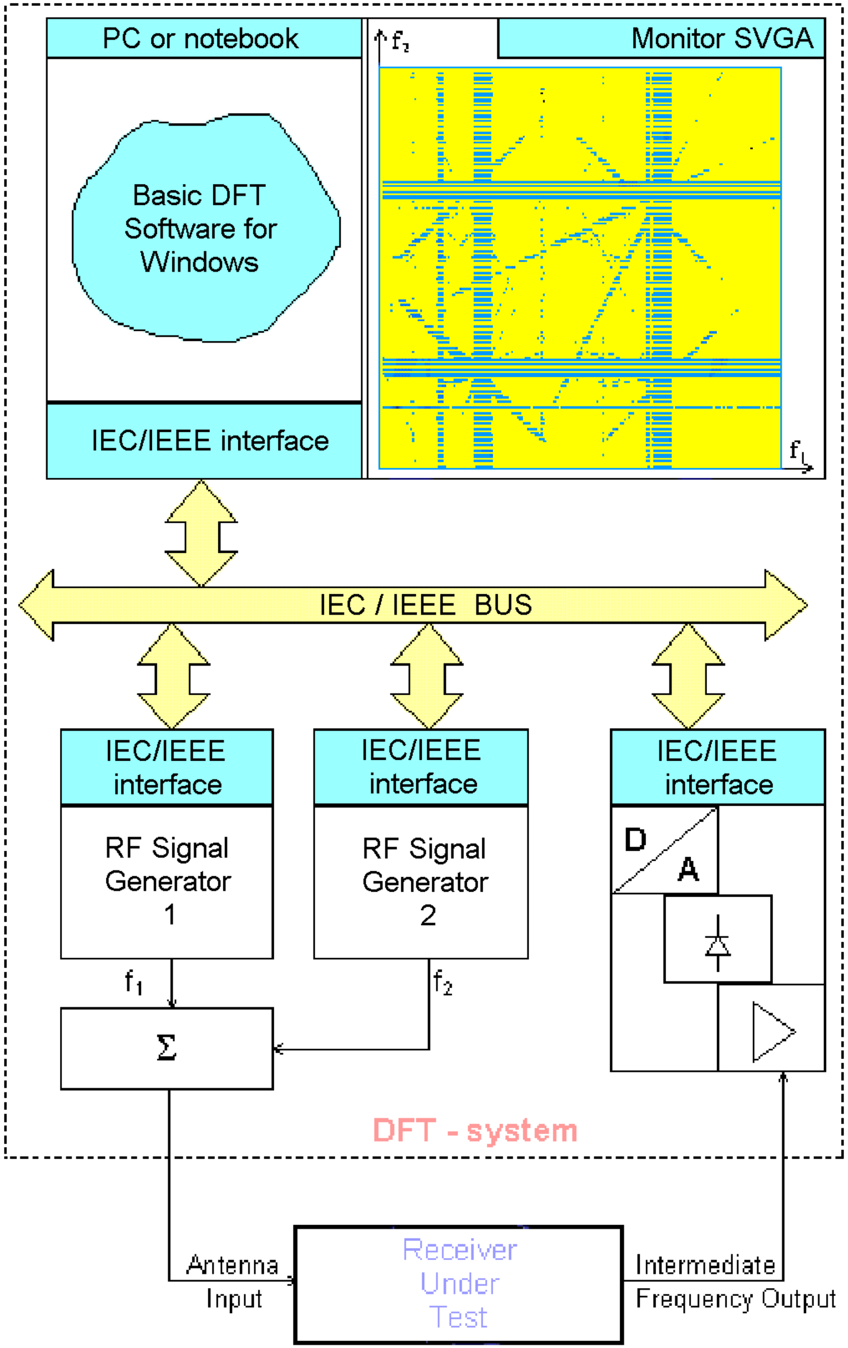
Automated Double Frequency Test System (DFTS)

DFTS

General potentialities:

- **automated detection, identification and measurement of parameters for the main channel and all image and intermediate radio receiver paths, through which interference can influence any radio devices;**
- **automated detection, identification and measurement of radio receiver susceptibility to nonlinear effects: blocking, cross modulation, all types and orders of bifrequency intermodulation, etc;**
- **electromagnetic compatibility analysis and prediction in the complex electromagnetic environment with the use of the radio receiver double frequency testing (DFT) results.**



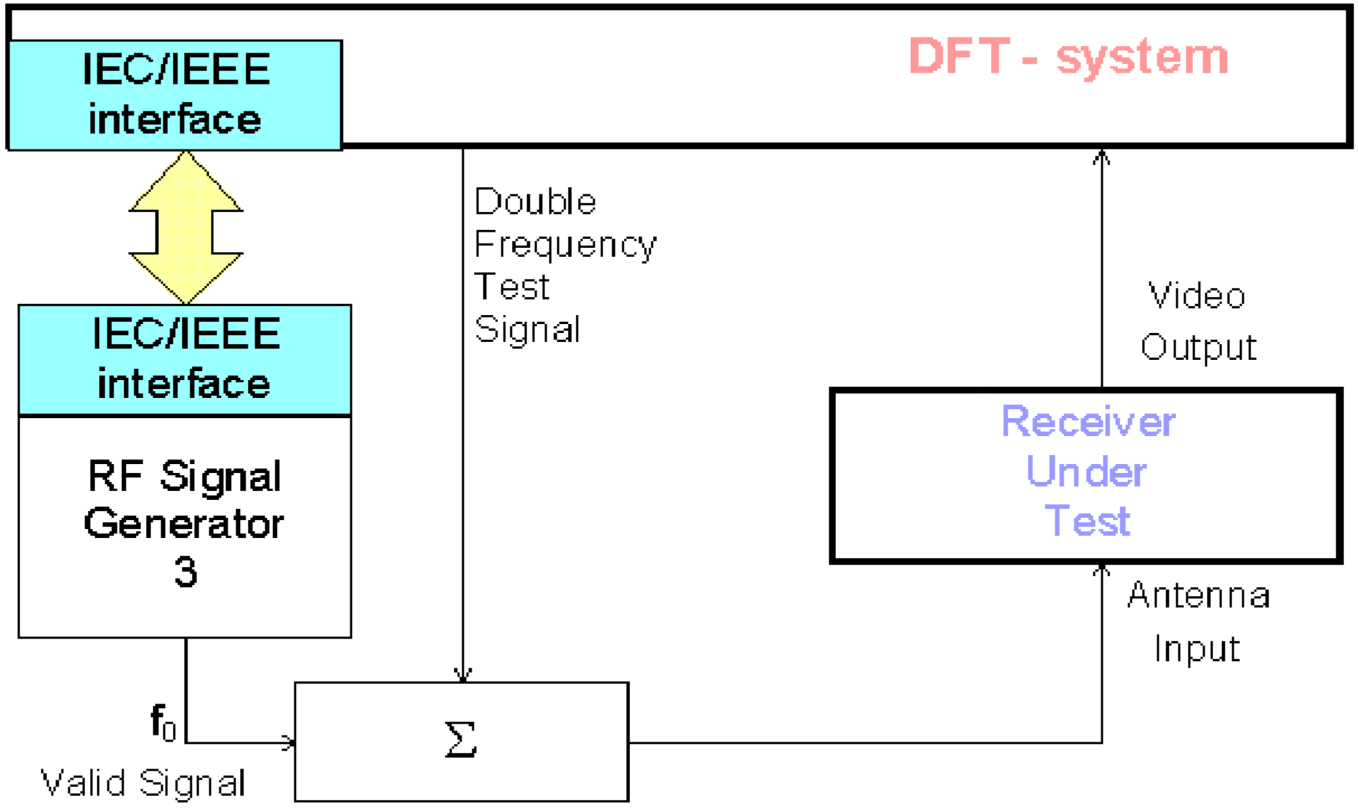
Basic block diagram of DFT realization

DFTS

The main idea of this technology:

- **radiolocation of the radio receiver through its antenna input, using the sum of two frequency sweeping signals (*Vf1>>Vf2*) and original synchronous tomography visualization of the receiver output on the PC display;**
- **discrete simulation of signal-noise-interference mixture transformation in the receiver (discrete EMC-analysis and prediction)**

DFTS

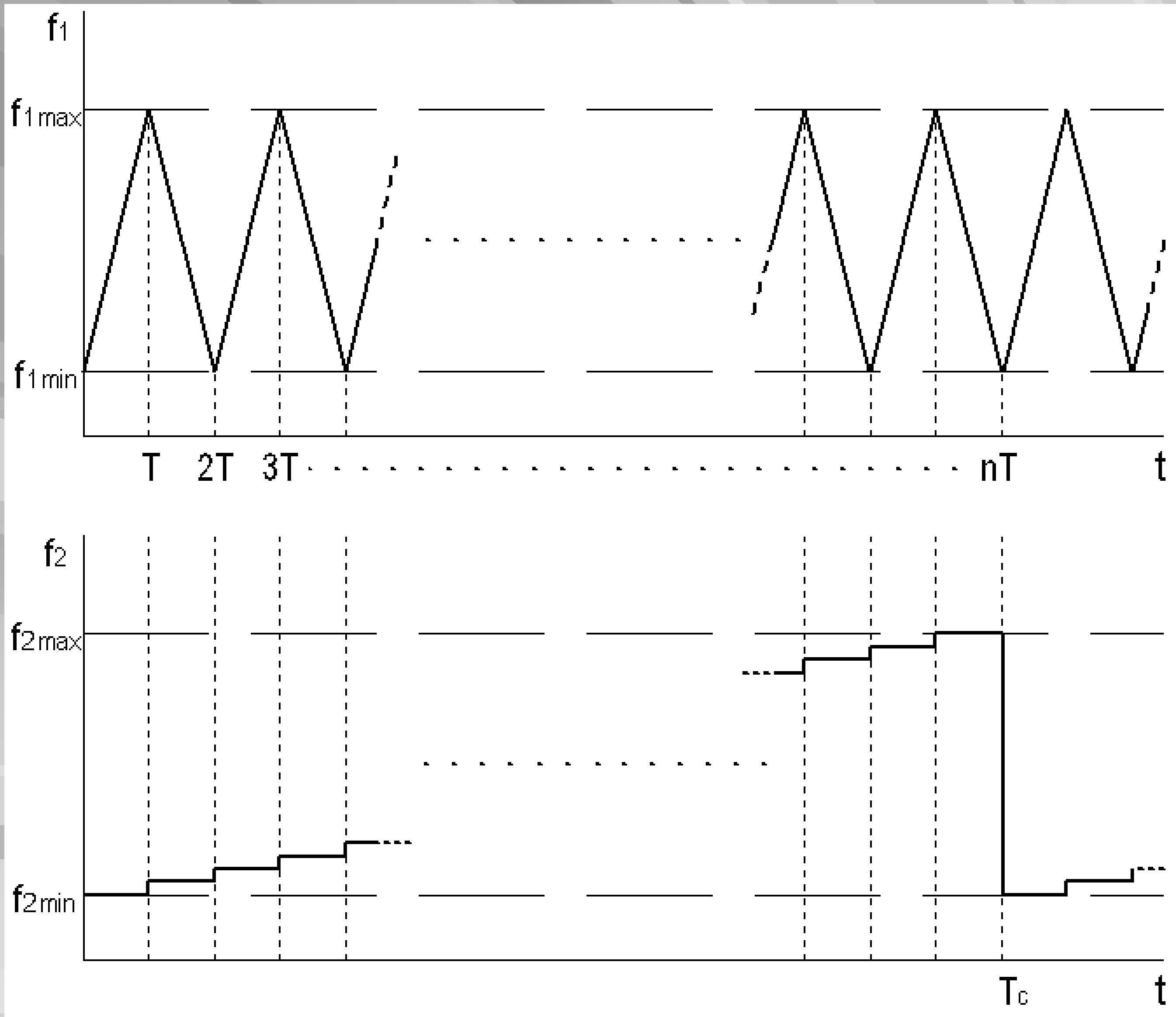


Double Frequency Testing of Coherent Receiver

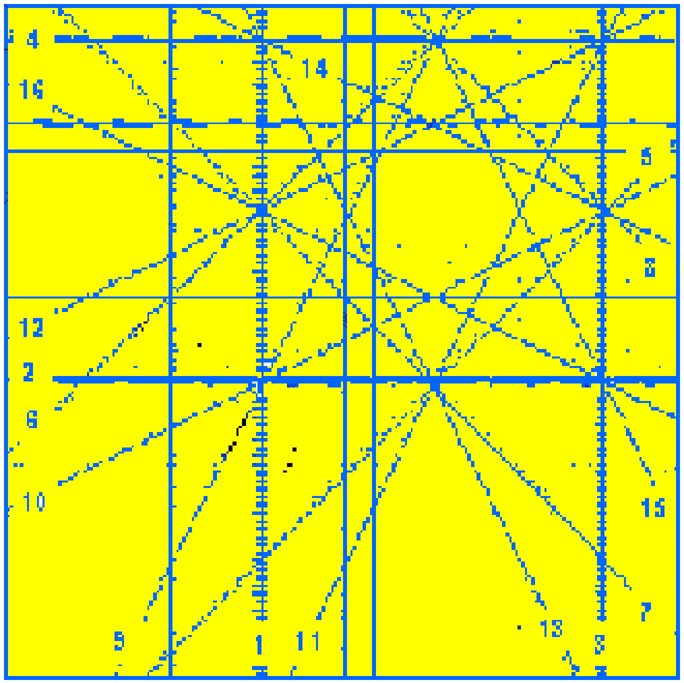
DFTS

Frequency of RF Signal Generator 1

Frequency of RF Signal Generator 2



DFTS



01.	$+01f_1+00f_2$	$= 01f_g - f_{int}$	order 01
02.	$+00f_1+01f_2$	$= 01f_g - f_{int}$	order 01
03.	$+01f_1+00f_2$	$= 01f_g + f_{int}$	order 01
04.	$+00f_1+01f_2$	$= 01f_g + f_{int}$	order 01
05.	$+01f_1-01f_2$	$= 00f_g + f_{int}$	order 02
06.	$-01f_1+01f_2$	$= 00f_g + f_{int}$	order 02
07.	$+01f_1+01f_2$	$= 02f_g - f_{int}$	order 02
08.	$+01f_1+01f_2$	$= 02f_g + f_{int}$	order 02
09.	$+02f_1-01f_2$	$= 01f_g - f_{int}$	order 03
10.	$-01f_1+02f_2$	$= 01f_g - f_{int}$	order 03
11.	$+02f_1-01f_2$	$= 01f_g + f_{int}$	order 03
12.	$-01f_1+02f_2$	$= 01f_g + f_{int}$	order 03
13.	$+02f_1+01f_2$	$= 03f_g - f_{int}$	order 03
14.	$+01f_1+02f_2$	$= 03f_g + f_{int}$	order 03
15.	$+02f_1+01f_2$	$= 03f_g + f_{int}$	order 03
16.	$+01f_1+02f_2$	$= 03f_g - f_{int}$	order 03

Automated Identification of Linear and Nonlinear Paths Detected in Radio Receiver

DFTS

The main advantages of this technology:

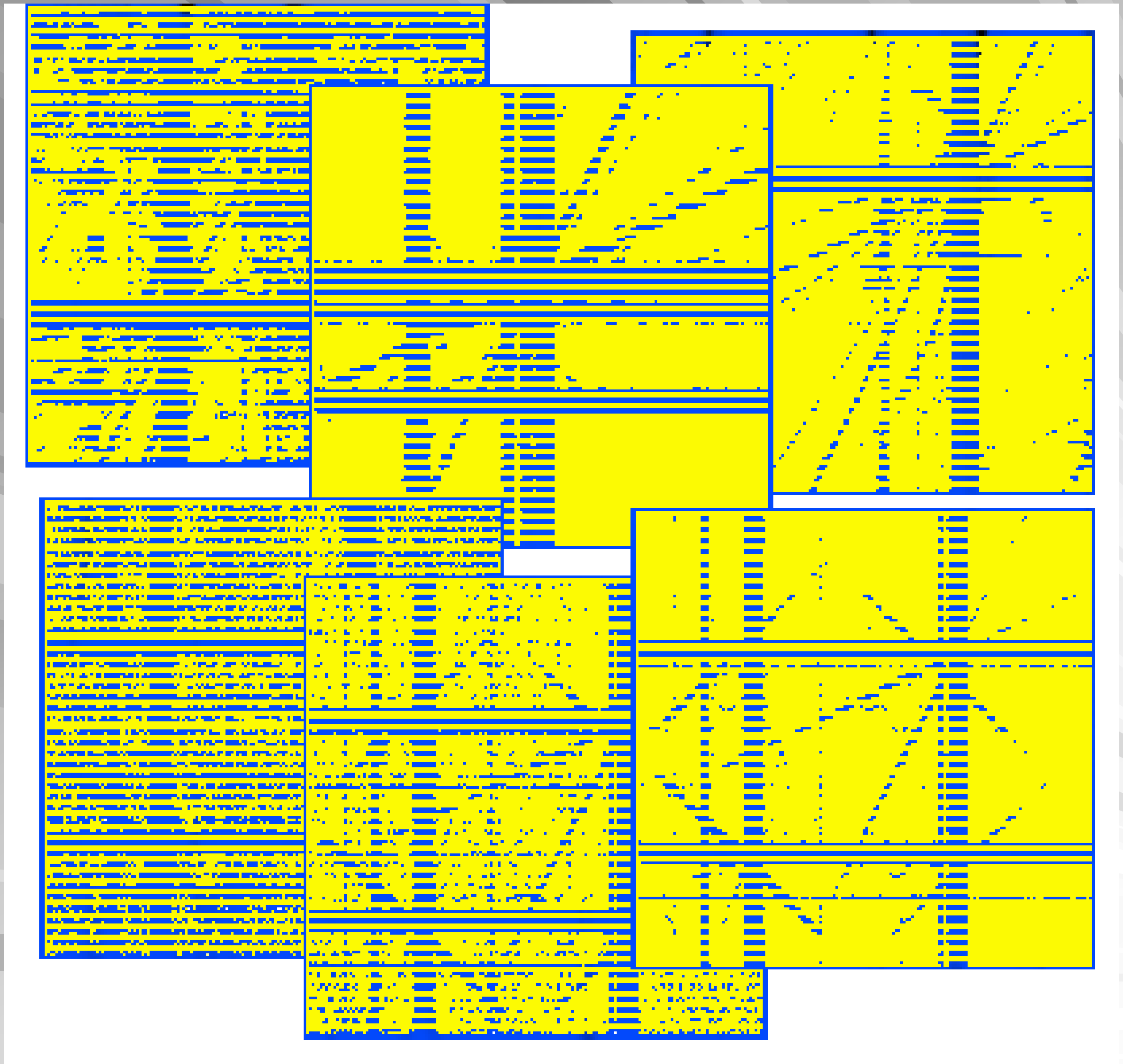
- **it is the most informative, expedient and efficient technology of radio receiver EMC testing and measuring;**
- **since 1988 it has been successfully used in USSR, Russia and Belarus for designing of the VHF, UHF, SHF and EHF radio receivers and systems used in military and civil aircrafts, satellites, ships etc;**
- **it can be realized in modern systems for standard measurement of nonlinear effects in radio receivers - blocking, cross modulation and intermodulation;**
- **It gives us comprehensive data for radio receiver behavior simulation in severe electromagnetic environment using discrete nonlinear simulating technology and for EMC problems solving**

DFTS

STAGE 1

Detection of all paths and phenomena which can affect receiver operation under the conditions of specified (predicted) maximum levels and ranges of possible working frequencies of input signals, including

- spurious response paths,
- paths (types) of two-signal intermodulation,
- blocking,
- cross modulation,
- excitation of input stages under the influence of strong out-of-band signals,
- locking of the local oscillator frequency by an input signal.



DFTS

STAGE 1, Essence:

Analysis of the form and cross-sections of the DF amplitude (transfer) characteristic of the receiver-under-test.

This characteristic is a dependence

$$H(f_1, f_2) = U_{out}\left(f_1, f_2 \middle| \begin{matrix} U_{1in} = const \\ U_{2in} = const \end{matrix} \right) \qquad (1)$$

of the signal level at the receiver output U_{out} on frequencies f_1, f_2 of the two test signals at the receiver input for fixed levels of these signals U_{1in}, U_{2in}.

Results: recording and visualization of cross-sections of the DF amplitude characteristic:

$$W_i(f_1, f_2 | U_{ti}) = sgn\{H(f_1, f_2) - U_{ti}\} \qquad (2)$$

at the specified threshold levels U_{ti} , $i=1,2,...$.

Levels U_{ti} exceed the level of the internal noise of the receiver at its output in accordance with the accepted criteria used for determination of the receiver sensitivity and susceptibility.

STAGE 2

Evaluation of the structure of obtained images of double frequency diagrams of the type (2) and identification of individual elements of these images.

Elements of images of double frequency diagrams are line segments; for coordinates $\{f_1, f_2\}$, the general equation for a single-conversion receiver is as follows:

$$k_1 f_1 + k_2 f_2 = k_g f_g + k_{int} f_{int};$$

$$k_1, k_2 = 0, \pm 1, \pm 2, ...; \quad k_g = 0, 1, 2, ...; k_{int} = \pm 1; \qquad (3)$$

$$min\{|k_1| + |k_2|\} = 1,$$

where f_g - local oscillator voltage frequency, f_{int} - intermediate frequency of the receiver.

DFTS

Examples of identification procedures:

- evaluation of inclined angle:

$$tg\alpha = -\frac{G_x k_1}{G_y k_2}; \quad G_x = \frac{f_{1\,max} - f_{1\,min}}{Dx}, \quad G_y = \frac{f_{2\,max} - f_{2\,min}}{Dy} \qquad (4)$$

- frequencies measurements:

$$\left.\begin{aligned} z_1 f_{11} + z_2 f_{21} + z_g f_{g1} &= f_{int\,1} \\ z_1 f_{12} + z_2 f_{22} + z_g f_{g2} &= f_{int\,2} \\ z_1 f_{13} + z_2 f_{23} + z_g f_{g3} &= f_{int\,3} \end{aligned}\right\}, \; z_1 = \frac{k_1}{k_{int}}, \; z_2 = \frac{k_2}{k_{int}}, \; z_g = \frac{k_g}{k_{int}} \qquad (5)$$

- measurement and comparison of modulation parameters of input and output signals (deviations, phase-shift angles, etc);
- classification of elements of double frequency diagram images (groups of linear elements);
- etc.

DFTS

STAGE 3

Measurements of characteristics and parameters (sensitivity, bandwidth, dynamic range) of the detected

- spurious response paths,
- intermodulation paths,
- characteristics of receiver susceptibility to blocking and cross modulation.
- measurement procedures in accordance with the relevant standards
- additional measurement procedures (in order to obtain necessary information about parameters of the receiver under test for purposes of consequent electromagnetic compatibility analysis and prediction).

DFTS

STAGE 4

Creating Functional Structural Mathematical Model of Radio Receiver-Under-Test including

- validation of the adequate high-order polynomial models of transfer characteristics of receiver input nonlinear devices/elements (radio frequency amplifiers, mixers, etc.) using results of testing and measuring at the above-mentioned Stage 3,
- validation of the frequency-domain mathematical models of frequency and spatial selectivity devices/elements (antenna, filters) using technical information and results of measurements.

DFTS

STAGE 5

EMC Analysis and Prediction in Board or Ground Systems using

- Functional structural mathematical modeling of the radio receiver-under-test (Stage 4),
- Propagation models related to the specific situation (diffraction or other models for on-board systems, ITU-R Models and Digital Area Maps for space-scattered systems or networks, EPM-73, etc.),
- Technique of Discrete Behavior-Level EMC Simulation using discrete frequency- and time-domain models of electromagnetic environment and FFT,
- “EMC-Analyzer” Expert system

DFTS

Basic results of DFTS utilization: **1**

Practical experience of using the DFTS for testing of radio broadcasting, radar, radio communications , radio monitoring and other receivers in different bands of the 0.1MHz-56GHz frequency range shows that:

- *utilization of the DFTS makes it possible to significantly enhance quality of receiver design* due to
  - timely detection and adjustment of the most dangerous paths of possible interference impact on a receiver in the predicted operational environment,
  - improvement in matching individual receiver elements in order to optimize contribution of every element to EMC characteristics of a receiver;
- *utilization of the DFTS makes it possible to substantially facilitate ensuring EMC in local ground-based and on-board groups of radio systems*;

DFTS

Basic results of DFTS utilization: 2

- *a number of new phenomena was discovered in the course of utilization of the DFTS,* including:
  - intermodulation oscillations in generators characterized by ***nonlinear*** dependency of a frequency of these oscillations on frequencies of signals which create these oscillations;
  - relationship between characteristics of spurious excitation of a receiver's RFA and characteristics of intermodulation which occurs in a receiver under the conditions of influence of strong signals on its output;
  - etc.

DFTS

Basic results of DFTS utilization: 3

- *utilization of the DFTS allows one to use numerous methods which are used in radiolocation for detection, identification and measurement of parameters of objects*:
  - correlation methods and geometric methods for detection and identification of objects;
  - techniques for detection and evaluation of parameters of paths with the use of the "noise path image";
  - conventional methods for compressing, storing and processing images;
- the DFTS can be implemented on the basis of a conventional modern measurement system for standard testing of receivers - *only development (customization) of the DFTS software and a more powerful computer to process double frequency diagram images and run databases are required*;
- in case radar receivers under test are equipped with display units, *the DFTS can be implemented in such manner that visualization of DF diagrams of these receivers will be carried out with the use of their display units*;

DFTS

Basic results of DFTS utilization: 4

- *the DFTS makes it possible to measure parameters of nonlinearity of input RFAs of a receiver including parameters of high (15th to 25th) orders,* which allows one to develop efficient mathematical models of input nonlinearity of a receiver which make possible
  - adequacy of representation of rough (blocking, cross modulation) and more subtle (intermodulation, local oscillator noise conversion) nonlinear phenomena in a wide range of input influences;
  - efficient utilization of the discrete technology for electromagnetic compatibility analysis with the use of discrete models of interference environment and FFT.

DFTS

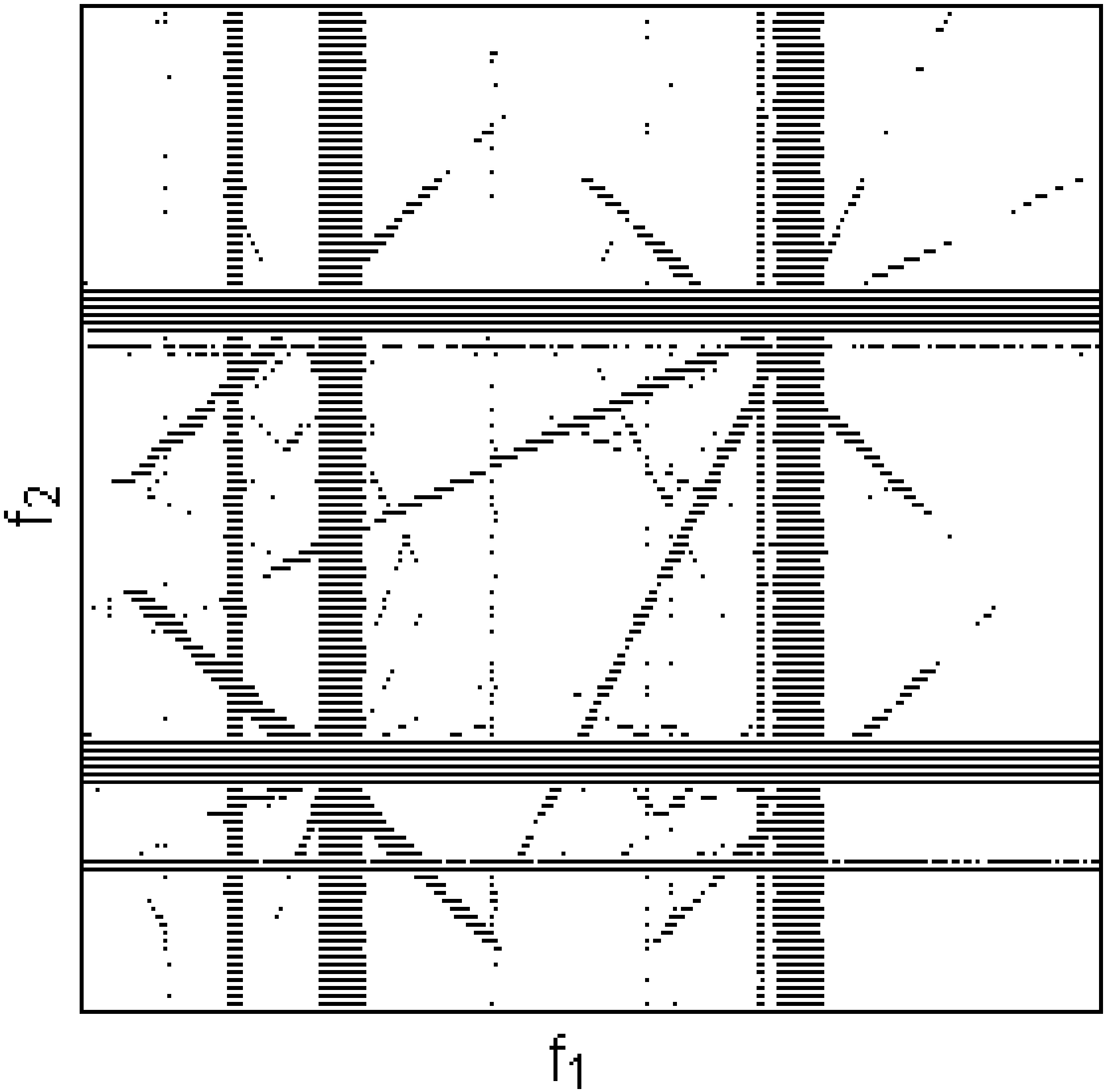


Fig.1a.

Double Frequency Diagram of a Radar Receiver for U_t / U_N=15dB

DFTS

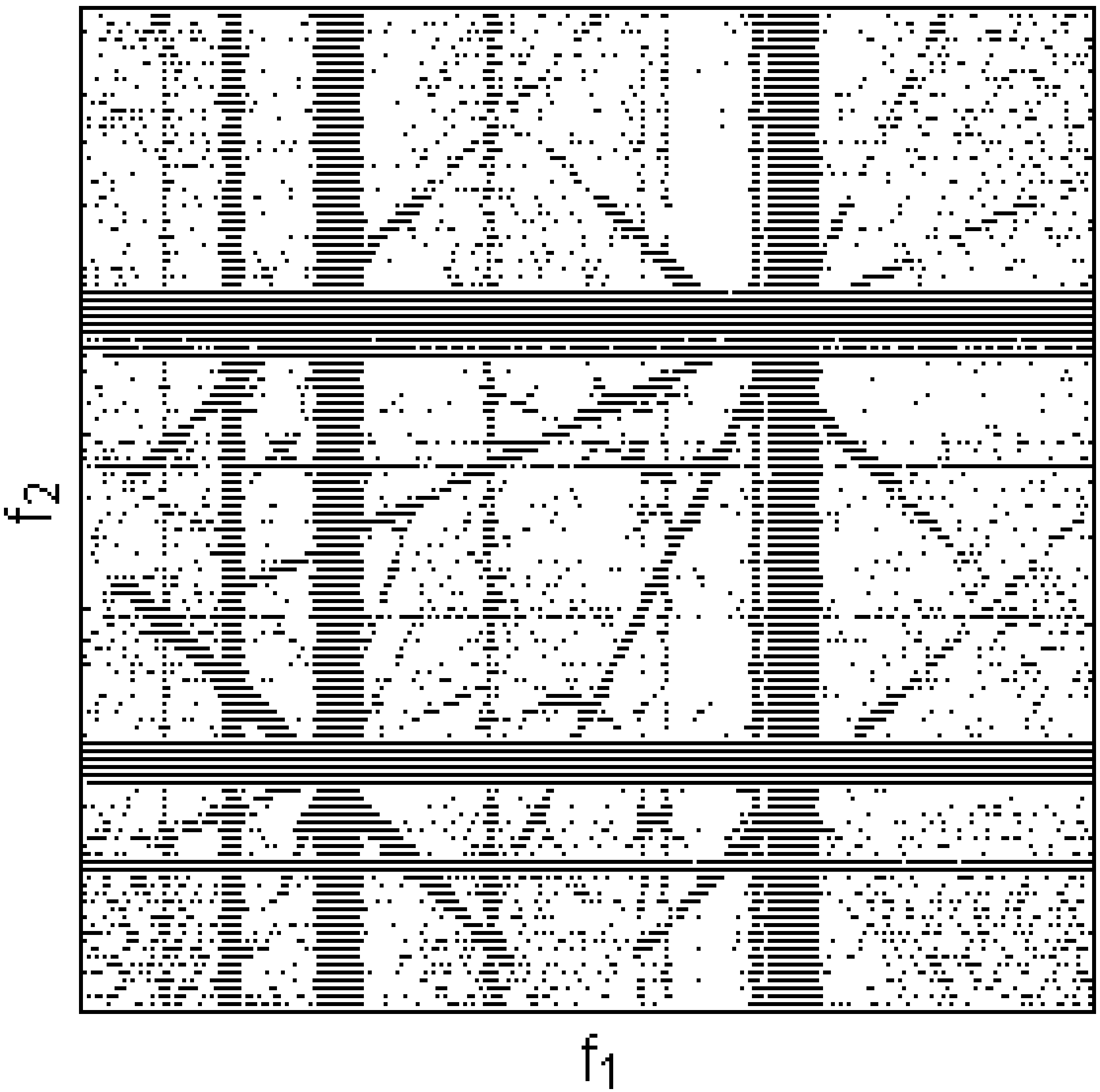


Fig.1b.

Double Frequency Diagram of a Radar Receiver for U_t / U_N=9dB

DFTS

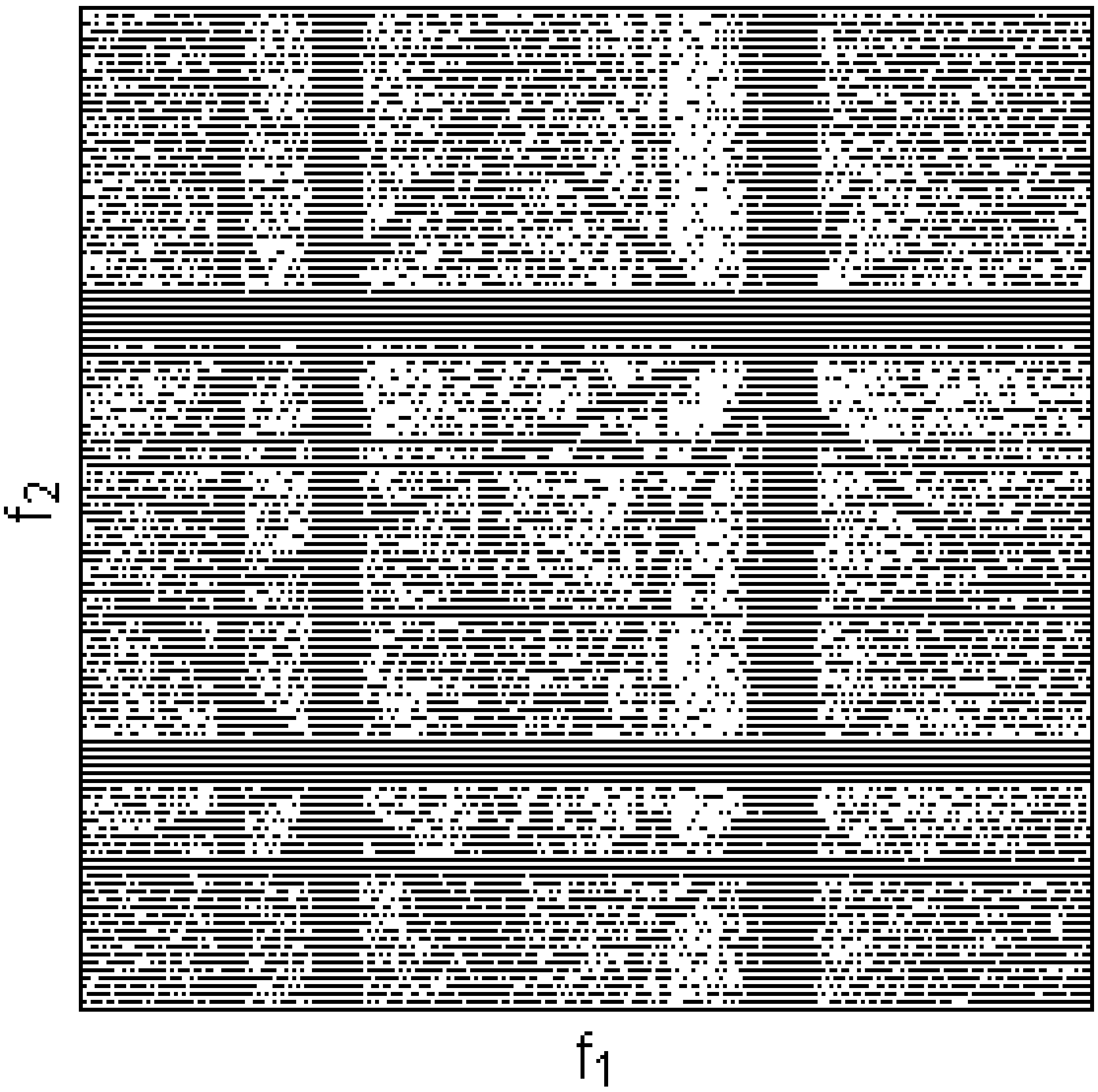


Fig.1c.

Double Frequency Diagram of a Radar Receiver for U_t / U_N=3dB

DFTS

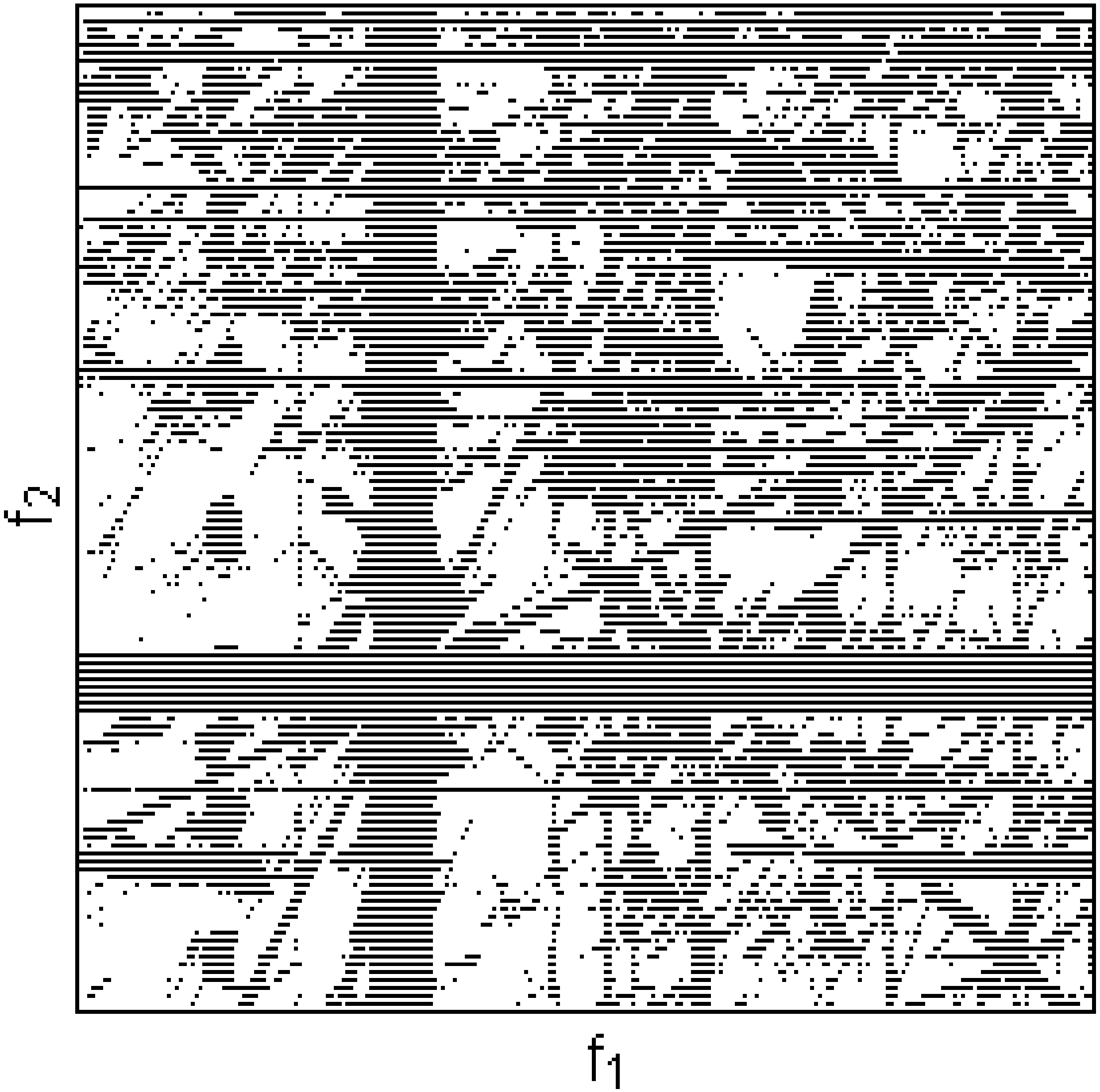
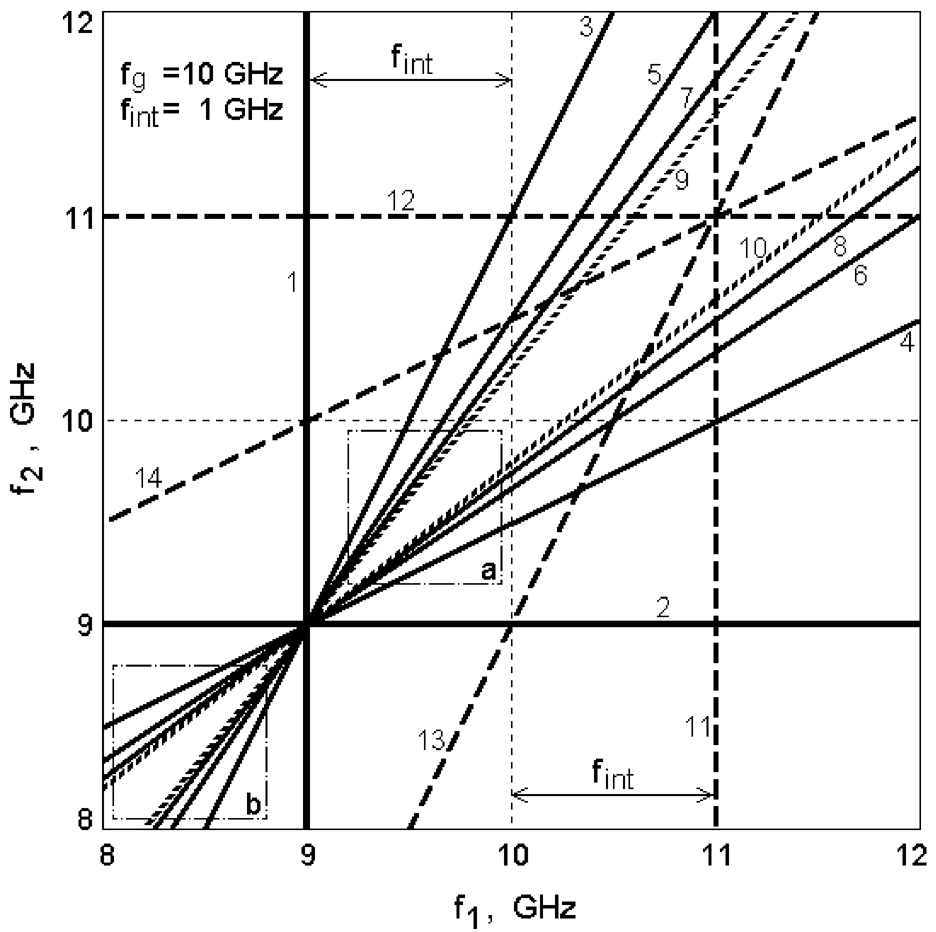


Fig.2.

Double Frequency Diagram of a Receiver with High-Level Input Test Signals



DFTS

Fig. 3a.

The 1st order node, the most common node since it contains images formed by the main receive channel (lines 1 and 2). This node is formed by intermodulation, receive channel and spurious response images of the types presented in table

No	Type	Order
1.	$f_1=f_g-f_{int}$	1
2.	$f_2=f_g-f_{int}$	1
3.	$2f_1-f_2=f_g-f_{int}$	3
4.	$2f_2-f_1=f_g-f_{int}$	3
5.	$3f_1-2f_2=f_g-f_{int}$	5
6.	$3f_2-2f_1=f_g-f_{int}$	5
7.	$4f_1-3f_2=f_g-f_{int}$	7

No	Type	Order
8.	$4f_2-3f_1=f_g-f_{int}$	7
9.	$(m+1)f_1-mf_2=f_g-f_{int}$	2m+1
10.	$(m+1)f_2-mf_1=f_g-f_{int}$	2m+1
11.	$f_1=f_g+f_{int}$	1
12.	$f_2=f_g+f_{int}$	1
13.	$2f_1-f_2=f_g+f_{int}$	3
14.	$2f_2-f_1=f_g+f_{int}$	3

DFTS

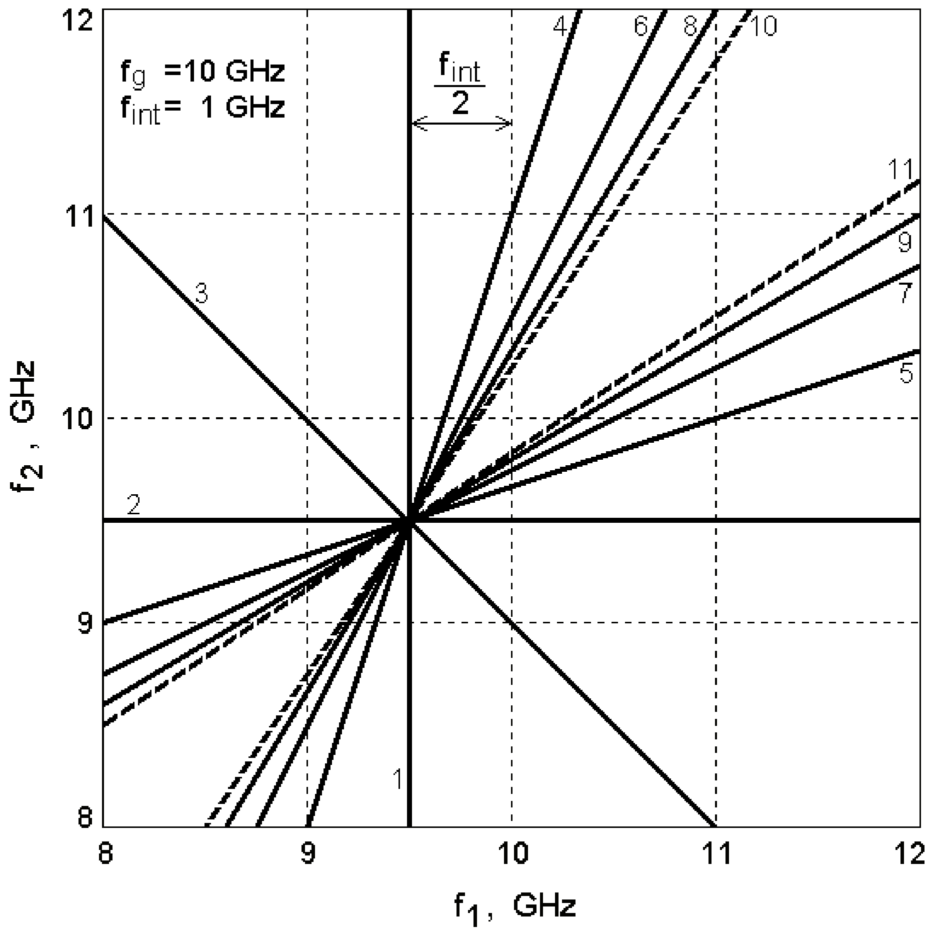


Fig. 3b.

The 2nd order node which is formed with the contribution of the local oscillator signal second harmonic and contains intermodulation and spurious response path images of the types presented in table

No	Type	Order
1.	$2f_1=2f_g-f_{int}$	2
2.	$2f_2=2f_g-f_{int}$	2
3.	$f_1+f_2=2f_g-f_{int}$	2
4.	$3f_1-f_2=2f_g-f_{int}$	4
5.	$3f_2-f_1=2f_g-f_{int}$	4
6.	$4f_1-2f_2=2f_g-f_{int}$	6

No	Type	Order
7.	$4f_2-2f_1=2f_g-f_{int}$	6
8.	$5f_1-3f_2=2f_g-f_{int}$	8
9.	$5f_2-3f_1=2f_g-f_{int}$	8
10.	$(m+2)f_1-mf_2=2f_g-f_{int}$	2m+2
11.	$(m+2)f_2-mf_1=2f_g-f_{int}$	2m+2

DFTS

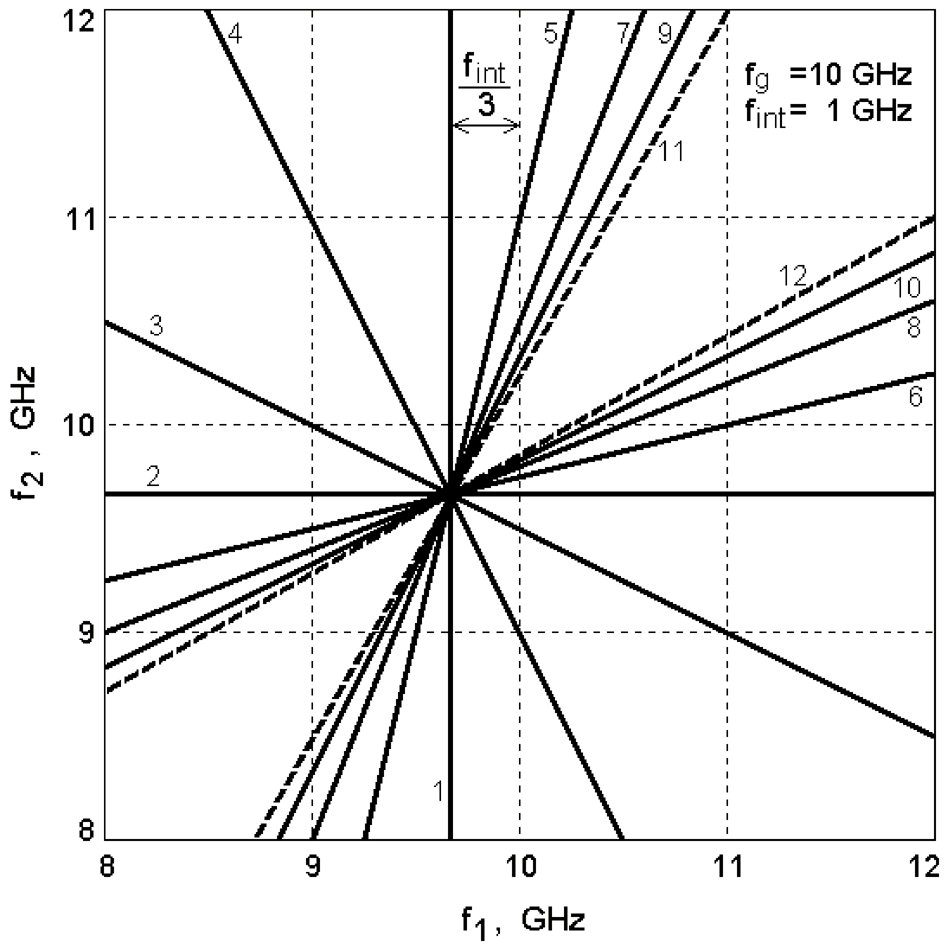


Fig. 3c.

The 3rd order node which is formed with the contribution of the local oscillator signal third harmonic and contains intermodulation and spurious response path images of the types presented in table

No	Type	Order
1.	$3f_1=3f_g-f_{int}$	3
2.	$3f_2=3f_g-f_{int}$	3
3.	$2f_2+f_2=3f_g-f_{int}$	3
4.	$2f_1+f_2=3f_g-f_{int}$	3
5.	$4f_1-f_2=3f_g-f_{int}$	5
6.	$4f_2-f_1=3f_g-f_{int}$	5

No	Type	Order
7.	$5f_1-2f_2=3f_g-f_{int}$	7
8.	$5f_2-2f_1=3f_g-f_{int}$	7
9.	$6f_1-3f_2=3f_g-f_{int}$	9
10.	$6f_2-3f_1=3f_g-f_{int}$	9
11.	$(m+3)f_1-mf_2=3f_g-f_{int}$	2m+3
12.	$(m+3)f_2-mf_1=3f_g-f_{int}$	2m+3

DFTS

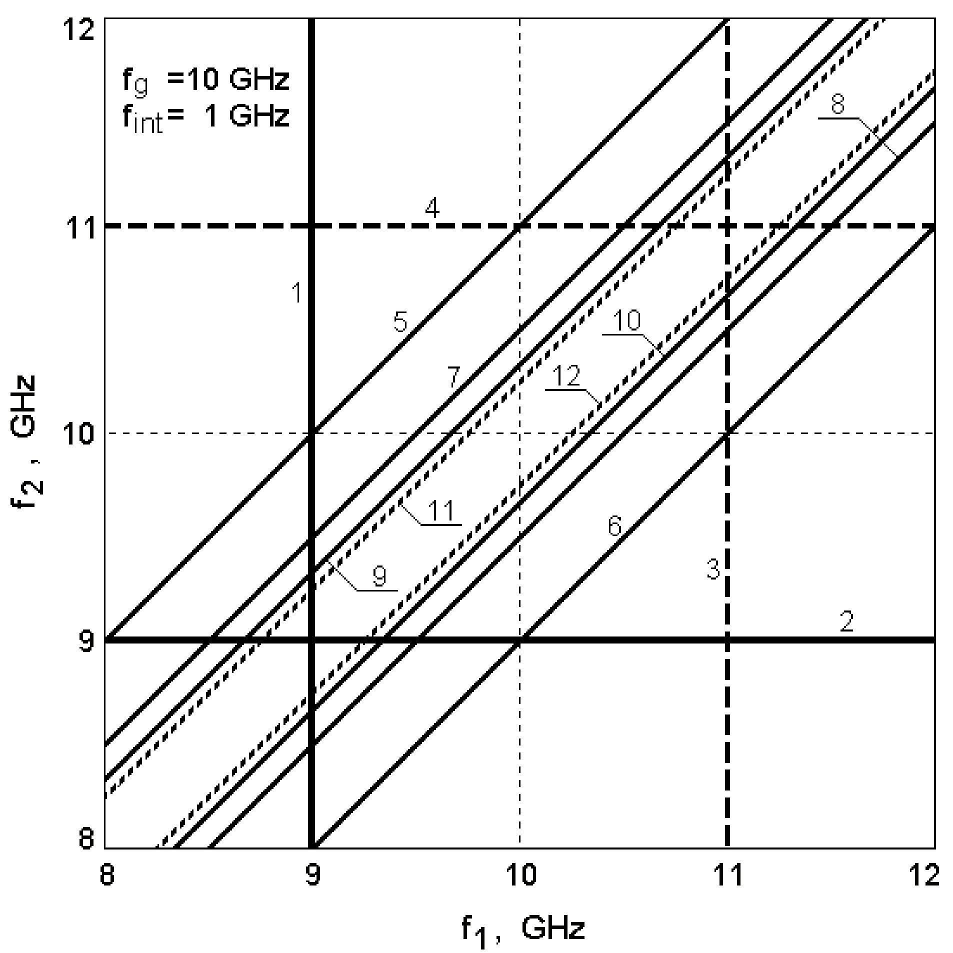
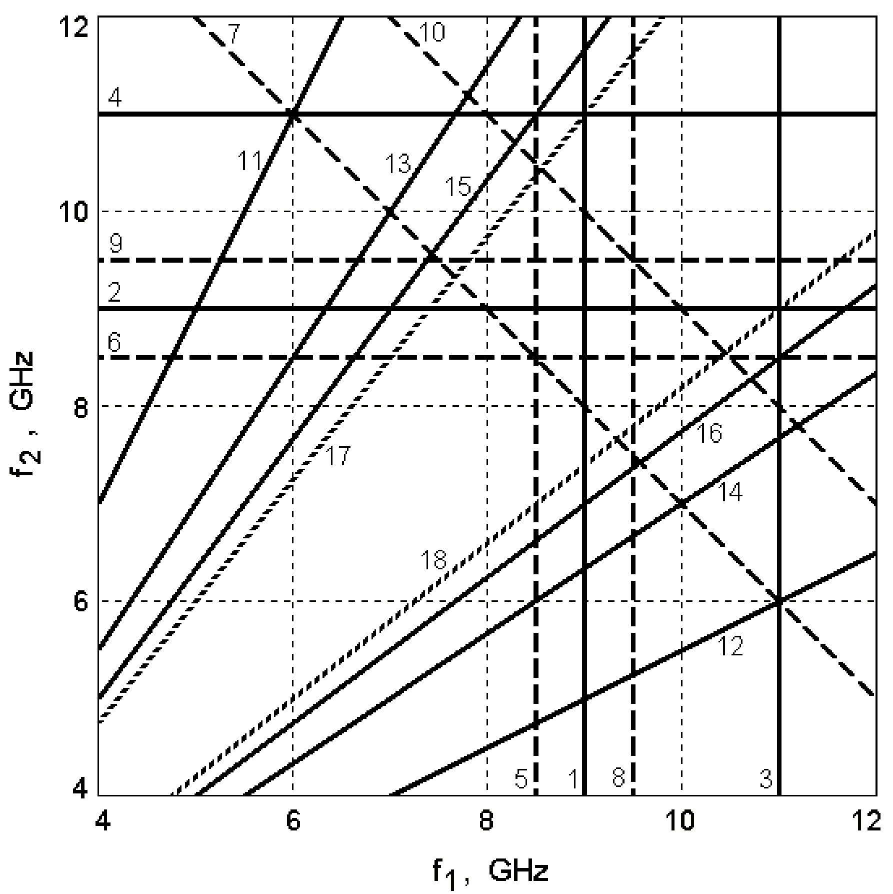


Fig. 3d.

A typical group of images formed by even order intermodulation due to direct passage of test signals nonlinear conversion products to the intermediate frequency path. This figure shows intermodulation and receive path images of the types presented in table

No	Type	Order
1.	$f_1=f_g-f_{int}$	1
2.	$f_2=f_g-f_{int}$	1
3.	$f_1=f_g+f_{int}$	1
4.	$f_2=f_g+f_{int}$	1
5.	$f_2-f_1=f_{int}$	2
6.	$f_1-f_2=f_{int}$	2

No	Type	Order
7.	$2f_2-2f_1=f_{int}$	4
8.	$2f_1-2f_2=f_{int}$	4
9.	$3f_2-3f_1=f_{int}$	6
10.	$3f_1-3f_2=f_{int}$	6
11.	$mf_2-mf_1=f_{int}$	2m
12.	$mf_1-mf_2=f_{int}$	2m



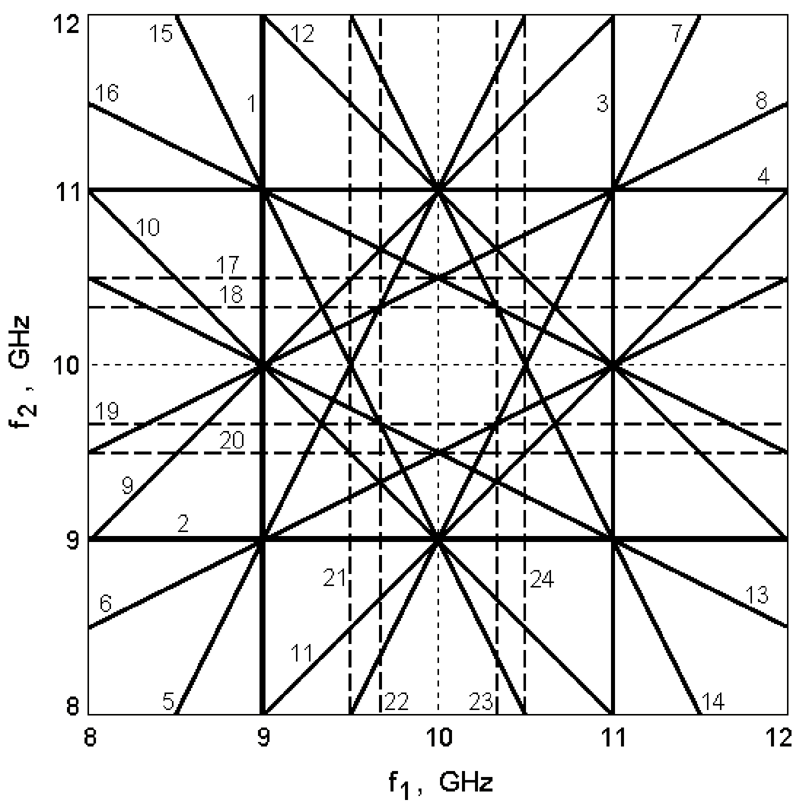
DFTS

Fig. 3e.

A typical group of images formed by intermodulation and spurious response paths present in a superheterodyne receiver with a parametric RFA. This group contains the types presented in table

No	Type	Order
1.	$f_1=f_g-f_{int}$	1
2.	$f_2=f_g-f_{int}$	1
3.	$f_1=f_g+f_{int}$	1
4.	$f_2=f_g+f_{int}$	1
5.	$2f_1=2f_g-f_{int}$	2
6.	$2f_2=2f_g-f_{int}$	2
7.	$f_1+f_2=2f_g-f_{int}$	2
8.	$2f_1=2f_g+f_{int}$	2
9.	$2f_2=2f_g+f_{int}$	2

No	Type	Order
10.	$f_2+f_1=2f_g+f_{int}$	2
11.	$2f_1-f_2=f_{int}$	3
12.	$2f_2-f_1=f_{int}$	3
13.	$3f_1-2f_2=f_{int}$	5
14.	$3f_2-2f_1=f_{int}$	5
15.	$4f_1-3f_2=f_{int}$	7
16.	$4f_2-3f_1=f_{int}$	7
17.	$(m+1)f_1-mf_2=f_{int}$	2m+1
18.	$(m+1)f_2-mf_1=f_{int}$	2m+1



DFTS

Fig. 3f.

A typical group of images formed by intermodulation and spurious response paths present in a superheterodyne receiver with a mixer at its input. This group contains the types presented in table

No	Type	Order
1.	$f_1=f_g-f_{int}$	1
2.	$f_2=f_g-f_{int}$	1
3.	$f_1=f_g+f_{int}$	1
4.	$f_2=f_g+f_{int}$	1
5.	$2f_1-f_2=f_g-f_{int}$	3
6.	$2f_2-f_1=f_g-f_{int}$	3
7.	$2f_1-f_2=f_g+f_{int}$	3
8.	$2f_2-f_1=f_g+f_{int}$	3
9.	$f_2-f_1= f_{int}$	2
10.	$f_1+f_2= 2f_g-f_{int}$	2
11.	$f_1-f_2= f_{int}$	2
12.	$f_1+f_2= 2f_g+f_{int}$	2

No	Type	Order
13.	$2f_2+f_1= 3f_g-f_{int}$	3
14.	$2f_1+f_2= 3f_g+f_{int}$	3
15.	$2f_1+f_2= 3f_g-f_{int}$	3
16.	$2f_2+f_1= 3f_g+f_{int}$	3
17.	$2f_2= 2f_g+f_{int}$	2
18.	$3f_2= 3f_g+f_{int}$	3
19.	$3f_2= 3f_g-f_{int}$	3
20.	$2f_2= 2f_g-f_{int}$	2
21.	$2f_1= 2f_g-f_{int}$	2
22.	$3f_1= 3f_g-f_{int}$	3
23.	$3f_1= 3f_g+f_{int}$	3
24.	$2f_1= 2f_g+f_{int}$	2

DFTS

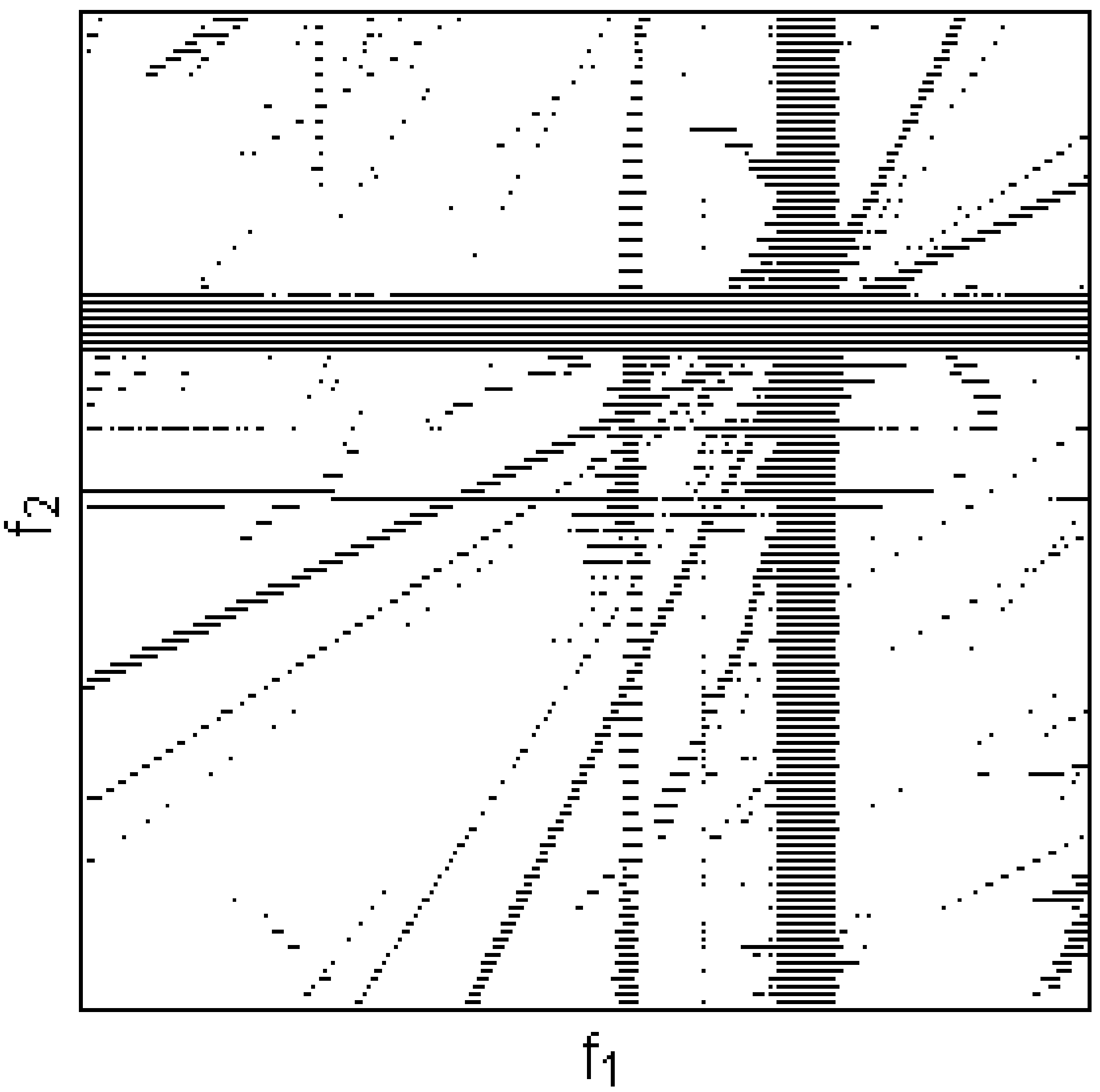


Fig.4.

Double Frequency Diagram for a Receiver with a Parametric RFA

DFTS

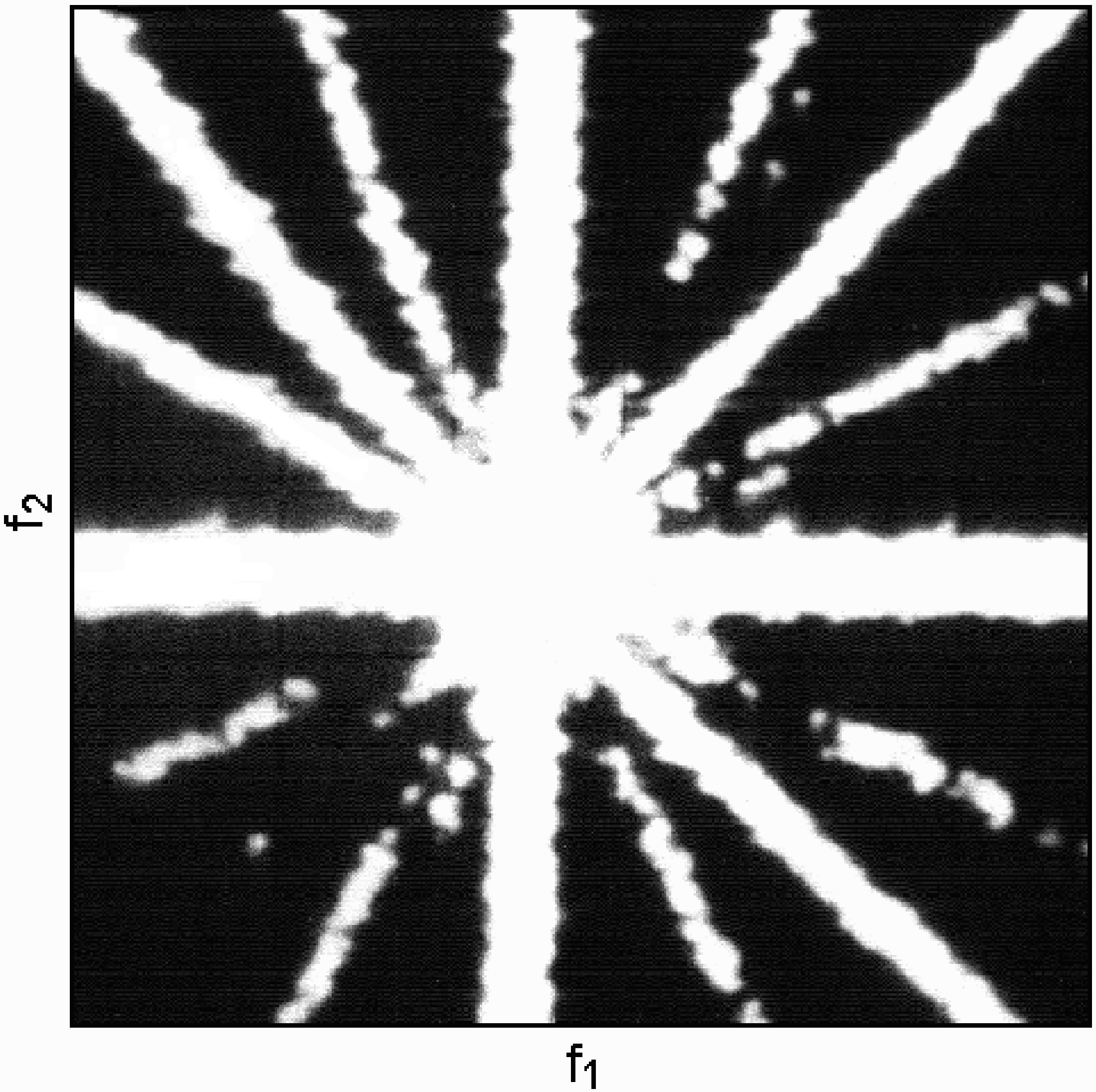


Fig.5.

Double Frequency Diagram of a RF-to-DC Radio Receiver (f_{int}=0)

DFTS

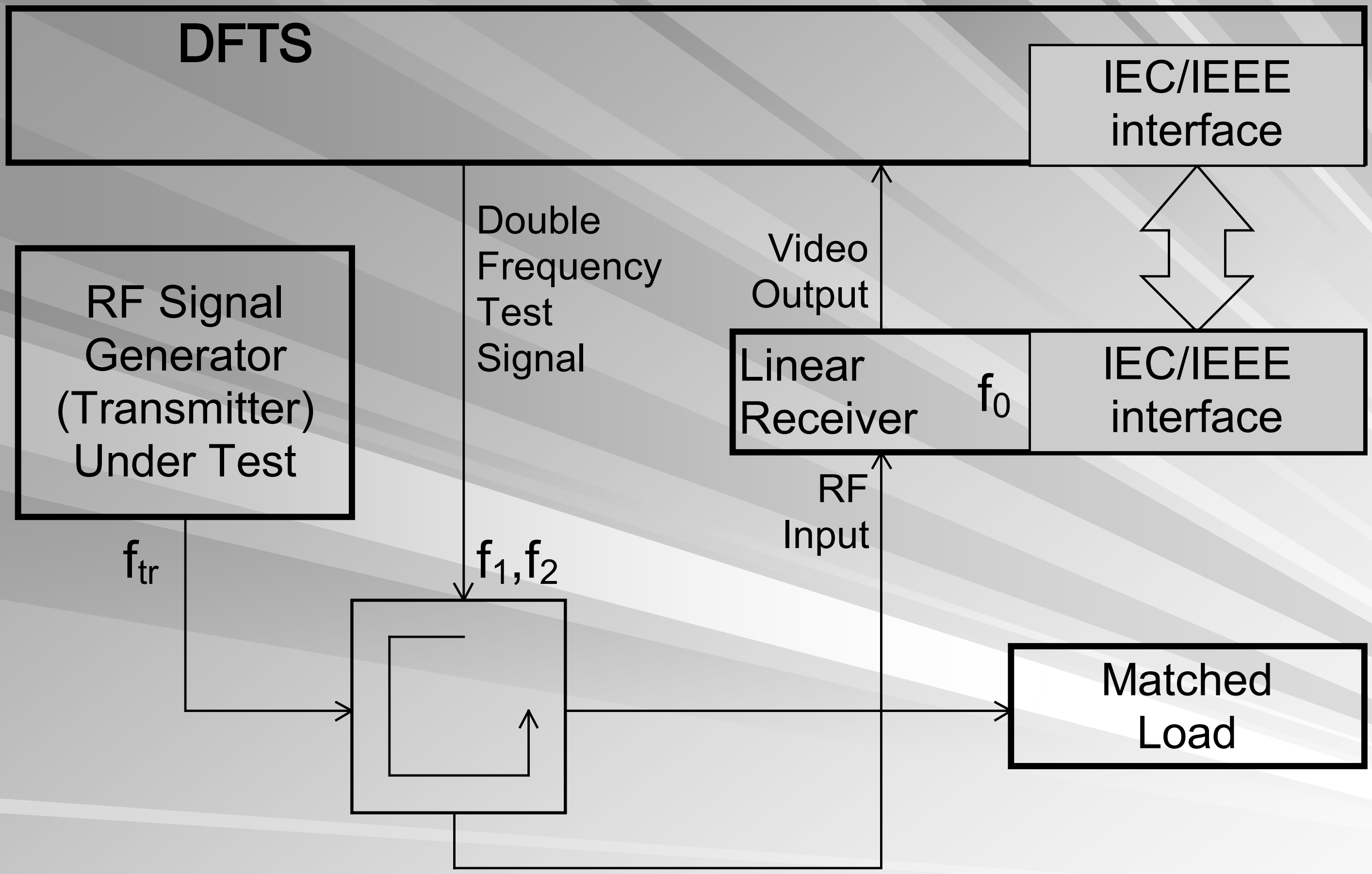


Fig.6.

Double Frequency Testing of RF Signal Generator or Transmitter

DFTS

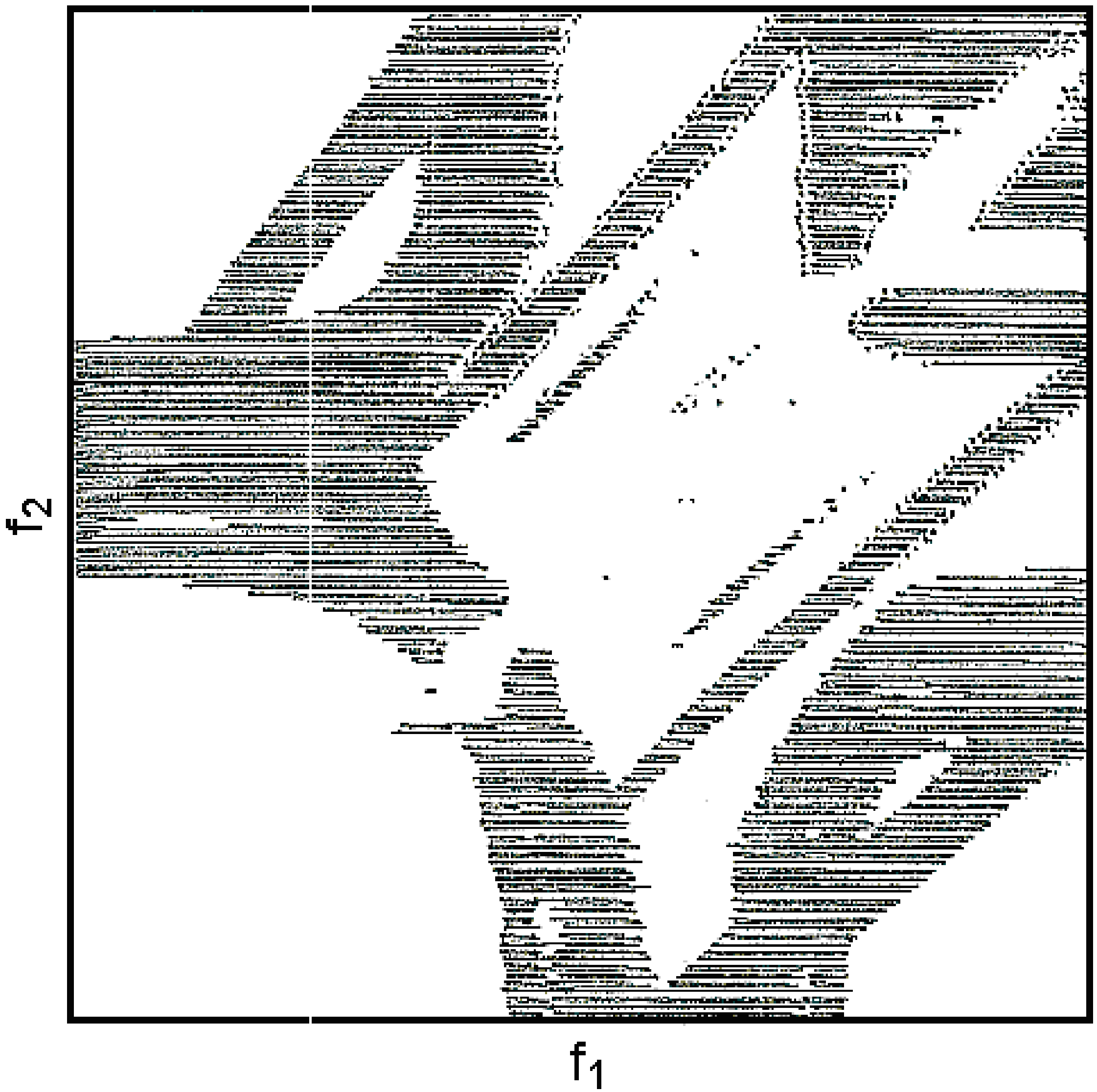


Fig.7.

Double Frequency Diagram for an IMPATT Diode Generator Showing Nonlinear Dependence of Frequencies of Some Intermodulation Oscillations on Test Signal Frequencies f_1 , f_2

DFTS

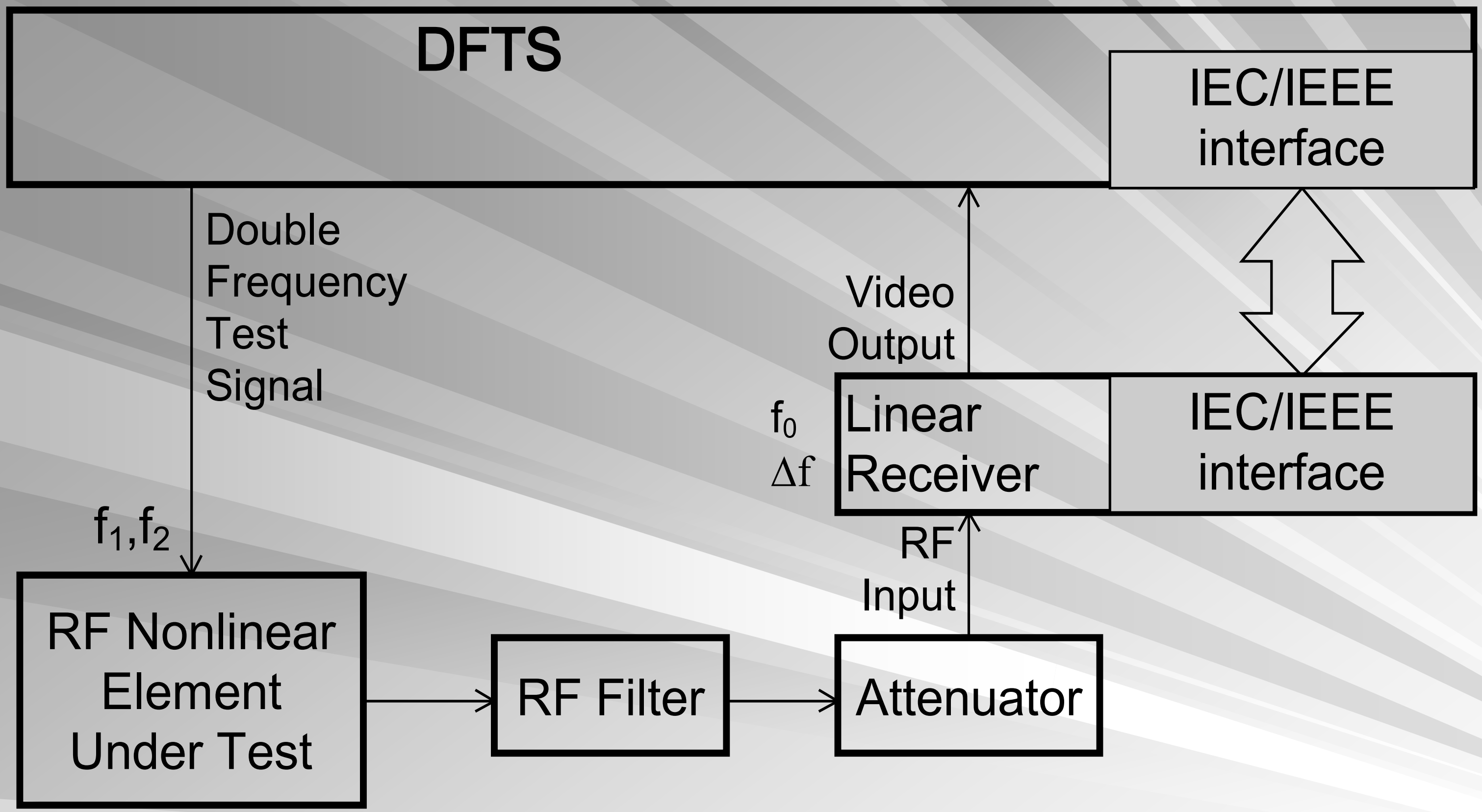


Fig.8.

Double Frequency Testing of RF Nonlinear Elements and Devices (RF & IF Amplifiers, Mixers, etc.)

DFTS

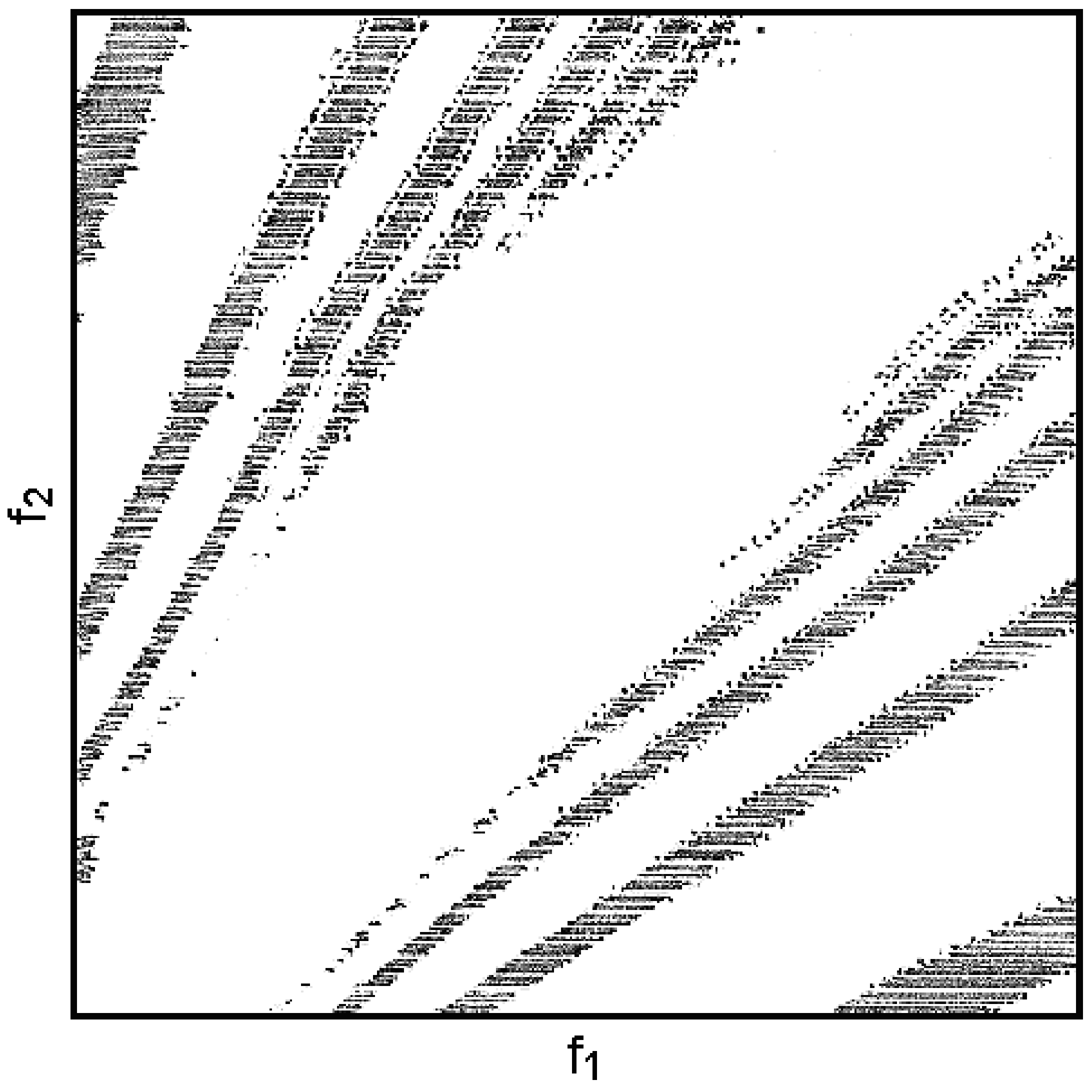


Fig.9.

Double Frequency Diagram of a Traveling-Wave Tube Amplifier

DFTS

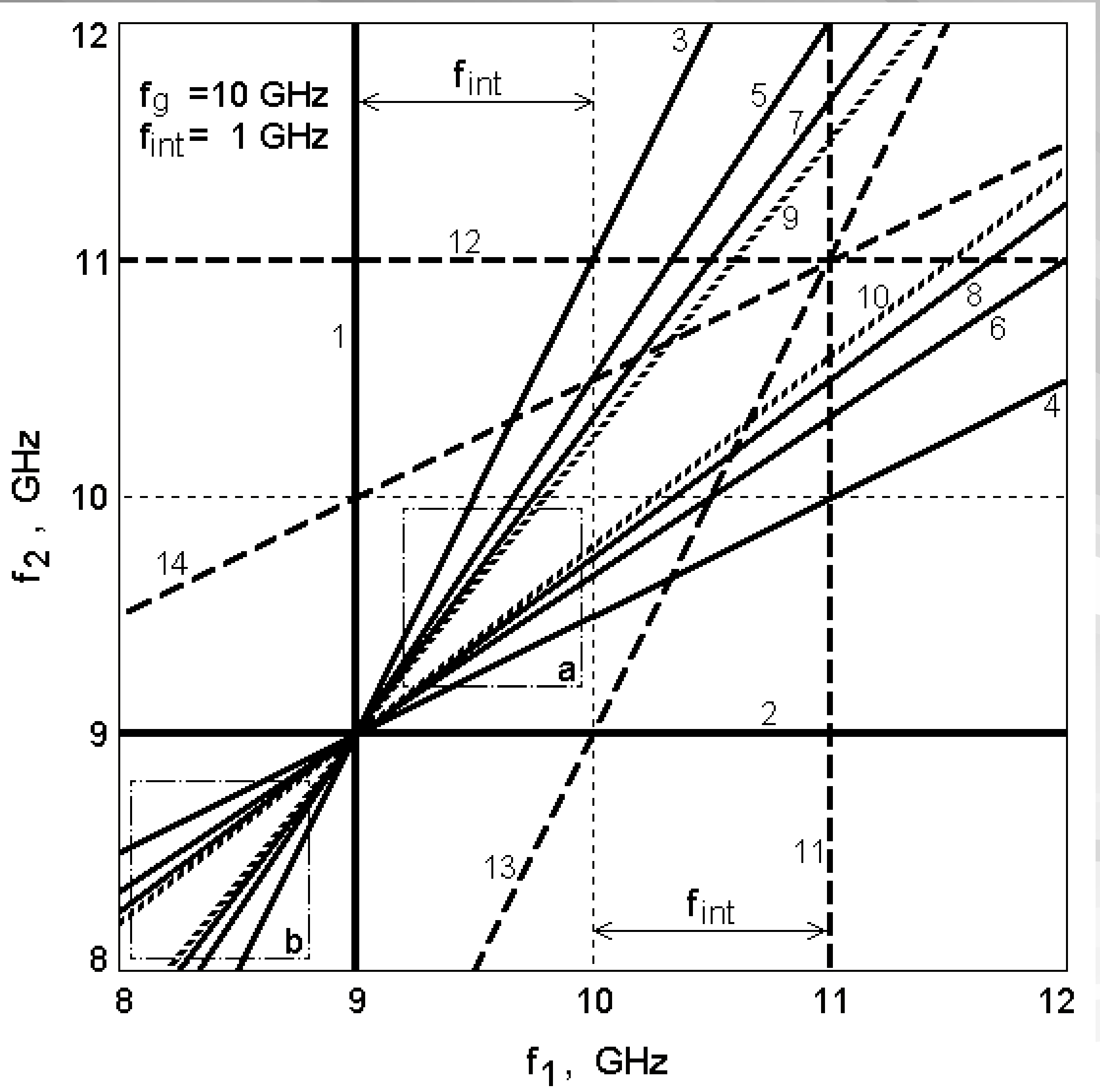


Fig.10.

Basic Double Frequency Diagram of Radio Receiver (see Fig. 3a)

<u>Area "a" is used for RFA testing</u>

DFTS

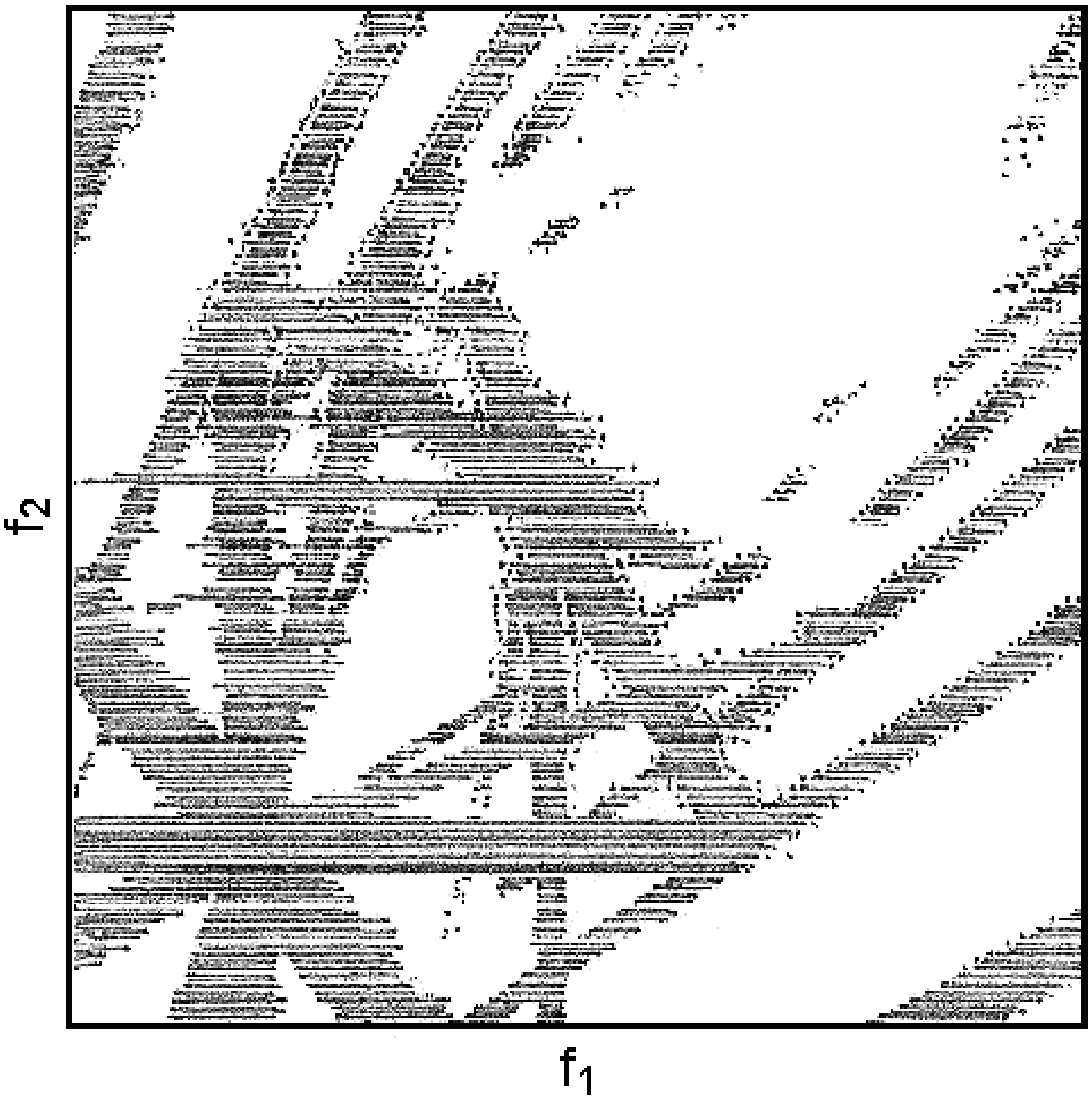


Fig.11.

Double Frequency Diagram of a Gunn Diode Amplifier

DFTS

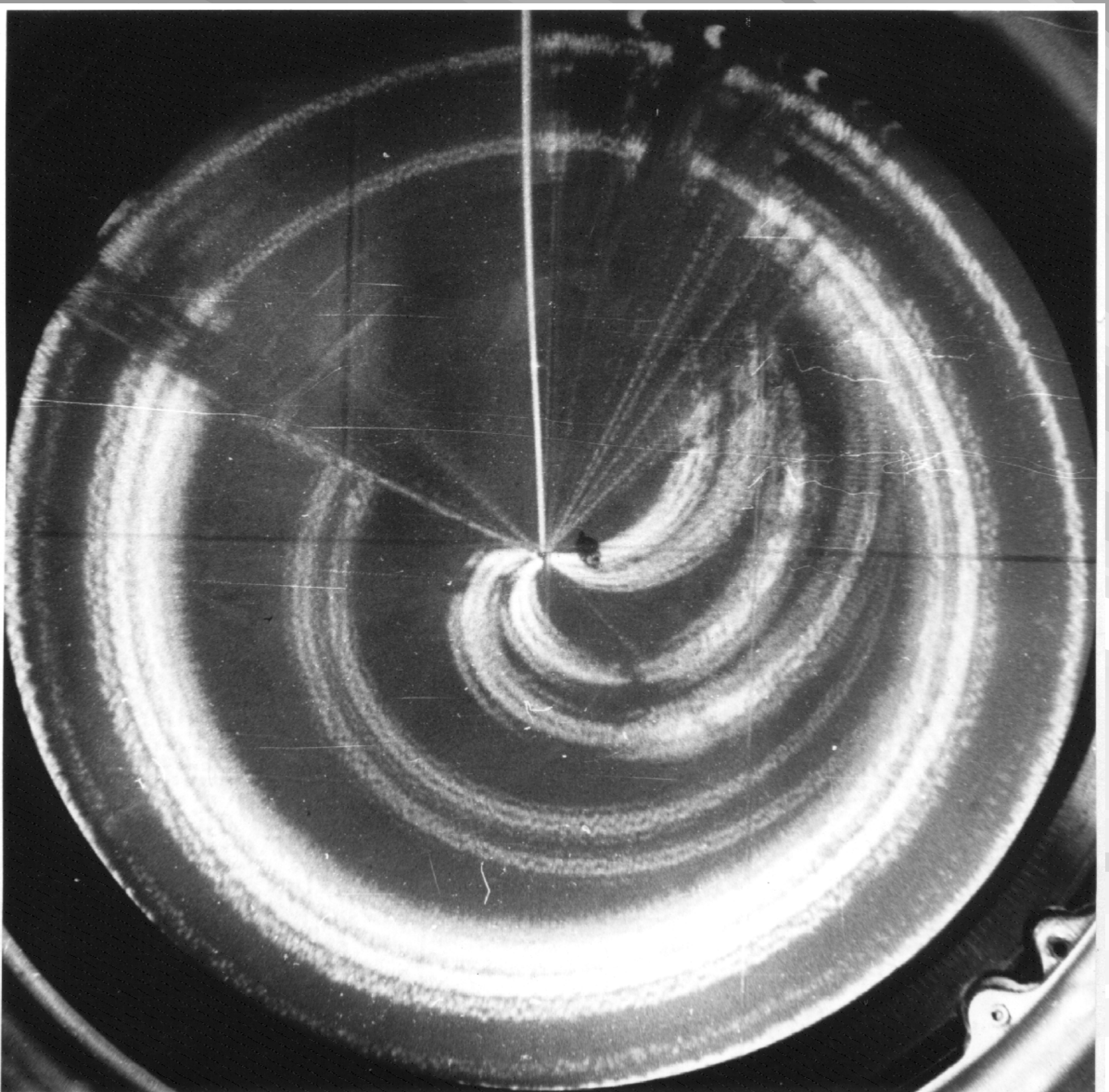
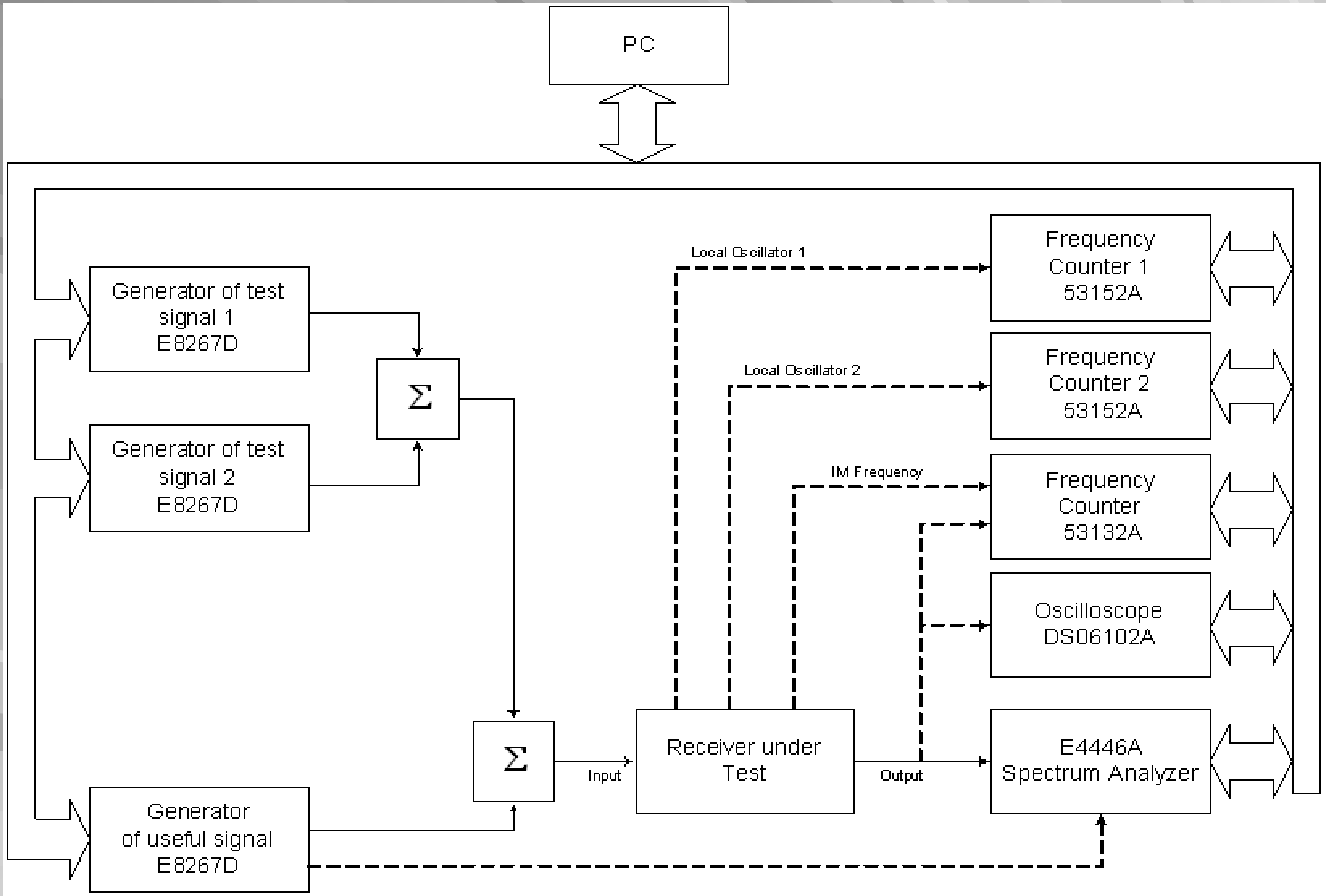


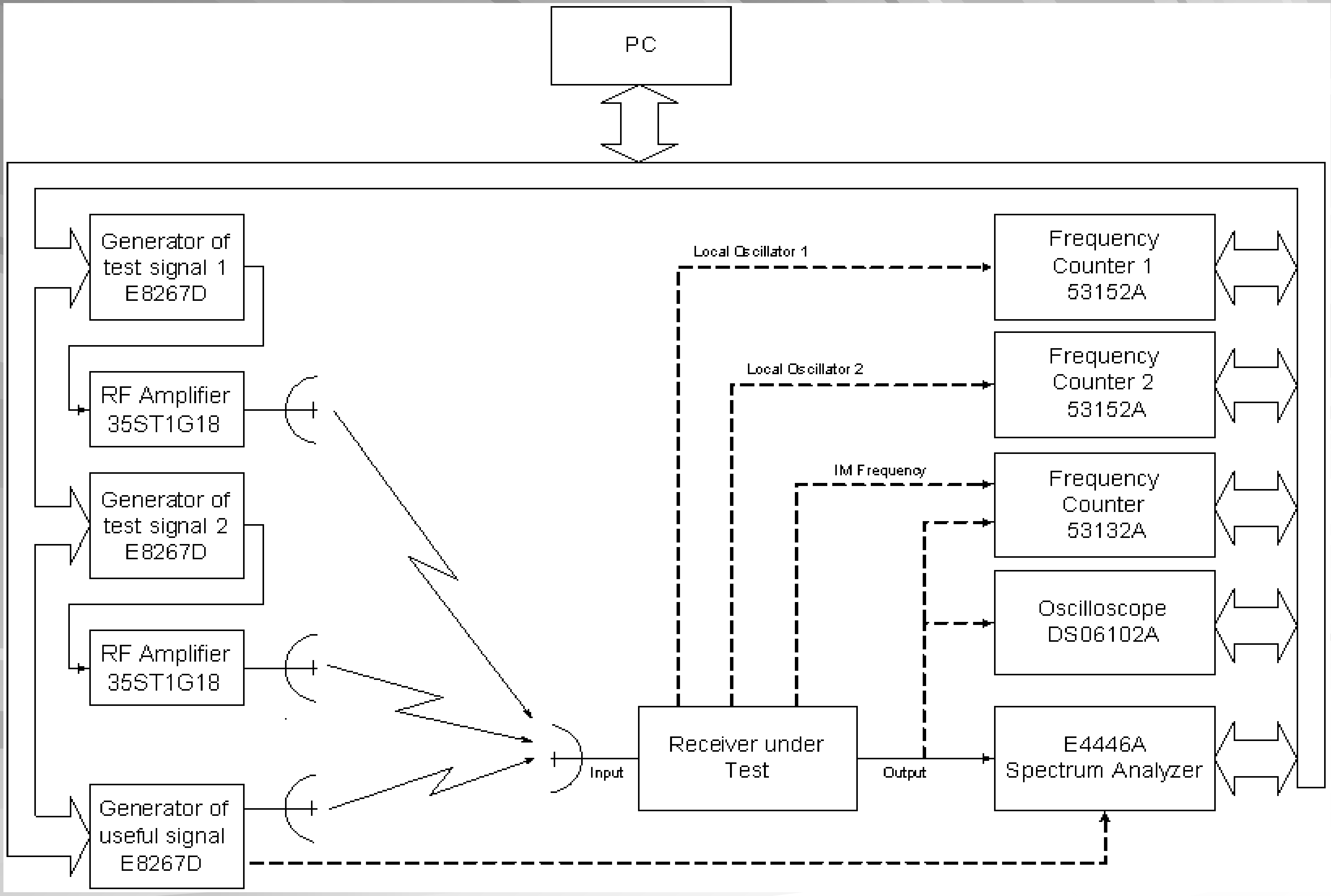
Fig.12.

Double-frequency diagram of the Tu-134 plane radar receiver

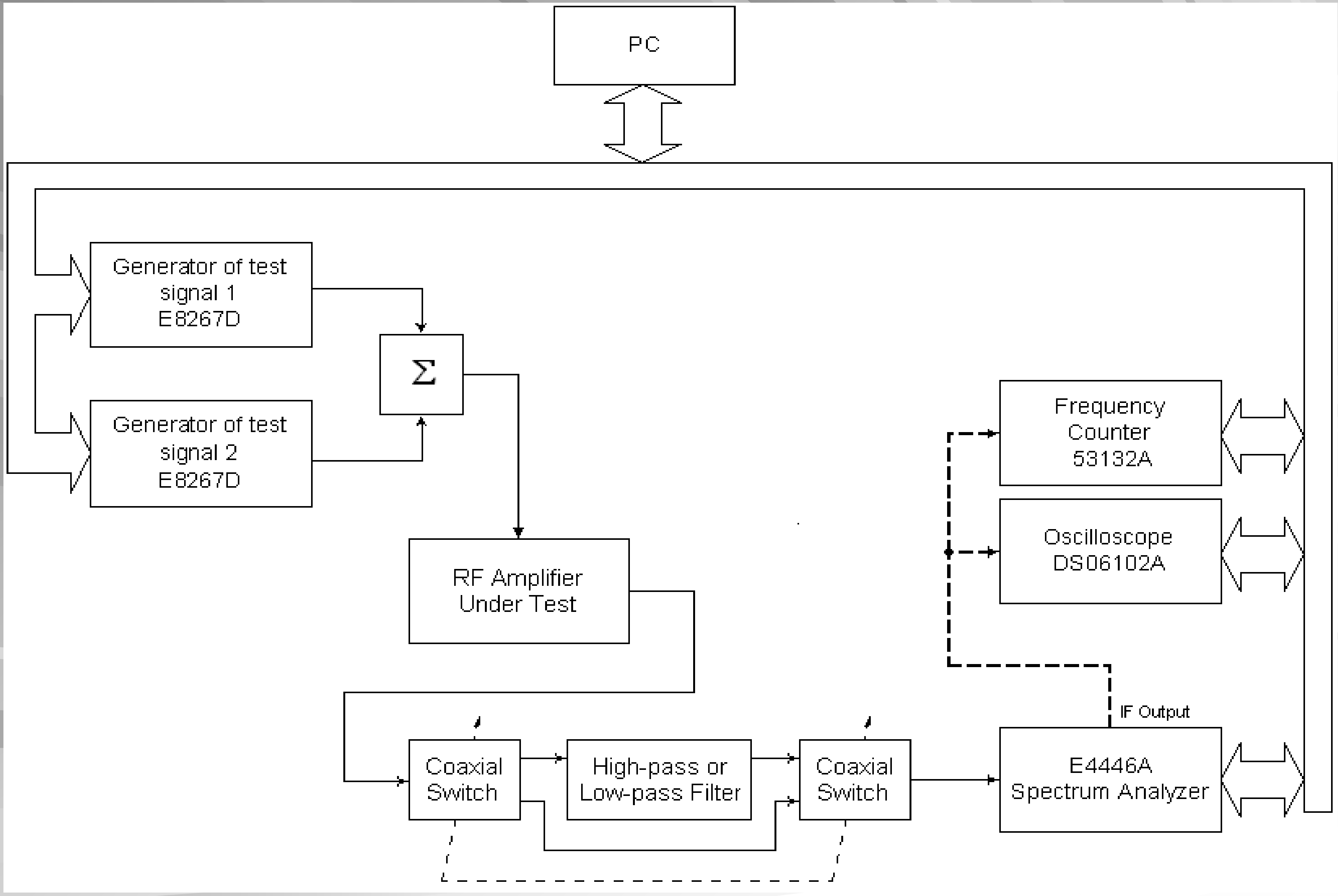
ADFTS example for Radio Receivers Testing (Type 1):



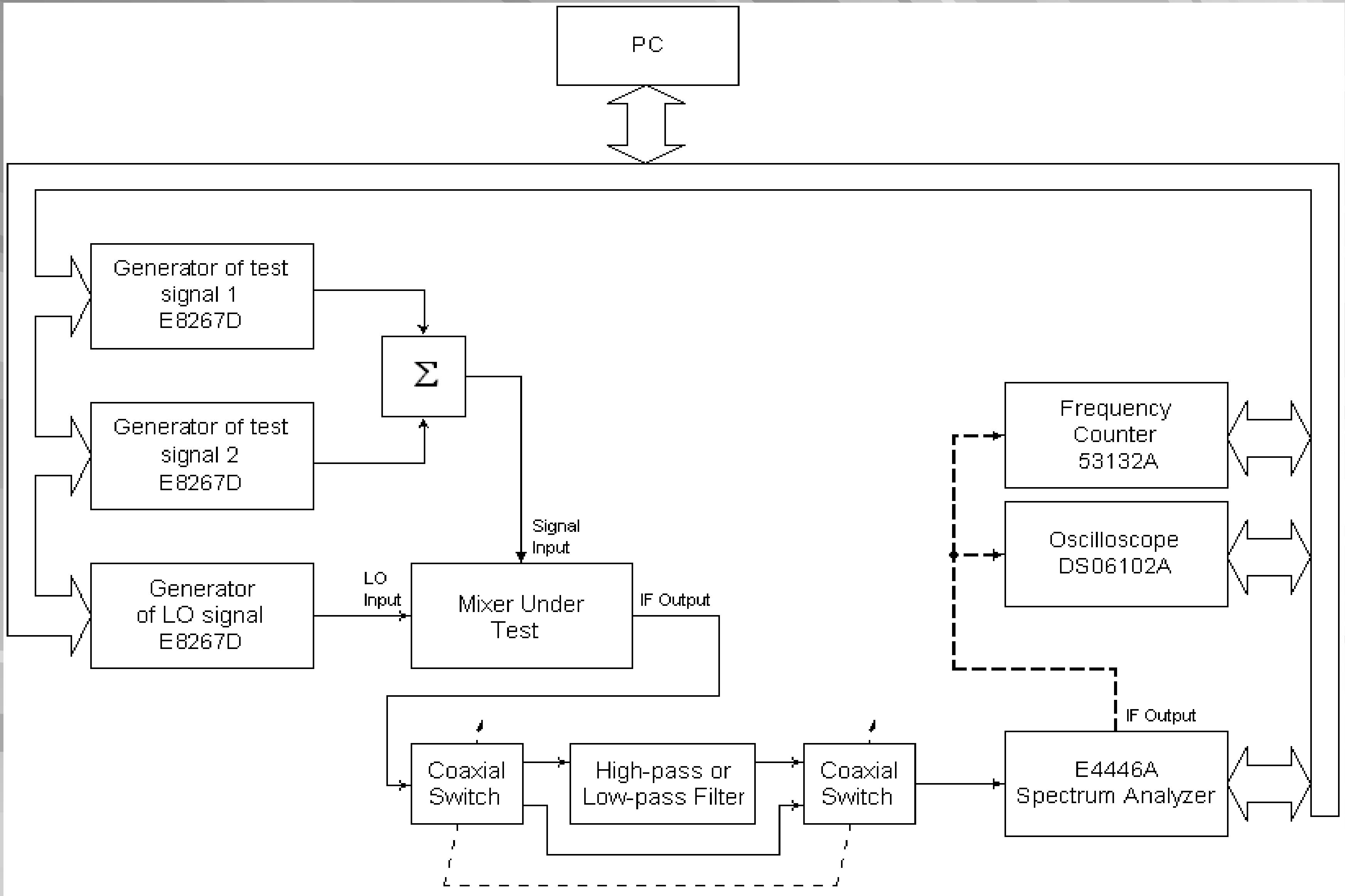
ADFTS example for Radio Receivers Testing (Type 2):



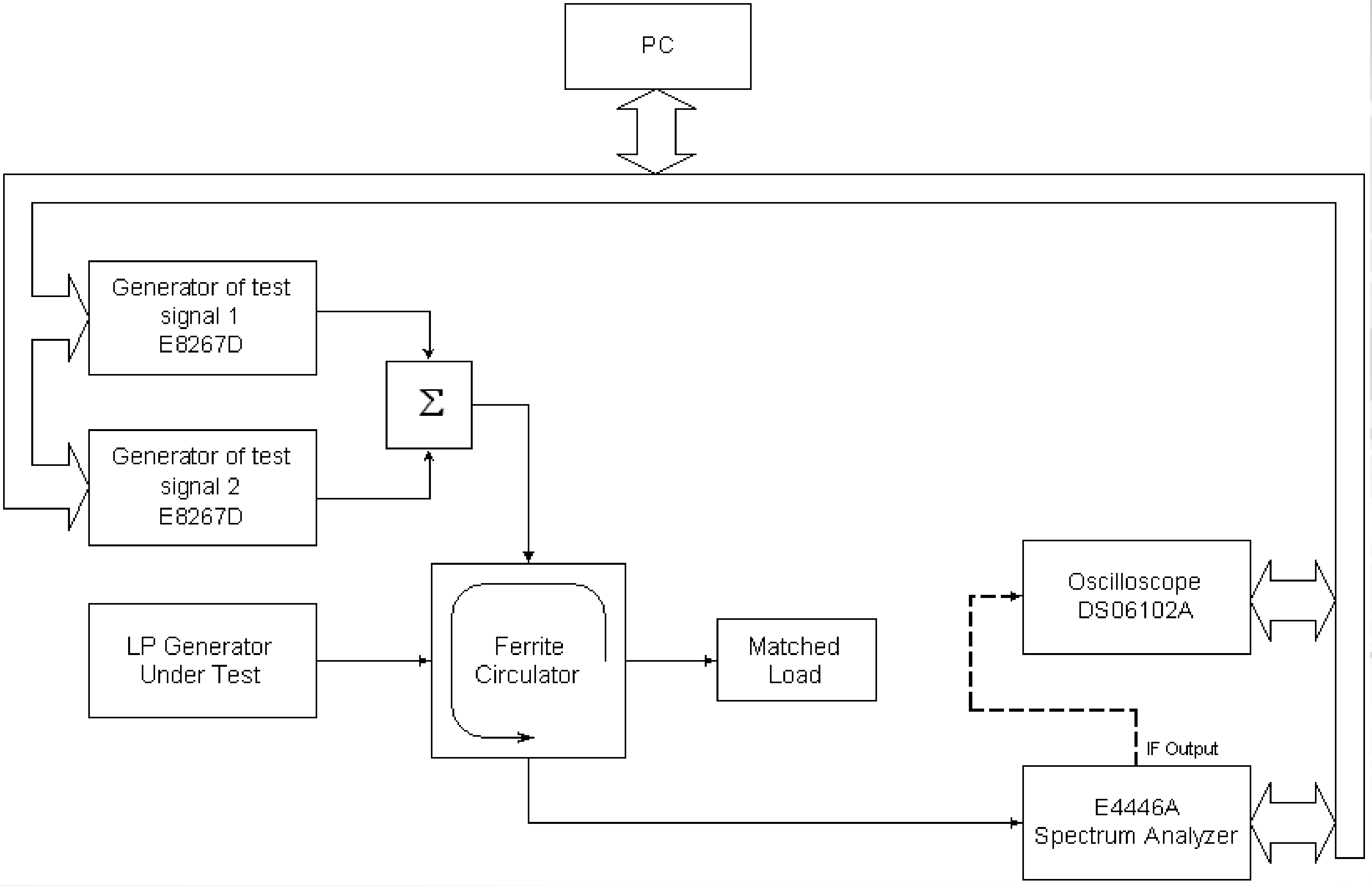
ADFTS example for RF Amplifier Testing:



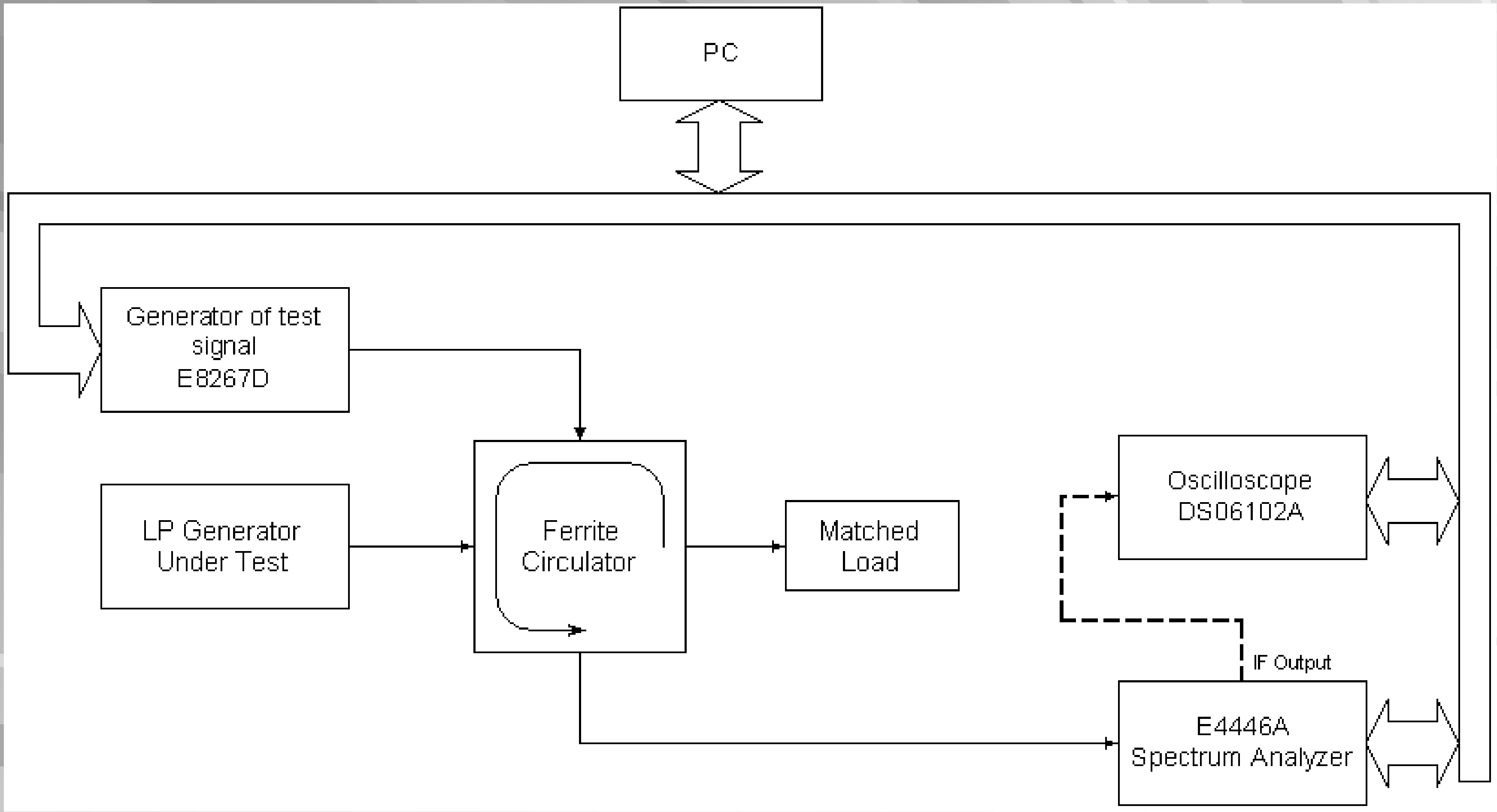
ADFTS example for Mixers Testing:



ADFTS example for LP RF Generator Testing (Type 1):



ADFTS example for LP RF Generator Testing (Type 2):



ADFTS Equipment (1)

Signal generator, Agilent Technologies, E8267D-544

- E8267D-1EH Improved harmonics below 2 GHz
- E8267D-602 Internal baseband generator, 64 MSa memory
- E8267D- UNT AM, FM, phase modulation, and LF output,
- E8267D-UNU Pulse modulation
- E8267D- UNX Ultra-low phase noise performance
- E8267D-007 Analog ramp sweep
- E8267D-H44 Frequency range 250KHz~43.5GHz

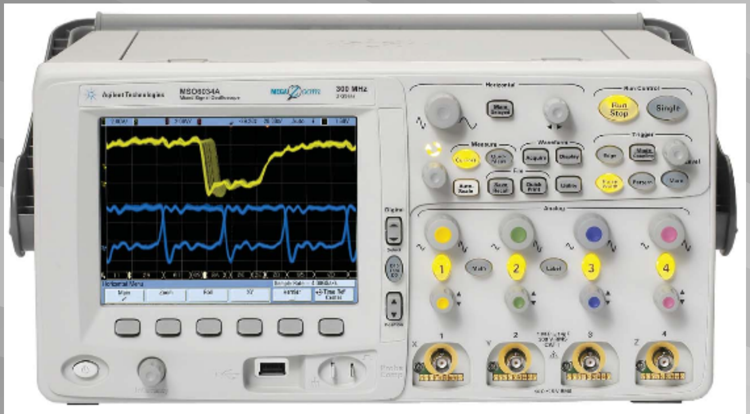
ADFTS Equipment *(2)*

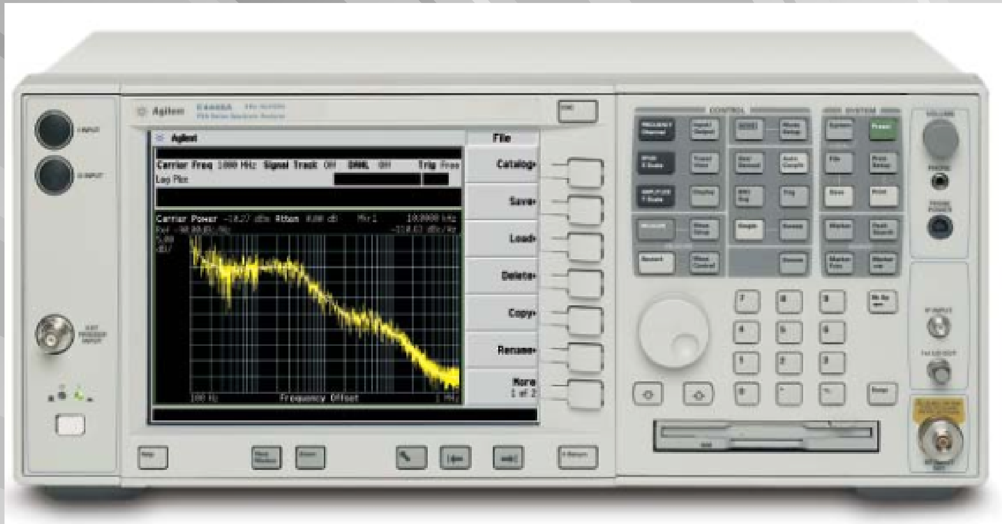
Frequency counters, Agilent Technologies, 53152A

Frequency counter, Agilent Technologies, 53132A

- 53132A-010 High Stability Oven Timebase
- 53132A-050 Add 5.0 GHz Channel 3 to standard 225 MHz Channels 1 and 2

ADFTS Equipment *(3)*



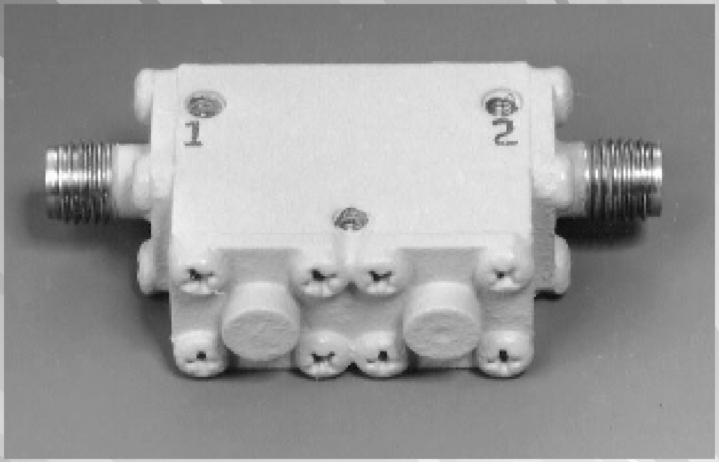


Multi-channel oscilloscope, Agilent Technologies, DSO6102A

Spectrum Analyzer, Agilent Technologies, E4447A

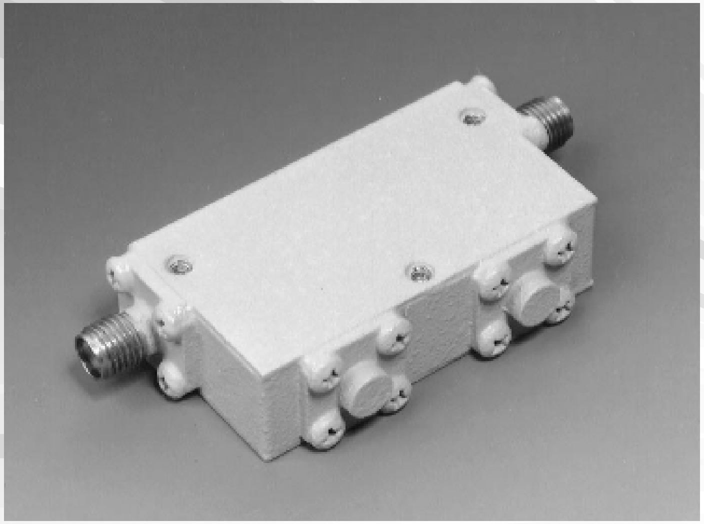
ADFTS Main Accessories *(1)*

Hybrid Power Divider (Summator)
0.5 GHz to-26,5 GHz



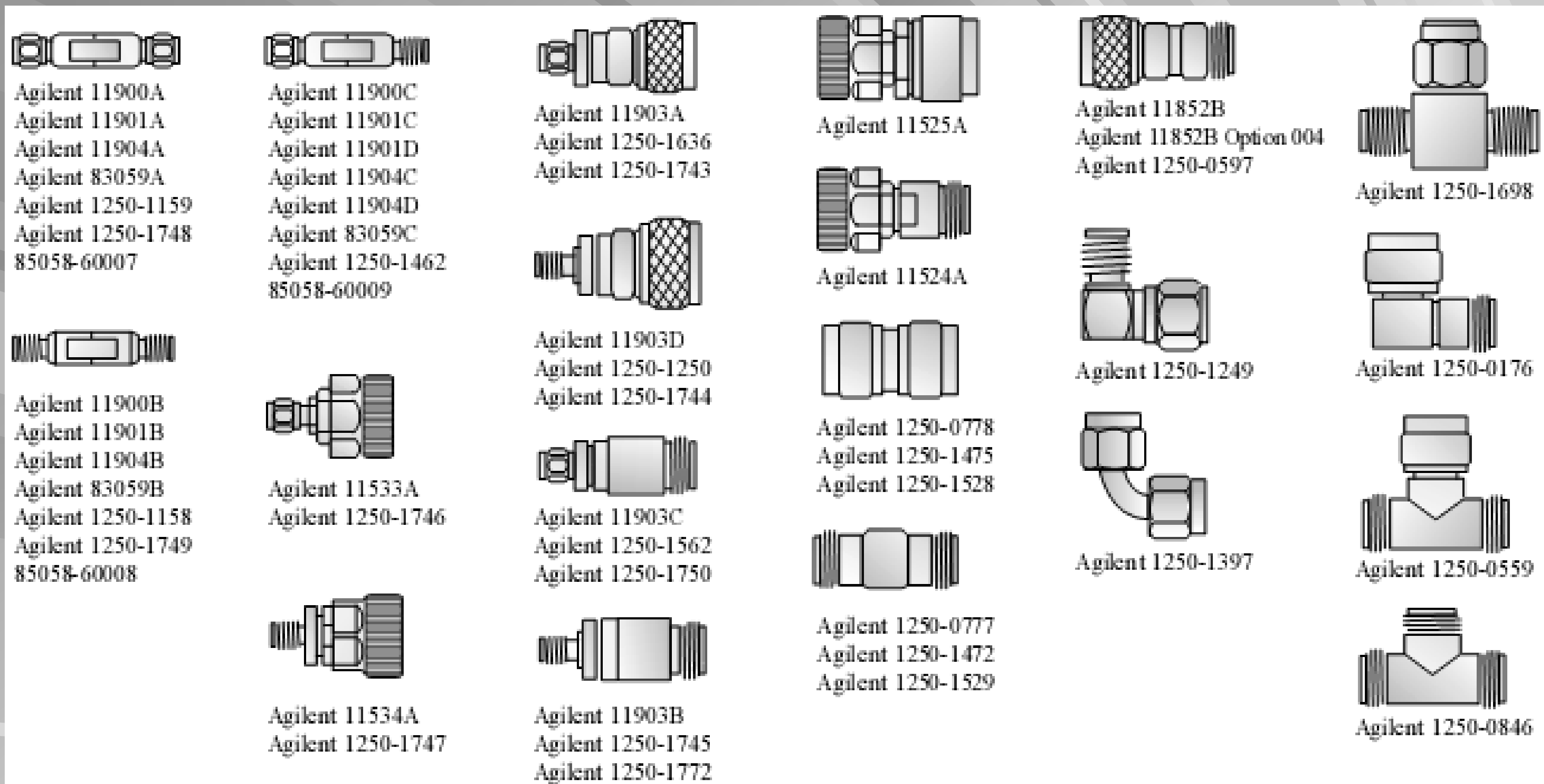
Coaxial Ferrite Circulator

Flexible Coaxial Cable with
Different connectors



Coaxial Ferrite Isolator

ADFTS Main Accessories (2)



Adapters SET for wide frequency range (DC to 40 GHz)

DFTS

There are no analogs of our technology for automated detection and identification of all linear and nonlinear paths in radio receiver!

- **You can use the best measuring equipment, but you need our software to use our measuring and simulating technology! We possess 40 USSR inventions used for realizing our technique!**
- **We have been successfully using and supplying this technology for ten years for testing of radio broadcasting, radio location, radio communication and other receivers in the frequency range 0.1kHz - 56GHz at radioelectronic and aerospace production facilities !**
- **If you want to know more about DFTS, please see *IEEE Trans. on EMC*, Vol.42, May 2000, pp. 213-225, *"Automated Double-Frequency Testing Technique for Mapping Receiver Interference Responses"***