# A Finger-Ring Shaped Wearable HANDset based on Bone-Conduction

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## Abstract

*This paper introduces a finger-ring shaped wearable HANDset. It uses the human finger as a transmission route for the receiving voice (bone conduction). Vibration noise is reduced using a newly-created microphone unit named "Duaphragm" that can suppress echo by about 70%. Duaphragm provides a small, low-power, and low-cost means of reducing vibration noise. In addition, a new LSI chip that integrates an accelerometer and a tapping command detector allows the handset to be controlled by tapping the fingertip on which the device is worn.*
***Keywords:*** *interface device, headset, noise cancel*

## 1. Introduction

In recent years, the miniaturization of wearable devices has been moving ahead at a rapid pace. Connecting wearable devices has become easier with the emergence of short-range wireless communication methods such as Bluetooth. This suggests the possibility of an ideal operating style of "wearables"; various tiny interface devices are flexibly combined to suit the situation.

The first commercialized wearable I/O device is a wireless headset for cellular phones. These small headsets are easy to wear continuously and seem to be ideal. They have not been widely used, however, in some countries such as Japan. The reason is that the surrounding people regard taking a telephone call via a headset or small earphone-microphone as "talking-alone". This issue will disappear when everyone wears their own small headset device. However, natural operating styles are required to increase the acceptance of new devices by society, especially in the early "wearable" era.

A wearable HANDset that uses the human hand or finger as the vibration transmission route[1] has a natural posture in that the user's hand is placed on the cheek when operating (**Fig.1**); this posture is not regarded as "talking alone". This arrangement also has good receiving performance and can reduce utterance volume even in noisy environments due to the use of the bone conduction receiving mechanism. Unfortunately, vibration noise tends to interfere with the microphone, since the receiving voice vibrates the chassis and microphone capsule (**Fig.2**). This vibration is noticed as a strong "echo" by the other party of the telephone call, and this disturbs comfortable communication. Existing systems use shock-mounts or canceling LSIs to reduce the vibration or echo. These mechanisms, however, are not suitable for wearable devices which must be extremely

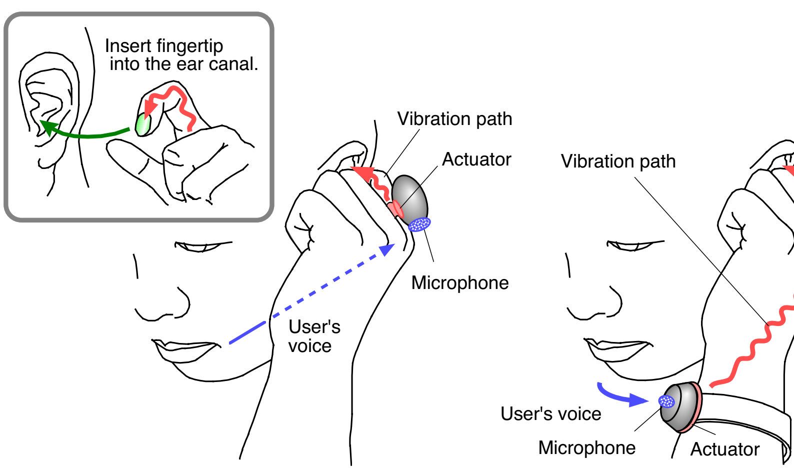


**Figure 1. Wearable HANDsets**
Human finger (& hand) is used as vibration transmission route.


**Figure 2. Vibration interference**
Vibration interferes with microphone.

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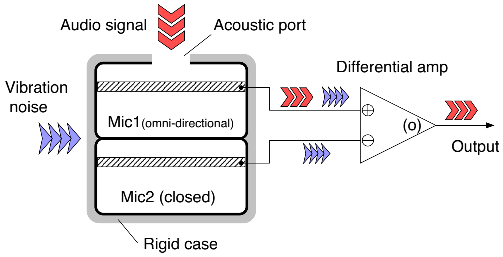


**Figure 3. Mechanism of Duaphragm**

Two microphone capsules are stacked.

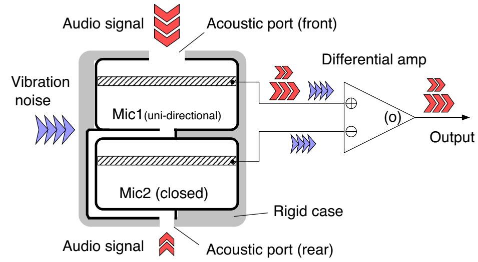


**Figure 4. Uni-directional type**

Mic1 has a small acoustic hole on the rear.

small and have low-power consumption.

This paper describes a bone conduction wearable HANDset that achieves echo cancellation using a new microphone mechanism named "Duaphragm". Duaphragm consists of two simple microphone capsules, and offers small, low-power, and low-cost vibration noise reduction. Buttonless control is also realized using a special LSI chip that integrates a small accelerometer with a finger-tip tapping action detector. Hooking operation is enabled by just rhythmically tapping the fingertips on which the device is worn.

## 2. Vibration noise reducer

The echo problem addressed in this paper, called "acoustic echo", is the interference of speaker sound with the microphone. Typical methods used to suppress acoustic echo and their issues are shown below.

- Acoustic separation of speaker and microphone:
  Air sealing is successful only for air-borne echo; it is not effective for vibration-transmitted echo which passes through the chassis itself.
- Shock-mounting microphone and speaker:
  This is effective against vibration echo, and offers low cost and zero power consumption, but the mounts must be large in order to achieve a good effect.
- Electronic echo cancellation LSI:
  This has good performance, but cost and power consumption are high.

The above discussion suggests that ordinary methods are not suitable for wearable devices that require small size and low power consumption. A well-known method for reducing acoustic noise is to use the differential signal of two microphones[2]. Unfortunately, such systems are not effective for reducing vibration noise. A vibration noise canceling microphone that mounts a small vibration sensor (accelerometer) in the microphone capsule[3] has been described, but it needs a complex cancellation circuit because it is difficult to match the vibration characteristics of microphone diaphragm to those of the accelerometer.

### 2.1. Duaphragm

This paper proposes a new vibration noise reduction mechanism named "Duaphragm", which uses an ordinary microphone capsule as a vibration sensor. The basic structure of Duaphragm is shown in **Fig.3**. Two microphone capsules (Mic1 and Mic2) are rigidly connected, and Mic2 is acoustically sealed[1]. The audio signal and vibration noise are both collected by Mic1. On the other hand, the sealed Mic2 detects only vibration noise. Therefore, the differential output of the two microphone capsules is just the acoustic signal.

The microphone capsules have identical internal structures, which makes the vibration characteristics easy to match. Moreover, the strength and phase of vibration noise detected by both microphone units are about the same due to the fact that Mic1 and Mic2 are rigidly connected. Vibration noise can thus be eliminated by a simple differential circuit without using a complex adaptive echo canceling mechanism. In addition, manufacturing costs can be greatly reduced using a mass-produced ECM (Electret Condenser Microphone) as both microphone capsules.

In this figure, vibration noise is reduced by processing the differential output. A simple alternative is to reverse the output of one microphone and then connect the outputs. For example, we can reverse the charging polarity of the electret membrane, or reverse the installation direction of one microphone.

The microphone shown in **Fig.3** is omni-directional. A uni-directional microphone is also realized by adding a backside acoustic hole to Mic1 (**Fig.4**).

### 2.2. Performance comparison

We compared Duaphragm to three ordinary methods (small shock mount[2], large shock mount[3] and echo canceling LSI[4]) in terms of noise reduction performance (**Fig.5**).

1 Mic2 has a tiny (less than 50$\mu$m) hole to stabilize internal air pressure. However, the acoustic isolation is greater than 40dB.
2 $\alpha$-gel blick 17 x 17 x 8mm
3 SONY CRS-3P

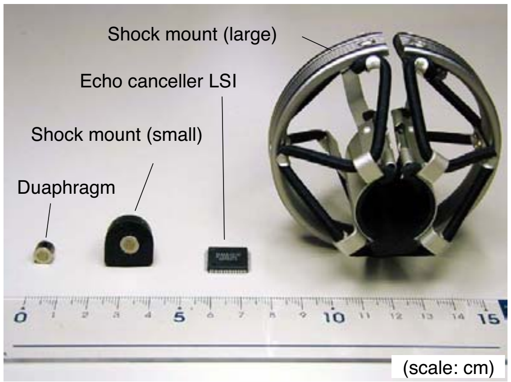


**Figure 5. Noise reduction methods**

Duaphragm is smaller than others.

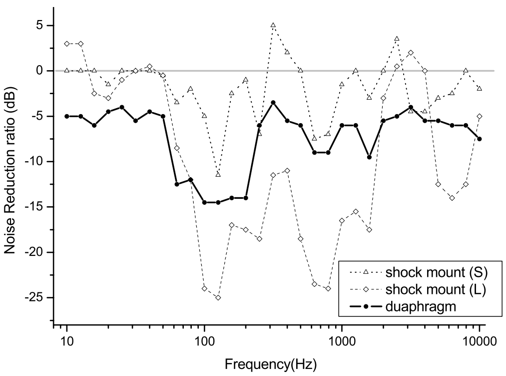


**Figure 6. Vibration noise reduction**

Duaphragm enables 5-15dB noise reduction.

**Table 1. Comparison of noise reduction methods.**

| Method | Volume ($mm^3$) | Power (mW) | Reduction ratio (dB) | Cost ($) |
|---|---|---|---|---|
| Shock mount (S) | 4800 | 0 | (-5) – 12 | $< 0.5$ |
| Shock mount (L) | 300000 | 0 | (-4) – 25 | 2 – 30 |
| Noise cancel LSI | 677 | 30 | (-1) – 33 | 2 – 20 |
| **Duaphragm** | **141** | **1** | **4 – 15** | $< 1$ |

The microphones and shock mounts were placed on a vibration exciter, and the frequency response of vibration interference (10Hz – 10kHz) was recorded. The reduction in vibration noise achieved by the Duaphragm prototype is shown in **Fig.6**. The results of each shock mount combined with a reference microphone capsule[5] are also shown.

The small shock mount offered no significant reduction effect. The large shock mount had good performance in the frequency band of 100Hz – 1kHz, but its size makes it impractical for wearable applications. Moreover, both shock mounts increase the noise level in some frequency bands. On the other hand, Duaphragm offered about 5dB (50%) noise reduction over the entire frequency band, and about 15dB (80%) reduction in the 100 – 200Hz range. The noise canceling LSI achieved a reduction of up to 33dB. However, it requires much electric power, and the reduction ratio changes significantly according to input signal conditions. In addition, many echo canceler LSIs drop the low (under 300Hz) and high (over 4kHz) frequency components, resulting in a deterioration of sound quality.

The noise reduction ratio, size, and power consumption of each method are shown in **Table1**. The table indicates that Duaphragm offers stable vibration noise reduction with small sizes and low power consumption (and low cost).

4 OKI MSM7731-02

5 Primo EM161: corresponds to Mic1 of Duaphragm

## 3. Ring-shaped HANDset

A finger ring shaped HANDset was developed using a Duaphragm microphone (**Fig.7**). It is worn on the base of the index finger. The received voice is converted into vibration by the actuator, and conveyed to the ear canal through the ring and the tip of the index finger. Vibration is also used for silent ringer. Duaphragm microphone is mounted at the back part of the chassis and is directed at the user's mouth when in use. The HANDset works as a Bluetooth headset device; it occupies 35cc and weighs 29g (including 6g ring).

**Fig.8** shows the effect of the echo reduction offered by the proposed microphone. A telephone call is established between an ordinary telephone [P] and the proposed HANDset [Q]. The figure indicates the echo amplitude returned to the telephone [P], when the short voiced segment

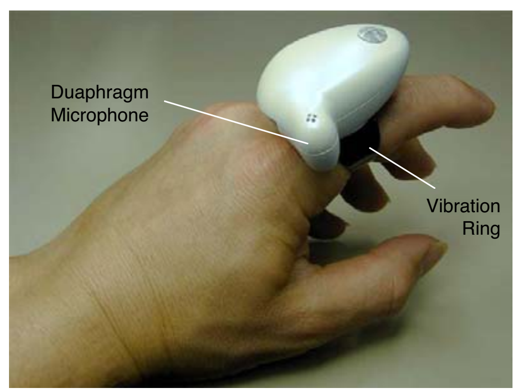


**Figure 7. Ring shaped HANDset**

Finger ring is vibrated.

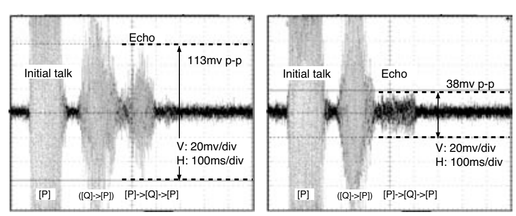


**Figure 8. Echo reduction**

(a) ordinary microphone / (b) Duaphragm

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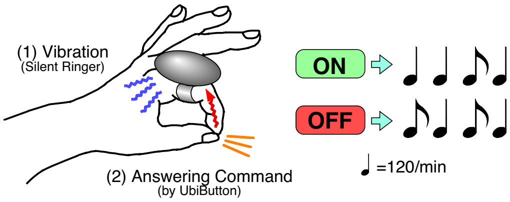


**Figure 9. UbiButton command**

Buttonless control is enabled by the UbiButton command.

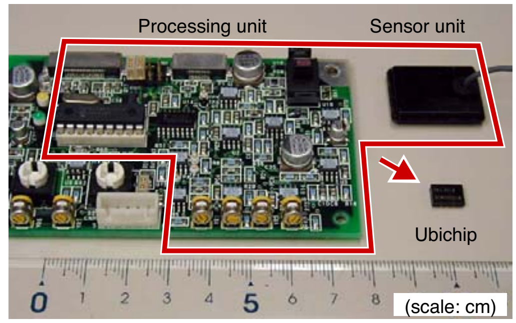


**Figure 10. UbiChip**

Accelerometer, filter, and command detector are packaged.

(/a/) is uttered into the microphone of [P]. In each figure, the leftmost peak is the original voice (at [P]), and echo is observed as the third peak ([P]→[Q]→[P]) about 400msec later (roundtrip delay time of cellular phone communication). The figure shows that the proposed microphone (b) suppresses the echo by about 9.5dB compared to the ordinary microphone (a).

### 3.1. UbiButton-control

Small wearable devices are difficult to operate due to their small buttons. The ring-shaped HANDset can be controlled by the tapping action of the finger-tip. An accelerometer (1-axis) detects the vibration generated by lightly tapping the thumb and the index finger on which the HANDset is worn. Commands are associated with particular tapping rhythms (**Fig.9**). This enables true "one-hand" operation, so the other hand is not needed for control. Unexpected operations caused by the vibration noise, such as hand motions or silent ringer, are reduced through the use of a steep-edged filter that passes only the tapping-specific frequency band (80 – 200Hz).

Though a tapping-based controller has been proposed[1], it is difficult to implement in a small wearable device, since it uses large analog circuits (4800mm$^2$) that consume much power (300mW). We developed an LSI package that integrates an accelerometer and tapping detector for the ring-shaped HANDset. The package is small (48mm$^2$) and has low power consumption (less than 10mW). **Fig.10** shows both the previous and the new integrated tapping detectors.

## 4. Application

The proposed vibration reduction microphone is suitable for appliances that utilize the vibration of all or a part of its chassis, such as bone conduction speakers and vibrators. Moreover, the proposed method can also be used for various appliances that are sensitive to vibration noise, such as cellular phones, voice recorders, and voice recognition units. It is especially suitable for wearable devices that cannot use large shock mounts, and for cost-sensitive consumer devices. Another possible application is with vehicle-mounted appliances that suffer from significant problems caused by vibration noise.

## 5. Discussion

Though the proposed microphone can well suppress vibration noise, it is not so effective at reducing background noise. Therefore, it does not fully utilize the advantages of the bone conduction receiver, which has good performance in noisy environments. It is possible to use another Duaphragm capsule for collecting background noise.

The finger-mounted "bone conduction microphone" can detect vibration generated by the utterance and can cut background noise completely. However, it is difficult to extract small utterance signals from strong vibration created by the received voice.

## 6. Conclusion

This paper proposed a small, cost-effective vibration reducing microphone (Duaphragm) that combines two microphone capsules, one of which is acoustically sealed. Duaphragm was used to create a finger-ring shaped bone conduction HANDset, and its echo reduction performance was confirmed. By miniaturizing the bone conduction HANDset, we aim to realize a truly "ring"-sized fulltime-wear voice interface device.

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