Quantitative Approach in Treatment of Tinnitus by Acoustical Stimulation

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***Abstract*—Tinnitus is the perception of phantom sounds in the ears or in the head without external sound sources even in the completely silent environment. There is no known effective medical treatment for tinnitus and acoustical stimulation has provided patients with some measure of relief. In this paper treatment method with acoustical stimulation has been investigated and simulated by neural oscillator model, simulation results are confirmed by clinical and physiological reports.**

Keywords-neural oscillator model; tinnitus; acoustic stimulation; noise masking

I. INTRODUCTION

Tinnitus is the conscious perception of sound that cannot be attributed to an external sound source [1]. It is sometimes referred to as 'phantom' auditory experience. The percept takes a variety of forms including tonal, hissing, ringing, whistling or 'cricket-like' sound. Tinnitus is prevalent in the general population, with approximately 10-15% of people experiencing it in some form. Two broad categories of tinnitus have been defined. 'Objective tinnitus' refers to the rare number of cases in which the sound source can be identified and may be audible to others. For example, abnormal blood flow pulsations in vessels adjacent to the middle-ear bones can cause the stapes to vibrate against the oval window. Objective tinnitus has also been associated with abnormal rhythmic muscle contractions that occur in number of disorders like aneurysm. In contrast, 'subjective tinnitus' refers to the more common form in which the source of the auditory sensation cannot be clearly identified. the latter tinnitus is caused by perceiving insignificant nervous signal generated in the inner ears and/or auditory nervous system as significant signal [2]. Then, it is hypothesized that a vicious cycle of nervous signal in the brain is generated by hyperacusis for the insignificant signal.

If tinnitus occurs in inner ear we use filter bank for modeling it [3] [4], but this paper focuses on type of tinnitus that generate in auditory nervous system. In this paper the goal is simulation tinnitus suppression mechanism by means of acoustic stimulation in the plastic neural network model for the human auditory system, from the view point of engineering and comparison of the simulation results with clinical data for confirming authenticity of the results.

II. MODEL AND METHOD

A. Model Description

The model consists of two excitatory neurons, E1 and E2, and one inhibitory neuron I. the S represents external stimulus to the excitatory neuron E1 [5][6][7][8]. We illustrate the model in Figure. 1. Its dynamics is described by

$$\frac{dx_1}{dt} = (-x_1 + c_{12}z_2 + S)/\tau_1$$

$$\frac{dx_2}{dt} = (-x_2 + c_{21}z_1 - c_{2I}z_I)/\tau_2$$

$$\frac{dx_I}{dt} = (-x_I + c_{I2}z_2)/\tau_3$$

$$z_j = \frac{2}{\pi}\tan^{-1} x_j \quad (1)$$

Although actual synapses in a brain intrinsically have plasticity and feature adjustability of the brain, the coupling from E2 to E1 is plastic, accordingly we have

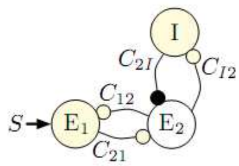

Figure 1. A neural network model

$$\frac{dc_{12}}{dt} = (-c_{12} + bz_2z_1 + c_0)/\tau_c \quad (2)$$

Where x_j, z_j and τ_j for j=1, 2, I are the state, the output, and the time constant in each neuron and c_{jk} for k=1, 2, I denote the coupling coefficient from the k-neuron to the j-neuron. c_0 is the bias of c_{12} and b is the coupling coefficient of E_1, E_2.

This model has a bistable state, A stable oscillatory state and a stable equilibrium (non-oscillatory) state coexist at a certain parameter region. the oscillation and the equilibrium correspond to generation and inhibition of tinnitus, respectively. In this paper we fixed the parameters such that $\tau_1 = 0.01$, $\tau_2 = 0.01$, $\tau_I = 0.02$, $\tau_c = 0.5$, $c_{21} = 10$, $c_{2I} = 10$, $c_{I2} = 20$, $c_0 = 3.0$, b=20.

We observed a stationary equilibrium under, fixed parameter and its initial state is $(x_1, x_2, x_I, c_{12}) = (5, -5, 5, 7)$. This equilibrium is in the origin, see Figure. 2. We also observed a stationary oscillation under the same parameters, but its initial state is $(x_1, x_2, x_I, c_{12}) = (-5, -1, -6, 9)$. The waveform of oscillation are illustrated in Figure. 3. Hence the stable oscillation and the stable equilibrium coexist under the same parameters [6].

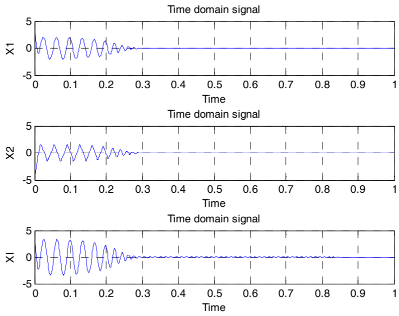

Figure 2. Non-oscillatory state

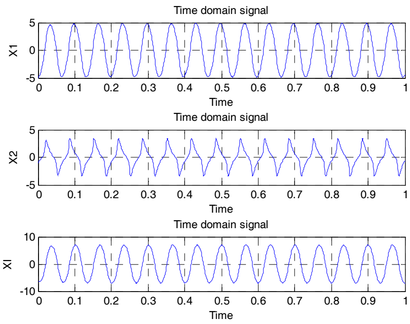

Figure 3. Oscillatory state

Bifurcation diagram of the oscillation is shown in Figure. 4. The curves indexed by Go indicate tangent bifurcation of the oscillation[7]. its lower limit of C12 is given by the nodical coordinate between the upper curve of Go and the line with C21=10, that is C12=6.618.

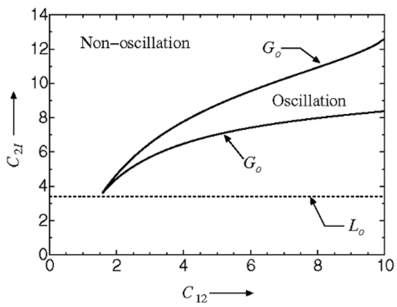

Figure 4. bifurcation diagram of the oscillation

So C12 is a parameter which can be used for investigate appearance and disappearance of tinnitus.

B. Acoustical Stimulation For Treatment Of Tinntus

As one of method for treatment of tinnitus is acoustical stimulation, there are two kind of acoustical stimulation. First type is tinnitus masking(TM), in this type sinusoidal signals with various pressure level and frequency and color noise with different band width and central frequency are used and the other is tinnitus retraining therapy(TRT) that white noise with different power spectral density are used . In some treatment methods a combination of these two techniques is used [9].Important parameters in acoustical stimulation are time of disappearance and power or RMS(Root Mean Square) value.

In this research MATLAB R2007a software and Pentium IV Personal Computer are used for all of the simulations.

III. RESULTS

A. Sinusoidal Stimulation

In this subsection first, a sinusoidal stimulus with 2 amplitude at 10 Hz frequency was applied for the duration of $2 \le t \le 8$. The left column figures show the waveforms of x_1, x_2, x_I , C_{12}, and S, respectively; their power spectra are illustrated at the right column figures, respectively. From the results, the value of C12 gradually reduces from the point of applying stimulus, and consequently the oscillation is inhibited.

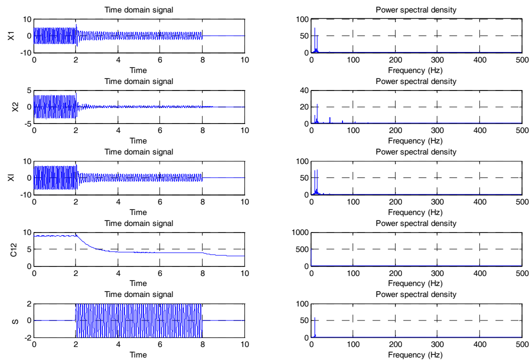

Figure 5. Inhibition of oscillation by sinusoidal stimulus with 2dB amplitude at 10 Hz frequency

Then in different frequency and amplitude, C12 was computed, as illustrated in Figure. 6 the value of C12 in some range is greater than 6.618 and consequently the oscillation is kept through whole simulation time .Therefore, inhibition of the oscillation by sinusoidal stimulus with appropriate frequency and amplitude is possible.

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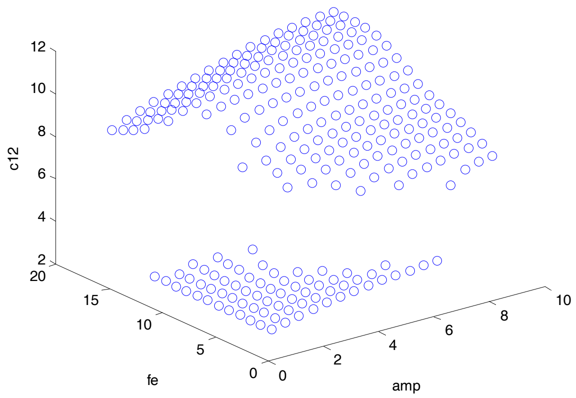

Figure 6. varies for each amplitude and frequency

Figure.7 shows minimum amplitude in various frequency which required for inhibition of the oscillation. As frequency increase, the amplitude decreases.

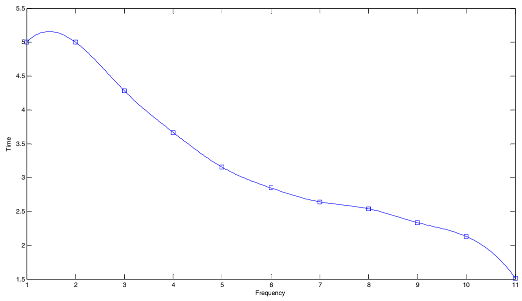

Figure 7. Minimum amplitude required in various frequency

1) *White Noise*

White noise and color noise most often are used for tinnitus treatment because these kinds of stimulations are more tolerable for patients for listening [10]. In this subsection Gaussian white noise with different RMS value was applied and minimum time for tinnitus disappear in each RMS illustrated in Figure.8. In cases that inhibition do not occur offer time is 20 that out of the range of simulation.

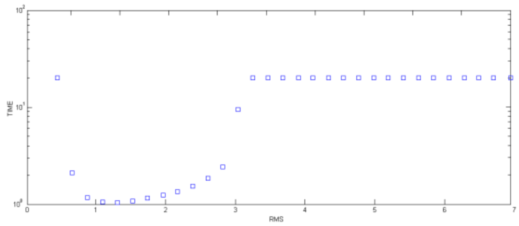

Figure 8. Minimal time for various RMS value

Hence, to inhibit the oscillation we have to adjust the RMS of stimulus to appropriate value.

2) *Narrow Band Noise*

If masking operation is done by signals in all frequencies, it also blocks sounds in the speech range and thus reduces communication ability for the patients Since as mentioned above treatment with white noise reduces communication ability for the patients [11], here color noise is used for stimulations. We employed a banded noise which is generated from Gaussian white noise through a band pass filter with band width of 10% central frequency. Minimum time for tinnitus disappear in different central frequency is shown in Figure. 9.

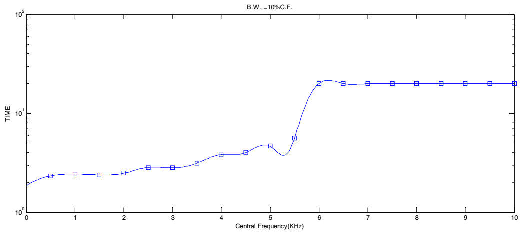

Figure 9. minimum time for tinnitus disappearance in different central frequency

As illustrated in above figure, as central frequency increase, the minimal time required for inhibition of the oscillation is decreases. This process has a threshold manner. Above a certain central frequency oscillation does not disappear which was shown by 20.

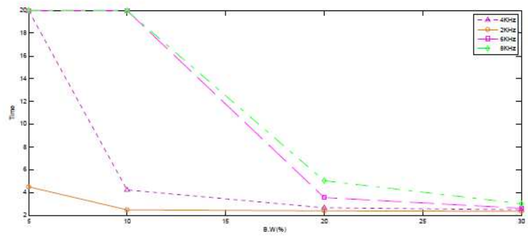

Figure 10. Minimum time for various band width in certain central frequency

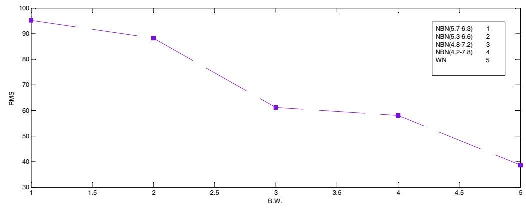

Figure 11. Minimum RMS value required for different band width

Figure. 10 and Figure. 11 show minimal time and RMS value in certain central frequency for different band width.

3) *Clinical Result*

Clinical assessment was done in ENT research center of Hazrat Rasul hospital in September 2009. The subjects were 16 adults with severe disabling tinnitus, ranging in age from 15 to 40. All subjects were evaluated for tinnitus, including audiograms and pitch matches. The tinnitus evaluation and treatment stimulus was produced using standard device.

All 16 subjects who completed the study reported minimum masking level (MML) is more than loudness match of tinnitus (LMT) (Figure.12).

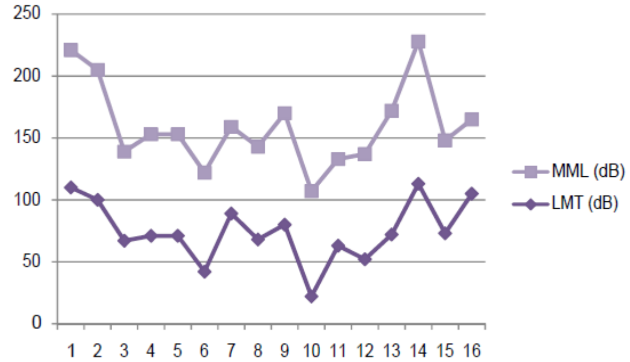

Figure 12. MML and LMT curve in 16 patients

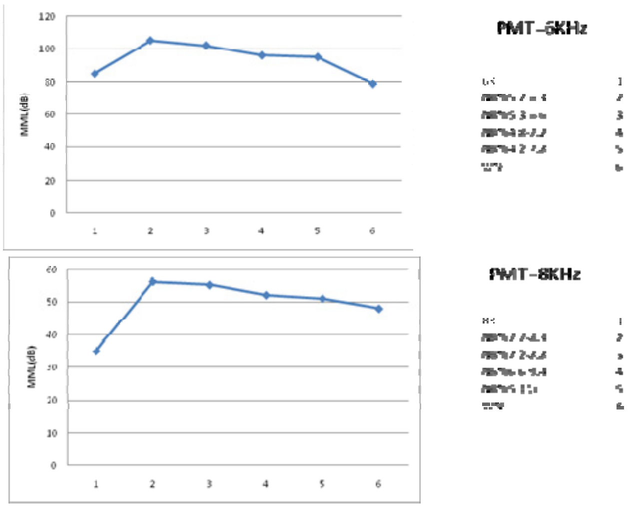

Figure 13. Minimal energy for different stimulus in 2 cases

Figure.13 shows minimal energy in various band width in two cases with different pitch match of tinnitus (PMT). As band width increase, the MML is decreases. This response is the same as simulation results (Figure.11).

IV. Discussion

Many simulations have done by sinusoidal or pure tone stimulation (with various amplitude and frequency) and results indicated that influence of frequency is a threshold manner (as shown in Figure. 6), additionally influence in a certain frequency, is more than other frequencies, but this frequency is not equal to oscillation frequency and in this frequency, amplitude which is required for inhibition of oscillation has minimum value (as shown in Figure. 7).

White noise because of stimulations are more tolerable for patients are used. As it could be seen in Figure. 8, if white noise energy increases, time which is required for inhibition reduces rapidly but after a certain RMS value time increases, Hence, to inhibit the oscillation we have to adjust the RMS of stimulus to appropriate value. This is important to keep the power requirements low, because of personal wearable masker battery life is limited.

Treatment with white noise reduces communication ability for the patients because of blocks sounds in the speech range, color noise is used. Moreover, color noise results are the same as white noise. Suppressor energy, at least should be equal to tinnitus energy, if Suppressor energy is less than tinnitus energy, inhibition does not occur.

As it could be seen in Figure.11, Figure. 12,Fig 13 simulation results are confirmed by clinical and physiological reports.

V. Conclusion

In this study a conceptual and computational neuronal network model with plasticity in the human auditory systemwas constructed to explain the mechanisms of tinnitus and its management by sound therapy. The model is bi-stable in a certain parameter region, where a stable oscillatory state and a stable equilibrium (non-oscillatory) state coexist. Through analysis of this model, it was shown that oscillation can be inhibited by supplying sinusoidal or noise stimulus to the model. For future work, we will simulate and evaluate the reappearance effect of tinnitus after stimulation in stimulation by various type of noise that occurs in clinical situations.

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