醫工學會誌 : 第11卷, 第1號, 1990
J. of KOSOMBE : Vol. 11, No. 1

研 究 論 文
90- 1 -01

# Frequency Responses of Ambulatory ECG Systems and Their Correction by a Compensation Circuit

**K. Iwao, A. Yokoi, S. Suzuki, T. Goto, K. Doniwa and M. Okajima**

**-Abstract-**

Frequency responses of ambulatory electrocardiogram systems[1] were measured. Phase shift was assessed by our improved Wagner's method.[2] The characteristics of the systems were found much worse than that of ordinary ECG equipment both in gain and phase responses. The decay of −3dB in amplitude observed in 0.2Hz and the lead of 45 deg in phase was observed in 0.6Hz. In order to investigate which of these 2 responses play major role in generating false S−T deviation, mathematical filters were Composed in a computer and actual ECGs were fed. The false S−T deviation were found to be caused mostly by enormous lead in phase, and then, the compensation circuit to diminish the lead in phase was inserted in the commercial systemes. The compensated systems showed no false deviation in S−T segment.

## 1. Introduction

In commonly used ambulatory electrocardiogram (ECG) through a DR magnetic tape recorder, the false deviations of S−T segment, that is, augmentation or distinguishment are frequently observed.[3,4] It can be the cause of mis-interpretation. The overall frequency responses were, therefore, checked with commercial ambulatory ECG systems and the false S−T deviations were found to be caused mostly by enormous lead in phase.[5,6]

We designed the compensation circuit to diminish the lead in phase and applied to the commerical ambulatory ECG systems.[7] The effect of the compensation circuit is reported in this paper.

〈접수 : 1989년 9월 21일〉
Fujita-Gakuen Health University, Toyoake, Nagoya Area, 470-11, Japan

## 2. Methods and Apparatus

### A. Measurement of Frequecy Responses

Frequeney responses, that is, frequency dependency of amplitude and phase were measured with the combination of 3 recorders and 2 analyzers. Amplitude characteristics were measured by the amplitude of the reproduced sinusoidal waveforms (1mV, 0.1~100Hz). Where, the amplitude of the reproduced waveforms at 10Hz was defined as 100 %.

Phase characteristics were measured by the unique search signal shown in Fig. 1(upper).

This search signal was proposed by Wagner for measuring the phase characteristics of chart recorders.

It was synthesized by the fundamental sinusoidal waveform and its third harmonics. The distortion (C−D) of the search signal waveform was

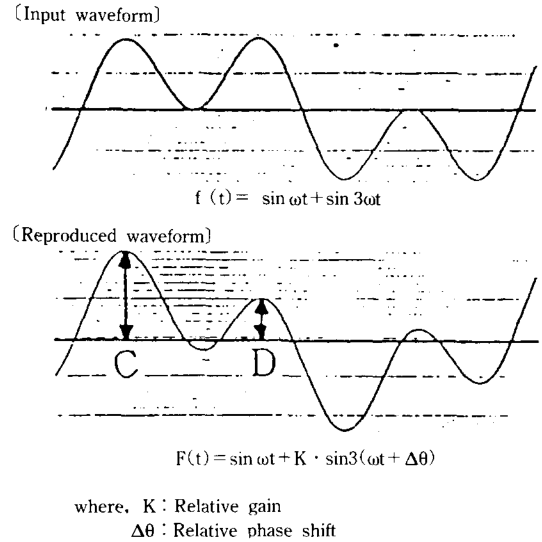


**Fig. 1** Search Signal for Measuring Phase Characteristics.

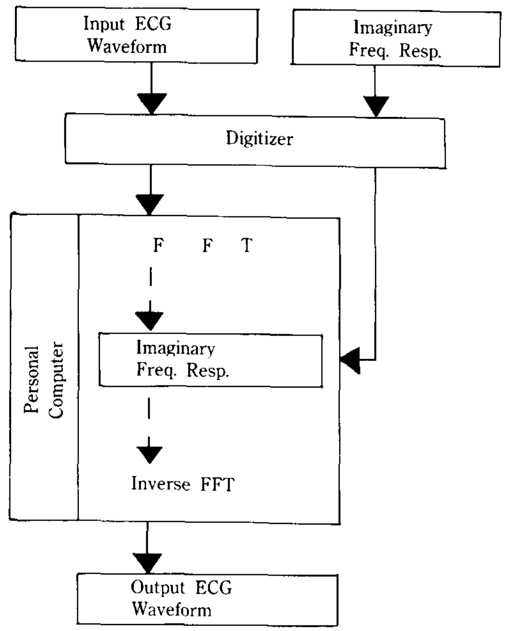


**Fig. 2** Structure of Simulation of Ambulatory ECG System.

caused by the relative phase shift ($\angle\theta$) of the 2 components waveforms (Fig. 1, lower). The relationship between $\angle\theta$ and $(C-D)$ was easily obtained by the computer Calculation.

The phase shift $\angle\theta$ was, therefore, estimated by measuring the value $(C-D)$ in the reproduced search signal waveform.

**B. Computer Simulation of Imaginary Frequency Responses of The Ambulatory ECG System**

It is necessary to observe the output waveform actually in order to understand how the input waveforms are distorted by the arbitrary frequency responses of the systems. Fig. 2 shows the computer simulation to know the distortion in the reproduced ECG waveforms through the system. The measured ECG waveform Ei(t) and imaginary frequency responses G(jω) were memorized by a digitizer. The Ei(t) was immediately transformed into Ei(jω) by FFT. The imaginary frequency responses were realized as digital filter. The output ECG waveform Eo(t) was produced by inverse FFT after the calculation as following in the personal computer.

$$\text{Amp.}:\ |Eo(j\omega)| = |G(j\omega)| \cdot |Ei(j\omega)| \cdots (1)$$

$$\text{Phase}:\ \wedge Eo(j\omega) = \wedge G(j\omega) + \wedge Ei(j\omega) \cdots\cdots (2)$$

In this simulation, our purpose was to know the influence of frequency responses on the deviation of S－T segment in the reproduced ECG waveform through the system.

C. Design of Compensation Circuit for Phase Shift Correction

If the compensation circuit(frequency response G(jω)) is attached to the output stage of ambulatory ECG system (frequency responses G2(jω), the overall frequency response will be changed into G1 (jω). The relationship among G1(jω), G2(jω) and G (jω) is described as following.

$$G1(j\omega) = G2(j\omega) \cdot G(j\omega) \cdots\cdots (3)$$

Therefore,

$$G(j\omega) = G1(j\omega)/G2(j\omega) \cdots\cdots\cdots\cdots (4)$$

In this study, the desired phase characteristic $G1(j\omega)$ was that of ordinary ECG equipment, that is, cut-off frequency is 0.05 Hz.

## 3. Results

### A. Frequency Responses of Ambulatory ECG System

Fig. 3 shows the measured frequency responses of the commercial system that were made by Japanese maker F. The tested system was the combination of 3 DR magnetic tape recorders and 2 analyzers. Besides, the frequency responses of ordinary ECG equipment was also drawn in Fig. 3 as a reference.

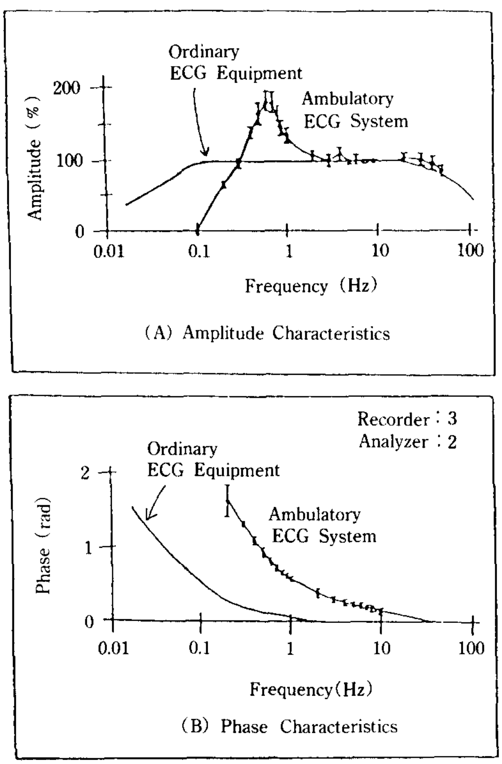


**Fig. 3** The Measured Frequency Responses of The Ambulatory ECG System.

Amplitude characteristics(Fig. 3(A) decayed remarkably at 0.1~0.2Hz and the peak was observed at 0.6~0.7Hz.

Phase characteristics(Fig. 3(B)) showed enormous lead in phase compared with ordinary ECG equipment and it was predicted that ECG waveform would be likely differentiated in lower frequency band.

### B. Cause of Augmentation of The Deviation in S−T Segment

Fig. 4 shows the example of the input, that is, the recorded ECG wave form and the reproduced ECG waveform through an commercial ambulatory system mentioned before.

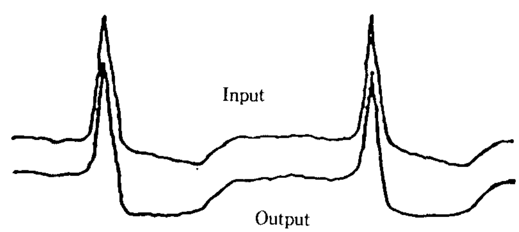


**Fig. 4** An Example of ECG Waveform Distortion Through The Ambulatory ECG System.

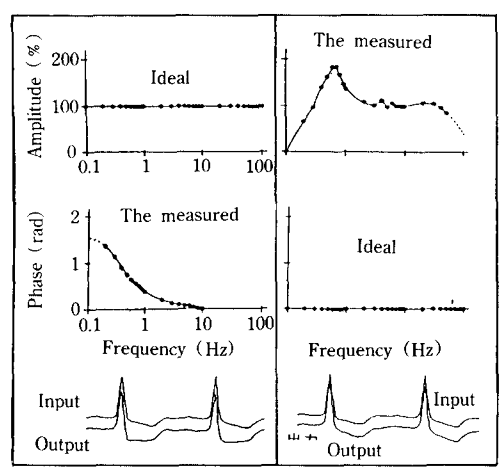


**Fig. 5** The Testification for Augmentation of The Deviation in S−T Segment by Simulation.

The deviation in S−T segment was remarkably augmented. Where, some types of waveforms were not affected by way of the system, because of the frequency components in those waveforms.

In order to investigate which of these 2 characteristics(amplitude and phase) play major role in generating false S−T deviation, a computer program was run with the following frequency response models.

a) The measured amplitude characte ristics plus fictious phase characteristic with no shift.

b) The fictious amplitude characteristics with no cut-off plus the measured phase characteristics.

The actual ECGs were fed into these simulation. As the results were shown in Fig. 5, false augmentation of S−T deviation were found to be caused mostly by enormous lead in phase.

**C. Compensation Circuit for Phase Shift Correction**

Intending to diminish the lead in phase of the ambulatory ECG equipment, a compensation circuit was made by 3 ICs and 2 CR circuits (Fig. 6).

The frequency responses of the circuit was induced from the expression (4) and expressed as following.

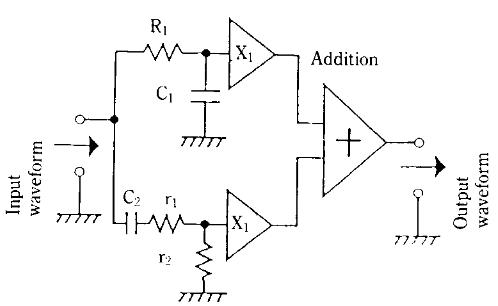


**Fig. 6** Compensation Circuit for Phase Lead Correction.
(R1=50KΩ, C1=60μF, r1=46.3KΩ, r2=6.7 KΩ, C2=60μF)

$$G(j\omega)=\frac{\tau_2}{\tau_1}\cdot\frac{1+j\omega\tau_1}{1+j\omega\tau_2} \quad \cdots\cdots(5)$$

Especially, the circuit was realized by the following transfer function.

$$G(j\omega)=\frac{\tau_2}{\tau_1}\cdot\left(\frac{1}{1+j\omega\tau_2}+\frac{j\omega\tau_1}{1+j\omega\tau_2}\right) \quad \cdots\cdots(6)$$

Where, $\tau_1=0.4$ sec, $\tau_2=3.2$ sec.

**D. Improvement of The Reproduced ECG Waveform by the Compensation Circuit**

The circuit was inserted in the commercial ambulatory ECG system. Fig. 7 shows the effects of the compensation circuit. That is, the middle 3 examples are the reproduced ECG waveforms through the system.

The right 3 are the improved wave forms through the compensation circuit. The distortion of S−T segment were remarkably eliminated. In the trial by 20 ECGs, the compensated system showed no false deviation in S−T segment.

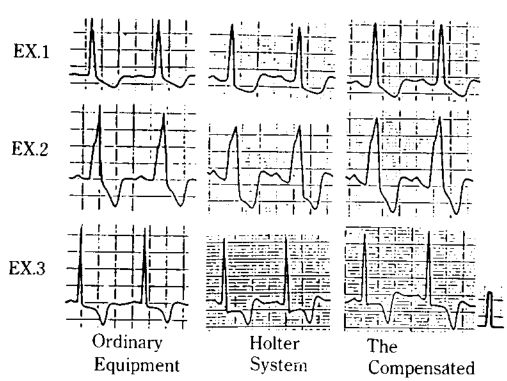


**Fig. 7** Improvement of Output Waveform by Compensation Circuit.

## 4. Conclusions

a) The measuring method and the measured data on frequency response, that is, amplitude and phase characteristic were shown in this paper.

b) Simulation program to realize arbitrary frequency responses as digital filters was developed and it was clarified that the cause of the artificial distortion in S−T segment was derived from the enormous lead in phase of the system.

c) The compensation circuit to diminish the lead in phase was invented and the distortion of S−T segment was eliminated by the circuit.

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