

# New Design of 12-Lead ECG Simulation Signal System with Simulated Noise Added

Duong Trong Luong, Nguyen Duc Thuan, Nguyen Thai Ha

**Abstract:** This paper presents a simulation system design of 12-lead electrocardiogram (ECG) signal. The simulated ECG signal is generated in analog form and can be added to certain types of noise such as simulated 50Hz power line noise or baseline wander. The original 12-lead ECG signal was taken from database on [www.physionet.org](http://www.physionet.org) website. Adding noise signals, selecting leads and signal display are performed by our designed software. The accuracy of simulated ECG signal is estimated by Mean Square Error (MSE) criterion. The proposed system was tested and showed the good results. The system can be used for testing designed circuits or can test actual clinical effect ECG devices. The designed system can supply convenient tools for Researchers, Designers in developing ECG products.

**Key words:** 12-lead ECG signal, simulated signal, baseline noise, Mean Square Error (MSE).

## I. INTRODUCTION

Electrocardiogram (ECG) is one of the most importance features in the heart diseases diagnosis. Nowadays, there are a lot of published scientific researches with the aim of improving the design of the ECG signal receiving circuits to increase accuracy, and reduce noise, which particularly are 50 Hz power line interference and baseline noise (mainly type of baseline wander). In many cases the simulated is needed. Currently, the ECG signal is usually only given in the digital form by some of software such as LabView, MatLab. This paper presents a solution to design of the analog simulated 12-lead ECG signal pattern. The design also allows the tool, which can add noise to pure ECG signal. Two types of noise used are 50 Hz power line noise and baseline wander. The noise level can be changed by the tool in designed software. The accuracy of the analog simulated 12-lead simulated ECG signal is evaluated through the Mean Square Error (MSE) criterion. Input data for the designed system was regarded as original ECG signal was selected from database records on [physionet.org](http://physionet.org) website [7].

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## II. IMPLEMENTATION

**The 12-lead ECG system:** Nowadays, most of ECG equipments use 12-lead ECG configuration, which show in the figure 1, included the limb leads (I, II and III), the augmented limb leads (aVR, aVL and aVF) and the chest leads (V1-V6) [1], [2].

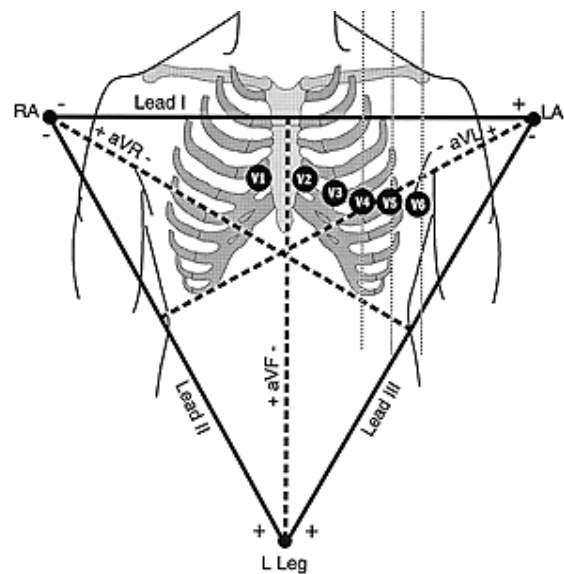


Figure 1. Shows the normal 12-lead ECG signal (there are no cardiovascular disease phenomenon) [2]

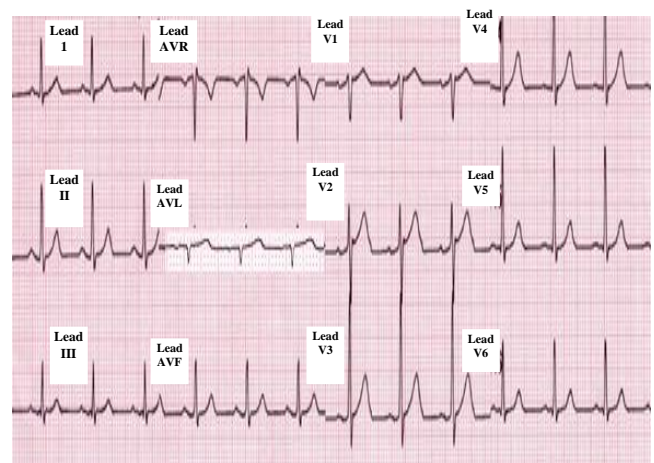


Figure 2. Normal 12-lead ECG signal

Base on the aim of creation of simulated 12-lead ECG signal pattern , the block diagram of hardware system is shown in the figure 3.

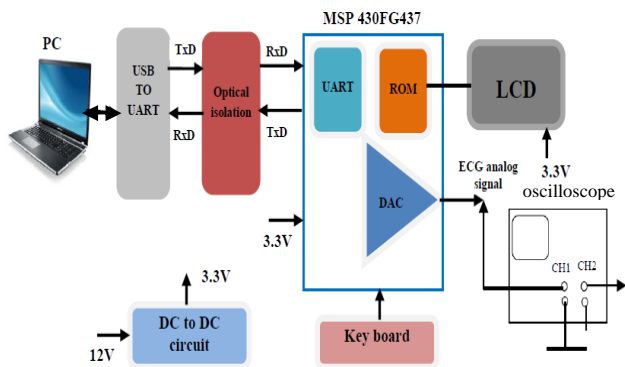


Figure 3. The block diagram of the analog simulated 12-lead ECG signal pattern system

The original 12 lead ECG signal data was taken from database records on [www.physionet.org](http://www.physionet.org) website [7] and loaded into the microcontroller (MCU) MSP 430FG437 through UART interface . Two 12 bit synchronous D/A converters are integrated in this MCU [3]. Information about Selected leads and noise signals added are displayed on the LCD through display controller from MCU. Adding noise signals, changing the of the noise signal level, leads selection and ECG signal display corresponding to the selected lead is done by the programming software. This software is programmed with visual C language. Avoiding the influence between the computer power and power supply of designed hardware module, the optical isolator L817B is implemented [4]. The controlled keys are connected to the signal controlled pins of MCU to handle selection of leads, and adding of noise signal. The algorithm for generating the pattern of analog simulated ECG signal is shown in the figure 4. In fact, measured ECG signal from human body usually contains several main type of noise such as power line interference, baseline wander and muscle noise [5],[6]. In many cases for analysis or research on the noisy ECG signal, the analog simulated ECG signal can be added 50Hz power line noise and baseline wander at the same time or different times. It can be expressed by the formula (1), (2) and (3).

$$Y(t) = S(t) + X(t) + B(t) \quad (1)$$

$$Y_1(t) = S(t) + X(t) \quad (2)$$

$$Y_2(t) = S(t) + B(t) \quad (3)$$

Where, S(t) is the pattern of analog simulated ECG signal, X(t) is 50Hz power line noise and B(t) is baseline noise with variable level. These two types of noise are simulated and generated by Labview software programming. The generated ECG signal from the proposed system is evaluated by Mean Square Error (MSE) criteria which determined by formula (4).

$$MSE = \frac{1}{N} \sum_{i=1}^N (x[n] - x'[n])^2 \quad (4)$$

Where, N is length of signal, x[n] is original signal, x'[n] is the simulated ECG reconstructed signal, which is generated in analog form.

### III. RESULTS AND DISCUSSION

The system generateted the pattern of analog simulated 12-lead ECG signal with frequency of 60Hz, maximum amplitude is 1.5V (depend on each of leads). To measure this ECG signal, the authors use digital Tektronix Oscilloscope TDS2024C. This device has some characteristics such as accuracy  $\pm 3\%$ ; sensitivity is 2mV; record length-2500 samples and 8bit resolution. The figure 5,6,7,8,9,10,11 illustrate three ECG graphs : one is the original ECG signal ( it was taken from database records on [www.physionet.org](http://www.physionet.org) website ), the second is analog signal on the oscilloscope and the last one is reconstructed simulated ECG signal using Labview 2012 for serveral of leads.

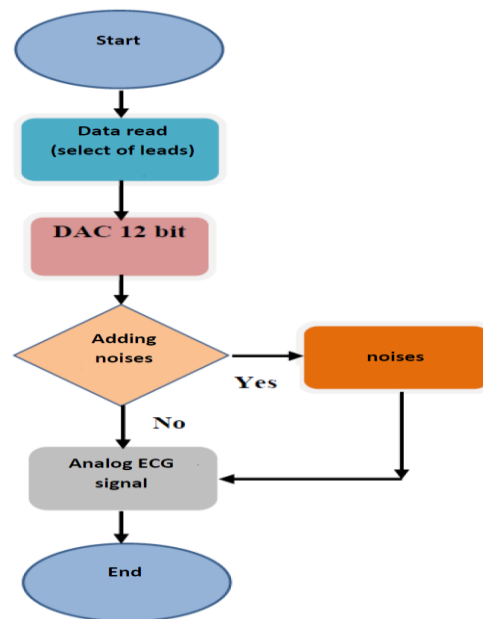


Figure 4. The flow chart for converting ECG data into analog signal with adding noises

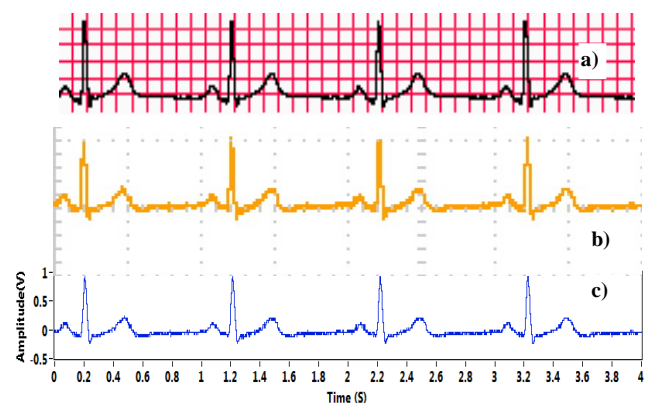


Figure 5. ECG signal from lead I. a) original ECG signal; b) Measured ECG signal by oscilloscope; c) reconstructed ECG signal using Labview

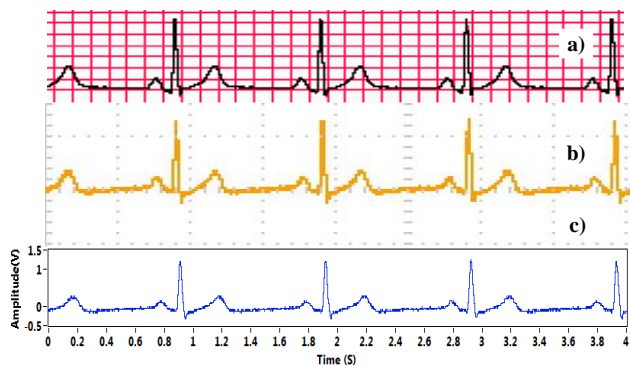


Figure 6. ECG signal from lead II. a) original ECG signal; b) Measured ECG signal by oscilloscope; c) reconstructed ECG signal using Labview

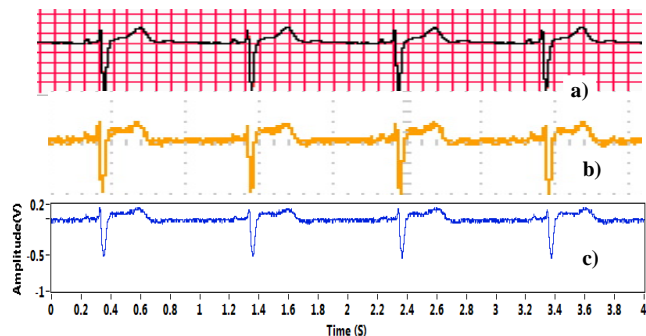


Figure 7. ECG signal from lead aVL. a) original ECG signal; b) Measured ECG signal by oscilloscope; c) reconstructed ECG signal using Labview

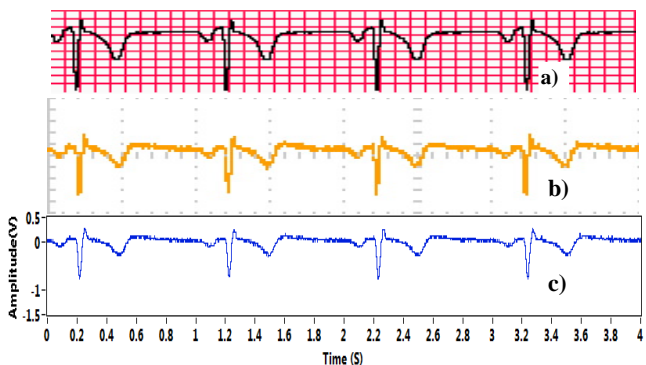


Figure 8. ECG signal from lead aVR. a) original ECG signal; b) Measured ECG signal by oscilloscope; c) reconstructed ECG signal using Labview

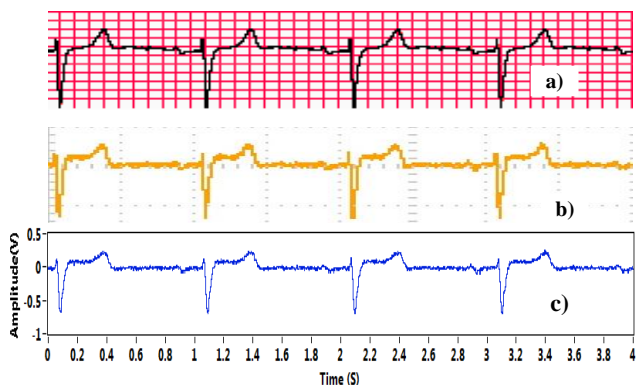


Figure 9. ECG signal from lead V1. a) original ECG signal; b) Measured ECG signal by oscilloscope; c) reconstructed ECG signal using Labview

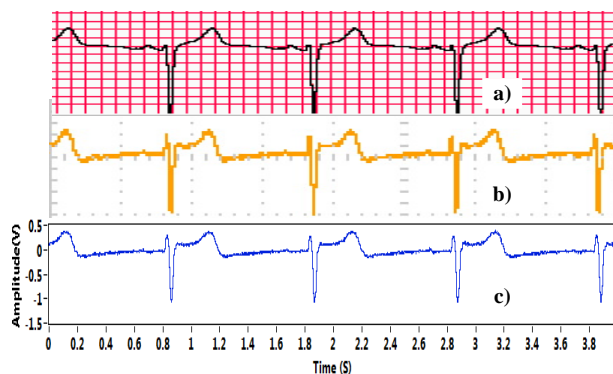


Figure 10. ECG signal from lead V2. a) original ECG signal; b) Measured ECG signal by oscilloscope; c) reconstructed ECG signal using Labview

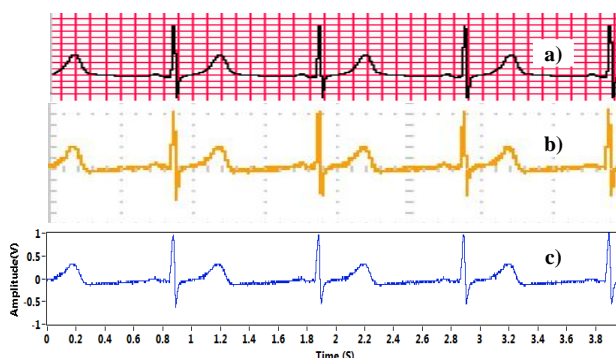


Figure 11. ECG signal from lead V3. a) original ECG signal; b) Measured ECG signal by oscilloscope; c) reconstructed ECG signal using Labview

The accuracy of the analog simulated ECG signal pattern which generated by the proposed system is compared with original ECG data is shown in the table 1 and table 2. For calculating the value of MSE, the authors use NI-USB 6008[8] and formula (4) and Labview programming languages.

Table 1. The MSE value of the leads I, II, III, aVR, aVL and aVF.

Original ECG						
M S E	Lead I	Lead II	Lead III	AVR	AVL	AVF
		0.018	0.0324	0.0232	0.017	0.007
Analog simulated ECG						



Table 2. The MSE value of the leads V1-V6.

Original ECG						
M S E	V1	V2	V3	V4	V5	V6
	0.008	0.03	0.026	0.027	0.028	0.02
	V1	V2	V3	V4	V5	V6
Analog simulated ECG						

The results in table 1 and table 2 show that the largest value of MSE is 0.0324 or 3.24%. This error may be due to errors of A/D conversion module and the errors of the components in the hardware circuit. This error is acceptable because of the fact that, often 12-lead ECG measurement equipments have deviation in the range of  $\pm 2\%$  to  $\pm 5\%$  [9]. In the case, when Investigation of noisy signal needed, the simulated ECG signal will be added to the power line noise with variable amplitude, for example of 1mV (shown in the figure 12) or baseline noise with frequency of 1Hz (shown in the figure 13). These two types of noise are generated by Labview software.

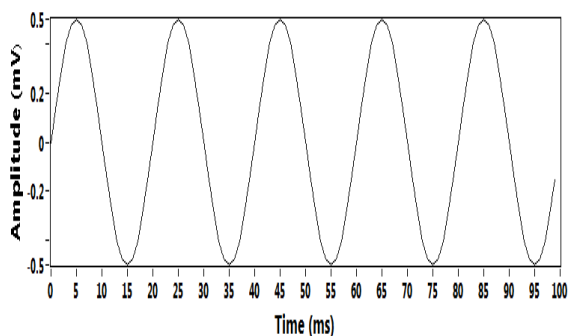


Figure 12. The 50Hz power line noise z with amplitude of 1mV

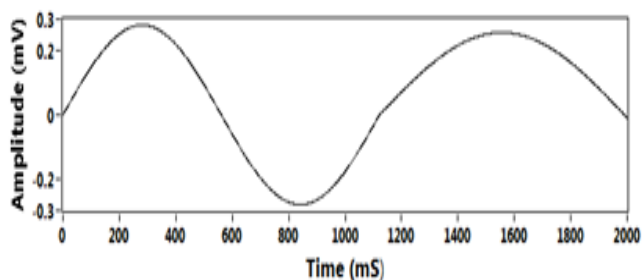


Figure 13. One type of baseline noise with frequency of 1Hz

The figure 14 and figure 15 show the result of the simulated ECG signal of lead II and V2, which contains 50Hz power line noise and measured by the digital oscilloscope TDS2024C.



Figure 14. The simulated ECG signal of lead II with 50Hz power line noise added.

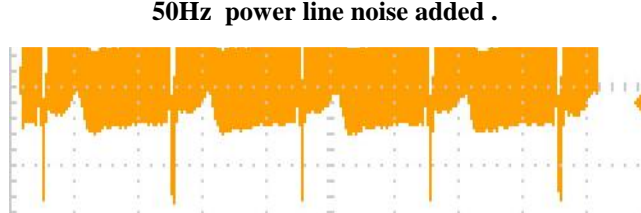


Figure 15. The simulated ECG signal of lead V2 with 50 Hz power line noise added.

The figure 16 and figure 17 show the result of the simulated ECG signal of lead II and V2, which contains base line noise and measured by the digital oscilloscope TDS2024C.

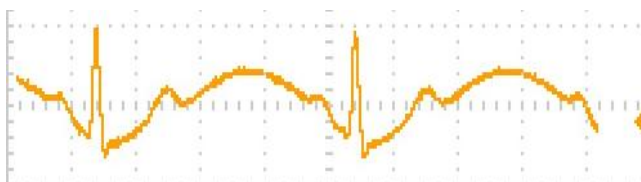


Figure 16. The simulated ECG signal of lead II with baseline noise( type of wander) added

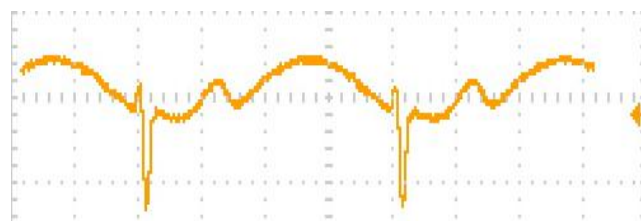


Figure 17. The simulated ECG signal of lead V2, which contains base line noise.

With these two types of noise which added to the simulated ECG signal allows using this signal as a input complex signal to experiment and test the designed circuits and estimate the quality of the ECG signal measuring equipments as so as in the studying of ECG signal processing. Figure 18 show the user interface (GUI) of proposed system. For this GUI, users can select the ECG signal from each of 12 leads to display. Another hand, users can select adding both of these noise contemporary or select adding one of two types of noise.

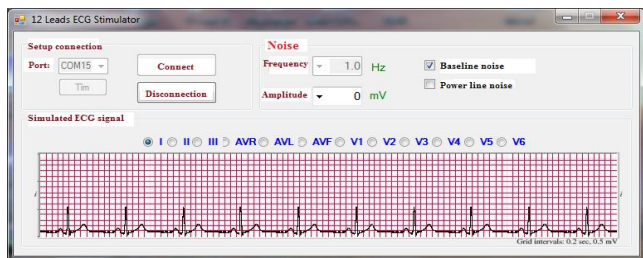


Figure 18. The user interface of proposed system which generates simulated 12-lead ECG signal.

Figure 19 shows the photograph of designed system in the testing

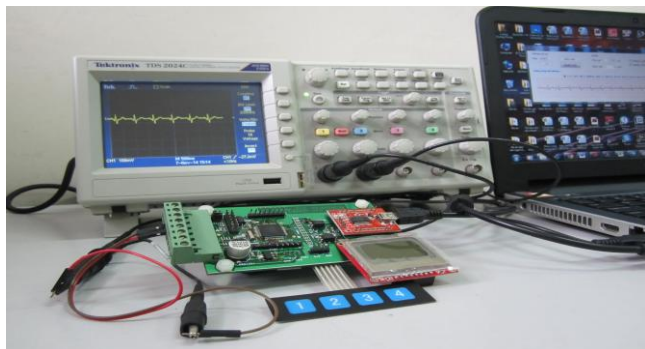


Figure 19. The designed system is in the testing

#### IV. CONCLUSION

The authors have designed the system of simulated 12-lead ECG signal in analog form. We also had designed the software to control system as adding noise signals, changing the of the noise signal level, leads selection and ECG signal display corresponding to the selected lead. In addition, two types of simulated common noise added allows the system to be used for multi-function. The proposed system has been tested and given good performance and reliability. The accuracy of system was estimated through MSE criterion. Results of estimation show that the maximum value of MSE is 0.0324, that is acceptable in practice. The system can be used for testing designed circuits or can test actual clinical effect ECG devices. The designed system can make great convenience for Researchers, Designers in developing ECG products.

#### REFERENCES

- [1] Frank G. Yanowitz, MD "Introduction to ECG interpretation". Intermountain Healthcare, 2012.
- [2] Dr. Truong Thanh Huong, "Normal ECG signal and ECG measuring". Lecture note, VietNam cardiovascular hospital, 2007.
- [3] <http://www.ti.com>
- [4] <http://www.ic-on-line.cn>
- [5] G.D. Clifford, F. Azuaje, and P. McSharry, "Advanced Methods and Tools for ECG Data Analysis". Norwood, MA, USA: Artech House, Inc., 2006.
- [6] Jungkuk Kim, Minkyu Kim, Injae Won, Seungyhul Yang, Kiyoun Lee, and Woong Huh, "An ECG signal processing Algorithm based on removal of wave deflections in time domain". The 31st Annual International Conference of the IEEE EMBS, Minneapolis, Minnesota, USA, September 2-6, 2009.
- [7] <http://www.physionet.org>
- [8] <http://www.ni.com/pdf/manuals/371303m.pdf>
- [9] <http://halinh-jsc.com/>: Nihon-Kohden-ECG-1150-851.html



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