OVERVIEW OF BENEFITS OF NOISE IN NEURAL SYSTEMS

Project Report

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TABLE OF CONTENTS

TABLE OF FIGURES

ABSTRACT –

It is often heard that noise degrades the original signal but noise enhancing the original signal is what's appealing to many research scientists right now. Stochastic facilitation is a type of stochastic resonance which is believed to improve processing in theoretical models of neural science as well as experimental neuroscience. However, it is also important to see the basics of stochastic resonance before talking about stochastic facilitation framework. A simple approach to observe the detectability and SNR improvement by adding noise in signal is presented. Although a lot of experimental approaches are yet to be performed to verify the role of noise in neural computation.[1]

***Index Terms*— Biologically relevant noise, Noise, Neural systems, Stochastic Resonance, Stochastic facilitation**

I. INTRODUCTION

THERE has been a lot of interest generating for stochastic biological noise in nervous system about its origin and impact. Noise can be described as variability generated because of the random fluctuations or disturbances. Noise can be potentially beneficial in some cases and when this happens the concept is known as Stochastic Resonance. [1] This broad concept gives a new angle to the interaction of information with noise and possibly defines the relation between noise and information in a new sense. [3] This phenomenon gives base for many research and modelling studies which considers noise to be a factor of enhancement in a lot of fields, but the field of neuroscience is of great interest.

II. STOCHASTIC RESONANCE

There is a complex and rather interesting relationship between the noise and the information. Generally, noise is referred to as unexpected or unwanted fluctuations which often degrades the information, but this claim was challenged by the report presented by Benzi and collaborators in 1981 on Stochastic Resonance. This report made everyone account noise and information as an interacting factor.

Stochastic Resonance is a phenomenon in a non-linear system where the presence of noise is for the betterment of output signal quality rather than its absence. There are a few terminologies that need further clarification. First one is Non-linear. In a linear system, noise is not said to be beneficial. The nonlinearities in non-linear system and random fluctuations of noise is what sometimes lead to more complex interactions and which further leads to stochastic resonance. The ‘better’ term also needs some clarification. The performance measures of the processing or transmission of a signal should be improved in the presence of noise. The third key term is noise. Noise itself being useful is a contradictory concept as it is described as being nuisance, undesirable or irritating. [2]

But the question is how Stochastic Resonance leads to the improvement of the information or input signal? What characteristics prove this improvement? One such characteristic is SNR. The main feature of Stochastic Resonance is that performance measure is assessed on the basis of a plot, that is, output signal to noise ratio (SNR). A plot of output SNR to the input noise intensity is observed to show a single maximum peak at a non-zero value. Such a plot is shown in Fig. 1. Also plots like these is shown by frequency-dependent systems that tend to have a maximum SNR at some resonant frequencies. However, they both are not same as the peak is ‘noise-induced’ in the case of Stochastic Resonance and not because of a particular frequency. [2]

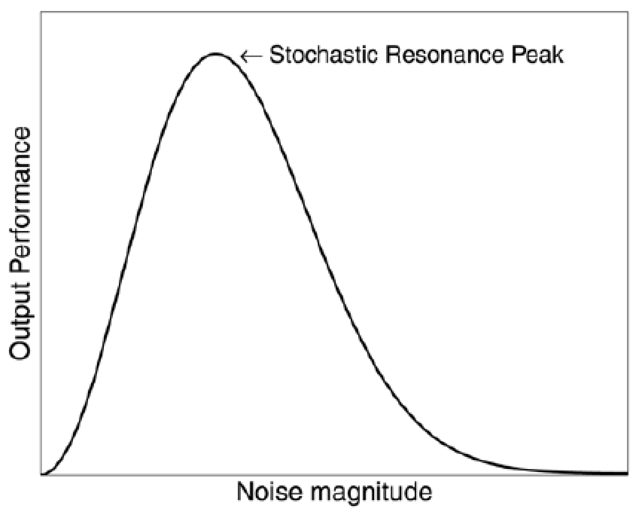

Fig 1. Output performance vs Noise curve showing Stochastic Resonance peak. [2]

Nowadays, Stochastic Resonance is frequently used in much wider sense as the presence of any kind of noise-improved signal processing. There are many studies and research categories using Stochastic Resonance concept in one way or another that can be classified as ‘noise benefits’ phenomenon. One such wide area of research is biological relevant noise. Few experiments on sensory receptors and neurons proved the concept of Stochastic Resonance using externally generated signal and noise. Though it remains a question, if endogenous noise is used by neurons to show Stochastic Resonance effects. The last couple of decades have proved to be an expanding body of experimental studies of Stochastic Resonance. Biologically detailed modelling studies is also of greater interest and to know Stochastic Resonance effects in the neurosciences. This derives a greater interest in the scientists, who still believe new studies and research needs to be done to put a light on biological relevant noises. [1] [2]

A. ***Classical Stochastic Resonance Model.***

The classical Stochastic Resonance model as shown in Fig. 2 have 3 stages. First being, the signal and noise generation and controls. Second is the 'models and rig and data acquisition' and the last and third one being, the 'signal processing' stage.

1. Firstly, there is a weak periodic signal at the input of a dynamically non-linear system.
2. In the absence of noise, that weak signal also known as 'Small Sub-threshold signal' is not detected by the system.
3. For the input signal to be statistically detected, a noise is added to it, which is typically a white gaussian noise.
4. Finally, a signal is detected at the output and the quality of the detected signal is measured by observing the output Signal to Noise Ratio (SNR). This SNR is based on calculations of the Power Spectral Density (PSD) of the signal.
5. For the result, SNR depicts as a single peak as discrete noise is added.

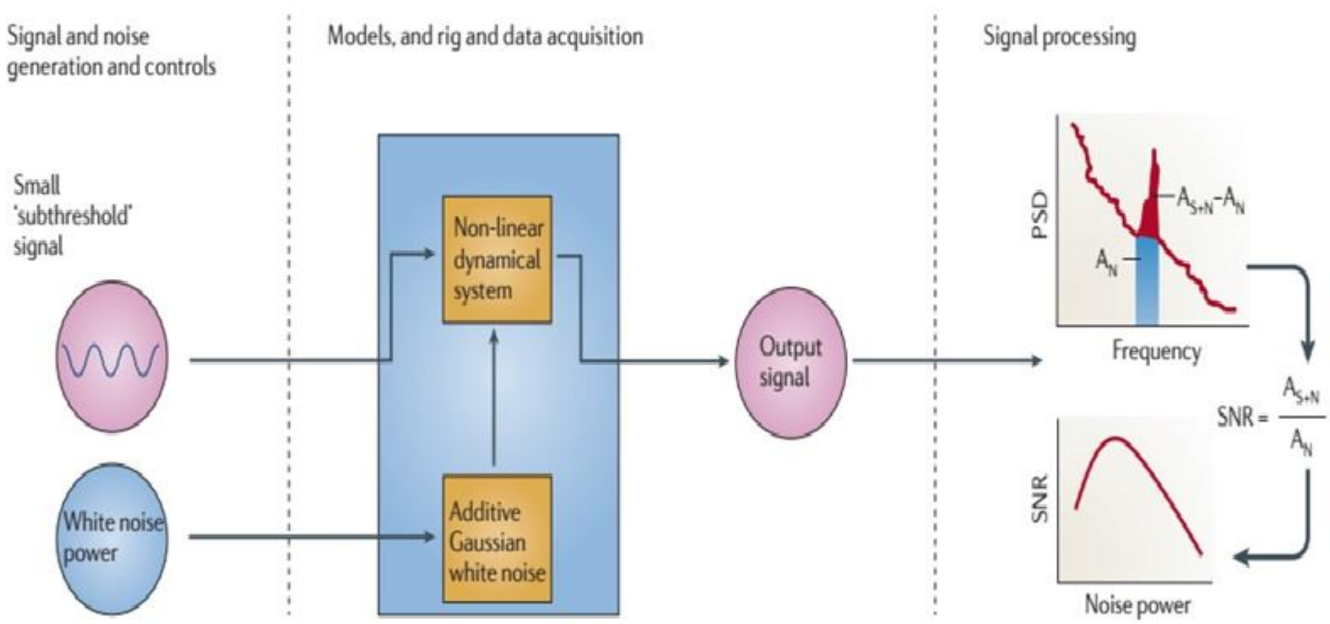

Fig. 2. The classical Stochastic Resonance model [1]

III. THE CONCEPT OF STOCHASTIC FACILITATION

The concept of Stochastic Facilitation was developed because of a few drawbacks of the basic Stochastic Resonance concept. The Stochastic Resonance system remains unclear to define the concepts in biological systems which brings the need for other approaches. It was not clear that which phenomenon can be labelled as Stochastic Resonance and remained a major problem. Also, the fact that finding the concept which can be labelled as Stochastic Resonance was not trivial. Though, the Stochastic Resonance concept did show the performance peak characteristics attained due to the introduction of noise but did not enlighten the frequency response concept for the same system.

However, in biological context, a new light and approach was needed to know whether or when the noise in neural systems benefit the neural system and if do, how? The concept of Stochastic Facilitation is to encompass all the research and studies related to the biologically relevant noise in the nervous system. Also, Stochastic Facilitation includes the constructive roles of these studies and not to forget Stochastic Resonance which can be called as a subset of Stochastic Facilitation.

Stochastic Facilitation is basically a six-step approach as shown in Fig. 3 to study the benefits of noise in neural systems.

1. This approach considers the need of defining a hypothesis which is related to the positive roles of noise in a biological system. This is also the first step of the six-step Stochastic Facilitation approach. The computational hypothesis is needed first in order to identify the role if biological noise in biological relevant system. One such example is using hypothesis in finding the information processing properties in nervous system. This approach is different from typical approaches and can be used in broader sense for new studies and experiments. Typical experiments considered the role of external noise in the neural system but the effect of internal noise how to control and reduce the internal noise was rarely shown in these experiments. The effect of internal noise plays a key role in understanding the Stochastic Facilitation in vivo systems. In order to prove the vivo Stochastic Facilitation, new studies and experiments need to be done using this approach. In past studies, a lot of factors were excluded to make systems potentially feasible and easily predict results. Over 30 years ago, Marr and Poggio, stated that the systems like brain that are too complex for computations should require descriptions like algorithms and nature of computation which is quite different from classical Stochastic Resonance which measures performance based on output signal to noise (SNR) ratio.
2. A model is needed which takes hypothesis relevant inputs to produce outputs. In the step 2

of the approach such a neural model is prepared.

3. A relevant signal which is based on the hypothesis stated is generated and noise which can be added or deleted from that signal is also generated. This accounts for the step 3 of the approach.
4. The signal and noise generated are now fed to the model as stated in step 2 to generate output.
5. The output obtained in step 4 is now processed in this step and called as step 5.
6. Finally, the hypothesis stated in step 1 is compared with the output in step 5, to see the validity of the hypothesis and assessed based on this.

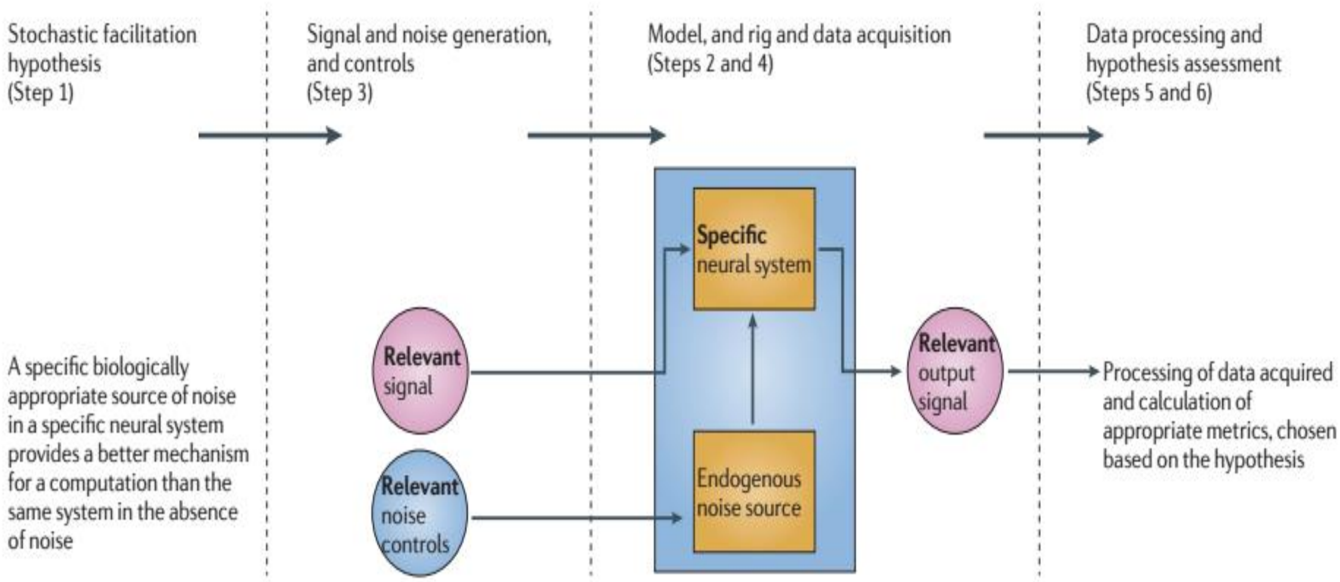

Fig. 3. The Stochastic Facilitation model [1]

It also shows that past research on Stochastic Resonance in neural systems did not consider hypothesis that are biologically appropriate, and it was isolated from other benefits of noise in biological systems. But after defining Stochastic Facilitation, all such research and concepts of Stochastic Resonance in neural systems is based on biologically appropriate hypothesis.

IV. EXPERIMENTAL STUDIES

A. Cricket Cercal System

In this experiment, cricket cercal system was taken into consideration. The cricket cercal system detects changes in air currents. These changes are caused by the presence of predators or conspecifics. The receptors from afferent nerve fibres are observed to get intracellular recordings. In the presence of noise, the receptors were stimulated as they are stimulated in a natural environment. The SNR and mutual information showed a maximum at non-zero levels of noise added. This is how, this experiment proved Stochastic Resonance in a broad sense. One application of using Stochastic Resonance by cricket cercal system is ‘Predator Avoidance’. [1]

B. Whole Human Brain

An experiment was done on human brain using electroencephalography (EEG) technique. EEG is used to detect synchronized neural oscillations. Adding low level of noises increases the neural model synchronization. In the experiment, a stimulus was introduced near the left ear and not to the right ear. As a result, synchronization within and between brain region was enhanced for added noise. Such results prove the concept of Stochastic Resonance and this can be used in applications like ‘Auditory Processing’. [1]

V. MODELLING STUDIES

There are some modelling studies presented on Neurons. These studies use either single compartment technique or detailed compartmental technique to study the concept of Stochastic Resonance. In one study on neuron, a signal is taken as input and using uhlenbeck noise process a noise is taken and it is believed that with the addition of noise interspike interval histogram is improved and such a study will mark the concept of Stochastic Resonance.

Another experiment on neuron using detailed compartmental technique uses random synaptic signal and associated noise and results in SNR improvements with benefits like interspike interval histogram and will also boost spectral power due to presence of noise. Such a study can have application in enhancing response during the arrival of synaptic events.

A modelling study on molecule and neurons is also presented over a decade considering single compartment technique. It is expected to show Stochastic Resonance by increase in mutual information when noise generated from a stochastic ion channel is added to a random aperiodic signal. [1]

VI. STOCHASTIC RESONANCE IN NEURAL SYSTEM

If we talk about stochastic resonance in neural system, then there is enough experimental evidence has been observed during the study in neural system. From that study it has also been noticed that there is a wide range of variety in outcomes of every experiments. Scientists and researchers have studied number of neural systems on different size scales. It includes wide variety of physical and biological systems, including bidirectional ring lasers, electronic circuits, crayfish mechanoreceptor, or voltage-dependent ion channels [4]. In the brain, it has been found in different types of sensory neurons in the hippocampus, in the brain stem, and in some cortical areas [4].

Most of the studies of stochastic resonance have been done with considering controlled artificial source of noise which affects the system dynamics. But when we consider *in vivo* study of actual neural system then using a controlled source of noise is not a valid consideration. Because in actual neural system noise is observed due to irregular activity of the medium and, therefore, not easily controlled by the experimentalist [4].

Here *in vivo* study means, it is a study which has been done on number of biological species which includes any living organism (it can be animal, human being, plant). Also, while studying a neural system for stochastic resonance it is necessary to take care that data collection techniques which we used during experiment should be more uniform. Generally, there are two types of data collection technique is being used which are as follow:

A. Extracellular recording:

It is basically a type of an electrophysiology technique. In this technique an electrode is placed into a living tissue to measure electrical activity that has been happening in a cell or a neuron.

B. Electroencephalography (EEG) and Magnetoencephalography (MEG):

Electroencephalography is an electrophysiological monitoring method which is mostly used for measuring and recording of electrical activity of the brain. This technique is generally used for non-human test entity. In this an electrode is placed along the scalp of biological entities to measure an electrical activity in brain. Magnetoencephalography is used for human.

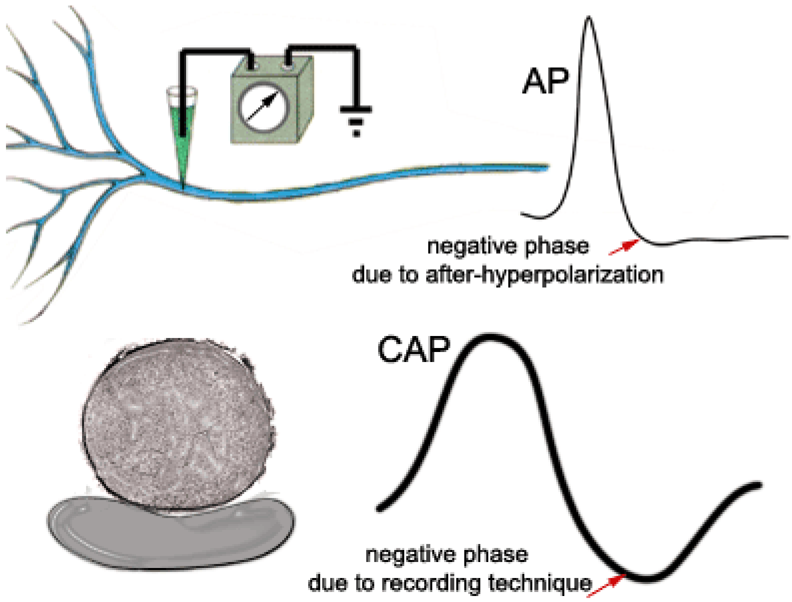

Fig 4. Extracellular recording [5]

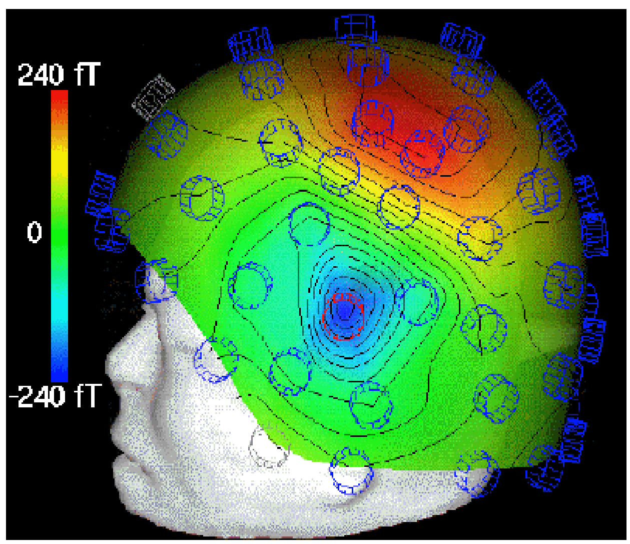

Fig 5. Magnetoencephalography [6]

Also, some of the studies consider the factors other than a signal-to-noise ratio to evaluate the effect of stochastic resonance. These factors include vowel coding, reflex output, coherence or synchronization, vowel coding, heart rate and neural entrainment, and evoked potentials etc [1]. In their study researchers simulate various activities such as air currents generated by animals during their prey, movement of water, sound, lights.

Also, when we are studying a stochastic resonance in neural system it is also important to consider that the model we are using for the study purpose is biologically realistic or not?

Now we will talk in brief about the single neuron model and how certain levels in this model pays an important role in study. In single neuron model has total five levels for abstraction detail which are as follow [1]:

1. Detailed compartmental
2. Reduced compartmental
3. Single compartment or point neuron
4. Cascade
5. Black box.

Researchers have found that the stochastic resonance is observed over all levels of single neuron model which eventually states that in single neuron model, stochastic resonance is not only associated with any specific level of abstraction detail. Each level has its own importance.

When we discuss about two different concept of stochastic facilitation then first one is classical definition of stochastic resonance in which only periodic signal is taken as an input and SNR is a measure for the performance of the model while the other outcome is newer definition in which any non-periodic signal is taken as an input for the system and it consider measures other than SNR which we have discussed earlier.

Also, in some cases performance is affected by the choice of signal. So, it can be considered as a significant factor while carrying out the study of stochastic resonance. Few theories states that neurons can be consider as a channel that should communicate input spike trains 1]. This can not be realistic. Neuron perform a substantial amount of computational integration in dendrites. In addition, neurons influenced by slow extracellular currents and often participate in many interleaved neural circuits [1].

VII. THE FUTURE OF STOCHASTIC FACILITATION RESEARCH

Studies that have been done by researchers and scientists in area of stochastic facilitation has given new direction in future research. So, newer ideas and approaches can lead to various biologically hypotheses for future study. Also, in future research there are certain prospects that need to be consider.

1. Building realistic models with realistic noise:

In study of stochastic facilitation, the model which is being used for the study should be realistic. Because in case of neural system if the model is not realistic then it will not give desire outcome what we are expecting. Along with the appropriate model, the noise which is taken into consideration should be realistic, which means whether the noise source is biological or artificially generated. Because both type of noise source has a different impact on outcome as the randomness in noise which is artificially generated is different as compared to biologically generated noise.

So, there are numerous sources of noise that can be used in stochastic facilitation but not all of them is relevant for the study. There is a list of biologically relevant studies that may contribute to stochastic facilitation in following figure. But some sources of noise like synaptic barrages and network connectivity can not be use for the study of stochastic facilitation. As we know that every randomness in the signal can not be considered as a source of noise.

In addition, it is necessary to check whether the randomness present in the signal is biological or not for *in vivo* study of stochastic facilitation.

In order to Build realistic models, it is necessary that we apply simplification appropriately, more importantly when considering the level of detail, type of neuron (for example, whether it is excitatory, bursting or inhibitory?), synaptic activity and any neuron-to-neuron connections [1]. Simplification of model should be such that, it can satisfy the desire computational goal of the system. Additional elements should be included in realistic model so neural system computation can be realize precisely. The choice of additional elements could be based on mathematical or numerical tractability, elegance, symmetry, completeness and noise source [1].

Noise Source	Description
Thermal noise	Also known as Johnson noise, thermal noise arises from random thermal agitation of charge carriers in electrical conductors, and appears as fluctuations in membrane potentials.
Stochastic molecular diffusion	Molecular interactions during calcium signalling in dendritic spines is inherently stochastic owing to diffusion, with potentially important consequences for synaptic plasticity.
Crosstalk noise	Spillover of synaptic vesicles to adjacent neurons can lead to unpredictable variability, as potentially could ephaptic coupling, whereby the electric field produced by adjacent neurons may cause changes in their membrane potentials.
Synaptic neurotransmitter release	Both the number of neurotransmitter molecules released from synaptic vesicles and the number of activated postsynaptic receptors seem to be random variables, and thus lead to stochastic variability in action potential generation.
Short-term plasticity	Several interacting effects can mean that even spikes that arrive regularly at axonal terminals may lead to irregular postsynaptic events. These effects include facilitation, adaptation, depression and recovery as well as the stochastic release of neurotransmitters from vesicles.
Ion channel gating and membrane noise	The stochastic nature of the opening and closing of ion channels is well known. This leads to fluctuations in neuron membrane potentials, and in turn affects action potential generation.
Synaptic barrages	Pyramidal neurons can have many thousands of synaptic connections with other neurons, and the numerous input events from these can lead to the neuron's membrane potential being in a state of increased or decreased, or fluctuating, conductance. This can have profound effects on the neuron's spiking properties.
Diversity owing to stochastic gene expression	Intrinsic biophysical properties vary over populations of neurons and have been shown to benefit neural coding. The notion that this kind of variability can lead to benefits is sometimes called diversity-induced resonance.
Network connectivity	Cortical neurons form connections with many other cortical neurons to form irregularly structured networks.
Sensory inputs	Disturbances can be extrinsic (such as background visual clutter) or intrinsic to biological transduction mechanisms.
Motor noise	Movements induced by muscle fibres are subject to variability through several mechanisms.

Fig 6. Biologically relevant sources of noise that may contribute to stochastic facilitation [1]

2. Biologically appropriate signals:

Another point which can affect the study of stochastic facilitation is the signals that are used as an input to the model. More importantly signal should be biologically relevant to make study impartial. Stochastic facilitation might be observed when input and output signals of the system are well defined within the context of a computational hypothesis [1].

For instance, output signal can consider as a sequence of action potential in response to an input signal. Another possibility is to define a computation in terms of the intervals between action potential initiations at the soma of a neuron and their arrival times at an axon terminal [1]. A third possibility is an external sensory input, such as sound pressure waves that enter the transduction mechanisms of the inner ear [1].

3. Stochastic facilitation may not require an input signal:

Conventionally stochastic facilitation is considered as a relative to input and output signal and its information processing. Recently in model of emergent synchronization of whole brain functional networks there was a confusion regarding that which features of the system should consider as an output and input signal. Although the lack of signal means that calling this effect stochastic resonance redefines the term — indeed, this type of effect is known as coherence resonance in statistical physics and has consistently been described as a different kind of noise enhanced effect from stochastic resonance — there would be no such ambiguity associated with calling it stochastic facilitation [1].

4. Distinguishing signal and noise:

To differentiate between signal and noise plays an important part to study a neural system for stochastic facilitation. And it is often finding that signal and noise is only different in terms of variability. In some systems it is observed that the signal that carrying an information has fluctuation as in the noise signal. And some sources of noise are so random in nature that it can not be utilized as an input signal for the computation. For example, if we consider two computation then there might be possible that input signal for one computation can behave as a noise signal for other computation which gives diverse result.

To make complication, although it is often assumed that a signal is not dependent of any type of noise source, which is not a good assumption [1]. Therefore, it will be always challenging to filter out the difference between noise and signal in future experiments and research. But at the end we can say that it will leads toward newer hypotheses in study of stochastic facilitation.

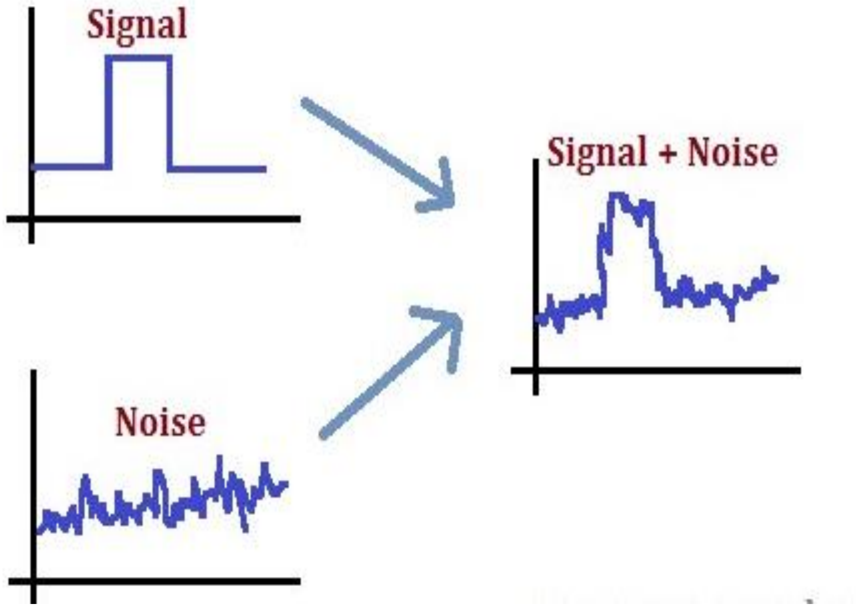

Fig 7. Differentiating signal and noise [7]

VIII. BRIDGING THEORY AND EXPERIMENT

So far, we have seen different theories and ideas that have been implemented in the study of stochastic resonance by experimentalists, modellers and theorists. So, at the end after reviewing all prospects the author has given one common definition of stochastic facilitation for the neurosciences as follow:

"Stochastic facilitation is observed within a specific neural system if a proposed computational goal is better achieved in the presence of random fluctuations originating from stochastic biologically relevant noise than in their absence" [1].

As we have seen before author gives a common framework for future experiments in neuroscience addressing stochastic facilitation. And as we discussed earlier it include total 6 steps which helps us to obtain biologically appropriate theories which gives more clear information about the stochastic facilitation. Also, to check whether the stochastic facilitation occurs or not, a biologically appropriate computational role of a neural system needs to be identified or proposed first [1].

Also, the hypothesis which we use for stochastic facilitation should be used in normal condition and with the lower noise level to check the performance. So, we can have the knowledge about that the biologically relevant noise is beneficial or not? But at the same time, it is somewhat difficult to implement and check the performance with different properties of noise and efficiency of computation.

Now we will discuss various studies in which stochastic facilitation is observed with different noise level or properties. In here we will talk about 3 studies and corelate with each other to find out and conclude the whole new or alternative concept of stochastic facilitation.

As a first case we talk about the study done by of Mazzoni *et al*. In their model they were trying to simulate the architecture and function of the V1 area of visual cortex and Lateral geniculate nucleus (LGN) of thalamus [1]. LGN sends a signal to V1 region of virtual cortex which act as an input. In which he showed that the information about the external stimulus is send to the V1 from LGN in the presence of external noise through synchronous activity in two specific channels. The computational aim of the Lateral geniculate nucleus is to successfully transmit the information that it receives about the spatial and temporal distribution of light on the retina to V1 [1].

Here he measures the performance of the system by the information exchange between LGN and V1 region of virtual cortex. He studied this system by controlling the noise level in LGN signal and as another approach he introduces V1-specific noise in order to change level and properties of noise [1]. At the end what he concludes that the addition of noise to the signal of LGN is beneficial for the information transmission between LGN and V1.

Also, to as an experimental evidence he uses an extracellular recording method to collect the data from the brain of monkey. He placed extracellular recording electrodes in LGN and V1 areas of monkeys. But at first, he trained the monkey to look at monitor which shows various visual. What he found difficult is that to identify which signal is input to LGN and V1 and which one is noise. A degradation in mutual information between Lateral geniculate nucleus and V1 neurons would confirm that synaptic noise of a specific type is require for the normal computational function of this network [1].

Second study includes papers written by Bezrukov and Vodyanoy shows that artificially generated external electric Noise can provide transduction of weak sine wave signals through the alamethicin channel in a lipid bilayer [1]. In this study he used a physical approach in which the choice of artificial noise with a Lorentzian power spectrum, and signal-to-noise ratio is considered as a measure of performance metric. He derives a model for the findings which includes mathematical expression which shows that the noise level affects the signal to noise ratio [1].

For this study author comments that, few elements of the model given by Bezrukov and Vodyanoy could possibly be accepted but this is not confirmed, because the model is mainly focused on derivation of an expression for the SNR in the output power spectrum for a noisy sine wave input [1].

Third study is done by ward and his colleagues in which they described stochastic resonance-modulated synchronization of the whole human brain. They try to show that when they add near-threshold acoustic noise to weak stimulus increase in local and global synchronization. Ward and colleagues did not develop their own models and came out with their own findings. In this study although the performance metric was unique in this study these models were not addressed directly except to predict the general effects of the noise [1].

IX. IMPLEMENTATION

There are a lot of concepts and theories in context with the Stochastic Resonance but with all that theory such as Stochastic Facilitation, as described in the main paper, it is important to verify the very basic Stochastic Resonance phenomenon before moving on to new approaches and experiments.

Our goal is to implement a system in which a simple noise overlap over an audio signal to see if the SNR relevantly increases and makes the signal more detectable. The audio signal is in the form of a subthreshold sine signal and noise is additive random white gaussian noise. The implementation is done using **Python 3.7** using signal processing and Python's predefined libraries in following steps:

1. A system is generated which have a certain threshold. A signal above this threshold is detected by the system and an output is generated. Any signal below this threshold is not detected by the system and no output is generated. This represents a neural system such as a neuron model which have a certain threshold. Any stimulus above this threshold will be detected by the model to provide an output and any stimulus below this threshold will not be detected by the neuron model.
2. A subthreshold sine wave signal is generated which needs to be passed through the system defined above. This subthreshold signal represents a subthreshold input stimulus such as an audio signal to our neurons which does not get detected by the system since this signal is below the threshold.
3. A random white gaussian noise is generated as it is the form of noise that's added to the subthreshold signals in the classical stochastic model.

4. The noise is added to the subthreshold signal in order to make the signal detectable at the system and to get the output. This represents the noise induced stimulus to the neuron model in which noise helps in the detection and better output performance of the system.
5. Different levels of random white gaussian noise is generated and added to the subthreshold signal and then fed to our system, to compare the output performance of the system at different levels of added noise.
6. Observing the output characteristics of our system we can verify the concept of Stochastic Resonance.

X. RESULTS

As stated above a subthreshold sinusoidal signal (Fig. 8) is taken and fed to a system to find the output of the system (Fig. 9). Clearly seen from Fig. that in the absense of noise no output is shown by our system.

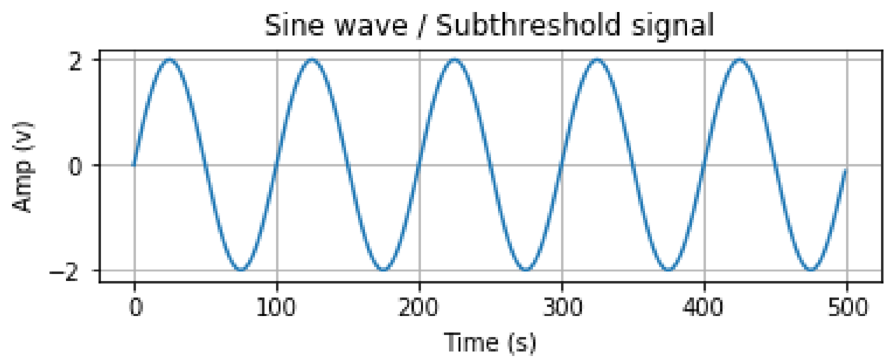

Fig 8. Subthreshold signal

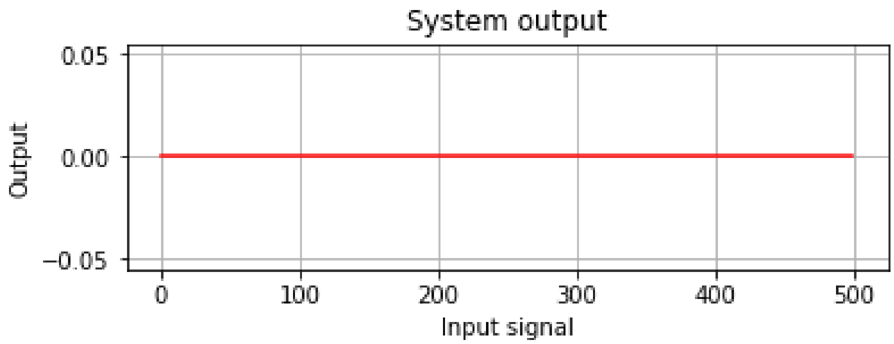

Fig 9. System output without noise added

To get the system output we added noise to our subthreshold signal which is then fed to our system to get the output. This is done using different levels of noises to see how the output of the system varies. When noise is added to the subthreshold signal and used as an input to our system an output is obtained by our system. When the noise level is increased in the next case, the output of the system increases, and this is verified by the result figures. Again, noise level is increased, and system output show an increase again. Thus, it is evident to say that adding noise effects the output performance characteristics of the system.

<u>1st level of noise added:</u>

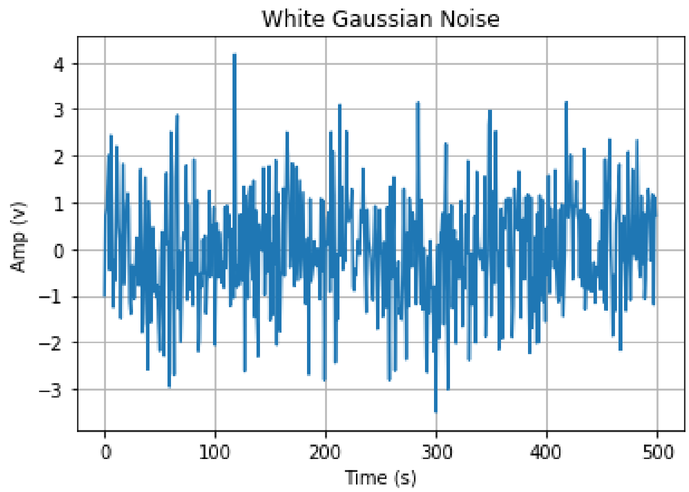

Fig 10. The white gaussian noise having 1st noise level

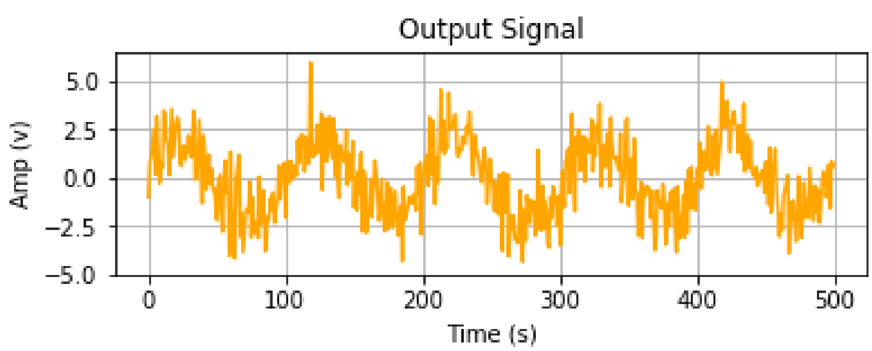

Fig 11. Output signal obtained by adding subthreshold signal and 1st noise level.

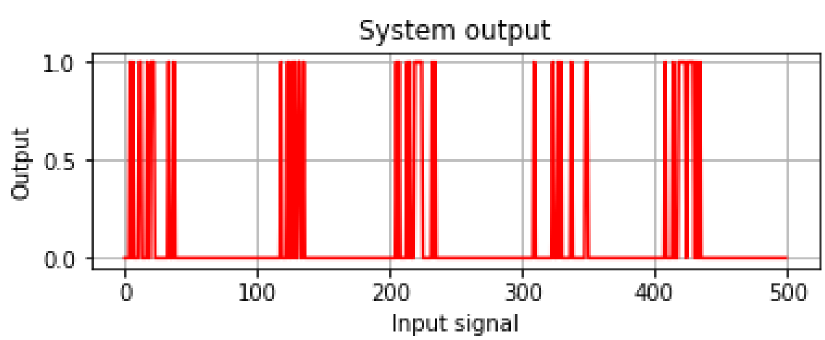

Fig 12. System output when input is noise induced by 1st noise level.

2nd level of noise added:

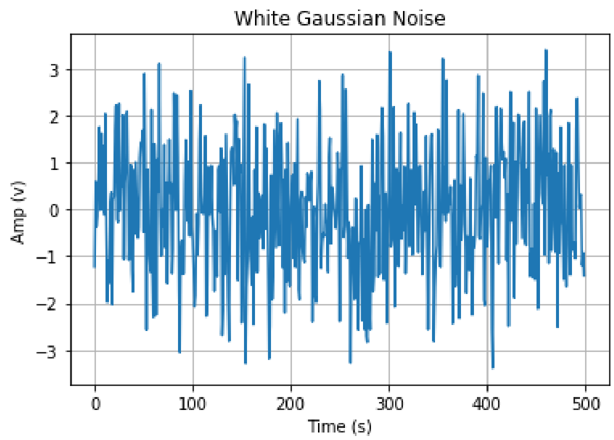

Fig 13. The white gaussian noise having 2nd noise level

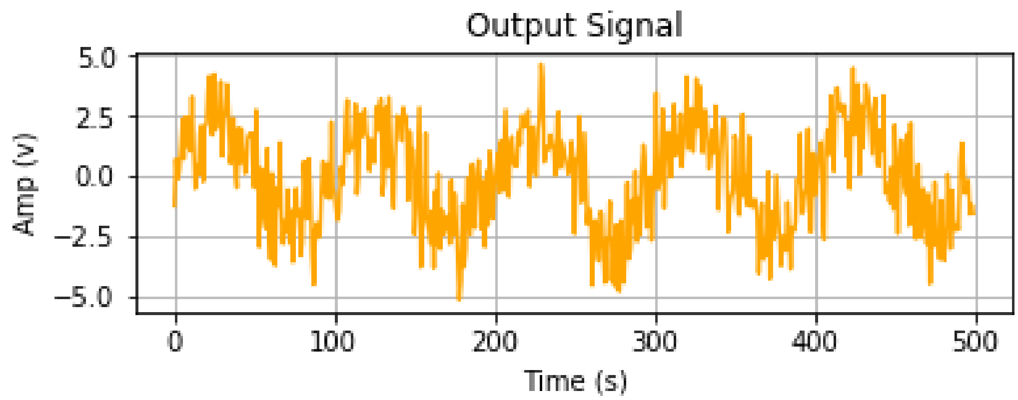

Fig 14. Output signal obtained by adding subthreshold signal and 2nd noise level.

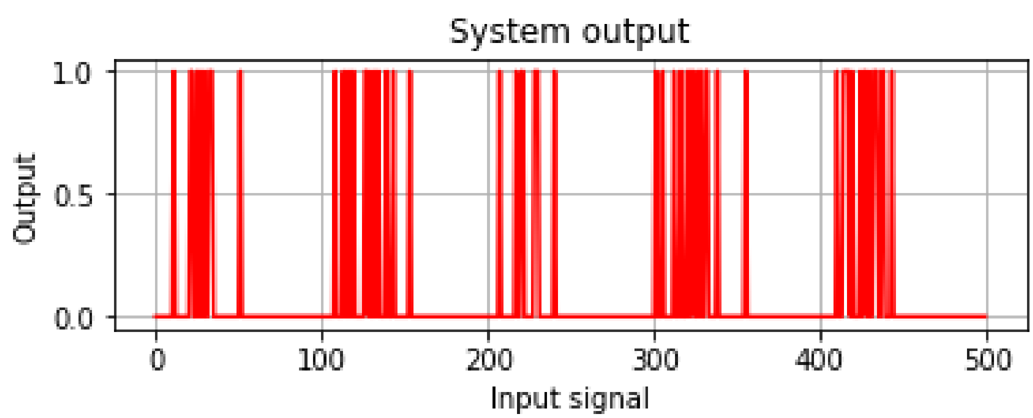

Fig 15. System output when input is noise induced by 2nd noise level.

3rd level of noise added:

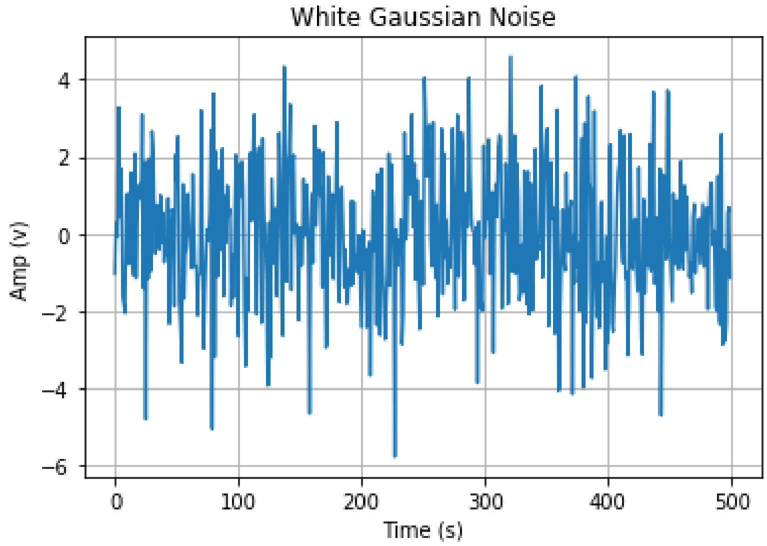

Fig 16. The white gaussian noise having 3rd noise level

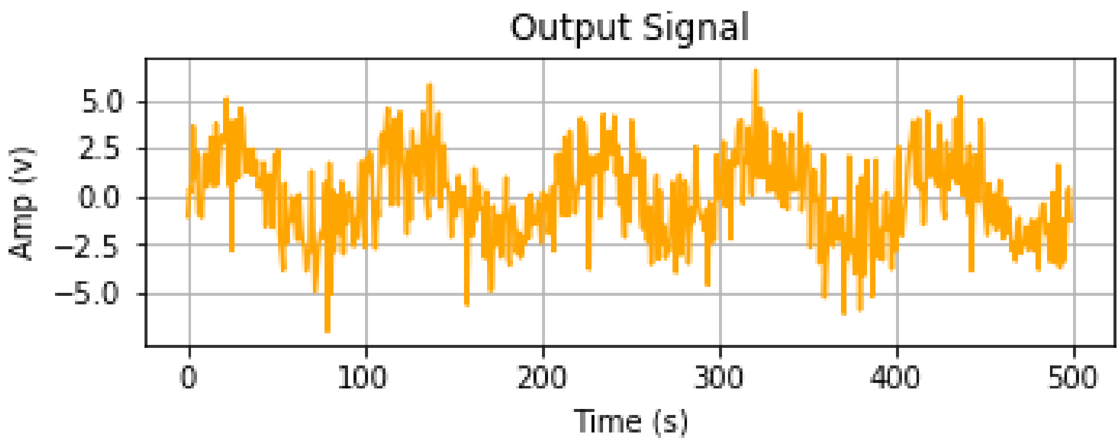

Fig 17. Output signal obtained by adding subthreshold signal and 3rd noise level.

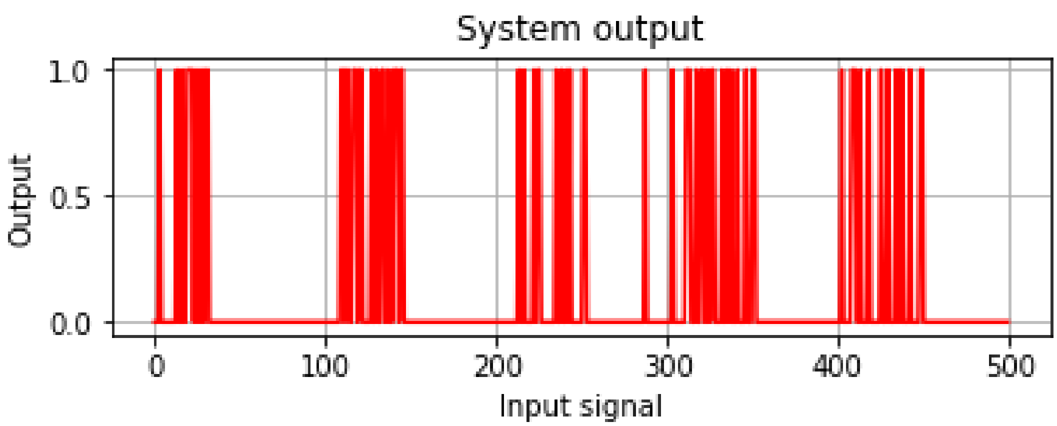

Fig 18. System output when input is noise induced by 3rd noise level.

4th level of noise added:

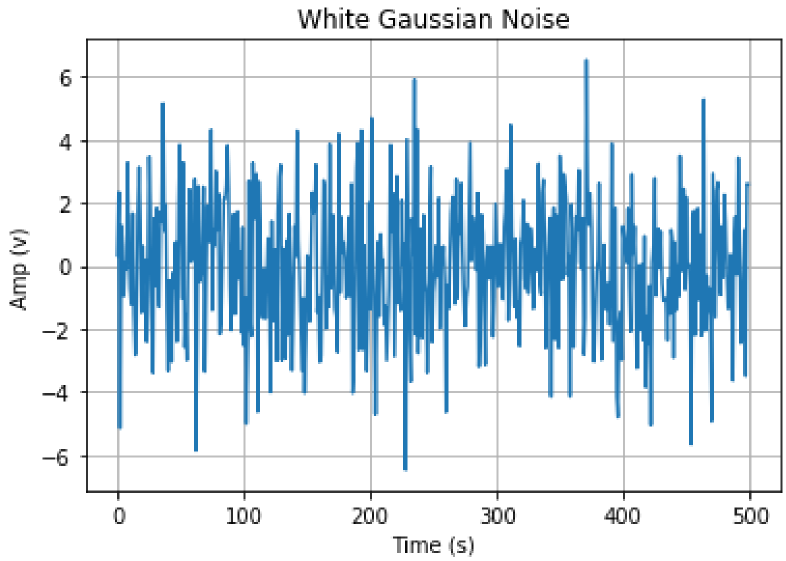

Fig 19. The white gaussian noise having 4th noise level

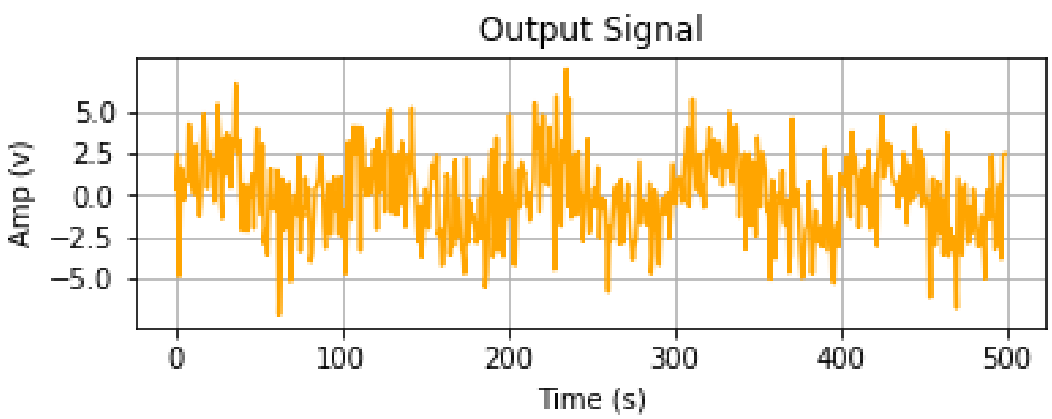

Fig 20. Output signal obtained by adding subthreshold signal and 4th noise level.

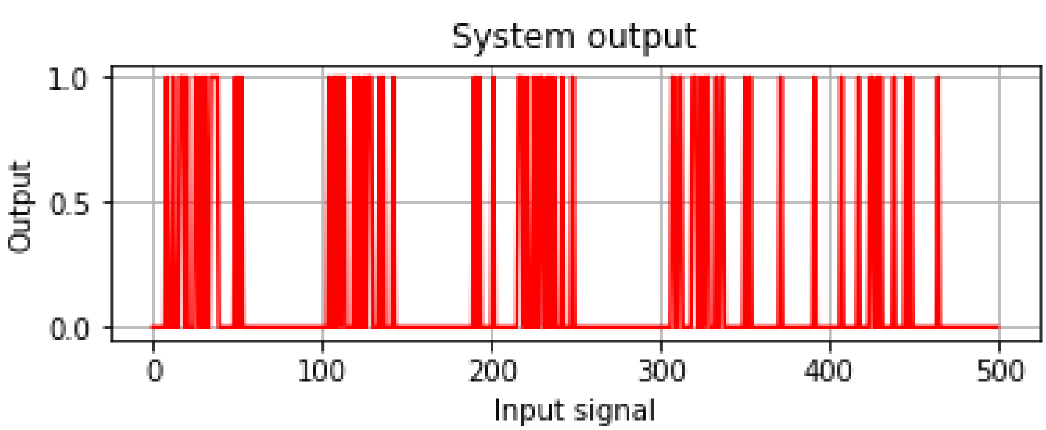

Fig 21. System output when input is noise induced by 4th noise level.

The above results prove that the output of the system is detected but what also needs to be seen is how useful this detection is in accordance to our signal. This is done by SNR. The signal to noise ratio is a measure of output signal power to the noise power and is an important factor when it comes to finding how much a system is improved by adding noise or generally to validate the concept of Stochastic Resonance. To find the SNR to noise plot or ‘stochastic resonance peak’ it required a lot of noise magnitudes to be added to the subthreshold signal one by one and then computing SNR for each to make a plot. We took 200 different levels of noise and added to the subthreshold signal to compute SNR one by one and then make a plot using Python 3.7. The plot we got does not strictly proves the concept of noise induced stochastic resonance peak but gives a proof that noise have some constructive effects in SNR improvement. In the Fig. 22, we can see a lot of times with added noise and increasing the magnitude of noise the system characteristics in terms of SNR is improved.

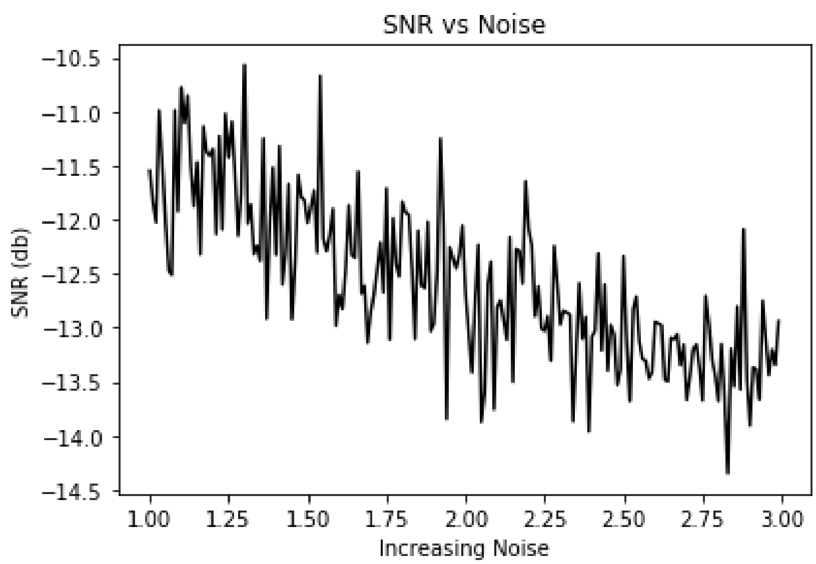

Fig 22. SNR vs Noise

XI. CONCLUSION

In this report we have discussed about the classical stochastic resonance which states that adding noise to input of non-linear system improve the detection of signal. And the system performance is only measured by signal-to-noise ratio. But the new concept of “Stochastic facilitation” has shown that the stochastic resonance is nothing but a part of more general term stochastic facilitation which uses the measures other than SNR as a performance metrices, which shows that it is not necessary to measure the performance in terms of signal-to-noise ratio. Also, the study of stochastic resonance in neuroscience is still incomplete as there is a confusion regarding the difference between noise and signal. So, more research in the study of the biologically appropriate noise may lead to better understanding and diverse viewpoints in other areas of neuroscience.

In terms of implementation of Stochastic Resonance phenomenon, we can conclude that systems show improved characteristics in the presence of noise in terms of subthreshold signal detection but the information regarding SNR improvement is a bit vague, as our system did not show a proper noise induced stochastic peak. However, we believe that a bit tuning with noise levels can improve our system to find noise induced stochastic peak.

REFERENCES

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[6] https://www.ese.wustl.edu/~nehorai/research/eegmeg/megarray.html

[7] https://conflictresearchgroupintl.com/differentiating-the-signal-from-the-noise-aka-determining-if-a-self-defense-class-is-crap/

APPENDIX

```
""" This code is presented to Prof. Dr. Hilmi Dajani for partial fulfillment of the requirements for the
course ELG7172/EACJ [W]– Topics in Signal Processing I. """

import numpy as np
import matplotlib.pyplot as plt
from math import pi
from scipy import random

plt.close('all')

"""Generating a Small subthreshold signal (Sine Wave)"""

A=2                              # amplitude
f=50                             # frequency
T=1/f                            #time period
fs=100*f                           #sampling freq
```

```
Ts=1/fs
cycles=5

t=np.arange(0,cycles*T,Ts)                    #defining t
signal = A*np.sin(2*pi*f*t)                  #defining the signal

plt.subplot(2,1,1)
plt.plot(signal)                             #plotting the signal
plt.title('Sine wave / Subthreshold signal')
plt.xlabel('Time (s)')
plt.ylabel('Amp (v)')
plt.grid(True)
plt.show()

signal_power = signal**2
signal_power_db = 10*np.log10(signal_power)


""" Generating a system with a threshold """

detected_signal = np.zeros(500,np.int16)
detected_signal_amp = np.zeros(500,np.int16)
for i in range(500):
    if (signal[i] >  2.5):
        detected_signal[i]=1;
        detected_signal_amp[i]=output[i]-2.5
plt.subplot(2,1,1)
plt.plot(detected_signal, 'red')
plt.title('System output')
plt.xlabel('Input signal')
plt.ylabel('Output')
plt.grid(True)
plt.show()


"""Generating random White Gaussian Noise, adding with the noise and then using it as an input
to our system"""

"""1st noise level"""

noise_power = 1.5
mean=0
noise = np.random.normal(mean, np.sqrt(noise_power), len(signal_power))
plt.plot(noise)
plt.title('White Gaussian Noise')
plt.xlabel('Time (s)')
plt.ylabel('Amp (v)')
plt.grid(True)
plt.show()
```

```
output = signal + noise
plt.subplot(2,1,1)
plt.plot(output, 'orange')
plt.title('Output Signal')
plt.xlabel('Time (s)')
plt.ylabel('Amp (v)')
ax = plt.gca()
ax.set_yticks(np.arange(-5, 5.1, 2.5))
plt.grid(True)
plt.show()

output_power = output**2
output_power_db= 10* np.log10(output_power)

detected_signal = np.zeros(500,np.int16)
detected_signal_amp = np.zeros(500,np.int16)
for i in range(500):
    if (output[i] >  2.5):
        detected_signal[i]=1;
        detected_signal_amp[i]=output[i]-2.5
plt.subplot(2,1,1)
plt.plot(detected_signal, 'red')
plt.title('System output')
plt.xlabel('Input signal')
plt.ylabel('Output')
plt.grid(True)
plt.show()



"""2nd noise level"""

noise_power = 2
mean=0
noise = np.random.normal(mean, np.sqrt(noise_power), len(signal_power))
plt.plot(noise)
plt.title('White Gaussian Noise')
plt.xlabel('Time (s)')
plt.ylabel('Amp (v)')
plt.grid(True)
plt.show()

output = signal + noise
plt.subplot(2,1,1)
plt.plot(output, 'orange')
plt.title('Output Signal')
plt.xlabel('Time (s)')
plt.ylabel('Amp (v)')
ax = plt.gca()
```

```
ax.set_yticks(np.arange(-5, 5.1, 2.5))
plt.grid(True)
plt.show()

output_power = output**2
output_power_db= 10* np.log10(output_power)

detected_signal = np.zeros(500,np.int16)
detected_signal_amp = np.zeros(500,np.int16)
for i in range(500):
    if (output[i] >  2.5):
        detected_signal[i]=1;
        detected_signal_amp[i]=output[i]-2.5
plt.subplot(2,1,1)
plt.plot(detected_signal, 'red')
plt.title('System output')
plt.xlabel('Input signal')
plt.ylabel('Output')
plt.grid(True)
plt.show()


"""3rd noise level"""

noise_power = 3
mean=0
noise = np.random.normal(mean, np.sqrt(noise_power), len(signal_power))
plt.plot(noise)
plt.title('White Gaussian Noise')
plt.xlabel('Time (s)')
plt.ylabel('Amp (v)')
plt.grid(True)
plt.show()

output = signal + noise
plt.subplot(2,1,1)
plt.plot(output, 'orange')
plt.title('Output Signal')
plt.xlabel('Time (s)')
plt.ylabel('Amp (v)')
ax = plt.gca()
ax.set_yticks(np.arange(-5, 5.1, 2.5))
plt.grid(True)
plt.show()

output_power = output**2
output_power_db= 10* np.log10(output_power)

detected_signal = np.zeros(500,np.int16)
detected_signal_amp = np.zeros(500,np.int16)
```

```
for i in range(500):
    if (output[i] >  2.5):
        detected_signal[i]=1;
        detected_signal_amp[i]=output[i]-2.5
plt.subplot(2,1,1)
plt.plot(detected_signal, 'red')
plt.title('System output')
plt.xlabel('Input signal')
plt.ylabel('Output')
plt.grid(True)
plt.show()


"""4th noise level"""

noise_power = 4
mean=0
noise = np.random.normal(mean, np.sqrt(noise_power), len(signal_power))
plt.plot(noise)
plt.title('White Gaussian Noise')
plt.xlabel('Time (s)')
plt.ylabel('Amp (v)')
plt.grid(True)
plt.show()

output = signal + noise
plt.subplot(2,1,1)
plt.plot(output, 'orange')
plt.title('Output Signal')
plt.xlabel('Time (s)')
plt.ylabel('Amp (v)')
ax = plt.gca()
ax.set_yticks(np.arange(-5, 5.1, 2.5))
plt.grid(True)
plt.show()

output_power = output**2
output_power_db= 10* np.log10(output_power)

detected_signal = np.zeros(500,np.int16)
detected_signal_amp = np.zeros(500,np.int16)
for i in range(500):
    if (output[i] >  2.5):
        detected_signal[i]=1;
        detected_signal_amp[i]=output[i]-2.5
plt.subplot(2,1,1)
plt.plot(detected_signal, 'red')
plt.title('System output')
plt.xlabel('Input signal')
plt.ylabel('Output')
```

```
plt.grid(True)
plt.show()



""" Generating 200 noise levels and adding to subthreshold signal to use as an input to our system
and then find relevant plot of SNR """


noise_power = 1
snr_array=np.zeros(200)
noise_power_array=np.zeros(200)
for j in range (200):
    noise_power_array[j]=noise_power;
    mean=0
    noise = np.random.normal(mean, np.sqrt(noise_power), len(signal_power))

    output = signal + noise
    output_power = output**2
    output_power_db= 10* np.log10(output_power)

    detected_signal = np.zeros(500,np.int16)
    detected_signal_amp = np.zeros(500,np.int16)
    for i in range(500):
        if (output[i] >  2.5):
            detected_signal[i]=1;
            detected_signal_amp[i]=output[i]-2.5

    detected_signal_power=detected_signal**2;
    avg_noise_power = np.mean(noise_power)
    avg_detected_signal_power = np.mean(detected_signal_power)
    snr_detected=avg_detected_signal_power / avg_noise_power
    snr_detected_db = 10* np.log10(snr_detected)
    snr_array[j]=snr_detected_db;
    print('SNR for this detected signal =' , snr_detected_db)
    noise_power=noise_power+.01;
plt.plot(noise_power_array,snr_array, 'black')
plt.title('SNR vs Noise')
plt.xlabel('Increasing Noise')
plt.ylabel('SNR (db)')
plt.show()

""" End of code """
```

PROJECT DISTRIBUTION

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