01 Jan 2001

High-Power Microwave Wideband Random Signal Measurement and Narrowband Signal Detection Against the Noise Background

Marina Koledintseva
Missouri University of Science and Technology

Alexander A. Kitaytsev

V. A. Konkin

Recommended Citation

M. Koledintseva et al., "High-Power Microwave Wideband Random Signal Measurement and Narrowband Signal Detection Against the Noise Background," *Proceedings of the IEEE International Symposium on Electromagnetic Compatibility, 2001. EMC. 2001*, Institute of Electrical and Electronics Engineers (IEEE), Jan 2001.
The definitive version is available at https://doi.org/10.1109/ISEMC.2001.950542

High-Power Microwave Wideband Random Signal Measurement and Narrowband Signal Detection Against the Noise Background

Marina Y. Koledintseva*
EMC Laboratory,
University of Missouri-Rolla,
1870 Miner Circle, Rolla, MO, USA

Alexander A. Kitaytsev
Ferrite Laboratory,
Moscow Power Engineering
Institute (Technical University),
14 Krasnokazarmennya St.,
Moscow, RUSSIA

Vsevolod A. Konkin
Ferrite Laboratory,
Moscow Power Engineering
Institute (Technical University),
14 Krasnokazarmennya St.,
Moscow, RUSSIA

Abstract: *A method of both measurement of power parameters of a microwave wideband intense random signal and detection of a narrow-band signal with unknown frequency and power against a background of this wideband signal is presented. This method is based on non-heterodyne frequency and power conversion using gyromagnetic converter that operates in two regimes: resonance detection and cross-multiplication. Wideband spectrum envelope of a random signal is visualized, and by switching two regimes and using correspondent filtration of the converted RF signal, the narrowband signals can be detected and measured. The block-scheme and operation of two-channel measuring device combining both functions are discussed.*

INTRODUCTION

Obtaining an adequate visual picture ('panorama') of the microwave spectra in a broad frequency range and measuring of their parameters is an actual problem at the design, testing, and using of microwave active devices (generators, amplifiers, active mixers). It is especially difficult to get true spectrum picture if the devices of high or middle power level radiate wideband random signals ("noise"), or if they are operating in multi-signal regime. Such problems take place, for example, at microwave signal amplification by wideband microwave output power tubes. Even at the harmonic input signal the output spectrum may be complicated. Application of traditional measuring devices (integral power meters, heterodyne spectrum analyzers, and measuring receivers) does not give adequate information about the spectrum. Problems arise at calibration of the measuring device if it has to operate with unmatched active sources, and it is necessary to identify the reception channels.

Application of gyromagnetic converters (GC) containing high-Q monocrystalline ferrite resonators at microwave frequencies is reliable, constructively simple, and relatively low-cost way of the solution of the above problems [1-3]. Principle of the GC operation is based on physical properties of ferrite resonators: stable non-linear resonance phenomena at the interaction with microwave random and deterministic signals. Due to the non-heterodyne principle of frequency conversion, GCs are free from parasitic channels of reception associated with heterodyne and intermodulation harmonics, and owing to frequency-selectivity they are resistant to microwave power overload.

* The co-author is originally with the Ferrite Laboratory of Moscow Power Engineering Institute (Technical University)

PANORAMIC MEASURER OPERATION PRINCIPLE

In 1970-ies in the Ferrite Laboratory of Moscow Power Engineering Institute (MPEI) there was designed the panoramic measuring device for spectrum power density. The device of the first generation visually reproduced spectrum envelope both in all the frequency range of observation ("panorama") and in its narrower parts and was capable of direct measuring of spectrum power density at the frequency of investigation. It was operating with signals having spectrum power density 0.1-100 W/MHz over frequency range 1-7 GHz. Resolution was determined by the resonance line of high-quality ferrogarnet monocrystalline resonator and did not exceed 10 MHz. The panoramic measurer was produced in small series and successfully used at the enterprises designing and exploiting high-power microwave electronic active devices. Later R&D conducted in MPEI allowed widening frequency and dynamic range of the device, as well as getting more functional possibilities so that it got the name "panoramic measurer of power parameters" [4].

The main parts of the measurer are gyromagnetic converter (GC) (Fig. 1) and measuring block with oscilloscopic display and recorder. GC operates in ***"resonance detection"*** (RD) regime. Part of its spectrum of a wideband noise signal that falls inside the FR resonance line causes nutational oscillations of the magnetization vector moment. The resulting magnetic flux variation induces voltage in the plain spiral microcoil surrounding the FR in equatorial plane (assume that this plane is (xy)) [1],

$$V(t) = k\frac{dM_z}{dt}\ . \qquad (1)$$

Then the spectrum of the converted signal is

$$\left|V(\omega_C)\right| = \omega_C kF(\omega_C)\,, \qquad (2)$$

where $F(\omega_C)$ is the spectrum of the longitudinal component of the magnetization vector. For the wideband microwave "noise" acting on the GC this spectrum is found using correlation analysis of random signals acting on a non-linear element [5]. The latter is the ferrite resonator described by the equation of magnetization vector motion (with dissipative term in modified Bloch's form [6], for example),

$$\frac{d\vec{M}}{dt} = -\mu_0\gamma\left[\vec{M}\times\vec{H}\right] + \frac{\omega_r}{\mu_0}\left(\chi_0\vec{H} - \mu_0\vec{M}\right), \qquad (3)$$

0-7803-6569-0/01/$10.00 © 2001 IEEE

where $\vec{H}$ is an effective magnetic field acting on the magnetic moment $\vec{M}$; χ_0 is static magnetic susceptibility; ω_r is relaxation frequency, $\mu_0 = 4\pi \cdot 10^{-7}$ H/m, and $\gamma = 1.76 \cdot 10^{11}$ C/kg. At small angles of the magnetization vector precession the longitudinal component M_z is related to the transversal components by a square-law equation [6],

$$M_z(t) = M_0 - \frac{1}{2M_0}\left(m_x^2(t) + m_y^2(t)\right), \qquad (4)$$

where M_0 is the equilibrium magnetization amplitude which coincides with saturation magnetization value for ferrogarnets.

The converted signal in the measuring device for spectrum power density (or power parameters) is processed by the wideband functional amplifier with special amplitude frequency characteristic $|K(\omega_C)| = K_0 / \omega_C$ to provide proportionality of the input spectrum power density at every frequency to the converted signal spectrum for adequate reproduction of the spectrum envelope.

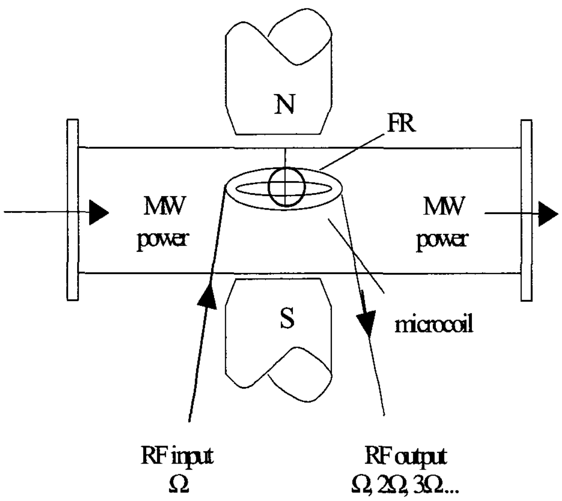

Figure 1. Gyromagnetic converter.

However, the above measurer allows measuring spectrum parameters of only wideband random signals ("noise"). If there are deterministic narrowband components present in the wideband signal, the measurer cannot tell inhomogeneities in the noise spectrum envelope from the narrowband ('harmonic') signals and cannot determine their intensity and frequency.

Two-Channel Device Operation

The method presented here allows combining mentioned above functions. Both regimes of the GC operation: *resonance detection (RD)* and *cross-multiplication (CM)* are used for this purpose [4].

At ***cross-multiplication regime*** the total magnetization field contains "constant" component $\vec{H}_{0z}$ (which is actually changed with "saw" law because of slow tuning the resonance frequency in the range of observation) and RF modulation part,

$$\vec{H} = \vec{H}_{0z} + h_{mz} \cdot \cos(\Omega t + \varphi). \qquad (5)$$

The possibility of revealing narrowband deterministic components (however, with unknown amplitudes and frequencies) against the wideband "noise" background is based on the redistribution of the converted signal spectrum when RF modulation of the ferrite resonance frequency is introduced, i.e. when there is switching from resonance detection to cross-multiplication and back.

The two-channel device was invented [7]. The schematic of the two-channel device is shown in Fig. 2. It was realized on the basis of the panoramic measurer power parameters and studied experimentally. The first ('measuring') channel of the device containing a wide-band functional amplifier works when the GC operates in the RD regime. The second channel contains the narrow-band block (for example, selective amplifier with central frequency at the second harmonic of the high-stable modulation signal. Usually, the modulation frequency is chosen several MHz, and low-pass and high-pass filters have corresponding cutoff frequencies.

Spectra of the converted additive sum "signal" + "noise" at RD and CM regimes differ. In RD regime there are "noise" and "noise & signal" continuous parts of spectrum, while at CM to these two parts the discrete "signal" spectrum is added (Fig.3).

The channels of the device are switched in turn. Simultaneously with the second channel commutation, the modulation from the stable quartz oscillator passes to the GC spiral microcoil, so that cross-multiplication regime is realized. When the first channel is switched on, the oscillator is switched off (resonance detection regime), and vice versa. Comparing two obtained envelopes of the same spectrum, it is possible to detect narrowband "signal" components in the "noise" spectrum and measure their parameters (see Fig.3,4).

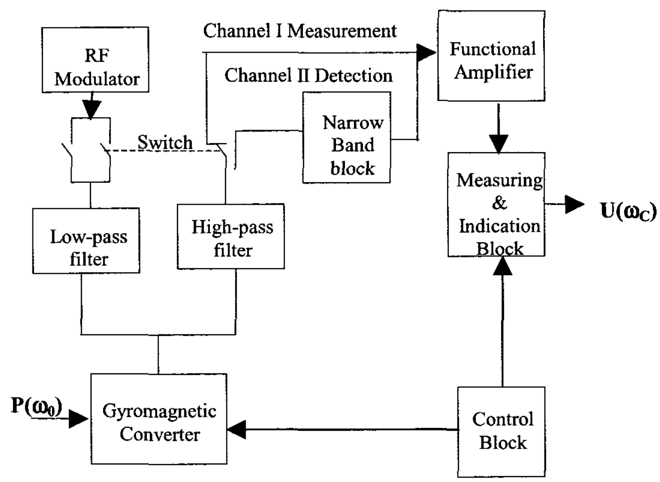

Figure 2. Two-channel panoramic measuring device.

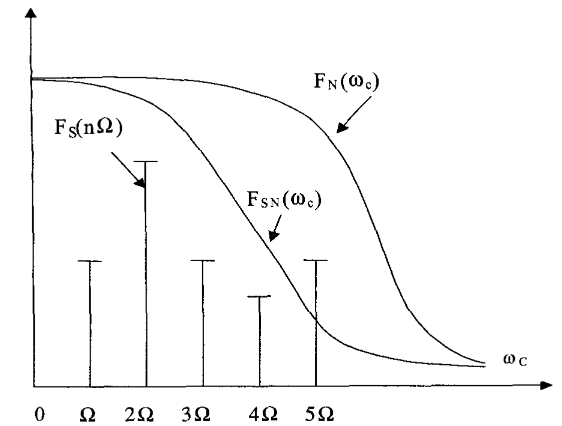

Figure 3. Components of the spectrum of the converted additive sum "signal" + "noise".

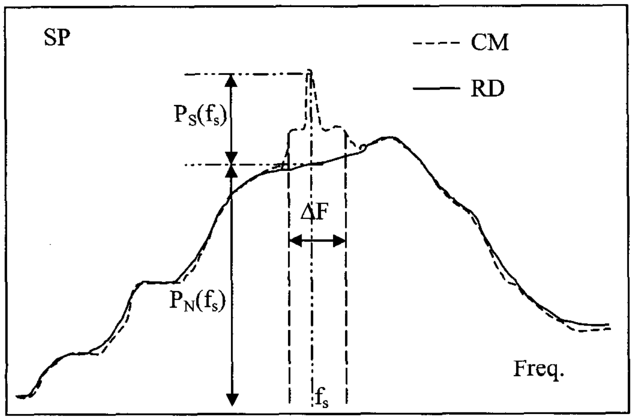

Figure 4. View of spectra in cross-multiplication and resonance detection regimes and detection a narrowband "signal" against the wideband random signal ("noise") background

It is important that the microwave signal instability does not lead to the necessity of the narrowband block pass-band widening. This is due to the non-heterodyne frequency conversion by a GC, since the frequency of a converted pure "signal" is independent of the microwave frequency carrier, but is determined by a harmonic of a modulation frequency,

$$\omega_C = n\Omega \text{ , n=2,3,4....} \qquad (6)$$

Minimum possible pass-band of the narrowband amplifier is determined only by the condition non-distortion of the spectrum envelope at fast sweeping at panoramic observation of the spectrum.

For the maximum signal-to-noise gain, it is necessary to operate at the optimum frequency and amplitude of modulation. The narrow-band block should be tuned to the second modulation harmonic (the most intensive one at this way of frequency conversion). The optimum normalized modulation amplitude is about $q=\mu_0\gamma h_z/\Omega=3.3...3.5$, and relative modulation frequency $p=\Omega/\delta=0.8\text{-}1.2$ corresponding to various input "signal"-to-"noise" ratios, where Ω is the modulation frequency, μ_0 is a permeability of vacuum, γ is gyromagnetic ratio, δ is the half of the ferrite resonance line width in terms of cyclic frequencies.

The experiments have shown that the device with narrow-band amplifier having pass-band Δf = 0.2 kHz tuned to the second harmonic of 1 MHz-modulation produced by high-stability quartz oscillator allows detecting reliably harmonic "signal" which power is 1000 times less than integral power of the "noise".

CONCLUSION

Using physical peculiarities of wideband random and narrowband deterministic signals interaction with monocrystalline ferrite resonators in gyromagnetic converter it is possible to provide both measuring of power parameters of wide-band intense noise and detecting narrow-band signals at the noise background. Essential increase of signal-to-noise ratio is achieved in the two-channel panoramic measuring device at simultaneous narrowband amplifier and RF modulation switching on. Due to frequency-selectivity and non-heterodyne principle of frequency conversion, the measuring devices using gyromagnetic converters are free from parasitic channels of reception associated with heterodyne and intermodulation harmonics, they are resistant to microwave power overload, and can be used for visualization and measuring power (spectrum) parameters of radiations produced by high-power microwave devices.

REFERENCES

[1] Balakov V.F. et al. Application of gyromagnetic effects in monocrystals of ferrites for measuring parameters of electromagnetic signals at microwaves. Proc. 5th Int. Conf. On Gyromagnetic Electronics and Electrodynamics. Moscow, 1980, Ed. Moscow Power Engineering Institute. V. 3, pp. 86-99 (in Russian).

[2] M.Y.Koledintseva, L.K.Mikhailovsky, A.A.Kitaytsev, Advances of Gyromagnetic Electronics for EMC problems. Proc. 2000 IEEE Symp. On EMC, August 21-25, 2000,Washington, DC.V.2, pp.773-778.

[3] Kitaytsev A.A., Koledintseva M.Y., Physical and Technical bases of using ferromagnetic resonance in hexagonal ferrites for electromagnetic compatibility problems, IEEE Trans. EMC, Vol. 41, No 1, Feb. 1999, pp.15-21.

[4] Kitaytsev A.A., Konkin V.A., Kratskin L.N. et al. Panoramic measuring device for microwave signal power parameters. Transactions of Moscow Power Engineering Institute No. 241. Moscow, MPEI. 1991, p.40-47 (in Russian).

[5] Levin, B.R., Theoretical Bases of Statistical Radioengineering, Part 1. Ed. "Soviet Radio", Moscow, 1966

[6] Lax, B. and Button, K.J., Microwave Ferrites and Ferrimagnetics. McGraw-Hill Book Company, Inc., 1962.

[7] Kitaytsev A.A., Koledintseva M.Y., Konkin V.A., Radchenko V.F., Savchenko N.I. Method of Spectrum Analysis of Wideband Noise Microwave Signals and the Device for its Realization. Russian Federation Patent No 2088945, Bulletin No 24, 1997, 27.09.97 on the application No 93021125/09 (020368) with priority of 21.04.93 (in Russian).