Analysis of Frequency Stability for Temperature Compensated Crystal Oscillator (TCXO)

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Abstract— *For decades, the quartz crystal has been used for precise frequency control. In the increasingly popular field of wireless communications, available frequency spectrum is becoming very limited, and therefore regulatory agencies have imposed tight frequency stability requirements. There are generally two techniques for controlling the stability of a crystal oscillator with temperature variations of the environment. They are temperature control and temperature compensation. Temperature control involves placing the sensitive components of an oscillator in a temperature stable chamber. Usually referred to as an oven-controlled crystal oscillator (OCXO), this technique can achieve very good stability over wide temperature ranges. Nevertheless, its use in miniature battery powered electronic devices is significantly limited by drawbacks such as cost, power consumption, and size. Temperature compensation, on the other hand, entails using temperature dependent circuit elements to compensate for shifts in frequency due to changes in ambient temperature. A crystal oscillator that uses this frequency stabilization technique is referred to as a temperature-compensated crystal oscillator (TCXO). With little added cost, size, and power consumption, a TCXO is well suited for use in portable devices.*

This paper presents the theory of temperature compensation, and a procedure for designing a TCXO and predicting its performance over temperature.

Keywords— *Crystal, Temperature Compensation, Frequency control, TCXO, Temperature dependent circuit.*

I. INTRODUCTION

In the modern world, a vibrating quartz crystal is the heart of nearly all frequency control devices. Quartz crystal oscillators provide accurate time and are the sources of precise frequency, which are electronic circuits that use the mechanical resonances of vibrating crystals of piezoelectric materials to create periodically varying electrical signals. The frequency stability, cost and size of quartz crystal oscillators has resulted in their ubiquitous usage as a frequency reference in electronic equipment. Crystal oscillators as frequency sources and frequency control components are most widely used in the time and frequency research and production fields, such as the IT industry, Communications, Electronic Instruments, Applied Electronic Techniques, Measurements, Aerospace systems, Radar, Military Industry, etc... In the modern world, a quartz crystal oscillator is the only option for a not too expensive but reasonably precise and stable frequency source. Although some other materials like ceramic resonators have been developed, their frequency stability and accuracy cannot compare with quartz crystals. According to different accuracy, stability and cost requirements, different types of crystal oscillators are employed. The temperature dependence of the crystal resonance is a generally recognized first order perturbation to the frequency accuracy of the crystal oscillator. Compensation of the temperature dependence has resulted in a classification of crystal oscillators based on the different temperature control methods, like SPXO (Simple Packaged Crystal Oscillator), which has no temperature compensation; TCXO (Temperature Compensation Crystal Oscillator), which uses analog or digital temperature compensation circuits; OCXO (Oven Controlled Crystal Oscillator), which uses an oven to control crystal temperature; and DOCXO (Double Oven Controlled Crystal Oscillator), which uses two temperature control ovens, one inside the other, to further improve the stabilization of the crystal temperature relative to variations in the ambient temperature. Many factors affect the frequency stability of an oscillator. These include variations in voltage, time, and temperature. Specifications for frequency stability are expressed as the amount of the divergence from the nominal operating frequency, usually in terms of a percentage or in parts per million (ppm).

There are generally two methods of controlling the instability of an oscillator due to temperature variations of its environment. The first is the method of temperature control. It involves the use of some kind of temperature stable chamber in which the sensitive components of the oscillator are placed. In the case of a crystal oscillator, the crystal is placed in a thermal oven that is held at a constant temperature. This circuit is called an oven-controlled crystal oscillator (OCXO). Generally amazing soundness over wide temperature extents can be accomplished. Be that as it may, there are a few weaknesses. The oven itself is normally a to some degree cumbersome unit that draws a lot of current to keep up a consistent temperature. This altogether confines its utilization in smaller than normal battery fueled electronic gadgets. What's more, an oven-balanced out oscillator needs an underlying warm-up period before it achieves a steady recurrence. In the applications where the size, current draw, and warm-up period are middle of the road, this way to deal with recurrence soundness is generally truly attractive. The second technique is temperature remuneration. This strategy involves the utilization of some sort of temperature subordinate hardware to interface with the reverberating segments of the oscillator. A crystal oscillator that utilizes this recurrence adjustment strategy is alluded to as a temperature-compensated crystal oscillator (TCXO). A TCXO can be actualized with a voltage-variable capacitor (varactor) circuit controlled by a temperature-subordinate voltage (produced either carefully or by thermistor systems), or utilizing explicit temperature-subordinate detached segments to modify the resounding recurrence of the circuit. The upsides of a uninvolved TCXO are: little added size to the general circuit; close to nothing (assuming any) additional present draw; and least warm-up period (the measure of time an oscillator circuit requires for self warming impacts to end up uniform and steady). In the event that the recurrence control necessities for a specific plan are not appallingly stringent (for example recurrence steadiness ~ ±2ppm over a working temperature go from – 20°C to +70°C), a temperature repaying circuit can be totally actualized utilizing discrete simple temperature-delicate segments.

This project presents the theory of temperature compensation, and a procedure for designing a TCXO and predicting its performance over temperature. First, the equivalent electrical circuit model and frequency stability characteristics for the AT-cut quartz crystal are developed, followed by a discussion on the theory of temperature compensation. Next, procedures for measuring a crystal's equivalent circuit parameters and frequency-temperature characteristics are described. A TCXO circuit topology is then introduced and equations are derived that express the frequency stability of the crystal oscillator as a function of the crystal's capacitive load. Finally, an example of the TCXO design process is demonstrated with the aid of a MATLAB script.

II. TCXO DESIGN

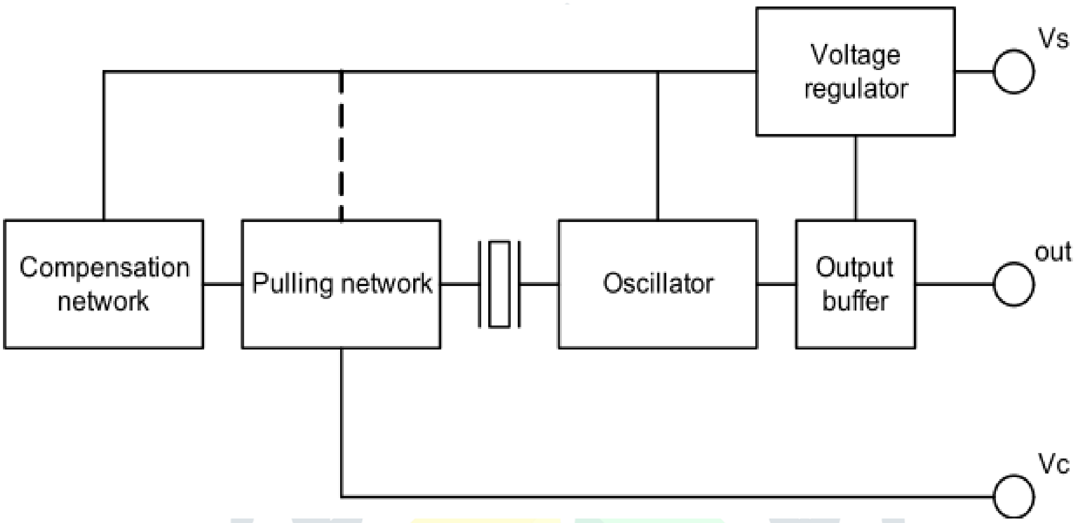


Fig.1 Block diagram for TCXO

Compensation network:

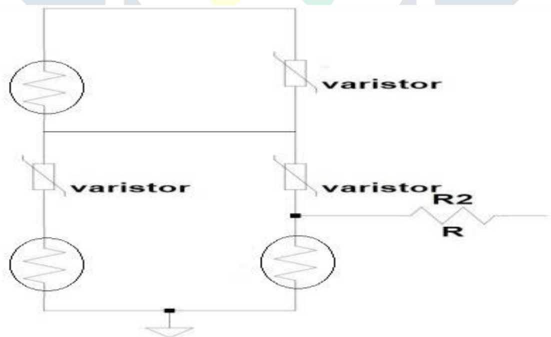


Fig.2 Compensation Network

The compensation network is the key to the operation of the whole system. An approximate curve for the temperature frequency response of the oscillator is seen above. In the compensation network Thermostats are used which are temperature dependent resistors that is used to correct the resistance value to compensate the ideal curve.

Oscillator pulling circuit:

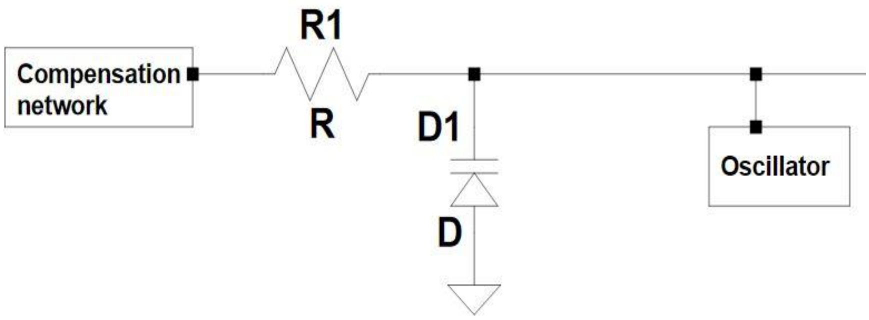


Fig.3 Oscillator pulling circuit

Once the voltage has been generated, this is applied to a circuit that can pull the frequency of the crystal oscillator. Typically this incorporates a varactor diode and some Band pass filtering. The capacitance of the varactor diode is adjusted for compensation purpose. Recurrence pushing is a proportion of the affectability of the oscillator yield recurrence to supply voltage, which is communicated in MHz/volt. Recurrence Pulling is a proportion of the recurrence change in light of a non-perfect burden. Them two influence the oscillator hardware and in a roundabout way the drive dimension of resonator and burden reactance. The adjustment in burden impedance alters the stage or sufficiency of the flag reflected into the oscillator circle, which changes the recurrence of the oscillators. The impacts can be lessened by utilizing a cushion enhancer and a low clamour voltage controller. They are not in the determinations of these oscillators. So for picking high recurrence precision oscillators, (for example, OCXOs with recurrence exactness of a few ppb) as framework segments, recurrence pushing and recurrence pulling may not be considered.

Crystal oscillator:

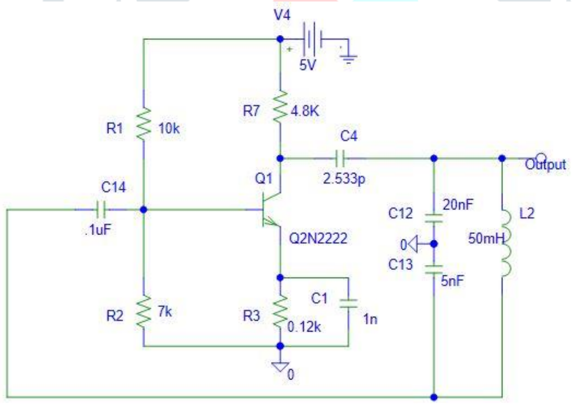


Fig.4 Colpitts oscillator

The oscillator circuit is normally a standard circuit, but one that is designed to give the operating conditions for the crystal with ideal drive levels, etc. The crystal will have all the undamped, damped oscillations. The crystal oscillator makes the Undamped oscillations continuous by giving a part of output again to the input side. So the Oscillator makes Signal levels remains constant throughout the process.

Buffer amplifier:

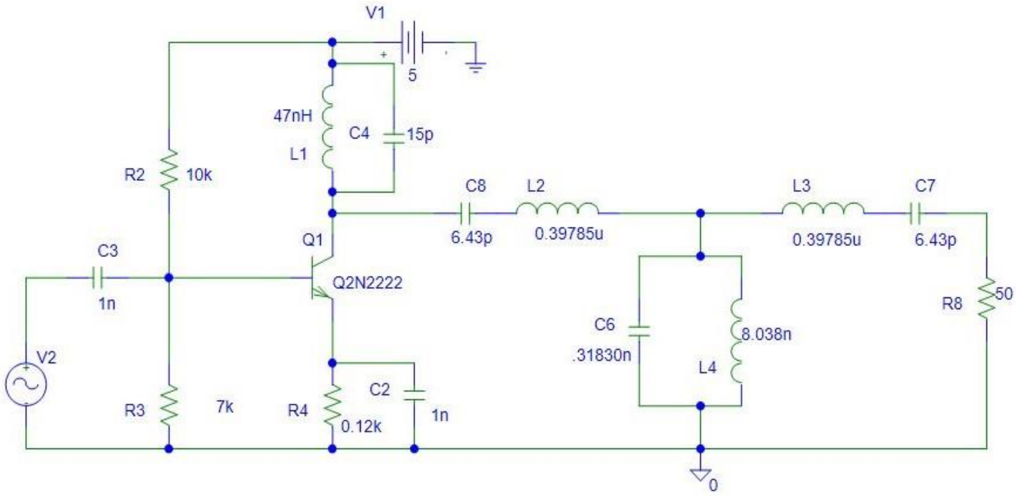


Fig 5 Amplifier with Bandpass filter

A buffer amplifier is required to give the increased drive to the output. It should provide isolation to the crystal oscillator from any external load changes that may be seen. Its then further connected to a bandpass filter to get a particular signal output.

Voltage regulator: In order to prevent external voltage changes from introducing unwanted frequency shifts, the overall TCXO should incorporate a voltage regulator which itself should not introduce unwanted temperature effects. In this project variable voltage regulator is used so that different voltage level regulation can be done as per requirement using biasing resistors. The voltage regulator used is LP2951,3 and RH1965.

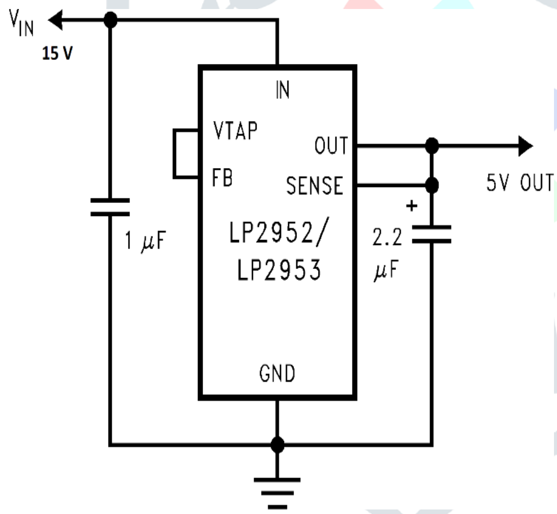
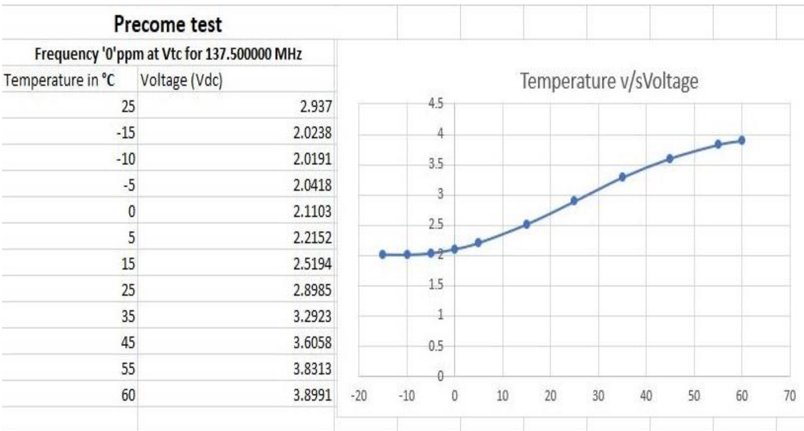


Fig.6 Block diagram of voltage regulator

III. Experimental Setups

(a) Precome test:


Precome test

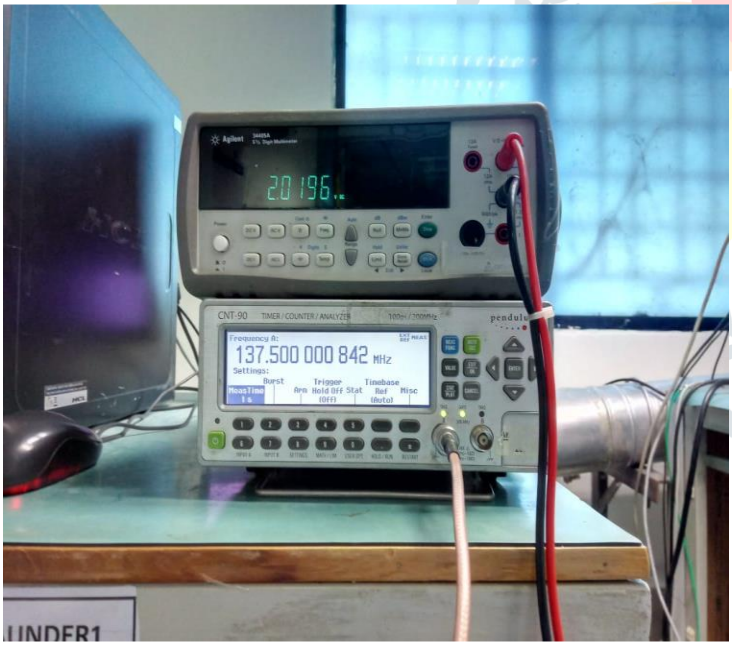
Frequency '0'ppm at Vtc for 137.500000 MHz	
Temperature in °C	Voltage (Vdc)
25	2.937
-15	2.0238
-10	2.0191
-5	2.0418
0	2.1103
5	2.2152
15	2.5194
25	2.8985
35	3.2923
45	3.6058
55	3.8313
60	3.8991

Fig.7 Precome Test setup

Fig.8 Result of Precome Test

Precome test is where the crystal is enclosed in an air tight chamber, where in which temperature can be varied in wide range to study the behaviour of the crystal in different temperature. In this experimental setup the temperature is varied from -15 to 60^0 C and it is kept in that temperature for an average of 15 minutes and the dc voltage is noted down and the graphs are plotted according to the output values, and the crystal characteristics and observed and then that values are put in the genetic algorithm tool of MATLAB software and compensation is achieved.

(b) Harmonics test



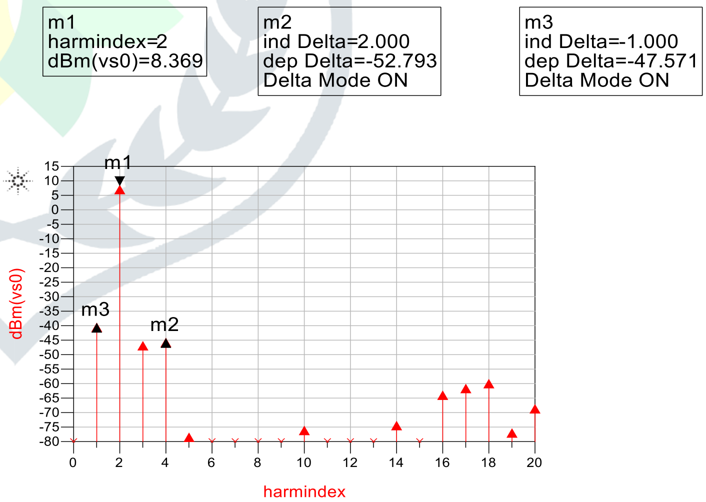


Fig. 9 Harmonic test setup

Fig. 10 Result of Harmonic test

The harmonic substance in the yield of an oscillator is more often than not of little significance and levels superior to anything 30dB underneath the crucial are promptly accomplished. A lot higher attenuation of harmonics might be accomplished when a specific harmonic falls on a basic recurrence as in a touchy recipient yet care must be taken to maintain a strategic distance from the re-age of the undesired harmonic when the oscillator flag is handled by the originator hardware. Sub-harmonics are available at some dimension when the yield of the oscillator is duplicated from a lower recurrence precious stone oscillator. The term sub-harmonic ought to be unmistakably characterized in the determination since a last yield recurrence might be accomplished with various precious stone frequencies and increase factors.

(c) Noise frequency test:

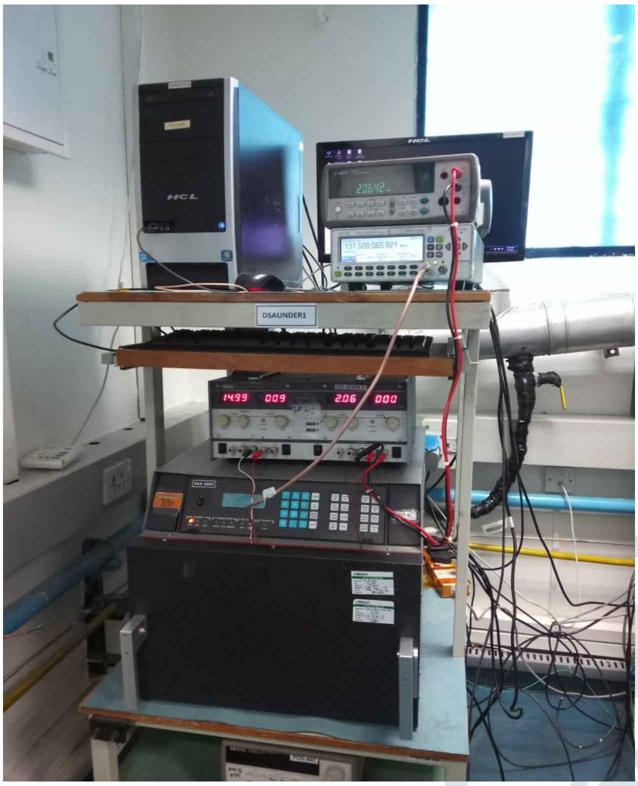


Fig.11 Noise frequency test setups

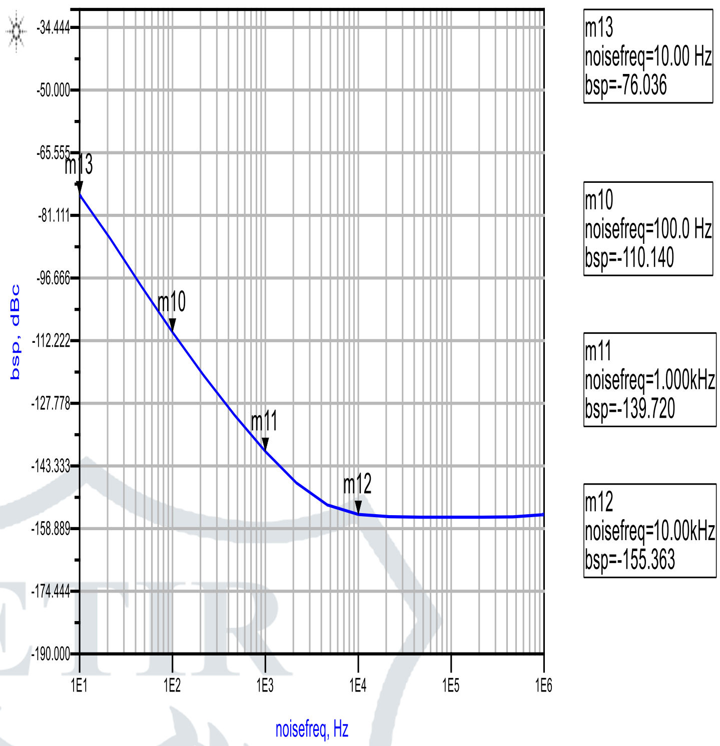


Fig.12 Result of Noise frequency test

There will be always noise present in any applications which includes oscillations and voltage. In this test the amount of noise which is present in the output waveform is measured and reduced by suitable methods and appropriate output signal is generated.

IV. Overall Results and DiscussiFig.13 Power Level Measurement

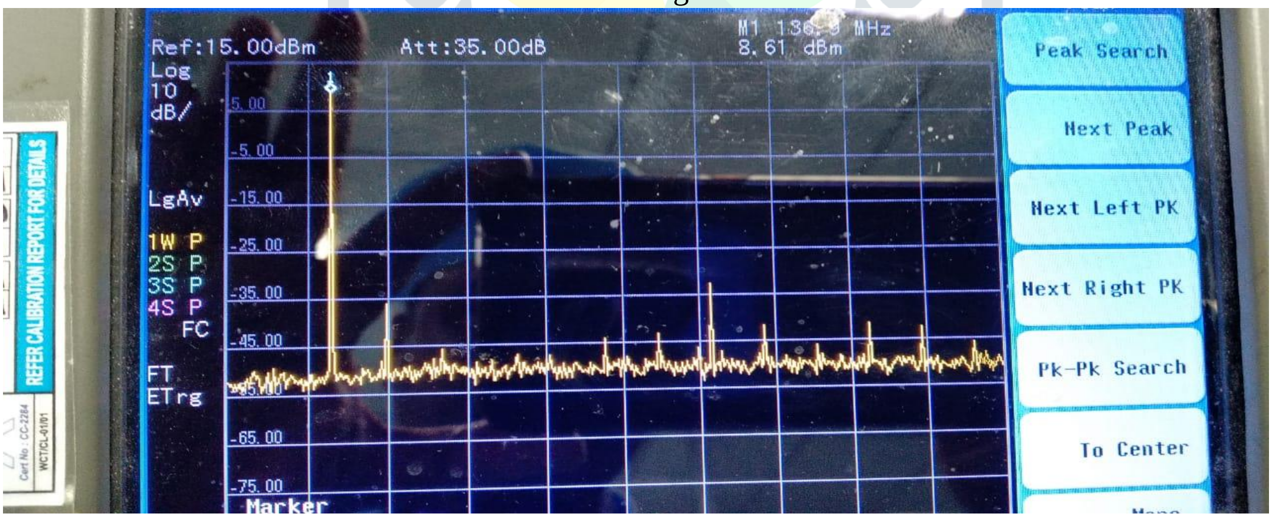
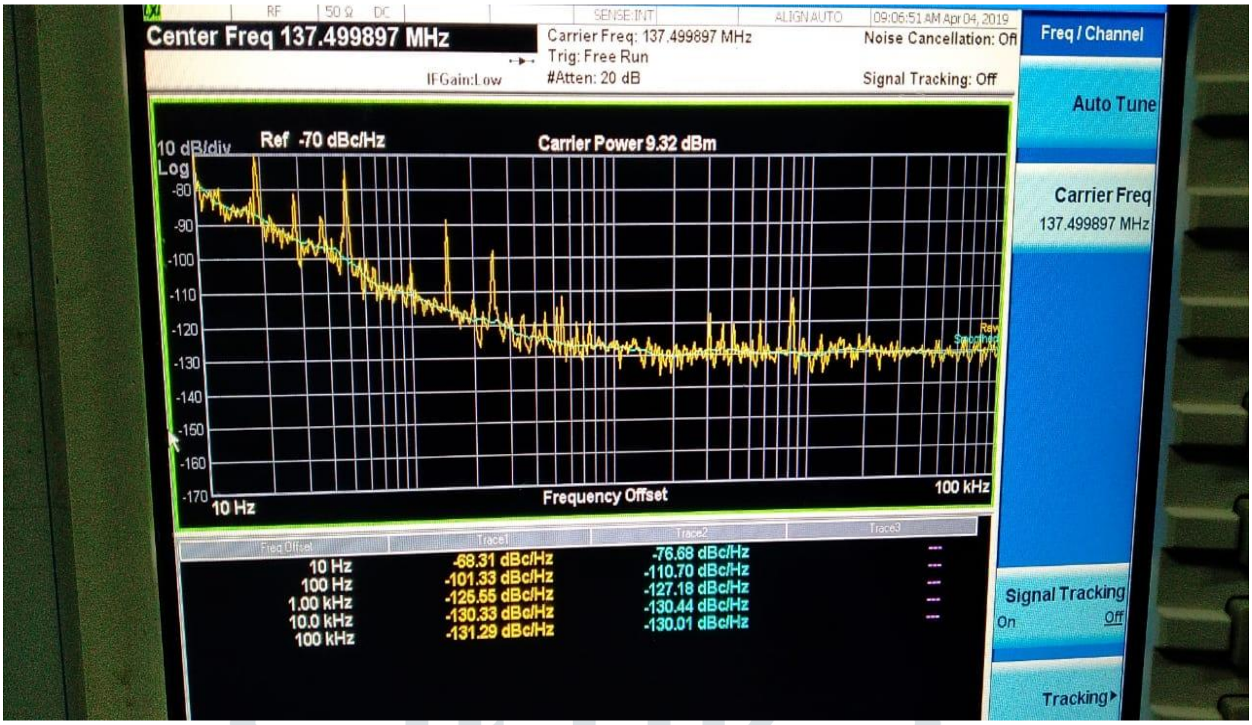


Fig. 14 Noise Measurement



In the results both the power level measurement and the noise measurement is shown, this is done to check whether the required output is generating after all the corrections in the output by the above tests done.

V. Conclusion

This paper presented the theory of temperature compensation of crystal oscillator is achieved by a thermistor network and a varactor diode. The design for Temperature compensated crystal oscillator (TCXO) is done by using compensation network, which is more reliable than Oven controlled crystal oscillator in terms of power and cost. TCXO is used in various applications like Radar Tracking, Aircraft, Microwave Receiver, local oscillator etc. A wide range of research is going on to improve the stability of oscillators for a long duration with maximum efficiency.

VI. Acknowledgement:

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VII.References:

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