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MEASURING OF NON-LINEARITY OF NOMINALLY LINEAR ELECTRONIC COMPONENTS AND NETWORKS

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Abstract – Traditional methods and new method for the small non-linearity measuring of electronic components and circuits are described in this paper. There are presented examples of measured intermodulation product levels on passive components.

Keywords: non-linearity, intermodulation distortion.

1. NON-LINEARITY AND INTERMODULATION

High intermodulating immunity is, besides the selectivity and low noise, one of the most monitored parameters of all radio equipment. Intermodulation signals are disturbing signals in general, which spring from two signals of different frequencies in the non-linearity. The frequency of the intermodulation signal f_n is different from the frequency of the exciting signal f_1 and f_2, The value $n_1=n_1+n_2$ is described as a order of the intermodulation product.

$$f_n = n_1 f_1 + n_2 f_2 \tag{1}$$

The power level of the intermodulation product increases with the raising power of the exciting signal and with increase of the non-linearity.

In the case of equal levels of exciting signals $P_1=P_2=P$ a power dependence of the level of intermodulation product P_n and order of product n (2) is usually supposed.

$$P_n = cP^n \tag{2}$$

c is a constant that is given by the deviation of the nonlinear dependence of non-linearity from the linear course.

In common systems, which are not too wideband, intermodulation products of the 3rd order cause the greatest difficulties because their frequency is near to the frequency of exciting signals.

The intermodulation immunity is observed by all active systems for signal processing. IP (intercept point) or intermodulation -free dyamic range is the basic coefficient of the intermodulation immunity, which it is possible to set according to the dependence P_n on P [4].

The non-linearity of the volt-ampere characteristic is minimal for passive systems and passive components. In contrary to active devices it is practical impossible to detect their non-linearity by direct measuring of the volt-ampere characteristic and it is difficult to approve it other way. Passive intermodulation distortion (PIM) is minimal too so it was said to be non-significant for a long time.

But the observation of the level of generated intermodulation products is fairly good diagnostic method for the observation of the quality of passive components, in which non-ferro-magnetic and non-ferroelectric materials are used. The observed non-linearity of these nominally linear components is the characteristic of the inhomogeneity and unstable barrier material. These can work a decrease of the component quality or its disturbance after a point of time. [1].

The observation of non-linearity or the passive intermodulation distortion is also a suitable observation method of the quality of all components, if we want to keep high linearity of the system, which will be made out of them. Modern miniature passive components, especially those in which ferroelectric and ferro-magnetic materials are used, can embody high non-linearity, that is also higher than the non-linearity of active devices.

The non-linearity of nominally linear components is not observed only on passive components.

The passive intermodulation distortion has been recently discussed as a source of the distortion in mobile radio system based station. There the intermodulation products come up from output signals of transmitters in filters, power combiner, cables, connectors and antennas. These frequencies fall into the band of receiving frequencies and the signals disturb also at minimal power levels.

2. NON-LINEARITY MEASURING

A non-linearity measuring of nominally linear parts and systems is difficult, because non-linearity which we want to measure, is minimal. It is rarely simple even to find acceptable dependence (VA characteristics, transfer function), which we could compare with the proportionality and measure the deviation. In addition, noise, temperature dependencies and drifts complicate d.c measuring and a.c measuring that stick to one frequency.

However, a sensible method of measuring the non-linearity is the observation of the creation of signals with frequencies different from the exciting signal on non-linearity. This process of the determination of non-linearity has already been worked up for diagnostics of resistors by the development of series apparatus CLT firm Radiometer in the 60s. The non-linearity has been evaluated according to the level of third harmonic of exciting signal generated by DUT. ($n = n_1 = 3$, $n_2 = 0$). The apparatus has the sensitivity about –160 dBc in optimal case and it is possible to use it for resistors with the value from tens Ω to hundreds of kΩ.

For the two-port network, both active and passive, a measuring system arrangement according to the Fig. 1 is very used today.

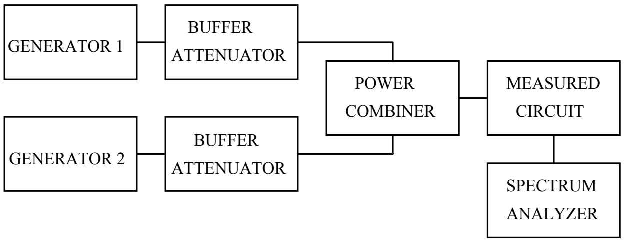

Fig. 1 Intermodulation distortion measurement

Experimental measuring has been provided especially on RF circuits and components by using frequencies of the order of hundreds of kHz till tens GHz. There has been used the method of non-linearity measuring by intermodulation distortion analysing. The measuring system has been made-up for some measuring from available laboratory measurement instruments. Measuring has been provided especially on two-port - amplifiers, transformers and filters [3].

Systems of this kind are also used for measuring of PIM, for example just for the purposes of mobile radio systems. Then they are supplemented by power amplifiers with output power at about 20 W, power load, which can develop the power output of the measuring object. Analyzer is low-level connected through directional coupler [5]. The sensitivity of these systems is usually very good. The level of intermodulation product is in that case about 160 dBc for the narrow bandwidth 100 Hz to 1kHz.

However arrangements of this kind are mostly single purpose. They enable just measuring of on objects with the normalized characteristic impedance (typically 50 Ω), which are well adjusted to the defined band of frequencies (900 MHz, 1800 MHz). It is impossible to measure components and parts, which do not correspond to these requirements.

Therefore we made a measuring system according to our own construction.

The measuring equipment has been constructed especially for the measuring of passive components all kinds of lumped parameters (R,L, C, contacts, wiring) and which have considerably different parameters so it is impossible to measure them unadjusted to the power circuits with defined characteristic impedance. It is even more difficult to match them. Schematic diagram of the system is shown in figure 2.

The system works on lower frequencies, c. 50 kHz until 4,5 MHz. Its construction goes out of available equipments and ought to achieve the maximum of the intermodulation immunity. Just this way it is possible to achieve a maximum sensitivity of measuring intermodulation signals generated by the measuring object do not overlap the signals which are generated by the system.

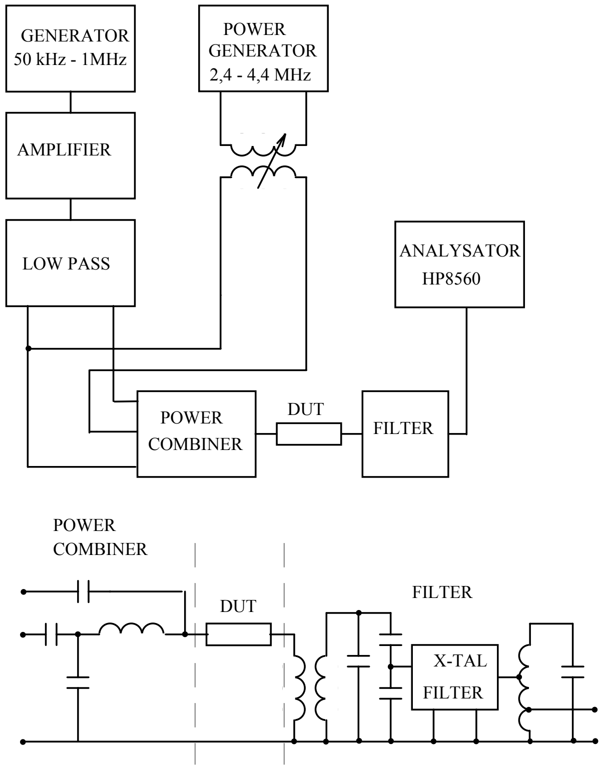

Fig. 2 Schematic diagram of measuring system

The most demanding parts of the system from the construction point of view are power combiner and filter. In these both exciting signals f_1 and f_2 with the high power act at the same time and undesirable IM products are likely to come up.

High requirements are set also on driving generators, which must embody a high spectral purity, so that order their signal noise in the frequency band of the evaluated signal does not reduce the sensitivity of the measuring.

Filter implicates the suppression of the exciting signal on input of the analyzer, because the dynamic range of analyzer (around 90 dBc) is not adequate for measuring PIM. Then it must have a minimal input impedance for an exciting signals, in order to reflect these signals and instead of being loaded with their power and higher impedance (real) for the evaluated signal, which goes through with the small attenuation. The design of the filter comes out of a piezoelectric crystal filter, which has suitable narrow band-pass characteristic and a great attenuation in the stop band. However, its intermodulation immunity is small for our function (see figure 3) and the filter does not bear up against power of the exciting signal. Therefore the filter was supplied by special tuned circuit with a high Q factor on a feeding side. The tuned circuit works like a high linear band pass filter and on the whole it remarkably improves characteristics of the filter. The transmission characteristic of the filter for narrow and wide band are displayed in figure 4, the frequency dependence of the input impedance modulus is in Fig. 5. They both correspond to the given requirements.

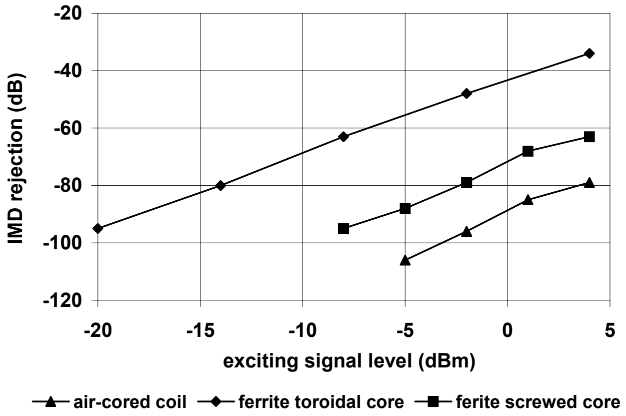

Fig. 3 Crystal filter with matching circuits f = 9 MHz, B = 2,5 kHz, f_1= 9,03 MHz, f_2 = 9,06 MHz

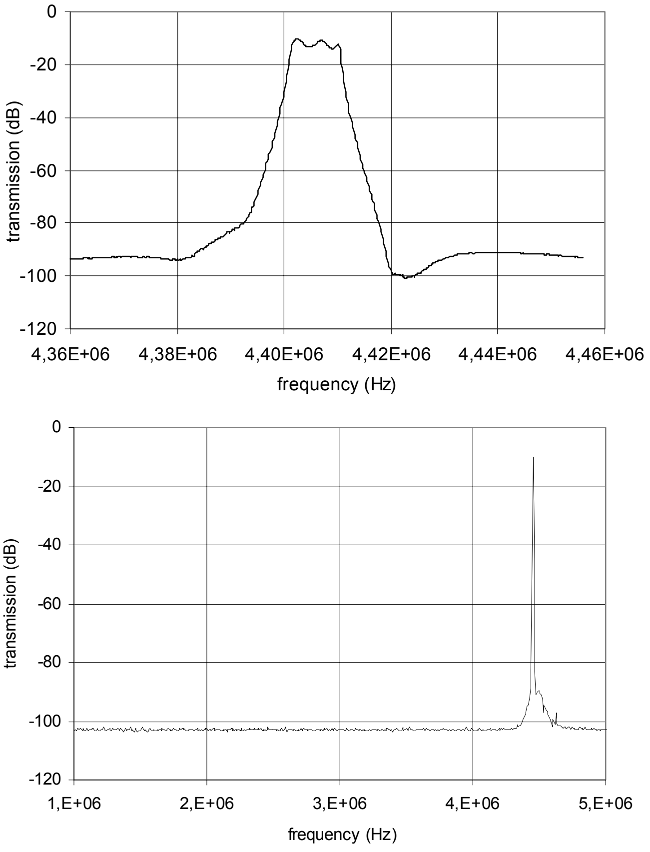

Fig. 4 Amplitude response of filter

The power combiner is implemented as a diplexer with high-pass and low-pass filter, which always transmits the signal of the connected generator and suppresses the signal of the second generator.

Only this way it is possible to provide the minimal influence of one generator on the second even if the load of the power combiner would be very mismatched. High intermodulation immunity implicates the using of special components. Coils must not have ferro-magnetic core. No ferro-magnetic materials can be used by the construction, not even as screws. Capacitor are micaceous, consisted of the unplated mica, because even the contact terminal with plating causes non-linearity. The frequency dependence of the transmission from generators to the DUT is illustrated in figure 6. The value of relative isolation of generators in used frequency bands is obvious.

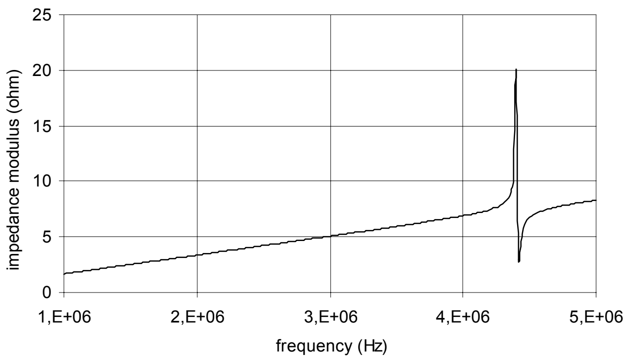

Fig. 5 Frequency dependence of input impedance of filter

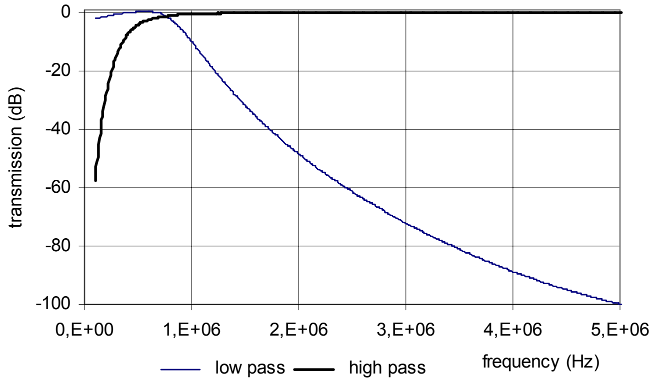

Fig. 6 Amplitude response of low and high pass

Generator 2,4 to 4,4 MHz is construed as the power (5W), tube, electron coupled oscillator, with a tuned circuit in the grid and in the anode of the tube, according to the construction marked earlier as ECO. So it is possible to provide both the required output power and the excellent spectral purity of the output signal by simple devices, see Fig. 7.

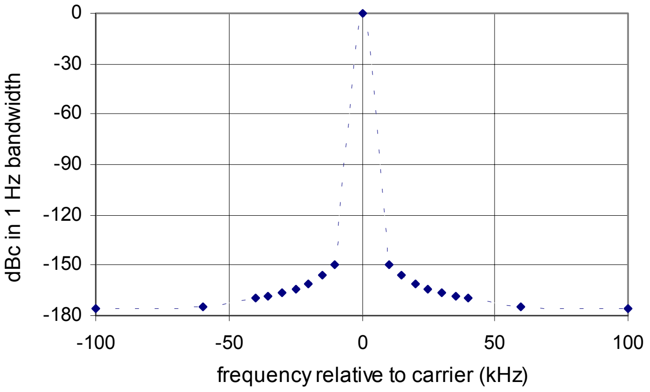

Fig. 7 Spectrum of power generator

Only a small frequency stability of the generator at load change is a disadvantage of this construction, so that it is necessary to watch the frequency and fine-tune the generator in some cases.

The frequency syntetizator with power wideband amplifier is used as the generator 50 kHz to 1 MHz. The 8-stages low-pass filter is placed on the output of the amplifier. It ensures the sufficient suppression of the disturbing signal and noise in the frequency band of measured signals.

The spectral analyzer HP 8560 is used for evaluating the intermodulating signal level.

The system has approximately 160 dBc sensitivity. It enables the measuring in the course of exciting currents through DUT 2x 1A and voltages into 50V.

3. THE RESULTS OF MEASURING

Series of measuring has been made so far by using the implemented system on linear components of circuits mainly with an aim to verify its usability for this kind of measuring.

All measuring has been practised for f_1 = 0,1 MHz, f_2 = 4,206 MHz, f_3 = 4,406 MHz. The preference of the frequencies in the range of tens kHz to units MHz, has minimal (even hardly demonstrable) influence on the indicated level of the non-linearity as emerged in the course of measuring further mentioned components. The connecting of all measured components into measuring circuits has been entirely provided by the soldering so that the measuring could not being influenced by the non-linearity of contact.

Some results of measuring are summarized in following graphs.

The graph in Fig. 8 shows results of the measuring of the non-linearity of wires and cables.

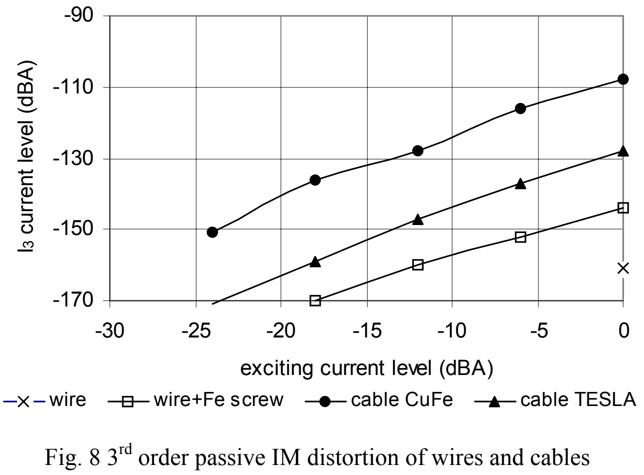

Fig. 8 3rd order passive IM distortion of wires and cables

Curve 1, let us say, the single point ,that represented measuring, introduces the level of non-linearity of the measuring system on the value of -160 dBc. This result was obtained through the connection of the measuring clamp by the short strong Cu wire, which could not have any non-linearity. Curve 2 represents the non-linearity of the same wire, besides which a 20 mm long M4 screw, was set in the distance of c. 10 mm perpendiculary tangential. The strong increase of the non-linearity proves a strong influence of ferro-magnetic. Curve 3 represents the non-linearity of the cheap 2,5m long coaxial cable with central wire of copper plated steel wire. It is evident that the non-linearity is caused by ferro-magnetic. Non-linearity of the comparable new RG 58U cable was not noted. The curve 4 represents the non-linearity of the 35 years old cable Tesla VFKP 300. This very old cable had its braiding gently corroded, so the non-linearity was caused.

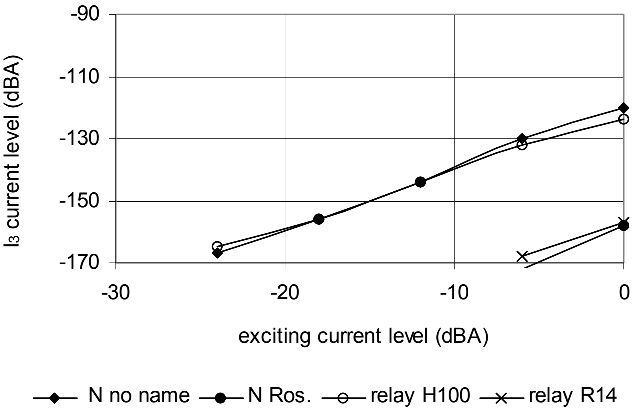

Fig. 9 3rd order passive IM distortion of contacts

Examples of the non-linearity of contacts are shown in figure 9. Curves 1 and 2 belong to the connector N (always a set of cable connector for RG 213 and flanged connector), curve 1 to connector fy. Rosenberger, curve 2 goes under cheap NO NAME connectors. The non-linearity is probably caused by nickel plated central contact, which is ferromagnetic. Curves 3 and 4 correspond to relay contacts. Curve 3 stays for the contact of relay H 100 fy. GM Electronic (relay 6A 250 VAC, PCB mounted) curve 4 belongs to the contact of the coaxial relay R14 fy Karasz (50 Ω, 1kW RF, relay for transmitter).

The examples of the non-linearity of passive components R and C are shown in figure 10.

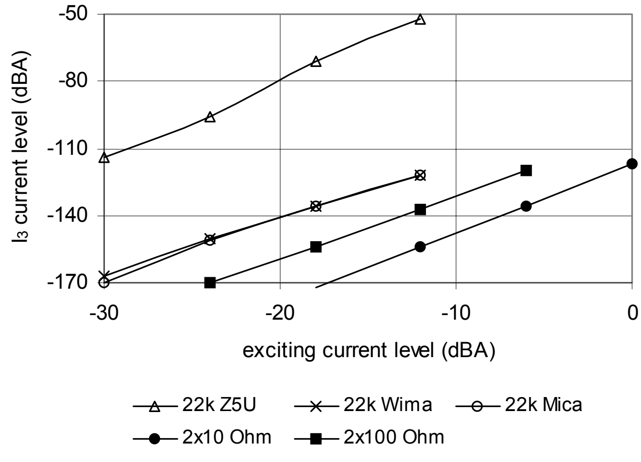

Fig. 10 3rd order passive IM distortion of R,C components

Curve 1 responds to resistors MLT 1 -10 Ω, curve 2 to resistors MLT 1 100 Ω. Two identical resistors were always measured parallel. Although resistors were considerably overloaded by measuring, their non-linearity in nominal loading c.-140 dBc was not significant. Curves 3,4,5 respond to the capacitor 22 nF, curve 3 to ceramics Z5U, curve 4 belongs to CF5 Wima, curve 5 to mica WK 202 17 Tesla. Ferroelectric properties of the ceramic implicate high non-linearity. The non-linearity of others capacitors is evidently made by contacts of the terminal on plating of dielectric. This measuring also documents the necessity to use special capacitors for construction of measuring circuit.

4. CONCLUSIONS

Introduced experimental equipment allows to evaluate very small non-linearity of passive components. Wires, cables, contacts and passive components were measured. The sensitivity and residual non-linearity are comparable with professional equipments with constant characteristic impedance 50 Ω. This research work is supported by the projects CEZ J048: 210000015 and GACR 102/01/1353.

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