Zařízení pro měření hemodynamických parametrů

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Abstrakt

Zařízení pro měření hemodynamických parametrů je komplexní zařízení umožňující synchronní snímání biologických signálů potřebných ke stanovení hemodynamických parametrů měřené osoby, především oscilometrických pulsací z manžet umístěných na paži a zápěstí, elektrokardiografického signálu (EKG) a fotoplethysmografického signálu (PPG). Oscilometrické pulsace je možné měřit jak při vypouštění manžet, což je při měření krevního tlaku běžné, tak ale i při jejich napouštění, což významně eliminuje artefakty způsobené deformací tkání.

The device allows the measurement of signals for determination of hemodynamic parameters, especially oscillometric pulsations from cuffs placed on the arm and wrist, electrocardiogram (ECG) and photoplethysmogram (PPG). Oscillometric pulsations could be measured both during inflating the cuffs as is usual, and during deflating the cuffs. It eliminates artefacts caused by tissue deformations.

Keywords:
krevní tlak, hemodynamické parametry, elektrokardiogram, fotoplethysmogram
blood pressure, hemodynamic parameters, electrocardiogram, photoplethysmogram

1 Zpráva

Návrh a realizace zařízení pro měření hemodynamických parametrů včetně diskuse zadávacích požadavků a možností realizovaného zařízení byly publikovány na konferenci 4th International Symposium on Applied Sciences in Biomedical and Communication Technologies (ISABEL 2011) v Barceloně, Španělsko a na mezinárodní konferenci Applied Electronics 2011 (APPEL 2011) v Plzni. Plné znění konferenčních příspěvků je nedílnou součástí této zprávy.

Výrobní dokumentace a fotografie realizovaného funkčního vzorku jsou uvedeny v příloze této zprávy.

2 Přílohy

1. Fotografie realizovaného přípravku, str. 11 a 12
2. Schéma zapojení, str. 13

Poděkování

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Measurement of Hemodynamic Parameters: Design of Methods and Hardware

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ABSTRACT

The paper deals with the design of method for primary screening of atherosclerosis based on hemodynamic parameters. The method combines sensing of blood pressure using two-cuffs system with sensing of plethysmography and electro-cardiography signals. The designed method provides not only the measurement of blood pressure as a standard parameter of cardiovascular system, but also the measurement of several hemodynamic parameters such as pulse wave velocity (PWV) or arterial stiffness index (ASI). The design and realization of the device for measuring parameters given above are also described in the paper.

Categories and Subject Descriptors

B.4.0 [**Input/Output and Data Communications**]: General; I.5.4 [**Pattern Recognition**]: Applications—*Signal Processing*

General Terms

Measurement, Design, Theory

Keywords

Hemodynamic Parameters, Atherosclerosis, Medical Electronics

1. INTRODUCTION

Cardiovascular diseases belong currently to the most frequent reasons of death. The significant disease of vessels system especially in Europe–American population is atherosclerosis [1]. This disease gradually produces irreversible changes of cardiovascular system. Unfortunately the diagnostics of the disease is very difficult in initial phases.

During the atherosclerosis lipids are attached on vessels walls, the elasticity and the diameter of vessels are significantly decreased. All these changes result in decrease of blood flow [2]. One of the manifestations of the atherosclerosis is ischemic disease. However immediate consequences of atherosclerosis could be many abrupt failures such as brain stroke or heart attack.

As it is well known the basic factors of atherosclerosis initialization are high age, smoking, failure of lipid metabolism, hypertension or diabetes mellitus.

Currently there are a few methods for relatively exact atherosclerosis diagnostics and for determination of vessels degradation degree. The most frequently used methods are measuring the ratio of systolic blood pressure on the ankle to systolic blood pressure on the arm, measuring of function and morphological changes of peripheral vessel walls, measuring of vessel walls compliance, measuring of coronary arteries calcification (calcium score), and finally the MRI of vessel walls. Not any one method could be easily used for wide population diagnostics, partly due to a difficulty of measurement, partly due to principal limitations of methods (such as limitation of methods infallibility for wide range of patients) and partly due to high costs of introduced methods.

It is evident that a suitable method has to be non-invasive with minimal stress for the patient, infallible for wide range of the patients, and inexpensive for frequent use in the health care system.

It seems that it is possible to measure any additional parameters during the oscillometric measurements of blood pressure with relatively easy changes in the measurement arrangement. The most important parameters are the hemodynamic parameters of the cardiovascular system, which could be used for primary screening of atherosclerosis [3, 4]. A highly important issue in this context is a regular and a periodic monitoring of blood pressure and hemodynamic

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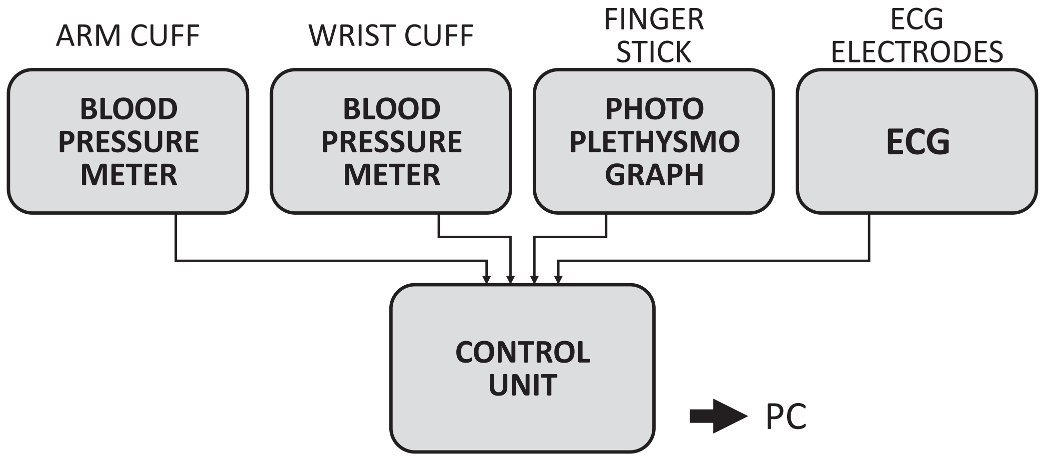

Figure 1: General Concept

parameters, especially PWV (pulse wave velocity) and AI (augmentation index).

Currently used automatic methods for measuring blood pressure have many imperfections of measuring on target group of patients such as patients with atherosclerosis, diabetes mellitus or preeclampsia. Frequent problems are high sensitivity for motion artifacts or low precision of measured values [5].

The auscultatory method for measurement of blood pressure (the method based on measurement of the Korotkoff sounds using the stethoscope) could be considered as the precise method. But unfortunately, the method could not be used for automatic measurements.

Regardless there are professional devices for measuring basic hemodynamic parameters such as ABI (ankle–brachial index; the ratio of the blood pressure in the lower legs to the blood pressure in the arms) [6], CAVI (cardio–ankle vascular index; an index reflecting the stiffness of the artery from the heart to ankles.) [7], AI (augmentation index; the proportion of central pulse pressure due to the late systolic peak) [8] or the change of the oscillation amplitude [9]. Unfortunately, all of the devices require precise measurement of the blood pressure. Introduced devices measure blood pressure using the oscillometric method, which is not suitable for patients with atherosclerosis and other diseases of cardiovascular system [10, 11]. It means the diagnostics of atherosclerosis using these devices is problematic in principle.

2. METHODS

Our approach is based on measuring selected hemodynamic parameters in conjunction with a precise measurement of the systolic blood pressure (SBP).

The high precision measuring of SBP is obtained using the standard oscillometric method (measuring the pulsations in arm cuff) in combination with measuring additional signals – oscillometric pulsations acquired in wrist cuff, plethysmography signal acquired using finger stick. In standard oscillometric method the mean arterial pressure (MAP) is only measured, the SBP and diastolic blood pressure (DBP) are computed using the 55/85 or similar methods[1].

The crucial problem of all these methods is the dependency of computed values on the patient. The methods are precise only for theoretical patient with good health and median characteristics, not for real patients. Our method solves this problem by combination of oscillometric pulsations in arm and wrist cuff with plethysmography signal obtained from the index finger in the same arm. The SBP is determined as a pressure in arm cuff during the deflating of cuff, when the first pulse in wrist cuff or in the plethysmogram has been achieved. It is a principal approach, because the SBP is not only computed, but measured directly. It means it is more precise than the standard oscillometric method. The method significantly decreases the patient dependency of the measured values.

For the estimation of atherosclerosis risk the following hemodynamic parameters have been chosen:

- PWV (pulse wave velocity),

  Pulse wave velocity (PWV), by definition, is the distance traveled by the wave divided by the time for the wave to travel that distance. Physically, the parameter PWV represents the velocity of the propagation of the pulse wave. The parameter is a highly reproducible parameter with strict correlation with occurrence of cardiovascular attacks [12, 13].

- AI (augmentation index),

  Augmentation index (AI) is defined as the proportion of central pulse pressure due to the late systolic peak, which is in turn attributed to the reflected pulse wave. The parameter AI is auxiliary parameter for atherosclerosis screening [14].

[1]For example, the commonly used 55/85 method derives the SBP and DBP from the amplitude of oscillations. The maximum amplitude of oscillations corresponds to mean arterial pressure (MAP). Systolic pressure is determined from the data already acquired. SBP can be determined by selecting the underlying pressure that corresponds to the amplitude of 55% of the maximum amplitude of oscillations (MAP) before the point of MAP. Furthermore, DBP is the underlying pressure when the envelope of oscillations has decreased to 85% of the maximal amplitude.

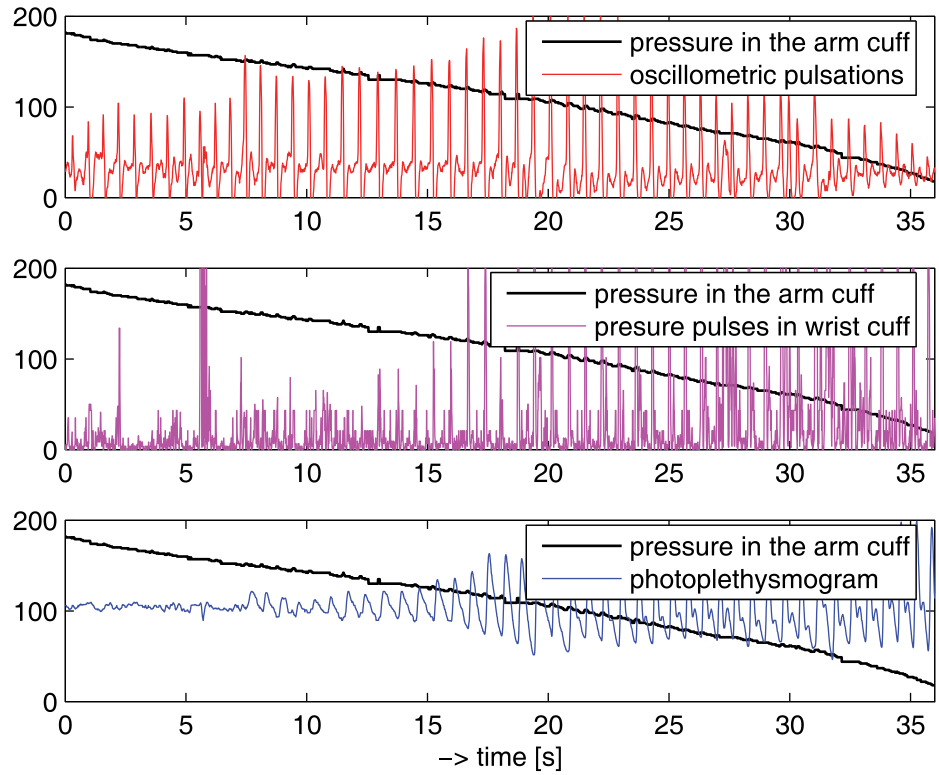

Figure 2: Example of Real Signals (M, 26 years, student)

- and ASI (arterially stiffness index).

  The parameter ASI is a measure of arterial stiffness or flexibility. The parameter ASI is in close connection with atherosclerosis [15, 16].

The PWV parameter could be determined using dual cuff system (combination of arm and wrist cuffs) or using signal from arm cuff and plethysmogram based on delay between systole on cuffs or plethysmogram. Furthermore, it seems that the more precise determination of PWV is possible with usage of ECG signal, which is significant for determination of the moment of the systole.

The AI and ASI parameters could be determined from the shape of oscillometric pulsations. It seems that the shape of pulsations depends on stiffness of arterial wall. The correlation between stiffness of arterial wall and atherosclerosis has been shown earlier [17].

3. HARDWARE REALIZATION

A special device has been designed for the described research. The device combines the dual–cuff blood pressure meter, plethysmograph and ECG. A general concept of the device is shown in Fig. 1.

The realization of blood pressure meter is very simple in principle. The meter consists of an air pump, controlled valve, pressure sensor (convertor of the air pressure to the voltage) and microprocessor. Inflating and deflating of the cuffs are controlled by the microprocessor. The processor also performs analog-to-digital conversion of output voltage from pressure sensor and calculations of required values [18].

The photoplethysmograph is realized very similarly as the pulse oximeter. It uses finger stick with LED and photodiode as a sensor of finger absorbance, which correlates with blood penetration of finger. The circuit design of plethysmograph consists of LED drivers, input amplifiers, sample/hold circuits and filters and processor unit with integrated A/D converters [19].

The realization of ECG is very common. It is designed as a standard well known ECG amplifier with feedback for the decreasing of power supply noise (50/60 Hz).

The device is controlled by a microprocessor, which performs not only the analog-to-digital conversion of all required signals and signal preprocessing, but also the data transfer to a PC via USB interface.

4. SOFTWARE SUPPORT

The hardware realization is completed with a software application. The application is developed in object language DELPHI, the USB communication is implemented in the same way as communication for a standard HID (human-interface-device). It means the device does not require a special driver for transfer the data to PC. The application is able to store data in CSV (comma-separated-values) format which is easily readable in Matlab or any other software for

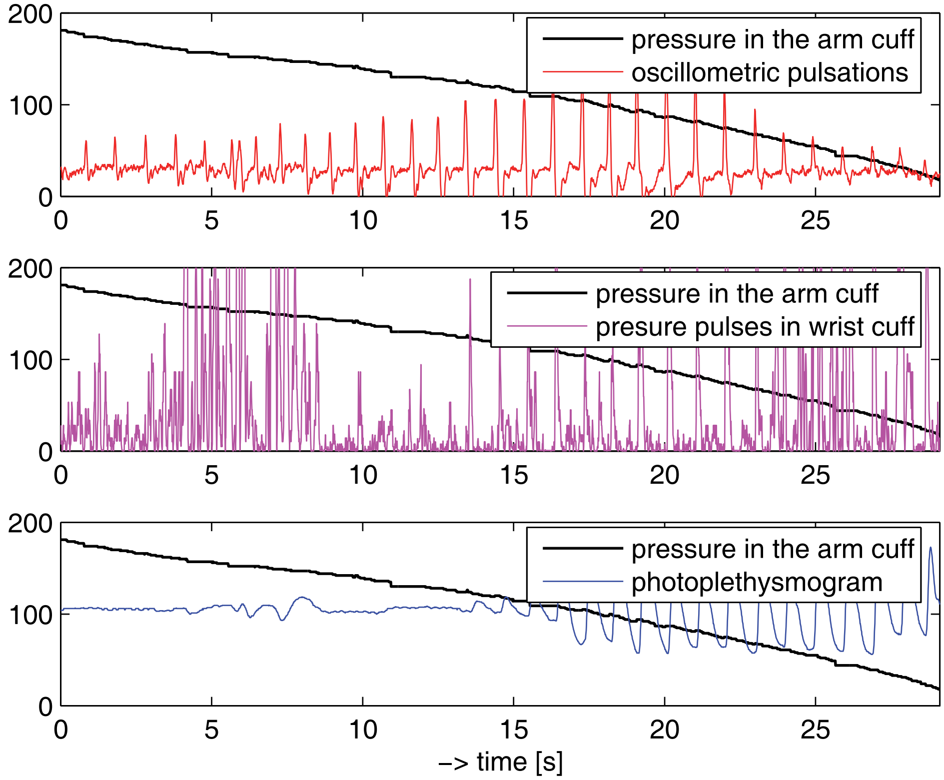

Figure 3: Example of Real Signals (W, 25 years, student)

engineering calculations. All the measured signals are sampled synchronously, of course. It is provided by firmware of control processor unit in the device directly.

5. RESULTS

The realized device has been used for measuring oscillations, wrist cuff pressure pulsations and plethysmogram on the test group of patients. The group consists of 25 patients recruited from the healthy young population for the test purposes. The signals have been stored in a signal database.

Examples of real signals are shown in Fig. 2 and Fig. 3. Each figure consists of three graphs. The upper graph shows the behaviour of oscillometric pulsations in arm cuff (AC component of pressure in the cuff) and the absolute pressure in the cuff (slowly decreasing behaviour). The middle graph shows the pressure pulses in wrist cuff (AC component; the cuff was inflated to subdiastolic pressure, about 40 mmHg). And finally, the bottom graph shows the photoplethysmogram, the signal from finger stick.

6. CONCLUSION

The summary of methods for atherosclerosis screening has been presented in this paper. In general, the methods based on oscillometric measurements of blood pressure are frequently used. These methods are relatively easy to use and cheap, unfortunately the results from these methods are not significant due to their low accuracy and also due to dependencies of obtained values on the patients.

The innovative method based on combination of dual–cuff blood pressure measuring system and the photoplethysmography and the ECG measuring has been described in this paper. The required device has been designed and realized and the initial tests have been performed.

The design of methods for evaluating signals and for determination of required hemodynamic parameters has to be done in next research.

7. ACKNOWLEDGMENTS

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Data Synchronization for Independent USB Devices

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***Abstract* – This paper deals with solving of the data synchronization problem during the data retrieval from independent devices. The data – oscillometry and photoplethysmography signals – are acquired using three independent measuring devices connected to PC via USB ports. The task is to obtain synchronized data. It means the problem is to sample signals in each device at the same time. The sampling of signals is triggered by internal counters independently in each device, the counters are commonly synchronized by general synchronization packets. The presented sampling method is robust and independent of the state of operating system on superordinate PC.**

I. INTRODUCTION

One of the most frequent affects of cardiovascular system is Atherosclerosis. It is a very dangerous disease, because it produces irreversible changes in cardiovascular system. Atherosclerosis causes that lipids are stored on the walls of blood vessels. It leads to decrease of vessels' elasticity, decrease of vessels' diameter and decrease of blood flow [1]. All of these consequences could be very dangerous for a patient with untreated Atherosclerosis. Unfortunately it is very hard to diagnose Atherosclerosis in an early phase.

The blood pressure measurement is a commonly used basic method for monitoring the cardiovascular system condition. It is used in both hospital and home care. The most frequently used method is non-invasive oscillometry based on evaluation of amplitude envelope of the oscillations in the sphygmomanometer cuff. This method is the standard method for automated blood pressure measurement.

It seems that the oscillometry method could be slightly rearranged. After the rearrangement the method would be able to provide not only information about blood pressure, but also other cardiovascular (hemodynamic) parameters. These could be used for early screening of Atherosclerosis. [2, 3]

The measurement of three signals – oscillometric pulsations from arm and wrist cuffs and photoplethysmographic curve – is required for accurate determination of blood pressure and other hemodynamic parameters. For measuring these signals, three independent modules could be used. The first one is a pulse oximeter that provides photoplethysmographic curve from the finger [4]. Next two modules are kits for non-invasive blood pressure measurement [5].

The modules are connected to a PC and the data from them are synchronized. Software application on the superordinate PC allows to control all devices via USB, synchronize the incoming data and save them into one file. It is possible then for example, to load the data and process the signals in MATLAB.

II. PRINCIPLE OF MEASUREMENT

Two types of measurement kits were used for acquiring the data.

For stopping the blood flow the blood pressure meter with an arm cuff has been used (see Fig. 1). It works in the principle of automated oscillometry measurement [5]. Second measurement kit is also a blood pressure meter with a wrist cuff. The cuff is inflated to pressure under diastolic pressure (typically 40 mmHg or 45 mmHg) and senses the pulses of blood flow on the wrist.

Both modules were developed for research in the field of signal processing and classification. They allow to measure and save raw data. Detailed description of the modules is in [5].

The third module is the module of pulse oximeter. It enables to sense the photoplethysmograph curve on a finger (see Fig 2). Unlike standard devices, the module allows to set some hardware parameters manually and to save raw data.

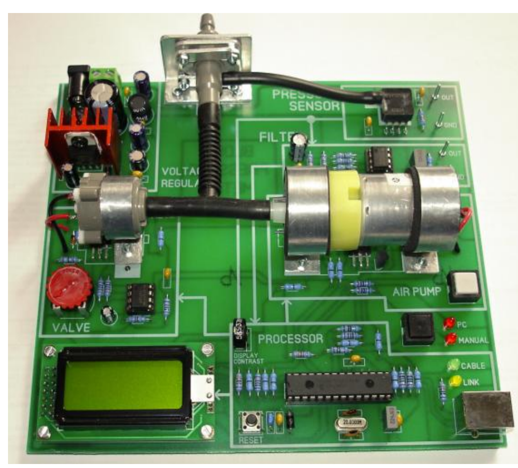

Fig.1: Blood pressure meter

Each module is connected to a PC via USB interface. One software application can control all modules, synchronize data and save them.

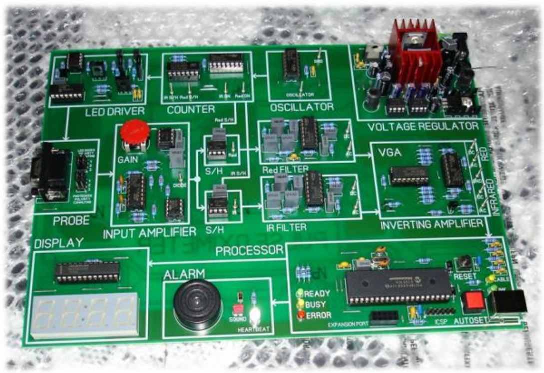

Fig. 2: Pulse oximeter

III. SYNCHRONIZATION

All three modules were developed as standalone modules. They communicate with superordinate PC via USB HID protocol as an independent devices, it means that no driver in PC is required. It is very convenient and easy for users, but it produces some problems. The main problem of using independent devices is to acquire synchronized data from all of them. For accurate processing and classification of obtained signals it is crutial to have signals sampled in the same time.

The solution of this problem has to fulfill some requirements. Firstly it has to be done without intervention to the current hardware realization and with minimal intervention to the current firmware. The second but not least requirement is to maintain compatibility with existing software applications.

Sampling frequency of signals in both types of modules is designed to 100 Hz, but internal interrupt loop runs in the frequency of 1 kHz at all modules. Each interrupt increments local variable. If the variable reaches 10, the analog values are read and sent to a PC and the local variable is set to zero. This solution gives the possibility to simple increase the sampling frequency, but it is not necessary because the maximal frequency component in measured signal is certainly lower than 50 Hz.

The synchronization of all modules is in general based on synchronization packets. Each synchronization packet is sent into all modules roughly at the same time.

Synchronization packet causes reset of local counters. Thus the accuracy of synchronization is 1 ms in total. An example of timing diagram from all modules before and after the synchronization packet is in the Figure 3. The upper part of figure shows the sequences of sampling pulses in non-synchronized devices, the lower part shows the sequences of sampling pulses in synchronized system.

We tested that Windows creates only very small delay to HID output packet (certainly less than 1 ms) in normal case. The problem can appear when you use HUB between modules and a PC. Windows XP SP2 and SP3 contain a bug on HID, which delays HID output report over interrupt OUT endpoint, just when a hub is inserted. For HID input, there is no delay in any Windows version. This problem is described in Microsoft Knowledge Base, article ID 940021 [6].

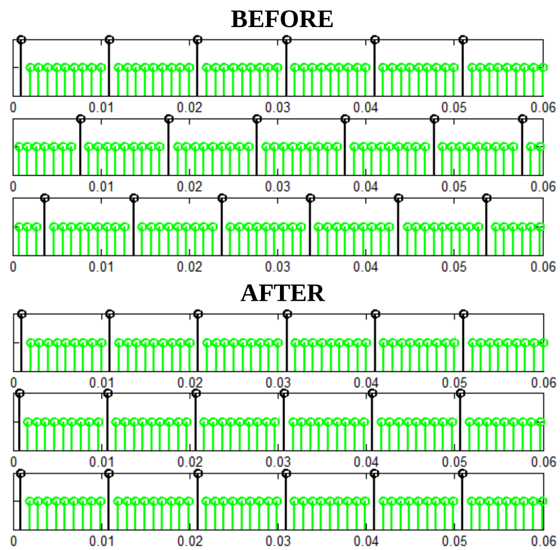

Fig. 3: Timing diagram, black (long) stem means time of reading analog value, green /short) stem is increment of local counter

IV. SOFTWARE

The hardware part is supported by a simple software application (see Fig. 4). The application controls all three modules separately.

Firstly, parameters of the pulse oximeter like red LED and IR LED light intensity and the gain of signals have to be set.

Next step is to inflate the wrist cuff to the pressure under diastolic pressure. This ensures that blood in the artery flows and we sense only pulses. After the measurement, the air valve is released and the cuff is deflated.

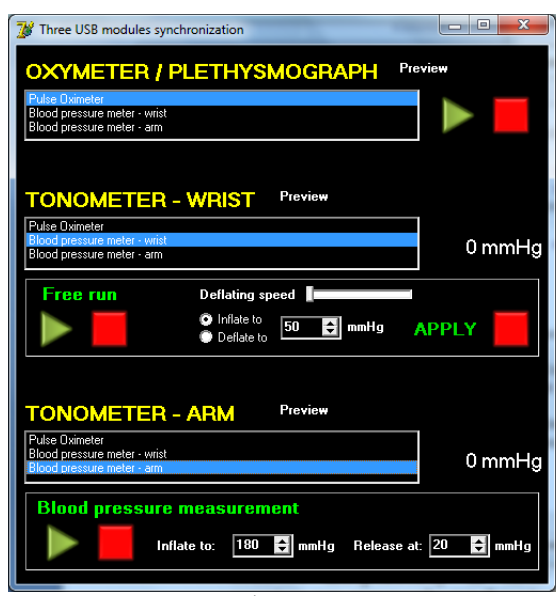

Fig. 4: Software application

Lastly, the measurement could be run. The arm cuff is inflated slightly above limit which is set in the application. It is usually pressure around 180 mmHg. Then, while the arm cuff is being deflated, the absolute pressure and oscillations are acquired.

After the measurement, the data are saved into a CSV file which can be loaded for example in MATLAB.

V. DATA VISUALISATION

Recorded signals could be visualized and analyzed using the supporting SW application (see Fig. 5). The figure shows that if the pressure in cuff is equal to the patient's systolic blood pressure, both the pulses in the wrist cuff and photoplethysmograph pulsations will appear. Systolic pressure can be calculated from oscillations in arm cuff, for example by the standard ratio method [7]. Systolic blood pressure can be determined by selecting the underlying pressure that corresponds to the amplitude of approximately 55% of the maxima amplitude of oscillations (which is mean arterial pressure, MAP) before the point of MAP. Using this method the diastolic blood pressure could be also determined as the underlying pressure that corresponds to the amplitude of approximately 85% of the maximum amplitude of oscillations after the point of MAP.

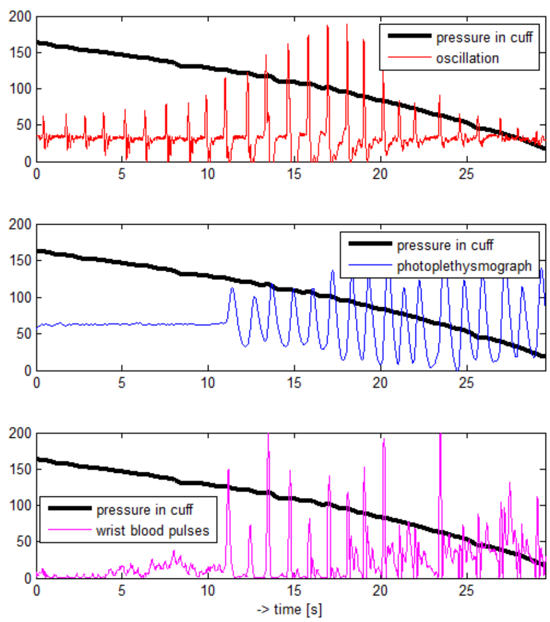

Fig. 5: Data visualization

VI. CONCLUSION

The principle of data synchronization of the independent USB devices was described. We used this method for synchronization of analog samples during a measurement of hemodynamic parameters of the cardiovascular system with minimal intervention on the current laboratory kits. From the visualization, we can see the systolic pressure measured with several automated methods. With this system, we can compare all methods in terms of their accuracy, repeatability and possibility of automated calculation. From all signals, we can also calculate several hemodynamical parameters of cardiovascular system like systolic and diastolic blood pressure, mean arterial pressure, pulse wave velocity, or augmentation index.

The developed application is very simple and allows to continuously read synchronized samples from all the devices. Raw data are saved into a text file that can be processed in MATLAB or another program.

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Přílohy

2.1 Fotografie realizovaného přípravku

2.2 Fotografie realizovaného přípravku

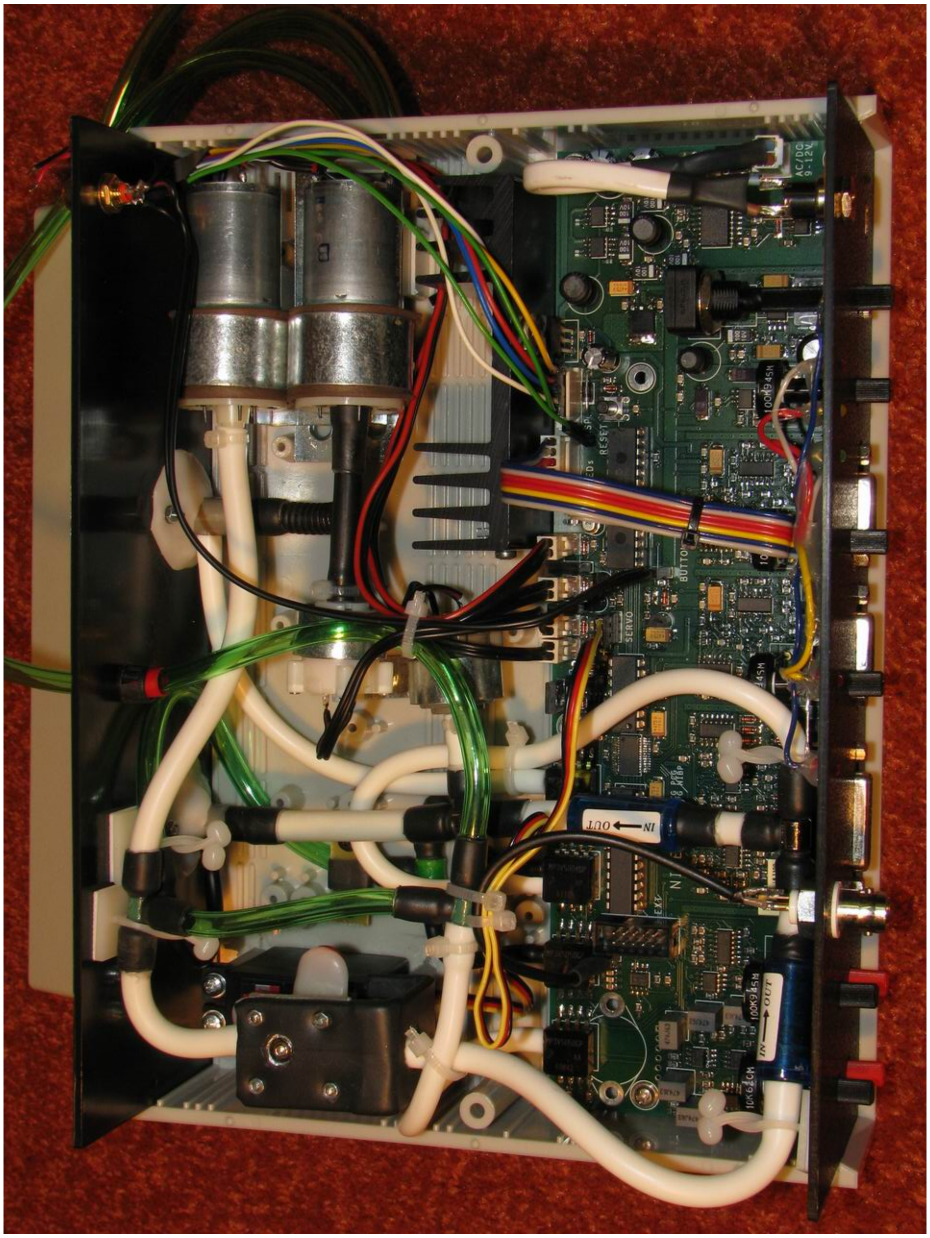
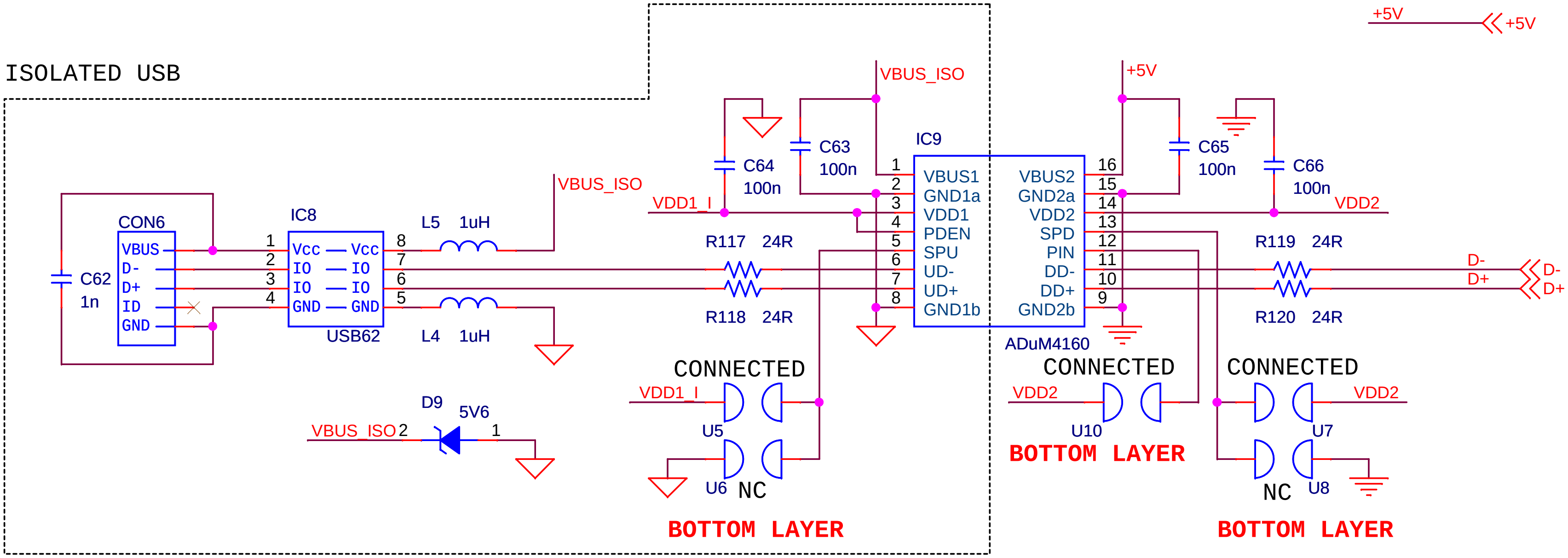


Schéma zapojení

1. USB připojení
2. napěťové regulátory
3. signálové zpracování
4. elektrokardiograf
5. fonokardiograf
6. plethysmograf (část I)
7. plethysmograf (část II)
8. snímání krevního tlaku
9. budiče vzduchových kompresorů a ventilů



Title	USB Isolation		
Size A	Document Number Dvorak Jan		Rev 1.0
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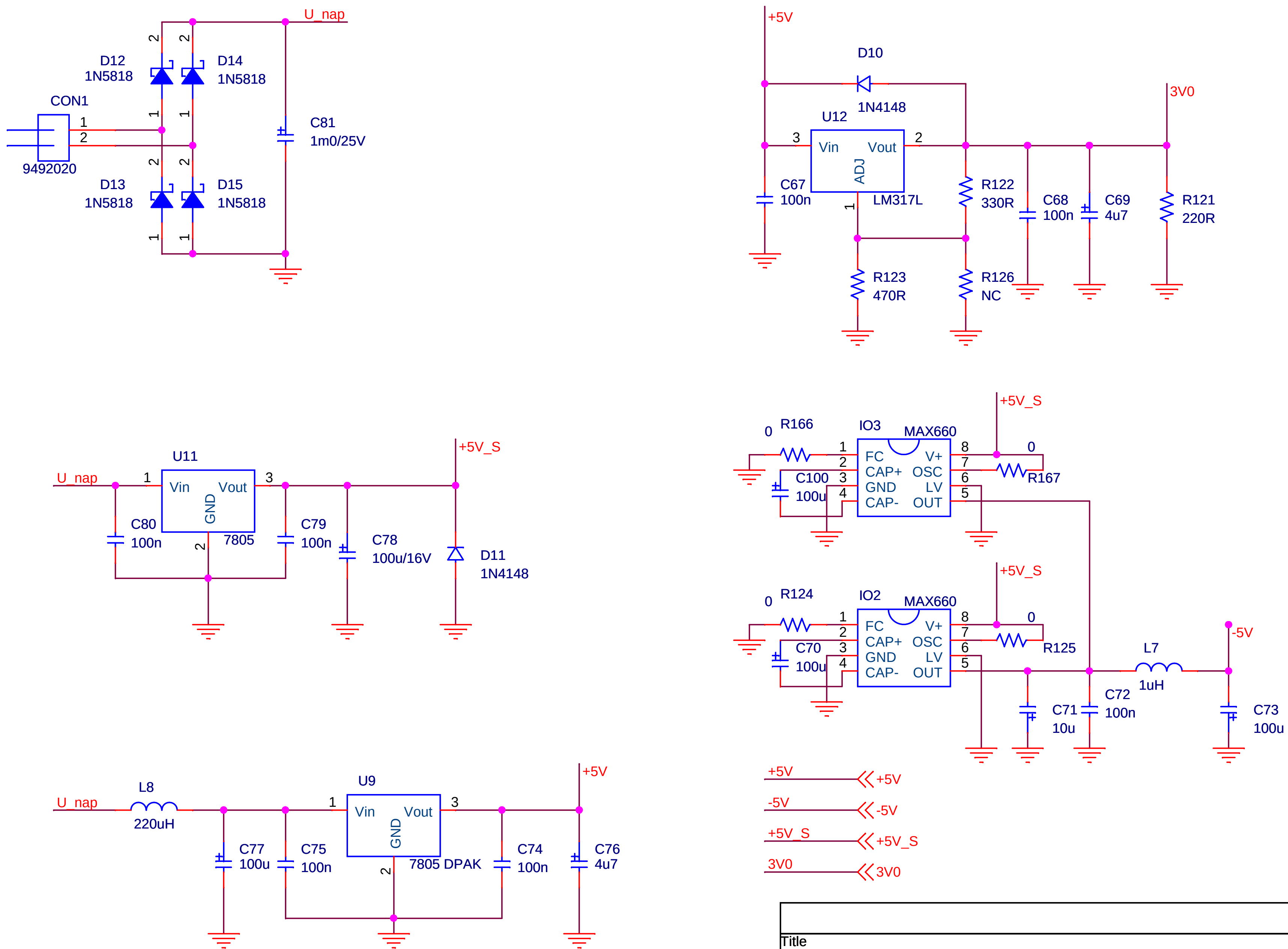

Title
Voltage regulators

Size	Document Number	Rev
A	Dvorak Jan	1.0

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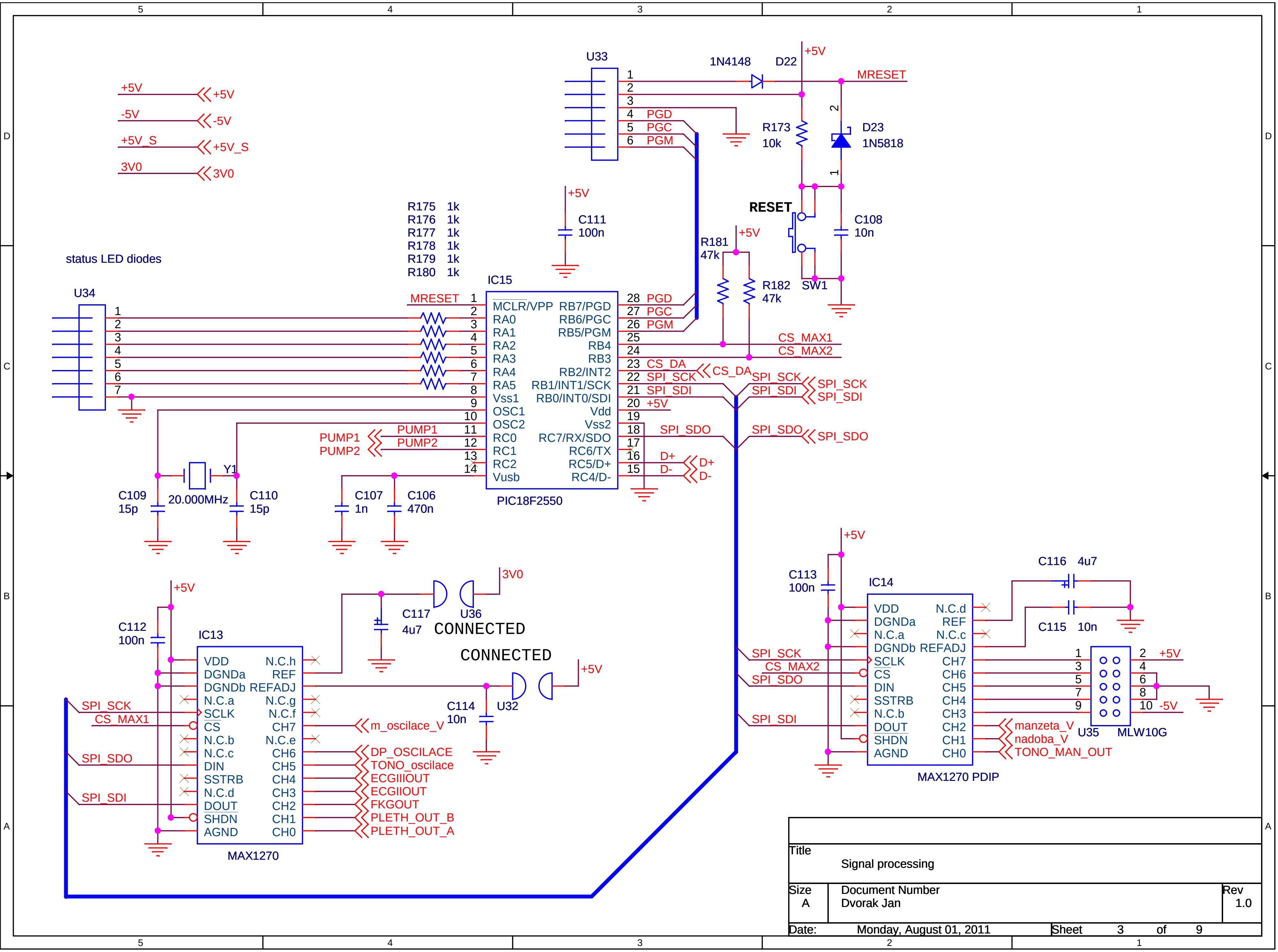

Title: Signal processing

Size	Document Number	Rev
A	Dvorak Jan	1.0

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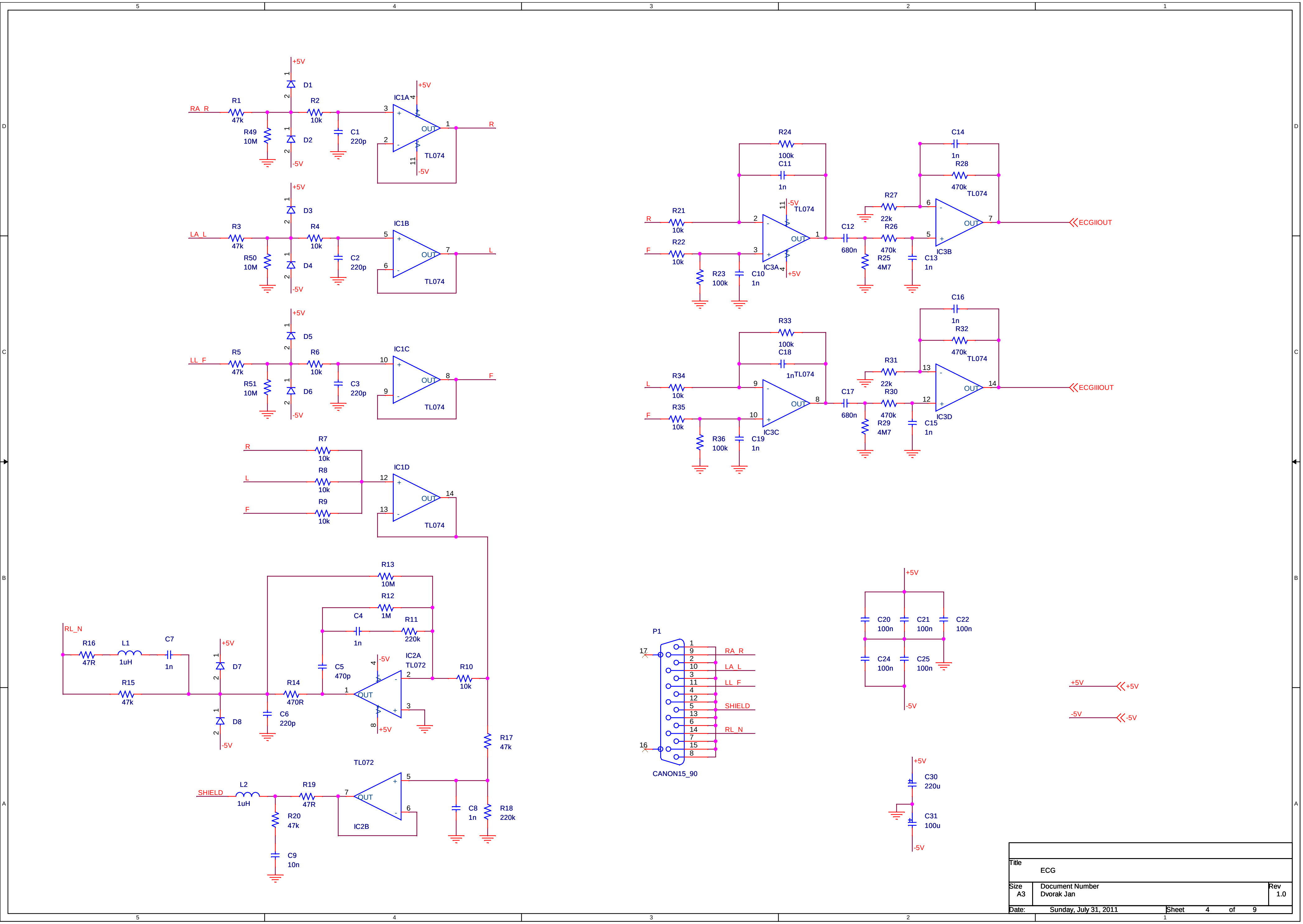

RA_R
R1 47k
R49 10M
D1
D2
R2 10k
C1 220p
IC1A
TL074
LA_L
R3 47k
R50 10M
D3
D4
R4 10k
C2 220p
IC1B
LL_F
R5 47k
R51 10M
D5
D6
R6 10k
C3 220p
IC1C
R7 10k
R8 10k
R9 10k
IC1D
RL_N
R16 47R
L1 1uH
C7 1n
R15 47k
D7
D8
C6 220p
R14 470R
R13 10M
R12 1M
C4 1n
R11 220k
C5 470p
IC2A
TL072
R10 10k
R17 47k
SHIELD
L2 1uH
R19 47R
R20 47k
C9 10n
IC2B
C8 1n
R18 220k
R21 10k
R22 10k
R23 100k
C10 1n
R24 100k
C11 1n
IC3A
C12 680n
R25 4M7
R26 470k
R27 22k
C13 1n
C14 1n
R28 470k
IC3B
ECGIIOUT
R34 10k
R35 10k
R36 100k
C19 1n
R33 100k
C18 1n
IC3C
C17 680n
R29 4M7
R30 470k
R31 22k
C15 1n
C16 1n
R32 470k
IC3D
ECGIIIOUT
P1
CANON15_90
SHIELD
RL_N
C20 100n
C21 100n
C22 100n
C24 100n
C25 100n
C30 220u
C31 100u
+5V
-5V
Title
ECG
Size
A3
Document Number
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1.0
Date: Sunday, July 31, 2011
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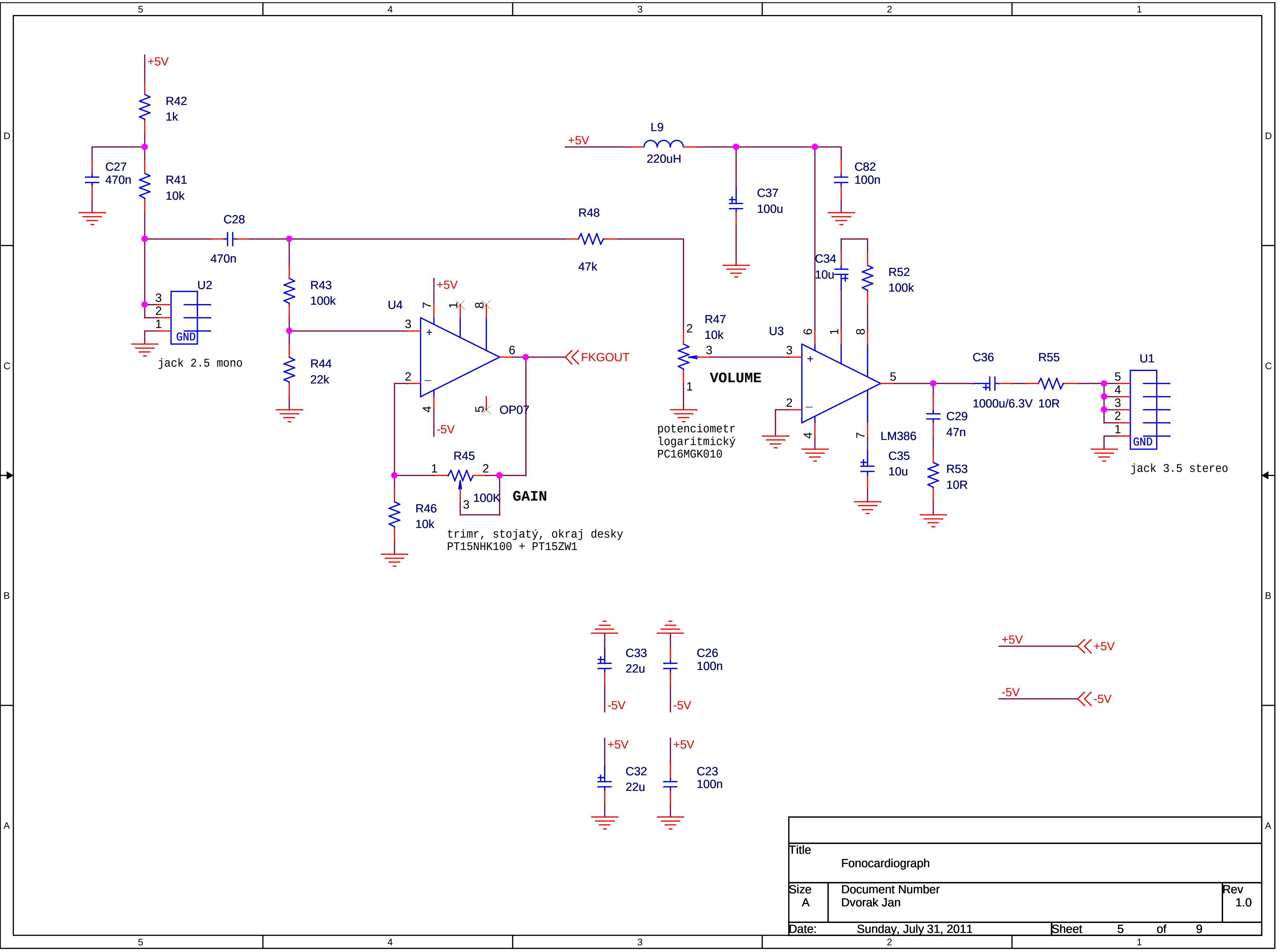

+5V
R42
1k
C27
470n
R41
10k
C28
470n
U2
3
2
1
GND
jack 2.5 mono
R43
100k
R44
22k
U4
7
1
8
3
2
6
4
5
+5V
-5V
OP07
FKGOUT
R45
1
2
3
100K
GAIN
R46
10k
trimr, stojatý, okraj desky
PT15NHK100 + PT15ZW1
+5V
L9
220uH
R48
47k
C37
100u
C82
100n
C34
10u
R52
100k
R47
10k
2
3
1
VOLUME
potenciometr
logaritmický
PC16MGK010
U3
6
1
8
3
2
5
4
7
LM386
C35
10u
C36
1000u/6.3V
R55
10R
C29
47n
R53
10R
U1
5
4
3
2
1
GND
jack 3.5 stereo
C33
22u
-5V
C26
100n
-5V
+5V
C32
22u
+5V
C23
100n
+5V
+5V
-5V
-5V
Title
Fonocardiograph
Size
A
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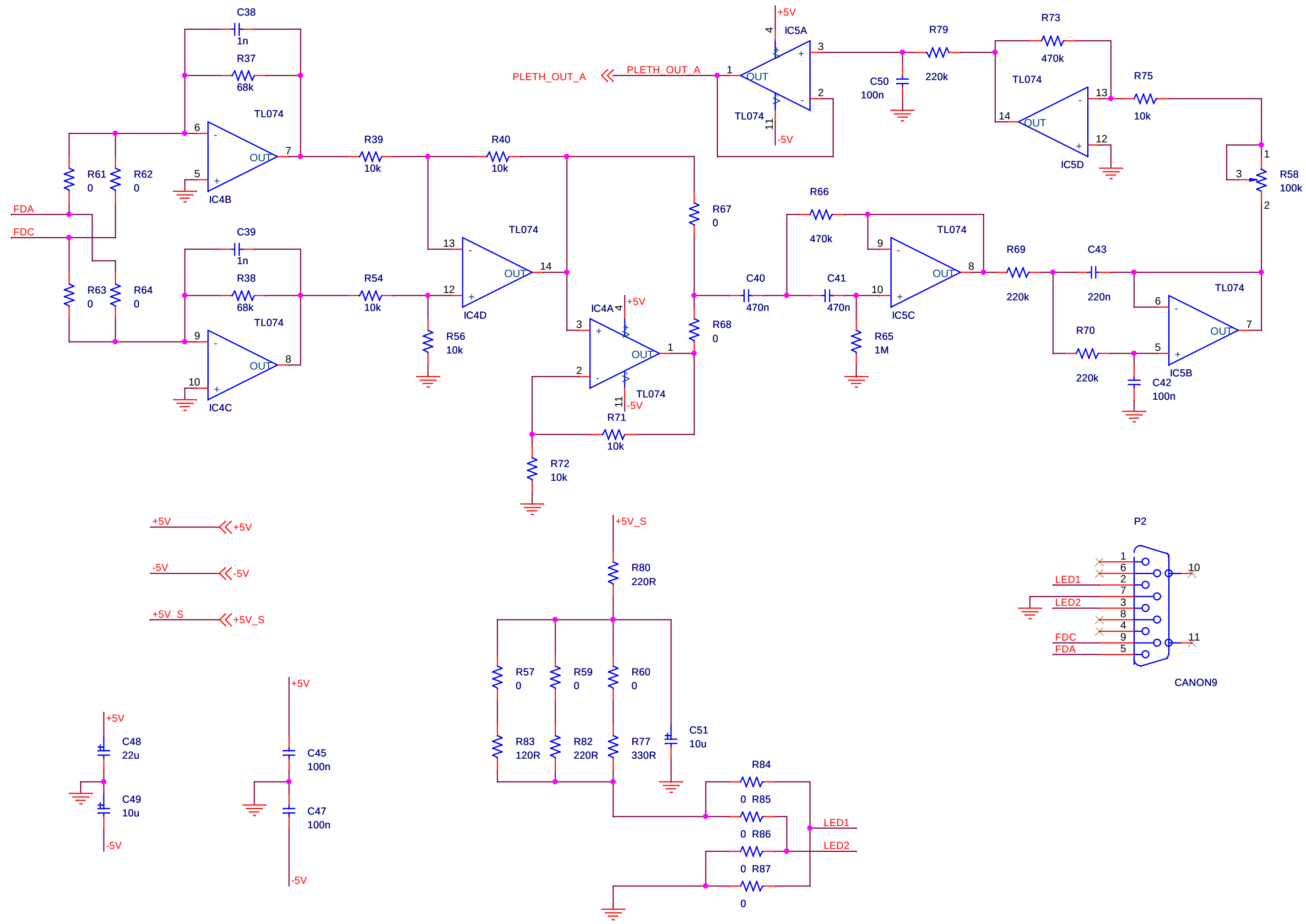

Title	Plethysmograph I.	
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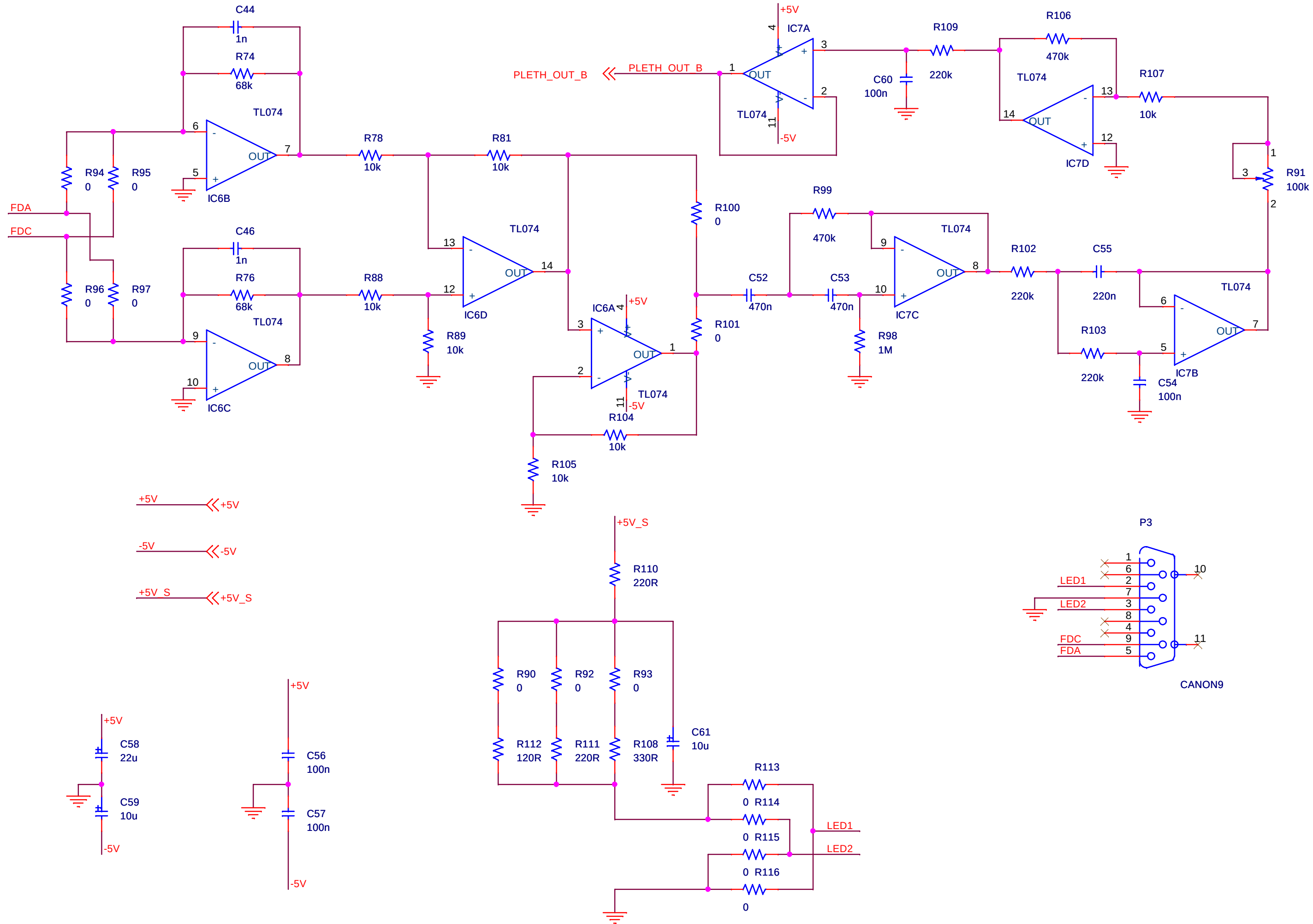

Title: Plethysmograph II.

Size	Document Number	Rev
A3	Dvorak Jan	1.0

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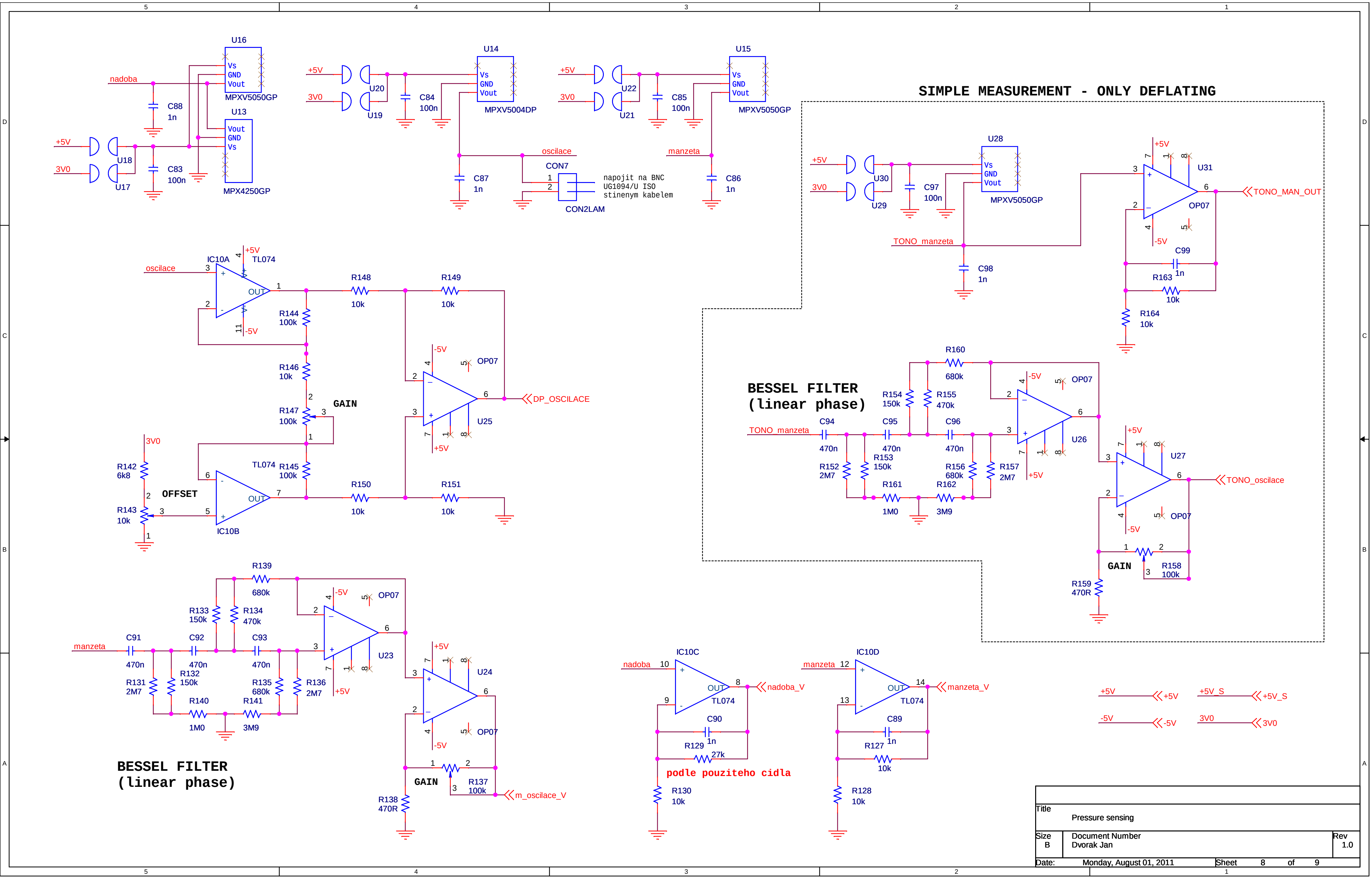

SIMPLE MEASUREMENT - ONLY DEFLATING
BESSEL FILTER
(linear phase)
BESSEL FILTER
(linear phase)
GAIN
OFFSET
GAIN
GAIN
podle pouziteho cidla
napojit na BNC
UG1094/U ISO
stinenym kabelem
U16 MPXV5050GP
U13 MPX4250GP
U14 MPXV5004DP
U15 MPXV5050GP
U28 MPXV5050GP
CON7 CON2LAM
IC10A TL074
IC10B
IC10C TL074
IC10D TL074
U23 OP07
U24 OP07
U25 OP07
U26 OP07
U27 OP07
U31 OP07
nadoba
manzeta
oscilace
TONO_manzeta
TONO_MAN_OUT
TONO_oscilace
DP_OSCILACE
m_oscilace_V
nadoba_V
manzeta_V
+5V
-5V
3V0
+5V_S
Title
Pressure sensing
Size
B
Document Number
Dvorak Jan
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1.0
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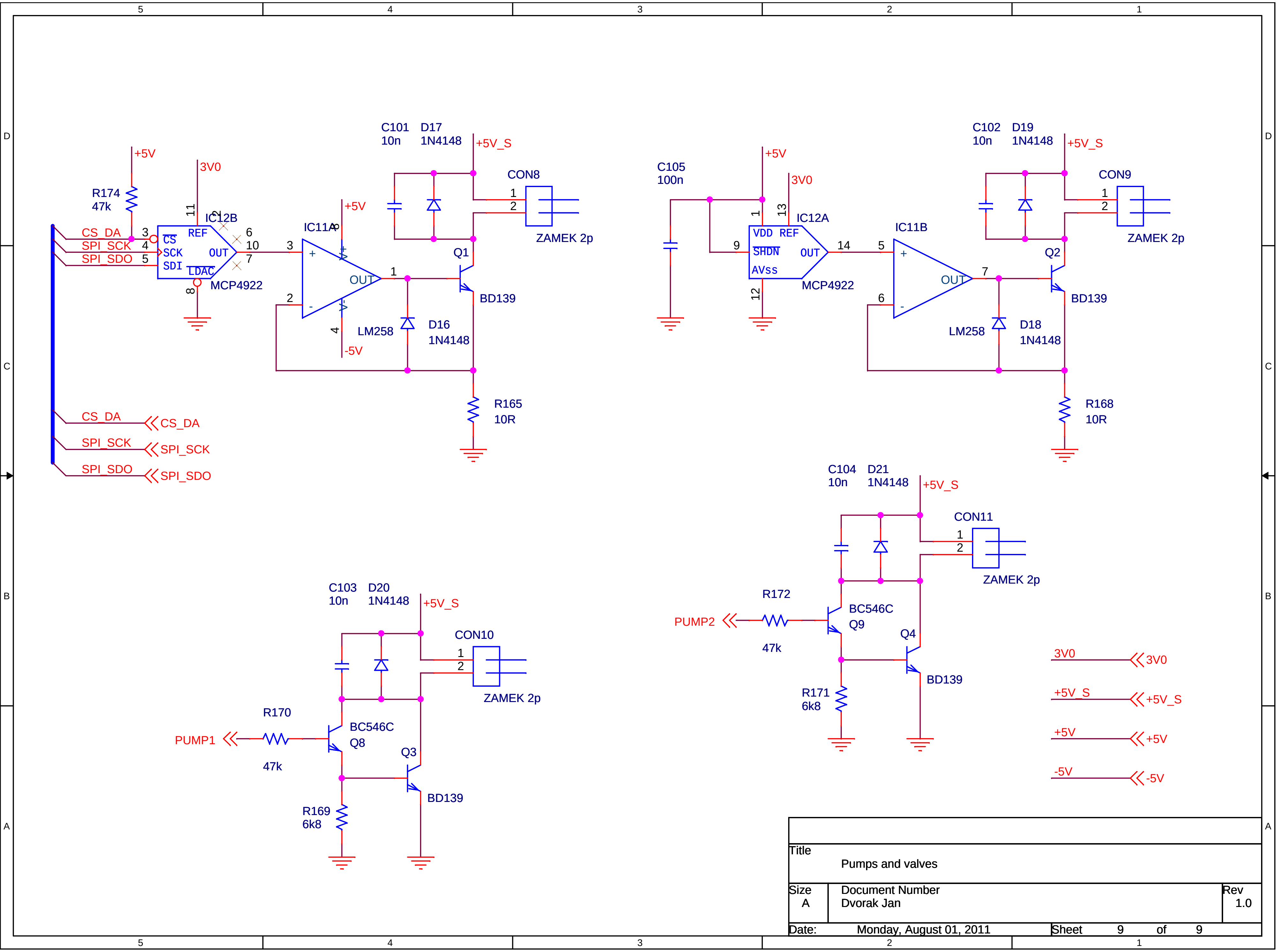

Title

Pumps and valves

Size	Document Number	Rev
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