# Equipment for measurement of nonlinearity of nominally linear components

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***Abstract:*** *Nonlinearity of a nominally linear component is a significant parameter, which informs about the difference of and investigated component from an ideal one. The higher is quality of the nominally linear component; the lower is level of its nonlinearity. Nonlinearity is caused by inhomogenities and unstable barriers in the component, which can, after some time, cause failure of the component. Nonlinearity is also a significant technical parameter of components, which work with more signals of different levels. Nonlinearity contributes here to generation of intermodulation distortion of current signals. It has been necessary, for our research, to investigate nonlinearity of adhesive joints. Because there is not equipment for measurement of nonlinearity of low-impedance components on the market, it has been necessary to construct it. Equipment is based on evaluation of intermodulation distortion, which is generated by the nonlinear component, when two sinusoidal signals are fed into it. Equipment makes a measurement of nonlinearity of 2. to 5. order possible. Measured level of nonlinearity is -170 dB with respect to the actuating signal. Maximum power of the actuating signal is 2 VA, the sensitivity of an indicator 50 nV. Some examples of measurements of nonlinearity of adhesive joints are shown.*

**Keywords:** evaporation, thin film, DOE, statistical testing

## 1. Introduction

The current versus voltage characteristics of nominally linear components is a straight line. However, there are many reasons, which can cause higher or lower difference of the current vs. voltage characteristics of the component from a straight line. The reason can me inhomogenity of function material of the component, lower quality of a fabrication process, properties of contacts, ageing of the function material and many others.

Therefore it seems to be very beneficial to study a level of nonlinearity of nominally linear components. Such the examination can bring significant information especially when the function material of the component is a composite one. Typical material of such the type is electrically conductive adhesive. It consists of conductive particles (filler) disseminated in insulating matrix (binder). Different shapes of particles are used, mostly balls with the diameter 6 to 10 μm or flakes with the dimensions 8 to 15 μm. Material of filler is usually silver, but experiments with Cu covered with silver layer, with plastic material covered with silver layer, with gold and palladium have also been carried out. Epoxy resin or silicone resin are usually used as the binder.

Electrically conductive adhesives have, in comparison with solders, higher level of noise and nonlinearity [1]. The reason is that contacts among conductive particles are often nonlinear by reason of different mechanisms of conductivity, which take place here. It is possible to involve tunneling, diffusion, Schottky emission and others among them. These mechanisms are mostly nonlinear, therefore they cause nonlinearity of the current versus voltage characteristics.

Quality of adhesive contacts is the higher; the lower is influence of nonlinear mechanisms on the total conductivity of adhesive joints. Therefore it can be very interesting to study nonlinearity of adhesive joints for manufacturers and users of electrically conductive adhesives. Also investigation of dependence of nonlinearity of the current vs. voltage characteristic of the joints on climatic ageing (thermal, combined thermal-humidity, humidity) or on ageing caused by dc current or current pulses as well as ageing caused by mechanical stress of the joints can give interesting results. Information about the change of nonlinearity can contribute also to study of mechanisms of conductivity of adhesives and make improvement of their quality possible [2].

## 2. Equipment and methods of measurement of nonlinearity of a current vs. voltage characteristic

There are different theories about a source of nonlinearity. Two basic ones are as follows:

- According to the first theory nonlinearity and noise are caused by one source and this source is thermal movement of vacancies in material (Zhigalsky, [3]).
- The second theory assumes that there are two different sources for noise and nonlinearity. Noise is caused by linear harmonic oscillators randomly distributed inside the material, whereas nonlinearity of the C-V characteristic is caused by randomly distributed rectifying contact (CLT manual, [4]).

The current vs. voltage characteristics of an ideal nominally linear component and a real one are shown in Fig. 1.

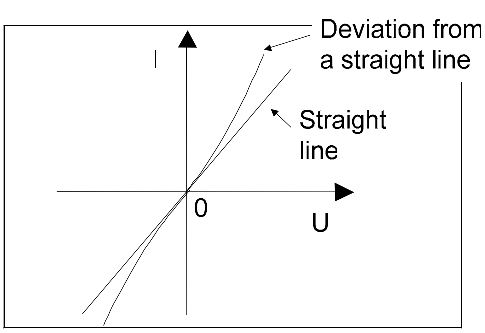


Fig. 1 Current vs. voltage characteristic of an ideal and a real nominally linear component

Under assumption that nonlinearity of the current vs. voltage characteristic is dominantly caused by potential barriers on the boundaries of conductive particles of the adhesive, it has been derived following formula:

$$I_D = sign(U)\cdot 2N_t A\cdot \exp\left(-\frac{e\phi}{kT}\right)\cdot \left[\frac{e|U|}{kT}+\frac{e^3|U|^3}{3!(kT)^3}+\frac{e^5|U|^5}{5!(kT)^5}+\dots\right] \quad (1)$$

Where $N_t$ … number of defects at the time $t$, $\phi$ … high of a potencial barrier, $A$ … material constant, $k$ … Boltzman constant, $T$ … temperature in K, $U$ … voltage.

The measurement based on application of the DC voltage or current is impossible because of very low level of nonlinearity (it is usual that the maximum deviation of the current vs. voltage characteristic from a straight line is under 1 %). Therefore it would be necessary to stabilize a DC source for a change lower than 0,1 % for the time of the measurement, it would be problematic to avoid to thermoelectric voltages etc.

Two basic principles are used for such the measurement:

1. A nonlinear component is powered by a sinusoidal current and voltages of the first and third harmonics are measured. A schematic diagram of equipment for such the measurement is shown in Fig. 2.

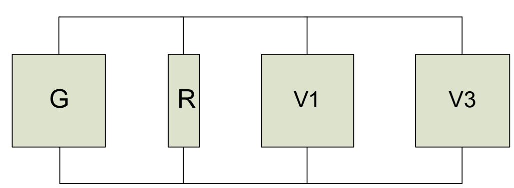


Fig. 2 Schematic diagram of equipment for measurement of nonlinearity by the method No. 1.

G … generator, R … measured contact, V1 … selective milivoltmeter with measuring frequency equal to the frequency of first harmonic, V2 … selective milivoltmeter with measuring frequency equal to the frequency of second harmonic

2. Measuring signals with two different frequencies f1 and f2, power a component under test. Intermodulation signals with different frequencies are generated as a result of nonlinearity of the current vs. voltage characteristic. Study of one or more selected components of these intermodulation signals gives information about the level of nonlinearity. A schematic diagram of equipment for such the measurement is shown in Fig. 3.

The amplitude of the measured intermodulation product depends on the type of nonlinearity and on the amplitude of powering signals. The voltage, noise and distortion of powering signals must not depend on the impedance of the measured contact.

The frequency f1 has been chosen 4.106 MHz, the frequency f2 150 kHz. The measured intermodulation frequency f has been 4.406 MHz.

The power HF generator has been constructed as the LC oscillator with an electron tube. The power LF generator has been of the type GR 158. The spectral analyzer HP 8650 has been used for measurement of the intermodulation signal. When specimens have been exchanged the input of the spectral analyzer has been shorted out by relays.

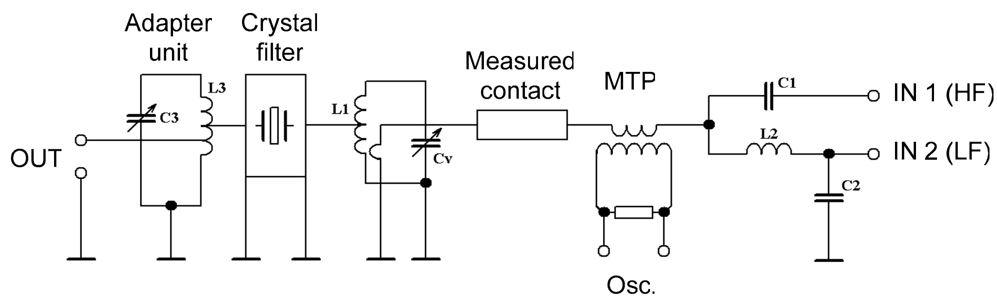


Fig. 3 Schematic diagram of equipment for measurement of nonlinearity by the method No. 2

Comparison of the method No. 1 and the method No. 2 gives following results: quality of the result obtained by the use of the method No. 1 depends strongly on quality of the sinusoidal current, which is used for powering of the measured component. Distortion of the powering signal causes significant decrease of accuracy of the measurement. It is also problematic to study nonlinearity in a wider frequency range, because it is difficult to make good tunable generator of the sinusoidal signal with requested quality.

The method of No. 2 needs also the use of high quality generators, but it is significantly advantageous in the measurement of products of nonlinearity. With respect to the spectrum of intermodulation products it is possible to choose a product with substantially different frequency in comparison with the frequency f1 and f2. In principle, the intermodulation products are described by following equation:

$$f = n.f_1 + m.f_2 \tag{2}$$

Where *n, m* … integral numbers.

Filters have been fabricated with minimum nonlinearity. Mica and vacuum capacitors, platinum resistors, and air core inductors have been used. The measurements have been carried out for the current values up to 1 A. Construction of the input part is shown in Fig. 4, construction of the output part in Fig. 5.

High attention has been paid to screening and grounding of equipment. It has been necessary to avoid ground loops. Therefore grounding has been carried out using short heavy cables to ground rod. Equipment has been screened by the use of Cu sheet with the thickness of 2 mm. The powering of generators and spectral analyzer has been carried out using net stabilizer.

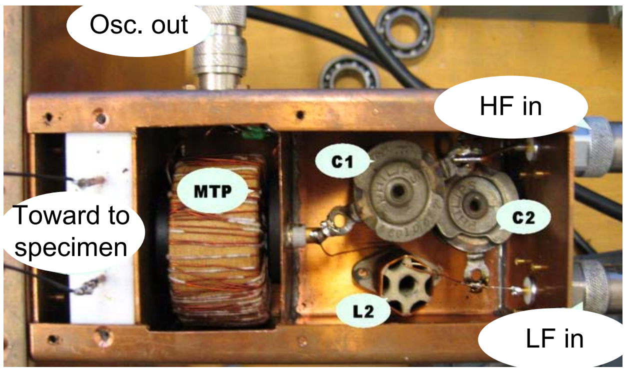


Fig. 4 Construction of the input part of equipment for measurement of nonlinearity

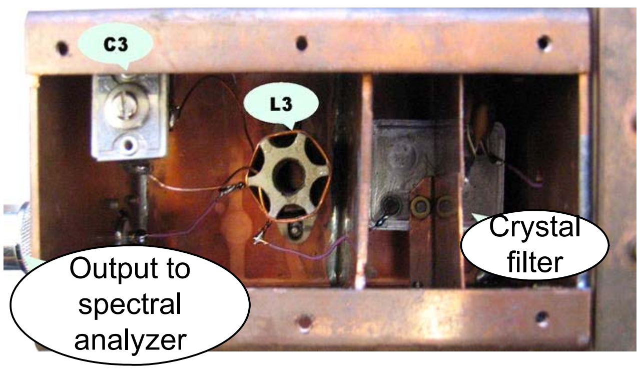


Fig. 5 Construction of an output part of equipment for measurements of nonlinearity

An example of the measurement of nonlinearity of adhesive joints is shown in Fig. 6.

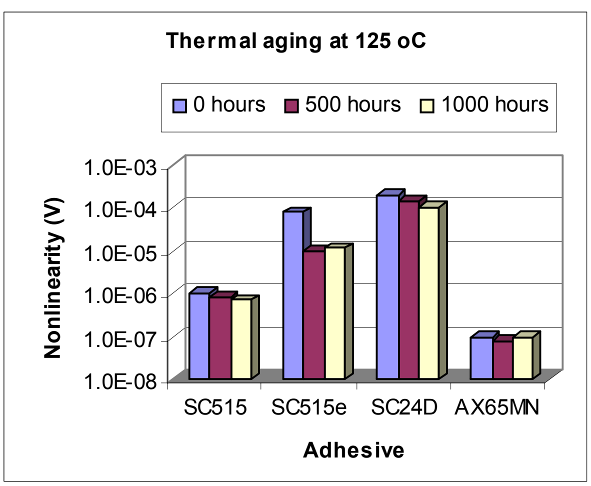


Fig. 6 Measurement of nonlinearity of adhesive joints

## Conclusions

Measurement of nonlinearity is a significant tool for evaluation of quality of electrically conductive adhesives, composite materials and some types of electronic components. Designed and constructed equipment makes the measurement highly accurate and usable in a wide frequency range. The principle of the measurement is unique.

Quality of adhesive as well as soldered joints has been examined using this equipment. Changes of conductive mechanisms caused by climatic aging, by DC current. by current pulses, and by mechanical stress, have also been analyzed using this measurement.

Application of this equipment is also in the field of investigation of linearity of nominally linear electronic components. There are very often strict requests to nonlinearity of the current versus voltage characteristic in many cases, especially, it the components are directed for higher frequencies.

It is necessary to stress that the measurement of nonlinearity is not "a usual type of a measurement". The measured signals have mostly very low level, and therefore measuring equipment has to be carefully grounded and screened. It is highly recommended to carry out this measurement inside a good screened room.

## References


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