0-30V / 5A DIGITAL POWER SUPPLY
WITH COMPUTER CONTROL

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Submitted to the Institute for Graduate Studies in
Science and Engineering in partial fulfillment of
the requirements for the degree of
Master of Science

Graduate Program in Electrical and Electronics Engineering
Boğaziçi University
2010

ACKNOWLEDGEMENTS

I am very grateful to my thesis supervisor Prof. Yasemin Kahya for encouraging and motivating me, trusting me and guiding me during my thesis. Without her valuable support it would have been very hard for me to complete my study.

I also want to extend my great thanks to Prof. Ömer Cerid for guiding me at the hard breakpoints and giving very important suggestions.

I would like to thank Prof. Günhan Dündar and Assoc Prof. Özcan Gülçür for their interest and evaluation of my thesis and being jury members.

I would like to thank Gökhan Yıldız, Yusuf Yıldırım, Övünç Doruk İzgen, İlkin Tacan, Çağatay Büyüktopçu, Selami Çevik, Erhan Gündoğan and Eren Uyar from Arçelik Company for their supports.

Finally, I would like to thank my wife, my mother and my father for their invaluable support and motivation at the important milestones of this thesis. I would also like to thank my little son Yunus Emre, for being a reason of extra motivation although he does not know.

ABSTRACT

0-30V / 5A DIGITAL POWER SUPPLY WITH COMPUTER CONTROL

Most of the electronic circuits require a DC power supply to operate. There are many designs and topologies covering different properties and specifications for DC power supplies.

The voltage and current range and accuracy, power capacity and quality, failure protections, isolations, robustness and reliability, power efficiency, size and ease of usage are some of the most important characteristics of power supplies.

A DC power supply with the parameters given in the following sections is designed and realized for the fulfillment of the Master of Science thesis. The criteria for making decisions on the design parameters were range, isolations and ease of use. The range is proposed to be 30VDC and 5A output. The isolation is realized both between the mains and the device and between the device and PC that, when connected, controls it. For the ease of use, a 4x4 keypad to enter data and a 2x20 character LCD to monitor data are used.

ÖZET

BİLGİSAYAR DENETİMLİ 0-30V / 5A SAYISAL GÜÇ KAYNAĞI

Elektronik devrelerin çoğu işlevlerini yerine getirebilmek için doğru akım kaynaklarına gereksinim duyar. Birçok farklı özellik ve spesifikasyonlarda çok çeşitli tasarım ve topolojiye sahip doğru akım kaynakları mevcuttur.

Gerilim ve akım aralığı ve doğruluğu, güç kapasitesi ve kalitesi, hata korumaları, yalıtımlar, sağlamlık ve güvenilirlik, güç verimliliği, boyutlar ve kullanım kolaylığı güç kaynaklarının en önemli karakteristiklerinden bazılarıdır.

Bu yüksek lisans tezinin yerine getirilmesi için, takip eden bölümlerde belirtilen parametrelere sahip bir doğru akım güç kaynağı tasarlanıp gerçekleştirilmiştir. Tasarım parametrelerine karar vermedeki ölçütler aralık, yalıtım ve kullanım kolaylığı olmuştur. Aralık 30VDC'ye ve 5A'e kadar çıkış verebilecek şekilde önerilmiştir. Hem şebeke ile cihaz arasında hem de bağlandığında cihazı kontrol eden bilgisayar ile cihaz arasında yalıtım bulunmaktadır. Kullanım kolaylığı için veri girmede kullanmak üzere 4x4 tuştakımı ve veri görüntülemede kullanmak üzere 2x20 karakter LCD kullanılmıştır.

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1. INTRODUCTION

All the electronic devices which are used in everyday life require some kind of energy to operate. The kind of energy can be electrical, but it can also be mechanical, chemical (gasoline, batteries, oil, natural gas, wood etc.), heat (thermal, steam etc.), kinetic (sound, wind etc.), magnetic etc as well [1].

As for the most of the electronic devices require electrical power, especially DC power, there are many kinds of DC power supplies designed for different purposes. Most of these devices require not only DC voltage but voltage that is also well filtered and regulated.

There are three types of electronic power conversion devices which are classified as follows according to their input and output voltages: 1) DC/DC converter; 2) AC/DC power supply; 3) DC/AC inverter. Each has its own area of use but the first two are the most commonly used [2].

A power supply converting AC line voltage to DC power must perform the following functions at high efficiency and at low cost:

1. Rectification: Convert the incoming AC line voltage to DC voltage.

2. Voltage transformation: Supply the correct DC voltage level(s).

3. Filtering: Smooth the ripple of the rectified voltage.

4. Regulation: Control the output voltage level to a constant value irrespective of line, load and temperature changes.

5. Isolation: Separate electrically the output from the input voltage source.

6. Protection: Prevent damaging voltage surges from reaching the output; provide back-up power or shut down during a brown-out.

An ideal power supply would be characterized by supplying a smooth and constant output voltage regardless of variations in the voltage, load current or ambient temperature at 100% conversion efficiency.

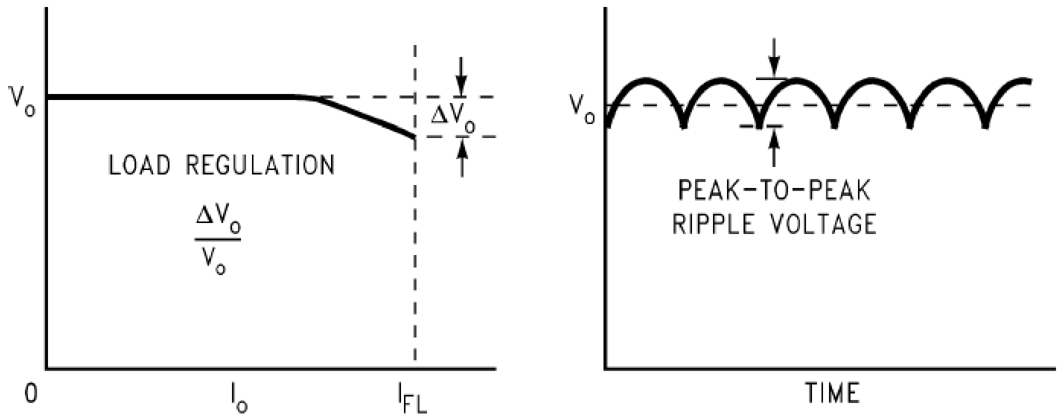


Figure 1.1. Power supply parameter definitions [3]

1.1. Linear Power Supplies

Linear power supplies are used in applications requiring extremely low noise, or in very low power applications where a simple transformer rectifier solution is adequate and provides the lowest cost. Examples are audio applications (low noise) and low power consumer applications, such as alarm panels (low cost) [3].

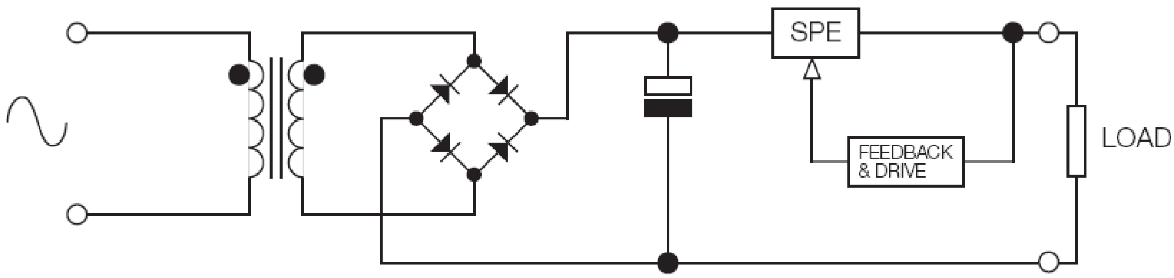


Figure 1.2. Basic linear power supply topology

The 50/60Hz mains transformer reduces the voltage to a usable low level, the secondary AC voltage is peak-rectified and a series pass element (SPE) is employed to provide the necessary regulation. The benefits of this solution are low noise, reliability and low cost. On the downside, these units are large, heavy and inefficient with a limited input voltage range.

1.2. Switch Mode Power Supplies

The use of switch mode topologies has reduced the size and improved the efficiency of power supplies by increasing the frequency of operation, reducing the physical size of transformers, inductors and capacitors, and utilizing an 'on or off' pulse width modulated (PWM) switching element to increase efficiency. The compromises in adopting this technique are increased ripple and noise on the output DC supply and the creation of both conducted and radiated EMI, which have to be managed.

1.2.1. The Isolated Fly-back Converter

Isolated fly-back converters are typically used in power converters up to 150W. The topology uses only one major magnetic component, which is a coupled inductor providing both energy storage and isolation. Energy transfer to the secondary and the load occurs during the switching element off-time.

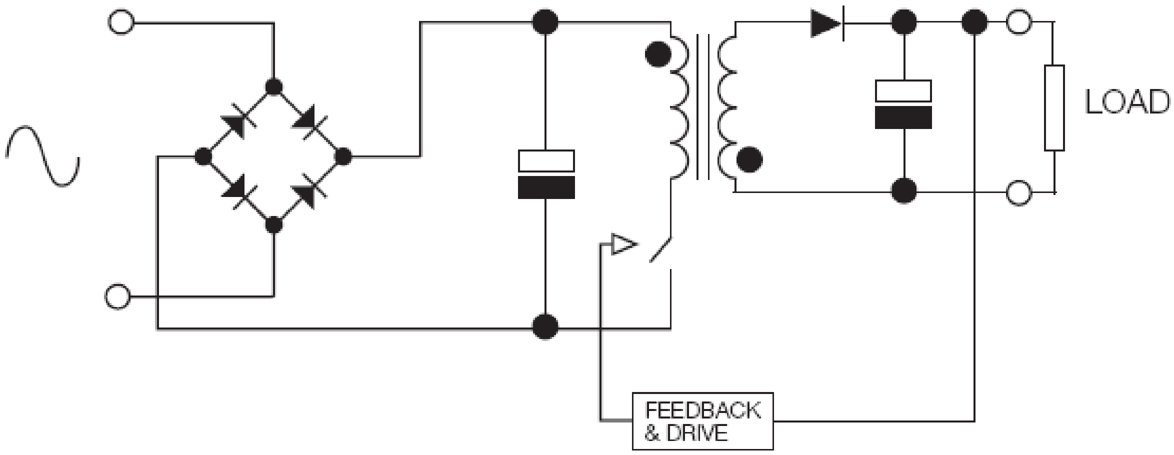


Figure 1.3. Flyback converter

1.2.2. Forward Converter

Forward converters are typically used in power supplies which operate in the range 100-300W. This topology uses two major magnetic components; a transformer and an output inductor. Energy transfer to the secondary and the load occurs during the switching element on-time. Forward converters are used in both AC power supplies and DC/DC converters.

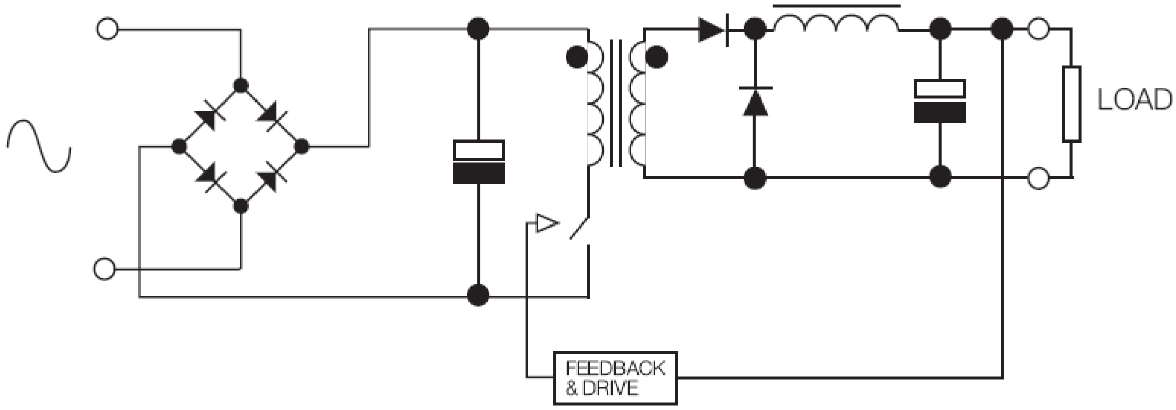


Figure 1.4. Forward converter

1.2.3. Boost Converter

Boost converters are used to step up the input voltage to produce a higher output voltage. They can be used to boost DC supplies but today are most commonly used in AC input power supplies above 100W, configured to provide active power factor correction (PFC). The following is the diagram of a standard boost converter.

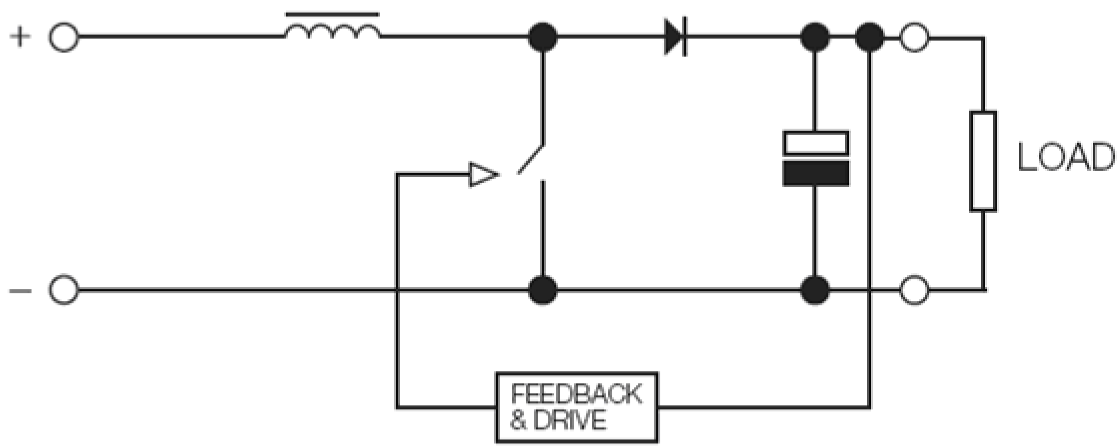


Figure 1.5. Boost converter

2. DESIGN METHODOLOGY

The design of the digital DC power supply has started with the decision of using either linear or switch mode topology. The selection ended with the linear type because of the proposal of wide output range (up to 30V and 5A).

The block diagram which was designed is explained in the next section.

The output voltage adjustment is realized by changing the value of the digital potentiometer as will be explained in details in the following sections.

2.1. Block Diagram Drawing

The block diagram was drawn to be as shown in Figure 2.1. Here the controller block consists of a microcontroller, a dual digital potentiometer, summing and amplifying operational amplifiers and additional auxiliary circuits.

The microcontroller is chosen to be ATMEGA16A, the keypad is a 4x4 one and the LCD is a 2x10 character type. PC interface is planned to be over USB or RS232. It is also used to measure the heatsink temperature.

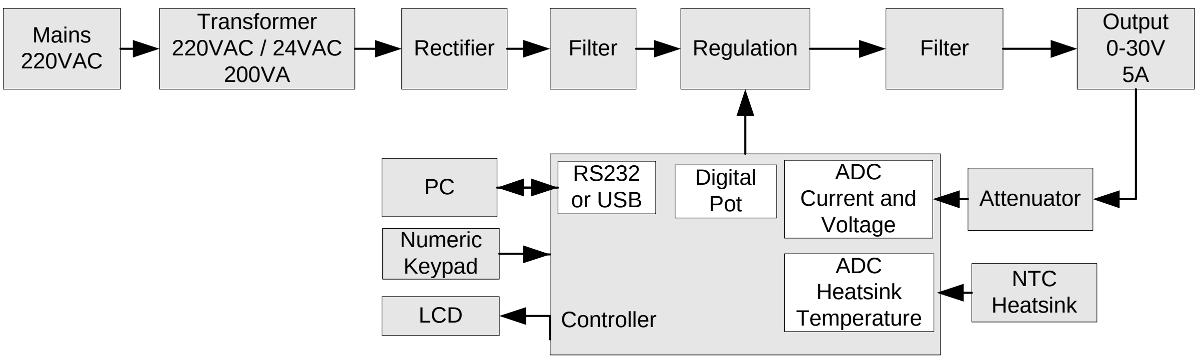


Figure 2.1. Block diagram of the power supply

2.2. Regulator Transistor Selection

The regulator transistors are chosen to be 4 x TIP142 NPN array. This transistor is a darlington type and has a minimum DC current gain of hFE = 1000 @ VCE = 4V, IC = 5A according to the Fairchild datasheet [4]. Four transistors are connected in parallel for load current sharing, which will be explained in next sections.

2.3. Paralleling Transistors for Current Sharing

Although Fairchild declares a maximum of 10A for the collector current IC, and a maximum of 4A for a VCE of 30V in the TIP142 datasheet; what must also be considered is the transistor power dissipation.

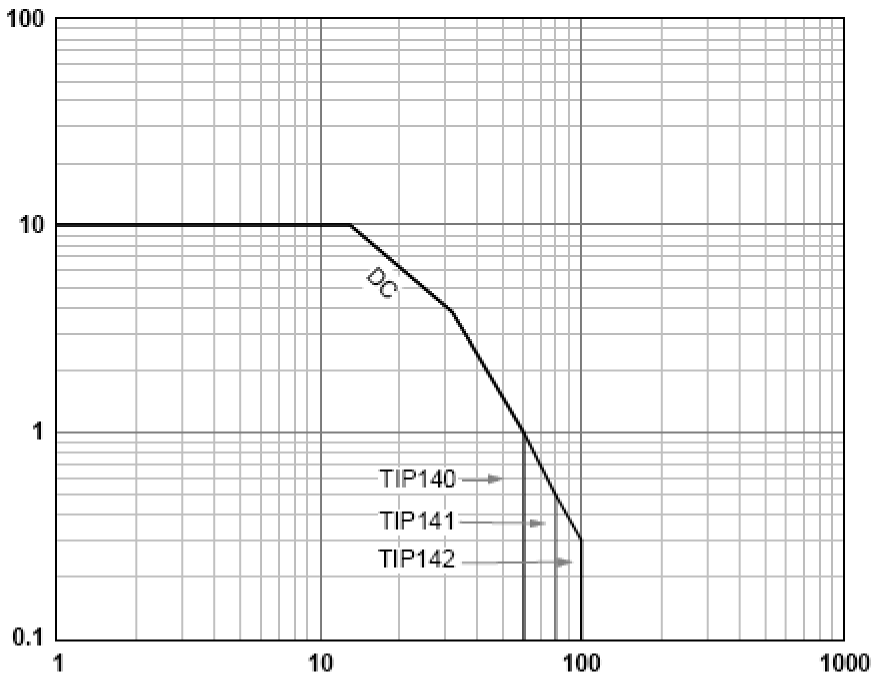


Figure 2.2. TIP142 safe operating area (V_{CE} vs. I_C) [4]

For a maximum V_{CE} of 30V, and a maximum output current of 5A, 150W power dissipation occurs; which is not allowed for TIP142. For safe operation, this dissipation is shared between 4 transistors.

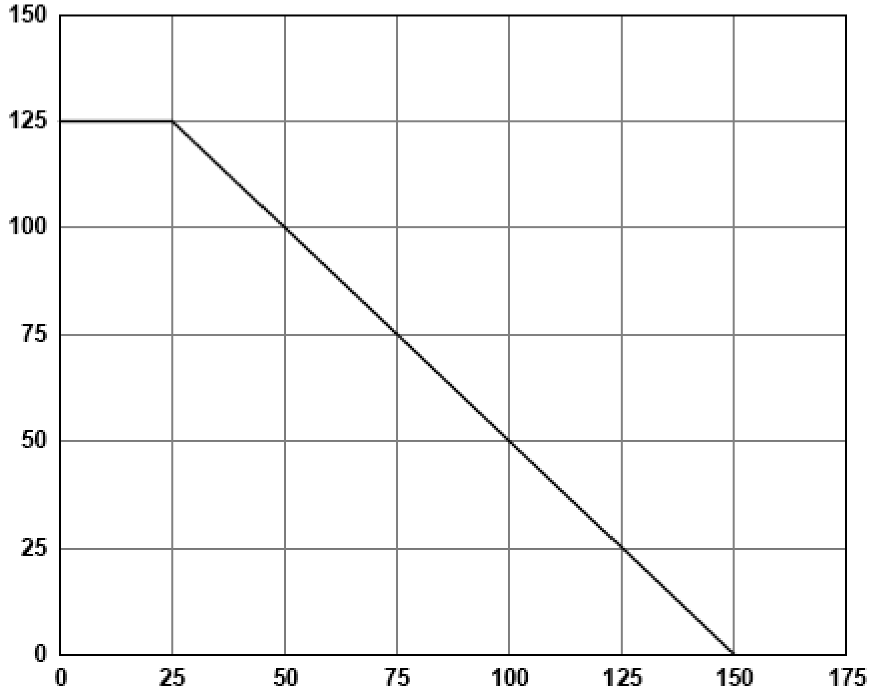


Figure 2.3. TIP142 power derating (T_C vs. P_C) [4]

2.4. Determination of the Emitter Resistance Values

In order to insure that the collector currents of the paralleled transistors are approximately equal, the configuration in Figure 2.4 is used. Emitter balancing resistors are used to force collector current sharing between the transistors [5].

The collector current mismatch can be determined by considering following equations (these calculations are made for two transistors in parallel):

$$V_{BE1} + V_1 = V_{BE2} + V_2 \quad (2.1)$$

$$\Delta V_{BE} = \Delta V \quad (2.2)$$

$$V_{BE} = V_{BE1} - V_{BE2} \quad (2.3)$$

$$\Delta V = V_2 - V_1 \quad (2.4)$$

Assuming

$$I_{E1} \cong I_{C1} \tag{2.5}$$

and

$$I_{E2} \cong I_{C2} \tag{2.6}$$

the collector current mismatch is equal to:

$$\frac{I_{C2} - I_{C1}}{I_{C2}} = \frac{\frac{V_2}{R_E} - \frac{V_1}{R_E}}{\frac{V_2}{R_E}} = \frac{V_2 - V_1}{V_2} = \frac{\Delta V}{V_2} = \frac{\Delta V_{BE}}{V_2} \tag{2.7}$$

And percent collector current mismatch is

$$\%Mismatch = \frac{\Delta V_{BE}}{V_2} x100\% \tag{2.8}$$

ΔVBE is usually small; V_2 should be 1.0V to 0.5V. So R_E may be calculated as

$$R_E = \frac{0.5V \rightarrow 1.0V}{I_{C1}} = \frac{0.5V \rightarrow 1.0V}{I_{C2}} = \frac{0.5V \rightarrow 1.0V}{I_C/2} \tag{2.9}$$

For 4 transistors in parallel;

$$R_E = \frac{0.5V \rightarrow 1.0V}{I_C/4} \tag{2.10}$$

Since the power supply output current rating is proposed to be 5A,

$$R_E = \frac{0.5V \rightarrow 1.0V}{5/4} = 0{,}4\Omega \rightarrow 0{,}8\Omega \qquad (2.11)$$

The emitter resistors are chosen to be 0,47R / 2W.

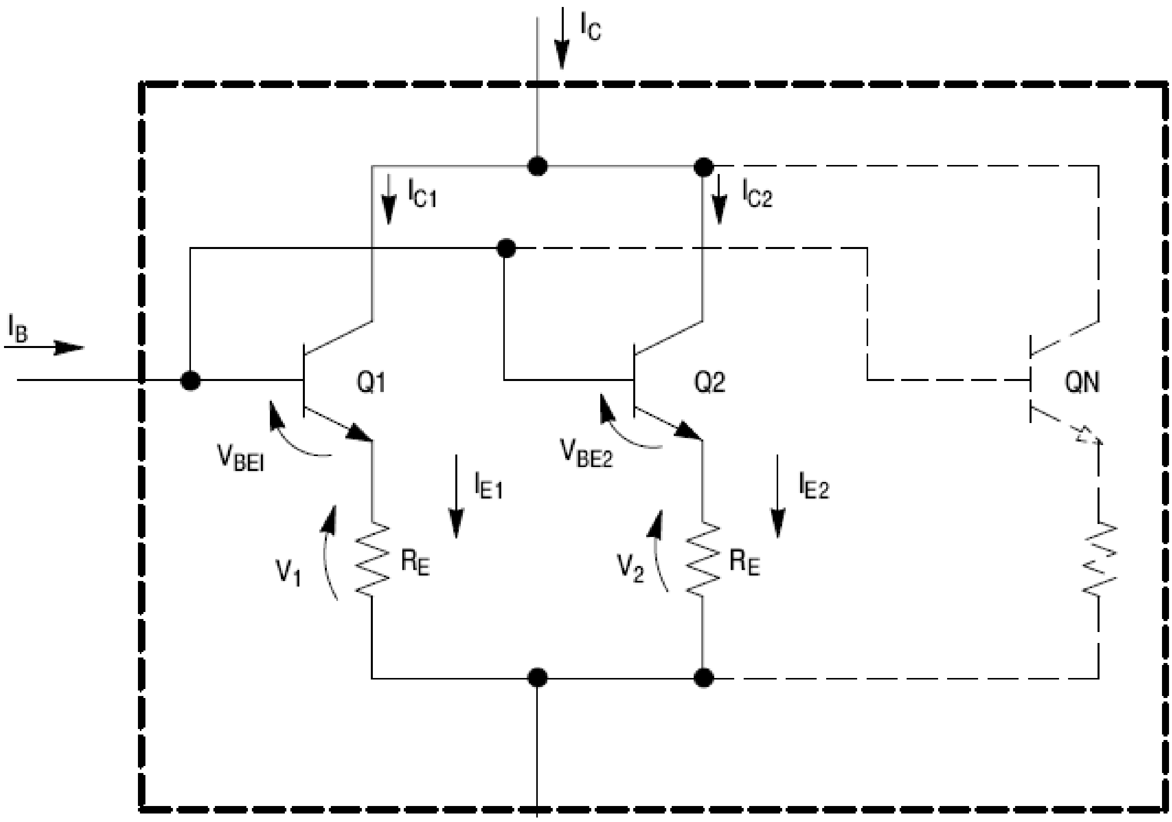


Figure 2.4. Paralleling transistors [5]

2.4.1. The User Interface

The user interface is proposed to be simple. So a 4x4 keypad and a 2x20 LCD are considered to be sufficient. The LCD is an easy to read, white over blue negative type [6].

A buzzer has been used to make hearable warnings. For the computer interface, a USB/RS232 connector is placed on the power supply.

2.4.2. The Overall Control Unit of the Power Supply

The schematic of the control unit of the power supply is as shown in Figure 2.5.

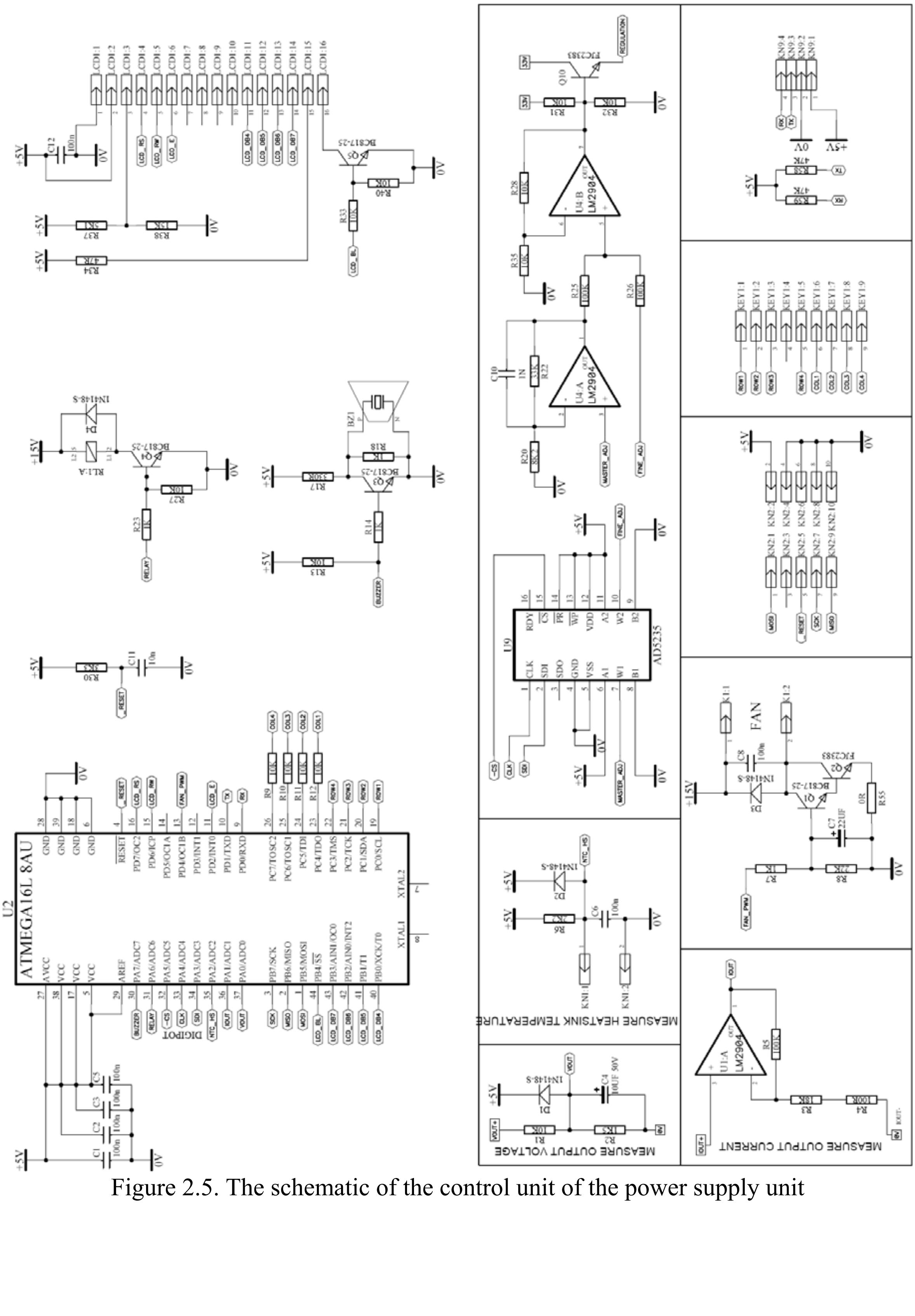


Figure 2.5. The schematic of the control unit of the power supply unit

2.4.1. The Overall Power Unit of the Power Supply

The schematic of the power unit of the power supply is as shown in Figure 2.6.

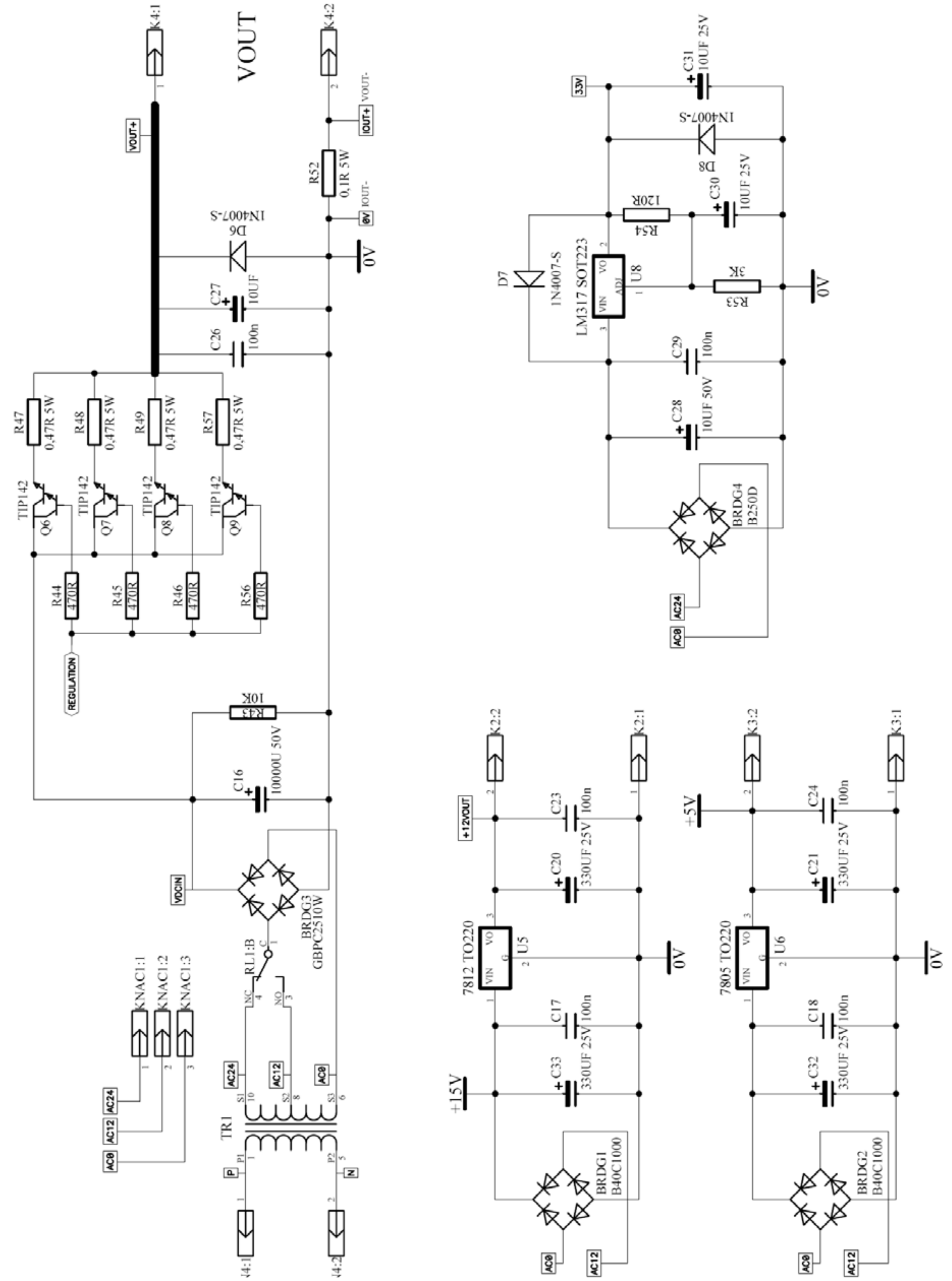


Figure 2.6. The schematic of the power unit of the power supply unit

2.4.2. Measuring the Output Voltage

The output voltage is simply attenuated by a voltage divider resistor network and fed into the microcontrollers ADC input. The ADC of the microcontroller is 10 bit so a resolution of 1024 steps is available. So the system is able to measure the output voltage in 30V / 1024 = 29,3mV resolution.

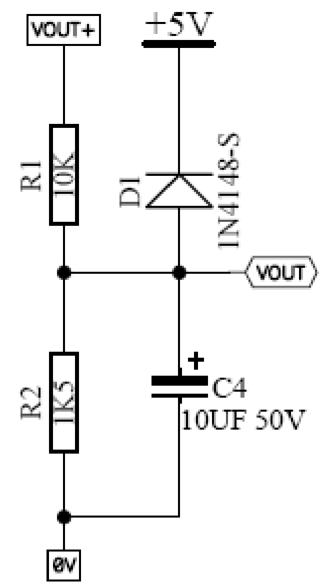


Figure 2.7. Output voltage measurement circuit

The output voltage is divided by this voltage divider resistor network as:

$$V_{OUT} = \frac{R_2}{R_2 + R_1} V_{OUT+} = \frac{1K5}{1K5 + 10K} V_{OUT+} = 0{,}13 * V_{OUT+} \qquad (2.12)$$

So for a maximum of 30V output voltage, the ADC input will have:

$$V_{OUT} = 0{,}13 * 30 = 3{,}9V \qquad (2.13)$$

The microcontroller code calculates and makes the necessary transformations on the measured ADC value to find the real output voltage.

Table 1 gives some of the generic ADC steps and corresponding voltage values. It is seen from this table that ADC steps above 800 are not usable for this design. But it is possible to change the voltage divider resistor values.

Table 2.1. Some generic ADC steps and corresponding voltages

ADC Step	Voltage	ADC Step	Voltage	ADC Step	Voltage	ADC Step	Voltage	ADC Step	Voltage
0	0,0000	10	0,0489	400	1,9550	850	4,1544	1015	4,9609
1	0,0049	20	0,0978	450	2,1994	900	4,3988	1016	4,9658
2	0,0098	30	0,1466	500	2,4438	920	4,4966	1017	4,9707
3	0,0147	50	0,2444	550	2,6882	950	4,6432	1018	4,9756
4	0,0196	100	0,4888	600	2,9326	1000	4,8876	1019	4,9804
5	0,0244	150	0,7331	650	3,1769	1010	4,9365	1020	4,9853
6	0,0293	200	0,9775	700	3,4213	1011	4,9413	1021	4,9902
7	0,0342	250	1,2219	750	3,6657	1012	4,9462	1022	4,9951
8	0,0391	300	1,4663	789	3,8563	1013	4,9511	1023	5,0000
9	0,0440	350	1,7107	800	3,9101	1014	4,9560		

Table 2.2. Corresponding output voltages to ADC steps of Table 1

ADC Step	Voltage	ADC Step	Voltage	ADC Step	Voltage	ADC Step	Voltage	ADC Step	Voltage
0	0,0000	10	0,3760	400	15,0387	850	31,9573	1015	38,1608
1	0,0376	20	0,7519	450	16,9186	900	33,8371	1016	38,1984
2	0,0752	30	1,1279	500	18,7984	920	34,5891	1017	38,2360
3	0,1128	50	1,8798	550	20,6782	950	35,7170	1018	38,2736
4	0,1504	100	3,7597	600	22,5581	1000	37,5968	1019	38,3112
5	0,1880	150	5,6395	650	24,4379	1010	37,9728	1020	38,3487
6	0,2256	200	7,5194	700	26,3178	1011	38,0104	1021	38,3863
7	0,2632	250	9,3992	750	28,1976	1012	38,0480	1022	38,4239
8	0,3008	300	11,2790	789	29,6639	1013	38,0856	1023	38,4615
9	0,3384	350	13,1589	800	30,0774	1014	38,1232		

Table 2 shows the real output voltage values for some ADC steps. It is more obviously seen from this table that steps above 800 are not usable.

2.4.3. Measuring the Output Current

The output current is measured by series shunt resistor method. A 100mΩ resistor is connected in series with the return path of the output and the voltage on it is measured.

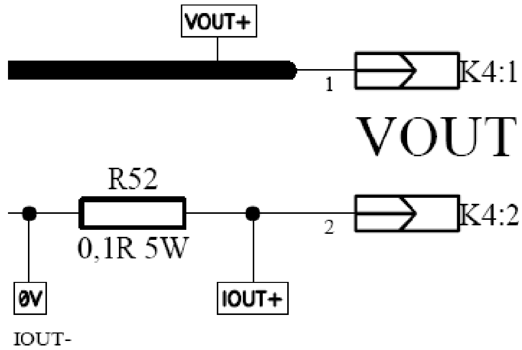


Figure 2.8. Output current shunt resistor

This voltage gives the output current with below relations:

$$V_{RSHUNT} = R_{SHUNT} * I_{OUT} = 0{,}1 * I_{OUT} \quad (2.14)$$

According to the proposed maximum output current, the maximum value for this voltage is 0,1Ω * 5A = 0,5V (In fact, as the design is made suitable to use up to 6A, it is 0,6V).

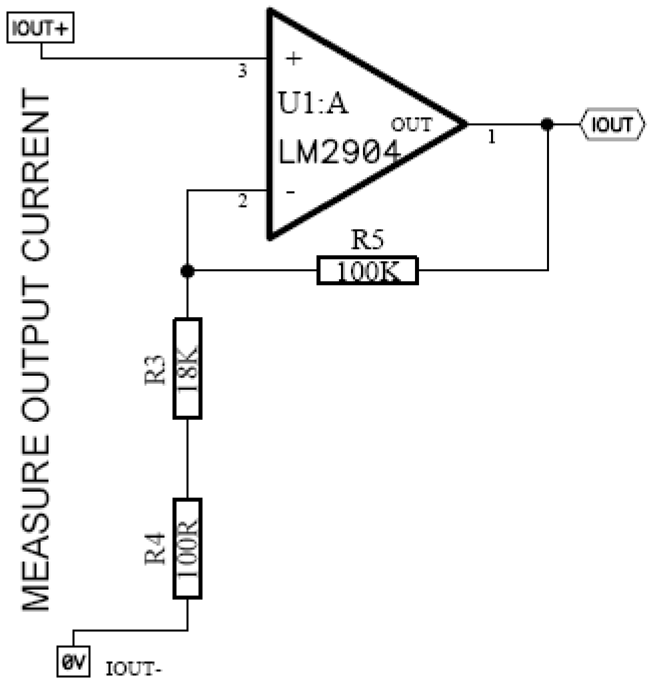


Figure 2.9. Output current measurement circuit

This voltage is amplified with an opamp as shown in Figure 2.9 before being fed into the ADC of the microcontroller. The node I_{OUT-} is in fact the circuit ground (0V). I_{OUT+} is the node of the positive reference side of the shunt resistor.

So the voltage at the output of U1:A opamp, which is at the ADC input of the microcontroller, is equal to:

$$V_{IOUT} = \frac{R3 + R4 + R5}{R3 + R4} V_{RSHUNT} = \frac{100 + 18K + 100K}{100 + 18K} V_{RSHUNT} \cong 6{,}525 * V_{RSHUNT} \quad (2.15)$$

For example, for the output current of 5A,

$$V_{RSHUNT} = 0{,}1\Omega * 5A = 0{,}5V \quad (2.16)$$

$$V_{IOUT} \cong 6{,}525 * 0{,}5 = 3{,}263V \quad (2.17)$$

On the other hand, for the output current of 6A,

$$V_{IOUT} \cong 6{,}525 * 0{,}6 = 3{,}915V \quad (2.18)$$

Table 3 gives the current measurement ADC input of the microcontroller and corresponding ADC values according to the incoming voltage.

Table 2.3. Some generic ADC steps and corresponding output voltages of the opamp

ADC Step	**Voltage**	**ADC Step**	**Voltage**	**ADC Step**	**Voltage**	**ADC Step**	**Voltage**	**ADC Step**	**Voltage**
0	0,0000	10	0,0489	400	1,9550	850	4,1544	1015	4,9609
1	0,0049	20	0,0978	450	2,1994	900	4,3988	1016	4,9658
2	0,0098	30	0,1466	500	2,4438	920	4,4966	1017	4,9707
3	0,0147	50	0,2444	550	2,6882	950	4,6432	1018	4,9756
4	0,0196	100	0,4888	600	2,9326	1000	4,8876	1019	4,9804
5	0,0244	150	0,7331	650	3,1769	1010	4,9365	1020	4,9853
6	0,0293	200	0,9775	700	3,4213	1011	4,9413	1021	4,9902
7	0,0342	250	1,2219	750	3,6657	1012	4,9462	1022	4,9951
8	0,0391	300	1,4663	789	3,8563	1013	4,9511	1023	5,0000
9	0,0440	350	1,7107	800	3,9101	1014	4,9560		

According to this table it can be seen that, the ADC value for 5A is between 650 and 700 (the actual value being equal to 667) and that for 6A is between 800 and 850 (the actual value being equal to 801). These ADC values can be calculated by preparing a full table containing all the ADC steps and corresponding voltages, not given here.

2.4.4. Measuring the Heatsink Temperature

The temperature of the heatsink that the current carrying transistors are connected is measured with an NTC circuit. Monitoring the transistors' junction temperatures is necessary because, in case of exceeding some specific value (150°C for TIP142), they are damaged, necessitating a preventive action to be taken.

The schematic for measuring the heatsink temperature is given in figure 2.10. The NTC and R6 together form a voltage divider network. The KN1 is connected to an EPCOS NTC with part number B57703M0103. This NTC has the value of 10KΩ at 25°C [7].

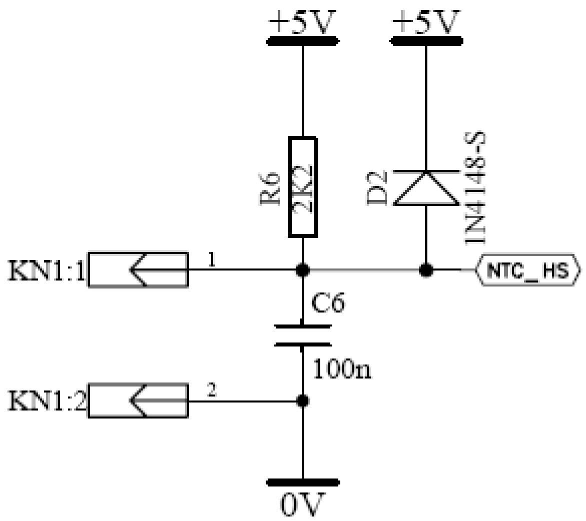


Figure 2.10. Heatsink temperature measurement circuit

For an NTC, the resistance depends on temperature according to formula [8]:

$$R_T = R_R * e^{B\left(\frac{1}{T} - \frac{1}{T_R}\right)} \quad (2.19)$$

Where,

R_T: The resistance of NTC in Ω at temperature T in K°.

R_R: The resistance of NTC in Ω at rated temperature T in K° (10KΩ for T=25°C).

T: Temperature in K°.

T_R: Rated temperature in K°.

B: B value, material-specific constant of NTC thermistor.

$$T = \frac{1}{\frac{1}{B}\ln(\frac{R_T}{R_R}) + \frac{1}{T_R}} \tag{2.20}$$

For the NTC B57703M0103,

$$R_R = 10000 \ \Omega \tag{2.21}$$

$$T_R = 273 + 25 = 298 \ ^{\circ}K \tag{2.22}$$

$$B = 3988 \tag{2.23}$$

So if R_T is measured or calculated, T can also be calculated by using the above formula and then converted to Celsius using (2.24).

$$T_C = \frac{1}{\frac{1}{B}\ln(\frac{R_T}{R_R}) + \frac{1}{T_R + 273}} - 273 \tag{2.24}$$

The ADC input of the microcontroller is fed with the voltage which is set by the value of the NTC and the series resistor R6.

$$V_{ADC\ (NTC)} = V_{CC} * \frac{R_{NTC}}{R_{NTC} + R_6} \tag{2.25}$$

The microcontroller receives this ADC value and calculates the voltage accordingly. From this voltage value, the value of R_{NTC} is calculated by the following formula:

$$R_{NTC} = R_6 * \frac{V_{CC}}{V_{CC} - V_{ADC\ (NTC)}} \tag{2.26}$$

V_{CC}, which the microcontroller supply voltage, is equal to 5V and R_6 is selected to be 2,2KΩ. After calculating this R_{NTC} value, the temperature of the NTC and hence the temperature of the heatsink are calculated according to the above formula.

Table 2.4. The voltages on the NTC and corresponding ADC values and temperatures

T (°C)	R6	R_NTC	VADC	ADC	T (°C)	R6	R_NTC	VADC	ADC	T (°C)	R6	R_NTC	VADC	ADC
-55	2200	963050	4,9886	1021	**25**	**2200**	**10000**	**4,0984**	**839**	77,5	2200	1370	1,9183	392
-50	2200	670100	4,9836	1020	27,5	2200	9029	4,0204	823	80	2200	1258	1,8190	372
-45	2200	471690	4,9768	1018	30	2200	8057	3,9276	804	82,5	2200	1165	1,7311	354
-40	2200	336500	4,9675	1016	32,5	2200	7294	3,8414	786	**85**	**2200**	**1072**	**1,6381**	**335**
-35	2200	242590	4,9551	1014	35	2200	6531	3,7401	765	87,5	2200	995	1,5570	319
-30	2200	177000	4,9386	1010	37,5	2200	5929	3,6468	746	90	2200	918	1,4718	301
-25	2200	130370	4,9170	1006	40	2200	5327	3,5386	724	92,5	2200	853	1,3971	286
-20	2200	97070	4,8892	1000	42,5	2200	4848	3,4393	704	95	2200	789	1,3192	270
-15	2200	72929	4,8536	993	45	2200	4369	3,3255	680	97,5	2200	734	1,2512	256
-10	2200	55330	4,8088	984	47,5	2200	3986	3,2218	659	**100**	**2200**	**680**	**1,1806**	**242**
-5	2200	42315	4,7529	972	**50**	**2200**	**3603**	**3,1044**	**635**	102,5	2200	634	1,1190	229
0	**2200**	**32650**	**4,6844**	**958**	52,5	2200	3295	2,9980	613	105	2200	589	1,0554	216
2,5	2200	29019	4,6477	951	55	2200	2986	2,8789	589	107,5	2200	550	0,9999	205
5	2200	25388	4,6013	941	57,5	2200	2737	2,7719	567	110	2200	511	0,9428	193
7,5	2200	22644	4,5572	932	60	2200	2488	2,6536	543	112,5	2200	478	0,8929	183
10	2200	19900	4,5023	921	62,5	2200	2286	2,5477	521	115	2200	445	0,8418	172
12,5	2200	17804	4,4501	910	65	2200	2083	2,4317	498	117,5	2200	417	0,7973	163
15	2200	15708	4,3857	897	67,5	2200	1918	2,3285	476	120	2200	389	0,7517	154
17,5	2200	14099	4,3251	885	70	2200	1752	2,2166	454	122,5	2200	366	0,7123	146
20	2200	12490	4,2512	870	72,5	2200	1617	2,1178	433	**125**	**2200**	**342**	**0,6722**	**138**
22,5	2200	11245	4,1819	856	**75**	**2200**	**1481**	**2,0117**	**412**					

Also the datasheet of the NTC gives a nominal resistance values table in the temperature range between -55°C to +125°C. Using this table and the selected resistor value of 2,2K, Table 4 is obtained.

2.4.5. Setting (Regulating) the Output Voltage

The user enters the desired output voltage data, using the 4x4 keypad. The microcontroller sets the dual digital potentiometer values according to the following explanation. There is a 1024 position nonvolatile dual digital potentiometer. Each of these potentiometers is used as a voltage divider, dividing the 5V supply. One of the digital potentiometers is used as a master adjust, the other one as a fine adjust.

The master adjust output is fed into a noninverting operational amplifier circuit with a gain of approximately 5. The fine adjust output is added to this amplified voltage by the use of a summing operational amplifier configuration. The output voltage of the power supply is equal to this voltage minus the VBE voltages of the following transistors. The microcontroller compares the measured output voltage with the set value, and according to the difference, sets these two digital potentiometers until the difference becomes smaller than some specific value. For example if the output voltage is set to be 12,4V; the microcontroller may set the MASTER_ADJ potentiometer voltage to have 2V and the FINE_ADJ potentiometer to have 2,4V at the center terminals.

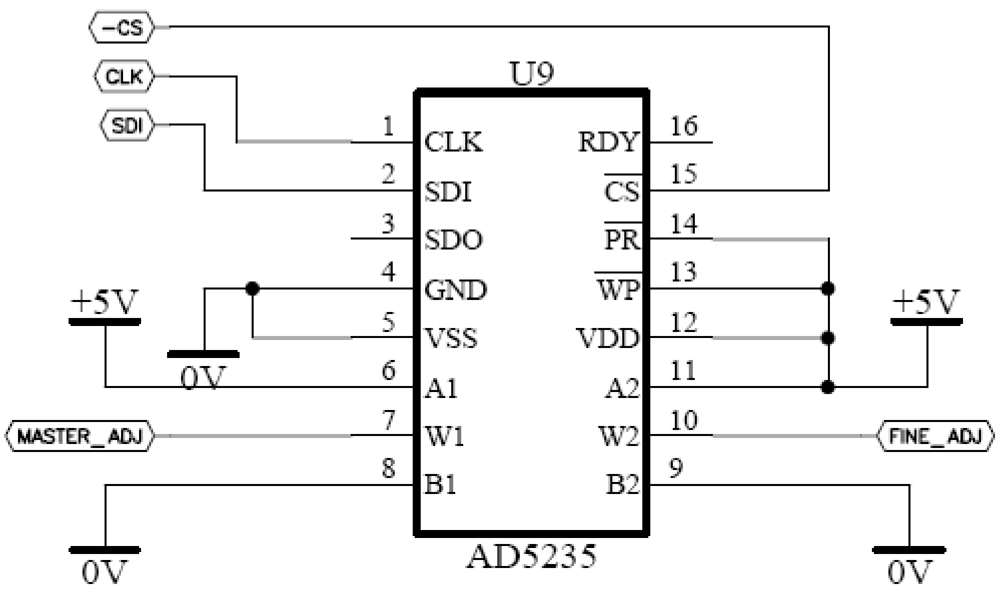


Figure 2.11. AD5235 dual digital potentiometer connections

The advantage of this configuration is that, the resolution is equal to 5V divided by the number of positions of the potentiometer, namely 1024. The regulation is accomplished by continuously measuring the output voltage and adjusting this dual potentiometer according to the difference with the set value. So if for any reason such as load change, temperature change, line voltage change etc.; the output voltage deviates from the set value (in positive or negative direction), it is immediately tried to be brought back to the original set value by using this method.

As explained above, in the circuit given in Figure 2.12, the MASTER_ADJ voltage is multiplied by 5 (U4:A operates as a noninverting amplifier) and then summed with the FINE_ADJ value (U4:B operates as a summing amplifier).

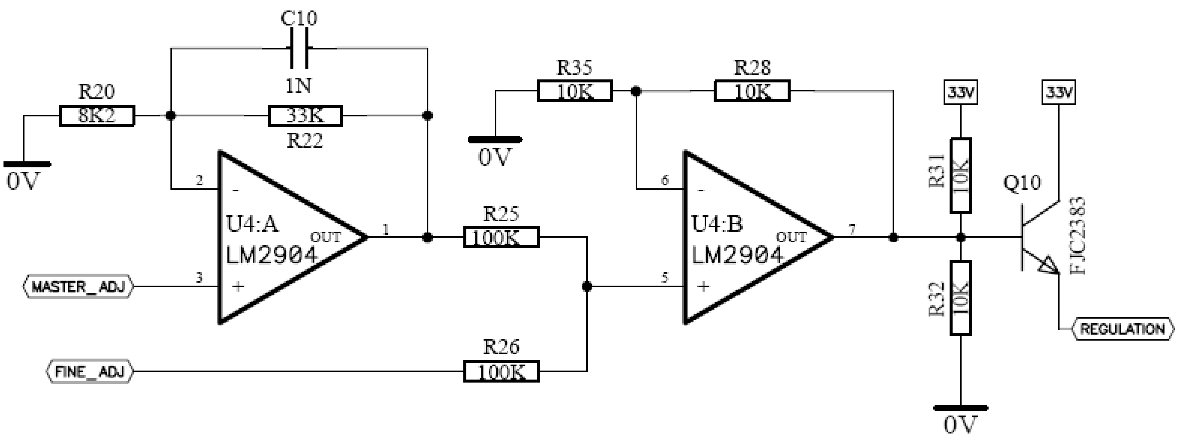


Figure 2.12. The voltage setting block

Q10 is just used for buffering the opamp output to the output transistors' bases.

So the output voltage at the 7th pin of the opamp is equal to:

$$V_{OP\,7} = V_F + V_M * \left(\frac{R_{20} + R_{22}}{R_{20}} \right) \tag{2.27}$$

where $V_F = V_{FINE\_ADJ}$ and $V_M = V_{MASTER\_ADJ}$

With the selected resistor values this voltage becomes approximately equal to:

$$V_{OP7} = V_F + V_M * \left(\frac{8,2K + 33K}{8,2K} \right) \cong V_F + 5 * V_M \qquad (2.28)$$

2.5. Microcontroller Decision and Connections

For the microcontroller, it was necessary to provide 8 pins for the keypad, 8 pins for the LCD, 3 analog channels for the ADC measurement of the output voltage and current and the heatsink temperature, 3 outputs for driving the digital potentiometer, 1 pin for the buzzer, 1 pin for the fan, RX and TX pins for the computer interface, and also the necessary programming pins. ATMEGA16A was a capable microcontroller for all these I/O pins.

The ATMEGA16A is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATMEGA16A achieves throughputs approaching 1 MIPS per MHz [9].

The ATMEGA16A provides the following features: 16K bytes of In-System Programmable Flash Program memory with Read-While-Write capabilities, 512 bytes EEPROM, 1K byte SRAM, 32 general purpose I/O lines, 32 general purpose working registers, a JTAG interface for Boundary-scan, On-chip Debugging support and programming, three flexible Timer/Counters with compare modes, Internal and External Interrupts, a serial programmable USART, a byte oriented Two-wire Serial Interface, an 8-channel, 10-bit ADC with optional differential input stage with programmable gain (TQFP package only), a programmable Watchdog Timer with Internal Oscillator, an SPI serial port, and six software selectable power saving modes.

The connections of the microcontroller are shown in Figure 2.13. PortA is used for reading ADC values of output voltage, output current and the NTC voltage for the temperature of the heatsink calculation. Also buzzer, relay and digital potentiometer drives are activated through this port. PortB is used for LCD data bits and programming. PortC is connected to the keypad interface. PortD is used for LCD control, computer interface and fan drive.

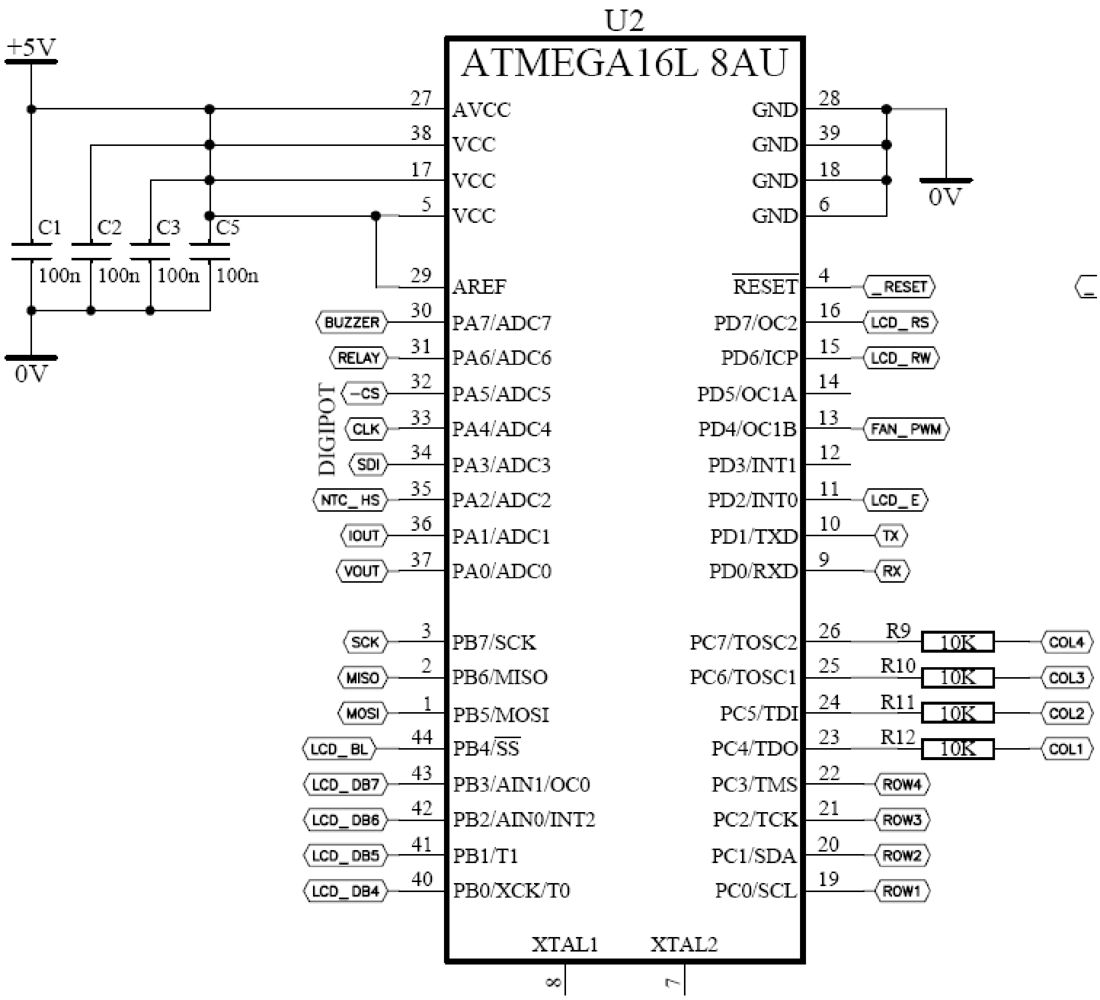


Figure 2.13. The microcontroller connections

2.6. Keypad Interface

A 4x4 keypad is used for data entering and managing the power supply. It has 4 rows and 4 columns, so 8 pins of the microcontroller were necessary.

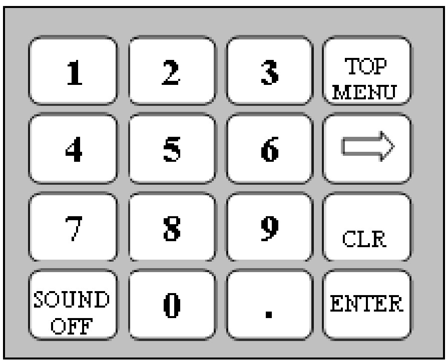


Figure 2.14. The 4x4 keypad and functions

Microcontroller continuously sends signals from the columns and reads for any returns from the rows. If for example after sending a high signal from the 3rd column, a high is read from the 2nd row, then this means that the key “6” is pressed.

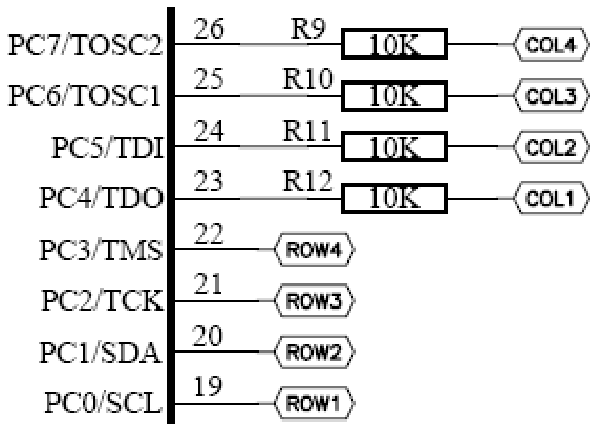


Figure 2.15. The keypad connections to the microcontroller

2.7. Computer Interface

The power supply is proposed to have a computer control interface. The hardware schematic is shown in Figure 2.16. Also a USB to serial port converter module has been used to connect the power supply directly from the USB port from the computer. That module makes the computer “see” the USB port as a serial communication port.

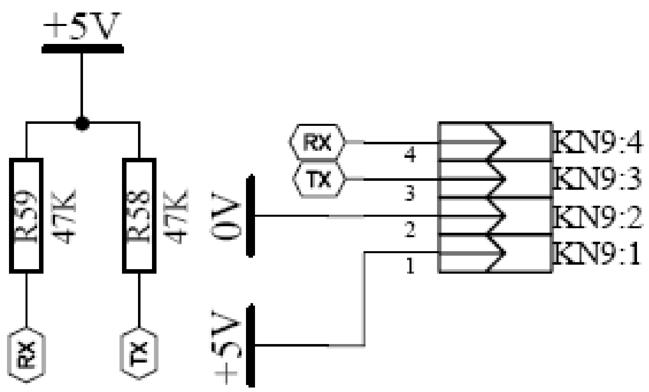


Figure 2.16. The communication connections with the microcontroller

2.8. LCD Interface

The LCD was selected to be a 2x20 character LCD, so that it is easy to show both the output voltage and current at the same time. The connections are as shown in Figure 2.17.

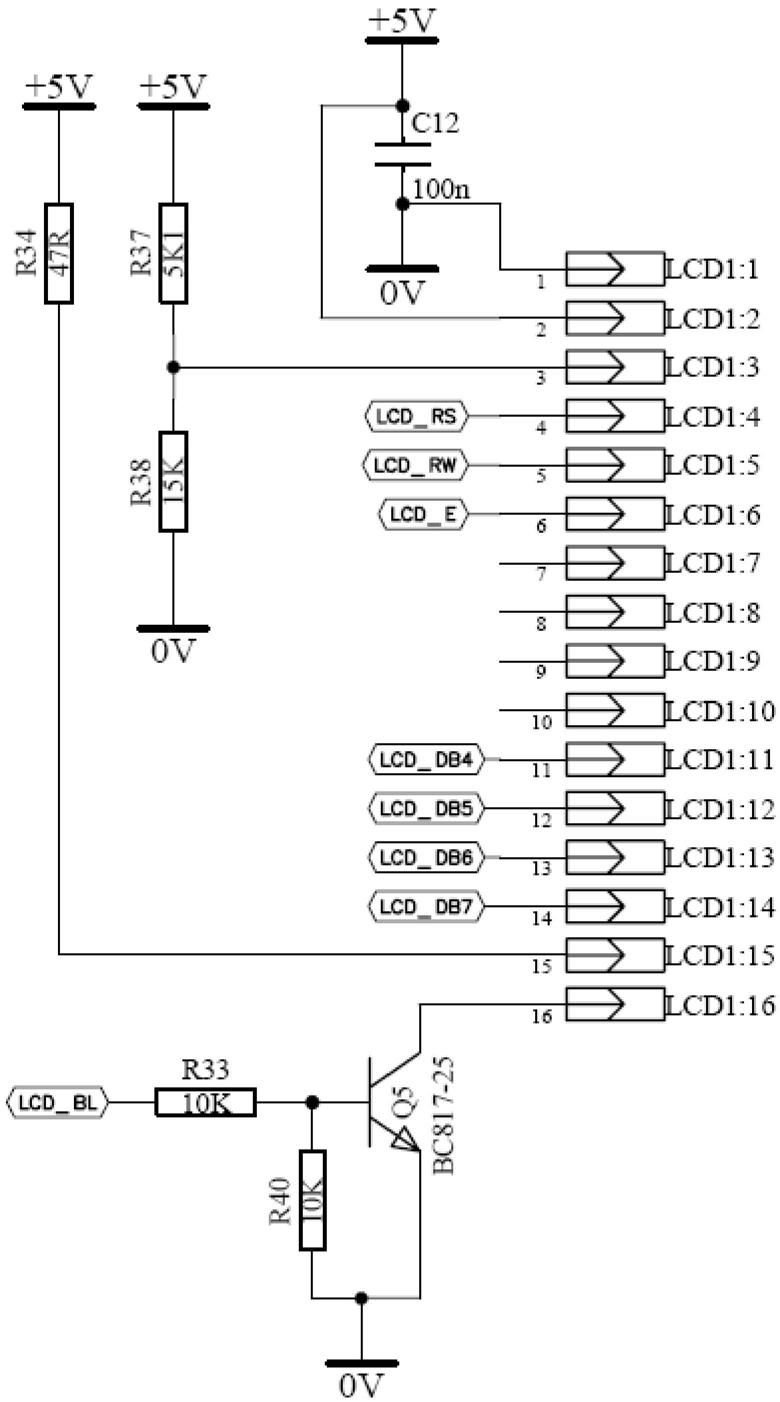


Figure 2.17. The LCD connections

2.9. Microcontroller Programming

For the programming of the microcontroller, standard ATMEL ISP10 connector structure is used. The connections are as shown in Figure 2.18.

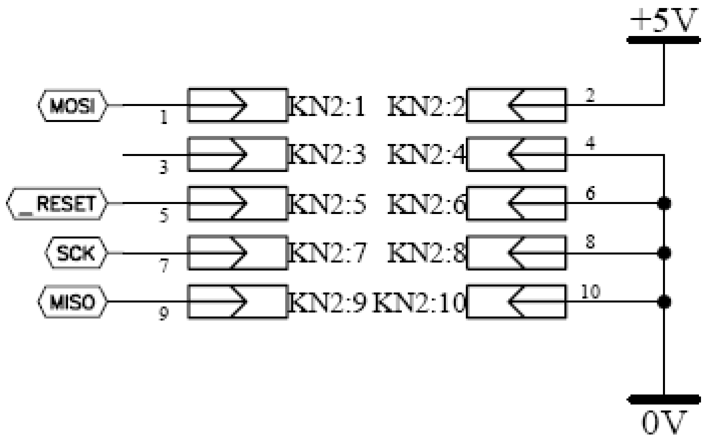


Figure 2.18. The ISP10 programming connector

2.10. Buzzer Circuit

The buzzer circuit is depicted in Figure 2.19. In this configuration, the microcontroller BUZZER output must be high to turn the buzzer on.

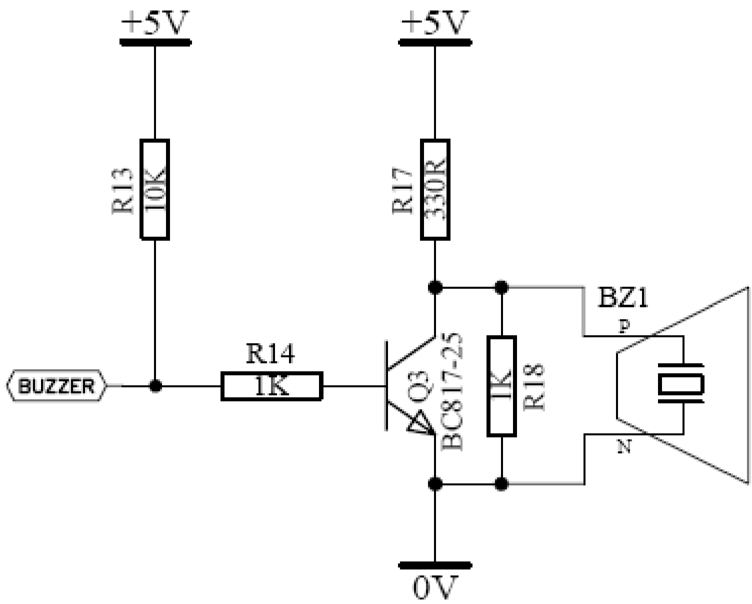


Figure 2.19. The Buzzer Circuit

2.11. Thermal (Heatsink) Considerations

The output voltage is proposed to be adjustable between 0-30V. As can be seen from the below schematic, the output of the transformer is rectified with a bridge rectifier and then filtered with an electrolytic capacitor.

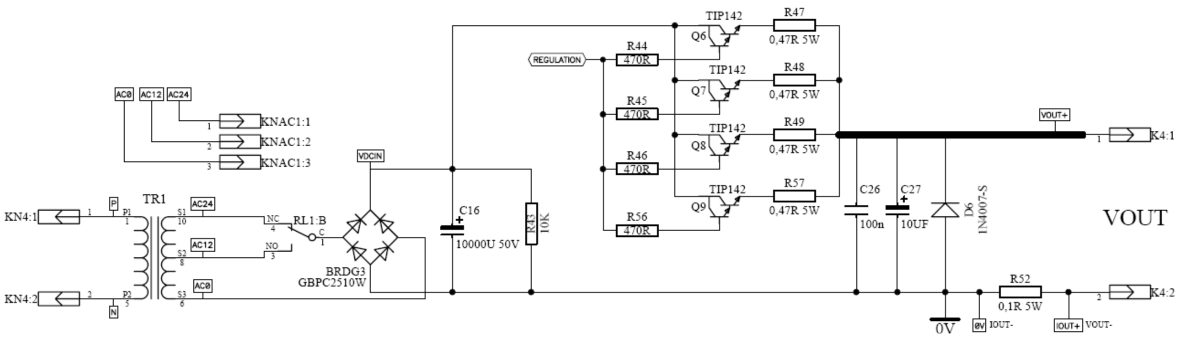


Figure 2.20. The power regulation part of the design

The voltage across this capacitor is approximately (assuming a forward voltage drop of 1V per diode of the bridge rectifier):

$$V_{C16} = V_{AC} * \sqrt{2} - 2 * V_D = 24 * \sqrt{2} - 2 * 1 = 31{,}94\,V \qquad (2.29)$$

The voltage across the power transistors collector – emitters are equal to:

$$V_{CE} = V_{C16} - V_{OUT} - (R_{47} * I_{OUT}) / 4 \qquad (2.30)$$

Ignoring the last term (because it is maximally equal to 0,47 x 5 / 4 = 0,5875V), and considering the worst case when V_{OUT} is set to 0V, we have $V_{CE} \cong V_{C16}$.

This means a power dissipation of totally

$$P_{TOTAL} = V_{CE} * I_{OUT} = 31{,}94 * 5 = 159{,}7W \qquad (2.31)$$

For safe operation, this dissipation is shared between 4 transistors as explained in previous sections (39,925 W per transistor at worst case).

Some additional action is taken to further reduce the power dissipation per transistor. As can be seen from the schematic, the transformer has 3 taps; namely AC0, AC12 and AC24. So when the output voltage is set below 13V, the AC12 terminal is used instead of AC24. This is accomplished by switching a relay through the microcontroller control when the user enters a voltage less then 13V. The power dissipations then become:

$$V_{C16} = 12 * \sqrt{2} - 2 = 14,97\,V \qquad (2.32)$$

$$P_{TOTAL} = V_{CE} * I_{OUT} = 14,97 * 5 = 74,85\,W \qquad (2.33)$$

In this case, the dissipation per transistor is reduced to 74,85 / 4 = 18,71W.

There is also a fan attached to the heatsink of these power transistors, which normally is off. This fan is turned on when the temperature measurement made by the microcontroller by using the NTC exceeds some specified value (50°C).

As explained before, for TIP142 transistors, Tjmax = 150°C. Power dissipation per transistor was previously calculated to be 18,71W at worst case.

For this power supply, it is assumed that the maximum working ambient temperature is Tamb = 50°C.

Combining the above, the necessary total thermal resistance from one transistor's junction to ambient is calculated as:

$$R_{th1(j-a)} = \frac{Tj\max - Tamb}{Pd} = \frac{150 - 50}{18,71} = 5,34\,(°C/W) \qquad (2.34)$$

Using the TIP142 datasheet, thermal resistance for the TO-3P package transistor is given as $R_{th1(j-c)}$ = 1 °C/W. Since $R_{th1(j-a)}$ is equal to:

$$R_{th1(j-a)} = R_{th1(j-c)} + R_{th1(c-hs)} + R_{th1(hs-a)} \quad (2.35)$$

Assuming $R_{th1(c-hs)} = 0{,}5$ °C/W;

$$R_{th1(hs-a)} = 5{,}34 - 0{,}5 - 1 = 3{,}84\ (°C/W) \quad (2.36)$$

Because the same heatsink is used for 4 transistors, the necessary thermal resistance for the overall heatsink is calculated to be

$$R_{th4(hs-a)} = 3{,}84 / 4 = 0{,}96\ (°C/W) \quad (2.37)$$

By using the demo software, "Hsink" from Frigus Primore, the thermal simulations are realized [10]. The four transistors' TO-3P packages and their placements on the heatsink were defined to this program as in Figure 2.21 (the same as in the real application). Each transistor is defined as a heat source. Also the power dissipation on each transistor is entered to be 18,7W (which is the maximum calculated) to the dissipation cells.

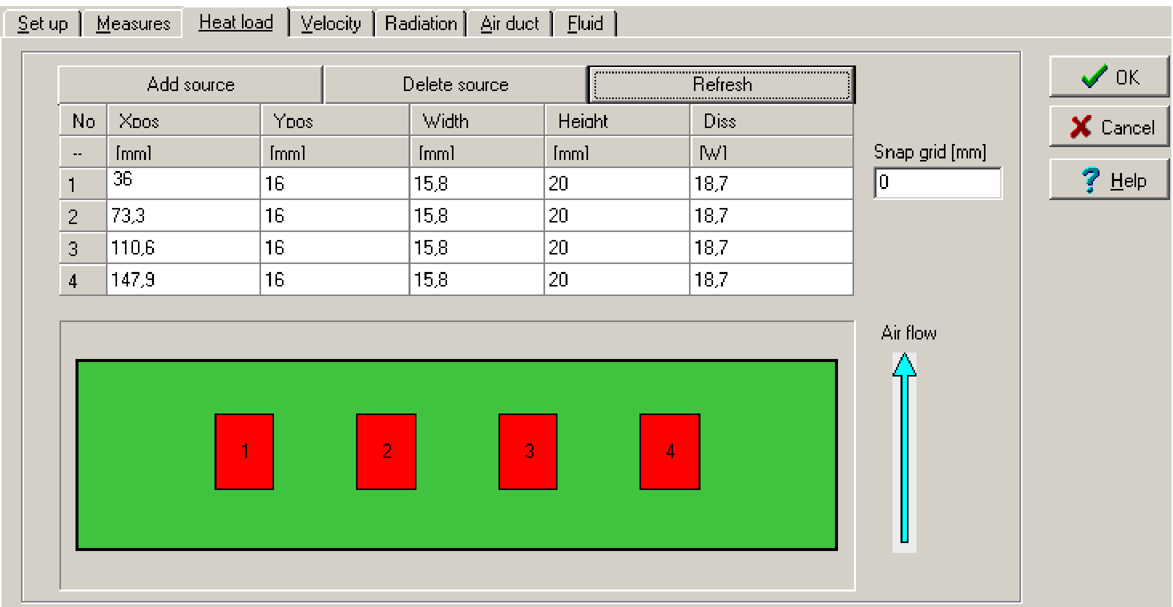


Figure 2.21. The heatsink simulation showing the power dissipations

The dimensions and the fin counts were also entered in that program. (The demo version allows 50mm for the depth, although the actual heatsink used was 70mm.

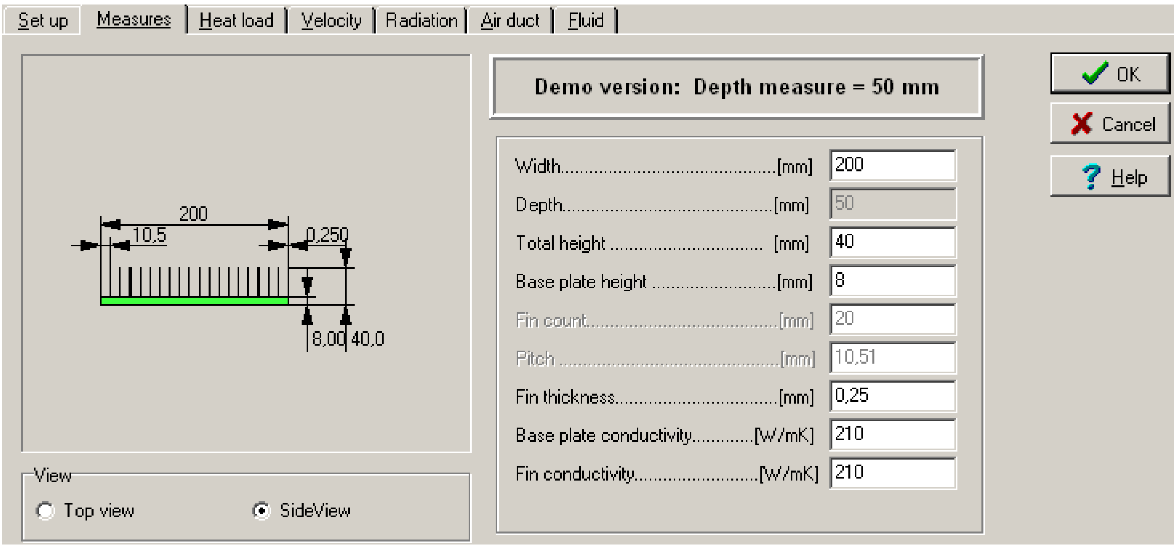


Figure 2.22. The heatsink simulation showing the heatsink dimensions

The simulations revealed a thermal resistance of 0,81°C/W for the heatsink defined assuming 1m/s air velocity.

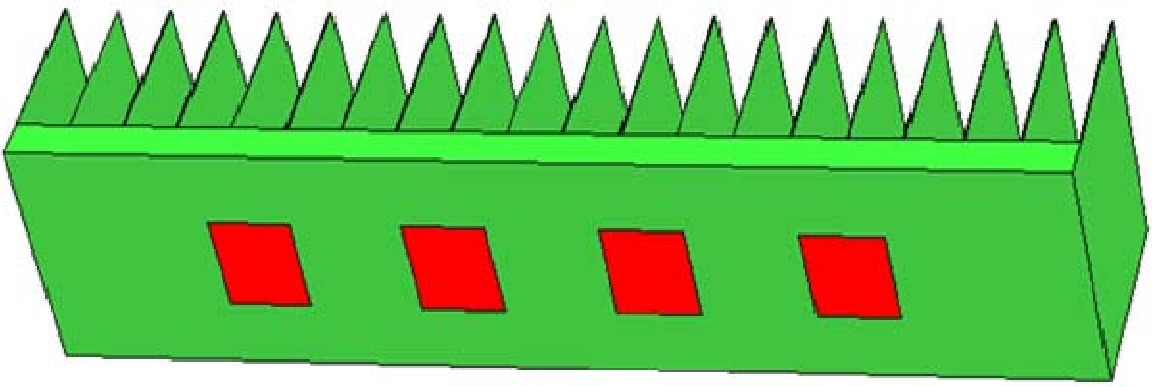


Figure 2.23. The 3D model for the heatsink and the transistors as heat sources

The distribution on the heatsink resulting from the simulation is depicted in Figure 2.24. It is seen that the transistors in the middle become the most heated. This is as expected since it is easier for the outer transistors to radiate heat with the help of the heatsink since they are able to use more fins. Using this result of the simulation, the fan is directed to the part of the heatsink where these transistors are mounted.

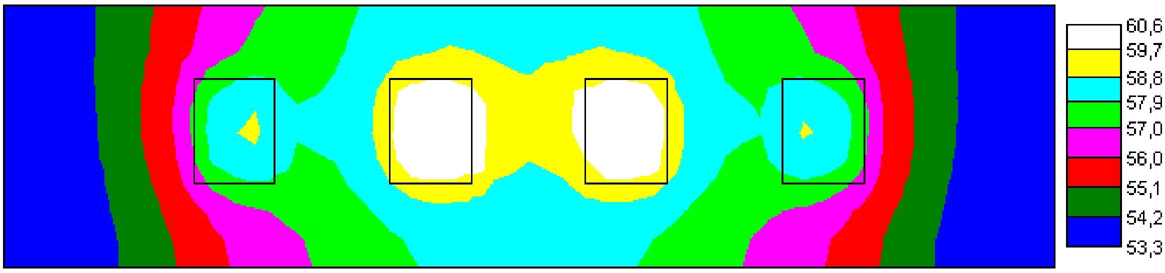


Figure 2.24. The result of the heatsink simulation showing the heat distribution

2.12. Output Overcurrent Protection

The output current is continuously monitored and displayed. If is exceeds 6A, the microcontroller immediately lowers the output voltage until the output current is below 6A and turns the buzzer signal on.

2.13. The PCB Design

The PCB design directly affects the proper operation of the power supply, therefore it is very important

Utmost efficiency is aimed in the placement within the power supply box. The approach was to place the power part and the controller parts as separate blocks and then to combine them.

It was important for the routing of current carrying routes to be thick enough. Also for the analog measurement paths, care was taken not to create long loops so that the measurements were minimally affected.

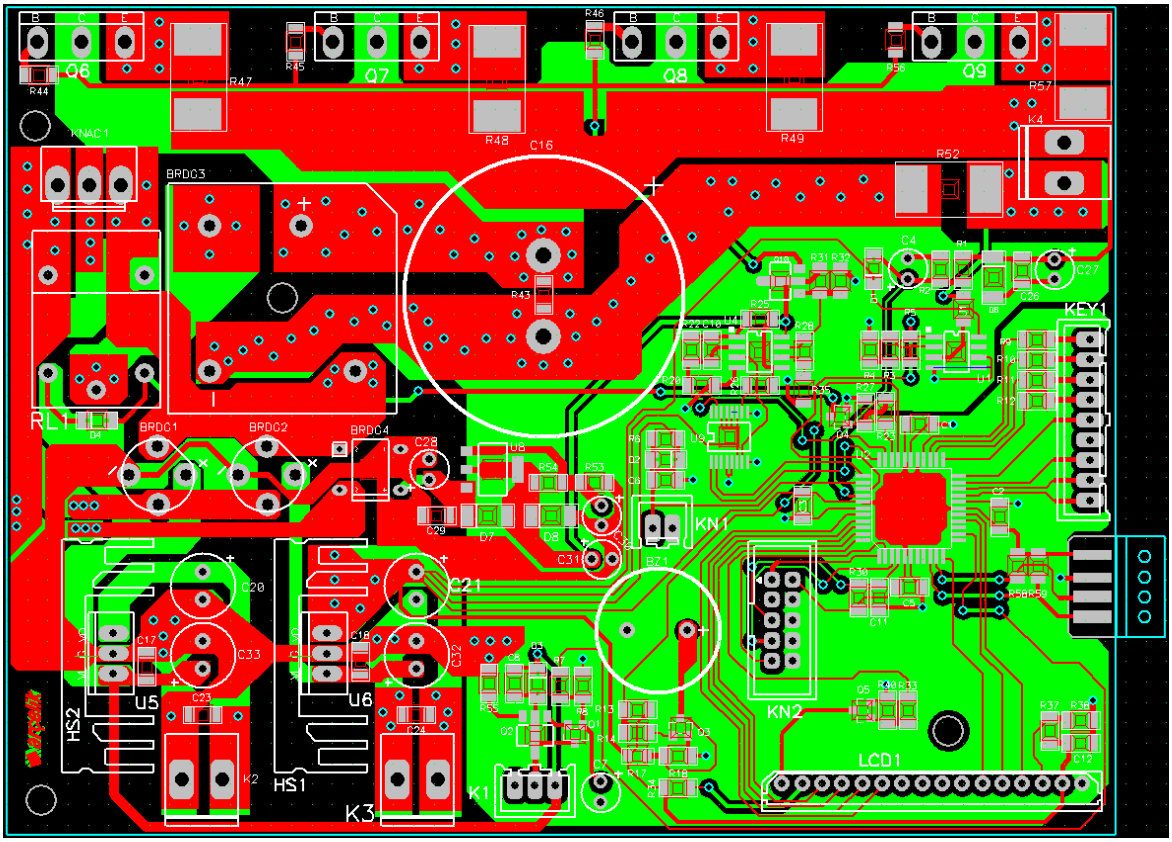


Figure 2.25. The PCB design of the power supply

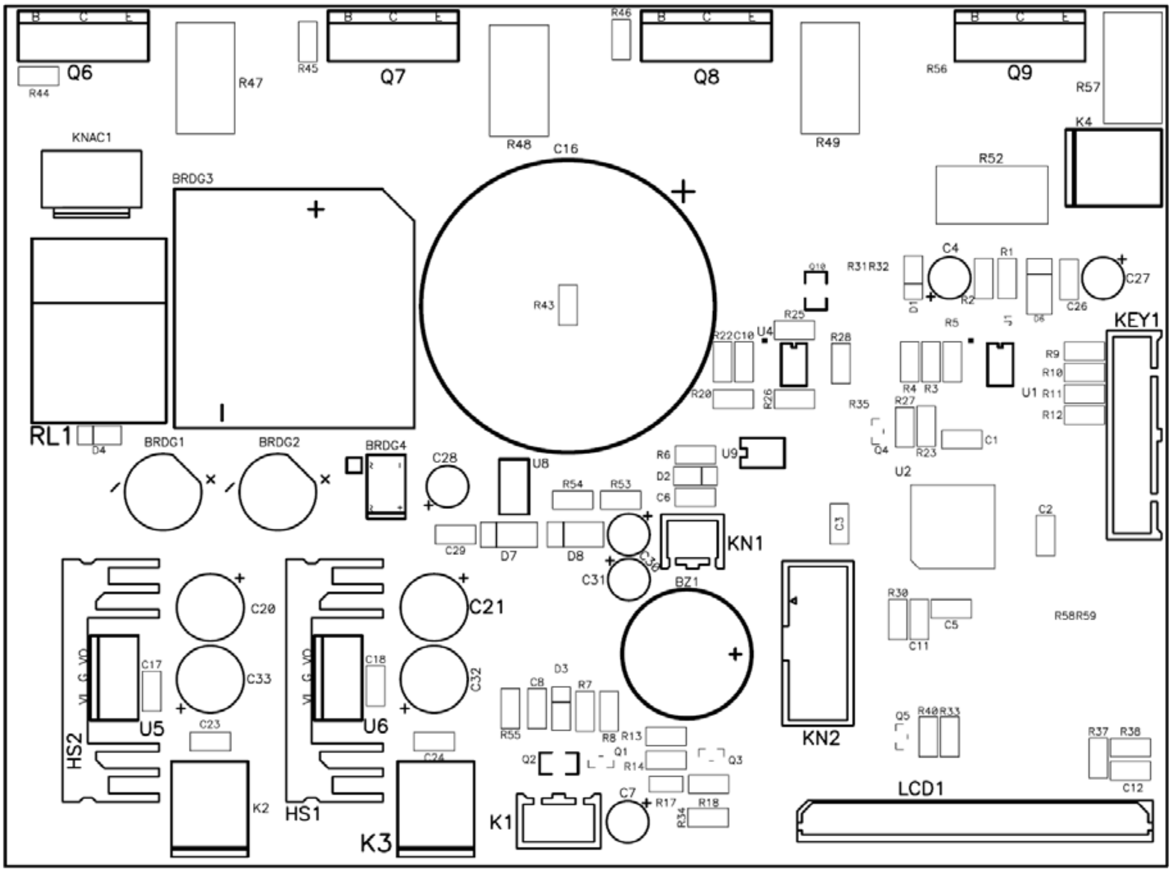


Figure 2.26. The top placement of the PCB of the power supply

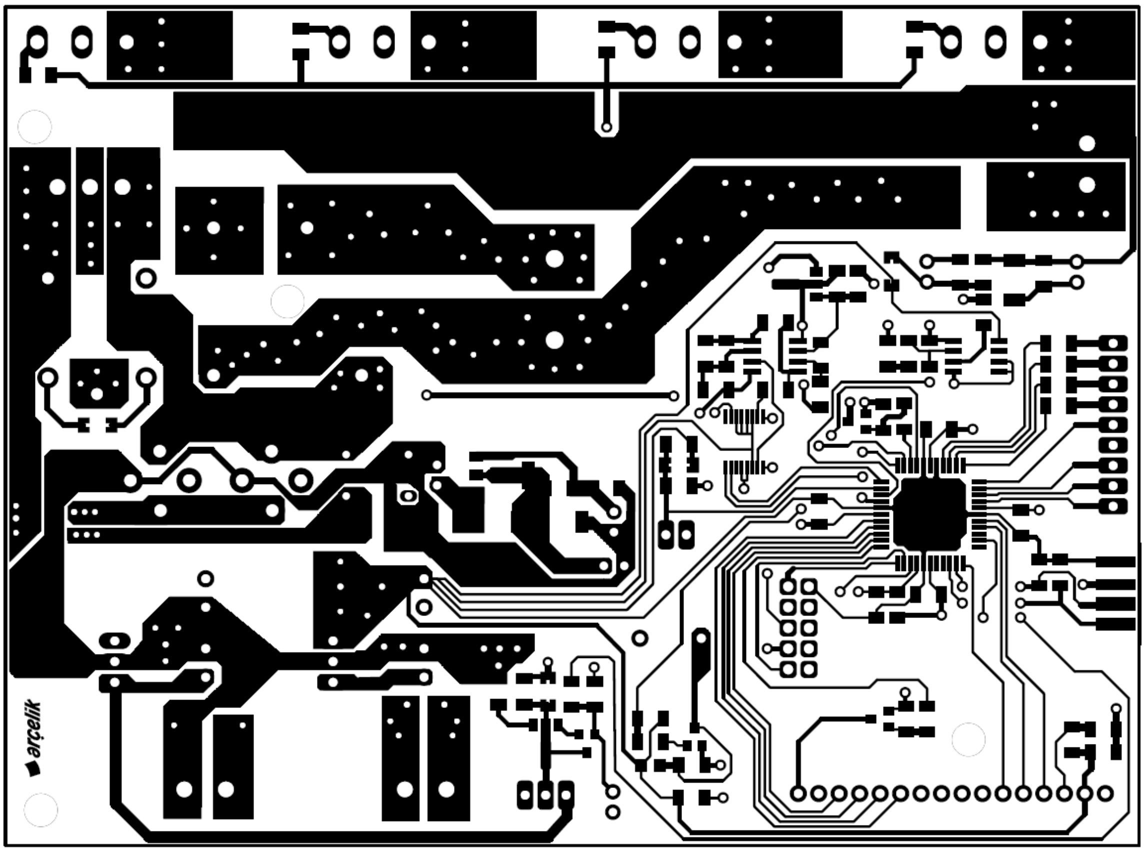


Figure 2.27. The top layer of the PCB of the power supply

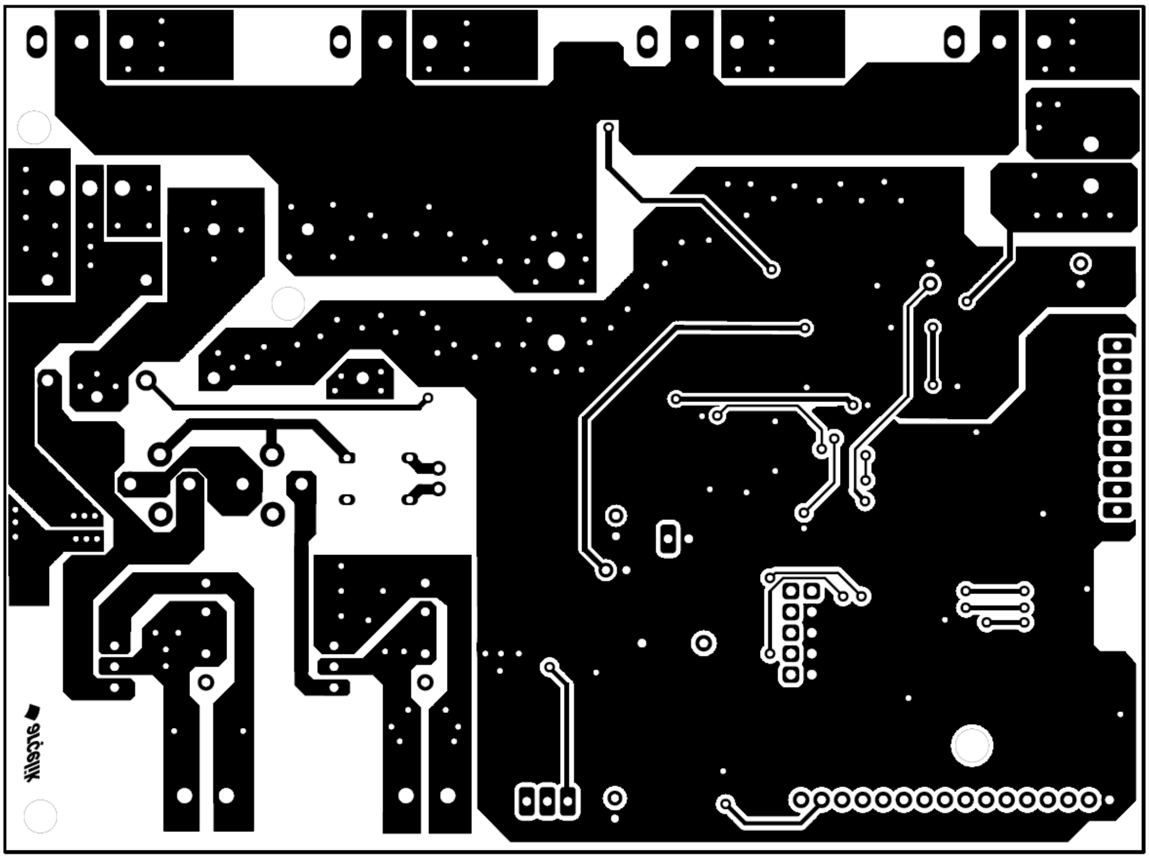


Figure 2.28. The bottom layer of the PCB of the power supply

3. SOFTWARE

3.1. The Embedded Code

The power supply uses the ATMEGA16A microcontroller. Standard AVRISP programmer was used to program it. The programming screen was as shown in Figure 3.1. The embedded code is given in the appendix and the CD accompanying this thesis.

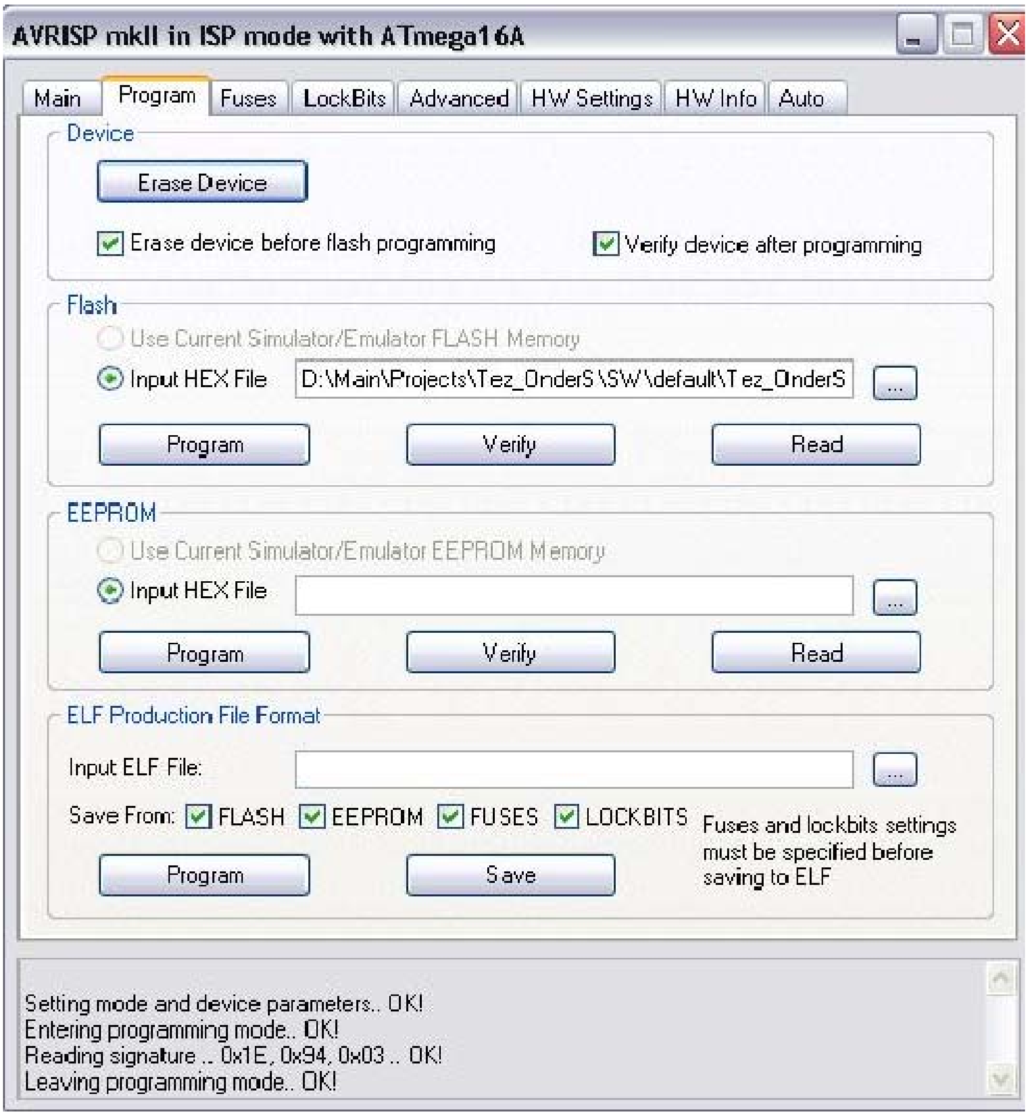


Figure 3.1. The programming screen of the programmer

3.2. The Computer Interface Program

The computer interface program has been developed on Microsoft Visual Studio using C#.NET. The connection to the computer is established over USB but a USB to serial converter module (FT232BL) has been used so that the program sees the connection as a serial port.

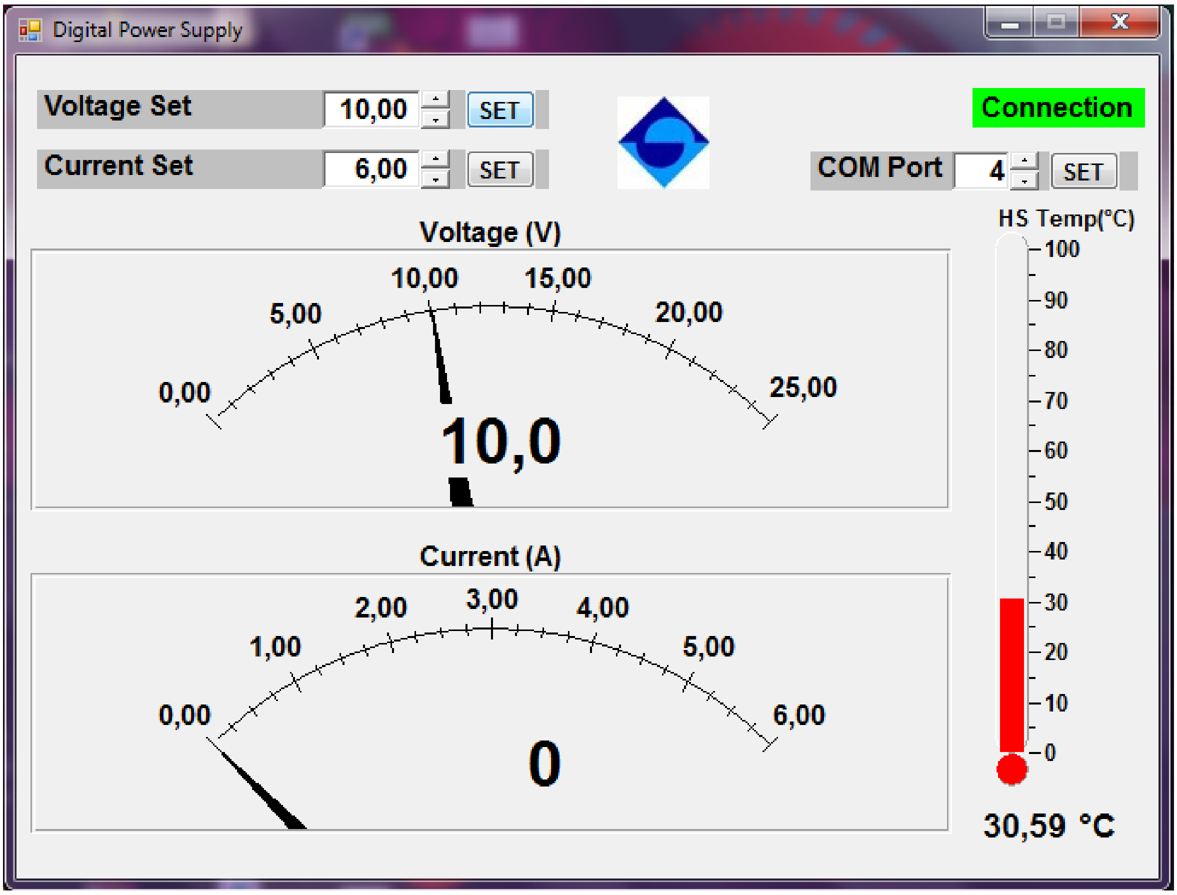


Figure 3.2. Computer control interface of the power supply

The voltage and current can be set and displayed from the computer interface. Also the heatsink temperature can be monitored from this interface.

4. RESULTS

Output currents and voltages were measured after the implementation of the design. The maximum output voltage can be set digitally to 26.0V by either using the numerical keypad or the computer interface. The current limit can be set from 0A to 6.0A.

4.1. Efficiency

An efficiency calculator has been prepared by using Excel, in which one enters the output voltage and output current to calculate corresponding efficiency. Table 5 shows this calculator. By the use of this calculator, Table 6 has been prepared, which shows the efficiency of the power supply according to some generic output voltages and currents. The efficiency of the power supply is calculated according to the formulas 4.1 and 4.2.

$$\%\eta = 100 * P_{OUT} / P_{IN} = 100 * V_{OUT} \cdot I_{OUT} / V_{IN} \cdot I_{IN} \quad (4.1)$$

$$I_{OUT} = I_{IN} \quad (4.2)$$

Table 4.1. Digital power supply efficiency calculator

Digital Power Supply Efficiency Calculator									
Enter Vout	=	26	V						
Enter Iout	=	5	A						
Vin	=	33,94	V						
Iout	=	Iin					=	5,00	A
Pout	=	Vout	*	Iout			=	130,00	W
Pin	=	Vin	*	Iin			=	169,70	W
% Efficiency	=	100	*	Pout	/	Pin	=	**76,60**	%

As can be seen from Table 6, the efficiency changes according to the output voltage. As well known, the efficiency of a linear regulator decreases as the output voltage decreases due to the increase of the voltage drop on the series pass transistors. So with the designed power supply, the maximum efficiency that can be achieved is equal to %76,60, because the output cannot reach up to 30V as explained.

Table 4.2. Efficiency of the power supply for various output voltages and currents

		Iout (A)				
Vout (V)		**1,00**	**2,00**	**3,00**	**4,00**	**5,00**
5,00		14,73	14,73	14,73	14,73	14,73
10,00		29,46	29,46	29,46	29,46	29,46
15,00		44,19	44,19	44,19	44,19	44,19
20,00		58,93	58,93	58,93	58,93	58,93
25,00		73,66	73,66	73,66	73,66	73,66
26,00		76,60	76,60	76,60	76,60	76,60
30,00		88,39	88,39	88,39	88,39	88,39

The power supply which was implemented is depicted in Figures 4.1, 4.2 and 4.3.

Figure 4.1. The completed power supply

Figure 4.2. The power supply from various angles

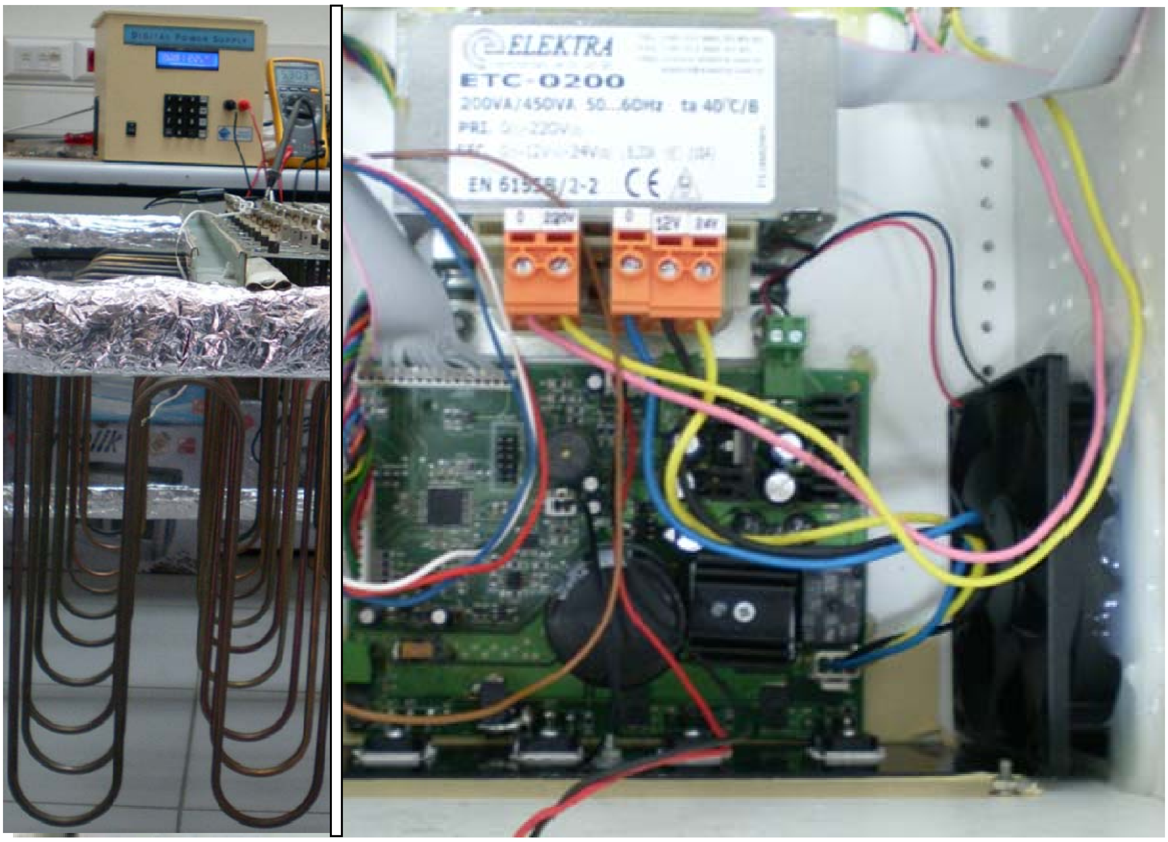


Figure 4.3. The inside of the power supply box and testing

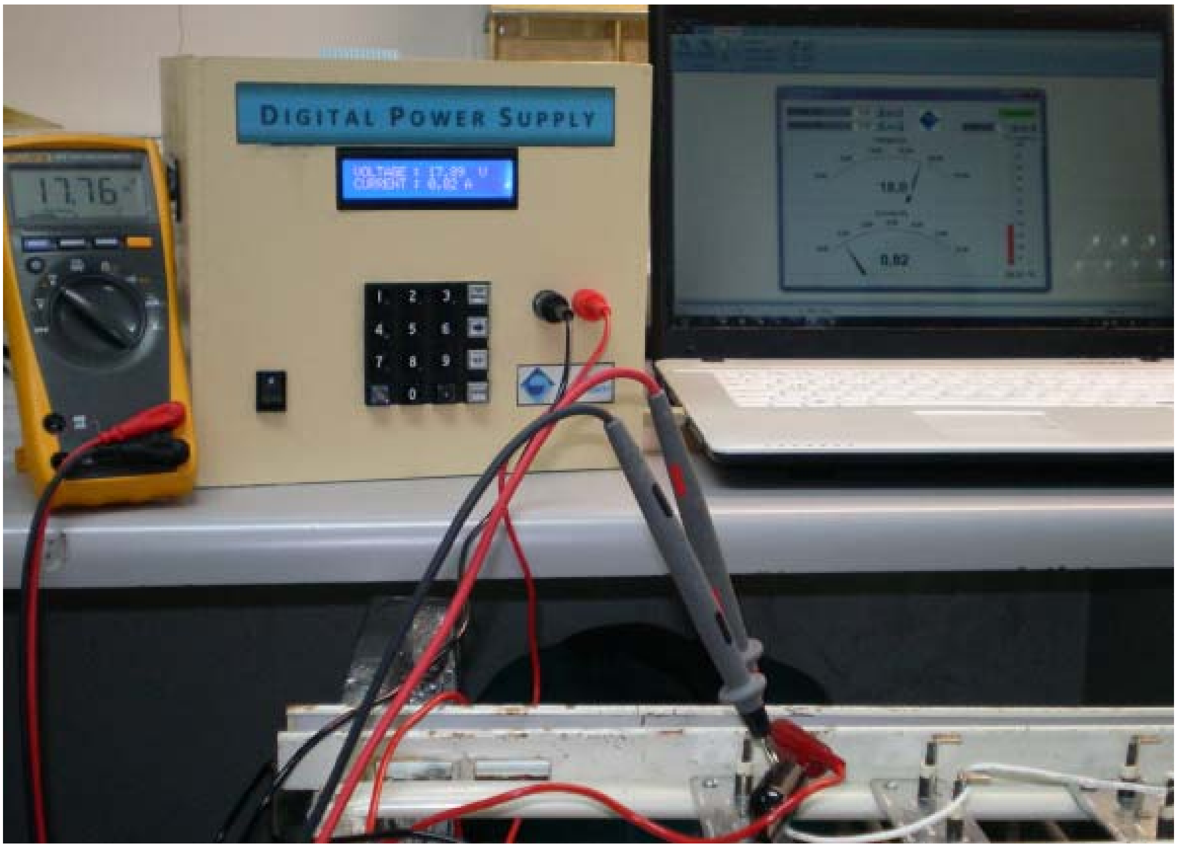


Figure 4.4. The power supply testing and computer connection

5. CONCLUSION & FUTURE WORK

The digital power supply designed here accomplishes the tasks proposed to some degree, but it may further be improved. Some of these improvements were mentioned in the previous sections but discuses further in this section. Most of the improvements explained in this section can be made easily to some degree, without making significant changes or updates.

Current and voltage measurement topologies in this design are thought to be sufficient for the tasks needed here. On the other hand, the resistor values, so the gains of the measurement circuits may be optimized by considering the use of full scale of the ADC resolution. To this end, first the operational amplifiers must be changed to rail-to-rail types. Then for the output current, the measurements may be made with 5A / 1024 = 4,88mA resolution, and for the output voltage with 30V / 1024 = 29,3mV resolution.

The main bridge rectifier of the design has power dissipation per leg (maximally)

$$P_{LEG} = If * Vf = 5A.1V = 5W \quad (5.1)$$

The datasheet gives $R\theta_{JC}$ = 1,9°C/W thermal resistance per leg [11], so this yields

$$Heat_{LEG} = PLEG * \mathrm{R}\,\theta_{\mathrm{JC}} = 5 * 1{,}9 = 9{,}5\,°C \quad (5.2)$$

For 4 legs, 9,5 x 4 = 38°C heat increase in total. Although a heatsink is attached to this bridge rectifier, the reliability may further be improved by connecting this bridge rectifier to the main heatsink.

Although it is proposed for the digital power supply to have maximally 5A output current, with the current topology it may be easily upgraded to higher values, even without making any changes to the number of power transistors. For the present prototype, it was tested up to 6A without any problems.

The power supply has a controlled fan drive, meaning that when the heat of the heatsink exceeds 50°C, the microcontroller drives the fan until the heatsink temperature falls below 40°C. This fan drive may be improved by using a PWM drive so that the power dissipated to drive the fan can be decreased. Also the mechanical design may be changed so that the fan blows through both the heatsink and the PCB.

The output voltage of the power supply can be set up to 26V for this prototype. The related calculations are given below:

The AC input voltage of the power supply is 24VAC with a peak voltage of

$$V_{DC\_in} = \sqrt{2} * V_{AC} = 33,94V \tag{5.3}$$

After the diode bridge, because of two forward voltage drops against the bridge rectifier, it becomes

$$V_{DC} = V_{DC\_in} - 2 * V_F = 31,94V \tag{5.4}$$

For the LM317 unit, according to the datasheet [12],

$$V_{LM317} = V_r\left(1 + \frac{R53}{R54}\right) + (I_{adj} * R53) \tag{5.5}$$

$$V_{LM317} = 1,25V\left(1 + \frac{3000}{120}\right) + (50uA * 3000) = 32,65V \tag{5.6}$$

But because the input to output differential voltage of the LM317 is minimally 3V,

$$V_{LM317OUT(MAX)} = V_{DC} - V_{DROP} = 31,94 - 3 = 28,94V \tag{5.7}$$

So the voltage labeled as 33V in the power part schematic (output of the LM317) is in fact maximally equal to 28,94V. This is the supply voltage of the opamp and transistor of the control part of the circuit where the output of the digital potentiometer drives the regulator transistors.

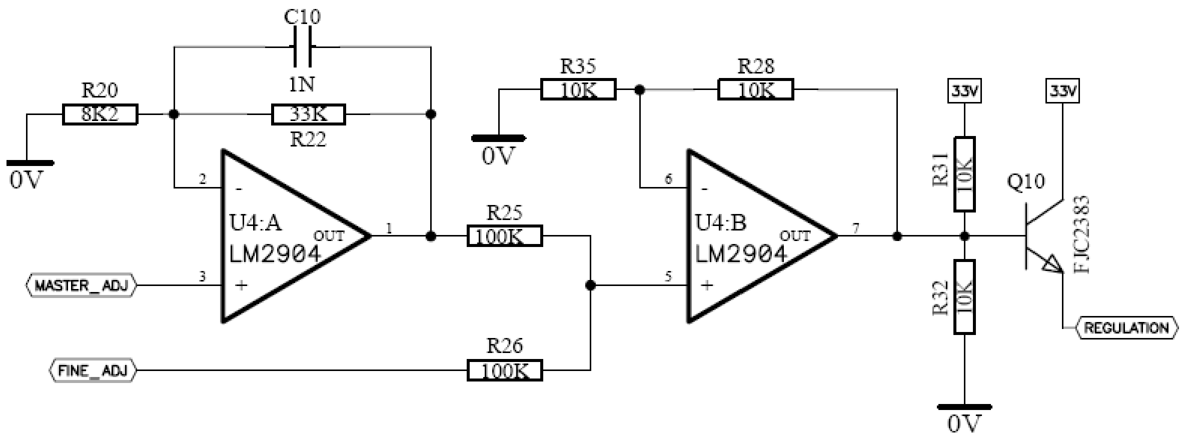


Figure 5.1. Digital potentiometer part

So the output of the U4:B can maximally be equal to

$$V_{U4B} = V_{CC} - 1{,}5 = 28{,}94 - 1{,}5 = 27{,}44V \tag{5.8}$$

Assuming the V_{BE} of FJC2383 to be 0,7V, the maximum value of the control voltage at the bases of the regulator transistors becomes equal to

$$V_{REGULATION} = V_{U4B} - V_{BE(Q10)} = 27{,}44 - 0{,}7 = 26{,}74V \tag{5.9}$$

According to these calculations and assumptions, the maximum DC output voltage is

$$V_{DC\_OUT\_MAX} = V_{REGULATION} - R_{47} * (I_{OUTMAX} / 4) - V_{BE(Q6)} \tag{5.10}$$

$$V_{DC\_OUT\_MAX} = 26{,}74 - 0{,}47 * (6/4) - 3 = 23{,}035V \tag{5.11}$$

By using a transformer with 26VAC output instead of 24VAC output, a maximum of 26,17V can be achieved.

APPENDIX A: DATASHEETS

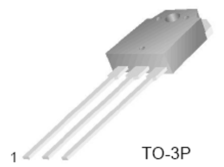
A.1. TIP142 Datasheet

FAIRCHILD SEMICONDUCTOR®

October 2008

TIP140/TIP141/TIP142
NPN Epitaxial Silicon Darlington Transistor

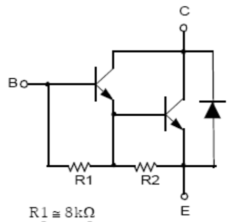
- Monolithic Construction With Built In Base-Emitter Shunt Resistors
- High DC Current Gain : h_{FE} = 1000 @ V_{CE} = 4V, I_C = 5A (Min.)
- Industrial Use
- Complement to TIP145/146/147



1 TO-3P

1.Base 2.Collector 3.Emitter

Equivalent Circuit



R1 ≅ 8kΩ
R2 ≅ 0.12kΩ

Absolute Maximum Ratings* T_a = 25°C unless otherwise noted

Symbol	Parameter	Ratings	Units
V_{CBO}	Collector-Base Voltage : TIP140 : TIP141 : TIP142	60 80 100	V V V
V_{CEO}	Collector-Emitter Voltage : TIP140 : TIP141 : TIP142	60 80 100	V V V
V_{EBO}	Emitter-Base Voltage	5	V
I_C	Collector Current (DC)	10	A
I_{CP}	Collector Current (Pulse)	15	A
I_B	Base Current (DC)	0.5	A
P_C	Collector Dissipation (T_C=25°C)	125	W
T_J	Junction Temperature	150	°C
T_{STG}	Storage Temperature	- 65 ~ 150	°C

* These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

Electrical Characteristics* T_a=25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Units
V_{CEO}(sus)	Collector-Emitter Sustaining Voltage : TIP140 : TIP141 : TIP142	I_C = 30mA, I_B = 0	60 80 100			V V V
I_{CEO}	Collector Cut-off Current : TIP140 : TIP141 : TIP142	V_{CE} = 30V, I_B = 0 V_{CE} = 40V, I_B = 0 V_{CE} = 50V, I_B = 0			2 2 2	mA mA mA
I_{CBO}	Collector Cut-off Current : TIP140 : TIP141 : TIP142	V_{CB} = 60V, I_E = 0 V_{CB} = 80V, I_E = 0 V_{CB} = 100V, I_E = 0			1 1 1	mA mA mA
I_{EBO}	Emitter Cut-off Current	V_{BE} = 5V, I_C = 0			2	mA
h_{FE}	DC Current Gain	V_{CE} = 4V, I_C = 5A V_{CE} = 4V, I_C = 10A	1000 500			
V_{CE}(sat)	Collector-Emitter Saturation Voltage	I_C = 5A, I_B = 10mA I_C = 10A, I_B = 40mA			2 3	V V
V_{BE}(sat)	Base-Emitter Saturation Voltage	I_C = 10A, I_B = 40mA			3.5	V
V_{BE}(on)	Base-Emitter On Voltage	V_{CE} = 4V, I_C = 10A			3	V
t_D	Delay Time	V_{CC} = 30V, I_C = 5A I_{B1} = 20mA, I_{B2} = -20mA R_L = 6Ω		0.15		μs
t_R	Rise Time			0.55		μs
t_{STG}	Storage Time			2.5		μs
t_F	Fall Time			2.5		μs

* Pulse Test: Pulse Width≤300μs, Duty Cycle≤2%

Typical Characteristics

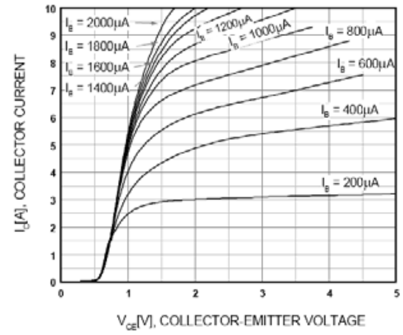


Figure 1. Static Characteristic

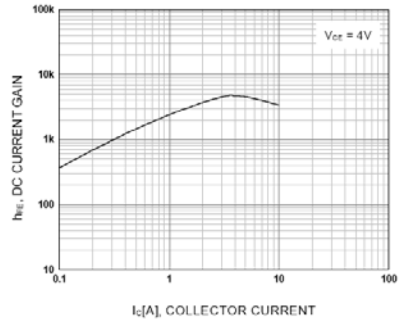


Figure 2. DC current Gain

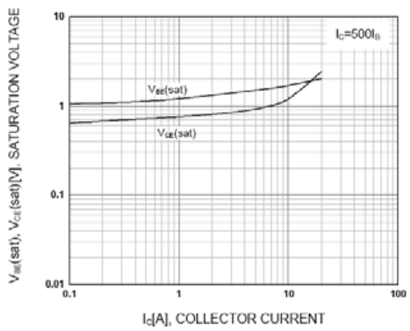


Figure 3. Base-Emitter Saturation Voltage Collector-Emitter Saturation Voltage

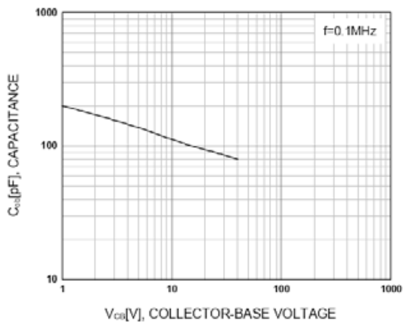


Figure 4. Collector Output Capacitance

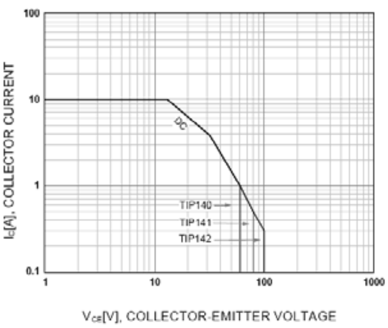


Figure 5. Safe Operating Area

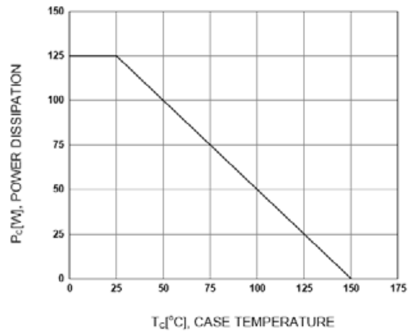


Figure 6. Power Derating

A.2. AD5235 Datasheet (Summary)

ANALOG DEVICES

Nonvolatile Memory, Dual 1024-Position Digital Potentiometer

AD5235

FEATURES

- Dual-channel, 1024-position resolution
- 25 kΩ, 250 kΩ nominal resistance
- Low temperature coefficient: 35 ppm/°C
- Nonvolatile memory stores wiper settings
- Permanent memory write protection
- Wiper setting readback
- Resistance tolerance stored in EEMEM
- Predefined linear increment/decrement instructions
- Predefined ±6 dB/step log taper increment/decrement instructions
- SPI® compatible serial interface
- 3 V to 5 V single supply or ±2.5 V dual supply
- 26 bytes extra nonvolatile memory for user-defined information
- 100-year typical data retention, $T_A = 55°C$
- Power-on refreshed with EEMEM settings

APPLICATIONS

- DWDM laser diode driver, optical supervisory systems
- Mechanical potentiometer replacement
- Instrumentation: gain, offset adjustment
- Programmable voltage to current conversion
- Programmable filters, delays, time constants
- Programmable power supply
- Low resolution DAC replacement
- Sensor calibration

GENERAL DESCRIPTION

The AD5235 is a dual-channel, nonvolatile memory,[1] digitally controlled potentiometer[2] with 1024-step resolution. The device performs the same electronic adjustment function as a mechanical potentiometer with enhanced resolution, solid state reliability, and superior low temperature coefficient performance. The AD5235's versatile programming via an SPI compatible serial interface allows 16 modes of operation and adjustment including scratchpad programming, memory storing and restoring, increment/decrement, ±6 dB/step log taper adjustment, wiper setting readback, and extra EEMEM for user-defined information such as memory data for other components, look-up table, or system identification information.

FUNCTIONAL BLOCK DIAGRAM

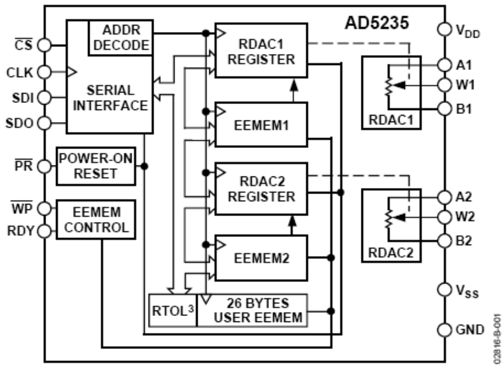


Figure 1.

In the scratchpad programming mode, a specific setting can be programmed directly to the RDAC[2] register, which sets the resistance between Terminals W–A and W–B. This setting can be stored into the EEMEM and is restored automatically to the RDAC register during system power-on.

The EEMEM content can be restored dynamically or through external $\overline{PR}$ strobing, and a $\overline{WP}$ function protects EEMEM contents. To simplify the programming, the independent or simultaneous linear-step increment or decrement commands can be used to move the RDAC wiper up or down, one step at a time. For logarithmic ±6 dB changes in wiper setting, the left or right bit shift command can be used to double or half the RDAC wiper setting.

AD5235 patterned resistance tolerance is stored in the EEMEM. The actual end-to-end resistance can, therefore, be known by the host processor in readback mode. The host can execute the appropriate resistance step through a software routine that simplifies open-loop applications as well as precision calibration and tolerance matching applications.

The AD5235 is available in a thin TSSOP-16 package. The part is guaranteed to operate over the extended industrial temperature range of −40°C to +85°C.

[1] The terms nonvolatile memory and EEMEM are used interchangeably.
[2] The terms digital potentiometer and RDAC are used interchangeably.
[3] R_{AB} tolerance.

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781.329.4700 www.analog.com
Fax: 781.326.8703

SPECIFICATIONS

ELECTRICAL CHARACTERISTICS—25 KΩ, 250 KΩ VERSIONS

V_{DD} = 3 V to 5.5 V, V_{SS} = 0 V, $V_A = V_{DD}$, V_B = 0 V, −40°C < T_A < +85°C, unless otherwise noted.
The part can be operated at 2.7 V single supply, except from 0°C to −40°C, where a minimum of 3 V is needed.

Table 1.

Parameter	Symbol	Conditions	Min	Typ[1]	Max	Unit
DC CHARACTERISTICS— RHEOSTAT MODE (All RDACs)						
Resistor Differential Nonlinearity[2]	R-DNL	R_{WB}	−2		+2	LSB
Resistor Integral Nonlinearity[2]	R-INL	R_{WB}	−4		+4	LSB
Nominal Resistor Tolerance	$\Delta R_{AB}/R_{AB}$	Dx = 0x3FF	−30		+30	%
Resistance Temperature Coefficient	$(\Delta R_{AB}/R_{AB})/\Delta T \times 10^6$			35		ppm/°C
Wiper Resistance	R_W	I_W = 1 V/R_{WB}, V_{DD} = 5 V, Code = 0x200		50	100	Ω
		I_W = 1 V/R_{WB}, V_{DD} = 3 V, Code = 0x200		200		Ω
Channel Resistance Matching	R_{AB1}/R_{AB2}	Ch 1 and 2 R_{WB}, Dx = 0x3FF		±0.1		%
DC CHARACTERISTICS— POTENTIOMETER DIVIDER MODE (All RDACs)						
Resolution	N				10	Bits
Differential Nonlinearity[3]	DNL		−2		+2	LSB
Integral Nonlinearity[3]	INL		−4		+4	LSB
Voltage Divider Temperature Coefficient	$(\Delta V_W/V_W)/\Delta T \times 10^6$	Code = half-scale		15		ppm/°C
Full-Scale Error	V_{WFSE}	Code = full scale	−6		0	LSB
Zero-Scale Error	V_{WZSE}	Code = zero scale	0		4	LSB
RESISTOR TERMINALS						
Terminal Voltage Range[4]	$V_{A, B, W}$		V_{SS}		V_{DD}	V
Capacitance[5] Ax, Bx	$C_{A, B}$	f = 1 MHz, measured to GND, Code = half-scale		11		pF
Capacitance[5] Wx	C_W	f = 1 MHz, measured to GND, Code = half-scale		80		pF
Common-Mode Leakage Current[5,6]	I_{CM}	$V_W = V_{DD}/2$		0.01	±2	μA
DIGITAL INPUTS AND OUTPUTS						
Input Logic High	V_{IH}	With respect to GND, V_{DD} = 5 V	2.4			V
Input Logic Low	V_{IL}	With respect to GND, V_{DD} = 5 V			0.8	V
Input Logic High	V_{IH}	With respect to GND, V_{DD} = 3 V	2.1			V
Input Logic Low	V_{IL}	With respect to GND, V_{DD} = 3 V			0.6	V
Input Logic High	V_{IH}	With respect to GND, V_{DD} = +2.5 V, V_{SS} = −2.5 V	2.0			V
Input Logic Low	V_{IL}	With respect to GND, V_{DD} = +2.5 V, V_{SS} = −2.5 V			0.5	V
Output Logic High (SDO, RDY)	V_{OH}	$R_{PULL-UP}$ = 2.2 kΩ to 5 V (see Figure 25)	4.9			V
Output Logic Low	V_{OL}	I_{OL} = 1.6 mA, V_{LOGIC} = 5 V (see Figure 25)			0.4	V
Input Current	I_{IL}	V_{IN} = 0 V or V_{DD}			±2.25	μA
Input Capacitance[5]	C_{IL}			5		pF
POWER SUPPLIES						
Single-Supply Power Range	V_{DD}	V_{SS} = 0 V	3.0		5.5	V
Dual-Supply Power Range	V_{DD}/V_{SS}		±2.25		±2.75	V
Positive Supply Current	I_{DD}	$V_{IH} = V_{DD}$ or V_{IL} = GND, T_A = 25°C		2	4.5	μA
	I_{DD}	$V_{IH} = V_{DD}$ or V_{IL} = GND		3.5	6.0	μA
Negative Supply Current	I_{SS}	$V_{IH} = V_{DD}$ or V_{IL} = GND, V_{DD} = +2.5 V, V_{SS} = −2.5 V		3.5	6.0	μA

AD5235

Parameter	Symbol	Conditions	Min	Typ[1]	Max	Unit
EEMEM Store Mode Current	I_{DD} (store)	$V_{IH} = V_{DD}$ or V_{IL} = GND, V_{SS} = GND, $I_{SS} \approx 0$		35		mA
	I_{SS} (store)	V_{DD} = +2.5 V, V_{SS} = −2.5 V		−35		mA
EEMEM Restore Mode Current[7]	I_{DD} (restore)	$V_{IH} = V_{DD}$ or V_{IL} = GND, V_{SS} = GND, $I_{SS} \approx 0$	0.3	3	9	mA
	I_{SS} (restore)	V_{DD} = +2.5 V, V_{SS} = −2.5 V	−0.3	−3	−9	mA
Power Dissipation[8]	P_{DISS}	$V_{IH} = V_{DD}$ or V_{IL} = GND		18	50	μW
Power Supply Sensitivity[5]	P_{SS}	ΔV_{DD} = 5 V ± 10%		0.002	0.01	%/%
DYNAMIC CHARACTERISTICS[5, 9]						
Bandwidth	BW	−3 dB, V_{DD}/V_{SS} = ±2.5 V, R_{AB} = 25 kΩ/250 kΩ		125/12		kHz
Total Harmonic Distortion	THD_W	V_A = 1 V rms, V_B = 0 V, f = 1 kHz		0.05		%
		V_A = 1 V rms, V_B = 0 V, f = 1 kHz, R_{AB} = 50 kΩ, 100 kΩ		0.045		%
V_W Settling Time	t_S	$V_A = V_{DD}$, V_B = 0 V, V_W = 0.50% error band, Code 0x000 to 0x200, R_{AB} = 25 kΩ/250 kΩ		4/36		μs
Resistor Noise Density	e_{N_WB}	R_{AB} = 25 kΩ/250 kΩ, T_A = 25°C		20/64		$nV/\sqrt{Hz}$
Crosstalk (C_{W1}/C_{W2})	C_T	$V_A = V_{DD}$, V_B = 0 V, measured V_{W1} with V_{W2} making full-scale change		90/21		nV-s
Analog Crosstalk	C_{TA}	$V_{DD} = V_{A1}$ = +2.5 V, $V_{SS} = V_{B1}$ = −2.5 V, measured $V_{W1}$with V_{W2} = 5 V p-p @ f = 1 kHz, Code 1 = 0x200, Code 2 = 0x3FF, R_{AB} = 25 kΩ/250 kΩ		−81/−62		dB

PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

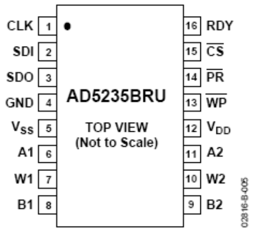


Figure 4. Pin Configuration

Table 4. Pin Function Descriptions

Pin No.	Mnemonic	Description
1	CLK	Serial Input Register Clock. Shifts in one bit at a time on positive clock edges.
2	SDI	Serial Data Input. Shifts in one bit at a time on positive clock CLK edges. MSB loads first.
3	SDO	Serial Data Output. Serves readback and daisy-chain functions.
		Commands 9 and 10 activate the SDO output for the readback function, delayed by 24 or 25 clock pulses, depending on the clock polarity before and after the data-word (see Figure 2, Figure 3, and Table 7).
		In other commands, the SDO shifts out the previously loaded SDI bit pattern, delayed by 24 or 25 clock pulses depending on the clock polarity (see Figure 2 and Figure 3). This previously shifted-out SDI can be used for daisy-chaining multiple devices.
		Whenever SDO is used, a pull-up resistor in the range of 1 kΩ to 10 kΩ is needed.
4	GND	Ground Pin, Logic Ground Reference.
5	V_{SS}	Negative Supply. Connect to 0 V for single-supply applications. If V_{SS} is used in dual supply, it must be able to sink 35 mA for 30 ms when storing data to EEMEM.
6	A1	Terminal A of RDAC1.
7	W1	Wiper terminal of RDAC1. ADDR(RDAC1) = 0x0.
8	B1	Terminal B of RDAC1.
9	B2	Terminal B of RDAC2.
10	W2	Wiper terminal of RDAC2. ADDR(RDAC2) = 0x1.
11	A2	Terminal A of RDAC2.
12	V_{DD}	Positive Power Supply.
13	$\overline{WP}$	Optional Write Protect. When active low, $\overline{WP}$ prevents any changes to the present contents, except $\overline{PR}$ strobe. CMD_1 and COMD_8 refresh the RDAC register from EEMEM. Execute a NOP instruction before returning to $\overline{WP}$ high. Tie $\overline{WP}$ to V_{DD}, if not used.
14	$\overline{PR}$	Optional Hardware Override Preset. Refreshes the scratchpad register with current contents of the EEMEM register. Factory default loads midscale 512_{10} until EEMEM is loaded with a new value by the user. $\overline{PR}$ is activated at the logic high transition. Tie $\overline{PR}$ to V_{DD}, if not used.
15	$\overline{CS}$	Serial Register Chip Select Active Low. Serial register operation takes place when $\overline{CS}$ returns to logic high.
16	RDY	Ready. Active-high open-drain output. Identifies completion of Instructions 2, 3, 8, 9, 10, and $\overline{PR}$.

A.3. ATMEGA16 Datasheet (Summary)

Features

- High-performance, Low-power AVR® 8-bit Microcontroller
- Advanced RISC Architecture
  - 131 Powerful Instructions – Most Single-clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 16 MIPS Throughput at 16 MHz
  - On-chip 2-cycle Multiplier
- High Endurance Non-volatile Memory segments
  - 16K Bytes of In-System Self-programmable Flash program memory
  - 512 Bytes EEPROM
  - 1K Byte Internal SRAM
  - Write/Erase Cycles: 10,000 Flash/100,000 EEPROM
  - Data retention: 20 years at 85°C/100 years at 25°C[1]
  - Optional Boot Code Section with Independent Lock Bits
    - In-System Programming by On-chip Boot Program
    - True Read-While-Write Operation
  - Programming Lock for Software Security
- JTAG (IEEE std. 1149.1 Compliant) Interface
  - Boundary-scan Capabilities According to the JTAG Standard
  - Extensive On-chip Debug Support
  - Programming of Flash, EEPROM, Fuses, and Lock Bits through the JTAG Interface
- Peripheral Features
  - Two 8-bit Timer/Counters with Separate Prescalers and Compare Modes
  - One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode
  - Real Time Counter with Separate Oscillator
  - Four PWM Channels
  - 8-channel, 10-bit ADC
    - 8 Single-ended Channels
    - 7 Differential Channels in TQFP Package Only
    - 2 Differential Channels with Programmable Gain at 1x, 10x, or 200x
  - Byte-oriented Two-wire Serial Interface
  - Programmable Serial USART
  - Master/Slave SPI Serial Interface
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal Calibrated RC Oscillator
  - External and Internal Interrupt Sources
  - Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby and Extended Standby
- I/O and Packages
  - 32 Programmable I/O Lines
  - 40-pin PDIP, 44-lead TQFP, and 44-pad QFN/MLF
- Operating Voltages
  - 2.7 - 5.5V for ATmega16A
- Speed Grades
  - 0 - 16 MHz for ATmega16A
- Power Consumption @ 1 MHz, 3V, and 25°C for ATmega16A
  - Active: 0.6 mA
  - Idle Mode: 0.2 mA
  - Power-down Mode: < 1µA

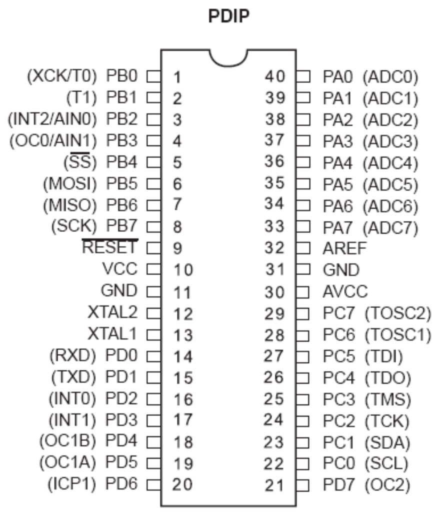
8-bit AVR® Microcontroller with 16K Bytes In-System Programmable Flash

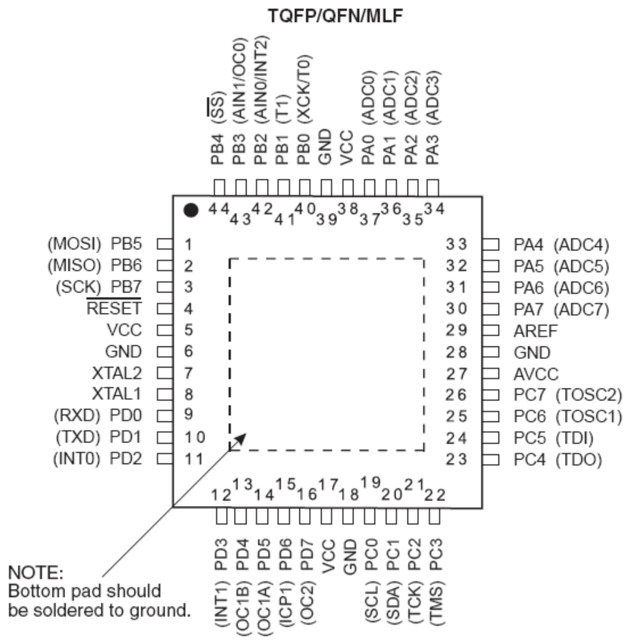
ATmega16A

8154B–AVR–07/09

Pin Configurations

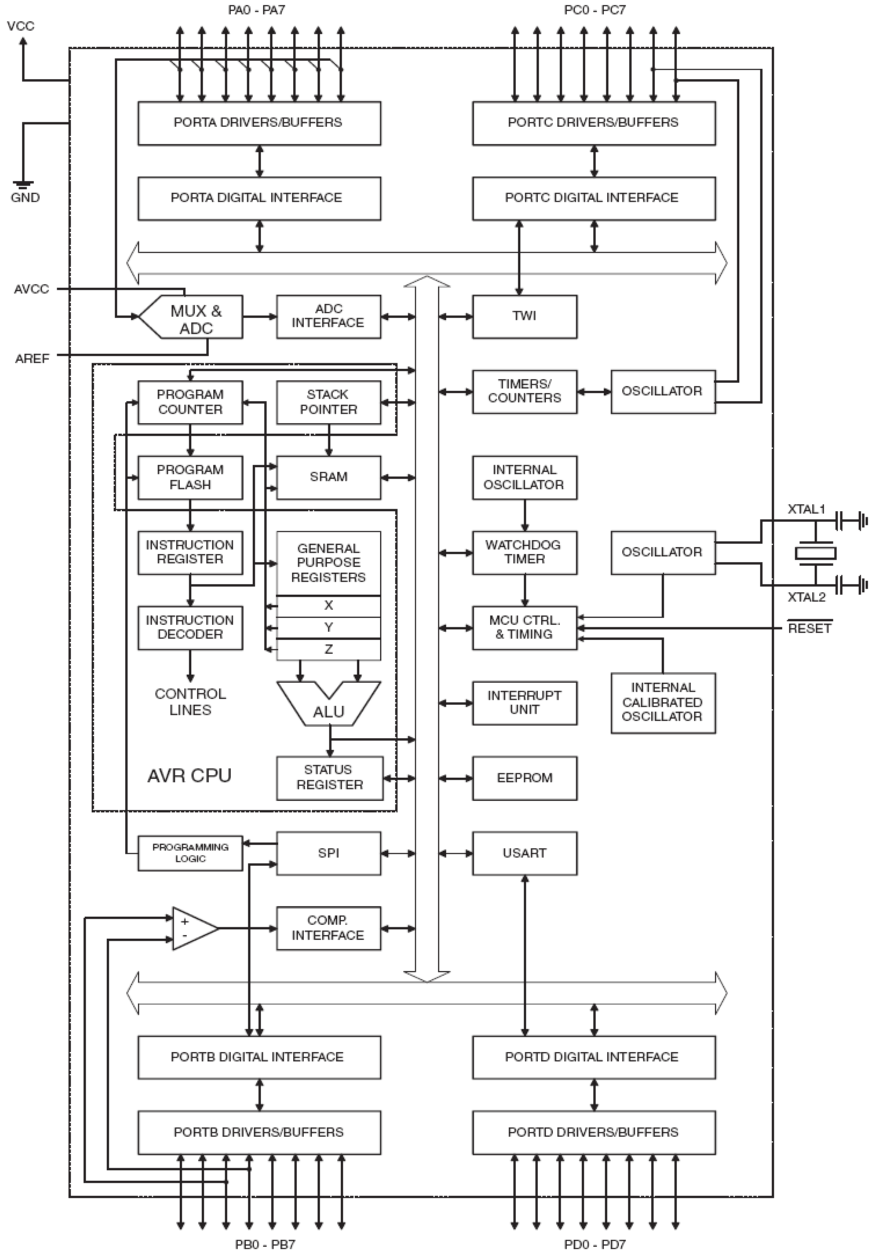
Figure 1-1. Pinout ATmega16A





Block Diagram

Figure 2-1. Block Diagram



ATmega16A

The AVR core combines a rich instruction set with 32 general purpose working registers. All the 32 registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in one single instruction executed in one clock cycle. The resulting architecture is more code efficient while achieving throughputs up to ten times faster than conventional CISC microcontrollers.

The ATmega16A provides the following features: 16K bytes of In-System Programmable Flash Program memory with Read-While-Write capabilities, 512 bytes EEPROM, 1K byte SRAM, 32 general purpose I/O lines, 32 general purpose working registers, a JTAG interface for Boundary-scan, On-chip Debugging support and programming, three flexible Timer/Counters with compare modes, Internal and External Interrupts, a serial programmable USART, a byte oriented Two-wire Serial Interface, an 8-channel, 10-bit ADC with optional differential input stage with programmable gain (TQFP package only), a programmable Watchdog Timer with Internal Oscillator, an SPI serial port, and six software selectable power saving modes. The Idle mode stops the CPU while allowing the USART, Two-wire interface, A/D Converter, SRAM, Timer/Counters, SPI port, and interrupt system to continue functioning. The Power-down mode saves the register contents but freezes the Oscillator, disabling all other chip functions until the next External Interrupt or Hardware Reset. In Power-save mode, the Asynchronous Timer continues to run, allowing the user to maintain a timer base while the rest of the device is sleeping. The ADC Noise Reduction mode stops the CPU and all I/O modules except Asynchronous Timer and ADC, to minimize switching noise during ADC conversions. In Standby mode, the crystal/resonator Oscillator is running while the rest of the device is sleeping. This allows very fast start-up combined with low-power consumption. In Extended Standby mode, both the main Oscillator and the Asynchronous Timer continue to run.

The device is manufactured using Atmel's high density nonvolatile memory technology. The On-chip ISP Flash allows the program memory to be reprogrammed in-system through an SPI serial interface, by a conventional nonvolatile memory programmer, or by an On-chip Boot program running on the AVR core. The boot program can use any interface to download the application program in the Application Flash memory. Software in the Boot Flash section will continue to run while the Application Flash section is updated, providing true Read-While-Write operation. By combining an 8-bit RISC CPU with In-System Self-Programmable Flash on a monolithic chip, the Atmel ATmega16A is a powerful microcontroller that provides a highly-flexible and cost-effective solution to many embedded control applications.

The ATmega16A AVR is supported with a full suite of program and system development tools including: C compilers, macro assemblers, program debugger/simulators, in-circuit emulators, and evaluation kits.

A.4. WH2002A-TMI-ET LCD Datasheet (Summary)

Winstar Display Co., LTD
華凌光電股份有限公司

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WEB: http://www.winstar.com.tw
E-mail: sales@winstar.com.tw
Tel:886-4-24262208 Fax：886-4-24262207

3.General Specification

Item	Dimension	Unit
Number of Characters	20 characters x 2Lines	–
Module dimension	116.0 x 37.0 x 13.9(MAX)	mm
View area	85.0 x 18.6	mm
Active area	73.5x 11.5	mm
Dot size	0.60 x 0.65	mm
Dot pitch	0.65 x 0.70	mm
Character size	3.20 x 5.55	mm
Character pitch	3.70 x 5.95	mm
LCD type	STN, Negative, Transmissive, Blue (In LCD production, It will occur slightly color difference. We can only guarantee the same color in the same batch.)	
Duty	1/16	
View direction	6 o'clock	
Backlight Type	LED White	

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Item	Dimension	Unit
Number of Characters	20 characters x 2Lines	—
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Duty	1/16	
View direction	6 o'clock	
Backlight Type	LED White	

4.Absolute Maximum Ratings

Item	Symbol	Min	Typ	Max	Unit
Operating Temperature	T_{OP}	-20	—	+70	℃
Storage Temperature	T_{ST}	-30	—	+80	℃
Input Voltage	V_I	V_{SS}	—	V_{DD}	V
Supply Voltage For Logic	V_{DD}-V_{SS}	-0.3	—	7	V
Supply Voltage For LCD	V_{DD}-V_0	-0.3	—	13	V

5.Electrical Characteristics

Item	Symbol	Condition	Min	Typ	Max	Unit
Supply Voltage For Logic	V_{DD}-V_{SS}	—	4.5	5.0	5.5	V
Supply Voltage For LCD *Note	V_{DD}-V_0	Ta=-20℃	—	—	5.7	V
		Ta=25℃	—	4.5	—	V
		Ta=70℃	3.8	—	—	V
Input High Volt.	V_{IH}	—	0.7 V_{DD}	—	V_{DD}	V
Input Low Volt.	V_{IL}	—	V_{SS}	—	0.6	V
Output High Volt.	V_{OH}	—	3.9	—	—	V
Output Low Volt.	V_{OL}	—	—	—	0.4	V
Supply Current	I_{DD}	V_{DD}=5V	1.0	1.2	1.5	mA

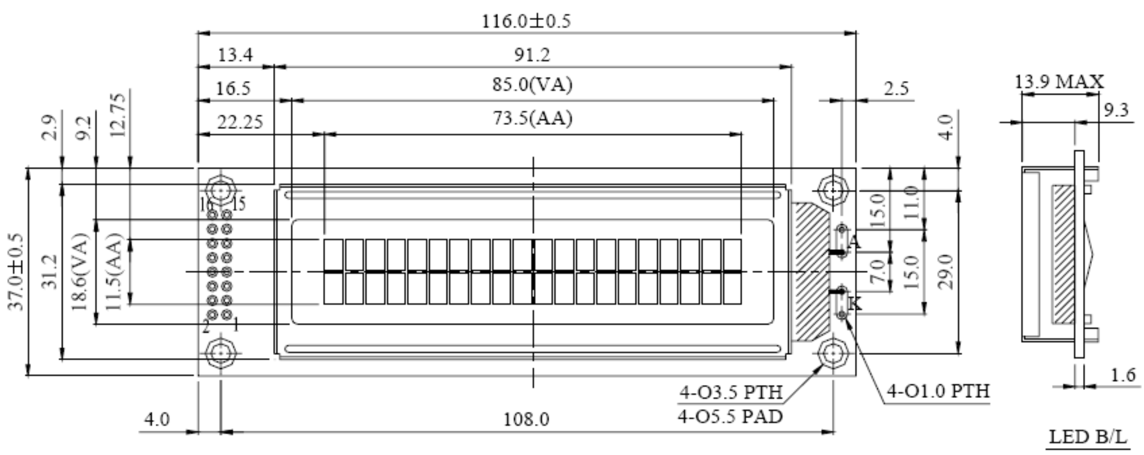
6.Optical Characteristics

Item	Symbol	Condition	Min	Typ	Max	Unit
View Angle	(V) θ	CR≧2	20	—	40	deg
	(H) φ	CR≧2	-30	—	30	deg
Contrast Ratio	CR	—	—	3	—	—
Response Time	T rise	—	—	150	200	ms
	T fall	—	—	150	200	ms

7.Interface Pin Function

Pin No.	Symbol	Level	Description
1	V_{SS}	0V	Ground
2	V_{DD}	5.0V	Supply Voltage for logic
3	VO	(Variable)	Operating voltage for LCD
4	RS	H/L	H: DATA, L: Instruction code
5	R/W	H/L	H: Read(MPU→Module) L: Write(MPU→Module)
6	E	H,H→L	Chip enable signal
7	DB0	H/L	Data bus line
8	DB1	H/L	Data bus line
9	DB2	H/L	Data bus line
10	DB3	H/L	Data bus line
11	DB4	H/L	Data bus line
12	DB5	H/L	Data bus line
13	DB6	H/L	Data bus line
14	DB7	H/L	Data bus line
15	A	—	LED +
16	K	—	LED—

8.Contour Drawing &Block Diagram



A.5. GBPC2510 Bridge Rectifier Datasheet (Summary)

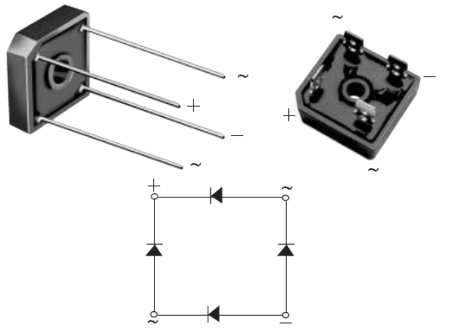
VISHAY

GBPC12, 15, 25 and 35

Vishay General Semiconductor

Glass Passivated Single-Phase Bridge Rectifier

GBPC-W GBPC



FEATURES

- UL Recognition file number E54214
- Universal 3-way terminals: snap-on, wire wrap-around, or P.C.B. mounting
- Typical I_R less than 0.3 µA
- High surge current capability
- Low thermal resistance
- Solder Dip 260 °C, 40 seconds
- Component in accordance to RoHS 2002/95/EC and WEEE 2002/96/EC

TYPICAL APPLICATIONS

General purpose use in ac-to-dc bridge full wave rectification for Power Supply, Home Appliances, Office Equipment, Industrial Automation applications.

MECHANICAL DATA

Case: GBPC, GBPC-W

Epoxy meets UL 94V-0 flammability rating

Terminals: Nickel plated on faston lugs or Silver plated on wire leads (E4 Suffix), solderable per J-STD-002B and JESD22-B102D. Suffix letter "W" added to indicate wire leads (e.g. GBPC12005W)

Polarity: As marked, positive lead by belevled corner

Mounting Torque: 20 inches-lbs. max.

MAJOR RATINGS AND CHARACTERISTICS	
$I_{F(AV)}$	12 A, 15 A, 25 A, 35 A
V_{RRM}	50 V to 1000 V
I_{FSM}	200 A, 300 A, 300 A, 400 A
I_R	5 µA
V_F	1.1 V
T_j max.	150 °C

MAXIMUM RATINGS (T_A = 25 °C unless otherwise noted)

PARAMETER		SYMBOL	GBPC12, 15, 25, 35							UNIT
			005	01	02	04	06	08	10	
Maximum repetitive peak reverse voltage		V_{RRM}	50	100	200	400	600	800	1000	V
Maximum RMS voltage		V_{RMS}	35	70	140	280	420	560	700	V
Maximum DC blocking voltage		V_{DC}	50	100	200	400	600	800	1000	V
Maximum average forward rectified output current (see Fig. 1)	GBPC12 GBPC15 GBPC25 GBPC35	$I_{F(AV)}$	12 15 25 35							A
Peak forward surge current single sine-wave superimposed on rated load	GBPC12 GBPC15 GBPC25 GBPC35	I_{FSM}	200 300 300 400							A
Rating (non-repetitive, for t greater than 1 ms and less than 8.3 ms) for fusing	GBPC12 GBPC15 GBPC25 GBPC35	I^2t	160 375 375 660							A^2 sec
RMS isolation voltage from case to leads		V_{ISO}	2500							V
Operating junction storage temperature range		T_J, T_{STG}	- 55 to + 150							°C

GBPC12, 15, 25 and 35

Vishay General Semiconductor

ELECTRICAL CHARACTERISTICS (T_A = 25 °C unless otherwise noted)											
PARAMETER		**TEST CONDITIONS**	**SYMBOL**	**GBPC12, 15, 25, 35**							**UNIT**
				005	**01**	**02**	**04**	**06**	**08**	**10**	
Maximum instantaneous forward drop per leg	GBPC12 GBPC15 GBPC25 GBPC35	I_F = 6.0 A I_F = 7.5 A I_F = 12.5 A I_F = 17.5 A	V_F	1.1							V
Maximum reverse DC current at rated DC blocking voltage per leg		T_A = 25 °C T_A = 125 °C	I_R	5.0 500							µA
Typical junction capacitance per leg		at 4 V, 1 MHz	C_J	300							pF

THERMAL CHARACTERISTICS (T_A = 25 °C unless otherwise noted)										
PARAMETER		**SYMBOL**	**GBPC12, 15, 25, 35**							**UNIT**
			005	**01**	**02**	**04**	**06**	**08**	**10**	
Typical thermal resistance per leg [(1)]	GBPC12-25 GBPC35	$R_{\theta JC}$	1.9 1.4							°C/W

RATINGS AND CHARACTERISTICS CURVES

(T_A = 25 °C unless otherwise noted)

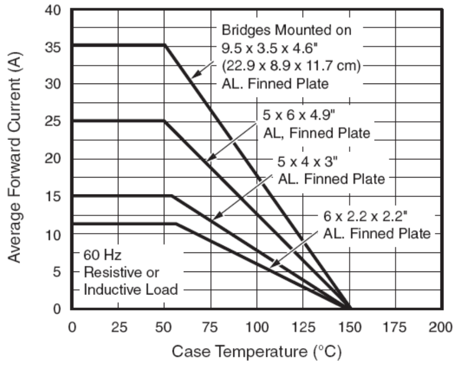


Figure 1. Maximum Output Rectified Current

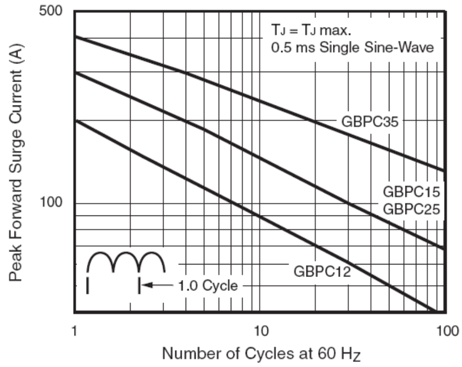


Figure 4. Maximum Non-Repetitive Peak Forward Surge Current Per Leg

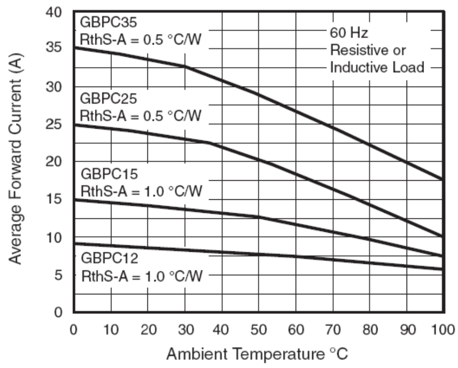


Figure 2. Maximum Output Rectified Current

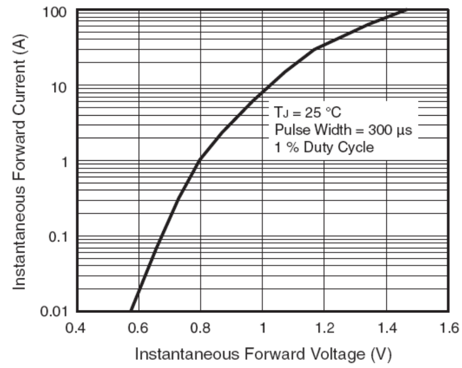


Figure 5. Typical Instantaneous Forward Characteristics Per Leg

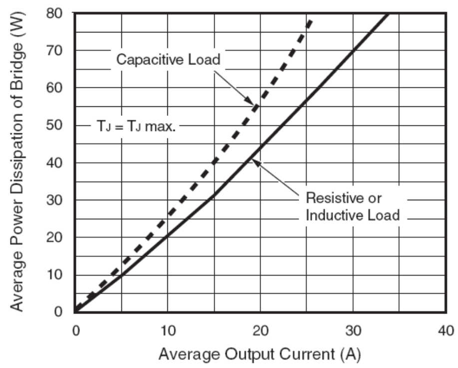


Figure 3. Maximum Power Dissipation

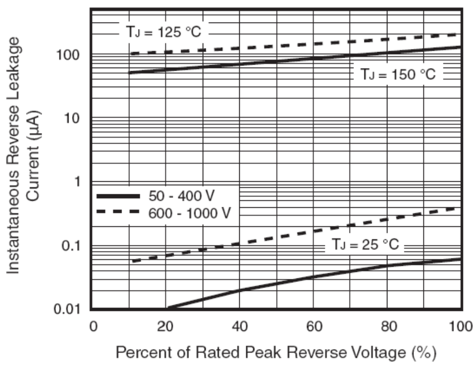


Figure 6. Typical Reverse Leakage Characteristics Per Leg

GBPC12, 15, 25 and 35

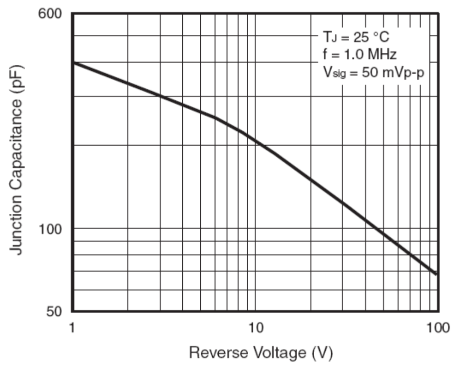


Figure 7. Typical Junction Capacitance Per Leg

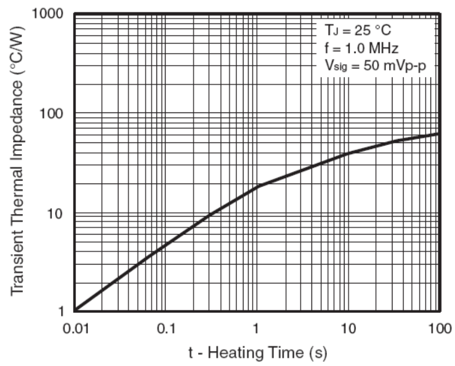
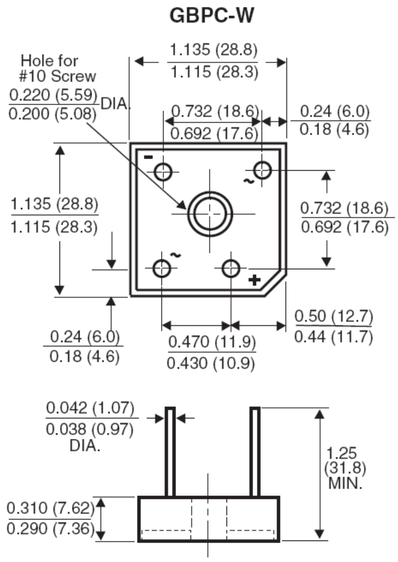
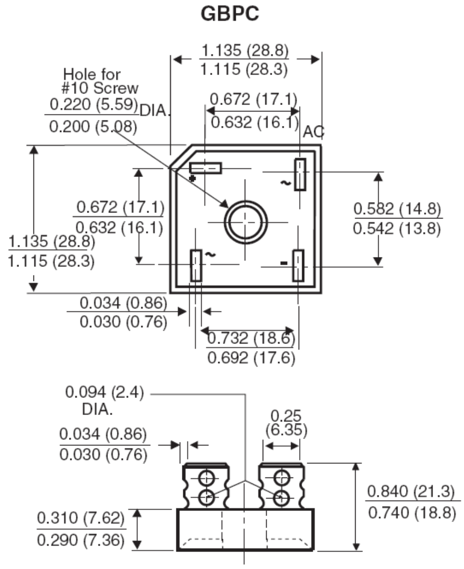


Figure 8. Typical Transient Thermal Impedance Per Leg

PACKAGE OUTLINE DIMENSIONS in inches (millimeters)





A.6. B57703M0103A017 NTC Datasheet (Summary)

EPCOS

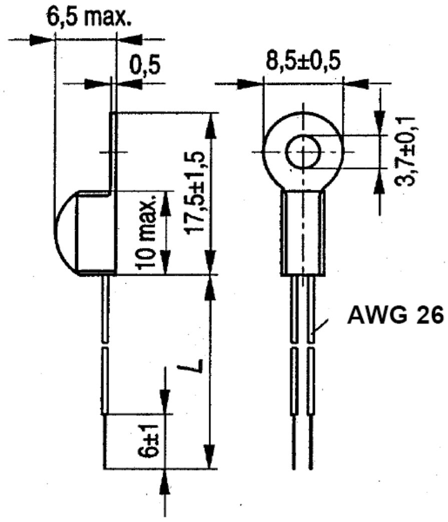
Product division: NTC	Product type: M703/10k/A017
Product name: NTC Probes	Ordering code: B57703M0103A017

Data sheet

Application
High-accuracy surface temperature measurement, e.g. on housing and pipes

Version
Thermistor encapsulated in metal-tag case (material: brass, tinned)
wire: AWG 26 (stranded, 7xAWG34)
copper, silver-plated
Insulation: PTFE, black

length of wire: L = 115 ± 10mm
stripped length: 6 ± 1mm, tinned



Data

Climatic Category (IEC 60068-1)		:	**55/125/56**
Lower category temperature		[°C] :	**-55**
Higher category temperature		[°C] :	**125**
Rated resistance R_n // Tolerance	Rn	[Ω // %] :	**10 000 // ± 2**
Rated temperature	T_n	[°C] :	**25**
B-value : $B_{(25/100)}$ // Tolerance	B_n	[K//%]:	**3988 // ± 1**
R/T-Curve no. // R_{25}		[n//Ω]:	**8016 // 10 000**
Power rating at 25°C	P_{25}	[mW]:	**150**
Dissipation factor (air)	G_{th}	[mW/K] :	**approx. 2,6**
Thermal cooling time constant (air)	T_{th}	[s] :	**approx. 28**
Dielectric strength (between NTC and metal-tag case)		[V] :	**1000**

EPCOS

Product division: NTC	Product type: M703/10k/A017
Product name: NTC Probes	Ordering code: B57703M0103A017

Data sheet

EPCOS OHG

NTC-RESISTANCE-TEMPERATURE-CURVE

R/T-Curve	**=**	**8016 / A01**	**B(25/100)**	**=**	**3988 K ± 1 %**
R at 25°C	**=**	**10000 Ω**	**R_N at 25 °C**	**=**	**10000 Ω ± 2 %**

Temp. [°C]	R Nom [Ω]	R Min [Ω]	R Max [Ω]	ΔR [±%]
-55	963.048	896.066	1.030.030	7,0
-50	670.100	626.238	713.962	6,5
-45	471.687	442.660	500.714	6,2
-40	336.500	317.054	355.947	5,8
-35	242.589	229.441	255.737	5,4
-30	177.000	168.016	185.984	5,1
-25	130.370	124.184	136.556	4,7
-20	97.070	92.772	101.368	4,4
-15	72.929	69.923	75.936	4,1
-10	55.330	53.211	57.449	3,8
-5	42.315	40.814	43.816	3,5
0	32.650	31.581	33.719	3,3
5	25.388	24.623	26.152	3,0
10	19.900	19.351	20.449	2,8
15	15.708	15.313	16.103	2,5
20	12.490	12.205	12.775	2,3
25	**10.000**	**9.800**	**10.200**	**2,0**
30	8.057	7.874	8.240	2,3
35	6.531	6.369	6.694	2,5
40	5.327	5.184	5.470	2,7
45	4.369	4.242	4.495	2,9
50	3.603	3.492	3.714	3,1
55	2.986	2.888	3.084	3,3
60	2.488	2.402	2.574	3,5
65	2.083	2.007	2.159	3,6
70	1.752	1.685	1.819	3,8
75	1.481	1.423	1.540	4,0
80	1.258	1.206	1.310	4,1
85	1.072	1.026	1.118	4,3
90	917,7	876,9	958,5	4,4
95	788,5	752,3	824,7	4,6
100	680,0	647,8	712,2	4,7
105	588,6	559,9	617,3	4,9
110	511,2	485,6	536,8	5,0
115	445,4	422,5	468,4	5,2
120	389,3	368,7	409,9	5,3
125	341,7	323,2	360,2	5,4

APPENDIX B: EMBEDDED CODE

In this appendix, the C codes running in the microcontroller are given.

```
#include "global.h"
#include <stdlib.h>
#include "definitions.h"
#include "timer.h"
#include "lcd.h"
#include "keypad.h"
#include "adc.h"
#include "spi.h"
#include "string.h"
#include "usart.h"
#include <util/delay.h>
#include <math.h>

#define LINE_LENGTH          20     //length of lcd
#define NR_OF_LINES          2      //nr of lines on lcd


#define RES1                        2200   //resistor that is connected to ntc in series.

//resistor values of current measurement circuit
#define R3_I                        18000
#define R4_I                        100
#define R5_I                        100000

#define CURRENT_CONSTANT                   ((R3_I+R4_I+R5_I)/(R5_I*117))       //current
constant that is used to calculate current

//temperature values to control fan and output activity
#define FAN_ACTIVATE_TEMP                  49
#define FAN_DEACTIVATE_TEMP         40
#define OUTPUT_DEACTIVATE_TEMP             110
#define OUTPUT_ACTIVATE_TEMP        100

#define SERIAL_INTERFACE_ADJ_DIVIDER 100    //used at interpreting serial incoming data

#define BUZZER_DURATION_LOW         50000  //buzzer duration

//menu structure
typedef enum
{
       TopMenu=0,
       SetVoltage,
       SetCurrent,
       SeeVI,
       SeeTemperature,
       About,
}T_Menu;

//trace processes
typedef enum
{
       None=0,
       VoltageCurrent,
       Temperature,
       PowerInOut,
}T_Trace;

//fan and output status is controlled via this enumeration
typedef enum
{
       DEACTIVE=0,
       ACTIVE,
}T_Status;

//language selection enum
```

```
typedef enum
{
        ENG,
        TR
}T_Lang;

//pin activation enum
typedef enum
{
        LOW=0,
        HIGH,
}T_PinStatus;

//menu structure. Used everywhere.
typedef struct
{
        T_Menu  menuType;
        int8            lcdTopLine[LINE_LENGTH];
        int8            lcdBottomLine[LINE_LENGTH];
        T_Trace traceSelected;
}T_MenuMatrix;

//helps controlling when and what to display on the lcd screen
typedef struct
{
        T_Menu  Type;
        int8            String[LINE_LENGTH];
        int8            trString[LINE_LENGTH];
}T_MenuString;

//menu strings.
T_MenuString   menuStringArray[]=
{
        {TopMenu,"     MAIN MENU     ","      ANA MENU     "},
        {SetVoltage,"    SET  VOLTAGE    ","    GERILIM AYAR    "},
        {SetCurrent,"    SET  CURRENT    ","      AKIM AYAR     "},
        {SeeVI," VOLTAGE - CURRENT ","    VOLTAJ-AKIM    "},
//      {SeeCurrent,"    SEE  CURRENT    "},
        {SeeTemperature,"    TEMPERATURE    ","      SICAKLIK      "},
        {About,"       ABOUT        ","      HAKKINDA      "},
};

//error strings
const int8 errorString[]="    OUT OF RANGE    ";
const int8 errorStringTr[]="    ARALIK  DISI    ";
const int8 heatError[]=" !HIGH TEMPERATURE! ";
const int8 heatErrorTr[]=" !YUKSEK  SICAKLIK! ";

//function prototypes
void initialization(void);
void processKey(void);
bool checkKey(void);
void cb10ms(void);
void cb100ms(void);
void cb500ms(void);
void cb1sn(void);
void doTracingProcesses(void);
void   setDigitalPot(void);
double powerOf10(uint8 val);
double getTemperature(void);
void buzzerOn(void);

//global variables
double          numericData;
double          decimalConvertedVal;
double          lastSetValue;
double          lastSetVoltageVal;
double          lastSetCurrentVal;
T_Trace         lastSetType;
uint8           nrOfProcessAfterDotKeyPressed;
uint8           howManyKeyPressedBeforeOK;
T_Status                fanStatus;
T_Status                outputStatus;
T_Lang          langStatus;
bool                    currentVoltageAdj=false;
```

```
bool           shortcutControl=false;

T_MenuMatrix   menuElement;
bool                  updateLCD;
bool           isDotPressed;


//main function of the program.
int main (void)
{
       initialization();

       while (true)
       {

              if (is10msElapsed)
              {
                     cb10ms();
                     is10msElapsed = false;
              }
              if (is1snElapsed)
              {
                     cb1sn();
                     is1snElapsed=false;
              }

       }
}

//initialization of ports, lcd, timer, usart and adc is done.

void initialization(void)
{
       resetVars();
       SREG_I=1;

       /* Port Directions */
       DDRA = (1<<PIN_BUZZER) | (1<<PIN_RELAY) | (1<<PIN_POT_CLK) | (1<<PIN_POT_CS) |
(1<<PIN_POT_SDI) ;
       DDRB = (1<<PIN_MOSI) | (1<<PIN_LCD_BL) | (1<<PIN_LCD_D7) | (1<<PIN_LCD_D6) |
(1<<PIN_LCD_D5) | (1<<PIN_LCD_D4);
       DDRC = (1<<PIN_COL1) | (1<<PIN_COL2) | (1<<PIN_COL3) | (1<<PIN_COL4);
       DDRD = (1<<PIN_LCD_RS) | (1<<PIN_LCD_RW) | (1<<PIN_LCD_E) | (1<<PIN_REG_PWM) |
(1<<PIN_FAN_PWM) |(1<<PIN_TX);

       PORTC = 0x0F;         //pull-up inputs
       BUZZER = 1;

       SREG_I = 1;
       LCD_BL=1;
       menuElement.menuType=TopMenu;
       memset(menuElement.lcdBottomLine,0x20,LINE_LENGTH);

       if (langStatus==ENG)
              memcpy(menuElement.lcdTopLine,menuStringArray[TopMenu].String,LINE_LENGTH);
       else

       memcpy(menuElement.lcdTopLine,menuStringArray[TopMenu].trString,LINE_LENGTH);


       menuElement.traceSelected=None;

       numericData=0;
       decimalConvertedVal=0;
       nrOfProcessAfterDotKeyPressed=0;
       howManyKeyPressedBeforeOK=0;


       menuElement.menuType=TopMenu;
       updateLCD=true;
       isDotPressed=false;

       fanStatus=DEACTIVE;
       outputStatus=ACTIVE;
       lastSetValue=0;
```

```
        lastSetType=None;

        lastSetCurrentVal=6;
        lastSetVoltageVal=0;

        langStatus=ENG;

        RELAY=DEACTIVE;

        INIT_USART();

        Timer0SetUp();
        ADCInit();

        resetVars();

        cbi(PORTD,RW);
        cbi(PORTD,E);
        _delay_ms(800);
        lcd_busy();
        lcd_init();
        lcd_clear();
        lcd_clear();
        lcd_clear();
        lcd_line1();
        lcd_string(menuElement.lcdTopLine);
        lcd_line2();
        lcd_string(menuElement.lcdBottomLine);
        _delay_ms(800);

        spiWrite(CMD_WRITE_TO_RDAC, MASTER_ADJ, 0);
        spiWrite(CMD_WRITE_TO_RDAC, FINE_ADJ, 0);

        buzzerOn();
}


void cb10ms(void)
{
        static uint8 index=0;
        double convertedVal;
        uint8 highNib,lowNib,highNib2,lowNib2,highNib3,lowNib3;
        uint16 adcVal,adcVal2;


        //checking whether a request has come from usart or not. If any request has come,
appropriate process is done.
        if (updateResults)
        {
                updateResults=false;
                if (serialSendRcvStatus==SET)
                {
                        if (serialDataType==VOLTAGE)
                        {
                                //numericData=0;
                                lastSetVoltageVal=setDataVal/SERIAL_INTERFACE_ADJ_DIVIDER;
                                lastSetType=VoltageCurrent;
                                lastSetValue=setDataVal/SERIAL_INTERFACE_ADJ_DIVIDER;
                                setDataVal=0;
                                if (lastSetVoltageVal>=13)
                                        RELAY=ACTIVE;
                                else
                                        RELAY=DEACTIVE;
                                usartTransmit(0x01);
                                usartTransmit(0x00);
                                usartTransmit(temp1);
                                usartTransmit(temp2);
                                usartTransmit(checksum);
                                checksum=0;
                        }
                        else if (serialDataType==CURRENT)
                        {
                                //numericData=0;
                                lastSetCurrentVal=setDataVal/SERIAL_INTERFACE_ADJ_DIVIDER;
                                lastSetType=VoltageCurrent;
```

```
					lastSetValue=setDataVal/SERIAL_INTERFACE_ADJ_DIVIDER;
					setDataVal=0;

					usartTransmit(0x01);
					usartTransmit(0x01);
					usartTransmit(temp1);
					usartTransmit(temp2);
					usartTransmit(checksum);
					checksum=0;
				}
			}
			else if (serialSendRcvStatus==GET)
			{
				uint32 dene;
				adcVal = getValueOfADCChannel(ADC_V);
				adcVal2=getValueOfADCChannel(ADC_I);

	convertedVal=((((((double)adcVal*(double)1.31)/(26.5))*0.7948)+0.0515)*0.9419-
0.0232)-(0.1*adcVal2*CURRENT_CONSTANT);
				convertedVal*=100;
				highNib=convertedVal/256;
				lowNib=(uint8)(((uint16)(convertedVal))&0x00FF);



				convertedVal=(double)(adcVal2)/117;
				convertedVal=convertedVal*((R3_I+R4_I+R5_I)/(R5_I));

				convertedVal*=100;
				highNib2=convertedVal/256;
				lowNib2=(uint8)(((uint16)(convertedVal))&0x00FF);

				convertedVal=getTemperature();
				convertedVal*=100;
				highNib3=convertedVal/256;
				lowNib3=(uint8)(((uint16)(convertedVal))&0x00FF);


				usartTransmit(2);
				usartTransmit(highNib);
				usartTransmit(lowNib);
				usartTransmit(highNib2);
				usartTransmit(lowNib2);
				usartTransmit(highNib3);
				usartTransmit(lowNib3);
				dene=((highNib3+lowNib3+highNib2+lowNib2+highNib+lowNib+2)%256);
				usartTransmit(255-(uint8)dene);

			}
		}


		//shortcut control by directly reading adc channel
		if (getValueOfADCChannel(ADC_I)>744)
		{
			spiWrite(CMD_WRITE_TO_RDAC, MASTER_ADJ, 0);
			spiWrite(CMD_WRITE_TO_RDAC, FINE_ADJ, 0);
			numericData=0;
			shortcutControl=true;
		}
		else
		{
			shortcutControl=false;
		}

		if (++index>=2)		//every 20 ms, check keypad.
		{
			if (outputStatus == ACTIVE)
			{
				if (keypadPoll())
				{
					buzzerOn();
					processKey();
				}
			}
```

```
		else
		{
			memset(menuElement.lcdBottomLine,0x20,LINE_LENGTH);
			memset(menuElement.lcdTopLine,0x20,LINE_LENGTH);
			if (langStatus==ENG)
				strcpy(menuElement.lcdTopLine,heatError);
			else
				strcpy(menuElement.lcdTopLine,heatErrorTr);
		}
		index=0;
	}

	//update lcd if it is necessary
	if (updateLCD)
	{
		lcd_clear();
		lcd_line1();
		lcd_string(menuElement.lcdTopLine);
		lcd_line2();
		lcd_string(menuElement.lcdBottomLine);
		updateLCD = false;
	}
}

//every 1 second, trace voltage and current values and adjust digital potentiometer
according to user entered values.
//Controlling fan activation and output status
void cb1sn(void)
{
	uint16 temp;

	doTracingProcesses();

	if (checkTopMenuKey())
	{
		initialization();
	}

	temp=getTemperature();

	if ((fanStatus==DEACTIVE) && (temp>FAN_ACTIVATE_TEMP))
	{
		fanStatus=ACTIVE;
		FAN_PWM=HIGH;
	}
	else if ((fanStatus==ACTIVE) && (temp<FAN_DEACTIVATE_TEMP))
	{
		fanStatus=DEACTIVE;
		FAN_PWM=LOW;
	}

	if ((outputStatus==ACTIVE) && (temp>OUTPUT_DEACTIVATE_TEMP))
	{
		outputStatus=DEACTIVE;
		spiWrite(CMD_WRITE_TO_RDAC, MASTER_ADJ, 0);
		spiWrite(CMD_WRITE_TO_RDAC, FINE_ADJ, 0);
	}
	else if ((outputStatus==DEACTIVE) && (temp<OUTPUT_ACTIVATE_TEMP))
	{
		outputStatus=ACTIVE;
		numericData=lastSetValue;
		setDigitalPot();
	}
}

//according to read key, this function do the necessary processes.
void processKey(void)
{
	int8 tempStr[5];
	uint16 tempVal=0;
	memset(tempStr,0x20,5);
	menuElement.traceSelected=None;
	memset(menuElement.lcdBottomLine,0x20,LINE_LENGTH);		//reset top and bottom
lines
	memset(menuElement.lcdTopLine,0x20,LINE_LENGTH);
```

```
	if (pressedKey == KEY_CHANGE)
	{
		if (menuElement.menuType != TopMenu)
		{
			if (menuElement.menuType < About)
			{
				menuElement.menuType++;
			}
			else
			{
				menuElement.menuType = SetVoltage;
			}
		}
		numericData = 0;
		isDotPressed=false;
		menuElement.traceSelected=None;
		if (langStatus==ENG)

	memcpy(menuElement.lcdTopLine,menuStringArray[menuElement.menuType].String,LINE_LENG
TH);
		else

	memcpy(menuElement.lcdTopLine,menuStringArray[menuElement.menuType].trString,LINE_LE
NGTH);

		memset(menuElement.lcdBottomLine,0x20,LINE_LENGTH);
	}
	else if (pressedKey == KEY_ESC)
	{
		menuElement.menuType = TopMenu;
		numericData=0;
		decimalConvertedVal=0;
		nrOfProcessAfterDotKeyPressed=0;
		howManyKeyPressedBeforeOK=0;
		isDotPressed=false;
		menuElement.traceSelected=None;
		if (langStatus==ENG)

	memcpy(menuElement.lcdTopLine,menuStringArray[menuElement.menuType].String,LINE_LENG
TH);
		else

	memcpy(menuElement.lcdTopLine,menuStringArray[menuElement.menuType].trString,LINE_LE
NGTH);
	}
	else if (pressedKey==KEY_DEL)
	{
		numericData=0;
		decimalConvertedVal=0;
		nrOfProcessAfterDotKeyPressed=0;
		howManyKeyPressedBeforeOK=0;
		isDotPressed=false;
		menuElement.traceSelected=None;
		if (langStatus==ENG)

	memcpy(menuElement.lcdTopLine,menuStringArray[menuElement.menuType].String,LINE_LENG
TH);
		else

	memcpy(menuElement.lcdTopLine,menuStringArray[menuElement.menuType].trString,LINE_LE
NGTH);
	}
	else if (pressedKey<KEY_OK)		//numeric key is pressed
	{
		if (menuElement.menuType==SetVoltage || menuElement.menuType==SetCurrent)
		{
			howManyKeyPressedBeforeOK++;
			if ((howManyKeyPressedBeforeOK <= 4) &&
(nrOfProcessAfterDotKeyPressed<=1))
			{
				if (isDotPressed)
				{
					nrOfProcessAfterDotKeyPressed++;
```

```
                                        numericData +=
(double)(pressedKey)/powerOf10(nrOfProcessAfterDotKeyPressed);
                                }
                                else
                                {
                                        numericData *= 10;
                                        numericData += pressedKey;
                                }
                                decimalConvertedVal = ((double)numericData)*100;
                                itoa(numericData,menuElement.lcdBottomLine,10);

                                if (isDotPressed)
                                {

                                        strcat(menuElement.lcdBottomLine,".");
                                        tempVal=decimalConvertedVal-
(((uint16)numericData)*100);
                                        itoa(tempVal,tempStr,10);
                                        strcat(menuElement.lcdBottomLine,tempStr);
                                }
                        }
                        else
                        {
                                itoa(numericData,menuElement.lcdBottomLine,10);
                                if (isDotPressed)
                                {
                                        strcat(menuElement.lcdBottomLine,".");
                                        tempVal=decimalConvertedVal-
(((uint16)numericData)*100);
                                        itoa(tempVal,tempStr,10);
                                        strcat(menuElement.lcdBottomLine,tempStr);
                                }
                        }
                }
                if (langStatus==ENG)

        memcpy(menuElement.lcdTopLine,menuStringArray[menuElement.menuType].String,LINE_LENG
TH);
                else

        memcpy(menuElement.lcdTopLine,menuStringArray[menuElement.menuType].trString,LINE_LE
NGTH);

        }
        else if (pressedKey==KEY_DOT)
        {
                if (menuElement.menuType==SetVoltage || menuElement.menuType==SetCurrent)
                {
                        itoa(numericData,menuElement.lcdBottomLine,10);
                        if ((howManyKeyPressedBeforeOK<4) && (nrOfProcessAfterDotKeyPressed <
2))
                        {
                                if (!isDotPressed)
                                {
                                        isDotPressed=true;
                                        strcat(menuElement.lcdBottomLine,".");
                                }
                                else
                                {
                                        strcat(menuElement.lcdBottomLine,".");
                                        tempVal=decimalConvertedVal-
((uint16)(numericData)*100);
                                        itoa(tempVal,tempStr,10);
                                        strcat(menuElement.lcdBottomLine,tempStr);
                                }
                        }
                        else
                        {
                                if (isDotPressed)
                                {
                                        strcat(menuElement.lcdBottomLine,".");
                                        tempVal=decimalConvertedVal-
((uint16)(numericData)*100);
                                        itoa(tempVal,tempStr,10);
                                        strcat(menuElement.lcdBottomLine,tempStr);
```

```
                        }
                }
        }
        if (langStatus==ENG)

    memcpy(menuElement.lcdTopLine,menuStringArray[menuElement.menuType].String,LINE_LENG
TH);
        else

    memcpy(menuElement.lcdTopLine,menuStringArray[menuElement.menuType].trString,LINE_LE
NGTH);

    }
    else if (pressedKey == KEY_OK)       //according to current menu type, ok key do
different process.
    {
        memset(tempStr,0x20,sizeof(tempStr));
        if (langStatus==ENG)

    memcpy(menuElement.lcdTopLine,menuStringArray[menuElement.menuType].String,LINE_LENG
TH);
        else

    memcpy(menuElement.lcdTopLine,menuStringArray[menuElement.menuType].trString,LINE_LE
NGTH);

        switch (menuElement.menuType)
        {
            case TopMenu   :     menuElement.menuType=SetVoltage;
                                 if (langStatus==ENG)

    memcpy(menuElement.lcdTopLine,menuStringArray[menuElement.menuType].String,LINE_LENG
TH);
                                 else

    memcpy(menuElement.lcdTopLine,menuStringArray[menuElement.menuType].trString,LINE_LE
NGTH);


    memset(menuElement.lcdBottomLine,0x20,LINE_LENGTH);
                                 break;

            case SetVoltage      :       if ((numericData >= 0.6) &&
(numericData<=25))
                                 {
                                     if (numericData<=13)
                                         RELAY=ACTIVE;
                                     else
                                         RELAY=DEACTIVE;
                                     double temp=0,temp2=0;
                                     buzzerOn();
                                     temp=numericData;
                                     setDigitalPot();
                                     temp2=numericData;
                                     numericData=temp;

    itoa(numericData,menuElement.lcdBottomLine,10);

    strcat(menuElement.lcdBottomLine,".");
                                     if (isDotPressed)
                                     {

    itoa(((double)numericData*100)-((int16)(numericData))*100,tempStr,10);

    strcat(menuElement.lcdBottomLine,tempStr);
                                     }
                                     else
                                     {

    strcat(menuElement.lcdBottomLine,"00");
                                     }
                                     lastSetType=VoltageCurrent;
                                     numericData=temp2;
                                     lastSetValue=numericData;
                                     lastSetVoltageVal=numericData;
```

```
                                                    }
                                                    else
                                                    {
                                                    numericData=0;
                                                    if (langStatus==ENG)

        strcpy(menuElement.lcdBottomLine,errorString);
                                                    else

        strcpy(menuElement.lcdBottomLine,errorStringTr);
                                            }
                                            break;

                case SetCurrent       :     buzzerOn();
                                            if ((numericData>0) &&
(numericData<=6))
                                            {
                                                    setDigitalPot();

        itoa(numericData,menuElement.lcdBottomLine,10);

        strcat(menuElement.lcdBottomLine,".");
                                                    if (isDotPressed)
                                                    {

        itoa(((double)numericData*100)-((int16)(numericData))*100,tempStr,10);

        strcat(menuElement.lcdBottomLine,tempStr);
                                                    }
                                                    else
                                                    {

        strcat(menuElement.lcdBottomLine,"00");
                                                    }

                                                    lastSetType=VoltageCurrent;
                                                    lastSetValue=numericData;
                                                    lastSetCurrentVal=numericData;
                                            }
                                            else
                                            {
                                                    numericData=0;
                                                    if (langStatus==ENG)

        strcpy(menuElement.lcdBottomLine,errorString);
                                                    else

        strcpy(menuElement.lcdBottomLine,errorStringTr);
                                            }
                                            break;

                case SeeVI            :
        menuElement.traceSelected=VoltageCurrent;
                                            doTracingProcesses();
                                            break;

                case SeeTemperature   :     menuElement.traceSelected=Temperature;
                                            doTracingProcesses();
                                            break;

                case About            :
                        {
                                            static uint8 aboutIndex=0;
                                            aboutIndex++;

                                            if ((aboutIndex%2))

        memcpy(menuElement.lcdBottomLine,"    BOGAZICI UNI   ",20);
                                            else

        memcpy(menuElement.lcdBottomLine,"    ONDER SUNETCI   ",20);

                                            break;
                }
```

```
                default         :       break;
            }

            isDotPressed=false;
            numericData=0;
            decimalConvertedVal=0;
            nrOfProcessAfterDotKeyPressed=0;
            howManyKeyPressedBeforeOK=0;
        }
        else if (pressedKey==KEY_BUZZER)
        {
            if (menuElement.menuType==TopMenu)
            {
                if (longPress==true)
                {
                    if(langStatus==ENG)
                        langStatus=TR;
                    else
                        langStatus=ENG;
                    longPress=false;
                }
                else
                {
                    if ((PINA & (1<<PIN_BUZZER))!=0)
                        cbi(DDRA, PIN_BUZZER);
                    else
                        sbi(DDRA, PIN_BUZZER);
                }
            }

            if (langStatus==ENG)

        memcpy(menuElement.lcdTopLine,menuStringArray[menuElement.menuType].String,LINE_LENG
TH);
            else

        memcpy(menuElement.lcdTopLine,menuStringArray[menuElement.menuType].trString,LINE_LE
NGTH);

            memset(menuElement.lcdBottomLine,0x20,LINE_LENGTH);
        }

        updateLCD=true;
}

//digital pot's adjustment takes place on this function
void setDigitalPot(void)
{
        static uint16 fineVal=0;
        uint16 adcVal=0;
        uint16 adcVal2=0;
        double convertedVal=0;
        uint16 quitCounter=0;
        double compVal;
        uint8 quitIndex=0;
        uint8 quitIndex2=0;

        if (!shortcutControl) //if there is not a shortcut
            {
        adcVal2=getValueOfADCChannel(ADC_I);
        convertedVal=(double)(adcVal2)/(117);
        convertedVal=convertedVal*((R3_I+R4_I+R5_I)/(R5_I));
        compVal=lastSetCurrentVal;
        if (lastSetCurrentVal==0)
            compVal=6;
        if (convertedVal<compVal)
        {
            currentVoltageAdj=false;
        }

        //Voltage control part. Program reads the voltage value and then adjust the pot
according to user entered voltage value
        if ((menuElement.menuType==SetVoltage) && (currentVoltageAdj==false))
        {
```

```
                adcVal=getValueOfADCChannel(ADC_V);
                adcVal2=getValueOfADCChannel(ADC_I);
                //convertedVal=((((double)adcVal*(double)1.31)/(26.5))*0.7948)+0.0515;

        convertedVal=((((((double)adcVal*(double)1.31)/(26.5))*0.7948)+0.0515)*0.9419-
0.0232)-(0.1*adcVal2*CURRENT_CONSTANT);
                //convertedVal=(((double)adcVal*5/1023)*(double)7.96);/*-
(0.1*adcVal2*((R3_I+R4_I+R5_I)/(R5_I*208)));*/
                while ((convertedVal-numericData<-0.01) || (convertedVal-numericData>0.01))
                {
                        quitCounter++;
                        adcVal=getValueOfADCChannel(ADC_V);
                        adcVal2=getValueOfADCChannel(ADC_I);

                        if (adcVal2>124*lastSetCurrentVal)
                                break;


        convertedVal=((((((double)adcVal*(double)1.31)/(26.5))*0.7948)+0.0515)*0.9419-
0.0232)-(0.1*adcVal2*CURRENT_CONSTANT);
                        //convertedVal=(((double)adcVal*5/1023)*(double)7.96);/*-
(0.1*adcVal2*((R3_I+R4_I+R5_I)/(R5_I*208)));*/


                        if (convertedVal > numericData)      //if read value is higher than
set value, decrease pot's register values
                        {
                                if ((convertedVal-numericData)>8)
                                {
                                        spiWrite(CMD_DEC_6DB, MASTER_ADJ, 0);
                                }
                                else if (((convertedVal-numericData)<0.9))
                                {
                                        if (((convertedVal-numericData)<0.05))
                                        {
                                                //if (++quitIndex>10);
                                                currentVoltageAdj=true;
                                                numericData=convertedVal;
                                                break;
                                        }
                                        if (fineVal != 0)
                                        {
                                                spiWrite(CMD_DEC_ONE_STEP, FINE_ADJ, 0);
                                                fineVal--;
                                        }
                                        else
                                        {
                                                spiWrite(CMD_DEC_ONE_STEP, MASTER_ADJ, 0);
                                                spiWrite(CMD_WRITE_TO_RDAC, FINE_ADJ, 5);
                                                fineVal=5;
                                        }
                                }
                                else
                                {
                                        spiWrite(CMD_DEC_ONE_STEP, MASTER_ADJ, 0);
                                        spiWrite(CMD_DEC_ONE_STEP, FINE_ADJ, 0);
                                        fineVal--;
                                }
                        }
                        else            //if read value is lower than set value, increase
pot's register values
                        {
                                if ((numericData-convertedVal)>8)
                                {
                                        spiWrite(CMD_INC_6DB, MASTER_ADJ, 0);
                                }
                                else if ((numericData-convertedVal)<0.9)
                                {

                                        if (((numericData-convertedVal)<0.05))
                                        {
                                                //if (++quitIndex>10);
                                                currentVoltageAdj=true;
                                                numericData=convertedVal;
                                                break;
```

```
                                    }
                                    if (fineVal <= 1020)
                                    {
                                           spiWrite(CMD_INC_ONE_STEP, FINE_ADJ, 0);
                                           fineVal++;
                                    }
                                    else
                                    {
                                           spiWrite(CMD_INC_ONE_STEP, MASTER_ADJ, 0);
                                           spiWrite(CMD_WRITE_TO_RDAC, FINE_ADJ, 1016);
                                           fineVal=1016;
                                    }
                             }
                             else
                             {
                                    spiWrite(CMD_INC_ONE_STEP, MASTER_ADJ, 0);
                                    spiWrite(CMD_INC_ONE_STEP, FINE_ADJ, 0);
                                    fineVal++;
                             }
                      }
                      if ((quitCounter>=1000) || (checkTopMenuKey()))     //if top key is
pressed while adjusting pot, it clears pot registers.
                      {
                             currentVoltageAdj=true;
                             numericData=convertedVal;
                             break;
                      }
               }
        }
        //Current control part. Program reads the current value from ADC and adjusts the pot
if read value is higher than entered current value
        else if (((menuElement.menuType==SetCurrent) ||
(menuElement.traceSelected==VoltageCurrent)) && (!currentVoltageAdj))
        {
               adcVal = getValueOfADCChannel(ADC_I);
               convertedVal=(double)(adcVal)/(117);
               convertedVal=convertedVal*((R3_I+R4_I+R5_I)/(R5_I));
               quitCounter=0;

               if (lastSetCurrentVal==0)
                      compVal=6;
               else
                      compVal=lastSetCurrentVal;

               if (convertedVal>6)
               {
                      spiWrite(CMD_WRITE_TO_RDAC, MASTER_ADJ, 0);
                      spiWrite(CMD_WRITE_TO_RDAC, FINE_ADJ, 0);
               }
               else
               {
                      while (convertedVal>=compVal)
                      {
                             currentVoltageAdj=true;
                             quitCounter++;
                             if (quitCounter>10)
                             {
                                    spiWrite(CMD_DEC_6DB, MASTER_ADJ, 0);
                                    spiWrite(CMD_DEC_6DB, FINE_ADJ, 0);
                             }
                             else
                             {
                                    spiWrite(CMD_DEC_ONE_STEP, MASTER_ADJ, 0);
                                    spiWrite(CMD_DEC_ONE_STEP, FINE_ADJ, 0);
                             }
                             adcVal = getValueOfADCChannel(ADC_I);
                             convertedVal=(double)(adcVal)/117;
                             convertedVal=convertedVal*((R3_I+R4_I+R5_I)/(R5_I));

                             if ((quitCounter>=100) || (checkTopMenuKey()))      //if top
key is pressed while adjusting pot, it clears pot registers.
                             {
                                    spiWrite(CMD_WRITE_TO_RDAC, MASTER_ADJ, 0);
                                    spiWrite(CMD_WRITE_TO_RDAC, FINE_ADJ, 0);
                                    break;
```

```
                              }
                       }
                }
        }
                }
}

//this function is called once in a second. Inside this function, control of voltage
current and temperature is done.
void doTracingProcesses(void)
{
        int8            tempStr[5];
        uint16  adcVal=0;
        uint16  adcVal2=0;
        double  convertedVal=0,tempVal=0;
        T_Menu  tempMenuType;
        double  tempData;
        memset(tempStr,0x20,5);
        tempData=numericData;
        if (!shortcutControl)
                {
        if (menuElement.traceSelected==VoltageCurrent)
        {

                memset(menuElement.lcdTopLine,0x20,LINE_LENGTH);
                memset(menuElement.lcdBottomLine,0x20,LINE_LENGTH);

                if (langStatus==ENG)
                {
                        strcpy(menuElement.lcdTopLine,"VOLTAGE : ");
                        strcpy(menuElement.lcdBottomLine,"CURRENT : ");
                }
                else
                {
                        strcpy(menuElement.lcdTopLine,"GERILIM : ");
                        strcpy(menuElement.lcdBottomLine,"AKIM        : ");
                }

                adcVal = getValueOfADCChannel(ADC_V);
                adcVal2=getValueOfADCChannel(ADC_I);

        convertedVal=((((((double)adcVal*(double)1.31)/(26.5))*0.7948)+0.0515)*0.9419-
0.0232)-(0.1*adcVal2*CURRENT_CONSTANT);
                //convertedVal=((((double)adcVal*(double)1.31)/(26.5))*0.7948)+0.0515;
                //convertedVal=(((double)adcVal*5/1023)*(double)7.96);/*-
(0.1*adcVal2*((R3_I+R4_I+R5_I)/(R5_I*208)));*/
                numericData=lastSetVoltageVal;
                menuElement.menuType=SetVoltage;
                setDigitalPot();
                itoa(convertedVal,tempStr,10);
                strcat(menuElement.lcdTopLine,tempStr);
                strcat(menuElement.lcdTopLine,".");
                tempVal=(uint16)(convertedVal*100)-((uint16)convertedVal)*100;
                if (tempVal<10)
                        strcat(menuElement.lcdTopLine,"0");
                itoa(tempVal,tempStr,10);
                strcat(menuElement.lcdTopLine,tempStr);
                strcat(menuElement.lcdTopLine,"  V");

                adcVal = getValueOfADCChannel(ADC_I);
                convertedVal=(double)(adcVal)/117;
                convertedVal=convertedVal*((R3_I+R4_I+R5_I)/(R5_I));
                numericData=lastSetCurrentVal;
                menuElement.menuType=SetCurrent;
                setDigitalPot();
                itoa(convertedVal,tempStr,10);
                strcat(menuElement.lcdBottomLine,tempStr);
                strcat(menuElement.lcdBottomLine,".");
                tempVal=(uint16)(convertedVal*100)-((uint16)convertedVal)*100;
                if (tempVal<10)
                        strcat(menuElement.lcdBottomLine,"0");
                itoa(tempVal,tempStr,10);
                strcat(menuElement.lcdBottomLine,tempStr);
                strcat(menuElement.lcdBottomLine," A");
```

```
                menuElement.traceSelected=VoltageCurrent;
                menuElement.menuType=SeeVI;
                updateLCD=true;
        }
        else if (menuElement.traceSelected==Temperature)
        {
                convertedVal=getTemperature();
                itoa(convertedVal,menuElement.lcdBottomLine,10);
                strcat(menuElement.lcdBottomLine,".");
                itoa((convertedVal*100)-((int16)(convertedVal))*100,tempStr,10);
                strcat(menuElement.lcdBottomLine,tempStr);
                memset(tempStr,0,sizeof(tempStr));
                tempStr[0]=0xB2;
                tempStr[1]='C';
                strcat(menuElement.lcdBottomLine,tempStr);
                menuElement.traceSelected=Temperature;
                updateLCD=true;
        }
        else if (menuElement.traceSelected==None)
        {
                tempMenuType=menuElement.menuType;
                if (lastSetVoltageVal)
                {
                        menuElement.menuType=SetVoltage;
                        numericData=lastSetVoltageVal;
                        setDigitalPot();
                        menuElement.menuType=SetCurrent;
                        numericData=lastSetCurrentVal;
                        setDigitalPot();
                }
                menuElement.menuType=tempMenuType;
        }
                }
        numericData=tempData;

}

//returns current temperature
double getTemperature(void)
{
        uint16 adcVal;
        double tempVal, convertedVal;
        adcVal = getValueOfADCChannel(ADC_NTC);

        tempVal=(double)(adcVal)/205.62;
        convertedVal=(1/((0.000250752256770311)*log((RES1*tempVal/(4.98-
tempVal))/10000)+0.00335570469798658))-273;

        return (convertedVal);
}

void buzzerOn(void)
{
        BUZZER=LOW;
        is100msElapsed=false;
        while (!is100msElapsed);
        is100msElapsed=false;
        while (!is100msElapsed);
        BUZZER=HIGH;
}

double powerOf10(uint8 val)
{
        double result=1;
        for (uint8 i=0;i<val;i++)
                result *= 10;

        return (result);
}
```

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