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EXCESS NOISE IN THICK FILM PIEZORESISTORS ON A STEEL SUBSTRATE

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Abstract: The work reports the measurements of the excess-noise coming from the thick-film piezo-resistors (TFRs) deposited on metallic substrates. The purpose of this paper is to single out the best combination of conductive, dielectric and piezoresistive inks in order to minimise the electronic noise. At this purpose a comparison between the excess noise measurements made of the same inks and geometric characteristics but screen printed and fired on alumina substrates, are reported. Moreover, the article gives a description of the measurement instrumentation used and, in particular, of the low noise preamplifiers.
Keywords: thick-film piezoresistors, noise measurement, metallic substrates

1 INTRODUCTION

The earliest evidence of thick-film resistors (TFRs) exhibiting piezoresistance dates back to the early 1970s [1]. However, the first sensor to use this effect did not appear until the early 1980s. Most of the early sensors were screen printed onto conventional ceramic substrates. Research in this area has been intensive and a number of papers reports their characteristics also in terms of noise [2,3,4]. In these papers, the main factors contributing to the excess noise are identified as bulk noise, generated in the volume of the resistor, and contact noise, arising from the region adjacent to the terminations.

Alumina substrates tend to be brittle and can fracture or even shatter if a strain of 700 micro strains, or greater, is applied. Hence, later research was aimed at TFRs printed on steel substrates, which offer a high flexural strength and greater allowable strains than their ceramic counterparts.

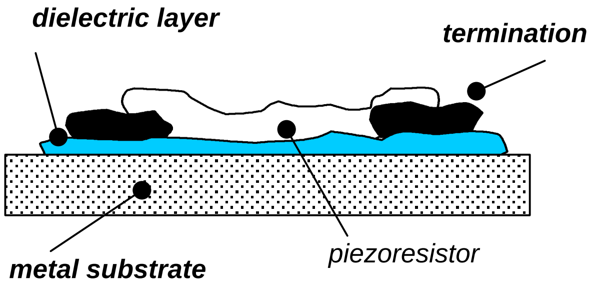
In a previous paper [5] it is shown that is possible to produce TFR strain gauges on stainless steel substrates by using a commercially available dielectric ink for the insulating layer together with standard conductor and resistor pastes. This approach allows gauges to be deposited on steel substrate such as load cell billets and cantilever beams at relatively low cost.

Previous experience on the use of sensors deposited on metal focused on how much excess noise depends on the screen printing process of the various films and on the type of pastes used to realize these same films. The bibliography does not report data on noise behaviour of piezoresistive sensors deposited on metal substrate. In order to have some data to evaluate the signal to noise ratio, as an aid to the sensor designer, and the influence of the isolating layer on the conduction process, an experimental apparatus to measure the low frequency noise, has been accomplished. The activity moreover let us to analyse and choose the combination of piezoresistive and conductive paste that minimizes the contact noise. Different specimens of adequate shape and dimensions and using different combinations of pastes have been characterized and the results are in the following reported. To make a comparison between sensors deposited on steel and those deposited on alumina, the noise of the specimens of the same characteristics but deposited an allumina substarte have been measured.

2 FABRICATION OF THE TFR STRAIN GAUGE ON STAINLESS STEEL

The fabrication technique essentially requires conventional thick-film processing facilities, which have been outlined in an earlier paper. The steel should have the following properties to assure good bonding at the steel/dielectric interface:

- (i) low carbon content
- (ii) low thermal coefficient of expansion (TCE) comparable with that of thick film inks
- (iii) surface stability at high temperatures
- (iv) low intrinsic cost

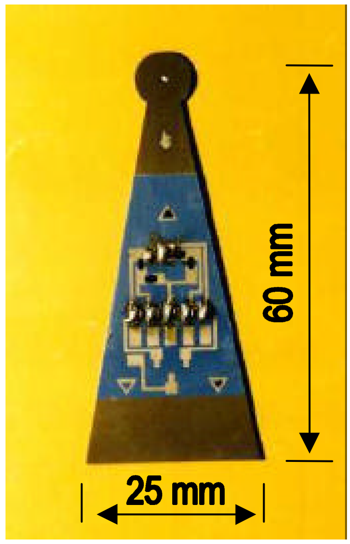


Processing conditions:

- Substrate : AISI430 stainless steel
- Dielectric layer: Heraeus IP9117
- Dried thickness : 25 ± 3 μm
- Firing: 60 minute to peak temperature of 850 °C
- Sheet resistivity: **10 kW/ð**

(a)

Longitudinal and transverse resistors



(b)

Figure 1. (a) Schematic view of the thick-film piezoresistor on metallic substrate (b) photograph of the resistor-termination pattern

Satisfactory results have been obtained using the ferritic AISI430 stainless steel sheet. The dielectric ink is screen printed onto the steel substrate (see Figure 1(a)), dried in air and fired at a peak temperature of 850°C on a belt furnace. Two sequentially fired layers are fired in order to minimise any pinholes that should occur. The conductor layer is then screened and fired and finally the resistor is added. This screen-printing sequence optimizes the terminations and eliminates interactions between the conductor and resistor during the firing process.

To make a comparison, different combinations have been chosen with the aim to define the most critical situations for resistor performance. The idea was to focus the attention on the dimensions normally used, 1mm x 1mm square terminated with Pd/Ag and Pt/Au inks. Table 1 lists the specimen together with the different commercial pastes adopted for the experimental analysis.

Table 1. Composition of the different specimens

Specimen	Resistance value	Conductive paste	Resistance paste
A	9504	Pd/Ag1204	DP1441
B	9780		
C	12277	Pt/Au9596	R8941
D	19794		
E	9830	Pt/Au9596	DP1441
F	10362		
G	14469	Pd/Ag1204	R8941
H	17780		

3 LOW NOISE PREAMPLIFIER

The system for noise measurement consists of a low-noise pre-amplifier and a spectrum analyzer. The low noise amplifier, optimized for the resistance values of the piezoresistors and reported in figure 2 has a bandwidth of 0.1 Hz up to 100kHz and a gain of 100 dB in the centre band. Its input stage

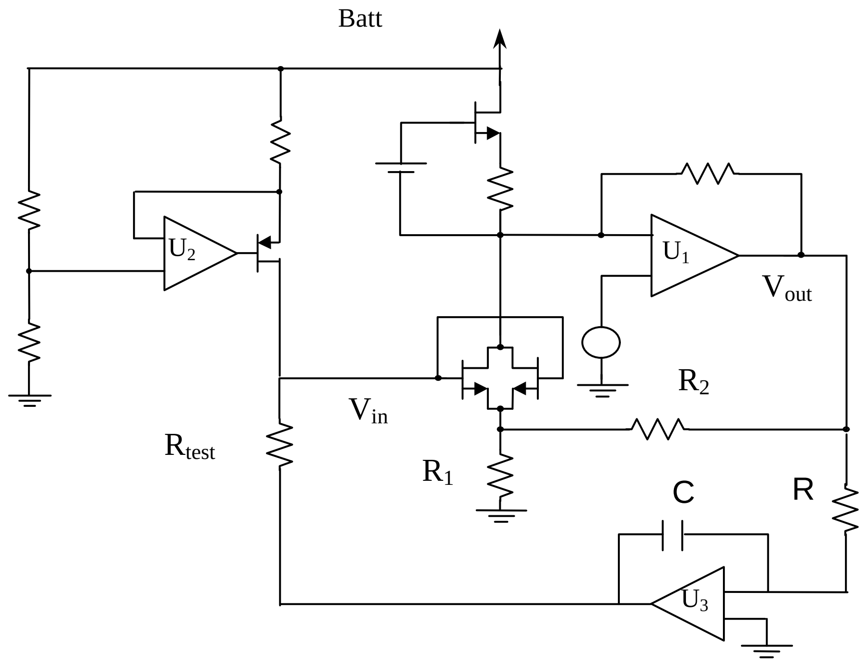


Figure 2. Block scheme of the low noise preamplifier.

uses two JFET transistors connected in parallel to each other; this stage is followed by a voltage current converter (U_1). The output of U1 is reported in input by a feedback path (R_1,R_2) that fixes the gain of this stage to $1+R_2/R_1$. The R_1 resistance value is low since its noise series is added directly to the resistor under test (R_{test}) noise generator. The JFET couple is polarized by a constant current injection into the two drains by a current generator made up of a JFET whose gate and source are connected by a battery and series resistance. The generator's configuration assures current stability against possible variations of the power supply [6]. Since a current must cross the R_{test} in order to evaluate the excess noise, a classical low noise current generator, including an operational amplifier (U_2) and a JFET, injects a d.c. current in R_{test}. The voltage on R_{test} induced by the d.c. current is not amplified because of the presence of the integrator (U_3) which provides and assures a d.c. output voltage null. In fact, the transfer function V_{out}/V_{in} is:

$$\frac{V_{out}}{V_{in}} = \frac{sRC\,(1+\frac{R_2}{R_1})}{sRC+1+\frac{R_2}{R_1}} \qquad (1)$$

where R,C,R_2,R_1 are the components values according to the symbol shown in figure 2. Equation (1) is the transfer function of a high-pass with a low frequency cut-off equal to:

$$f_{-3dB} = \frac{1+R_2/R_1}{2\pi RC}. \qquad (2)$$

The preamplifier, together with the supply battery, is inserted in an electromagnetic and thermal shield to diminish the effect of possible electrical interference and low frequency temperature variations.

In order to evaluate the degree of measurement uncertainty, the system has been tested by using a 10 kΩ metallic layer resistance as R_{test}. The power density spectrum of the input equivalent noise voltage is reported in figure 3. The flat part of the spectrum (frequency greater than 1 kHz) is just a little higher than the value corresponding to thermal noise of the 10 kΩ metallic layer resistance while the initial part of the curve corresponds to a noise of the 1/f type introduced by the amplifier. Note the presence of a peak at 50 Hz.

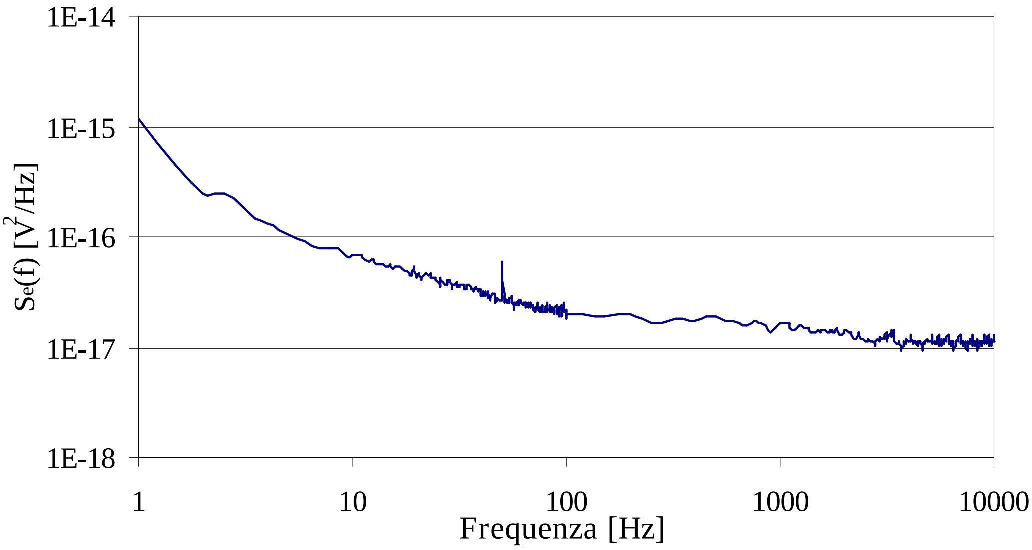


Figure 3. Power density spectrum of the input equivalent noise of a 10 kΩ metal layer resistor

4 EXPERIMENTAL SET-UP AND RESULTS

The experimental set-up used is shown in figure 4. Because the noise must be measured at low frequency where the excess noise is much greater than the thermal noise contribution, a low pass filter has been added to the processing chain before the input of the spectral analyzer. This filter is again supplied by the batteries, and has a frequency cut-off at 100 Hz with an attenuation of 40 dB/decade. The acquisition frequency of the spectral analyzer is 25 kHz while the acquisition window is 2s. Moreover the power spectral density has been obtained by averaging 300 consecutive measurements.

On every specimen described in the second paragraph, four different values of dc current have been applied to R_{test} and the power density spectrum has been limited in the frequency range from 1 up to 100 Hz. Figure 5 shows the power density spectrum of the equivalent input voltage noise of C specimen. Four curves are reported, each obtained for different current values: from the top to the bottom the curves correspond respectively to 445 uA, 115 uA, 80 uA, 12 uA. Moreover the power density spectrum of the equivalent input noise of a metal layer 10 kΩ resistor is reported in the same

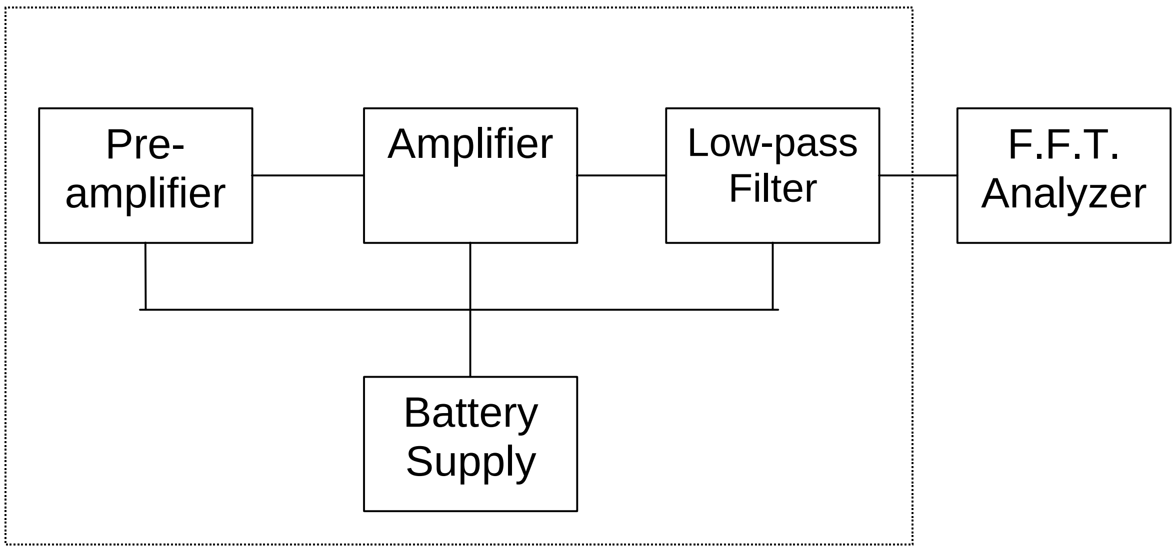


Figure 4. Block scheme of the measurement noise system.

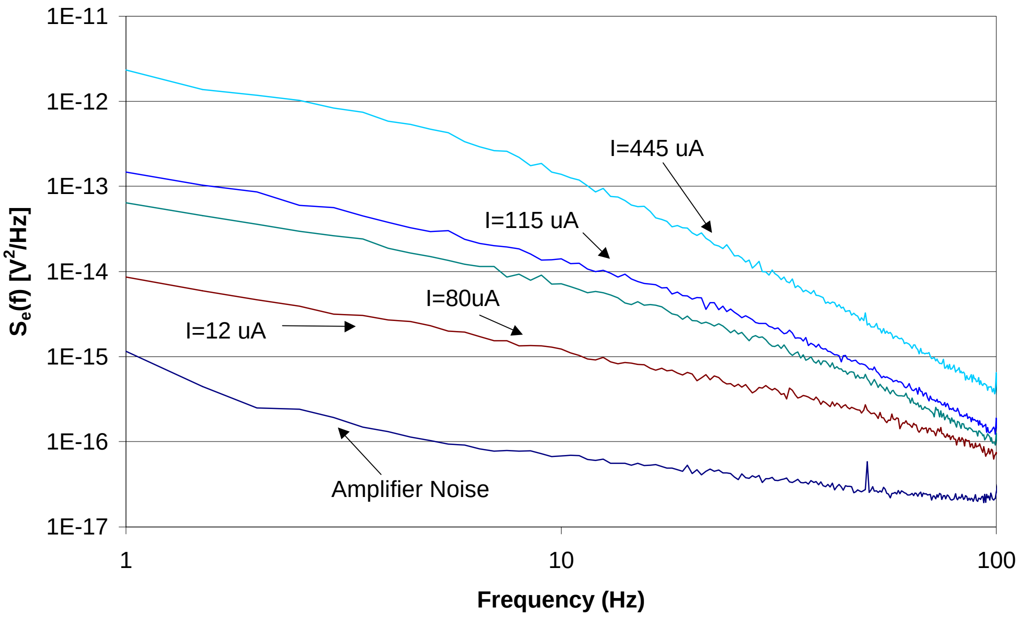


Figure 5. Comparison of the equivalent input noise power density spectrums between the C specimen when crossed by different I_{dc} values and the 10 kΩ metal layer resistor

figure 5 to make a comparison and a validation of the measurement done. Note the behaviour of type 1/f of the measured data, especially in low frequency, where the contribution of the excess noise is prevalent with respect to the thermal contribution. Similar curves have been measured on the other specimens. For each specimen, from the curve obtained by using 445 μA, the Noise Index (N.I.) [7] has been calculated, as suggest by bibliography; the noise index value is reported as μV/V. Table 2 summarises the results obtained.

By comparing the N.I. of specimens having the same composition of paste (conductive and resistance), but different substrates, no significance difference is evident. Moreover except one case, the N.I. due to the metal substrate is just greater than the corresponding specimen having the alumina substrate.

Moreover the N.I. value of the alumina substrate for specimen F and H (having respectively DP1441 and R8941 as resistive paste and Pt/Au9596 and Pd/Ag1204 as conductive paste) have been compared with the value reported in the data sheet of the manufactures. The measurement conditions are the same: substrate alumina 96%, area 1mmx1mm, thickness 25 μm ± 3 μm, fired at 850 °C peak temperature for ten minutes; the values of the Noise Index are very close. At last, a comparison of the

Table 2. Noise index of the different specimens

Conductive paste	Resistance paste	Substrate	Noise Index (μV/V)
Pd/Ag1204	DP1441	metal	0.482
		allumina	0.474
Pt/Au9596	R8941	metal	0.427
		allumina	0.469
Pt/Au9596	DP1441	metal	0.525
		allumina	0.456
Pd/Ag1204	R8941	metal	0.423
		allumina	0.411

N.I. of four different pastes combinations screen printed on the metal substrate, shows that the resistance paste using the R8941 has less noise.

5 CONCLUSIONS

Noise coming from different piezoresistive sensors deposited by using thick film technologies on metallic and alumina substrate was measured. The results obtained let us to identify behaviour less noisy of the R8941 paste with respect to DP1441 paste also on the metal substrate. The comparison between piezoresistive sensors deposited on a metallic substrate and piezoresistive sensors deposited on alumina substrate has shown us a substantial similarity between their noise characteristics. It seems therefore that the isolating layer between the metallic substrate and the paste, does not significantly modify the noise characteristics of the sensors.

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