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Design of a Sound-to-Vibration Alerting Device for Enhancing Situational Awareness in Deaf Individuals

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Keywords:
Amplitude modulation; Deaf; Envelope detector; Vibration alerting; Vibrator driver.

Highlights:

- *Extract the general shape of the audio signal using the envelope detector.*
- *Conversion of audio frequencies to low vibration frequencies.*
- *A signal with a suitable vibration frequency and amplitude proportional to the sound intensity.*

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Abstract: Deaf individuals often struggle with a lack of awareness of their surroundings and face challenges in communicating due to their inability to perceive surrounding sounds. This study presents a novel design and implementation of an electronic circuit that senses and amplifies surrounding sounds, converting them into specific vibrations to alert deaf individuals through their skin about the presence of nearby sounds. The circuit comprises an audio sensor (microphone), an audio amplifier, a sound frequency converter to low vibration frequencies, and a specialized circuit to drive a vibrator that synchronizes with the sound's presence. The vibration intensity corresponds to the sound intensity, providing the deaf individual with a sense of the sound's shape and intensity in the environment. This design simplifies the circuit to reduce costs while maintaining efficiency, making it suitable for portable use. Additionally, the study proposes a method to enhance performance by sending wireless signals with specific modulation, which can be converted at the receiver into distinct vibration patterns, enabling the deaf individual to recognize different types of alerts or the identity of the caller.

تصميم جهاز تنبيه بالصوت والاهتزاز لتعزيز الوعي الظرفي لدى الأفراد الصم

قيس الدبان
قسم الهندسة الكهربائية/ كلية الهندسة / جامعة تكريت / تكريت – العراق.

الخلاصة
يعاني فاقدي السمع (الصم) من عدم إدراكهم لما يجري حولهم من احداث بشكل طبيعي فضلا عن صعوبة تواصلهم مع الاشخاص القريبين , ذلك لأنهم لا يشعرون بالاصوات المحيطة حولهم، لذا تم تصميم وبناء دائرة الكترونية تقوم بتحسس الاصوات المحيطة وتكبيرها وتحويلها الى إهتزازات متوافقة مع الصوت لاشعار الاصم عن طريق الجلد بوجود الصوت حوله. وتتكون الدائرة باختصار، من متحسس صوتي (لاقط) ودائرة تكبير الصوت ثم محول الترددات الصوتية الى ترددات الاهتزازات الواطئة ثم دائرة خاصة لسوق الهزاز ليهتز بالتزامن مع وجود الصوت وبشدة اهتزازية تتناسب مع شدة الصوت لتعطي الاصم فكرة عن شدة الصوت في البيئة المحيطة وشكل المقطع الصوتي وطوله بدلا من مصفوفة من الهزازات. في هذا التصميم تم الحرص على ان تكون الدائرة مبسطة قدر الامكان لتقليل كلفتها، مع كفاءتها لتكون مناسبة للاستعمال و قابلة للحمل. كذلك تم اقتراح طريقة لتحسين الاداء وتوسيعه، تخص الاستجابة للنداءات و للتنبيهات الهامة وذلك بواسطة ارسال اشارة لاسلكية بتضمين معين يمكن تحويلها عند المستلم الى اشارة اهتزاز مميزة يتعرف من خلالها الاصم على نوع التنبيه او هوية المنادي.

الكلمات الدالة: النهج، نطاق التبريد، برج التبريد، الحشوات، الأداء.

1.INTRODUCTION

The blessing of hearing is one of the great blessings that Allah has bestowed upon humans because it has a profound effect on understanding the events around them, and even in sleep. An individual who lacks this sense misses an important aspect of the sense of what is going on around, as well as the natural response to it. Compounding this, and as a result of it, many of them lost their speech skill. Since ancient times, people who have been afflicted with this disability have tried to reduce its negative impact, their families and those around them helped them using sign language that depends on the sense of sight, as it helped a lot; however, it requires directing the eyes of the deaf towards the direction of the sign; otherwise, there is no use for this method. Therefore, another method is required to alert the deaf, which could be a mechanical notification through the skin. With the advancement of technology, man has tried to find more effective means in this field, including what improves the performance of the hearing mechanism for the hard of hearing (through amplifying the sound) [1]. Alternatively, someone who has a defect in the eardrum only with the health of the inner ear, a microphone and vibrator are implanted in the meatus to transmit sound vibrations from the surrounding environment to the inner ear via the ossicles, bypassing the damaged eardrum membrane. However, this method does not benefit the person who has a defect in his/her inner ear [2]. Another assistive technology is the use of a flashing light to warn of exceptional cases, such as a knock on the door or a phone ringing [1]. There are more complex methods where microprocessors are used to distinguish the nature of the received sound according to the frequencies [3, 4], i.e., whether it is the sound of a human, an animal, a car alarm, or a door knocking, for example. Also, to determine the direction of the sound source, the resolution is output through an array of vibrators [5, 6] or visually on a mobile screen, for example. Speech may be distinguished using speech recognition programs to convert it into written, readable sentences; however, it is in the process of development due to the difficulty of producing appropriate algorithms [7]. These methods are accurate in communicating information and are helpful; however, they are characterized by their high cost and the delay in producing the results, and the visual ones require directing the eyes to the screen. In this paper, a method of mechanical alteration or notification through vibration is used; however, the frequencies that the skin distinguishes are low and much less than the sound frequencies, as well as the narrowness of its frequency band compared to the audio waves bandwidth, which reaches up to 20KHz [8]. Therefore, it is necessary to convert sound frequencies to a low frequency so that a person can feel it as a vibration on the skin. As soon as there is a sound, there is a vibration so that the deaf know that a sound is around him/her. Thus, the information obtained by the deaf is straightforward; it is only the distinction between the presence of a sound or its absence. To give the deaf a broader idea about the shape and intensity of the existing sounds, the general shape of the sound signal must be extracted and then generate vibrations at low frequencies in a manner consistent with the existing sound shape in terms of its intensity and length of its syllables. The primary objectives of this study are:

- To design a cost-effective and efficient vibration alerting device for the deaf.
- To simplify the circuit design while maintaining appropriate performance.
- To explore the use of wireless signals to enhance the device's functionality and usability.

2.PROCEDURE

To achieve primary objectives, the sound from the surrounding environment must first be captured by a microphone, then amplified using an audio amplifier circuit, and then the general shape of the audio signal envelope (ASE) must be extracted using the envelope detector circuit. This process is similar to amplitude demodulation [9], as shown in Fig. 1. As for the appropriate vibration frequency (within the skin vibration perception threshold) [10], a low-frequency oscillator was used to generate such a signal, which is an astable multivibrator [11], and it was adjusted to give a fixed frequency and amplitude. A modulation of the resulting signal (representing the shape of the audio clip) from the envelope detector, with oscillator signal, is achieved by amplitude modulation process (AM) [9], as shown in Fig. 1. to produce a signal with a suitable frequency for the vibration (fv) and amplitude proportional to the sound intensity. Thus, the deaf will get important information about the general shape of the sound, which includes the length (duration) of the sound syllables and the intensity of the sound signal. Changing the vibration frequency was not relied upon as long as the ability to distinguish frequencies in the skin nerves was weak [10]. The circuit function can be explained by the block diagram shown in Fig. 2.

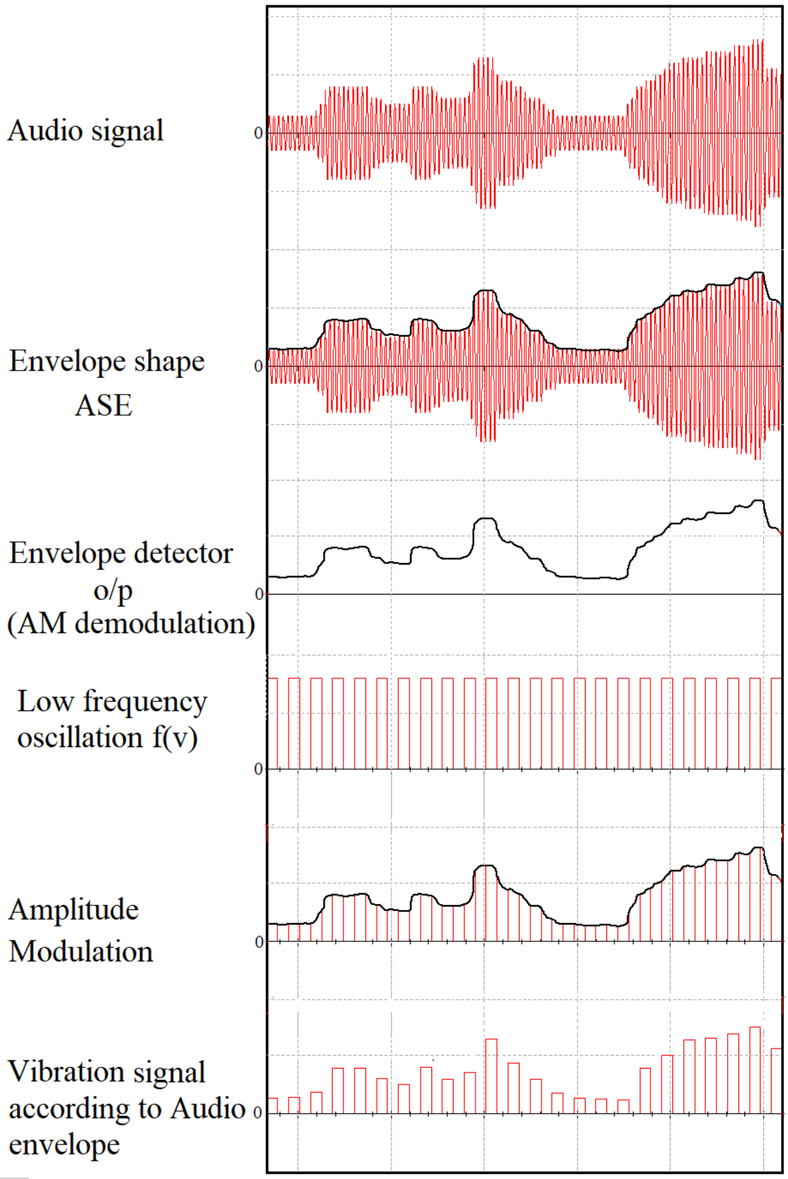


Fig. 1 Conversion of Audio Frequencies to Low Vibration Frequencies f(v).

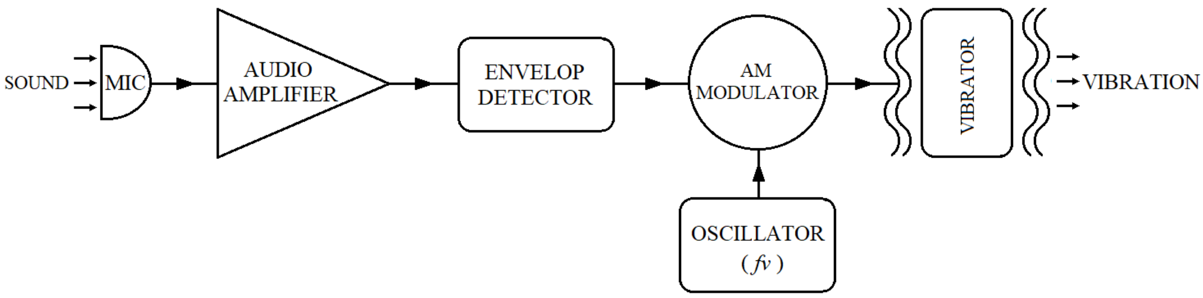


Fig. 2 Block Diagram of the Vibration Alerting Device VAD.

This method accomplishes the following:

- Converting sound frequencies to low frequency (vibrator frequency (fv)).
- The vibration intensity is proportional to the intensity of the sound signal.
- Synchronization between the vibration and the audio syllables.

2.1. The Electronic Circuit

In designing the practical circuit, the following principles are adopted:

- The design must be as efficient and simple as possible.
- The (*first* design) is achieved using only transistors as active elements.
- A common and available voltage source (5V) is used to allow the use of batteries.

The electronic circuit, as shown in Fig. 3, consists of a (condenser-type) microphone due to its suitable characteristics in terms of a wide frequency range and quality of sensitivity [8], a pre-amplifier circuit that uses an appropriate bias impedance to raise the working point of the transistor T1 to the active region [9], a buffer circuit, common collector (by T2) to strengthen the current also isolate and protect the previous stage, and a coupling capacitor to prevent direct current from affecting the next stage. After the buffer, a two-amplifier stages are connected in cascade, both are common emitter (by T3 and T4). The gain of one stage is given by:

$$Av = \beta \frac{R_L}{R_i} \tag{1}$$

The current gain of the transistor used is β=75. The gain is adjusted by Pot1 to amplify the audio signal to an appropriate level, achieved with a biasing that puts the operating point at the beginning of the active region, so that only the positive part of the audio signal will be amplified.

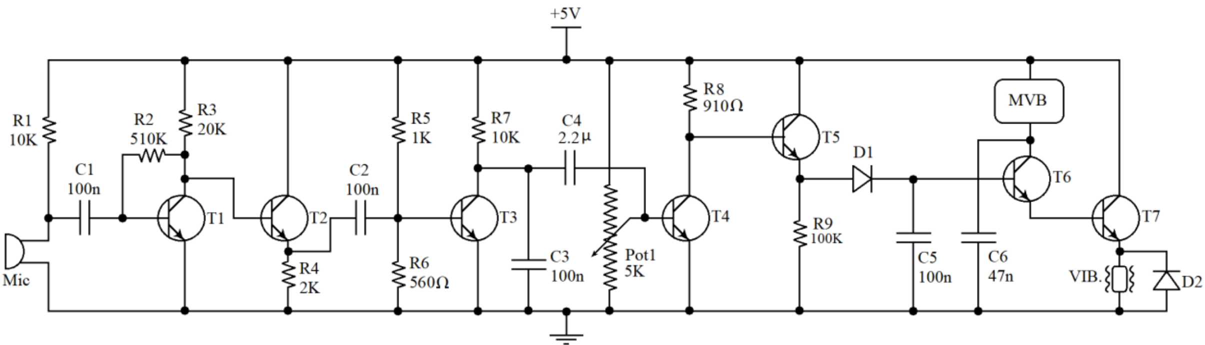


Fig. 3 Electronic Circuit of the Vibration Alerting Device.

A coupling capacitor C4 is connected between the two amplifiers to prevent DC current between the stages, and a bypass capacitor C3 is used to reduce the noise. The amplified signal is applied to another buffer circuit (by T5) and then to the envelope detector by D1 and capacitor C5 of (47-100) nf (according to audio signal parameters) to obtain a signal that represents the envelope of the audio signal, see Fig. 1 and Fig. 6.

2.2. Astable Multivibrator

To generate the low frequency signal that it convenient for the vibrator, i.e. about 200Hz, an astable multivibrator is used because it is simple and good stability referred by (MVB) in (Fig. 3). Its circuit is shown in (Fig. 4). The variable resistance (pot2) is used over the two-charging resistance R11 and R12 to provide a frequency adjustment without changing in duty cycle [11].

2.3. AM Modulation Circuit

The output of the envelope detector is then applied to the Amplitude Modulator. The base of the transistor T6 will receive the envelope of the audio signal, while its collector is connected to the output of the low-frequency oscillator (astable multivibrator). The output is from the emitter T6, which represents a modulated signal (AM signal), as shown in Fig. 7.

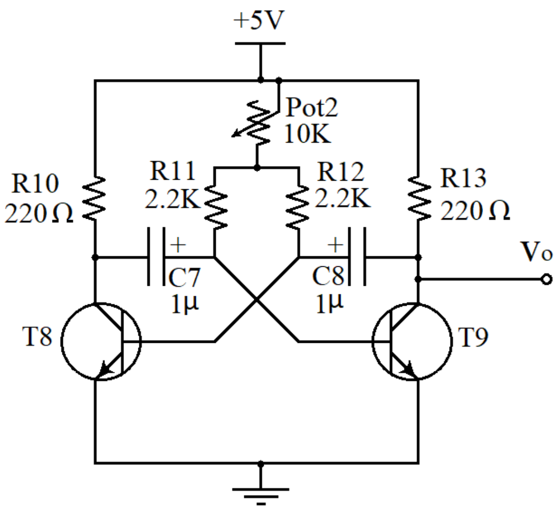


Fig. 4 Astable Multivibrator Circuit.

2.4. Vibrator

A suitable vibrator must be selected to fulfill the following specifications:

1- It has linear properties, i.e., the intensity of vibration is proportional to the amplitude of the input voltage V(p-p).

2- It is efficient at a suitable vibration frequency for the skin alerting.

3- Fast response (not rotating mass type but linear vibrator type).

4- To be portable, the vibrator must be small and light.

The selected vibrator was for one of the mobile phones, which meets the required specifications. The practical circuit was implemented on a breadboard, as shown in Fig. 5.

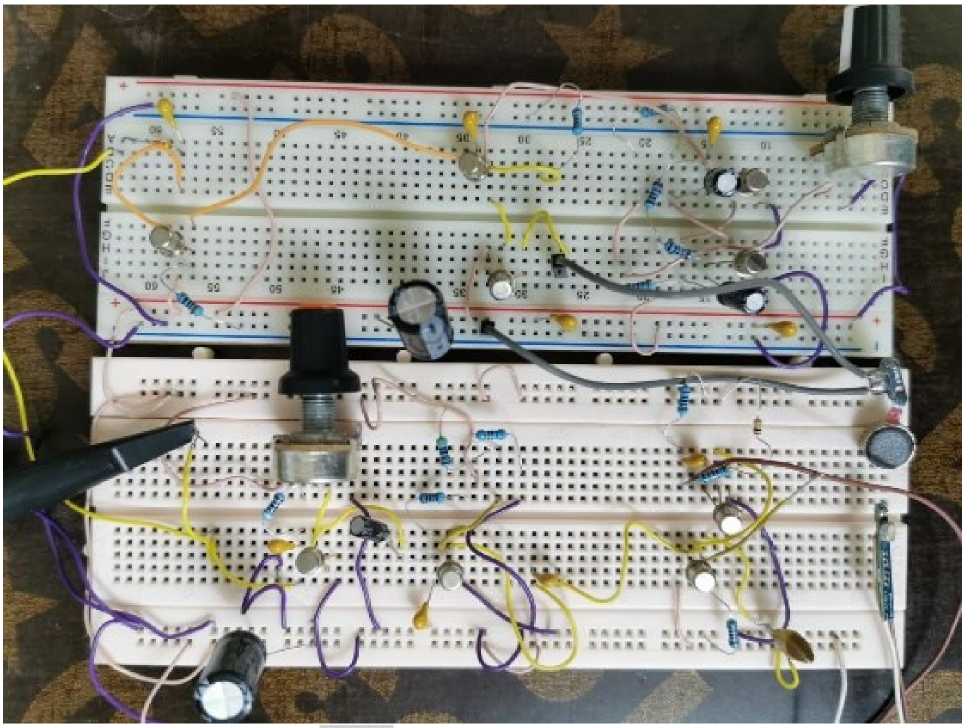


Fig. 5 The Practical Circuit.

3.CIRCUIT PERFORMANCE

The performance of the circuit in general was good, as an appropriate audio sensitivity was obtained, and all stages of the circuit worked at a reasonable level. Figure 6 presents two tests of the envelope detector circuit performance for two different audio signals. It shows the envelope output compared to the positive part of the audio signal. Figure 7 also presents two tests to show the modulator performance and the vibrator driver output at the emitter of T7.

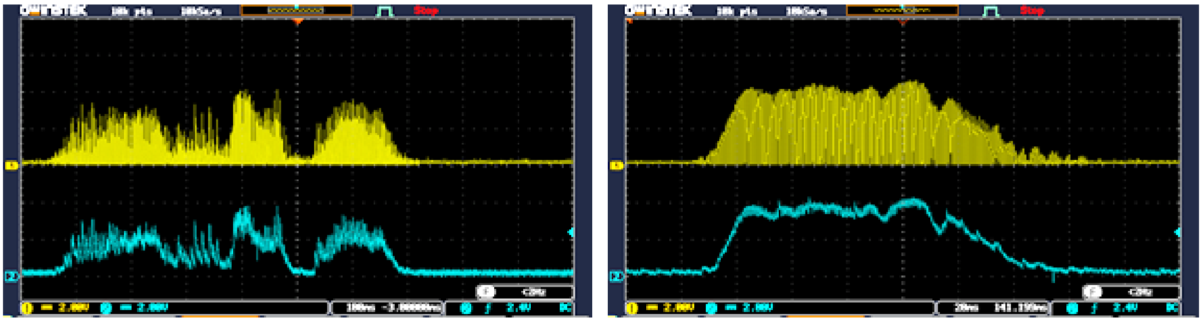


Fig. 6 Two Tests of the Envelope Detector, the Positive Part of the Audio Signal (at the Top), and the Output of the Envelope Detector (at the Bottom).

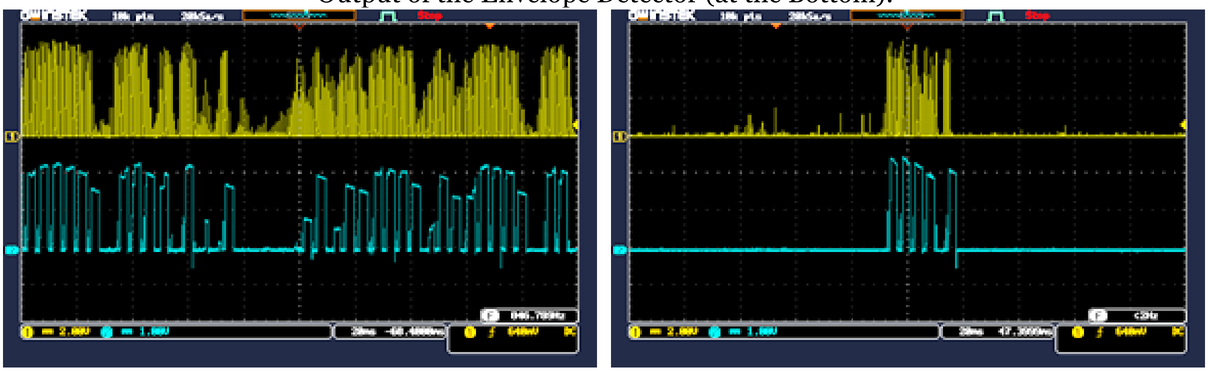


Fig. 7 Two Tests of the Vibrator Driver, the Positive Part of the Audio Signal (at the Top), and the Output of the Vibrator Driver (at the Bottom).

4.PERFORMANCE ENHANCEMENT OF THE VIBRATING ALARM

A vibrating alarm can be enhanced to meet some requirements of the hearing-impaired, the visually impaired, or the blind.

4.1.First Suggestion: Hearing-Impaired Respond to Calls and Important Alerts

There are two important issues that deaf people suffer greatly from:

1- Difficulty responding to people's calls, as well as identifying them, especially from his/her family members or work colleagues.

2- Difficulty responding to important alerts, such as doorbell ringing, fire alarm, and others.

The response to these two things must be as fast as possible, and the delay in responding to them constitutes a dilemma for the deaf, which negatively affects the practical and psychological aspects.

4.1.1.Suggested Technique (Wireless Calling and Alerting)

To help the deaf respond quickly to alarm or calling signals, another technology can be added to the vibrating alert to improve its performance by using radio waves. It is possible to send a distinctive wireless signal (from a transmitter in the alarm device or from a small transmitter portable with the caller) with a relatively short wavelength, which is sent after being modulated in a (specific) pattern. Then, it is received by a receiving circuit integrated with the vibrator circuit (as implemented) for the deaf. It is de-demodulated and transformed into a distinct vibration pattern that people who are deaf or hard of hearing can feel and recognize as an alert signal or a call from the specified person.

4.1.2.Need for Modulations

After the hearing-impaired person receives the signal and recognizes it as an alarm or a call signal, the deaf person also needs to know who called them, especially when there are many people around them, meaning that they need to identify the caller or, for an alarm signal, any alarm. To achieve this goal, the transmitter signal was modulated with a specific code that can be detected upon receipt and converted into a specific vibrational pattern indicating the identity of the caller, or alarm type [12]. Two types of modulation were proposed for this purpose.

4.1.3.Proposed Modulation Types

To achieve flexibility in vibration discrimination, facilitating the modulation of the signal in the transmitter and easing its demodulation in the receiver, one of the following types of modulation is suggested:

1- Pulse width modulation (PWM).
2- Amplitude shift keying (ASK) [13, 14].

4.1.4.Transmitter

The transmitter generally consists of an electronic oscillator and a code generator; the oscillator generates the carrier wave. It is in a high-frequency range (to ensure the antenna is short in length and suitable for sending signals over close distances of about 20 meters). It is chosen so that it is away from interference with other existing frequencies, and the output signal must be of a fixed and stable value. Also, a specific code was prepared by the code generator for modulating the carrier with one of the two modulation types. Then, the modulated signal was sent by the small monopole antenna to the receiver circuit, as shown in the block diagram of the transmitter in Fig. 8.

4.1.5.Receiver

On the other side, in the receiver circuit, which is built-in with a vibrator sensor circuit, the modulated signal was received by a small antenna and amplified. Then, the modulation was simply removed by an envelope detector. Then, it was sent to the vibrator driver circuit, as shown in Fig. 9.

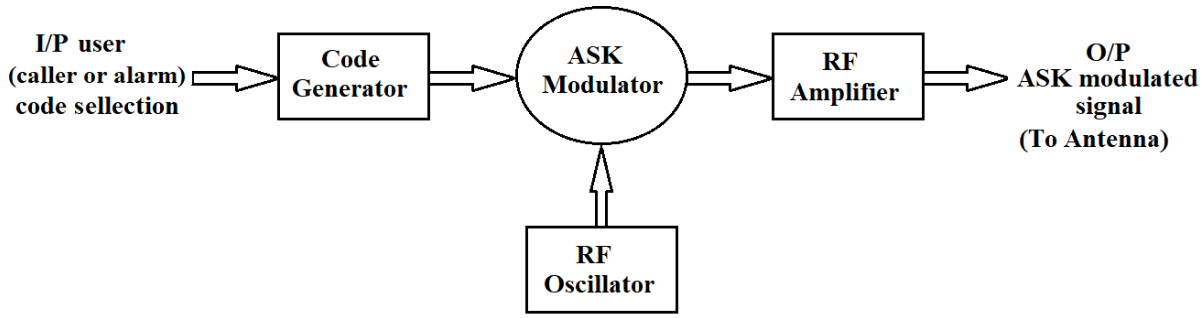


Fig. 8 Block Diagram of the (Calling and Alarming) Circuit in the Transmitter.

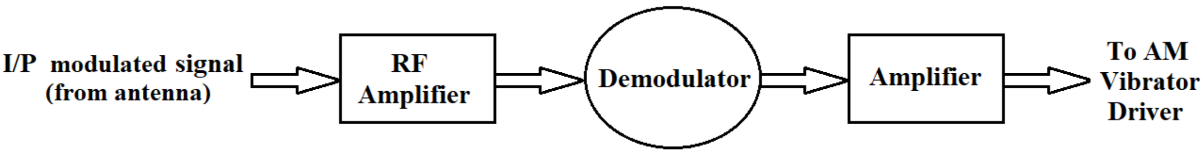


Fig. 9 Block Diagram of the (Calling and Alarming) Circuit in the Receiver.

4.1.6.Vibration Pattern in Pulse Width Modulation (PWM)

In pulse width modulation (PWM), the variation is only in the pulse width (duty cycle) while keeping the code cycle time constant. The time of the code cycle (or the frequency of the code cycle) was selected so that the width of the shortest pulse within it is enough for the recipient (with hearing loss) to sense and distinguish the vibration during it. Each user (caller or alarm) is assigned a specific pulse width that distinguishes it from others. This type of modulation is suitable for three or four users, to ensure that there is no confusion in the discrimination. The modulated signal is sent to the receiver in a repeating series of these pulses. Figure 10 shows several PWM signals with a single frequency of 1Hz (code cycle time is 1 second), with different pulse widths.

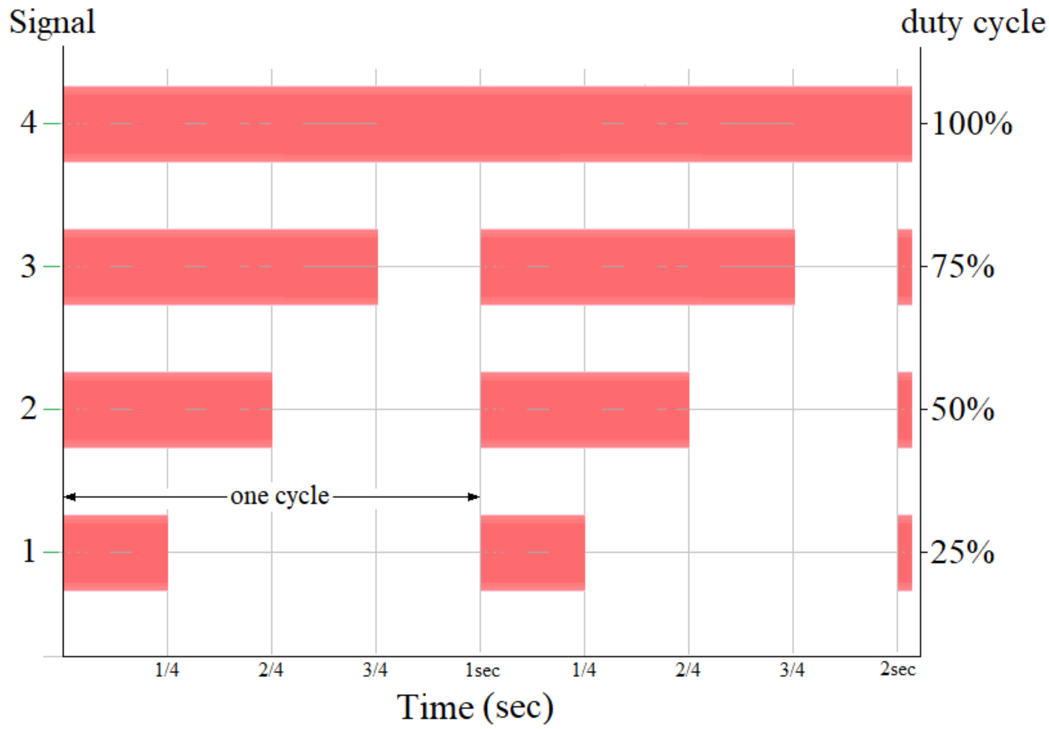


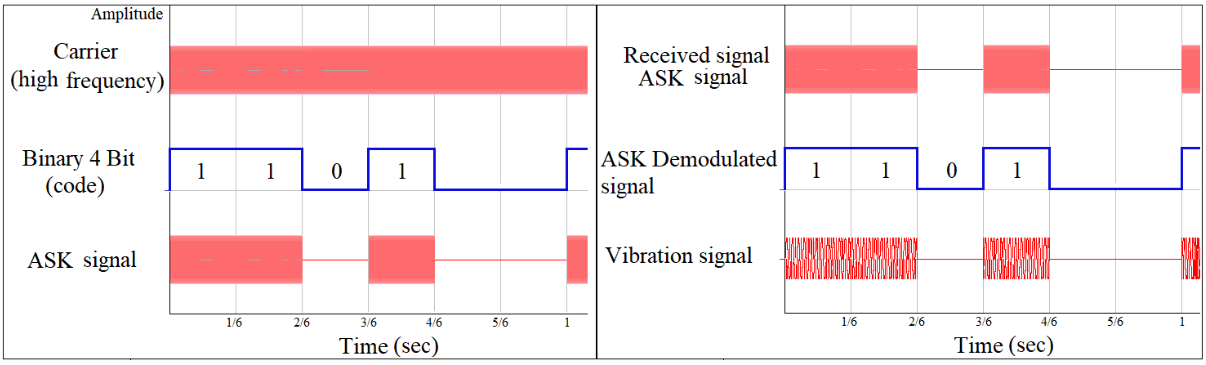
Fig. 10 Four PWM Signals, Differ in Pulse Width with Same Cycle Time (1 sec).

4.1.7.Vibration Pattern in (ASK) Modulation

In amplitude shift keying (ASK) modulation, the code consists of a few Bits that repeat themselves after a small and sufficient off-time interval (To). The number of users for this feature depends on the number of Bits per code (bits/code). For example, for a code consisting of four Bits, 16 codes can be generated; however, in practice, useless codes such as (0000), which are difficult to distinguish from the usual sound pattern, must be removed so that the deaf can discriminate the code and its source (caller or alarm type). However, people who are deaf or hard of hearing require practical experimentation and training.

4.1.8.Digital Code Time (Tc)

The time of the digital code (Tc) is chosen so that it is enough to contain a vibration pattern at the recipient that can be sensed and distinguished through the sensory cells in the deaf skin. Suppose the same cycle time is chosen in the case of PWM, i.e., (Tc=1 sec) for a four-digit code, which repeats itself after a time interval (for example, two digits long). The time of one Bit (Tb) will be (Tb= 1/6 sec ≃ 167 msec), and the Bit rate is (6 Bit/sec). Then, the code signal is modulated with the carrier and transmitted by a small antenna, as shown in Fig. 11(a). The transmitter must be a small, compact device, and for the caller, it must be easy to carry or wear, e.g., attached to a ring on one of the fingers of one hand, and contain a button for calling. At the receiver, the signal is received by a small antenna and demodulated by the envelope detector, then sent to the circuit of the previous vibrator driver. Thus, a distinctive vibration pattern can be obtained and depends on the shape of the modulated code, see Fig. 11 (b). In both types of modulation, the received signal after demodulation does not require a decoding technique, as vibration according to the code pattern is enough for the deaf to feel the type of code that indicates the identity of the sender, i.e., this is done by the deaf himself/herself.



(a) Transmitter (b) Receiver

Fig. 11 Binary Code and ASK Signal at (a) Transmitter, (b) Receiver.

4.1.9.Difference of Calling Signal Over Regular Sounds

The calling signal is distinguished from the regular sound signal by the following:

1- It has a continuous, constant value interspersed with a sharp cut-off.

2- It changes periodically, as the code repeats itself periodically, either directly or after a certain time interval.

Thus, it is easy to distinguish the alarm or calling signal from other sound signals, and the same caller can be distinguished from others by its code. The overall block diagram of the vibrating alert device is shown in Fig. 12.

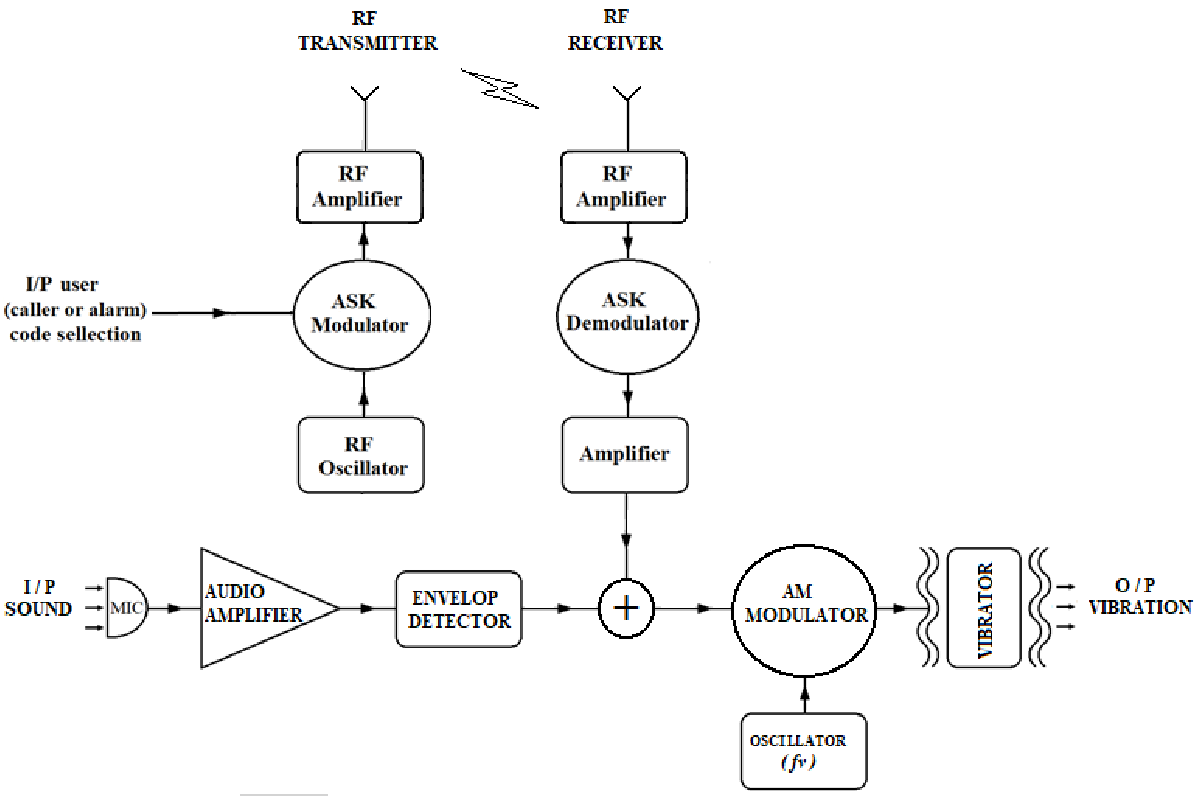


Fig. 12 Overall Block Diagram of the Vibrating Alert Device.

4.2.Second Suggestion: Using Vibrating Alerts to Assist the Visually Impaired or Blinded

The vibrating alert features can be used to help the visually impaired as well, by generating a vibrating pattern (or sound signals) according to the proximity of the objects to the person (blind) [15], where a suitable (proximity sensor) can be used (instead of the microphone) to sense the approach of the objects and give an electrical signal according to the distance the object is approached. Then, this signal is converted into vibration (or sound) so that its intensity changes as the object approaches the sensor [16] and in the same circuit as the vibrating acoustic sensor. When it is necessary to sense side or high objects, for example, more than one sensor can be used with modulation of a vibration signal in PWM method, so that the width of the pulse changes according to the sensing angle, while its intensity changes according to the degree of proximity to the object, for example, or using more than one vibrator [17].

4.2.1.Proximity Sensor Location

The location of the proximity sensor may be fixed on the person's body (the blind person), such as on the leg and/or arm, the front and sides of the shoe, or on the stick carried by the blind person.

4.3.Use of other Calling Techniques

Also, the vibrating alarm can be supplemented in the receiver's circuit using a light alarm [18, 19], by adding a decoder circuit and connecting its output to a group of small lamps (LEDs). One of these lamps will light up depending on the shape of the code that represents the identity of the caller. This circuit is turned on only if the wireless (calling) signal is received.

5.DISCUSSION

- Comparison with Existing Solutions: The proposed vibration alerting device offers several advantages compared to existing solutions.
- Cost-Effectiveness: Unlike many high-cost and complex systems, this device is designed to be affordable while maintaining high performance. The use of readily available components contributes to its low cost.
- Simplicity and Efficiency: The simplified circuit design ensures ease of use and efficient operation. The device's ability to convert sound to vibrations in real-time provides immediate feedback, a critical advantage over systems with processing delays.
- Versatility: The potential for wireless signal integration enhances the device's versatility, allowing it to be adapted for various alerting needs, including emergencies.

6.CONCLUSION

A vibration pattern compatible with the existing sound was obtained in terms of synchronization and strength (vibration intensity), as shown in (Figs. 6 and 7). Thus, the circuit can, through the vibrator, give important information about the nature of the existing sounds through a single vibrator instead of an array of vibrators. The deaf can be trained to use the device, and with frequent use, a greater benefit can be achieved; however, it needs practical experiments. However, due to the relatively low circuit voltage, a limitation in controlling the sensitivity in picking up sound was encountered. However, the noise must be considered, as well as a limitation in controlling the power level of vibration. This issue can be overcome by choosing a higher circuit DC source voltage. To be more practical, the circuit can be scaled down with integrated circuits and using surface-mounted components. To improve the circuit's performance, in addition to the intensity factor, the frequency factor can be added; the distinction between sounds according to frequency can be achieved by using electronic filters. For example, it is possible to use three filters for low, medium, and high frequency bands. Each of them can be connected to a curvature detector and a vibrator driver circuit, so the system has three vibrators, each of which vibrates according to a frequency band associated with it. Thus, a deaf person can have a greater idea of the intensity and frequency of the sounds. The wireless calling method is an important technique for alerting and responding. Proposed modulation of the alarm or calling signal can give a distinct vibration pattern for ease in discrimination; however, it requires experimentation and training for practical aspects.

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NOMENCLATURE

AM	Amplitude Modulation.
ASE	Audio Signal Envelope.
ASK	Amplitude Shift Keying.
AV	Amplifier Voltage Gain.
β	Transistor Current Gain, (Ic/Ib).
DC	Direct Current.
fv	Sensible Vibration Frequency.
I/P	Input Signal.
MIC	Microphone.
MVB	Astable Multivibrator Circuit.
O/P	Output Signal.
pre-amp	Primary Amplified.
Pot	Potentio-devider.
PWM	Pulse Width Modulation.
T	Transistor.
Tb	One Bit Duration (Sec).
Tc	Digital Code Time.
To	Off Time Interval.
VAD	Vibration Alerting Device.

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