# FREQUENCY ENTRAINMENT OF NONLINEAR OSCILLATORS

BY

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بسم الله الرحيـــم الرحمن

" وما أوتيتم من العلم الا قليـــــلا "

" وقل ربى زدنـــى علمـــاَ "

" صدق الله العظيم "

بسم الله الرحمن الرحيم

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# SUMMAMRY

The phenomenon of entrainment/synchronization/locking of nonlinear oscillators has been presented. Different recent studies and applicaltions have been also reviewed.

The parametric behaviour of microwave semiconductor devices oscillators has been theoretically treated and analyzed. The resulted analytic equations were numerically computed to explain device performance characteristics specially when driven lby a aperiodic wave at one frequency and perturbed by a weak one at different frequencies.

The basic properties of subharmonic frequency entrainment/locking have been thoroughly investigated using the describing fucntion technique (DFT). General expressions for subharmonic locking range and related describing functions are deduced and the results of their calculations are represented graphically for interpretation of the analysis.

The entrainement phenomenon has been also realized experimentally. Two techniques have been used in this respect, that is the sweep frequency technique by designing a cricuit encorporating a sweep frequency generator

with a CRO as a detecting devices; while the other technique, the spectrum analysis technique, is based on monitoring the output spectrum of the entrained oscillator on abroad band spectrum analyzer.

Reasonable results are generally obtained emphasizing the importance of the studied phenomenon for oscillator and amplifier stablization and the various applications in the microwave range of frequencies.

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# CHAPTER [1]

# INTRODUCTION

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## INTRODUCTION

The response of a self sustaining system to a harmonic exitation is due to a free oscillation term and a forced-oscillation term having nearly the same frequencies [1]. Thus the response exhibits strong beating behaviours. When the two terms combine to yield a single frequency response, i.e. the free oscillation term is entrained by the forced-oscillation term, a ph enomenon known as entrainment or locking (synchronization) occurs.

When the two terms separate to yield on a periodic response, they are said to be unlock. In other words, the phenomenon of entrainment is usually called pulling out.

The spectrum purites of solid state oscillators, such as avalanche and Gunn diode oscillators, are found to be much more improved by using synchronization techniques which on the other hand results in a reduction of the existing noise [2].

Among other functions, injection-locked oscillators can be used to accomplish oscillator frequency stablization, power amplification, frequency up conversion and frequency multiplication, FM modulation and demodulation.

Injection-locking of a microwave oscillator circuit by a reference weak signal is usually done by using a microwave circulator. The frequency range over which synchronization is obtained, for a given ratio of reference-signal input to oscillator out put power, is defined as the locking range of the oscillator.

Four types of synchronization/injection-locking methods have been developed:

i) Fundamental -wave injection locking [3], where the frequency of the injection signal $f_i$ is nearly equal to the free- running oscillation frequancy $f_o$ to be locked.

ii) Subharmonic/hormonic injecteion locking [4]. In sub-hormonic locking, $f_i$ is nearly equal to $1/nf_o$ where as in harmonic locking $f_1$ is nearly equal to $nf_o$ where n is an integer, n $\geqslant 1$.

iii) Sideband -wave injection- locking [5], where two injection signal are used, one of which is a low frequency signal $f_{i1}$, and the other a signal with frequency $f_{i2} = f_o + f_{i1}$.

The first and the third techniques have wider locking bandwidth (i.e tuning bandwidth) than the second, when compared for a particular gain, with increasing frequency, however, it becomes more difficult to realize a low-noise injection signal source with frequency nearly equal to be stabilized.

The advantage of the second technique is that a low frequency signal can be used for injection. But unfortunately, the tuning bandwidth becomes narrower when the order of multiplication n is increased.

**iv)** Another technique to overcome the above mentioned difficulties was proposed by Okamoto [6]. It utlizes the parameters interaction which is caused by providing a high-Q Idler cavity in the vicinity of an oscillating element and by injecting a signal whose frequency is much lower than the oscillation frequency. This method has much wider tuning bandwith than of the conventional sub-harmonic injection locking technique.

To understand the properties of injection locking, specially concerning subharmonic and harmonic looking, the general theory developed by Daikoku and Mizushima [7] has been presented. The model used leads to a more general locking equation than Adder's [8] as the effect of the device nonlinear susceptance in included. The subharmonic and harmonic locking characteristic do not a rise straight-forwardly from kurokawa's [9].

The entrainment subject is still under foucs of many researchers, the recent work was developed by John E. Carlstron (1985)- [10] where a phase locked second harmonic Gunn oscillator, mechanically tunable from 65 to 115 GHZ, has been developed for use as a local oscillator in mil-limeter radio astronomy, and shigginogi (1985). [11] was studing the locking behavior of microwave multiple-device ladder oscillator, also different models and their mathematical expressions were developed [12] to study the microwave oscillators since the first Van der Pol oscillator model. Synchronization of mutliple device oscillators was also analyzed by S.S arkar and Gupta (1986)- [13]. They showed that the external Q of the oscillator circuit decreases towards a limiting value as the number of devices is increased. This limiting value is determined by the Q of an individual device. It is also shown that improvement of the locking range with an increase in the number of devices is rapid when the locking gain is rapid when the locking gain is very low and independent of the increase of the number of devices. A new microwave frequency discriminator has been also implemented based on the principle of injection synchronization [14]. This proposed injection- looked hybrid discriminator (ILHD) is found to be superior to the convensional (HD) in view of its higher figure of merit.

In this thesis four chapters are introduced:

The second chapter deals with theoretical treatement of some nonlinear properties of the IMPATT or Read a valanche diode, based upon the somewhat idealized Read model, this theory presents a qualitatively meaningful explanation of certain "parametric" effects that are troublesome to the designers of amplifier and oscillator networks. An analytic treatment is given for frequency conversion effects that appear when the device is strongly driven by one continuous signal, and simultaneously perturbed by a weak signal at another frequency or by noise. Some computer techniques are used for numerical evaluation to provide results for expected performance characteristics.

The third chapter deals with the basic properties of subharmonic frequency entrainment/injection locking, as well as differences between subharmonic and fundamental injection locking, where (DFT) is applied [24].
The detailed analysis is given for locking to the third subharmonic, but necessary expressions for generalizing the treatment to other than third subharmonic locking are provided.

In chapter four experimental investigation of the above mentioned phenomenon was carried out. The characteristics of the nonlinear Gunn-diode oscillators together with current-voltage characteristics, are plotted experimentaly. Frequency and power dependance on bias voltage characteristics; were verified. Two techniques were used in investigation of the synchronization-entrainment of the above oscillator. The first is the sweep frequency technique where investigation is done by sweeping a master source frequency across the frequency $f_o$ of the unlocked oscillator and observe how the oscillator frequency and output power are influenced. The second technique is the spectrum analysis one; where the complete spectrum of the driven oscillator is monitored on a spectrum analyzer. The change in output spectrum during the locking process are recorded and photographed giving a clear insight on the synchronizing locking phenomenon.