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45 W USB-PD Power over Ethernet Flyback Converter

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Circuit Description

The design described herein is an Isolated 45 W USB-PD compatible, Power over Ethernet input voltage range compatible, constant voltage power supply. When this demonstration board is used in conjunction with the [NCP1096GEVB](#) IEEE 802.3bt compliant demonstration board, use with Power over Ethernet to USBPD applications within smart building designs can be achieved.

The featured power supply is a Fixed Frequency Flyback design utilizing ON Semiconductor NCP12700 PWM controller, the NCP4306 synchronous rectifier controller, FDMS86255 primary side MOSFET, and an FDMS86202 synchronous MOSFET, and the FUSB3307 USB-PD controller. This design note provides the circuit schematic details, PCB and BOM for 45 W Power over Ethernet to USB-PD compatible power supply stage.

Key Features

- Power Over Ethernet Compatible Input Range from 37 V to 57 V
- High Full Load and Average Efficiency
- Very Low Ripple and Noise
- Smooth Startup Operation
- Low Parts Count
- Inherent SCP And OCP Protection
- Thermal and OVP Protection
- Multiple Probe Points for Evaluation
- USB-PD 5V–20V Operation

REFERENCE DESIGN



Figure 1. Full View of the Board

SPECIFICATIONS

	PD Output Specification
Output Voltage	5 V, 9 V, 12 V, 15 V, 20 V
Nominal Current	5V/3A, 9V/3A, 12V/3A, 15V/3A, 20V/2.25A
Max Current	5V/3A, 9V/3A, 12V/3A, 15V/3A, 20V/2.25A
Min Current	Zero

ON Devices	Application	Input Voltage	Output Power	Topology	I/O Isolation
NCP12700 NCP4306 FDMS86255 FDMS86202 FUSB3307	Smart Building, Internet of Things	37 V – 57 V	Up to 45 W	Fixed Frequency Flyback	Isolated (3 kV)

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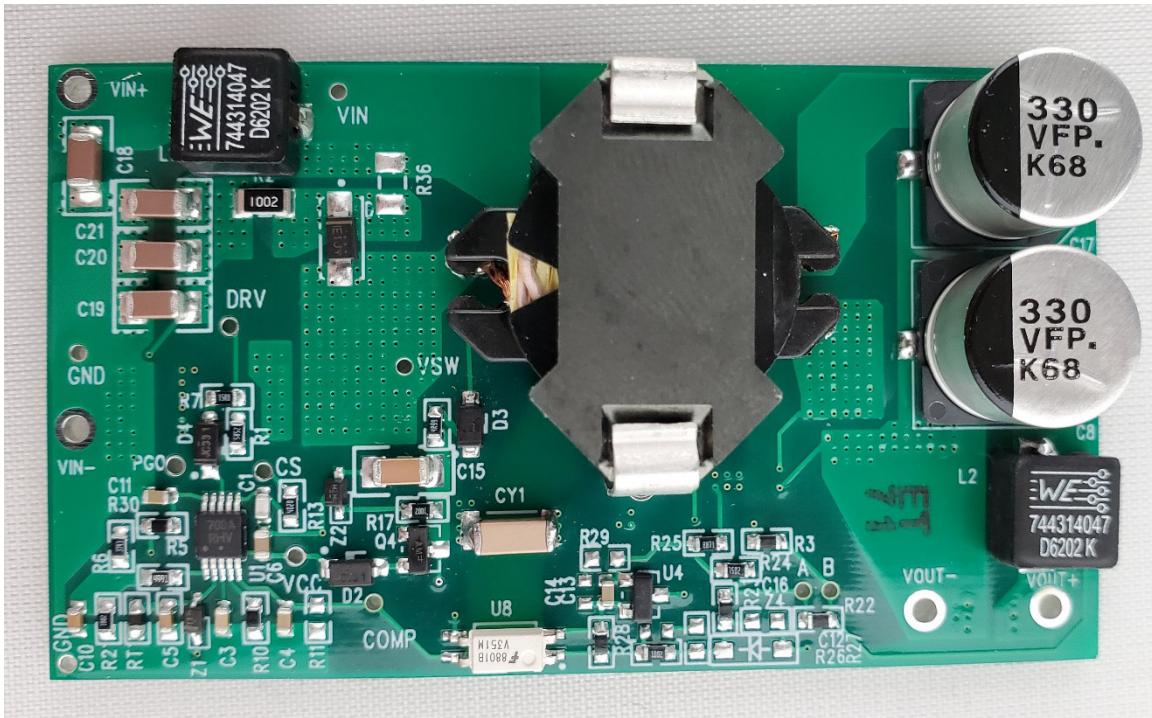


Figure 2. Top View of the Board

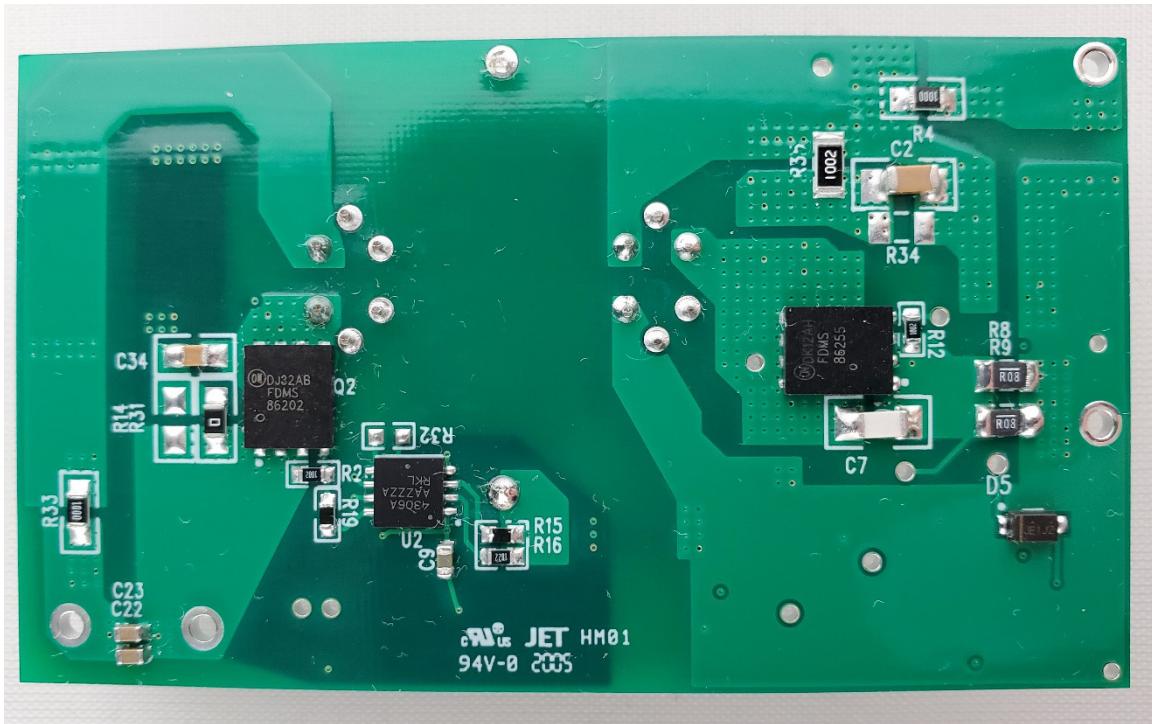


Figure 3. Bottom View of the Board

TND6333/D

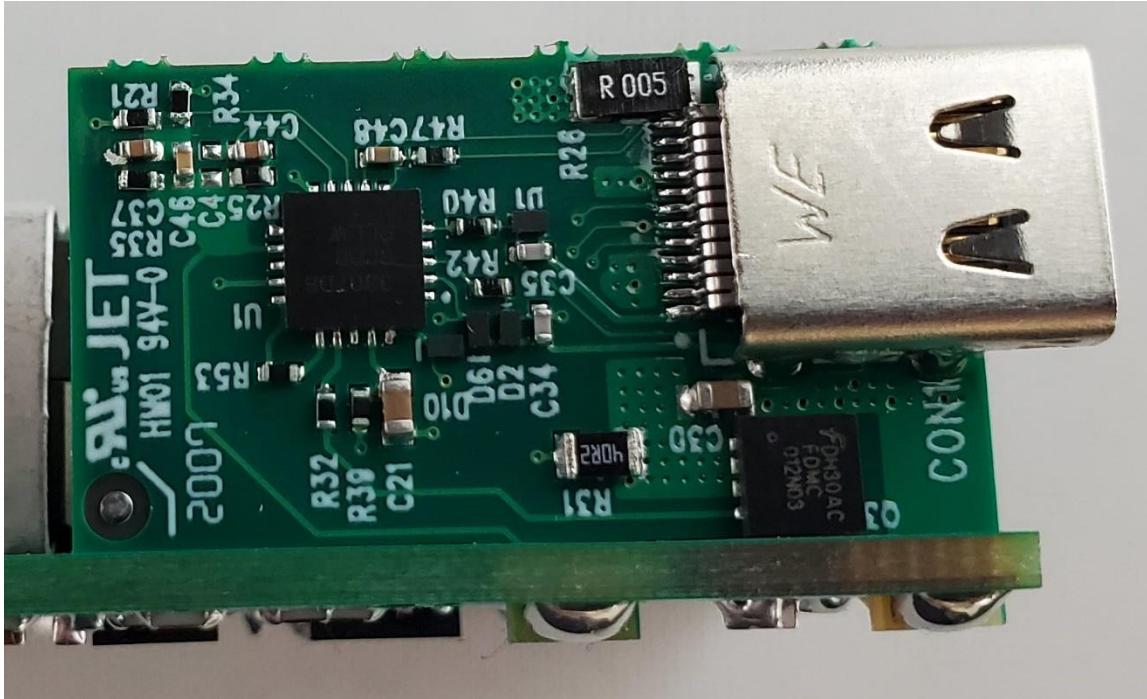


Figure 4. FUSB3307 Daughter Board

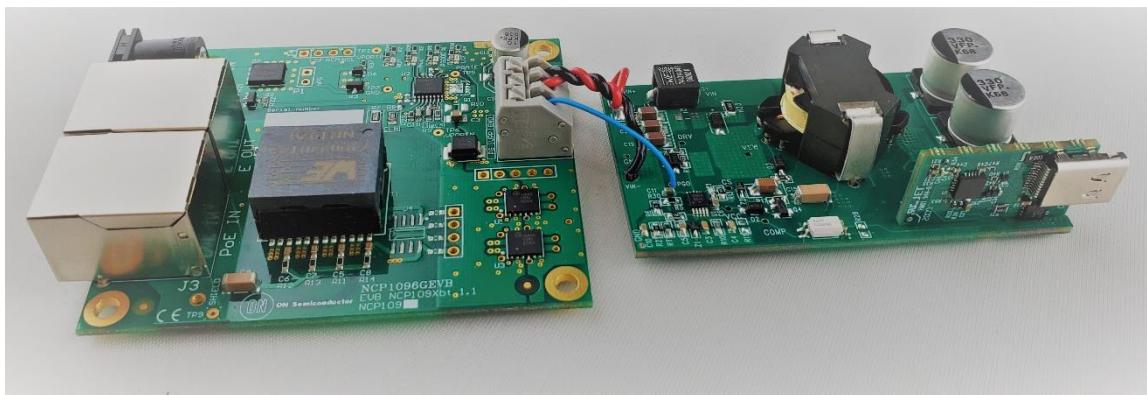


Figure 5. Power over Ethernet Complete Solution with NCP1096GEVB

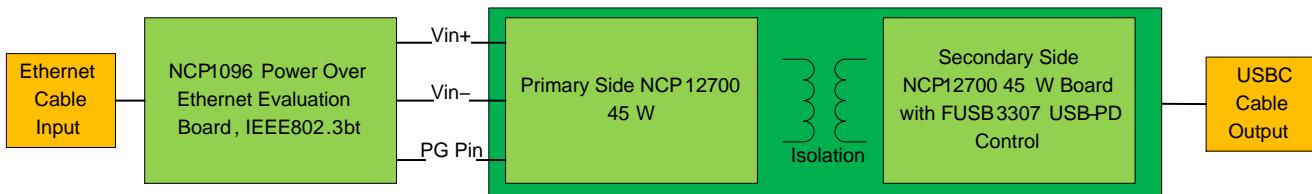


Figure 6. Power over Ethernet Complete Solution Block Diagram

TND6333/D

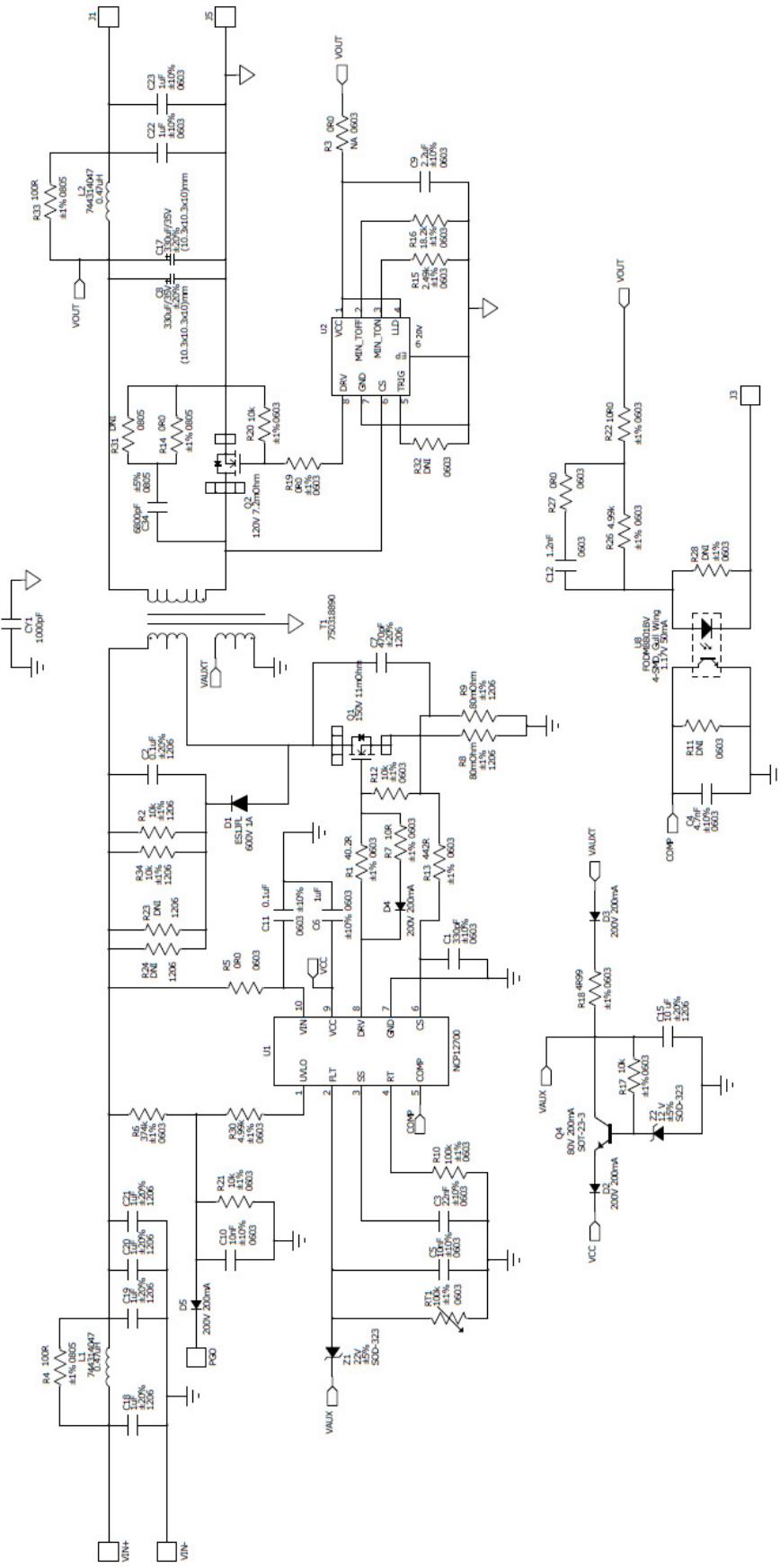


Figure 7. NCP12700 45 W Main Board Schematic

TND6333/D

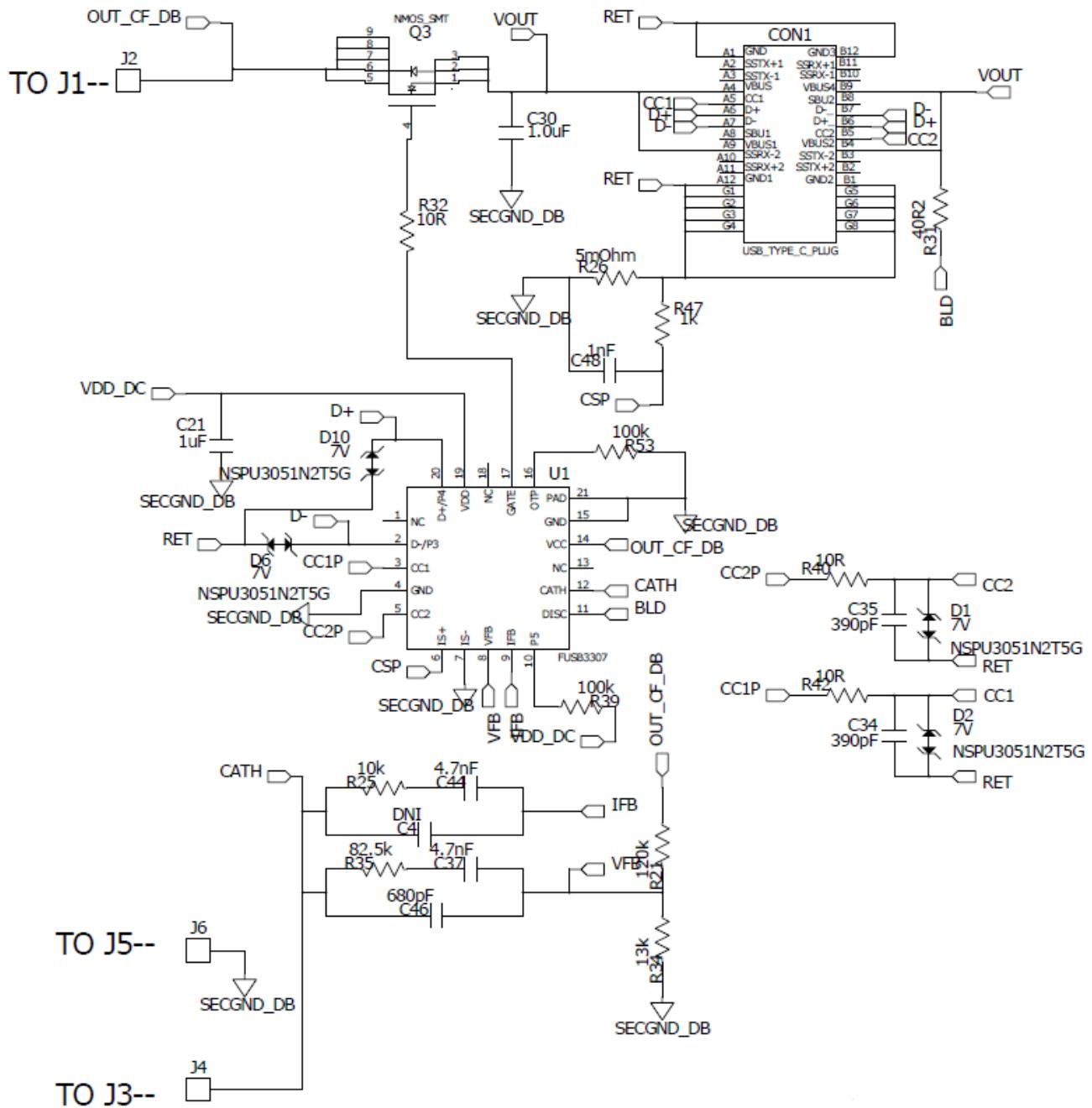


Figure 8. FUSB3307 USBPD Daughter Card Schematic

Layout

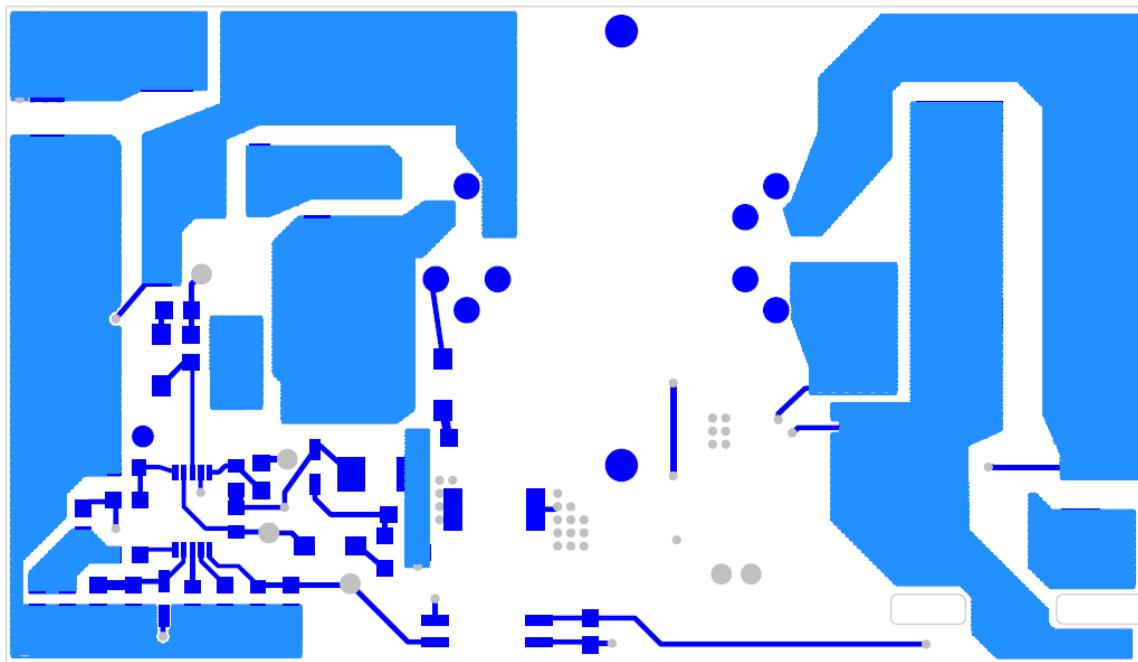


Figure 9. Layout Top Layer

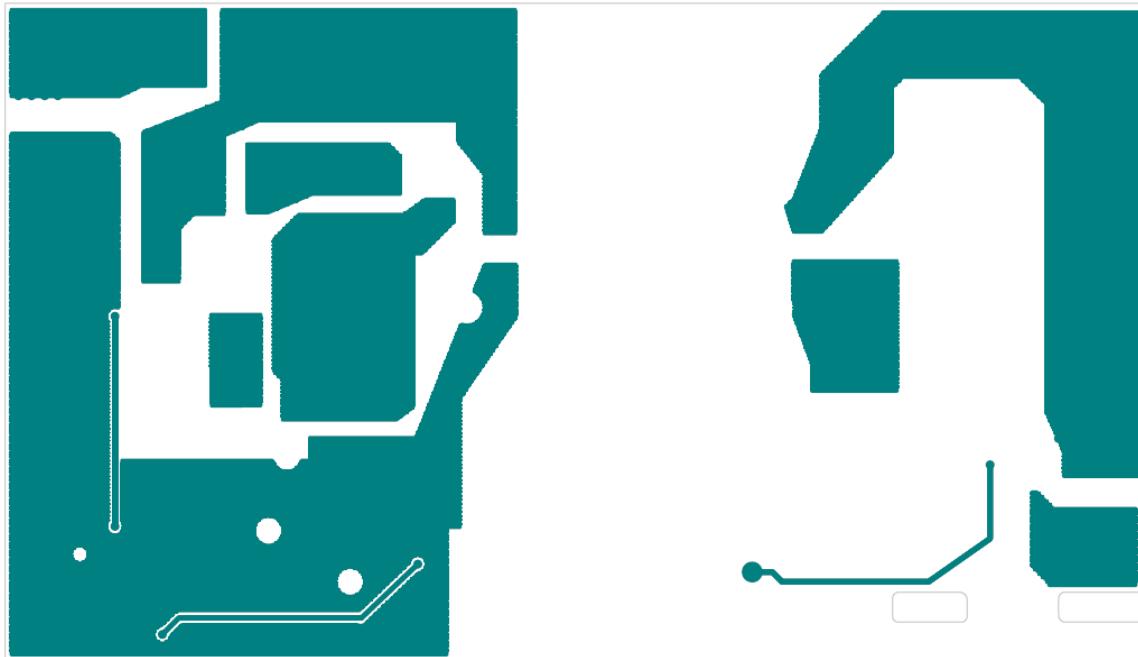


Figure 10. Layout Inner Layer 1

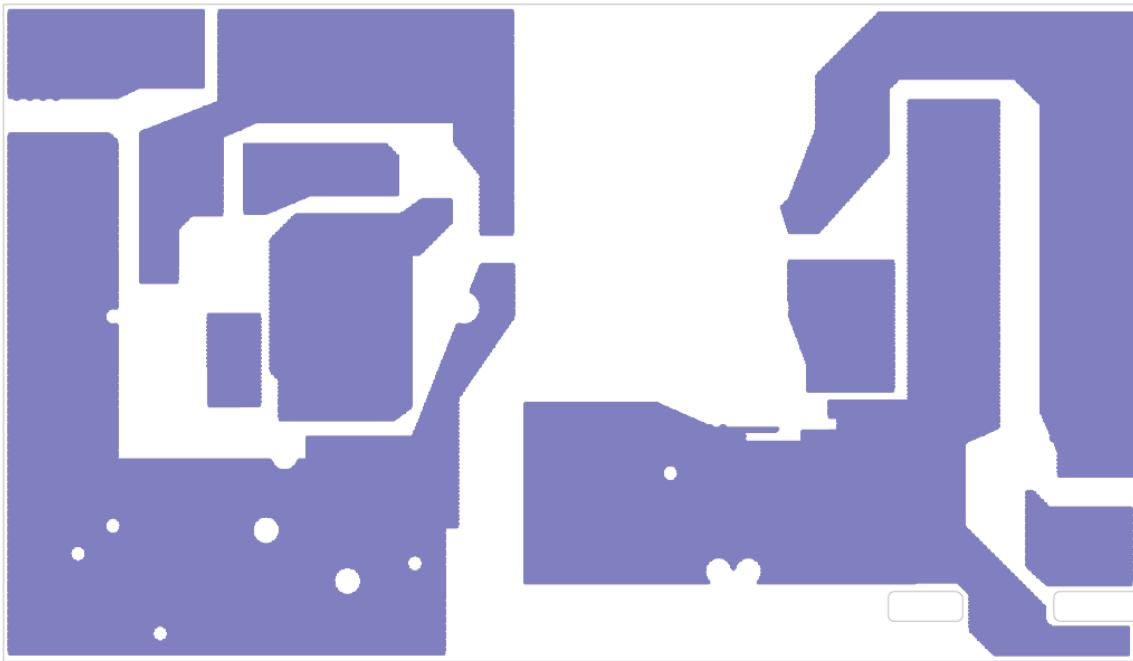


Figure 11. Layout Inner Layer 2

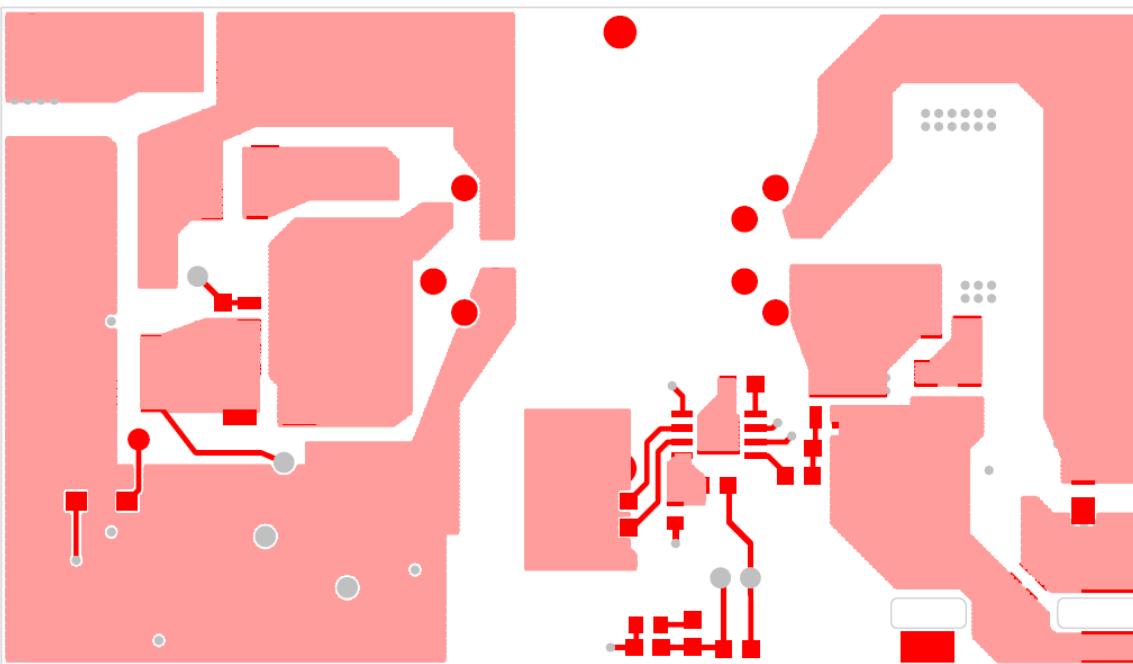


Figure 12. Layout Bottom Layer

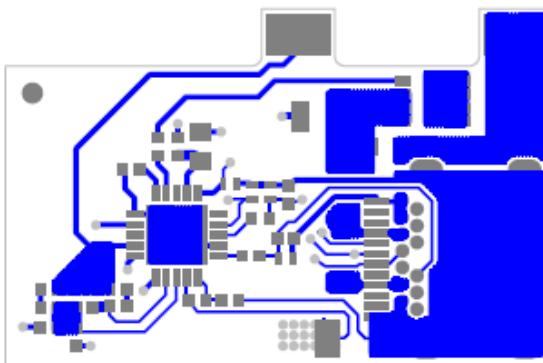


Figure 13. FUSB3307 Layout Top Layer

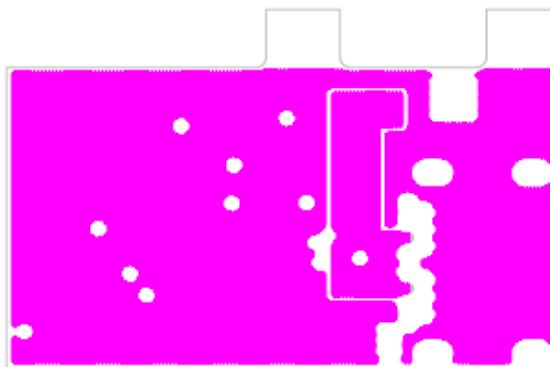


Figure 14. FUSB3307 Layout Inner Layer 1

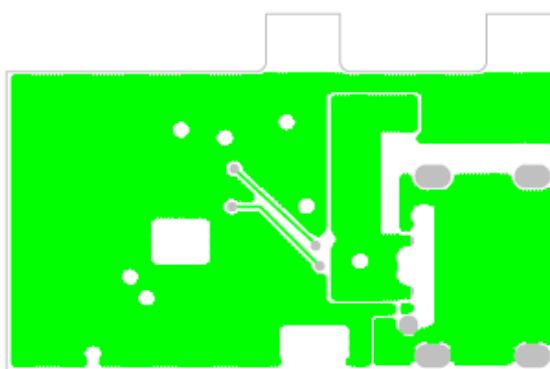


Figure 15. FUSB3307 Layout Inner Layer 2

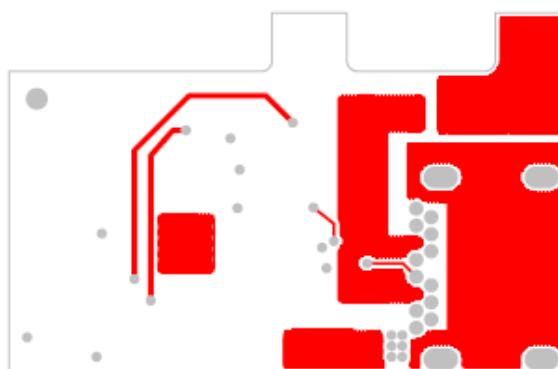


Figure 16. FUSB3307 Layout Bottom Layer

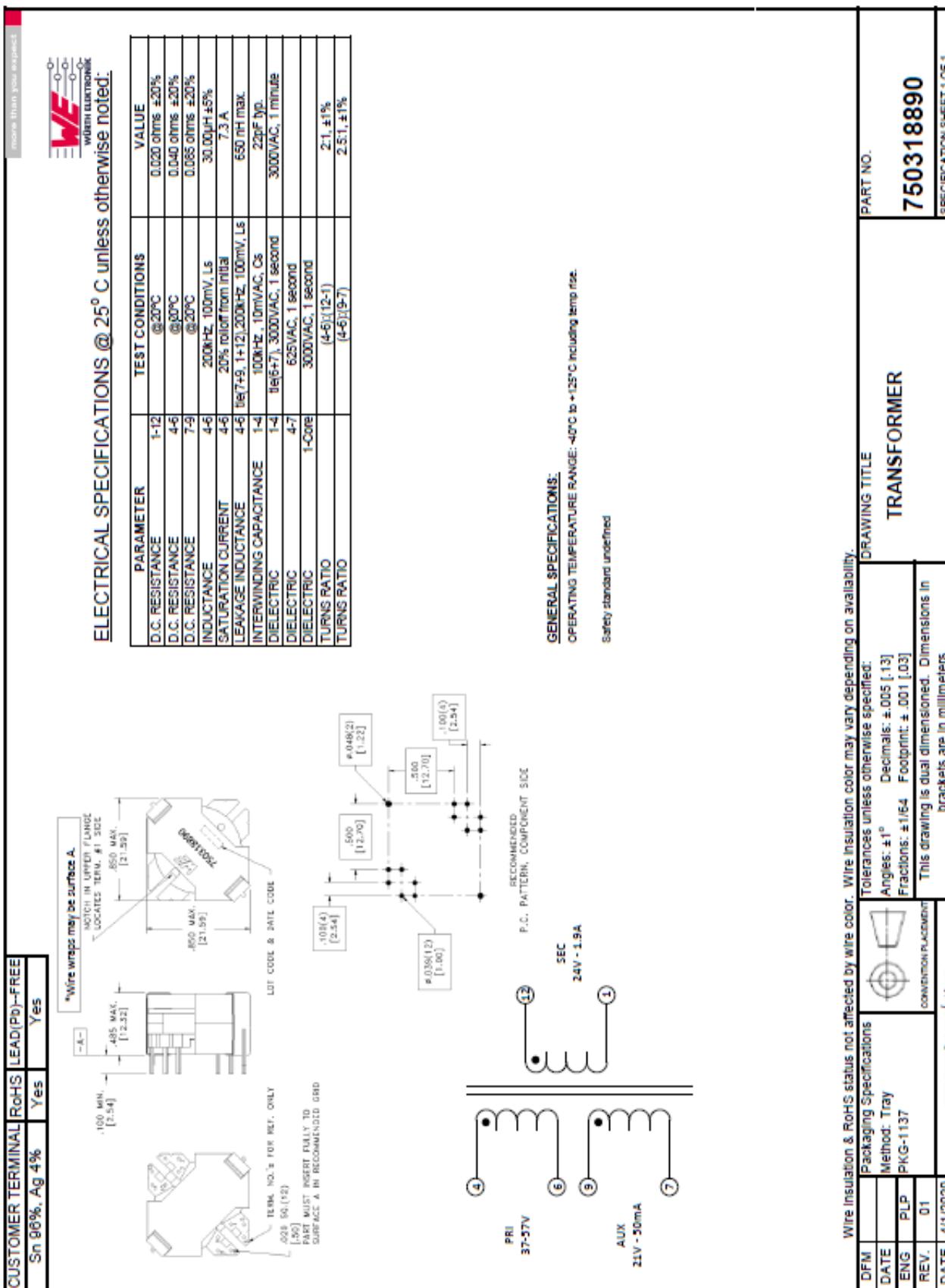


Figure 17. Transformer Specification

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Efficiency

5V Out Efficiency vs. Output Power

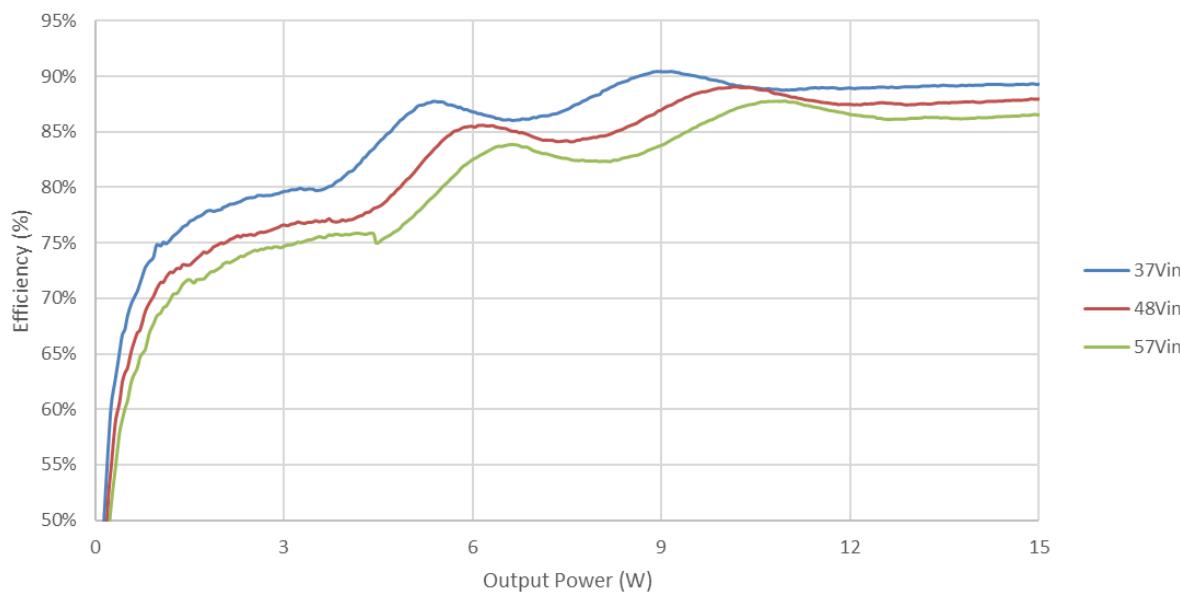


Figure 18. 5 V Output Efficiency Plot

9V Out Efficiency vs. Output Power

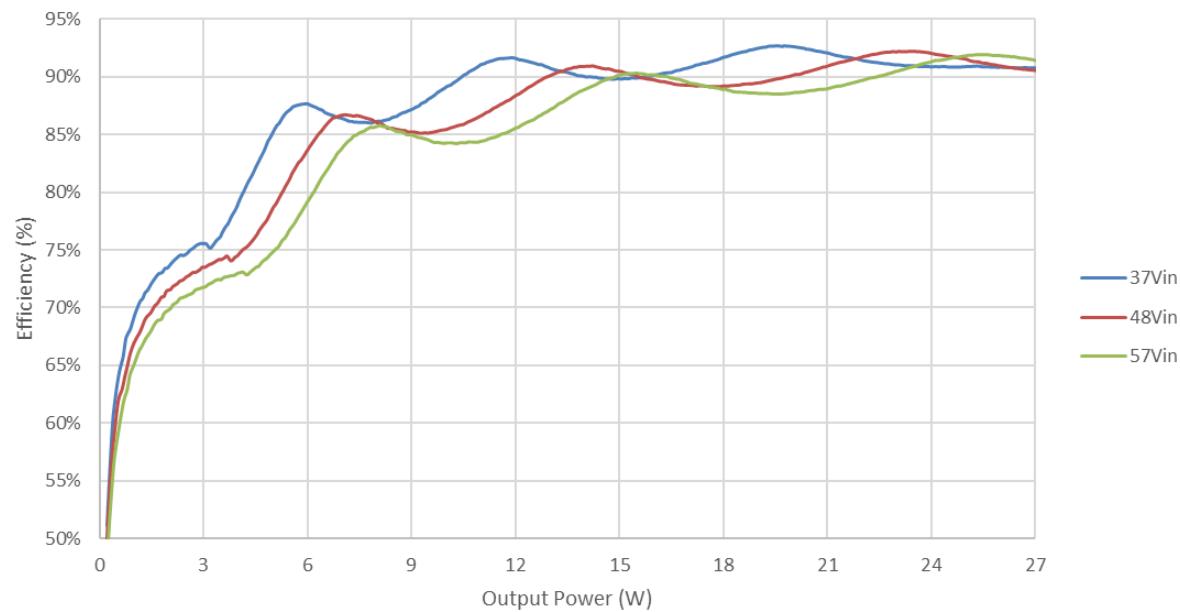


Figure 19. 9 V Output Efficiency Plot

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12V Out Efficiency vs. Output Power

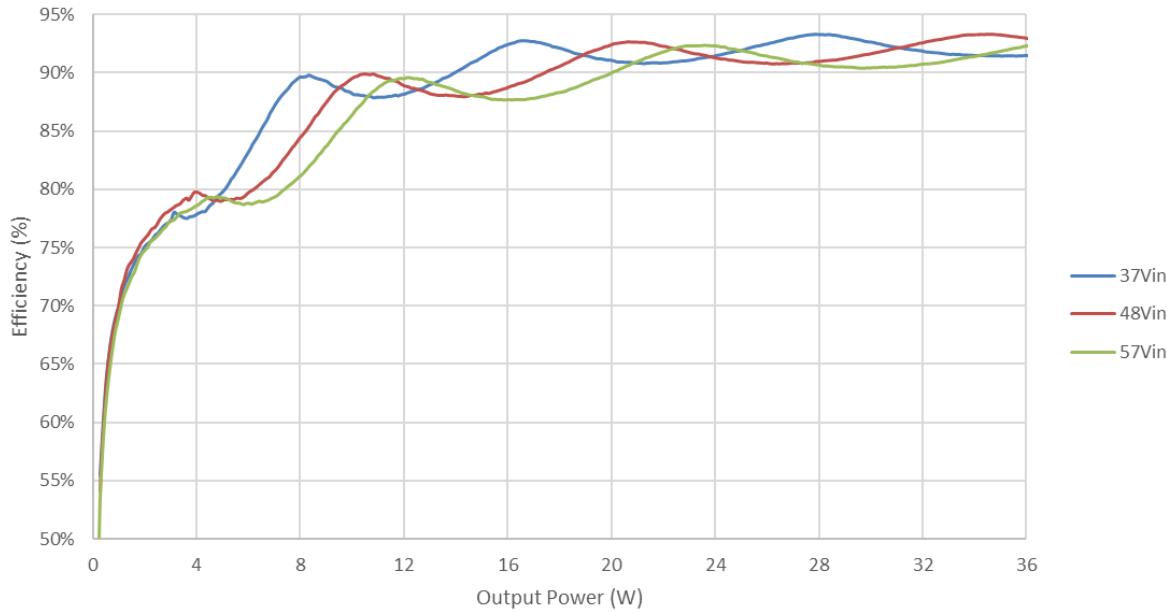


Figure 20. 12 V Output Efficiency Plot

15V Out Efficiency vs. Output Power

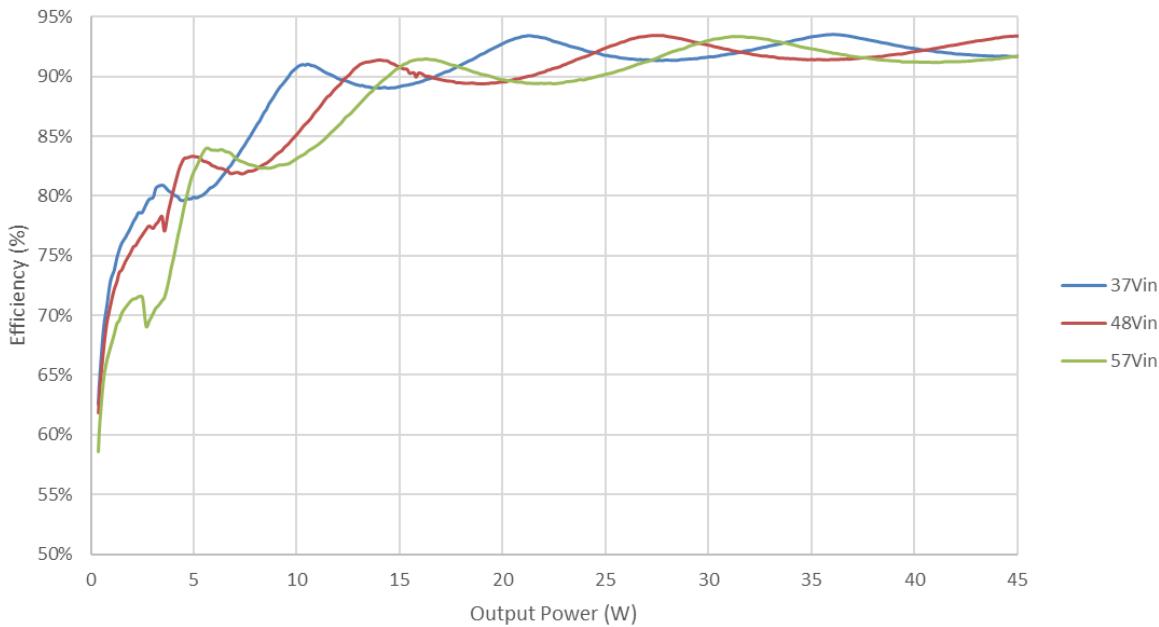


Figure 21. 15 V Output Efficiency Plot

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20V Out Efficiency vs. Output Power

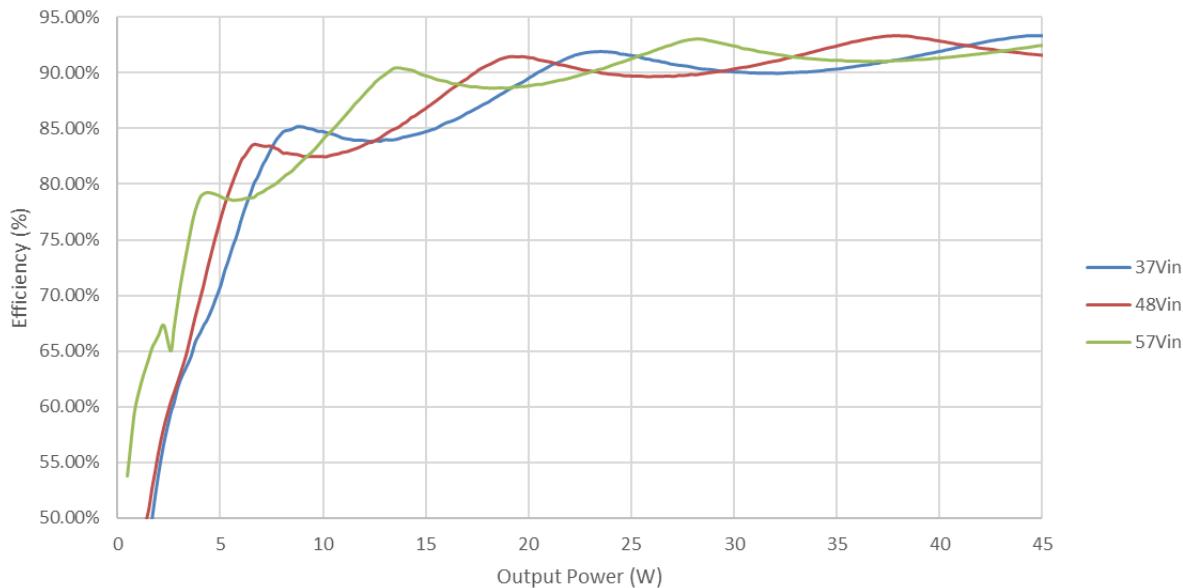


Figure 22. 20 V Output Efficiency Plot

Operating Waveforms

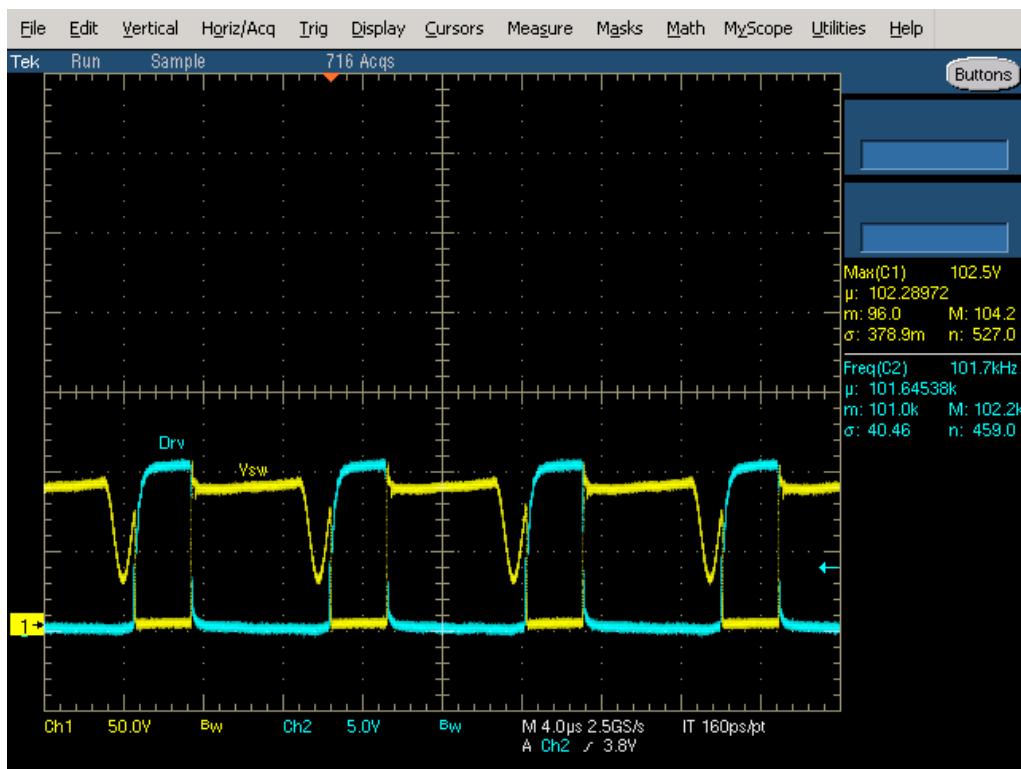


Figure 23. Normal DCM Operating Waveform 48 V Input

TND6333/D

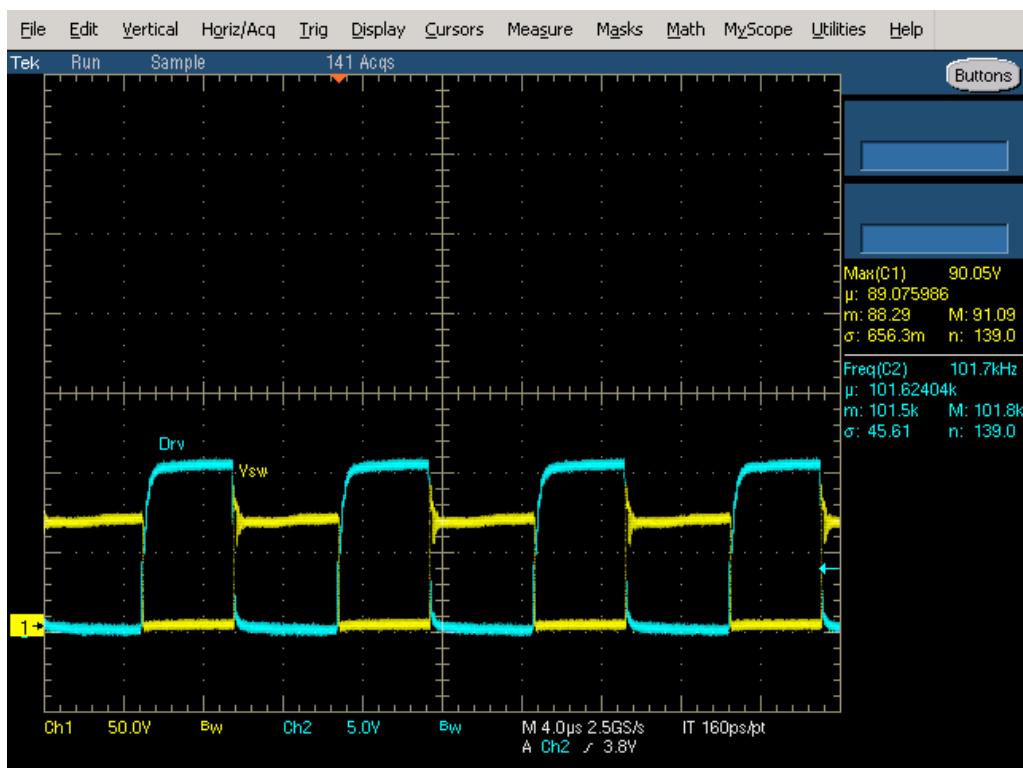


Figure 24. Normal CCM Operating Waveform 48 V Input

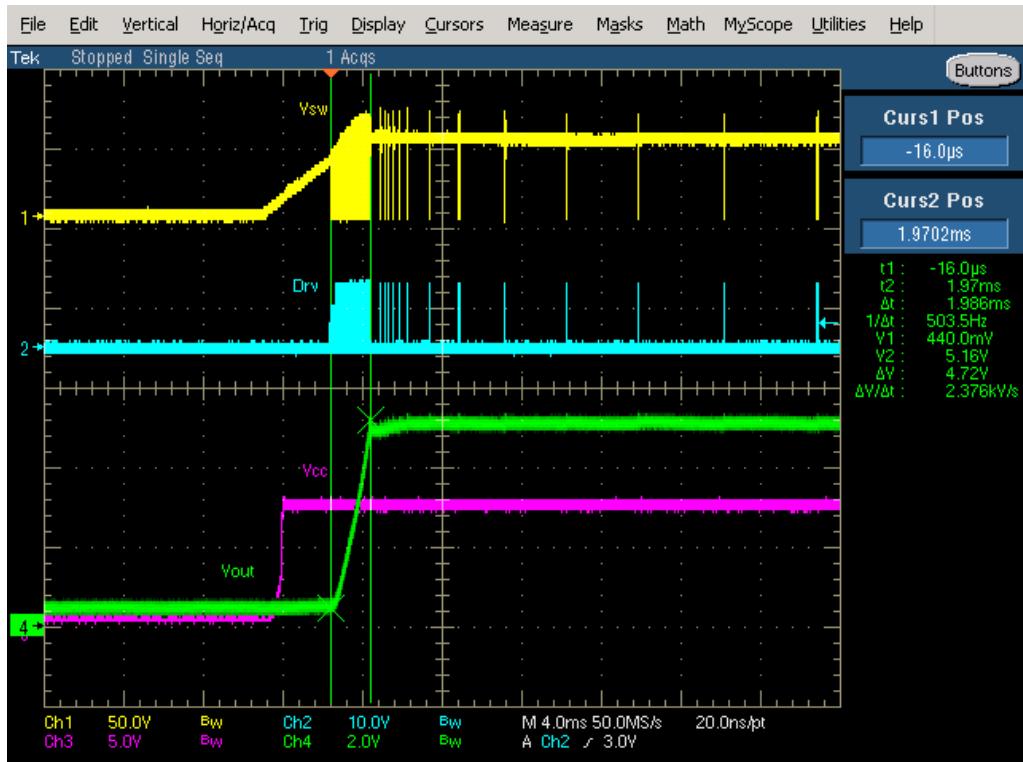


Figure 25. 48 V Input Startup Waveform

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Full Load Output Ripple Waveforms

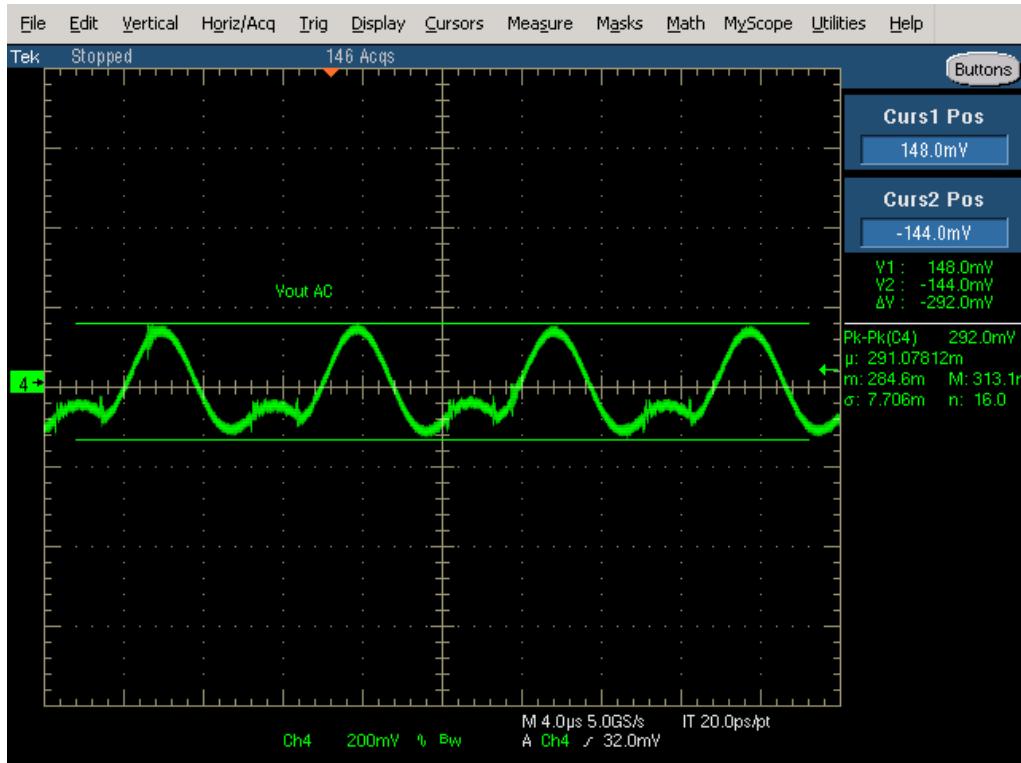


Figure 26. 37 V Input 5 V Output Ripple

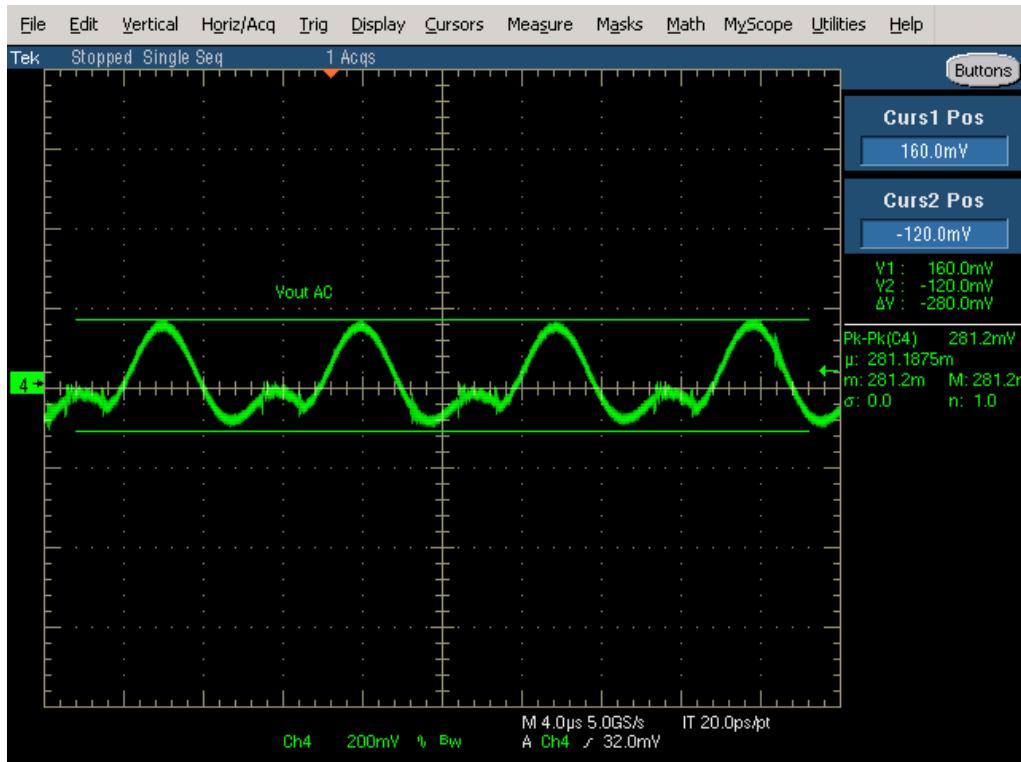


Figure 27. 48 V Input 5 V Output Ripple

TND6333/D

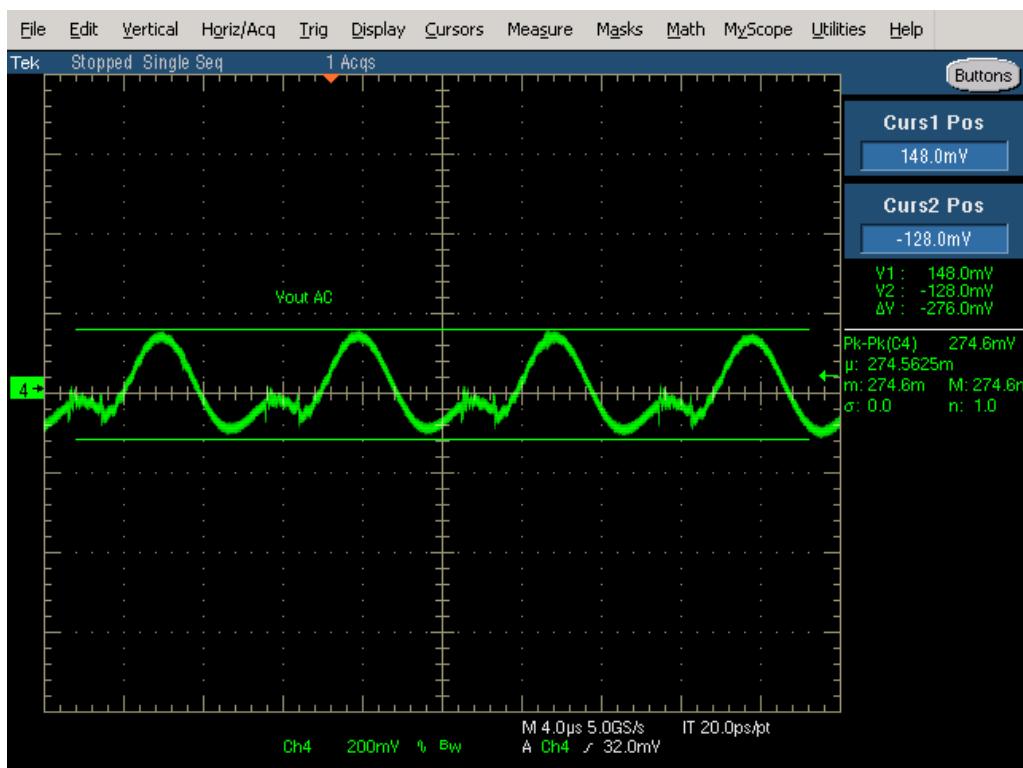


Figure 28. 57 V Input 5 V Output Ripple

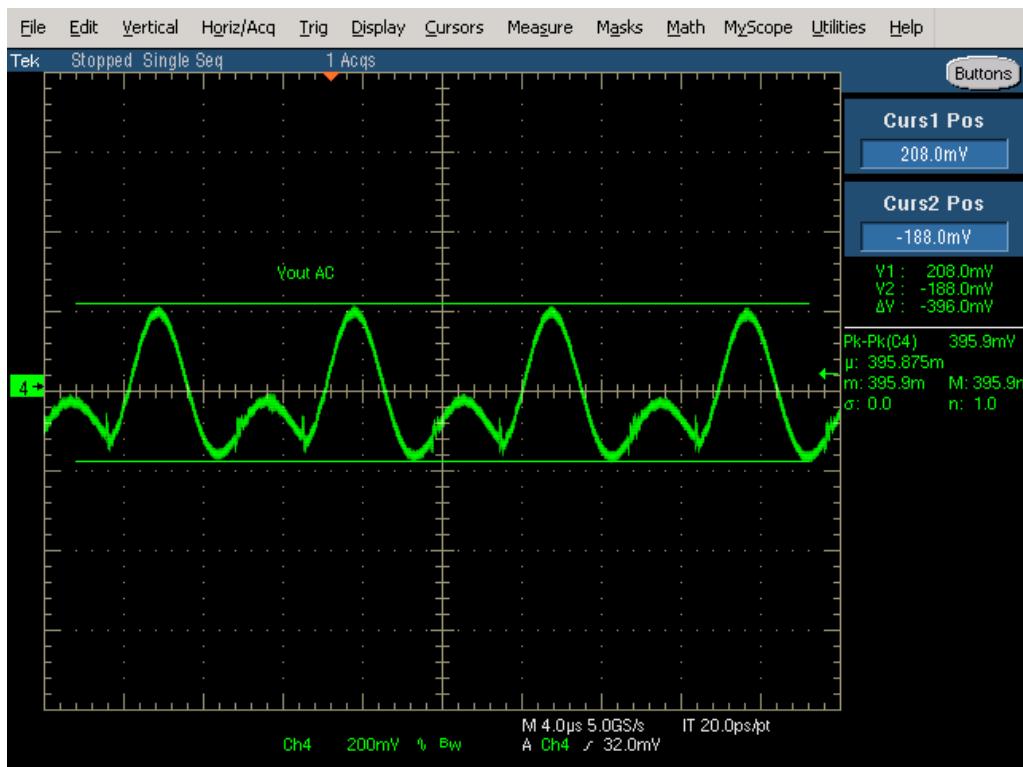


Figure 29. 37 V Input 9 V Output Ripple

TND6333/D

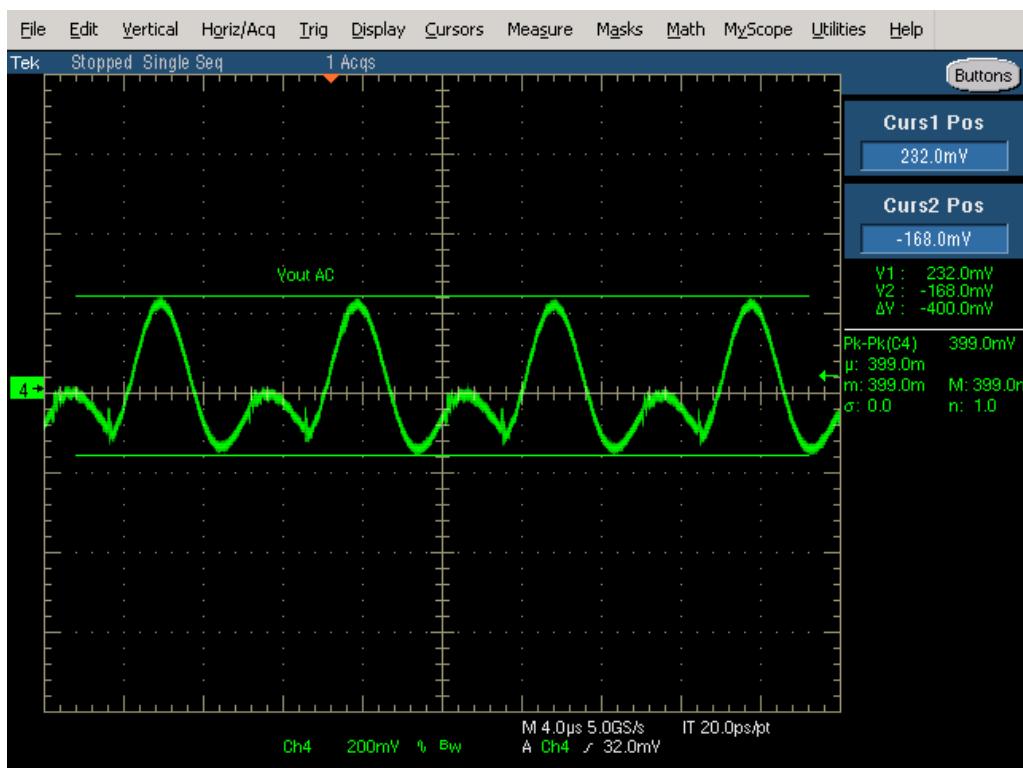


Figure 30. 48 V Input 9 V Output Ripple

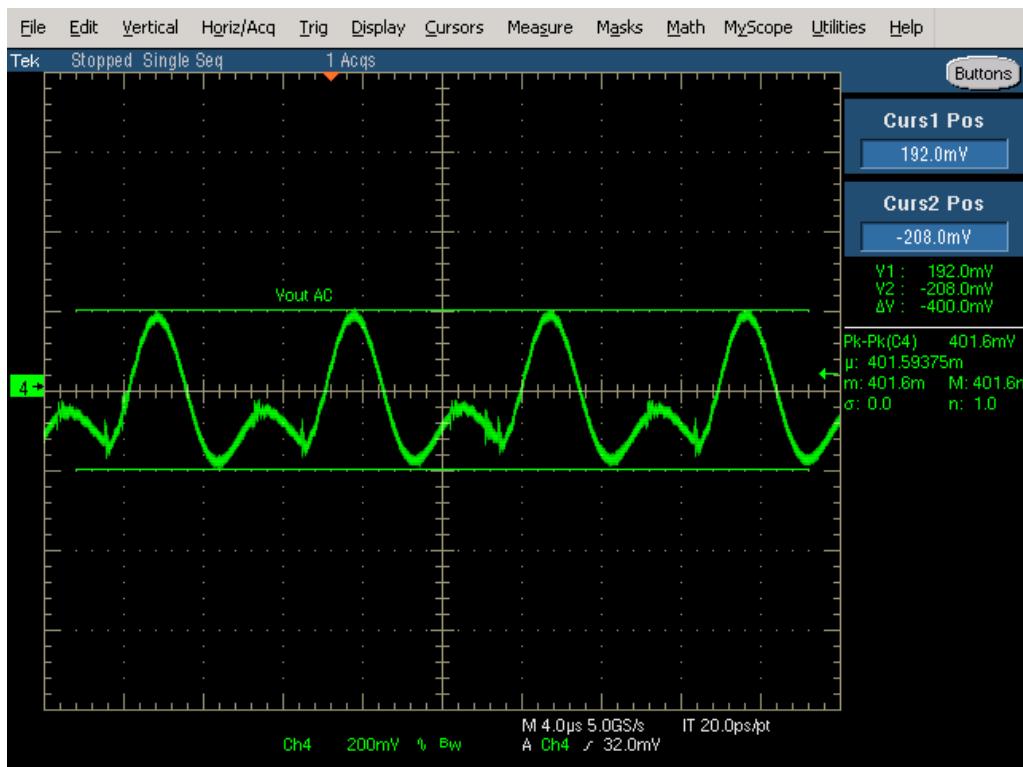


Figure 31. 57 V Input 9 V Output Ripple

TND6333/D

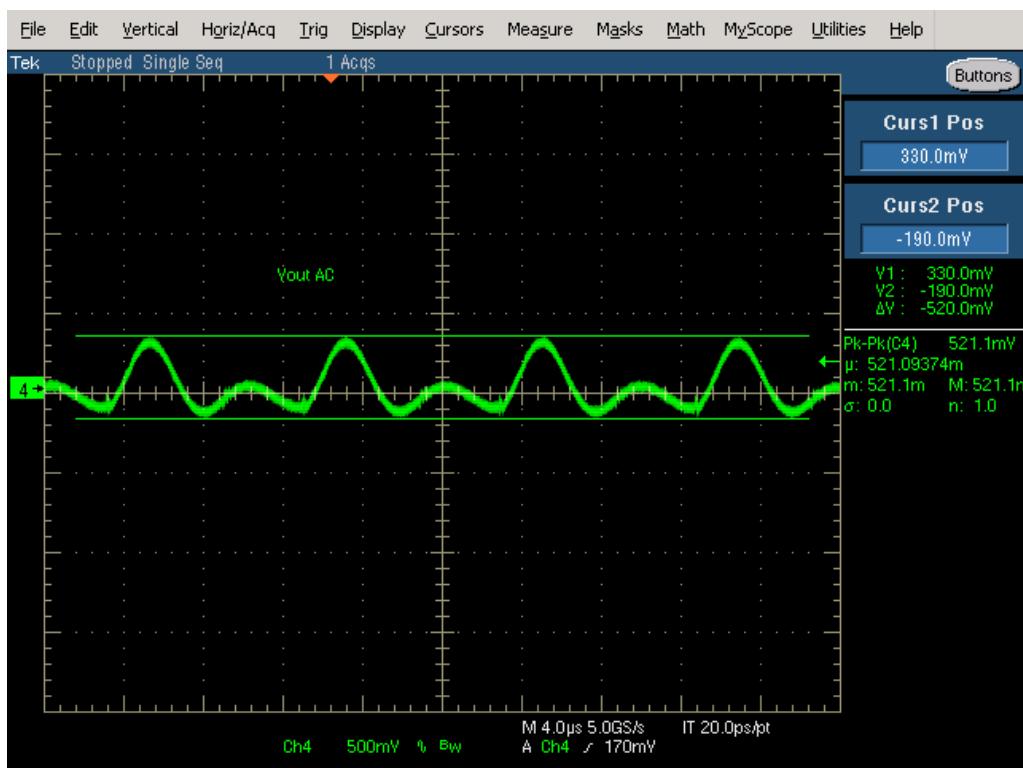


Figure 32. 37 V Input 12 V Output Ripple

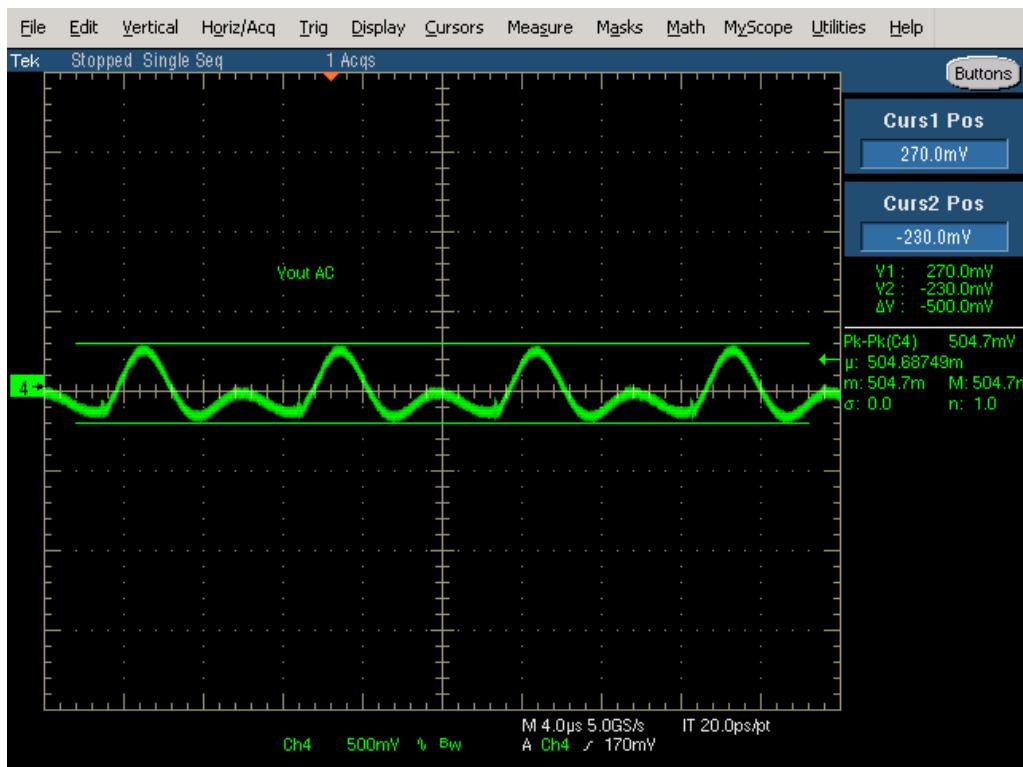


Figure 33. 48 V Input 12 V Output Ripple

TND6333/D

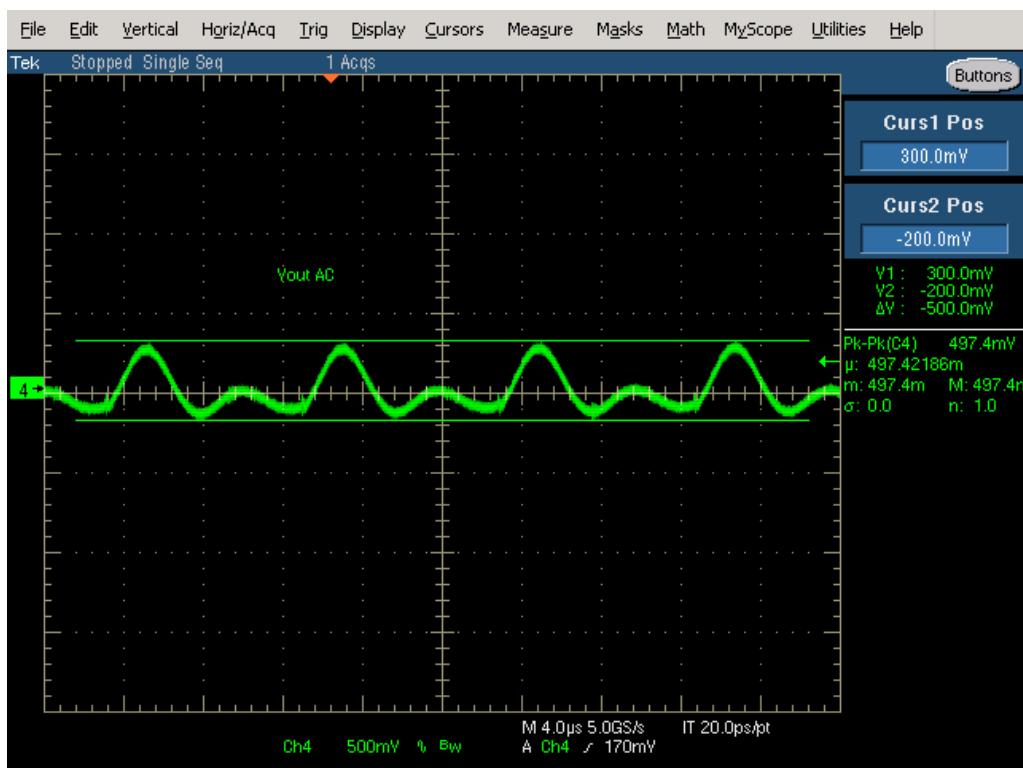


Figure 34. 57 V Input 12 V Output Ripple



Figure 35. 37 V Input 15 V Output Ripple

TND6333/D

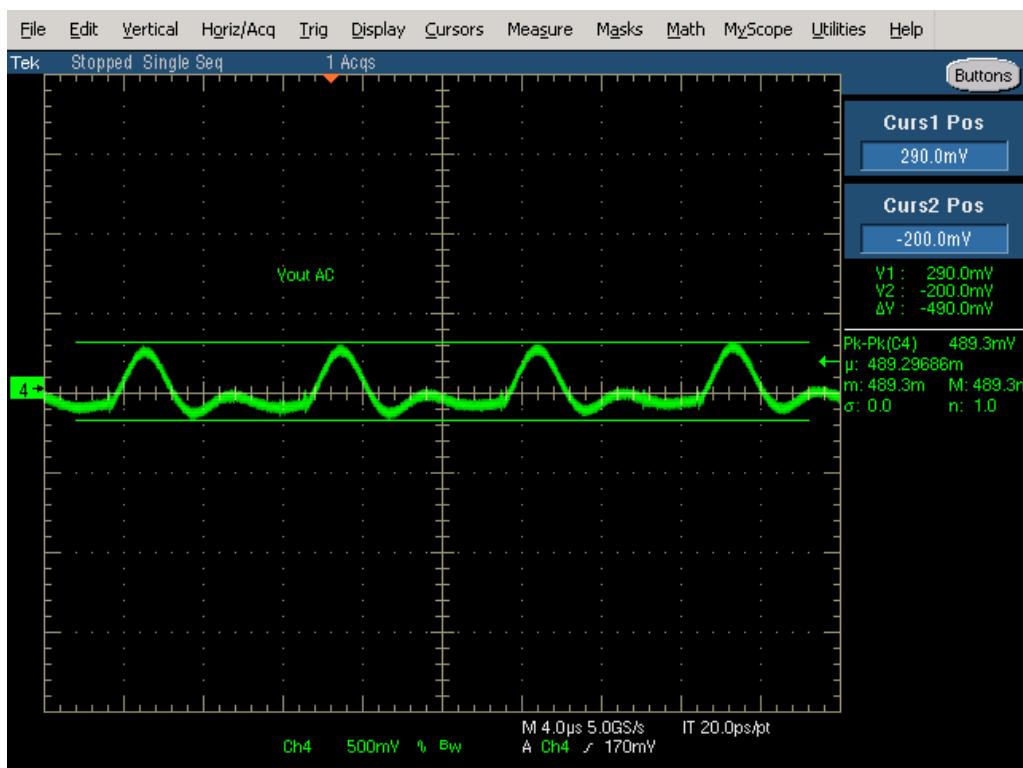


Figure 36. 48 V Input 15 V Output Ripple



Figure 37. 57 V Input 15 V Output Ripple

TND6333/D

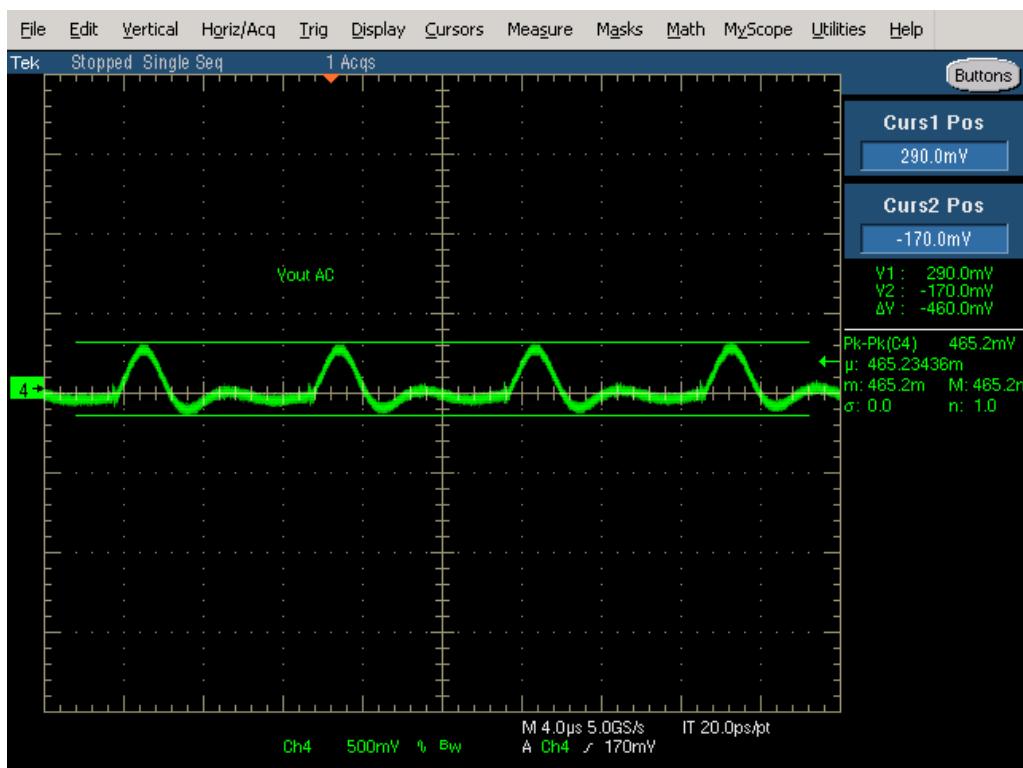


Figure 38. 37 V Input 20 V Output Ripple

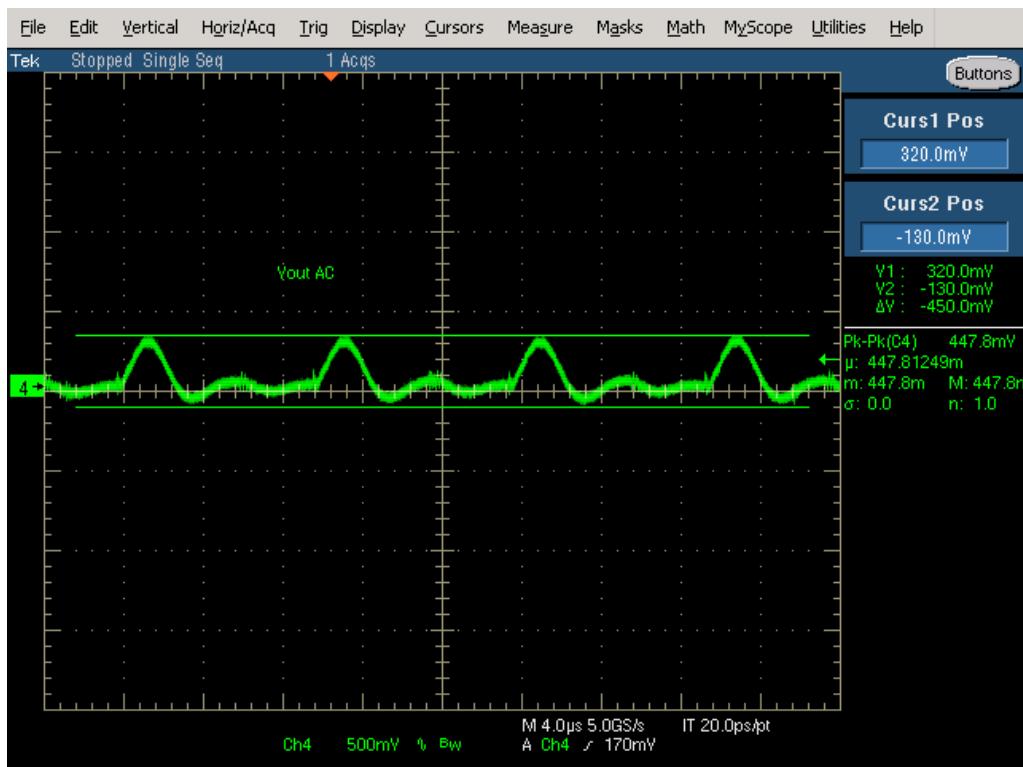


Figure 39. 48 V Input 20 V Output Ripple

TND6333/D

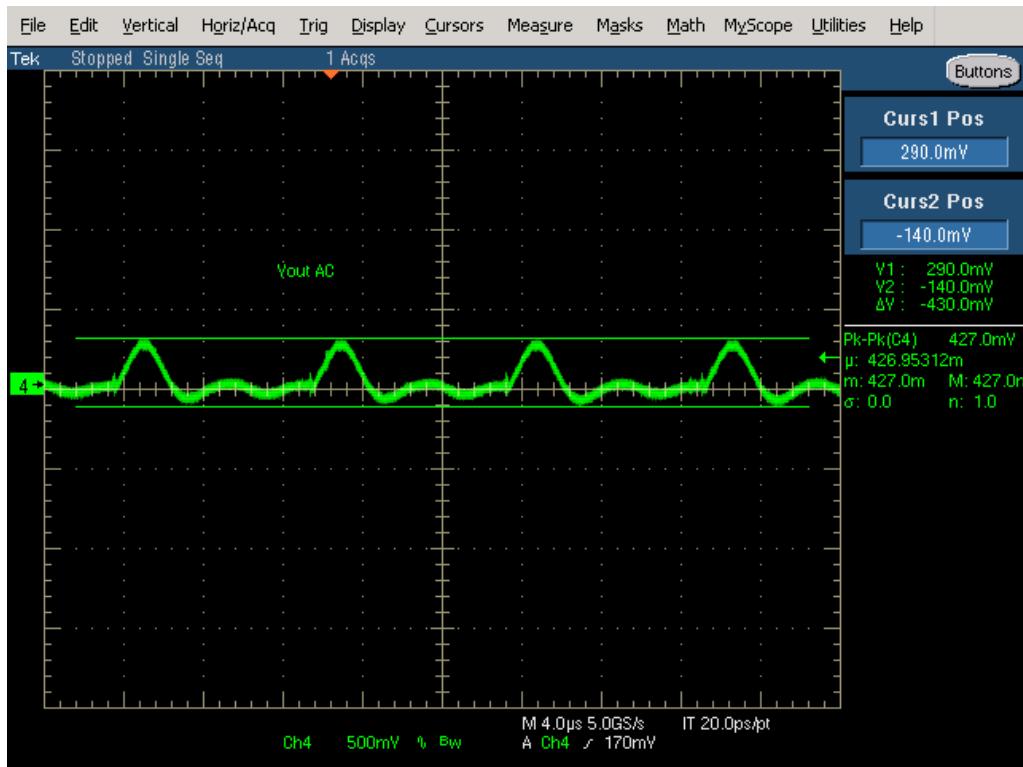


Figure 40. 57 V Input 20 V Output Ripple

Transient Response Waveforms (150 mA/μs, 20 ms, 0 – 3 A)



Figure 41. 37 V Input 5 V Output Transient Response

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Figure 42. 48 V Input 5 V Output Transient Response



Figure 43. 57 V Input 5 V Output Transient Response

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Figure 44. 37 V Input 9 V Output Transient Response



Figure 45. 48 V Input 9 V Output Transient Response

TND6333/D



Figure 46. 57 V Input 9 V Output Transient Response



Figure 47. 37 V Input 12 V Output Transient Response

TND6333/D



Figure 48. 48 V Input 12 V Output Transient Response



Figure 49. 57 V Input 12 V Output Transient Response

TND6333/D



Figure 50. 37 V Input 15 V Output Transient Response



Figure 51. 48 V Input 15 V Output Transient Response

TND6333/D



Figure 52. 57 V Input 15 V Output Transient Response



Figure 53. 37 V Input 20 V Output Transient Response

TND6333/D



Figure 54. 48 V Input 20 V Output Transient Response



Figure 55. 57 V Input 20 V Output Transient Response

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Feedback Bode Plots

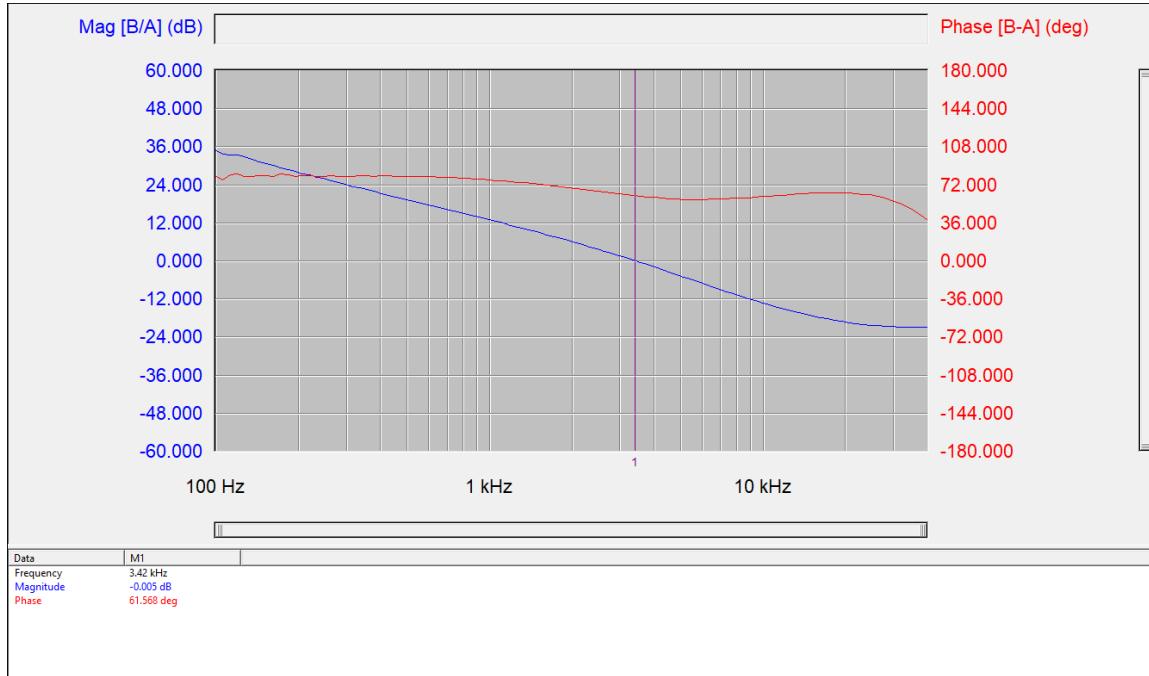


Figure 56. 37 V Input 5 V Output Bode Plot

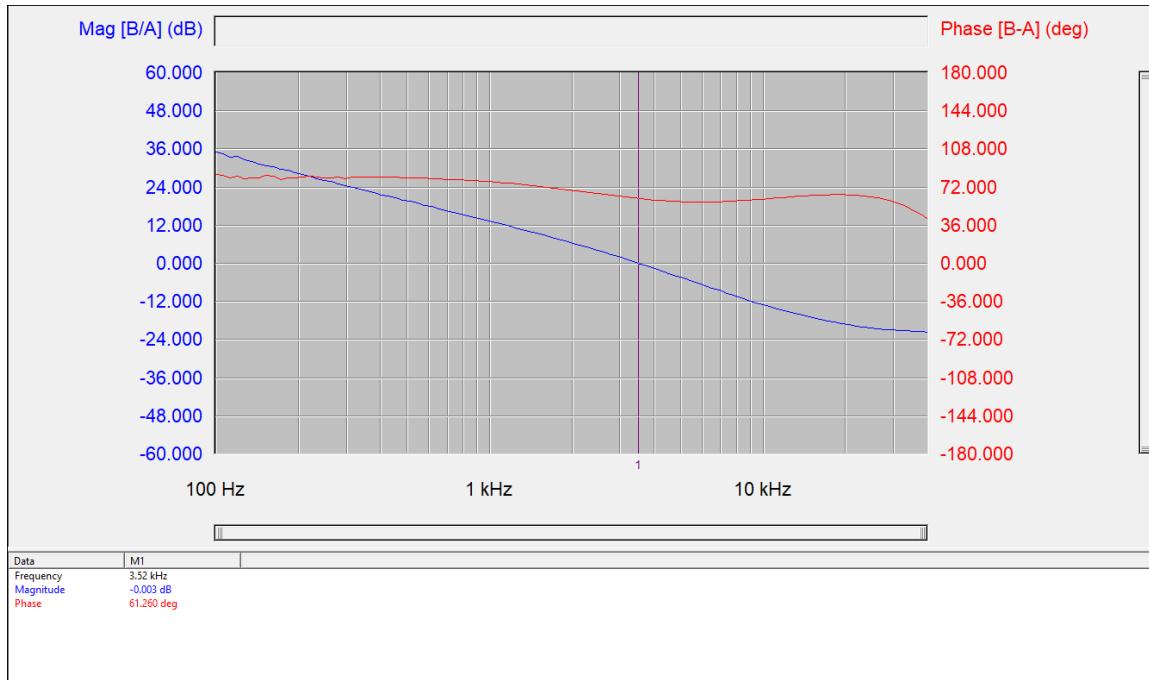


Figure 57. 48 V Input 5 V Output Bode Plot

TND6333/D

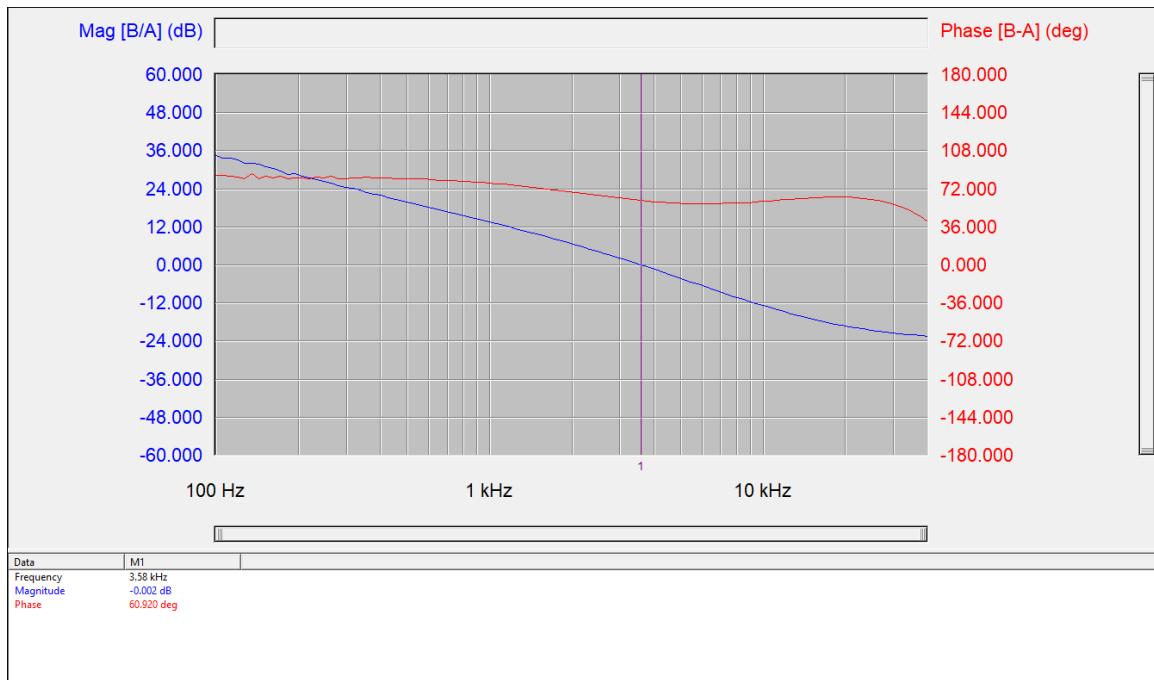


Figure 58. 57 V Input 5 V Output Bode Plot

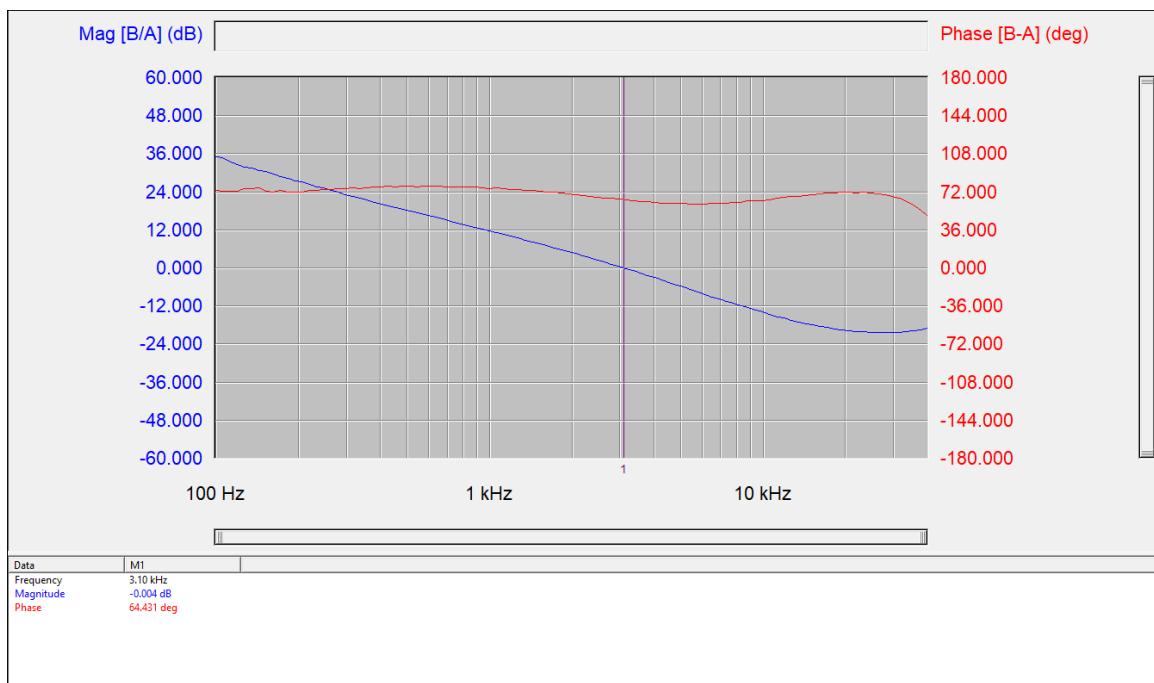


Figure 59. 37 V Input 9 V Output Bode Plot

TND6333/D

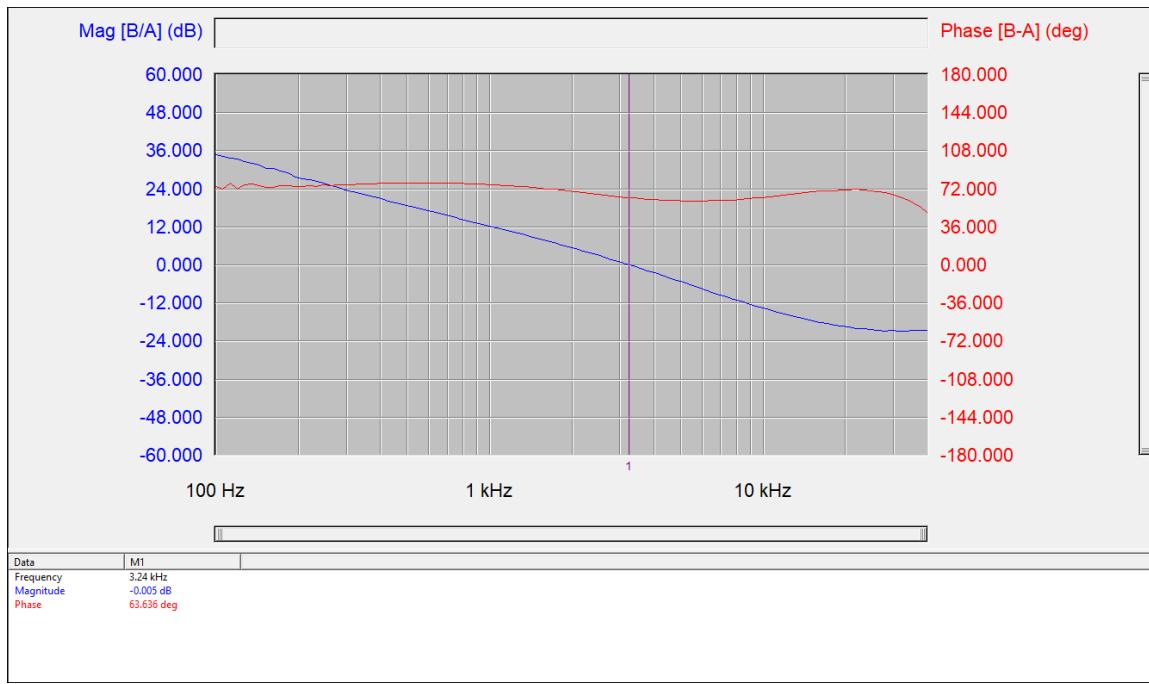


Figure 60. 48 V Input 9 V Output Bode Plot

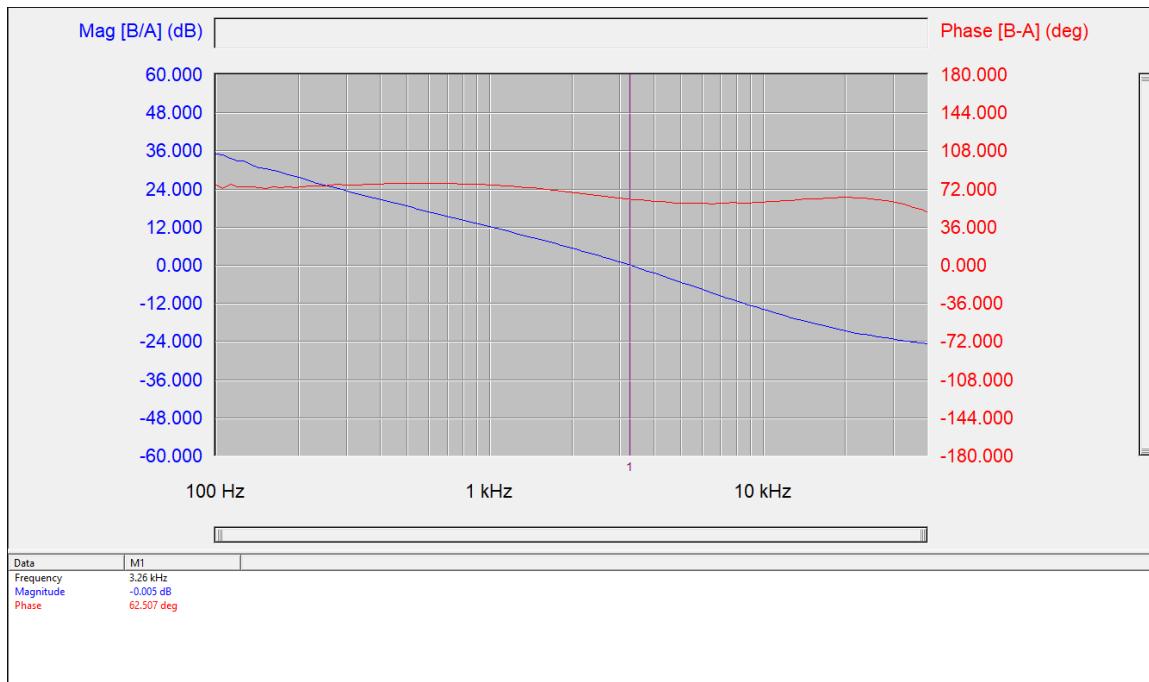


Figure 61. 57 V Input 9 V Output Bode Plot

TND6333/D

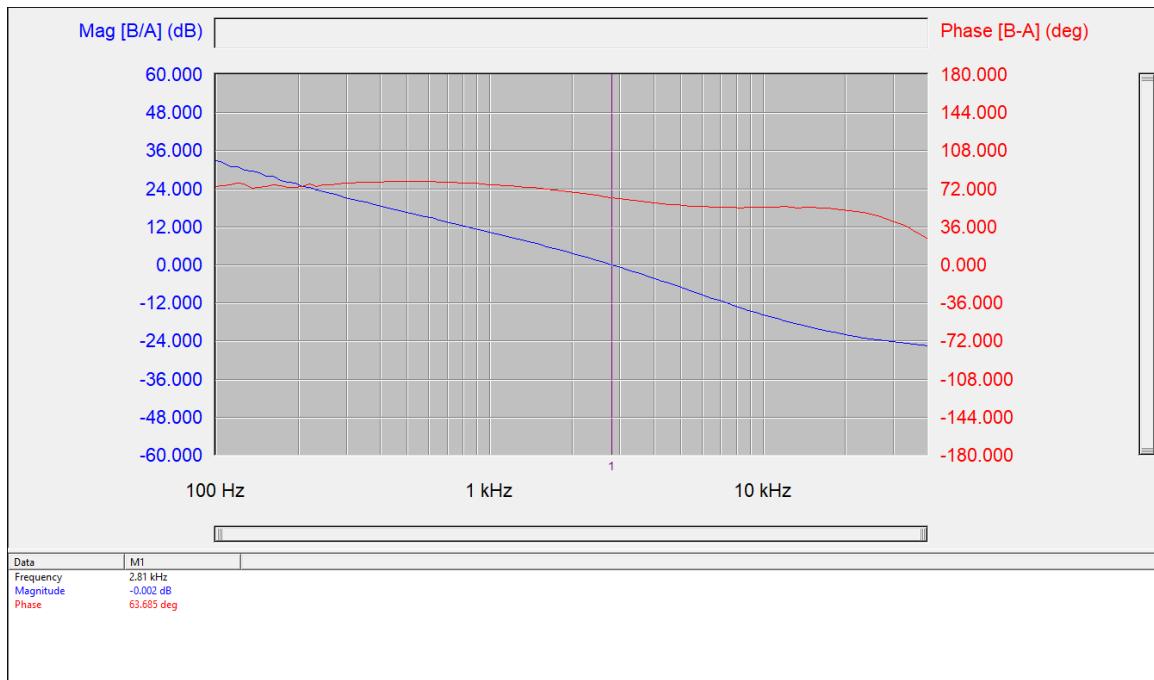


Figure 62. 37 V Input 12 V Output Bode Plot

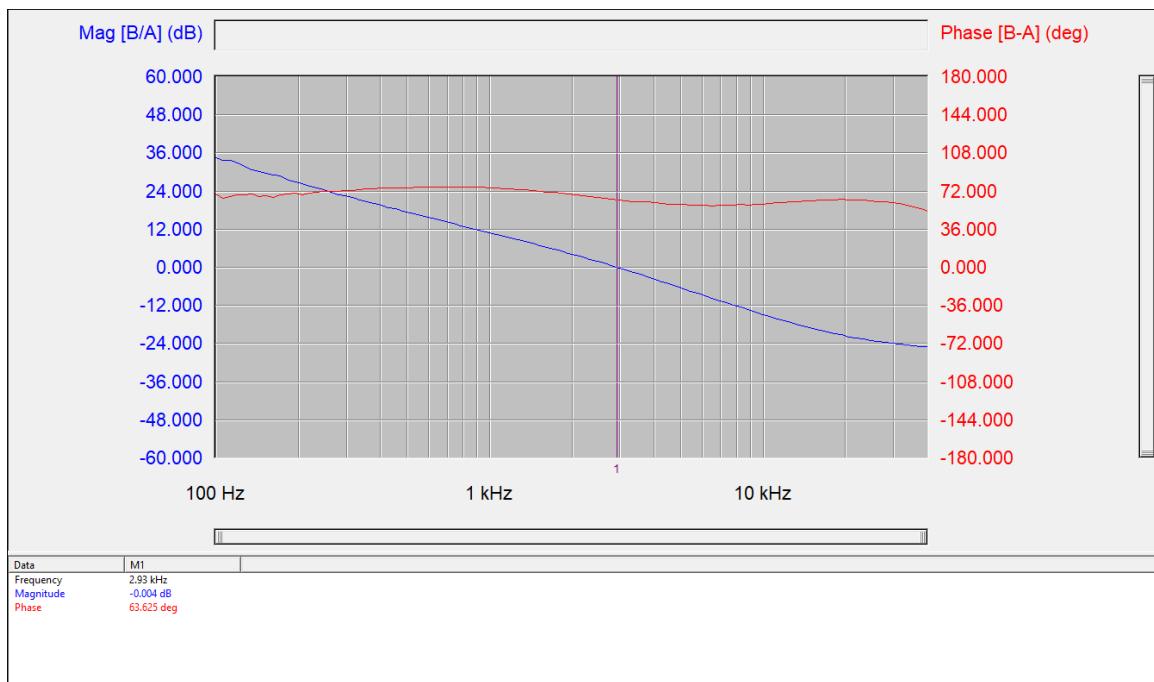


Figure 63. 48 V Input 12 V Output Bode Plot

TND6333/D

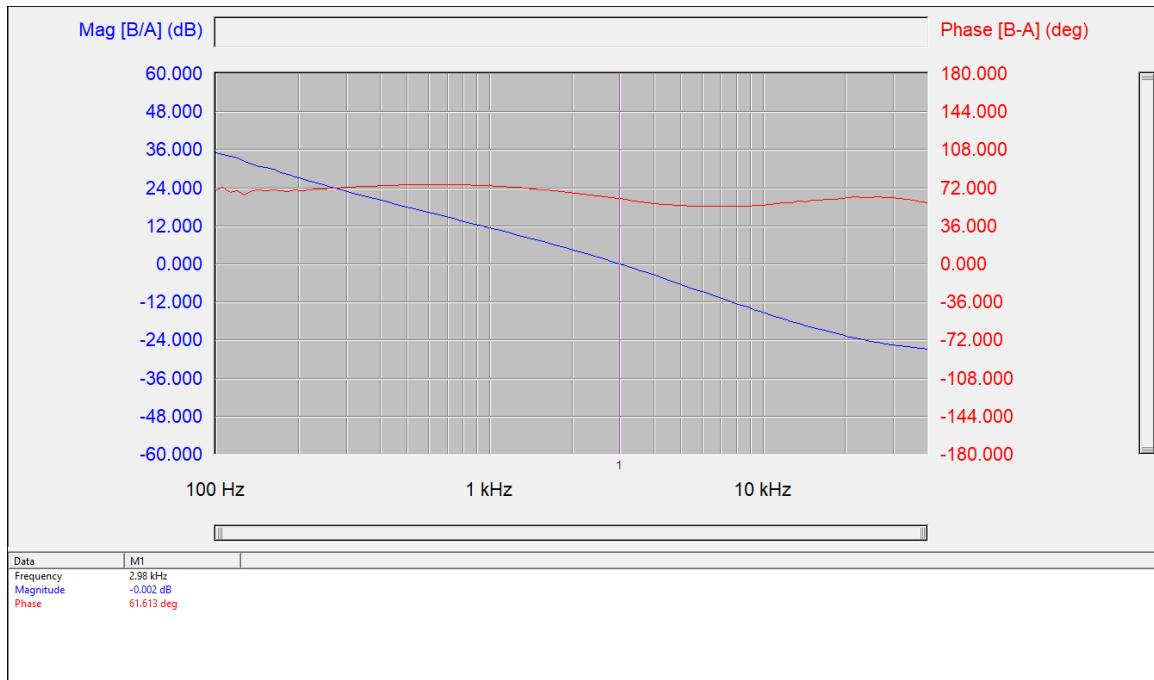


Figure 64. 57 V Input 12 V Output Bode Plot

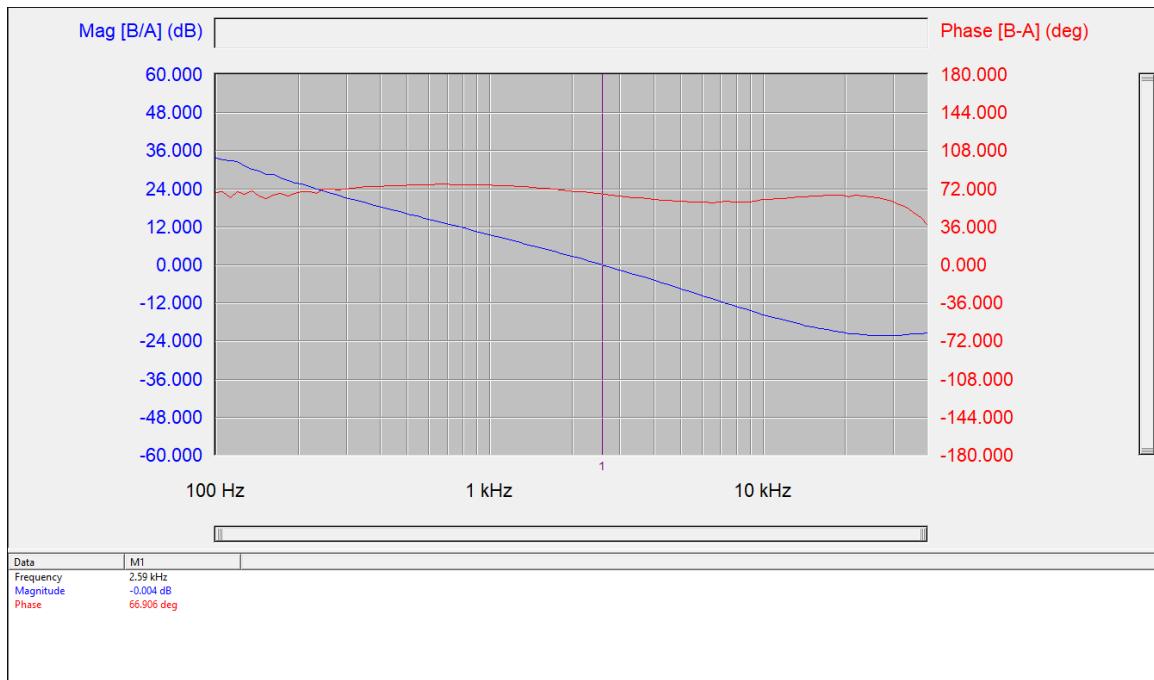


Figure 65. 37 V Input 15 V Output Bode Plot

TND6333/D

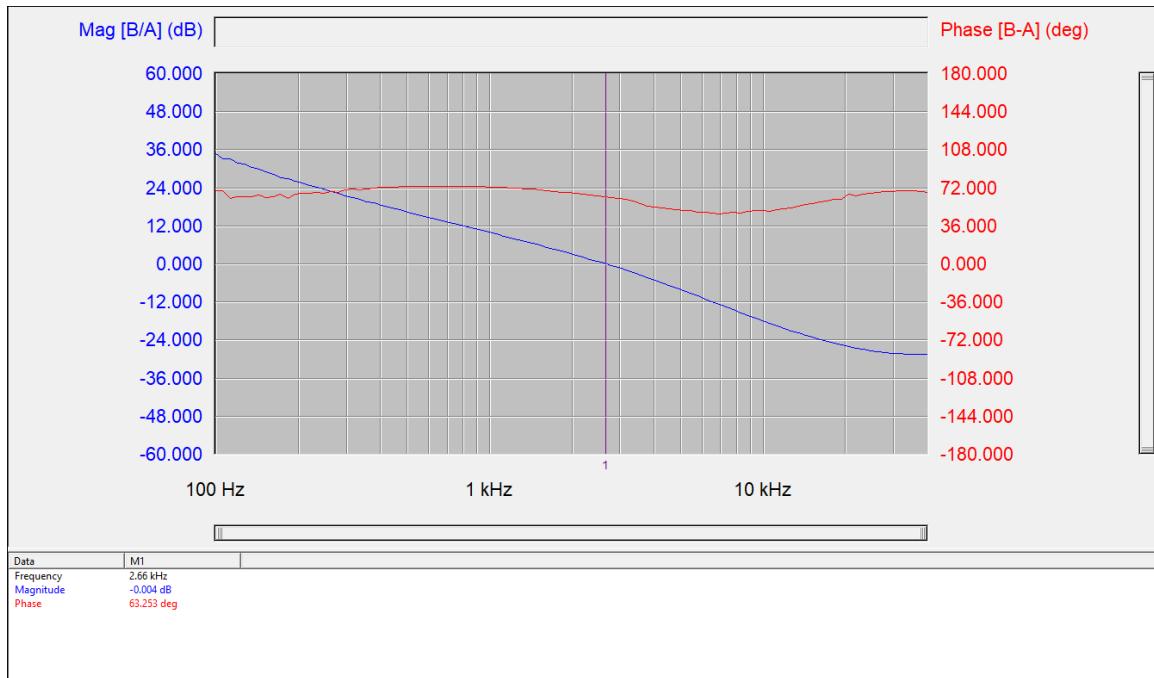


Figure 66. 48 V Input 15 V Output Bode Plot

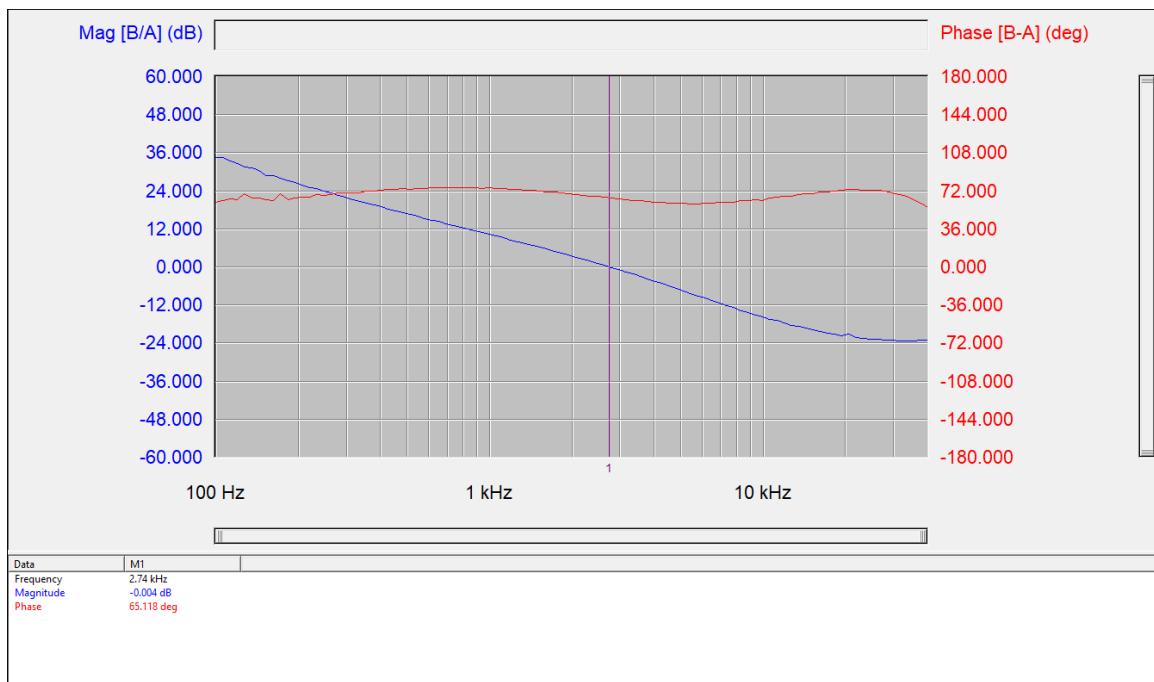


Figure 67. 57 V Input 15 V Output Bode Plot

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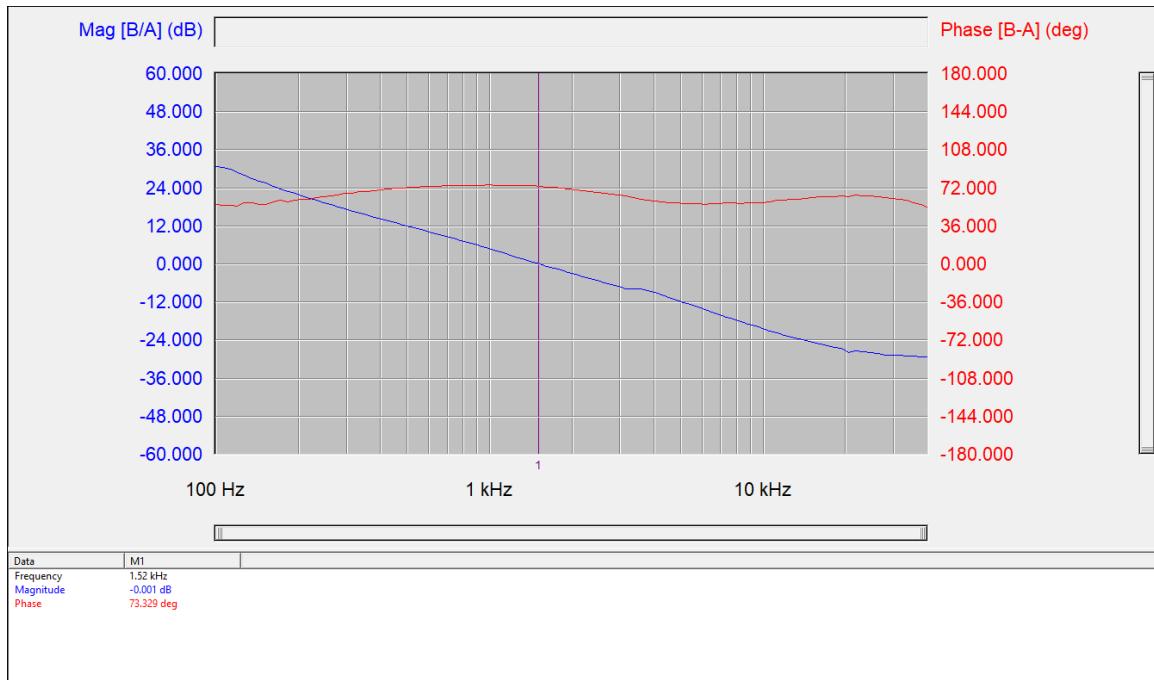


Figure 68. 37 V Input 20 V Output Bode Plot

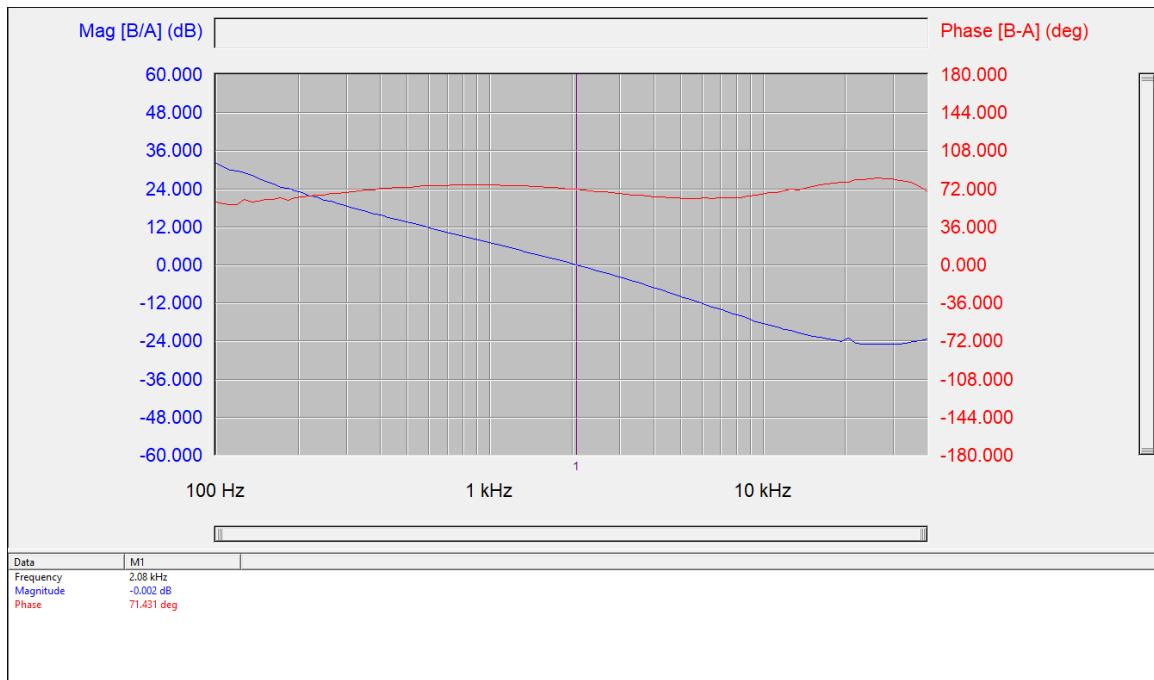


Figure 69. 48 V Input 20 V Output Bode Plot

TND6333/D

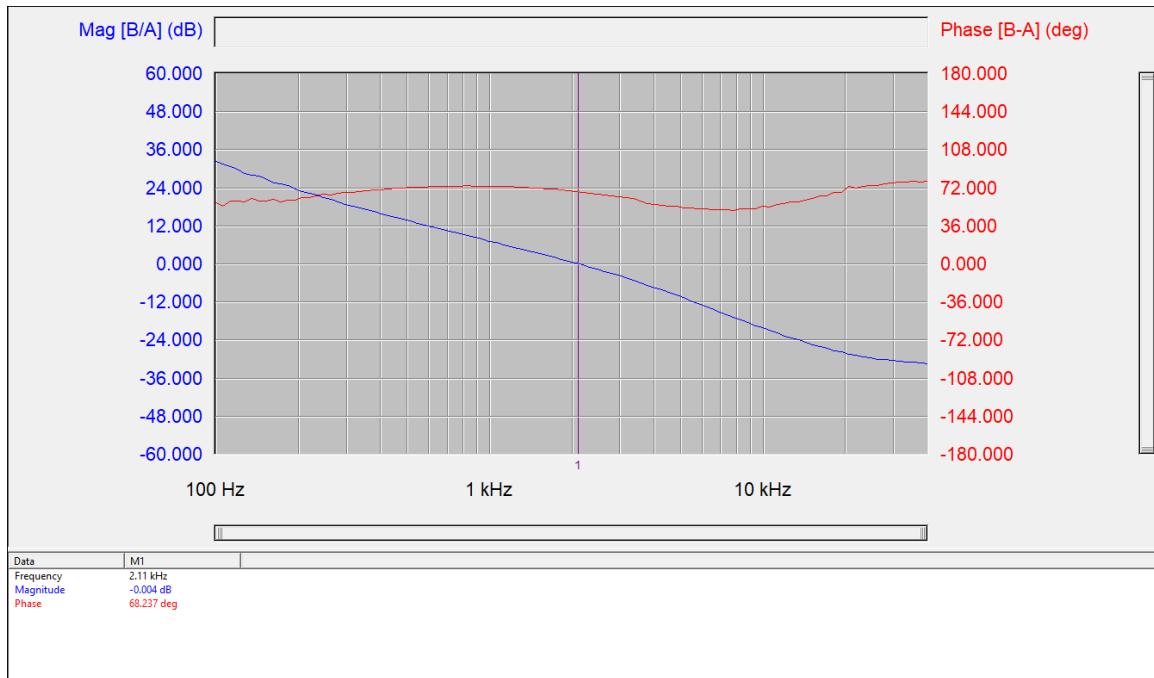


Figure 70. 57 V Input 20 V Output Bode Plot

Thermal Captures (Full Load)

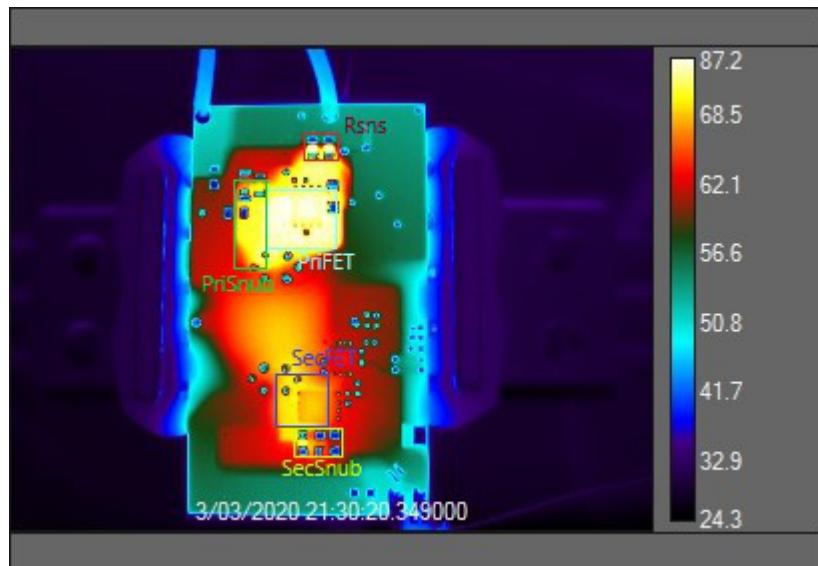


Figure 71. 37 V Input 15 V Output Thermals Bottom

	R Sense	Primary FET	Primary Snubber	Secondary FET	Secondary Snubber
Mean [C]	64.42	76.51	63.97	67.52	60.67
Max [C]	87.16	79.40	77.58	69.92	75.42

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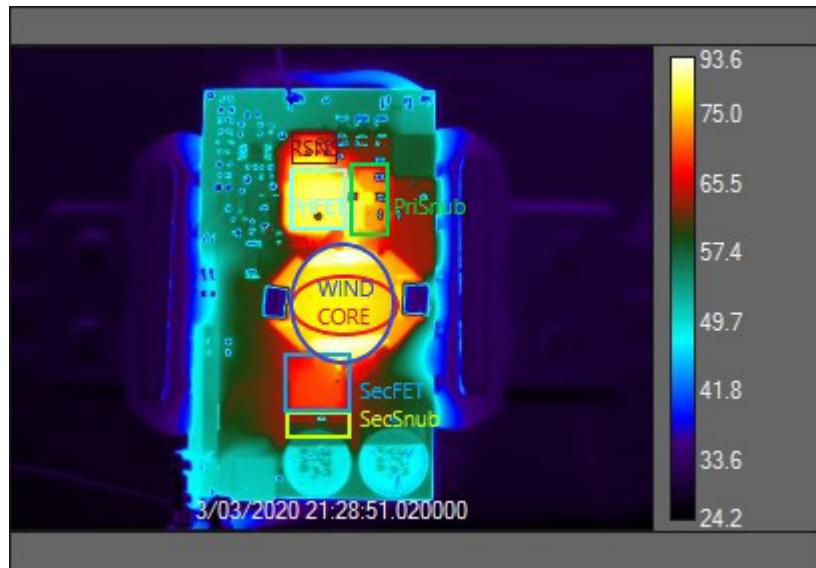


Figure 72. 37 V Input 15 V Output Thermals Top

	R Sense	Primary FET	Primary Snubber	Windings	Core	Secondary FET	Secondary Snubber
Mean [C]	70.65	77.04	65.07	77.39	69.69	68.59	64.29
Max [C]	77.39	79.26	77.63	93.52	77.73	76.83	69.09

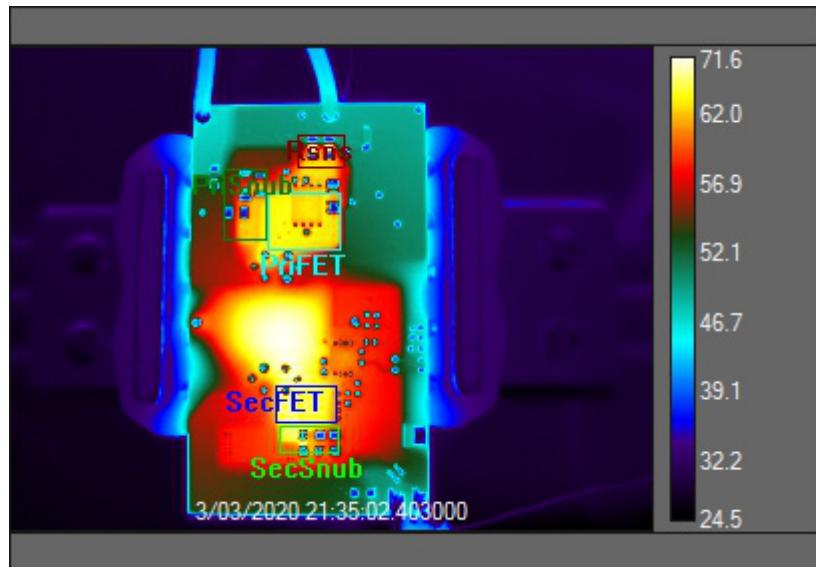


Figure 73. 48 V Input 15 V Output Thermals Bottom

	R Sense	Primary FET	Primary Snubber	Secondary FET	Secondary Snubber
Mean [C]	54.67	61.45	55.44	63.31	56.52
Max [C]	71.61	63.30	62.87	65.23	65.02

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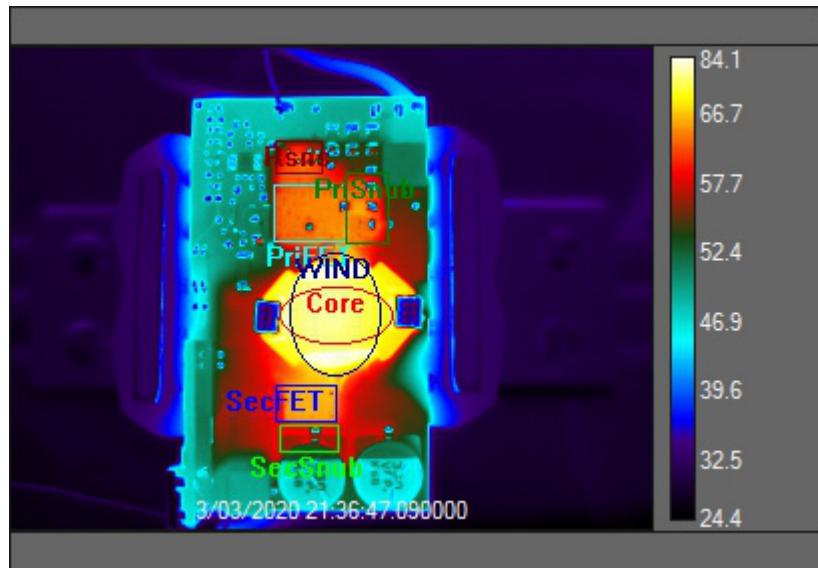


Figure 74. 48 V Input 15 V Output Thermals Top

	R Sense	Primary FET	Primary Snubber	Windings	Core	Secondary FET	Secondary Snubber
Mean [C]	57.87	61.40	58.66	72.45	72.00	62.81	55.58
Max [C]	62.48	63.50	63.59	84.06	74.30	65.27	61.83

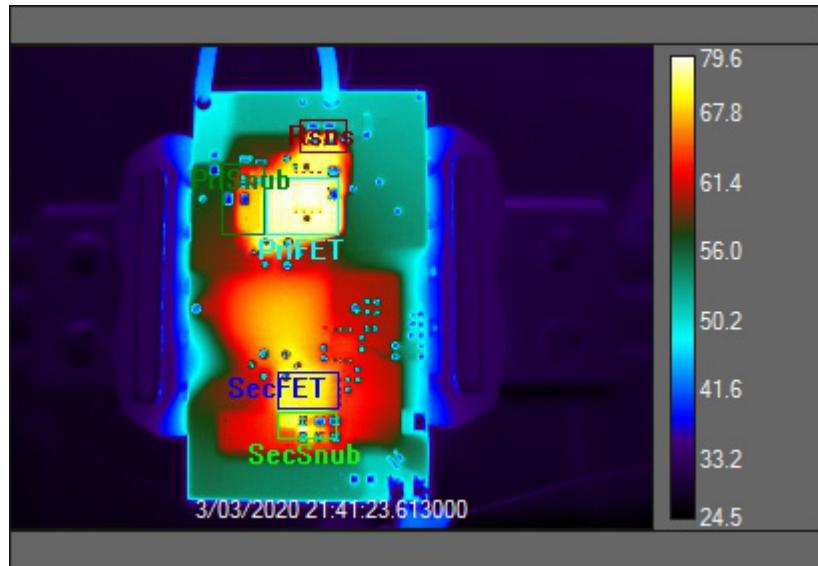


Figure 75. 57 V Input 15 V Output Thermals Bottom

	R Sense	Primary FET	Primary Snubber	Secondary FET	Secondary Snubber
Mean [C]	59.08	74.34	60.73	68.53	63.06
Max [C]	75.86	76.95	74.16	70.86	79.64

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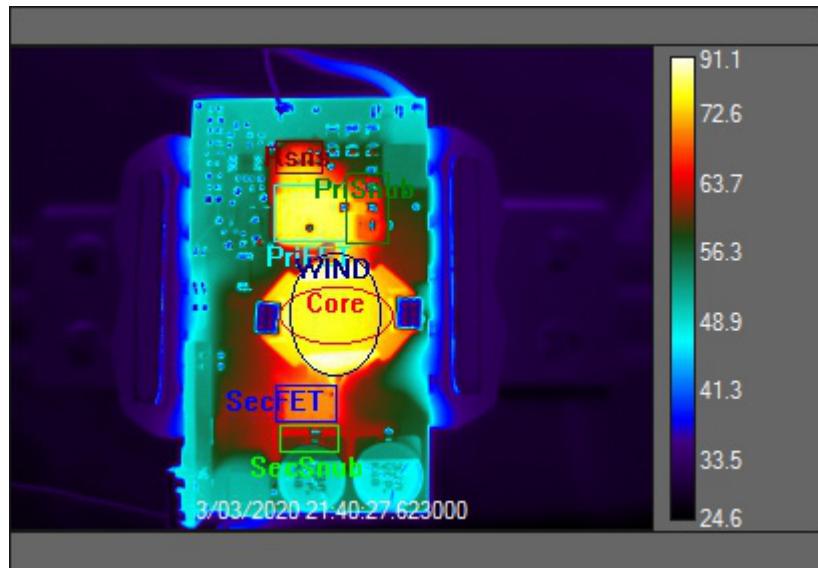


Figure 76. 57 V Input 15 V Output Thermals Top

	R Sense	Primary FET	Primary Snubber	Windings	Core	Secondary FET	Secondary Snubber
Mean [C]	65.23	74.26	64.92	75.48	74.20	68.79	59.16
Max [C]	73.68	76.20	75.29	91.06	76.58	70.95	64.88

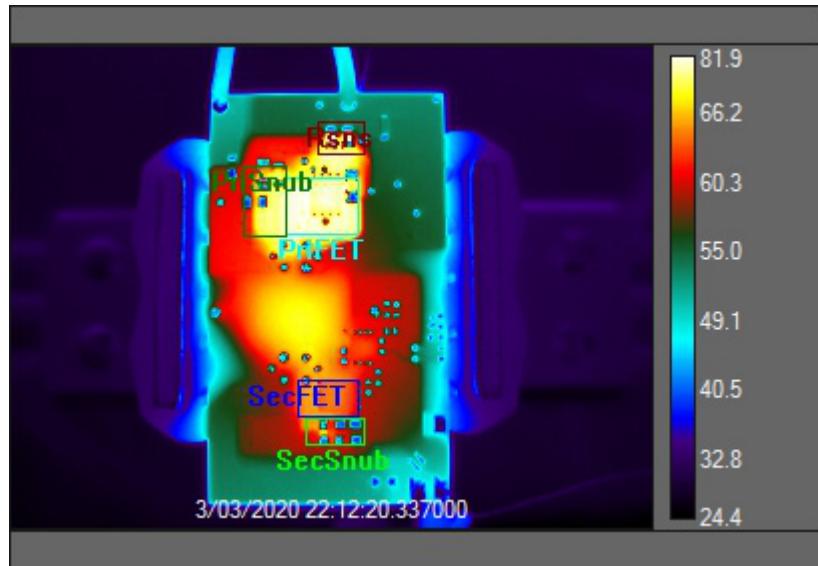


Figure 77. 37 V Input 20 V Output Thermals Bottom

	R Sense	Primary FET	Primary Snubber	Secondary FET	Secondary Snubber
Mean [C]	60.35	71.12	65.02	63.38	55.15
Max [C]	81.92	73.55	72.55	65.09	67.38

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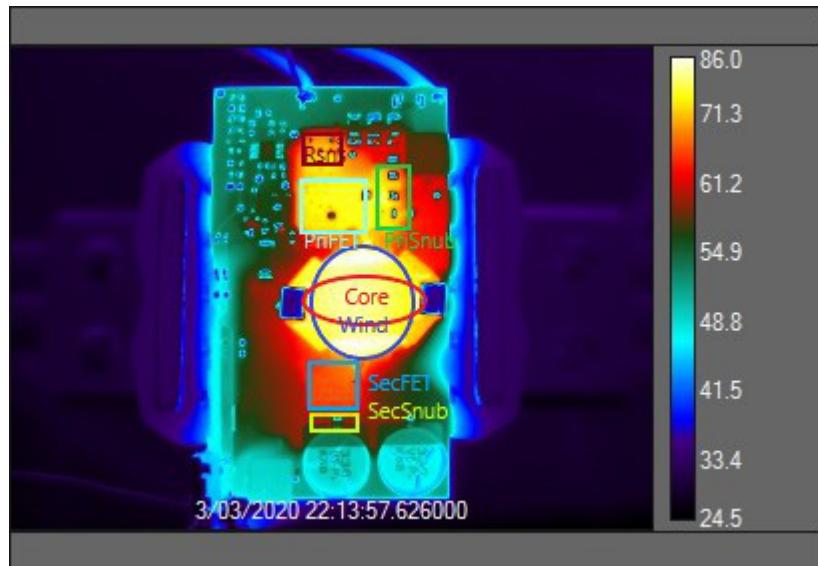


Figure 78. 37 V Input 20 V Output Thermals Top

	R Sense	Primary FET	Primary Snubber	Windings	Core	Secondary FET	Secondary Snubber
Mean [C]	61.39	71.33	66.33	74.64	73.89	63.27	55.76
Max [C]	71.28	73.41	74.25	85.86	75.95	66.18	62.26

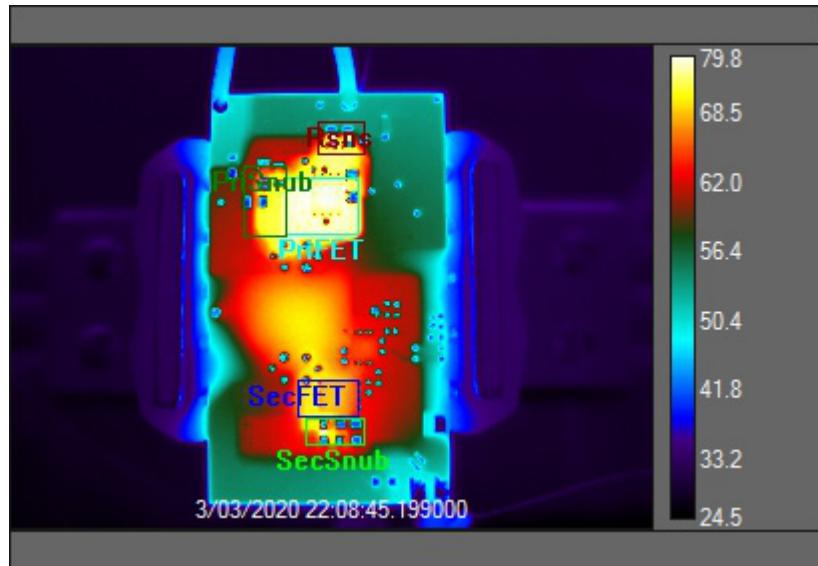


Figure 79. 48 V Input 20 V Output Thermals Bottom

	R Sense	Primary FET	Primary Snubber	Secondary FET	Secondary Snubber
Mean [C]	60.85	75.51	65.38	67.70	59.69
Max [C]	79.77	78.31	76.62	69.98	79.26

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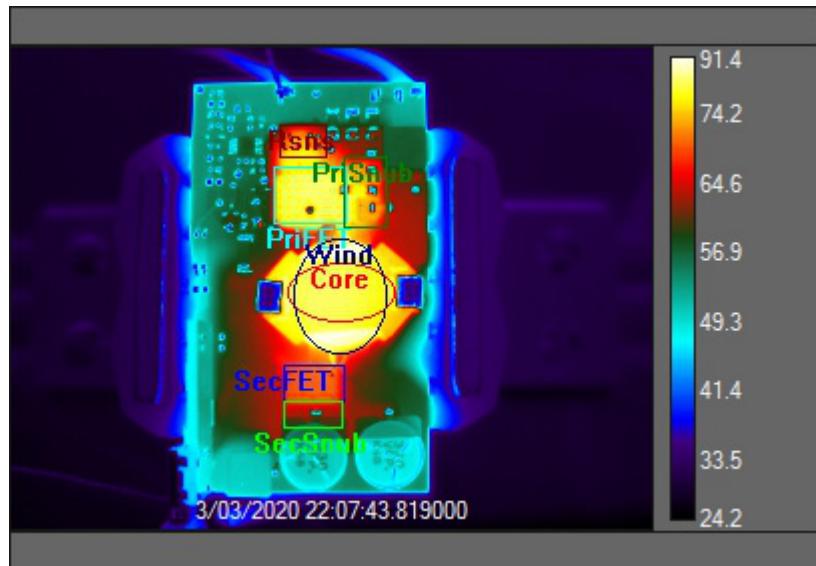


Figure 80. 48 V Input 20 V Output Thermals Top

	R Sense	Primary FET	Primary Snubber	Windings	Core	Secondary FET	Secondary Snubber
Mean [C]	68.58	76.16	69.55	78.01	77.04	68.74	60.70
Max [C]	75.93	78.31	78.00	91.37	78.04	70.94	67.10

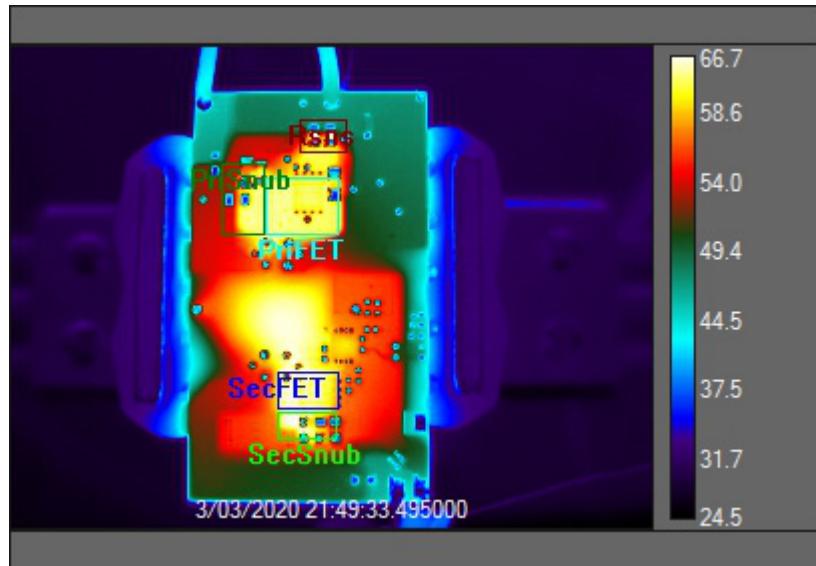


Figure 81. 57 V Input 20 V Output Thermals Bottom

	R Sense	Primary FET	Primary Snubber	Secondary FET	Secondary Snubber
Mean [C]	51.65	59.76	55.20	60.45	56.18
Max [C]	66.48	61.40	61.44	62.12	66.75

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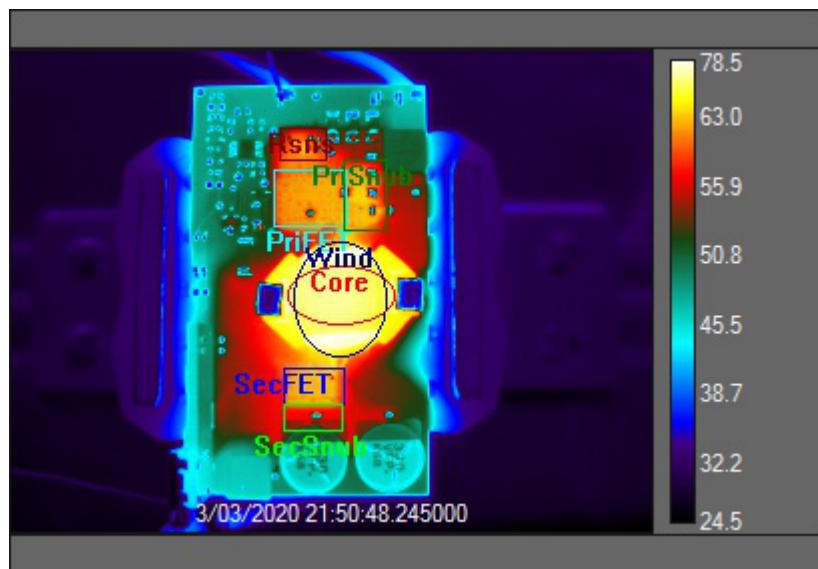


Figure 82. 57 V Input 20 V Output Thermals Top

R Sense	Primary FET	Primary Snubber	Windings	Core	Secondary FET	Secondary Snubber
Mean [C]	57.79	60.70	58.92	69.11	68.66	61.36
Max [C]	63.23	62.73	63.66	78.45	69.73	62.84

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BILL OF MATERIALS MAIN BOARD

Qty	Reference	Manufacturer Part Number	Value	Digikey Part Number
1	T1	750318890 Rev 01	30uH ML29D	
4	R3 R5 R19 R27	CRCW06030000Z0EAC	0R0	541-4012-1-ND
1	R10	CRCW0603100KFKEA	100k	541-100KHCT-ND
2	R7 R22	ERJ-3EKF10R0V	10R0	P10.0HCT-ND
4	R12 R17 R20-21	CRCW060310K0FKEB	10k	541-2978-1-ND
1	R16	CRCW060318K2FKEA	18.2k	541-18.2KHCT-ND
1	R15	CRCW06032K49FKEA	2.49k	541-4044-1-ND
1	R6	CRCW0603374KFKEA	374k	541-374KHCT-ND
2	R26 R30	CRCW06034K99FKEAC	4.99k	541-3985-1-ND
1	R1	CRCW060340R2FKEA	40.2R	541-40.2HCT-ND
1	R13	CRCW0603442RFKEA	442R	541-442HCT-ND
1	R18	CRCW06034R99FKEA	4R99	541-4.99HHCT-ND
3	R11 R28 R32		DNI	
1	CY1	502R29W102KV3E-****-SC	1000pF	709-1269-1-ND
1	C11	CGA3E3X7S2A104K080AB	0.1uF	445-6938-1-ND
1	C12	C0603C122K5RACTU	1.2nF	399-7851-1-ND
3	C6 C22-23	CGA3E3X5R1H105K080AB	1uF	445-7878-1-ND
1	C9	GRM188R61H225KE11D	2.2uF	490-10733-1-ND
1	C3	CGJ3E2X7R1E223K080AA	22nF	445-8125-1-ND
1	C1	C0603C331K4RAC7867	330pF	399-17406-1-ND
1	C4	8.85012E+11	4.7nF	732-7957-1-ND
2	C5 C10	CGA3E2X7R1H103K080AA	10nF	445-5662-1-ND
1	C34	C0603C682K2RAC7867	6800pF	399-14536-1-ND
1	C2	C1206C104KARACTU	0.1uF	399-4674-1-ND
1	C15	CGA5L3X5R1H106M160AB	10 uF	445-12883-1-ND
4	C18-21	C3216X7R2A105K160AA	1uF	445-4467-1-ND
1	C7	C0603C471K2RACTU	470pF	399-9085-1-ND
2	C8 C17	EEE-FP1V331AP	330uF/35V	PCE4445TR-ND
3	J1 J3 J5	NA	NA	
4	D2-5	MMSD3070	200V 200mA	MMSD3070TR-ND
1	Q2	FDMS86202	120V 7.2mOhm	FDMS86202CT-ND
1	Q1	FDMS86255	150V 11mOhm	FDMS86255CT-ND
1	U8	FODM8801BV	1.17V 50mA	FODM8801BV-ND
2	L1-2	744314047	0.47uH	732-1155-1-ND
3	PGO VIN+ VIN-	01-1036		
1	Q4	BSS64L	80V 200mA	BSS64LT1GOSCT-ND
1	Z2	MM3Z12VST1G	12 V	MM3Z12VST1GOSCT-ND
1	Z1	MM3Z22VT1G	22V	MM3Z22VT1GOSCT-ND
1	U1	NCP12700BDNR2G		NCP12700BDNR2GOSCT-ND
1	U2	NCP4306AADZZAMN1TBG	20V	NCP4306AADZZ-ZAMN1TBGOSCT-ND
1	RT1	ERT-J1VV104J	100k	P10555CT-ND
1	R14	CRCW08050000Z0EA	0R0	541-0.0ACT-ND
2	R4 R33	CRCW0805100RFKEAC	100R	541-3979-1-ND
1	R31		DNI	

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BILL OF MATERIALS MAIN BOARD (continued)

Qty	Reference	Manufacturer Part Number	Value	Digikey Part Number
1	D1	ES1JFL	600V 1A	ES1JFLCT-ND
2	R2 R34	HRG3216P-1002-B-T1	10k	408-1949-2-ND
2	R8-9	WSLP12065L000FEA	80mOhm	WSLP-.005CT-ND
2	R23-24		DNI	

BILL OF MATERIALS DAUGHTER BOARD

Qty	Reference	Manufacturer Part Number	Value	Digikey Part Number
1	C46	C0402C681G5GACTU	680pF	399-14285-2-ND
1	C4		DNI	
2	C37 C44	CGA2B2X7R1H472K050BE	4.7nF	445-173711-1-ND
1	C30	CL10A105KL8NNNC	1.0uF	1276-1861-1-ND
1	R32	CRCW040210R0FKED	10R	541-3964-1-ND
1	R21	CRCW0402120KJNED	120k	541-120KJCT-ND
1	R34	CRCW040213K0JNED	13k	541-13KJCT-ND
2	R40 R42	CRCW040210R0FKED	10R	541-3964-1-ND
2	R39 R53	RC0402FR-07100KL	100k	
1	R25	CRCW040210K0FKEDC	10k	311-100KLRCT-ND
1	R35	CRCW040282K5FKEDC	82.5k	541-3959-1-ND
1	R47	CRCW04021K00FKTD	1k	541-5098-1-ND
3	J2 J4 J6	NA	NA	541-2957-1-ND
1	U1	FUSB3307		
1	C48	CC0402JRX7R9BB102	1nF	
2	C34-35	GRM1555C1H391JA01J	390pF	311-1351-1-ND
1	Q3	FDMC012N03		490-6236-1-ND
1	R31	AC0805FR-0740R2L	40R2	FDMC012N03CT-ND
4	D1-2 D6 D10	NSPU3051N2T5G	7V	AC0805FR-0740R2L-ND
1	C21	0603DD105KAT2A	1uF	NSPU3051N2T5GOSCT-ND
1	CON1	6.32723E+11	NA	478-0603DD105KAT2ACT-ND
1	R26	WSLP12065L000FEA	5mOhm	732-9618-1-ND

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