ISSN 1726-5479

SENSORS & TRANSDUCERS

vol. 120
9 /10

TEDS Sensors, IEEE 1451 Standards

International Frequency Sensor Association Publishing

IFSA

Sensors & Transducers

Volume 120, Issue 9, September 2010 **www.sensorsportal.com** **ISSN 1726-5479**

Sensors & Transducers Journal (ISSN 1726-5479) is a peer review international journal published monthly online by International Frequency Sensor Association (IFSA).
Available in electronic and on CD.

Sensors & Transducers Journal

Contents

Volume 120
Issue 9
September 2010

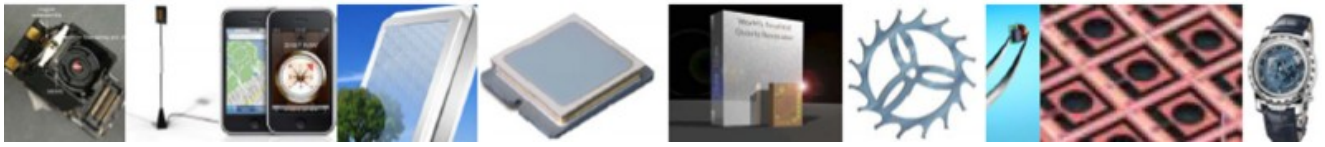
www.sensorsportal.com

ISSN 1726-5479

Research Articles

Authors are encouraged to submit article in MS Word (doc) and Acrobat (pdf) formats by e-mail: editor@sensorsportal.com
Please visit journal's webpage with preparation instructions: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm

International Frequency Sensor Association (IFSA).



The Sixth International Conference on Systems

ICONS 2011

January 23-28, 2011 - St. Maarten,
The Netherlands Antilles

Important deadlines:

Submission (full paper)	September 25, 2010
Notification	October 20, 2010
Registration	November 5, 2010
Camera ready	November 5, 2010

http://www.iaria.org/conferences2011/ICONS11.html

Tracks:
- Systems' theory and practice
- System engineering
- System instrumentation
- Embedded systems and systems-on-the-chip
- Target-oriented systems [emulation, simulation, prediction, etc.]
- Specialized systems [sensor-based, mobile, multimedia, biometrics, etc.]
- Validation systems
- Security and protection systems
- Advanced systems [expert, tutoring, self-adapting, interactive, etc.]
- Application-oriented systems [content, eHealth, radar, financial, vehicular, etc.]
- Safety in industrial systems
- Complex Systems

The Seventh International Conference
on Networking and Services

ICNS 2011

May 22-27, 2011 - Venice, Italy

Important deadlines:

Submission (full paper)	January 10, 2011
Notification	February 20, 2011
Registration	March 5, 2011
Camera ready	March 20, 2011

http://www.iaria.org/conferences2011/ICNS11.html

Tracks:
- ENCOT: Emerging Network Communications and Technologies
- COMAN: Network Control and Management
- SERVI: Multi-technology service deployment and assurance
- NGNUS: Next Generation Networks and Ubiquitous Services
- MPQSI: Multi Provider QoS/SLA Internetworking
- GRIDNS: Grid Networks and Services
- EDNA: Emergency Services and Disaster Recovery of Networks and Applications
- IPv6DFI: Deploying the Future Infrastructure
- IPDy: Internet Packet Dynamics
- GOBS: GRID over Optical Burst Switching Networks

The Third International Conference
on Bioinformatics, Biocomputational Systems and Biotechnologies

BIOTECHNO 2011

May 22-27, 2011 - Venice, Italy

Tracks:

A. Bioinformatics, chemoinformatics, neuroinformatics and applications
- Bioinformatics
- Advanced biocomputation technologies
- Chemoinformatics
- Bioimaging
- Neuroinformatics

B. Computational systems
- Bio-ontologies and semantics
- Biocomputing
- Genetics
- Molecular and Cellular Biology
- Microbiology

C. Biotechnologies and biomanufacturing
- Fundamentals in biotechnologies
- Biodevices
- Biomedical technologies
- Biological technologies
- Biomanufacturing

Important deadlines:

Submission (full paper)	January 10, 2011
Notification	February 20, 2011
Registration	March 5, 2011
Camera ready	March 20, 2011

http://www.iaria.org/conferences2011/BIOTECHNO11.html

Sensors & Transducers Journal, Vol. 120, Issue 9, September 2010, pp. 1-12

www.sensorsportal.com

Sensors & Transducers

ISSN 1726-5479

http://www.sensorsportal.com

Design of a Modular Signal Conditioning Circuit for Biopotential Sensors

Winncy Y. DU, Winston JOSE, Jake ASKELAND
Mechanical & Aerospace Engineering Department
San Jose State University, San Jose, California 95116, USA
Tel.: +1-408-924-3866, fax: +1-408-924-3995
E-mail: winncy.du@sjsu.edu

Received: 5 August 2010 /Accepted: 14 September 2010 /Published: 27 September 2010

Abstract: Biosignal conditioning (BC) is critical in biomedical instruments because it directly affects measurement accuracy, reliability, and repeatability. BC also presents a great challenge due to the small amplitude of biosignals and their ease of corruption with noise and other disturbances. This paper describes a modular BC system developed for biopotential sensors that can preserve useful information while removing unwanted noise and interference components. This BC circuit includes an instrumentation amplifier, an active 1st-order high-pass filter with Sallen-Key configuration, a 5^{th}-order low-pass Bessel filter, and a 2^{nd}-order Twin-T notch filter. The order of these filters and the associated components in each filter can be easily changed to adapt to different biosignals (*modular* feature). Data acquisition and sampling were performed using a USB6009 module with a built-in A/D converter. Testing of a real electrocardiogram on the designed signal conditioning circuit demonstrated comparable outputs to commercial devices. *Copyright © 2010 IFSA.*

Keywords: Biosignal conditioning, Modular circuit, ECG signal

1. Introduction

Biosignal conditioning (BC) has played a key role in biomedical instruments and biosensors. A well designed BC circuit can significantly improve measurement accuracy, reliability, and repeatability. However, BC also presents a great challenge because: (1) biosignals are inherently weak (0.001 mV-100 mV with a typical value of 1 mV. See Fig. 1), (2) they are easily corrupted with noise and other disturbances such as power line interference, impulse noise, electrostatic potentials, stray capacitance, and nearby electronic devices, and (3) biosignal artifacts can be introduced by subject

movement and muscle tension [2]. Fig. 1 shows the amplitude and frequency range of common biopotential signals [3]. Note that the electrocardiogram (ECG) signal is located in the middle range of the biosignals with amplitude of 0.1 mV-10 mV and frequency of 0.01 Hz-250 Hz. Therefore, the ECG signal, representative of a typical biosignal, was selected as the working model for design and implementation of the modular BC circuit.

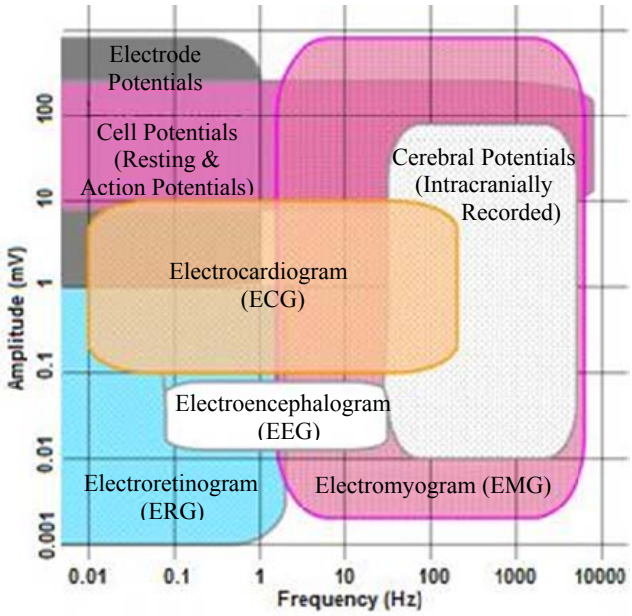


Fig. 1. Common biosignal amplitude and frequency ranges [3].

Several works on ECG signal conditioning are reported in the literature [4-[13]. Tenedero *et al.* [4] developed an ECG circuit with a bandwidth of 0.05 Hz - 40 Hz. An AD620 instrumentation amplifier (IA) was employed due to its low noise, low input bias current, low offset voltage, low power, and high Common Mode Rejection Ratio (CMRR) of 100 dB. Three filters were used between the IA and the data acquisition unit: an isolation amplifier (isolates 60 Hz power line and also protects the patient from cardiac shock), a high-pass filter with a cutoff frequency of 0.05 Hz, and a low-pass filter with a cutoff frequency of nearly 100 Hz. The sampling rate in the ADC (analog to digital conversion) for the ECG signal is 500 Hz. Fulford-Jones *et al.* designed a portable, low-power ECG system [5]. An operational amplifier (op-amp) embedded in a single INA321 chip was used due to its low noise and low power consumption. This op-am has a CMRR of 94 dB. A high-pass feedback filter corrects any DC shift occurring over time. Their ADC sampling rate is 120 Hz. Matviyenko [6] used a CY8C27443 microcontroller for ECG signal acquisition and processing. The IA embedded in the controller has a CMRR of 60 dB. According to the author, this low CMRR was acceptable due to the unique design which placed a differential low-pass filter before the IA to reduce radio frequency interference (RFI), because RFI error cannot be filtered out after the ECG signal has been rectified by the IA. A 2 kHz cutoff frequency high-pass filter was placed at the output of the IA. A buffer amplifier and an inverting amplifier were also used to cancel the RFI interference. The ADC sampling rate is 240 Hz.

ECG conditioning circuits from two industry leaders, *Texas Instruments* (TI) [7] and *Analog Devices Inc.* (AD) [8], were also reviewed. TI's circuitry features an INA321 IA with several unique features: a power down mode that shuts down the circuit when the supplied current is less than 1mA (for power saving), embedded op-amps in the microcontroller, a feedback loop that maintains a constant DC level, and a 512 Hz sampling rate. Further filtering was digitally implemented to remove power line noise

and to provide a pass band of 6 Hz-30 Hz. In AD's design, the ECG circuit uses AD's AduC842 (an integrated "system on chip") to perform amplification, digital filtering, and A/D conversion.

2. Obtaining an Real ECG Signal

An Electrocardiogram (ECG) is a small electric wave generated during heart activity, usually recorded by electrodes placed at specific points on the body. Three limb leads are commonly used to construct an *Einthoven's triangle* (see Fig. 2) [15]. An ECG wave can be recorded by placing leads at electrically equidistant points on the body from the heart, thus maximizing the potential difference between leads [16].

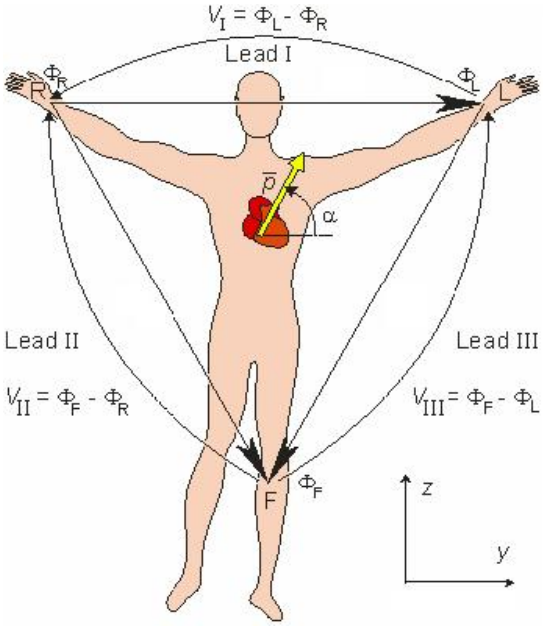


Fig. 2. Einthoven's triangle and limb lead configuration (from [15]).

The three leads are configured as:
Lead I: positive electrode on the left arm (*L)*, negative electrode on the right arm (*R*);
Lead II: positive electrode on the left leg/foot (*F)*, negative electrode on the right arm (*R*);
Lead III: positive electrode on the left leg/foot (*F)*, negative electrode on the left arm (*L*).

V_I, V_{II}, and V_{III} denote the voltage of Lead I, Lead II, and Lead III respectively. Φ_L, Φ_R, and Φ_F are the voltage potentials at the points *L*, *R*, and *F* respectively. The *Cardiac Vector*'s magnitude $|\overline{P}|$ and direction α can be expressed by [16]:

$$|\overline{P}| = 2\sqrt{(V_I^2 + V_{II}^2 - V_I V_{II})/3}\,, \tag{1}$$

or

$$|\overline{P}| = 2\sqrt{(V_I^2 + V_{III}^2 + V_I V_{III})/3}\,, \tag{2}$$

$$\alpha = \tan^{-1}\left((V_I - 2V_{II})/(\sqrt{3}V_I)\right), \tag{3}$$

or

$$\alpha = \tan^{-1}\left((V_{II} + V_{III})/(-\sqrt{3}V_I)\right), \tag{4}$$

For accurate recording of cardiac signals, the bandwidth of the ECG recording system is very important. The American Heart Association (AHA) recommends a minimum bandwidth of 150 Hz for children between the ages of 12 to 16 years; and a minimum bandwidth of 125 Hz for adults [17].

The electrode used for recording the ECG signal is silver-silver chloride (Ag-AgCl). It has the following important features: (1) it is non-polarizable, meaning that current flows freely across the electrode junction. No electrons accumulate in the junction as in a polarizable electrode; (2) it generates less noise (<10 μV). The Ag-AgCl electrode has an AgCl layer deposited on an Ag plate. The Cl^- ions move in the human body (in the electrolyte). In the AgCl layer, these Cl^- ions are converted to electron flow in the Ag plate and these electrons are sent out through a connecting wire. This Ag-AgCl structure reduces the DC offset potential to a very small value. A conductive gel is used to minimize the disturbance of the double charge layer.

3. Signal Conditioning Circuit Design and Implementation

3.1. Overall Structure of the BC Circuit

The typical ECG signal obtained from the Ag-AgCl electrodes is 1 mV in amplitude and it is easily corrupted by noise. The main sources of noise include respiration, motion artifacts, muscle contraction, electrode contact noise, power line interference, RFI, and electromagnetic interference (EMI). In certain situations, noise can completely override the ECG waves and make the amplified signal useless. To effectively remove unwanted noise and preserve the useful components of ECG signals, the following biosignal conditioning schemes and sequence were developed:

1. Amplify the raw ECG signal with an instrumentation amplifier to raise the signal voltage level;
2. Use a high-pass filter to eliminate DC offset developed between electrodes;
3. Apply a low-pass filter to remove high frequency noise;
4. Filter out power line interference using a notch filter;
5. Convert the filtered analog ECG signal to digital for computer display and/or further digital signal processing and analyses.

To ensure the BC circuit design could be adapted to condition other biosignals with different magnitudes and frequencies, several modular boards which make it easy to change, modify, or insert electronics were developed or employed. A block diagram of the BC circuit is shown in Fig. 3. The following sections will discuss component functions and features.

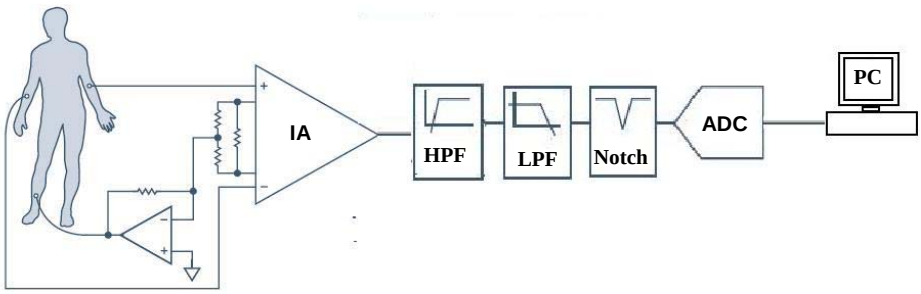


Fig. 3. Overall block diagram of the ECG conditioning circuit.

3.2. AD8220 Instrumentation Amplifier

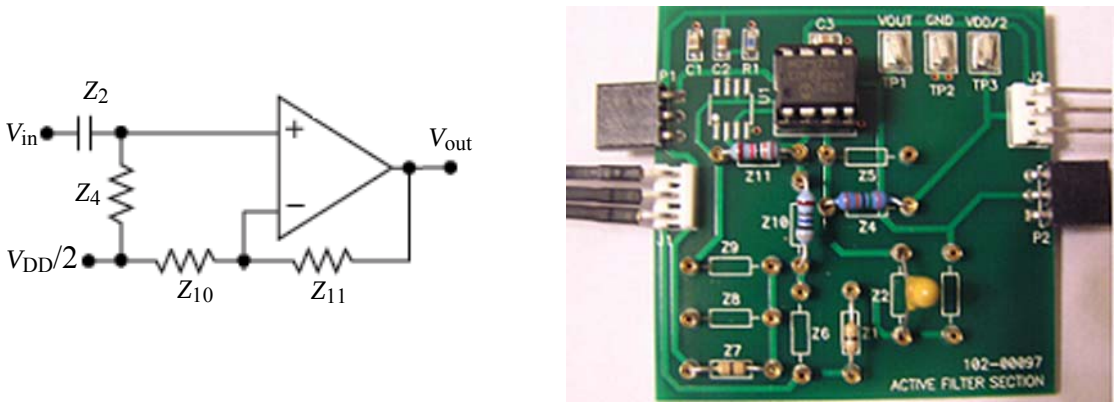
An *Analog Devices*' AD8220 instrumentation amplifier (IA) and an evaluation board were used first to amplify the ECG signal obtained from the potential difference between the right and left arm electrodes (Lead I in Fig. 2). The AD8220 was selected due to its wide operating range in noisy environments, low input bias current of 10 pA, high CMRR with little effect from RFI, and adjustable gain [18]. The evaluation board was used for easy prototyping.

Since the voltage source V_s of the AD8220 is ±5V, the gain G was conservatively set at 19 to avoid both output voltage saturation, although a higher gain is achievable with this IA. At this setting, a typical 1.0 mV ECG signal is amplified to 19.0 mV – well below the V_s level. The gain resistor R_g is calculated by [19]:

$$R_g = \frac{49.4\,\text{k}\Omega}{G-1} = \frac{49.4\,\text{k}\Omega}{19-1} = 2.74\,\text{k}\Omega \tag{5}$$

3.3. 1st-order Active High-pass Filter (HPF)

After the ECG signal is amplified, it passes through a non-inverting active high-pass filter (HPF) to eliminate DC offset developed between the electrodes and further amplify the ECG signal. This active HPF consists of a MCP6271 op-amp, a RC filter (capacitor Z_2 and resistor Z_4) and the gain resistors Z_{10} and Z_{11} arranged in a Sallen-Key configuration (Fig. 4 (a)). The circuit board is shown in Fig. 4 (b).



(a) (b)

Fig. 4. (a) 1st-order HPF with Sallen-Key configuration; (b) Circuit board of the HPF filter.

Since an ECG signal has a frequency range of 0.01-100 Hz, to ensure the most useful ECG signals pass through the HPF, a cutoff frequency f_c of 0.033 Hz, instead of 0.01 Hz, was chosen in consideration of manufacturing tolerances for electronic components. Z_2 was set to 6.8 μF for a faster response. Therefore, the resistor Z_4 has a value of:

$$Z_4 = \frac{1}{2\pi Z_2 f_c} = \frac{1}{2\pi(6.8\times10^{-6})(0.033)} = 710\,\text{k}\Omega \tag{6}$$

In addition, Z_{10} and Z_{11} were set to 806 Ω and 13 kΩ respectively. The resulting HPF gain, G_{HPF}, is:

$$G_{HPF} = 1 + \frac{Z_{11}}{Z_{10}} = 1 + \frac{13000}{806} = 17.13 \tag{7}$$

3.4. 5th-order Active Bessel Low-pass Filter

After passing through the HPF, the ECG signal is sent to a low-pass filter (LPF) to remove its high frequency noise components. 160 Hz was chosen as the cutoff frequency based on the normal ECG frequency range as well as the AHA guidelines for minimum ECG frequency bandwidth. The LPF is a cascaded 5th-order active Bessel filter which has excellent transient and linear phase response [20]. In comparison, other filter types, like the Chebychev, have overshoot (ripple) in their passband magnitude response and transient response. To achieve modularity, an active filter kit from *Microchip Technology* was employed for the filter setup. A total of three active filters were needed to form this 5th-order Bessel filter (see Fig. 5).

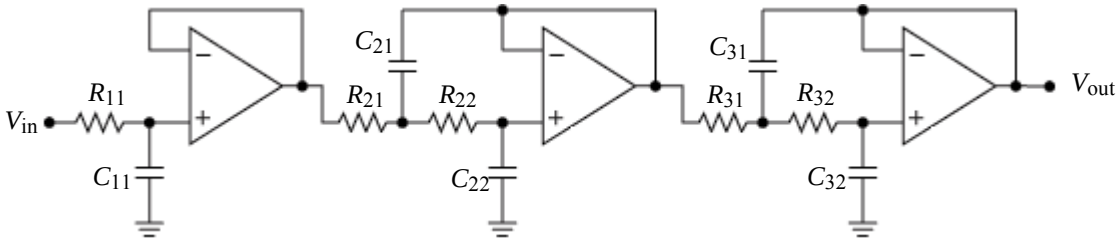


Fig. 5. Circuit diagram of the 5th-order active Bessel LPF.

The first filter is an active 1st-order LPF which has a real pole in its transfer function; the second and the third filters both have 2nd-order Sallen-Key topologies (each has a pair of complex conjugate poles in their transfer function). All three filters use unity gain (the Sallen-Key topology inherently has excellent gain accuracy as a unity-gain buffer). The unity gain configuration also requires less components – two resistors versus four resistors in non unity-gain designs, thus reducing thermal noise caused by resistors. The resistors and capacitors in the LPF were determined as follows, considering Filter 2 first:

1. Set f_c = 160 Hz:

$$f_c = \frac{1}{2\pi\sqrt{R_{21}R_{22}C_{21}C_{22}}} = 160 \text{ Hz} \tag{8}$$

2. Let m be the ratio of R21 and R22, n the ratio of C21 and C22, i.e.:

$$\begin{cases} R_{21} = mR \\ R_{22} = R \end{cases} \qquad \begin{cases} C_{21} = nC \\ C_{22} = C \end{cases} \tag{9}$$

3. Let Q-factor = 1 (for better filter performance at cutoff frequency without significant overshoot), i.e.,

$$Q = 1 = \frac{\sqrt{R_{21}R_{22}C_{21}C_{22}}}{C_{22}(R_{21} + R_{22})} = \frac{\sqrt{mn}}{m+1} \tag{10}$$

4. Choose m and determine n based on Q setting,
If $m = 1$, then from (10) $n = 4$.

5. Select C and calculate R based on f_c:
C should not be too small since low capacitor values can result in significant errors due to parasitic capacitance. Chose $C = 0.068$ μF, thus:

$$\begin{cases} C_{21} = 4(0.068) = 0.272 \ \mu\text{F} \\ C_{22} = 0.068 \ \mu\text{F} \end{cases} \tag{11}$$

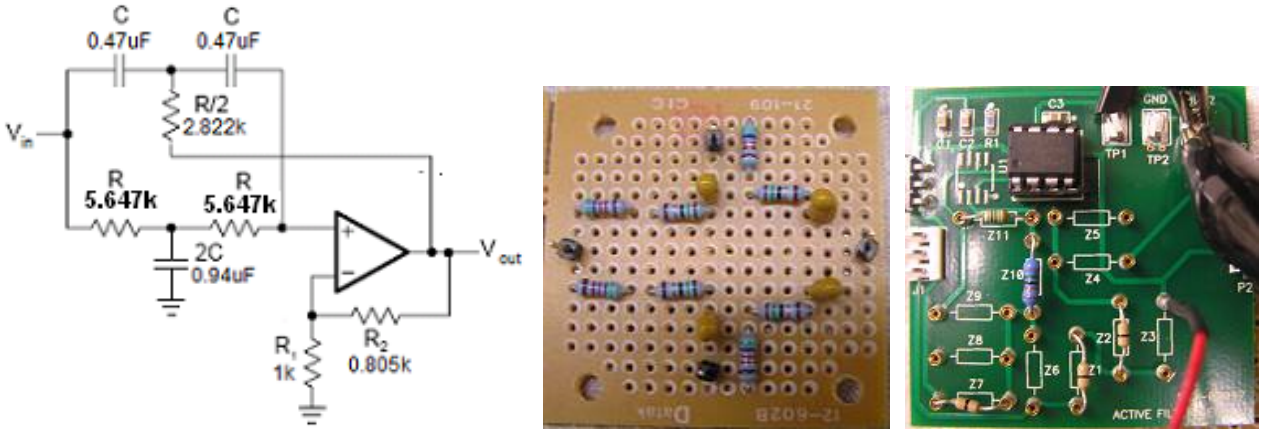
From equation (8),

$$R = \frac{1}{2\pi C f_c \sqrt{mn}} = \frac{1}{2\pi(0.068\times10^{-6})(160)\sqrt{(1)(4)}} = 7.318 \ \text{k}\Omega \begin{cases} R_{21} = mR = (1)(7.318) = 7.318 \ \text{k}\Omega \\ R_{22} = R = 7.318 \ \text{k}\Omega \end{cases}$$

Similarly, Filter 1 can be designed by letting $f_c = 160$ Hz, $Q = 1$, $n = 4.5$, $m = 2$, $C = 0.068$ μF, and calculating $C_{11} = 0.068$ μF, $R_{11} = 14.628$ kΩ; Filter 3 designed as $C_{31} = 0.306$ μF, $C_{32} = 0.068$ μF, $R_{31} = 9.752$ kΩ, and $R_{32} = 4.876$ kΩ. All op-amps in the LPF are MCP6271. This CMOS chip has a 2 MHz *Gain Bandwidth Product* (GBWP) and a 65° phase margin. It also supports rail-to-rail input and output swing [21].

3.5. Notch/Band-reject Filter

A *notch* or *band-reject* filter is typically used in biomedical instrumentation to suppress a certain frequency or range of frequencies in signals. The 60 Hz power field interference is still left in the ECG signal and needs to be rejected. This requires a small transition bandwidth or high Q factor to achieve the steeper roll-off. A Twin-T notch filter is one of the few RC networks capable of providing an infinite deep notch at a particular frequency. Two "T" shape RC filters combined with a MCP6271 op-amp, as shown in Fig. 6a, form an active notch filter. The Q factor can be raised from the usual 0.3 to 2.5 (a Q factor of 50 or more is achievable). Further, the op-amp provides low output impedance and high input impedance, making it possible to use large resistance values in the "T"' so that only small capacitors are required, even at low frequencies.



(a) (b) (c)

Fig. 6. The Twin-T notch filter to remove 60 Hz powerline noise (a); Notch filter circuit board: passive portion (b); and the active portion (c).

With f_n = 60 Hz and C = 0.47 μF, the resistor value in the filter is:

$$R = \frac{1}{2\pi f_n C} = \frac{1}{2\pi(60)(0.47\times10^{-6})} = 5.647\,\text{k}\Omega$$

Another advantage of the Twin-T configuration is that the quality factor, Q, can be altered via the inner gain G without modifying the notch frequency f_n. To achieve a Q factor of approximately 2.5, resistances of R_1 = 1.0 kΩ and R_2 = 805 Ω were chosen,

$$Q = \frac{R_1}{2(R_1 - R_2)} = \frac{1\times10^3}{2(1\times10^3 - 805)} = 2.564$$

The resulting filter gain is:

$$G = 1 + \frac{R_2}{R_1} = 1 + \frac{806}{1000} = 1.806$$

The designed notch filter is shown in Fig. 6 (b) and (c). Fig. 6 (b) shows the passive portion of the Twin-T filter, while Fig. 6(c) shows the active portion of the filter. The resistors placed in series on the passive portion provide a total resistance of 5.647 kΩ; while the two resistors, R_1 and R_2, on the active filter board set the Q factor and gain G of the filter. A +5 V power supply is provided to the MCP6271 (similar to V_{dd} in an LPF circuit); all grounds on both the passive and active boards are connected to a 2.5 V reference (similar to $V_{dd}/2$ in an LPF circuit).

3.6. Right Leg Drive Circuit

A right leg drive circuit is used to cancel the common-mode signal between the left and right arm electrodes by inverting, amplifying, and then feeding the signal back to the body through the right leg electrode. As shown in Fig. 7, there are three leads connected to the body: a left arm lead, a right arm lead, and a right leg lead. Two AD708 dual op-amps are used: the first one acts as a buffer with a unity gain, and the second one acts as an inverter and amplifier (i.e., inverting amplifier). A gain of 68.19 was achieved with the 866 kΩ and 12.7 kΩ gain resistors (i.e., G = 866 ÷ 12.7 = 68.19). A 0.068 μF capacitor in the feedback loop was used to maintain the stability of the right leg drive circuit. The 499 kΩ resistor at the output end limits the current driven to the body for patient protection. This right leg drive circuit was built on a 3.81 cm × 3.81 cm prototyping board. The AD8220 requires a ±5 V DC power supply.

The ±5V DC source in the BC circuit comes from a ±5V power supply circuit. It consists of two 9 V batteries and two voltage regulators. The NTE977 regulates the +9 V power supply to +5 V, while the NTE1917 regulates the -9 V supply to -5 V. The overall ECG signal conditioning circuit is shown in Fig. 8. The high-pass, the low-pass, and the notch filters were connected in cascading series. The ±5 V power supply circuit is located between the right leg drive board and the USB6009. All circuits and evaluation boards, along with the USB 6009 data acquisition device, were mounted on a 40.64 cm × 20.32 cm base board made of static-dissipative clear cast acrylic sheet. Each circuit or module, as well as their associated components can be easily changed or modified to adapt to different needs for different biosignals.

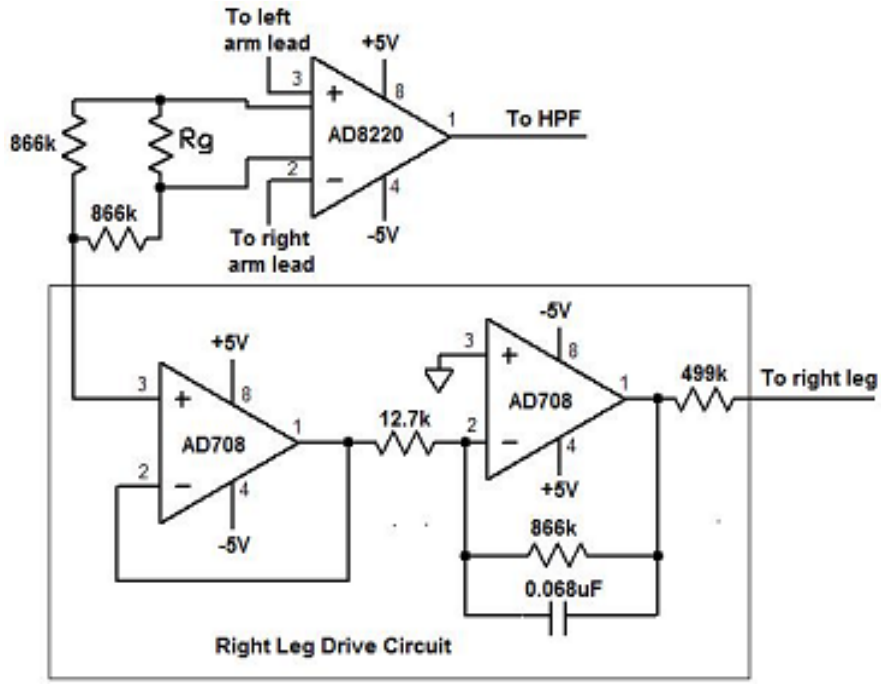


Fig. 7. The right leg drive circuit using two AD708 op-amps and one AD8220.

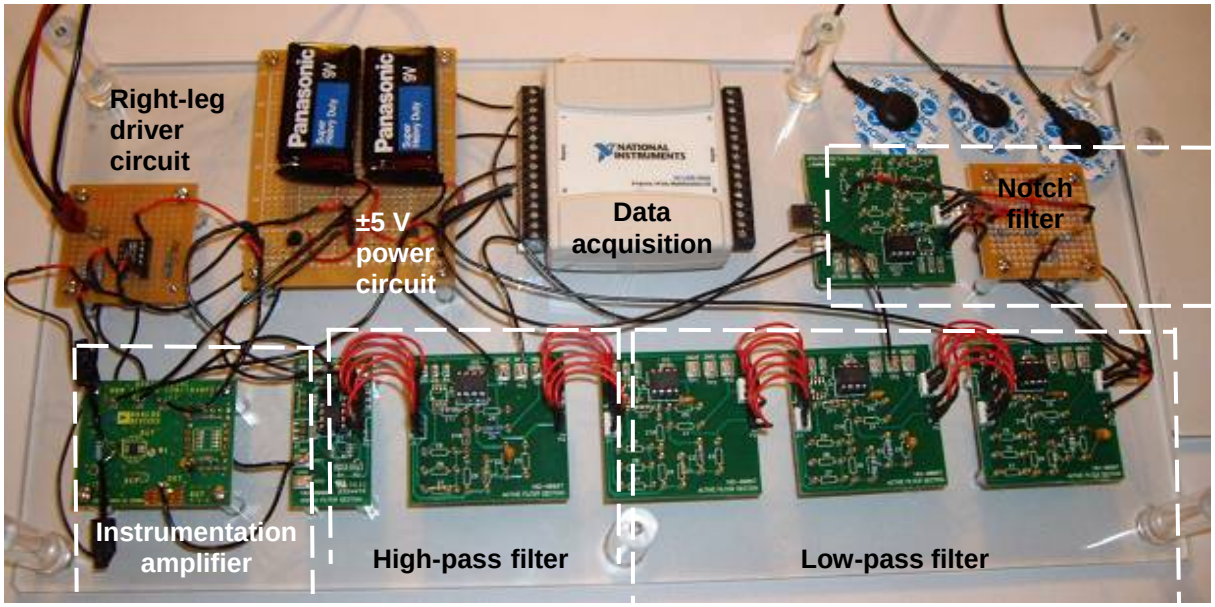


Fig. 8. The signal conditioning circuit assembly.

4. ECG Signal Testing Using the Designed BC Circuit

The designed BC circuitry was tested on a real ECG signal from a human subject. The ECG was recorded by the three Ag-AgCl electrodes attached to the body and sent to the right leg drive circuit. It then passed through the IA, the HPF, the LPF, and finally the notch filter for a series of conditioning. In order to examine and display the filtering result at each stage, a USB6009 unit and LabView program [22] were used for data acquisition, analog to digital conversion, and display. The output of each filter was captured at the V_{OUT} pin located at the top edge of each filter board and was connected to one of the terminals on the USB6009 unit. Fig. 9 shows the ECG outputs at each filtering stage.

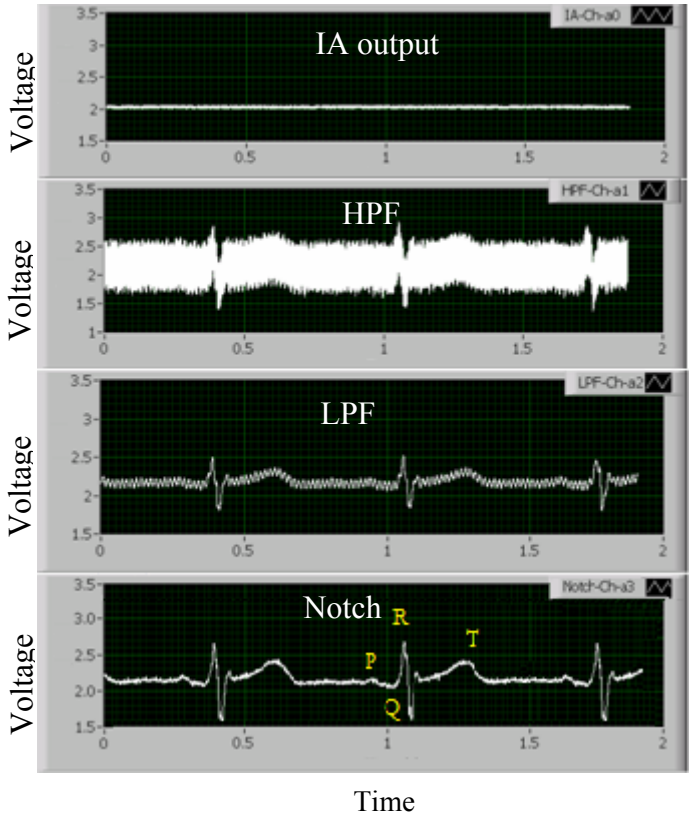


Fig. 9. ECG outputs at each stage of signal conditioning – IA, HPF, LPF, and notch filter.

The initial IA amplification (with a gain of 19) only alters the ECG voltage level, no significant ECG features were observed. The output of the high-pass filter started to show the peaks of the ECG signal, but there was high frequency noise riding on the base signal. This high frequency noise was removed by the low-pass filter, but power line interference was still visible. The ECG peaks – *P*, *R*, *S*, *T* – became more distinct after the LPF. The consecutive notch filter was able to remove the power line noise, making the base signal much clearer. The *P*, *Q*, *R*, *S*, *T* peaks were now more distinguishable. This final output of the ECG waveform confirms that the designed ECG conditioning circuit works properly.

5. Conclusions

A functional modular biopotential signal conditioning device was designed, built, and tested. The device consists of an instrument amplifier (AD8220), a 1st-order active high-pass filter (containing a MCP6271 op-amp and a RC filter in Sallen-Key configuration), a 5th-order active Bessel low-pass filter (consisting of a 1st-order LPF and two 2nd-order Sallen-Key filters), and a T_{win}-T active notch filter (combining two "T" shape RC filters with a MCP6271 op-amp). A right leg drive circuit was added in order to cancel the common-mode signal between the left and right arm electrodes. A power supply circuit provides a ±5 V DC source for the system using two 9V batteries and two voltage regulators (NTE977 regulates +9 V power supply to +5 V; NTE1917 regulates -9 V supply to -5 V).

A real ECG signal was recorded from a human subject and was passed through each filter module. The ECG output at each stage was recorded, displayed, and examined. The IA first amplified the original ECG signal to raise its voltage level. At this stage, no visible ECG peaks were observed. After the high-pass filter and further amplification, the "bump" features of the ECG signal started to appear,

although there was high frequency noise riding on the ECG output. The subsequent low-pass filter attenuated the high frequency component. However, 60 Hz power line interference was still visible. At this stage, the ECG peaks – *P*, *R*, *S*, *T* – became more distinct. The notch filter was able to remove the power line noise, resulting in a very clear and smooth ECG signal with *P*, *Q*, *R*, *S*, *T* peaks even more distinguishable. This final output of the ECG waveform confirmed that the designed ECG conditioning circuit functioned properly and comparable with commercial products.

The merits of this system not only lie its excellent functionality, but also its flexible modularity. Each filter unit or modular circuit, as well as their associated components, can be easily changed or modified to adapt to other biosignals with different amplitudes and frequencies. The system could also be used to condition other non-biosignals. The device provides a useful educational platform for students to learn, step-by-step, signal conditioning principles, function and construction of active and passive filters, electronic components, interface, and LabVIEW programming tools.

Acknowledgements

The authors thank graduate students, David Chan, and Mike Meakins, for their work on testing the modular circuits using real ECG signals.

References

[1]. W. J. Tompkins, Biomedical digital signal processing: C language examples and laboratory experiments for the IBM PC, *Prentice Hall, Inc.,* 1993.

[2]. I. Provaznik, Adaptive systems in ECG processing, Ph.D. Dissertation, *Technical University of Brno*, Czechoslovakia, 1995.

[3]. http://www.elin.ttu.ee/mesel/Study/Subjects/0070BME/Content/BioElect/Signals/SignDiap.gif

[4]. C. M. Tenedero, M. A. Raya, and L. G. Sison, Design and implementation of a single-channel ECG amplifier with DSP post-processing MATLAB, Instrumentation, Robotics, and Controls Laboratory, *University of Philippines* (http://www.upd.edu.ph/~irc/pubs/local/tenedero-design.pdf).

[5]. T. Fulford-Jones, G. Wei, and M. Welsh, A portable, low-power, wireless two-lead EKG system, in *Proceedings of. the 26th Annual International Conference of the IEEE Engineering in Medical and Biology Society (EMBS)*, San Francisco, CA, USA, 1-5 September 2004, pp. 2141-2144.

[6]. S. Matviyehko, Low-cost EKG pulsometer, Application Note AN2284, *Cypress Semiconductor Corp.,* San Jose, CA, USA, January 2006.

[7]. M. Raju and R. Heart, EKG monitor using the MSP430FG439, Application Report SLAA280, *Texas Instrument Inc.,* Dallas, TX, USA, October 2005 (http://focus.ti.com/lit/an/slaa280/slaa280.pdf).

[8]. E. Company-Bosch and E. Hartmann, ECG front end design is simplified with MicroConverter, *Analog Dialogue*, 37-11, Analog Devices Inc., Norwood, MA, USA, November 2003. (http://www.analog.com/analogdialogue).

[9]. S. R. Seydnejad and R. L. Kitney, Real-time heart rate variability extraction using the Kaiser window, *IEEE Transactions on Biomedical Engineering*, Vol. 44, No. 10, 1997, pp. 990-1005.

[10].N. A. Blackburn, Enhancing ECG quality: update on site selection, skin preparation, and electrode placement, Technical Report, *Conmed Corporation,* Utica, NY, USA, November 2003.

[11].J. J. Carr and J. M. Brown, Introduction to Biomedical Equipment Technology, 3rd ed., *Prentice Hall, Inc.,* 1998.

[12].H. Hosseini, H. Nazeran, and K. J. Reynolds, ECG noise cancellation using digital filters, in *Proceedings of the 2nd International Conference on Bioelectromagnetism*, Melbourne, Australia, 15-18 February 1998, pp. 151-152.

[13].J. D. Bronzino, The Biomedical Engineering Handbook, *CRC Press, Inc.,* 1995.

[14].T. Stilson, Biopotential sensors (http://soundlab.cs.princeton.edu/learning/tutorials/sensors/node10.html).

[15].J. Malmivuo and R. Plonsey, Bioelectromagnetism – Principles and Applications of Bioelectric and Biomagnetic Fields, *Oxford University Press,* 1995.

[16].G. Wolfe, The professional biomed on ECG troubleshooting 101 (http://biomedgbis.com/ecg.htm).
[17].P. Rijnbeek, J. Kors, and M. Witsenbur, Minimum bandwidth requirements for recording of pediatric electrocardiograms, *Circulation 2001*, American Heart Association, No. 104, pp. 3087-3090.
[18].JFET input instrumentation amplifier with rail-to-rail output in MSOP package, AD8220 Datasheet, *Analog Devices Inc.*, Norwood, MA, USA, 2006-2010: (http://www.analog.com/static/imported-files/data_sheets/AD8220.pdf).
[19].L. Count and C. Kitchin, A designer's guide to instrumentation amplifiers, 2nd ed., *Analog Devices Inc.*, Norwood, MA, USA, 2004.
[20].J. Karki, Active low pass filter design, Application Report, *Texas Instrument Inc.*, Dallas, TX, USA, September 2002.
[21].MCP6271/2/3/4/5, *Microchip Technology Inc.*, Chandler, AZ, USA, 2004.
[22].C. Chang, J. Han, and D. Ramjeet, LabVIEW™ design of a vectorcardiograph and 12-lead ECG monitor, report submitted to Department of Electrical and Computer Engineering, *University of Manitoba*, Canada, 2003.

The Second International Conference
on Sensor Device Technologies and Applications

SENSORDEVICES 2011

August 21-27, 2011 - French Riviera, France

Important deadlines:

Submission deadline	March 23, 2011
Notification	April 30, 2011
Registration	May 15, 2011
Camera ready	May 22, 2011

Tracks:
- Sensor devices
- Photonics
- Infrared
- Ultrasonic and Piezosensors
- Sensor device technologies
- Sensors signal conditioning and interfacing circuits
- Medical devices and sensors applications
- Sensors domain-oriented devices, technologies, and applications
- Sensor-based localization and tracking technologies

http://www.iaria.org/conferences2011/SENSORDEVICES11.html

The Fifth International Conference on Sensor
Technologies and Applications

SENSORCOMM 2011

August 21-27, 2011 - French Riviera, France

Important deadlines:

Submission deadline	March 23, 2011
Notification	April 30, 2011
Registration	May 15, 2011
Camera ready	May 22, 2011

Tracks:
- APASN: Architectures, protocols and algorithms of sensor networks
- MECSN: Energy, management and control of sensor networks
- RASQOFT: Resource allocation, services, QoS and fault tolerance in sensor networks
- PESMOSN: Performance, simulation and modelling of sensor networks
- SEMOSN: Security and monitoring of sensor networks
- SECSED: Sensor circuits and sensor devices
- RIWISN: Radio issues in wireless sensor networks
- SAPSN: Software, applications and programming of sensor networks
- DAIPSN: Data allocation and information in sensor networks
- DISN: Deployments and implementations of sensor networks
- UNWAT: Under water sensors and systems
- ENOPT: Energy optimization in wireless sensor networks

http://www.iaria.org/conferences2011/SENSORCOMM11.html

The Fourth International Conference on Advances
in Circuits, Electronics and Micro-electronics

CENICS 2011

August 21-27, 2011 - French Riviera, France

Important deadlines:

Submission deadline	March 23, 2011
Notification	April 30, 2011
Registration	May 15, 2011
Camera ready	May 22, 2011

Tracks:
- Semiconductors and applications
- Design, models and languages
- Signal processing circuits
- Arithmetic computational circuits
- Microelectronics
- Electronics technologies
- Special circuits
- Consumer electronics
- Application-oriented electronics

http://www.iaria.org/conferences2011/CENICS11.html

Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

Submission of papers

Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 8-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm Authors must follow the instructions strictly when submitting their manuscripts.

Advertising Information

Advertising orders and enquires may be sent to sales@sensorsportal.com Please download also our media kit: http://www.sensorsportal.com/DOWNLOADS/Media_Kit_2009.pdf