

# Representation and Analysis of Radio Receivers' Susceptibility and Nonlinearity by the Use of 3D Double-Frequency Characteristics

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**Abstract** — Radio receivers' EMC testing technology based on measurement of 3D double-frequency characteristic by the use of two frequency-sweeping signals is described. This characteristic simplifies the detection and identification of all linear and nonlinear interference responses (spurious, intermodulation, etc.) of the receiver. For four types of microwave receivers, the abilities of operation in presence of high-level out-of-band signals are compared by measurement and analysis of their 3D double-frequency characteristics. Experimental results demonstrating delicate and new interference effects in receivers (areas of nonlinear noise and areas of spurious generation arising at certain ratios between the frequencies of undesired input signals, etc.) are given.

**Keywords** – radio receiver, nonlinear interference, spurious response, intermodulation

## I. INTRODUCTION

The standardized technology of radio receiver's EMC testing through its antenna input [1], [2], [3] allows one to get the information for decision-making on the receiver's operability in the most probable electromagnetic environment. However in the most difficult conditions of operation, when radio reception is carried out in the presence of high-level out-of-band signals (for example, on board systems with a lot of radio transmitters, or when searching the interferers near to high-power transmitters), this information is in many cases insufficient for estimation of radio reception possibility and probable ways of the receiver defeat by interference through the antenna input.

In such complicate cases, the necessary information about the receiver properties can be obtained by the use of highly-informative Automated Double-Frequency Testing Technique (ADFTT) [4]. ADFTT is able to detect, recognize, and measure the characteristics and parameters of all really existing linear and nonlinear interference responses and phenomena in the receiver.

In this paper, we present the results of comparative testing the receivers used in radio monitoring and spectrum management systems by the instrumentality of ADFTT's modern implementation [5].

## II. ADFTT PRINCIPLES AND IMPLEMENTATION

The main peculiarity of the ADFTT (which distinguish the ADFTT from the standardized techniques of radio receivers' two-signal testing [1], [2], [3]) consists in measurement and analysis of a double-frequency characteristic (DFC) of the receiver under test (RUT):

$$H(f_1, f_2) = P_{out}(f_1, f_2 | P_{1in} = const, P_{2in} = const), \quad (1)$$

where  $P_{out}$  is the output signal level observed if two test signals at frequencies  $f_1$  and  $f_2$  with levels  $P_{1in}$  and  $P_{2in}$  are applied to the RUT input (Figs. 1 and 2).

The levels  $P_{1in}$  and  $P_{2in}$  are selected taking into account the forecast of expected conditions of radio reception, and in certain situations these levels can 10...20 dB exceed a threshold of RUT susceptibility to nonlinear effects (intermodulation, desensitization, etc.)

The DFC (1) can be visualized as a three-dimensional (3D) plot (ref. [5] and Fig. 7 below) and/or as a color map. The double-frequency diagram (DFD – ref. Figs. 3, 4, 5, 6, and 8 below) is a specific color map of the DFC: the response levels below the threshold  $P_t$  are not displayed in DFD. The level  $P_t$  is usually taken equal to the susceptibility of the RUT to channel interference.

As a rule, the DFC (1) is measured with the use of unmodulated test signals and IF output of the RUT – this makes it possible to reduce the measurement time by several digits (e.g., for DFC size of 8001\*201 points, the measurement time is reduced from several tens of hours to several minutes).

The testing of a receiver by ADFTT is performed in 3 stages. The first two stages (i.e., the detection and recognition of receiver interference responses that describe probable ways of the receiver defeat by interference) are implemented by the measurement, visualization, and analysis of the DFCs. Then the standardized characteristics and parameters of the detected responses are measured (stage 3). At stage 3, modulated test signals (and the demodulator output of the RUT – if it is necessary to increase the analysis accuracy) are often used.

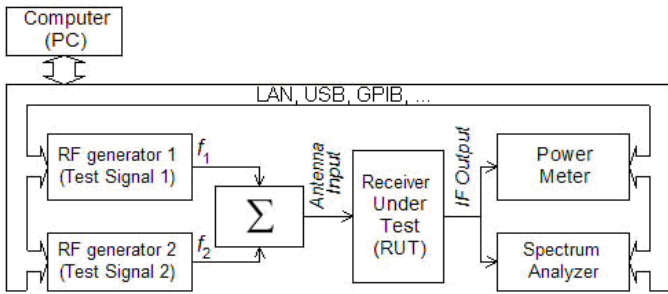


Figure 1. Basic structure of a measurement system for radio receiver testing by ADFTT

TABLE I. PARAMETERS OF RECEIVERS UNDER TEST

Parameter	RUT1	RUT2	RUT3	RUT4
Intermediate frequency $f_{IF}$ , MHz	0.455	10.7	10.7	45.0
Number of frequency conversions	3	2	2	4
3-dB bandwidth, kHz	110.0	120.0	110.0	150.0
Sensitivity, dBm	-102	-106	-106	-107
Output threshold level $P_t$ , dBm	-32.0	-100.0	-75.2	-77.5
Maximum dimension (depth), cm	52	31	26	20
Approximate price, thousand \$	100	3.3	1.2	0.5

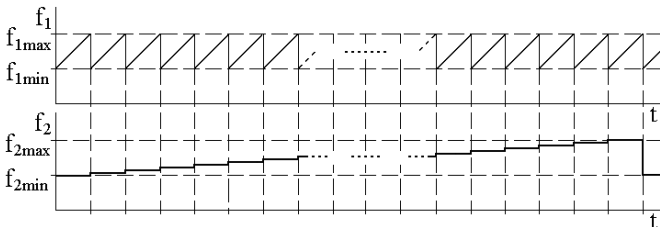


Figure 2. Linear frequency sweeping of the test signals in ADFTT:  $f_1$  and  $f_2$  are the frequencies of the fast- and slow-sweeping test signals

III. COMPARATIVE TESTS OF RADIO RECEIVERS

Four samples of the radio receivers (RUT1 – RUT4) used in modern radio monitoring systems have been tested comparatively: RUT1 is one of the most perfect, complicated, and expensive receivers; RUT2 is rather widespread and cheaper; RUT3 and RUT4 are the most widespread and cheap scanning receivers of previous generation; RUT4 is the simplest one. DFDs of these receivers are given in Figs. 3, 4, 5, and 6. These DFDs are measured in the following conditions: the levels  $P_{1in}$ ,  $P_{2in}$  of the test signals are 70 dB above the RUT's sensitivity at the tuning frequency of 1 GHz, test signals are sweeping from 0.8 GHz to 1.2 GHz. Parameters of RUTs are given in Table I.

Lines presented in the DFDs (ref. Figs. 3...6) are images of the desired response, the spurious and intermodulation responses of different types and orders. The equation of these lines for the RUT having three frequency conversions is [5]

$$z_1 \cdot f_1 + z_2 \cdot f_2 + z_3 \cdot f_{LO1} + z_4 \cdot f_{LO2} + z_5 \cdot f_{LO3} = f_{IF} \quad (2)$$

where  $z_1$ - $z_5$  are integer coefficients,  $f_{LO1}$ - $f_{LO3}$  are the frequencies of local oscillators, and  $f_{IF}$  is the intermediate frequency at the RUT output.

The DFD of RUT1 (Fig. 3) contains only images of its desired response at the tuning frequency  $f_t$  (a horizontal line and a vertical line) and insignificant traces of images of 3<sup>rd</sup>-order intermodulation (short segments of inclined lines crossed at the point  $f_1=f_2=f_t$ ). Thereby, the operability of RUT1 is nearly not affected by the input out-of-band signals of levels up to 70 dB above its sensitivity.

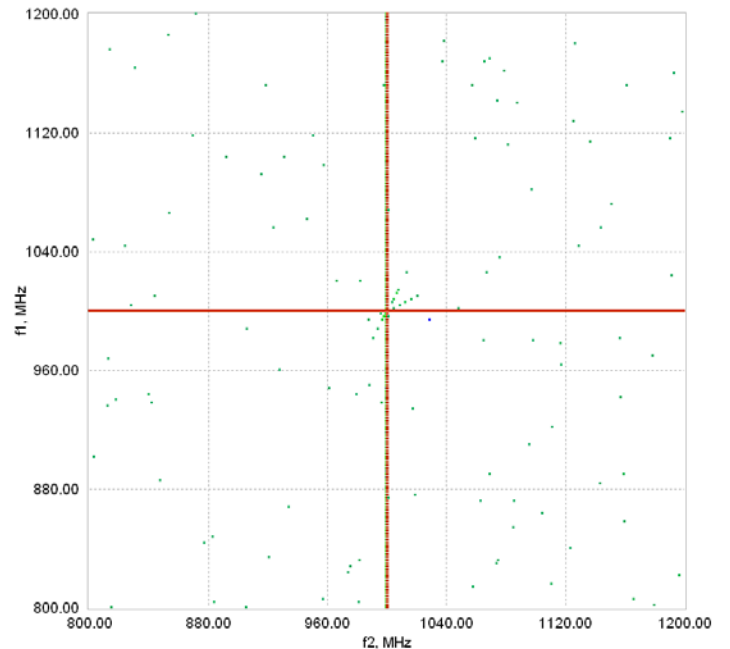


Figure 3. Double-frequency diagram (DFD) of RUT1

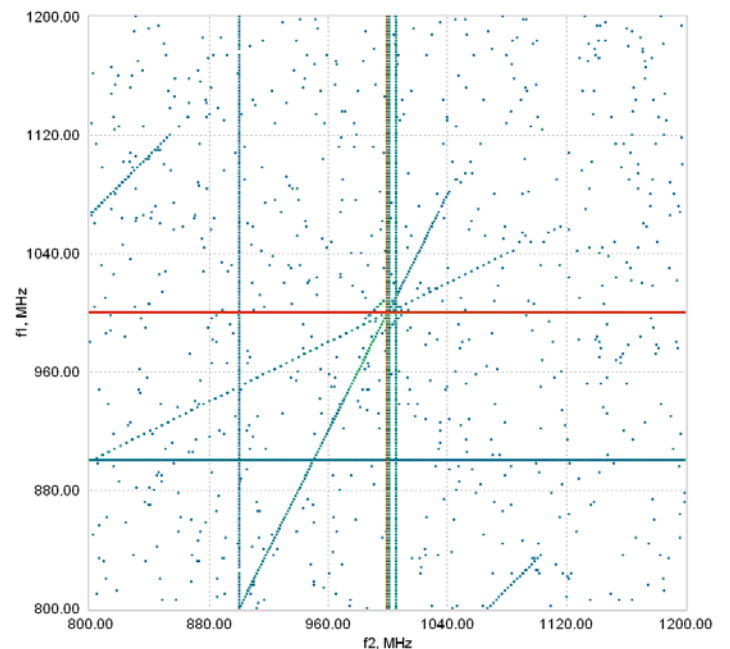


Figure 4. Double-frequency diagram (DFD) of RUT2

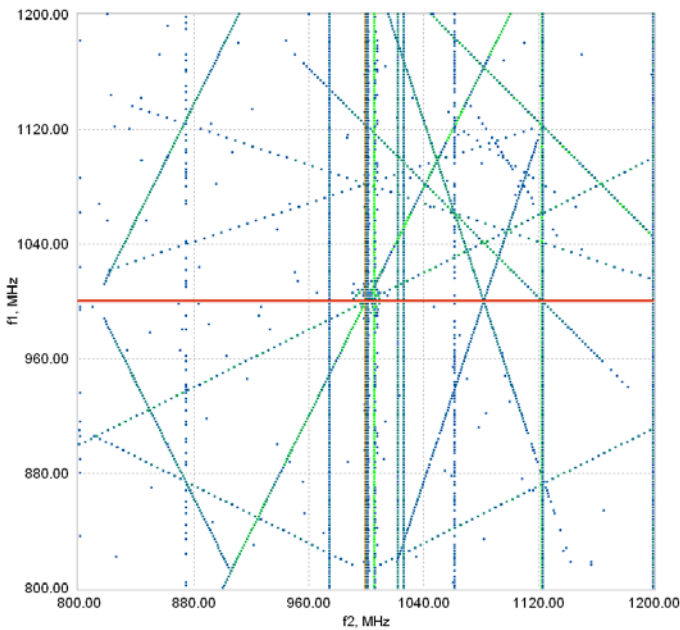


Figure 5. Double-frequency diagram (DFD) of RUT3

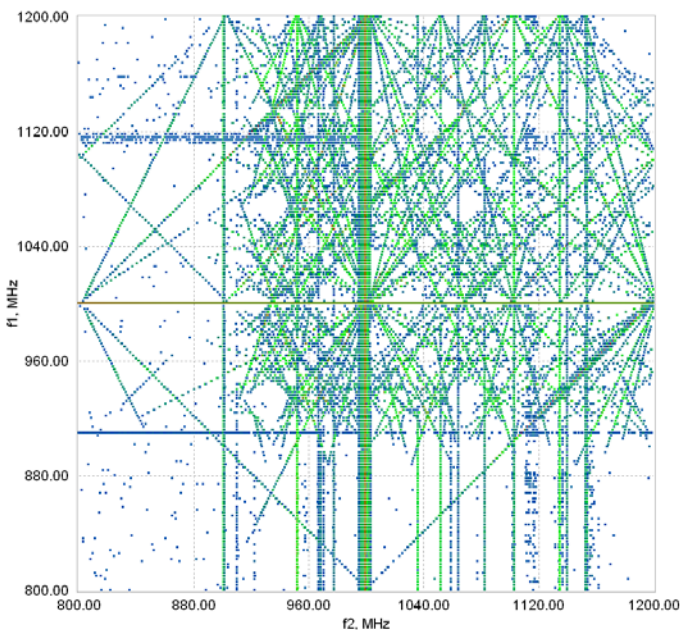


Figure 6. Double-frequency diagram (DFD) of RUT4

The DFD of RUT2 (Fig. 4) contains the images not only of the desired response but also of the following interference responses: 1) 2<sup>nd</sup> order intermodulation in the first mixer  $\{f_{1,2} - f_{2,1} = f_{IF1}\}$ , where  $f_{IF1}$  is the 1<sup>st</sup> intermediate frequency of 266.7 MHz; 2) 3<sup>rd</sup> order intermodulation  $\{2f_{1,2} - f_{2,1} = f_i\}$ ; 3) two spurious responses (represented by pairs of horizontal and vertical lines crossed at the spurious response frequency; the horizontal line may be absent because the horizontal resolution of the DFD is much better than the vertical one: 8001 points as against 201), one of them is located only 5 MHz above the tuning frequency. All the detected responses were recognized by the technique described in [5] – the results are summarized in Table II, where “MX order” is a total order

of frequency mixing (which is a sum of absolute values of  $z_1 \dots z_4$ ), “IM order” is an order of intermodulation (which is equal to the sum of absolute values of  $z_1$  and  $z_2$ ).

The DFD of RUT3 (Fig. 5) also contains many images of spurious and intermodulation responses (Table III).

The main cause of the interference responses detected in RUT2 and RUT3 (as compared to RUT1) is more appreciable front-end nonlinearity and, at the same time, less efficient frequency filtering in the front end.

At last, the DFD of RUT4 (Fig. 6) contains so many images of interference responses (up to very high orders) that it is unreasonable to recognize any of them because RUT4 can not operate under the influence of so high levels of out-of-band signals as 70 dB above the sensitivity. This fault of RUT4 is mainly caused by the following:

1) By artificial adding of two intermediate frequencies without additional filtering: from the 2<sup>nd</sup> mixer output, the 45 MHz signal directly comes to the input of the 3<sup>rd</sup> mixer, after which the 10.7 MHz signal is finally filtered (and converted back to 45 MHz).

2) By inefficient frequency selectivity at the input: only a high-pass filter having the 3-dB-cutoff frequency of 940 MHz is used (which is clearly reflected in Fig. 6).

TABLE II. RESPONSES OBSERVED IN FIGURE 4

No.	MX order	IM Order	Z1	Z2	Z3	Z4
1.	3	2	-1	1	0	-1
2.	3	2	1	-1	0	-1
3.	9	2	2	0	0	-7
4.	9	2	0	2	0	-7
5.	5	3	-2	1	1	-1
6.	5	3	1	-2	1	-1
7.	9	3	0	-3	3	-3

TABLE III. RESPONSES OBSERVED IN FIGURE 5

No.	MX order	IM Order	Z1	Z2	Z3	Z4
1.	4	2	0	-2	1	1
2.	4	2	-1	-1	1	1
3.	4	3	1	-2	0	1
4.	4	3	-2	1	0	1
5.	5	3	-1	2	-1	1
6.	5	3	2	-1	-1	1
7.	6	3	1	2	-2	1
8.	6	3	2	1	-2	1
9.	6	4	-3	1	1	1
10.	6	4	1	-3	1	1
11.	8	4	2	2	-3	1
12.	8	4	3	1	-3	1
13.	8	4	1	3	-3	1
14.	8	4	0	4	-3	1
15.	14	4	0	4	1	-9
16.	9	5	-2	-3	3	1
17.	9	5	-3	-2	3	1
18.	10	5	0	-5	2	3
19.	11	6	0	-6	4	-1
20.	14	6	0	-6	1	7
21.	14	7	0	7	-4	-3
22.	12	7	0	-7	3	2

## IV. DELICATE PHENOMENA DETECTED IN RECEIVERS

The ADFTT-based testing of radio receivers makes it possible to detect not only the traditional spurious and intermodulation responses of various types and orders but also a number of specific nonlinear effects that also break the receivers' operability in the presence of high-power out-of-band signals. The following effects were found in majority of inspected receivers, including the most perfect and expensive:

1) A spurious generation arising in RUT at a certain combination of frequencies of two powerful out-of-band input signals and having a very high level (nearly equal to the saturation level of the receiving path). It is observed as specific bursts in 3D plot of DFC (Fig. 7) and as curvilinear or specific regularly-shaped red-color-coded elements in DFD (Fig. 8).

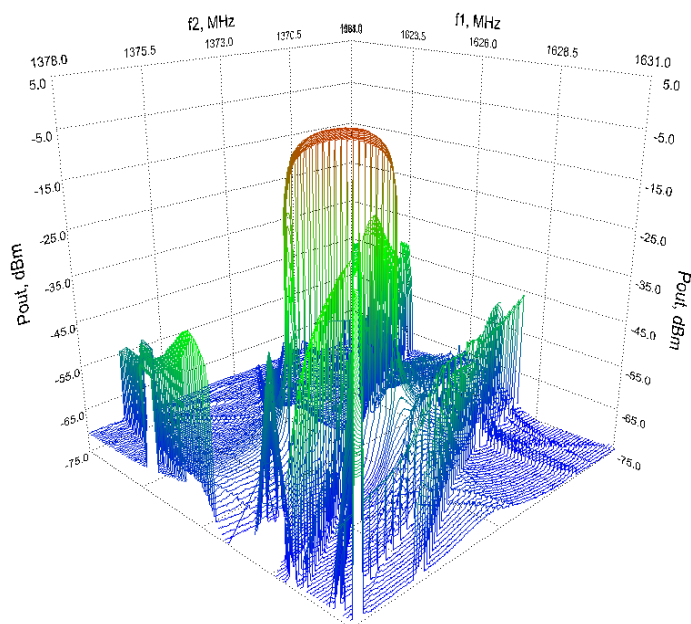


Figure 7. 3D DFC of RUT1: the spurious generation is observed at a certain combination of the test signal frequencies (corresponding DFD is given in Fig. 8)

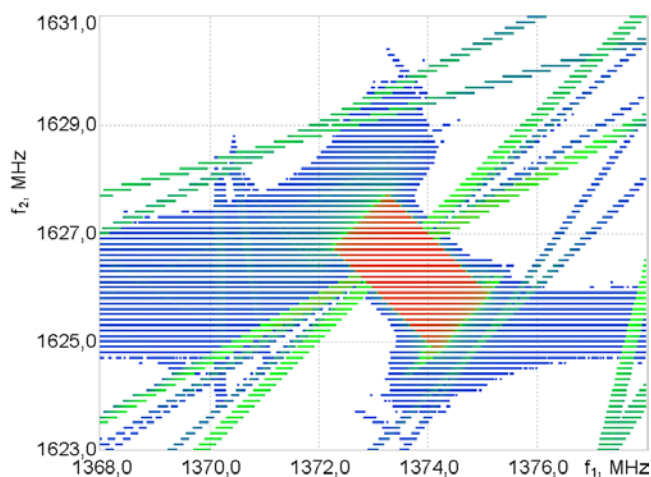


Figure 8. DFD of RUT1: the double-frequency affected point (in red) and the nonlinear noise area (curvilinear image).

2) An intermodulation with nonlinear dependence of its frequency on the test signal frequencies ( $f_1$  and  $f_2$ ), which have been observed in receivers [5] and generators [4]. Conjecturally, this intermodulation is caused by mixing of the test signals with the above-mentioned spurious generation. As a rule, the level of this intermodulation is 15...30 dB less than the level of the spurious generation.

3) A low-level noise-like spurious generation, which looks as curvilinear blue-color-coded areas in DFD (Fig. 8). Usually, the level of this generation exceeds the RUT's internal noise level by not more than 15...20 dB.

## V. CONCLUSION

The ADFTT makes it possible to obtain a great volume of impartial and very useful information on the receiver's operability in a given electromagnetic environment.

The results of comparative analysis given in Section III demonstrate not only the efficiency of the ADFTT but also the tradeoff between the receiver's performance and cost: high-quality and expensive receiver is needed for radio monitoring and spectrum measurements in severe electromagnetic environment (e.g., near to powerful transmitters), but much more simple and cheap receiver is enough for solving the same problems in the absence of high-level undesired signals.

The absence of nonlinear effects in receivers is an important condition of their operability in severe electromagnetic environment. The ADFTT makes it possible to detect all existing nonlinear effects, both traditional (spurious responses, intermodulation, etc.) and specific (ref. Section IV). Note that the traditional effects can in principle be detected by the traditional techniques [1], [2], [3] (and ADFTT essentially simplifies and speeds up their detection and recognition), but it is practically impossible to detect the specific phenomena without ADFTT since there is no method to predict such phenomena.

Three-dimensional display of the DFC and color coding of the RUT response level simplify the visual analysis of measured DFCs and DFDs for detection and recognition of various interference effects.

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