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Exploring Non Linearity in Acoustics for Generating Glottal Excitation for Laryngeotomee

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***Abstract*—** Speech is a bio-acoustic signal, initiated by vocal folds in the larynx and spectral shaping is provided by vocal tract. Persons who suffer from laryngeal cancer require removal of vocal chords and use artificial larynx to generate speech, which is unintelligible. In this paper, a novel method for providing excitation to the vocal tract for generating alaryngeal speech has been investigated. For this study, low frequency ultrasonic excitations were given to transducers whose output signal was interfered in air to generate a beat frequency and to explore non linearity of air for demodulation of amplitude modulated ultrasonic waves. Low frequency ultrasonic ranges of 14 kHz to 22 kHz were utilized for investigations as these can be generated with low cost equipment. The results and spectrograms obtained indicated that when these frequencies were interfered in air at room temperature of 25^{o} to 35^{o}, a beat frequency was generated in the audio frequency range. The ultrasonic frequencies interfered had a relative frequency difference of about 100 Hz to 600 Hz to account for different pitch periods for males, females, and children. The experimentation with the recorded beat frequency showed that it is able to produce speech when passed through the vocal tract.

***Keywords*—** Non-linear acoustics; amplitude demodulation; ultrasonic excitations; glottal excitation; alaryngeal speech..

I. INTRODUCTION

Over some years there has been an increase in using radiating force of ultrasonics [1-3] for imaging and characterizing and in turn differentiating between normal and abnormal tissues, thereby, rendering low frequency ultrasonic excitation safe for human diagnostic purposes [4], [5]. It is known that when a normal person wants to communicate with fellow human beings through speech, he makes use of the vocal chords in the larynx at the base of the throat [6], [7].

The vocal chords enveloped by the larynx situated at the upper end of the trachea can shape the continuous air flowing from the lungs into puffs of air which while passing through the entire vocal tract and the articulators in the mouth is given a certain spectral shape to form the speech signal [6], [7]. Now in persons whose vocal chords along with larynx have removed experience voice blackout [8] and they have to undergo speech therapy to produce communicable speech. They may also use external and internal prosthetic devices to aid them in speech formation [9-12]. Such a commonly used device is an external artificial electronic larynx, also called as electrolarynx [11], [12] since it is easy to use and can be used immediately after a laryngeotomy operation. It is a hand held device and the vibrating plate or membrane on one end is tightly coupled to the throat while the other end is held by the hand. The major drawback of this device is that it produces a lot of background noise and since it produces only a monotonous tone, the speech produced has spectral deficit [13]. The artificial larynx when coupled to the neck causes the vibrations to propagate through the neck tissue on to the vocal tract. The neck tissue is a highly non-uniform mass of muscle and membrane. When the sound propagates through such a medium, there is an amplitude variation and phase shift of various harmonics of the impressed sound wave [13]. Secondly, since the transmission loss is inversely proportional to frequency, the low frequency components in the signal are attenuated. Sometimes the vibrations may not propagate through the medium at all. Such is the case when the neck muscles have thickened due to the radiation generally given after the laryngectomy operation [14]. Inefficient coupling of the device to the body results in the deficiency of low frequency. The other difficulties of the speech generated by artificial larynx are the presence of background noise and substitution of voiced segments instead of unvoiced segments. All these problems deteriorate the quality of the speech generated by this technique [15], [16]. Researchers have investigated many digital processing techniques to enhance the quality and intelligibility of alaryngeal speech [17-21].

This external prosthetic device can have a better performance if it is designed innovatively and the innovation being in that instead of using a electromechanical coupling device, low ultrasonic waves can be used for speech augmentation [22-25]. An external electrolarynx working on the principle of interference of two or more ultrasonic waves to produce a beat frequency due to the non-linear property [26-31] of propagation of ultrasonic waves in air. Investigations have revealed that this is possible and the necessary equations governing this have been amply discussed in the literature [32-44].

In this paper ultrasonic waves have been used for generating glottal excitations for those persons whose larynx or vocal chords have been removed due to any laryngeal disease which is mostly cancer. The theory of non-linearity is provided in the following section using mathematical equations. Results and discussions are presented in Section 2. The conclusions are discussed in Section 3.

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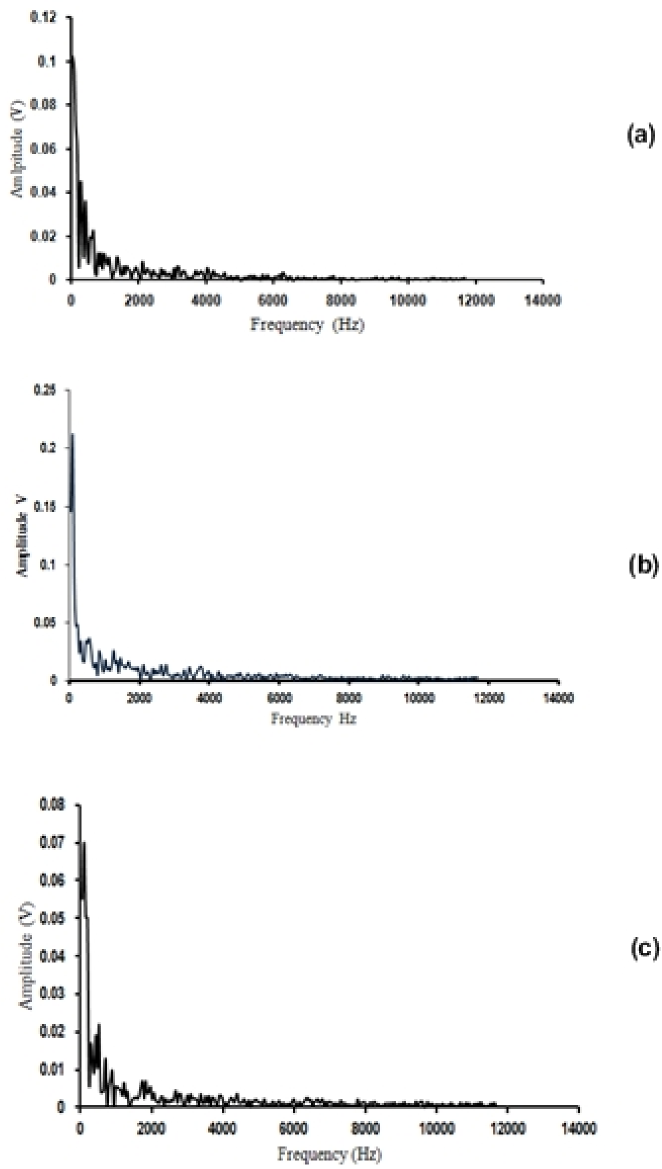

Fig 1. Spectral envelope obtained by applying Hilbert transformation on the recorded signal after non-linear interaction of sinusoidal signals differing in frequency by (a) 200 Hz, .(b) 400 Hz, and (c).600 Hz.

II. Equations Governing Non-Linear Theory

When two finite amplitude sound waves having different frequencies interact with one another in a fluid, new sound waves or secondary waves whose frequencies correspond to the sum and difference of the primary waves may be produced as the result [45].This phenomena is known as 'nonlinear interaction of sound waves' or the scattering of sound by sound [46]. Lets consider the equation

$$\partial^2P/\partial t^2 - C_o^2\nabla^2\rho=\partial^2T_{ij}/\partial x_i\partial x_j \quad (1)$$

where ρ is density of fluid and T_{ij} is the stress tensor. This is Lighthills arbitrary fluid motion equation. Taking equation into consideration arbitrary fluid motion for inhomogeneous wave equation which is satisfied by the sound pressure of secondary waves produced by non linear interaction is derived and is given by

$$\nabla^2P_s-(1/C_o^2)(\partial^2P/\partial t^2)= -\rho_o\partial q/\partial t \quad (2)$$

$$q=(\beta/\rho_o^2 C_o^4)\partial/\partial t(P_1^2)$$

where P_s is the the secondary wave sound pressure, P_1 is the primary wave sound wave pressure, β is the non-linear fluid parameter, and C_o is the small signal sound velocity.

The solution of (2) may be expressed by the superposition of the integral of the Green's function and virtual second source. So we have

$$P_s= \rho/4\pi\iiint_v (1/|\mathbf{r}-\mathbf{r}'|)\,\partial/\partial t\,[q(\mathbf{r}, t-|\mathbf{r}-\mathbf{r}'|/C_o]d\mathbf{r}' \quad (3)$$

Here r is the observation point position vector and v is the non-linear interaction space.

III. Results and Discussions

In this study low frequency ultrasonic waves have been used to investigate the non-linear demodulation of in air. Low frequency signals in the range of 14 kHz to 22 kHz were utilized for this purpose. Two ultrasonic frequencies with an intermediate frequency difference of 200 Hz, 400 Hz and 600 Hz, respectively, were interfered so as to produce a beat frequency in the audible range. The motive behind this is to use ultrasonic frequencies for glottal excitation in those persons who have their larynx surgically removed because of cancer or any other laryngeal disease as discussed earlier. Fig.-1 shows the results of 17 kHz and 17.2 kHz, 17 kHz and 17.4 kHz, and 17 kHz and 17.6 kHz. These frequencies were produced with low cost infrastructure available readily and were then interfered in air. The interfered output was recorded and subjected to Hilbert transformation to extract the low frequency spectrum. Fig. 2 shows the spectrograms of the above low frequency ultrasonic waves when interfered in air. It is interesting to note that in Fig. 2(a) that when a 10 kHz signal was interfered with itself, the spectrogram indicates a frequency at 10 kHz whereas when the interfering signals differ in frequency as 200 Hz, 300 Hz, and or 600 Hz, there is a spectral shift to the audible range. First column in the Fig, 2 is for 17 kHz for second column is for 18 kHz.

IV. Conclusions

Investigations were carried out to study the production of audible beat frequencies in the range of 200 Hz to 600 Hz using low frequency ultrasonic waves for generating glottal excitation. The analysis using spectrum and spectrograms showed that it is possible to generate the audible glottal excitation and reducing the background noise, which is a problem in conventional artificial larynx. The encouraging results showed that background noise may be reduced drastically by using even low frequency ultrasonic waves and there by generating excitation by interference.

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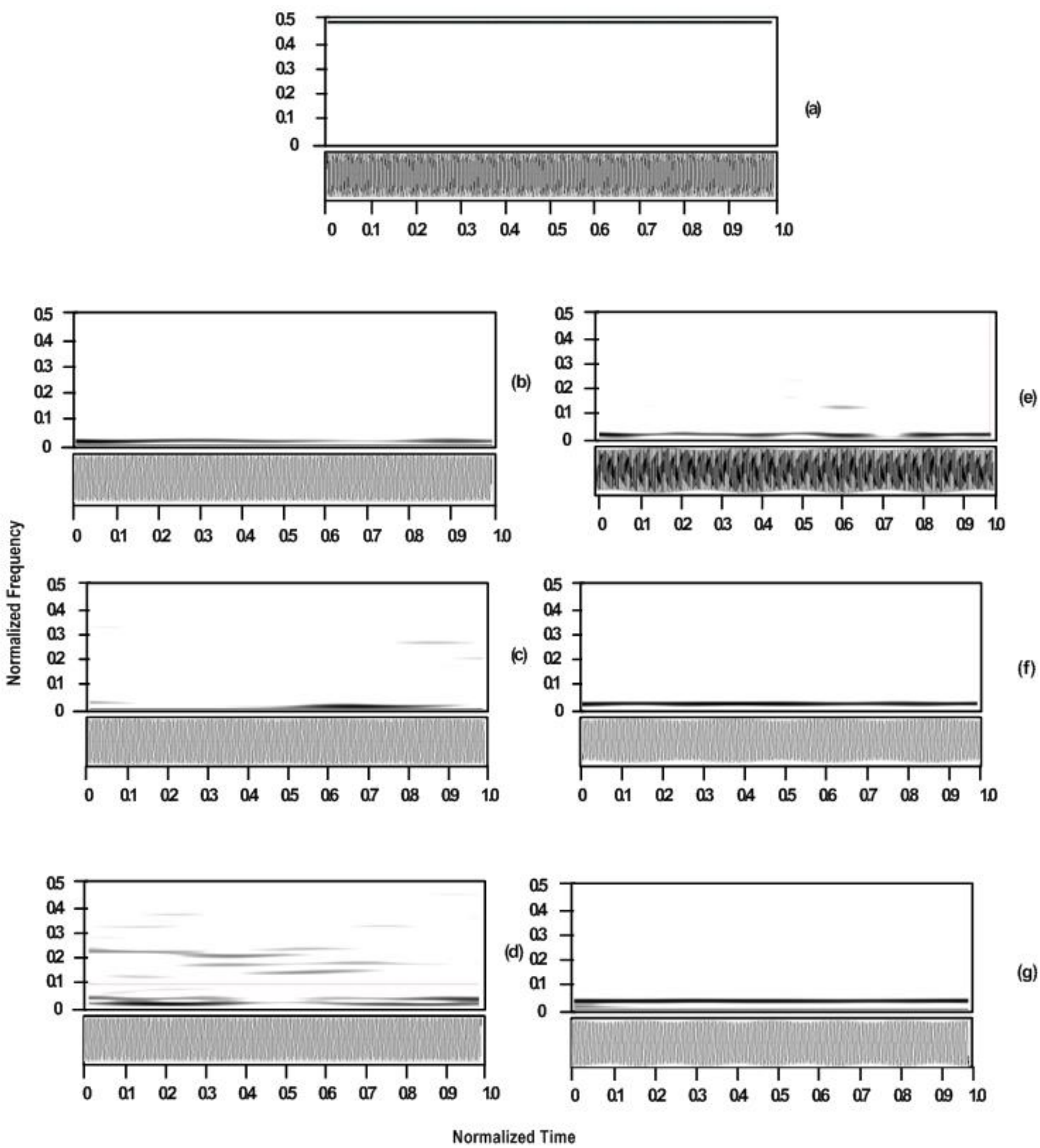

Fig. 2. Spectrograms obtained of the recorded signal after non-linear interaction of sinusoidal signals differing in frequency by (a). 200 Hz, (b). 400 Hz, and (c). 600 Hz.

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