Faculty of Electronics, Telecommunications and Information Technology

TECHNICAL UNIVERSITY OF CLUJ-NAPOCA ROMANIA

CAD Techniques

~Voltage regulator~

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Group: 2021

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1.Project requirements

Design a voltage regulator having the following informations:

-The input voltage is Vi=220V;

-The output voltage is [Vo1,Vo2]=[5V,9V];

-The current is limited to 2A;

2.Theoretical support

2.1. Introduction

To understand the requirement it is necessary to understand what a voltage regulator is and what functionality does it have.

A voltage regulator is an electronic device that maintains the voltage of a power source between acceptable limits.

How it works?

Starting with an ac voltage, a steady dc voltage is obtained by rectifying the ac voltage, then filtering to a dc level and, finally, regulating to obtain a desired fixed dc voltage. The regulation is usually obtained from an IC voltage regulator unit, which takes a dc voltage and provides a somewhat lower dc voltage, which remains the same even if the input dc voltage varies or the output load connected to the dc voltage changes. Zener diodes have a mode due to which it can act as a voltage regulator. This mode is known as the reverse breakdown voltage operation. During this mode, the Zener diode maintains constant output DC voltage signal while the AC ripple voltage signal is completely blocked.

2.2. Applications of voltage regulators:

-Motor vehicles of all types to match the output voltage of the generator to the electrical load and to the charging requirements of the battery.

-A solar power plant generates electricity based on the intensity of sunlight. It needs a regulator to ensure a regulated constant output signal.

-Computers, televisions, laptops and all sorts of devices are powered using this concept.

2.3. Linear Regulators

Two types of transistor voltage regulators are the series voltage regulator and the shunt voltage regulator. Each type of circuit can provide an output dc voltage that is regulated or maintained at a set value even if the input voltage varies or if the load connected to the output changes.

Advantages:

-low ripple voltage- less fluctuation in the output

-fast response time

-low electromagnetic interference

-simple circuit configuration

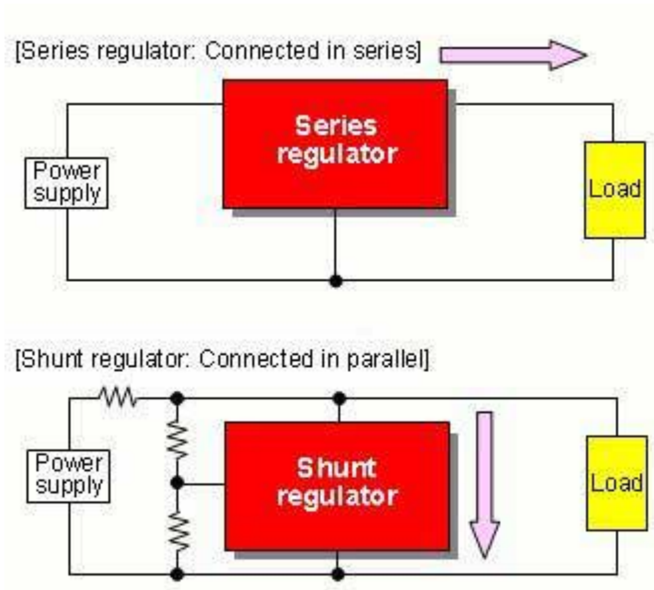
Disadvantages:

-low efficiency

-a lot of heat dissipated- needs a heat sink

-requires more space

-output voltage cannot exceed the input voltage



A. Series Regulator Circuit

The regulating operation can be described as follows:

If the output voltage decreases, the increased base-emitter voltage causes transistor Q1 to conduct more, thereby raising the output voltage—maintaining the output constant.

If the output voltage increases, the decreased base-emitter voltage causes transistor Q1 to conduct less, thereby reducing the output voltage—maintaining the output constant.

Op-Amp Series Regulator:

The op-amp compares the Zener diode reference voltage with the feedback voltage from sensing resistors R1 and R2. If the output voltage varies, the conduction of transistor Q1 is controlled to maintain the output voltage constant.

B. Shunt Regulator Circuit

A shunt voltage regulator provides regulation by shunting current away from the load to regulate the output voltage. The input unregulated voltage provides current to the load. Some of the current is pulled away by the control element to maintain the regulated output voltage across the load. If the load voltage tries to change due to a change in the load, the sampling circuit provides a feedback signal to a comparator, which then provides a control signal to vary the amount of the current shunted away from the load. As the output voltage tries to get larger, for example, the sampling circuit provides a feedback signal to the comparator circuit, which then provides a control signal to draw increased shunt current, providing less load current, thereby keeping the regulated voltage from rising.

Op-Amp Shunt Regulator:

The Zener voltage is compared to the feedback voltage obtained from voltage divider R1 and R2 to provide the control drive current to shunt element Q1. The current through resistor RS is thus controlled to drop a voltage across RS so that the output voltage is maintained.

2.4. Switching regulators

Switching voltage regulators consist of a series device that is repeatedly switched on and off at a high frequency. The duty cycle is used to control the amount of charge supplied to the load. The duty cycle is controlled by a feedback system that is very similar to the one in the linear regulator. Switching regulators have a high efficiency because the load is either on or off which means it dissipates no energy when it is off.

Advantages:

-output voltage can be greater than the input voltage

-high efficiency -the load is either on or off

-it can generate an opposite polarity voltage signal

Disadvantages:

-increased noise

-complicated design

-high interference

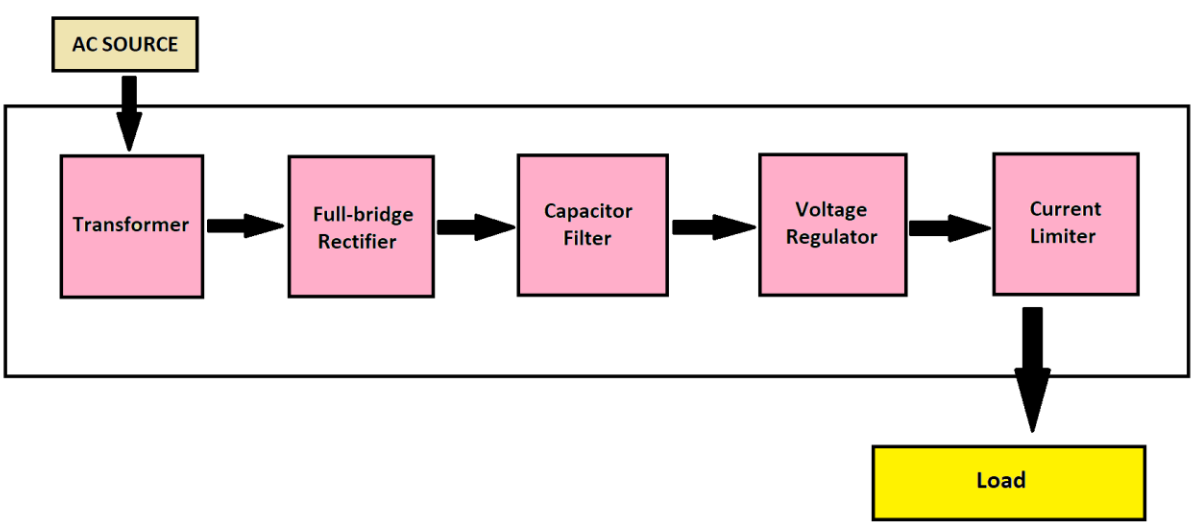
-more external parts required

3. Block diagram

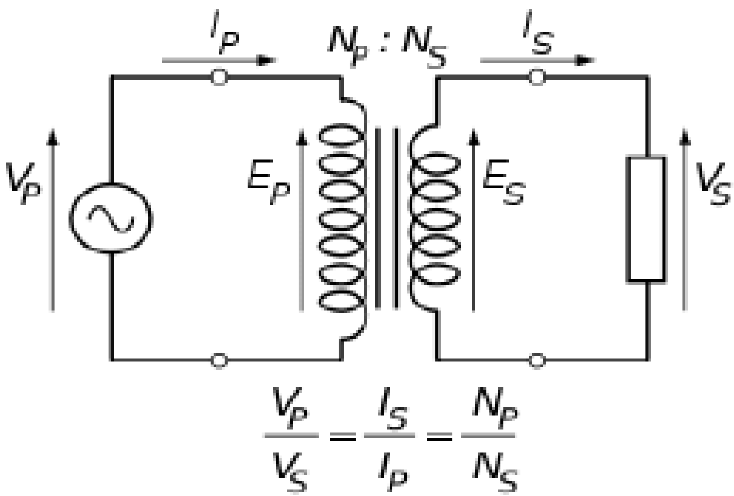
3.1. Introduction

The ac voltage is connected to a transformer, which steps that ac voltage down to the level for the desired dc output. A diode rectifier then provides a full-wave rectified voltage that is initially filtered by a simple capacitor filter to produce a dc voltage. This resulting dc voltage usually has some ripple or ac voltage variation. A regulator circuit can use this dc input to provide a dc voltage that not only has much less ripple voltage but also remains the same dc value even if the input dc voltage varies somewhat or the load connected to the output dc voltage changes.

3.2. Block diagram

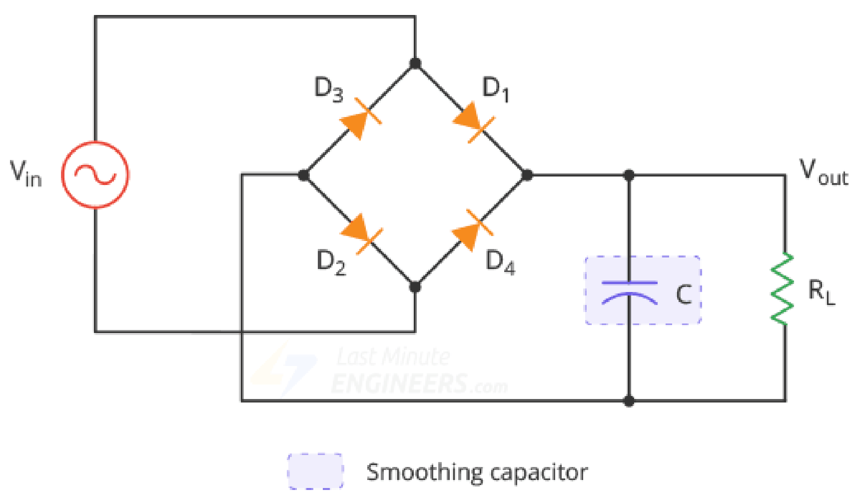


3.3. Transformer



A transformer can increase or decrease voltage or current levels according to the turns ratio, as explained below. In addition, the impedance connected to one side of a transformer can be made to appear either larger or smaller (step up or step down) at the other side of the transformer, depending on the square of the transformer winding turns ratio.

3.4. Full-bridge rectifier



Power Diodes can be connected together to form a full wave rectifier that convert AC voltage into pulsating DC voltage for use in power supplies.

The four diodes labelled D_1 to D_4 are arranged in “series pairs” with only two diodes conducting current during each half cycle. During the positive half cycle of the supply, diodes D1 and D2 conduct in series while diodes D3 and D4 are reverse biased and the current flows through the load as shown below.

The positive half-cycle:

During the negative half cycle of the supply, diodes D3 and D4 conduct in series, but diodes D1 and D2 switch OFF as they are now reversed bias. The current flowing through the load has the same direction as before.

The negative half-cycle:

As the current flowing through the load is unidirectional, so the voltage developed across the load is also unidirectional, therefore the average DC voltage across the load is 0,63Vmax.

3.5. Capacitor Filter

A very popular filter circuit is the capacitor-filter circuit. A capacitor is connected at the rectifier output, and a dc voltage is obtained across the capacitor. This filter circuit increases the average DC output level as the capacitor acts like a storage device. The smoothing capacitor converts the rippled output of the rectifier into a smoother DC output.

3.6. Voltage regulator

A voltage regulator is an electronic device that maintains the voltage of a power source between acceptable limits.

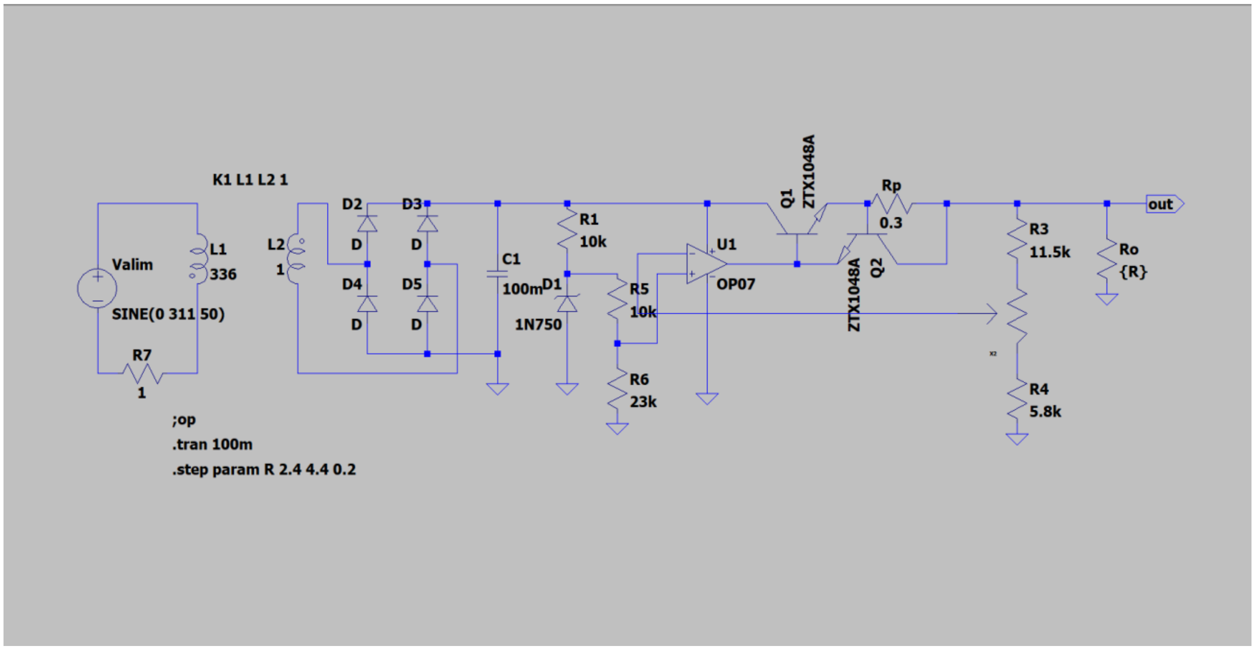
3.7. Current limiter

Current limiter circuits are key to power supplies, protecting them in cases of a short circuit or other overload condition.

3.8. Load

The device which takes electrical energy is known as the electric load. In other words, the electrical load is a device that consumes electrical energy in the form of the current and transforms it into other forms like heat, light, work, etc. The electrical load may be resistive, inductive, capacitive or some combination between them.

4. Electrical scheme and calculus



For the circuit I picked ZTX1048A model for the two transistors Q1 and Q2 and an OP07 Operational Amplifier. The Zener Diode I used, 1N750, has the Breakdown Voltage 4,7V.

The initial value given is 220V RMS, so the transformer that I made has a sinusoidal voltage of 220*sqrt(2)=311V, the peak value.

I gave the capacitor a 100mF value and to find out the values of L1 and L2, I used the formula V1/V2=sqrt(L1/L2);

Sqrt(L1/L2) is equal to 18,3V, which means that L1/L2=336, so I chose L1 =336H and L2 =1H.

The DC Voltage obtained is 15,6V;

Because the breakdown voltage on the Zener Diode is 4,7V and a lower value is needed, I tried to obtain 3,3V . for that I added the resistances R5 and R6 and I calculated their values with a voltage divider:

R6/(R5+R6)*4,7=3,3V, from where it results that R5=10k and R6=23k.

Because the circuit has negative feedback, I used the formula from FEC, V+=V-. V+ takes the value obtained by the Zener diode and the voltage divider, so V+=3,3V;

For V-, the formula for the voltage divider contains more elements due to the variation of the potentiometer.

V-=(R4+kP)/(R4+R3+P);

From that, I equaled V+ with V- to find out the resistances R3 and R4.

If the potentiometer takes P=10k, we have the two situations:

When k=0, (R4+R3+10)/R4 *3,3V= 9V;

When k=1, (R4+R3+10)/(R4+10) *3,3V= 5V;

From these two equations it results that R3=11,5k and R4=5,8k.

From FEC courses I took the formula Vbe=Imax* Rp to find Rp.

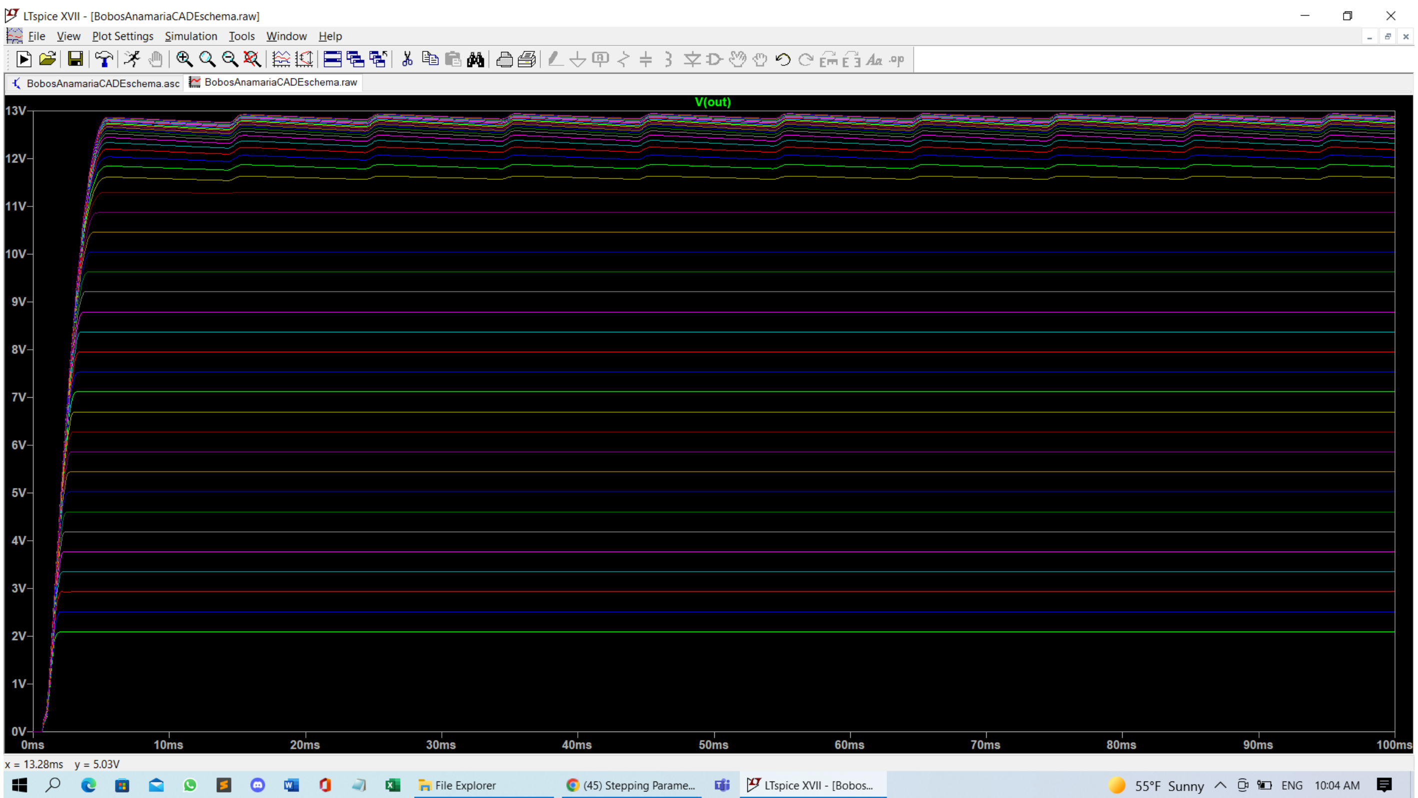
Knowing that Vbe, on= 0,6V and Imax=2A, I found that Rp=0,3V.

5. Simulation Results

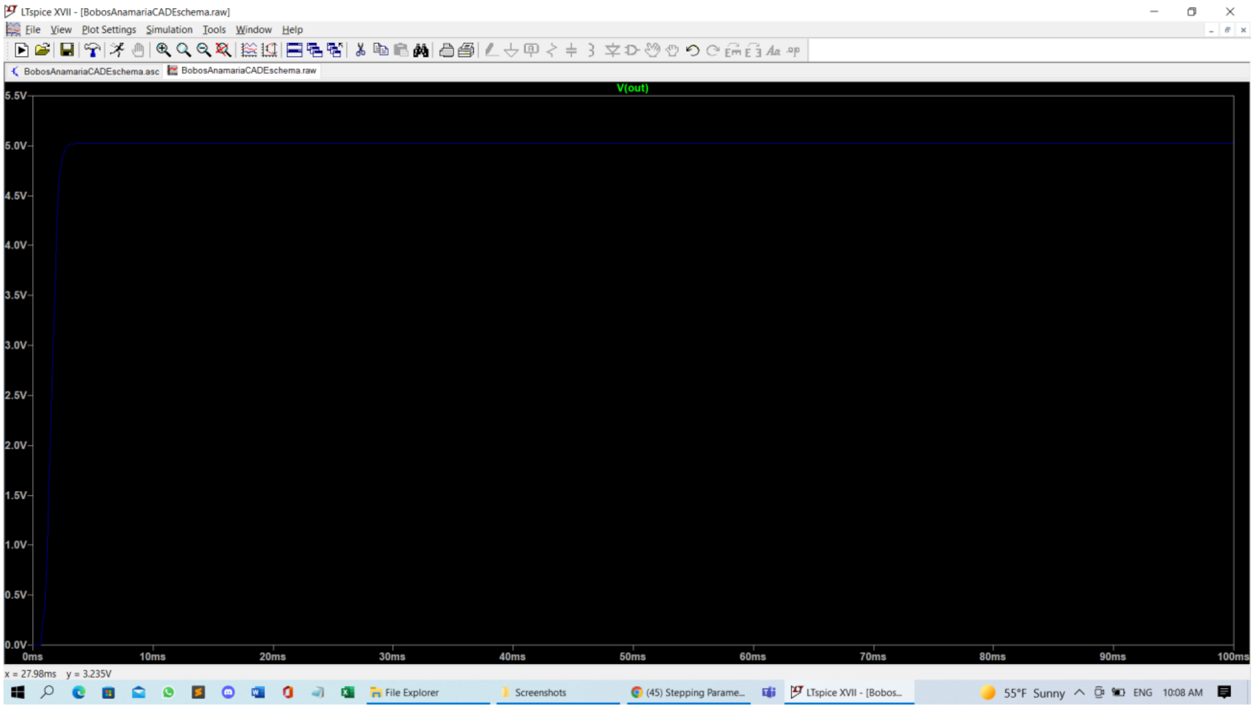
Simulations of the Output Voltage.

From the parametric analysis for Ro, where the start value is 1 Ohm and the stop value is 10 Ohms, with an increment of 0,2 , we can observe the following situations:

When the potentiometer is in the k=1 position and Ro=2,4 Ohms, the output voltage is equal to 5.



When the potentiometer is in the k=1 position and Ro=2,4 Ohms, the output voltage is equal to 5V, and when the potentiometer is in the k=1 and R0=4,4 Ohms, the output voltage is equal to 9V.

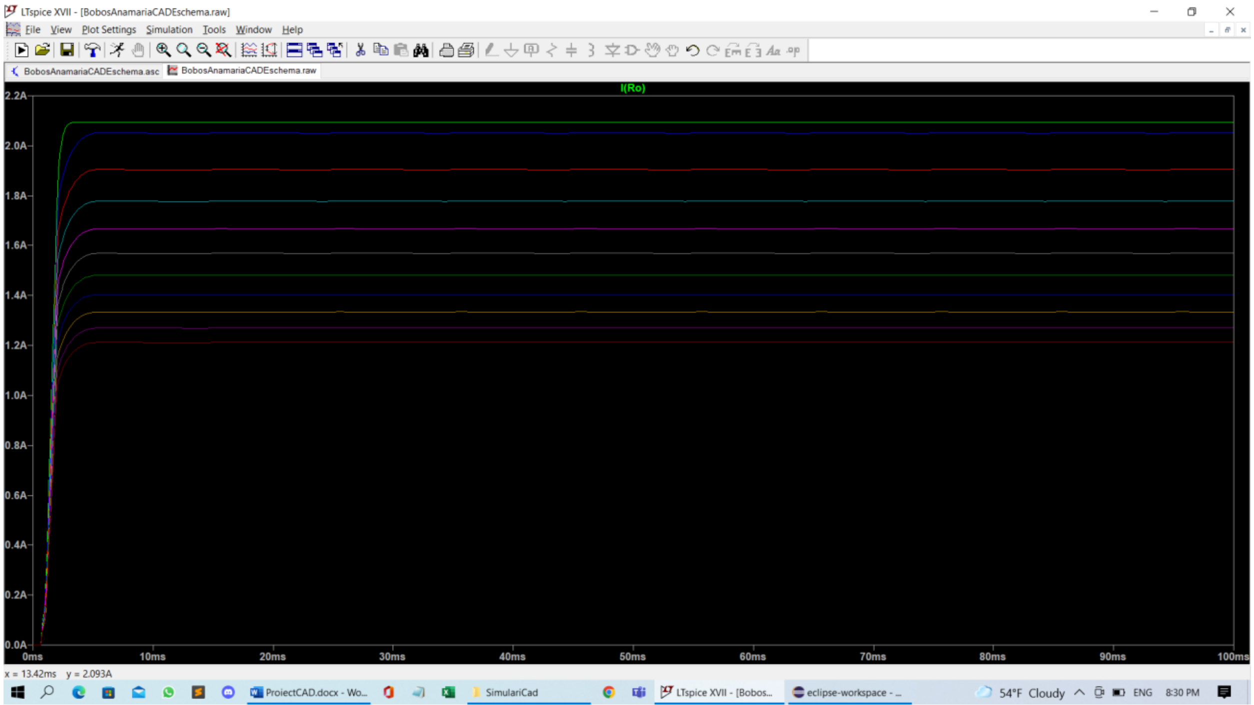


When the potentiometer is in the k=99 position and Ro=2,2 Ohms, the output voltage is equal to 5V;

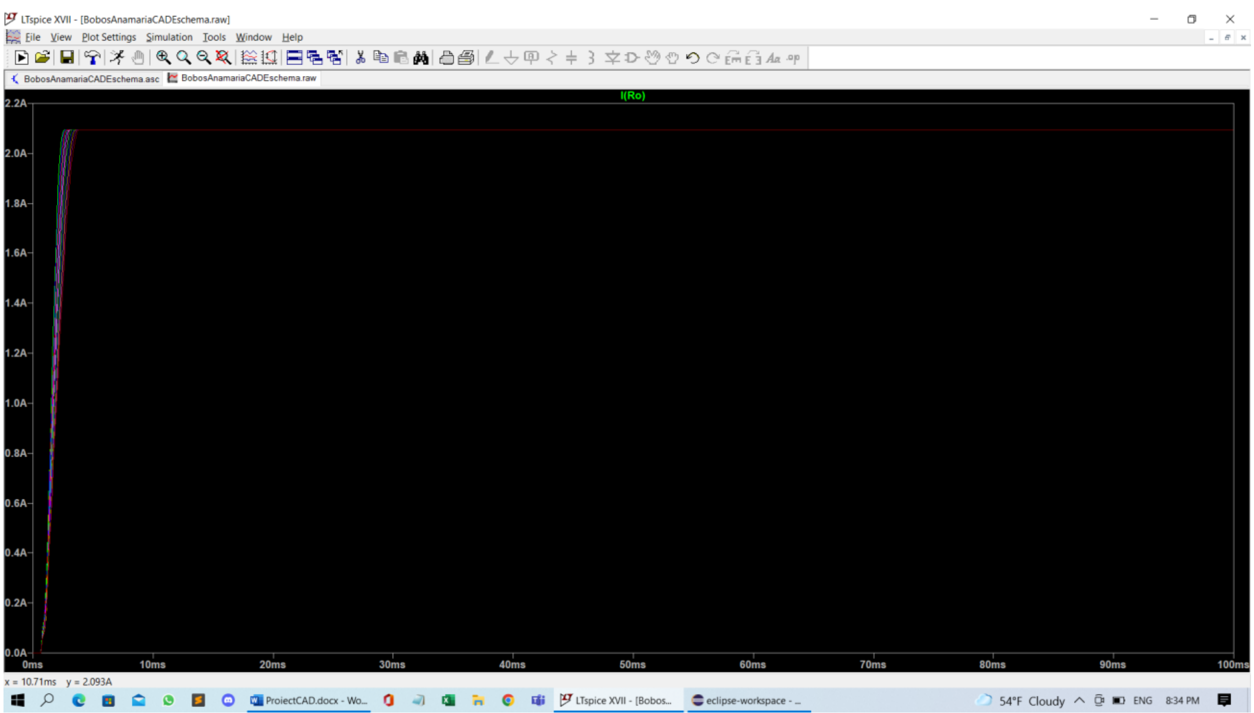
Therefore, the range for Ro for the circuit to have the output voltage between [5;9] V is [2,4; 4,4] Ohms.

Simulations of the current:

Between the range [2,4; 4,4] Ohms for Ro, the current for the k=99 position can be observed in the next parametric analysis simulation:



Changing the potentiometer position to k=1, we can see that the maximum given current of 2A is reached.



6. Specifications and Bill of Materials

Data sheets

Standard Resistor Values (±5%)						
1.0	10	100	1.0K	10K	100K	1.0M
1.1	11	110	1.1K	11K	110K	1.1M
1.2	12	120	1.2K	12K	120K	1.2M
1.3	13	130	1.3K	13K	130K	1.3M
1.5	15	150	1.5K	15K	150K	1.5M
1.6	16	160	1.6K	16K	160K	1.6M
1.8	18	180	1.8K	18K	180K	1.8M
2.0	20	200	2.0K	20K	200K	2.0M
2.2	22	220	2.2K	22K	220K	2.2M
2.4	24	240	2.4K	24K	240K	2.4M
2.7	27	270	2.7K	27K	270K	2.7M
3.0	30	300	3.0K	30K	300K	3.0M
3.3	33	330	3.3K	33K	330K	3.3M
3.6	36	360	3.6K	36K	360K	3.6M
3.9	39	390	3.9K	39K	390K	3.9M
4.3	43	430	4.3K	43K	430K	4.3M
4.7	47	470	4.7K	47K	470K	4.7M
5.1	51	510	5.1K	51K	510K	5.1M
5.6	56	560	5.6K	56K	560K	5.6M
6.2	62	620	6.2K	62K	620K	6.2M
6.8	68	680	6.8K	68K	680K	6.8M
7.5	75	750	7.5K	75K	750K	7.5M
8.2	82	820	8.2K	82K	820K	8.2M
9.1	91	910	9.1K	91K	910K	9.1M

For the transistors:

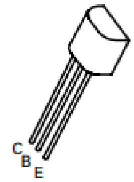
NPN SILICON PLANAR MEDIUM POWER HIGH GAIN TRANSISTOR

ZTX1048A

ISSUE 3 – FEBRUARY 1995

FEATURES
* V_{CEV}=50V
* Very Low Saturation Voltages
* High Gain
* 20 Amps pulse current

APPLICATIONS
* LCD Backlight Convertors
* Emergency Lighting
* DC-DC Convertors



E-Line
TO92 Compatible

ABSOLUTE MAXIMUM RATINGS.

PARAMETER	SYMBOL	ZTX1048A	UNIT
Collector-Base Voltage	V_{CBO}	50	V
Collector-Emitter Voltage	V_{CEO}	17.5	V
Emitter-Base Voltage	V_{EBO}	5	V
Peak Pulse Current	I_{CM}	20	A
Continuous Collector Current	I_C	4	A
Base Current	I_B	500	mA
Power Dissipation at T_{amb}=25°C	P_{tot}	1	W
Operating and Storage Temperature Range	T_j:T_{stg}	-55 to +200	°C

ZTX1048A

ELECTRICAL CHARACTERISTICS (at T_{amb} = 25°C unless otherwise stated).

PARAMETER	SYMBOL	ZTX1048A			UNIT	CONDITIONS.
		MIN.	TYP.	MAX.		
Collector-Base Breakdown Voltage	$V_{(BR)CBO}$	50	85		V	I_C=100μA
Collector-Emitter Breakdown Voltage	V_{CES}	50	85		V	IC=100μA
Collector-Emitter Breakdown Voltage	V_{CEO}	17.5	24		V	IC=10mA
Collector-Emitter Breakdown Voltage	V_{CEV}	50	85		V	IC=100μA, V_{EB}=1V
Emitter-Base Breakdown Voltage	$V_{(BR)EBO}$	5	8.7		V	I_E=100μA
Collector Cut-Off Current	I_{CBO}		0.3	10	nA	V_{CB}=35V
Emitter Cut-Off Current	I_{EBO}		0.3	10	nA	V_{EB}=4V
Collector Emitter Cut-Off Current	I_{CES}		0.3	10	nA	VCES=35V
Collector-Emitter Saturation Voltage	$V_{CE(sat)}$		27 55 110 210	45 75 150 245	mV mV mV mV	I_C=0.5A, I_B=10mA* I_C=1A, I_B=10mA* I_C=2A, I_B=10mA* I_C=4A, I_B=20mA*
Base-Emitter Saturation Voltage	$V_{BE(sat)}$		860	950	mV	I_C=4A, I_B=20mA*
Base-Emitter Turn-On Voltage	$V_{BE(on)}$		860	950	mV	IC=4A, V_{CE}=2V*
Static Forward Current Transfer Ratio	h_{FE}	280 300 300 220 50	440 450 450 330 80	1200		I_C=10mA, V_{CE}=2V* I_C=0.5A, V_{CE}=2V* I_C=1A, V_{CE}=2V* I_C=4A, V_{CE}=2V* I_C=20A, V_{CE}=2V*
Transition Frequency	f_T		150		MHz	I_C=50mA, V_{CE}=10V f=50MHz
Output Capacitance	C_{obo}		60	80	pF	V_{CB}=10V, f=1MHz
Switching Times	t_{on}		130		ns	I_C=4A, I_B=40mA, V_{CC}=10V
	t_{off}		180		ns	I_C=4A, I_B=±40mA, V_{CC}=10V

For the Zener Diode:

- 1N746A-1 THRU 1N759-1 AVAILABLE IN JAN, JANTX AND JANTXV PER MIL-PRF-19500/127
- 1N4370A-1 THRU 1N4372A-1 AVAILABLE IN JAN, JANTX AND JANTXV PER MIL-PRF-19500/127
- DOUBLE PLUG CONSTRUCTION
- METALLURGICALLY BONDED

1N746 thru 1N759A
and
1N746A-1 thru 1N759A-1
and
1N4370 thru 1N4372A
and
1N4370A-1 thru 1N4372A-1

MAXIMUM RATINGS

Operating Temperature: -65°C to +175°C
Storage Temperature: -65°C to +175°C
DC Power Dissipation: 500 mW @ +50°C
Power Derating: 4 mW / °C above +50°C
Forward Voltage @ 200mA: 1.1 volts maximum

ELECTRICAL CHARACTERISTICS @ 25°C

JEDEC TYPE NUMBER (NOTE 1)	NOMINAL ZENER VOLTAGE V_Z @ I_{ZT} (NOTE 2)	ZENER TEST CURRENT I_{ZT}	MAXIMUM ZENER IMPEDANCE (NOTE 3) Z_{ZT} @ I_{ZT}	MAXIMUM REVERSE CURRENT I_R @ V_R		MAXIMUM ZENER CURRENT I_{ZM}
	VOLTS	mA	OHMS	µA	VOLTS	mA
1N4370A	2.4	20	30	100	1.0	155
1N4371A	2.7	20	30	60	1.0	140
1N4372A	3.0	20	29	30	1.0	125
1N746A	3.3	20	28	5	1.0	120
1N747A	3.6	20	24	3	1.0	110
1N748A	3.9	20	23	2	1.0	100
1N749A	4.3	20	22	2	1.0	90
1N750A	4.7	20	19	5	1.5	85
1N751A	5.1	20	17	5	2.0	75
1N752A	5.6	20	11	5	2.5	70
1N753A	6.2	20	7	5	3.5	65
1N754A	6.8	20	5	2	4.0	60
1N755A	7.5	20	6	2	5.0	55
1N756A	8.2	20	8	1	6.0	50
1N757A	9.1	20	10	1	7.0	45
1N758A	10.0	20	17	1	8.0	40
1N759A	12.0	20	30	1	9.0	35

NOTE 1 Zener voltage tolerance on "A" suffix is ±5%. No Suffix denotes ± 10% tolerance, "C" suffix denotes ± 2% tollerance and "D" suffix denotes ± 1% tolerance.

NOTE 2 Zener voltage is measured with the device junction in thermal equilibrium at an ambient temperature of 25°C ± 3°C.

NOTE 3 Zener impedance is derived by superimposing on I_{ZT} A 60Hz rms a.c. current equal to 10% of I_{ZT}

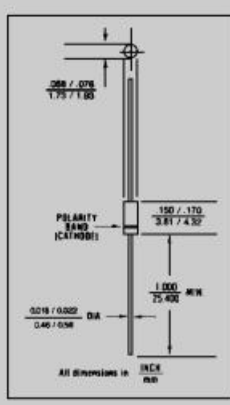


FIGURE 1

DESIGN DATA

CASE: Hermetically sealed glass case. DO – 35 outline.

LEAD MATERIAL: Copper clad steel.

LEAD FINISH: Tin / Lead

THERMAL RESISTANCE: ($R_{\Theta JEC}$): 250 °C/W maximum at L = .375 inch

THERMAL IMPEDANCE: ($Z_{\Theta JX}$): 35 °C/W maximum

POLARITY: Diode to be operated with the banded (cathode) end positive.

MOUNTING POSITION: Any.

Microsemi

6 LAKE STREET, LAWRENCE, MASSACHUSETTS 01841
PHONE (978) 620-2600 FAX (978) 689-0803
WEBSITE: http://www.microsemi.com

For the Operational Amplifier:

https://www.analog.com/media/en/technical-documentation/data-sheets/OP07.pdf

Bill of Materials:

-AC Source: 311V Source-15353 Ron

-Resistances: 0,3 Ohm- 0,15 Ron

4,4 Ohm- 0,34 Ron

11,5 kOhm- 2,48 Ron

5,8 kOhm - 0,51 Ron

10 kOhm x2- 1,16 Ron

23 kOhm - 2,67 Ron

-Zener Diode 1N746: 10 Ron

-Transformer: 17,6 Ron

-Capacitor: 10mF- 3,73 Ron

-Op Amp: op07- 75 Ron

Total Costs: 15466,74 Ron

7. References

Electronic devices and circuit theory- Robert Boylestad, Louis Nashelsky

https://www.derf.com/an-overview-on-voltage-regulators/

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