NOISE RELIABILITY INDICATORS IN SMT CHIP RESISTORS

Miloš Chvátal
Doctoral Degree Programme (1), FEEC BUT
E-mail: xchvat03@stud.feec.vutbr.cz

Supervised by: Jan Pavelka
E-mail: pavelka@feec.vutbr.cz

ABSTRACT

The possible exploitation of low frequency noise and non-linearity measurements for thin film resistor characterisation is presented. The low frequency noise spectrum is of the $1/f^{a}$ type and it is due to two sources: fundamental quantum $1/f$ noise and excess $1/f$ noise. It is frequently observed that excess $1/f$ noise is related to the microscopic sample structure and the manufacturing technology. The non-linearity of A-V characteristic is proportional to the distortion of pure harmonic signal applied to the measured sample. Carrier transport in thin resistive layers is not strictly linear and the third harmonic voltage is proportional to the third power of electric field intensity or current density.

1. INTRODUCTION

In the last decade $1/f$ noise in resistive layers has been extensively studied. It became evident that occurrence of $1/f$ noise can serve as a measure of the technology standard. We concentrated our efforts on $1/f$ noise in metallic films to find correlation between the occurrence of $1/f$ noise and non-linearity of the U-I characteristics and generally the manufacture technology.

The main problem consists in the identification of the source of this kind of noise. Current theories of $1/f$ noise assume that there are two sources of $1/f$ noise, namely, i) fundamental quantum $1/f$ noise and ii) excess $1/f$ noise. According to Hooge [1], $1/f$ noise is due to carrier mobility fluctuations.

It is frequently observed that excess $1/f$ noise is related to the microscopic sample structure and the manufacture technology. This kind of noise is particularly sensitive to surface and interface defects [2]. There are manufacture techniques which give small dispersion of the mean characteristic values, such as resistance or currents. On the other hand these devices can exhibit large dispersion of the noise characteristics. So, for example, metal thin film resistors have lower $1/f$ noise than granular film resistors made from cermet thick films or carbon resistors.

The resistor noise is proportional to the current density and this property makes it a valuable characteristic for detection of imperfections and abnormalities in many types of resistors. The main advantages of noise measurements are that the tests are less destructive, faster and more sensitive than DC measurements after accelerated life tests.

Third harmonic testing is an in-line screen frequently used by manufacturers in the USA and Europe to detect and eliminate potential infant mortal failures in passive components. The test is fairly rapid and convenient. It is important that the associated equipment is relatively inexpensive. Third harmonic testing is used with several different types of thick and thin film resistors. Such screening is occasionally advertised, thus, as a general means of ensuring reliable behaviour of part that pass this test. Main question is included in correlation between third harmonic test rejects and long-term reliability test rejects.

2. NOISE MEASUREMENT TECHNIQUE

2.1. MEASUREMENTS OF NOISE SPECTRAL DENSITY

The block diagram of the basic apparatus is shown in Fig. 1. Measuring set-up consists of noise voltage source, low impedance low noise preamplifier, optional passive LP or HP filter and also with computer which is served for processing of measured data and in our case also for controlling preamplifier.

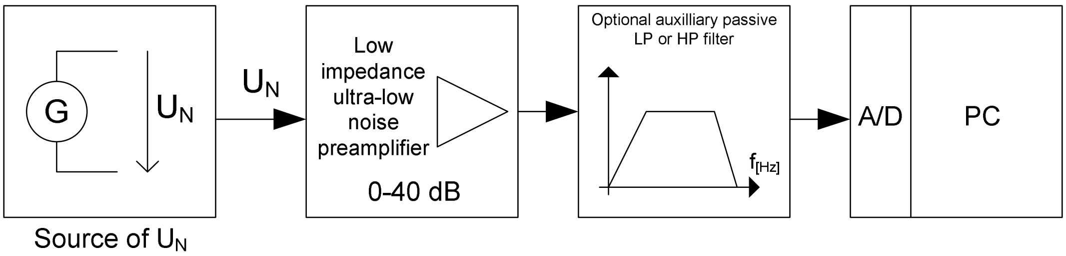


Fig. 1: Block diagram of the experimental set-up

Noise signal, which is a random physical process, is fetched to low noise amplifier where the extremely low signal is amplified to the level, which is acceptable for further processing with A/D card in a computer. Due to low level of noise signal mentioned above, we require unique properties of the amplifier, the emphasis is laid especially on amplification (typically 100 dB and more) and also on intrinsic noise of the amplifier (exemplary 10^{-18} V^2/Hz), which must be much lower than level of measured noise. Amplifier is also equipped with selective filters (slope at least 40 dB/decade) to obtain amplified signal in a selected narrow band and communication interface for controlling its functions by computer. Schematic of the noise set-up is shown in Fig. 2. where R_x is the measured sample and R_L is the load resistance. Load resistance was 22 kΩ for measured resistors.

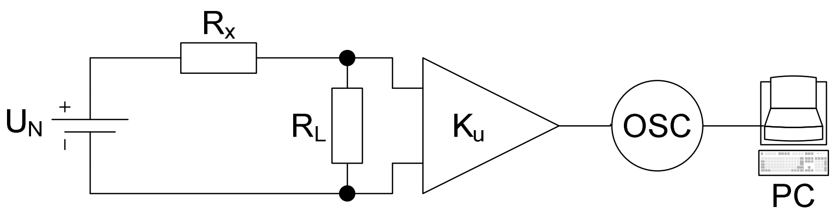


Fig. 2: Schematic chart of the noise experimental set-up

It is necessary to keep certain conditions during the measurement to obtain correct interpretation of measured data. The main effects which may affect measured data are:

- modification of temperature or field strength of magnetic or electric field during measurement,
- parasitic signal 50 Hz,
- decrease of power supply voltage.

All technologies give rise to approximately the same behaviour from the point of view of the $1/f$ noise.

The general empirical relation for voltage noise spectral density is given by:

$$S_U(f) = C\frac{U^\beta}{f^\gamma}, \tag{1}$$

where $\beta = 2$, and $\gamma = 1$, constant C can be expressed using Hooge parameter α_H and the total number of particles, taking part in the conduction process.

$$C = C_Q = \frac{\alpha_H}{N}, \tag{2}$$

where C_Q is a dimensionless parameter unlike parameter C dimensioned in general case, that's why C_Q can be used as quality and reliability indicator for thick film resistors.

From (1) and (2) we can express:

$$C_Q = \frac{\alpha_H}{N} = S_U(f)\cdot\frac{f}{U^2}. \tag{3}$$

This indicator has been used for resistor quality and reliability evaluation for many years.

2.2. MEASUREMENTS OF THIRD HARMONIC

The measuring method is based on the distortion of the first harmonic signal by non-linearity of resistance [3, 4]. It can be shown, that the number of harmonics can approximate any kind of voltage time dependence with different amplitudes superimposed upon the basic frequency. If an ac voltage is applied to a component, where the current paths consist of perfect elements the corresponding current will exhibit a true picture of the applied signal. In this case the transmission is linear. If the elements on the other hand are imperfect, the current will be distorted and will generate a voltage inside the component that will produce a correspondingly distorted signal. We can tell that in passive components, like resistors, the non-linearity is connected with physical anomalies [5].

For the resistor quality evaluation the non-linearity indicator NLI can be used:

$$NLI = -20\log(U_3/U_1^{\,3}), \tag{4}$$

where U_3 is the third harmonic voltage and U_1 is the first harmonic voltage, both in volts [V]. When the same value of the first harmonic voltage is applied to all samples the value of the third harmonic voltage U_3 can be used as the indicator for the sample quality evaluation.

3. RESULTS

Measurements were carried out for two groups of samples denoted as A and B. Ten samples of SMT chip resistors were in each group. The resistance of all measured samples was 22 kΩ.

3.1. MEASUREMENTS OF NOISE SPECTRAL DENSITY IN SMT CHIP RESISTORS

The noise spectral density for all samples can be described as a superposition of $1/f^a$ noise and thermal noise. The voltage fluctuation spectral density S_U versus frequency plot for resistor A01 is shown in Fig. 3. The plot consists of two components, namely, *a* - thermal noise, whose spectral density $S_{UT} = 4kTR$, and *b* - $1/f$ type noise.

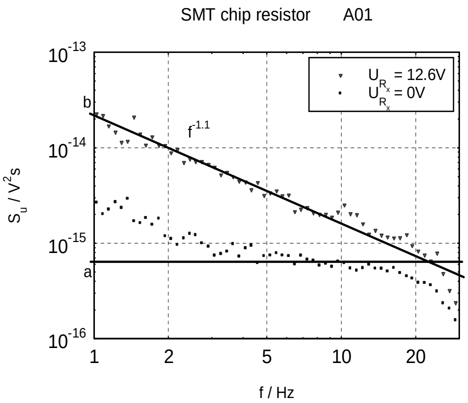
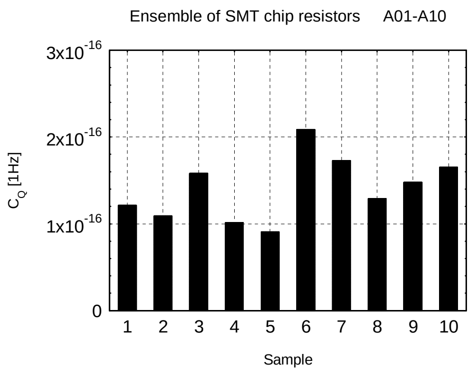
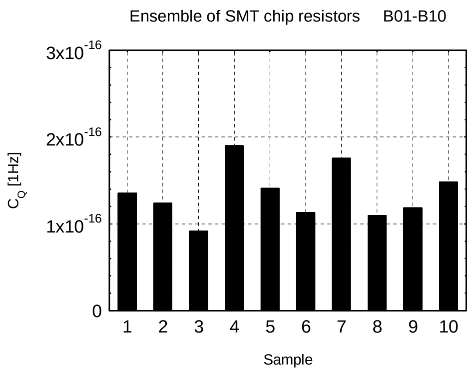


Fig. 3: The voltage noise spectral density of SMT chip resistor sample A01

Indicator C_Q calculated for measurement resistors is shown in Fig. 4.



a)



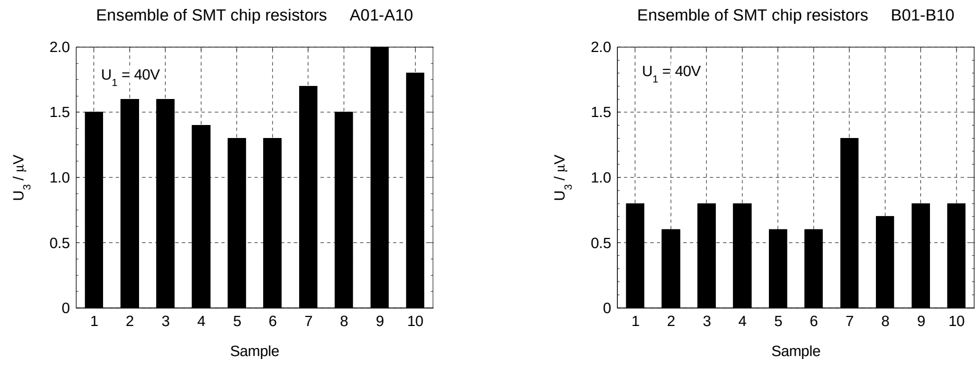
b)

Fig. 4: The normalized noise voltage spectral density at 1Hz of samples

a) A01 to A10, b) B01 to B10

3.2. MEASUREMENTS OF NON-LINEARITY IN SMT CHIP RESISTORS

Non-linearity of thick film resistors is proportional to the distortion of pure harmonic signal applied to the sample. The measure of this distortion is the amplitude of third harmonic signal U_3. The results measured for our samples are shown in Fig. 5.



a) b)

Fig. 5: Non-linearity measurement of samples a) A01 to A10, b) B01 to B10

4. CONCLUSIONS

The aim of the article was to find the quality and reliability indicators based on the evaluation of low frequency noise and transport characteristics of thick film resistors. Noiseless resistors with a very low 1/*f* component are more stable in the course of stressing. For reliability prediction noise parameters, such as the noise quality indicator C_Q and the third harmonic voltage U_3, can be used. The mean value of C_Q and U_3 of samples A is higher than samples B. It follows that samples B are high-quality than samples A.

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