Impact of Insulation Resistance of MLC Capacitor on Hysteresis Parameter of an OCXO

Kamalkumar S
R and D
Rakon India Pvt. Ltd.
Bangalore, India
Kamalkumar.s@rakon.com

Nalini CV
R and D
Rakon India Pvt. Ltd.
Bangalore, India
Nalini.cv@rakon.com

Chandrashekar M
R and D
Rakon India Pvt. Ltd.
Bangalore, India
Chandrashekar.mariyappa@rakon.com

Summary-Experimental study done to estimate and identify the degradation of Hysteresis parameter of an OCXO, revealed the dependency of IR value of MLCC. Lower the value of IR results in nonlinear behavior of capacitance over temperature range due to high leakage current in MLCC. Due to which temperature sensitivity of OCXO becomes nonlinear and frequency output follow nonlinearity, results in increased hysteresis error. This analyses sensitize and bring effectiveness in selection of MLCC for OCXO.

Key words: OCXO, MLCC, IR, CMOS, SMD, Hysteresis, response time, Insulation resistance, leakage current, Hysteresis.

I. INTRODUCTION

This paper demonstrates the relation between an insulation resistance of MLCC and Hysteresis parameter of an OCXO. Hysteresis of output frequency is a key parameter of an OCXO, which directly links with thermal behavior of the components

This is the first time that we have established relationship between Hysteresis of an OCXO over temperature and IR parameters of MLCC which is a part of Temperature control section of an OCXO. The paper details about the behavior of MLCC of different suppliers with different IR values over temperature range with respect to variation of capacitance of capacitor and also details on the change in Oven response time based on IR value. Magnitude of leakage current of MLCC depends on the different IR value.

II. METHODS/RESULTS

Multilayer chip capacitor (MLCC) plays a key role in defining Hysteresis performance of an OCXO. Analysis was done on different parameters of MLCC and found Insulation resistance (IR) of Capacitor has a direct impact on Hysteresis parameter of an OCXO

Identified capacitor belongs to temperature controller section of OCXO, defines temperature response time (τ) of an Oven and τ has a relation with Insulation resistance. Low IR increases leakage current of MLCC over range of temperature (-40 °C to 85°C) which results in nonlinear variation of capacitance and this will directly impact on the response time of OCXO against the ambient temperature changes.

Experiments conducted on SMD OCXOs of 10MHz, 5V CMOS output to estimate the dependency of hysteresis on insulation resistance of identified MLCC(2.2UF X7R 0603) in Temperature control section

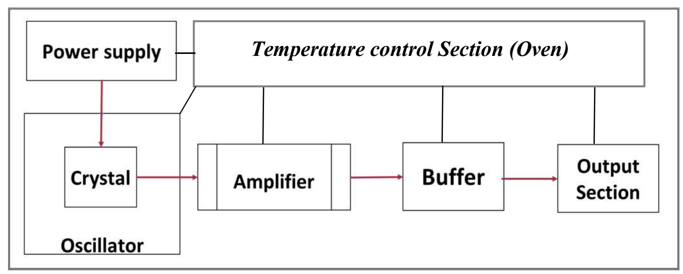

Fig. 1. Block diagram of OCXO

Fig.1 shows block diagram of OCXO, where the paper concentrate mainly on Temperature control section (Oven). OCXO temperature control section is designed to maintain Oven set temperature internal Temperature and all components inside OCXO subjected to set temperature throughout the operating life. Performance of the temperature control section plays important role in hysteresis parameter of OCXO and hence behavior and selection of each component is critical.

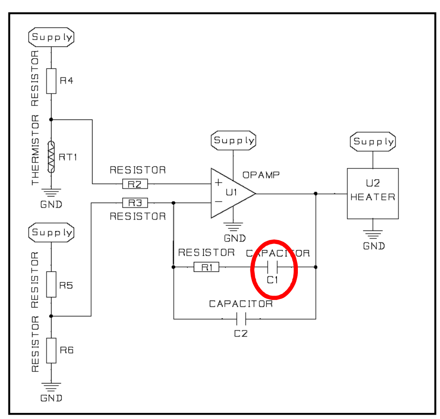

Fig. 2. Temperature control section of OCXO and C1

Capacitor C1 is a part of Temperature control section as shown in Fig.2 and Change in value with respect to temperature result in huge impact on hysteresis. C1 together with Resistor R1 defines the oven response time of temperature control section. Different IR value of C1 changes the Hysteresis performance of OCXO.

Based on the test results and experimental studies conducted, it is confirmed, Higher the value of IR of capacitor better the Hysteresis performance. This was confirmed on samples as detailed in the Tabel1. OCXO samples from Supplier 2 capacitor with IR value less than 300MOhms resulted in degraded hysteresis performance greater than ±0.5ppB. Whereas OCXO samples from Supplier1 capacitor with IR value more than 1G Ohms resulted in Good Hysteresis performance less than ±0.3ppb over temperature range -40 to 85Deg.

In General, Insulation resistance depends on the capacitance value of a capacitor and remains same for different packages and voltages.

Based on the Experiments, minimum IR required for C1 is > 500M Ohms. IR Changes with respect to variation of temperature from -40Deg to 85Deg corresponds to 0.3eV activation energy, which is lower compared to the conductivity of ceramic materials. Requirement is relaxed for the MLCC with High volumetric efficiency. For Example, 2.2uF, 0603 package capacitor has 500Mohms where as 1uF capacitor with same package has 1G Ohms of IR value.

The value of IR for both commercial and military MLCCs are not dependent on Size and rated voltage and inversely proportional to Capacitance of the capacitor. This gives the information that the resistivity ρ of ceramic MLCCs is constant as in Eq. (1),[1]

$$IR = (\rho \times \varepsilon \times \varepsilon 0)/C \quad (1)$$

Where ε - Dielectric constant
This denies to study data that reflects the leakage currents and ρ, changes noticeably with the Electric field. The Insulation Resistance value defined as the ratio of rated voltage to the current measured after 2 minutes of supply voltage.

Considered MLCC from two different suppliers for experimental study, Where Supplier 1 has IR > 1GΩ and supplier 2 has IR < 300 MΩ.
OCXO with Supplier 1 capacitor (high IR) has low hysteresis error compared to low IR capacitor from Supplier 2 as shown in Fig 3 and Fig 4, plotted with frequency variation over a range of temperature in terms of voltage. OCXO hysteresis response with Low IR capacitor is not consistently varied with respect to variation in temperature, which results in wide loop characteristic behavior of > ±0.5ppb .This is considered as failure against the specification of ±0.3ppb.

OCXO hysteresis response with High IR capacitor is maintained consistent with respect to variation in temperature, results in narrow loop characteristics behavior as shown in Fig 4 is < ±0.3ppB.

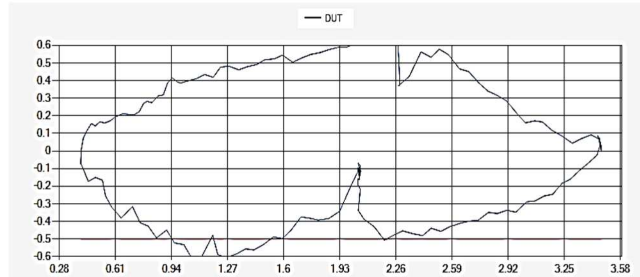

Fig 3: OCXO with Supplier 2 capacitor with low IR corresponding Hysteresis behavior over range of temperature in terms of voltage.

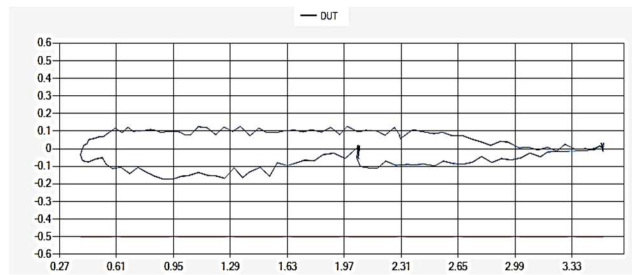

Fig 4: OCXO with Supplier 1 capacitor with high IR corresponding Hysteresis behavior over range of temperature in term voltage

Estimated the impact of C1 with different value of IR on Temperature control section (Oven) response time over a range of temperature 25 to 100Deg, as shown the Fig 5

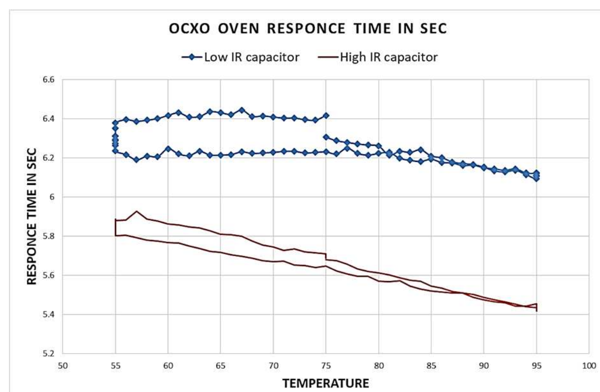

Fig 5 Variation of response time of an OCXO

Considered MLCC from failed OCXO for Hysteresis performance to estimate response time with Low IR value capacitor resulted in volatile behavior with respect to change in temperature and OCXO with High value of IR, resulted in Narrow distribution and constant in variation of response time with respect to temperature.

Capacitors removed from failed OCXOs and subjected for below mentioned tests:

1. Measured capacitance and IR value for the capacitors from failed OCXOs (Hysteresis failed) as shown in Table1.

TABLE 1 REFLECT THE DETAILS ON IR VALUE MEASURED ON CAPACITORS C1 FROM FAILED OCXOS AND HYSTERESIS VALUE.

Component	**Cap(uF)**	**IR(MΩ)**	
Equipment	**HP-4278A**	**Agilent 4339B**	
Condition	**1Vrms 1KHz**	**10V, 120sec**	**OCXO Hysteresis**
Specification	**1.98~2.42**		**< ±0.5ppB**
Supplier2- Sample 5	2.34	289	> ±0.5ppB
Supplier2- Sample 6	2.32	301	> ±0.5ppB
Supplier2- Sample 7	2.32	295	> ±0.5ppB
Supplier2- Sample 8	2.31	303	> ±0.5ppB
Supplier2- Sample 9	2.27	296	> ±0.5ppB

2. Replace the low IR capacitor C1 with High IR capacitors on the same OCXOs and tested for Hysteresis parameter, Measured capacitance and IR value for the capacitors from failed OCXOs as shown in Table2

TABLE 2 REFLECT THE DETAILS ON IR VALUE MEASURED ON CAPACITORS C1

Component	**Cap(uF)**	**IR(MΩ)**	
Equipment	**HP-4278A**	**Agilent 4339B**	
Condition	**1Vrms 1KHz**	**10V, 120sec**	**OCXO Hysteresis**
Specification	**1.98~2.42**		**< ±0.5ppB**
Supplier1- Sample 1	2.27	1224	< ±0.3ppB
Supplier1- Sample 2	2.24	1055	< ±0.3ppB
Supplier1- Sample 3	2.22	1032	< ±0.3ppB
Supplier1- Sample 4	2.26	1213	< ±0.3ppB

III. DISCUSSION/INTERPRETATION

1. Method of Measurement -IR value

The Agilent 4339B Electrometer/High Resistance Meter used to measure the IR and capacitance of the capacitor. The accuracy of the measurement is with ±0.6% and a maximum resistance measurement of 10^5 Ω to 10^{15} Ω. The IR and leakage current can be measured in two basic methods series and parallel methods as shown in Fig 4 and Fig 5.

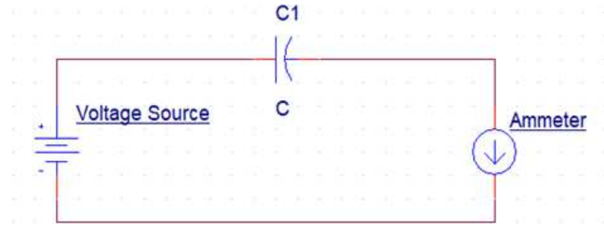

Fig 4 Series Method for Insulation Resistance Measurement [2]

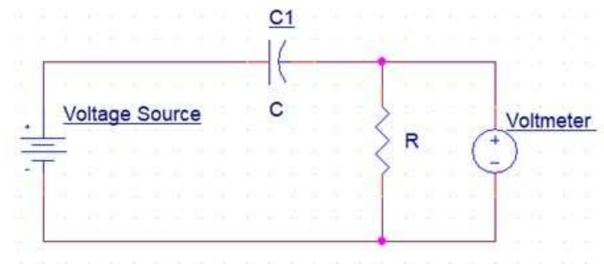

Fig 5 Parallel Method for Insulation Resistance Measurement [2]

In the series method, a High Resistance meter is placed in series with the capacitor and voltage source.
In this measurement, we applied a rated voltage to the capacitor for 120sec based on the capacitance and measure the leakage current flowing through capacitor after fully charged. Current will start to decrease and level off as shown in Fig 6 this is called as Leakage current.

Then we can calculate the insulation resistance of MLCC by ohm's law, R = V/I.[2]

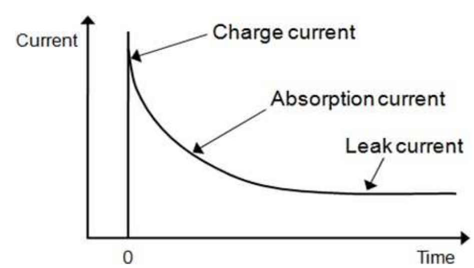

Fig 6 Behavior of MLCC current vs. charging time [2]

Note three distinct current levels: charge current (peak MLCC current), absorption current (exponential decay due to device RC time constant) and steady-state leakage current.

MLCCs are made of dielectric material which is non zero loss and practically not a perfect insulator hence there will be a certain leakage current based on type of dielectric material and different dielectric material used to have different IR value because of composition of different materials . Therefore there are few reasons for lower IR and High leakage currents such as Moisture, Temperature experienced by capacitor, dielectric contamination, Loss of Volatile materials, Oxidation, material cracking. IR value measurement is really useful in determining extent to which the Insulation property have been affected due to deteriorative influences and also helpful to determine if the MLCC is Low Quality or counterfeit

2. *Measure hysteresis of capacitance of a capacitor over range of temperature 55°C to 100°C as shown in Fig 7.*

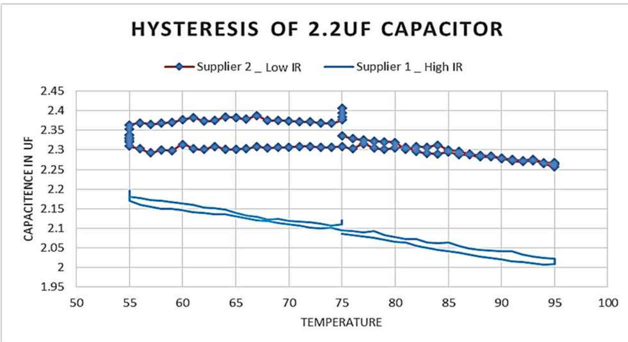

Fig 7 Variation of capacitance of capacitor over a range of temperature

Removed the Low IR value capacitor from the failed OCXO and tested for capacitance over a range of temperature 55Deg to 100Deg. Plotted wide loop of capacitance value, capacitance value at same temperature at different instant of time is with different value. Capacitance is volatile with respect to change in temperature as shown in Fig 7_dotted line same test conducted on the High IR value capacitor and noticed narrow spread of capacitance over temperature range. Capacitor with High IR value is nonvolatile in nature and behaving good hysteresis characteristic as shown in Fig 7_solid line

3. *Measure the leakage current of a MLCC over range of temperature 25°C to 100°C as shown in Fig 8*

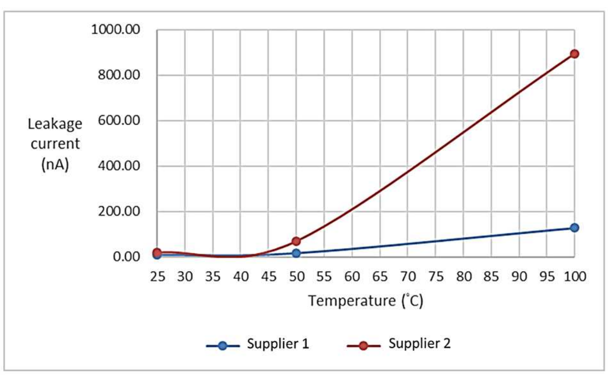

Fig 8 Leakage current of a MLCC over range of temperature

Capacitor from failed OCXO with Low IR value and High IR value are subjected to leakage current measurement over range of temperature 25deg to 100Deg, the trail clearly distinguished the reason for hysteresis failure by high leakage current with failed capacitor and very low leakage current with Good hysteresis capacitor.

The analysis will give a good knowledge on selection of MLCC for an OCXO with respect to insulation resistance.

IV. Conclusions

Identification of suitable alternate MLCC is highly challenging for the current developments in 5G technology, based on the critical requirements at 5G application, selection of MLCC need a detailed study and implementing for mass production with High quantity will face different challenges in preventing alternate part entry into the supply chain.

In this paper we have detailed about the performance, importance and impact of MLCC from different suppliers with different IR values and leakage current on OCXO performance. Several tests that help to identify suitable MLCCs based on application. Based on the electrical characteristics of OCXO with different values of IR capacitors, we can use a IR value testing method to test IR value measurement over temperature range as detailed in paper.

Hysteresis of an OCXO is dependent on Insulation resistance of a MLCC, lower value of insulation resistance would degrades and higher value improves the performance of frequency hysteresis over range of temperature. This paper sensitize on selection of MLCC for an OCXO application and helpful to Electronics industries on selection of right MLCC for specific application.

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