# Comparative Analysis of Infrasonic Cardiac Signals

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## Abstract

*We have studied and compared three different signals of the same category of infrasonic cardiac signals together; namely, SCG, ULF-BCG and EMFIT recordings. The results demonstrate interesting similarities and differences between these signals and help us to understand some of the mechanisms behind the genesis of these waves. For instance, it was demonstrated that the rapid systolic ejection wave on SCG corresponds to similar waves on the other two signals which further confirms its origin to be the rush of blood in the aorta.*

## 1. Introduction

The seismocardiogram (SCG) belongs to a category of cardiac signals that have their main components in the infrasonic range (less than 20 Hz) and reflect the mechanical function of the heart as a pump. During the past century, extensive research has been conducted on interpretation of these signals in terms of their relationship to cardiovascular dynamics and their possible application in diagnosing cardiac abnormalities.

Signals such as the SCG, ultra-low frequency ballistocardiogram (ULF-BCG) and apexcardiogram reflect the displacement, velocity, or acceleration of the body in response to the heart beating. Today, new microelectronics and signal processing technologies have provided unprecedented opportunities to make the mechanical heart assessment of practical use by improving understanding of heart behavior and its diagnostics.

Different methods that were used to acquire these signals are shown in Fig. 1. The SCG is recorded by attaching an accelerometer to the chest at the sternum. The ULF-BCG is recorded using a suspended bed and an accelerometer attached to the bed frame to measure the ultra-low frequency changes of the center of mass of the whole body. The EMFIT signal is recorded either from underneath the back or buttocks while sitting.
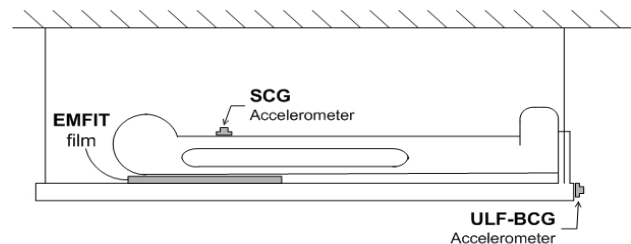


Fig.1. Data acquisition setup

The recorded signal morphology will vary with the measurement method and observation zone employed, but all the techniques appear to sense similar electromechanical events of the heart. The basic physiology behind all these signals is as follows. With each heart beat, blood rushes upward and strikes the aortic arch. The impact is great enough to give the whole body an upthrust. When the descending blood slows down, there is a rebound effect which gives the body a downthrust but not as intense as the earlier upthrust. These signals are normally recorded together with the ECG; thus, an understanding of the electromechanical performance of the heart can be achieved all together.

The BCG traces the movement of the body as an effect of the blood mass ejected by the heart with each contraction to show arterial circulation [1], [2]. Changes and abnormalities in the BCG have been correlated to various cardiac diseases and they are well documented [3], [4].

The EMFIT, thin-film quasi-piezoelectric sensor, produced by EMFIT Ltd, was also used to record the electromechanical activities of the heart due to ventricular vibration and blood circulation [5]. Using the EMFIT sensor for this purpose is well established and a group at the Tampere University of Technology in Finland has investigated diagnosing heart disease using the EMFIT sensor in a chair-type ballistocardiograph [5], [12], [13].

Sometimes referred to as sternal acceleration BCG [6], SCG is more practical for clinical use. American cardiologist Salerno and seismologist Zanetti popularized the SCG technique for clinical use [7], [8]. Later groups have shown the medical relevance of SCG [6], [9].

In order to better understand the genesis of the waves in infrasonic cardiac signals, we studied and compared these signals in the same context and briefly investigated their similarities and differences. With this comparative study we aimed to reproduce the original acquisition setups for these signals and report our findings as a reference to researchers working in this area, enabling them to compare their recordings with other similar recordings.

## 2.  Methods

As explained previously, in this paper we are presenting the results of comparison of three different infrasonic cardiac signals and in this section we explain them briefly. The sensors used for the recording of these signals can be seen in Fig.2 and we used National Instruments data acquisition equipment for sampling the signals at 2.5 KHz.

*A.  SCG*

The SCG signal was obtained as described by Salerno and Zanetti [7] using the same piezoelectric accelerometer placed on the sternum in the midline with its lower edge at the xiphoid process. The sensor is model 393C from PCB Piezotronics that has a linear response between 0.3 and 800Hz and sensitivity of 1.0 V/g.

*B.  ULF-BCG*

The BCG system used in this experiment is an ultra-low frequency bed pendulum and is made of a piece of stretched canvas attached to the ends of a rectangular wooden frame measuring approximately 207 cm by 78 cm and weighing approximately 8 kg [16]. The frame is suspended at four points from the ceiling with 3 m long steel wire rope. A model 4381 piezoelectric accelerometer from Brüel & Kjær was fixed to the bed to measure the longitudinal acceleration such that headward movement was positive [17]. The accelerometer has a charge sensitivity of 10.07 pC/m/s$^2$ and frequency response of 0.1 Hz to 4800 Hz.

*C.  EMFIT*

The well-tested commercial sensor technology by EMFIT Ltd. was also used to observe the mechanical activities of the heart. We used model L-4060 which is approximately 40cm by 60cm, as shown in Figure 2. The sensor was located on the suspended ULF-BCG bed so that subjects lay on top of it supinely making a large contact with the film.
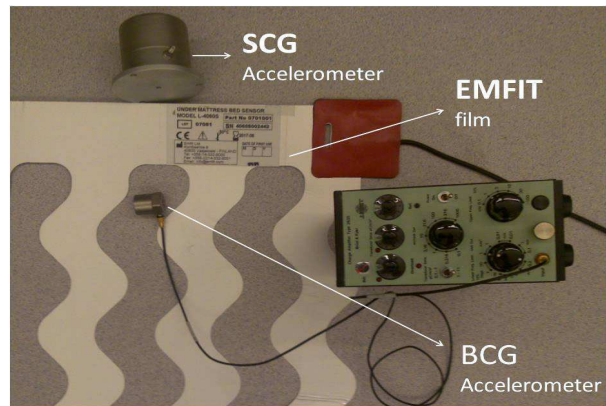


Fig.2. Sensors used for the acquisition of signals.

The EMFIT sensor is a permanently charged elastic film. If a force is induced to the film, a change in charge is generated which can be detected at the sensor output with a simple charge amplifier. For instance, if a pressure around 100 kPa is induced, the EMFIT sensitivity will be above 100 pC/N [10]. We implemented the slightly modified version of the charge amplifier suggested by EMFIT [11] to convert the change in charge to voltage.

## 3.  Results

We recorded the three simultaneous signals of SCG, ULF-BCG and EMFIT film recording by asking our five participants to lie supine on the suspended bed as in Fig.1. All five participants were healthy male adults between 25-32 years old. Our comparison of the EMFIT recording from the suspended bed to the tracings as in the literature [10] proved to us that we were not recording a correct signal; thus, we repeated the tests on a stable bed again by recording SCG and EMFIT separately as can be seen in Fig. 3. The signals in this figure were filtered between 2Hz to 20Hz.

For the other four subjects we have plotted the recording of their ULF-BCG and SCG in Fig. 5 and the R wave of the ECG wave has been marked by a vertical black line.

## 4.  Discussion and conclusions

Based on previous studies on the characterization of SCG waves using echocardiography and other modalities, we have the following observations on the three signals studies in this paper:

*SCG:* As can be observed from Fig. 3, SCG has two components. One corresponds to the ventricular vibration that coincides with the S1 and S2 in the simultaneous phonocardiogram signal. The other component, shown as RE after S1, corresponds to arterial circulation in the
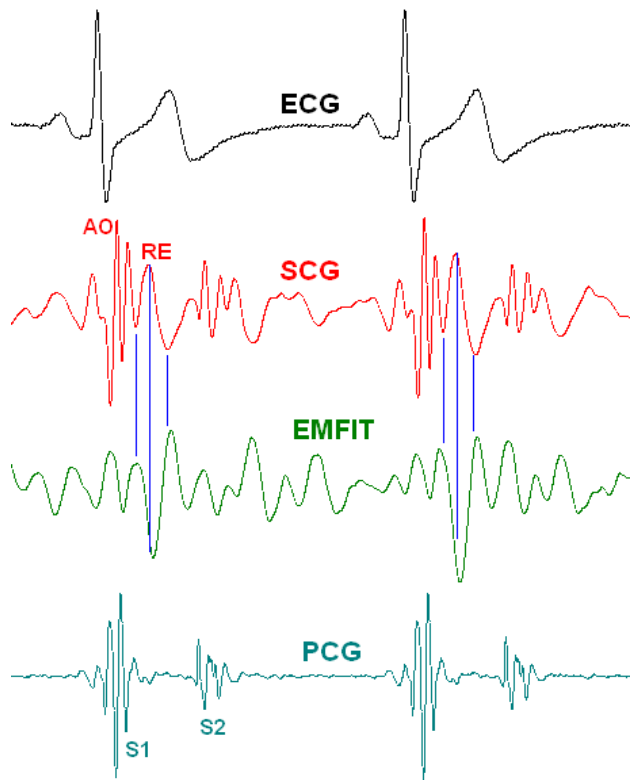
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Fig.3. A typical simultaneous recording of SCG and EMFIT sensor together with phonocardiogram (PCG) on a stable bed. AO: aortic valve open, RE: rapid systolic ejection.

aorta and coincides with significant waves in both the ULF-BCG and EMFIT recordings as seen in Fig. 3 and Fig. 5. In particular, Fig. 5 shows that the starting point of RE on the SCG corresponds to the I wave of the ULF-BCG. It has been shown previously that the IJ wave on ULF-BCG corresponds to the pushing on the blood into the aorta. This is also confirmed by our Doppler echocardiography findings in the past as in Fig. 4.

On the other hand the same RE wave on the SCG corresponds to a reverse replica of itself on the EMFIT recording. The change of polarity is expected to happen between the EMFIT and SCG because when the blood rushes into the aorta it creates a positive force in the z-direction pushing the SCG accelerometer up while taking force off the EMFIT film to create a negative slope on that signal.

*EMFIT recording:* Considering that SCG has been previously studied using echocardiography, by looking at the EMFIT signal we can hypothesize that its waves prior to the aortic valve open point on the SCG corresponds to atrial contraction. The waves marked in blue vertical lines on Fig. 3 correspond to rapid systolic ejection while the waves after S2 are diastolic waves. These findings
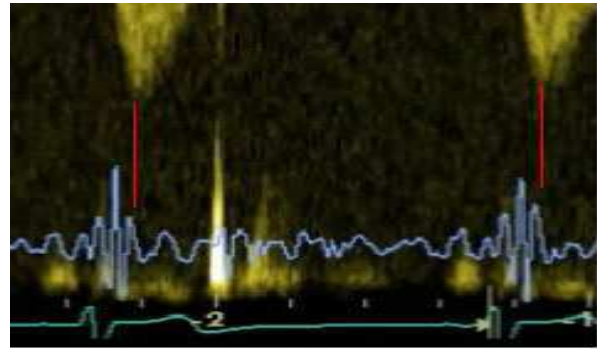


Fig.4. Simultaneous Doppler echocardiogram recorded by GE vivd 7 and SCG. The red line shows the peak of rapid systolic ejection, the blue line is SCG and the green line is ECG. The subject is the same subject as in Fig.3.

demonstrate that the EMFIT signal is affected by direct cardiac vibrations as well as arterial circulation.

*ULF-BCG:* It is noticed from Fig.5 that the HIJ complex, the significant component of ULF-BCG, is right after the aortic valve opening point on the SCG signal. This assures us that this complex originates from the arterial flow. While the aortic valve starts to open, the inertia of the long columns of blood in the arterial trunks opposes acceleration as though there is an obstruction a short distance beyond the aortic valve [19].

Therefore, the first portion of the blood moving out of the ventricles distends the proximal portions of these arteries. Sudden distention of the proximal arterial segments induces a rebound of blood toward the ventricles creating the negative slope of the HI segment. Finally the rapid ejection of blood out of the ventricle creates the positive sloped IJ component whose start coincides with the start of the SCG rapid ejection (RE) complex as seen in Fig. 5, as previously explained.

As a future work we are planning to extract features from all these three signals and to compare them quantitatively and in more detail. In parallel we are using 3D finite element electromechanical model of the heart to determine the ventricular vibration portion of the signals [15].

## Acknowledgements

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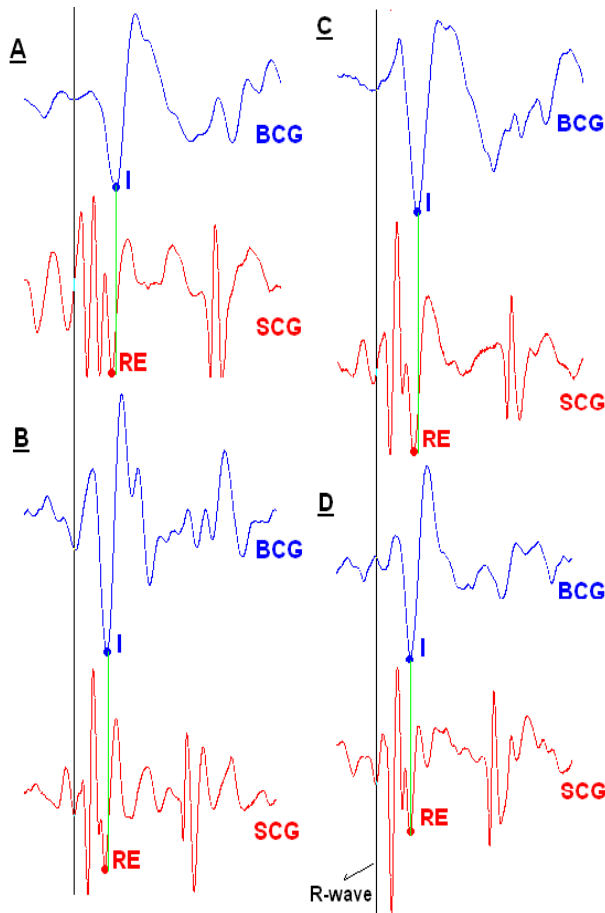
Fig. 5. One cycle of simultaneous recording of SCG and ULF–BCG for four subjects. The black vertical line shows the ECG R wave and the I wave on BCG is connected by a green vertical line to the rapid systolic ejection waves starting point (RE) on the SCG.

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