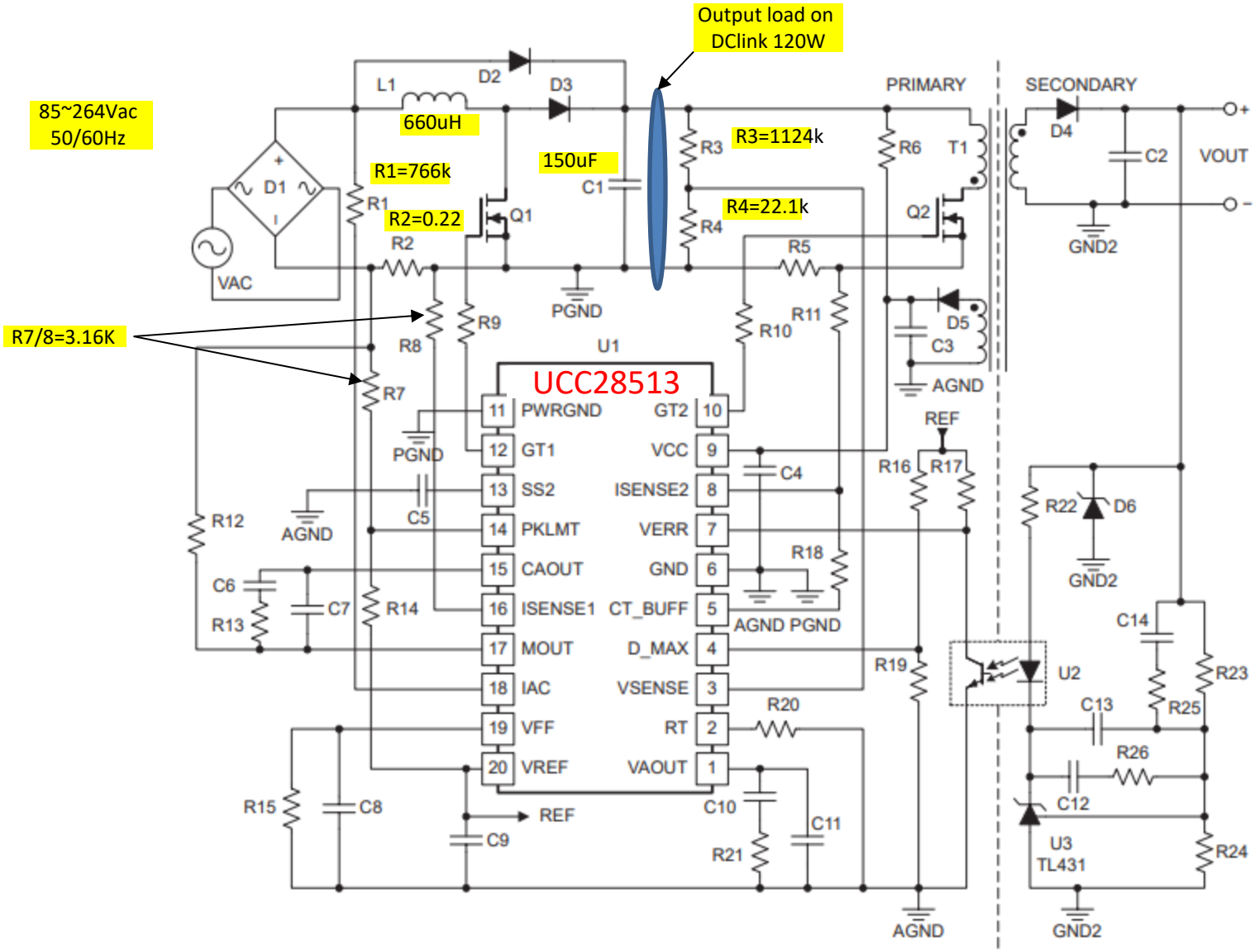
UCC28513 questions, Alex W., 11/17/2022

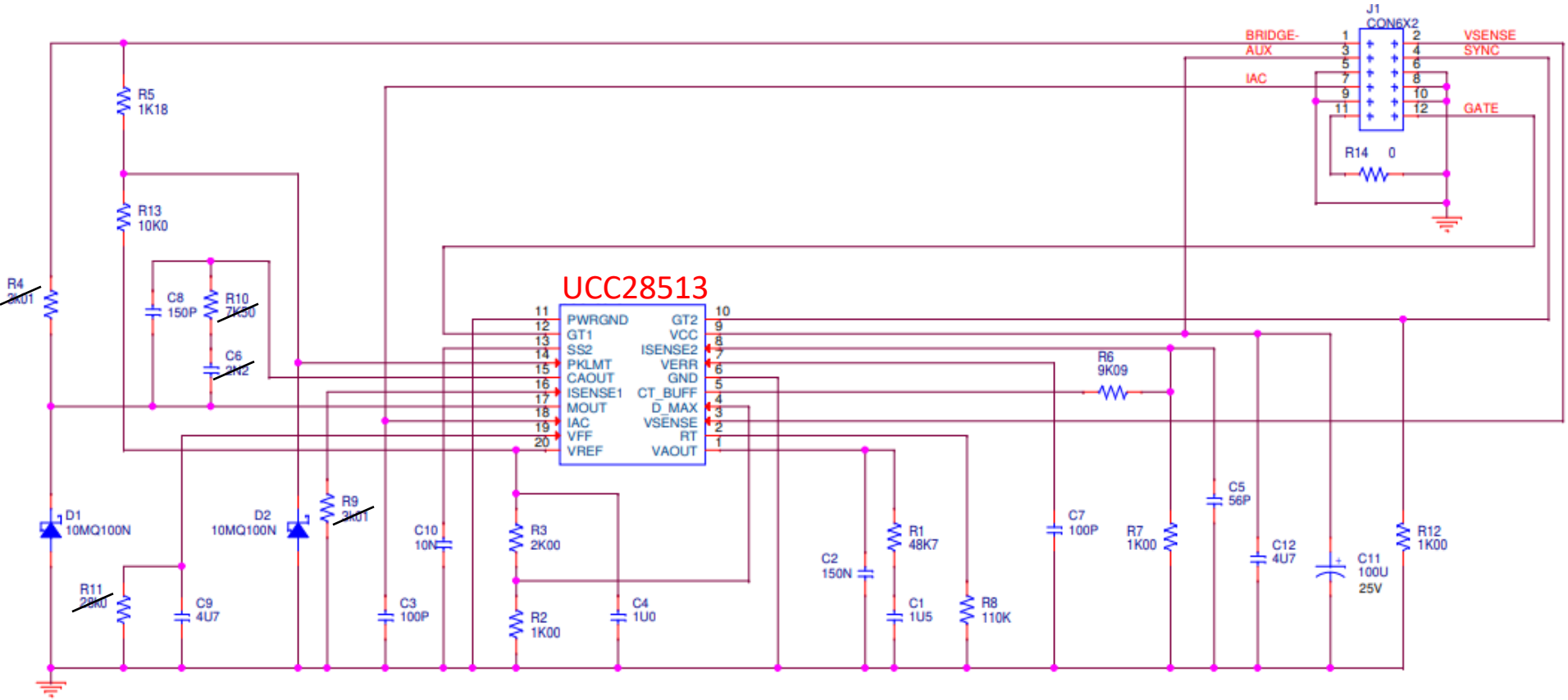
- The boost stage design is based on UCC28513. The PFC stage works well up to 200-220Vac input. Above this voltage range there are significant distortions at the points where sinusoidal input voltage reaches to its positive and negative peaks
- Output voltage is 385Vac
- Input voltage range is 85-264Vac; 50/60Hz
- The load on DC link output is 120W max
- Boost stage switching frequency is 277kHz
- Verified that the Vcc aux supply and Vref are stable
- Observed that the AC ripple on DC link goes up at around 200Vac but not sure it this is the reason or the result
- Observed that the duty cycle is about 70% at the peak sine wave at 85Vac but drops down to ~15% at the peaks of 220Vac at which point I start get distortions on the input current.
- The provided test results are at ~30W output power. It was observed that changing the load did not affect the behavior at around 220Vac.

Questions:

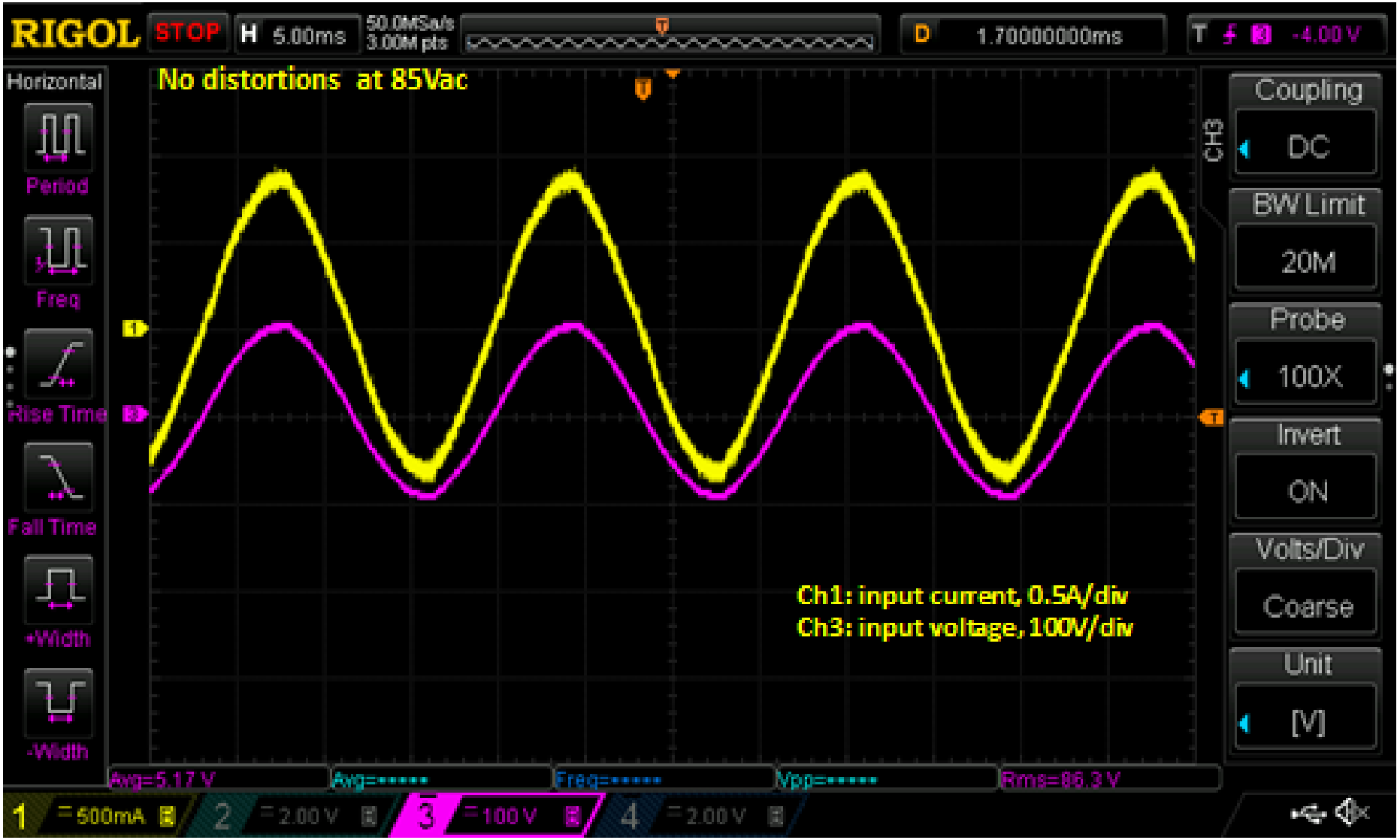
1. Based on the design values, what could potentially cause the distortions at the peak of sine waves at and above ~ 200Vac?
2. Fig. 36 on data sheet talks about max capacitance vs min duty cycle. What capacitor is referred in Fig 36?

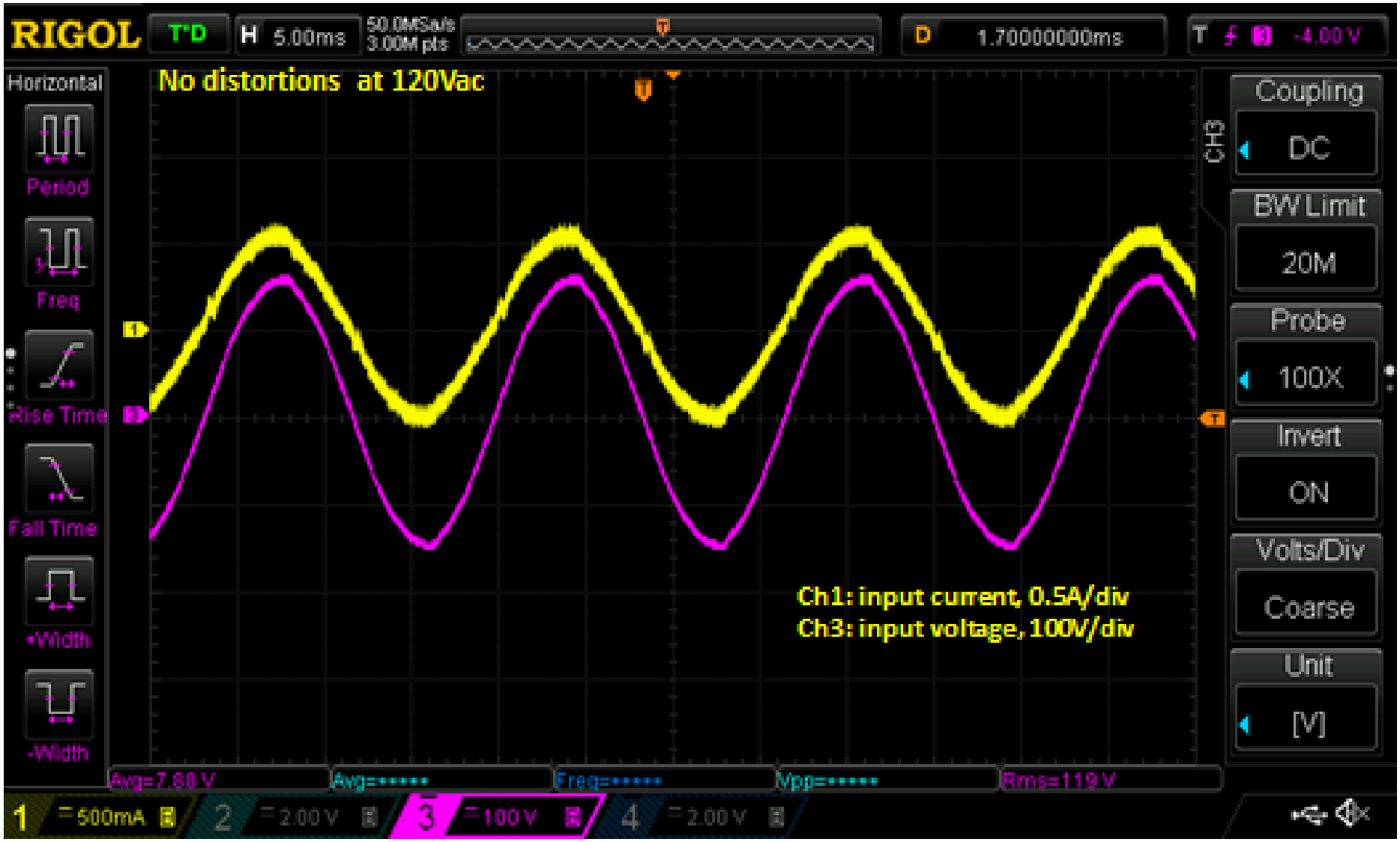

Output load on DClink 120W
85~264Vac 50/60Hz
L1
660uH
D2
D3
R1=766k
R2=0.22
150uF
C1
R3
R3=1124k
R4
R4=22.1k
R5
R6
T1
Q1
Q2
PRIMARY
SECONDARY
D4
C2
VOUT
GND2
D1
VAC
R1
R2
PGND
R7/8=3.16K
R8
R9
R10
R11
U1
UCC28513
D5
C3
AGND
R7
11 PWRGND
12 GT1
13 SS2
14 PKLMT
15 CAOUT
16 ISENSE1
17 MOUT
18 IAC
19 VFF
20 VREF
GT2 10
VCC 9
ISENSE2 8
VERR 7
GND 6
CT_BUFF 5
D_MAX 4
VSENSE 3
RT 2
VAOUT 1
REF
R16
R17
C4
R18
AGND PGND
R12
C5
C6
R13
C7
R14
R15
C8
C9
R20
C10
C11
R21
R19
U2
R22
D6
C14
R23
R25
C13
R26
C12
U3
TL431
R24
AGND
GND2

RefDes on data sheet	RefDes in design	values
R1	R47+R50	766K
R2	R43	0.22
R8/R12	R4/R9	3.16K
R3	R44+R49	1124K
R4	R60	22.1k
C1	C32	150uF
L1	L2	660uH
R13	R10	15.8K
C6	C6	680pF
C7	C8	150pF
R15	R11	30.1K
C8	C9	4.7uF
C10	C1	1.5uF
C11	C2	150nF
R21	R1	48.7K
R14	R13	10K
R7	R5	1.18K
C9	C4	1uF

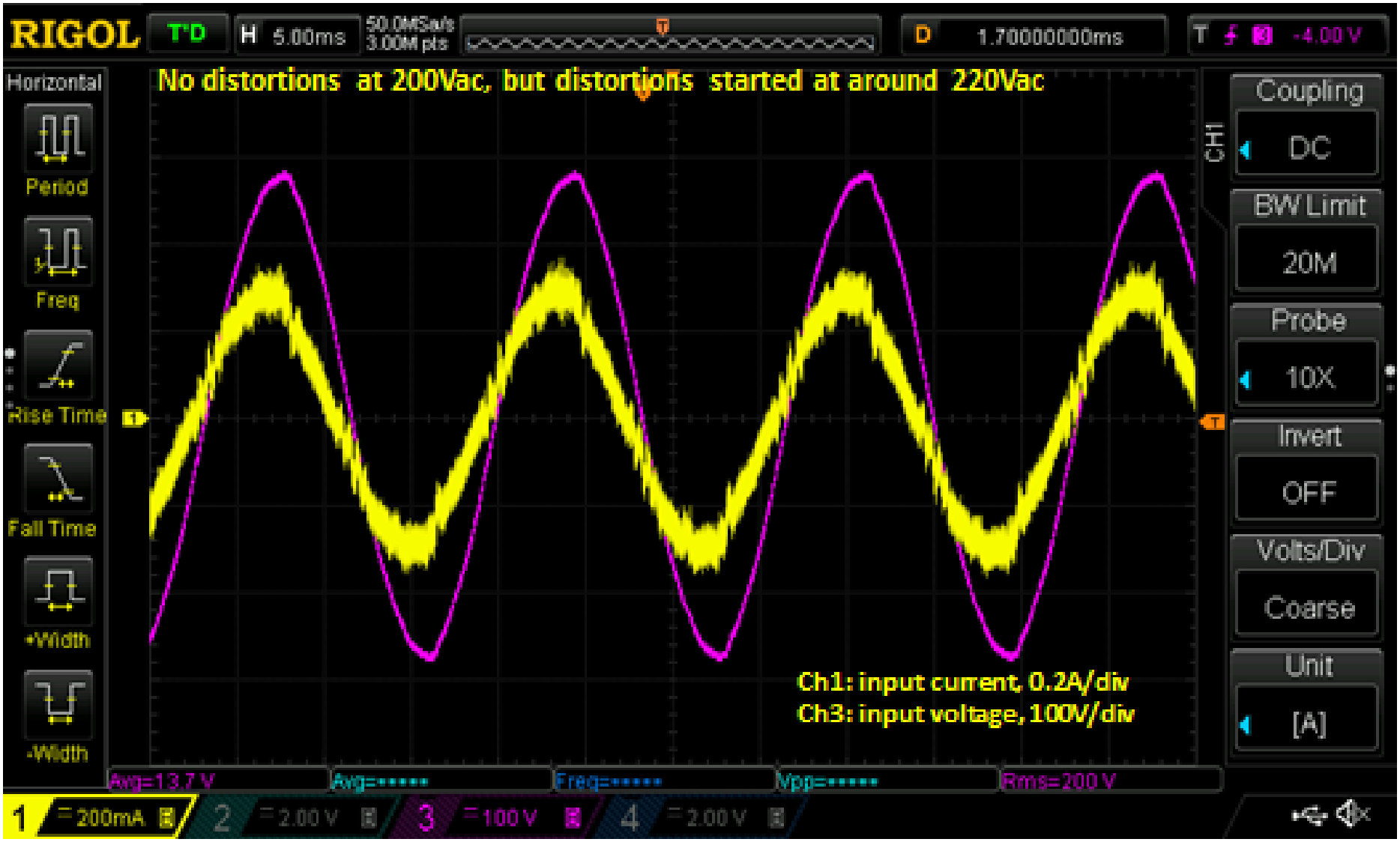


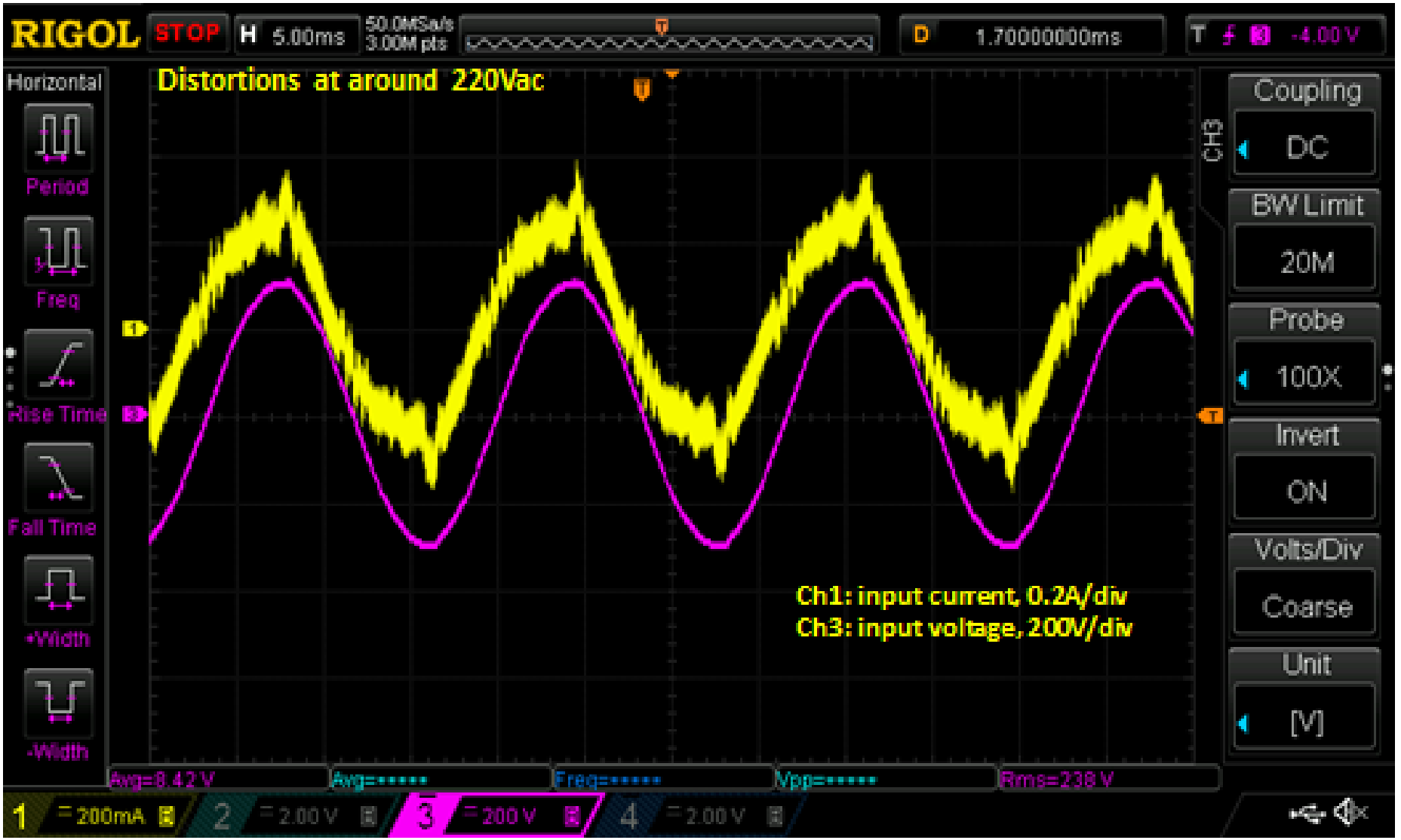
RefDes on data sheet	RefDes in design	values
R8/R12	R4/R9	3.16K
R13	R10	15.8K
C6	C6	680pF
R15	R11	30.1K

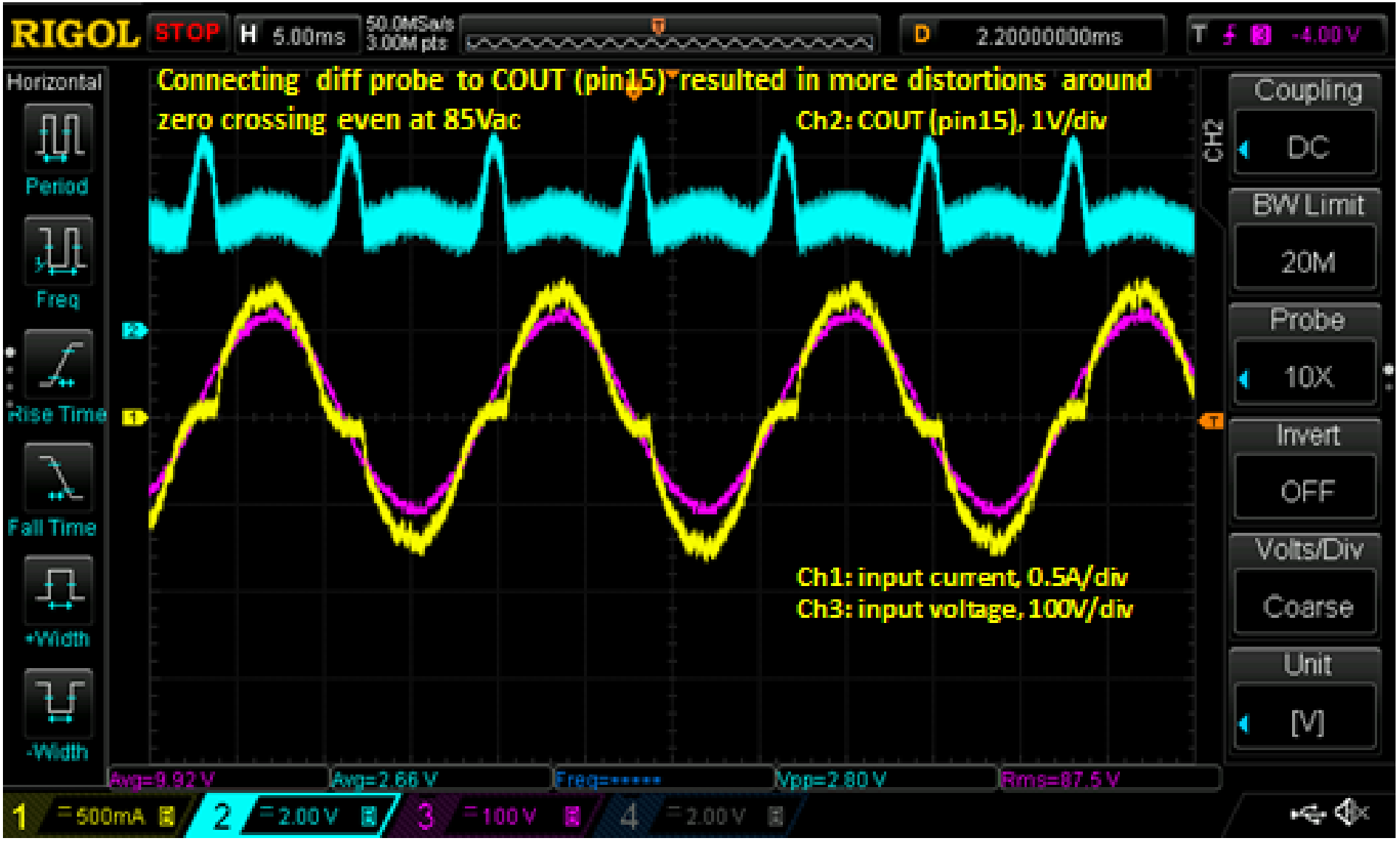

RIGOL
STOP
H 5.00ms
50.0MSa/s
3.00M pts
D 1.70000000ms
T -4.00 V
Horizontal
No distortions at 85Vac
Period
Freq
Rise Time
Fall Time
+Width
-Width
CH3
Coupling
DC
BW Limit
20M
Probe
100X
Invert
ON
Volts/Div
Coarse
Unit
[V]
Ch1: input current, 0.5A/div
Ch3: input voltage, 100V/div
Avg=5.17 V
Avg=******
Freq=******
Vpp=******
Rms=86.3 V
1 500mA
2 2.00 V
3 100 V
4 2.00 V

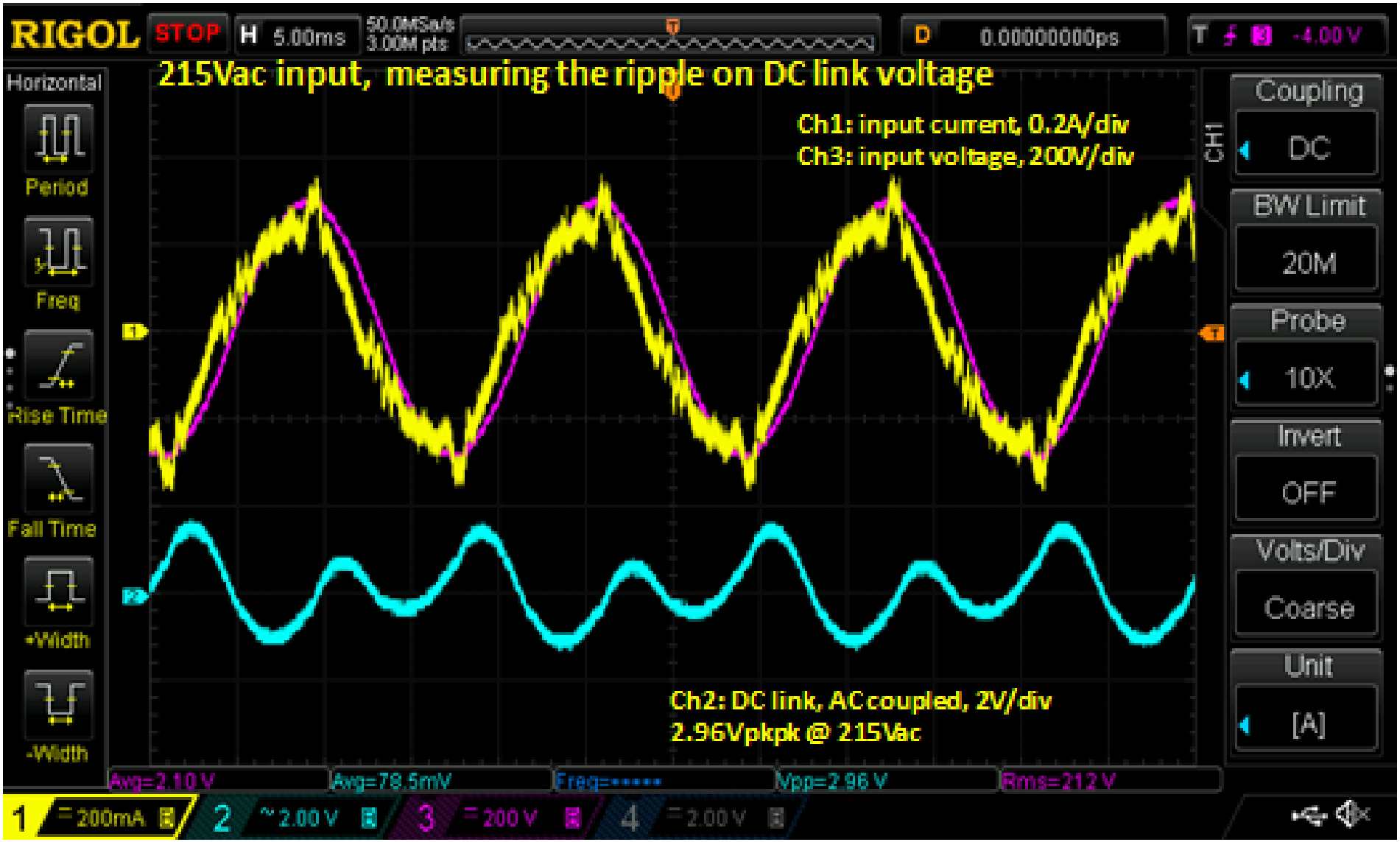

RIGOL
T'D
H 5.00ms
50.0MSa/s
3.00M pts
D 1.70000000ms
T -4.00 V
Horizontal
Period
Freq
Rise Time
Fall Time
+Width
-Width
No distortions at 120Vac
Ch1: input current, 0.5A/div
Ch3: input voltage, 100V/div
CH3
Coupling
DC
BW Limit
20M
Probe
100X
Invert
ON
Volts/Div
Coarse
Unit
[V]
Avg=7.88 V
Avg=
Freq=
Vpp=
Rms=119 V
1 500mA
2 2.00 V
3 100 V
4 2.00 V

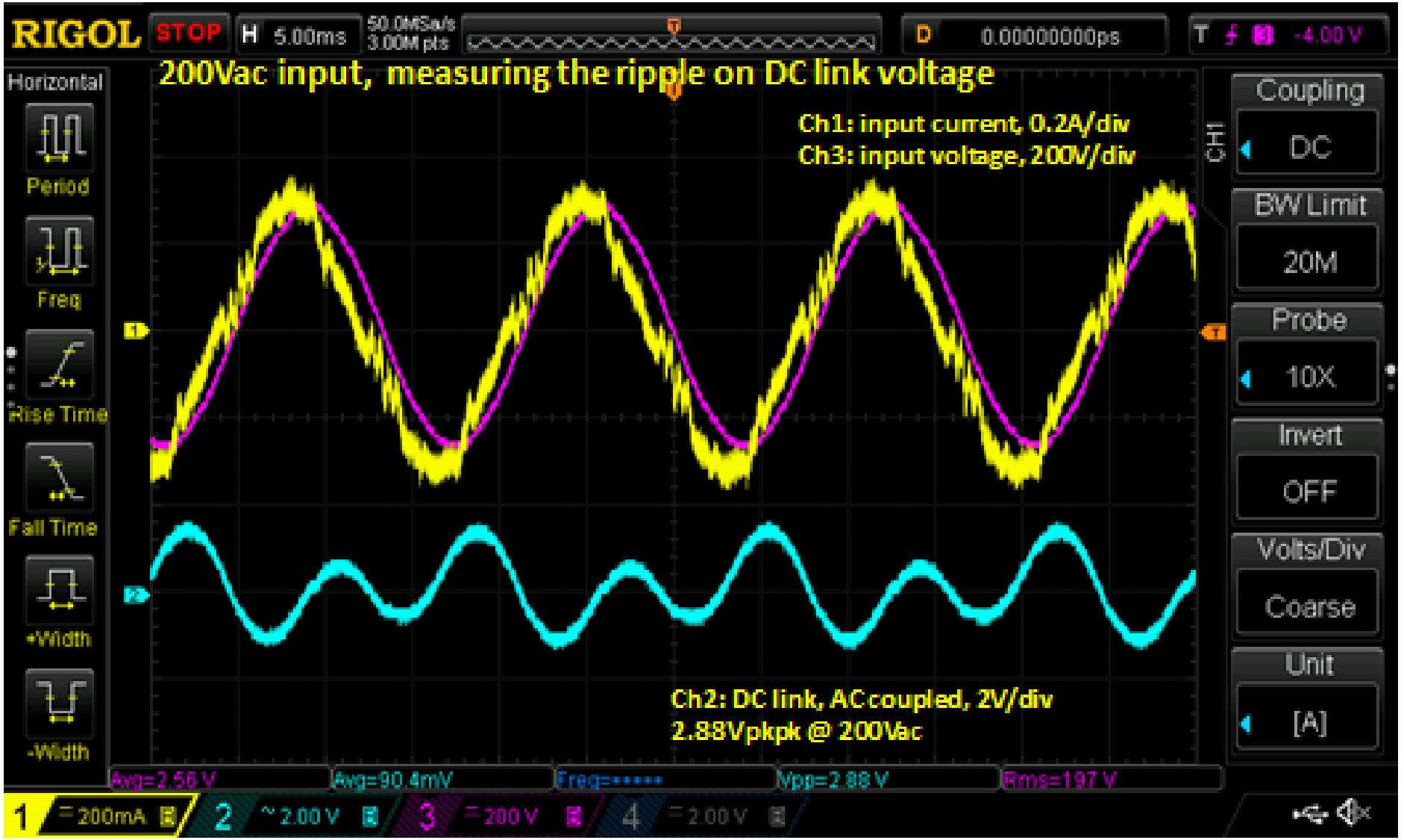
No distortions at 200Vac input, displacement between current and voltage is probably caused by the input capacitors on EMI filter




RIGOL
STOP
H 5.00ms
50.0MSa/s
3.00M pts
D 1.70000000ms
T -4.00 V
Horizontal
Distortions at around 220Vac
Period
Freq
Rise Time
Fall Time
+Width
-Width
CH3
Coupling
DC
BW Limit
20M
Probe
100X
Invert
ON
Volts/Div
Coarse
Unit
[V]
Ch1: input current, 0.2A/div
Ch3: input voltage, 200V/div
Avg=8.42 V
Avg=*****
Freq=*****
Vpp=*****
Rms=238 V
1 200mA
2 2.00 V
3 200 V
4 2.00 V


RIGOL
STOP
H 5.00ms
50.0MSa/s
3.00M pts
D 2.20000000ms
T -4.00 V
Horizontal
Period
Freq
Rise Time
Fall Time
+Width
-Width
Connecting diff probe to COUT (pin15) resulted in more distortions around zero crossing even at 85Vac
Ch2: COUT (pin15), 1V/div
Ch1: input current, 0.5A/div
Ch3: input voltage, 100V/div
CH2
Coupling
DC
BW Limit
20M
Probe
10X
Invert
OFF
Volts/Div
Coarse
Unit
[V]
Avg=9.92 V
Avg=2.66 V
Freq=******
Vpp=2.80 V
Rms=87.5 V
1 500mA
2 2.00 V
3 100 V
4 2.00 V


RIGOL
STOP
H 5.00ms
50.0MSa/s
3.00M pts
D 0.000000000ps
T -4.00 V
215Vac input, measuring the ripple on DC link voltage
Ch1: input current, 0.2A/div
Ch3: input voltage, 200V/div
Ch2: DC link, AC coupled, 2V/div
2.96Vpkpk @ 215Vac
Horizontal
Period
Freq
Rise Time
Fall Time
+Width
-Width
CH1
Coupling
DC
BW Limit
20M
Probe
10X
Invert
OFF
Volts/Div
Coarse
Unit
[A]
Avg=2.10 V
Avg=78.5mV
Freq=
Vpp=2.96 V
Rms=212 V
1 200mA
2 2.00 V
3 200 V
4 2.00 V

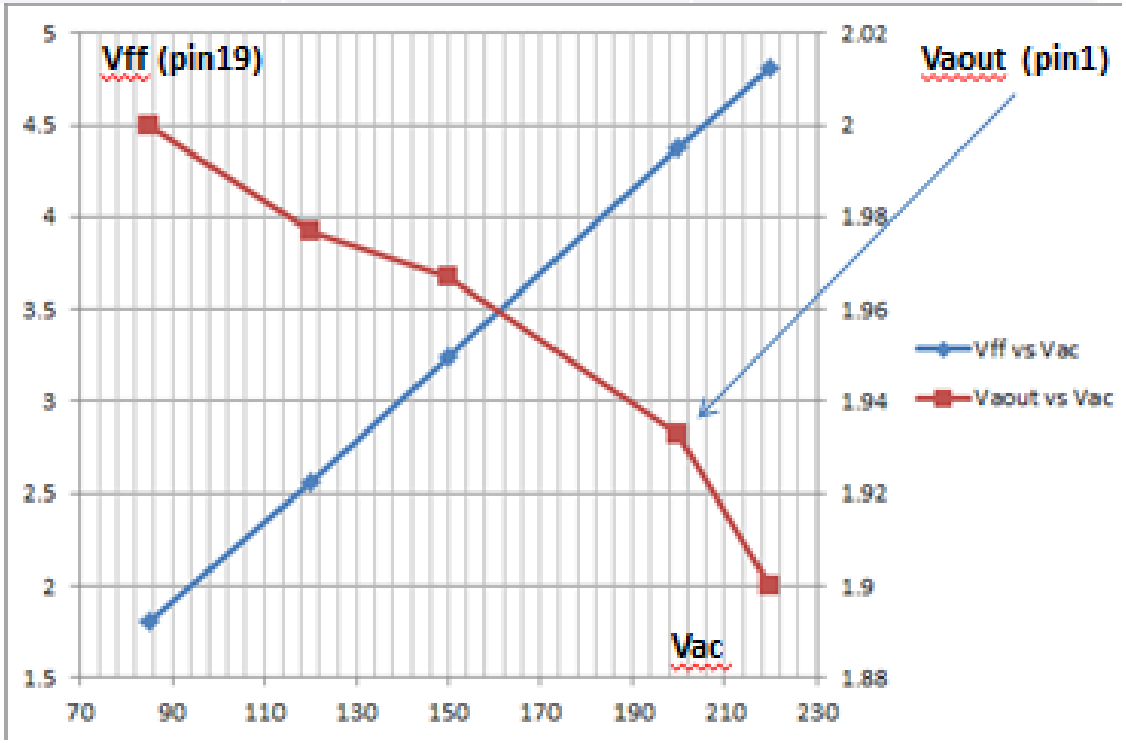

RIGOL
STOP
H 5.00ms
50.0MSa/s
3.00M pts
D 0.000000000ps
T -4.00 V
200Vac input, measuring the ripple on DC link voltage
Ch1: input current, 0.2A/div
Ch3: input voltage, 200V/div
Ch2: DC link, AC coupled, 2V/div
2.88Vpkpk @ 200Vac
Horizontal
Period
Freq
Rise Time
Fall Time
+Width
-Width
CH1
Coupling
DC
BW Limit
20M
Probe
10X
Invert
OFF
Volts/Div
Coarse
Unit
[A]
Avg=2.56 V
Avg=90.4mV
Freq=*****
Vpp=2.88 V
Rms=197 V
1 200mA
2 2.00 V
3 200 V
4 2.00 V

Input voltage (Vrms)	Vff on pin19 w/ DiffProbe (Vdc)	Vaout on pin1 w/ DVM (Vdc)
85	1.80	2.000
120	2.56	1.977
150	3.24	1.967
200	4.38	1.933
220	4.81	1.900

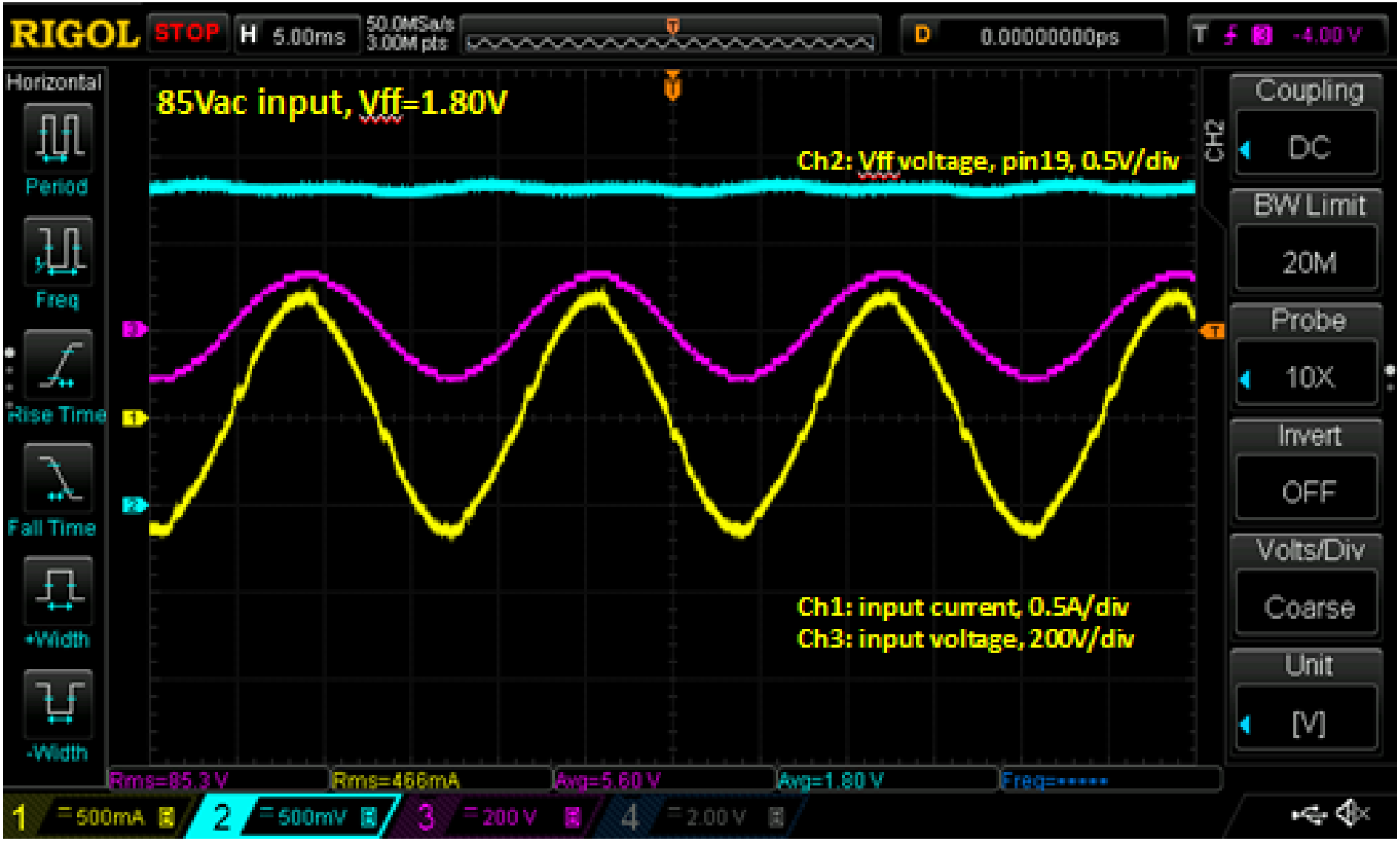
$0 \le i_{IAC}(t) \le 500\ \mu A,$

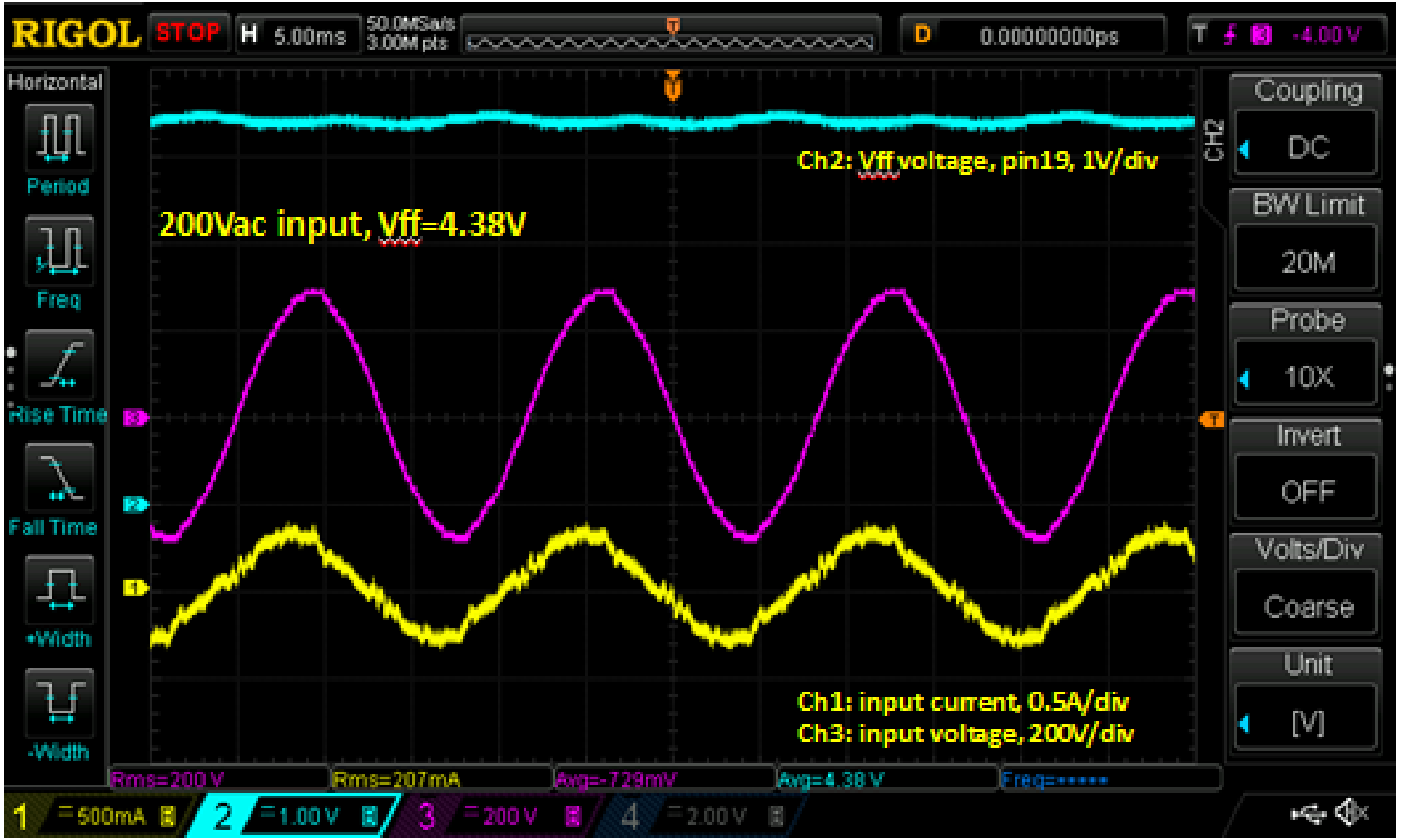
$0 \le V_{VAOUT}(t) \le 5\ V,$

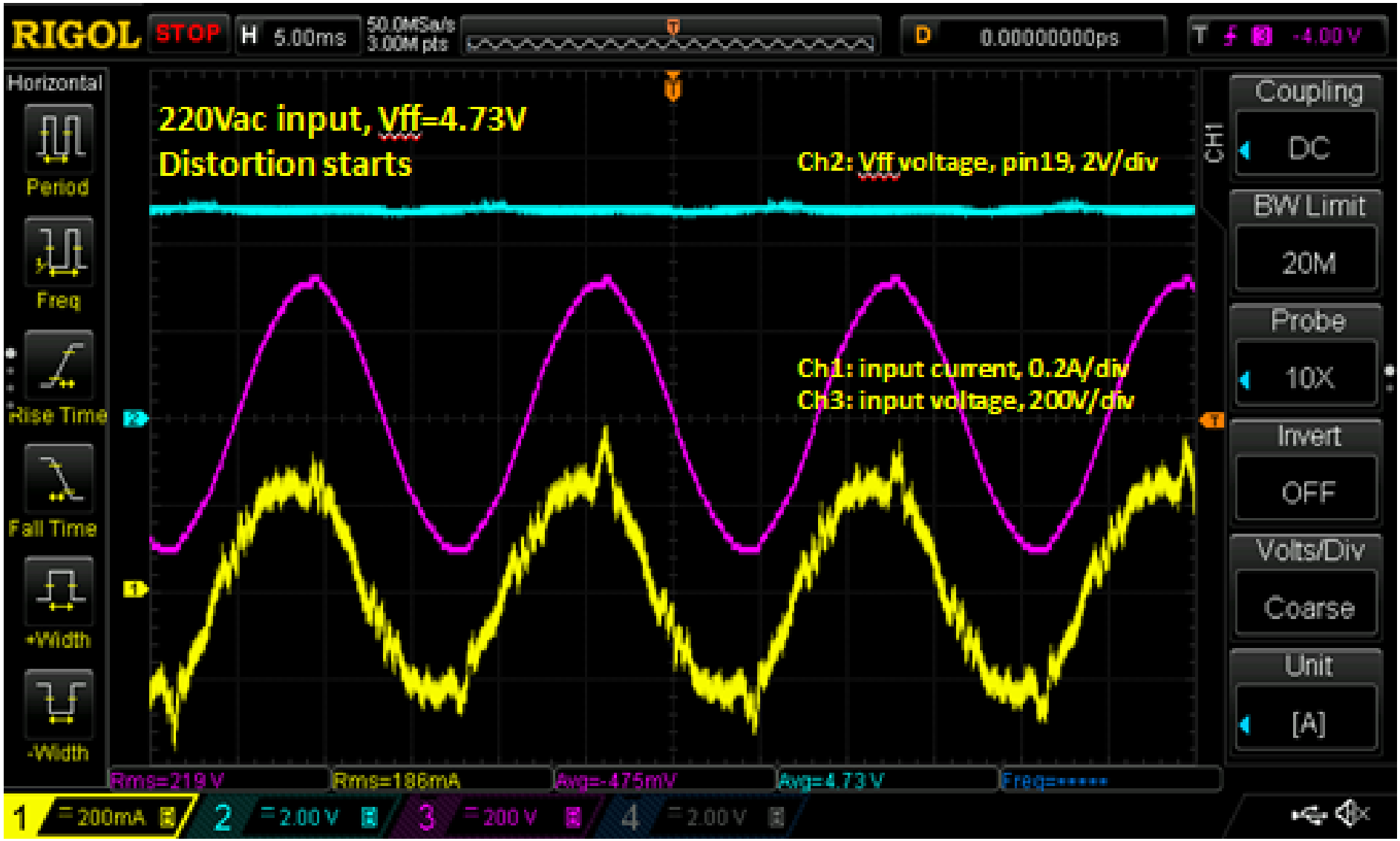
$1.4\ V \le V_{VFF} \le V_{VREF} - 1.4\ V$



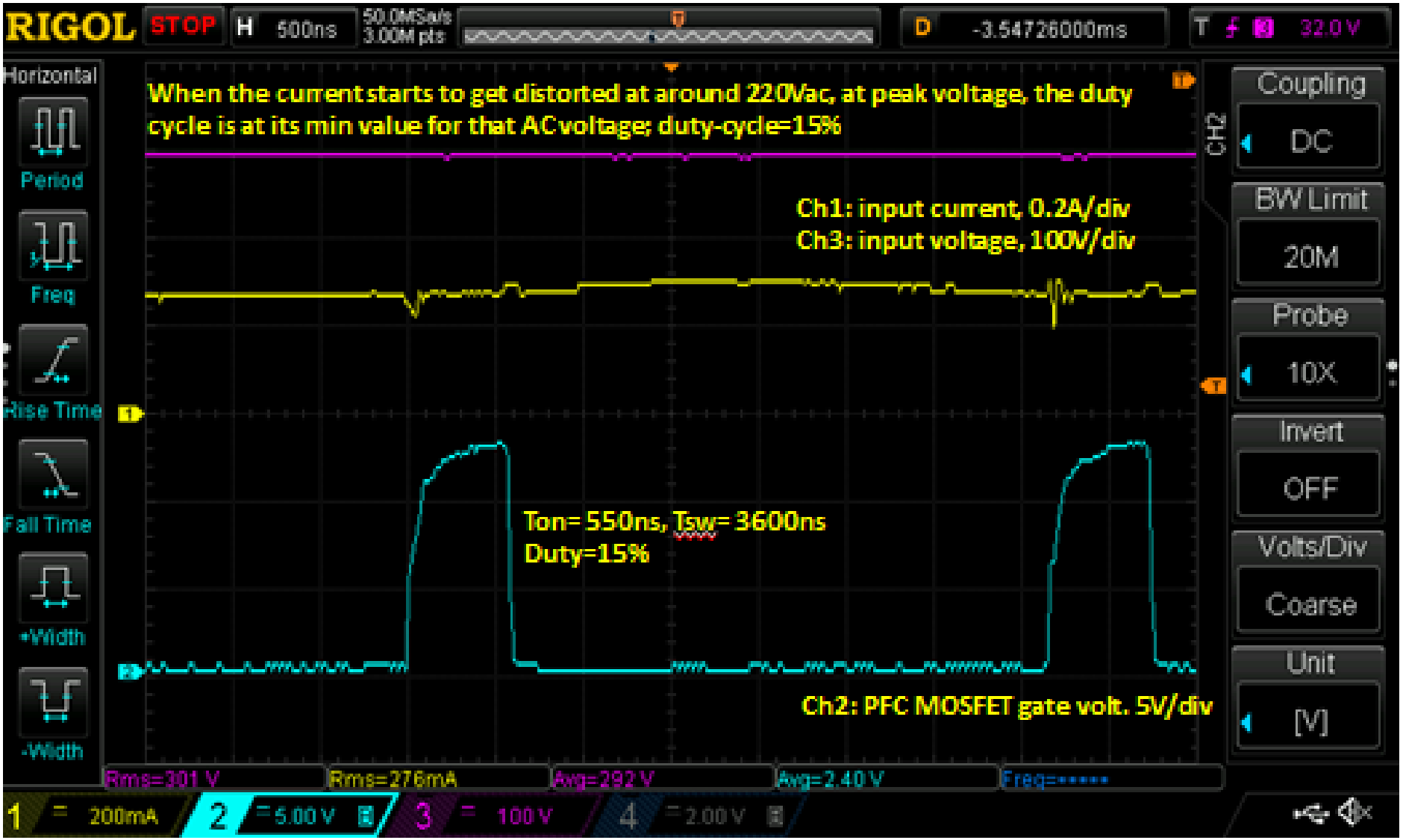
- Vff increases proportionally and Vaout drops inversely as Vac increases.
- Vaout seems to start low at 2V and not varying within its full range of 0-5V


RIGOL
STOP
H 5.00ms
50.0MSa/s
3.00M pts
D 0.000000000ps
T -4.00 V
Horizontal
Period
Freq
Rise Time
Fall Time
+Width
-Width
85Vac input, Vff=1.80V
Ch2: Vff voltage, pin19, 0.5V/div
Ch1: input current, 0.5A/div
Ch3: input voltage, 200V/div
CH2
Coupling
DC
BW Limit
20M
Probe
10X
Invert
OFF
Volts/Div
Coarse
Unit
[V]
Rms=85.3 V
Rms=466mA
Avg=5.60 V
Avg=1.80 V
Freq=*****
1 =500mA
2 =500mV
3 =200 V
4 =2.00 V

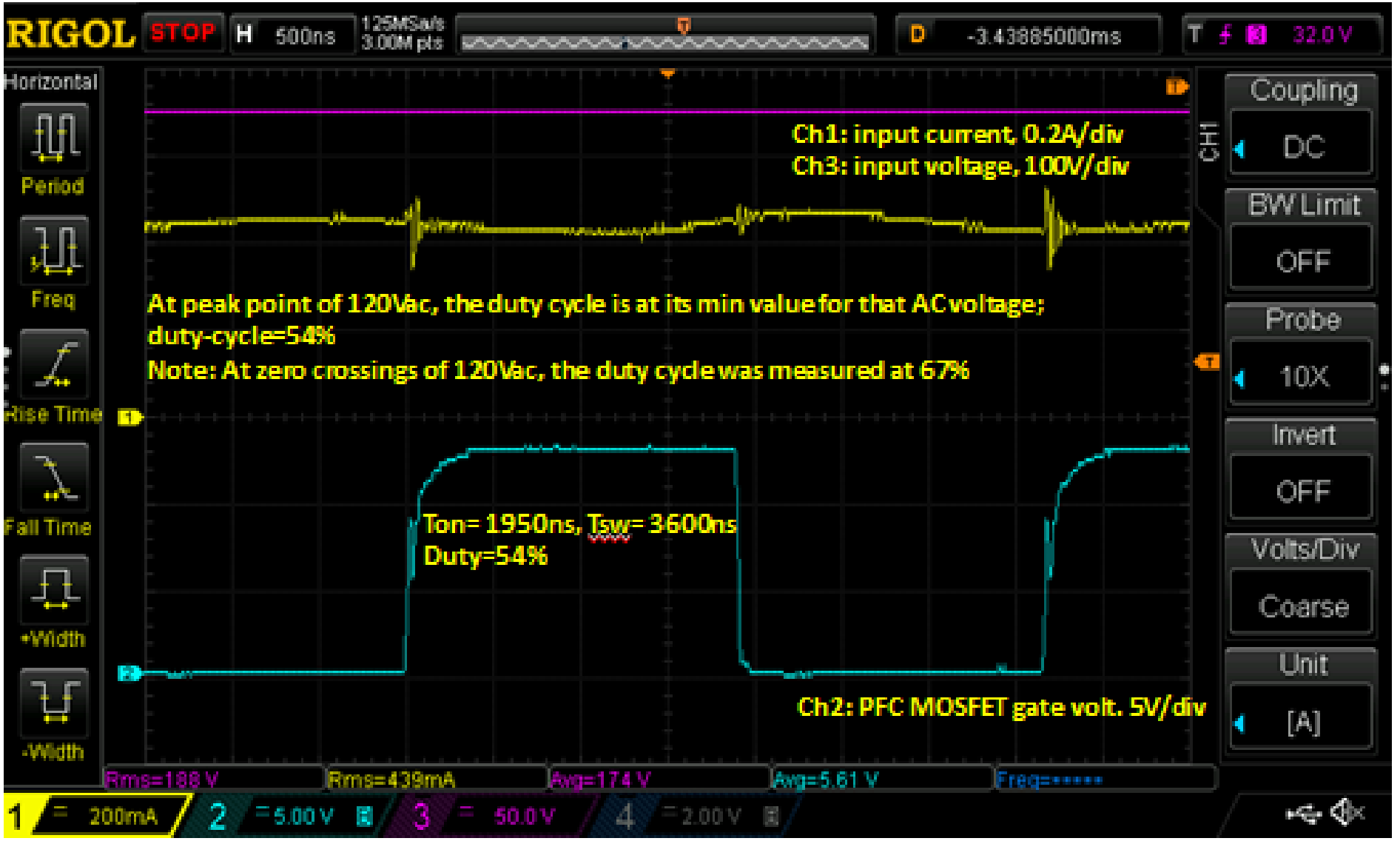

RIGOL
STOP
H 5.00ms
50.0MSa/s
3.00M pts
D 0.000000000ps
T -4.00 V
Horizontal
Period
Freq
Rise Time
Fall Time
+Width
-Width
Ch2: Vff voltage, pin19, 1V/div
200Vac input, Vff=4.38V
Ch1: input current, 0.5A/div
Ch3: input voltage, 200V/div
CH2
Coupling
DC
BW Limit
20M
Probe
10X
Invert
OFF
Volts/Div
Coarse
Unit
[V]
Rms=200 V
Rms=207mA
Avg=-729mV
Avg=4.38 V
Freq=*****
1 500mA
2 1.00 V
3 200 V
4 2.00 V


RIGOL
STOP
H 5.00ms
50.0MSa/s
3.00M pts
D 0.00000000ps
T -4.00 V
Horizontal
Period
Freq
Rise Time
Fall Time
+Width
-Width
220Vac input, Vff=4.73V
Distortion starts
Ch2: Vff voltage, pin19, 2V/div
Ch1: input current, 0.2A/div
Ch3: input voltage, 200V/div
CH1
Coupling
DC
BW Limit
20M
Probe
10X
Invert
OFF
Volts/Div
Coarse
Unit
[A]
Rms=219 V
Rms=186mA
Avg=-475mV
Avg=4.73 V
Freq=*****
1 200mA
2 2.00 V
3 200 V
4 2.00 V

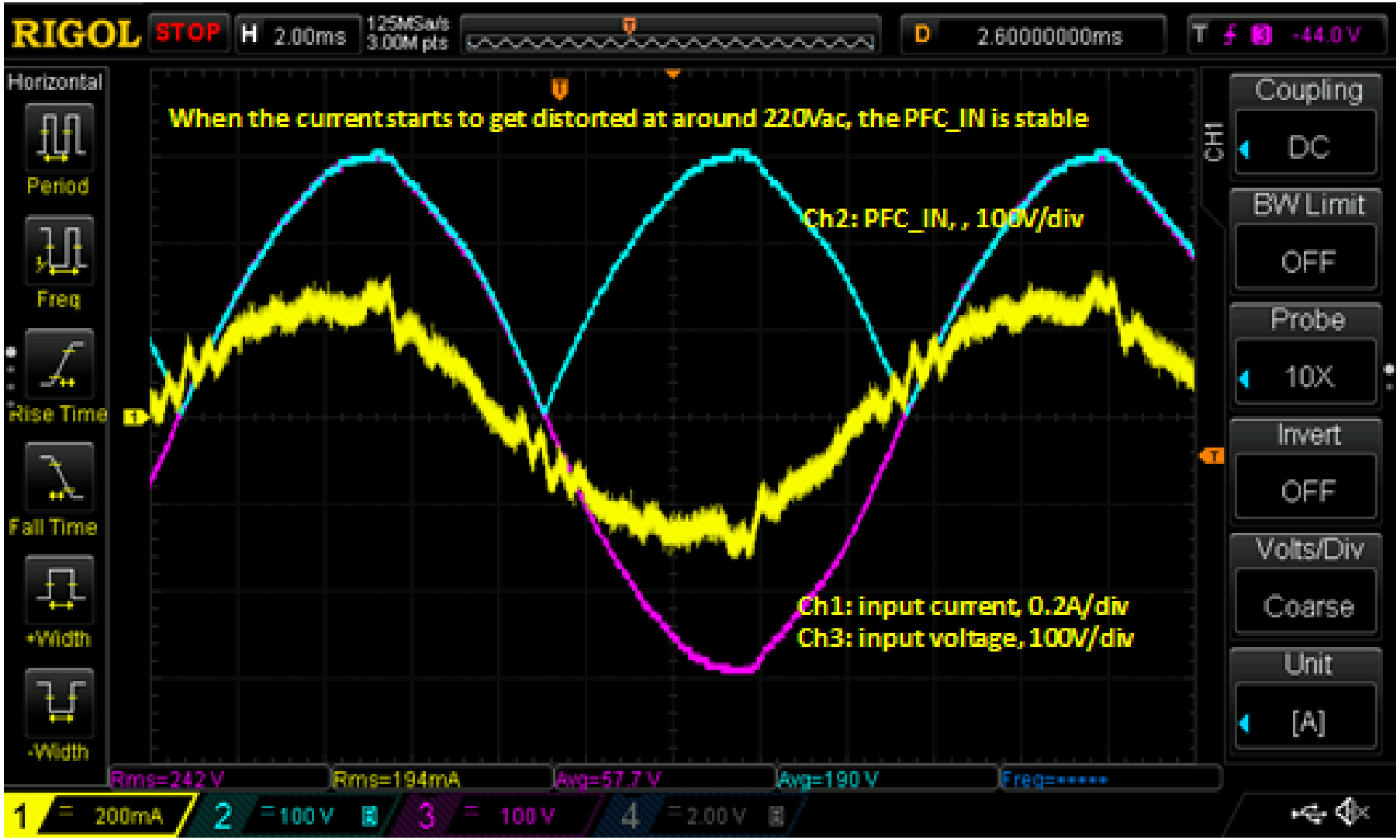
At the peak of sinewaves when distortion starts, the duty cycle of boost MOSFET is about 15%



At the peak of sinewaves at 120Vac, the duty cycle of boost MOSFET is about 54%



At 220Vac when distortions starts, the rectified input voltage (used for Vff) is shown below



Referring to Fig 36 in the data sheet of UCC28513DW, what specific capacitor controls the min duty cycle?

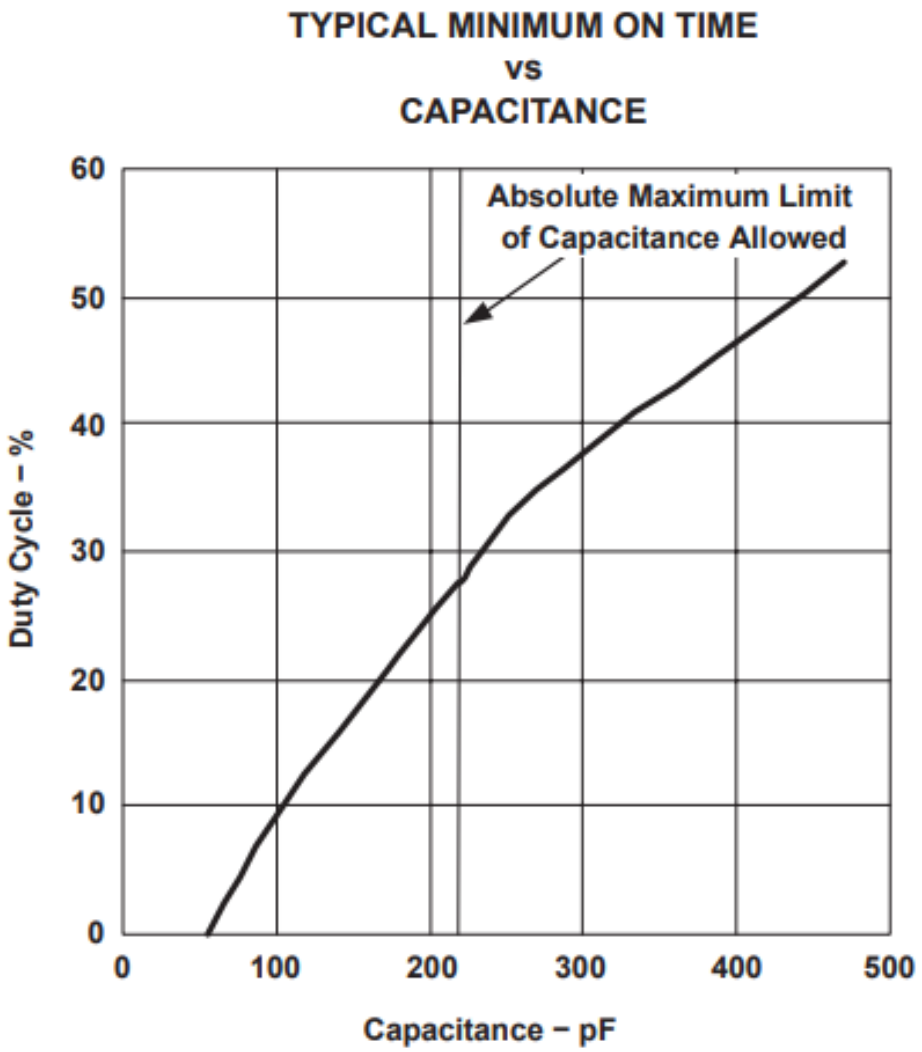
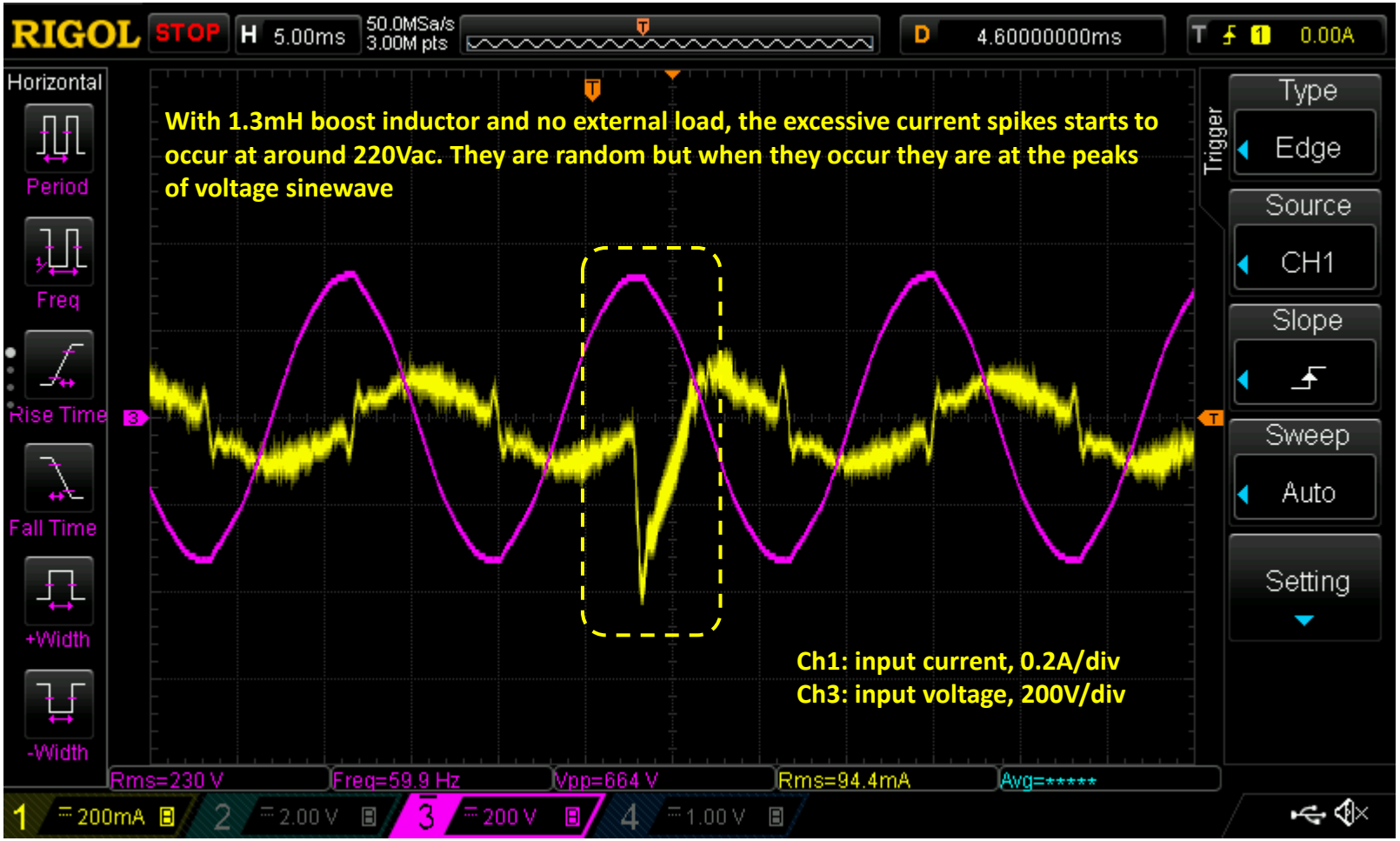


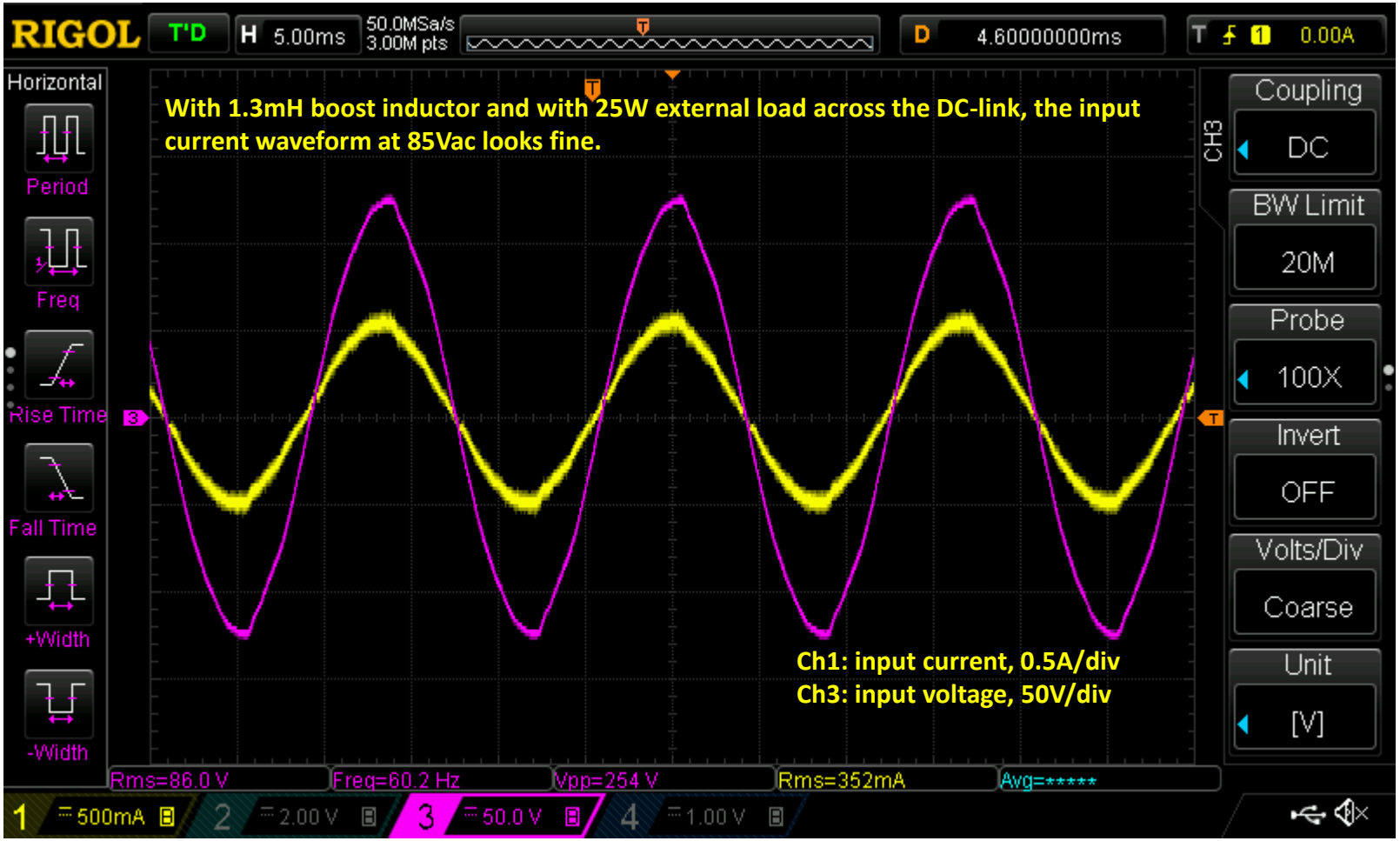
Figure 36

Note: The capacitor on Isense2 affects the min duty cycle on GATE2 output, PFC is on GATE1 output

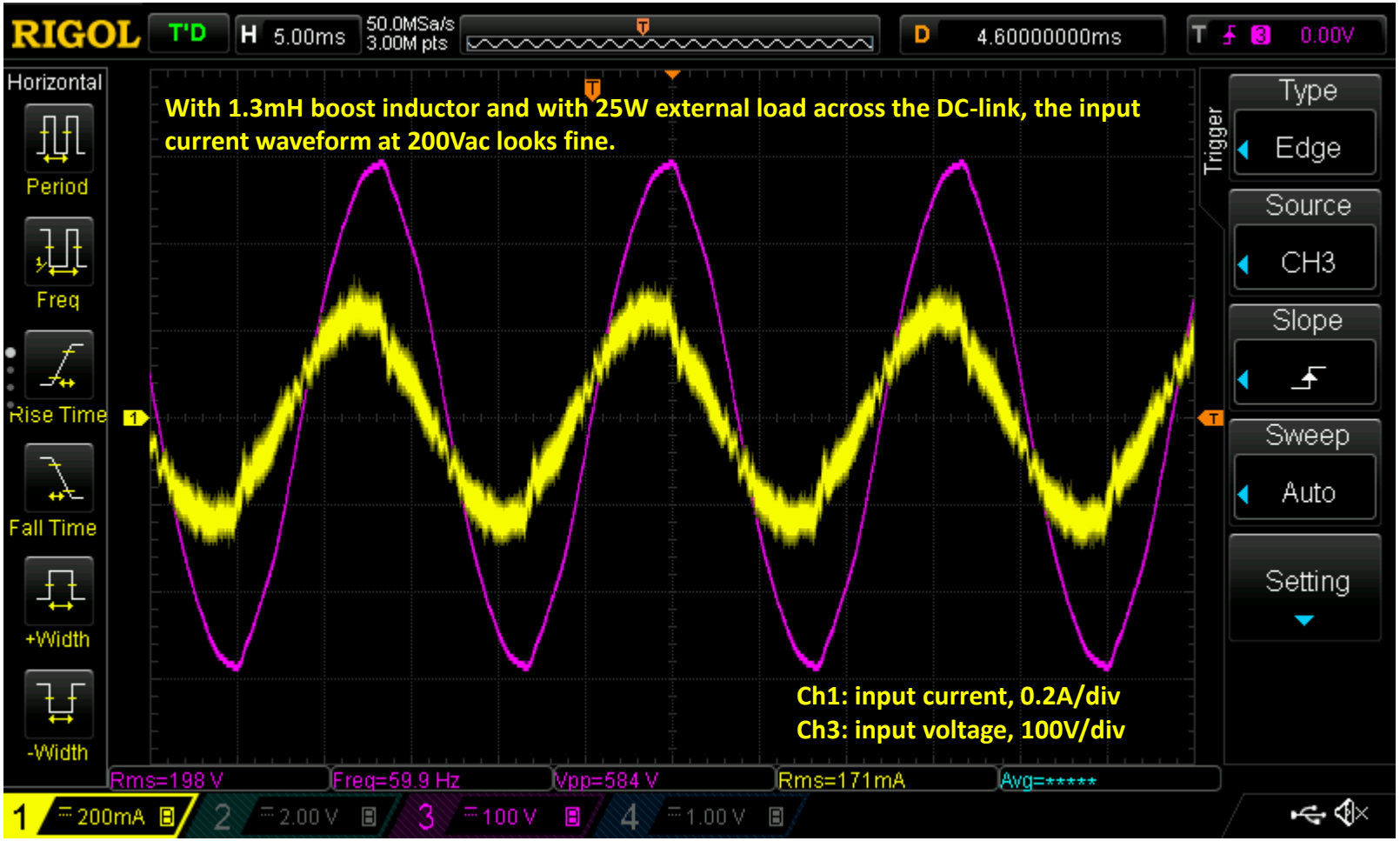
Boost inductor is changed from 660uH to 2x660uH= 1.32mH



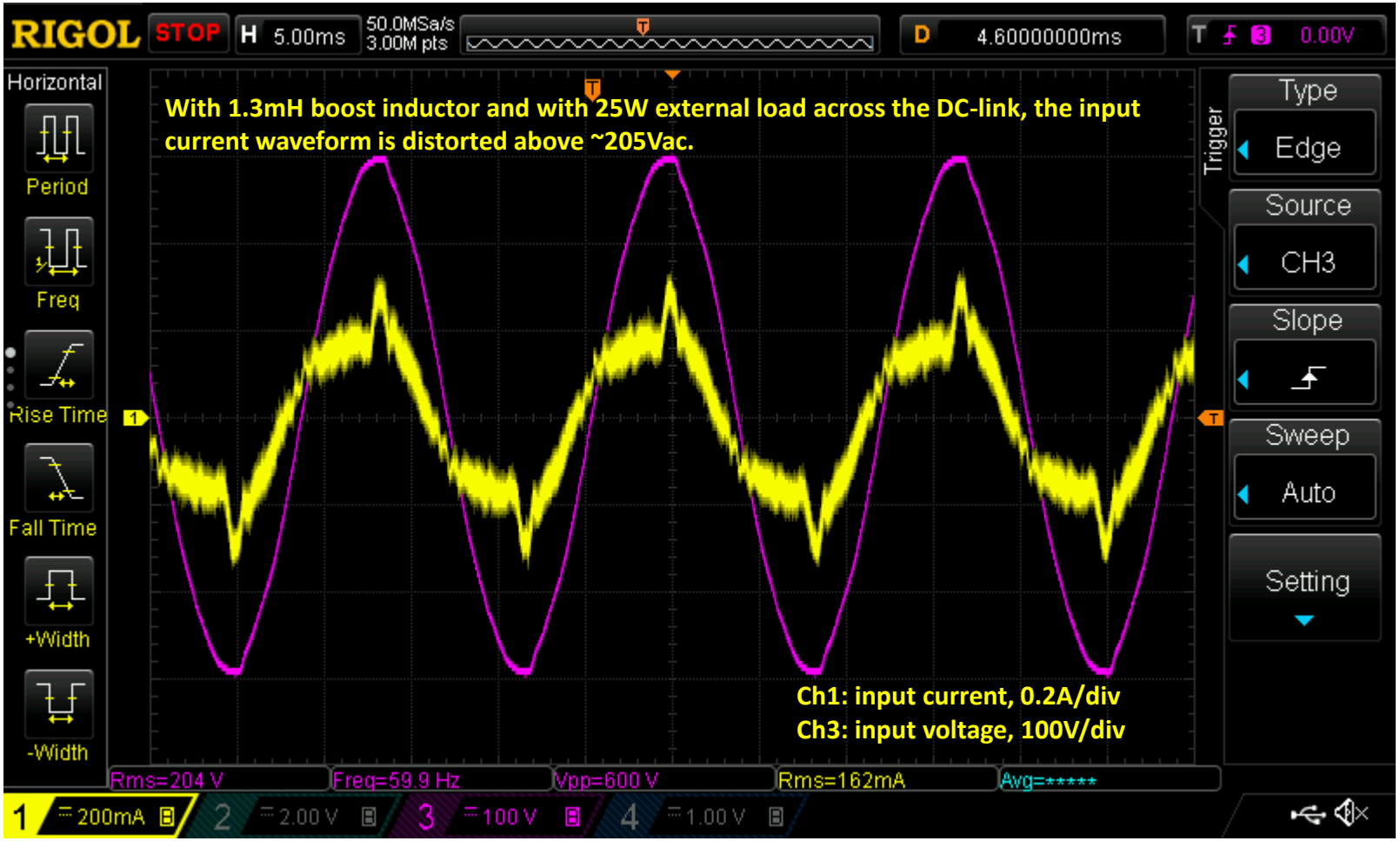
Boost inductor is changed from 660uH to 2x660uH= 1.32mH



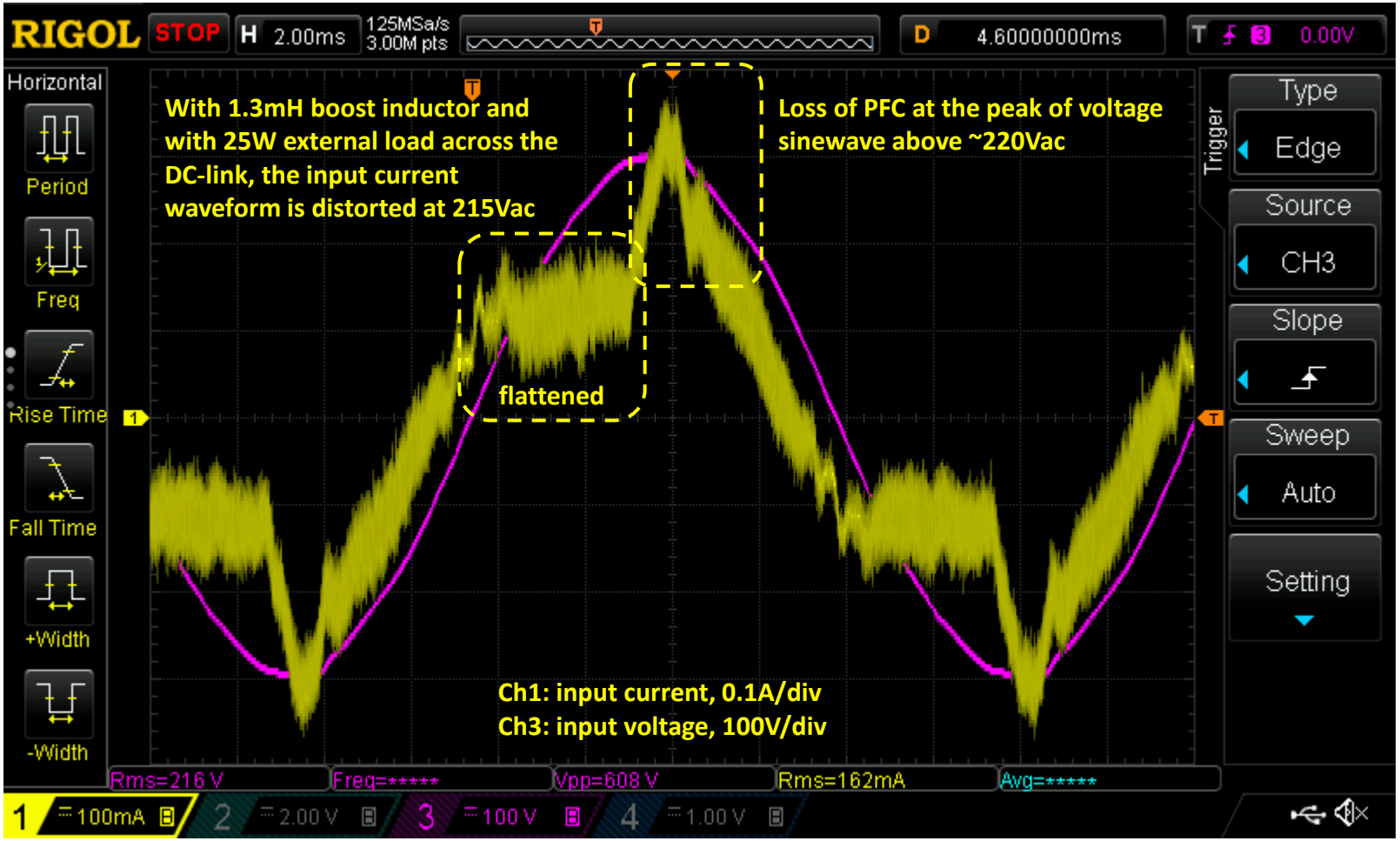
Boost inductor is changed from 660uH to 2x660uH= 1.32mH



Boost inductor is changed from 660uH to 2x660uH= 1.32mH

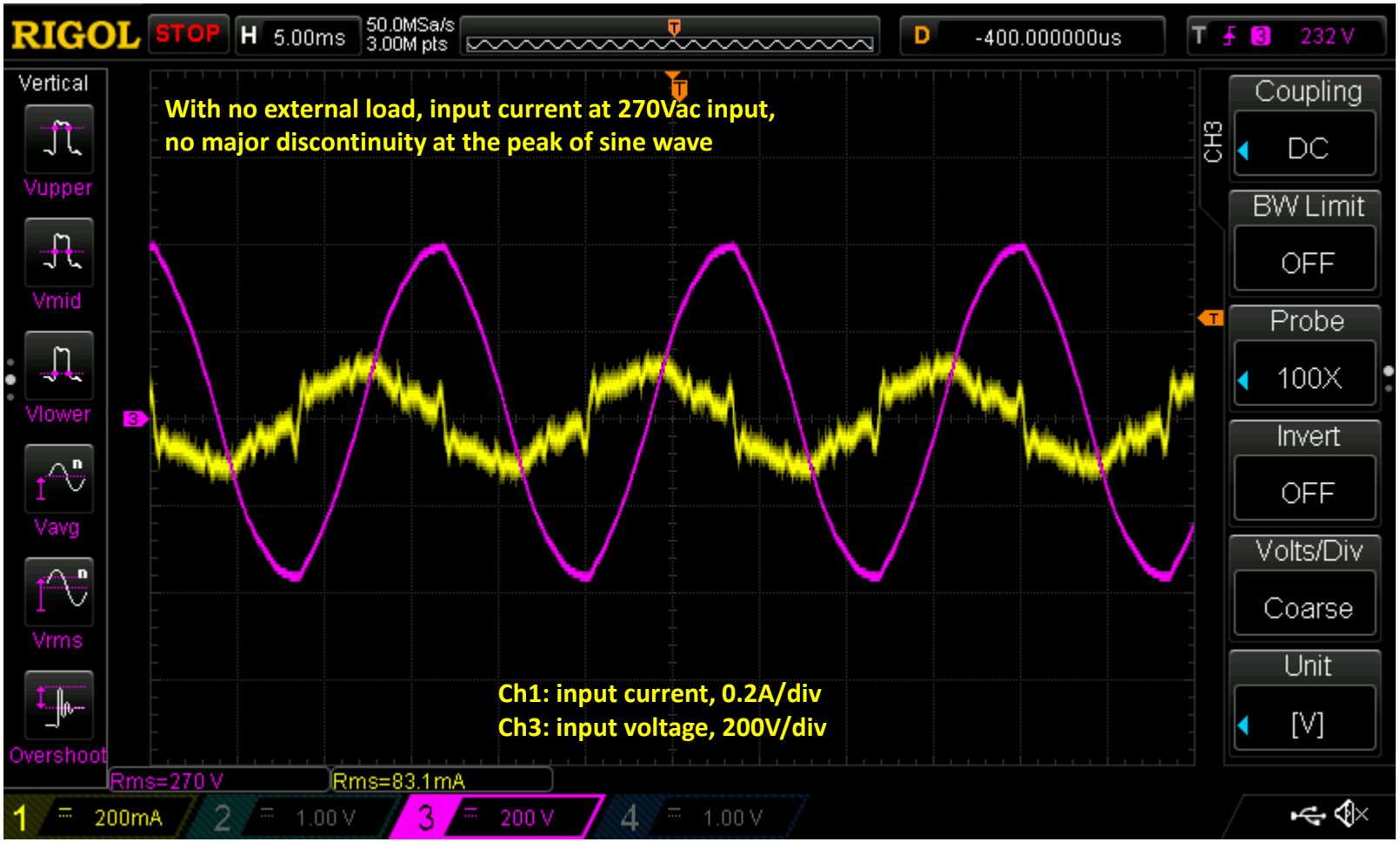


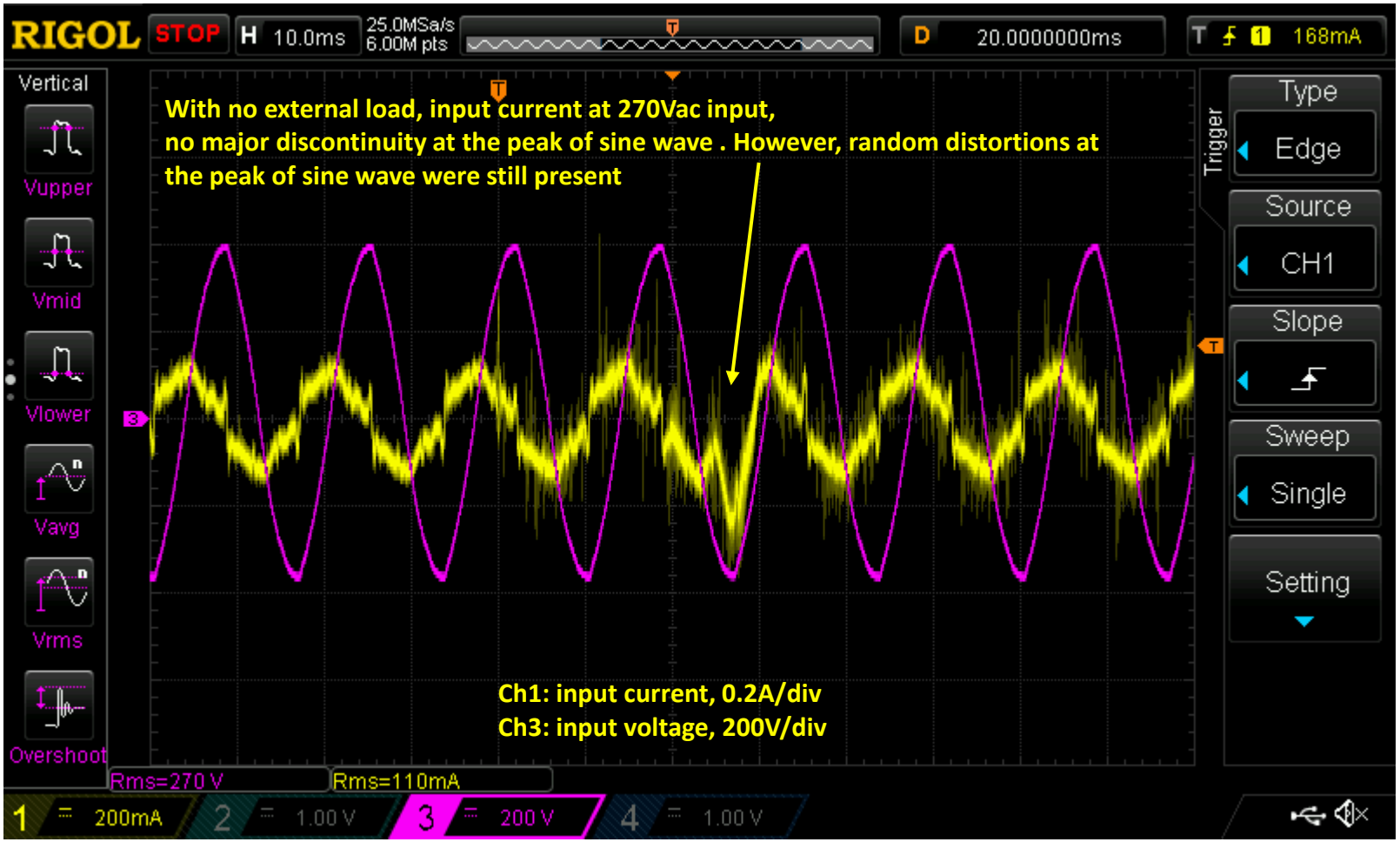
Boost inductor is changed from 660uH to 2x660uH= 1.32mH

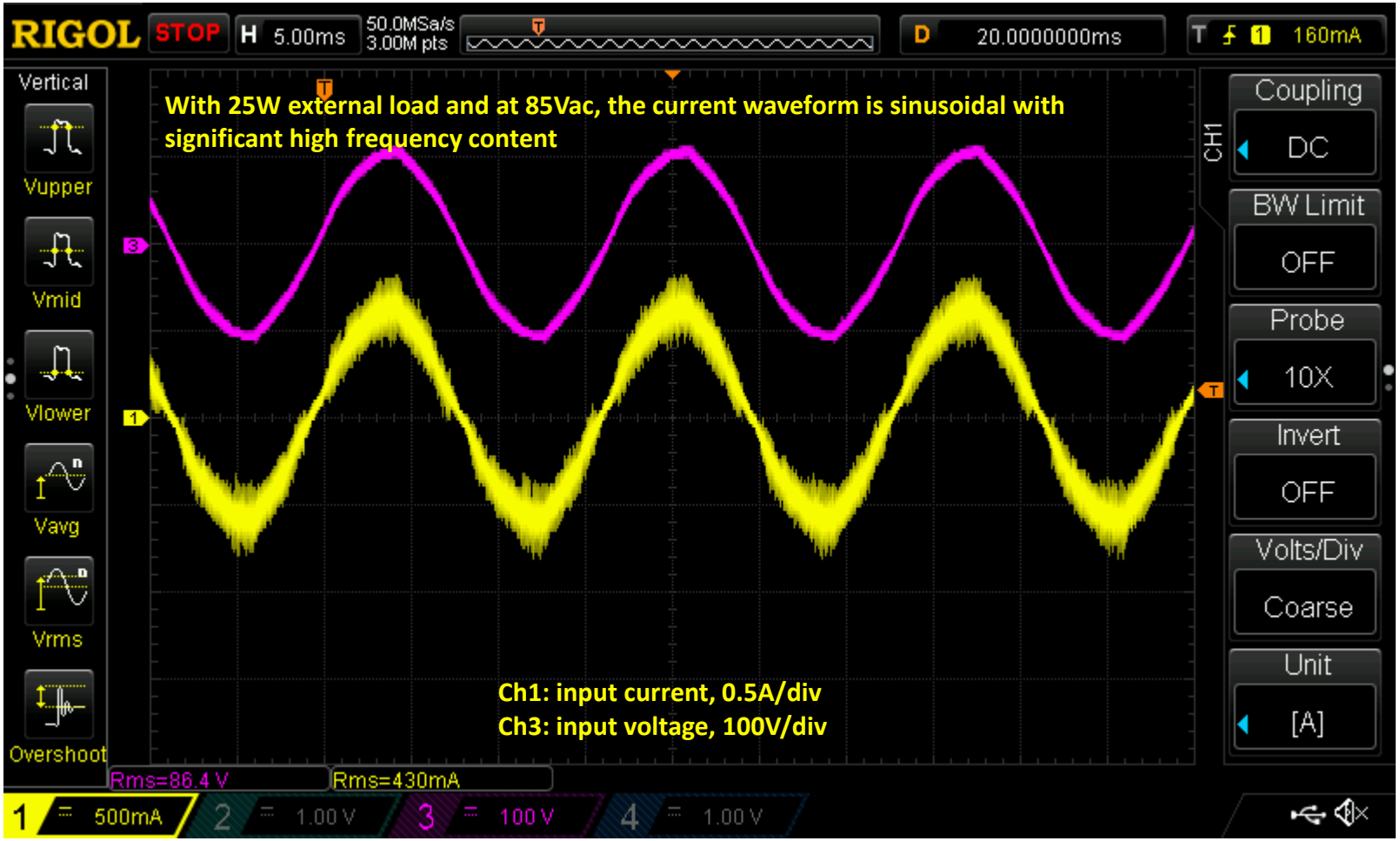


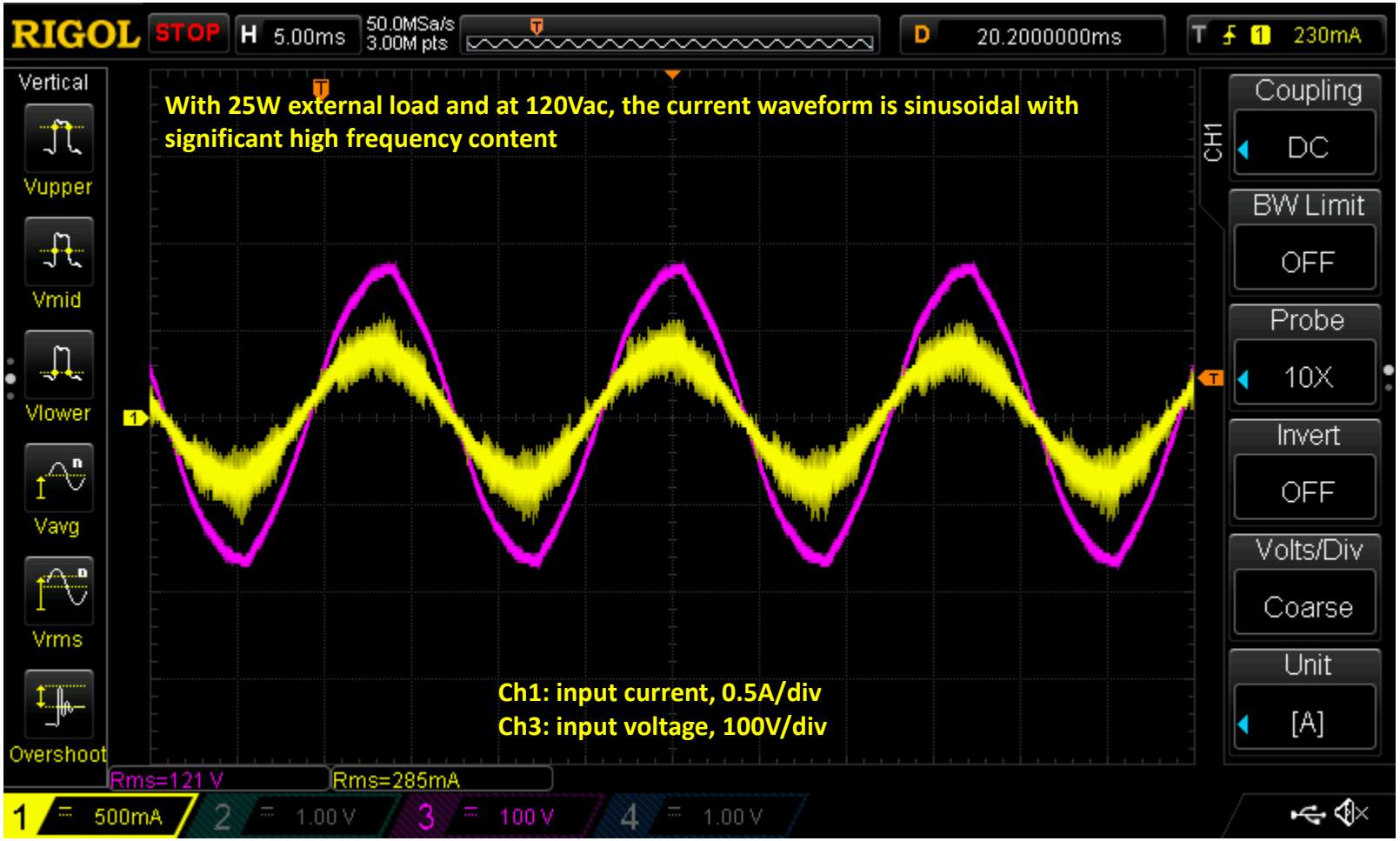
RefDes on data sheet	RefDes in design	values	Values on 12/11/2022
R1	R47+R50	766K	
R2	R43	0.22	**0.44**
R8/R12	R4/R9	3.16K	**2.74K**
R3	R44+R49	1124K	
R4	R60	22.1k	
C1	C32	150uF	
L1	L2	660uH	
R13	R10	15.8K	**55K (56K//3.3Meg)**
C6	C6	680pF	**233pF (200p//33p)**
C7	C8	150pF	**33pF**
R15	R11	30.1K	
C8	C9	4.7uF	
C10	C1	1.5uF	
C11	C2	150nF	
R21	R1	48.7K	
R14	R13	10K	
R7	R5	1.18K	**1.50K (3.3K//2.74K)**
C9	C4	1uF	

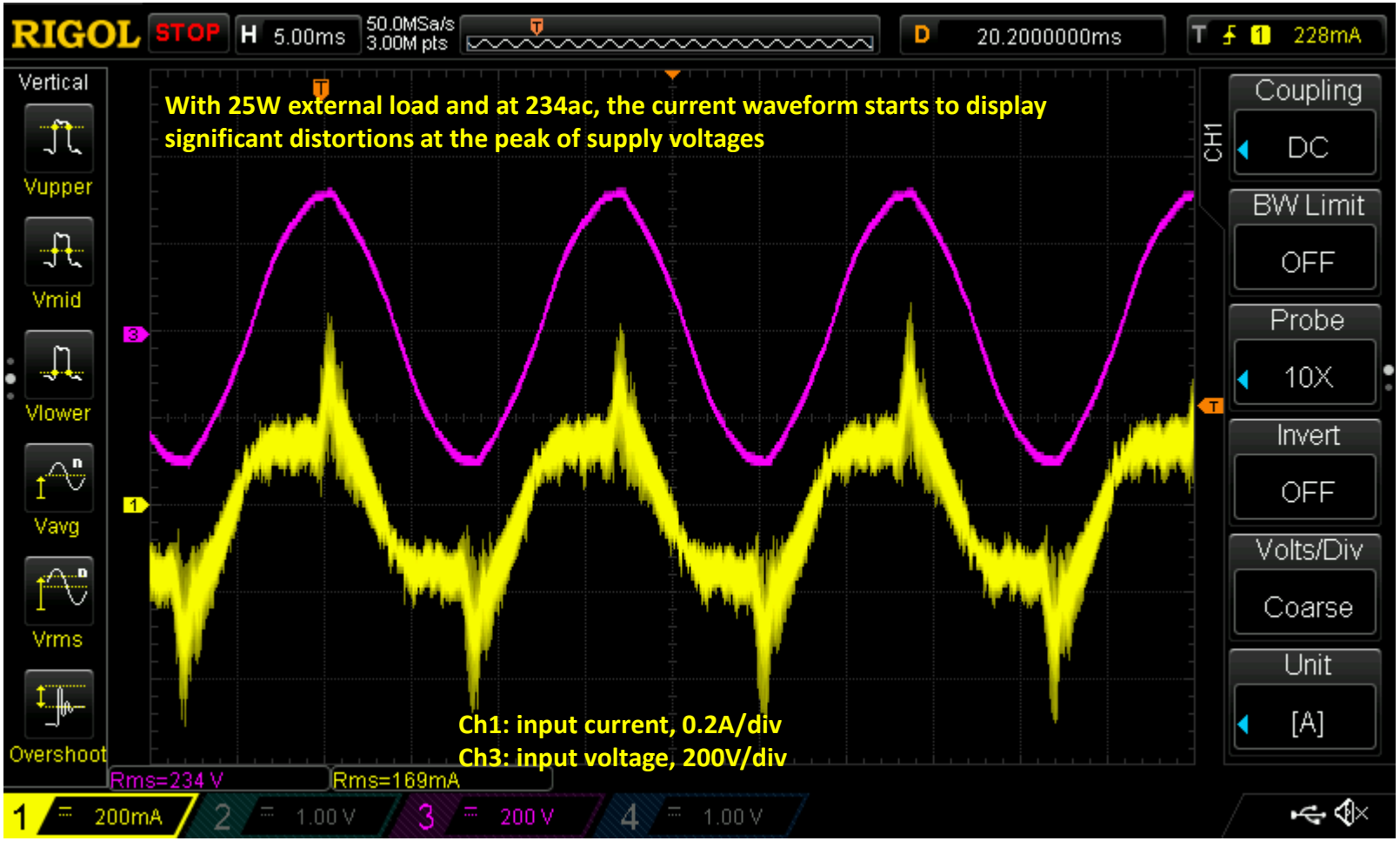
Changes made on 12/11 are highlighted


RIGOL
STOP
H 5.00ms
50.0MSa/s
3.00M pts
D -400.000000us
T 232 V
Vertical
Vupper
Vmid
Vlower
Vavg
Vrms
Overshoot
With no external load, input current at 270Vac input,
no major discontinuity at the peak of sine wave
Ch1: input current, 0.2A/div
Ch3: input voltage, 200V/div
Rms=270 V
Rms=83.1mA
1 200mA
2 1.00 V
3 200 V
4 1.00 V
CH3
Coupling
DC
BW Limit
OFF
Probe
100X
Invert
OFF
Volts/Div
Coarse
Unit
[V]


RIGOL
STOP
H 10.0ms
25.0MSa/s
6.00M pts
D 20.0000000ms
T 168mA
Vertical
Vupper
Vmid
Vlower
Vavg
Vrms
Overshoot
With no external load, input current at 270Vac input,
no major discontinuity at the peak of sine wave . However, random distortions at
the peak of sine wave were still present
Trigger
Type
Edge
Source
CH1
Slope
Sweep
Single
Setting
Ch1: input current, 0.2A/div
Ch3: input voltage, 200V/div
Rms=270 V
Rms=110mA
1 200mA
2 1.00 V
3 200 V
4 1.00 V


RIGOL
STOP
H 5.00ms
50.0MSa/s
3.00M pts
D 20.0000000ms
T 160mA
Vertical
Vupper
Vmid
Vlower
Vavg
Vrms
Overshoot
With 25W external load and at 85Vac, the current waveform is sinusoidal with significant high frequency content
Ch1: input current, 0.5A/div
Ch3: input voltage, 100V/div
CH1
Coupling
DC
BW Limit
OFF
Probe
10X
Invert
OFF
Volts/Div
Coarse
Unit
[A]
Rms=86.4 V
Rms=430mA
1 500mA
2 1.00 V
3 100 V
4 1.00 V


RIGOL
STOP
H 5.00ms
50.0MSa/s
3.00M pts
D 20.2000000ms
T 230mA
Vertical
Vupper
Vmid
Vlower
Vavg
Vrms
Overshoot
With 25W external load and at 120Vac, the current waveform is sinusoidal with significant high frequency content
Ch1: input current, 0.5A/div
Ch3: input voltage, 100V/div
Rms=121 V
Rms=285mA
1 500mA
2 1.00 V
3 100 V
4 1.00 V
CH1
Coupling
DC
BW Limit
OFF
Probe
10X
Invert
OFF
Volts/Div
Coarse
Unit
[A]


RIGOL
STOP
H 5.00ms
50.0MSa/s
3.00M pts
D 20.2000000ms
T 228mA
Vertical
Vupper
Vmid
Vlower
Vavg
Vrms
Overshoot
With 25W external load and at 234ac, the current waveform starts to display significant distortions at the peak of supply voltages
Ch1: input current, 0.2A/div
Ch3: input voltage, 200V/div
Rms=234 V
Rms=169mA
1 200mA
2 1.00 V
3 200 V
4 1.00 V
CH1
Coupling
DC
BW Limit
OFF
Probe
10X
Invert
OFF
Volts/Div
Coarse
Unit
[A]

Measuring inductor current vs gate voltages, 12/18

There are only two current probes at the moment:

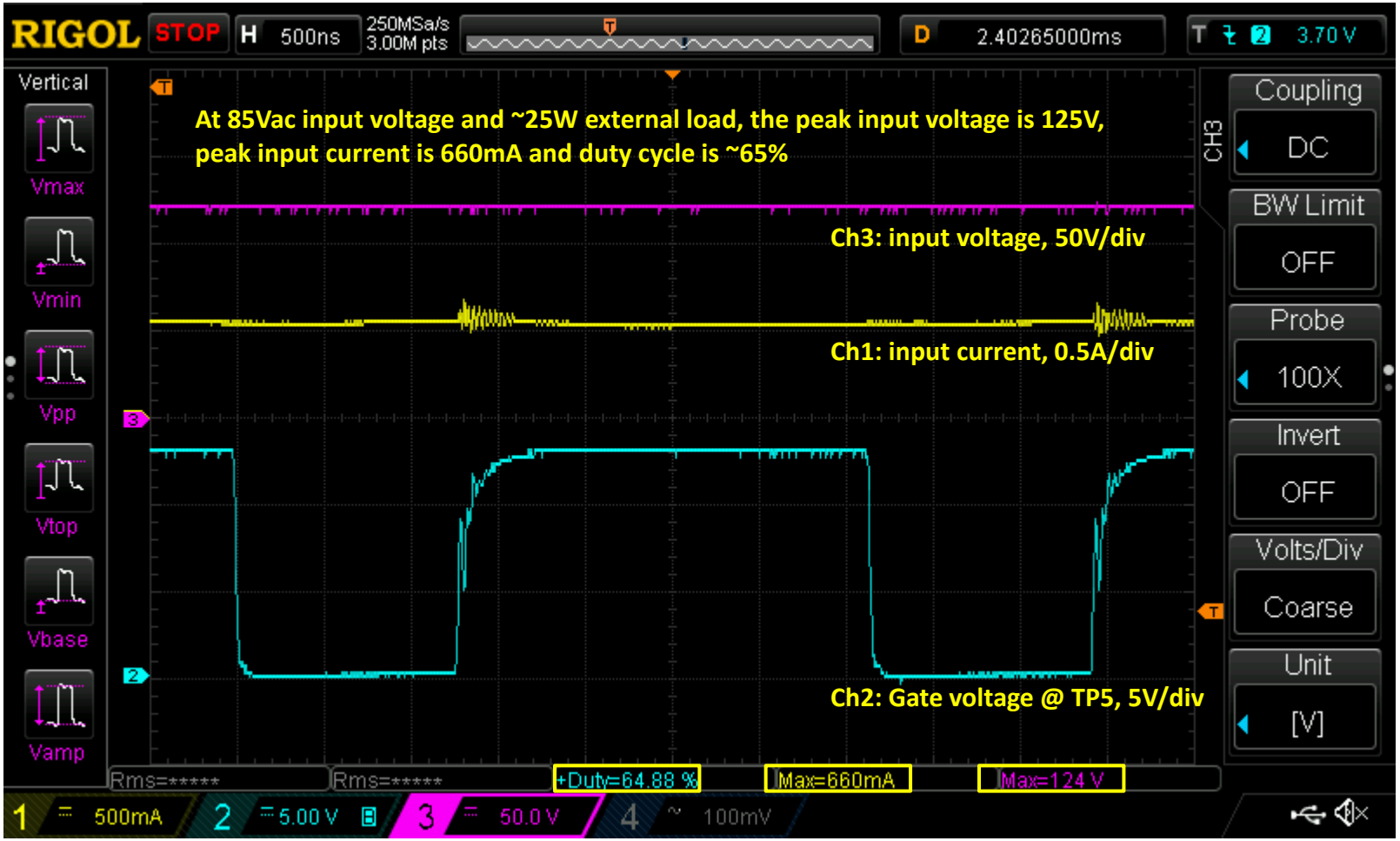
Ch1: Fluke 80i-110S has limited bandwidth and is used to measure 60Hz input current only.

Ch4: Rogowski probe, CWTUM-015-B, is used to measure the high frequency switching ripple only.

In addition, a 100mΩ and 20mΩ sense resistor was connected in series with inductor and the voltage across the resistor was measured with a differential probe. However, doing so resulted in further instability and distortion and therefore abandoned.

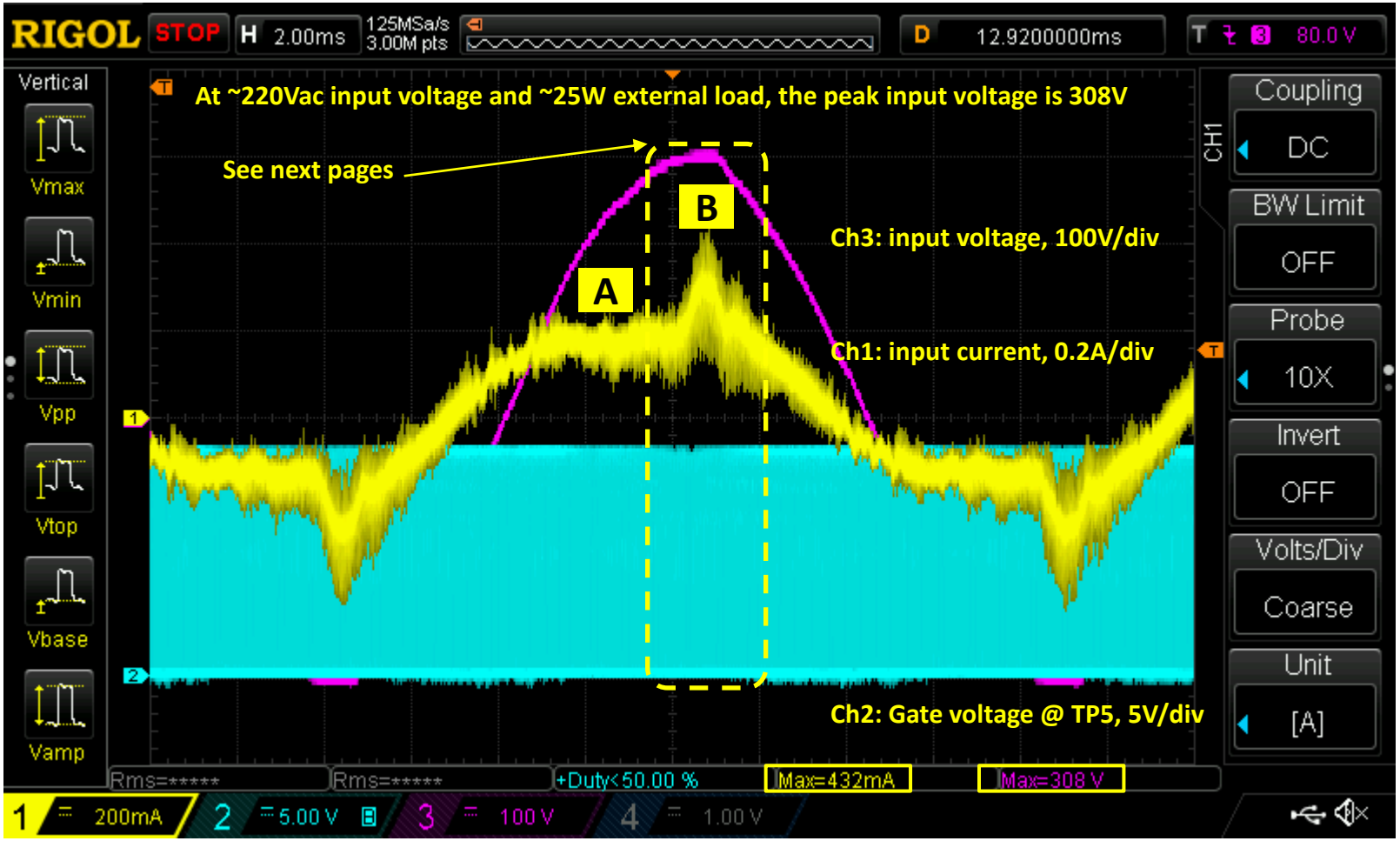
Measuring inductor current vs gate voltages, 12/18

Ch1: Current probe is Fluke 80i-110S, which has limited bandwidth and is used to measure 60Hz input current



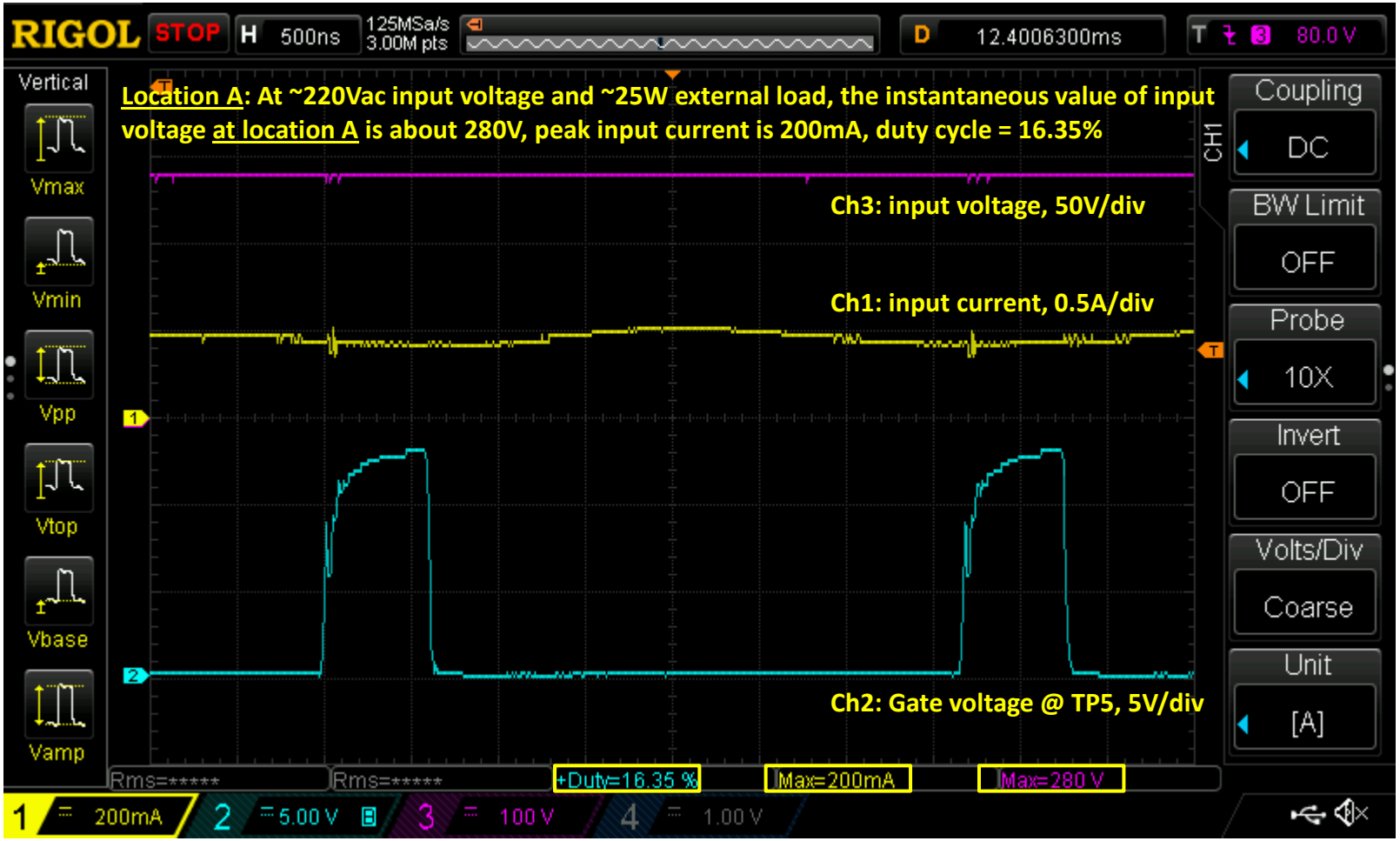
Measuring inductor current vs gate voltages, 12/18

Ch1: Current probe is Fluke 80i-110S, which has limited bandwidth and is used to measure 60Hz input current



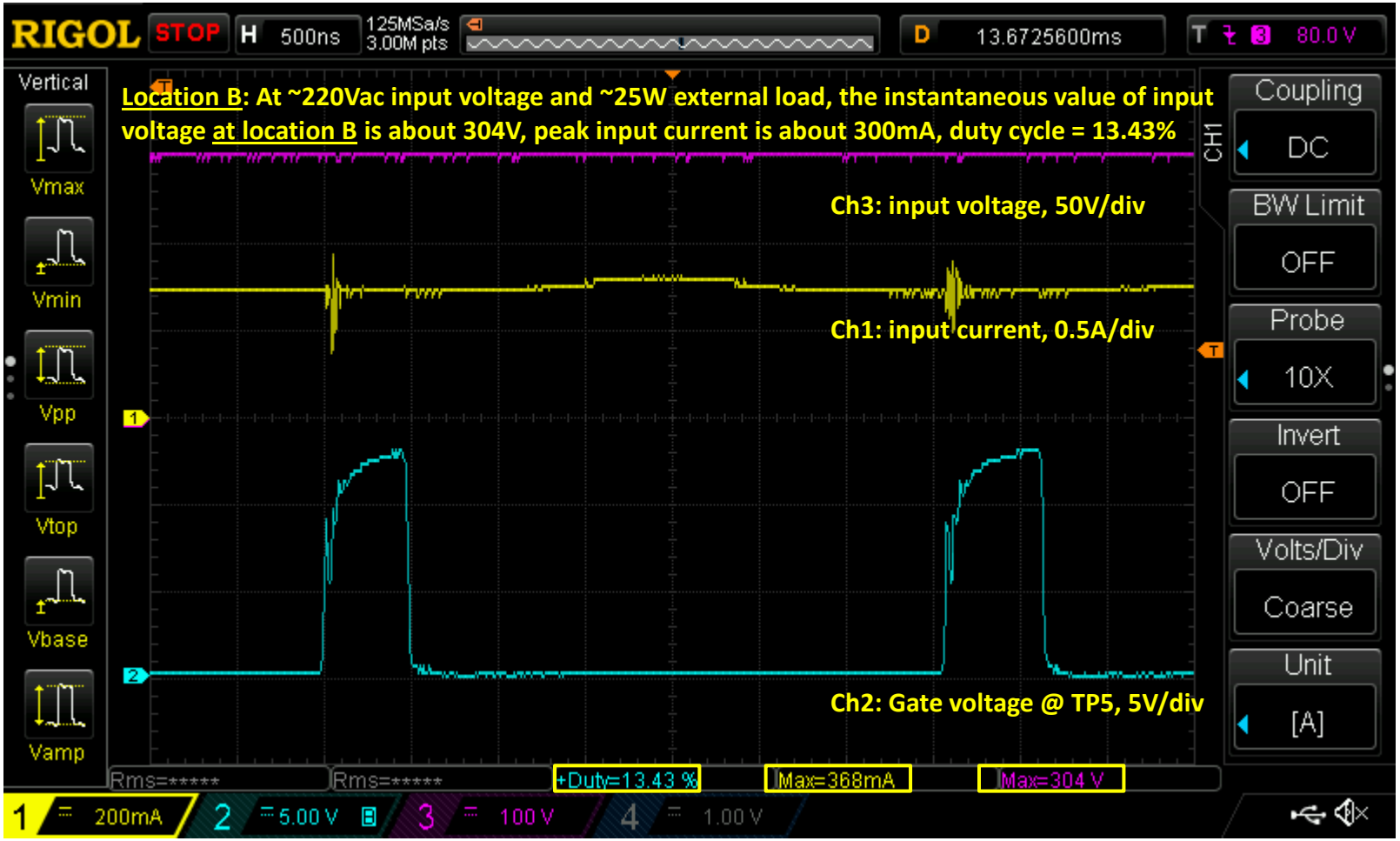
Measuring inductor current vs gate voltages, 12/18

Ch1: Current probe is Fluke 80i-110S, which has limited bandwidth and is used to measure 60Hz input current



Measuring inductor current vs gate voltages, 12/18

Ch1: Current probe is Fluke 80i-110S, which has limited bandwidth and is used to measure 60Hz input current

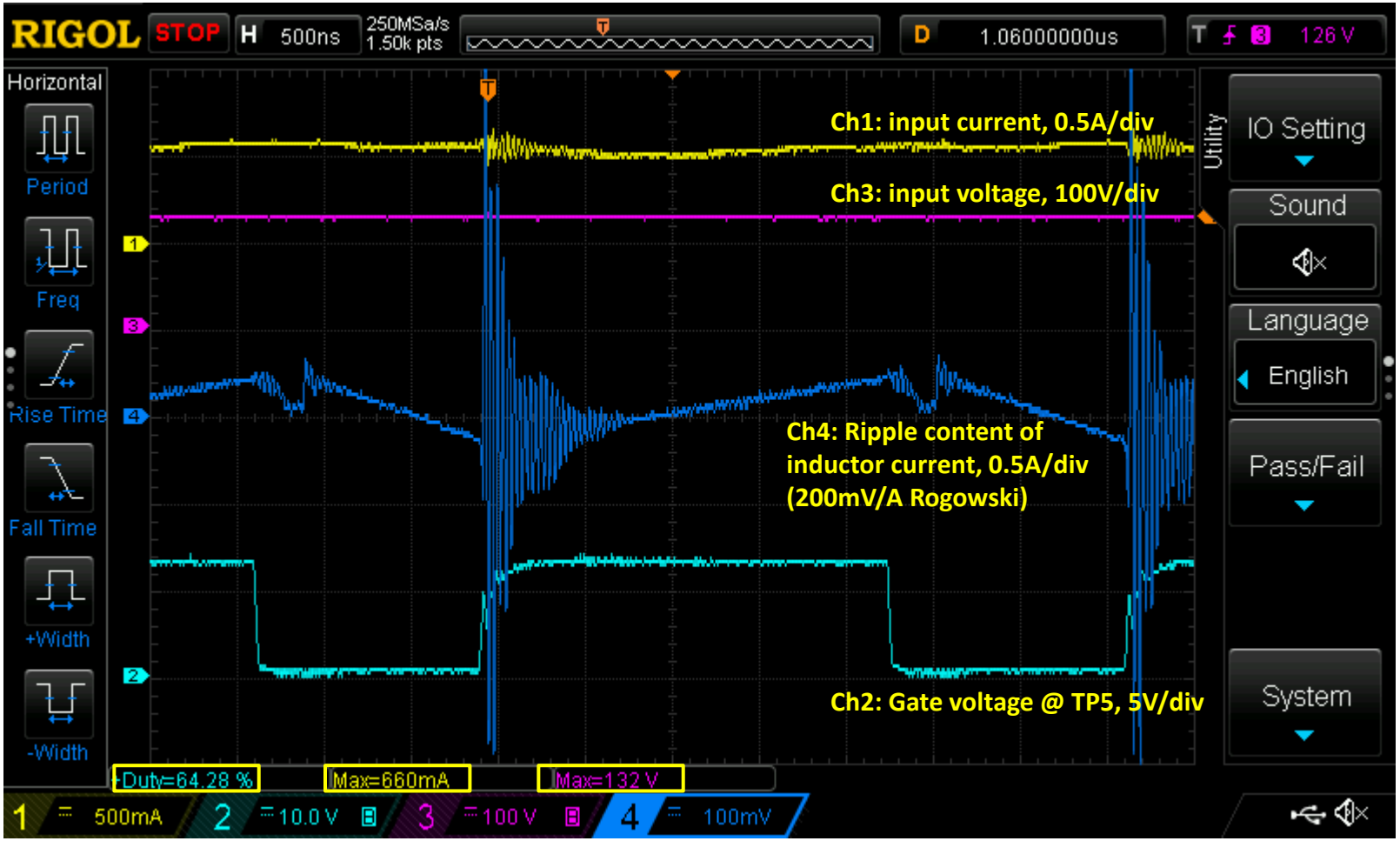


Measuring inductor current vs gate voltages, 12/18

Ch1: Current probe is Fluke 80i-110S, which has limited bandwidth and is used to measure 60Hz input current

Ch4: Current probe is Rogowski CWTUM-015-B, which can measure high frequency only.

At the peak of 85Vac input voltage and ~25W external load, the instantaneous value of input voltage is 132V, peak input current is 660mA, duty cycle = 64.28%



Measuring inductor current vs gate voltages, 12/18

Ch1: Current probe is Fluke 80i-110S, which has limited bandwidth and is used to measure 60Hz input current

Ch4: Current probe is Rogowski CWTUM-015-B, which can measure high frequency only.

At the peak of 220Vac input voltage and ~25W external load, the instantaneous value of input voltage is 312V, peak input current is ~300mA (location B), duty cycle is about 14.2%