Dual Band, Microwave and TV White Space, Oscillator Design for Mitigation of Rain Attenuation

Tsion Lemma Zula

A Thesis submitted to

The department of Electronics and Communication Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Electronics and Communication Engineering

Office of Graduate Studies

Adama Science and Technology University

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Feyisa Debo (PhD)________	______________	________________
Name of major Advisor	Signature	Date

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LIST OF ACRONYMS AND ABBREVIATIONS

AC	Adaptive Coding
ACM	Adaptive Coding and Modulation
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
dB	Deci Bell
CME	Cognitive Management Entity
CMOS	Complementary Metal Oxide Semiconductor
CR	Cognitive Radio
CTE	Contract Telecommunication Engineering
DTV	Digital TV
EIRP	Effective Isotropic Radiated Power
FCC	Federal Communication Commission
FD	Frequency Diversity
FFT	Field Effect Transistor
FSL	Free Space Loss
FM	Fade Margin
FMT	Fade Mitigation Technique
FOM	Figure of Merit
GHz	Giga Hertz
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union Recommendation
LC -VCOs	LC-Voltage Control Oscillator
LOS	Line-of-Sight

MHz	Mega Hertz
MOS	Metal Oxide Semiconductor
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
NMA	National Metrological Agency
PC	Power Control
RF	Radio Frequency
RSD	Raindrop Size Distribution
RSL	Receive Signal Level
RSS	Received Signal Strength
SNR	Signal to Noise Ratio
SD	Site Diversity
TD	Time Diversity
TL	Transmission Line
TVWS	Television White Space
VCO	Voltage Controlled Oscillator
VHF	Very High Frequency
UHF	Ultra High Frequency
USRP	Universal Software Radio Peripheral
UTM	University of Technology of Malysia

ABSTRACT

In this research, a new dual band oscillator was designed for the application of frequency diversity of microwave line of sight communication. A different type of attenuation mitigation technique was implemented in Microwave band. Frequency diversity technique is one of attenuation mitigation technique. However, mitigation by frequency diversity using TV white space (TVWS) frequency band, which is a current research area, is a new idea. This technique can be implement on any of rural Microwave link distance starting from 5km to 50km. The level of rain attenuation calculation derived from the collected local rain data and by using specification of Microwave specific link. ITU-R recommendation was used to determine specific attenuation and threshold level. This thesis also consists of a new design of a dual band VCO, which is a small part of RF design but it is a major headache for designer. This VCO can operate in both Microwave (11GHz), and TVWS, which is the secondary user of the television frequency (470-862MHz in Ethiopia case). The design of VCO simulated using a software of AWR Design Environment. This oscillator can generate a required dual frequency band. Switching technique was used to convert from one operating frequency to another. The basic idea of this oscillator is to use single band oscillator at a time and switch off another. Therefore, when the signal of microwave degrades, it switches and uses another frequency band, which is the TV white space band. Switching is the easiest and least power consuming of dual band oscillator techniques. The major performance measurement of oscillator such as (Tuning voltage, phase noise, output power, and tuning frequency range) was measured. The major interesting output of this work is, its low phase noise of the higher and lower band -120@
1MHz offset and -146 @1MHz offset respectively. In addition to its, figure of merit (FoM) is -167dBc/Hz and -200dBc/Hz of higher and lower band (0.5 and 11) GHz carrier frequency respectively. The power dissipation is 2.2mW, 0.67V DC voltage, 24% tuning range and Q-factor of tank is 22. However, the above result is sufficient, the phase noise gap of the two band is a little high because of a long gap between a higher and lower band. Therefore, this area will need further research.

Key words: **TV white space, VCO, Rain fades, Frequency Diversity, ITU-R, and CMOS.**

CHAPTER ONE
INTRODUCTION

1.1. Background of the study

Atmospheric effects are frequency dependent, where in general high frequency associated with higher losses. Rain attenuation is the main problem on terrestrial links, which is, operating frequency of above 10 GHz. Rain fade, is the reduction of the signal power level due to rain rate leading to low quality system, it has considered as the major problem facing microwave link design. Based on the different characteristics of attenuation, fade mitigation techniques classified into three major approaches such as Adaptive Power control techniques, Adaptive transmission techniques and Diversity techniques.

This research work uses frequency diversity techniques, using the signal band, which is highly attenuated by rain, had switched, and then the signal have transmitted to TV white space band, which is the secondary user of the television frequency. In a switching receiver, the signal from the transmitter will receive until the strength of the signal reach some prescribed threshold. When the signal of microwave degrades, it switches and uses another frequency band, which is the TV white space band. Switching is the easiest and least power consuming of the frequency diversity processing techniques [1]

In this research, both the transmitter and receiver operate at two frequency bands: the lower is at TV white space and higher at microwave frequency. The microwave frequency that is above 10 GHz would come attenuated by rain fade because attenuation increase when we goes from lower frequency to higher frequency of microwave.

In Ethiopia television frequency, there is huge amount of unused frequency spectrum. The television broadcast, which is in ultra-high frequency starts from 470 MHz up to 862 MHz, had considered [2]. Since, according to [3] all 54 national TV transmitters use UHF band. The rain rate is the rate of the accumulated rainwater in rain gauge measured in mm/hr. Rain intensity *R* (mm/hr.) is the most important quantity for the determination of rain attenuation.

However, the signal strength at microwave band could be very low due to rainy time of channel fading. So that using one channel cooperatively with secondary channel can improve the signal strength performance.

The frequency switching technique and rain mitigation modeling would introduced in this research. In addition, the rain attenuation distribution had studied in a rural microwave link of Ethiopia. Those links are any of 10 -50 km link distance found in the rural area of the country.

Designed oscillator, switches between even (higher frequency band) and odd (lower frequency band) modes of resonant. Here the switches that used for the selection of mode does not carry a current. Because of this, switching device does not affect overall phase noise.

There are two techniques to design multiband oscillator: The first one is making one or more inductors idle, but those idle inductors will increase the phase noise of the local oscillator. The second technique is using switched LC resonators that means all capacitor and inductors controlled by switching mechanism.

The basic idea of this oscillator is to use single band oscillator at a time and switch off another band. The oscillation frequency bands are TVWS, which is unused Television frequency of UHF (470-862) MHz, and Microwave band (above 10GHz) which applied for Television band and Microwave communication respectively. The oscillator had designed for the application of frequency diversity technique. A frequency diversity technique, which, used to mitigate the rain attenuation in the microwave communication. The main purpose of this diversity is to use dual frequency band, therefore when the attenuation of microwave communication becomes above certain threshold level the oscillation frequency converts from higher operating frequency to lower frequency of operation.

The different parameter of oscillator such as tuning range, phase noise, output power consumption, simulated using a software of NI AWR Design Environment. Tuning range of oscillator controlled by varying the supply voltage. Therefore, the oscillator known as voltage controlled oscillator (VCO).

1.2. Problem Statements

Rain fading is a major problem in transmitting the signal in wireless communication and a major source of attenuation for microwave propagation above 10 GHz. There are many researches done on the area of rain mitigation techniques for different country's climate. However, those techniques not much investigated properly according to Ethiopian local rain rate. Therefore, weakness of received signal is major problem for communication system. It is clear that using another frequency band can increase the strength of received signal.

In Ethiopia, microwave transmission systems are limited in themselves with respect to the scalability of the transmission capacity, because the number of repeater stations is limited due to limited radio frequency sources and geographical conditions.

The real problem is the inefficient spectrum allocation and its usage. This is because as we see the current communication technology of the country, there is no applicable efficient technologies like TV white space for properly utilize the available radio frequency spectrum.

The other major problem for the application of frequency diversity is, designing an oscillator, which generate a dual frequency band. However evaluating the main parameters of oscillator like (output power consumption, phase noise, tuning frequency range, area of circuit) is acritical issue. Therefore, designing oscillator for dual frequency band can reduce the complexity of installing microwave and TVWS communication towers as well as it has an important effect to implement frequency diversity technique.

In order to solve the above problem there must be a different research on the area of technique of rain attenuation mitigation as well as designing oscillator that generate required frequency.

1.3. Significance of the Study

According to the study of [2], in the Ethiopian television frequency, there is huge amount of unused frequency spectrum. Since TV transmission is at VHF/UHF band, it has important properties or features such as signal can propagate longer distance. This signal can penetrate walls and other materials, can travel from miles away, penetrate foliage, stone, brick and even metal to reach all the corners inside a building. Those qualities made them work as TV signals. As well as signals are not easily affect by environmental factors such as rain and fewer base units are required to cover greater area. It is also a great economical advantage for microwave design engineers. As describe in [4] p. 82, Overbuilding microwave link is uneconomical but frequency diversity improves this problem.

In any country of the world, the frequency spectrum is a limited resource. However, there is higher vacant TV channels are available in Ethiopia. This is due to a limited television broadcast channels of Ethiopia. Due to the above particular characteristics of the low radio frequencies, the TV white space link functions as a backup link for the microwave link at rainy periods. Therefore, the available frequency spectrum will be utilize properly.

After Digital Switchover a portion of TV, analogue channels become entirely vacant due to the higher spectrum efficiency of digital TV (DTV) [5]. Then these cleared channels reallocated by regulators to other services through auctions. In addition to cleared spectrum, after the DTV transition there will be typically a number of TV channels in a given geographic area that are not being used by DTV stations, because such stations would not be able to operate without causing interference to co-channel or adjacent channel stations.

Unique to TVWS is, implementing cognitive radio, to sense the environment over huge swaths of spectrum and adapt to it since the radio does not have primary rights to any pre-assigned frequencies. Designing VCO for TV white space is also has appositive impact for telecommunication researchers. This is because of TV white space is a current research area.

Another importance of this research is to introduce efficient communication system that will reduce the signal attenuation and will increase the strength of signal. The main aim of this research is to study the current rain attenuation distribution as well as the impact on microwave communication of Ethiopia as well as to introduce a new unused frequency that is TV white space. This is due to implementing a switching technique as solution for the problem of rain attenuation.

Generating the required frequency has a positive impact for designing Voltage Control oscillator (VCO). This is a very essential for translation of frequency on a transceiver. Any radio communication system uses oscillator to generate the required frequency signal. 'They can be used in mobile phones, wireless routers, radios, test equipment and GPS navigation systems' [6]

According to [7], LC VCOs are usually great choices for RF applications because of desirable and sufficient start-up conditions, appropriate phase noise low power consumption. In order to obtain low phase noise with low consumption power, two LC oscillators are coupled.

This oscillator switches of application frequency according to the threshold of signal attenuation range. According to [8], voltage control oscillator designed based on the input controlled voltage source. As the name indicates voltage controlled, the supply voltage has a mechanism of controlling the tuning range of frequency of operation.

Cross-coupled LC-VCO has a wide tuning range and quite low phase. As described on [9], cross-coupled LC oscillator topology achieves lower phase noise and ease of integration than a relaxation or ring oscillators. Therefore, LC-tank VCOs are preferred in high quality RF receivers.

In GHz applications, a CMOS VCO always apply the LC tank structure. It combines of a single on-chip spiral inductor with fixed inductance low quality factor, and band-switching capacitors to adjust the required resonant frequency. Pure VCO is required for a dense channel spacing for efficiently utilize the available bandwidth. Therefore, a single wideband VCO can be used to cover those several bands.

1.4. Objectives

1.4.1 General objective

The general objective of this research is to investigate Dual Band, Microwave and TV white space, Oscillator Design for Mitigation of Rain Attenuation in local area of Ethiopia.

1.4.2 Specific objective

The specific objectives of this research considered on the scope of microwave and Television frequency (UHF/VHF), Rain Attenuation Mitigation Technique and Designing Dual Band Oscillator where clearly listed below.

- To collect and analyze the rain data and investigate rain fade and determine rain rate distribution at different frequency range using ITU prediction of modeling.
- To study of the different rain attenuation mitigation technique and determine quantity of fading on local microwave communication of Ethiopia and to find out the threshold attenuation level.
- To design dual band oscillator, which can cover microwave and TV white space frequency of operation and get acceptable parameter specification.
- To compare and contrast the designed oscillator with the previous one.

1.5. Limitations of the study

1.5.1 Limitations of Passive Elements

The Passive elements that were used in oscillator design are resistors, capacitors and inductors. The main limitation of those components is mainly on their frequency response limitation. When choosing passive components for the final circuit design, several factors need to be consider.

When choosing resistors value, there must to take into consideration its high power consumption and limiting tolerances. Inductors have also tolerances, power limits, taken in consideration and for capacitors, voltage rating, maximum capacitance power consumption, leakage current, and self-discharge time constant must take into consideration. Therefore, even if the above constraints are available in current technology; getting a compromised output passive element, especially a good inductor is a major challenge.

1.5.2 Tuning Range

Tuning range is a major challenge for any type of oscillator. The frequency range and the tuning voltage affect tuning sensitivity. For a given specific tuning voltage, increasing the frequency range needs an increase in the tuning sensitivity and the same result of reverse one. There is also for a given frequency range increasing the tuning voltage range decreases the tuning sensitivity.

In order to design a circuit with high quality factor (Q), the tuning bandwidth must be made small.

A wide tuning range is very difficult to achieve in oscillators. Making excessive low output swings also exacerbate the effects of the internal noise of the oscillator**.** At higher frequency, it is difficult to provide sufficient negative resistance to cancel the losses of the resonator because the core transistors cannot be very large due to the parasitic capacitance they add to the tank, thus it limits the oscillation frequency.

CHAPTER TWO
LITERATURE REVIEW

2.1. Fading on Microwave Line of Sight Communication

Line of sight (LOS) radio links of microwave communication above 900MHz provide different applications by means of broadband connectivity of telecommunication using radio equipment. Some applications of LOS's are data communication, Telephone channels Facsimile (now usually in a digital data format), Video, especially conference TV, Program channels, Telemetry (which is a specialized subset of data).

As described by [4] book, *Radio System Design for Telecommunications*, on p. 19, 'Fading is defined as any time varying of phase, polarization, and/or level of a received signal' A major dominant factor in path loss variation of microwave above 10GHz is rain fade and can have an effect below that frequency at low elevation.

Atmospheric parameters, such as level of temperature, pressure and comparative humidity [10] are very important parameters to define how much signals are affected when they propagate through the atmosphere, particularly under the so-called clear-air situations· As we move towards to higher frequency, microwave propagation more affected by the rain. ITU Fading also described as 'attenuation' to calculate the quantity of fading of received signal or to find the measured statistical behavior of signal.

Fading can affect all, Microwave communication, starting from a frequency range of 0.3 to 300 GHz. The quantity of fading will vary with different geographical area. Therefore, fading will be the cause of different weather conditions. There are different types of fading that affect microwave line of sight communication as demonstrated by Roger L. Freeman, on pages 19 -31 [4].

Multipath fading is one of major type of fading on microwave band especially on line of sight (LOS) communication link. It is mainly the reason of distribution, which is from high data rate of communication. Multipath fading depth or fading rate is how much signal strength at the receiver differs from its free-space rate it also stated in decibels (dB). Therefore as stated by the same scholar, on the page 20, ‘Fade depths can exceed 20 dB, particularly on longer LOS paths and more than 30 dB on longer troposcatter paths’. Power fading is other types of fading that affect microwave link. It is a result of a change of beam of the receiving antenna**.** Fading Due to Earth Bulge is also from the positive refractive index. Duct and Layer Fading can also continue for days or hours and more widespread during dark time. K-Factor Fading: this type of fading is depends on the value of K-factor.

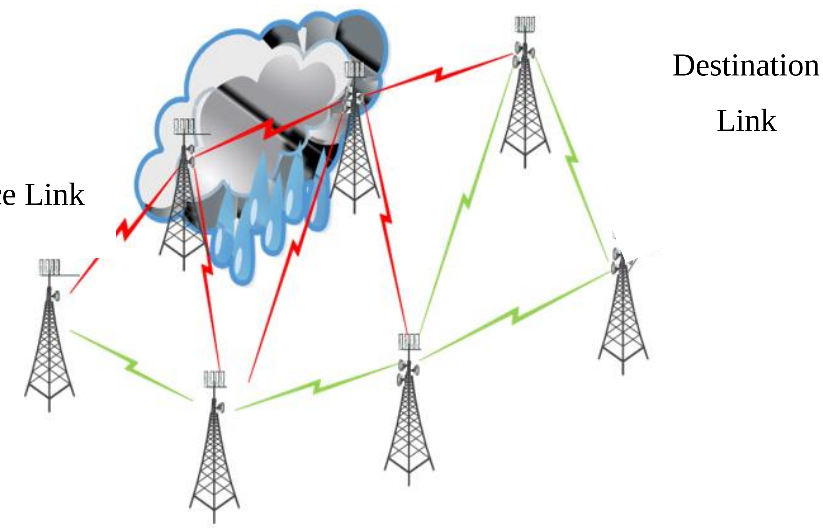

Figure 1.Topology of the network, red lines are which partially affected by rain

(Red links: Affected links by rain; Green links: Non affected links) [11]

The most common multipath fading of microwave communication is rain fade. Rain fade attracts mainly the frequency, which is greater than 10GHz. Rain fade is selective, because of selectivity behavior, frequency diversity or space diversity technique is most effective to mitigate the fade margin. Estimation of rain outage time calculation based on ITU-R prediction model, had recommended by ITU.

2.2. Theory of Fade Margin Calculation

There are three types of calculation methods for fade margin, such as by Using the Rayleigh Fading Assumption, Path Classification Method and An ITU-R Method.

Rayleigh fading method uses link margin availability versus time availability table of Rayleigh distribution. This table works for any percent of time availability.

The second one is Path Classification Method: In this method, fade margin had been quantified based applying only to that of, over land and with unobstructed LOS situations. This method had classified to method-one and two, and it had developed from ITU reports and the data of LOS radio links of Siemens classification (A, B and C) depends on characterization of paths.

The third one is An ITU-R Method, which determines with a very small percentage of time. Geo-climatic factor-K uses for both land links and over-water links. Estimation of the K value can be from contour maps for specific percentage of time.

2.3. Techniques of Rain Attenuation mitigation

There are different techniques used for the purpose of rain attenuation mitigation in microwave communication**.** In the physical layer, Fade Mitigation Technique (FMT) for can be divided in three different ways as described on [12].

2.3.1. Power control techniques

This is to transmit power level fitted to propagation impairments. Changing the effective isotropic radiated power (EIRP) of the signal to increase the received signal of Carrier to Noise Ratio. In this method, there are two distinct approaches based on the condition of the uplink or downlink signal power had augmented to combat rain fade. Uplink power control is done by varying the transmit power as a direct proportion to the attenuation on the link while downlink power control refers to manipulation of the downlink signal power according to the rain attenuation profile.

1.3.2. Adaptive coding and Modulation

This technique also known as Signal processing technique. This technique works based on Adaptive coding or Modulation changing the\signal parameter to increase the received signal strength. Therefore, Adaptive and modulation falls in this category of FMTs. The system works by automatically and adjusting modulation and forward error correction to improve link availability during a severe rain period. Adaptive waveform is the process of fade compensated by a more effective modulation technique and coding scheme,

2.3.3. Diversity techniques

This is the fade avoided by the use of another less impaired links. Choosing a different path or time to take advantage of decorrelation of the phenomenon experienced. This technique exploits the spatio-temporal variability of rain fade intensity and has the following forms.

There are different types of diversity technique, which had been describing in [13] is:

- Multipath/frequency diversity
- Spatial/space diversity
- Temporal/time diversity
- Polarization diversity
- Angle diversity
- Antenna diversity

Frequency Diversity-takes advantage of lesser degree of rain fade intensity at lower frequencies to switch transmission to these bands during intense rain periods.

Space Diversity- the probability of two spatially excluded links being in a rain cell is low. The space diversity scheme uses this concept to reroute the transmission one path least affected by rain.

Time Diversity- In this scheme the information had forwarded multiple times with delays in between, i.e. when the channel conditions are favorable. This not suitable for real time applications.

In this research work, the transmission of communication channel of communication system uses, which are different frequencies that where, affected by rain in frequency domain. This is an advantage to use frequency diversity technique. In the result, over several frequency band, it is possible to obtain different independently fading signal. Therefore, the frequency carrier signals are modulating through unlike carriers of signals in frequency diversity scheme.

2.3.3.1. Rain Attenuation Mitigation through Frequency Diversity

Frequency diversity had implemented by transmitting information on more than one carried frequency. As described in [4], Frequency diversity has different advantage, 'Not only does it provide a full order of diversity and resulting diversity gain, but it also provides a fully redundant path, improving equipment reliability'.

Frequency diversity is a technique to transmit the signal using several frequency channels or spread over a wide spectrum that affected by frequency selective fading. As shown on the graph below, for operation of frequency diversity, system two transmitter, one for each frequency at the transmitting end and two receivers at the receiving end are required.

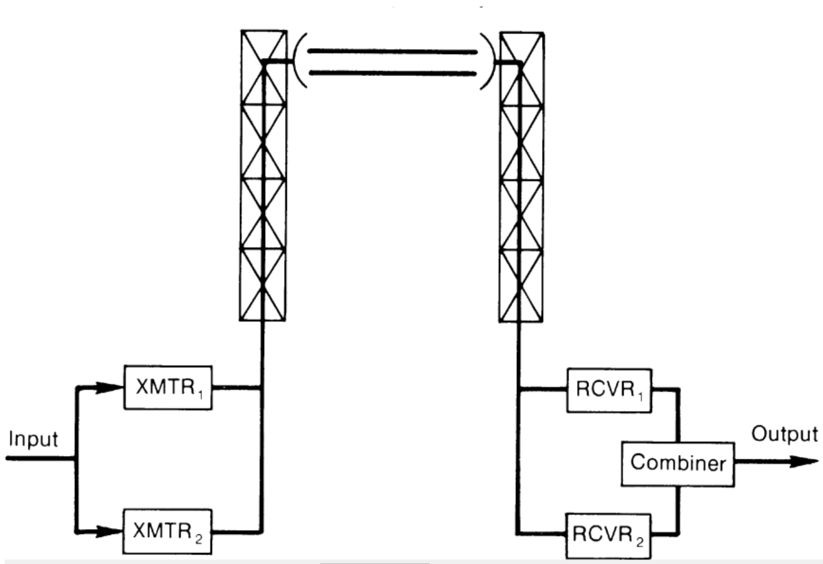

Figure 2. Simplified functional block diagrams distinguishing frequency. [4]

Here in the frequency diversity technique the switching of frequency band used for choosing a suitable channel. The operating spectrum chosen based on the maximum rain attenuation threshold, distribution that could transmit on signal. Therefore, the highly attenuated microwave frequency band will switched off and the transmission channel, changed to lower frequency band.

2.4. Related Works on Attenuation of Microwave Communication

According to the spectrum allocation and microwave usage of different country, there are different research papers on the area of techniques of rain attenuation mitigation. Related research papers discussed below.

In recent studies of [14], a frequency diversity technique of rain fade mitigation had discussed. In this research an experimental work was conducted for Malaysia using the frequency diversity fade mitigation technique to overcome the rain fade in microwave point to point (P2P) terrestrial communication link. This paper presents the summary of rain effects studies for lower operating frequency, 5.8 GHz, part of C band and compare to higher operating frequency, 26 GHz, which is Ka band in a tropical environment.

Findings on the effect of rain at lower and higher operating frequency in microwave link and solution to overcome it by implementing Switching Circuit as Fade Mitigation Technique (FMT). The received signal strength (RSS) data and rain fall intensity data were recorded for 24 hours daily over period of 12 months(Jan 2013 – Dec 2014) in 1 minute interval. The collected rain rate data where analyzed with some prediction models.

The main outcome of this research paper shows that there is negligible effect of rain for 5.8 GHz link whereas it very strong on the 26 GHz link. The observed signal fading was 15 dB to 35 dB attenuation during measurement period. The fade mitigation technique used where, dual frequency by shifting the operating frequency to lower band (5.8 GHz) while heavy rain and shifting back to normal position at higher operating frequency (26 GHz) using the threshold level as reference.

The circuit tested using the threshold in terms of voltage as a sensor for shifting purposes. In the experimental setup of the link-distance is 1.30 km and both the transmitter and receiver frequency of operation is both 5.8GHz and 26GHz. The experimental test bed for rain rate measurement had observed at 0.01% of time, the rain rate was 120 mm/h and the rain attenuation recorded was 34 db. Whenever the threshold level is below the required value for the 26GHz link, which is below -82 dBm or below 1.0 V, the circuit will shift from 26 GHz link to 5.8 GHz link. Once the threshold is below -82 dBm or greater than 1.0 V volt, the circuit will shift back from 5.8 GHz link to 26GHz link.

As a limitation, according to ITU recommendation, rain rate data must collect for at least two years and the link path length used 1.30km, which is very short length while microwave link path was above 10km length.

The paper of [15], covers the general diversity technique, fade types and parameters of fading. The Diversity Processing Techniques discussed and compared according to power consuming. There are three types of diversity processing techniques: Switching, Selecting and Combining.

In switching method, the signal will receive only from one antenna of transmitting according to the prescribed threshold and if when the signal degrades, another antenna had switched in. This technique is the easiest and best power consuming of antenna periods of fading and de-synchronization may occur while the quality of one antenna degrades and another antenna link is established.

The second one is selection of the signal from the transmitted by comparing and choosing the best signal to noise ratio had been taken by receiver.

The third one is combining; all antennas maintain established connections at all times. The signals are then combined and presented to the receiver and since all the receive paths must remain energized; it is also consuming the most power.

In this paper, there is no any implemented real data and only the theoretical study had done. It is necessary to implement simulation or data's had needed to compare the result. There is also no mathematically expressed comparison method.

As demonstrated in [16]Frequency diversity improvement factor determines the performance of diversity techniques and it defined as the ratio of outage percentage of time with specific fade margin to outage percentage with the same fade margin at the diversity frequency. In this paper, the improvement factor of frequency diversity had predicted and modeled from 5-40 GHz. The prediction technique had based on ITU-R and had used the measured rain rate. The improvement factor model had investigated according to the fade margin; the frequency separation used was 5GHz. The measured rain rate in Malaysia was118 mm/hr. at 0.01% had used to predict the specific rain attenuation for 5 to 40 GHz frequency band.

In the research work of ’Developing a frequency diversity models for rain fade mitigation Malaysia’ [1], In this paper the frequency diversity prediction models for rain fade mitigation from 5 up to 40 GHz was proposed and developed. This rain attenuation had predicted based on ITU-R rain attenuation of prediction method, using the measured rain rate of Malaysia.

In the paper, the estimated gains are not uniform along the frequency range of 5-40 GHz; hence, gain model had proposed for different frequency separation (5, 10, 15, 20 GHz) 0.001 to 1% outages. Another general model had proposed for any path length at 0.01% outage only. Therefore, the frequency diversity model is proposed. However, this model is limited to1km length only the proposed gain model are validated by comparing the measured rain attenuation data at 15, 23, 26, 38 GHz frequencies in UTM Skudai.

Another approach here the effect of the frequency separation, the outage percentage and the path length on the gain models are discussed. The effect of fade margin on the improvement factor had also investigated. In this research paper, the frequency diversity prediction models for rain fade mitigation from 5 up to 40 GHz was proposed and developed. This rain attenuation had predicted based on ITU-Rain attenuation prediction method by using the measured rain rate of Malaysia.

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‘Frequency Diversity Method in Reduction of Signal Fading on Wireless Communication Network in Nigeria’ [17], the reduction of signal fading using frequency diversity technique had presented. This system has two transmitter and two receivers. If there is a failure of signal on the transmitter, another transmitter will switched on automatically the signal will transmit with the second transmitter. By using MATLAB simulation, bit error rate and signal to noise ratio analyzed. According to this simulation comparison of theoretical transmission with frequency diversity technique had done.

The output of the simulation describes that effect of fading can be reduced by using diversity to transmit the signal over multiple. By using the same SNR, the maximum BER of theoretical transmission is 0.226368 and the maximum BER of frequency diversity is 0.093600. On the other hand, this research paper does not collect any real data from Nigeria instead, they only generated random signal, then by using combining method and calculated the bit error rate.

'Microwave Attenuation Studies Due to Rain for Communication Links Operating in Malaysia' [18]. This paper studies the rain attenuation of prediction models for the design of microwave terrestrial line-of-sight (LOS) systems and the results of this investigation in Malaysia. Here the rain attenuation model is predicted using MATLAB and PATHLOSS software. ITU-R Rec.530 Prediction model and Global Crane Prediction Model had used to model the rain attenuation by MATLAB prediction program of 'Rainsoft.m'.

The path loss software, which is from Contract Telecommunication Engineering (CTE), had used to measure the attenuation value of rain in the frequencies of microwave and it is used to investigate the effect of rain rate including the rain attenuation loss. This software has two working features, Microwave and VHF-UHF worksheet it also gives the rain prediction model of ITU-R 530 and Global Crane method.

The result of ITU-R Recommendation 530 Prediction model is in the frequency range of 4-400GHz with 99.99% link availability. This model is used to study which raindrop size distribution (RSD) is suitable to design the microwave link in Malaysia. The RSD proposed by Ajayi has estimated a much lower attenuation with respect to the Din and ITU predictions.

The same computation had studied for Global Crane prediction model for the frequency ranging 4 to 400 GHz with 99.99% link availability. The generated plots defined that the attenuation data using the RSDs proposed by Din and Ajayi, where almost aligned to each other with respect to attenuation result estimated from ITU-R RSDs.

The author finally compared the vertical polarization effect between the ITU-R Rec.530 and Global Crane Prediction Model using the attenuation vs frequency graph. The result is that the

Global Crane Prediction model predict a much higher attenuation compared to those predicted by using ITU-R Prediction Model. Although the two attenuation prediction models is computed based on the same propagation path length and the same RSDs, none of the prediction matches closely with each other.

The limitation of this paper is, only the attenuation prediction model had done and compared but it is better to investigate the mitigation technique for the predicted model.

In the paper ‘Application of Hybrid Diversity Techniques for Improvement of Microwave Radio Link Performance in Niger Delta Region’ [19], the microwave radio of link performance had improved by using both frequency and space diversity technique called hybrid diversity. In this paper measurements are obtained using the Barnett-Vigrant mathematical model at Path loss exponent of receive signal level (RSL), free space loss (FSL) and fade margin (FM) is examined for chosen antenna configuration for the selected microwave radio link. Here the proposed highest link availability values are FM = 40.52 dB, RSL = -45 dB and FSL = 140.48.

The separated path had developed by having two channels separated in frequency. These two paths are also had separated in space and time. This paper is select a radio link and presents the performance of hybrid diversity. The hybrid diversity technique is implemented by transmitting the transmit signal from the second frequency diversity path on the lower antenna at one end.

The space diversity arrangement can also provide full equipment redundancy (when automatically switched standby transmitters are used) but does not provide a separate end-to-end operational path. Space diversity requires additional antennas as compared to frequency diversity arrangement.

Since frequency diversity requires the use of two frequencies, this technique requires two transmitters and two receivers and space diversity technique has a single transmitting but multiple receiving antennas. Therefore, the system cost is high. The primary disadvantage of frequency diversity is that it doubles the amount of frequency spectrum required.

‘Prediction of Rain Attenuation and Impact of Rain in Wave Propagation at Microwave Frequency for Tropical Region (Uttarakhand, India)’ [20]. In (Uttarakhand) India, where excessive rainfall is a common phenomenon throughout the year and rainfall rate varies very much in small location over a small distance.

In this paper, exponential models where used to determine the attenuation level for k-region (India) which can be used for region having similar condition. The result had provided useful estimation of rainfall attenuation on microwave links in tropical regions. The analyzed predicted attenuation data had compared with ITU-R measured rain attenuation. The main aim of this research is to study the difference between measured rain attenuation in tropical Almora, Uttarakhand, India, and provide mitigation technique based on ITU-R predictions.

Methodology used: Calculation of Excess Path Attenuation, Long-term statistics of rain attenuation had evaluated for the location by using ITU-R coefficients and method, which had directly downloaded from ITU-R. Measurement of data had collected from different weather data collection center.

Converting Rainfall into Rain Rate: Since most of the data from weather data collection center had been available in millimeter (mm.) and rain attenuation was related to rain rate in mm/hr. rather than rainfall intensity in (mm), it is necessary to first convert the available rainfall data into rainfall rate. Divide the given data by observation time (10 min, 20 min, etc.) by using conversion equation of

$$R_D = L*60/T. \tag{2.1}$$

Where R_D is the rain rate in mm/hr. and L is the maximum rainfall in mm for time interval T min. The results had been using the specific attenuation method approach for prediction of rain attenuation on microwave links (frequencies 10 GHz, 20 GHz, 30 GHz, and 60 GHz) had evaluated using the 20-year rainfall data for Almora, Uttarakhand.

All observed graphs where plotted using MATLAB for the rainfall values taken from Indian Meteorological Department Pune (India) and attenuation values are calculated.

The calculated and the plotted graph describes that, the total atmospheric attenuation was very high as the rainfall rate for the location is high. For higher frequencies at higher rainfall rate, the total atmospheric attenuation increases constantly and can be very high and it increases constantly whereas rain attenuation after a limit starts to decrease.

Both predicted and measured values are the same, which shows that ITU-R model performs well for the low rainfall rate at low frequencies.

However, more tests and analysis needs to be do in order to validate the proposed measures for further understand. Their physical meaning and existence was apply the finding to search for ways of enhancing the system. Here only the level of attenuation and the impact of rain had studied in microwave communication, but it needs some mitigation technique.

'Estimation of rain attenuation based on ITU-R Model for Terrestrial link in Libya' [21]. This paper uses three terrestrial links in Libya. The rain rate exceeded for 0.01% was calculated and rain attenuation had obtained by changing the percentage of time exceedance. The distribution of rain rate ($R_{0.01}$) was obtain from ITU Recommendation by using ITU maps and data collected from local of three different sites and after that, values are compared. The result of this comparison was that, the specific attenuation obtained from local data is much greater by value of 2.2821 dB/km, 3.865 dB/km, and 4.882 dB/km than ITU map is much smaller than computed from for those of three cities.

From the simulation, the specific attenuation had determined by varying the frequency of operation and changing polarization of horizontal and vertical. A result of that, attenuation was increases according with the increasing of frequency above 10 GHz. The horizontal polarization had higher attenuation than vertical polarization.

However, frequency diversity was uses to combat all the three causes of unavailability, the failure of a receiver or transmitter does not cause an outage and during routine maintenance, the traffic can be forces onto one of the Transmitter/Receiver paths.

2.5. TV White Space

From ITU report, [22], TV white spaces (TVWS) are portions of spectrum left unused by broadcasting, also referred to as interleaved spectrum. Widely, TVWS are also referred to as those currently unoccupied portions of spectrum in the terrestrial television frequency bands in the VHF and UHF TV spectrum ‘‘TV white spaces in the Ultra High Frequency Television bands have been particular interest owing to the superior propagation characteristics as compared to the higher frequency bands.

The amount of available TV white space varies with location and time. TV broadcast services operate on the licensed Very High Frequency (VHF) and Ultra High Frequency (UHF) radio spectrum which have a favorable propagation and penetration characteristics and can cover a wide area with relatively small transmission power. In most cases, not those entire allocated spectrum had utilized efficiently due to different reasons. The part of allocated spectrum which is not used at a given time and geographic location is called TV white space (vacant spectrum).

In ‘Feasibility Study of TV White Space for Broadband Internet’ [2] , the scholar discusses the general availability of TVWS in Ethiopian and then he studied and investigated in Ethiopia. There is huge amount of TV white space availability, since currently maximum of four channels can be simultaneously used in anywhere in the county, but there is 21-29 channels are available in television frequency of ultra-high frequency (UHF) spectrum.

Finally, he proposed and recommended that TV white space is best option to provide communication service in Ethiopia. His recommendation for future work was, selecting specific area and to do detail analysis.

2.6. Fundamentals of Oscillator Design

The supply voltage is common for both inductor and capacitor. So that the resonance will takes place when voltage of inductor is equal to the negative of voltage of capacitor ($V_L = -V_C$). This will occur when the reactance's are equal ($X_L = X_C$) as shown figure below.

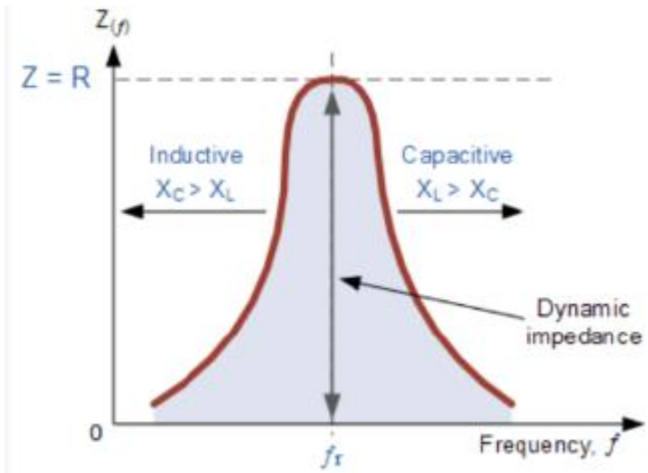


Figure 3. Oscillation at resonance frequency [23]

The Admittance of parallel circuit has given as:

$$Y = G + BL + BC \tag{2.2}$$

$$Y = 1/R + 1/j\omega L + j\omega C \tag{2.3}$$

At Oscillation or resonant frequency, $X_L = X_C$ and the total susceptance B (imaginary part of admittance) is zero so that, the Admittance is at its minimum and equal to Conductance.

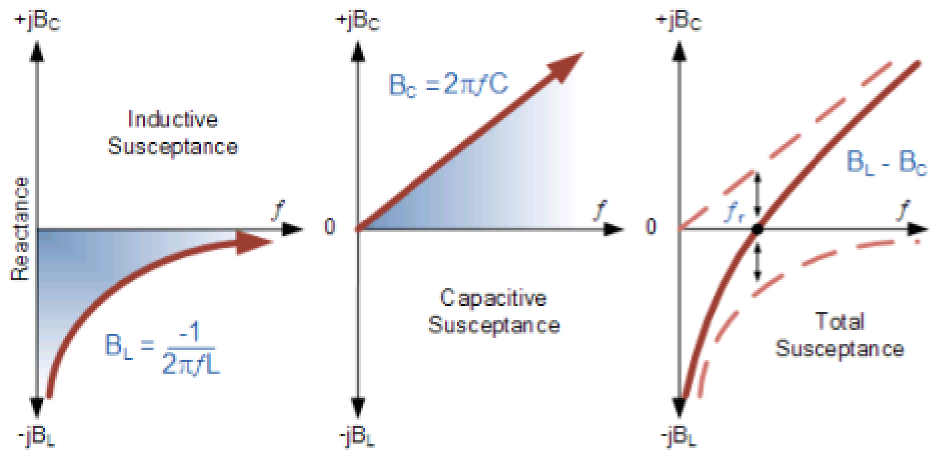


Figure 4. susceptance at resonance. [23]

From the above conditions that two oscillation criteria are [Left-Handed Resonator]:

Re{Z} > Mag(-R)

Im{Z} = 0

Where Z is the impedance of the tank.

The resonance frequency can be derived from the above reactance equation such that:

$X_L = X_C \Rightarrow 2\pi f L = 1/\pi f C$ (2.4)

$f^2 = 1/2\pi L * 2\pi C = 1/4\pi^2 LC$

$f_r = \mathbf{1/2\pi}\sqrt{LC}$ Hz or $\omega_r = 1/\sqrt{LC}$ (rads) (2.5)

The other important thing is Impedance (Z) of parallel resonator circuit. Here the impedance changes with oscillation frequency. At resonance, the impedance of parallel circuit is at its resistance vale, so that value represent the maximum impedance of the circuit. Therefore, we can calculate as,

$Z = L/RC$ (2.6)

2.6.1 LC Oscillator circuit

A simple oscillator is composed of a series or parallel LC tank or resonator and active device as shown in figure below.

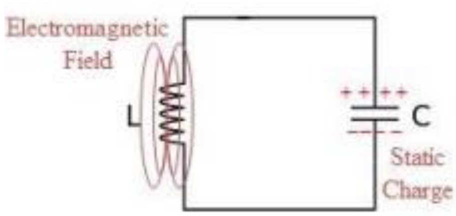


Figure 5. Electric and magnetic field of simple LC circuit. [6]

Oscillation will occur when energy stores in the electric field capacitor and the magnetic field of inductor. After that, energy will transfer back and forth constantly on both electric and magnetic field.

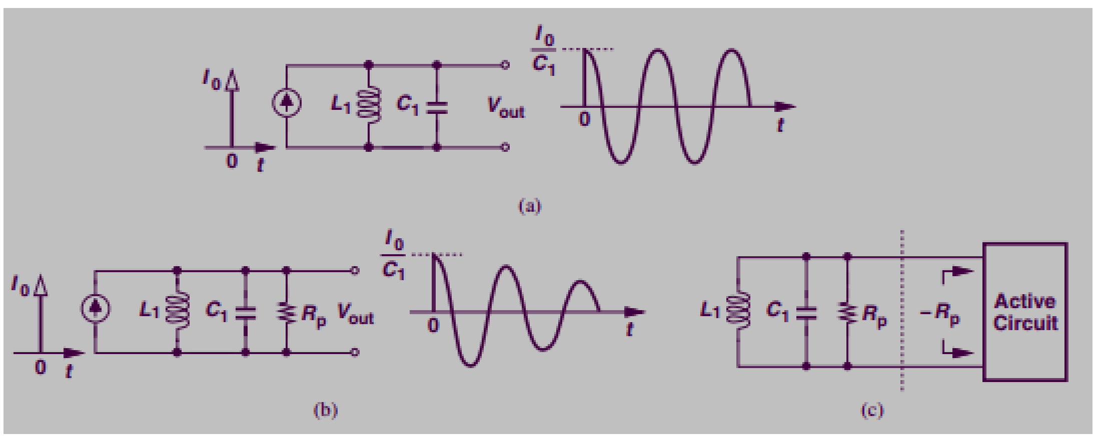


Figure 6. '(a) Response of an ideal tank to an impulse, (b) response of a lossy tank to an impulse. [8] on page,509.

The parallel negative resistance ($-R_P$) from the graph used to compensate the losses of the tank circuit. Parallel resistance (R_P) is the representation of combined losses of Inductor L1 and Capacitor C1. V_{out} is the peak voltage amplitude across the capacitance.

To resonate without any loss the parasitic resistance that comes from the inductor and capacitor must be compensate. A negative resistance will be from the active circuit, which will be cross-coupled transistors ($M_1$and M_2).

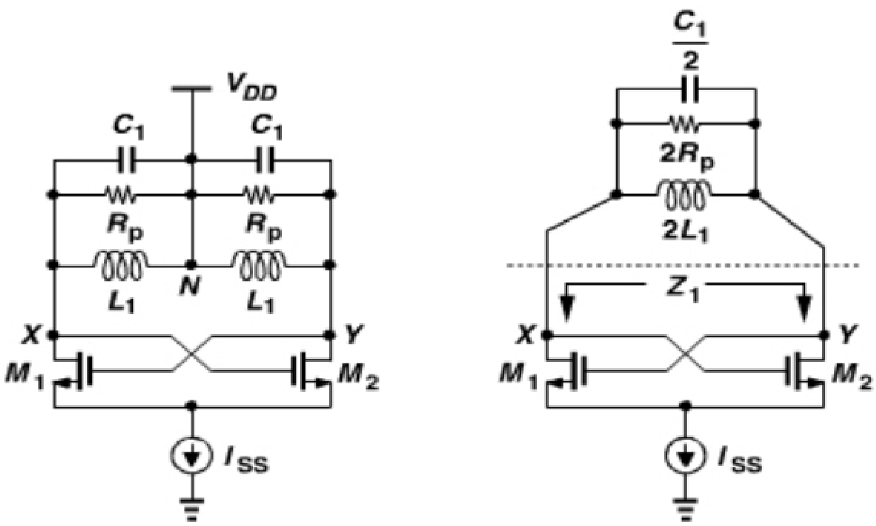


Figure 7. Cross-coupled LC resonator. [8]

2.6.2 Ring Oscillator

The ring oscillator was formed by using a number of delay stages which is the last stage of out-put is the in-put of the first stage [24]. For oscillation to occur the circuit have to provide a phase shift of 2π and must have voltage gain of unity at the oscillation frequency. As shown in the figure below the out-put of each stage X, Y and Z is a three delay stages acts as an amplifier. The expression of gain at [8] page, 507, is ‘With the high loop gain, the oscillation amplitude grow exponentially until the transistors enter the triode region at the peaks, thus lowering the gain’.

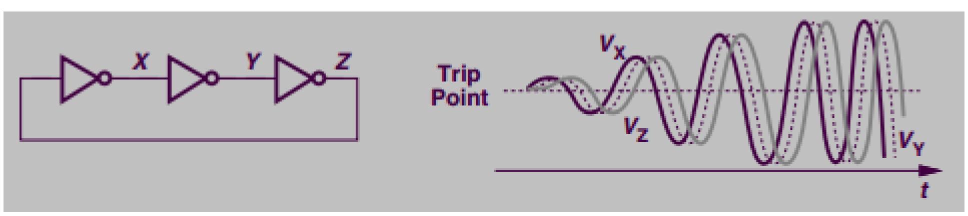


Figure 8. Ring oscillator and its waveforms [8]

The comparisons of LC oscillator and ring oscillator had done on the same paper based on major parameters, which is, the power consumption and phase noise characteristics. Therefore, LC oscillator has better noise characteristics than ring oscillator. However, ring oscillator has a good performance of power consumption. Because of less area on the chip, the ring oscillators are widely used on the real technology.

2.6.3 Basic Parameters of Oscillator Design

There are different basic parameters used in an oscillator for the case of performance measurement. Those parameters are frequency tuning range, oscillation frequency, power consumption and phase noise at a particular offset frequency. However most of the time, the major challenges occur on phase noise, and power dissipation.

Phase noise will occur when the oscillator deviates and disturb the zero crossing which is the integer multiples of period ($T_{C=}$ $2\pi/\omega_c$).

The figure below shows how the noise distributes on the time dome waveform. The second output of a waveform shows the effect of noise on the phase of signal.

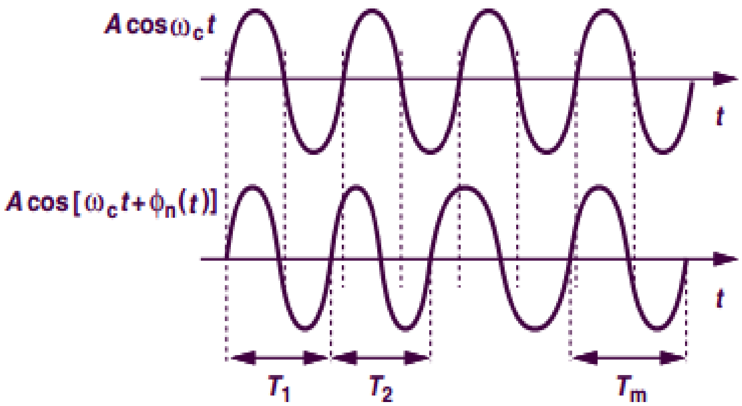


Figure 9. Output waveforms of an ideal and a noisy oscillator [25]

From the above discussion, the spectrum of the oscillator will depart from the center of frequency (ω_c). The differences, which the phase noise far from frequency of oscillation is, offset frequency (Δf).

The phase noise is how much noise density is relative to the carrier frequency it defined as the noise power normalized to carrier power and has a unit of dBc/Hz. The unit dBc refers to normalization of noise power to carrier power.

The power consumption of oscillator is determined by considering the quality factor (Q) of the circuit. In its simplest form, the quality factor, Q, indicates how close to ideal an energy-storing device is. As discussed on [26], an integrated resonators, the overall tank Q has normally dominated by the Q of the inductors. The design of high-Q inductors is a topic of the current research area. In the ideal capacitor, there is no dissipations of energy, it exhibits an infinite Q, but when there is a series resistance with capacitor, it reduces its quality factor. If a parallel resistance models the resistive loss in the capacitor, there will be loss of energy, because an ideal (infinite Q) results only if parallel resistance is equal to∞. In general, simulations are necessary to determine the behavior of complex lossy networks. Therefore, Q of the inductor dominates the total Q of the tank circuit. In addition, the tuning range of a VCO had strongly affected by the inductor. The figure below shows how Q of inductor had effect on oscillator design.

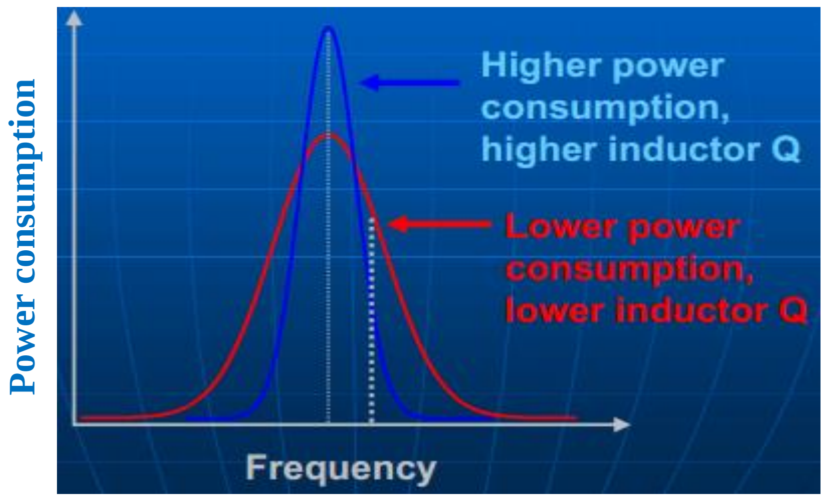


Figure 10. Power spectrum with Q of inductor [44]

A common performance measurement parameter, which is Figure of Merit (FOM) formula, includes both power consumption and phase noise at a specific offset frequency, can express overall performance overall performance. The formula from [27] expressed as equation below.

$$FOM = PN - 20\log\left(\frac{f_0}{\Delta f}\right) + 10\log\left(\frac{P_{diss}}{1mW}\right) \tag{2.7}$$

2.7. Voltage Control Oscillator (VCO)

'Voltage Controlled Oscillators (VCO) are an integral part of Radio Frequency (RF) transceivers and fully integrated dual band VCO's play an important role in dual-band transceivers required for multifunction services' [28]. The local oscillator of transceiver must be tunable with a certain frequency range. The voltage control oscillator is used to tune the frequency by varying the supply voltage or electronically. From the expression of [29] , Voltage-Controlled-Oscillators (VCO) are one of the key building blocks of frequency synthesizers and they are usually classified in two families: harmonic (LC based) and relaxation oscillators (ring-based)'.

Therefore, as the name indicates the input voltage will control the frequency of oscillation by changing from ω1 to ω2 as the control voltage goes from V1 to V2. The mathematical characteristics of the output frequency expressed as

$$\omega_{out} = K_{VCO}\, V_{cont} + \omega_o \qquad (2.8)$$

where ω_{out} : output frequency.

K_{VCO}: The gain or sensitivity of VCO expressed in rad/Hz/V.

ω_o : The intercept point on the vertical axis.

As expressed in [25], 'it is desirable that this characteristic be relatively linear, i.e., K_{VCO} not change significantly across the tuning range'. The following figure shows the above characteristics.

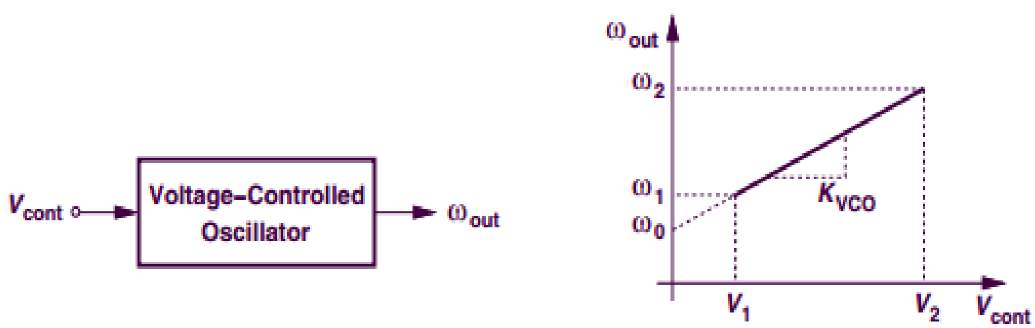


Figure 11.VCO characteristic [25]

2.7.1 Type of VCOs

A VCO is typically implemented by use of a LC tank but the LC tank/resonator does not oscillate indefinitely by itself since the energy stored within inductor and varactor gets dissipated in their equivalent resistive losses in every cycle. This resonator circuit must entail a self-sustaining mechanism that allows its own noise to grow and become a periodic signal and then maintain oscillations by compensating the losses in the tank. Therefore, choosing proper topology of oscillator is mandatory to achieve optimum performance. The most frequently used topologies in the area of high-speed electrons are LC resonator, Colpitts, and ring oscillators.

Based on types of waveforms produced, there are two types of VCO:
Harmonic oscillator: this type of oscillator generates a sinusoidal waveform. It consists of an amplifier, which provides adequate gain and a resonant circuit that feeds back signal to the input. Oscillation occurs at the resonant frequency where a positive gain arises around the loop. Some examples of harmonic oscillators are crystal oscillators and LC-tank oscillators.
Relaxation oscillator: This kind of oscillators are able to generate saw tooth or triangular waveform. These can provide a wide range of operational frequency with minimum external components. Relaxation oscillator VCOs can have three topologies: grounded-capacitor VCOs, emitter-coupled VCOs, and delay-based ring VCOs. The amount of time in each state depends on the time for a current to charge or discharge a capacitor.
Harmonic oscillators are better than relaxation oscillators in some following aspects:-

- Frequency stability with respect to temperature, noise, and power supply.
- A crystal or tank circuit controls the accuracy of frequency.

2.7.2 Techniques of Dual Band VCO

Traditionally multiplexing different sources on a chip was widely implemented to cover wide range of frequency. However, in higher frequencies, multiplexing gives bad result of output characteristics of high phase noise, high power utility and wide area. In general, there are four methods used for the case of switching technique.

According [30] 'One way to improve design economics in the multi-VCO requirement is to employ band switching in the VCO. If the frequency switching required isn't very large (say within 20%), it may commonly be realized within the same tank circuit, by switching "on" or "off" an additional capacitor or inductor. However, if the required switching is more than 30%, it becomes very difficult to satisfy both wideband and low noise requirements in a single design.

The first popular method is switching capacitor or inductor [31], [32], [33]. In this case, the value of a single-resonance resonator's capacitance or inductance changes the oscillation frequency. The capacitor of the tank will directly connect with the switch. So that the parasitic capacitance of switch will decrease the quality factor of oscillator. The second method works by making switched oscillator and the third technique uses switching varactor, 'a dual-band oscillator using a novel varactor-switching mode technique, where no switched current source or switched MOSFET is used and the capacitance of varactor can be used to switch the common(even) and differential (odd) mode for different frequency outputs' [34]. The fourth method is the mode selection or switching of differential and common mode of different oscillation frequencies. The switching element of this oscillator is either current source or MOSFET. Here we can get different oscillation frequencies of differential and common mode single resonance resonator.

2.7.3 Tuning devices (Varactor)

The oscillation frequency easily will change by varying the value of reactive elements. As we know that the capacitances of active devices can be changed by varying the gate and/or drain voltage.

The design, characterization, and modeling of the varactors significantly affect the overall performance of the LC VCO. Varactors are a very important part of resonator. Varactors where used for the tuning purpose of frequency band. Tuning range of oscillator had determined by Varactor capacitor, as expressed in [35], the range of the varying capacitor from maximum capacitor value to minimum capacitor determines the range of frequency of oscillation. Tuning of frequency had implemented by varying the input voltage of the capacitor. Therefore, a capacitor is a voltage dependent device. The value of maximum and minimum value of capacitance of varactor and the quality factor of varactor from parasitic of series resistance with capacitor are a major parameter of varactor [30].

2.7.3.1 Fundamental properties of varactors

A varactor is a specially designed P-N junction diode, whose capacitance changes significantly in reverse bias mode. There are three important parameters characterizing varactors. The first is the capacitance ratio at two reverse voltages; this value characterizes the tuning ability of the varactor capacitance and is one of the most important parameters. The second is the value of capacitance at a given voltage. The third is the series resistance of the varactor.

The varactor diode used for tuning has a predominant effect on the Q, phase noise and tuning range of the resonator. As discussed in [36], Varactors are sources of variable capacitances, and are used as frequency tuning elements in the LC-tank VCOs. One option when tuning the LC-tank VCOs, is to use a reverse biased p-n junction varactor. However, this varactor does not scale with technology, and suffers from low Cmax/Cmin, limiting the available frequency tuning range. In addition, there is the possibility that the p-n junction varactor may become forward biased with large-amplitude swings, leading to additional losses in the circuits.

When an external voltage source is connected to the diode in reverse-bias (with the negative side of the volt-age source connected to the diode P layer and the positive side of the voltage source connected to the N layer) the thickness of the depletion layer increases. As the external voltage magnitude is increased, the depletion layer thick-ness also increases until one of two breakdown effects occurs. The voltage at which breakdown occurs is called "breakdown voltage," V_B or V_{BR}.

From the description of the PN junction and its depletion layer, it should be clear that a PN junction meets the definition of a capacitor: two conductors separated by dielectric. The portions of the doped P and N layers that are not included within the depletion layer can be considered conductors. The depletion layer is free of charge carriers, so it forms a nearly ideal dielectric. The distance that separates the two conductors is controlled by the magnitude and polarity of the bias voltage, as well as by the doping concentration of the n layer.

Virtually all varactor diodes are constructed with circular top contacts, so the varactor diode is modeled as a cylindrical section composed of three sections: P layer, dielectric layer and N layer. Then, the capacitance of the diode is vary with reverse biased voltage.

Another well known varactor readily available in CMOS technology, is the MOS transistor itself. An NMOS varactor consisting of a thin oxide layer, a top metal contact representing the poly gate, and a P-doped substrate. A second metal layer forms an ohmic contact to the bulk of the semiconductor.

The capacitance vs. area ratio is higher for the MOS-type varactor than the p-n junction varactor, resulting in higher capacitance tuning ranges. The MOS-varactors are also showing strong capacitance variation within a few hundreds of milli-volts, making them useful for low power operating circuits.

The maximum tuning of capacitive range can be defined by the formula of:

$$T_v = C_{vmax}/C_{vmin} \qquad (2.9)$$

Where the maximum and minimum values of Cv are denoted by C_{vmax} and C_{vmin} respectively. The tuning range can be estimated based on the resonance frequency of resonator is expressed as:

$$\omega = 1/\sqrt{L.Cv}$$

In the ideal case, the tuning range can be calculated by:

$$\Delta\,\omega = 1/\sqrt{L.Cvmax} - 1/\sqrt{L.Cvmin} \qquad (2.10)$$

2.7.4 Active Device

The resonator needs enough negative resistance at each resonance frequency to start an oscillation. As described in [26], a standard approach for differential VCOs is the use of cross-coupled transistors to generate a negative resistance sufficient to overcome the equivalent parallel resistance of the VCO tank circuit.

Therefore, the solution to reduce the parasitic capacitances associated to inductor and varactor is allowing to accommodate core transistors with sufficient width. To reduce the parasitic capacitance (i.e. the capacitance to substrate) of inductor and varactor the layout of each has been optimized.

As the capacitance of transistors is comparable to or larger than that from the varactors, so the parasitic capacitance of the transistor are also minimized. It is done by making the metal interconnection between the two transistors shorter or by directly cross connecting the drain to gate. Hence reducing the loss and parasitic capacitance of the interconnects. These techniques were utilized to realize either low phase noise or a wide tuning VCOs CMOS technology.

2.8. Recent Works on VCO

As defined on [24], 'A voltage controlled oscillator (VCO) is the most important part in analog and digital communication systems'. In the design of this paper, a single LC VCO provides minimum power consumption of 7.59 mW at 32 nm CMOS technology and also it has a phase noise of -85 dBc/Hz @10MHz. This VCO has an oscillation frequency of near 100GHz, which is a high operating frequency. The components of active devise such as CMOS transistors had used to compensate the losses of designed tank circuit. Here, negative resistance must cancel out by the parasitic resistances, which comes from inductor and capacitor. The negative resistance was connects the cross-coupled transistors to the tank. The negative resistance had created which, had the equal value of conductance with transistors trans-conductance.

In this higher frequency of operation, the tuning range starts from 91.8 to 97.4 GHz. In this designed oscillator, the output power varies between -4 and -8 dBm over the tuning frequency range. Here with a forth order LC resonator, the high speed of VCO on a CMOS technology had attained.

Finally comparison with other designed oscillators had done. From other higher frequency of operation the performance characteristics of [24], had better than others did.

A dual band oscillator was designed and simulated. VCO had used to tune the frequency of 51.6 GHz to 64.6 GHz. The transformers inductor was uses for tuning of frequency. Therefore, dual band had obtained by making ON and OFF condition of the switch. The input voltage was controls the frequency of oscillation by changing from zero to one V. The major drawback of this oscillator is that phase noise contribution by multiple MOS switch. When one MOS switch is ON/OFF and gate biasing of another MOS switch is changing from 0 V to 1 V lower band and upper band of frequency from 51.6 GHz to 58.4 GHz and 58.3 GHz to 64.6 GHz respectively is obtained [27].

The left-handed (LH) resonator was uses to generate dual band of higher carrier frequencies. The circuit of LH resonator consists of a series capacitor and shunt inductor. Therefore, the output characteristic becomes nonlinear. LH Transmission Line (TL) can easily build using multiple sages of LH unit cell, which has good feature compared with RH TL [37].

In the paper [28], a VCO had designed for 5 GHz and 12GHz frequency band. The frequencies had selected by controlling bias of varactor rather than switched capacitor. This design also uses a common LC resonator for both higher and lower frequency of oscillation. The tuning ranges of the oscillation frequency versus varactor control voltage (V_{tune}) which was tunes from (0 to 1 V). This oscillator had implemented in 0.18µm CMOS technology. It also have a dual resonant frequency of operation.

The output tuning range of operation was between 4.78–5.19 GHz and 12.19–12.61 GHz and the phase noise was -117.16 dBc/Hz and -112.15 dBc/Hz at 1 MHz offset, respectively. The power consumption at the lower frequency of operation and the higher frequency of operation had 3.2/2.72 mA and 2.56/2.18 mW respectively, by supply of 0.8V.

The limitation of this oscillator is the frequency tuning of the VCO is performed by varying the capacitance or inductance, and conventional tuning by varactors does not have a sufficient tuning range because of the limitations of the varactor capacitor ratio (Cmax/Cmin).

CHAPTER THREE

MATERIALS AND METHODS

In this research, data collection, analysis, design and simulation was implemented according to the flow lists of below.

3.1. Methods of Data Collection

The research methods used in this study was based on the quantitative data available at literature review, climate data on concerned locations in Ethiopia. According to the requirement of the design type and data analysis technique used in this research, a literature reviews had taken as one of the secondary data source.

The second data was collected based on International Telecommunication Union (ITU) recommendation; a minimum of one-year of one-minute rain data is required for the calculation of rain attenuation. ITU recommends that, if one-minute rain data is not available on the local area, the data estimation can obtained from the recommendation of [38]. In this recommendation, the rain data must be the conversion of one-minute rain rate, which measured on mm/hr. Otherwise the collected data should have to be measure by automatically in one-minute interval.

According to this recommendation, a one-minute integration time of rain rate data collected from Jimma experimental measurements of rainfall, from a Davis Vantage weather station installed at Jimma University, Ethiopia.

3.2. Methods of Data Analysis

In this research, all attenuation calculations regarding rain data analysis and calculating rain fade is depends on the ITU-Recommendation methods. As recommended on [38] , the first step of rain data analysis is obtaining rain rate of R0.01 exceeded for 0.01% of time, which is one-minute integration time.

3.2.1. Calculation methods of rain rate exceeded at 1-minute percent of time.

The cumulative frequency of rain data is a very important parameter to find one-minute exceedance. It has obtained by collecting all one-year data and then leaving all zeros from the collected data. After that, the exceedance of one minute determined by the formula [39]:

$$\text{Exceedance (R0.01)} = \frac{C.F*100*T}{Nd*24*60}. \tag{3.1}$$

Where C.F: Cumulative Frequency, which determines the cumulative frequency of each rain rate starting from cumulative of lower frequency rain rate to higher frequency rate.

Nd: A number of days in a year

T: Measured period of interval, which is a taken measurement period of interval (like 1min, 15min, or 60min).

3.1.2 Steps of Rain Fade Calculation method

The rain attenuation of microwave frequencies above 10 GHz will obtained by using ITU-Recommendation [3]. Rain fades vary with frequency, location, polarization and rainfall rate. As discussed in [38] the attenuation of frequency of microwave below 5 GHz can ignored. Attenuation will affect frequencies above 5 GHz. The long-term depth of fade in dB can calculated from the long-term rain data and according to Rec. ITU-R P.530-17.

However as described in [40] the drops of rain have a length arrangement during the fall, their alignment of revolution being vertical, the fade differs according to whether the wave is horizontally or vertically polarized. It appears, in the course of spread of signal or propagation, as a component whose polarization is orthogonal to the expected polarization due to a phenomenon named as cross - polarization.

To calculate the rain attenuation we need to know:

- Distance of the microwave station in Km.
- The frequency of operation.
- The polarization of the signal

The first step is computing R0.01 exceeded for 0.01% of time, which is one-minute integration time measured in mm/hr.

The second step is finding specific attenuation (ϒ) in dB/Km for the specific frequency of operation, polarization, rain rate of interest using recommendation of [41].

The third step can be computing D_{eff} of microwave link, which can calculated by multiplying actual link distance (d) by a distance factor r. The formula of distance factor r is

Given by, [38] :

$$r = \frac{1}{0.477 d^{0.633} R_{0.01}^{0.073 \cdot \alpha} f^{0.123} - 10.579(1 - \exp(-0.024 d))} \tag{3.2}$$

Where $R_{0.01}$ is rain rate exceeded for 0.01% of the time.

α is regression coefficients of vertical polarization of specific frequency.

f is operating frequency.

d is actual link distance.

The fourth step can be computing attenuation exceeded for 0.01% of time, which has given by:

$$A = \Upsilon * D_{eff} \tag{3.3}$$

Where:

A is the rain loss in dB

ϒ is the specific attenuation (dB/Km).

D_{eff} is the effective path length through the troposphere in Km.

The final step is determining the received signal level which can be expressed by signal to noise ratio (SNR).

The received signal level is calculated by [10]:

Pr = Pt + Grx + Gtx – Lsys – Lfs (dB) (3.4)

Where, P_t is the transmitter power output at the antenna input. This is the amount of microwave carrier output power, usually expressed in dBm. Pr is received power, Grx is gain of receiver, Gtx = gain of transmitter, Lsys is system loss and Lfs is free space loss.

The performance of a radio link is determined by the percentage of the time the signal will be below the threshold of the radio receiver relative to the total time period. Therefore, the fade margin, which is the difference between the receiver nominal signal level and the receiver threshold level, has to be calculated by Fade margin (FM) = Pr - Rxth

The performance of a communication system is estimated based on the achievable signal to noise ratio (SNR) at receiver.

Therefore, SNR is given by the equation of:

$$S/N = \frac{\mathrm{Pt}*\mathrm{Gt}*\mathrm{Grx}}{KTBLsys}\left(\frac{\lambda o}{4\pi d}\right)^2 \tag{3.5}$$

The received power can also expressed as:

$$Pr= \frac{\mathrm{Pt}*\mathrm{Gt}*\mathrm{Grx}}{Lsys}\left(\frac{\lambda o}{4\pi d}\right)^2 \tag{3.6}$$

Where K = Boltzmann's constant is equal to $1.38*10^{-23}$ J/K, B = bandwidth of link (Hz), d is link distance (m) and T is the system effective noise temperature (K) which is equal to 290 K. To find SNR, we don't need to calculate the above equation of 3.5 and 3.6, all λ and temperature are included in the free space loss. So that SNR calculated easily as:

SNR = Pr-10log(BW)/Hz + 174 (dBm).

3.3. Methods of Oscillator Design

As discussed on the literature part, oscillator design method needs to focus on different performance parameters. Therefore, this part mainly considered on necessary conditions of oscillator. The design was started by selecting resonator structure. After that understanding and calculating of the major source of the parasitic resistance value of the tank and how to generate, the negative conductance, which, will compromise the loss of the tank.

3.3.1 Necessary Conditions on Oscillator Design

The resonator circuit must entail a self-sustaining mechanism that allows its own noise to grow and become a periodic signal and then maintain oscillations by compensating the losses in the tank. The next section describes the way of representing an oscillator circuit. There is one-port model circuit [42], has shown in Figure 12 below.

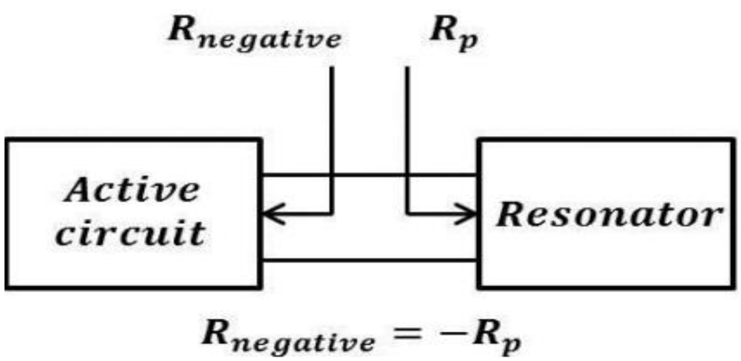


Figure 12. One-port model [42]

As mentioned above, a LC resonator does not oscillate indefinitely. The oscillations are sustained by providing sufficient negative resistance ($R_{negative}$) to cancel the losses of the resonator. An active network is needed to generate this negative resistance, so that the equivalent parallel resistance (Rp) seen by lossless resonator is infinite.

The 2-ports representation of a LC oscillator is shown in Figure below (a) with a typical schematic realization of such VCO shown in (b), where NMOS transistor M1-M2 provides negative resistance to compensate the losses of the tank. As shown in (a), the open loop gain of active circuit is given by equation below,

$G(j\omega_o)*H(j\omega_o) = G_m *Z(j\omega_o)$ (3.7)

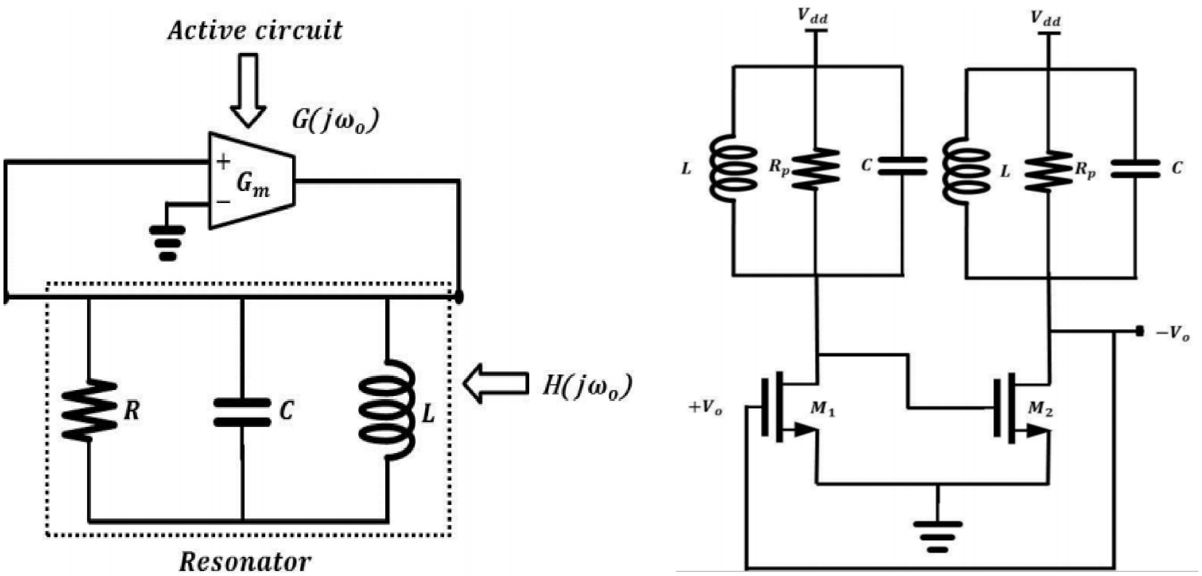


Figure 13. LC oscillator (a) General structure and (b) Schematic [42]

Therefore according to Barkhausen criteria, $|Gm.Z(j\omega)| = Gm.R > 1$and phase shift around the loop is zero or integer multiple of 2π. Such that $<Gm.Z(j\omega) = 0^o \pm 2\pi n$. As with single stage, common source amplifier gives a phase shift of 180°, so it is not possible to attain oscillation. Hence, two stage of common source amplifier are connected in series in feedback loop, as shown in Figure 13 above (b). So the condition of oscillation is as given by equation 3.8 below.

$|Gm.Z(j\omega)|^2 = (Gm.R_p)^2 \geq 1$ and $Gm.R_p > 1$ (3.8)

3.3.2. Design Techniques

The oscillator designing technique is one of the major challenge. However, in this design some consideration had taken to solve. The major designing considerations of oscillator was based on the key parameters, such as power consumption, phase noise, tuning range.

3.3.2.1 Generally Considered Design procedure

According to tuning techniques and phase noise issues, some procedure for the design of LC VCOs is as listed below. This research focuses first on the topology of taken and assuming the following parameters are given: the center frequency for both higher and lower both band. According to [25], it is recommended to select reasonable values of Output power, output voltage, and iterate if necessary. Of course, the output swing must be chosen so as not to stress the transistors.

The procedure consists of the following steps:

- Based on the power budget and hence the maximum allowable I_{SS}, select the tank parallel resistance, Rp, so as to obtain the required voltage swing, $(4/\pi)I_{SS}Rp$.
- Select the smallest inductor value that yields a parallel resistance of Rp at ω_o, i.e., find the inductor with the maximum $Q = Rp/(L\omega_o)$. (3.9)
- Determine the dimensions of M1 and M2 such that they experience nearly complete switching with the given voltage swings. To minimize their capacitance contributions, choose minimum channel length for the transistors.
- Calculate the value of varactor capacitance, that can be added to reach the lower and of the tuning range.
- Calculate the varactor Q and if the varactor Q is high enough, such a design also has the highest tank Q. At this point, calculate or simulate the phase noise for different frequencies across the tuning rang.

3.3.2.2 Switching Method

A switching network is used to select one oscillation frequency and switched off others frequency of oscillator. Therefore, this technique based on mode selection, which is even, and odd resonant mode.

Mode switching between differential mode at low frequency and common mode at high frequency. The differential mode means that voltages appearing at two tank ports have opposite polarities and the common mode, the same polarities. Mode switching allows the VCO to operate at two resonant frequencies with a single LC tank [43].

There have been two means to switch. One is a regenerative multiplication method, in which a frequency divider or a multiplier is used to obtain another band other than fundamental band of a given VCO [33], [32] . The frequency band is determined by dividing or multiplying ratio. However, this entails additional circuitries that are not used to generate a carrier signal, causing large power consumption. The other is a switched-capacitor method, which is more frequently used in lower frequency than GHz-regime [31]. It employs a capacitor with a series connected switch, which controls the capacitance of a LC tank.

3.3.2.3. Oscillation Condition

A parallel LC resonant circuit stores energy both in the magnetic and electric field by inductor and capacitor respectively. Therefore, the stored energy will transfer constantly back and forth between those two fields.

The setup to allow the tuner to change the state of the swept voltage source. Tune on the left "Vdc" parameter and watch the phase noise change slightly.

Oscillation occurs in parallel LC circuit when the current of the circuit is in-phase with the supply voltage and the components of the two reactive circuits are cancel each other. At resonance, as expressed in chapter-three the admittance of the circuit becomes its minimum value and equal to the conductance of the circuit.

This oscillator consists of two parts: an LC resonator and a trans-conductance network. In order to vary the frequency of an LC oscillator, the resonance frequency of its tank(s) must be varied. Since it is difficult to vary the inductance electronically [25].

The two resonant modes are: an even mode and an odd mode.

In even mode, the two LC tanks resonate in phase,

$$F_{resonant} = ½\,\pi\,\sqrt{LC}\ \text{(GHz)} \tag{3.10}$$

Where L is inductor (nH) and C is Capacitor (pF)

Odd mode: In this case, the two *LC* tanks are 180 out of phase, therefore the capacitor sees differential voltage at its two terminals. So that we can get the equivalent capacitors which consists of two *LC* tanks. Thus, the resonant frequency calculated by:

$$F_{resonant} = 1/2\,\pi\,\sqrt{L(C + 2Cs)} \tag{3.11}$$

3.3.3 Choice of VCO active device

It is possible to use both bipolar devices and FETs within a VCO, using the same basic circuit topologies. The bipolar transistor has a low input impedance and is current driven, while the FET has a high input impedance and is voltage driven. The high input impedance of the FET is able to better maintain the Q of the tuned circuit and this should give a better level of performance in terms of the phase noise performance where the maintenance of the Q of the tuned circuit is a key factor in the reduction of phase noise.

Another major factor is the flicker noise generated by the devices. Oscillators are highly non-linear circuits and as a result the flicker noise is modulated onto VCO as sidebands and this manifests itself as phase noise. In general, bipolar transistors offer a lower level of flicker noise and as a result VCOs based around them offer a superior phase noise performance.

3.3.2 Performance Parameters of Oscillator

3.3.2.1 Quality Factor (Q)

The quality factor relates the maximum or peak energy stored in the circuit (the reactance) to the energy dissipated (the resistance) during each cycle of oscillation meaning that it is a ratio of resonant frequency to bandwidth and the higher the circuit Q, the smaller the bandwidth. The quality factor of the tank calculated as:

$$\text{Bandwidth (BW)} = \frac{f\text{r}}{Q\ of\ tank} \qquad (3.12)$$

Where f_r is resonant frequency and BW is band width.

Inductive reactance (X_L) at resonance frequency is given below and quality factor(Q) of inductor determined.

$$X_L = 2\pi f L \qquad (3.13)$$

$$\text{Quality factor of inductor } (Q_L) = \frac{\boldsymbol{R}}{\boldsymbol{x_L}} = 2\,\frac{\boldsymbol{R}}{\boldsymbol{2\pi f X_L}} \qquad (3.14)$$

The higher and lower frequency band will be

$$f_{\text{H}} = f\text{r} - + \frac{1}{2}\text{BW} \qquad (3.15)$$

$f_{H} = f r + \frac{1}{2} BW$

On the other side, quality factor describes the relationship of the energy stored of ideal circuits and the designed one. Therefore, ‘In its simplest form, the quality factor indicates how close to ideal energy storing device is’ [25]

The series resistance R_S reduces the Q of the circuit, so that

$$Q_S = 1/C\omega / R_S. \tag{3.16}$$

If the loss capacitor is the parallel resistive loss, Q is defined as:

$$Q_P = R_P / 1/C\omega \tag{3.17}$$

Similarly applying for inductors

$$Q_S = L\omega/R_S \tag{3.18}$$

$$Q_P = R_P/L\omega \tag{3.19}$$

From the relation of the Q-factor of inductor and Q-factor of capacitor, the Q-factor of parallel resonance circuit is inverse relation with the series circuit.

The Q of capacitor in [8], is typically higher than for inductor. That is the reason why usually the Q- factor in resonators and matching networks are determined by the inductor rather than capacitor performance. Therefore, the Q of resonator has significant impact on the noise and must be kept as high as possible. At low to moderate frequencies, the Q-Factor of resonator has clearly determined by the inductor in the resonator requiring lots of turns and large area. Thus, inductor exhibits significant resistive losses associated with the large series of resistance of lines and the coupling to the lossy substrate.

3.3.2.2 Phase Noise

Phase noise will occur when the oscillator deviates and disturb the zero crossing which is the integer multiples of period ($T_{C} = 2\pi/\omega_c$).

Let define in mathematical expression:

$$x(t) = A \cos \omega_c t: \tag{3.20}$$

It is ideal perfect periodic output. When noise added on phase the equation will rewritten to:

$$x(t) = A\cos[\omega_c t + \Phi n(t)], \tag{3.21}$$

where $\Phi n(t)$ is the quantity of added random phase noise.

3.3.2.2.1 Measuement of Phase Noise L(f) dBc/Hz

There are two sources of phase noise influencing the wireless receiver circuit:

- Extrinsic noise - Noise from other circuits
- Intrinsic noise - Noise due to the VCO circuit.

In this work the VCO noise (Intrinsic noise) discussed in detail, but Calculating phase noise by hand is very complicated. It is very easy to simulate on Radio frequency (RF) design simulators. Therefore, let us describe some techniques as much as possible in accordance with the design. In the designed oscillator, band-switching circuit has designed without affecting the phase noise of performance.

The output phase noise spectrum expressed by Leeson's formula.

$$L(\Delta f) = 10\, log \frac{Spectral\ dencity\ of\ noise}{Power\ of\ carrier} \tag{3.22}$$

$$L(\Delta f) = 10 \log \frac{Spectral\ dencity\ of\ noise(\Delta f)}{Power\ of\ signal} \text{ in dBc/Hz} \tag{3.23}$$

Phase noise in VCO derives from two categories, noise from active device and noise from the tank.

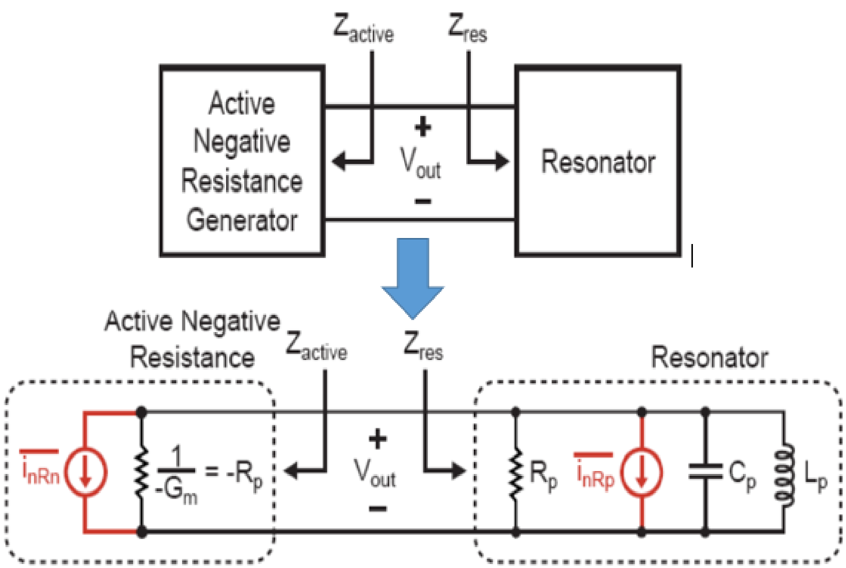


Figure 14. Calculation of Intrinsic Phase Noise in Oscillators [44]

The negative resistance of active device from above figure uses to cancel the energy loss that comes from oscillator. To calculate the impedance of the LC resonance at ω, consider the parallel circuit below:

$$Z_{tank}(\omega) = \frac{1}{j\omega C_p} \| j\omega L_P = \frac{j\omega L_P}{1-\omega 2 L_p C_p} \qquad (3.24)$$

$\omega = \omega_o + \Delta\omega$, Where ω_o is the resonance frequency which is equal to $\frac{1}{\sqrt{LpCp}}$.

$$Z_{tank}(\Delta\omega) = \frac{j(\omega o + \Delta\omega)L_P}{1-(\omega o + \Delta\omega)2 L_P C_P} \qquad (3.25)$$

Simplifying the equation and neglecting $\Delta\omega^2 L_P C_P$ and making $1-\omega^2 L_P C_P$ = zero, $Z_{tank}(\Delta\omega)$ becomes $-\frac{j}{2}\frac{Rp}{\omega o Cp}\left(\frac{\omega o}{\Delta\omega}\right)$

The loss of parallel LC tank has modeled according to Q –function:

$$Q = R_P \omega_o C_P \quad \Rightarrow \quad \frac{1}{\omega o Cp} = \frac{Rp}{Q} \qquad (3.26)$$

$$\text{Therefore } Z_{tank}(\Delta\omega) = -\frac{j}{2}\frac{Rp}{Q}\left(\frac{\omega o}{\Delta\omega}\right) \qquad (3.27)$$

$$|Z_{tank}(\Delta f)|^2 \approx \left(\frac{Rp}{2Q}\frac{fo}{\Delta f}\right)^2 \qquad (3.28)$$

The overall noise of output spectral density derived by assuming the noise of active device and noise of the tank.

$$\frac{v^2 out}{\Delta f} = \left(\frac{i^2 nRp}{\Delta f} + \frac{i^2 nRn}{\Delta f}\right) |\, Z_{tank}\,(\Delta f)\,|^2 \;=\; \frac{i^2 nRp}{\Delta f}\left(1+\frac{i^2 nRn}{\Delta f} \Big/ \frac{i^2 nRp}{\Delta f}\right) |\, Z_{tank}\,(\Delta f)\,|^2 \qquad (3.29)$$

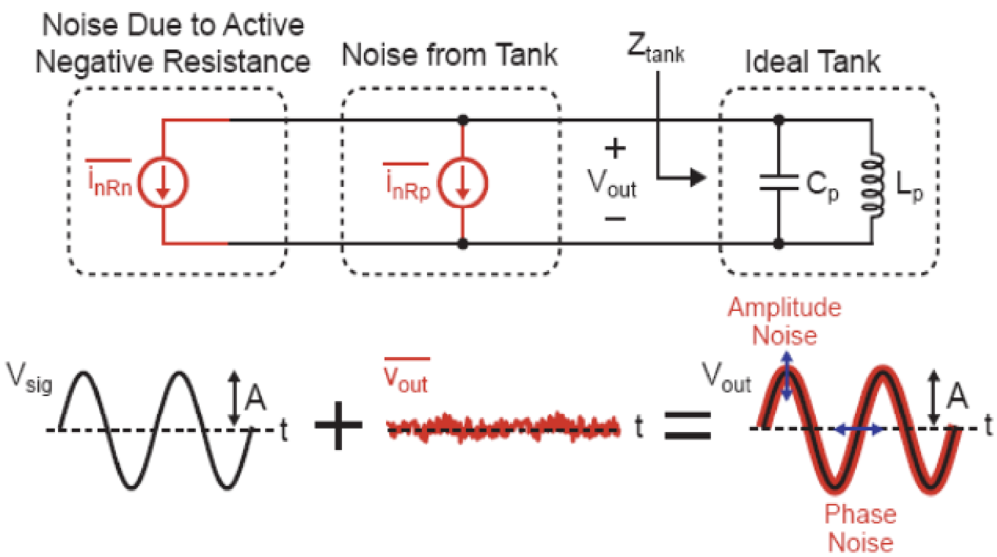


Figure 15. Separation into Amplitude and Phase Noise. [44]

The above graph represents both the magnitude and phase noise that have overall impact on the oscillator but as discussed in above section the oscillators amplitude noise suppressed by feedback. Therefore from the above equation:

$$F(\Delta f) = \frac{Total\ noise\ in\ tank\ at\ frequency\ of\ \Delta f}{Nose\ in\ tank\ due\ to\ tank\ loss\ at\ frequency\ \Delta f} = 1+\frac{i^2 nRn}{\Delta f} \Big/ \frac{i^2 nRp}{\Delta f} \qquad (3.30)$$

The above equation becomes:

$$\frac{v^2 out}{\Delta f} = \frac{i^2 nRp}{\Delta f}\,(F(\Delta f))\, |\, Z_{tank}\,(\Delta f)\,|^2$$

Inserting the noise from tank due to parallel resistor (R_P), $\frac{i^2 nRp}{\Delta f} = 4KT\frac{1}{Rp}$ and

$|\, Z_{tank}\,(\Delta f)\,|^2 \approx \left(\frac{Rp}{2Q}\frac{fo}{\Delta f}\right)^2$ to the above overall noise of output spectral density equation, we get the expression of:

$\frac{v^2 out}{\Delta f} = = 4KT \frac{1}{Rp}$ F(Δf) $(\frac{Rp}{2Q}\frac{fo}{\Delta f})^2 = 4KT$ F(Δf)R_P $(\frac{1}{2Q}\frac{fo}{\Delta f})^2$

Finally, noise impact splits evenly between phase and amplitude. Therefore, the equation of phase noise becomes half of the total noise.

$\frac{v^2 out}{\Delta f}|_{phase} = 2KT$ F(Δf)R_P $(\frac{1}{2Q}\frac{fo}{\Delta f})^2$

Using the Leeson's formula of output:

$$L(\Delta f) = 10 \log \frac{Spectral\ dencity\ of\ noise}{Power\ of\ carrier} = 10 \frac{\log Snoise(\Delta f)}{Psig} \qquad (3.31)$$

Where S_{noise} (Δf) $= \frac{1}{Rp}\frac{v^2 out}{\Delta f}$ and $P_{sig} = \frac{V^2 sig,rms}{Rp}$

Where all calculations of power referenced to the tank loss resistance, R_P

$$L(\Delta f) = 10 \log \frac{2KT\ F(\Delta f)}{Psig} (\frac{1}{2Q}\frac{fo}{\Delta f})2 \qquad (3.31)$$

Therefore as shown in figure below Single sideband phase noise is defined as the noise power in a 1- Hz bandwidth at some offset frequency from the carrier, oscillation frequency, and has the units of dBc/Hz.

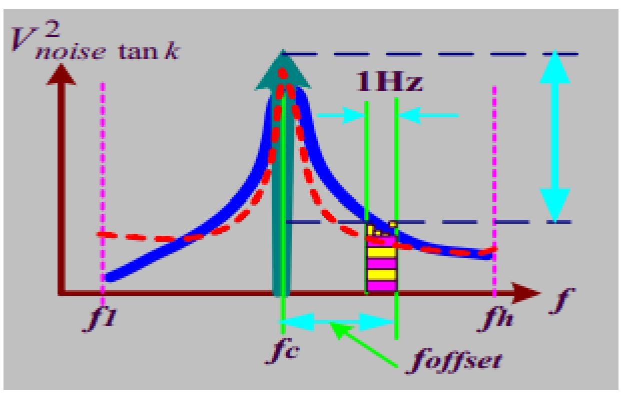


Figure 16. Characterization of noise sideband in frequency domains [26]

There are two important thing should be noticed from the above phase analysis equations, first, the thermal noise from the cross-coupled pair is independent part in the phase noise analysis. Second, the frequency of the LC tank will be affected by the noise generated from the current source, which worsens the phase noise.

3.3.2.3 Figure of Merit of VCO's

Reactive components such as capacitors and inductors are often described with a figure of merit called Q, the phase noise L(Δω) and power dissipation P_{DC} are all expressed with a general figure of merit(FOM) of oscillator as described in equation below.

$$FOM = L(\Delta\omega) - 20\log\left(\frac{f_0}{\Delta f}\right) + 10\log\left(\frac{P_{DC}}{1mw}\right)$$

$$FOM_T = L(\Delta\omega) - 20\log\left(\frac{f_0}{\Delta f}\right) + 10\log\left(\frac{P_{DC}}{1mw}\right) - 20\log\left(\frac{FTR}{10\%}\right) \quad (3.32)$$

3.4. Tools and Materials

3.4.1. Rain Data Analysis and fade Calculation Tools

After the data collection, analysis of rain data was started with loading all rain rate and ordering systematically by using the tool of Microsoft excel-2016. Depending on rain rate and amount of data, working on Microsoft Excel, chart drawing, sketch, and document analysis was implemented based on required parameter.

The technique of finding rain attenuation value has done based on formula, which was determined by studying other works on the area. Modeling of rain attenuation has done based on ITU-Rain fade prediction model. According to this model the cumulative distributions of rain rate and rain attenuation has calculated. Comparison of rain attenuation with different frequency range has expressed in detail.

The above data collection and analysis methods had summarized as the following table.

Table 1. Data collcetion, tools and techniques of data analysis

Objective of the Study	Data collection method	Tools and Analysis Techniques
➢ To collect and analyze the rain data ➢ Determining distribution of rain at different frequency range. ➢ To determine quantity of fading	➢ 1-minute rain rate data, from weather station installed at Jimma University, Ethiopia	➢ Working on Microsoft Excel, chart drawing, sketch, and document analysis

3.4.1. Oscillator Design Tools

The Design of oscillator was based on the parameters require in the oscillation design. In this research, NI AWR Design Environment v13 Edition was used to design dual band oscillator. The software has a basic menu, windows, components and commands. Some of the major components function where discussed as listed below:

- Microwave Office (MWO) used to create circuit designs including layout and simulation.
- Visual System Simulator (VSS) uses to create system simulations and to incorporate Microwave Office circuit designs.
- Analog Office (AO) uses to create circuit designs and display various measurements in graphical form.
- Monolithic Microwave Integrated Circuit (MMIC) uses to show features and designs.

This software is very easy to use and all circuits are easily determine from the element component. The AWR design environment provides many simulators that can easily run from the same schematics. In the project section, we can draw our circuit schematics, graph by easily selecting the required parameter, create an equation, taking design note, and creating our own data folders.

CAPTER FOUR

4. RESULT AND DISCUSSION

4.1. Rain Data collection and Analysis

4.1.1. Rain Fade Margin Calculation

Step -1. Determining the rain rate, exceeded for 0.01% of the time ($R_{0.01}$). From Exceedance Vs Rain Rate (mm/hr.) graph below $R_{0.01\%}$ becomes 117mm/hr and as well as from the formula (3.1) of Exceedance at 0.01 minute of integration ($R_{0.01}$) $=\frac{C.F*100*T}{Nd*24*60}$. = 117mm/hr.

Step -2. Calculate the specific attenuation (ϒ).

$$\Upsilon = kR^{\alpha}_{0.01\%} \text{ dB/km.}$$

Where k and α are regression coefficients of vertical polarization at 11GHz and $R_{0.01\%}$ = 117 mm/hr.

At 11GHz, k =0.01731and α = 1.1617.

Therefore, $\Upsilon = 0.0173*117^{1.1617} = 4.374$ dB/Km.

Step -3. Compute the effective path length, d_{eff}, of the link by multiplying the actual path length d by a distance factor r. An estimate of this factor is taken from ITR-R is (from equation 3.2):

$$r = \frac{1}{0.477d^{0.633}R_{0.01}^{0.073 \cdot \alpha} f^{0.123} - 10.579(1-\exp(-0.024d))}$$

Where d = 16(Km) is the path length from Jimma site to Mujja. Therefore, r becomes 0.28

Then d_{eff}, is d.r = 16*0.28 = 4.48km.

Step -4. The total rain attenuation can be evaluated by integrating the specific attenuation along the path and also it expressed by the unit of decibel (dB). The path attenuation (A), exceeded for 0.01% of the time, calculated by:

$A0.01\% = \Upsilon * d_{eff} = 22.3$ (dB).

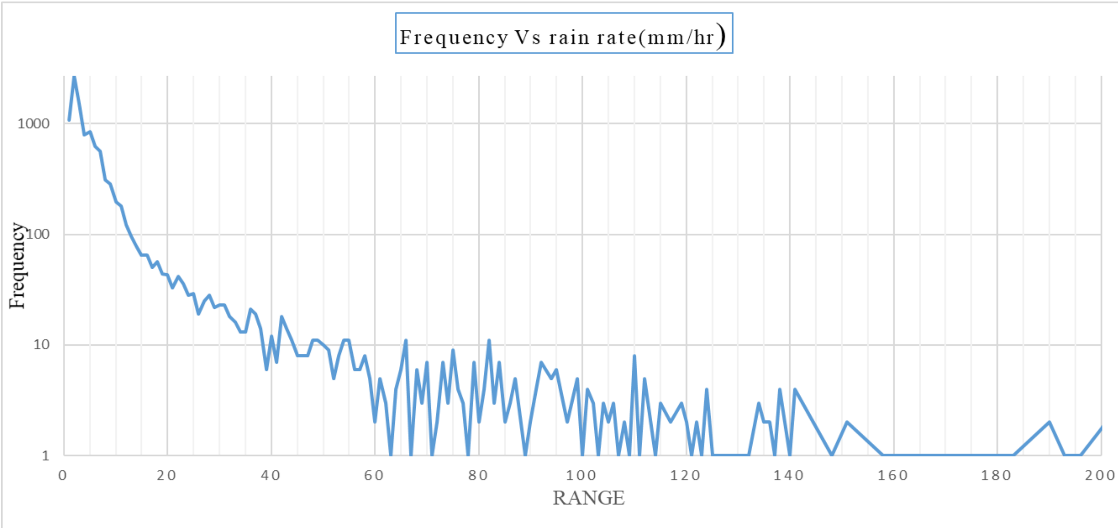


Figure 17. The one year range of rain rate in mm/hr with its frequency

In figure 17, the graph shows the cumulative frequency of rain data with different rain rate change. It has obtained by collecting all one-year data and then leaving all zeros from the collected data.

The graph (figure 18) below shows one-minute exceedance with different rain rate. It describes that the rain rate has inverse proportionality with percent of one-minute exceedance. According to ITU-R rain rate of one minute integration time ($R_{0.01}$) is required for the determination of rain attenuation. So that here it becomes 117mm/hr.

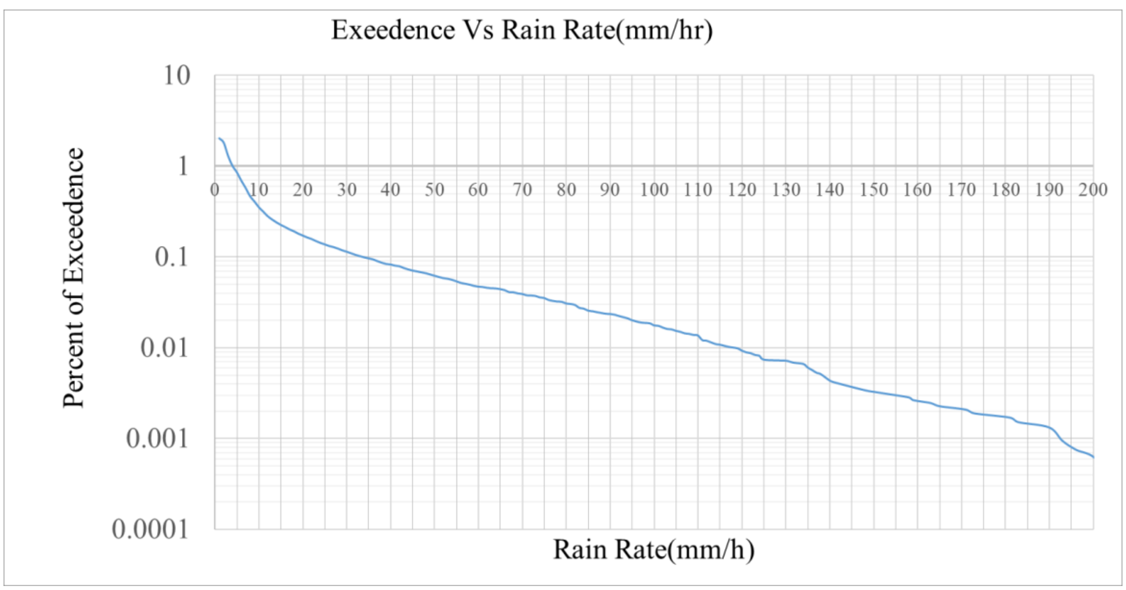


Figure 18. one-minute exceedance with different rain rate

The following graph summarizes all the above discussion and shows the rain attenuation in (dB) with respect to percent of time exceedance and rain rate in mm/hr. It also shows the attenuation level with respect to each of percent of exceedances.

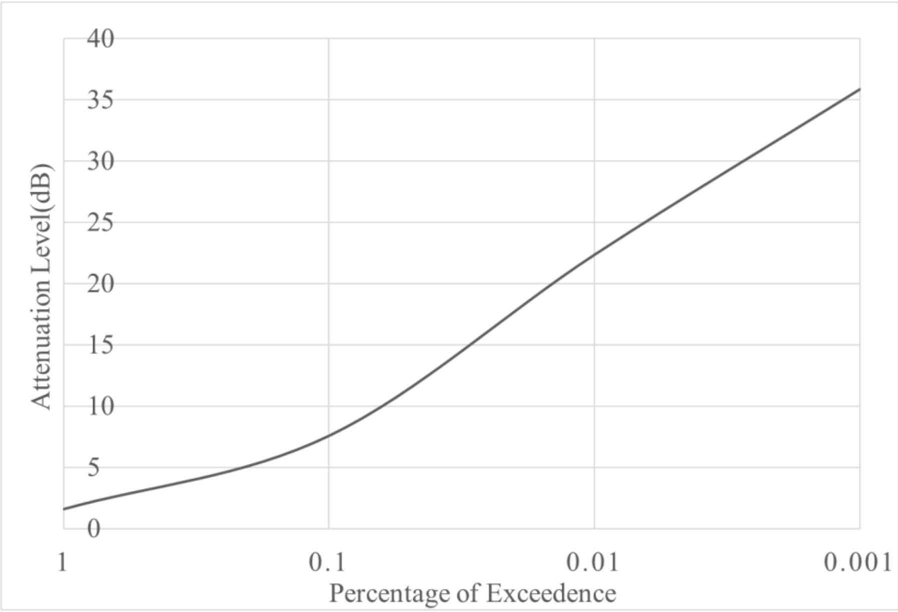


Figure 19. Level of attenuation in dB respect to percentage of exceedance

After all, we are going to calculate the received signal, the fade margin and signal to noise ratio at rain attenuati on with 0.01 percent of time exceedance and rain rate in mm/hr with the following general equations. All the required parameters are taken from the microwave link of Jimma and its measurements are listed in tabe-2 of below and result is summarized in table3.

Total received power with at receiver end without rain attenuation, from equation (3.4):

Pr = Pt + Gtx + Grx − Lfs – Lsys = -57(dB)

With rain attenuation (A0.01%)

Pr =-57(dB) – A0.01% (dB)

Pr = -57dB – 22.38dB = -79.38dB or -49dBm.

Link Margin = Pr - R_{XTH} = -49dBm +76.2dBm =27.2dBm.

SNR = Pr-10log(BW)/Hz + 174 (dBm) = 73dBm

SNR = -49 - 73.36 + 174 =51.6 dBm or 21.6 dB.

Table 2. Parameter specification of link Jimma to Mujja

Parameter	Link_1	Link_2
Antenna height(m)	10	15
Antenna gain(dBi)	42	42
Tx line unit loss(dB/100)	4.53	4.53
Tx line loss(dB)	0.91	0.91
Frequency(GHz)	11	11
True azimuth(0)	220.97	40.97
Vertical angle	1.48	-1.59
Link distance(km)	6.26	
Free space loss(dB)	139.9	
Rx threshold level(dBm)	76.2	76.2
Effective frequency spacing(MHz)	21.7	
Atmospheric absorption loss (dB)	0.3	
Tx power (dBm)	30	
Polarization	Vertical	

Table 3. Calculated parameters for SNR with different % of time exeedence

% of Exceedence	Freq. (GHz)	Link.D (km)	Rain.R (mm/hr.)	Attenuation (dB)	Prx(dBm)	L.M(dBm)	SNR(dB)
0.001	11	16	195	35.8775	-62.877	-16.6775	7.82245
0.01	11	16	117	22.3805	-49.380	-3.1805	21.3194
0.1	11	16	35	7.60785	-34.607	11.5921	36.0921
1	11	16	5	1.62254	-28.6225	17.5774	42.0774

4.2 Voltage Control Oscillator Design

This portion is the design of a Voltage Control Oscillator (VCO) oscillator. It uses a swept DC voltage source for supply of voltage to control the oscillation. The simulation analysis divided into two main parts. First, a linear analysis of the oscillator measured in order to determine the correct oscillation frequency. The second part of the measurement is a nonlinear analysis using the OSCAPROBE element, which is signal oscillator simulator. The frequency of oscillation and number of important oscillator performance characteristics like output power spectrum, phase noise and tuning range were also calculated. It also shows how the oscillator's frequency changed with bias voltage. The final modeling was shown in the schematic known as VCO that is shown in the figure below.

4.2.1 Architecture Design

The design architecture have two parts, which is tank circuit, and a negative resistance source to compensate the loss of tank.

Due to its relatively good Phase Noise (PN) performance, the topology of cross-coupled differential transistor LC-tank oscillator had selected.

As shown in Figure below, the LC-tank VCO consists of differential pair of LC resonator and for tuning oscillator frequency, two varactors are employed. The cross-coupled pairs of transistor are employed to provide a negative resistance that will compensate the produced parallel resistance loss.

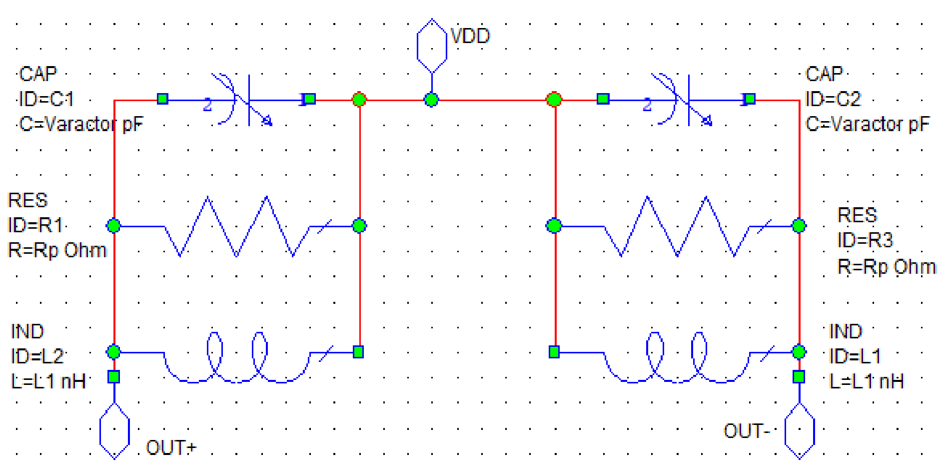


Figure. 20 Differential circuit of LC tank

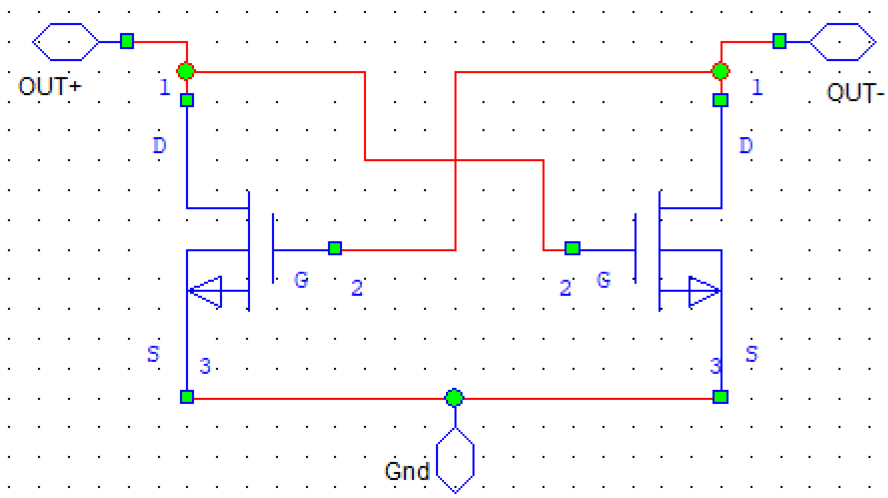


Figure 21. Circuit of negative resistance.

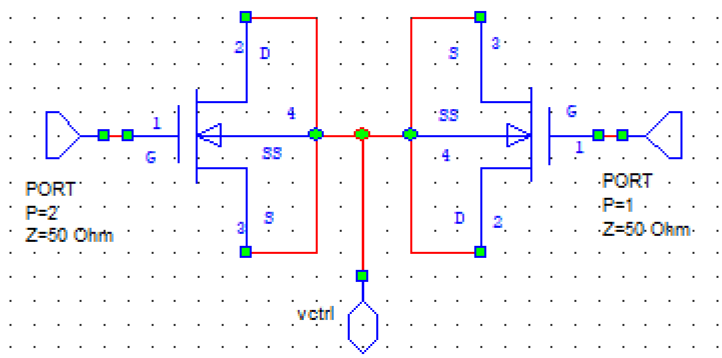


Figure 22 Architecture of Varactor

4.2.2 Design Calculation

There are different parameters that need to be known before the design start. The required resonant frequency and the tuning range of capacitor is a major one. For the calculation of that parameter, the parallel resistance of inductor, the serious resistance of varactor and the quality factor (Q) of both inductor and varactor has to be calculate.

4.2.2.1Oscillation Frequency Calculation

This oscillator consists of two parts: LC resonator and a switching network as well as it has two resonant mode: an even mode (common mode) and an odd mode (differential mode). The oscillation frequency is calculated by considering this two resonant modes.

Even mode: In this mode, the two LC tanks resonate in phase and the switch capacitors (Cs) see a zero voltage drop and do not carry current. Therefore, the resonator can be reduced to two LC tanks. Therefore, the higher resonant frequency will be calculated (equation 3.10)as:

Fresonant $=\frac{1}{2\pi\sqrt{LC}}$

Where L=0.1nH and C=2.1Pf,

Fresonant =11GHz

Odd mode: In this case, the two LC tanks are 180^{o} out of phase, Therefore the capacitor sees differential voltage at its two terminals. So that we can get the equivalent capacitors which consists of two LC tanks. Thus, the resonant frequency at lower band was calculated by(equation 3.11):

Fresonant $=\frac{1}{2\pi\sqrt{\mathrm{L(C+2Cs)}}}$

Where L=0.1nH, C=2.1pF and Cs =0.5nH

Fresonant =0.5GHz(500MHz)

4.2.2.2 Tank Loss and Negative Resistance

The major cause of tank loss is the parallel resistance of inductor and serious resistance of varactor. Those resistance is depends on the quality factor of inductor and varactror. Choosing the Q-factor of inductor is a major challenge because of both increasing and decreasing will affect the tuning range, phase noise and output power. However, in this research the value of Q of inductor is determined by considering the level of effect of resonant frequency. This is because of the same inductor has used for both the higher and lower resonant frequency. According to comparison figure of below, very low Q-factor of inductor affects the resonant frequency.

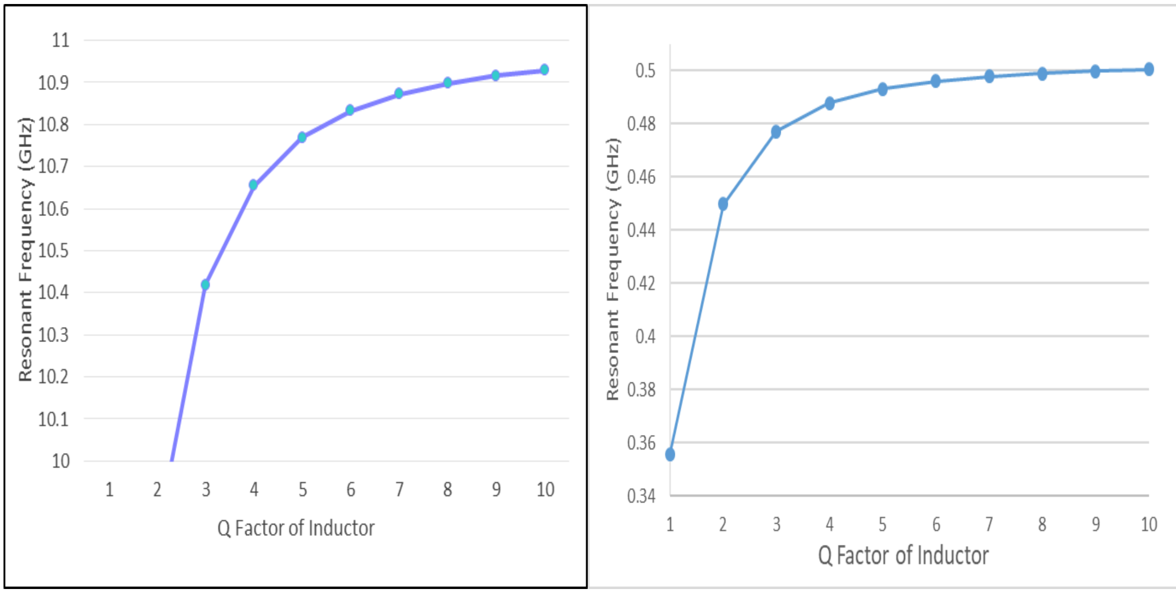


Figure 23. Comparison of Q- factor for higher and lower resonant frequency.

The serious inductor resistance and parallel varactor resistance does not affect the performance of the tank so that it is not necessary to determine from those parameter. Therefore, the second required Q value is determined directly from serious resistance of varactor. But at resonance the reactance of capacitor and inductor has equal value. i.e $X_L = X_C$.

- Tank resistive Loss:

The tank resistive loss is determined form the addition of both parallel resistance of inductor and serious resistance of varactor.

Therefore, parallel resistance will be determined by using serious to parallel conversion of serious to parallel circuit and using the equation of:

$\omega_o = \frac{1}{\sqrt{LsC}}$ and

With series resistance due to inductor losses (LS, Rs),

$\omega_o = \frac{1}{\sqrt{\frac{1}{LsC} - \frac{Rs^2}{Ls^2}}}$, Ls $=2L= 0.2*10^{-9}$, C $= 2.1*10^{-12}$ and $\omega_o = 2.\pi.f$. Therefore, Rs becomes 9.79(Ohm).

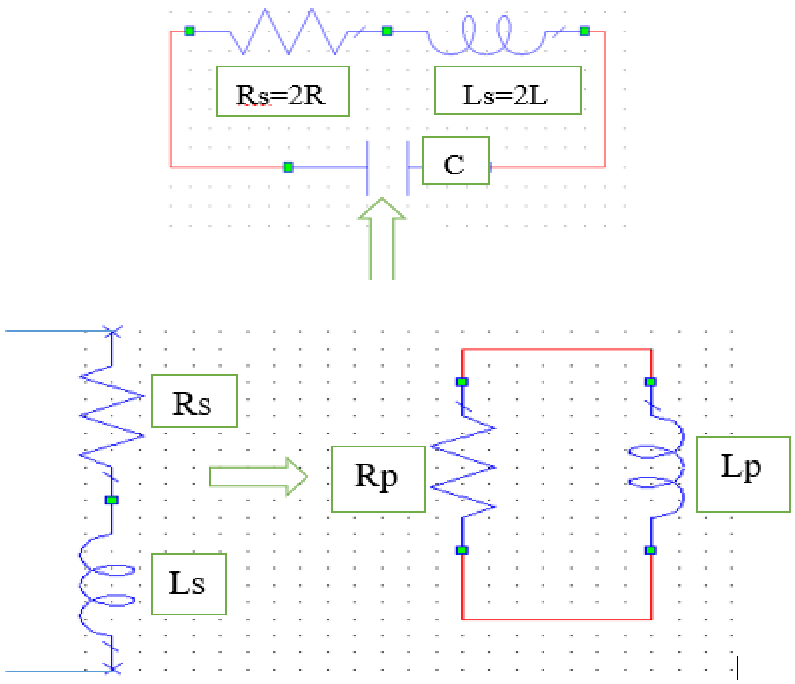


Figure 24. conversion of serios to parallel circuit

Know we can calculate Rp from the circuit,

$1/Rp + 1/j\ \omega_o Lp = 1/Rs + j\ \omega_o Ls$. By simplifying Rp will become 6.8 ≈ 7(Ohm).

The degree to which the inductor impedances, the flow of current is due to its inductive reactance. Therefore, it is calculated from the formula of (equation 3.14):

$Q_L = X_L/R_P = 2.\pi.f.L/R_P$, $Q_L = 1.2$

The second one is from tank varactors resistance Loss.

$Q_c = 1/C.\omega.R_S = 2$.

Therefore total tank resistance loss is

$1/R_{tank} = (1/Rp + 1/\ Rs)\ =(1/7 + 1/9.79)$

$R_{tank} =\ 4$ (Ohm).

- Negative resistance.

Cross-coupled pairs are employed to provide negative resistance. According to Barkhausen criteria, Rnegative = -2/Gm = 7, Therefore,

-Gm = 0.3 (Ohm).

Where, Gm is the trans-conductance of transistor's cross-coupled pair.

So, to achieve sufficient negative resistance 2/Gm, with less parasitic capacitance, altered firstly the size of the transistor W/L ,secondly the tail or bias current Id. In other words, smaller W/L are chosen, for a required power, since it will reduce the parasitic capacitance. Hence, the frequency tuning range will be less affected. So transconductance (Gm) of transistor is given by

Gm = $\sqrt{2\mu Cox\frac{W}{L}Id}$ =.Where W is transistors gate width, L is the gate length, Cox is oxide thickness, μ dielectric permittivity of gate oxide. and Id is DC current.

To calculate the DC current using the transistor used in the simulation,

Where C_{ox} = 0.15nm.

Gm =0.3, W/L 10 μm, and μ = $3.45*10^{-11}$ F/m.

$\mu.C_{ox} = 517*nA/V^2$

Id = 8.7mA.

4.2.2.3 Tuning range

The tuning range of oscillator depends on varactors capacitor and calculated as:

$$\Delta\ \omega = 1/\sqrt{L.Cvmax} - 1/\sqrt{L.Cvmin} \qquad (4.1)$$

According to the required bandwidth, which is limited by the lower frequency, band of TVWS,

The estimated efficient BW is 0.5GHz = Δf.

The tuning capacitor become, Cvmax –Cvmin= 2.2pF -2pF = 0.2pF.

So that the varactor capacitance ratio becomes Cvmax /Cvmin=1.1.

The higher band tuning frequency range becomes:

$\Delta F_{\text{higher-band}} = 1/2\pi\sqrt{L.Cvmax} - 1/2\pi\sqrt{L.Cvmin} = (10.73 - 11.25)$ GHz.

$\Delta F_{lower\text{-}band} = 1/2\pi\sqrt{L(C2 + Cvmax)}$ - $1/2\pi\sqrt{L(C2 + Cvmin)}$ = (0.35 -0.85) GHz.

Therefore, Tuning Range in percent is calculated by:

$$\frac{Cvmax - Cvmin}{\frac{Cvmax + Cvmin}{2}} = \frac{2.2 - 2}{\frac{2.2+2}{2}} \approx 10\%$$

4.2.2.4 Power Consumption

The power consumption of oscillator is determined by considering the quality factor (Q) of the circuit. In its simplest form, the quality factor, Q, indicates how close to ideal an energy-storing device is. Q of tank will be limited and determined by the higher frequency of oscillation.

Qtank = $F_{resonance}$/Bw = 11GHz/0.5GHz= 22.

Using equation of Vtank = 2/π.I.Rp

The output power with a 0.5V vdd and 8.8mA bias current is 0.4Mw.

4.2.2.5 Phase Noise

Therefore, the phase noise calculation (from eq. 3.23) will be $L(\Delta f)$= $10\log\frac{2KT\,\mathrm{F}(\Delta f)}{Psig}\left(\frac{1}{2Q}\frac{fo}{\Delta f}\right)2$

Where, k = 1.38 * 10^{-23} J/K denotes the Boltzmann constant and T =300k the absolute temperature. f_o is the lower and higher carrier frequency (0.5 and 11) GHz with band width of Δf =0.5.

4.2.2.6 Figure of Merit (FoM)

The phase noise has been normalized in terms of figure of merit (FoM) and it is used for approximation of VCO performance.

The figure of merit (FOM) and total figure of merit (FOMT) for evaluating VCO performance is calculated from equation of (eq.3.32):

$$FOM = L(\Delta\omega) - 20\log\left(\frac{f_0}{\Delta f}\right) + 10\log\left(\frac{P_{DC}}{1mw}\right)$$

$$FOM_T = L(\Delta\omega) - 20\log\left(\frac{f_0}{\Delta f}\right) + 10\log\left(\frac{P_{DC}}{1mw}\right) - 20\log\left(\frac{FTR}{10\%}\right)$$

Where fo is the carrier frequency, Δf is the frequency offset, L(Δf) is the phase noise measured at an offset Δf from the carrier and P_{DC} is the DC power dissipation in mW consumed by the VCO. In the designed VCO, the FoM at 1 MHz offset frequency with P_{DC} = 2.2mW, PN = -120 dBc/Hz and at fo = 0.5 GHz becomes -167.5 dBc/Hz. In addition, for higher band using PN = -146dBc/Hz, fo =11GHz and 1MHz offset is equal to -200dBc/Hz.

4.2.3 Band Selection Technique

When differential and common signals are applied to LC-tank, the resonant frequency is determined with two different resonant. By switching this different signal, the circuit can make an oscillator with common LC-tank have two different resonant frequencies.

Here, varactors are used for frequency tuning not for band switching. The mode switching is accomplished by controlling current sources.

The mode-selection network, which controls current sources, selects operation mode and frequency switch occur for high band mode and lower band mode. The circuit in figure 25 below shows that the two resonant mode of operation.

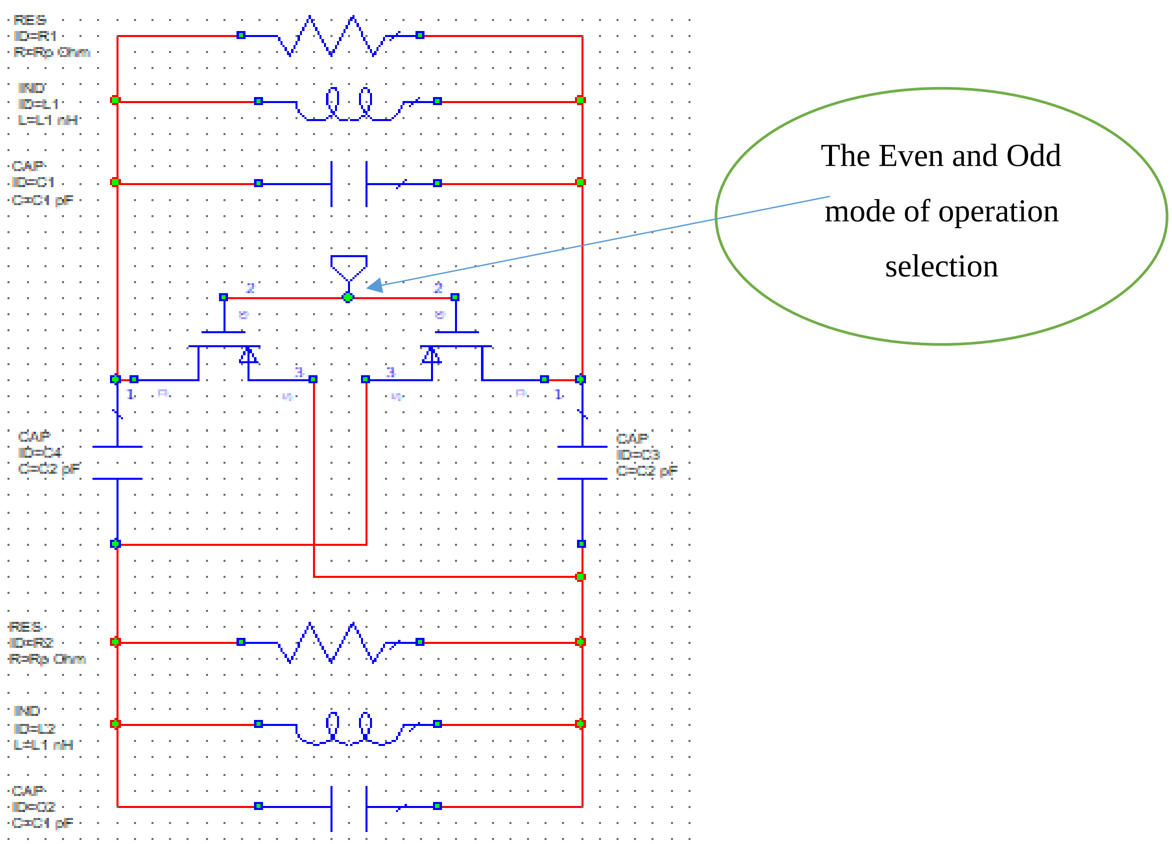


Figure 25. The two resonant mode of operation

In the graph Rs is the Switching resistance of transistor. When the two LC tanks resonate in-phase, the voltage across the capacitor (C2) is zero this is called even mode of operation. On the other hand, when the two tanks resonate at 180 out-of-phase, the current will flow across the external capacitor and resonant frequency changed from higher frequency to lower frequency or odd mode of operation..

The following graph, on figure 26, shows that change in value of switch resistance with its impedance value.

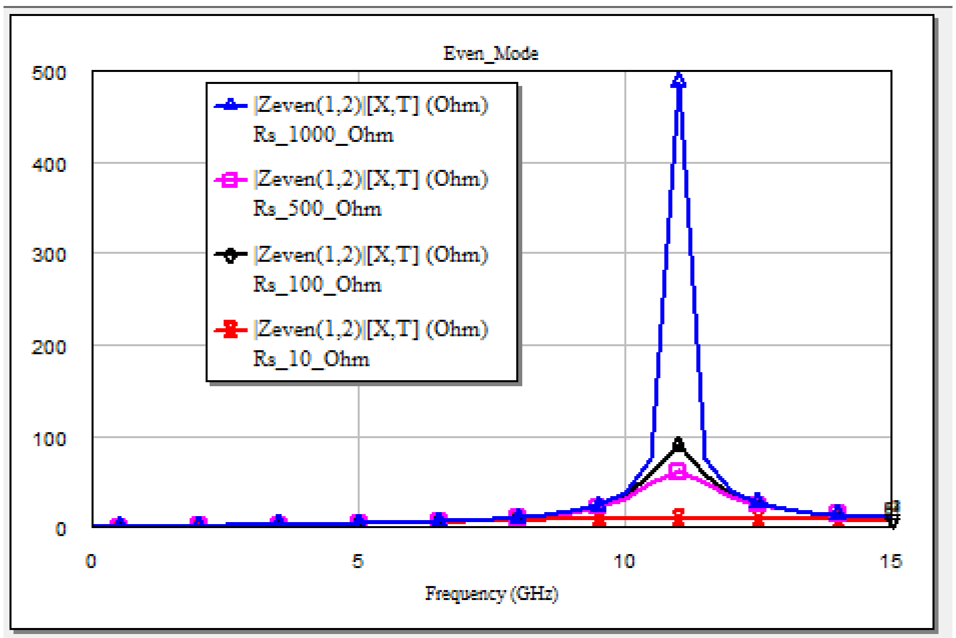


Figure 26. Change in switch resistance with operation frequency.

After all, when we change the switch resistance to lower, or when switch is off the oscillation will convert from higher frequency (11GHz) of operation to lower (0.5 GHz). The graph below, figure 27, is at lower frequency.

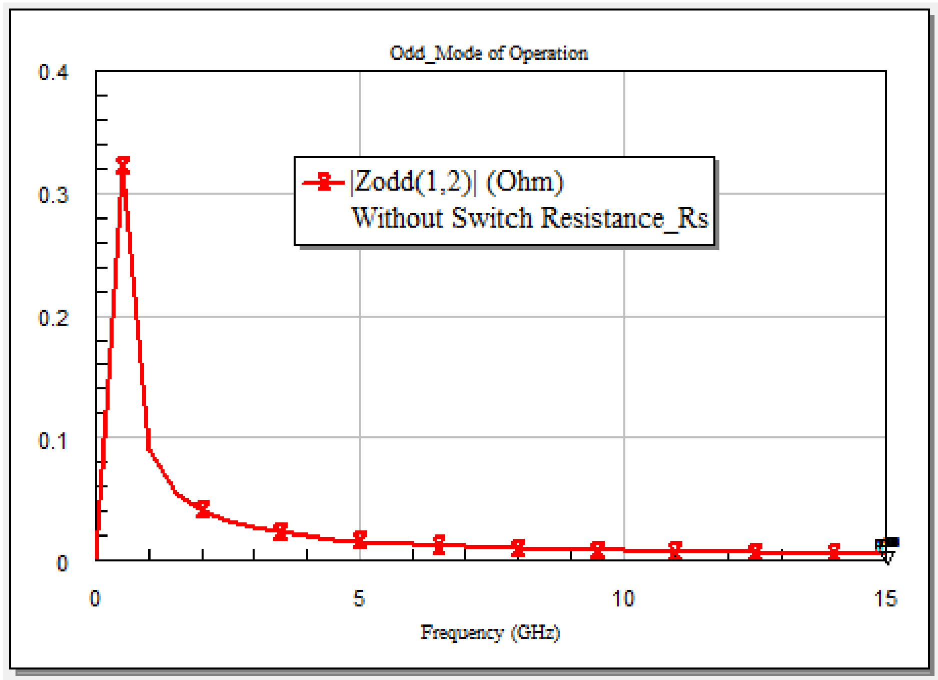
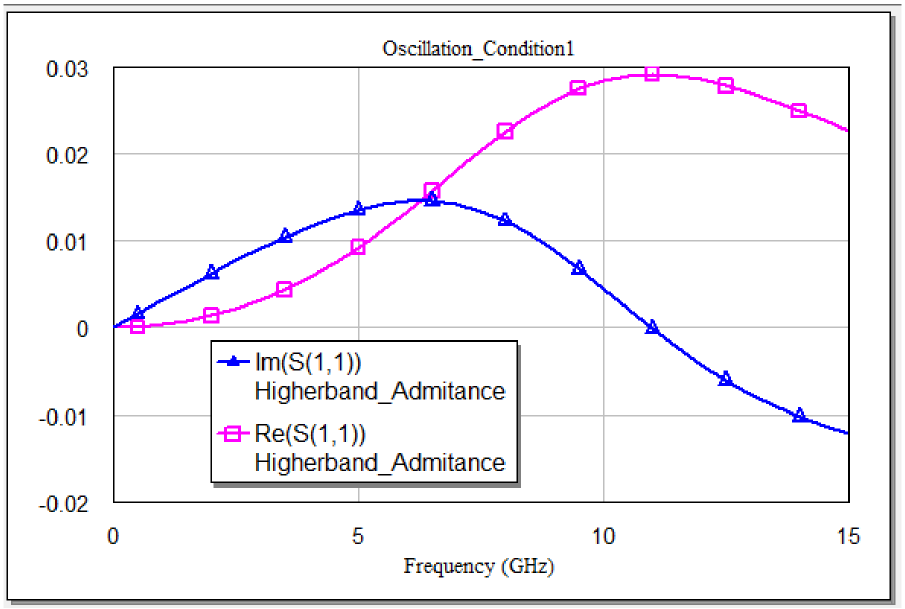


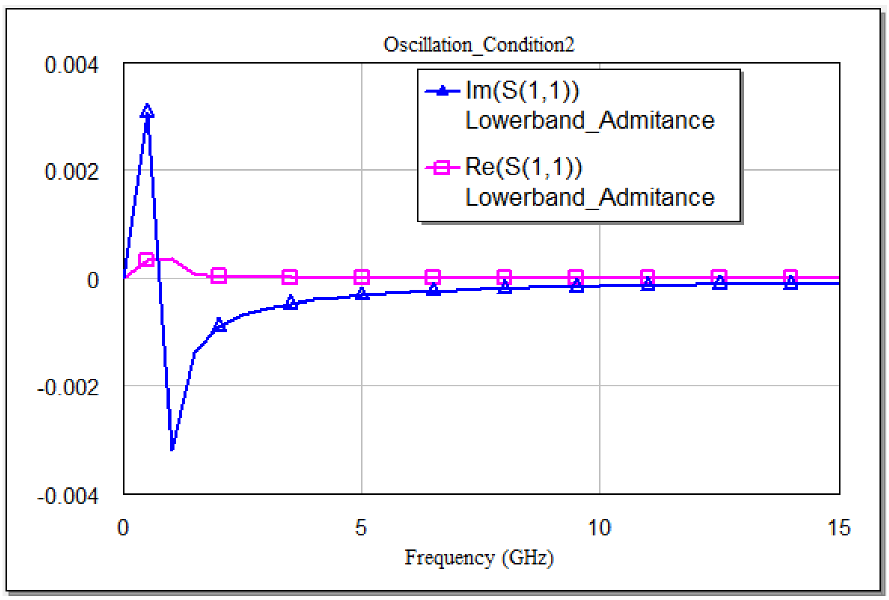
Figure 27. Output impedance on Odd mode of operation

4.2.2 Linear Oscillation Output

Linear Oscillation Conditions shows the total admittance for both inputs of the tank circuit and the negative resistance source. This was accomplished by creating an equation with a variable Y_total, and graphing its real, which is conductance (G), and imaginary, which is susceptance(S) parts. Y_total is defined in the browser window "Output Equations" as the sum of the admittance of the tank circuit (Y_tank) and the admittance of the negative resistance (Y_Negative Resistance) source.



(A)



(B)

Figure 28Oscillation Condition of Higher band(A)and Lowerband (B)

The above graph (A) and (B) gives a result of total suceptance zero at higher operating frequency (11GHz) and lower operating frequency (0.5GHz) and its Conductance is at maximum real value. The graph shows that, oscillation occurs where the Susceptance is at zero value as the conductance at minimum value. The voltage tuner can be used to tune the DC voltage levels for changing the tuning range of oscillation. The oscillation frequency was controlled by the supply voltage source.

4.2.3 Nonlinear Simulation of the Oscillator

This is the second part of the analysis process, which can be determined under consideration of important oscillation parameters. This measurement was accomplished using the OSCAPROBE element. As shown in figure below, nonlinear analysis is done by connecting the tank and negative resistance. The OSCAPROBE was inserted in parallel between the tank circuit and the negative resistance source. OSCAPROBE is a voltage source that sweeps over a specified range of frequencies and voltages until it finds a point, which the current flow through it, is zero. At this point, the circuit is in a stable or steady state of oscillation.

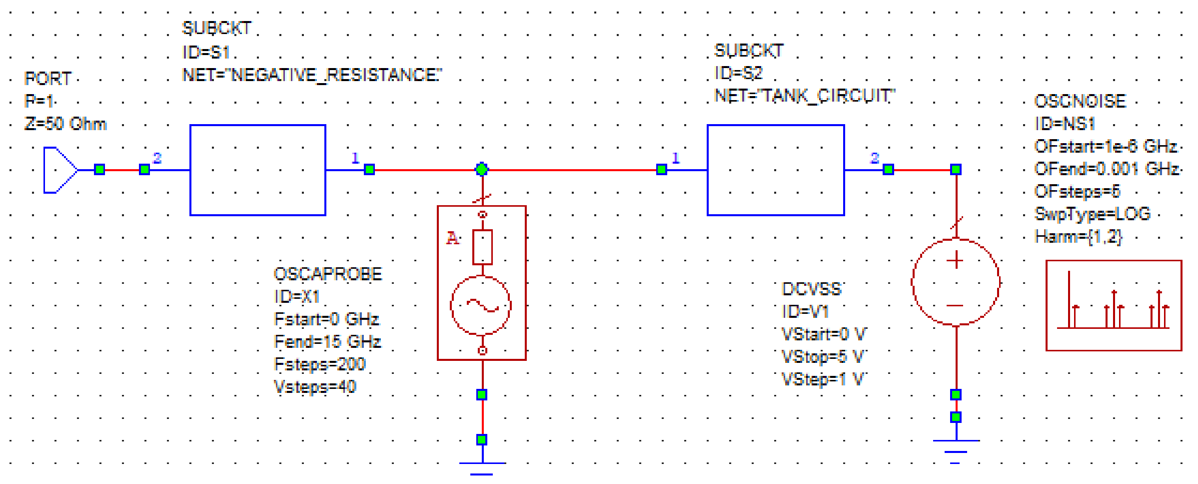


Figure 29, VCO Schematic-for nonlinear measurement

There is also an OSCNOISE element measures the phase noise of oscillator. The DC voltage source to control the varactor bias can be swept from 0 to 5 V. The negative resistance is used to compensate the loss of tank circuit. The resulting measurements where explained and drawn on the next section.

4.2.4 Simulation of output of Performance Parameters

4.2.4.1. Phase Noise

Phase noise is a major significant factor to obtain the noise performance of the LC oscillator. Here the plot showing the single sideband phase noise of the oscillator. This graph is set up to allow the tuner to change the state of the swept voltage source. The following output graph, In figure 29, is the phase noise at in dBc/Hz with Δf = 1MHz from the carrier.

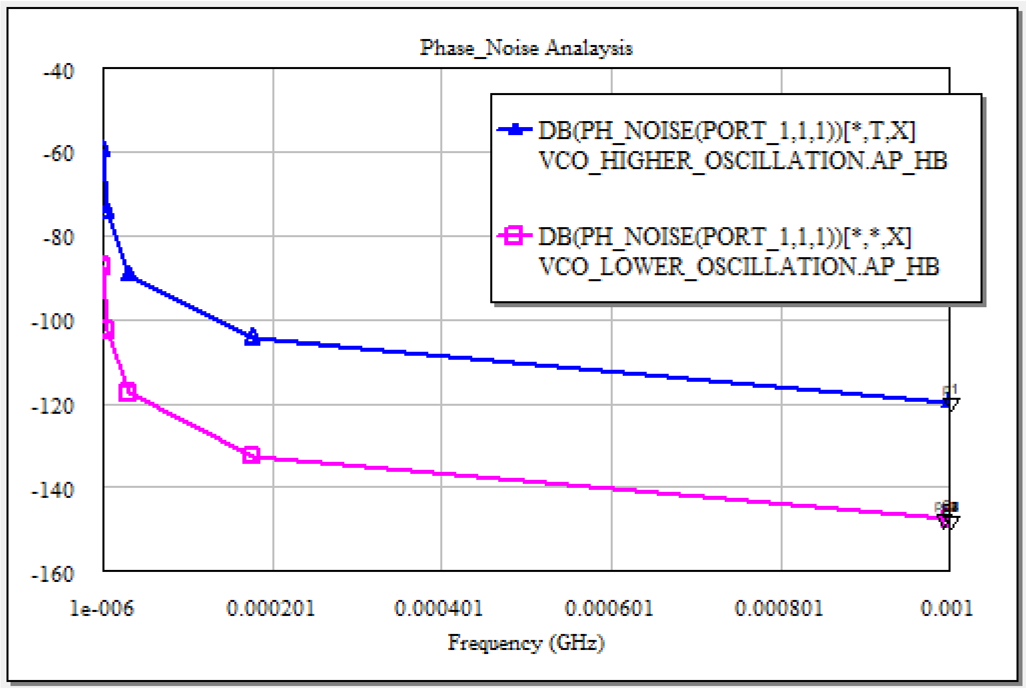


Figure 30. Phase noise with respect to Δf from carrier frequency

The outcomes of phase noise with an offset of 1 MHz from the carrier shown above is equal to -146 dBc/Hz and -120 dBc/Hz for lower and higher band respectively.

4.2.5. Output Power

The Plot showing the output power spectrum for the oscillator. This graph is set up to allow the tuner to change the state of the swept voltage source. Tune on the left "Vdc" parameter and watch the spectrum change. Therefore, here the spectrum of output power at 0.7GHz is 3.2dBm.

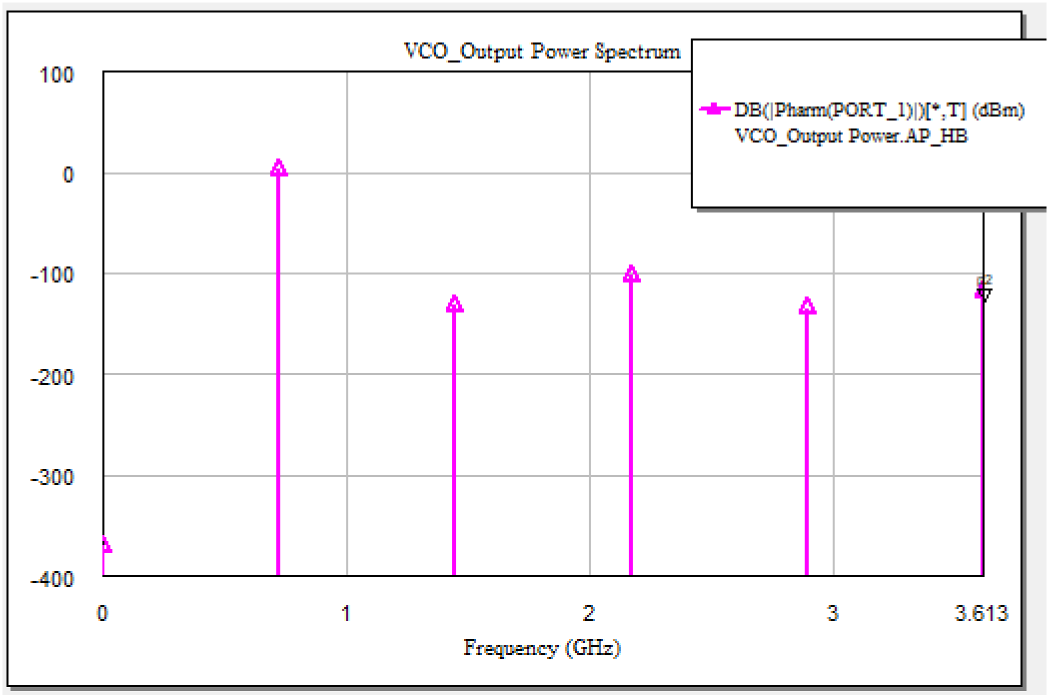


Figure 31 Output Power Spectrum for a lower band of oscillation

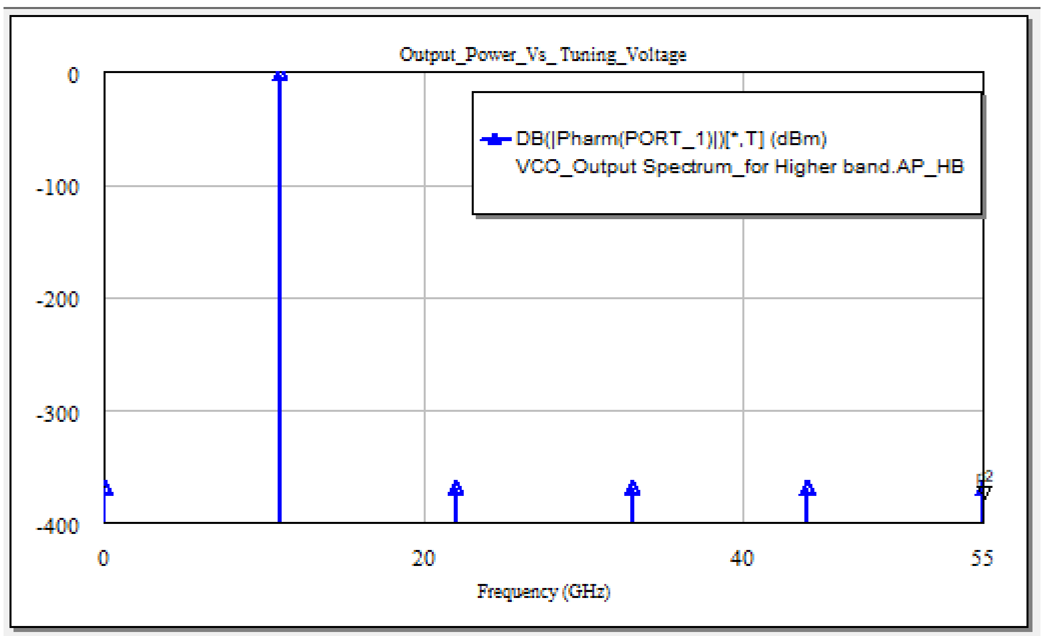


Figure 32 Output Power Spectrum for a higher band of oscillation

The graphs 31 and 32 shows the harmonic output of the lower and the higher operating frequency respectively. It describes the energy level with different frequency sequence and expressed in dBm.

4.2.5. Tuning Range with voltage control

- Varactor's Capacitor Range

The figure below is the capacitance range, which determines the tuning range of oscillation. The voltage control of MOS varactor is used. Therefore, the maximum and the minimum of capacitor range is determined only by changing the length of MOS circuit.

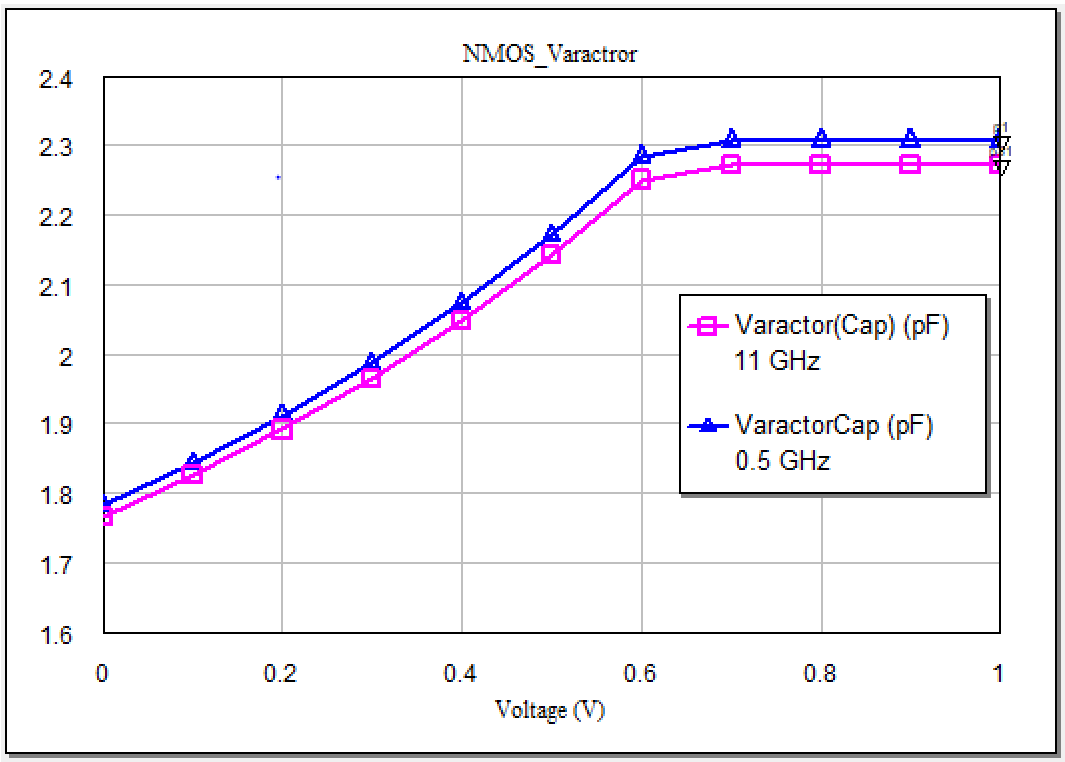


Figure 33. Capacitor Tuning Range with controlling voltage:

The plot showing the tuning range of the oscillator by the DC source. The swept voltage setting was used as the x-axis for this graph.

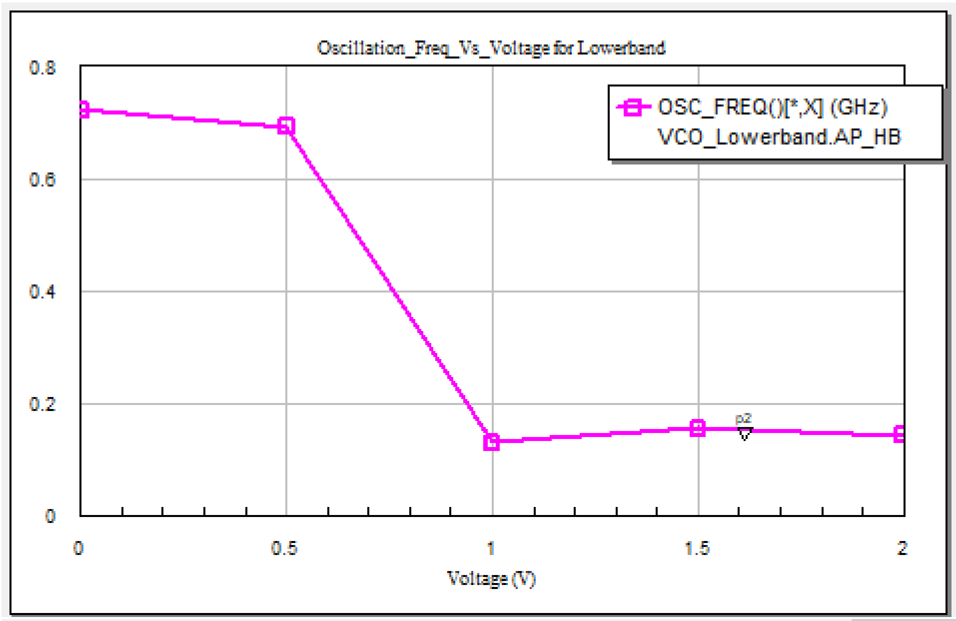


Figure 34 Lower band oscillation with voltage control

The above graph is the output oscillation of Lower band VCO. The maximum to minimum tuning range of oscillation is (0.75 – 0.11) GHz respectively. Therefore, this range of oscillation covers all the frequency band of operating frequency of TVWS. On the other hand in figure below the tuning range of VCO of higher band is a microwave range of operation which is (12 – 8) GHz of maximum to minimum respectively.

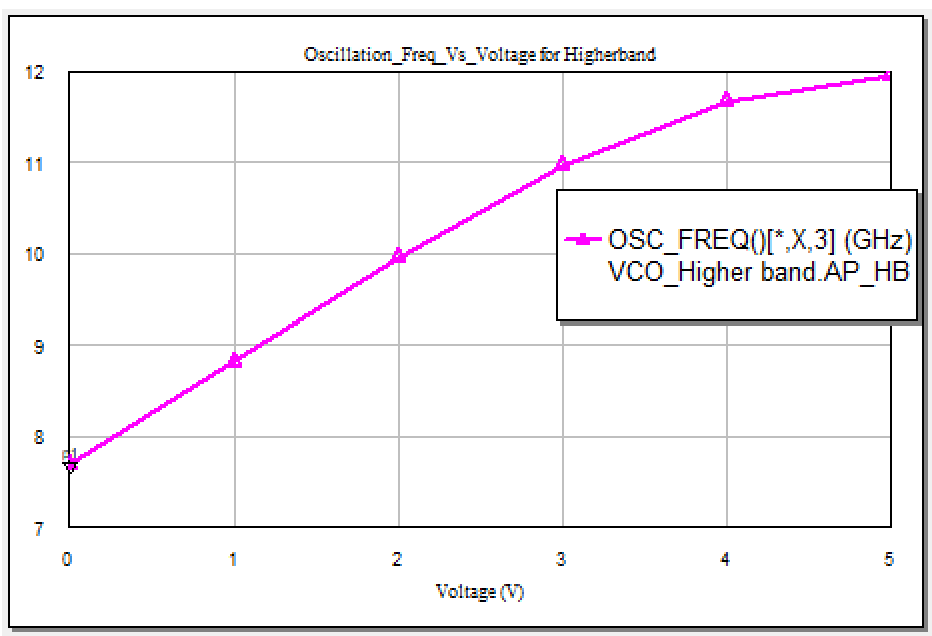


Figure 35Higher band tuning range with control voltage.

4.2.6 Output Waveforms

VCO oscillators are electronic circuits, which was controlled by DC voltage supply and that generate a continuous harmonic output waveform with a defined frequency. Therefore, it is a time domain representation. Output Waveform- Plot showing the output voltage waveform for the oscillator. This graph shown in figure below is set up to allow the tuner to change the state of the swept voltage source. As we see from graph the swing voltage output is 0.6V with time domain of X-axis.

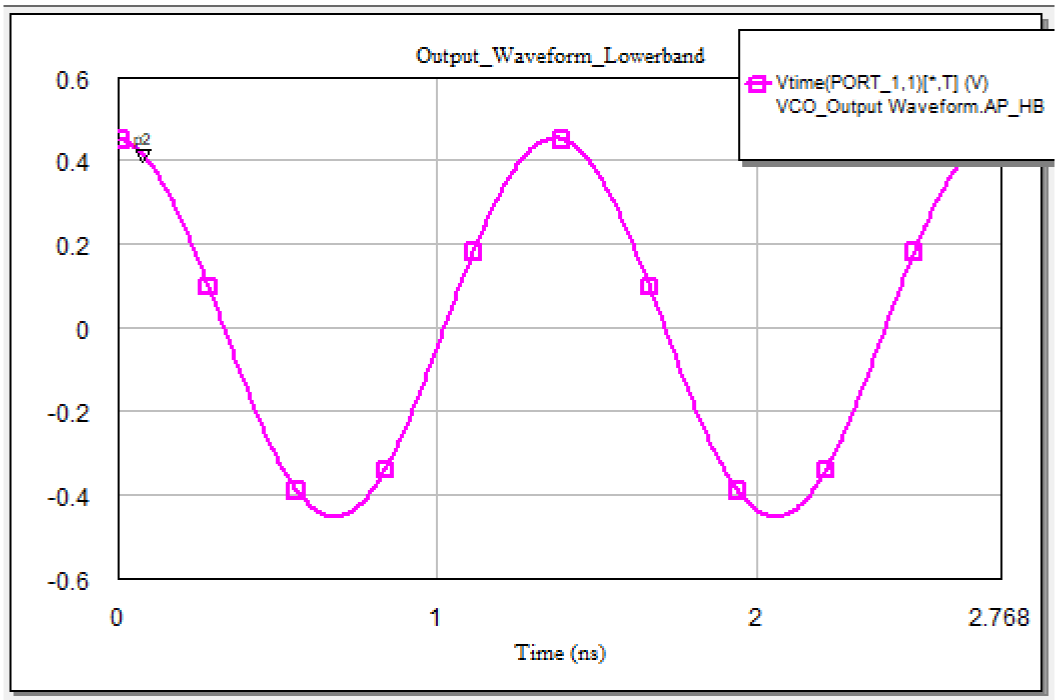


Figure 36. Output waveform in time domain

4.3 Modeling of Band switch

As discussed in previous the band switching will implement based on the received signal (SNR) of microwave link. Therefore, a typical microwave oscillator consists of frequency selective network and active devices. The passive frequency selective network determines the generated frequency depending on its resonance frequency, while the active core provides enough negative resistance to compensate for any loss in the resonant structure.

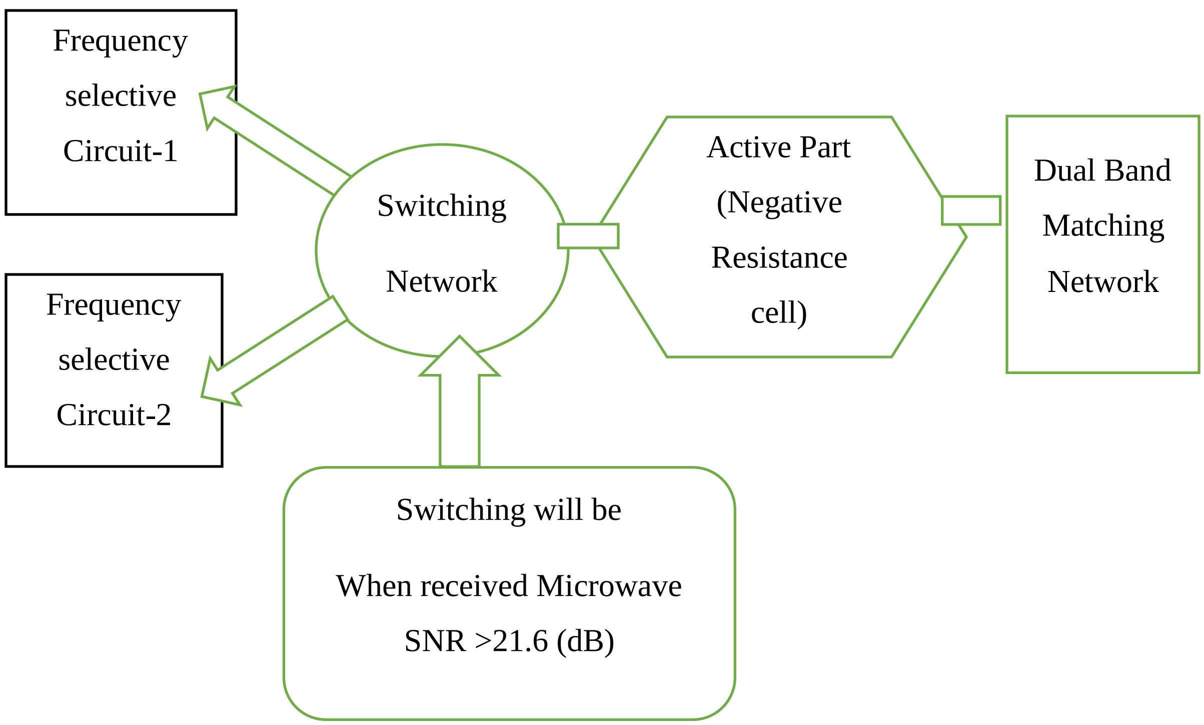


Figure 37. Modeling of frequency switching system

The individual frequency selective unit elements are placed in parallel, while a switch selects one of them to produce the required frequency output. The method of using parallel frequency selective circuit may degrade the phase noise due to coupling among the resonant elements, which are placed in parallel. a dual-band output matching network used for optimum output power efficiency to a 50 Ω load at both the designed frequencies.

4.3.1 Loop for switching of oscillation condition

If multiple receiving antennas are sufficiently spaced apart from one another, their received signal levels are almost independent in fading channel or fading level. A decision circuit can simply pick the antenna that offers the highest signal-to-noise ratio (SNR). In this case, when SNR of microwave band is below the threshold level, which is 21.6 dB, the decision circuit will convert to lower frequency band.

The following loop is a decision loop used to decide frequency switching based on the SNR (dB) level of receiver. It makes decision to operate whether at lower or at higher frequency. % r is received signal level in dB, it may vary with the rain rate. However, according to calculated rain rate data, the SNR vary from 7 to 42 dB and this is for a single link. Therefore, r is taken from 0 to 50 dB.

```
r = 0:50;

% The threshold SNR = s (dB).

s = 21.6;

% The Higher Microwave operating frequency (h) in GHz.

h = 11;

% The Lower TV-White Space operating frequency (l) in GHz.

l =0.5 ;

disp(' r ')

disp('Check value of r :')

if r > = s

   disp('Select higher frequency)

else r < = s

   disp('Select lower frequency')

end
```

4.4 Performance summary and comparison

The designed dual band oscillator had a good performance comparing with other research works. This VCO design provides better frequency tuning performance as compared to other VCO designs. From this comparison table, it is seen that when we compared the phase noise performance with other work, it got a very good performance result.

Table 4. Comparison of dual band VCO with major parameter

Performance Comparison Parameters	Ref [36]	Ref [37]	Ref [28]	Ref [27]	This work
Operating Frequency(GHz)	900	21	5.11	58.1	11
	1.8	55	12.2		0.5
Phase Noise(dBc/Hz) @Carrier(GHz)	-125 @ 0.6MHz offset	-100.8@ 1MHz offset	-117.16 @1MHz offset	-116.5 @10MHz	-146@ 1MHz offset
	-123 @ 0.6MHz offset	-86@ 1MHz offset	-112.15 @1MHz offset		-120 @1MHz offset
Voltage Supply(V)			0.8	1	0.67
Dissipation Power(mW)	16	14	2.56/2.18	6.32	2.2
Tuning range(GHz)	0.823-0.867		4.78-5.14	22.4%	24%
	1.640-1.814		12.19-12.61		
FOM(dBc/Hz)	-176@0.865	-175.8	-187.2	-184.69	-167.5
	-181@1.812	-170	190.5		-200

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

In this research, the frequency diversity technique of rain attenuation mitigation has been studied. The work was started by studying different research works on the area of rain attenuation mitigation technique, finding attenuation level during rain time, designing dual band oscillator, which operate on both microwave and TV-white space frequency range.
Collecting and analyzing rain data was accomplished using Microsoft Office. The attenuation level was calculated using 11GHz microwave operating frequency and a particular microwave link, which is most rural microwave distance link of Ethiopia. Attenuation level was investigated using ITU prediction model and distribution of rain rate at different frequency range determined. Designing dual band, microwave and TV white space voltage control oscillator had done for the purpose of frequency diversity band switching mechanism. This is because of the need of an appropriate frequency reference to operate. However PLL is the most popular system to synthesize frequencies since it allows tuning the operating frequency while achieving good noise performances. To make the PLL variable, a VCO is needed and it is the heart of the system.

With the advantage of analog to digital transition in TV broadcasting, a substantial amount of spectrum has become available in the TV bands mainly in rural area. To take advantage of this, frequency diversity technique has a great impact for a better utilization of this spectrum.

The oscillator has designed to take place switching based on the threshold level of rain attenuation on microwave communication. Based that threshold value it will only log to the TV white space frequency whenever attenuation occur on microwave band.

Whenever the threshold level is below the required value, which is at high rain rate, the operating frequency of oscillator will shift from the microwave frequency to TV white space frequency. Once the threshold value of rain rate become at a required value, the circuit will shift back from TV white space link to microwave link. In other words, the TV white space link acts as a redundancy link for microwave link.

The switching network circuit, which used for band selection was also discussed. A voltage signal had used as control input to vary the output frequency range. The differential and common mode signal was used to create two different frequency of oscillation. The two modes that are even-mode, the parallel-tuned LC-tank takes no part in affecting the oscillation frequency, whereas in the odd-mode, the parallel-tuned LC-tank plays the role on changing the oscillation frequency. Finally comparison of dual band VCO based on major parameters had done.

5.2. Recommendation

There are different recommendations for the future researcher. The first one is more studying required on the area of TV White Space and Cognitive Radio. Cognitive secondary access to TVWS involves detection of the available spectrum holes in the TV band. This will help to determine the exact amount of frequency spectrum on TVWS.

The large band gap between the higher and lower frequency of operation requirement will makes the fully integrated VCO design more challenging to meet low phase noise requirement for the application.

Other suggestions to include integrating the design with a mixer and LNA to test its performance in a front-end system, and using more lumped components to further increase the performance of the circuit.

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APENDIXES

Apendix-1

Table 5 ITU-R Parameters for the Estimation of Specific Attenuation

Frequency(GHz)	K_H	α_H	K_V	α_V
1	0.0000259	0.9691	0.0000308	0.8592
1.5	0.0000443	1.0185	0.0000574	0.8957
2	0.0000847	1.0664	0.0000998	0.9490
2.5	0.0001321	1.1209	0.0001464	1.0085
3	0.0001390	1.2322	0.0001942	1.0688
3.5	0.0001155	1.4189	0.0002346	1.1387
4	0.0001071	1.6009	0.0002461	1.2476
4.5	0.0001340	1.6948	0.0002347	1.3987
5	0.0002162	1.6969	0.0002428	1.5317
5.5	0.0003909	1.6499	0.0003115	1.5882
6	0.0007056	1.5900	0.0004878	1.5728
7	0.001915	1.4810	0.001425	1.4745
8	0.004115	1.3905	0.003450	1.3797
9	0.007535	1.3155	0.006691	1.2895
10	0.01217	1.2571	0.01129	1.2156
11	0.01772	1.2140	0.01731	1.1617
12	0.02386	1.1825	0.02455	1.1216
13	0.03041	1.1586	0.03266	1.0901
14	0.03738	1.1396	0.04126	1.0646
15	0.0448	1.1233	0.05008	1.0440
16	0.05282	1.1086	0.05899	1.0273
17	0.06146	1.0949	0.06797	1.0137
18	0.07078	1.0818	0.07708	1.0025
19	0.08084	1.0691	0.08642	0.9930
20	0.09164	1.0568	0.09611	0.9847
21	0.1032	1.0447	0.1063	0.9771
22	0.1155	1.0329	0.1170	0.9700
23	0.1286	1.0214	0.1284	0.9630
24	0.1425	1.0101	0.1404	0.9561
25	0.1571	0.9991	0.1533	0.9491
26	0.1724	0.9884	0.9780	0.9421
27	0.1884	1.6948	0.1813	0.9349
28	0.2051	0.9679	0.1964	0.9277
29	0.2224	0.9580	0.2124	0.9203
30	0.2403	0.9485	0.2291	0.9129