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

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Introduction

1. Automated Double-Frequency Test System (ADFTS) is a very efficient tool for EMC testing of radio receivers and RF-components (amplifiers, mixers, generators, etc.)

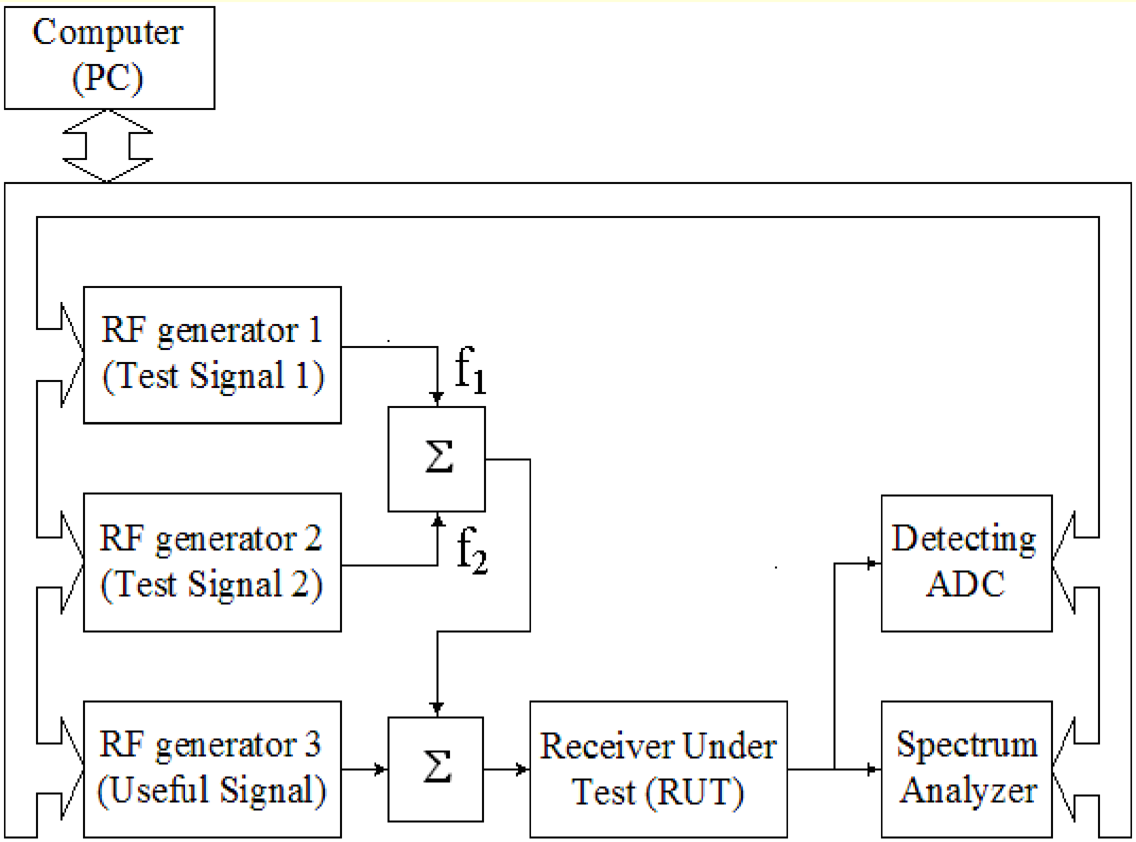
2. The ability of simple detection and recognition of all nonlinear effects appearing in the Device Under Test (DUT) is an advantage of the ADFTS over traditional measurement systems

3. In this work, we make a comparative analysis of interference responses and nonlinear effects observed in radio receivers of different complexity and price (four samples) by the instrumentality of the ADFTS

Contents

Automated Double-Frequency Test System (ADFTS)

Basic ADFTS Structure
for Radio Receiver EMC Testing

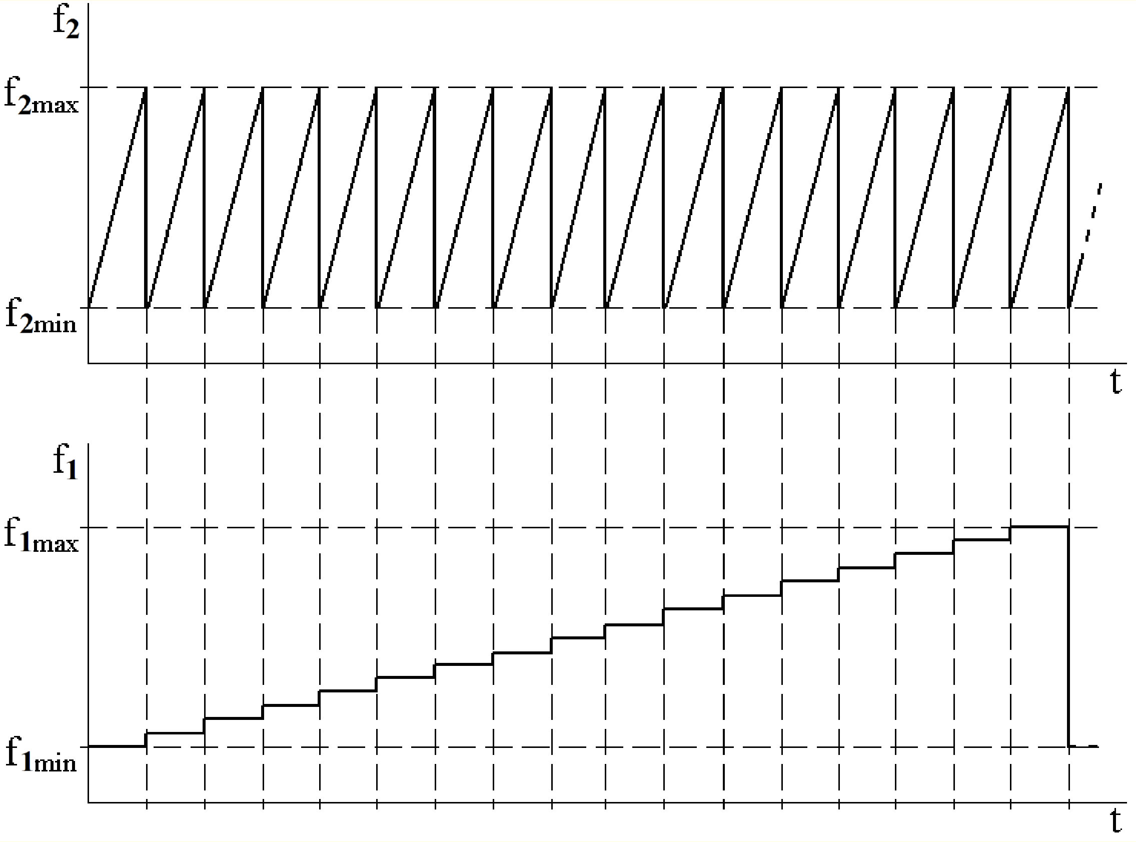


__Main idea of ADFTS:__

- Receiver under test (RUT) is fed by the sum of two frequency-sweeping signals with constant levels
- Speed of sweeping is different (as in television):
  f1 sweeps slowly, and
  f2 sweeps fast
- The response at the RUT output is measured and plotted as a function of the input frequencies f1 and f2

Automated Double-Frequency Test System (ADFTS)

Principle of RF generators' frequency sweeping in ADFTS



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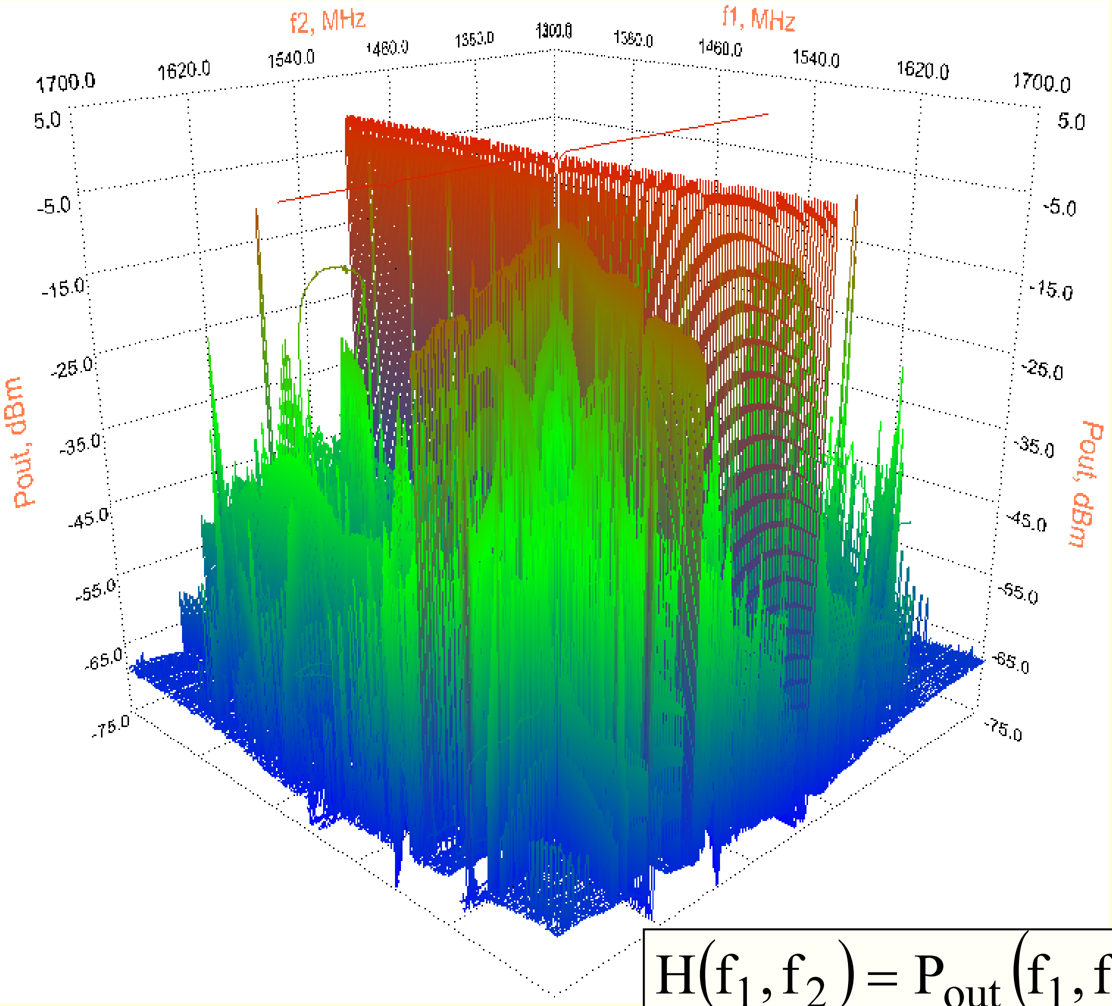
Automated Double-Frequency Test System (ADFTS)

Double-Frequency Characteristic (DFC): 3D Plot



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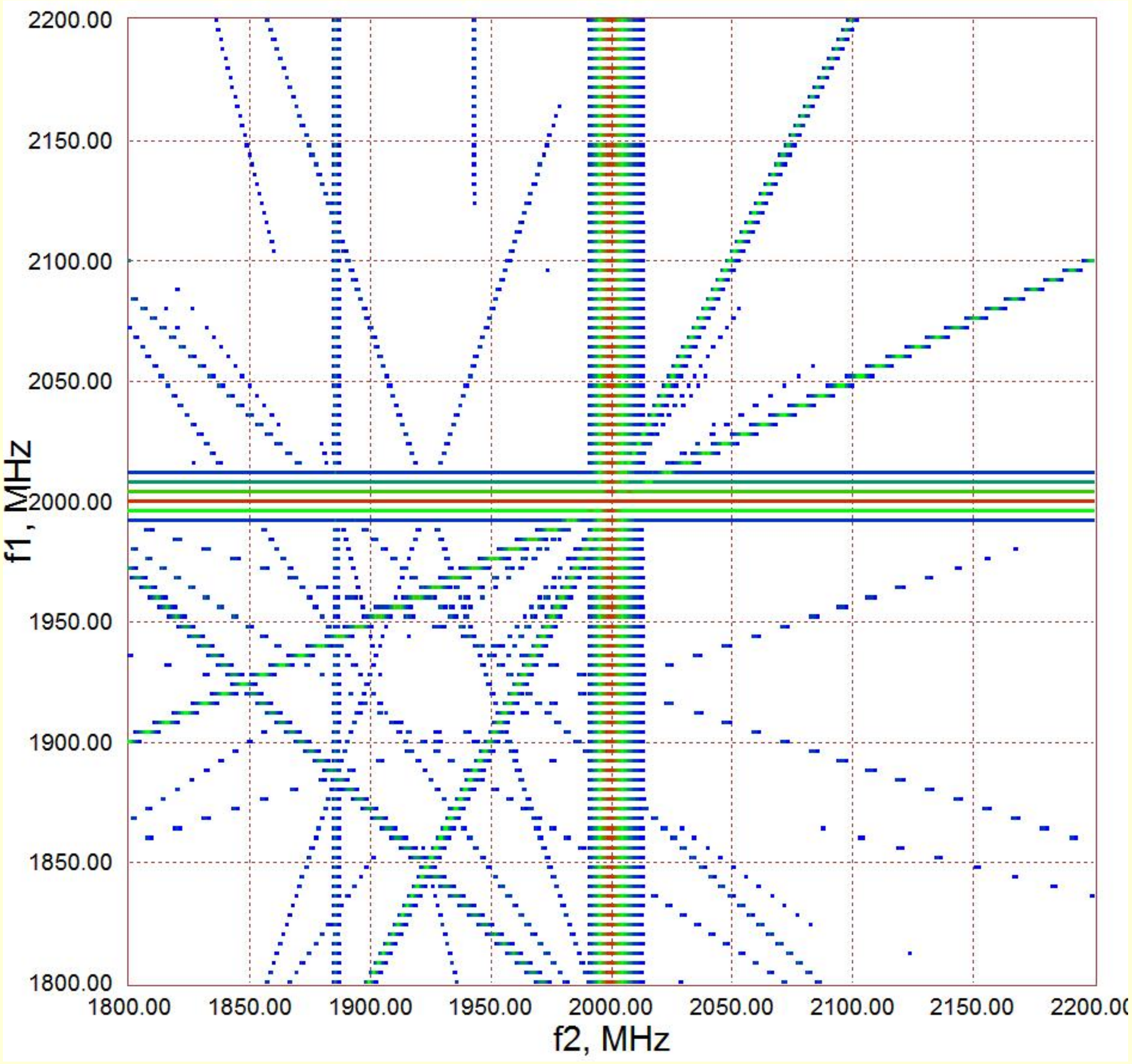
$$H(f_1, f_2) = P_{out}\left(f_1, f_2 \middle| \; P_{1in} = const, \; P_{2in} = const\right)$$

Automated Double-Frequency Test System (ADFTS)

Double-Frequency Characteristic (DFC): DFD Plot



DFD Plot:

- Double-Frequency Diagram (DFD) is a color map plot of the DFC (similarly to geographic maps)
- Only the levels over the user-defined threshold (Pt) are displayed in the DFD
- DFD has a diagonal symmetry
- Each line in the DFD represents a response (desired, or spurious, or intermodulation) of the DUT

Contents

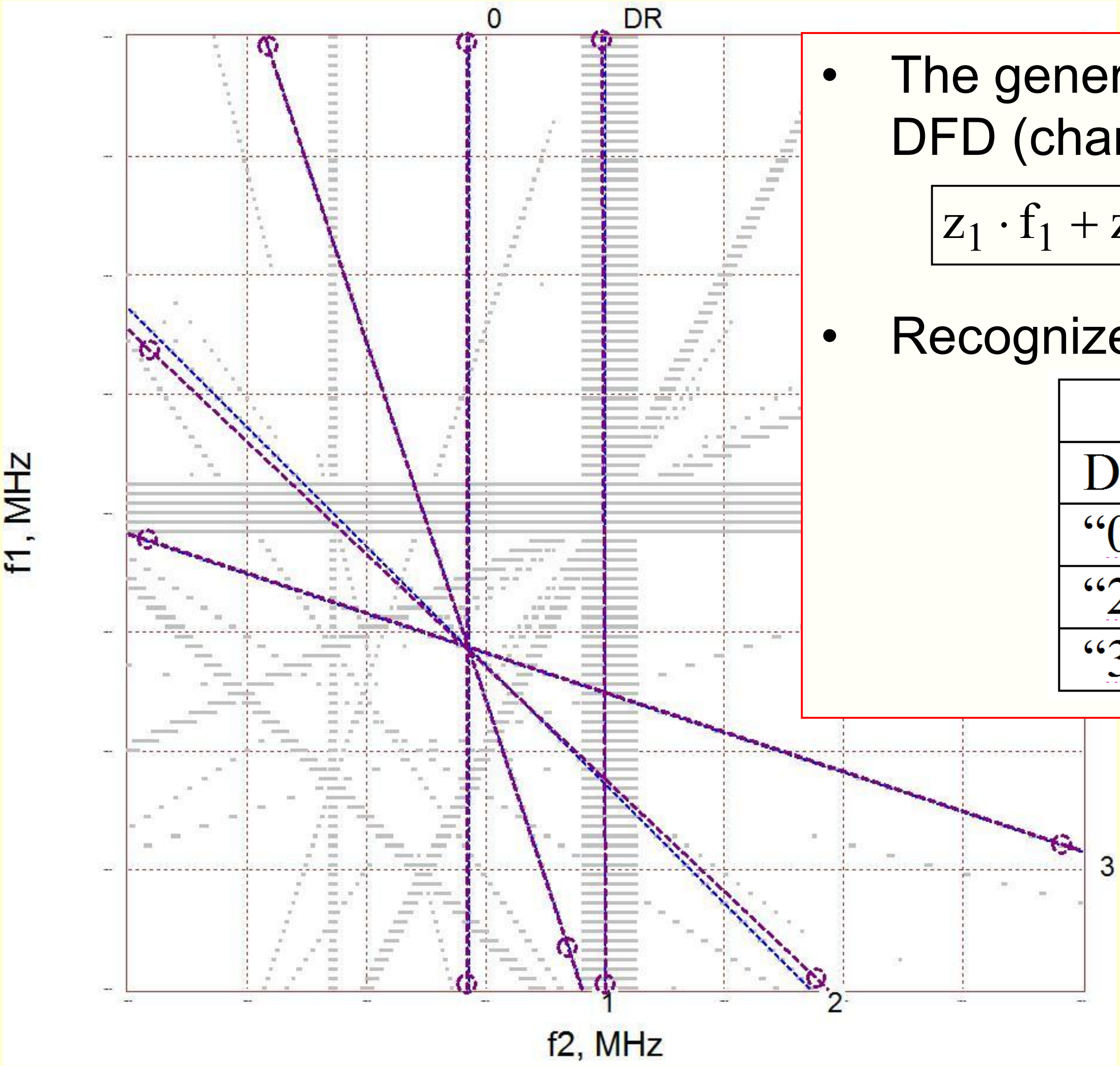
Automated Double-Frequency Test System (ADFTS)

Measurement stages

1. Detection of RUT's interference responses
   - Measure the RUT Double-Frequency Characteristic (DFC)
   - Plot the Double-Frequency Diagram (DFD): each line represents a response
2. Recognition of the detected responses
   - Take the DFD and use the Marker Line Technique: you will get the response coefficients {Zi} in the channeling equation
3. Measurement of characteristics and parameters of the recognized responses
   - Use standardized characteristics (desired response selectivity, spurious response selectivity, intermodulation selectivity, etc.)
   - Use standardized parameters (susceptibility, bandwidth, shape factor, etc.)

Automated Double-Frequency Test System (ADFTS)

Recognition of responses: Marker Line Technique



- The general equation for lines in DFD (channeling equation):

$$z_1 \cdot f_1 + z_2 \cdot f_2 + z_3 \cdot f_{LO} = f_{IF}$$

- Recognized response coefficients:

	z_1	z_2	z_3
DR	0	-1	1
"0"	0	-4	3
"2"	2	-2	3
"3"	3	-1	3

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Table 1. Parameters of Receivers under Test (RUTs)

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

RUT1 – RUT4 are used in modern radio monitoring systems:

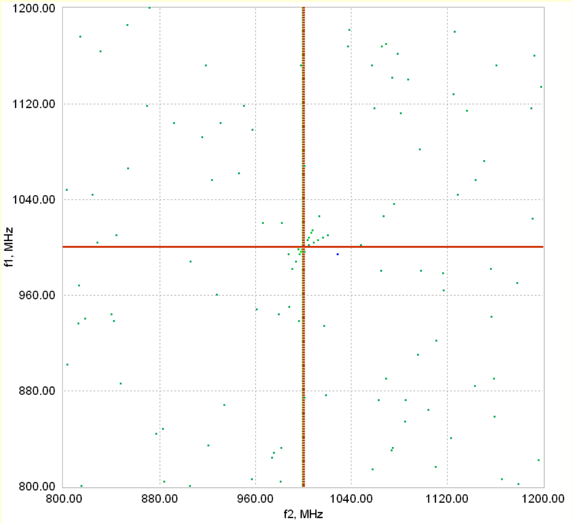
RUT1 is one of the most perfect scanning measuring receiver,

RUT2 is rather widespread and cheaper scanning receiver,

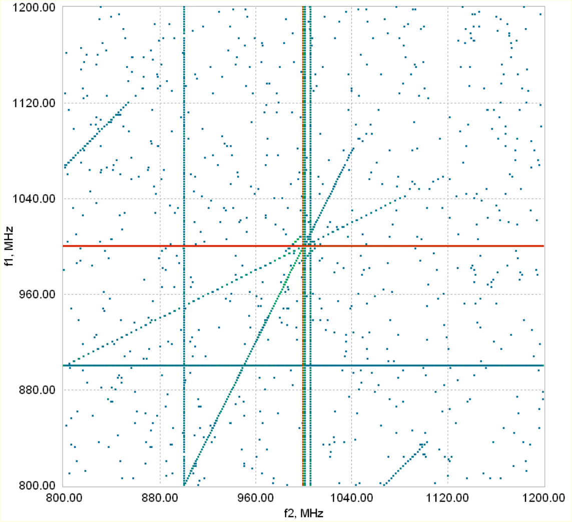
RUT3, RUT4 are most widespread and cheap scanning receivers of previous generation,

RUT4 is the simplest and cheapest one

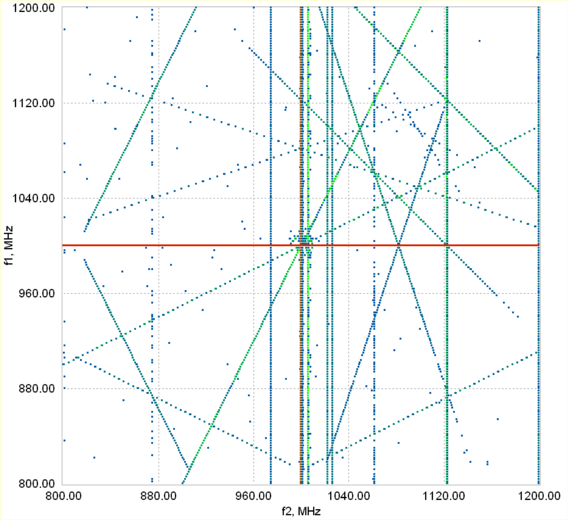
Comparative tests of radio receivers



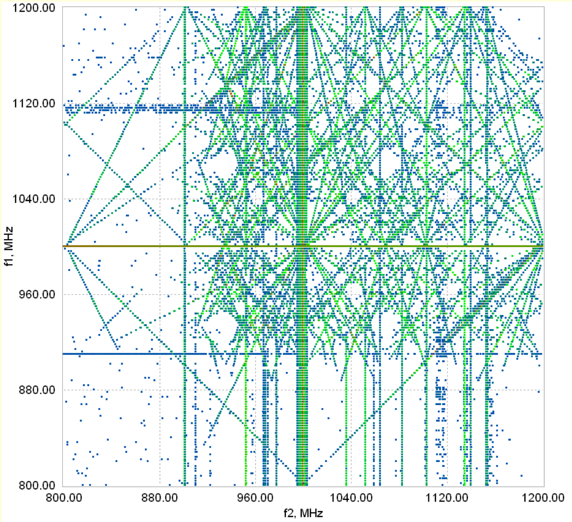
RUT 1



RUT 2



RUT 3



RUT 4

For each receiver, we measured the DFD and recognized the responses observed in the DFD

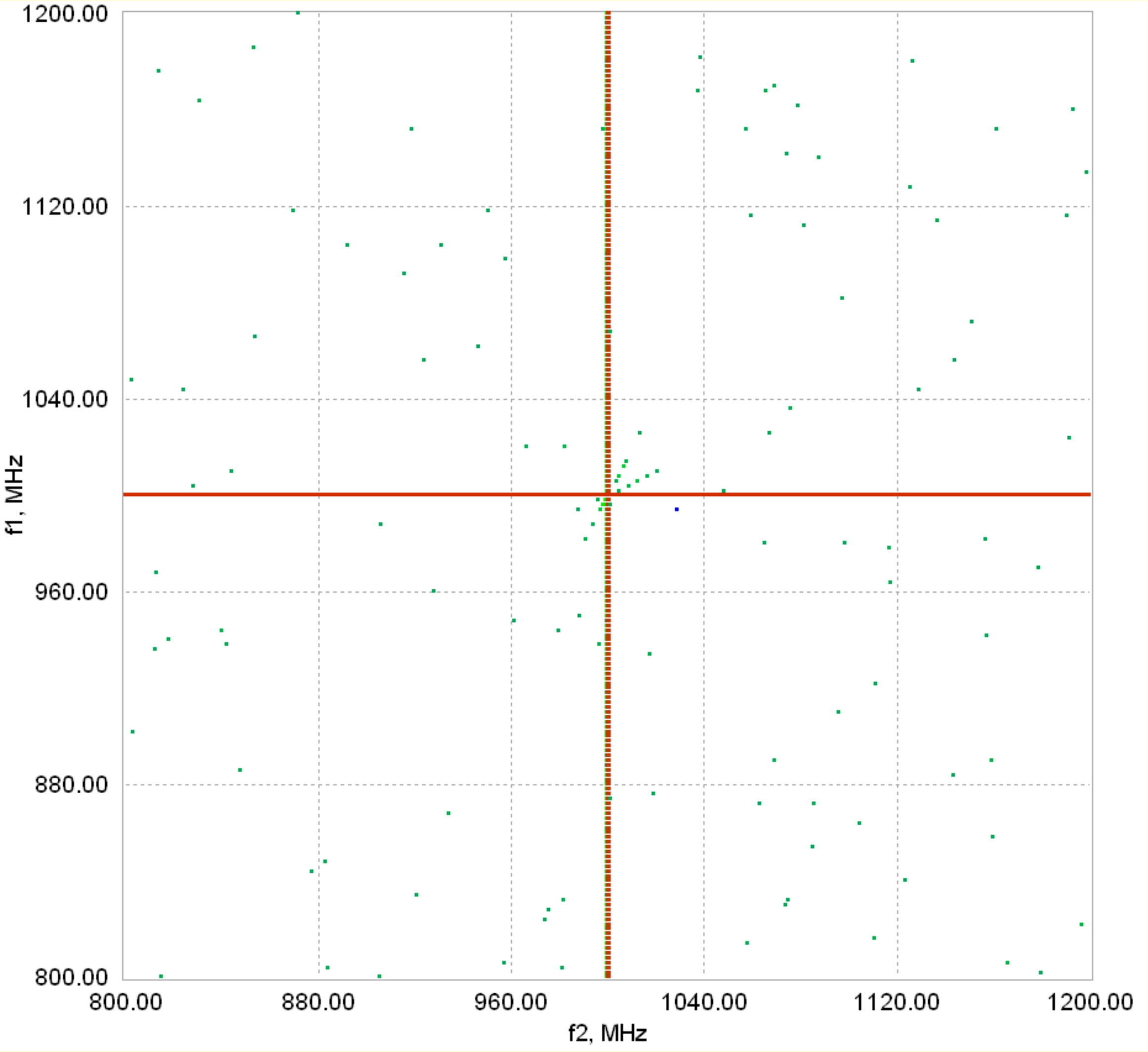
Parameters of the measurements:

- Tuning frequency of each receiver is 1 GHz
- Parameters of the test signals:

= Frequency sweeping range is [0.8, 1.2] GHz

= Levels P_{1in}, P_{2in} are 70 dB above the receiver sensitivity

Comparative tests of radio receivers

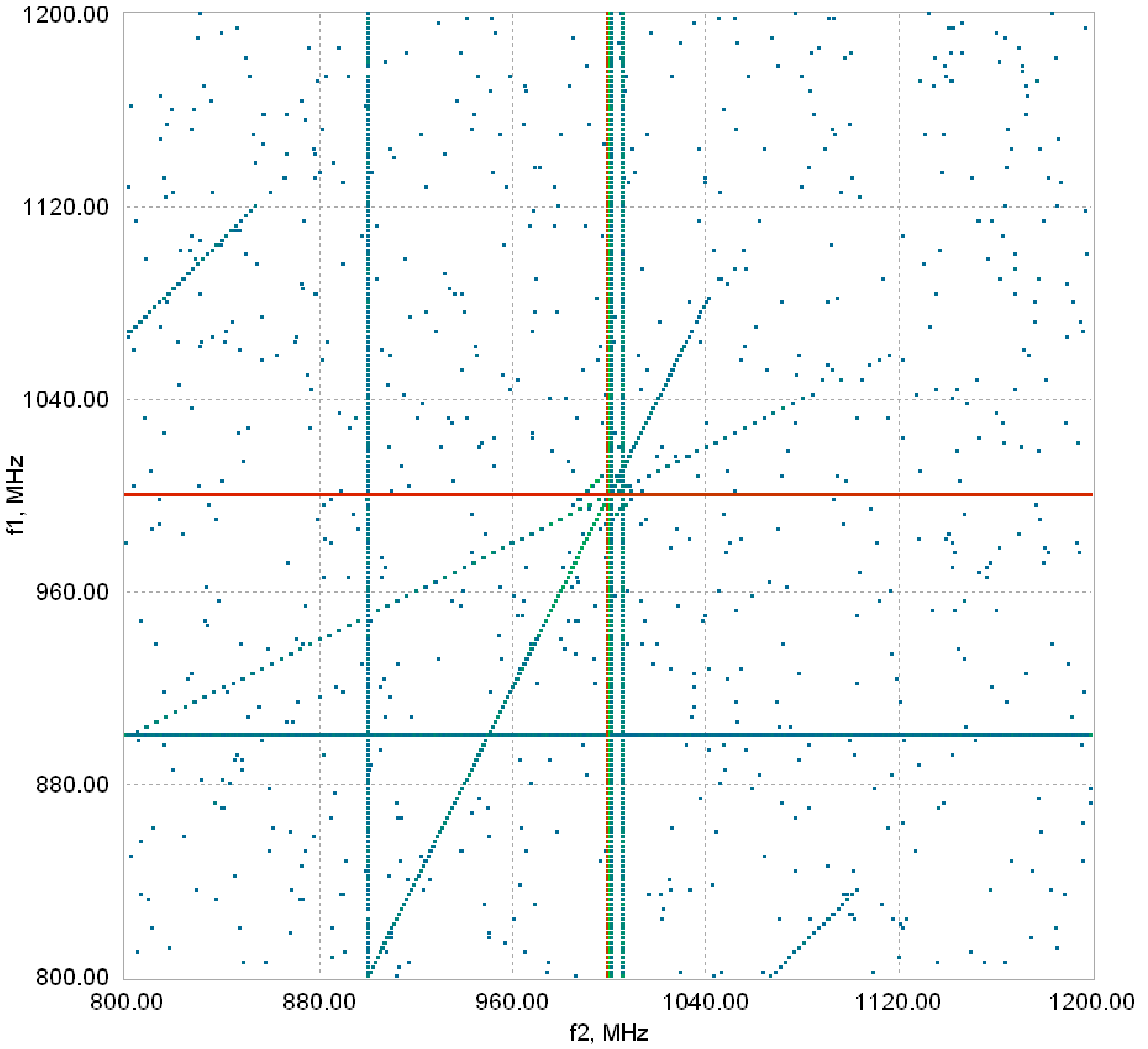


DFD of RUT1

DFD contains:
1) images of the desired response at the tuning frequency f_t (a horizontal line and a vertical line), and
2) insignificant traces of images of 3rd-order intermodulation (short segments of inclined lines crossed at the point $f_1=f_2=f_t$).

The operability of RUT1 is nearly not affected by the input out-of band signals of levels up to 70 dB above its sensitivity.

Comparative tests of radio receivers



DFD of RUT2

(the description
is given
in the next slide)

Comparative tests of radio receivers

DFD of RUT2

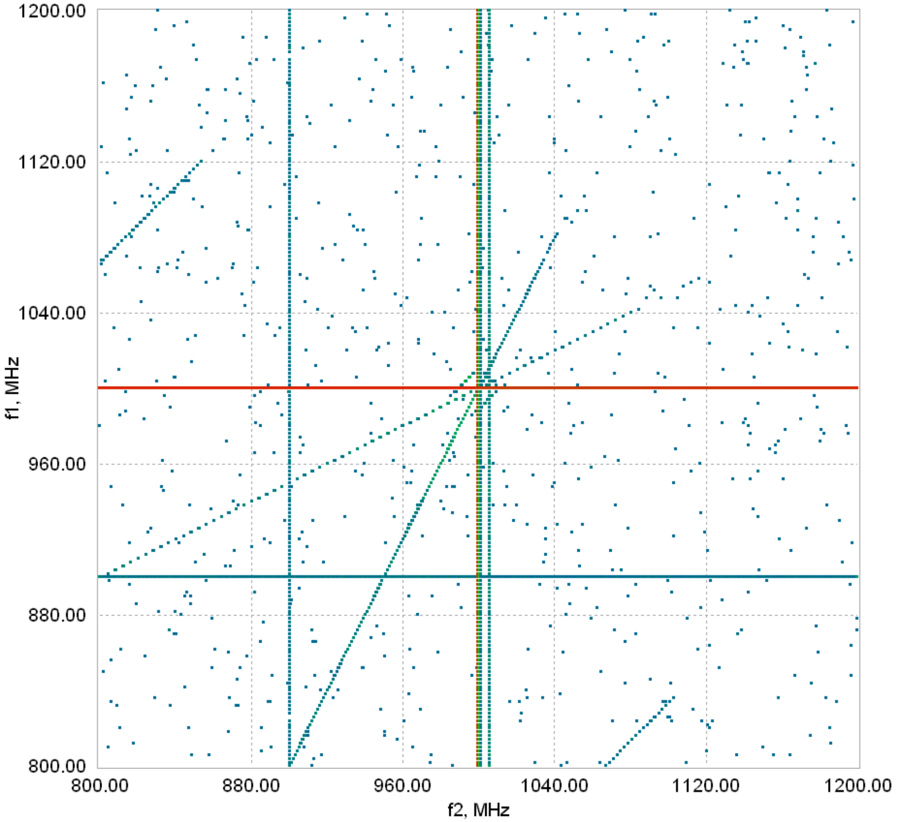


Table 2. Responses detected in RUT2

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

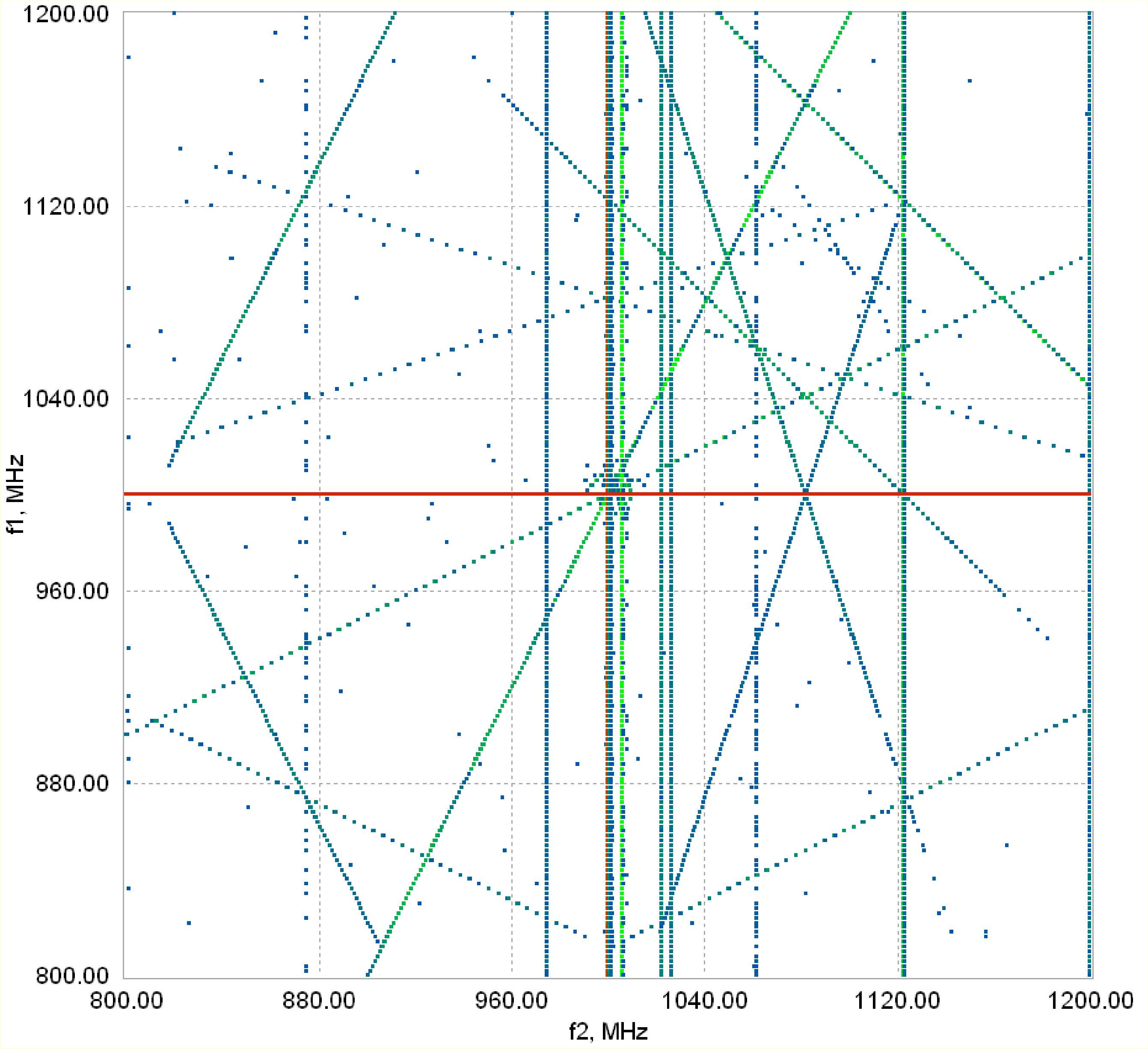
The DFD of RUT2 contains the images not only of the desired response but also of the following interference responses:

1) 2nd order intermodulation in the first mixer $\{f_{1,2} - f_{2,2} = f_{IF1}\}$, where f_{IF1} is the 1st intermediate frequency of 266.7 MHz;

2) 3rd order intermodulation $\{2f_{1,2} - f_{2,2} = f_t\}$;

3) two spurious responses (represented by pairs of horizontal and vertical lines crossed at the spurious response frequency.

Comparative tests of radio receivers



DFD of RUT3

The DFD contains many images of spurious and intermodulation responses (their description is given in the next slide)

Comparative tests of radio receivers

Table 3. Responses detected in RUT3

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

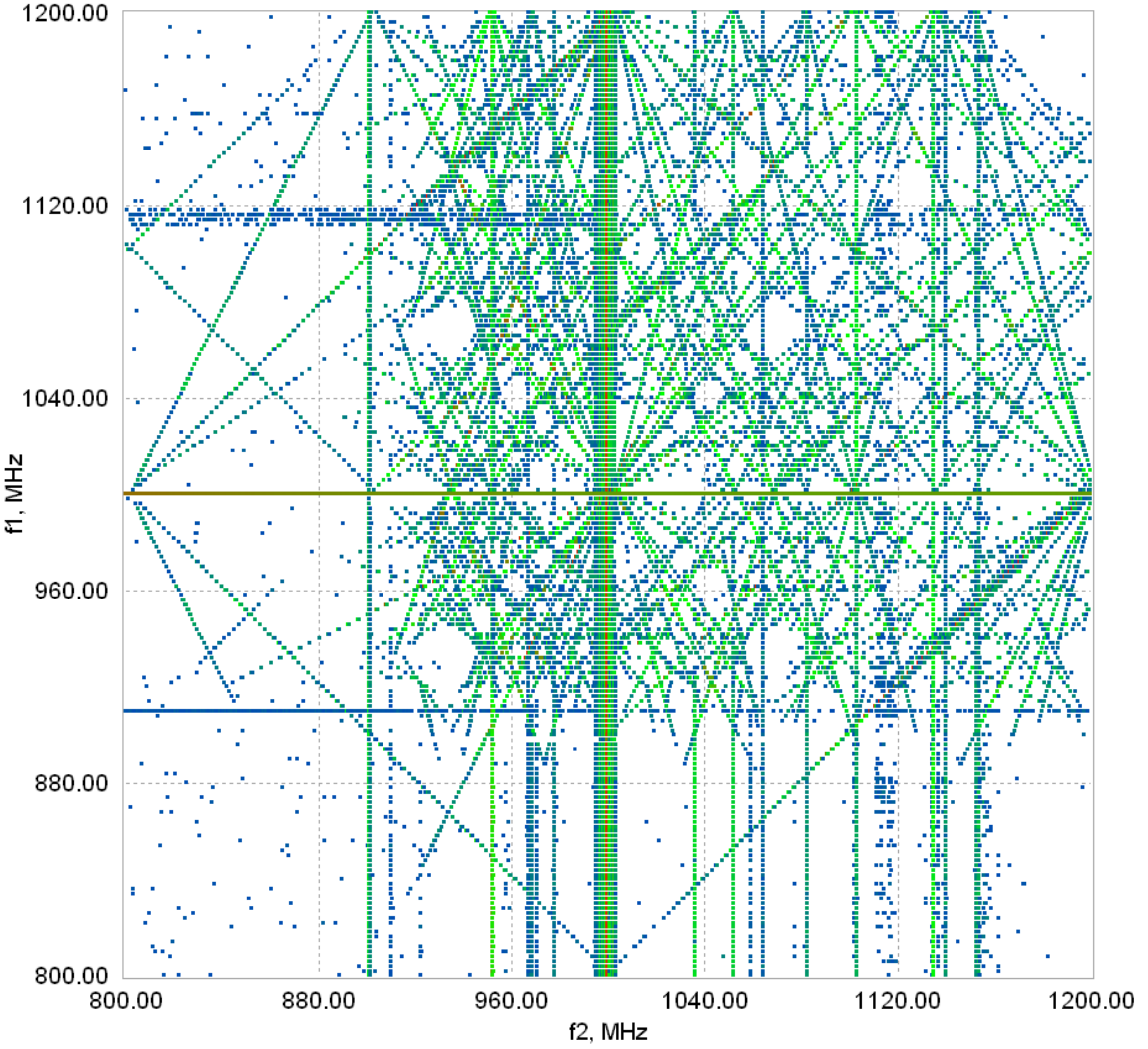
The main reasons of the interference responses detected in RUT2 and RUT3 (as compared to RUT1) are:

1) More appreciable front-end nonlinearity

2) Less efficient frequency filtering in the front end

Comparative tests of radio receivers

DFD of RUT4



The DFD contains many images of interference responses up to very high orders. Therefore, RUT4 can not operate if the levels of out-of-band signals are 70 dB above the sensitivity. This fault of RUT4 is mainly caused by the following reasons:

1) By artificial adding of two intermediate frequencies without additional filtering: from the 2nd mixer output, the 45 MHz signal directly comes to the input of the 3rd 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 the DFD).

Contents

Delicate phenomena detected in receivers

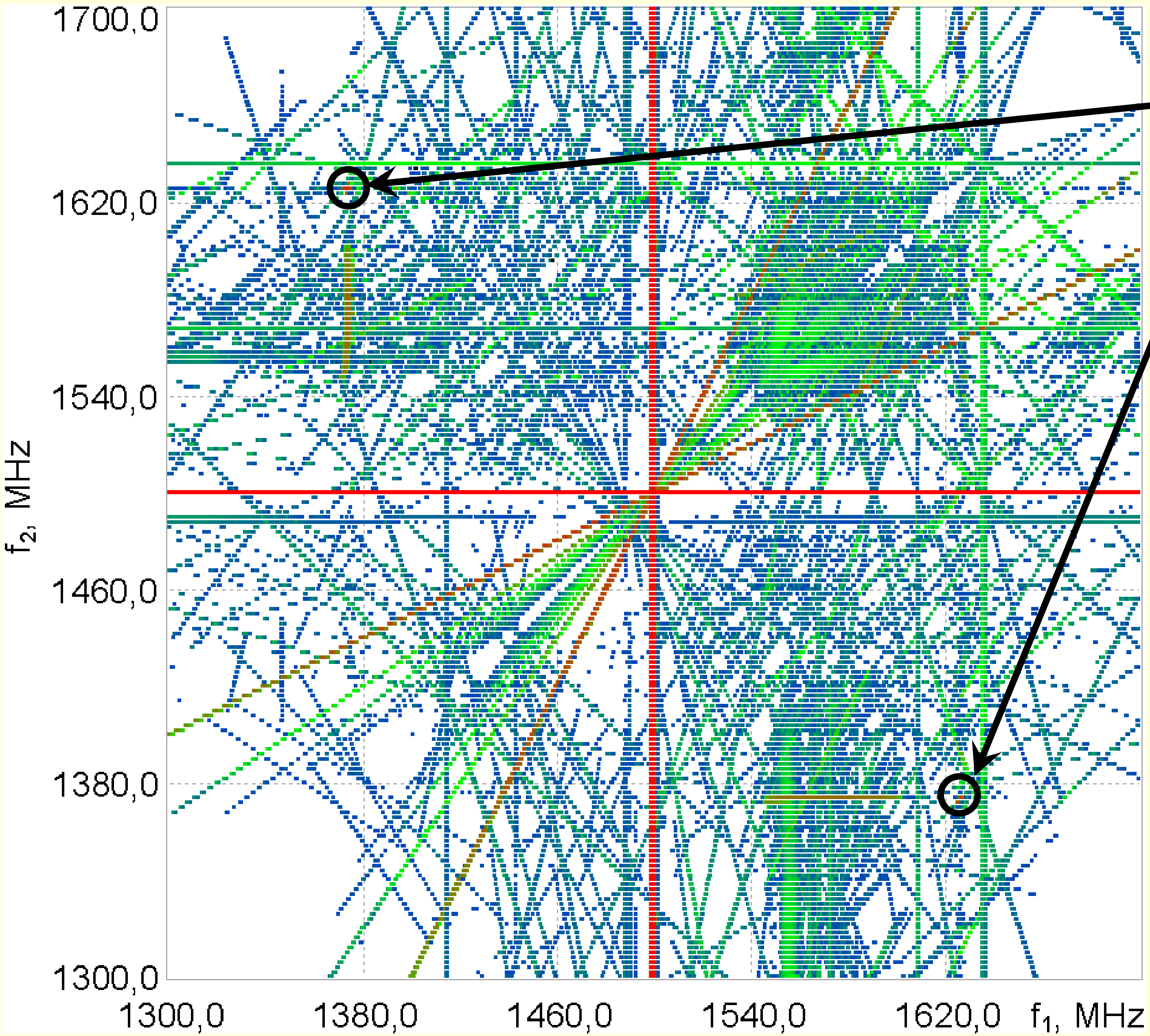
1. **A spurious generation arising in RUT at a certain combination of frequencies of two powerful out-of-band input signals. This generation has a very high level (nearly equal to the saturation level of the receiving path). It is observed as specific bursts in 3D plot of DFC and as curvilinear or regularly-shaped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

2. **An intermodulation with nonlinear dependence of its frequency on the test signal frequencies (f1 and f2). Conjecturally, this intermodulation is caused by mixing of the test signals with the 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 DFDs. Usually, the level of this generation exceeds the RUT's internal noise level by 15…20 dB.**

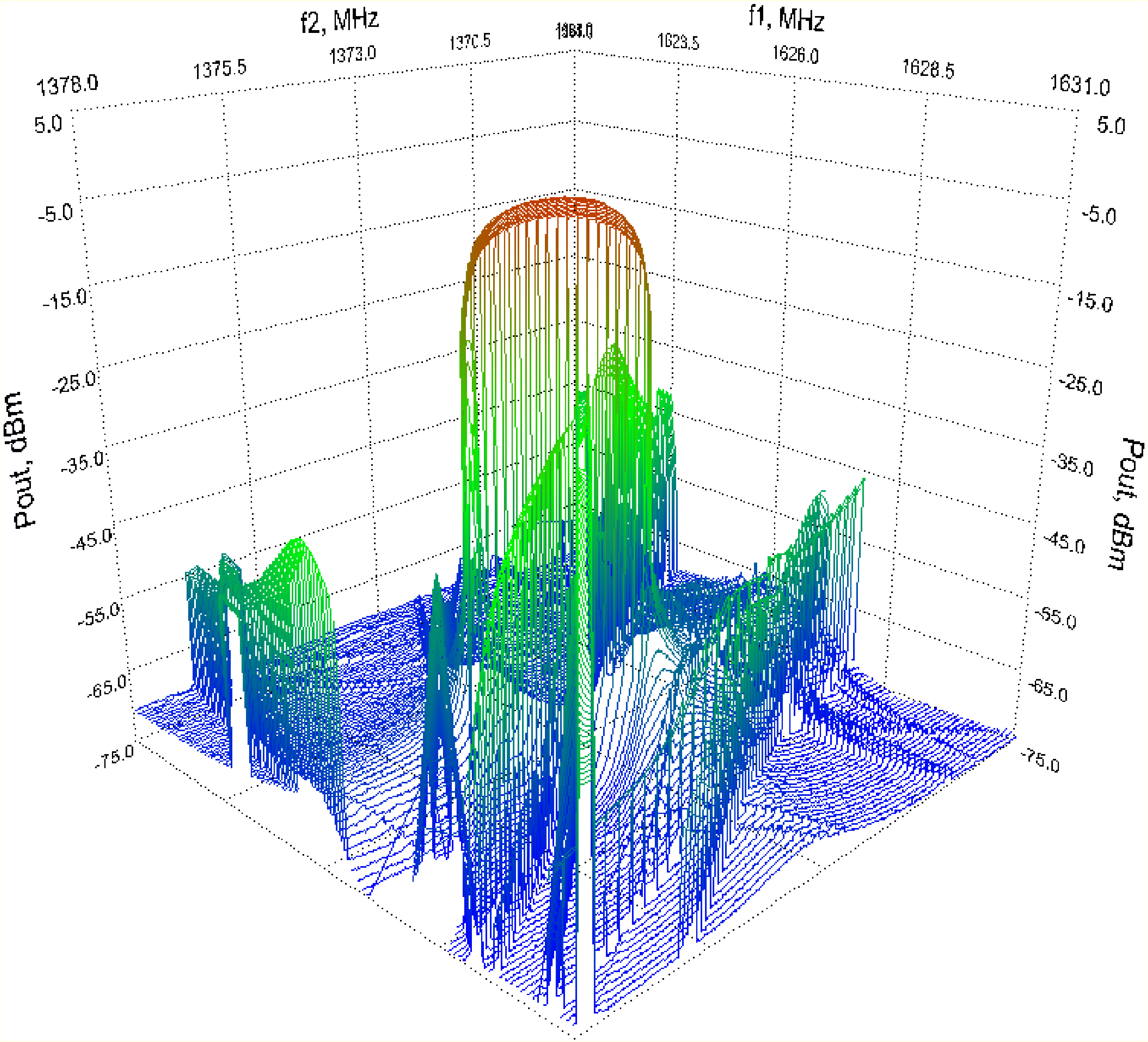
We found these phenomena in majority of inspected receivers, including the most perfect and expensive

DFC of RUT1 tuned at 1.5 GHz (DFD plot)



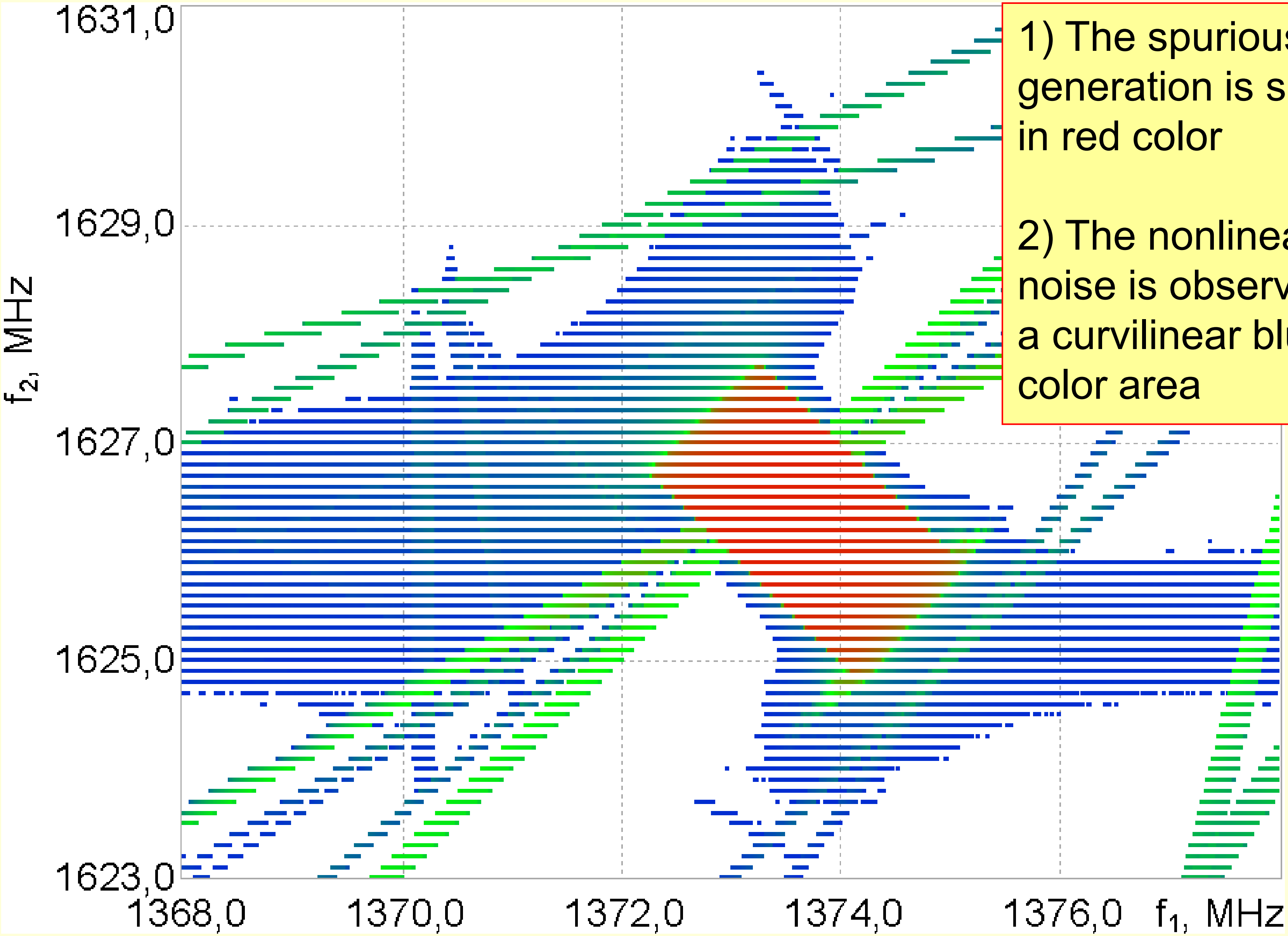
The specific points are shown in circles

DFC of RUT1 in a vicinity of the specific point (3D plot)



The spurious generation is observed as a red-color burst

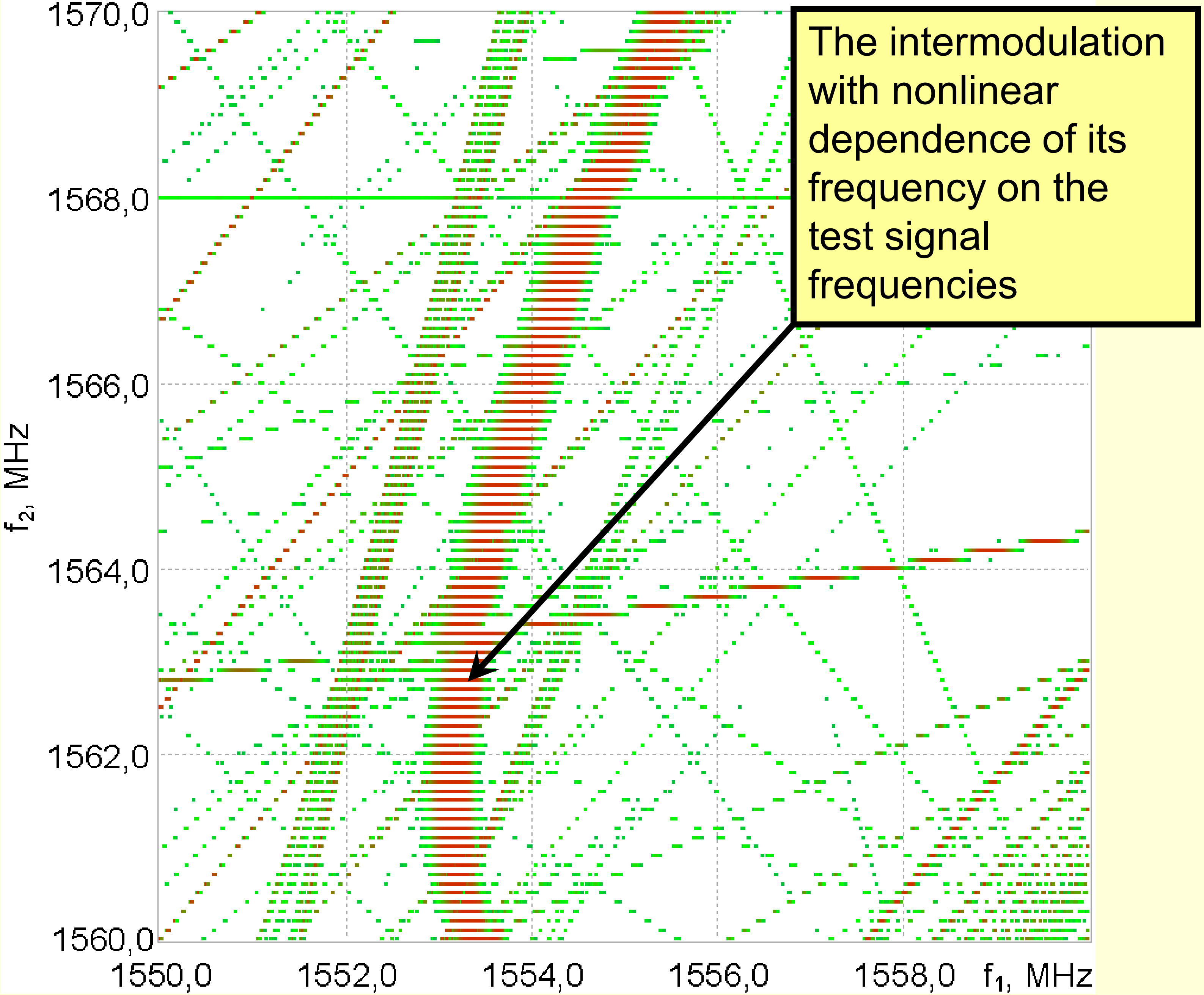
DFC of RUT1 in a vicinity of the specific point (DFD plot)



1) The spurious generation is shown in red color

2) The nonlinear noise is observed as a curvilinear blue-color area

DFD of RUT 1 with an unusual intermodulation



Conclusion

1) The presented results of comparative analysis demonstrate 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.
2) The absence of nonlinear effects in receivers is an important condition of their operability in severe electromagnetic environment. The ADFTS makes it possible to detect and recognize all existing nonlinear effects, both traditional (spurious responses, intermodulation, etc.) and specific.
3) The traditional effects can in principle be detected by the traditional techniques, (and ADFTS essentially simplifies and speeds up their detection and recognition), but it is practically impossible to detect the specific phenomena without ADFTS since there is no method to predict such phenomena.
4) Three-dimensional display of the DFC and color coding of the RUT response level simplify the visual analysis of measured DFCs in the process of detection and recognition of various interference effects.

Thank you very much for your attention!

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