1/f NOISE STUDIES IN CERTAIN PHYSICAL SYSTEMS

CHAPTER 1
INTRODUCTION TO 1/f NOISE

1.1. INTRODUCTION

The study of noise in physical systems is perhaps one of the most selective fields of physical sciences. The study being fundamental in nature, attracted several investigators [1-3] emerging from diversified fields. The vast and still expanding literature on the subject of noise had its beginning with "Brownian Movement" [1]. Pollen grains in water were observed to be in motion. These motions were neither due to the currents in the fluid nor from its evaporation, but belonged to the particle itself. Later Einstein [2] showed that Brownian movement arose directly from the incessant and random bombardment of the molecules of the surrounding liquid, and thus arose the concept of "fluctuations". These fluctuations are therefore a consequence of the discrete nature of the matter. Such fluctuations are generally referred to as "noise". It has become a common practice to call the fluctuating component of any measurable quantity as noise. There are different manifestations of noise and hence different causes. Therefore classification of noise phenomena is difficult. Van Vliet has given [3] some broad guidelines on how to classify noise phenomena. She defined the terms "characteristic noise phenomena" and "non-characteristic noise phenomena". Characteristic noise phenomena are those which are reducible to noise sources, associated with a characteristic time constants of the source. An example for such noise phenomena is the burst noise. Non-characteristic noise phenomena are those fluctuation processes which are not reducible to noise sources such as quantum 1/f noise. In such phenomena, actual representation of the noise as an 'effect' is not directly noticed. The earliest noise phenomena discovered were thermal noise due to the thermal motion of the constituent electrons and shot noise due to the corpuscular nature of transport. 1/f noise and burst noise are both low frequency noise phenomena.

1/f noise phenomenon was first studied as an excess low frequency noise in vacuum tubes and later in semiconductor devices. Since the mid-fifties 1/f noise (referred as low frequency noise) has been observed as fluctuations in the physical parameters of the systems. Most of the studies were totally unrelated to each other and certain of these were not related to the devices themselves. In most cases the observed 1/f noise couldn't be fully explained by any of the models developed. For example, 1/f noise has been observed as fluctuations in average seasonal temperature [4], annual amount of rainfall [4], rate of traffic flow [5], potential across nerve or synthetic membranes [4,6], rate of insulin uptake in diabetics[6], GNP of economics [4,7], loudness or pitch of music[8], earthquake cycles [7], sunspot cycles [7], thunderstorms [9], height of the floods of the Nile or Ganges [10] so on and so forth.

Certain features of 1/f noise phenomena are highly striking and common to most of the studies. First feature is the unique common nature commonly found in most of the systems and the second is its unique noise spectrum. pass The 1/f noise spectrum has been observed to bear many similarities in diversified systems. These common features suggest some universal mechanism associated with 1/f noise. It has not been possible to identify any universal noise mechanism so far. The second feature regarding the nature of 1/f noise spectrum in physical systems is mathematical rather than physical. Attempts are on to identify different physical mechanisms giving rise to the same 1/f noise spectrum. This work is directed to assist this investigation.

The various models which have been proposed to explain the 1/f noise studies are to be briefly mentioned along with experimental evidences. Handel's model is separately dealt exploring its applicability

Burst noise is a form of low frequency electrical noise. The literature on burst noise shows a first mention of it by Mongomery[11] in 1952. This work do not attempt to explain the phenomena.

1.2. GENERAL PROPERTIES OF THE 1/f NOISE :

In the past, 1/f noise has been variously called as current noise, excess noise, flicker noise (usually in connection with fluctuations in electronic emission from a thermionic emission from a thermionic cathode), semiconductor noise (before it was appreciated that it also appears in metals and aqueous electrolytes) and contact noise (although it was quite well known that 1/f noise is not generally a contact effect). All these names have been dropped recently and only the name 1/f noise has been retained. In the various research papers on 1/f noise, it has been cautioned by most authors that the name 1/f noise common to all manifestations of the phenomena should not be taken to imply the existence of a common physical mechanism giving rise to them all.

Table 1.1 - Physical Systems (of Interest) that Exhibit 1/f Noise [7]

S.No	SYSTEM	OBSERVED QUANTITY
1.	CARBON FILM	CURRENT
2.	METAL FILM	CURRENT
3.	SEMICONDUCTOR (G R)	CURRENT
4.	METAL CONTACT	CURRENT
5.	SEMICONDUCTOR CONTACT	CURRENT
6.	IONIC SOLUTION CONTACT	CURRENT
7.	SUPERCONDUCTOR	FLUX FLOW
8.	VACUUM TUBES	CURRENT
9.	JUNCTION DIODE	CURRENT
10.	SCHOTTKY DIODE	CURRENT
11.	ZENER DIODE	CURRENT
12.	BIPOLAR TRANSISTOR	CURRENT
13.	FIELD EFFECT TRANSISTOR	CURRENT
14.	THERMOCELL	THERMO EMF
15.	ELECTROLYTIC CONCENTRATION CELL	VOLTAGE
16.	QUARTZ OSCILLATOR	FREQUENCY
17.	PLANET EARTH (5 DAYS MEAN OF ROTATION)	FREQUENCY
18.	SOUND AND SPEECH SOURCES	LOUDNESS
19.	NERVE MEMBRANE	POTENTIAL
20.	HIGHWAY TRAFFIC	CURRENT
21.	SUNSPOTS	ACTIVITY
22	HALL EFFECT	HALL VOLTAGE
23	LED	INTENSITY
24	RADIOACTIVITY	α OR β COUNT

Low frequency fluctuations showing a power spectral density inversely proportional to the frequency are observed in various physical, technical, biological and economic systems. This peculiar phenomenon which is called 1/f noise or flicker noise has stimulated the research efforts of numerous scientists since the early work of Johnson [12] and Schottky [13]. In the past an impressive number of papers have been devoted to the experimental and theoretical aspects of 1/f noise. Today this subject seems to be more fascinating than ever before. A remarkable sign of growing interest has been Tokyo Symposium in 1977, which solely dealt with 1/f fluctuations[14]. The Fifth International Conference on Noise (Bad Nauheium 1978, Fed Rep of Germany) 1978 and subsequent Noise Conferences provided ample scope for 1/f noise. Table 1 reveals the important systems in which 1/f fluctuations have been studied. In the field of noise research, it has been generally experienced that the well known exception for which the experimental predictions is 1/f noise. Therefore the research on 1/f noise is full of controversies. The basic problem of the origin of 1/f noise in general remains unsolved till now. The exciting question whether 1/f noise is a general fluctuation phenomena inherent in the collective motion of particles or is a property of a specific systems is still a challenge. Following are a few outstanding features of the 1/f noise phenomenon. Van der Ziel [15] and Hooge [16] have presented excellent surveys of the state of the art of 1/f noise in physical systems. The main aspects of the 1/f noise are (the discussion is centered around device noise and can be extended to any other phenomena) :

(1) Power spectral density : The shape of the power spectral density is of the f^{1} type with lying [17] between 0.8 and 1.4. This spectral shape has been observed over a wide range of frequencies from 10^{-6} Hz to 10^{6} Hz or higher.

(2) Amplitude distribution [18]: The amplitude distribution of 1/f noise is strongly Gaussian [14]. Although considerable deviations from a Gaussian distributions have been observed, they are attributed to interference effects with additional low frequency noise components particularly burst noise.

(3) Stationarity : A process is said to be statistically stationary when the statistical properties are independent of the epoch in which they are measured. In the 1/f noise literature one comes across statements to the effect that 1/f noise is a stationary fluctuation as well as those saying that it exhibits some degree of non stationary. In order to clarify the situation, two kinds of noises namely the band limited 1/f noise and low pass filtered 1/f noise have to be studied. The band limited

1/f noise is that for which the power spectral density is defined only for any frequency between the upper and lower angular frequencies of the band considered while, the low pass filtered 1/f noise is that in which the low frequency components down to zero frequency are present. The band limited fluctuation corresponds to the actual situation encountered in experimental measurements of 1/f noise since all observed 1/f noise is band limited either directly by filtering or indirectly by a limited observation time and such a process is found to be statistically stationary while, low pass filtered 1/f noise is a theoretical abstraction and is non stationary.

(4) Current dependence. In homogenous conducting materials, it has been verified that there is a current squared (I^2) dependence of noise which led to the belief that 1/f noise originates from fluctuations in conductivity. However, in junction devices such as diodes and transistors, the current spectral density is observed [20] to be proportional to I^{γ} with γ between 1 and 2.

(5) Temperature dependence: From the above property since 1/f noise depends on current and current depends on temperature, it is to believe that 1/f noise depends on temperature. The studies of Eberhard and Horn [21] have shown the dependence of 1/f noise in metal films on temperature. Similar results have also been obtained by May and Hardwood[22]. According to Handel [23] , in semiconductors, there is a certain temperature dependence due to absorption and description of gases or water vapour on the surface, due to changes in the concentration of the carriers. Also in thermally stable carbon resistors there is a very low temperature dependence. Therefore Handel has concluded that in general 1/f noise has insignificant [23] temperature dependence. It is equally important to know the properties of the other low frequency noise phenomenon, the burst noise.

1.3. GENERAL PROPERTIES OF THE BURST NOISE PHENOMENON:

Burst noise is also called as popcorn noise. This name stems from the fact when it is fed into a loud speaker, the result sounds like corn popping. Burst noise is usually present along with thermal noise , shot noise and 1/f noise. The following are a few important properties of the phenomenon.

(1) The phenomenon presents itself usually as a bistable step type wave form of uniform amplitude with randomly varying time intervals between steps. Such a wave form resembles a random telegraph signal. However complex step waveforms involving more than two or three levels have also been observed. The bistable burst noise waveforms are found to be strongly asymmetric.

(2) In the case of bistable burst noise signals, the probability density functions of the times spent by the signal in each of the two states follow an exponential law while the number of bursts in a fixed time interval is entirely described by poissonian statistics.

(3) The power spectral density has a 1/f spectral pattern. However, it has been recently shown [24] that burst noise due to defects lying in the bulk of the semiconductor will show a Lorentzian power spectrum whereas defects residing in the oxide will give rise to a 1/f spectrum.

It is equally important to know the various models presented for 1/f noise. These models were partially successful in explaining the nature of general 1/f noise. However refinements are required for each of the models to fully explain the situation. The following chapter presents select 1/f noise models which have been quite successful in explaining at least one or two noise phenomena.

CHAPTER 1 - REFERENCES

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