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Some Consideration to Uncertainties by Defining the Resistance Value of a Thin Film Resistor

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Abstract – **The accuracy of the resistance value is one of the main characteristics of a precise resistor. One have to ensure narrow tolerances of R of the finished device, getting into account the uncertainties in the design and in the technological processes. This paper deals with some of the factors, producing errors in the initial calculation and the followed manufacturing of the resistor.**

Keywords – **Precise resistor, tolerance, surface resistance, nominal resistance value, construction and technology**

I. INTRODUCTION

The resistor is an electronic element, which dissipates certain power when electric current is flowing trough it. The device serves for current regulation and for voltage divider in the electronic schemes. Manufacturing resistors with thin film metallization creates a physical structure with a big thermal capacity, small dimensions and optimal characteristics using DC, AC or microwave signals [1]. One of the requirements for precise resistors [2, 3] is the *little tolerance* of their resistance value compared to the nominal value.

The realization of this requirement presumes from one site clarity in the theoretical calculations of the nominal resistance of the device, and from other taking into account the constructive and technological errors by their manufacturing.

II. THEORETICAL UNCERTAINTIES BY CALCULATING THE RESISTOR'S VALUE

The main kinds of resistors are "meander" (Fig. 1) or linear (Fig. 2) type. The configuration of the "meander" type is shown below. The resistance of such resistor is given [5] by the formula:

$$\boldsymbol{R}=R_s\left[\frac{lW}{nw^2}-0.08\frac{l}{nw^2}\right]\approx R_s\frac{NW}{a+w}\ [\Omega] \qquad (1),$$

where l,a,W and w are the geometric dimensions of the resistor; $N=\frac{l}{w}$ – is the number of squares in the resistive layer along it's length L, called *form coefficient* and is denoted with k_f; $R_s=\frac{\rho}{d}\ [\Omega/\square]$ - surface resistance of the layer, determined by the specific volume resistance ρ of the layer's material and d - the geometric thickness of the layer.

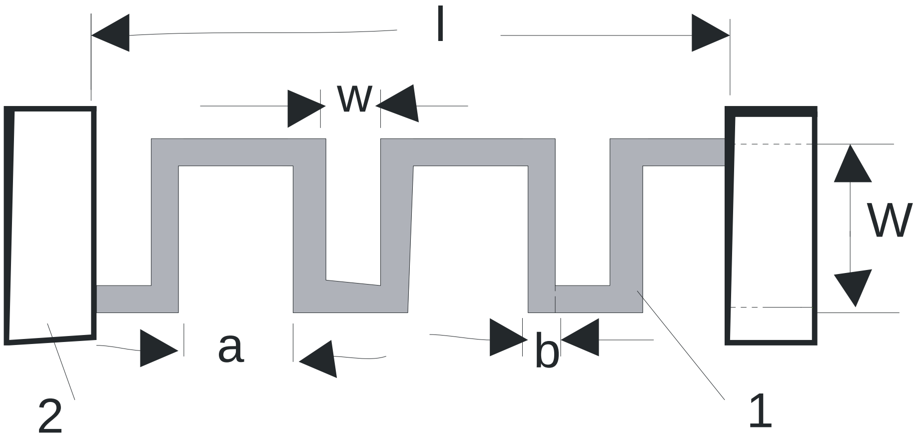

Fig. 1. "Meander" type resistor: ***1.*** resistive layer ***2.***contact

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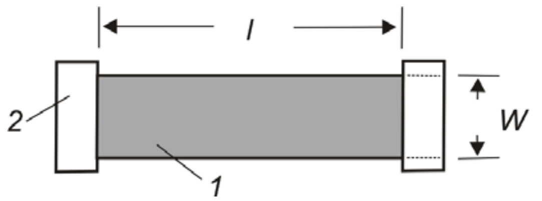

Fig. 2. Linear type resistor

In the approximate form of formula (1) the small contribution of the corner squares in comparison with these from the linear part is neglected. Some authors [4] and manuals [5] accept for designing IC the contribution of a corner square in the total resistance value to be about 50 % of $R_{s.}$. We will use the more accurate form in (1).

Let's express the possible errors on the base of this formula. The absolute error of the resistance ***ΔR*** is expressed by:

$$\boldsymbol{\Delta R}=\frac{\Delta R_s lW}{w(a+w)}+\frac{R_s W\Delta L}{w(a+w)}+\frac{(a+2w)R_s lW\Delta w}{w^2(a+w)^2}+$$

$$+\frac{R_s l\Delta W}{w(a+w)}+\frac{R_s LW\Delta a}{w(a+w)^2} \qquad (2),$$

And the relative ε_R with:

$$\varepsilon_R=\frac{\Delta R_s}{R_s}+\frac{\Delta l}{l}+\frac{\Delta W}{W}+\left(1+\frac{w}{a+w}\right)\frac{\Delta w}{w}++\frac{\Delta a}{a}+w$$

(3)

In the main cases of realized chip resistors and resistor networks a and b are small in comparison with L and then:

$$\varepsilon_R=\frac{\Delta R_s}{R_s}+\frac{\Delta l}{l}+\frac{\Delta W}{W}+\frac{\Delta w(1+\frac{w}{a})}{w}++\frac{\Delta a(1-\frac{w}{a})}{a}$$

$$\cong \frac{\Delta R_s}{R_s}+\frac{\Delta l}{l}+\frac{\Delta W}{W}+$$

$$+\frac{\Delta w}{w}+\frac{\Delta a}{a}\cong \varepsilon_1+\varepsilon_2+\varepsilon_3+\varepsilon_4+\varepsilon_5 \qquad (4),$$

The above expression shows that the full relative error ε_R of the resistors value of a "meander" type resistor is a sum of 5 different relative errors.

Here $\varepsilon_1=\frac{\Delta R_s}{R_s}=\varepsilon_{Rs}$ is the *relative error of the surface resistance*, the other ε_2, ε_3, ε_4 and ε_5 are the relative errors of the geometric dimensions *l, W*, *w* and *a* respectively. The sum of the latter 4 we can denote with ε_g and call *relative geometric* error. Then we get for the total relative error ε_R :

$$\varepsilon_R \cong \varepsilon_1+\varepsilon_2+\varepsilon_3+\varepsilon_4+\varepsilon_5 = \varepsilon_{R_s}+\sum_{i=2}^{5}\varepsilon_i = \varepsilon_{Rs}+\varepsilon_g$$

(5)

The error in the surface resistance ε_{Rs} (first member in (5)) due in general to the change of the main free path <*L*> of the electric carrier inside the layer, which is caused by their scattering. In the volume of metal alloys (NiCr for example), the main mechanisms of scattering are scattering by defects in the crystal structures and by impurities. This reason influences the conductivity of a thin film of a metal alloy. Besides that the change in the thickness of the resistive film along it's length define the different scattering of the electrons by different layer's thickness. Besides that we will mention, that during the formation of the layer close to the dielectric substrate structures not inherent for the bulk species form. At last oxides, nitrides and other dielectric and semiconductor substances are incorporated in the layer during the deposition. This changes the type of conductivity from pure metallic to such one witch is based on the conductivity between neighbor conducting islands and to other type of scattering of the carriers on the borderline between the conducting and dielectric face. All these factors influence simultaneously R_s and TCR are not enough clear theoretically developed, so the processes connected with them are phenomenological described. Their influence upon R_s and TCR on precise resistors is described somewhere [6].

Here we will considerer theoretically the *relative geometric error* ε_g, which is expressed by:

$$\varepsilon_g \cong \frac{\Delta l}{l}+\frac{\Delta W}{W}+\frac{\Delta w}{w}+\frac{\Delta a}{a}\cong \varepsilon_2+\varepsilon_3+\varepsilon_4+\varepsilon_5 \qquad (6)$$

This error is a sum of relative errors, done during achieving the calculated dimensions of the resistors. It dues in general to two kinds of errors: *a)* errors in the photolithographic process – diffraction phenomena, under etch etc. and *b)* errors during the deposition process when masks are used. The typical error from technological point of view is $\Delta a = \Delta w$. Besides that it can be shown that ε_g = min when $a = w$. The theoretical conclusion which can be made is that the minimal sensibility of the resistance *R* to any changes of the geometrical dimensions the most appropriate configuration of the resistor is when the width of the resistor pad is equal to the distance between the inner sides of two meanders. Unfortunately in most cases this condition is in contradiction with requirement for optimal array of the elements in the scheme, so for the final decision one has to make a compromise.

III. Constructive and Technological Uncertainties Connected with the Geometrical Dimensions of the Resistor

Here we will show on the base of examples how by designing a precise resistor an appropriate configuration can be chosen so that the changes in the technological process minimum influence the final resistive value.

It is obvious that the little the resistor geometry the greater the resistors value change due to dimensions changes. This problem is most severe by designing which includes bright range of geometries, where resistor values deviate much from the nominal when technological changes occur. Fig. 3 illustrates the case of high ohm, narrow resistors, which are sensitive to under etching of the resistive layer und bright low ohm resistors, witch are sensitive to under etching of the contacts.

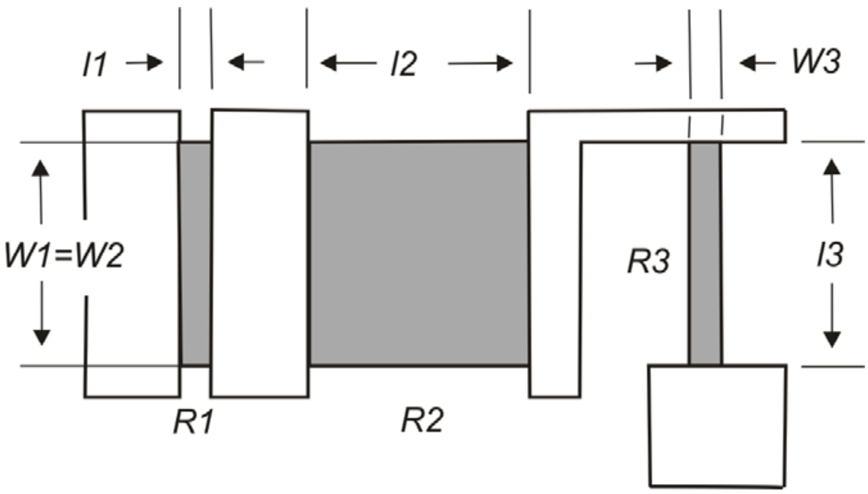

Fig. 3. Constructive possibilities by different dimensions ratio in the resistor

- ***R1*** value increases fast because of contact under etching

Example: A resistor 25µ long and 250µ bright with R_s= 100 [Ω/□] increases its value by 40%, when the contact is under etched both sides by 5µ.

- ***R2*** suggests an optimum ratio of the changes due to under etching of both the resistive film and the contacts.

Example: A resistor 250µ x 250µ with the same R_s= 100 [Ω/□] changes its value only by 4%, if the resistor or contact dimensions changes by 5µ.

- ***R3*** will change rapidly as a result of resistor's under etching.

Example: A 15 µ bright, 150 µ long with R_s= 100 [Ω/□] will change its value by 67%, when under etched from both sides by 5µ.

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