ECEN303 : Analogue Design Exercise 2020

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June 15, 2020

Contents

1 Introduction

This report outlines the design of a duel output (mains) AD/DC power supply. It must meet the following specifications:

- Accept NZ mains AC input
- 5V, 3A output with a V_out ripple $\leq$0.5%
- 2.5V, 100mA output with a V_out ripple $\leq$0.1%
- Total cost under US$30

The basic overview of this topology is a AD/DC fly-back stage from mains to an intermediate voltage and 2 buck DC/DC converters to give the final output supplies.

This was achieved primarily with the use of TI-WEBENCH Power Designer [?] for design and simulation/evaluation.

2 AC/DC

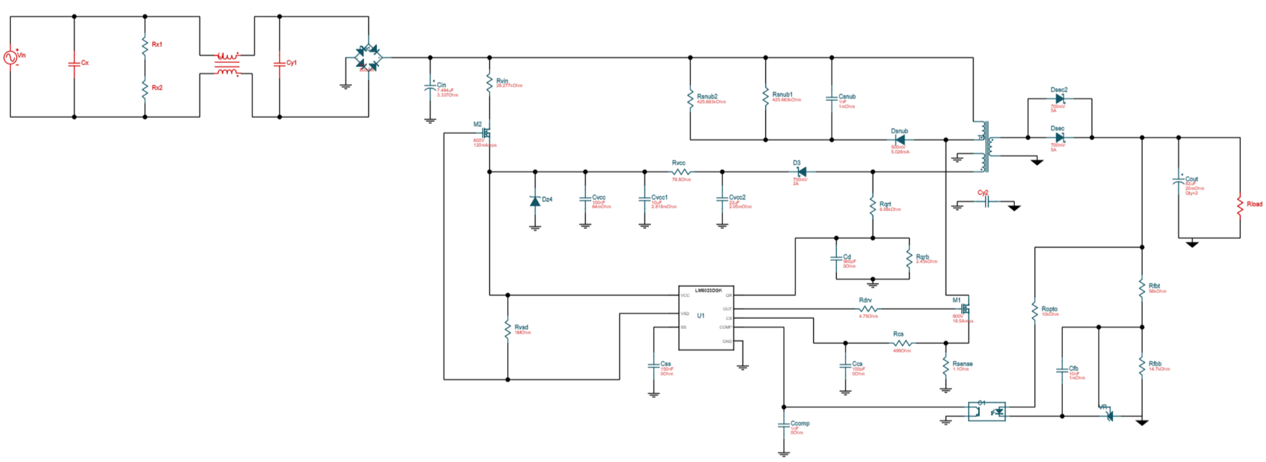


Figure 1.

2.1 Design

This First input stage of the PSU is an AC/DC fly-back converter. It was designed to take standard New Zealand mains as an input; this is 230V with a ±6% tolerance [?], ie min/max of 216/244.

It outputs a intermediate voltage (further buck conversion stages) at a nominal 12V, 2A max current to facilitate the current draw from both output stages.

It includes an input stage EMI filter (see Figure 1), that allows the 50Hz AC through but has a high impedance to any higher frequency.

As this design could not be simulated, it is assumed to operate at its noted nominal efficiency with ideal output ripple.

2.2 Results

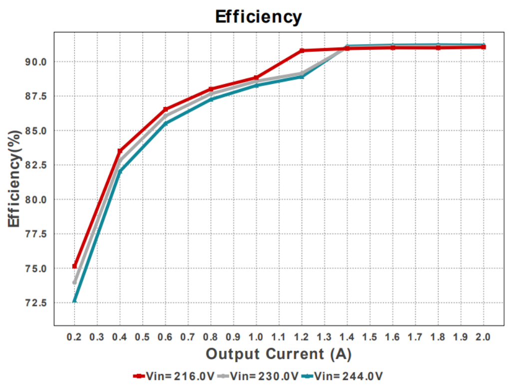


Figure 2.

An efficiency simulation was run. The design is shown to have a nominal operation efficiency of 91%, with characteristic curve shown in Figure 2.

3 DC/DC 5V 3A

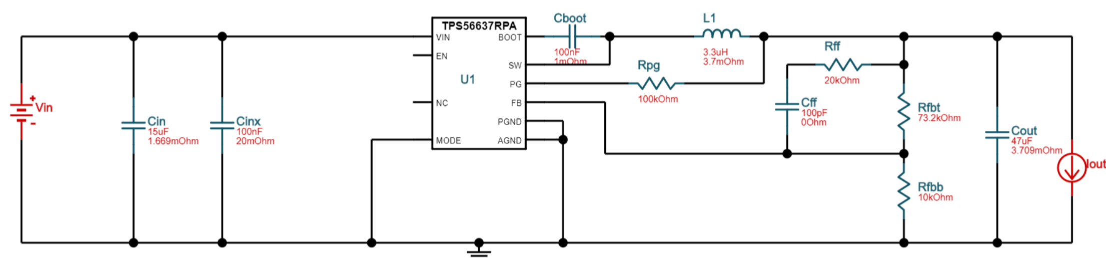


Figure 3.

3.1 Design

This first output stage is specified to supply 5V at 3A, this was achieved with the above buck converter design. Chosen for it's high efficiency, and low footprint/complexity.

It was required to meet the ripple tolerance outlined above and take the first stage intermediate output as the nominal input voltage.

3.2 Results

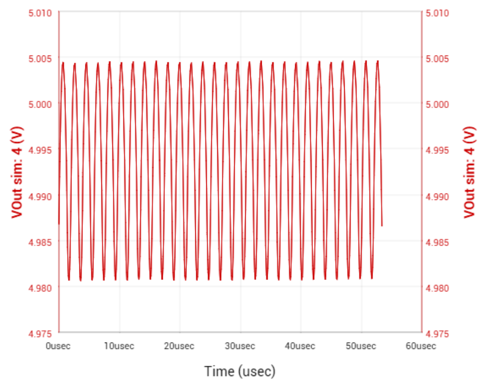


Figure 4.

A steady state analysis simulation was run to evaluate its output ripple performance. The Results of which are seen in figure 4. This design evaluated to a Vout p-p of 23.667 mV, ie a 0.47334% ripple. This is within spec (0.5)

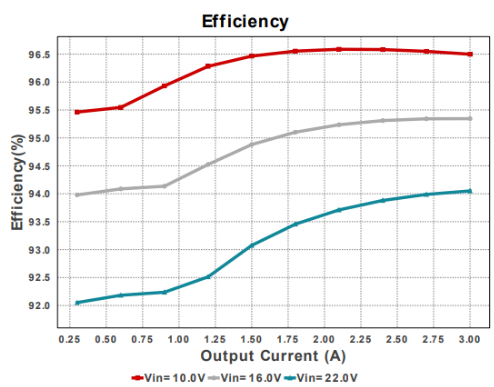


Figure 5.

An efficiency simulation was run. The design is shown to have a nominal operation efficiency of 94.1%, with characteristic curve shown in Figure 5.

4 DC/DC 2.5V 100mA

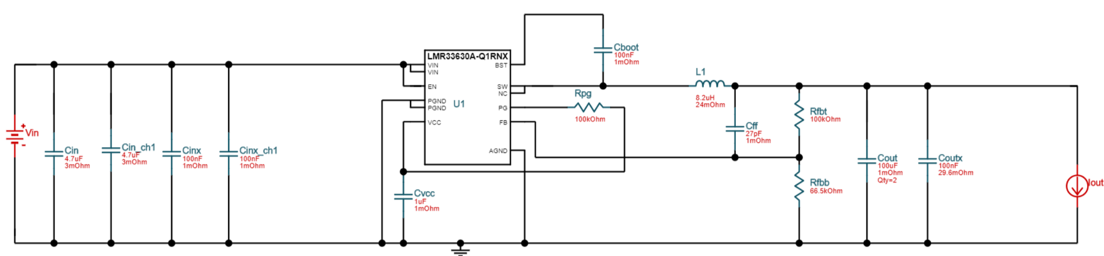


Figure 6.

4.1 Design

This next stage is specified to supply 2.5V at 100mA, this was achieved with the above buck converter design. Chosen for it's high efficiency, and low footprint/complexity. In this case do to low expected power draw its efficiency will not overly impact total design, however it was still optimised to that.

It was required to meet the ripple tolerance outlined above and also take the first stage intermediate output as the nominal input voltage.

4.2 Results

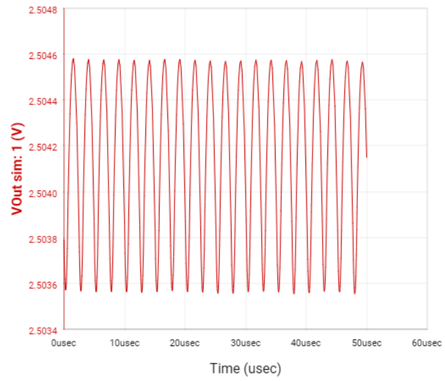


Figure 7.

A steady state analysis simulation was run to evaluate its output ripple performance. The Results of which are seen in figure 7. This design evaluated to a Vout p-p of 1.502 mV mV, ie a 0.06008% ripple. This is within spec (0.1)

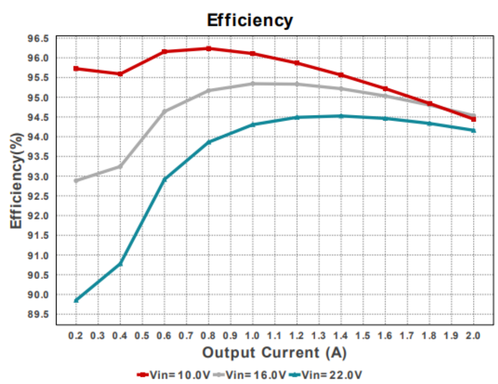


Figure 8.

An efficiency simulation was run. The design is shown to have a nominal operation efficiency of 94.2%, with characteristic curve shown in Figure 8.

5 Final Design and Protection

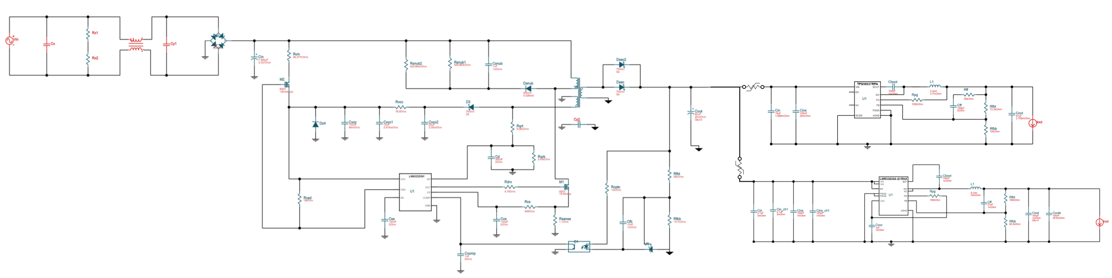


Figure 9.

5.1 Design

To complete the design the 3 above stage must be combined, and added over-current protection included for each stage. This is achieved with resettable poly-fuse, with a trip current of 1.5A. The designs themselves are feedback based so this is the only required addition.

5.2 Results

Total Efficiency:
Calculate the power out of each output buck stage:

$$\begin{aligned} P_{o-5V} &= 5V \cdot 3A \\ &= 15W \end{aligned}$$

$$\begin{aligned} P_{o-2.5V} &= 2.5V \cdot 100mA \\ &= 0.25W \end{aligned}$$

Calculate the power into each output buck stage, to get power draw AC/DC stage:

$$\begin{aligned} P_i &= \frac{P_o}{\eta} \\ P_{i-5V} &= \frac{15W}{0.941} \\ &= 15.940W \end{aligned}$$

$$\begin{aligned} P_{i-2.5V} &= \frac{0.25W}{0.942} \\ &= 0.265W \end{aligned}$$

$$P_{i-5V} + P_{i-2.5V} = 16.205W$$

Power into the AC/DC stage:

$$\begin{aligned} P_i &= \frac{P_o}{\eta} \\ P_{i-AC} &= \frac{16.205}{0.91} \\ &= 17.808W \end{aligned}$$

Now we calculate the overall efficiency:

$$\begin{aligned} \eta &= \frac{P_o}{P_i} \\ &= \frac{P_{o-5V} + P_{o-2.5V}}{P_i} \\ &= \frac{15.25}{17.808} \\ &= 86\% \end{aligned}$$

In total, the PSU has a final overall efficiency of 86%, both stages meet their ripple requirements and the total BOM cost (see Appendix) is under US$30, coming to US%18.22

Appendix

AC/DC Parameters

Design Inputs

Name	Value	Description
Iout	2.0	Maximum Output Current
VinMax	244.0	Maximum input voltage
VinMin	216.0	Minimum input voltage
Vout	12.0	Output Voltage
acFrequency	50.0	AC Frequency
base_pn	LM5023	Base Product Number
source	AC	Input Source Type
Ta	30.0	Ambient temperature

5V DC/DC Parameters

Design Inputs

Name	Value	Description
Iout	3.0	Maximum Output Current
VinMax	22.0	Maximum input voltage
VinMin	10.0	Minimum input voltage
VinTyp	12.0	Typical input voltage
Vout	5.0	Output Voltage
base_pn	TPS56637	Base Product Number
source	DC	Input Source Type
Ta	30.0	Ambient temperature

2.5V DC/DC Parameters

Design Inputs

Name	Value	Description
Iout	2.0	Maximum Output Current
VinMax	22.0	Maximum input voltage
VinMin	10.0	Minimum input voltage
VinTyp	12.0	Typical input voltage
Vout	2.5	Output Voltage
base_pn	LMR33630AQ1-WSON	Base Product Number
source	DC	Input Source Type
Ta	30.0	Ambient temperature

AD/DC Transformer

WEBENCH® Transformer Report

#	Name	Value
1.	Core Part Number	B66317G0000X187
2.	Core Manufacturer	TDK
3.	Coil Former Part Number	B66208W1010T001
4.	Coil Former Manufacturer	TDK

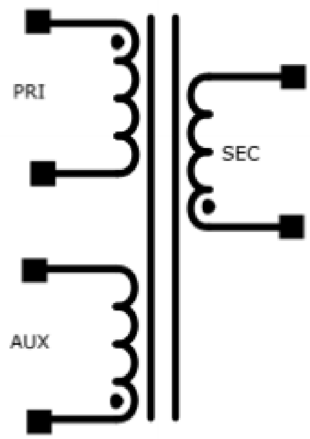
Transformer Electrical Diagram

Primary

Turns	171.0
AWG	32.0
Layers	3.0
Strands	1.0
Insulation Type	Heavy Insulated Magnet Wire

Auxiliary

Turns	6.0
AWG	28.0
Layers	1.0
Strands	4.0
Insulation Type	Heavy Insulated Magnet Wire



Secondary

Turns	7.0
AWG	27.0
Layers	1.0
Strands	3.0
Insulation Type	Triple Insulated

BOM

Part	*Manufacturer*	*Part Number*	*Quantity*	*Price ($)*	*Footprint (mm²)*	*Description*
				ACDC 12V		
Rdrv	Vishay-Dale	CRCW04024R75FKED	1	0.01	3	Resistance: 4.75 Ω Tolerance: 1.0% Power: 63 mW
Cd	MuRata	GRM1555C1H561JA01J	1	0.01	3	Cap: 560 pF Total Derated Cap: 560 pF VDC: 50 V ESR: 0 Ω Package: 0402
Cin	CUSTOM	CUSTOM	1	*0.17*	NA	Cap: 7.48 µF Total Derated Cap: 7.5 µF VDC: 362.32 V ESR: 3.34 Ω Package: null
Dsec2	Diodes Inc.	B560C-13-F	1	0.17	83.27	Type: Schottky VRRM: 60 V Io: 5 A
Cvcc2	TDK	C2012X5R1V226M125AC	1	0.33	6.75	Cap: 22 µF Total Derated Cap: 22 µF VDC: 35 V ESR: 2.05 mΩ Package: 0805
Dz4	ON Semiconductor	MMBZ5244BLT1G	1	0.02	14	Type: SMT VRWM: 14 V
Rsense	Vishay-Dale	CRCW12061R10FKEA	1	0.01	10.92	Resistance: 1.1 Ω Tolerance: 1.0% Power: 250 mW
M2	Infineon Technologies	BSP135H6327XTSA1	1	0.54	76.5	VdsMax: 600 V IdsMax: 120 mAmps
Cvcc1	TDK	C2012X5R1V106K085AC	1	0.17	6.75	Cap: 10 µF Total Derated Cap: 1.9 µF VDC: 35 V ESR: 2.82 mΩ Package: 0805
Rsnub2	CUSTOM	CUSTOM	1	0.01	NA	Resistance: 425.66 kΩ Tolerance: 0.0% Power: 0 W
Dac	Diodes Inc.	HD06-T	1	0.13	62.1	Type: Switching-Bridge VRRM: 600 V Io: 800 mA
Cfb	MuRata	GRM033R70J103KA01D	1	0.01	2.08	Cap: 10 nF Total Derated Cap: 10 nF VDC: 6.3 V ESR: 1 mΩ Package: 0201
Rfbb	Vishay-Dale	CRCW040214K7FKED	1	0.01	3	Resistance: 14.7 kΩ Tolerance: 1.0% Power: 63 mW
VR	Texas Instruments	TL431IDBVR	1	0.06	16.39	IkMin: 400 mA InitialAccuracy: 1.5% ReferenceOutput: 2.5 V
Cvcc	Kemet	C0805C104M5RACTU	1	0.01	6.75	Cap: 100 nF Total Derated Cap: 100 nF VDC: 50 V ESR: 64 mΩ Package: 0805
Rsnub1	CUSTOM	CUSTOM	1	0.01	NA	Resistance: 425.66 kΩ Tolerance: 0.0% Power: 0 W
U1	Texas Instruments	LM5023MM-2/NOPB	1	0.38	23.6	
D3	Fairchild Semiconductor	SS26FL	1	0.07	11.7	Type: Schottky VRRM: 60 V Io: 2 A
Rvin	CUSTOM	CUSTOM	1	0.01	NA	Resistance: 26.28 kΩ Tolerance: 0.0% Power: 0 W
Rvcc	Vishay-Dale	CRCW040276R8FKED	1	0.01	3	Resistance: 76.8 Ω Tolerance: 1.0% Power: 63 mW
Rcs	Vishay-Dale	CRCW0402499RFKED	1	0.01	3	Resistance: 499 Ω Tolerance: 1.0% Power: 63 mW
O1	Fairchild Semiconductor	FOD817A	1	0.11	71.06	CTR_Min: 80.0% CTR_Max: 160.0% IcMax: 50 mmA
Ccs	Samsung Electro-Mechanics	CL21C101JBANNNC	1	0.01	6.75	Cap: 100 pF Total Derated Cap: 100 pF VDC: 50 V ESR: 0 Ω Package: 0805
Ccomp	MuRata	GRM1555C1H102JA01J	1	0.01	3	Cap: 1 nF Total Derated Cap: 1 nF VDC: 50 V ESR: 0 Ω Package: 0402
Ropto	Yageo	RC0201FR-0710KL	1	0.01	2.08	Resistance: 10 kΩ Tolerance: 1.0% Power: 50 mW
T1	Core=TDK CoilFormer=TDK	'G0000X187 CoilFormer=B6620	1	0.22	569.35	Core Type: E25/13/7 Core Material: N87 Turns Ratio(Nps): 171:7
Rfbt	Susumu Co Ltd	RR1220P-563-D	1	0.01	6.75	Resistance: 56 kΩ Tolerance: 0.5% Power: 100 mW
Rqrb	Vishay-Dale	CRCW04022K43FKED	1	0.01	3	Resistance: 2.43 kΩ Tolerance: 1.0% Power: 63 mW
Rqrt	Vishay-Dale	CRCW04026K98FKED	1	0.01	3	Resistance: 6.98 kΩ Tolerance: 1.0% Power: 63 mW
Css	Panasonic	ECPU1C154MA5	1	0.17	10.92	Cap: 150 nF Total Derated Cap: 150 nF VDC: 16 V ESR: 0 Ω Package: 1206
Cout	Panasonic	35SVPF82M	2	0.63	106.09	Cap: 82 µF Total Derated Cap: 160 µF VDC: 35 V ESR: 20 mΩ Package: 8x11.9
Dsnub	CUSTOM	CUSTOM	1	*5*	NA	Type: ? VRRM: 1.02 kV Io: 5.03 mA
Csnub	MuRata	GRM31A7U2J102JW31D	1	0.09	10.92	Cap: 1 nF Total Derated Cap: 1 nF VDC: 630 V ESR: 1 mΩ Package: 1206
Dsec	Diodes Inc.	B560C-13-F	1	0.17	83.27	Type: Schottky VRRM: 60 V Io: 5 A
M1	STMicroelectronics	STW21N90K5	1	3.2	123.2	VdsMax: 900 V IdsMax: 18.5 Amps
Rvsd	Vishay-Dale	CRCW08051M00FKEA	1	0.01	6.75	Resistance: 1 MΩ Tolerance: 1.0% Power: 125 mW
VR			**Total Price $**	**11.81**		
				DCDC 5V		
Cinx	MuRata	GRM188R71H104KA93D	1	0.02	4.68	Cap: 100 nF Total Derated Cap: 87 nF VDC: 50 V ESR: 20 mΩ Package: 0603
U1	Texas Instruments	TPS56637RPAR	1	1.32	16	
Cin	TDK	C2012X5R1V156M125AC	1	0.21	6.75	Cap: 15 µF Total Derated Cap: 1.2 µF VDC: 35 V ESR: 1.67 mΩ Package: 0805
Cout	MuRata	GRM31CR61A476KE15L	1	0.26	10.92	Cap: 47 µF Total Derated Cap: 21 µF VDC: 10 V ESR: 3.71 mΩ Package: 1206
L1	Coilcraft	XAL1010-332MEB	1	1.71	159.6	L: 3.3 µH DCR: 3.7 mΩ IDC: 25 A
Rpg	Vishay-Dale	CRCW0402100KFKED	1	0.01	3	Resistance: 100 kΩ Tolerance: 1.0% Power: 63 mW
Cboot	MuRata	GRM155R71C104KA88D	1	0.01	3	Cap: 100 nF Total Derated Cap: 100 nF VDC: 16 V ESR: 1 mΩ Package: 0402
Rfbb	Vishay-Dale	CRCW040210K0FKED	1	0.01	3	Resistance: 10 kΩ Tolerance: 1.0% Power: 63 mW
Rfbt	Vishay-Dale	CRCW040273K2FKED	1	0.01	3	Resistance: 73.2 kΩ Tolerance: 1.0% Power: 63 mW
Cff	Kemet	C0402C101K4GACTU	1	0.01	3	Cap: 100 pF Total Derated Cap: 100 pF VDC: 16 V ESR: 0 Ω Package: 0402
Rff	Vishay-Dale	CRCW040220K0FKED	1	0.01	3	Resistance: 20 kΩ Tolerance: 1.0% Power: 63 mW
			Total Price $	**3.58**		
				DCDC 2.5V		
Rfbb	Vishay-Dale	CRCW040266K5FKED	1	0.01	3	Resistance: 66.5 kΩ Tolerance: 1.0% Power: 63 mW
Rfbt	Vishay-Dale	CRCW0402100KFKED	1	0.01	3	Resistance: 100 kΩ Tolerance: 1.0% Power: 63 mW
L1	Coilcraft	XAL6060-822MEB	1	0.82	71.56	L: 8.2 µH DCR: 24 mΩ IDC: 8 A
Cout	MuRata	GRM32ER60J107ME20L	2	0.52	14.7	Cap: 100 µF Total Derated Cap: 150 µF VDC: 6.3 V ESR: 1 mΩ Package: 1210
Cin_ch1	MuRata	GRM31CR71H475KA12L	1	0.22	10.92	Cap: 4.7 µF Total Derated Cap: 2.9 µF VDC: 50 V ESR: 3 mΩ Package: 2220
Cinx	MuRata	GRM188R72A104KA35D	1	0.05	4.68	Cap: 100 nF Total Derated Cap: 82 nF VDC: 100 V ESR: 1 mΩ Package: 0603
Cboot	MuRata	GRM155R71C104KA88D	1	0.01	3	Cap: 100 nF Total Derated Cap: 100 nF VDC: 16 V ESR: 1 mΩ Package: 0402
Cin	MuRata	GRM31CR71H475KA12L	1	0.22	10.92	Cap: 4.7 µF Total Derated Cap: 2.9 µF VDC: 50 V ESR: 3 mΩ Package: 2220
Cinx_ch1	MuRata	GRM188R72A104KA35D	1	0.05	4.68	Cap: 100 nF Total Derated Cap: 82 nF VDC: 100 V ESR: 1 mΩ Package: 0603
Coutx	TDK	CGA3E2X7R1H104K080AA	1	0.01	4.68	Cap: 100 nF Total Derated Cap: 100 nF VDC: 50 V ESR: 29.6 mΩ Package: 0603
Cvcc	Kemet	C0603C105K8PACTU	1	0.01	4.68	Cap: 1 µF Total Derated Cap: 1 µF VDC: 10 V ESR: 1 mΩ Package: 0603
U1	Texas Instruments	LMR33630AQRNXRQ1	1	0.88	12	
Rpg	Vishay-Dale	CRCW0402100KFKED	1	0.01	3	Resistance: 100 kΩ Tolerance: 1.0% Power: 63 mW
Cff	MuRata	GRM1555C1H270JA01D	1	0.01	3	Cap: 27 pF Total Derated Cap: 27 pF VDC: 50 V ESR: 1 mΩ Package: 0402
			Total Price $	**2.83**		
Protection	Bel Fuse Inc.	0ZCH0075AF2E	2	0.42		PTC RESET FUSE 24V 750MA 1210
Full			***FULL BOM COST USD $***	***18.22***		