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Fast Electrocardiogram Amplifier Recovery after Defibrillation Shock

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***Abstract**: A procedure for fast ECG amplifier recovery after defibrillation shocks was developed and simulated in the MATLAB environment. Exponentially decaying post-shock voltages have been recorded. Signals from the AHA database are taken and mixed with the recorded exponential disturbances. The algorithm applies moving averaging (comb filter) on the compound input signal, thereby obtaining the samples of the disturbance. They are currently subtracted from the input signal. The results obtained show that its recovery is practically instantaneous.*

***Keywords:** Defibrillation shock, Electrocardiogram amplifier recovery, Automatic external defibrillation*

Introduction

Recently, the use of defibrillators became widespread practice, due to multiple cases of sudden cardiac death [4], resulting mostly from ventricular fibrillation [1].

The success of this action depends to a great extent on ECG recording or monitoring as soon as possible after the shock pulse. According to approved requirements [6, 7, 10], the recording of the ECG signal should be restored not later than 5 to 10 s after defibrillation shock. However, recently there is an enhanced interest in immediate assessment of the post-shock rhythm [9].

Predominantly patented hardware solutions for reduction of the restoration time have been proposed. Some of them use switchable RC circuit in an integrator, built as feedback to the amplifier second stage [8, 11]. Such solutions lead to generation of artifacts, as the switching occurs mostly during non-zero amplifier output voltage. [12] proposes to change dynamically the high-pass filter time-constant. [5] reports for the use of compensation voltage to the stage following the RC circuit. In both patents, the efficiency is not commented. No transient processes after defibrillation are presented.

Method

Exponentially decaying post-shock voltages have been recorded. They have a slowly varying time-constant τ with initial value τ_{init} from 1 through 5 s when paddle electrodes are used. Further, τ increases approximately with 0.1% of τ_{init} per sample.

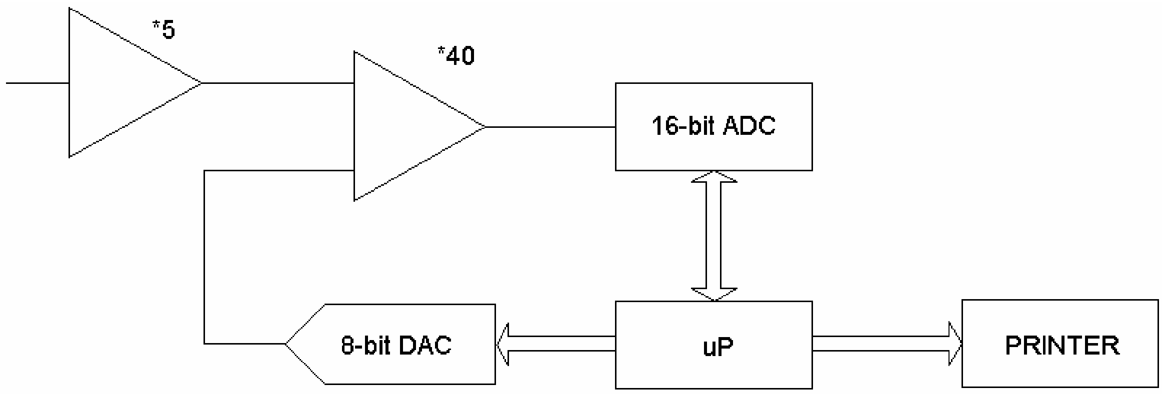
A procedure for fast ECG amplifier recovery after defibrillation shocks was developed and simulated in the MATLAB environment. Signals from the AHA database are taken and mixed with the recorded exponential disturbances. Then the procedure is applied and the filtered signal with the residual disturbance is shown.

Algorithm and amplifier structure

The algorithm applies moving averaging (comb filter) on the compound input signal, thereby obtaining the samples of the disturbance. They are currently subtracted from the input signal.

The moving averaging is dynamic. At the beginning, the first zero of the comb filter f_1 is equal to 3 Hz, corresponding to a cut-off frequency of about 1.5 Hz. Then the sample number used for computation is increased gradually until the first zero reaches f_2=1 Hz (0.5 Hz cut-off). The higher cut-off frequencies contribute to a fast initial recovery. The residual disturbances are better suppressed during the following filtering with lower cut-off frequencies.

The software is written in anticipation of a further implementation in real time. The computed values are rounded. In order to reach a desired accuracy, it is necessary to process a 200-times DC amplified signal. This is possible using the structure shown in the diagram bellow [2, 3]. The amplifier gain is divided in two parts, 5 for the first stage and 40 for the second one. A 16-bit ADC is connected to the second stage output. Each time the corresponding voltage approaches the saturation level, a µP system controlling the data flow sets an 8-bit DAC, so that an appropriate voltage is generated at its output, thus shifting the signal towards the zero at the input of the second stage.



Results and discussion

The results obtained with different values of **τ** are shown in Fig. 1÷6. The traces are as follows: 1) exponential disturbance; 2) input ECG signal A8001D1 taken from the AHA database; 3) processed ECG signal; 4) input and processed signal during the first 5 seconds presented in extended time-scale; 5) zoomed difference between input and processed signal.

Obviously, the transient process is very fast. Since the first stage comes out of saturation, the isoelectric line enters almost immediately within the range of ±2 mV (related to the amplifier input), i.e. in the paper margin of a 40 mm recorder. The residual disturbance remains less than 20 µV after the 5-th second.

Tha signal recovery is practically instantaneous in cases of $\boldsymbol{\tau}_{\mathbf{init}}$=3 and 5 s (Fig. 1, Fig. 2). When the disturbahce is of $\boldsymbol{\tau}_{\mathbf{init}}$=1 s, the signal returns in the range of ±1 mV in 2 seconds. The restoration is accelerated if $\mathbf{f_1}$=2.5 Hz (Fig. 4). However, the residual disturbance is slightly higher compared to that in Fig. 3. The same events may be observed for τ_{init}=3 and 5 s (Fig. 5, Fig. 6).

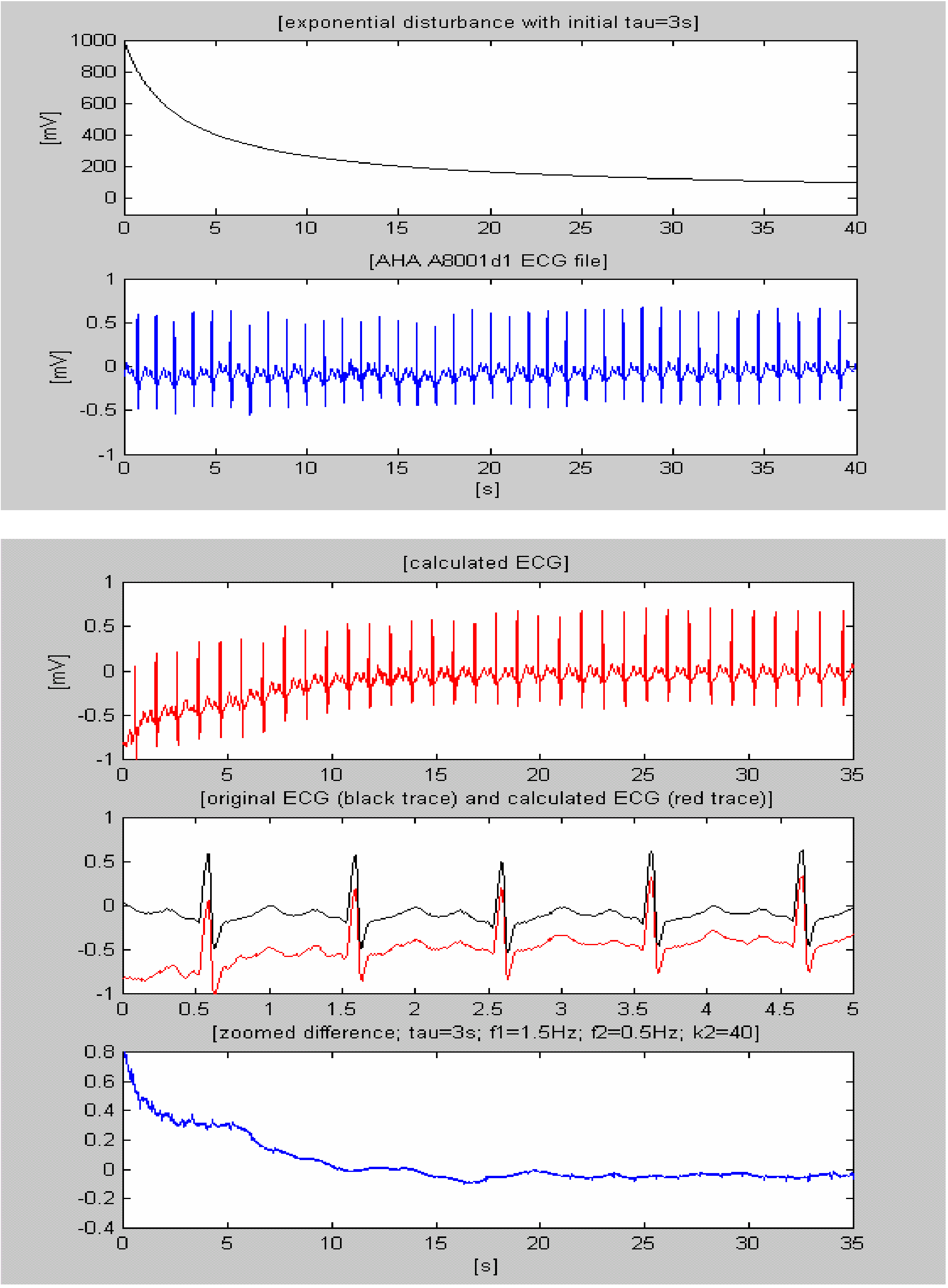


Fig. 1

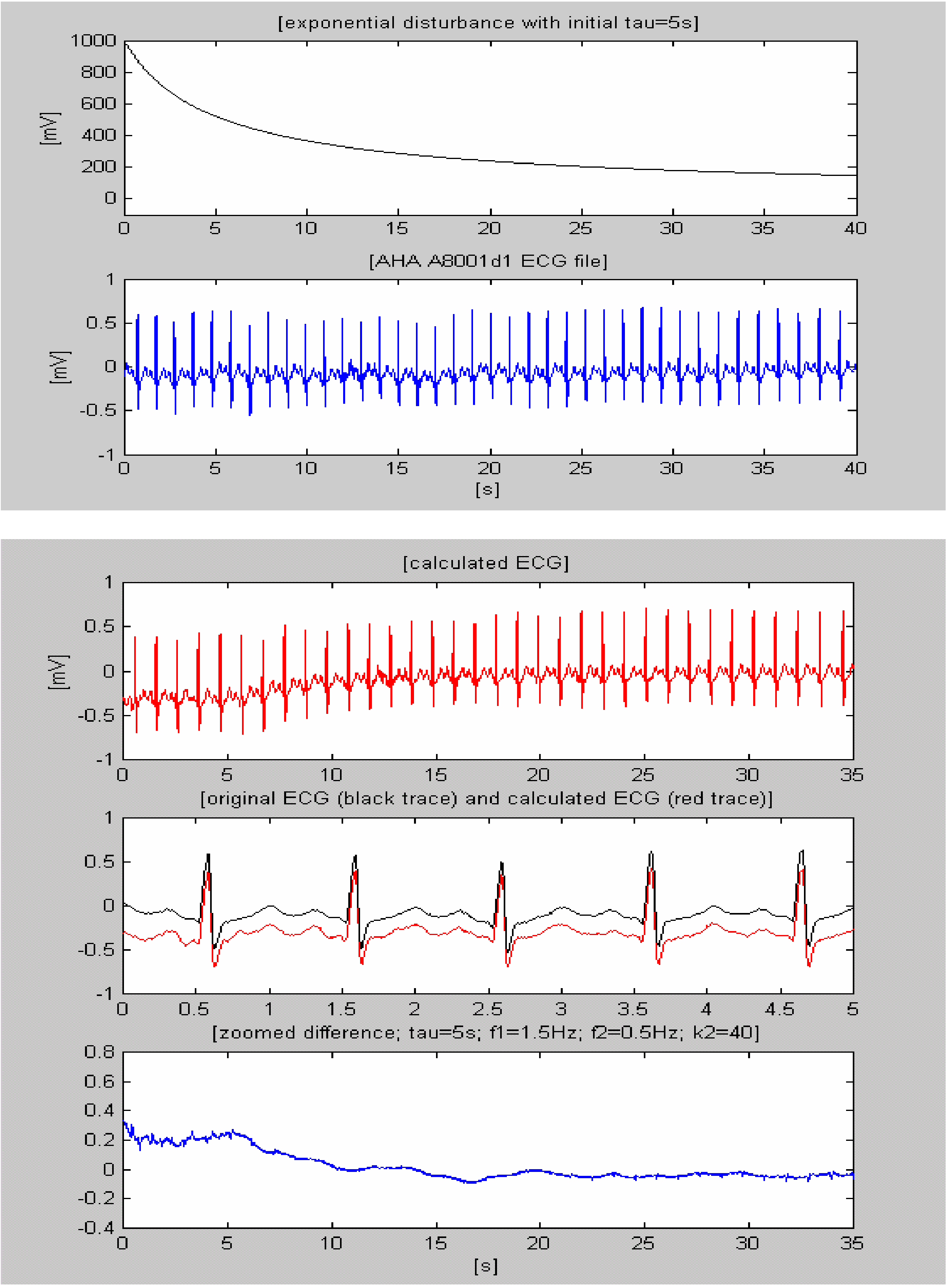
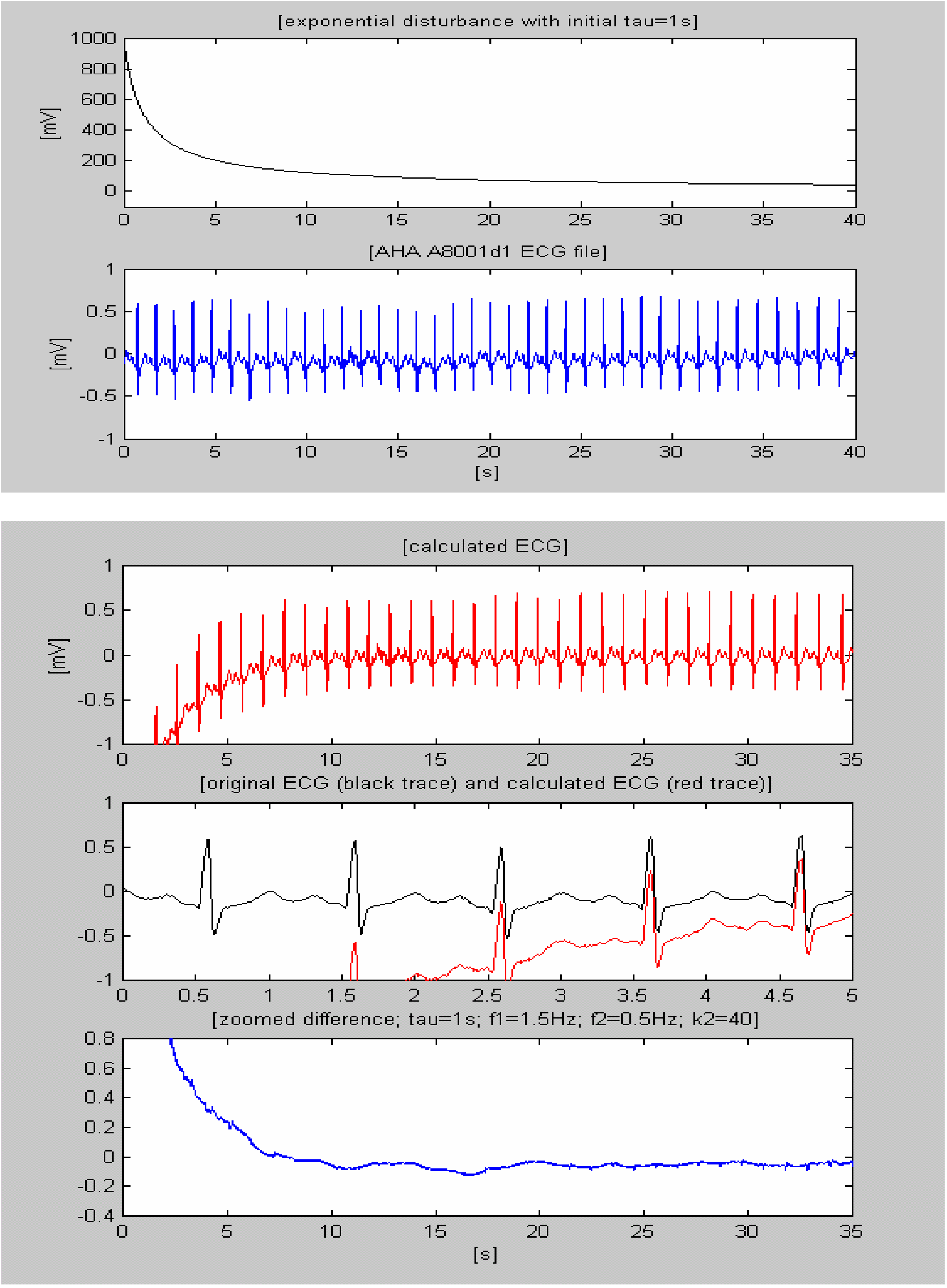

[exponential disturbance with initial tau=5s]
[mV]
1000
800
600
400
200
0
0 5 10 15 20 25 30 35 40
[AHA A8001d1 ECG file]
[mV]
1
0.5
0
-0.5
-1
0 5 10 15 20 25 30 35 40
[s]
[calculated ECG]
[mV]
1
0.5
0
-0.5
-1
0 5 10 15 20 25 30 35
[original ECG (black trace) and calculated ECG (red trace)]
1
0.5
0
-0.5
-1
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5
[zoomed difference; tau=5s; f1=1.5Hz; f2=0.5Hz; k2=40]
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0 5 10 15 20 25 30 35
[s]

Fig. 2



[exponential disturbance with initial tau=1s]
[mV]
[AHA A8001d1 ECG file]
[mV]
[s]
[calculated ECG]
[mV]
[original ECG (black trace) and calculated ECG (red trace)]
[zoomed difference; tau=1s; f1=1.5Hz; f2=0.5Hz; k2=40]
[s]

Fig. 3

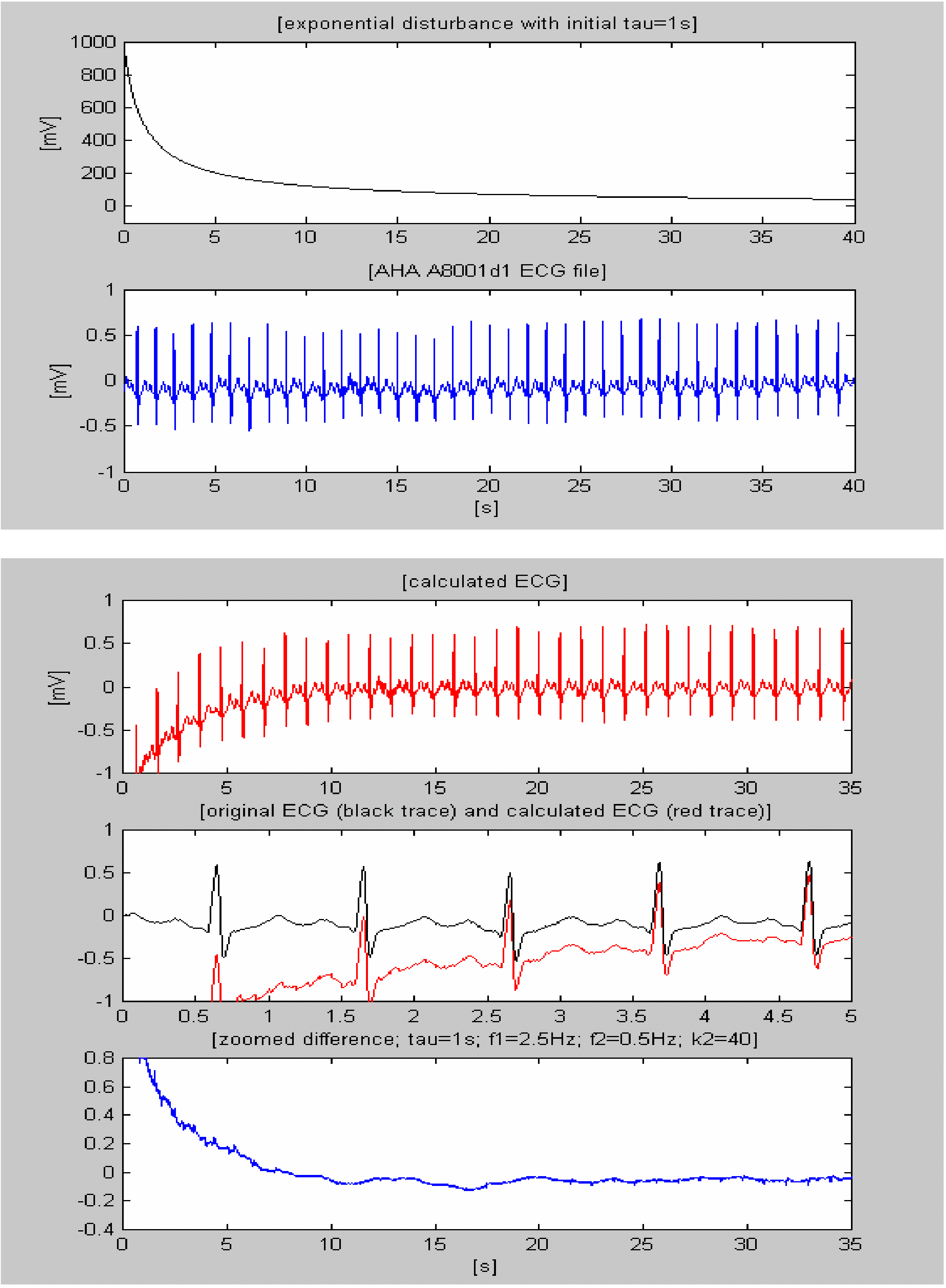

[exponential disturbance with initial tau=1s]
[mV]
[AHA A8001d1 ECG file]
[mV]
[s]
[calculated ECG]
[mV]
[original ECG (black trace) and calculated ECG (red trace)]
[zoomed difference; tau=1s; f1=2.5Hz; f2=0.5Hz; k2=40]
[s]

Fig. 4

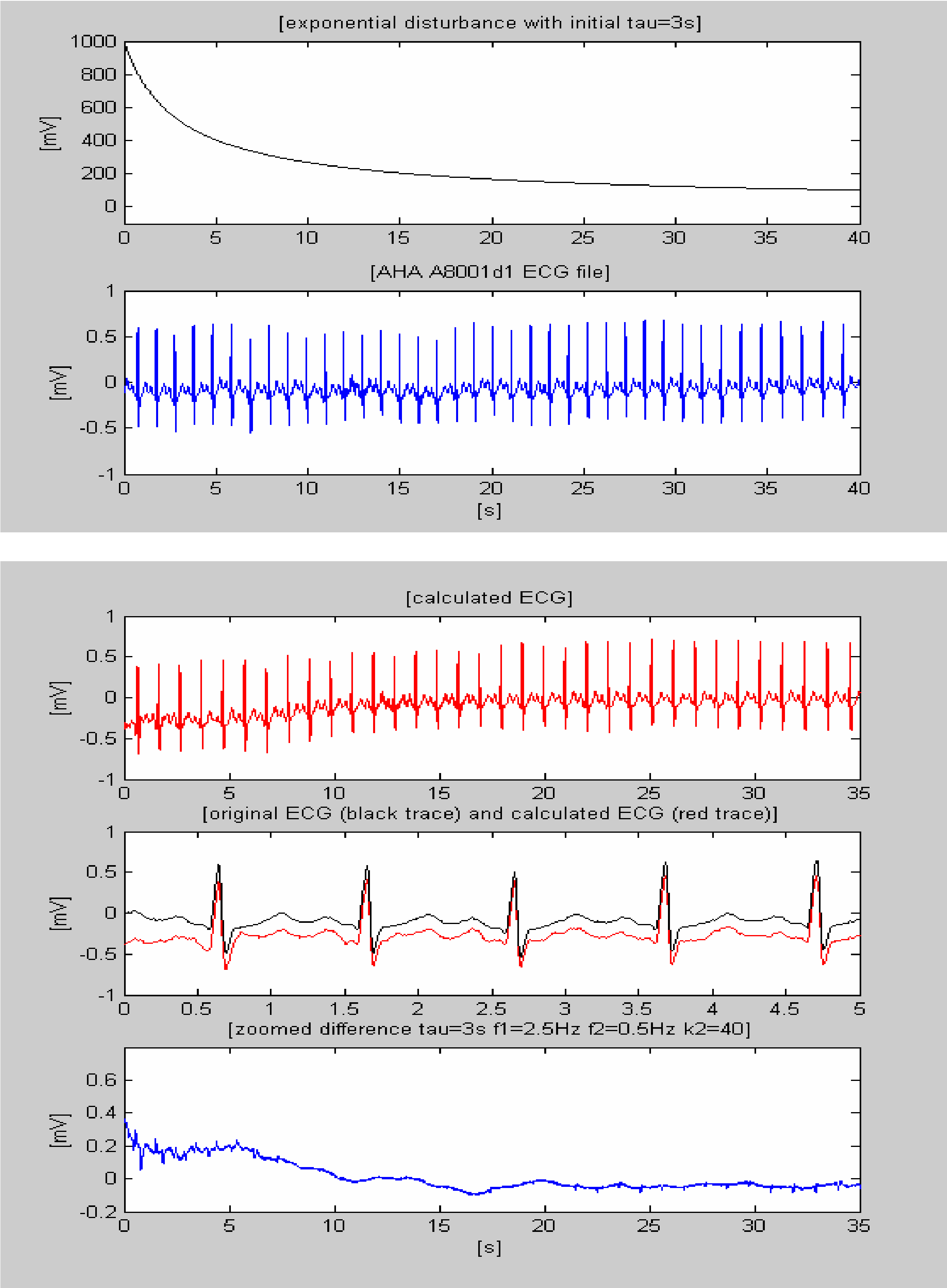

[exponential disturbance with initial tau=3s]
[mV]
[AHA A8001d1 ECG file]
[mV]
[s]
[calculated ECG]
[mV]
[original ECG (black trace) and calculated ECG (red trace)]
[mV]
[zoomed difference tau=3s f1=2.5Hz f2=0.5Hz k2=40]
[mV]
[s]

Fig. 5

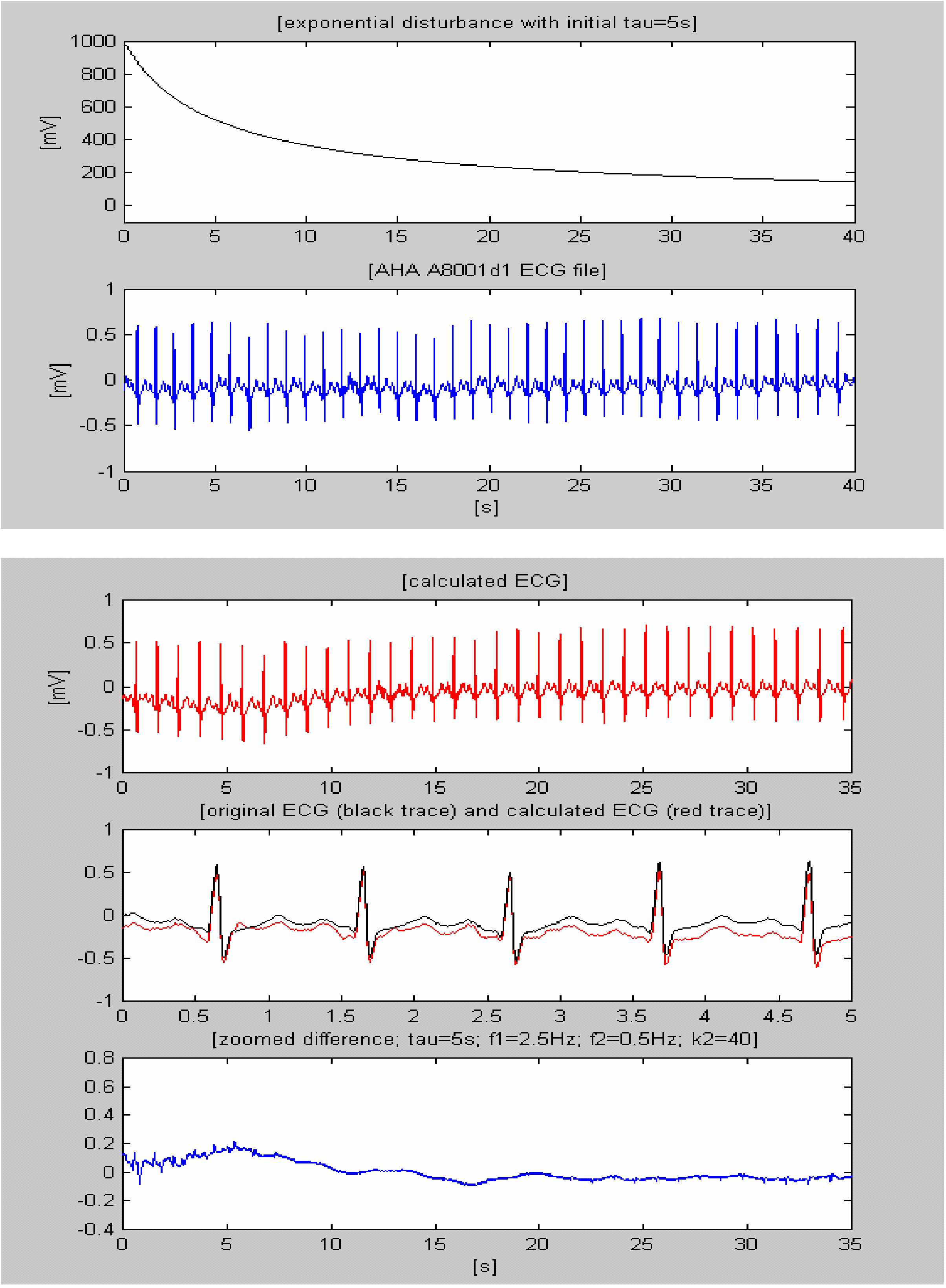

[exponential disturbance with initial tau=5s]
[mV]
1000
800
600
400
200
0
0 5 10 15 20 25 30 35 40
[AHA A8001d1 ECG file]
[mV]
1
0.5
0
-0.5
-1
0 5 10 15 20 25 30 35 40
[s]
[calculated ECG]
[mV]
1
0.5
0
-0.5
-1
0 5 10 15 20 25 30 35
[original ECG (black trace) and calculated ECG (red trace)]
1
0.5
0
-0.5
-1
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5
[zoomed difference; tau=5s; f1=2.5Hz; f2=0.5Hz; k2=40]
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0 5 10 15 20 25 30 35
[s]

Fig. 6

Conclusions

In addition for the extremely fast recovery with low residual disturbance, another advantage of the procedure is that any cut-off $f_2/2$ may be set by the software, even 3.2 s, which is normally used for morphological analysis.

The disadvantage of the procedure is that it ignores the first 164 ms of the signal (sampled with 250 Hz) and starts the recording with the same delay with respect to real time. The delay reaches up to 500 ms at the 6-th second and does not change further. It is recommended to continue the recording at the end of the 40-th second by excluding the procedure. Thus the ECG signal will be monitored and/or recorded in real time. The relevant information for the heart activity immediately after the defibrillation shock remains available for decision-making by the cardiologist.

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