ST8500 Current control, surge protection and thermal control strategies

Introduction

The goal of this document is to provide a description of Current Control, Surge Protection and Thermal Protection management in ST8500 device.

Current Control, Surge Protection and Thermal Protection have the purpose to protect the Line Driver against anomalous events.

- **Current Control** manages the current flowing into Line Driver, basing on available Power budget.
- **Surge Protection** is active for spurious current spikes due to transient events on Power Line.
- **Thermal Protection** is necessary to avoid an excessive temperature increase and consequent drop on transmission performance.

If not properly managed, all 3 above events could bring to permanent damages in the Line Driver circuitry.

1 Document conventions

1.1 List of abbreviations

Table 1. List of abbreviations

Abbreviation	Description
CC	Current Control
CSF	Current sense feedback
CDN	Coupling/Decoupling network
EUT	Equipment Under Test
LD	Line driver
LSB	Least Significant Byte
MSB	Most Significant Byte
OFDM	Orthogonal Frequency Division Multiplexing
PHY	Physical Layer of the PLC stack
PLC	Power Line Communication
SP	Surge Protection
TP	Thermal Protection

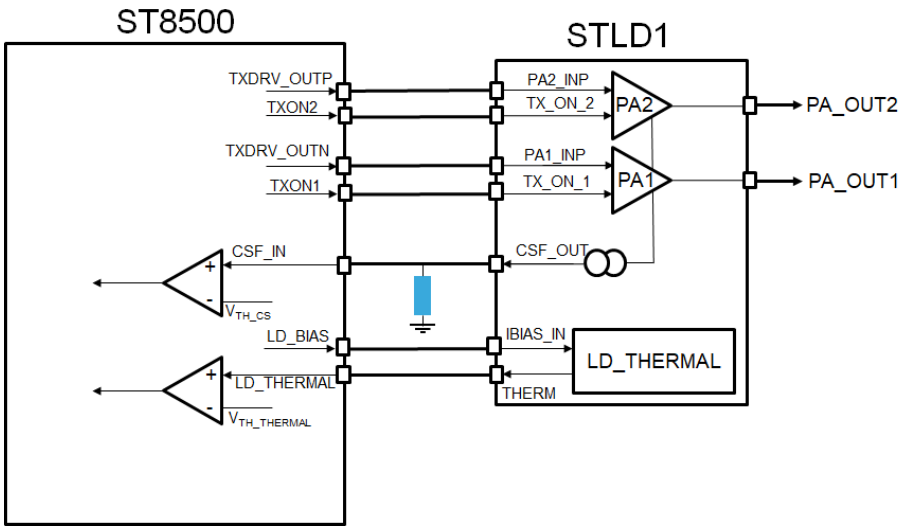
2 Block diagram

A simplified block diagram of connections between ST8500 and STLD1 is shown in Figure 1.

The PA output current feedback is provided by the STLD1 on CSF_OUT pin, which is converted into voltage by a resistor and sampled by an ST8500 internal comparator connected to CSF_IN pin.

The thermal feedback is provided by the STLD1 on LD_THERMAL line, based on the reference current provided on LD_BIAS by the ST8500.

Figure 1. ST8500 block diagram



3 Current control and surge protection specifications

3.1 Current control

Current Control acts in the following way: based on CS_SEL input value, the LD output current is kept below the related threshold value.

3.1.1 Current control on G3-PLC

Table 2 shows different thresholds for current control trigger on G3-PLC protocol (PE: *ST8500_G3_v1390B5EC_4.4.9*, RTE: *STARCOM_G3_RT_FW_r1_6rc2_BA_key0*).

Please note that these are **I(PAOUT) RMS** target values.

Table 2. CFS_IN thresholds vs current limit on G3-PLC

CS_SEL value	CSF_IN Current control comparator threshold typ [V]	G3-PLC		
		Cenelec-a	Cenelec-b	Fcc
		I (PAOUT) Rms Value [A]	I (PAOUT) Rms Value [A]	I (PAOUT) Rms Value [A]
0x0	0.240	0.224	0.432	0.192
0x1	0.269	0.250	0.484	0.241
0x2	0.299	0.280	0.543	0.269
0x3	0.329	0.383	0.600	0.302
0x4	0.359	0.476	0.600	0.302
0x5	0.386	0.666	0.666	0.338
0x6	0.429	0.829	0.747	0.381
0x7	0.472	0.917	0.827	0.421
0x8	0.514	1.006	1.032	0.472
0x9	0.556			0.472
0xA	0.786			0.665
0xB	0.856			0.741
0xC	0.926			0.829
0xD	0.996			0.932
0xE	1.066			0.932
0xF	1.135			1.038

If CS_SEL value is set higher than 0xF, the current control strategy is disabled.

Note that CSF current ratio has a non-negligible spread; therefore, current values can vary by +/- 2dB with respect to the nominal value.

3.1.2 Current control on PRIME 1.4

Table 3 shows different thresholds for current control trigger on PRIME 1.4 protocol (PE: *ST8500_PRIME_1_4_CPU_v908,* RTE: *ST8500_PRIME_1_4_RT_v6250*). Please note that these are **I(PAOUT) RMS** target values.

Table 3. **CSF_IN thresholds vs current limit on G3-PLC**

CS_SEL value	CSF_IN Current control comparator threshold typ [V]	PRIME 1.4, BPSK-ROB modulation, scheme B							
		I (PAOUT) RMS value [A]							
		CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8
0x0	0.240	0.155	0.338	0.358	0.415	0.683	0.376	0.572	0.308
0x1	0.269	0.173	0.380	0.402	0.485	0.767	0.420	0.638	0.343
0x2	0.299	0.193	0.423	0.445	0.526	0.863	0.473	0.715	0.384
0x3	0.329	0.215	0.477	0.501	0.595	0.970	0.526	0.800	0.433
0x4	0.359	0.241	0.526	0.556	0.639	1.068	0.592	0.892	0.489
0x5	0.386	0.266	0.588	0.621	0.691		0.659	0.997	0.548
0x6	0.429	0.297	0.659	0.698	0.859		0.736	1.106	0.614
0x7	0.472	0.373	0.719	0.779	0.987		0.826		0.684
0x8	0.514	0.415	0.749	0.873	1.085		0.920		0.766
0x9	0.556	0.466	0.895	0.983			1.027		0.855
0xA	0.786	0.815	0.977	1.095					1.060
0xB	0.856	0.888							
0xC	0.926	1.064							
0xD	0.996								
0xE	1.066								
0xF	1.135								

If CS_SEL value is set higher than 0xF, the current control strategy is disabled.

Note that CSF current ratio has a non-negligible spread; therefore, current values can vary by +/- 2dB with respect to the nominal value.

3.2 Surge protection

The ST8500 integrates a second comparator on CSF_IN for Surge Protection. Since a surge event creates spurious current peaks with shorter duration and higher amplitude, an independent detection is needed.

Surge protection is activated if LD output current rises above the CC_SURGE (CSF_IN surge comparator threshold) value.

Table 4 shows different thresholds for surge protection trigger. Note that the spread of the CSF current ratio parameter impacts also the Surge protection algorithm.

Table 4. **CC_Surge comparator thresholds**

CS_SURGE_SEL value	CC_SURGE comparator threshold (typ) [V]	$I(PA_{OUT})$ Inst. value [A]
0x0	0.485	1.627
0x1	0.527	1.768
0x2	0.569	1.909
0x3	0.799	2.680
0x4	0.869	2.915

CS_SURGE_SEL value	CC_SURGE comparator threshold (typ) [V]	$I(PA_{OUT})$ Inst. value [A]
0x5	0.939	3.150
0x6	1.009	3.385
0x7	1.079	3.619
0x8	1.149	3.854
0x9	1.222	4.099
0xA	1.290	4.327
0xB	1.362	4.569
0xC	1.430	4.797
0xD	1.502	5.038
0xE	1.570	5.266
0xF	1.650	5.535

3.3 Current control and surge protection attributes

For the ST8500 device, management of Current control and surge protection is done by setting the attributes:
phyCurrentSenseMaxThreshold & *phyCurrentSenseSpikesFilter* on G3-PLC.
phyCurrentControlMaxThreshold & *phyCurrentControlSpikesFilter* on PRIME 1.4.

3.3.1 G3-PLC attributes

phyCurrentSenseMaxThreshold attribute represents the maximum value of voltage/current sustained before current control activation. Its size is 16 bits and has the following characteristic:

- Bits 0-7: set CS_SEL for current control
- Bits 8-15: CS_SEL_SURGE for surge protection

phyCurrentSenseSpikesFilter attribute represents the minimum time interval over the current threshold value, expressed in number of 38.4 MHz AFE clock cycles, necessary to trigger the comparator output. The size of this attribute is 32 bits, arranged as follows:

- Bits 0-15: spike filter for current control
- Bits 16-31: spike filter for surge protection

Default values are shown in Table 5 .

Table 5. Default attributes related to current control and surge protection on G3-PLC

Attribute	G3-PLC		
	CEN-A	CEN-B	FCC
phyCurrentSenseMaxThreshold	0x0F08	0x0F08	0x0F0F
phyCurrentSenseSpikesFilter	0x000100CF	0x00010079	0x000F001F

These values have been characterized and validated by ST; however, the two attributes are exported for possible adjustment based on field experience. ST strongly recommends, in case of need, to act only on *phyCurrentSenseMaxThreshold* attribute.

An indication of CC activation is into *G3PHY-DATA.Confirm*:

- CSThresholdEvents: The number of events that triggers the current control algorithm during the frame transmission. If this value is equal to zero, no CC intervention occurred.
- TxPowerBegin: The transmission power at the begin of the frame transmission.

- TxPowerEnd: The transmission power at the end of the frame transmission.

3.3.2 Prime 1.4 attributes

phyCurrentControlMaxThreshold attribute represents the maximum value of voltage/current sustained before current control activation. Its size is 32 bits and has the following characteristic:

- Bits 0-7: set CS_SEL for current control on preamble section.
- Bits 8-15: set CS_SEL_SURGE for surge protection on preamble section.
- Bits 16-23: set CS_SEL for current control on payload section.
- Bits 24-31: set CS_SEL_SURGE for surge protection on payload section.

phyCurrentControlSpikesFilter attribute represents the minimum time interval over the current threshold value, expressed in number of 38.4 MHz AFE clock cycles, necessary to trigger the comparator output. The size of this attribute is 32 bits, arranged as follows:

- Bits 0-15: spike filter for current control.
- Bits 16-31: spike filter for surge protection.

Default values are shown in Table 6 .

Table 6. Default attributes related to current control and surge protection on PRIME 1.4

Channel #	phyCurrentControlMaxThreshold	phyCurrentControlSpikesFilter
1	0x0F0C0F0A	0x00000060
2	0x0F0A0F09	0x00000055
3	0x0F0A0F08	0x00000040
4	0x0F080F05	0x00000035
5	0x0F040F03	0x00000030
6	0x0F090F08	0x00000022
7	0x0F060F05	0x00000021
8	0x0F0A0F09	0x00000018

These values have been characterized and validated by ST; however, the two attributes are exported for possible adjustment based on field experience. ST strongly recommends, in case of need, to act only on bits 16-23 of *phyCurrentControlMaxThreshold* attribute (as an example, for channel #1, default 0x0F**0C**0F0A, byte highlighted in **bold**).

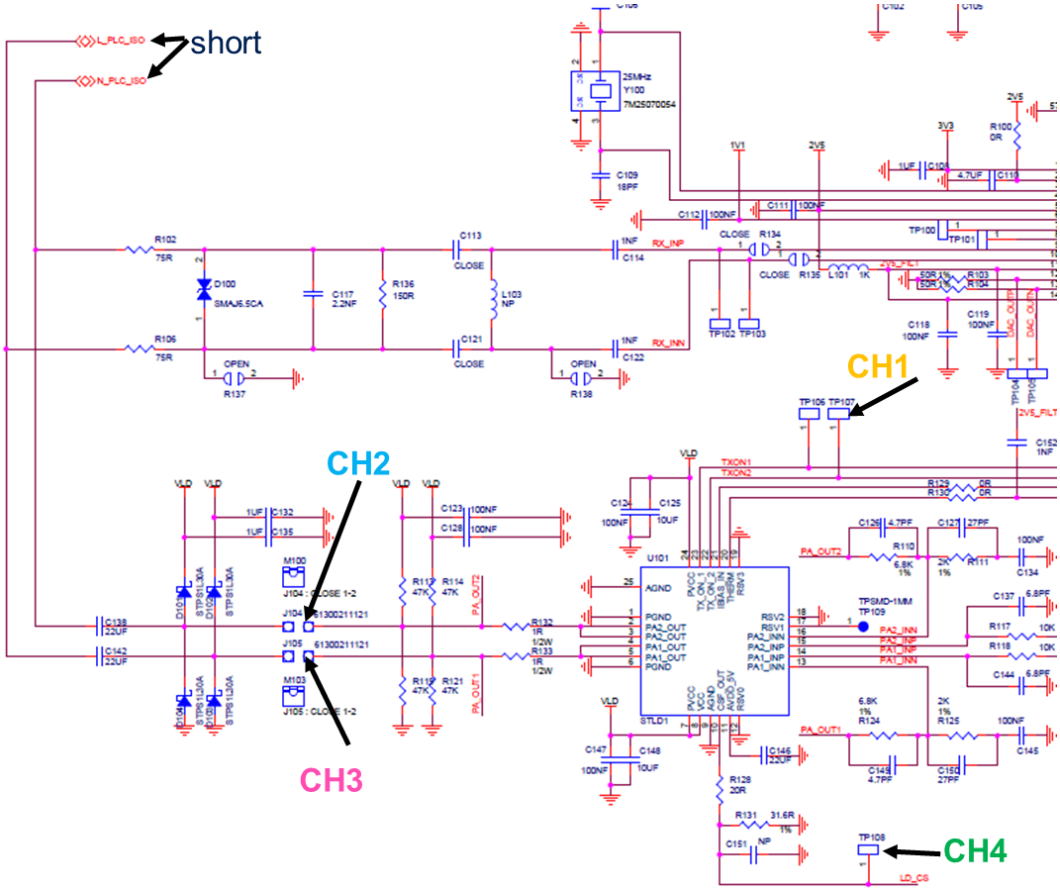
Another relevant attribute is *phyCurrentControlStatus*, with 16 bit size, arranged as follows:

- Bits 0-7: number of Current Sense Threshold events fired during last transmissions. It corresponds to the number of dB decrease during last transmission and is an indication of current control activation (if this value is equal to 0x00, no CC intervention).
- Bits 15-8: transmission power configured at the beginning of transmission (maximum: level 0, minimum: level 7).

4 Current control and surge protection characterization

The following sections will show 3 cases: no intervention, current control activation and surge protection trigger.
Characterization has been performed on G3-PLC with FW version 4.4.9.
Measurement setup is shown in Figure 2 .

Figure 2. Current control and surge protection characterization setup



4.1 No intervention

Test #1 was done with the following conditions:

- PVCC = 15 V
- Short circuit between L-N
- G3-PLC ROBO Differential modulation
- CEN-A band
- Packet size: 128 bytes
- TX Power: 0x1C
- *phyCurrentSenseMaxThreshold* (default): 0x0F08
  - CS_SURGE SEL = 0x0F → Target values:
    - CSF_IN_SURGE comparator threshold = 1.650 V
    - I(PA_OUT) Inst. value = 5.535 A
  - CS_SEL = 0x08 → Target values:
  - I(PA_OUT) RMS value = 1.006 A
- *phyCurrentSenseSpikesFilter* (default): 0x000100CF

Figure 3. Test #1 – results

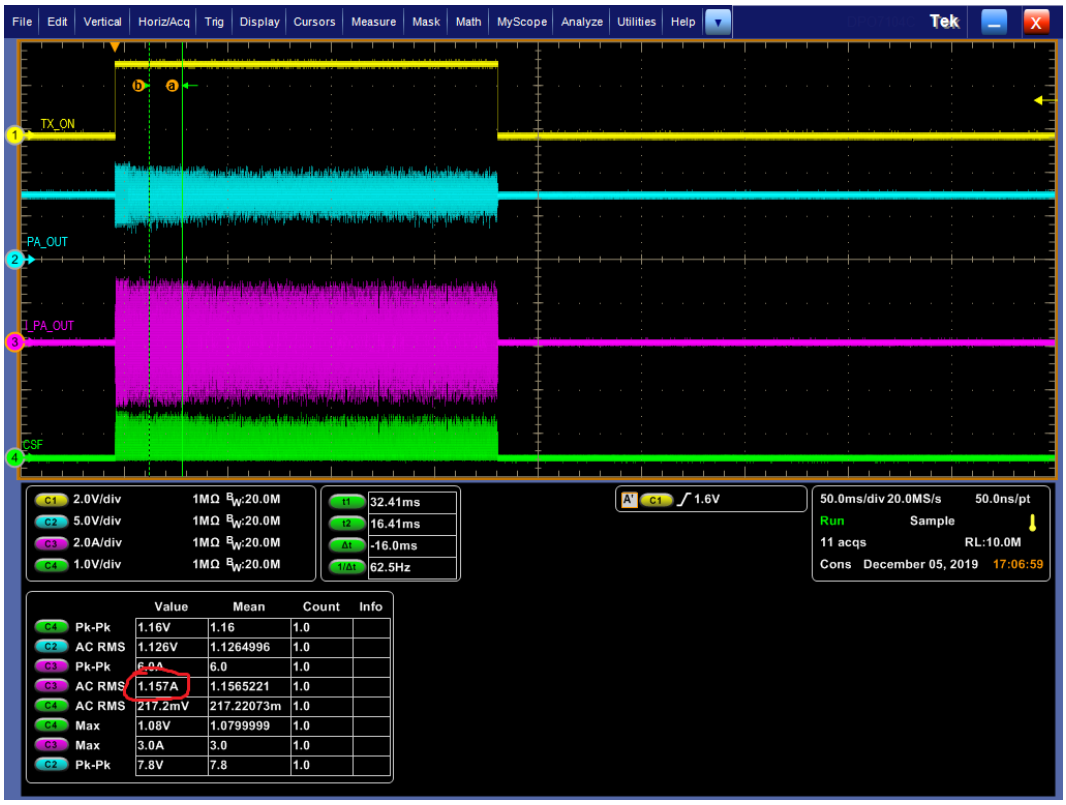
In this case, current control wasn't triggered & no surge events occurred.

4.2 Current control activation

Test #2 was done with the following conditions:

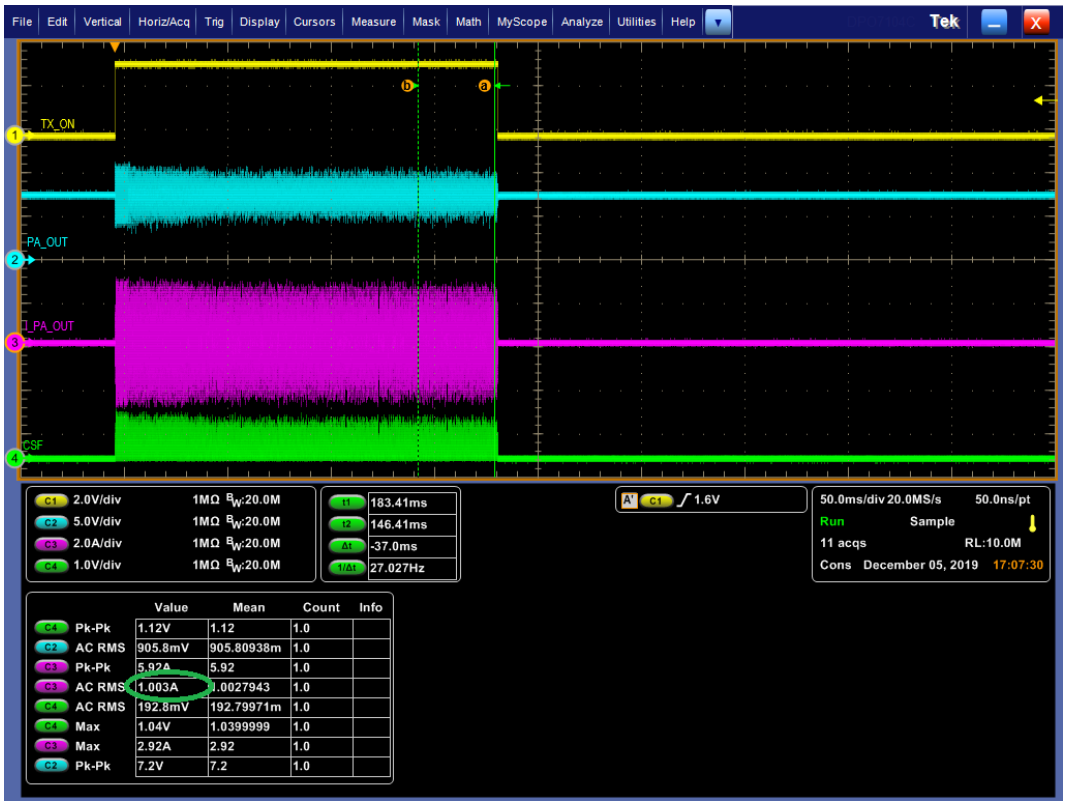
- PVCC = 15 V
- Short circuit between L-N
- G3-PLC ROBO Differential modulation
- CEN-A band
- Packet size: 128 bytes
- TX Power: 0x20
- *phyCurrentSenseMaxThreshold* (default): 0x0F08
  - CS_SURGE SEL = 0x0F → Target values:
    - CSF_IN_SURGE comparator threshold = 1.650 V
    - I(PA_OUT) Inst. value = 5.535 A
  - CS_SEL = 0x08 → Target values:
    - I(PA_OUT) RMS value = 1.006 A
- *phyCurrentSenseSpikesFilter* (default): 0x000100CF

Figure 4. Test #2 – before CC intervention



I(PA_OUT) RMS value = 1.157 A > 1.006 A → Current Control was correctly triggered.

Figure 5. **Test #2 – after CC intervention**



I(PA_OUT) RMS value = 1.003 A < 1.006A → the Current Control algorithm has effectively reduced the current below the threshold value.

4.3 Surge protection activation

Test #3 was done with the following conditions:

- PVCC = 15 V
- Short circuit between L-N
- G3-PLC ROBO Differential modulation
- CEN-A band
- Packet size: 128 bytes
- TX Power: 0x1C
- *phyCurrentSenseMaxThreshold* (default): 0x0608
  - CS_SURGE SEL = 0x06 → Target values:
    - CSF_IN_SURGE comparator threshold = 1.009 V
    - I(PA_OUT) Inst. value = 3.385 A
  - CS_SEL = 0x08 → Target values:
  - I(PA_OUT) RMS value = 1.006 A
- *phyCurrentSenseSpikesFilter* (default): 0x000100CF

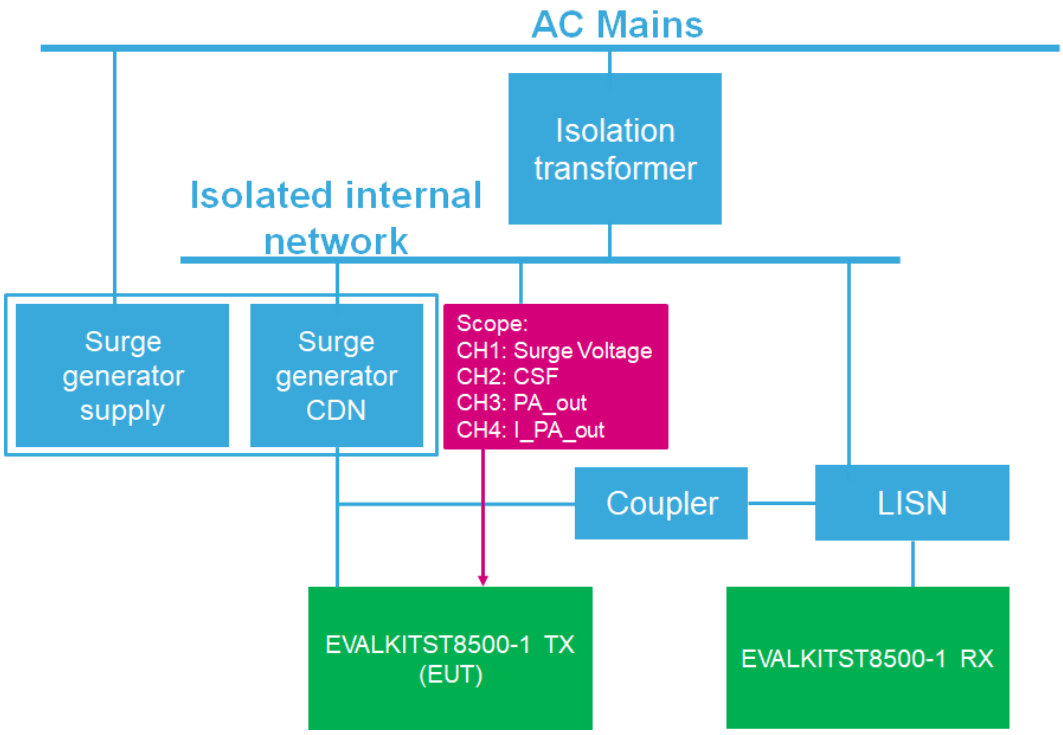
Figure 6. Test #3 – results

A surge event was detected (CSF_IN voltage value = 1.04 V > 1.009 V) and the transmission was immediately interrupted.

5 Surge protection behavior vs IEC 61000-4-5 surge immunity test

Surge immunity test was performed with the setup shown in Figure 7 .

Figure 7. Surge immunity test setup



The purpose of this test is to verify the impact on protection intervention during a PLC transmission when real surge spike occurs on EUT. The applied stress is according to IEC 61000-4-5, level 4 (4 kV).

The trial was done under two different conditions:

1. Surge with EUT not transmitting
2. Surge with EUT in transmission mode

The waveforms from one surge test event in condition 1 (coupling = L vs N, polarity = positive, phase shift = zero) are shown in Figure 8.

Figure 8. Condition 1 waveforms

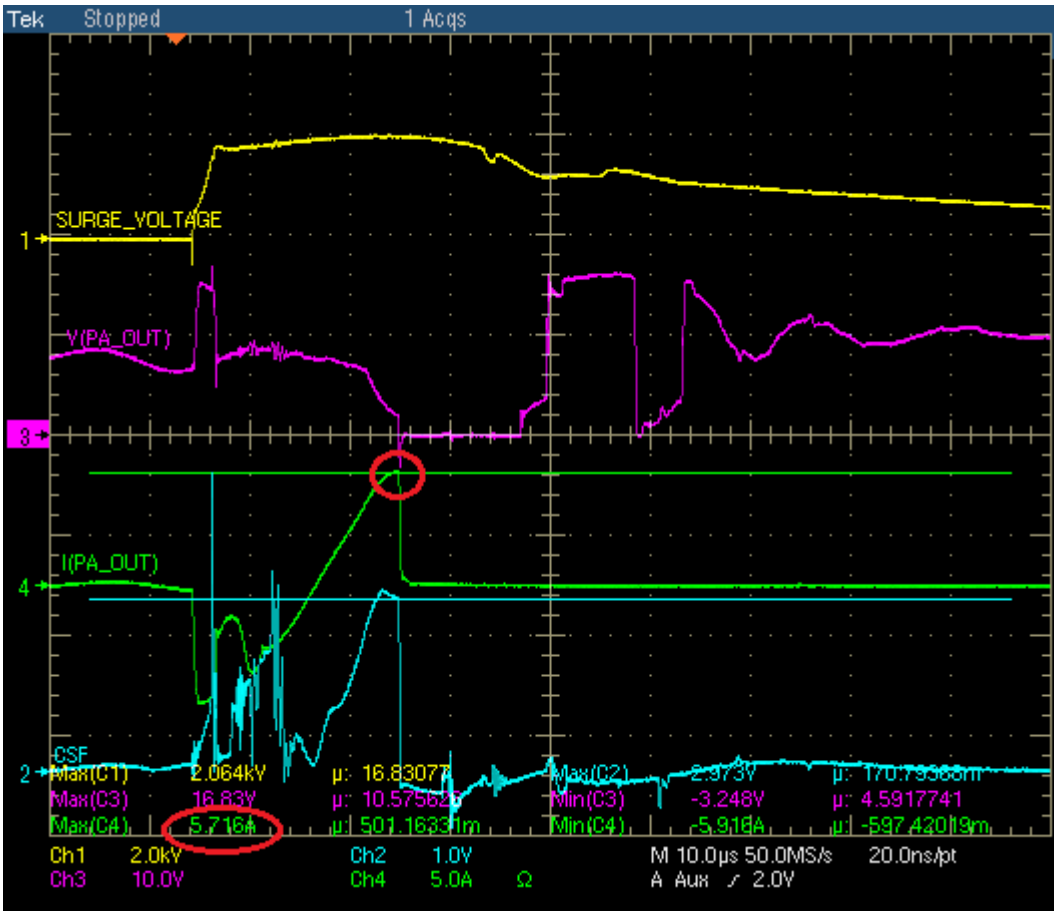
Surge voltage maximum amplitude is 2 kV, due to load impedance at EUT side and to the activation of clamp circuitry of EUT.

CSF first spike is evidently due to inductive effects, since the EUT is not in transmission, so it is not to be considered a real signal on CSF.

As expected, I(PA_OUT) is null, since the EUT wasn't transmitting.

The waveforms from one surge test event in condition 2 (coupling = L vs N, polarity = positive, phase shift = zero) are depicted in Figure 9.

Figure 9. Condition 2 waveforms – SP intervention



On Figure 9 , the effect of surge protection is visible: the transmission is turned off immediately when CSF surge threshold voltage is reached (1.650V as default value). Therefore, I(PA_out) becomes null.

Even in condition 2, the first CSF spike can be attributed to inductive effects. The actual CSF signal corresponds to the real I(PA_OUT) current waveform reaching 5.7 A peak (excessive current with respect to the normal operational conditions) while the CSF voltage correspondingly exceeds the surge protection threshold, activating the protection.

Surge protection is triggered when spurious current spike occurs during one transmitted frame. The Line Driver is enabled again at the next transmission request.

6 Thermal protection characterization

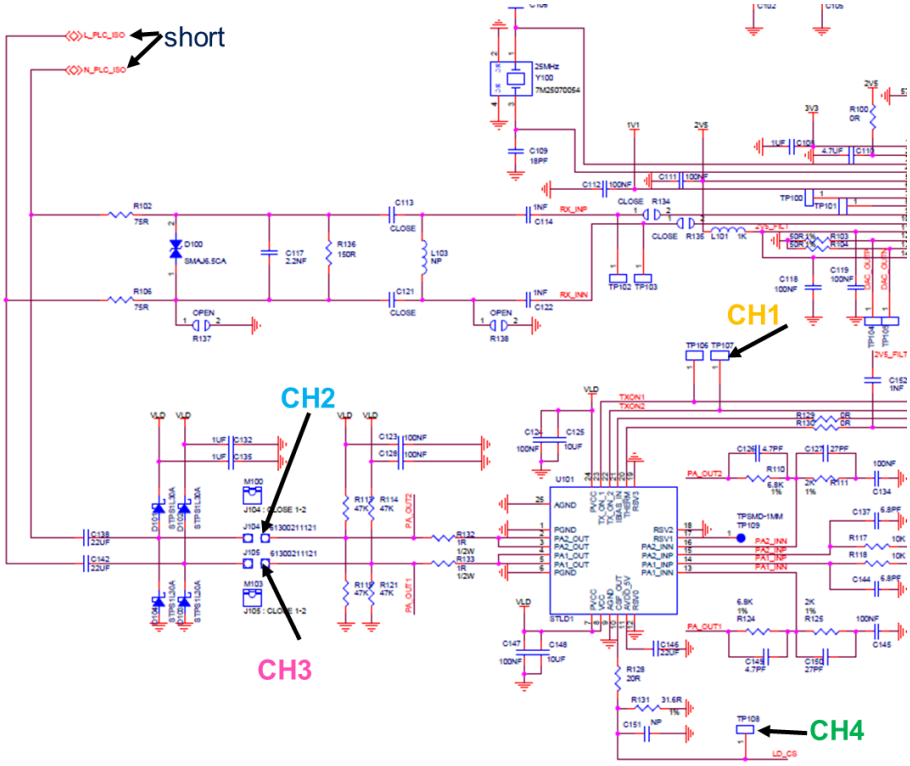
In the ST implementation of G3-PLC, information of STLD1 thermal status is provided by the attribute *phyThermalStatus*. Its size is 8 bits. It stores the thermal status coming from STLD1 thermometer.

The bits 0-3 correspond to LD_THERMOMETER and their mapping is the following:

- 0: T < 70°C;
- 1: 70°C ≤ T < 100°C;
- 2: 100°C ≤ T < 125°C;
- 3: 125°C ≤ T < 170°C;
- 4: T ≥ 170°C

Here below the measurement setup used for Thermal Protection activation.

Figure 10. Thermal protection trigger setup



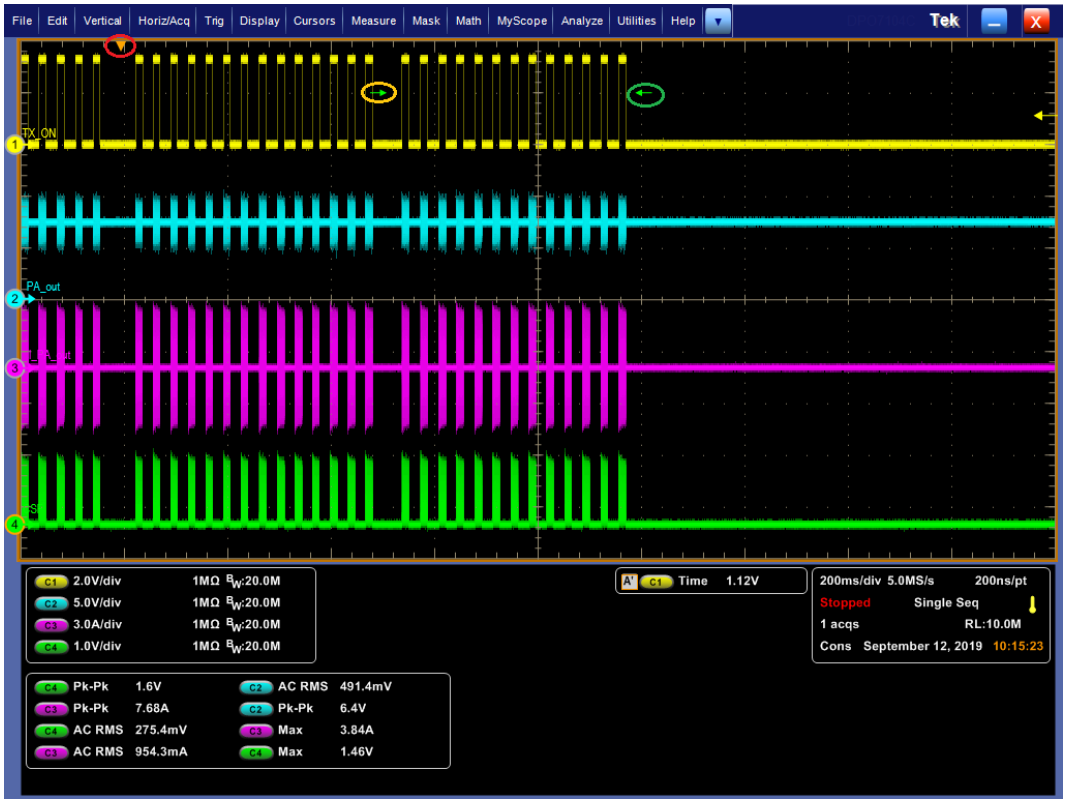
Test #4 has been performed with

- PVCC = 15 V
- Short circuit between L-N
- G3-PLC ROBO Differential modulation
- FCC band
- TX Power: 0x20

- Capture of first 3 thermal events

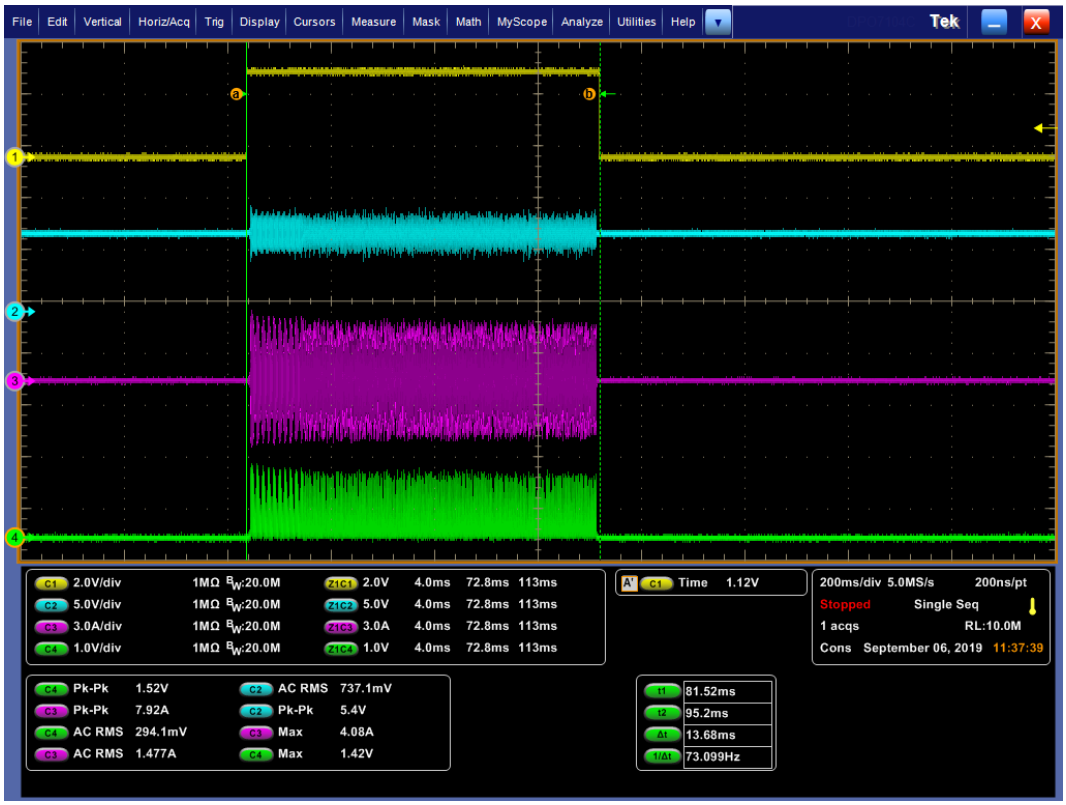
```
Test
Test TX Target  COM15
2019-09-12 09:32:29.144123 WARNING: Thermal warning rised 201
2019-09-12 09:32:29.671807 WARNING: Thermal warning rised 216
2019-09-12 09:32:30.160525 WARNING: Thermal warning rised 230
test done
```

Figure 11. Thermal protection events



Packet duration is around 14 ms, as shown in Figure 13.

Figure 12. **Packet duration measurement**



The transmit cycle time (distance between start of one packet and next one) is around 34 ms, as shown in Figure 14.

Figure 13. **Transmit cycle time measurement**

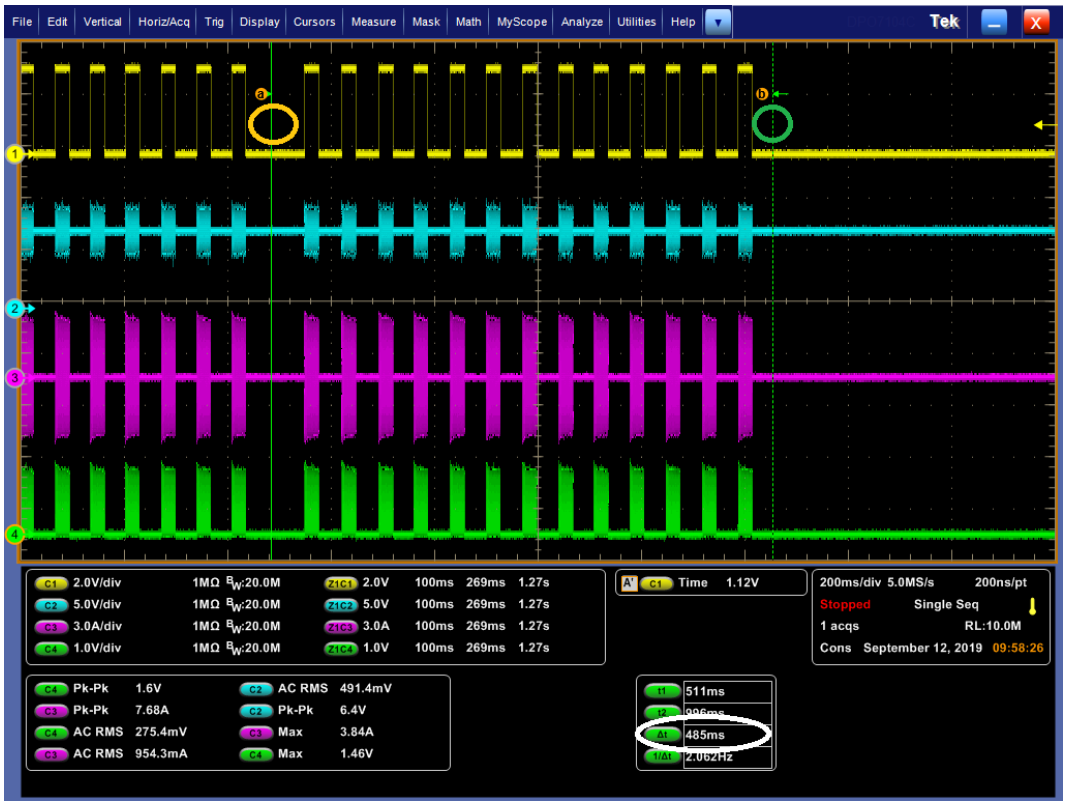
Based on these results, it's possible to find a correlation between thermal event numbers and event time.

Considering in detail event #2 (yellow circle) and event #3 (green circle), the first thermal event occurred at transmitted packet #216 and the second one at packet #230: it means that there is a distance of 14 cycles.

```
Test
Test TX Target  COM15
2019-09-12 09:32:29.144123 WARNING: Thermal warning rised 201
2019-09-12 09:32:29.671807 WARNING: Thermal warning rised 216
2019-09-12 09:32:30.160525 WARNING: Thermal warning rised 230
test done
```

Time interval between event #2 & event #3 is around 485 ms. This result is consistent with the distance of 14 cycles (time interval between two packets is about 34 ms, so 485/34 ≈ 14).

Figure 14. **Time interval measurement between thermal event #2 and #3**



Revision history

Table 7. **Document revision history**

Date	Version	Changes
26-Nov-2020	1	Initial release.

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