC} is able to successfully complete the CCM low-frequency phase within 30 pulses ($MAX_COUNTER_LF$) corresponding to 120 ms, then it will be able to successfully complete the capacitance charge in the 130 ms remaining for the CCM high-frequency phase without exceeding the t_{ccm_cycle} (typ. 250 ms).

Revision history

Table 15. Document revision history

Date	Revision	Changes
16-Mar-2026	1	First release.

Contents

1	Capacitive Charging Mode (CCM) for Hybrid STi²Fuse	2
2	Activation Details	3
3	Capacitive charging examples	7
3.1	Example of 14.7 mF C _{LOAD} charged in Normal mode	9
3.2	Example of 14.7 mF C _{LOAD} charged in Fail-safe mode	11
3.3	Example of 10 mF C _{LOAD} charged in Normal mode using different V _{CC} values	16
3.4	Examples of C _{LOAD} charged in Normal mode using different values of capacitance	21
3.5	Examples of CCM depending on cables used to connect VCC and or C _{LOAD}	24
3.6	Examples of CCM varying I _{NOM} and t _{NOM}	28
3.7	Examples of CCM launched on a short circuit to GND	33
3.8	Examples of CCM launched on both CH _x	35
3.9	Examples of CCM launched at hot temperatures	36
3.10	Examples of CCM launched on different e-fuse products with different R _{DS(ON)} and I _{PEAK}	38
3.11	Examples of CCM interruptions	43
3.12	Examples of CCM trial with t _{CHARGE} close to t _{ccm_cycle}	50
	Revision history	55
	List of figures	57
	List of tables	59

List of figures

Figure 1.	Channel state diagram.	2
Figure 2.	CAPCR _x bit at 1 triggers CCM of channel _x while EXIT_CAPCR _x bit at 1 exits CCM of channel _x in Normal mode .	3
Figure 3.	Example of DI _x toggling to activate CCM in Fail-safe mode.	3
Figure 4.	CCM switching evolution	4
Figure 5.	CCM flow chart.	5
Figure 6.	Waveforms acquired during Trial 1	9
Figure 7.	Zoomed image of previous capture focusing on last portion of low frequency and highlighting different periods between LF and HF portions	10
Figure 8.	Zoom on 1 st CCM pulse showing that I _{PEAK} is achieved.	10
Figure 9.	Waveforms acquired during Trial 2	11
Figure 10.	Zoomed image of previous capture focusing on last portion of low frequency and highlighting different periods between LF and HF portions	12
Figure 11.	Zoomed image on pulses on DI1 pin to activate CCM in Fail-safe mode. The CCM started after few us of 5 th pulse if the $t < t_{di_mon}$ (87 μ s in this example)	12
Figure 12.	Waveforms acquired during Trial 2 B.	13
Figure 13.	Zoomed image on pulses on DI1 pin on Trial 2 B. The CCM is not started after a few μ s since 5 th pulse if the $t > t_{di_mon}$ (421 μ s in this example).	13
Figure 14.	Zoomed image on pulses on DI1 pin. The CCM is not started after a few μ s since 5 th pulse if the $t > t_{di_mon}$ (313 μ s in this example).	14
Figure 15.	GUI image collected after Trial 2 B and 2 C highlighting that the CH1 is latched OFF.	14
Figure 16.	Zoomed image on pulses on DI1 pin. The CCM is not started after a few μ s since 5 th pulse if the $t > t_{di_mon}$ (292 μ s in this example).	15
Figure 17.	Waveforms acquired during Trial 3	17
Figure 18.	Waveforms acquired during Trial 4	18
Figure 19.	Waveforms acquired during Trial 4 without activating CCM.	18
Figure 20.	GUI image acquired after Trial 4 without activating CCM	19
Figure 21.	Waveforms acquired during trial 5.	20
Figure 22.	Waveforms acquired during Trial 6	22
Figure 23.	Waveforms acquired during Trial 7	23
Figure 24.	Waveforms acquired during Trial 8	25
Figure 25.	Waveforms acquired during Trial 9	26
Figure 26.	Waveforms acquired during Trial 10	27
Figure 27.	Waveforms acquired during Trial 11.	29
Figure 28.	Zoomed view of CCM portion in high frequency acquired during Trial 11	29
Figure 29.	Waveforms acquired during Trial 12	30
Figure 30.	Zoomed view of CCM portion in high frequency acquired during Trial 12	31
Figure 31.	Waveforms acquired during Trial 13	32
Figure 32.	Zoomed view of CCM portion in high frequency acquired during Trial 13	32
Figure 33.	Waveforms acquired during Trial 14	33
Figure 34.	GUI image acquired after Trial 14 in which CCM is aborted due to MAX_COUNTER_LF achievement.	34
Figure 35.	Waveforms acquired during Trial 15	35
Figure 36.	Waveforms acquired during Trial 16	37
Figure 37.	Waveforms acquired during Trial 17	39
Figure 38.	GUI image acquired at the end of Trial 17 in which CCM is aborted due to MAX_COUNTER_LF achievement	39
Figure 39.	Waveforms acquired during Trial 18	40
Figure 40.	Waveforms acquired during Trial 19	42
Figure 41.	Waveforms acquired during Trial 18 C with CCM interruption after 100 ms from start.	44
Figure 42.	GUI image acquired at the end of Trial 18 B highlighting I _{TLOFF} and I _{PEAK} flags	44
Figure 43.	Waveforms acquired during Trial 18 C with CCM interruption after 100 ms from start.	45
Figure 44.	Waveforms acquired during Trial 18 D with CCM interruption and exit after 40 ms from start.	46
Figure 45.	Waveforms acquired during Trial 18 E with CCM interruption and exit after 90 ms from start.	47
Figure 46.	Waveforms acquired during Trial 18 F with CCM aborted after 60 ms from start in Fail-safe mode.	48

Figure 47.	GUI image acquired at the end of Trial 18 F highlighting no faults. The reading of ADCVSR0 at 90d indicates V_{OUT0} @ 2.2 V from ADC	48
Figure 48.	Waveforms acquired during Trial 18 G with CCM aborted after 80 ms from start in Fail-safe mode.	49
Figure 49.	Waveforms acquired during Trial 20	51
Figure 50.	Waveforms acquired during Trial 21	52
Figure 51.	Waveforms acquired during Trial 22	53
Figure 52.	GUI image acquired at the end of Trial 18 F highlighting no faults. The reading of ADCVSR0 at 98d indicates V_{OUT0} @ 2.4 V from ADC	53
Figure 53.	Waveforms acquired during Trial 23	54

List of tables

Table 1.	CCM parameters	5
Table 2.	Overall results obtained in CCM trials performed for the VNF9D1M5Q	7
Table 3.	Overall results obtained in CCM trials performed for the VNF9D3Q	8
Table 4.	CCM starts based on t_{di_mon}	13
Table 5.	t_{CHARGE} vs applied V_{CC}	16
Table 6.	t_{CHARGE} vs applied C_{LOAD}	21
Table 7.	t_{CHARGE} vs cables used on VCC and/or OUT_x	24
Table 8.	t_{CHARGE} vs applied I_{NOM} and t_{NOM}	28
Table 9.	t_{CHARGE} vs cables used on VCC and/or OUT_x	36
Table 10.	t_{CHARGE} vs e-fuse product using 14.7 mF	38
Table 11.	t_{CHARGE} vs e-fuse product using 10 mF and $V_{CC} = 13.5$ V	39
Table 12.	t_{CHARGE} vs e-fuse product using 10 mF and $V_{CC} = 13.5$ V	41
Table 13.	t_{CHARGE} vs e-fuse product using 14.7 mF	43
Table 14.	Various examples of CCM on VNF9D3Q in Normal mode with $I_{NOMx} = 2$ A	50
Table 15.	Document revision history	55

IMPORTANT NOTICE – READ CAREFULLY

STMicroelectronics NV and its subsidiaries (“ST”) reserve the right to make changes, corrections, enhancements, modifications, and improvements to ST products and/or to this document at any time without notice.

In the event of any conflict between the provisions of this document and the provisions of any contractual arrangement in force between the purchasers and ST, the provisions of such contractual arrangement shall prevail.

The purchasers should obtain the latest relevant information on ST products before placing orders. ST products are sold pursuant to ST’s terms and conditions of sale in place at the time of order acknowledgment.

The purchasers are solely responsible for the choice, selection, and use of ST products and ST assumes no liability for application assistance or the design of the purchasers’ products.

No license, express or implied, to any intellectual property right is granted by ST herein.

Resale of ST products with provisions different from the information set forth herein shall void any warranty granted by ST for such product.

If the purchasers identify an ST product that meets their functional and performance requirements but that is not designated for the purchasers’ market segment, the purchasers shall contact ST for more information.

ST and the ST logo are trademarks of ST. For additional information about ST trademarks, refer to www.st.com/trademarks. All other product or service names are the property of their respective owners.

Information in this document supersedes and replaces information previously supplied in any prior versions of this document.

© 2026 STMicroelectronics – All rights reserved