Imagine it. Build it. Control it.™

LSS Pro
Power Stages

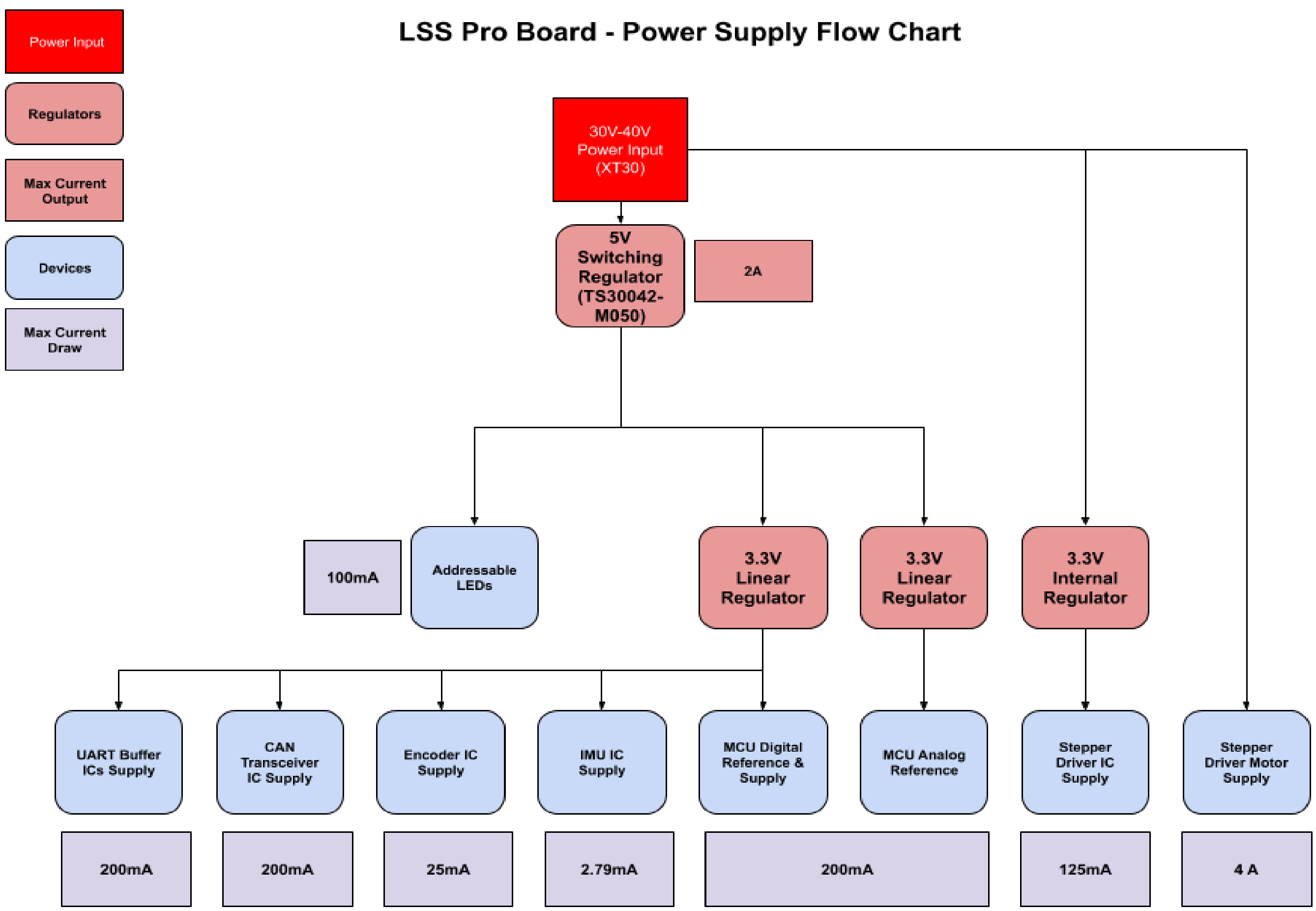
Goal

The PRO Controller PCB will have LEDs that are 5V powered and different ICs that are 3.3V powered (MCU, IMU, Enocder, Tri-state Buffers, etc..). The main power input of the PRO would be 30V-40 to power the stepper driver IC and the stepper motor. Therefore, we need to convert the main power input to a steady 5V and 3.3V which we can use for the different components mentioned above and an accurate 3.3V reference for the analog reference to obtain steady and accurate analog sensors measurements (voltage, temperature, current, etc..).

Proposed Solution (4 power stages) :

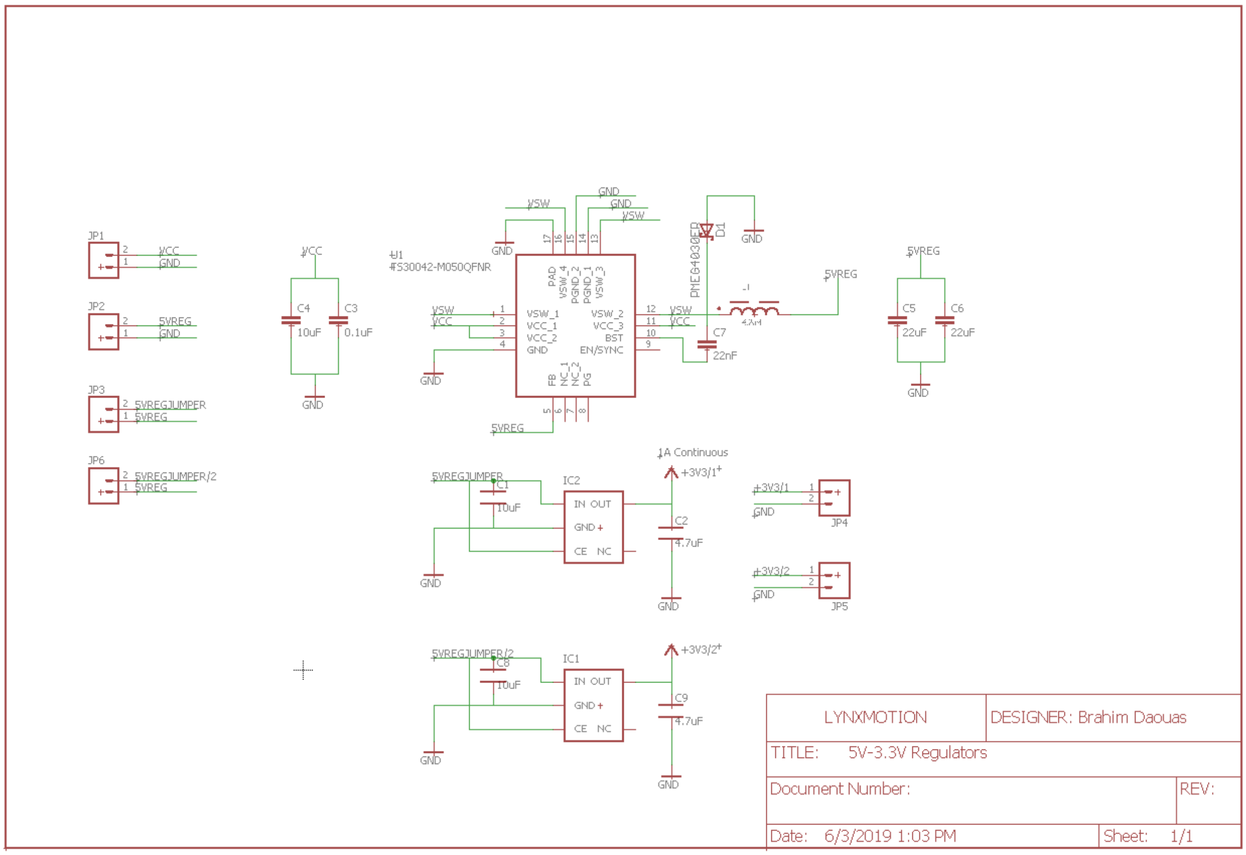
The main 30V-40V power supply (Stage 1) will directly power the stepper driver for motor supply and the logic power of the stepper driver through its internal regulators. The main power will also convert to 5V through a 5V/2Amps switching regulator (buck converter). A buck converter (Stage 2) has been chosen for efficiency reasons as using a linear to convert 40V to 5V will have about 87.5% power loss. The 5V switching regulator output will be converted to 3.3V through two separate 3.3V linear regulators (Stage 3) : one 3.3V output will be used to power

the MCU and a second 3.3V regulator to power the other 3.3V operating ICs (IMU, Encoder, buffers, CAN Transceiver, etc..). The output of the 5V switching regulator will also power the RGB Addressable LEDs. A 3.3V voltage reference chip will be used for the analog reference input of the MCU (Stage 4).
All the above is summarized in the following flow chart :

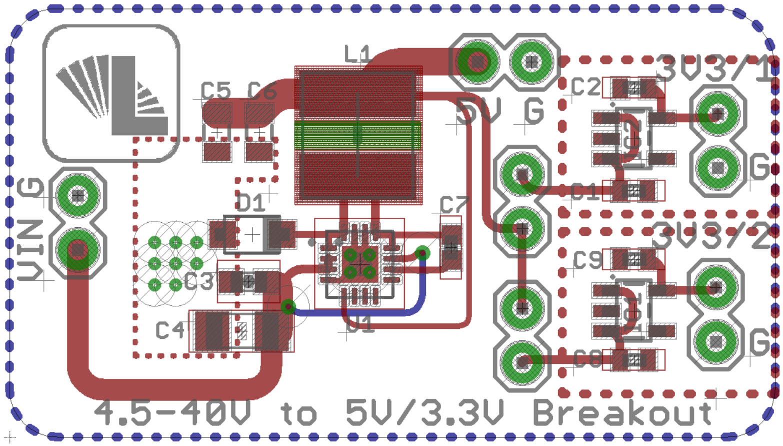


Pre-prototype V1 Design

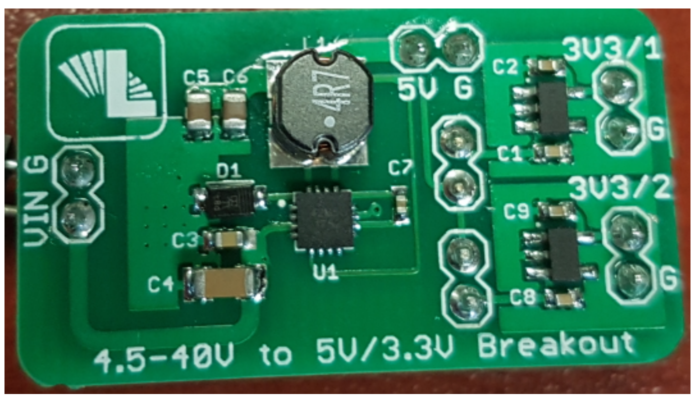
For testing purposes, we decided to design a breakout board for a 5V switching regulator in cascade with 2x 3.3V linear regulators. The 5V switching regulator chosen was the **TS30042-M050QFNR** which is a DC/DC synchronous fixed 5V switching regulator with 2A maximum current output, fully integrated power switches, internal compensation, and full fault protection. The switching frequency of 1MHz enables the use of smaller components resulting in minimal board space and reduced BOM costs. The 3.3V linear regulator chosen is the **XC6222B331** which is a highly accurate, low noise, high ripple rejection, low dropout, and low power consumption high speed CMOS voltage regulator with 700mA maximum current output and 120mV @ Iout = 300mA dropout voltage and 65dB @ 1 KHz ripple rejection.



Schematic of the 5V/3.3V Regulators Breakout (Pre-prototype V1)



PCB Layout of the 5V/3.3V Regulators Breakout (Pre-prototype V1)



Assembled 5V/3.3V Regulators Breakout (Pre-prototype)

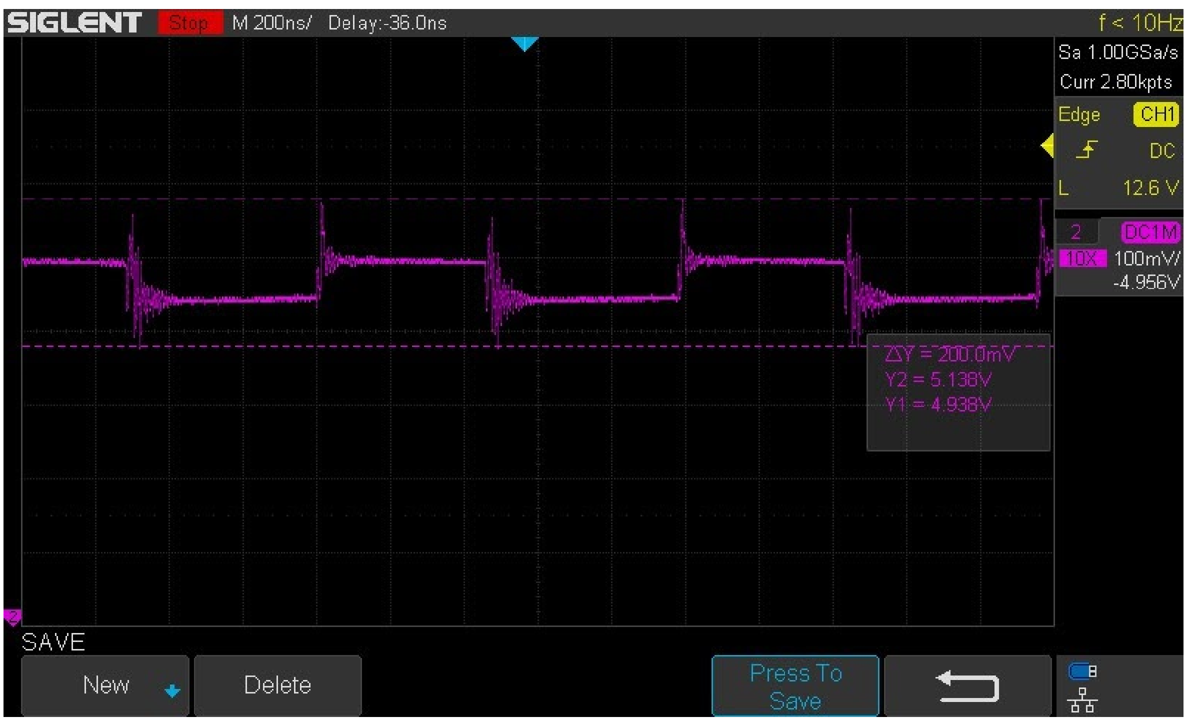
Tests

5V Switching/Buck TS30042-M050QFNR

Regulator	Voltage Input (V)	Current Input (mA)	Load (mA)	Load (Ohms) V/I	Voltage Output RMS (V)	Voltage Output Max (V)	Voltage Output Min (V)	Efficiency (%)	Temperature (°C)
5V (TS30042-M050QFNR)	10	280	500	≈10	5.04	5.2	4.8	90.00%	32
	20	150	500	≈10	5.01	5.2	4.8	83.50%	40

2Amps max current	30	100	500	≈10	5.02	5.2	4.8	83.67%	46
	10	530	1000	≈5	5.05	5.4	4.8	95.28%	39
	20	270	1000	≈5	5.02	5.4	4.8	92.96%	49
	30	190	1000	≈5	5.02	5.2	4.8	88.07%	66
	10	1100	1500	≈3.33	5.01	5.4	4.6	68.32%	74
	20	560	1500	≈3.33	5	5.2	4.6	66.96%	95
	30	390	1500	≈3.33	5	5.4	4.6	64.10%	127

TS30042 5V Output (Vin = 10V, 550mA load) :

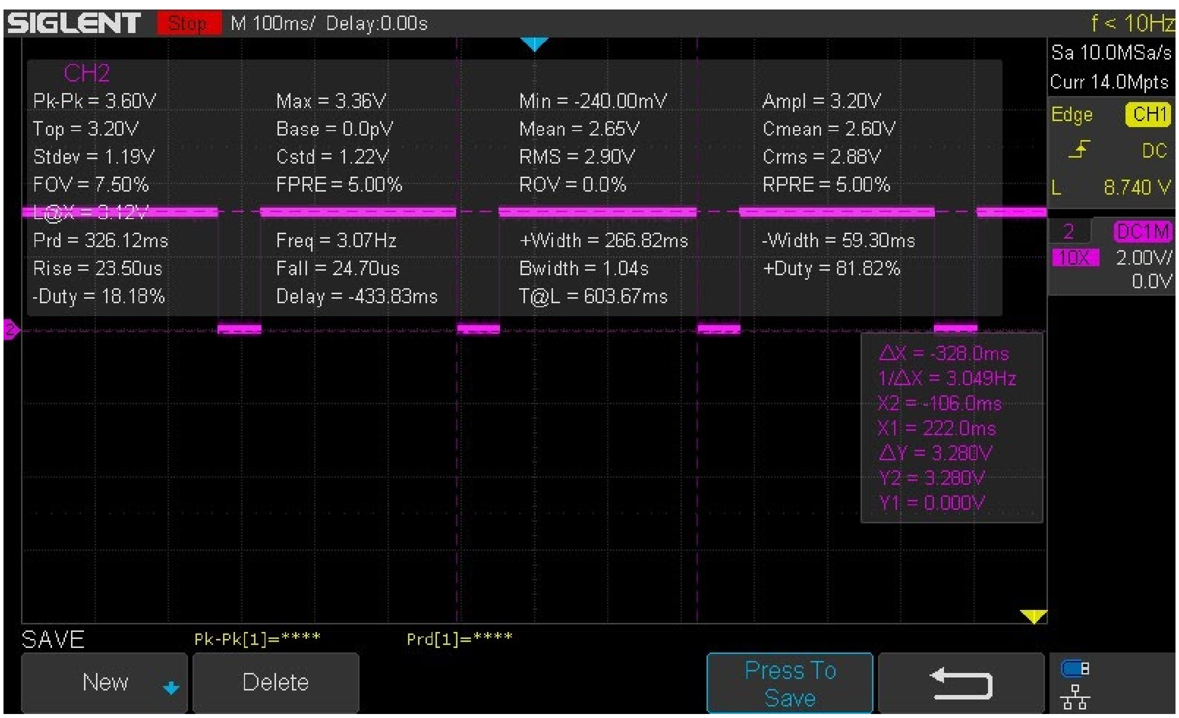


1MHz switching frequency with a 200mV pk-pk

We can also notice a ringing effect on the output which is caused by the switching regulator's output inductor that has a parasitic capacitance that forms a resonant circuit at a high frequency. With a Vin = 30V and 1000mA load, the TS30042 has a 5.02V RMS output and 88% efficiency which is acceptable for our application. The ringing effect at 1MHz with a 200mV pk-pk is also acceptable.

3.3V Linear TS30042-M050

XC6222B331 3.3V Output cascaded directly with the TS30042 with a 550mA load :



We noticed based on the above picture that the XC6222 is shutting down due to thermal dissipation performance.
With the TS30042 5V as input, the XC6222 temperature rise up to 102°C in about 2 seconds and starts cutting-off after 5 seconds.
We have tested the XC6222 with a fully charged Li-on battery cell (4.2V input) and we noticed that the XC6222 is not cutting-off and reaches a steady temperature of about 60°C.
Therefore, we concluded that the TS30042 switching regulator 5V output has a negative effect on the XC6222 performances.

Thermal Dissipation Calculations :
The XC6222 LDO has a thermal shut down circuit inside and the circuit should be activated and cut off the voltage regulation.
VIN: 5V
VOUT: 3.3V
IOUT: 550mA

- Ploss: (5v-3.3v) x 550mA = 935mW

Page. 24 in datasheet indicates the power dissipation performance of XC6222 (SOT-23-5) + a specific PCB pattern.
The power dissipation limit at 25 deg. is 600mW.

Under their condition, mathematically the power loss is over a power dissipation performance of XC6222 (SOT-23-5)
On the other hands, SOT-89 package supports 1300mW at 25 degree C ambient temperature based upon the page 25 out of 27 on the attached data sheet.
It also makes sense that on the 2nd test with the 4.2V input, the 3.3V regulator would run cooler.

Total power dissipation = Ploss: (5v-3.3v) x 550mA = 935mW
Total power dissipation = Ploss: (4.2v-3.3v) x 550mA = 495mW

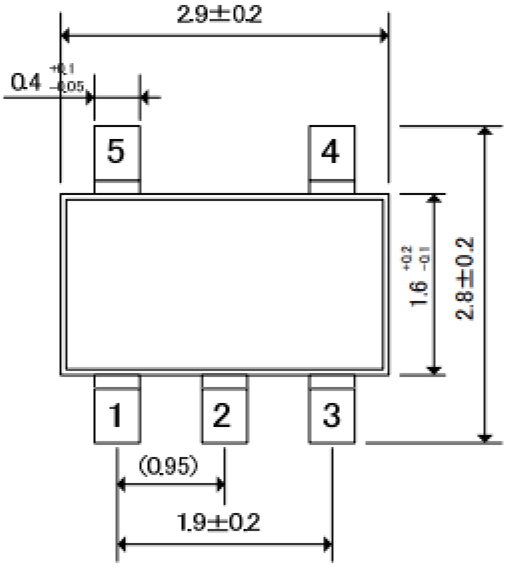
We also need to reduce the peak ripple voltage to a minimum

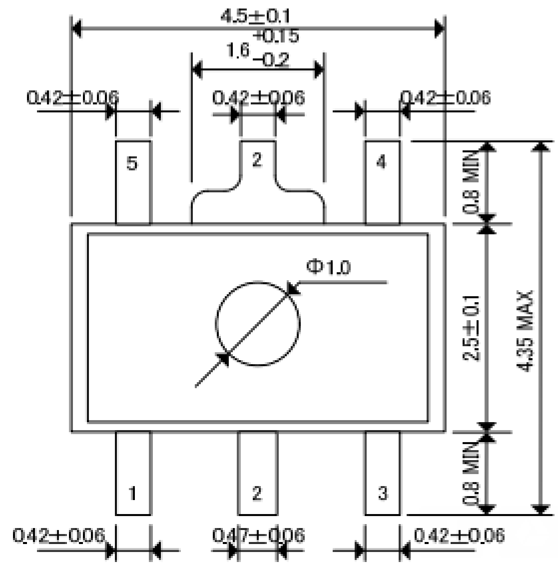
Therefore, 3 possible solutions will need to be verified :

- Replace the 3.3V package from SOT-25 to SOT-89

●SOT-89-5

●SOT-25



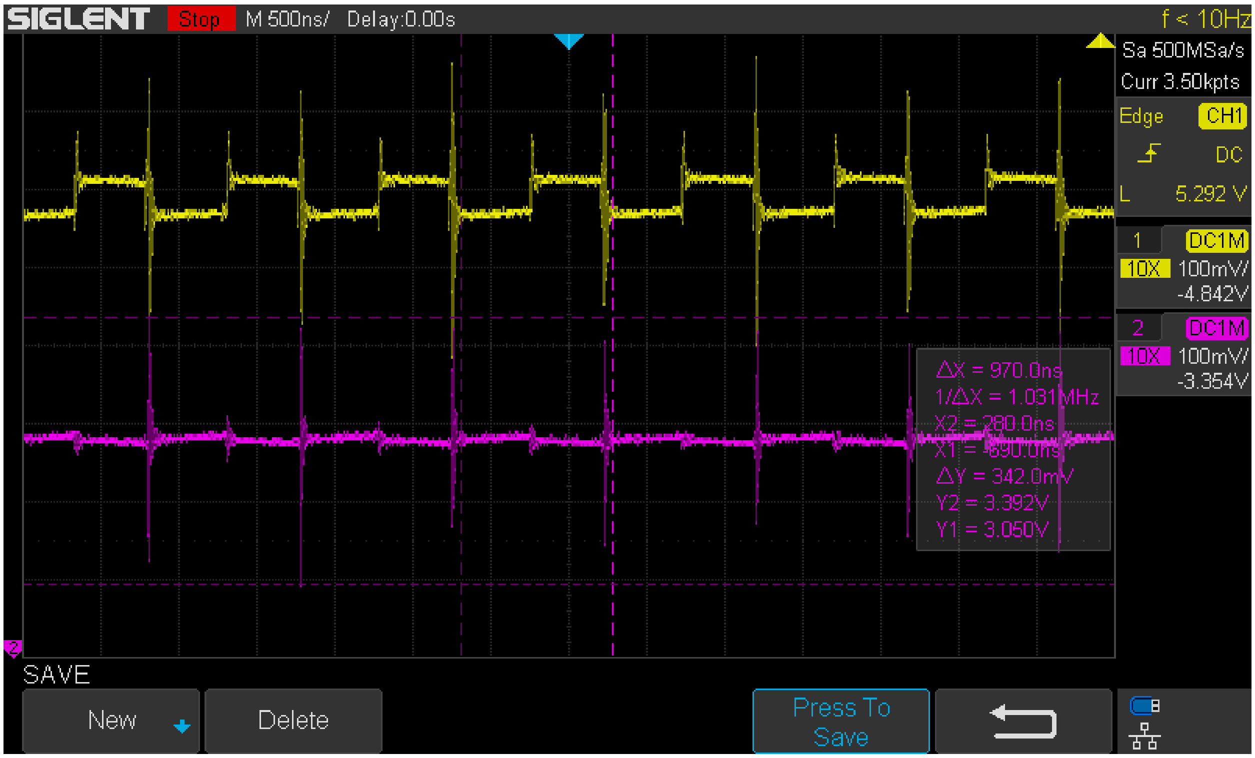


- Reduce the output of the 1st stage buck regulator (TI:TS30042) to 3.6Volts. The drop voltage from E2 on page 7 of the datasheet is 200mV max. This would reduce the Total power dissipation to: Ploss: (3.6v-3.3v) x 550mA = 165mW
- Reduce the 1MHz voltage ripples from the 1st stage switching regulator to a minimum with a chip bead/inductor in between the 1st stage and 2nd stage regulators

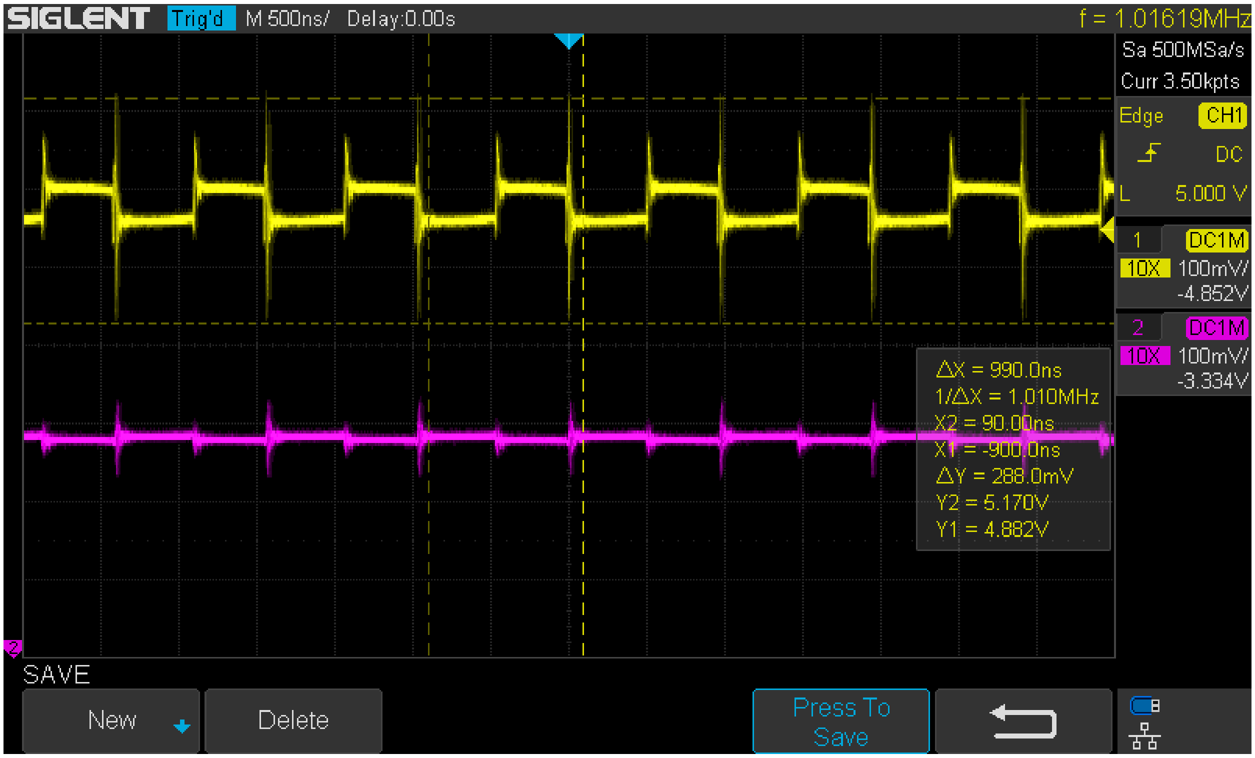
3rd Solution Tests :

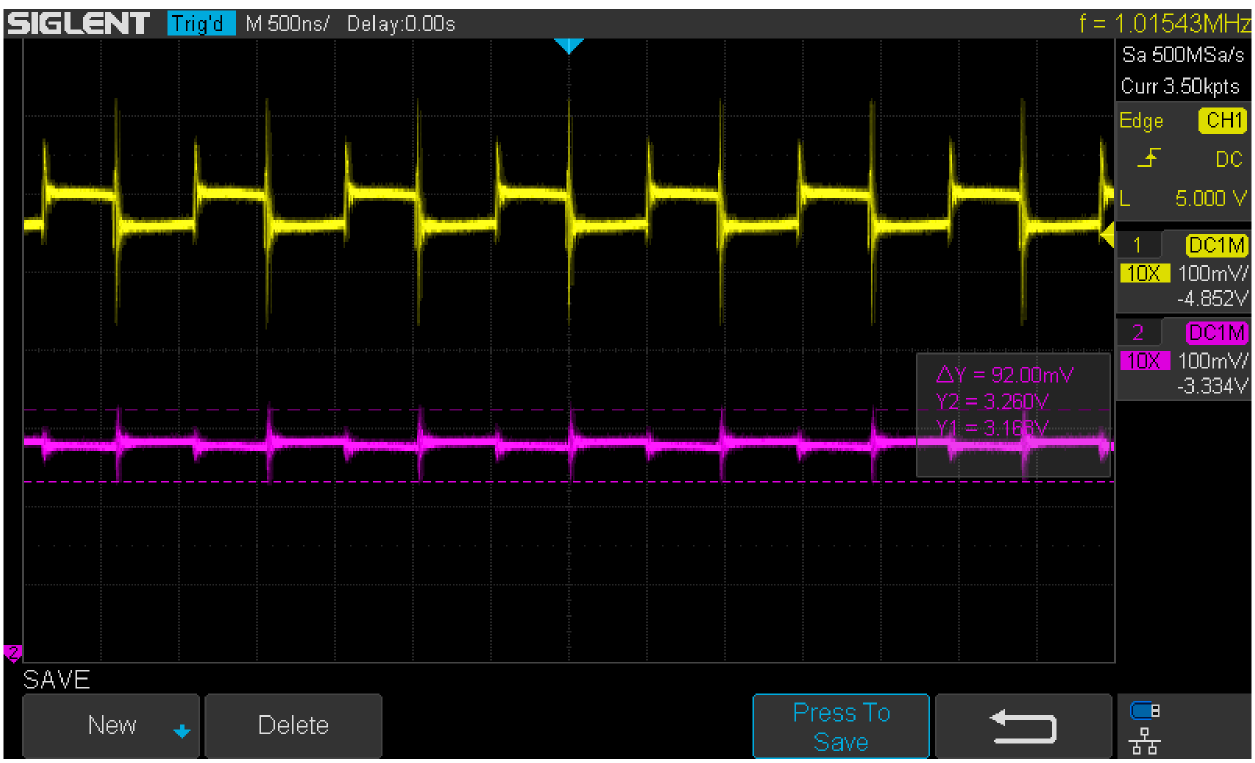
Tested 2 different inductors soldered between the 1st stage and 2nd stage regulators :

- RLB0912-102KL :
  https://www.digikey.ca/product-detail/en/bourns-inc/RLB0912-102KL/RLB0912-102KL-ND/2352768
  Inductance : 1mH
  Current Rating (Amps) : 400mA
  Current - Saturation : 350mA
  DC Resistance (DCR) : 4.3Ohm Max
  Q @ Freq : 55 @ 252kHz
  Frequency - Self Resonant : 1.9MHz

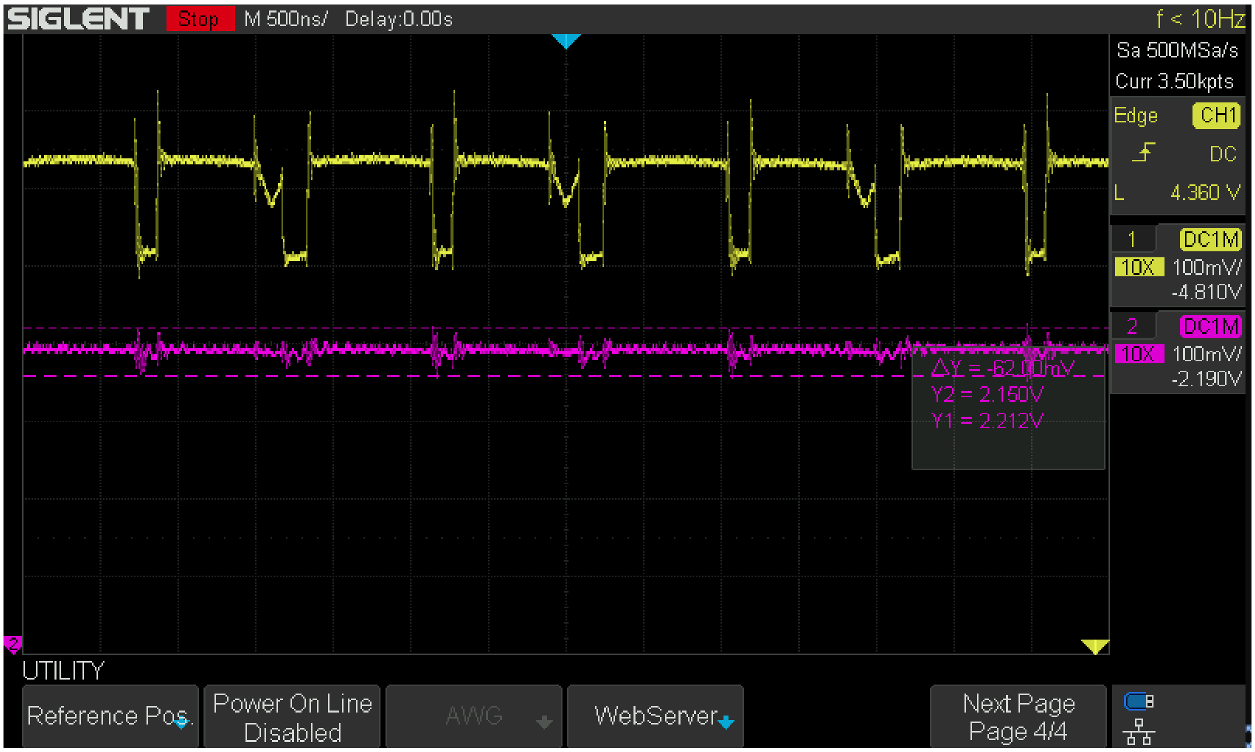


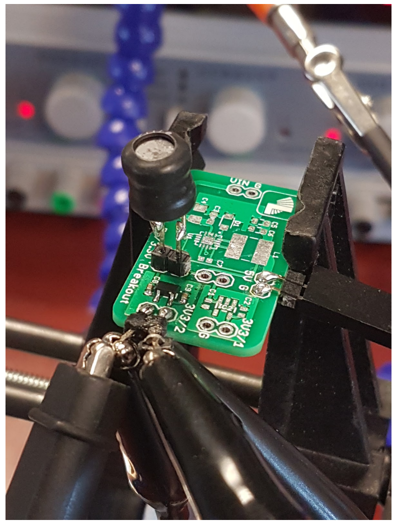
- RL895-102K-RC : https://www.digikey.ca/product-detail/en/bourns-inc/RL895-102K-RC/RL895-102K-RC-ND/3193297
  Inductance : 1mH
  Current Rating (Amps) : 300mA
  DC Resistance (DCR) : 1.84Ohm Max
  Q @ Freq : 40 @ 252kHz
  Frequency - Self Resonant : 1.3MHz


SIGLENT
Trig'd
M 500ns/
Delay:0.00s
f = 1.01619MHz
Sa 500MSa/s
Curr 3.50kpts
Edge
CH1
DC
L
5.000 V
1
DC1M
10X
100mV/
-4.852V
2
DC1M
10X
100mV/
-3.334V
ΔX = 990.0ns
1/ΔX = 1.010MHz
X2 = 90.00ns
X1 = -900.0ns
ΔY = 288.0mV
Y2 = 5.170V
Y1 = 4.882V
SAVE
New
Delete
Press To Save

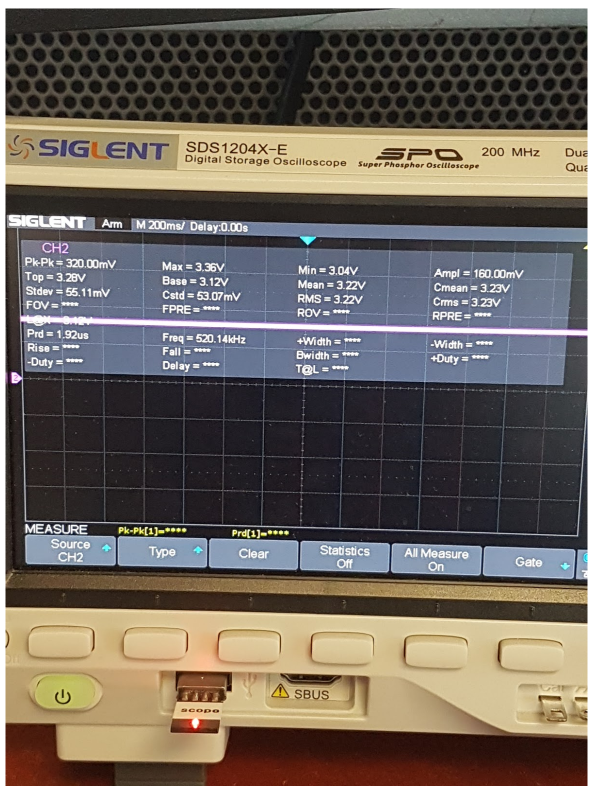

SIGLENT
Trig'd
M 500ns/
Delay:0.00s
f = 1.01543MHz
Sa 500MSa/s
Curr 3.50kpts
Edge
CH1
DC
L
5.000 V
1
DC1M
10X
100mV/
-4.852V
2
DC1M
10X
100mV/
-3.334V
ΔY = 92.00mV
Y2 = 3.260V
SAVE
New
Delete
Press To Save

3.3V output (purple) / 5V (yellow) with input & output inductors (Vin = 30V and 550mA load) :

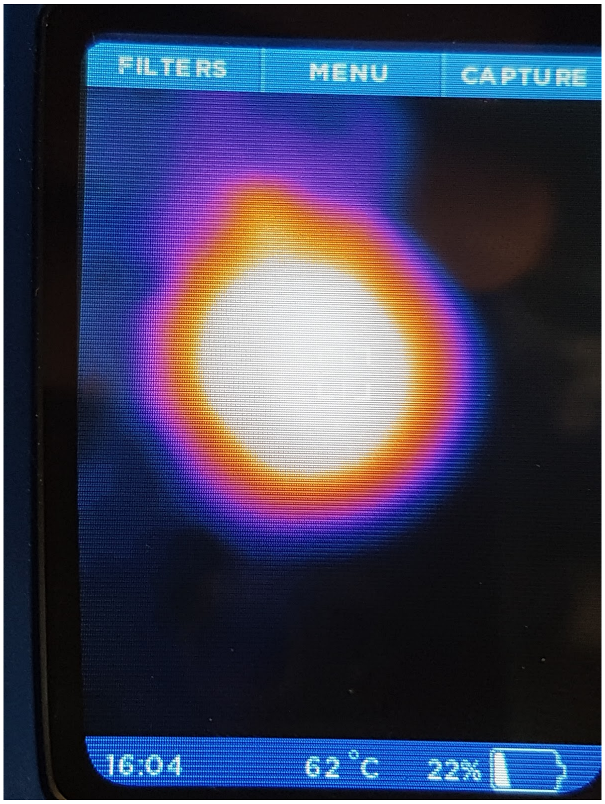




Adding 1mH inductor in series with the 3.3V linear regulator input



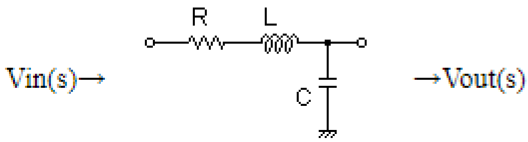
3.3V linear regulator output results with the inductor



3.3V linear regulator operating temperature with the inductor

With an LC low pass filter (formed by the inductor in between the 2 regulators and the input capacitor of the 3.3V regulator), the 1MHz ripples are slightly attenuated but most importantly, the 3.3V regulator doesn't cut-off anymore :

The LC Low pass filter created has the following characteristics :



Transfer Function:

$$G(s)=\frac{100000000}{s^2+50000s+100000000}$$

Cut-off frequency

fc = 1591.549430919[Hz]

Quality factor

Q = 0.2

Damping ratio

$\zeta = 2.5$

Pole(s)

p = -332.17570757239[Hz]

$|p|$= 332.17570757239[Hz]

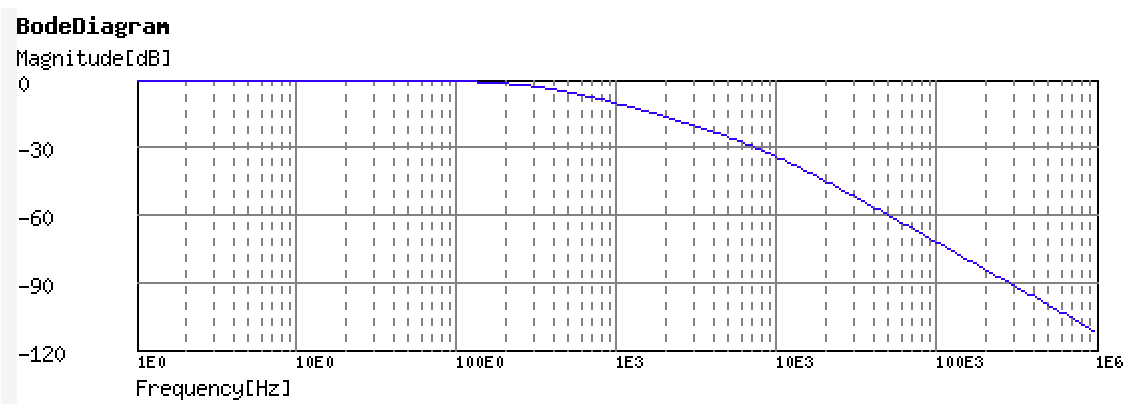
p = -7625.5714470224[Hz]

$|p|$= 7625.5714470224[Hz]

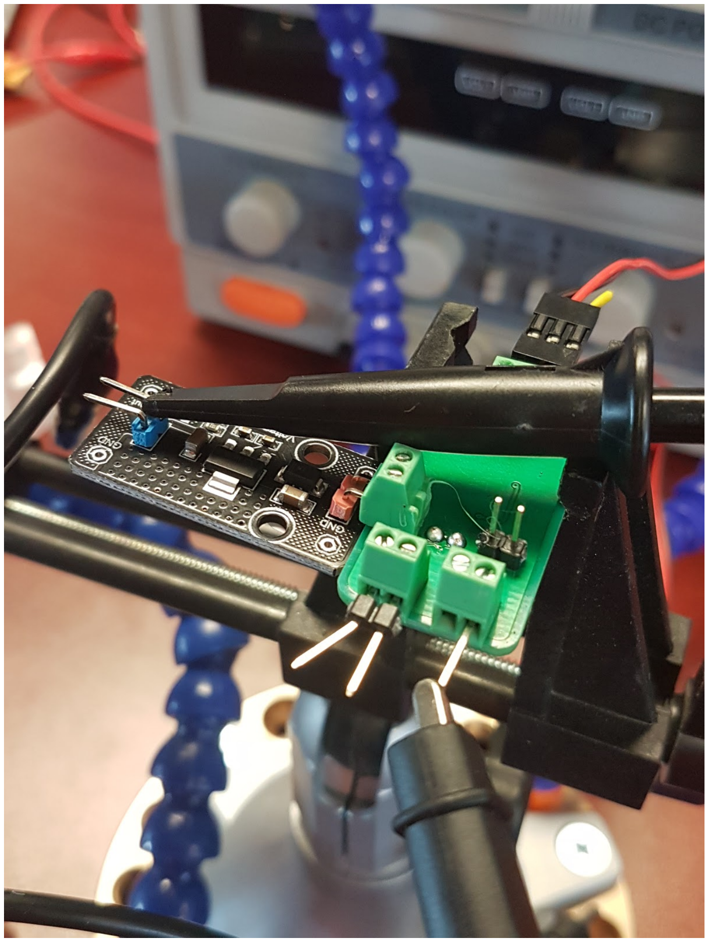
Phase margin

pm= INF[deg] (f =0[Hz])

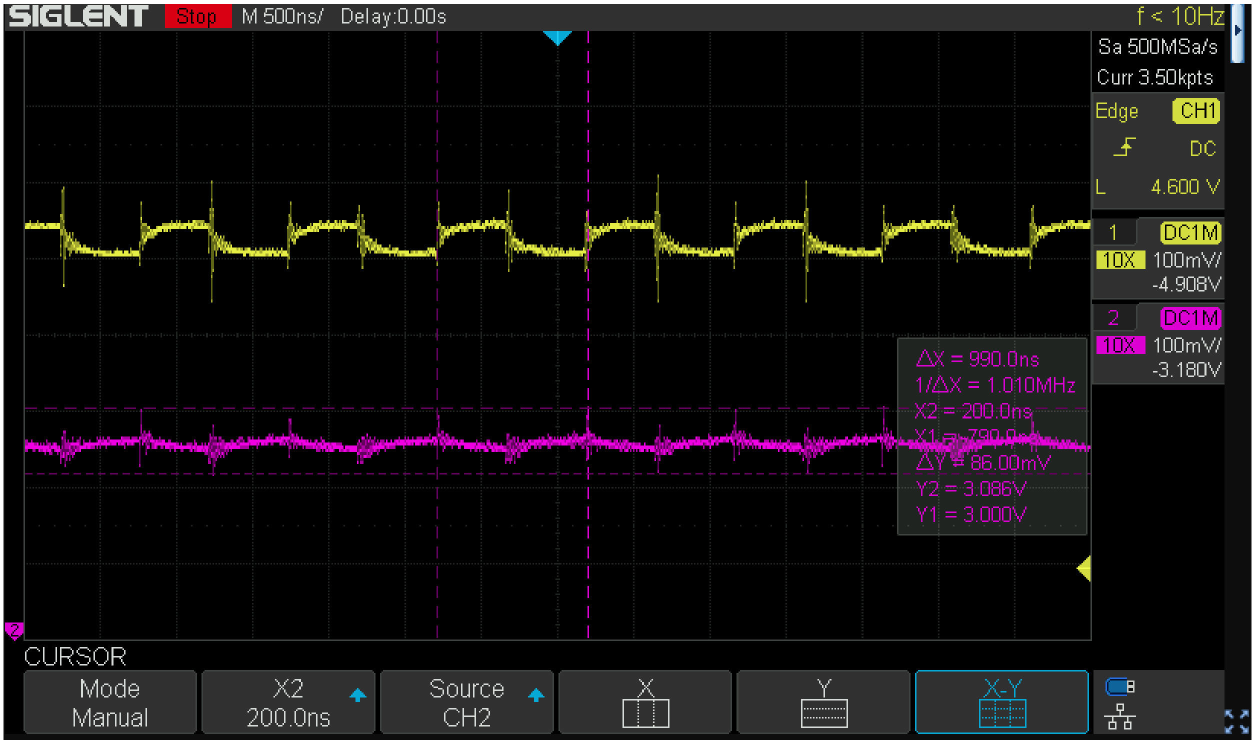
Bode diagram



Replaced the XC6222 3.3V regulator with the AMS1117 3.3V regulator which we connected to the 5V switching regulator on the pre-prototype V1 board :



The AMS1117 3.3V doesn't cut-off on temperature and the pk-pk ripples are more attenuated. However, the AMS1117 has more voltage drop compared to the XC6222 with a 550mA load :
AMS1117 3.3V output (purple) / 5V (yellow) (Vin = 10V and 550mA load) :

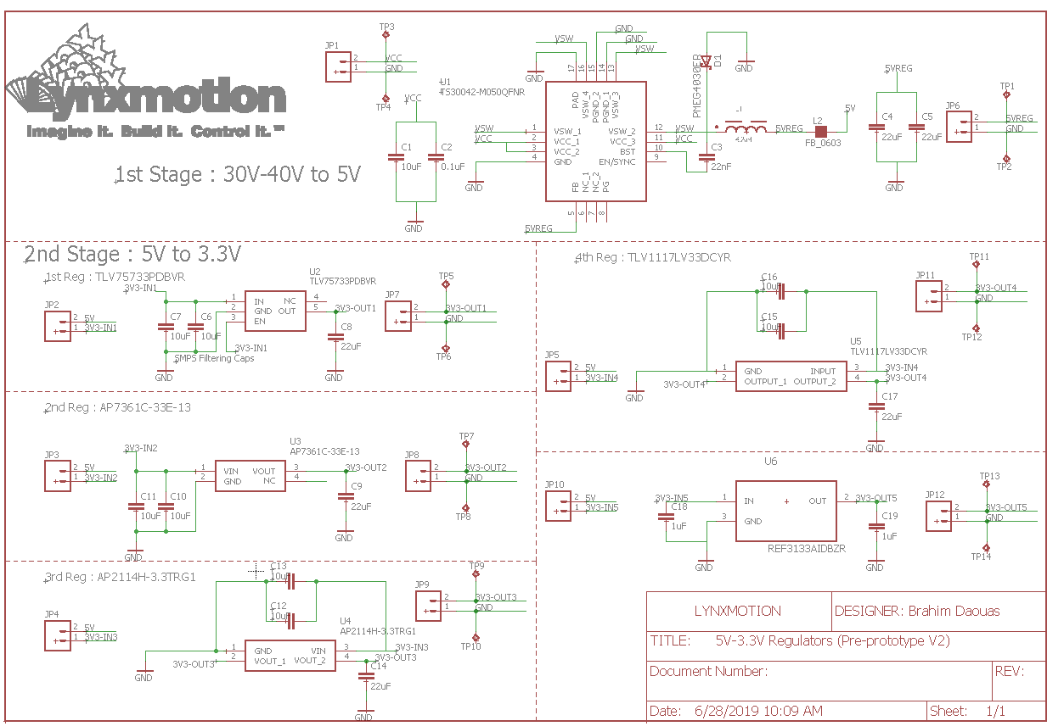


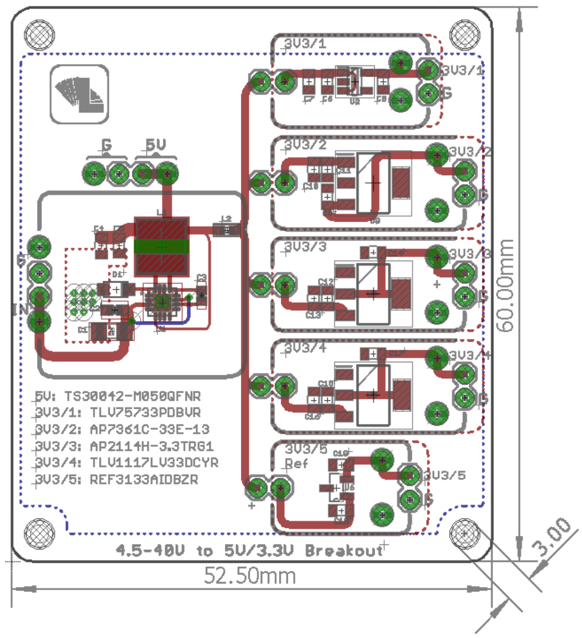
With these tests we have concluded that the XC6222 3.3V linear regulator is not efficient for our application. Therefore, a pre-prototype V2 will have to be designed with several others 3.3V linear regulators to be tested in cascade with the 5V switching regulator.

Pre-prototype V2 Design

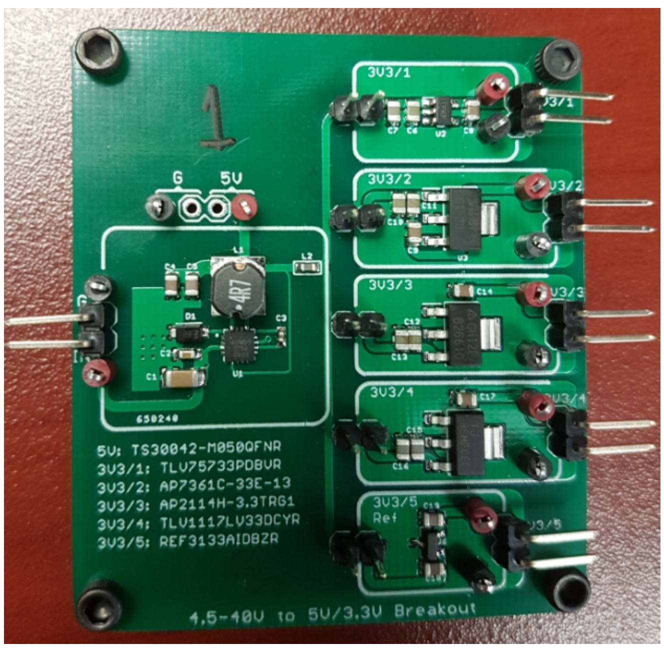
Next step was to test several 3.3V regulators in cascade with the 5V switching regulator. For this purpose, we developed a new board Pre-prototype V2 with the following 3.3V regulators :

Manufacturer Part Number	Voltage - Input (Max)	Current - Output	PSRR	Voltage Dropout (Max)	Supplier Device Package	Datasheet
TLV75733PDBVR	5.5V	1A	52dB (1kHz ~ 1MHz)	0.475V @ 1A	SOT-23-5	http://www.ti.com/lit/ds/symlink/tlv757p.pdf
AP7361C-33E-13	6V	1A	75dB ~ 55dB (1kHz ~ 10kHz)	0.36V @ 1A	SOT-223	https://www.diodes.com/assets/Datasheets/AP7361C.pdf
AP2114H-3.3TRG1	6V	1A	65dB (100Hz ~ 1kHz)	0.75V @ 1A	SOT-223	https://www.diodes.com/assets/Datasheets/AP2114.pdf
TLV1117LV33DCYR	5.5V	1A	75dB (120Hz)	1.3V @ 800mA	SOT-223-4	http://www.ti.com/lit/ds/symlink/tlv1117lv.pdf





PCB Layout of the 5V/3.3V Regulators Breakout (Pre-prototype V2)



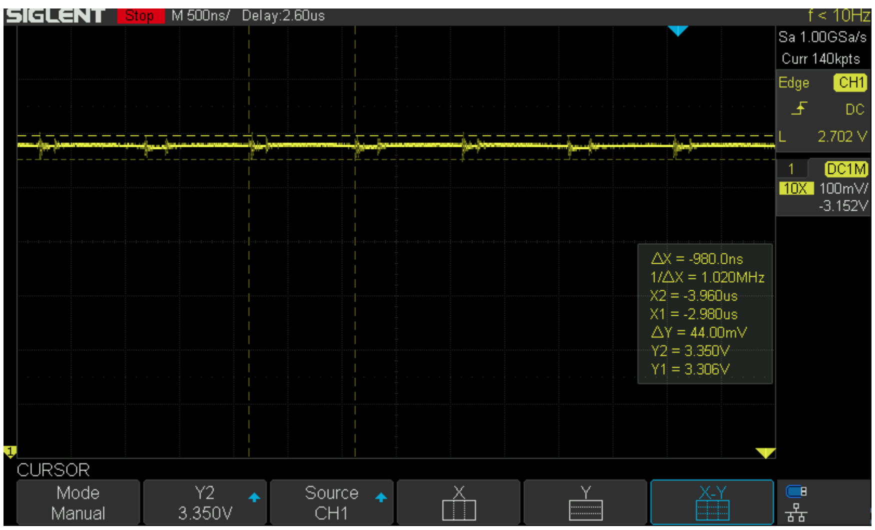
Assembled 5V/3.3V Regulators Breakout (Pre-prototype V2)

3 versions of the Pre-prototype V2 have been assembled for testing with 3 different 5V output chip bead L2 :

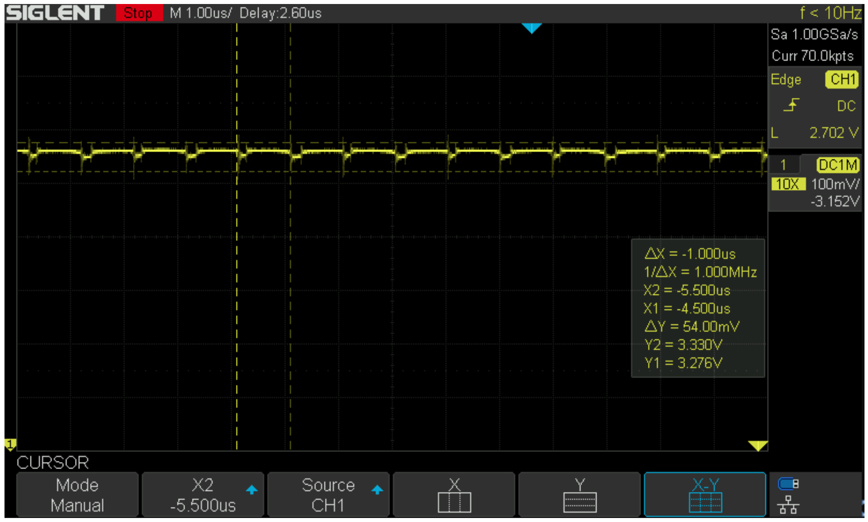
- Pre-prototype V2/1 : 120 Ohms @ 100MHz
- Pre-prototype V2/2 : 300 Ohms @ 100MHz
- Pre-prototype V2/3 : 100 Ohms @ 100MHz

Tests have shown that the Pre-prototype V2/2 board had an overall better 3.3V output stability than the two other boards
Complete test results are shown in this sheet :
https://docs.google.com/spreadsheets/d/145N4n2y6rkgCv3jdxKm-5fOuP1pSTkM7ndF6-NQ_sXc/edit#gid=1868966053

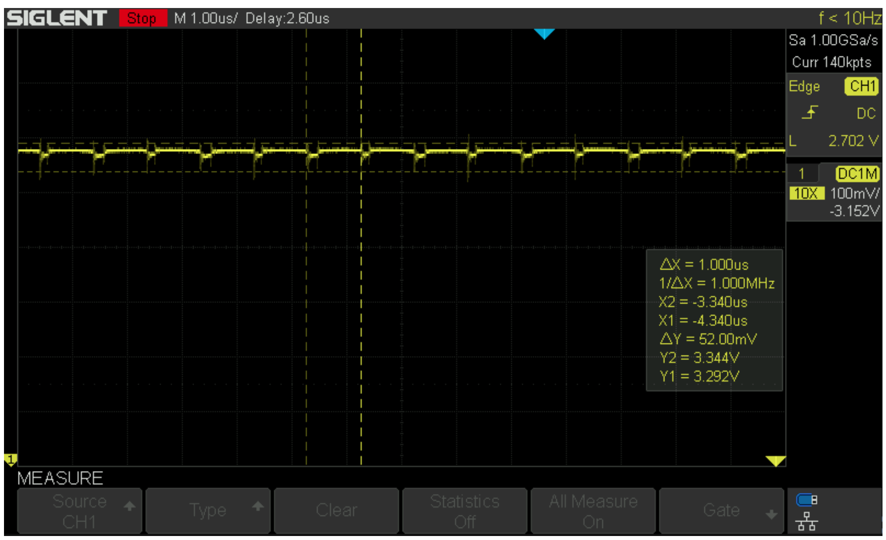
Also, the AP7361C-33E-13 3.3V regulator seems to have the best 3.3V performances in terms of PSRR (power supply rejection ratio) and stability on the Pre-prototype V2/2 board compared to the other 3.3V regulators :



AP7361C-33E-13 3V3/2 Output



AP2114H-3.3TRG1 3V3/3 Output



TLV1117LV33DCYR 3V3/4 Output

Based on these results, we chose to use 1x TS30042-M050QFNR 5V regulator to power the LEDs from the input power supply of 12V-40V, 2x AP7361C-33E-13 to power the 3.3V IC (MCU, IMU, Encoder, Tri-state Buffers, etc..) and 1x REF3133AIDBZR as a 3.3V reference for the MCU's ADC.