International Journal of Physical Sciences Vol. 2 (4), pp. 104-111, April, 2007
Available online at http://www.academicjournals.org/IJPS
ISSN 1992 - 1950 

*Full Length Research Paper*

# A sonar system modeled after spatial hearing and echolocating bats for blind mobility aid

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Accepted 30 March, 2007

**This paper present a sonar system modeled after human spatial hearing and echolocating bats. It's composed of three transducers, one transmitter which plays the role of the mouth of the bat that transmits echolocating signal and two receivers located respectively near the left ear and the right ear so as to mimic human ears configuration. Inaudible ultrasound echoes captured at the receivers are converted into audible sound using the Doppler shift frequency induced by the user during his movement. The two resulting audible Doppler signals are conveyed binaurally to the user through stereophonic earphones. The amplitude of these audible signals depends on the reflecting properties of the objects detected and their location. It increases as the distance between the system and the object decreases of about 10 decibels per meter. The intensity difference between them increases linearly with the azimuth of 0.34 decibel per degree. Experiments carried out with this sonar system show that it can be helpful to blind people in spatial sensing by supplying information regarding his movement as well as objects movement and their spatial location at the left side, at the right side or in front of him.**

**Key words:** Sonar system, blind mobility aid, spatial hearing, Doppler effect.

## INTRODUCTION

Blind people are faced with many problems such as independent and graceful travel. It is well known that visually impaired people use their hearing sense to compensate for their reduced eyesight. For instance, they can recognize sound sources. Human spatial hearing was analyzed by many authors (Blauert, 1999; Moore, 1997) who established that both monaural and binaural attributes of the ear input signals contribute to forming the position of the auditory event. High frequency sound is lateralized on the basis of the interaural level difference, while monaural sound level serves to define the distance of the auditory event.

This paper focuses on the electronic blind mobility aid,: which can be achieved according to two types of system optical system that use an optical sensor (Petrie et al., 1996; Sawa et al., 2002; Maingreaud et al., 2002; Pissaloux, 2002; Pissaloux et al., 2003), and ultrasonic system that uses an ultrasonic sensor. Sonar techniques, namely Frequency Modulation (FM) and pulsed echo techniques have been widely used in ultrasonic blind mobility aid, presumably because they are well suited for localizing objects (Kay, 1964; Pressey, 1977; Heyes, 1981; Wael, 1989; Ifukube et al., 1991). Our approach was motivated by the human spatial hearing which blind people use in the case of sound sources, and by the bat echolocation. In this paper, an ultrasonic blind mobility aid device is achieved by mimicking both the human ears configuration and the echolocating bats, and by implementing a technique to convert inaudible ultrasound echoes into audible sounds.

In the next section, our sound navigation and ranging (sonar) model is described. Then the converting method is presented, followed by experimental results which validate it use as a blind mobility aid device.

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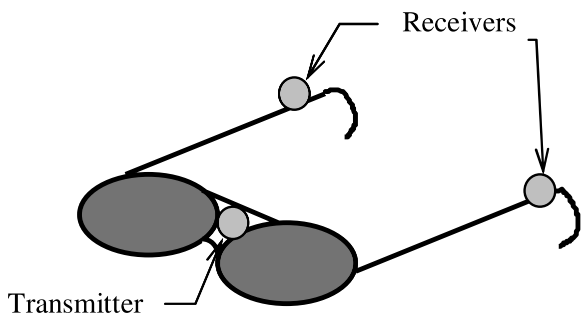



a)

b)

**Figure 1.** The configuration of the three transducers mimicking the human ear configuration a) Transducers mounted in a pair of spectacles b) Transducers placed on a dummy head.

## MATERIALS AND METHODS

### Description of our sonar system model

The biophysical mechanism of the binaural hearing is based on a kind of coder-decoder system, where the coding is performed by the antenna structure made up by the head and the ears, while the decoding is performed on different higher levels of the auditory system (Bodden, 1994). Our system consists of three ultrasonic transducers, one transmitter and two receivers mounted in a pair of spectacles. One receiver is located near the left ear and the other near the right ear, so as to mimic the binaural hearing coder system mentioned above. The transmitter is located between the two glasses so that in our bat-like sonar system (Barshan and Kuc, 1992) it plays the role of the mouth of the bat which transmits echolocation signals (Galambos and Griffin, 1940; Nachtigall and Moore, 1988; Waters and Vollrath 2003; Thomas et al., 2004).

The two receivers capture the echoes reflected back by objects. The configuration of the three transducers, one acting as a transmitter and the others as the receivers is shown in Figure 1. To take advantage of the sonar system model described here, ultrasound echoes captured at the receivers must be converted into audible sounds.

### Conversion of ultrasound echoes into audible sounds

Blind people run the risk of colliding with an obstacle only when they are in movement relatively to their environment. Consequently Doppler effect, which is based on the movement, was used to convert ultrasound echoes into audible sounds (Bitjoka, 1994). Any object in movement within the environment of our device induces a Doppler signal at each receiver whose frequency, less than 500 Hz (Bitjoka and Pourcelot, 1999) is in the audible range.

### The mobility aid device

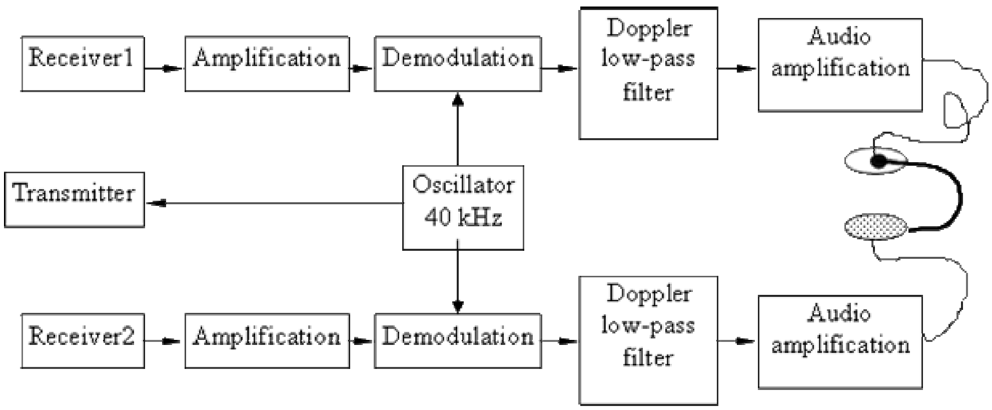
It is composed of three 40 kHz ± 1 kHz wide-beam (55°) ultrasound transducers mounted in a spectacle frame and connected to an electronic system. The electronic system (Figure 2a and 2b) consists of two identical processing channels, which detect the audible Doppler signal. In operation, a crystal-controlled 40 kHz oscillator (Figure 2c) drives a 40 kHz ultrasonic transmitter that transmits a beam of unmodulated continuous wave. The received echo at each channel is amplified (Figure 2d) mixed with the transmitted signal using analog switch (Figure 2e), then low-pass filtered at 390 Hz (Figure 2f and 2h) and amplified (Figure 2g). The two resulting low frequency signals are conveyed binaurally to the user through stereophonic earphones. Our blind mobility aid device is small (155 x 92 x 45 $mm^3$), lightweight (150 g) and driven by a standard 9 V battery (Figure 2b). The amplitude of the audible signal is a function of the reflecting properties of the object as well as its location. It increases as the distance between the blind and the object decreases of about 10 decibels per meter (10 dB/m). The intensity difference between the Doppler signals reaching the two ears, measured at 110 Hz (Figure 3), increases linearly ($R^2 = 0.992$) with the azimuth of 0.34 decibel per degree (0.34 dB / °). The phase difference between the Doppler signals reaching the two ears, measured at 110 Hz, is ambiguous.

### Test of validation

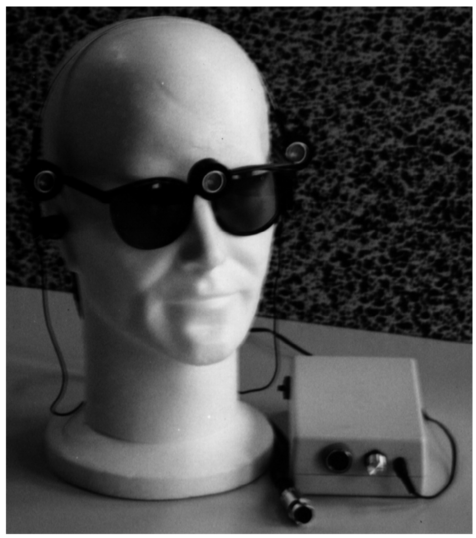
Experiments were carried out by twenty blind people exhibiting good hearing abilities. They were preceded by a short training in the functioning of the device. The objective was not to evaluate the blind mobility aid, but to verify the validity of our sonar model. Two categories of experiments were achieved. The first category consisted in detecting moving objects and the change in their speeds. The second category consisted in detecting the proximity of obstacle and their location at the left side, at the right side or in front of the user. Experiments concerning the left/right location or lateralization were carried out on a straight, 1.5 m wide path, with cylindrical posts 14 cm in diameter, 3 m in height, planted on each edge as shown in Figure 4a. These cylindrical posts were alternatively placed in the left edge and in the right edge, and separated each other of 2 m (Figure 4b). Experiments consisted in walking through this path, indicating every time the location of the post detected.

## RESULTS AND DISCUSSION

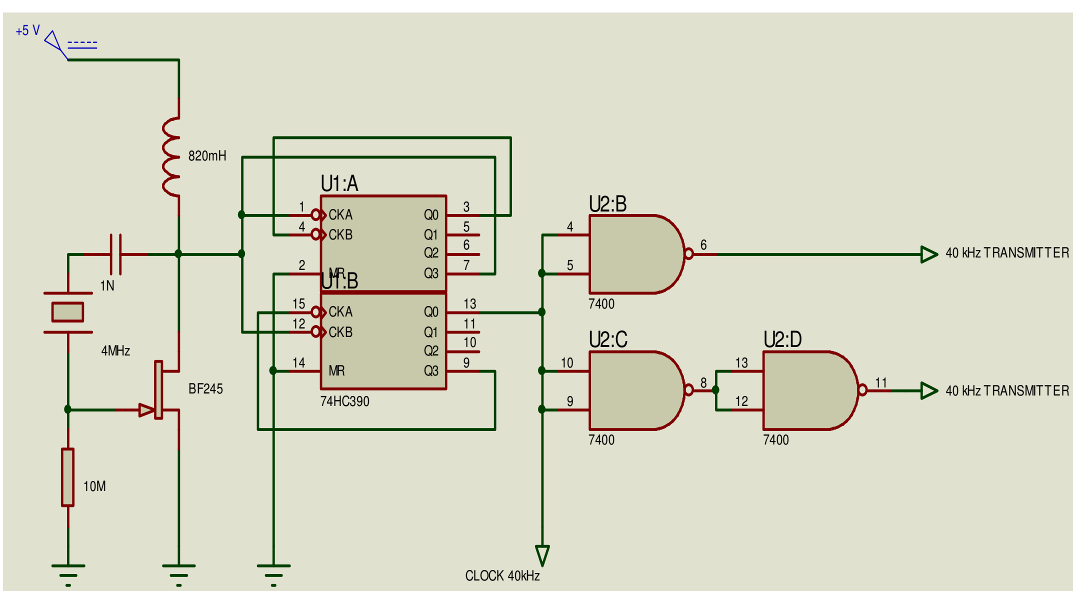
For the first category of experiments, every user was able to detect a moving hand, a walker and encountered objects on the walking path for example. Indeed, the audible sound reaching the ears of the user is a Doppler signal, whose frequency is linearly related to the speed of the moving object detected. Since the Doppler signal is correlated to movement, the user receives an audible sound only if there is a moving object in his environment. However all users were not able to discriminate between a fast and a slow movement. Good discrimination was made in 67 ± 8% of cases. This result can be justified by the fact that an audible sound with frequency $F_0$ seems


Receiver1
Amplification
Demodulation
Doppler low-pass filter
Audio amplification
Transmitter
Oscillator 40 kHz
Receiver2
Amplification
Demodulation
Doppler low-pass filter
Audio amplification

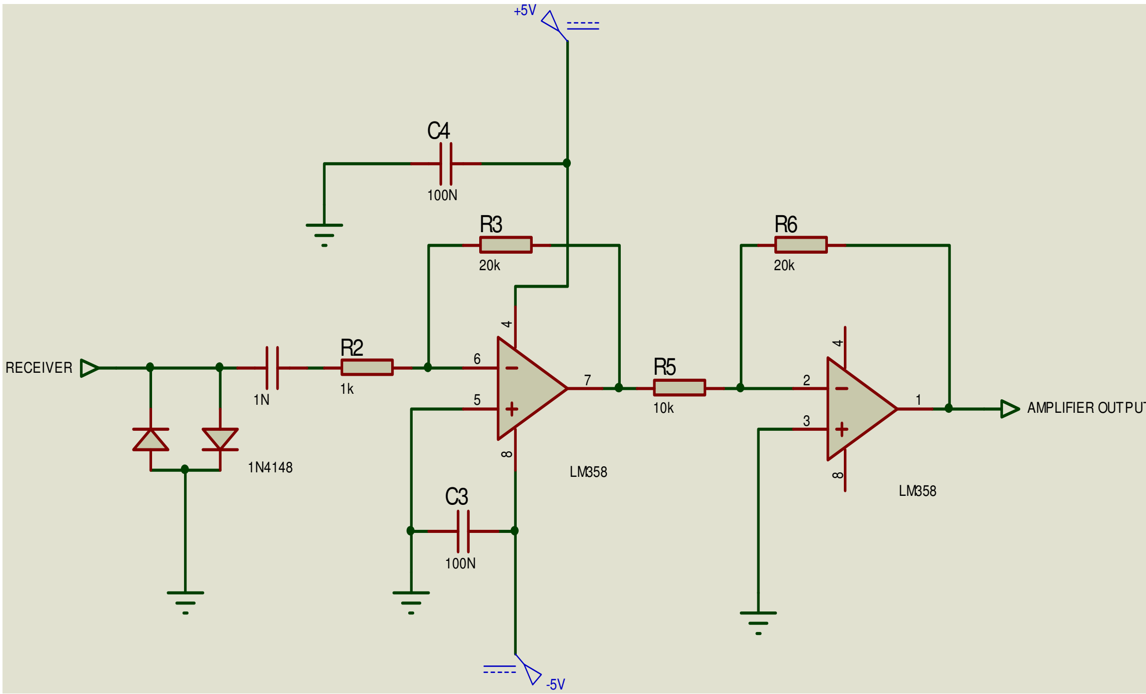
a)



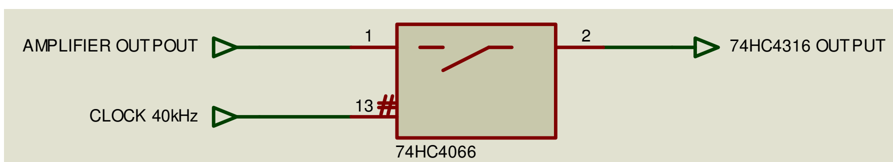
b)


+5 V
820mH
1N
4MHz
BF245
10M
U1:A
CKA
CKB
MR
Q0
Q1
Q2
Q3
U1:B
CKA
CKB
MR
Q0
Q1
Q2
Q3
74HC390
U2:B
7400
U2:C
7400
U2:D
7400
40 kHz TRANSMITTER
40 kHz TRANSMITTER
CLOCK 40kHz

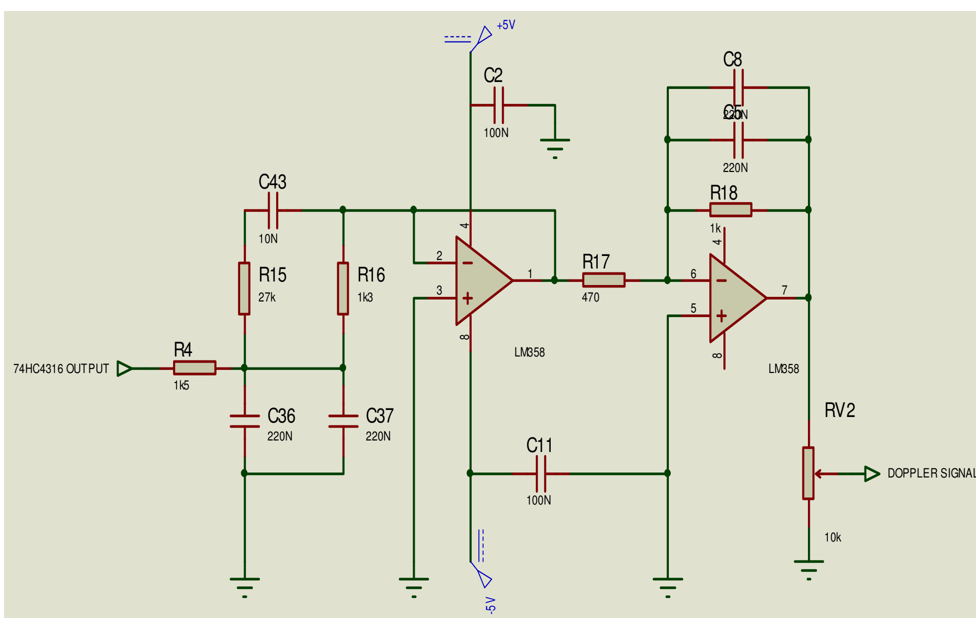
c)


+5V
C4
100N
R3
20k
R6
20k
RECEIVER
1N
R2
1k
1N4148
R5
10k
LM358
C3
100N
LM358
AMPLIFIER OUTPUT
-5V

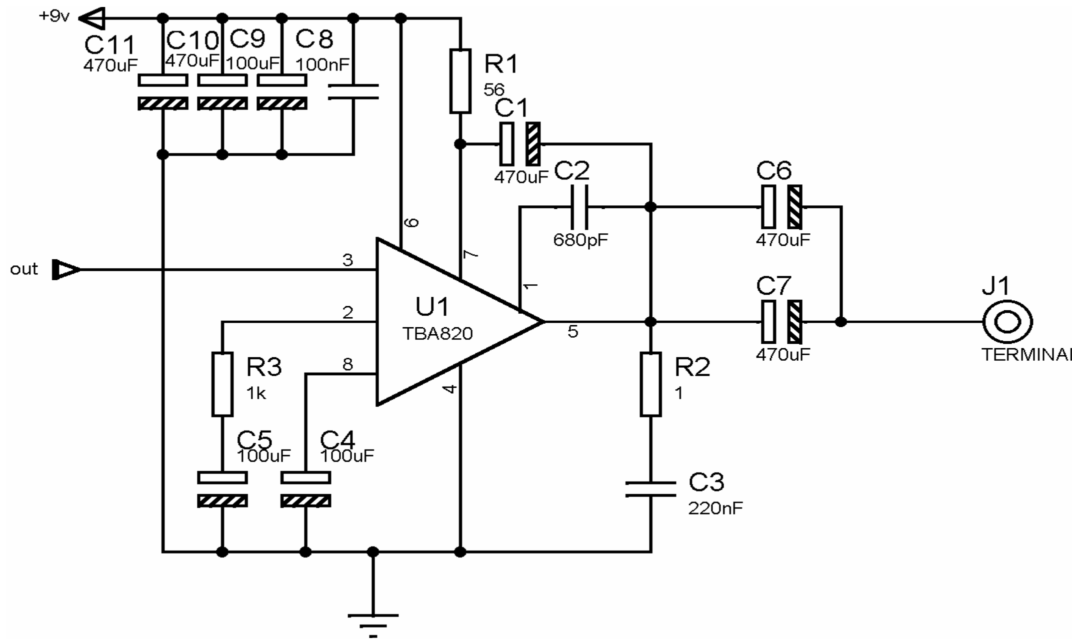
d)


AMPLIFIER OUTPOUT
CLOCK 40kHz
74HC4066
74HC4316 OUTPUT

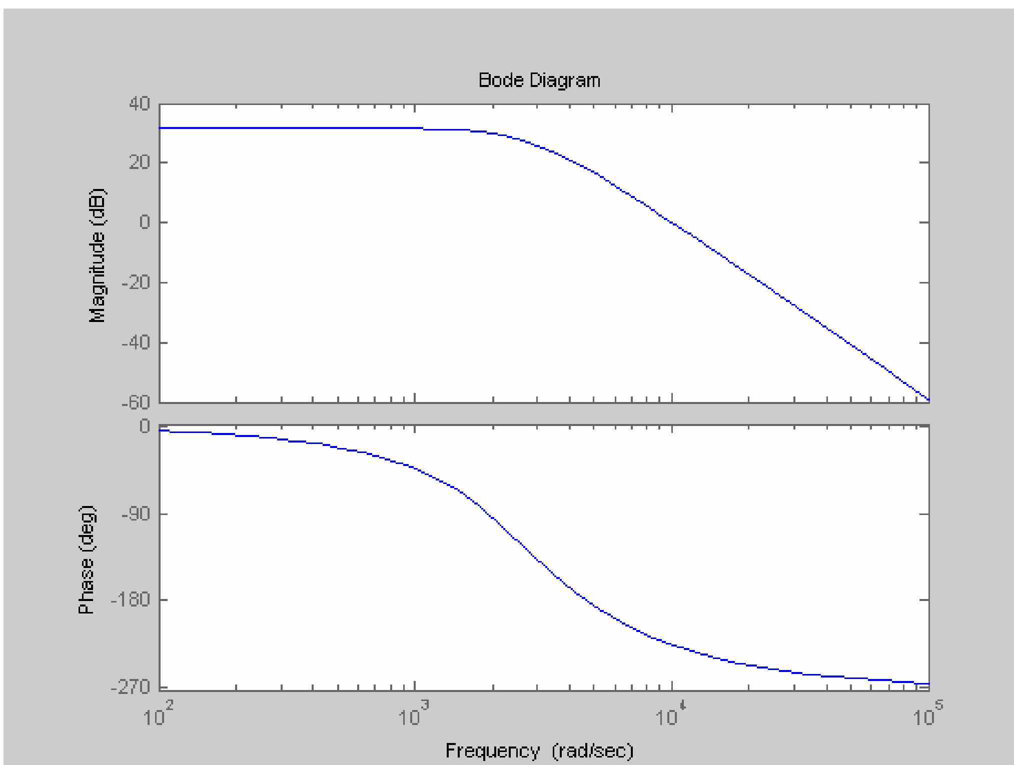
e)


+5V
C2
100N
C8
220N
R18
1k
C43
10N
R15
27k
R16
1k3
R17
470
LM358
LM358
74HC4316 OUTPUT
R4
1k5
C36
220N
C37
220N
C11
100N
RV2
DOPPLER SIGNAL
10k
-5V

f)




g)




h)

**Figure 2.** The blind mobility aid device a) The block diagram of the electronic system. b) A photograph of the device. c) The crystal-controlled 40 kHz ultrasonic transmitter circuit. d) The ultrasonic receiver amplification circuit. e) The demodulation circuit with the 74HC4066 analog switch. f) The Doppler low-pass filter circuit. g) The Audio amplification circuit. h) The Doppler low-pass filter response simulated with Matlab®.

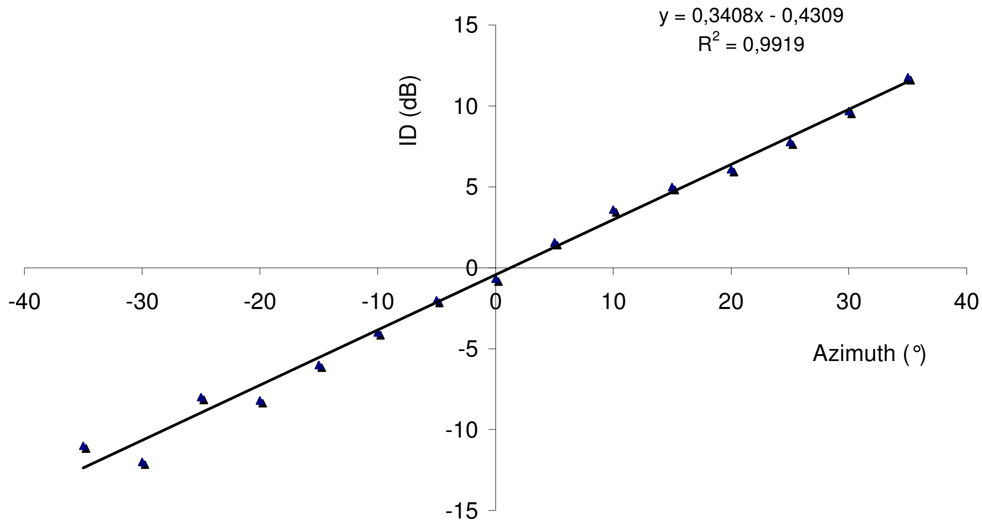
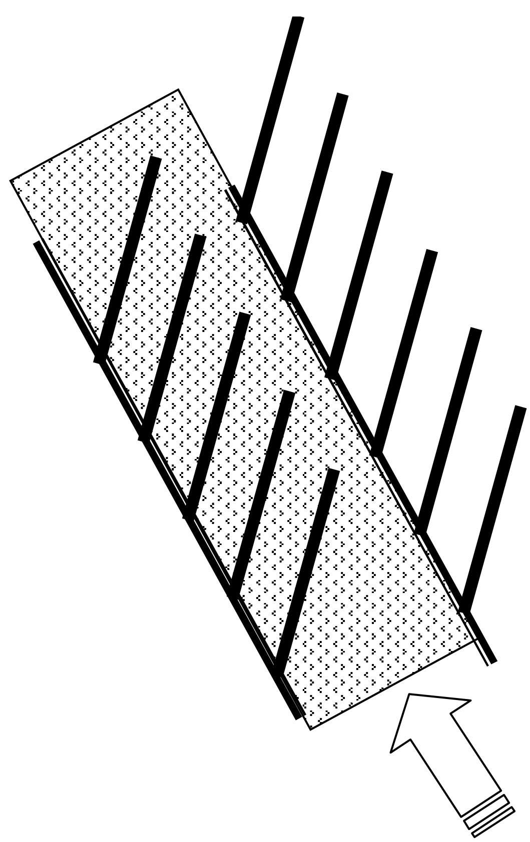
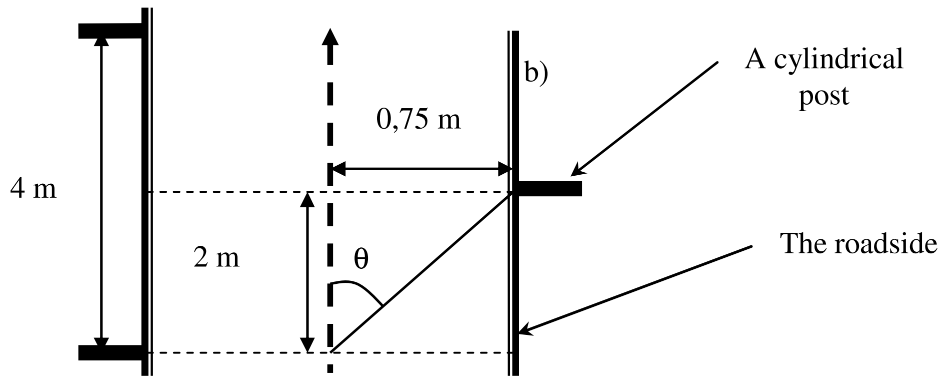



**Figure 3.** The intensity difference (ID) measured with a 17 cm diameter sphere on a Doppler signal (110 Hz).



a)




b)

**Figure 4.** a) Arrangement of cylindrical posts for experiment concerning the left/right location (lateralization) b) A detail of the experimental path showing the azimuth θ.

to be of frequency $F \neq F_0$ depending on his intensity, particularly if $F_0$ is low than 1 kHz.

Concerning experiment on the detection of the proximity of obstacles, 72 ± 13% of the users was capable to detect the proximity of a wall, a lamppost and other object sufficiently reflective to produce an audible sound with significant intensity. Indeed, it has been shown that the distance of the auditory event decreases with increa-sing sound level at the ears. For instance a level rising of 20 dB leads to a halving of the distance of the auditory event. The result presented here was obtained when users were familiar with their environment.

During experiment on the location of objects at the left side, at the right side or in front of the user, 85 ± 5% of good lateralization was obtained. The best performances (100% of good lateralization) were obtained when the user was capable to walk in the middle of the path, following a straight line. In this case, the azimuth θ (Figure 3b) has the minimum value that is, 20.6° and the intensity difference between the two sounds reaching the ears of the user is 6 dB. For other azimuth where θ is small, the intensity difference between the two sounds reaching the ears of the user is also small and their phase difference can led to wrong lateralization. Our results are in agreement with studies on sound localization which asserted that human being localize sound using binaural difference cues (interaural level difference and interaural time difference) for azimuth (Blauert, 1999). High freque-ncy sound is lateralized on the basis of the interaural level difference. Indeed, the ultrasound wavelength of our device, 8.5 mm, is small compared to the size of the head which casts a shadow over one receiver according to the location at the left or at the right side of the user. Objects detected with our device must then be lateralized on the basis of the ultrasound level difference reaching the two receivers, thus the sound level difference reaching the ears of the user after conversion via the Doppler effect. When using our device in a residential area, where objects are not regularly set out in the environment, the user need to move the head to lateralize them with great certainty. Since the Doppler signals transmitted to the user are complex sounds, whose frequency, phase and intensity vary rapidly with time, depending on the environment of the user and his walking speed, we think that both the acoustic cues considered in this paper (intensity difference and phase difference) and other spectral features of these signals contribute to the localization of objects. The scattering properties of 40 kHz ultrasound by the head of the user of our device play a central role on these spectral features (Katz, 1998; Aytekin et al., 2004).

## Conclusion

In this paper a sonar system modeled after human spatial hearing and echolocating bats was achieved. It's composed of three transducers, one transmitter which plays the role of the mouth of the bat that transmits echolocating signal and two receivers located respec-tively near the left ear and the right ear so as to mimic human ears configuration. It delivers two audible Doppler signals conveyed binaurally to the user through stereo-phonic earphones. The amplitude of the audible Doppler signal delivered by this sonar system depends on the reflecting properties of the objects detected and their location. It increases as the distance between the system and the object decreases of about 10 decibels per meter (10 dB / m). The intensity difference between the Doppler signals reaching the two ears increases linearly with the azimuth of 0.34 decibel per degree (0.34 dB / °). Experiments carried out with this sonar system show that it can be helpful to blind people in spatial sensing by supplying information regarding his movement as well as objects movement and their spatial location at the left side, at the right side or in front of him.

## ACKNOWLEDGMENT

The authors thank Professor Philip Nelson, Deputy Vice-Chancellor of the University of Southampton (UK) and former Director of the Institute of sound and vibration research, for fruitful discussion. We thank Dr. Mahop Crépin Marie, Assistant Professor at Howard University (USA) and former senior lecturer at the University of Ngaoundéré, for his valuable comments on an earlier version of this manuscript.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