

Non-linearity Diagnostics for Conductive Adhesives

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Abstract-The level of intermodulation products that are generated represents the extent of non-linearity for any electronic component. To determine the quality of connections with conductive adhesives the technique of evaluating non-linearity was used as a diagnostic method. The used measuring equipment is based on the evaluation of intermodulation distortion, which is generated by the non-linear component, when two sinusoidal signals are supplied. The equipment measures non-linearity of 3 orders. The measured level of non-linearity is -180 dB with respect to the actuating signal. The maximum current of the actuating signal is 2x 2A, the sensitivity of the indicator is 10 nV.

I. Non-linearity and intermodulation

The technique of determining non-linearity of nominal linear electronic components is an important non-destructive diagnostic method for assessing the quality and reliability of the components. The principle of the method lies in evaluating non-homogeneities and unstable barriers in the component that might cause after some time changes of the component's properties or its malfunctions. For components using conductive layer for their operation, the ohmic non-linearity can be also used as a degree of their current noise. It is necessary to investigate the non-linearity of adhesive connections.

Intermodulation signals are generally disturbing signals, which develop from two signals of different frequencies in non-linearity. The frequency of the intermodulation signal f_n is different from the frequency of the exciting signal f_1 and f_2 (1), Fig 1. The value $n=n_1+n_2$ is described as an order of the intermodulation product.

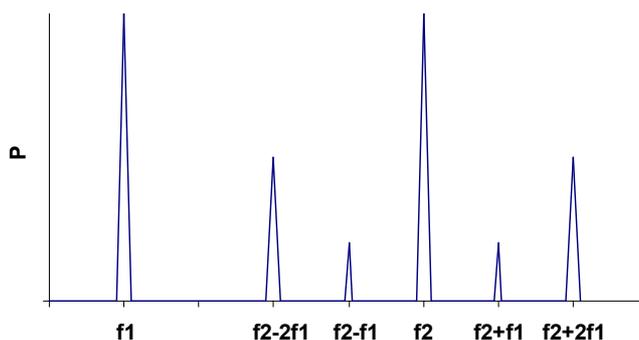


Figure 1. Dependence of power intermodulation products on frequencies

$$f_n = n_1 f_1 + n_2 f_2 \quad (1)$$

The power level of the intermodulation product increases with the rising power of the exciting signal and with increasing non-linearity. In case of equal levels of exciting signals $P_1=P_2=P$ the power dependence of the intermodulation product level P_n and the order of product n (2) is usually supposed.

$$P_n = cP^n \quad (2)$$

c is a constant that is given by the deviation of the non-linear dependence of non-linearity from the linear course. The non-linearity of the volt-ampere characteristic is minimal for passive systems and passive components. For

joints, this has to be absolutely minimal because the connection is a passive component and – what is more – it has only minimal values of the nominal resistance, inductance, and capacity. The observation of the level of generated intermodulation products is a fairly good diagnostic method for the observation of the quality of adhesive joints, in which non-ferro-magnetic and non-ferro-electric materials are used.

II. Intermodulation Distortion Measurement

The equipment for the measurement of intermodulation products is based on the diagram depicted in Fig. 2.

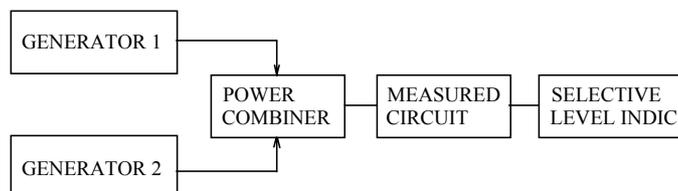


Figure 2. Intermodulation distortion measurement

The measuring equipment can be made from measurement instruments available in the laboratory. This fundamental measuring is possible especially for two-port– amplifiers, filters, and transformers.

Two sinusoidal signals from two generators are supplied to the input of the measured circuit. A power combiner is used for the connection to the input of the measured circuit to secure appropriate matching and minimization of mutual influence of the generators. The required intermodulation product is evaluated at the output of the measured circuit with a selective level indicator. For the measurement it is possible to use a measuring receiver, selective microvoltmeter, and spectrum analyzer, which is currently used the most often.

The measurement of active low-power circuits is not difficult because when the power output of the coming signals is low, the measured circuit generates a great level of intermodulation products that is much greater than the level of intermodulation products generated by other elements of the equipment. The given intermodulation product is unambiguously produced by the measured circuit.

The measurement of passive circuits, cables, connectors, and joints represents a much more complicated situation [1]. When the measurement is performed, the coming power output is approximately by 3 orders higher while the indicated levels of intermodulation products are by approximately 3 orders lower than in common active circuits.

The measuring signal generators have to provide the measured circuit with a signal of the power output of units up to tens of W (e.g. [2] used 20W). The signal has to demonstrate high spectral purity; the spacing of the noise and the disturbing signals in the frequency area, where the intermodulation products are evaluated to the carrier, is close to 200 dBc/Hz. The output generator amplifiers of the power output also have to demonstrate a considerable immunity against load impedance mismatch. Ideally, they are guaranteed to operate with the maximum power output up to any load ($SWR \rightarrow \infty$). These requirements are however mostly difficult to fulfill, especially in commercial facilities. The power output amplifiers are guaranteed to operate without any malfunction, if the load is reflectionless or if the reflection coefficient at the output is reduced (e.g. $SWR \leq 3$); the signal generators' spectral purity is much worse (see Fig. 3).

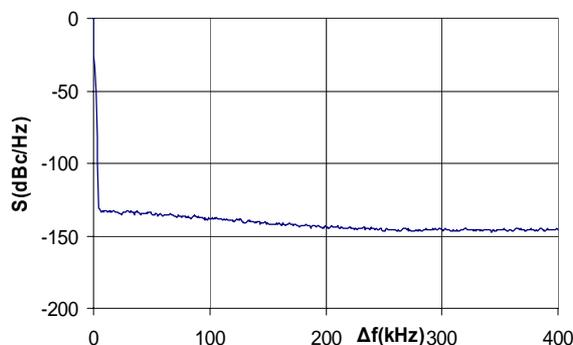


Figure 3. Frequency spectrum of sine-wave signal generator SMY 01 at frequency 4.1 MHz with frequency spacing of carrier 0 to 400 kHz

The power combiner is another part of the equipment, which is necessary to devote one's attention to. If we suppose the operation of some device is in the frequency area of approximately 0.1 to 30 MHz, the corresponding construction of the power combiner is a lumped elements circuit with balanced transformer with ferro-magnetic core, that will generate intermodulation products of the level -60 to -100 dBc.

The measurement of a passive one-port is also more complicated than the measurement of a two-port. The measuring equipment has to secure that the signals are separated at the clamps of the one-port, ensure the supply of exciting signals with minimal losses to the measured device and take the intermodulation products to the level indicator.

The selective level indicator, the spectrum analyzer, is the last part of the measuring equipment. Once again its dynamic range has to be approximately twice as big as in other common devices.

Special measuring equipment solves the above mentioned problems. A block diagram of the measuring equipment is displayed in Fig. 4.

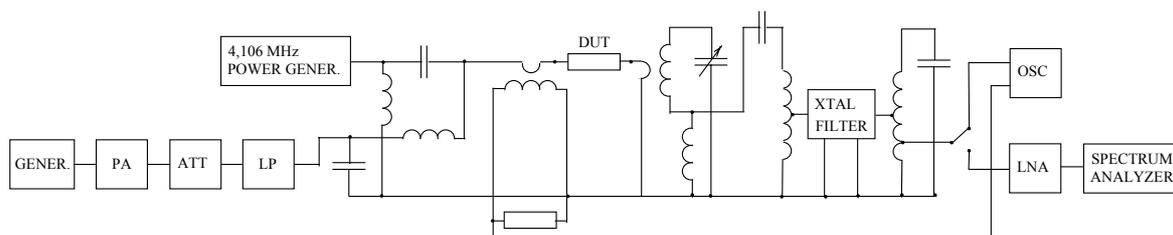


Figure 4. Block diagram of the measuring equipment

The measuring equipment is constructed for operation in fixed frequency plan. IM product of 3rd order should be indicate on the frequency of 4.406 MHz; the frequency of the 1st exciting signal is 4.106 MHz, the frequency of the 2nd exciting signal is 0.15 MHz.

The power generator 4.106 MHz is a special device designed for this very purpose. Its construction is based on the following requirements: spectral purity, output power, resistance to impedance mismatch, and frequency stability. The generator is controlled by crystal oscillator with low noise background. The signal from the oscillator is further amplified by tuned two-stage amplifier with amplification approximately 2×20 dB for the output power of 50 W. The power stage of the amplifier is solved by a transmitting tube (829 type), because the tube amplifier is much more resistant to any overload than the solid state amplifier. Thus the resistance to impedance mismatch is better secured. The narrow amplitude characteristic of the amplifier causes further increase of the S/N ratio in the area of the measuring frequencies against the oscillator and reaching the final value of approximately 180 dB (see Fig. 5).

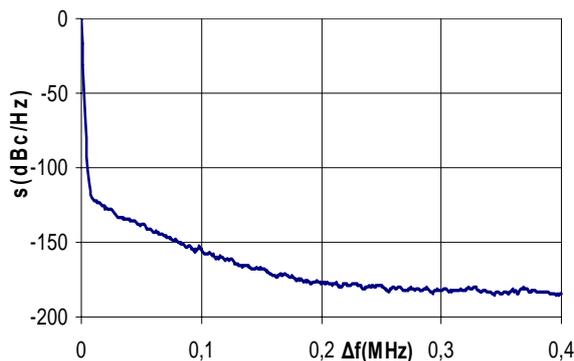


Figure 5. Frequency spectrum of generator 4,106 MHz

The second generator can be implemented easier using commercial equipment and parts with regard to higher frequency spacing to the measuring frequency.

The undesirable disturbing signals that are produced by the generator in the area of measuring frequencies can be cleared out by a filter, e.g. a low-pass filter, because the measuring frequency is almost one order higher than the operating frequency of the generator.

The second generator comprises a commercial signal generator Agilent 33120, a linear power amplifier Frankonia FLL-75 and a LP filter. The signal generator supplies a test signal of low level, approximately 0 dBm, with the possibility to control amplitude and frequency. The signal to noise ratio in the range of measuring

frequencies to carrier corresponds to the signal to broadband noise ratio and it ranges from -120 to -140 dBc/Hz. The used amplifier supplies the maximum output power of 75 W; its gain is 40 dB and noise from 10 to 16 dB. The security attenuator and filter are connected at the output of the amplifier. The filter makes it possible to achieve further marked improvement of the signal to noise ratio. The total suppression of disturbing products of the second generator in the measuring frequency reaches approximately 180 dB (see Fig. 6).

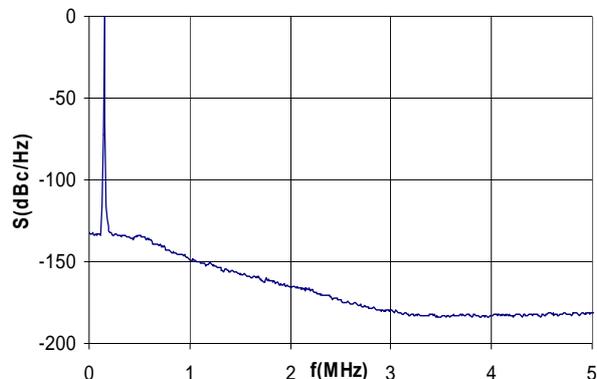


Figure 6. Frequency spectrum of generator 0.15 MHz

The power combiner is implemented as a diplexer with high-pass and low-pass filter, which always transmits the signal of the first generator and suppresses the signal of the second generator. Only in this way it is possible to secure minimal influence of one generator on the other even when the load of the power combiner is considerably mismatched. High inter-modulation immunity implies the use of special components. The coils cannot have ferro-magnetic core. No ferro-magnetic materials can be used for the construction, not even for screws. The capacitors are micaceous, consisting of non-plated mica with electrodes made of metal foil, since even the contact of terminal with plating causes non-linearity. A current sensor, which also serves as an indication of service current during the measurement, is inserted at the output of the power combiner.

The band pass filter ensures separation of the measured intermodulation signal with very small level from power exciting signals. Then, there needs to be minimal input impedance for the exciting signals in order to reflect these signals and not to be loaded with their power and higher impedance (real) for the evaluated signal, which is with low attenuation. The first circuit of the filter is a special tuned circuit with high Q factor and intermodulation immunity on the feeding side. The circuit again has to be designed by a special way, it has an air coil and a vacuum capacitor placed in a dimensional shield, see Fig.7. The total suppression of both exciting signals by the filter is better than 100 dB; the attenuation of the measured signal is at 6 dB.

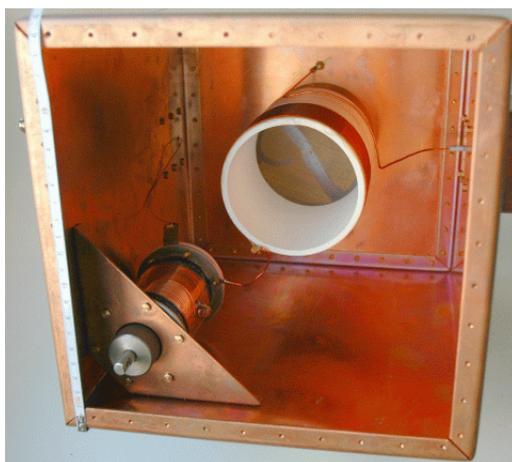


Figure 7. Input resonant circuit of the filter

The low noise amplifier increases the total sensitivity of the measuring system by about 20 dB in comparison with single spectrum analyzer.

The spectrum analyzers HP 8560 or R-S ESPI are used for evaluating the intermodulation signal level.

An oscilloscope is used to determine the level of the exciting currents in the measured circuit and to check the

level at the output filter after the device was manipulated or a sample was changed.

This arrangement allows for work with currents up to 2 A and power to 47 dBm in the measuring circuit. The arrangement sensitivity is approximately -180 dBc with regard to the noise floor and IM noise floor of the equipment at the maximum level of the excitation signal.

III. Non-linearity Diagnostics

For the diagnosis of conductive adhesives a testing preparation has been constructed that simulates the assembly of SMD resistor type 1206 at PCB [3]. To prevent any influence of the testing preparation on the measurement results, no part of the preparation should demonstrate indicated non-linearity. Thus it is necessary to avoid using any ferro-magnetic or ferro-electric material for the construction of the preparation. The impact of ferro-magnetic materials on non-linearity is very strong. It is not possible to use Ni interlayer at galvanic gold plated PCB line, steel core of conductor with copper outside layer or only steel screw in the distance of 20 mm from the copper conductor given the IM level -150 to -110 dBc. The PCB preparation thus uses only brush copper layer; the resistor is substituted by silver block of the same dimension as the 1206 resistor.

Tested joints were made on a printed circuit board of samples (see Fig. 8). They were assembled with seven silver blocks using electrically conductive adhesive.

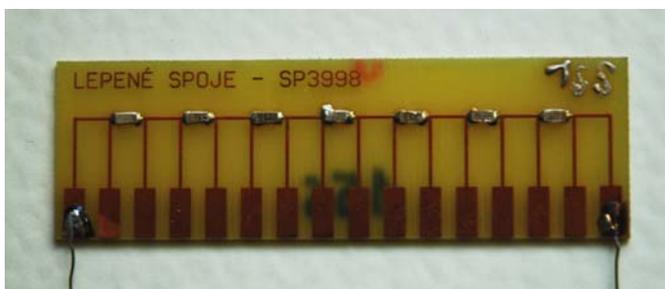


Figure 8. Daisy chain of resistors assembled using electrically conductive adhesive

A typical diagram of the IM product measured for conductive adhesives joint is depicted in Fig. 9.

When diagnosing conductive adhesives joints the monitoring of the non-linearity makes it possible to identify even small changes in the joint. The changes on the level of IM are approximately by one order bigger than the changes of the joint's ohmic resistance. The situation is illustrated in Fig. 10 depicting the influence of the time the conductive adhesives joints are exposed to short current impulses (1 μ s, 80 A, 50 Hz) using electrically conductive adhesive ER55MN from Amepox Company. It is a typical sample of single component silver filled electrically conductive adhesive. This adhesive has epoxy-phenolitic base resin and is especially prepared for making to copper material and for high temperature resistant application [4].

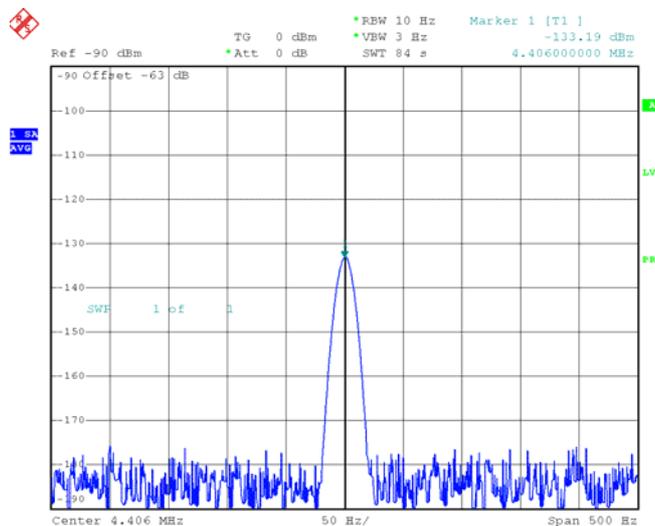


Figure 9. Output signal with IM level of -133 dBc

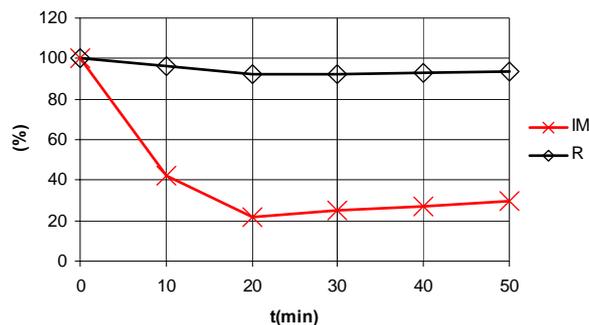


Figure 10. Change of resistance and IM level in reaction to exposition time. Initial values:
 $R_0=35\text{ m}\Omega$, IM level 125 dBc.

IV. Conclusions

The presented experimental equipment makes it possible to evaluate even very small non-linearity of all passive one-ports.

The device allows for performing measurements even in objects with very small impedance that cannot be connected in common measuring circuits with the characteristic impedance of $50\ \Omega$ and fulfill the requirements of matching. The equipment can be well used for measuring the non-linearity of joints, contacts, conductor connectors, cables and passive components. The level of exciting signals, the sensitivity and residual non-linearity are comparable with professional equipments with constant characteristic impedance of $50\ \Omega$.

Acknowledgements

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