

Power supplies

by Russell Maguire

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Assignment 1 – Regulated Power Supplies

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1 Introduction

The following report will demonstrate and analyse advanced design methodologies and associated issues with contemporary implementation technologies.

1.1 Aims and Objectives:

The aims and objectives of this assignment are to accommodate a client's design specification for a new power supply.

The aims of this assignment are to:

- Illustrate a good knowledge of advanced design practices.
- Analyse advanced electronic systems that are able to achieve complex analogue functions.
- Design advanced electronic systems to a client's specifications.

The objectives are to:

- Design a new power supply to a customer's specification.
- Simulate and evaluate the power supply to enable a full analysis of the characteristics of the power supply.

The design of the power supply will allow for the electrical, thermal and physical requirements. Data sheets and literature will be scrutinized for relevant information for the design.

2 Background Research

Extensive research has been carried out on power supply design and it can be seen that there are fundamental components required. The power supply can be better understood by separating the parts into a block diagram, an example of this can be seen in figure 1 below.

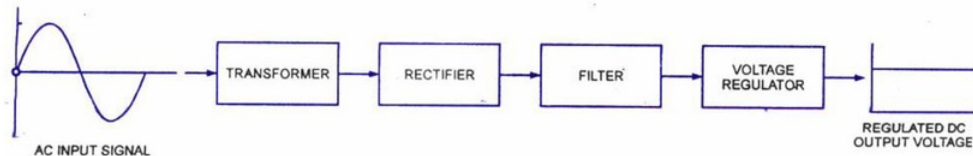


Figure 1 - Block diagram of DC power supply - (jojo, 2015)

2.1 Transformers

When observing figure 1 the first stage of the power supply is the transformer. The transformer will enable the power supply to alter the input AC voltage to a smaller and more appropriate voltage. It will not provide the final voltage as this will be further reduced and modified by the next three stages. For an example we will use 12V. A typical step down transformer contains a ferromagnetic core and 2 windings, as can be seen in the simplistic illustration in figure 2. There is an incoming supply of 240V on the primary winding which is wound around the core 200 times. The secondary winding is then wound around the core 20 times. This will then provide the next part of the power supply a 12V due to the windings being on a 20:1 ratio.

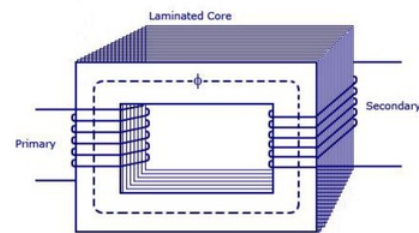


Figure 2 - Transformer - (electronics-tutorials, 2017)

2.2 Rectifiers

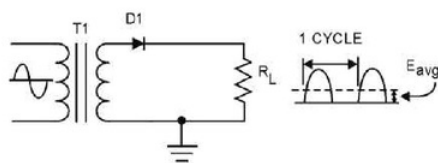


Figure 3 (electronics-tutorials, 2017)

When referring to figure 1 it can be seen that the next step to consider is the rectifier. This part of the circuit is responsible for modifying the AC to DC. There are two types of considerations for rectifiers depending on the specification. These are half wave rectification and full wave rectification.

It can be seen that in figure 3 below a half wave rectifier circuit. The half wave rectifier works by allowing voltage through the diode in the positive

range of the incoming supply and blocking it when the sine wave goes in to the negative range. This produces the non-continuous or pulsating signal as shown in figure 3.

The second method "full wave rectification" can use 2 diodes on a centre tapped transformer or 4 diodes as shown in figure 4. This method has the ability to providing a continuous signal as shown in figure 5.

The reason for this full wave signal is due to the diodes allowing the signal to pass on positive sine wave and flipping the negative sign wave and passing it to the same output as the positive plain but blocking it from passing to the negative region of the circuit as shown in figure 4.

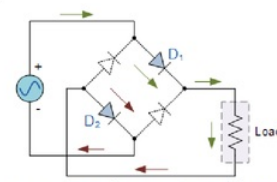


Figure 4 - Full wave circuit (electronics-tutorials, 2017)

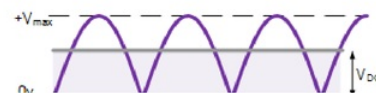


Figure 5 - full wave signal - (electronics-tutorials, 2017)

2.3 Filters

The third stage of the power supply is the filter block. As can be seen in figure 5 the output of the power supply at this stage is very lumpy and can give a varying DC supply, for some applications this may be fine but for more sensitive electronics a more refined signal is required. A method of smoothing this variable DC signal is to use a capacitor. The capacitor is connected to the output of the rectifier and earth; this enables the capacitor to charge up when the rectified signal is rising and discharge when the signal is reducing.

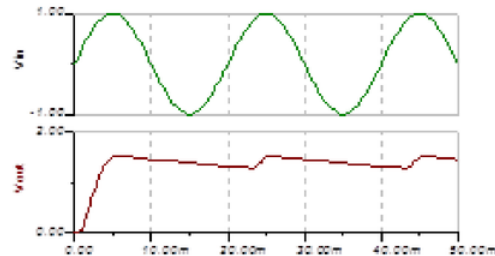


Figure 6 - Smoothing signal

It can be seen in figure 6 that the capacitor has the ability to fill in the troughs as it discharges giving a far superior DC signal.

2.3 Voltage regulators

It can be understood that there are many variations of voltage regulations, however the three main types used in industry are Zener Diode as a shunt regulator, a Series control Regulator and an integrated circuit Regulator.

2.3.1 Zener Diode

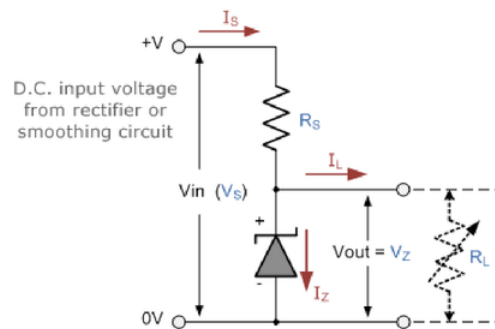


Figure 2 - Zener diode - (electronics-tutorials, 2017)

It can be seen above that the Zener diode is regulating the voltage by allowing a precise volt drop, and the rest of the voltage is then lost on R_s or series resistor. R_s is used to limit the current flow through the diode and V_{out} which is now relatively stable can be taken across the diode as shown in figure 2.

2.3.2 Series controlled regulator

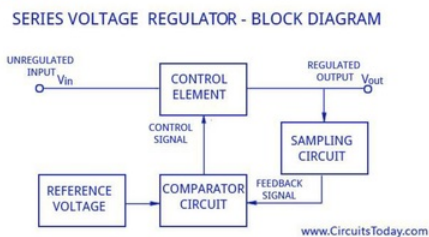


Figure 3 - Series controlled regulator - (John, 2015)

This method relies upon a series of components such as resistors, a Zener diode, transistors and a capacitor. When observing the block diagram in figure 3 the methodology used is that when the Voltage at V_{out} is sampled and then compared to the reference voltage adjustments are carried out by the "control element" that would encompass a series variable resistor and a Zener diode. This would allow the regulator the ability to adjust V_{out} depending on the demand.

2.3.2 Integrated circuit regulator

This method utilises pre-built microchips that offer differing regulation characteristics for different applications.

2.3.2.1 L7805



Figure 4 - L7805 - (ST Microelectronics, 2014)

The L78's are a 3 pin positive regulator, that can offer numerous fixed voltage outputs (ST Microelectronics, 2014). There is the ability to embed internal current limiting, thermal protection and safe area protection. With the correctly selected heatsink applied the component can provide 1.5A. Maximum Ratings, this can be seen by the characteristic of the dropout voltage vs junction temperature in the annexe as annexe 1.

Features

- Output current up to 1.5A
- Variety of output voltages from 5 – 24V
- Thermal overload protection
- Short circuit protection
- 2% output voltage tolerance.

Table 3: Electrical characteristics of L7805A

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	$T_J = 25^\circ\text{C}$	4.9	5	5.1	V
V_O	Output voltage	$I_O = 5\text{ mA to }1\text{ A}, V_I = 7.5\text{ to }18\text{ V}, T_J = 25^\circ\text{C}$	4.8	5	5.2	V
V_O	Output voltage	$I_O = 1\text{ A}, V_I = 18\text{ to }20\text{ V}, T_J = 25^\circ\text{C}$	4.8	5	5.2	V
ΔV_O (%)	Line regulation	$V_I = 7.5\text{ to }25\text{ V}, I_O = 500\text{ mA}, T_J = 25^\circ\text{C}$		7	50	mV
		$V_I = 8\text{ to }12\text{ V}, T_J = 25^\circ\text{C}$		10	50	mV
		$V_I = 7.3\text{ to }20\text{ V}, T_J = 25^\circ\text{C}$		7	50	mV
ΔV_O (%)	Load regulation	$I_O = 5\text{ mA to }1\text{ A}$		25	100	mV
		$I_O = 5\text{ mA to }1.5\text{ A}, T_J = 25^\circ\text{C}$		30	100	mV
		$I_O = 250\text{ to }750\text{ mA}$		8	50	mV
I_Q	Quiescent current	$T_J = 25^\circ\text{C}$		4.3	6	mA
					6	mA
ΔI_Q	Quiescent current change	$V_I = 8\text{ to }23\text{ V}, I_O = 500\text{ mA}$			0.8	mA
		$V_I = 7.5\text{ to }20\text{ V}, T_J = 25^\circ\text{C}$			0.8	mA
		$I_O = 5\text{ mA to }1\text{ A}$			0.5	mA
SVRR	Supply voltage rejection	$V_I = 8\text{ to }18\text{ V}, f = 120\text{ Hz}, I_O = 500\text{ mA}$		68		dB
V_D	Dropout voltage	$I_O = 1\text{ A}, T_J = 25^\circ\text{C}$		2		V
eN	Output noise voltage	$T_A = 25^\circ\text{C}, B = 10\text{ Hz to }100\text{ kHz}$		10		$\mu\text{V}/V_O$
R _O	Output resistance	$f = 1\text{ kHz}$		17		m Ω
I_{SC}	Short circuit current	$V_I = 35\text{ V}, T_A = 25^\circ\text{C}$		0.2		A
I_{SP}	Short circuit peak current	$T_J = 25^\circ\text{C}$		2.2		A
$\Delta V_O/T$	Output voltage drift			+1.1		mV/°C

Figure 5 - Max current - (ST Microelectronics, 2014)

2.3.2.2 LM317

This regulator is a three terminal positive voltage adjustable regulator, and has the ability of delivering in excess of 1.5A over a variety of voltages from 1.25V to 37V. This device can be found in many applications such as desktop PC's, energy harvesting, power bank solutions and many more (Texas Instruments, 2013)



Figure 6 - LM317 (Texas instruments, 2016)

Features

- Voltage range between 1.25 and 37V.
- Can deliver >1.5A
- Short circuit limiting
- Thermal protection
- Output safe area compensation (Texas instruments, 2016)

The specifications for this chip can be found as a data sheet in the annexe as annexe 2. In a typical application an example circuit is proved in the data sheet, this can be seen in figure 7 below.

8.2 Typical Application

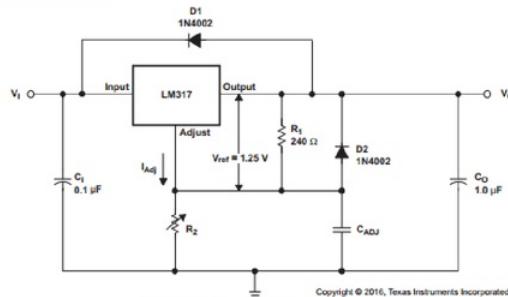


Figure 9. Adjustable Voltage Regulator

8.2.1 Design Requirements

- R1 and R2 are required to set the output voltage.
- C_{ADJ} is recommended to improve ripple rejection. It prevents amplification of the ripple as the output voltage is adjusted higher.
- C_I is recommended, particularly if the regulator is not in close proximity to the power-supply filter capacitors. A 0.1-μF or 1-μF ceramic or tantalum capacitor provides sufficient bypassing for most applications, especially when adjustment and output capacitors are used.
- C_O improves transient response, but is not needed for stability.
- Protection diode D2 is recommended if C_{ADJ} is used. The diode provides a low-impedance discharge path to prevent the capacitor from discharging into the output of the regulator.
- Protection diode D1 is recommended if C_O is used. The diode provides a low-impedance discharge path to prevent the capacitor from discharging into the output of the regulator.

Figure 7 - Typical circuit - (Texas instruments, 2016)

It can be seen that R1 and R2 are used as a voltage reference by using the voltage divider rule, and as stated the capacitor is used to improve ripple rejection.

2.3.2.3 Lm723

This regulator is mostly utilised for series regulator applications (Texas Instruments, 2013). This chip has the ability to deliver up to 150mA but can also with the aid of bypass transistors control larger loads. This type of regulator can be found in temperature controllers, shunt regulators and current regulators.



Figure 8 - LM723 - (Texas Instruments, 2013)

Features as can be seen in figure 9.

- Can deliver up to 150mA without any external pass transistor
- With external transistors it can control up to 10A
- Max input voltage at 40V.
- Output voltage adjustable from 2V – 37V (Texas Instruments, 2013)

TEXAS
INSTRUMENTS

LM723, LM723C

www.ti.com

SNVS708C – JUNE 1999 – REVISED APRIL 2013

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

ABSOLUTE MAXIMUM RATINGS⁽¹⁾⁽²⁾

Pulse Voltage from V^+ to V^- (50 ms)		50V
Continuous Voltage from V^+ to V^-		40V
Input-Output Voltage Differential		40V
Maximum Amplifier Input Voltage (Either Input)		8.5V
Maximum Amplifier Input Voltage (Differential)		5V
Current from V_Z		25 mA
Current from V_{REG}		15 mA
Internal Power Dissipation Metal Can ⁽³⁾		800 mW
CDIP ⁽³⁾		900 mW
PDIP ⁽³⁾		660 mW
Operating Temperature Range		
LM723		-55°C to +150°C
LM723C		0°C to +70°C
Storage Temperature Range Metal Can		
		-65°C to +150°C
PDIP		-55°C to +150°C
Lead Temperature (Soldering, 4 sec. max.)		
Hermetic Package		300°C
Plastic Package		260°C
ESD Tolerance		1200V
(human body model, 1.5 kΩ in series with 100 pF)		

- (1) "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not ensure specific performance limits.
- (2) A military RETS specification is available on request. At the time of printing, the LM723 RETS specification complied with the Mil and Max limits in this table. The LM723E, H, and J may also be processed as a Standard Military Drawing.
- (3) See desoldering curves for maximum power rating above 25°C.

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- (3) See derating curves for maximum power rating above 25°C.

Figure 9 - Maximum ratings - (Texas Instruments, 2013)

2.3.2.4 LM1723

This type of chip can offer a positive or negative regulation and can deliver up to 150mA or larger controlled current output by utilising external bypass transistors.



Figure 10 - LM1723 - (Motorola, 2016)

Features

- Voltage is adjustable from 2Vdc to 37Vdc
- Can deliver up to 150mA without bypass
- 0.03% load regulation
- 0.01% line regulation
- Variable short circuit protection. (Motorola, 2016)

It can be seen in figure 11 the maximum ratings available for the chip.

MC1723C

MAXIMUM RATINGS ($T_A = +25^\circ\text{C}$, unless otherwise noted.)

Rating	Symbol	Value	Unit
Pulse Voltage from V_{CC} to V_{EE} (50 ms)	$V_{I(p)}$	50	V_{pk}
Continuous Voltage from V_{CC} to V_{EE}	V_I	40	Vdc
Input–Output Voltage Differential	$V_I - V_O$	40	Vdc
Maximum Output Current	I_L	150	mAdc
Current from V_{ref}	I_{ref}	15	mAdc
Current from V_Z	I_Z	25	mA
Voltage Between Noninverting Input and V_{EE}	V_{ie}	8.0	Vdc
Differential Input Voltage	V_{id}	± 5.0	Vdc
Power Dissipation and Thermal Characteristics $T_A = +25^\circ\text{C}$ Derate above $T_A = +25^\circ\text{C}$ Thermal Resistance, Junction–to–Air	P_D $1/\theta_{JA}$ θ_{JA}	1.25 10 100	W mW/ $^\circ\text{C}$ $^\circ\text{C}/\text{W}$
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-65 to $+175$	$^\circ\text{C}$
Operating Ambient Temperature Range	T_A	0 to $+70$	$^\circ\text{C}$

Figure 11 (Motorola, 2016)

3. Design Method, choices and calculation

To enable a productive and cost efficient approach for this design a bottom up method will be employed. This is due to the cost of the end product being required to be inexpensive so of the shelf parts will be used, this will also allow the design and production timescale being sped up.

3.1 Specification

The customer has requested that the following specification be followed. The application of the power supply is for an instrument controller that has an LED display, 5 output relays and analogue output.

- Supply Voltage is 230V AC
- Output voltage is 12V DC $\pm 5\%$
- Output max current is 1.2A $\pm 2\%$
- Temperature range from -10°C to 40°C
- Maximum dimensions are 119.4mm x 119.4mm x 80mm (to fit enclosure refer to annexe 6)

3.2 Design method

To enable the design to meet the specification the process will be worked from output to input. A block diagram of this is illustrated below.

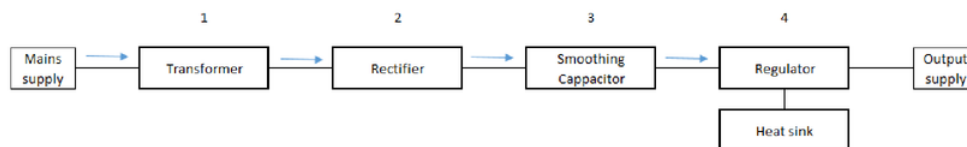


Figure 12 - Design block diagram

It can be seen that the first element to design is the Regulator and a suitable Heat sink.

3.2.1 Regulator

As per the research it can be seen that there are a variety of regulators depending on the application. To satisfy the specification the regulator of choice is the LM723 this is due to the LM723 having a better line and load regulation when compared to the lm317 and the lm1723, this can be observed in the pictures below from the data sheets.

PARAMETER	TEST CONDITIONS ⁽¹⁾		MIN	TYP	MAX	UNIT
Line regulation ⁽²⁾	$V_I - V_O = 3\text{ V to }40\text{ V}$	$T_J = 25^{\circ}\text{C}$		0.01	0.04	%V
		$T_J = 0^{\circ}\text{C to }125^{\circ}\text{C}$		0.02	0.07	
Load regulation	$I_O = 10\text{ mA to }1500\text{ mA}$	$C_{ADJ}^{(3)} = 10\text{ }\mu\text{F},$ $T_J = 25^{\circ}\text{C}$	$V_O \leq 5\text{ V}$		25	mV
			$V_O \geq 5\text{ V}$	0.1	0.5	%V _O
		$T_J = 0^{\circ}\text{C to }125^{\circ}\text{C}$	$V_O \leq 5\text{ V}$	20	70	mV
			$V_O \geq 5\text{ V}$	0.3	1.5	%V _O

Figure 13- LM317 (Texas instruments, 2016)

Parameter	Conditions	LM723			LM723C			Units
		Min	Typ	Max	Min	Typ	Max	
Line Regulation	$V_{IN} = 12\text{V to } V_{IN} = 15\text{V}$		0.01	0.1		0.01	0.1	% V_{OUT}
	$-55^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$			0.3				% V_{OUT}
	$0^{\circ}\text{C} \leq T_A \leq +70^{\circ}\text{C}$						0.3	% V_{OUT}
	$V_{IN} = 12\text{V to } V_{IN} = 40\text{V}$		0.02	0.2		0.1	0.5	% V_{OUT}
Load Regulation	$I_L = 1\text{ mA to } I_L = 50\text{ mA}$		0.03	0.15		0.03	0.2	% V_{OUT}
	$-55^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$			0.6				% V_{OUT}
	$0^{\circ}\text{C} \leq T_A \leq +70^{\circ}\text{C}$						0.6	% V_{OUT}

Figure 14 - LM723 - (Texas Instruments, 2013)

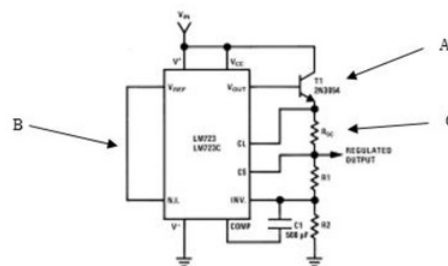
Line Regulation ($T_A = 25^{\circ}\text{C}$) $\left\{ \begin{array}{l} 12\text{ V} < V_{IN} < 15\text{ V} \\ 12\text{ V} < V_{IN} < 40\text{ V} \end{array} \right.$ ($T_{low} < T_A < T_{high}$) $12\text{ V} < V_{IN} < 15\text{ V}$	Regline	-	0.01	0.1	% V_O
		-	0.1	0.5	
		-	-	0.3	
Load Regulation (1.0 mA < I_L < 50 mA) $T_A = 25^{\circ}\text{C}$ $T_{low} < T_A < T_{high}$	Regload	-	0.03	0.2	% V_O
		-	-	0.6	

LM1723 - (Motorola, 2017).

Figure 15 -

This can also be compared to the L7805 and the data sheet snippet in figure 5. It is also clear that the lm723 is far superior than utilising a Zener diode as this application requires short circuit protection and it is known that the regulator has very good regulation when compared to a diode.

To design the circuit that encompasses the LM732 the data sheet has a variety of circuit configurations. The configuration that will be utilised is shown in figure 19 in the Annexe labelled "Annexe 3". This was derived by observing the specification requirements to table 1 of the data sheet thus giving 10V.



Typical Performance

Regulated Output Voltage	+15V
Line Regulation ($\Delta V_{IN} = 3\text{V}$)	1.5 mV
Load Regulation ($\Delta I_L = 1\text{A}$)	15 mV

Figure 19. Positive Voltage Regulator (External NPN Pass Transistor)

Figure 16 - LM723 circuit - (Texas Instruments, 2013)

There are certain values that have to be adhered to enable the regulator to operate as designed. These are

- $C_{ref} = 0.1\mu\text{f}$ (this is found on pg. 4 of the datasheet, this enables a low harmonic noise operation).
- $V_{ref} = 7.15\text{V}$ (again this is given on the data sheet).
- $R1 = 4.87\text{k}\Omega$ and $7.15\text{k}\Omega$ this is given on pg 8 of the data sheet.

These values can also be derived by transposing the given expression.

$$V_{out} = \left(V_{ref} \left(\frac{R1 + R2}{R2} \right) \right)$$

LM723

Figure 20 (ST products,

- A. It can be seen that the external pass transistor is utilised to allow more current to pass this is due to the internal limitations of the LM723 being able to offer 150mA.
- B. Arrow B shows that this section of the circuit is the reference voltage for the output. To enable fine tuning of the output voltage it is possible to alter the values of R1 and R2 as mentioned previously.
- So
- C. Figure 16 arrow C indicates the circuit that is responsible for the current limiting of the load. It can be seen that the RSC resistor is calculated utilising the data sheet, therefore the formula for this is $I_{LIMIT} = \frac{V_{sense}}{RSC}$ therefore as 0.6 is given in the data sheet and the specification requires a maximum isc of 1.2A then then RSC can be found by transposing the formula to give $\frac{0.6V}{1.2A} = 0.5\Omega$
- Therefore RSC = 0.5Ω.

Figure 17 – Chart- (Texas Instruments, 2013)

The last value to be found is the required Vin which when referring to the block diagram in figure 12 is provided after the smoothing capacitor.

When referencing the data sheet Vin is give as

$$V_{in} = 12V \leq V_{in} \leq 40V \text{ and } (V_{in} - V_{out}) \geq 3.0V$$

The 3V is found in the data sheet as shown below.

Input-Output Voltage Differential	3.0	38
-----------------------------------	-----	----

Figure 18 – differential - (Texas Instruments, 2013)

Therefore

$$V_{in} - V_{out} = [V_{in} - V_{out} + 2\phi] \geq 3V$$

Therefore

$$V_{in} \geq V_{out} + 2\phi + 3V = 10 + 1.2 + 3$$

So the following is calculated.

$$V_{in} \geq 14.2V$$

It can be seen that the minimum input voltage to the rectifier is 14.2V

3.2.2 Capacitor

The next step of the power supply design is the smoothing capacitor selection; by following the “Linear & Switching Voltage regulator handbook” a step by step guide will be followed.

1. The first step is to determine VC; this is the average full load DC output voltage of the capacitor input filter (Semiconductor, 2002).

Therefore

$$1.VC = V_{in} + \frac{1}{2} \text{ripple} + 10\%$$

Vin was calculated previously as 14.2V.

The ripple is calculated as follows

$$2. \text{Ripple in} = \frac{\text{Ripple out}}{\text{Gain}}$$

As the ripple rejection of 74db is shown on page 3 of the data sheet in the annexe for the regulator input specification, this value will have to be converted to gain using the following equation.

$$Av = 20 \log \frac{V_{out}}{V_{in}}$$

This gives the value of

$$\text{Antilog} \frac{-74}{20}$$

2. By referring back to equation the following is true

$$\text{Ripple in} = \frac{600mv \text{ (data sheet)}}{10^{\frac{-74}{20}}} = 3Vp - p$$

With these values we can input them in to equation 1 to find VC

$$VC = 14.2 + 1.5 + 10\% = 16V$$

Therefore VC = 16V

3. The next parameter to be found is VM, this is the Maximum no load output voltage (Semiconductor, 2002).

$$VM = VC + 50\%$$

Therefore VM = 25V

4. IO is also a requirement and is the full load output current; this can be found in the design specification as 1.2A.
5. F is the input line frequency, as this is the UK this is set as 50hz.

In summary the parameters found are:

$$\begin{aligned} VC &= 16V \\ V_{ripple} &= 3Vp-p \\ VM &= 25V \\ IO &= 1.2A \\ F &= 50hz \end{aligned}$$

6. Utilising the ripple attenuation expression

$$rf = \frac{v_{ripple}}{2\sqrt{2} \times VC} \times 100$$

The following answer is found rf = 6.6%

7. Next parameter to be found is w_{cr1} ; this can be found in the handbook and is shown below.

Figure 19 - RMS voltage (Semiconductor, 2002)

It can be seen from the graph that $w_{cr1} = 7$ to 15 as signified by the yellow circle at 6.6% ripple attenuation. Due to this attenuation the nearest parameter to follow is 10 which gives 10% as the ripple factor.

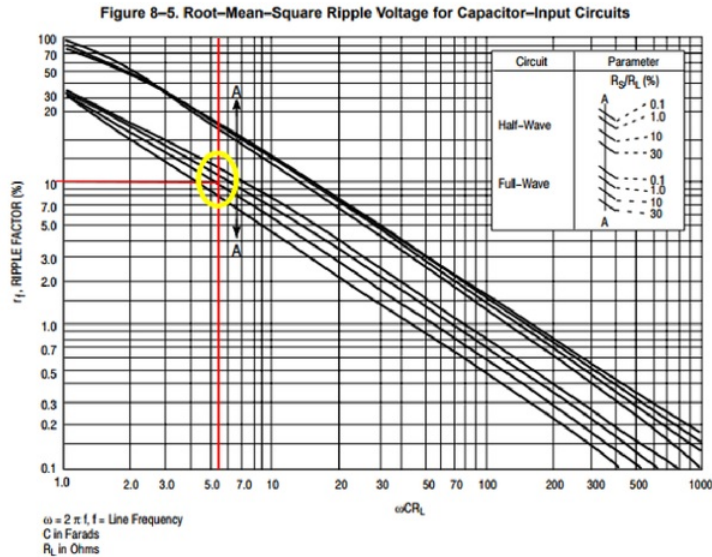


Figure 20 - graph (Semiconductor, 2002)

8. It can be seen that R_s is the sensing resistor and R_L is the load resistance. Therefore

$$RL = \frac{V_c}{I_o} = 16\Omega$$

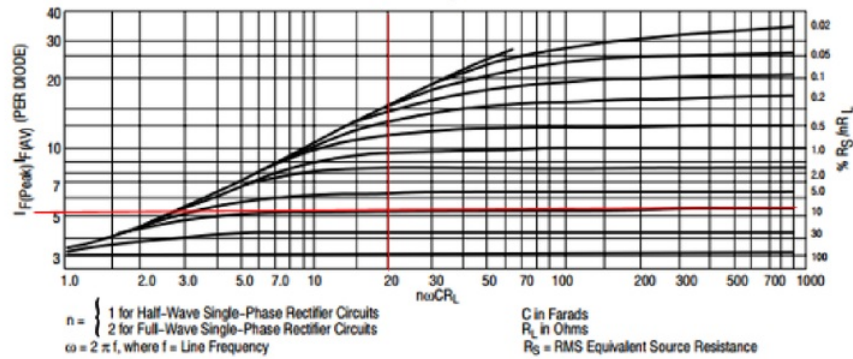


Figure 21 - R_s/RL (Semiconductor, 2002)

From this graph it can be deduced that $R_s/2R_L = 10\%$ as it is half the value the bottom value is doubled due to $2 \times w_{cr1}$ therefore 20% so it can be deduced that I.F. peak x I.F. avg was 5.2.

$$R_s = 0.2 \times 16 = 3.2\Omega$$

With all the parameters found a final calculation of the ideal capacitor can be made using the following equation.

$$C = \frac{wcr l}{2\pi \times 50 \times 16} = 1989\mu f$$

By using RS the following capacitor was selected.

**Panasonic Aluminium Electrolytic Capacitor 2000µF
25V dc 16mm Through Hole TP RADIAL Series +135°C**

RS Stock No. 732-8226
Brand Panasonic
Mfr. Part No. EEUTP1E2025



Image representative of range

✓ 14 In stock for FREE next working day delivery

£2.31

Price Each (In a Pack of 2)

Units	Per unit	Per Pack*
2 - 48	£2.31	£4.62
50 +	£2.08	£4.16

Quantity Units

Add to basket

[Check stock levels](#)
[Add to a parts list](#)

*price indicative

Figure 22- RS capacitor (RS, 2017)

The reason this capacitor was selected is due to its size, life expectancy, ripple current, price and capacitance value.

When referring to the capacitor specification which can be found in the annexe as annexe 5, it can be seen that the expected life expectancy as 2000 – 5000 hrs which is adequate for the application. The size is minimal at 16mm diameter by 20mm for the enclosure and offers a lower than required ripple current at 2.3A peak to peak. It can be seen that the price is low at £2.31 and it has a suitable capacitance for the specification of 2000µf.

3.2.3 Rectifier

To determine the rectifier the following parameters need to found according to the handbook.

1. I.F = IO/2 (due to it being full wave rectification). I.F is the average current per diode (Semiconductor, 2002).

Therefore

$$I.F. = \frac{1.2}{2} = 0.6A$$

2. When considering the graph on figure 21 it was realised that I.F peak = 5.2 x 0.6 = 3.12A.
3. Peak inverse voltage = 2Vm +20% - 50% for safety margin (Semiconductor, 2002). Therefore as VM = 25V then for s safe margin 50V will be used.
4. The final parameter to be found is the maximum surge current (Isurge).

Therefore

$$Isurge = \frac{Vm}{(Rs + ESR)}$$

ESR is the minimum series resistor or filter capacitor (Semiconductor, 2002). This has been neglected ##

So the following is calculated.

$$Isurge = \frac{25}{3.2 + 0} = 7.8A$$

The following is an appropriate rectifier for the circuit.

Diodes Inc SBR05M60BLP-7, Bridge Rectifier, 60V, 4-Pin DFN4

RS Stock No: 922-8583
Brand: DiodesZetex
Mfr. Part No: SBR05M60BLP-7

3000 in stock for FREE next working day delivery

£0.236
Price Each (On a Reel of 3000)

Units	Per unit	Per Reel**
3000 - 6000	£0.236	£708.00
6000 +	£0.224	£672.00

Quantity: 3000 Units [Add to basket](#)

[Check stock levels](#) [Add to a parts list](#)

*Price indicative

Technical Reference

- [RoHS Certificate of Compliance](#)
- [Datasheet](#)
- [Statement of conformity](#)

Figure 23- Rectifier - (RS, 2017)

It can be seen that the rectifier is relatively cheap at 0.236p compared to a similar alternative of 0.335p.

When referring to the specification in the annexe as annexe 7 it can be seen that this rectifier has the acceptable specification of enabling 60V peak inverse voltage. It can also maintain the required 7.8A surge current due to its max at 8A. The size is appropriate for the enclosure being only 3.1 x 3.1 x 0.58mm.

3.2.4 Transformer

To choose the appropriate transformer the following is carried out to deduce the RMS voltage of the secondary leg. Therefore the following equation is carried out.

$$V_S = \frac{\{V_m + (n)1.0\}}{\sqrt{2}}$$

n=2 for full wave and 1 for half wave

So,

$$V_S = \frac{\{25 + 2\}}{\sqrt{2}} = 19V_{rms}$$

20V ac 2 Output Through Hole PCB Transformer, 3VA

RS Stock No: 924-476
Brand: RS Pro

£5.16
Price Each

Units	Per unit
1 - 9	£5.16
10 - 24	£4.03
25 +	£3.75

Quantity: 1 Units [Add to basket](#)

[Check stock levels](#) [Add to a parts list](#)

Technical Reference

- [RoHS Certificate of Compliance](#)
- [RS Pro Datasheet](#)
- [Statement of conformity](#)
- [Build or Repair PCB Symbols & Footprints](#)

Essential extras

Transformer 200W 100V/250V/0V

Figure 24 - Transformer - (RS, 2017)

When referring to the transformers specification which can be found in the annexe as annexe 8 it can be seen that the second leg can deliver up to a maximum of 20Vrms from 230V on the primary. The dimensions are also suitable for the enclosure at 25x42x35.

3.2.5 Heatsink

The last component to select for the regulator is the heat sink, as before the manual will be followed.

The first calculation to be carried out is whether a heatsink is required. The maximum desired temperature is 75°C, so $T_J \text{ max} = 75^\circ\text{C}$.

PD is the average output voltage x output current = $20 \times 0.6 = 12\text{W}$.

TA is ambient temperature of 18°C

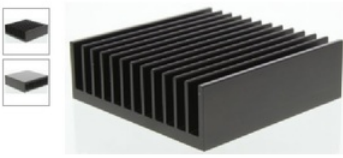
Using the equation

$$\theta_{SA} = \frac{T_J - T_A}{P_D} - \theta_{CS} - \theta_{JC}$$
$$\theta_{SA} = \frac{75 - 18}{12} - 1.6 - 1.5 = 1.65^\circ\text{C/W}$$

It can be seen that the following heatsink from RS can be used.

Heatsink, Luxeon LED 6 Ring, 1.79°C/W, 101.6 x 101.6 x 31.75mm

RS Stock No: 104-005
Brand: AARVID THERMALLOY
Mfr. Part No: 7662030540100



Product Details

BGA Heatsink, Luxeon Ring LED
Heatsinks suitable for Luxeon Ring Light Sources
BGA Heatsinks

5 in stock for FREE next working day delivery

£13.24
Price Each

Units	Per unit
1 - 49	£13.24
50 - 99	£12.57
100 - 249	£11.32
250 - 499	£10.76
500 +	£10.22

Quantity: Units [Add to basket](#)

[Check stock levels](#) [Add to a parts list](#)

Technical Reference

- [RoHS Certificate of Compliance](#)
- [Datasheet](#)
- [Statement of conformity](#)

Figure 25 - Heatsink - (RS, 2017)

This heat sink has the ability to dissipate 1.79°C per Watt and can fit into the enclosure required.

4.1 layout

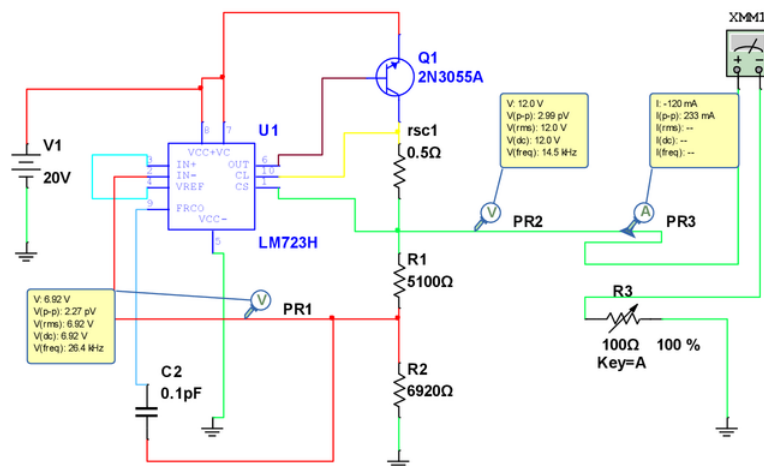


Figure 28 - Test 3

On the final test utilising a variable load the load has been increased to 100% or 100Ω. To be expected as a smaller load is required the current draw is less at 122mA and the voltage is steady at 12Vdc.

Below is a log of the full test.

Variable load			
Load	Vin	Vout	Current out
0	20	0.00124	1.22
2	20	2.44	1.22
4	20	4.88	1.22
6	20	7.31	1.22
8	20	9.73	1.22
10	20	11.9	1.19
12	20	12	1
14	20	12	0.858
16	20	12	0.751
18	20	12	0.667
20	20	12	0.601
30	20	12	0.401
40	20	12	0.301
50	20	12	0.24
60	20	12	0.2
70	20	12	0.172
80	20	12	0.15
90	20	12	0.134
100	20	12	0.12

4.3 Variable supply

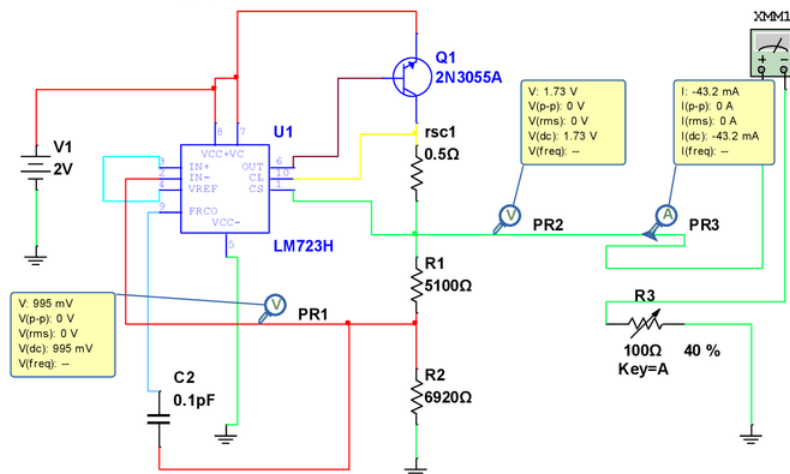


Figure 29 - Test 4

In this test the load is fixed at 40Ω and the supply to the rectifier is varied. On this instance the supply is set at 2V. It can be seen that as the input supply is so low the rectifier is not able to supply an adequate supply. This is to be expected.

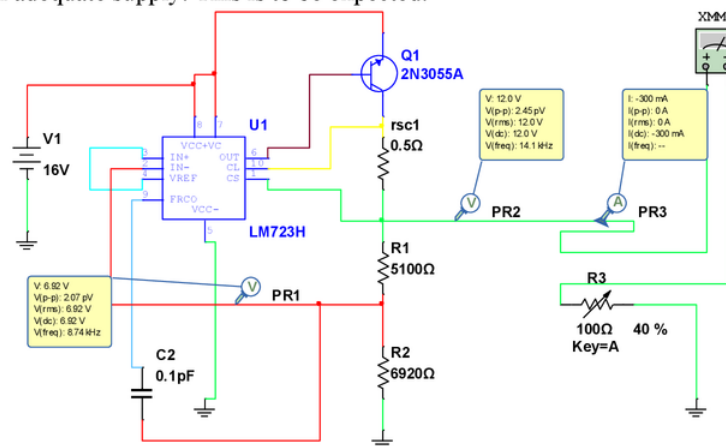


Figure 30 - Test 5

The input supply has been raised to 16V on this occasion and it can be seen that the output supply is stable at 12V and 200mA.

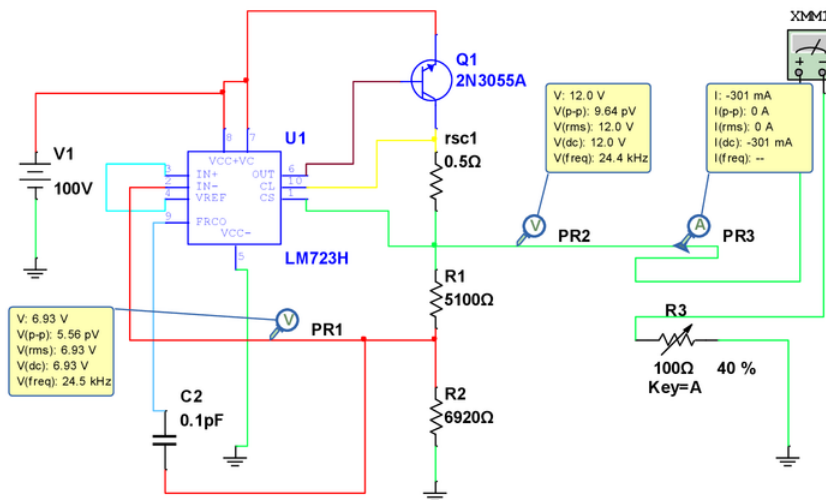


Figure 31 - Test 6

In this test the input supply has been increased to 100V and the regulator is holding the output voltage healthy at 12V.

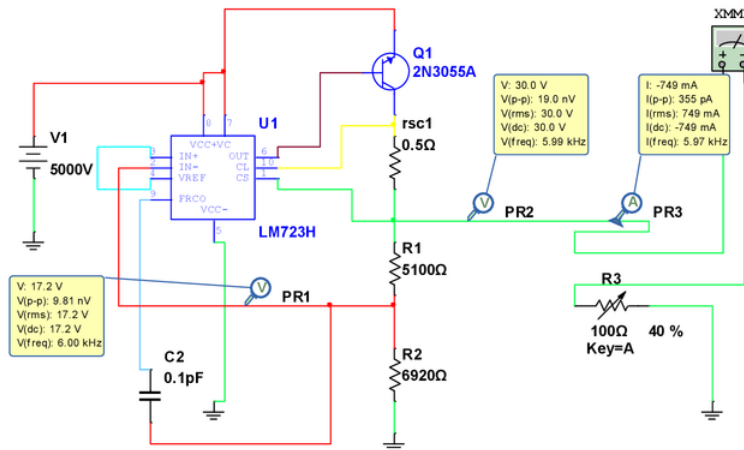


Figure 32 - Test 7

In this test the input voltage has been increased to a large value of 5KV. It can be seen that the regulator has been overcome and is allowing 30V to pass.

Below is the log of the full test

Variable supply			
Load	Vin	Vout	Current out
40	2	85.6	0.002
40	4	1.73	0.043
40	6	3.54	0.0885
40	8	5.39	0.135
40	10	7.26	0.181
40	12	9.14	0.228
40	14	11	0.276
40	16	12	0.3
40	18	12	0.301
40	20	12	0.301
40	30	12	0.301
40	40	12	0.301
40	50	12	0.301
40	100	12	0.301
40	500	12	0.301
40	1000	12.1	0.301
40	2000	12.1	0.301
40	3000	12.1	0.301
40	4000	12.6	0.315
40	5000	30	0.749

Figure 33 - Table 1 – Variable load

It can be seen from the table that the optimal voltage using the simulator is signified by the green boxes. In reality it would not be safe to operate the regulator at more than the data sheet rated maximum value of 40V. However this table does signify how good the regulator is at keeping at steady output voltage from 16V to 40V input voltage and is able to deal in large spikes of voltage if needed.

Variable load			
Load Ω	Vin	Vout	Current out
0	20	0.00124	1.22
2	20	2.44	1.22
4	20	4.88	1.22
6	20	7.31	1.22
8	20	9.73	1.22
10	20	11.9	1.19
12	20	12	1
14	20	12	0.858
16	20	12	0.751
18	20	12	0.667
20	20	12	0.601
30	20	12	0.401
40	20	12	0.301
50	20	12	0.24
60	20	12	0.2
70	20	12	0.172
80	20	12	0.15
90	20	12	0.134
100	20	12	0.12

Figure 34 - Table 2 - Variable load

It can be seen that when there is a varied load required from the regulator its optimal load is between 10Ω (specification is $5\%\pm$ for the Voltage) and 100Ω or higher. It is also important to notice that the current limiting employed by the regulator does operate even when there is a short circuit on the load thereby only allowing 1.22A which is as per specification of 1.2A with $5\%\pm$.

4.3 Complete circuit

From the above testing it can be seen that the rectifier design was a success, the next step is to build the complete circuit and employ all the components selected during the design. Below is the complete power supply.

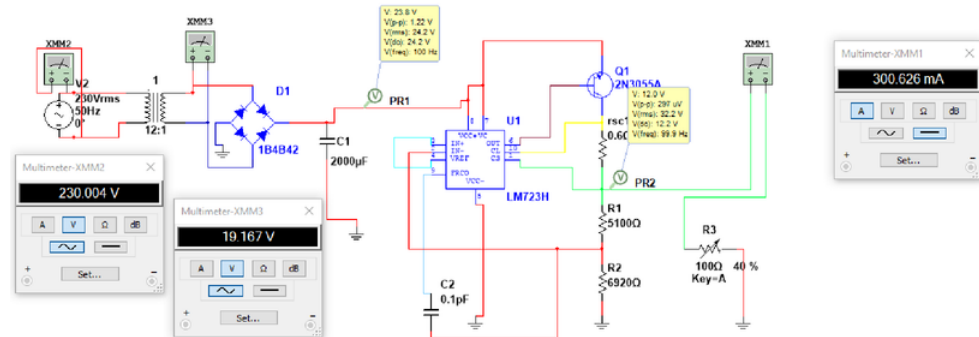


Figure 35- Complete power supply circuit

As it is not possible to select the exact component from RS, very similar components are selected to keep any real life discrepancies to a minimum.

It can be seen that the transformer has a 12:1 turn ratio to deliver the required 19V AC as per the design.

The bridge rectifier is a full wave s per design and the capacitor was selected to be 2000µF.

It can be seen that the by utilising the bridge rectifier and capacitor the voltage into the regulator has increased from 19.16VDC to 24.2V DC. This is due to the full wave regulator utilising the full wave in to the supply leg.

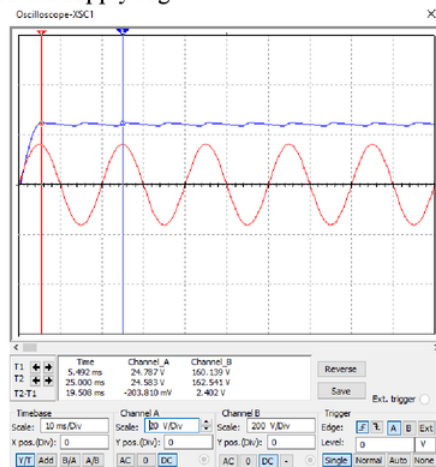


Figure 36 - Oscilloscope

Figure 36 is a picture of the oscilloscope that has been connected to show how the 230VAC supply has been stepped down, rectified and smoothed to produce the 24.7VDC blue line in figure 36.

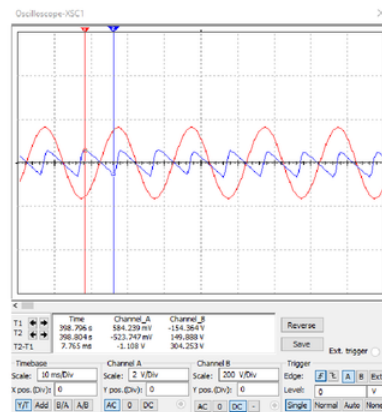


Figure 37 - Oscilloscope 2

From this oscilloscope a measurement of the ripple has been taken. It can be seen that it has a maximum ripple of 1.1V p-p. When comparing to the design requirements to the simulation it can be seen that the capacitor is able to smooth the DC to within the 3V p-p required.

In summary when referring to figure 35 the input supply and output supply met the specification. When applying the complete circuit to the regulator there were no discrepancies as the output voltage and current 12VDC and 300.6mA are exactly the same when examining the regulator alone.

5. Conclusion

In conclusion it can be seen that aims and objectives of this assignment to accommodate a client's design specification for a new power supply were achieved

This was due to the aims of this assignment being achieved by:

- Illustrating a good knowledge of advanced design practices.
- Analysis of advanced electronic systems that achieve complex analogue functions.
- A design of advanced electronic system for client's specifications was met.

The objectives achieved were to:

- Design a new power supply to a customer's specification. It can be seen that this was achieved through the design and testing of the power supply.
- Simulate and evaluate the power supply to enable a full analysis of the characteristics of the power supply. It can be seen that this was achieved on many occasions during the testing and evaluation of the power supply within this assignment.

The design of the power supply allowed the electrical, thermal and physical requirements of the specification to be met. And data sheets and literature were thoroughly scrutinized for relevant information for the design as well as testing

In summary it is clear that the assignment has achieved a completed design and test of a power supply that has met the design specification laid out at the start.

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7. Annexe for diagrams, data sheets, results tables ETC.

7.1 Annexe 1 – Data sheet for LM7805

Positive voltage regulator ICs Maximum ratings

3 Maximum ratings

Table 1. Absolute maximum ratings

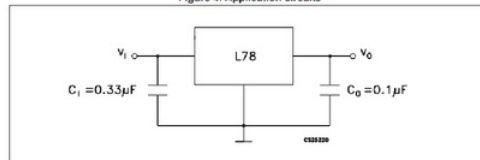
Symbol	Parameter	Value	Unit
V_I	DC input voltage	for $V_O = 5$ to 18 V	35
		for $V_O = 20, 24$ V	40
I_O	Output current	Internally limited	
P_D	Power dissipation	Internally limited	
T_{STG}	Storage temperature range	-65 to 150	°C
T_{OP}	Operating junction temperature range	for L78xxC, L78xxAC	0 to 125
		for L78xxAB	-40 to 125

Note: Absolute maximum ratings are those values beyond which damage to the device may occur. Functional operation under these conditions is not implied.

Table 2. Thermal data

Symbol	Parameter	DPAK	DPAK	TO-220	TO-220FP	Unit
$R_{\theta JA}$	Thermal resistance junction-case	3	8	5	5	°C/W
$R_{\theta JA}$	Thermal resistance junction-ambient	62.5	100	50	60	°C/W

Figure 4. Application circuits



Positive voltage regulator ICs Electrical characteristics

5 Electrical characteristics

$V_I = 10$ V, $I_O = 1$ A, $T_J = 0$ to 125 °C (L7805AC), $T_J = -40$ to 125 °C (L7805AB), unless otherwise specified⁽¹⁾.

Table 3. Electrical characteristics of L7805A

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	$T_J = 25^\circ\text{C}$	4.9	5	5.1	V
V_O	Output voltage	$I_O = 5$ mA to 1 A, $V_I = 7.5$ to 18 V	4.8	5	5.2	V
V_O	Output voltage	$I_O = 1$ A, $V_I = 18$ to 20 V, $T_J = 25^\circ\text{C}$	4.8	5	5.2	V
$\Delta V_O^{(1)}$	Line regulation	$V_I = 7.5$ to 25 V, $I_O = 500$ mA, $T_J = 25^\circ\text{C}$		7	50	mV
		$V_I = 8$ to 12 V		10	50	mV
		$V_I = 8$ to 12 V, $T_J = 25^\circ\text{C}$		2	25	mV
		$V_I = 7.3$ to 20 V, $T_J = 25^\circ\text{C}$		7	50	mV
$\Delta V_O^{(1)}$	Load regulation	$I_O = 5$ mA to 1 A		25	100	mV
		$I_O = 5$ mA to 1.5 A, $T_J = 25^\circ\text{C}$		30	100	mV
		$I_O = 250$ to 750 mA		8	50	mV
I_q	Quiescent current	$T_J = 25^\circ\text{C}$		4.3	6	mA
ΔI_q	Quiescent current change	$V_I = 8$ to 23 V, $I_O = 500$ mA			0.8	mA
		$V_I = 7.5$ to 20 V, $T_J = 25^\circ\text{C}$			0.8	mA
		$I_O = 5$ mA to 1 A			0.5	mA
SVR	Supply voltage rejection	$V_I = 8$ to 18 V, $f = 120$ Hz, $I_O = 500$ mA		68		dB
V_d	Dropout voltage	$I_O = 1$ A, $T_J = 25^\circ\text{C}$		2		V
eN	Output noise voltage	$T_A = 25^\circ\text{C}$, $B = 10$ Hz to 100 kHz		10		$\mu\text{V}/V_O$
R_O	Output resistance	$f = 1$ kHz		17		m Ω
I_{sc}	Short circuit current	$V_I = 35$ V, $T_A = 25^\circ\text{C}$		0.2		A
I_{mp}	Short circuit peak current	$T_J = 25^\circ\text{C}$		2.2		A
$\Delta V_O/\Delta T$	Output voltage drift			-1.1		mV/°C

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Figure 11. Adjustable output regulator (7 to 30 V)

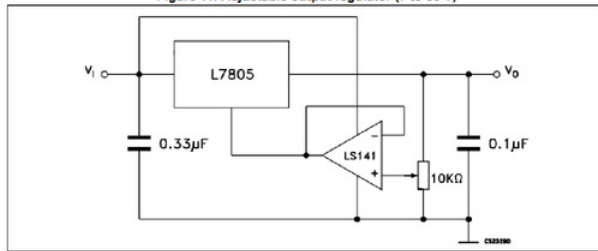
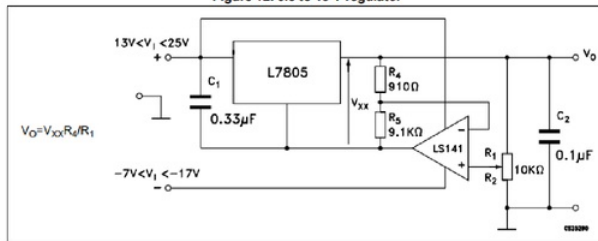


Figure 12. 0.5 to 10 V regulator



Performance

7 Typical performance

Figure 28. Dropout voltage vs. junction temperature

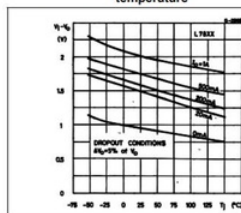


Figure 29. Peak output current vs. input/output differential voltage

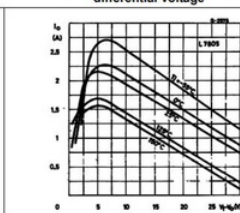


Figure 30. Supply voltage rejection vs. frequency

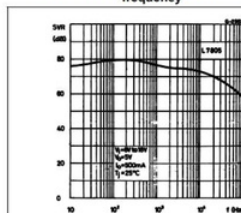


Figure 31. Output voltage vs. junction temperature

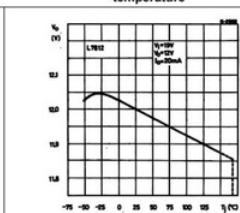


Figure 32. Output impedance vs. frequency

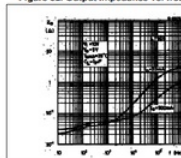


Figure 33. Quiescent current vs. junction temp.

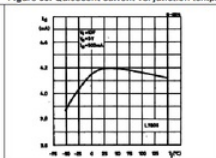


Figure 34. Load transient response

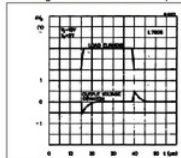


Figure 35. Line transient response

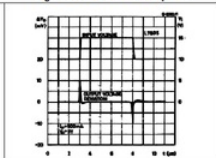
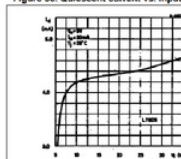


Figure 36. Quiescent current vs. input voltage



7.2 Annexe 2 – LM317

LM317

SLVS044X–SEPTEMBER 1997–REVISED SEPTEMBER 2016

www.ti.com

6 Specifications

6.1 Absolute Maximum Ratings

over virtual junction temperature range (unless otherwise noted)⁽¹⁾

	MIN	MAX	UNIT
$V_i - V_o$		40	V
T_j		150	°C
Lead temperature 1.5 mm (1/16 in) from case for 10 s		260	°C
T_{stg}	-65	150	°C

(1) Stresses beyond those listed under **Absolute Maximum Ratings** may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under **Recommended Operating Conditions** is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

6.2 ESD Ratings

	MAX	UNIT
V_{ESD} Electrostatic discharge	2500	V
	1000	V

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

	MIN	MAX	UNIT
V_o	1.25	37	V
$V_i - V_o$	3	40	V
I_o	0.01	1.5	A
T_j	0	125	°C

6.4 Thermal Information

THERMAL METRIC ⁽¹⁾	LM317				UNIT
	DCY (SO1-223)	KCS (TO-220)	KCT (TO-220)	KTT (TO-263)	
	4 PINS	3 PINS	3 PINS	3 PINS	
$R_{\theta JA}$	68.8	23.5	37.9	38.0	°C/W
$R_{\theta JC(top)}$	43.2	15.9	51.1	36.5	°C/W
$R_{\theta JB}$	18.9	7.9	23.2	18.9	°C/W
ψ_{JT}	3.0	3.0	13.0	6.9	°C/W
ψ_{JB}	18.8	7.8	22.8	17.9	°C/W
$R_{\theta JC(bot)}$	NA	0.1	4.2	1.1	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report.

6.5 Electrical Characteristics

over recommended ranges of operating virtual junction temperature (unless otherwise noted)

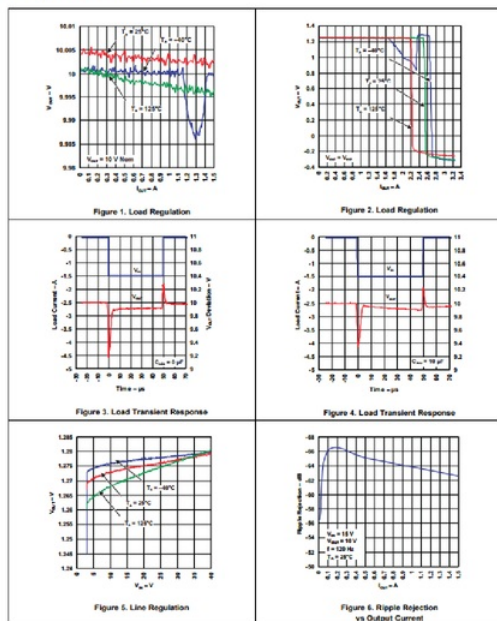
After recommended ranges of operating virtual TEST CONDITIONS (unless otherwise noted)					
PARAMETER	TEST CONDITIONS ⁽¹⁾		MIN	TYP	MAX UNIT
Line regulation ⁽²⁾	$V_I - V_O = 3 \text{ V to } 40 \text{ V}$	$T_J = 25^\circ\text{C}$ $T_J = 0^\circ\text{C to } 125^\circ\text{C}$	0.91 0.92	0.01 0.07	0.04 %/V
Load regulation	$I_O = 10 \text{ mA to } 1500 \text{ mA}$ $C_{ADJ}(R) = 10 \mu\text{F}$ $T_J = 25^\circ\text{C}$ $T_J = 0^\circ\text{C to } 125^\circ\text{C}$	$V_O \leq 5 \text{ V}$ $V_O \geq 5 \text{ V}$ $V_O \leq 5 \text{ V}$ $V_O \geq 5 \text{ V}$	25 0.1 20 0.3	0.1 0.5 10 0.3	mV %/V mV %/V
Thermal regulation	25-ms pulse, $T_J = 25^\circ\text{C}$			0.93	0.07 %/W
ADJUST terminal current				50	100 μA
Change in ADJUST terminal current	$V_I - V_O = 2.5 \text{ V to } 40 \text{ V}$, $P_D \leq 20 \text{ W}$, $I_O = 10 \text{ mA to } 1500 \text{ mA}$			0.2	5 μA
Reference voltage	$V_I - V_O = 3 \text{ V to } 40 \text{ V}$, $P_D \leq 20 \text{ W}$, $I_O = 10 \text{ mA to } 1500 \text{ mA}$		1.2	1.25	1.3 V
Output-voltage temperature stability	$T_J = 0^\circ\text{C to } 125^\circ\text{C}$			0.7	%/V
Minimum load current to maintain regulation	$V_I - V_O = 40 \text{ V}$			3.5	10 mA
Maximum output current	$V_I - V_O \leq 15 \text{ V}$, $P_D \leq P_{D(MAX)}$ $V_I - V_O \leq 40 \text{ V}$, $P_D \leq P_{D(MAX)}$, $T_J = 25^\circ\text{C}$			1.5 0.15	2.2 0.4 A
RMS output noise voltage (R of V_O)	$f = 10 \text{ Hz to } 10 \text{ kHz}$, $T_J = 25^\circ\text{C}$			0.003	%/V
Pipeline rejection	$V_O = 10 \text{ V}$, $f = 120 \text{ Hz}$ $C_{ADJ} = 0 \mu\text{F}$ ⁽³⁾ $C_{ADJ} = 10 \mu\text{F}$ ⁽⁴⁾			57 62	dB
Long-term stability	$T_J = 25^\circ\text{C}$			0.3	1 %/k hr

(1) Unless otherwise noted, the following test conditions apply: $V_I - V_O = 5 \text{ V}$ and $I_{O(MAX)} = 1.5 \text{ A}$. $T_J = 0^\circ\text{C to } 125^\circ\text{C}$. Pulse testing techniques are used to maintain the junction temperature as close to the ambient temperature as possible.

(2) Line regulation is expressed here as the percentage change in output voltage per 1-V change at the input.

(3) C_{ADJ} is connected between the ADJUST terminal and GND.(4) Maximum power dissipation is a function of $T_J(\text{max})$, I_O , and T_J . The maximum allowable power dissipation at any allowable ambient temperature is $P_D = (T_J(\text{max}) - T_A)/\theta_{JA}$. Operating at the absolute maximum T_J of 150°C can affect reliability.

6.6 Typical Characteristics



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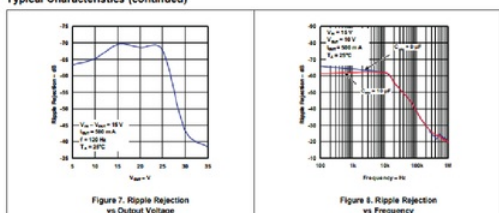
Product Folder Link: LM317

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LM317 SEPTEMBER 1987 • REVISED SEPTEMBER 2016

Typical Characteristics (continued)



7.3 Annexe 3 - lm723

	LM723, LM723C
www.ti.com	DS16792G –JAN 1989–REVISED APRIL 2013
These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.	
ABSOLUTE MAXIMUM RATINGS⁽¹⁾⁽²⁾	
Power Voltage from V^- to V^+ (20 ms)	50V
Continuous Voltage from V^- to V^+	40V
Input-Output Voltage Differential	40V
Maximum Amplifier Input Voltage (either input)	0.5V
Maximum Amplifier Input Voltage (common-mode)	5V
Current from V_{CC}	25 mA
Current from V_{EE}	15 mA
Internal Power Dissipation	
Metal Can (H)	800 mW
CDIP (H)	800 mW
PDSIP (H)	600 mW
Operating Temperature Range	
LM723	-55°C to +125°C
LM723C	0°C to +70°C
Storage Temperature Range	-65°C to +150°C
Metal Can	
PDSIP	-65°C to +150°C
Lead Temperature (soldering, 4 sec. max.)	300°C
Thermal Resistance	200°C/W
PDSIP Package	200°C/W
ESD Tolerance	1,000V

(1) Unless Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not ensure specific performance levels.
 (2) A military RETS specification is available on request. At the time of printing, the LM723 RETS specification complied with the Min and Max limits in this table. The LM723E, H, and J may also be procured as a Standard Military Drawing.
 (3) See derating curves for maximum power rating above 25°C.

Figure 38 (Texas Instruments, 2013)
Characteristics

ELECTRICAL CHARACTERISTICS ⁽¹⁾⁽²⁾⁽³⁾⁽⁴⁾							
Parameter	Conditions	LM723			LM723C		
		Min	Typ	Max	Min	Typ	Max
Line Regulation	$V_{IN} = 12V$ to $V_{IN} = 15V$	0.01	0.1	0.3	0.01	0.1	0.3
	$-55^{\circ}C \leq T_A \leq +125^{\circ}C$						
	$0^{\circ}C \leq T_A \leq +70^{\circ}C$						
	$V_{IN} = 12V$ to $V_{IN} = 40V$	0.02	0.2	0.5	0.1	0.5	0.5
Load Regulation	$I_L = 1 mA$ to $I_L = 50 mA$	0.03	0.15	0.6	0.03	0.2	0.6
	$-55^{\circ}C \leq T_A \leq +125^{\circ}C$						
	$0^{\circ}C \leq T_A \leq +70^{\circ}C$						
Ripple Rejection	$f = 50 Hz$ to $10 kHz$, $C_{REF} = 0$	74			74		
	$f = 50 Hz$ to $10 kHz$, $C_{REF} = 5 \mu F$	86			86		

(1) Unless otherwise specified, $T_A = 25^{\circ}C$, $V_{IN} = V^+ = V^- = 12V$, $V^- = 0$, $V_{OUT} = 5V$, $I_L = 1 mA$, $R_{SC} = 0$, $C_1 = 100 pF$, $C_{REF} = 0$ and divider impedance as seen by error amplifier $\leq 10 k\Omega$ connected as shown in Figure 4. Line and load regulation specifications are given for the condition of constant chip temperature. Temperature drifts must be taken into account separately for high dissipation conditions.
 (2) A military RETS specification is available on request. At the time of printing, the LM723 RETS specification complied with the Min and Max limits in this table. The LM723E, H, and J may also be procured as a Standard Military Drawing.
 (3) Specified by correlation to other tests.
 (4) L_1 is 40 turns of No. 20 enameled copper wire wound on Ferroxcube P3622-3B7 pot core or equivalent with 0.009 in. air gap.

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 Product Folder Links: LM723 LM723C
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Figure 39 (Texas Instruments, 2013)

ELECTRICAL CHARACTERISTICS⁽¹⁾⁽²⁾⁽³⁾⁽⁴⁾ (continued)

Parameter	Conditions	LM723			LM723C			Units
		Min	Typ	Max	Min	Typ	Max	
Average Temperature Coefficient of Output Voltage (θ_V)	$-55^{\circ}C \leq T_A \leq +125^{\circ}C$		0.002	0.015				$\mu V/^{\circ}C$
	$0^{\circ}C \leq T_A \leq +70^{\circ}C$				0.003	0.015		$\mu V/^{\circ}C$
Short Circuit Current Limit	$R_{SC} = 10\Omega$, $V_{OUT} = 0$		65		65			mA
Reference Voltage		6.95	7.15	7.35	6.80	7.15	7.50	V
Output Noise Voltage	$10 Hz$ to $10 kHz$, $C_{REF} = 0$		86		86			μV_{rms}
	$10 Hz$ to $10 kHz$, $C_{REF} = 5 \mu F$		2.5		2.5			μV_{rms}
Long Term Stability			0.05		0.05			$\mu V/1000 hrs$
Standby Current Drain	$I_L = 0$, $V_{IN} = 30V$		1.7	3.5	1.7	4.0		mA
Input Voltage Range		9.5		40	9.5		40	V
Output Voltage Range		2.0		37	2.0		37	V
Input-Output Voltage Differential		3.0		38	3.0		38	V
θ_{JA}	PDIP					105		$^{\circ}C/W$
θ_{JA}	CDIP		150					$^{\circ}C/W$
θ_{JA}	H10C Board Mount in Still Air		165			165		$^{\circ}C/W$
θ_{JA}	H10C Board Mount in 400 LF/Min Air Flow		66			66		$^{\circ}C/W$
θ_{JC}			22			22		$^{\circ}C/W$

(5) For metal can applications where V_Z is required, an external 6.2V zener diode should be connected in series with V_{OUT} .

Figure 40 (Texas Instruments, 2013)
Performance characteristics

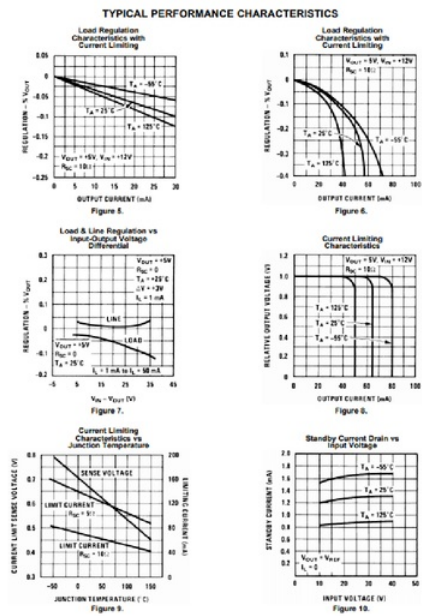


Figure 41 (Texas Instruments, 2013)

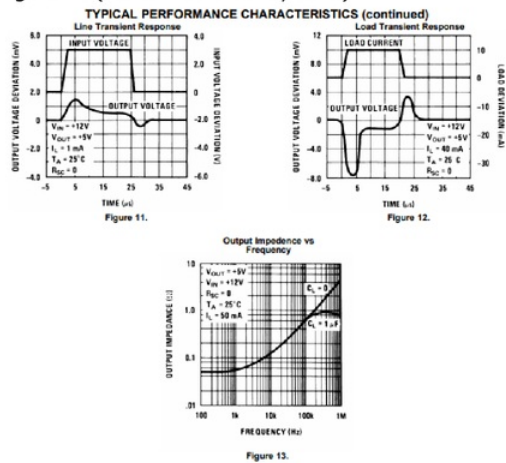


Figure 42 (Texas Instruments, 2013)

MAXIMUM POWER RATINGS

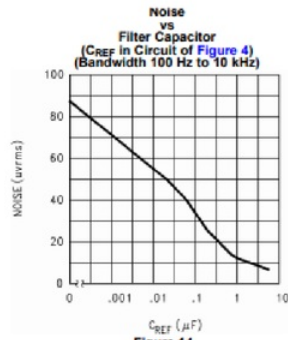


Figure 14.

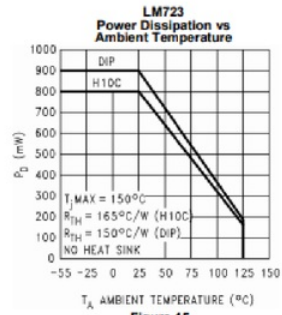


Figure 15.

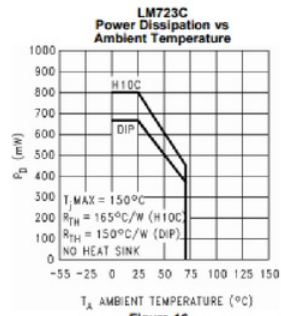
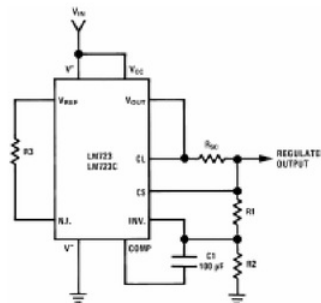


Figure 16.

TYPICAL APPLICATIONS



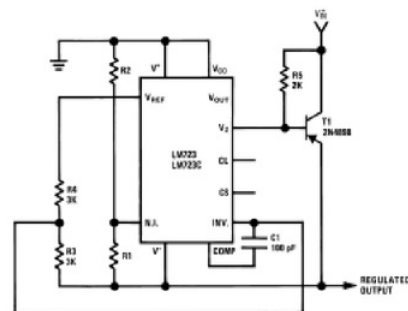
$$\text{Note: } R3 = \frac{R1 \cdot R2}{R1 + R2}$$

for minimum temperature drift.
R3 may be eliminated for minimum component count.

Typical Performance

Regulated Output Voltage	15V
Line Regulation ($\Delta V_{IN} = 3V$)	1.5 mV
Load Regulation ($\Delta I_L = 50 \text{ mA}$)	4.5 mV

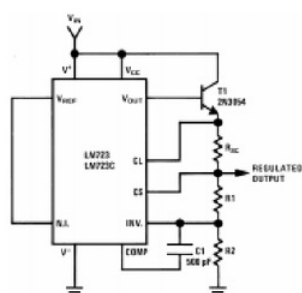
Figure 17. Basic High Voltage Regulator ($V_{OUT} = 7$ to 37 Volts)



Typical Performance

Regulated Output Voltage	-15V
Line Regulation ($\Delta V_{IN} = 3V$)	1 mV
Load Regulation ($\Delta I_L = 100 \text{ mA}$)	2 mV

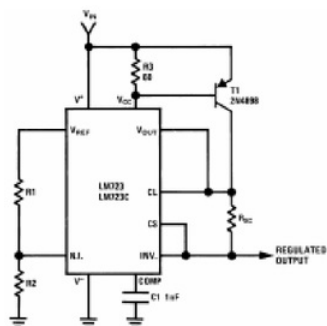
Figure 18. Negative Voltage Regulator



Typical Performance

Regulated Output Voltage	+15V
Line Regulation ($\Delta V_{IN} = 3V$)	1.5 mV
Load Regulation ($\Delta I_L = 1A$)	15 mV

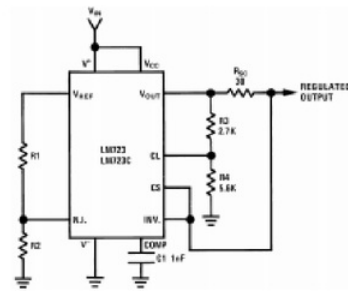
Figure 19. Positive Voltage Regulator (External NPN Pass Transistor)



Typical Performance

Regulated Output Voltage	+5V
Line Regulation ($\Delta V_{IN} = 3V$)	0.5 mV
Load Regulation ($\Delta I_L = 1A$)	5 mV

Figure 20. Positive Voltage Regulator (External PNP Pass Transistor)

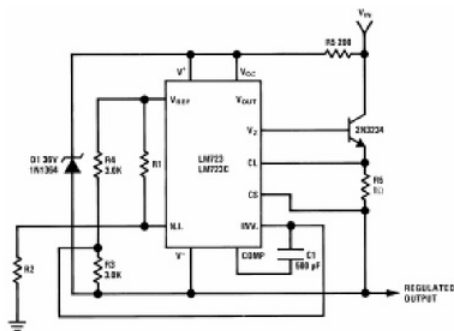


Typical Performance

Regulated Output Voltage
 Line Regulation ($\Delta V_{IN} = 3V$)
 Load Regulation ($\Delta I_L = 10 \text{ mA}$)
 Short Circuit Current

+5V
 0.5 mV
 1 mV
 20 mA

Figure 21. Foldback Current Limiting



Typical Performance

Regulated Output Voltage
 Line Regulation ($\Delta V_{IN} = 20V$)
 Load Regulation ($\Delta I_L = 50 \text{ mA}$)

+50V
 15 mV
 20 mV

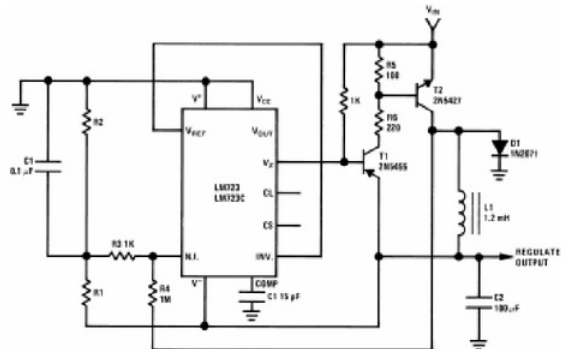
Figure 22. Positive Floating Regulator



-100V
30 mV
20 mV

+5V
10 mV
80 mV

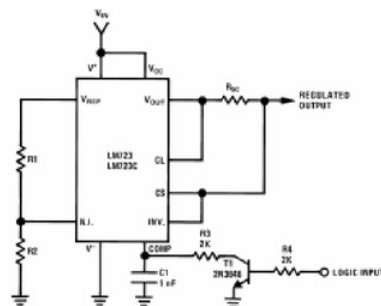
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Typical Performance

Regulated Output Voltage	-15V
Line Regulation ($\Delta V_{IN} = 20V$)	8 mV
Load Regulation ($\Delta I_L = 2A$)	6 mV

Figure 25. Negative Switching Regulator

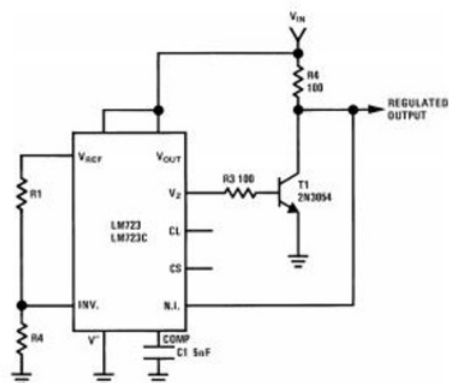


Note: Current limit transistor may be used for shutdown if current limiting is not required.

Typical Performance

Regulated Output Voltage	+5V
Line Regulation ($\Delta V_{IN} = 3V$)	0.5 mV
Load Regulation ($\Delta I_L = 50 \text{ mA}$)	1.5 mV

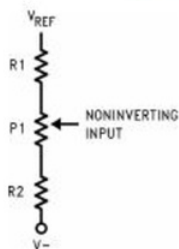
Figure 26. Remote Shutdown Regulator with Current Limiting



Regulated Output Voltage
 Line Regulation ($\Delta V_{IN} = 10V$)
 Load Regulation ($\Delta I_L = 100 \text{ mA}$)

+5V
 0.5 mV
 1.5 mV

Figure 27. Shunt Regulator

Figure 28. Output Voltage Adjust ⁽¹⁾

(1) Replace R1/R2 in figures with divider shown in Figure 28.

7.4 Annexe 4

MC1723C

MAXIMUM RATINGS ($T_A = +25^\circ\text{C}$, unless otherwise noted.)

Rating	Symbol	Value	Unit
Pulse Voltage from V_{CC} to V_{EE} (50 ms)	$V_{I(p)}$	50	V_{pk}
Continuous Voltage from V_{CC} to V_{EE}	V_I	40	Vdc
Input–Output Voltage Differential	$V_I - V_O$	40	Vdc
Maximum Output Current	I_L	150	mA
Current from V_{ref}	I_{ref}	15	mA
Current from V_z	I_z	25	mA
Voltage Between Noninverting Input and V_{EE}	V_{ie}	8.0	Vdc
Differential Input Voltage	V_{id}	± 5.0	Vdc
Power Dissipation and Thermal Characteristics $T_A = +25^\circ\text{C}$ Derate above $T_A = +25^\circ\text{C}$ Thermal Resistance, Junction–to–Air	P_D $1/\theta_{JA}$ θ_{JA}	1.25 10 100	W mW/°C °C/W
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-65 to $+175$	°C
Operating Ambient Temperature Range	T_A	0 to $+70$	°C

Figure 43 (Motorola, 2016)

Electrical Characteristics

ELECTRICAL CHARACTERISTICS ($T_A = +25^\circ\text{C}$, $V_{IN} = 12\text{ Vdc}$, $V_O = 5.0\text{ Vdc}$, $I_L = 1.0\text{ mAdc}$, $R_{SC} = 0$, $C_1 = 100\text{ pF}$, $C_{ref} = 0$ and divider impedance as seen by the error amplifier $\leq 10\text{ k}\Omega$ connected as shown in Figure 2, unless otherwise noted.)

Characteristics	Symbol	Min	Typ	Max	Unit
Input Voltage Range	V_I	9.5	–	40	Vdc
Output Voltage Range	V_O	2.0	–	37	Vdc
Input–Output Voltage Differential	$V_I - V_O$	3.0	–	38	Vdc
Reference Voltage	V_{ref}	6.80	7.15	7.50	Vdc
Standby Current Drain ($I_L = 0$, $V_{IN} = 30\text{ V}$)	I_{IB}	–	2.3	4.0	mAdc
Output Noise Voltage ($f = 100\text{ Hz to } 10\text{ kHz}$) $C_{ref} = 0$ $C_{ref} = 5.0\text{ }\mu\text{F}$	V_n	– –	20 2.5	– –	$\mu\text{V(RMS)}$
Average Temperature Coefficient of Output Voltage ($T_{low} < T_A < T_{high}$)	TCV_O	–	0.003	0.015	%/ $^\circ\text{C}$
Line Regulation ($T_A = 25^\circ\text{C}$) $\begin{cases} 12\text{ V} < V_{IN} < 15\text{ V} \\ 12\text{ V} < V_{IN} < 40\text{ V} \end{cases}$ ($T_{low} < T_A < T_{high}$) $12\text{ V} < V_{IN} < 15\text{ V}$	Regline	– – –	0.01 0.1 –	0.1 0.5 0.3	% V_O
Load Regulation ($1.0\text{ mA} < I_L < 50\text{ mA}$) $T_A = 25^\circ\text{C}$ $T_{low} < T_A < T_{high}$	Regload	– –	0.03 –	0.2 0.6	% V_O
Ripple Rejection ($f = 50\text{ Hz to } 10\text{ kHz}$) $C_{ref} = 0$ $C_{ref} = 5.0\text{ }\mu\text{F}$	RR	– –	74 86	– –	dB
Short Circuit Current Limit ($R_{SC} = 10\text{ }\Omega$, $V_O = 0$)	I_{SC}	–	65	–	mAdc
Long Term Stability	$\Delta V_O / \Delta t$	–	0.1	–	%/1000 Hr.

NOTE: T_{low} to $T_{high} = 0^\circ$ to $+70^\circ\text{C}$

MC1723C

Figure 4. Maximum Load Current as a Function of Input-Output Voltage Differential

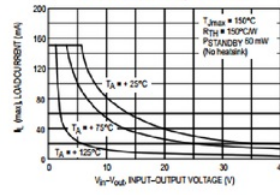


Figure 5. Load Regulation Characteristics Without Current Limiting

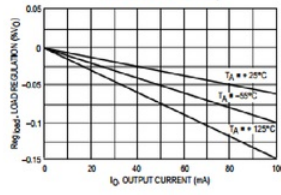


Figure 6. Load Regulation Characteristics With Current Limiting

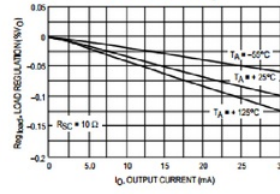


Figure 7. Load Regulation Characteristics With Current Limiting

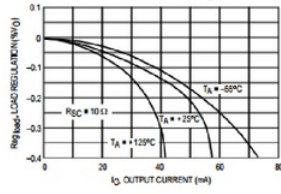


Figure 8. Current Limiting Characteristics

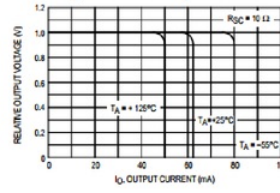


Figure 9. Current Limiting Characteristics as a Function of Junction Temperature

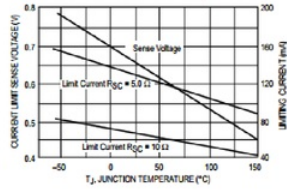


Figure 44 (Motorola, 2016)

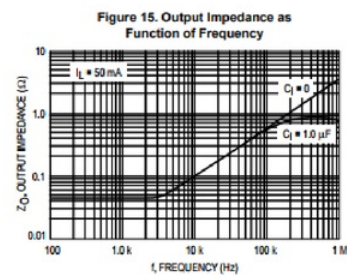
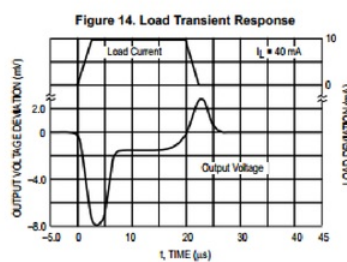
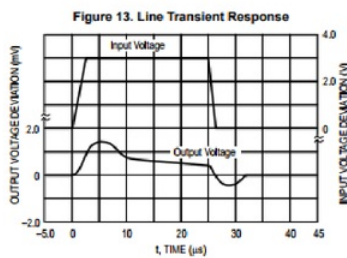
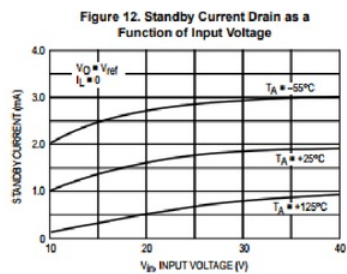
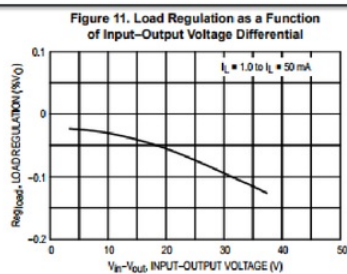
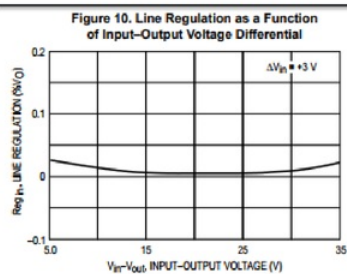


Figure 45 (Motorola, 2016)

7.5 Annexe 5

Panasonic Aluminium Electrolytic Capacitor 2000µF
25V dc 16mm Through Hole TP RADIAL Series +135°C

HS Stock No. 732-8228
Brand Panasonic
Mfr. Part No. ECU1P1E20Z5

Panasonic



Image representative of range

Product Details

1P Series
Panasonic 1P Series Type A electrolytic capacitors feature excellent endurance between 2000 and 5000 hours(dependent on case size) at +125°C. At +135°C, the endurance is between 1000 and 2000 hours(dependent on case size). At high frequency, these radial capacitors provide high ripple current, approximately 20% to 40% higher than the 1A series.
Compact size
Smaller than the Panasonic 1A Series
AEC-Q200 qualified (some deviations apply)
High reliability
Low impedance
Long life
Applications
Panasonic 1P Series Type A electrolytic capacitors are suitable for use in industrial instruments due to their high reliability.

☐ Add product to Compare

Specifications

Not what you're looking for? Select the attributes you require, then click the button below

☐ Capacitance	2000 µF
☐ Technology	Electrolytic
☐ Voltage	25 V dc
☐ Mounting Type	Through Hole
☐ Dimensions	16 (Dia.) x 20mm
☐ Height	20mm
☐ Diameter	16mm
☐ Minimum Operating Temperature	-40°C
☐ Medium Operating Temperature	+125°C
☐ Lead Pitch	7.5mm
☐ Construction	Radial
☐ Series	1P RADIAL
☐ Lifetime	2000 h, 5000 h
☐ Leakage Current	500 µA
☐ Ripple Current	2.38A
☐ Lead Diameter	0.8mm
☐ Tolerance	±20%
☐ Terminal Type	Through Hole
☐ Tolerance Minus	-20%
☐ Tolerance Plus	+20%
☐ Equivalent Series Resistance	29mΩ
☐ Select all	

14 in stock for FREE next working day delivery

£2.31
(Price Each (in a Pack of 2))

Units	Per unit	Per Pack*
2 - 48	£2.31	£4.62
50 +	£2.08	£4.16

Quantity Units [Add to basket](#)

Check stock levels [Add to a parts list](#)

Price indicative

Packaging Options: [?](#)

☒ Standard Pack ☐ Production Pack

Technical Reference

RoHS Certificate of Compliance

Datasheet

Statement of conformity

Build or Request PCB Symbol & Footprint

Essential extras

HS 160 0.7mm Wire Lead Free Solder, +217 → +219°C Melting Point, 0.5% Copper, 98.5% Tin, 3% Silver, 500g

£51.49

[Quick View](#)

7.6 Annexe 6 - enclosure

1554 Polycarbonate Enclosure, 119.4 x 119.4 x 80mm

RS Stock No. 868-5129
Brand Hammond
Mfr. Part No. 1554P2GYCL



Product Details

Specifications

Not what you're looking for? Select the attributes you require, then click the button below

☐	Body Material	Polycarbonate
☐	External Dimensions	119.4 x 119.4 x 80mm
☐	External Length	119.4 mm
☐	External Width	119.4 mm
☐	External Height	80 mm
☐	Series	1554
☐	Select all	

7.8 Annexe 7 – Bridge rectifier

Diodes Inc SBR05M60BLP-7, Bridge Rectifier, 60V, 4-Pin DFN4

HS Stock No. 222-0505
Brand: DiodesInc
Mfr. Part No. SBR05M60BLP-7

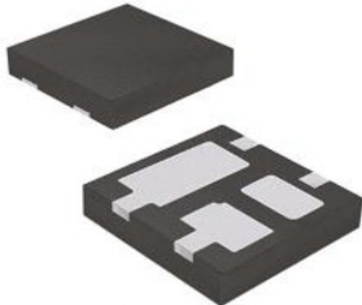


Image representative of range

5000 in stock for FREE next working day delivery

£0.236

(Price Each (On a fleet of 3000))

Units	Per unit	Per fleet
3000 - 6000	£0.236	£708.00
6000 +	£0.224	£872.00

Quantity

5000

Units

Add to basket

Check stock levels

Add to a parts list

Type indicative

Technical Reference

RoHS Certificate of Compliance

Datasheet

Statement of conformity

Product Details

Performance Rectifiers, SBR (Super Barrier Rectifier), Diodes Inc
Diodes and Rectifiers, Diodes Inc

☐ Add product to Compare

Specifications

Not what you're looking for? Select the attributes you require, then click the button below

☐ Bridge Type	Single Phase
☐ Peak Reverse Repetitive Voltage	60V
☐ Mounting Type	Surface Mount
☐ Package Type	DFN4
☐ Pin Count	4
☐ Diode Technology	Silicon Junction
☐ Configuration	Single
☐ Peak Non-Repetitive Forward Surge Current	8A
☐ Maximum Operating Temperature	+150 °C
☐ Minimum Operating Temperature	-55 °C
☐ Peak Forward Voltage	400mV
☐ Peak Reverse Current	20mA
☐ Length	3.1mm
☐ Height	3.1mm
☐ Dimensions	3.1 x 3.1 x 0.58mm
☐ Width	3.1mm
☐ Select all	

7.9 Annexe 8 – Transformer

20V ac 2 Output Through Hole PCB Transformer, 3VA

RS Stock No. 504-470
Brand RS Pro



£5.16

Price Each

Units	Per unit
1 - 9	£5.16
10 - 24	£4.03
25 +	£3.78

Quantity 1 Units [Add to basket](#)
[Check stock levels](#) [Add to a price list](#)

[Log in](#) to download 3D models

Technical Reference

- [RoHS Certificate of Compliance](#)
- [RoHS Footprint](#)
- [Statement of conformity](#)
- [RoHS or Recycled PCB Symbol & Footprint](#)

Essential extras

Passives 220µF Polypropylene Capacitor 11 275V ac ±10% Tolerance Through Hole SMDLok Series
£0.314
[Quick View](#)

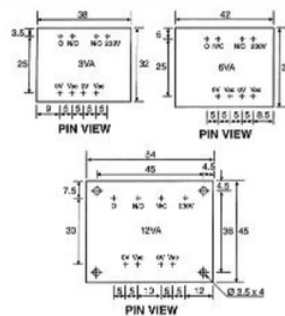
Passives 470µF Polypropylene Capacitor 11 275V ac ±20% Tolerance Through Hole SMDLok Series
£0.40
[Quick View](#)



Product Details

220 Vdc Primary Transformer
Fully enclosed bobbin
Extra pins for secure board mounting
100% electrical and bath tested
Tested in accordance with IEC 60335-25 and EN 60742

Insulation	Class B (130°C)
Isolation (Primary to Secondary)	4 kV rms
Isolation (Windings to core)	2 kV rms
Pin Length x Diameter	5 x 1 mm
Maximum Winding Temperature Rise	<105 °C
Input Voltage	220 Vdc



Approvals
SEES
Standards
IEC 60335, EN 60742

Open Frame - Laminated
PCB mounting means transformers with a single 220Vdc or twin 115Vdc 3000Hz primary winding. Independent secondary windings may be connected in series or parallel to give a wide range of output voltage and current options.
Double section multi bobbin construction
Full varnish impregnation

Technical specifications					
VA	regulation	dimensions (mm)		pins (mm)	weight
nominal	typ. (%)	L	L	L	(kg)
3	20	38	30	5	1 0.14
6	20	43	38	5	1 0.18
12	12	54	45	5	1 0.4

* above the PCB

Power supplies

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

82/100

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GRADING FORM: CSG-RUBIC

RUSSELL MAGUIRE**82****RESEARCH-INFORMED LITERATURE**

There was evidence of further reading and research with the inclusion of a reference list and appropriate in text referencing. Your interpretation and understanding of the additional research was good. Your references were appropriate to the task and your reference list was of an appropriate length for this assignment.

8**KNOWLEDGE AND UNDERSTANDING**

The knowledge and understanding of the subject demonstrated by this assignment was generally excellent. There were very few gaps in your knowledge of the basic principles and the higher level concepts were very well explained. Your explanation of the design process and calculations was also excellent and extended your knowledge well beyond that contained in the course notes.

26**ANALYSIS**



Your analysis of the task was generally satisfactory, both in class and as shown in this assignment. You have demonstrated good analytical skills and your approach to the task was logical. You carried out a short analysis and a short conclusion. Further work – in your conclusion, you should relate the results to the original specification and to accepted theory.

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PRACTICAL APPLICATION AND DEP.



Your application of practical skills for this task was generally very good. You used the resources available in MultiSim appropriately when designing the circuit and you used appropriate options for testing and evaluating the circuit performance. You managed to design an efficient circuit that functioned within the specification and achieved this by only asking for assistance when appropriate. Your results were comprehensive and should have allowed for a good conclusion to be attempted.

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SKILLS FOR PROFESSIONAL PRAC.



In this assignment you have demonstrated skills in working individually and also collaboratively. Your written report was very well structured and written in a coherent and logical way. The report was presented in a professional manner using appropriate language and formatting, good diagrams in appropriate places, good sentence/paragraph structure and clear calculations. One observation is to be careful with inconsistent fonts.

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