A HETERODYNE CIRCUIT FOR MEASURING THE SPECTRAL CHARACTERISTICS OF KA-BAND NANOSECOND HIGH POWER MICROWAVE PULSES

A.I. KLIMOV[1], E.V. EMELYANOV[2], V.YU. KONEV[1], P.V. PRIPUTNEV[1], V.V. ROSTOV[1], R.V. TSYGANKOV[1], A.Y. YUSHCHENKO[2]

[1]INSTITUTE OF HIGH CURRENT ELECTRONICS, SIBERIAN BRANCH, RUSSIAN ACADEMY OF SCIENCES TOMSK, RUSSIA, KLIMOV@LFE.HCEI.TSC.RU

[2]JSC "SCIENTIFIC-RESEARCH INSTITUTE OF SEMICONDUCTOR DEVICES", TOMSK, RUSSIA

Identifying and an analysis of an operating mode of a relativistic nanosecond microwave oscillator substantially depend on the results of measuring the spectral characteristics of the microwave pulse of the oscillator [1]. In the Ka-band, measuring the nanosecond microwave pulse spectrum is currently possible using real-time broadband digital oscilloscopes [2]. However, these oscilloscopes usually have a high price, which may make them not always available for academic laboratories. In this regard, among other methods [1, 3] for measuring the spectral characteristics of the high-power microwave pulses, the heterodyne method is relevant. This method is based on the transfer of the spectrum to a low-frequency range, which allows the use of more narrow-band, and, therefore, less expensive oscilloscopes.

Suitable circuits can be developed on the basis of semiconductor mixing diodes [4, 5] operating at micro to milliwatt levels of input microwave power and output signals from tens to hundreds of millivolts. However, other versions of the devices [6] designed for a much higher input pulsed microwave power can be created on the basis of detectors on hot carriers [7] and kilowatt magnetrons for the local oscillators. The output signals of such meters can range from tens to hundreds of volts. But these devices are more bulky, complex and expensive, so that their use is justified only in the case of strong electromagnetic interference. If the circuit is screened from the interference by being placed in a screened room remote from the experimental setup, and the measured signal can be transmitted to it via a coaxial cable with acceptable attenuation without significant distortion, the use of a device on semiconductor elements is more preferable. In this work, an attempt was made to develop such a device designed to measure the spectral characteristics of high-power microwave pulses of Ka-band.

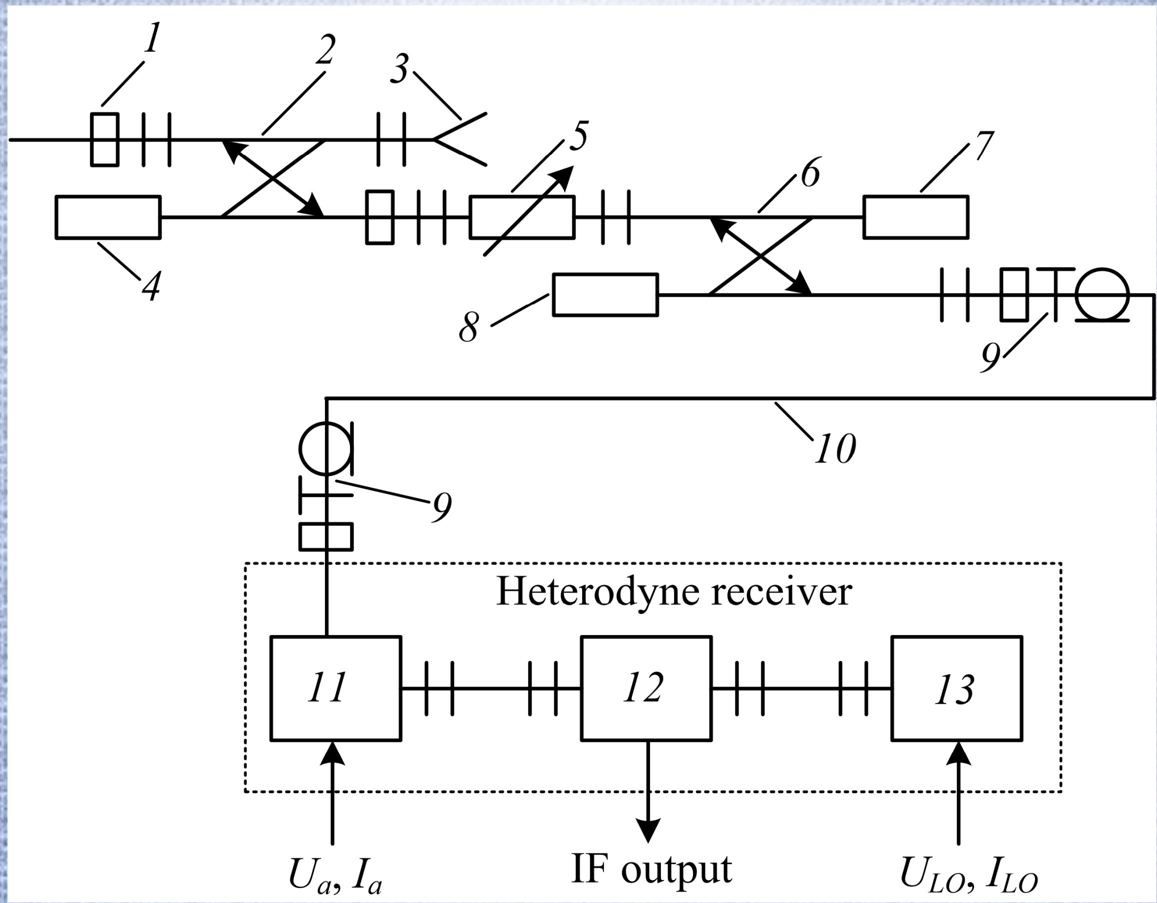

Fig. 1. Scheme of the circuit : *1* – input waveguide (7.2×3.4 mm) antenna like [8]; *2* – input waveguide directional coupler; *3* – horn antenna; *4* – termination of the output waveguide of the input directional coupler; *5* – variable waveguide attenuator; *6* – additional waveguide directional coupler; *7* – termination of the input waveguide of an additional waveguide directional coupler; *8* – termination of the output waveguide of an additional directional coupler; *9* – coaxial-to-waveguide adapters; *10* – SM86FEP Huber Suhner cable (10 m) with 11_SMA_50-2-15/111_ME Huber Suhner RF connectors; *11* – electronic attenuator (MIS MSM207-02); *12* – mixer (MIS MM605); *13* – local oscillator (based on MIS HMC506 and two frequency multipliers using MISs HMC578 and HMC814 with wideband fixed attenuators on MIS MP503).

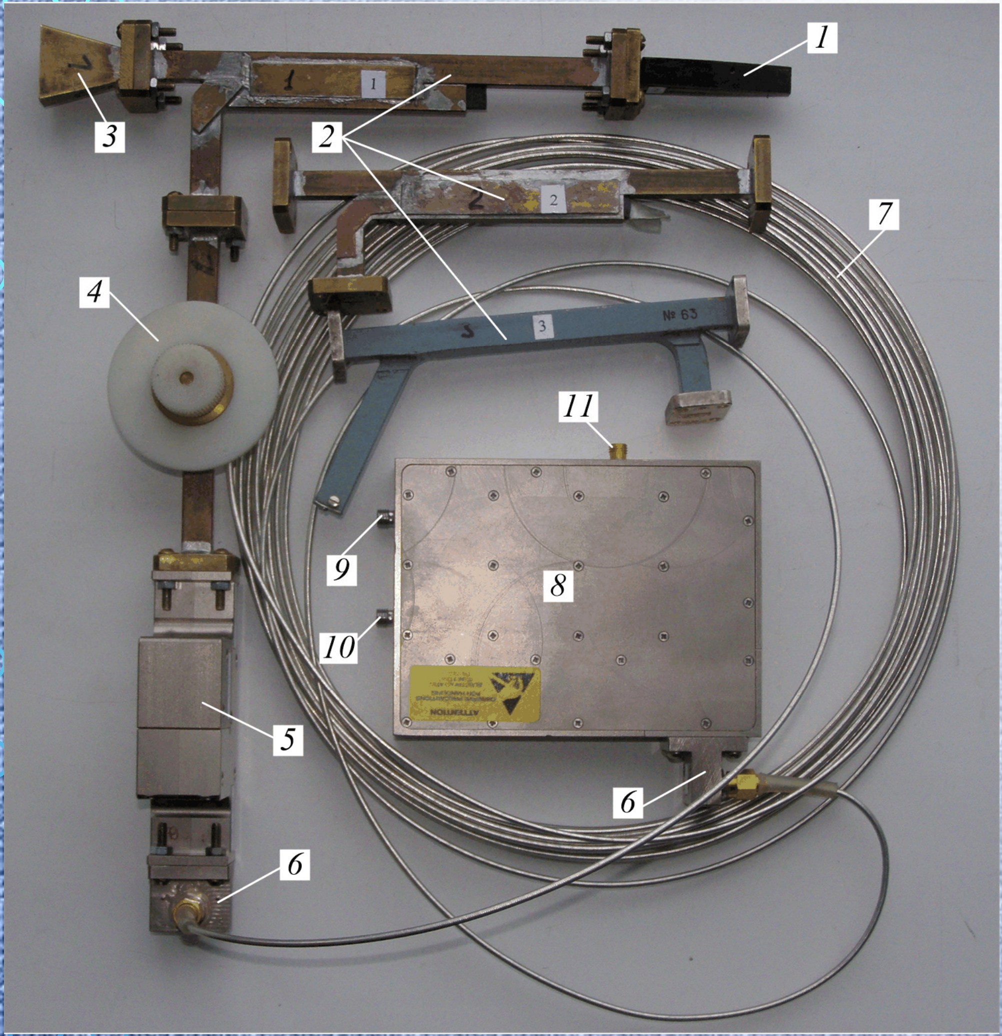

Fig. 2. Photograph of the circuit elements for measuring the spectral characteristics of Ka-band nanosecond high-power microwave pulses:

1 – receiving waveguide antenna; *2* – input waveguide directional couplers (No. 1, No. 2, and No. 3); *3* – horn antenna (the termination of the main waveguide of the input directional coupler; *4* – variable waveguide attenuator; *5* – additional waveguide directional coupler; *6* – coaxial-to-waveguide adapters; *7* – coaxial cable; *8* – heterodyne receiver; *9* – power supply connector of the heterodyne receiver; *10* – connector of the control the electronic attenuator; *11* – IF signal output connector.

The microwave signal received by the waveguide antenna *1*, attenuated to the acceptable level by one of the three directional couplers *2*, the attenuator *5* and the additional directional coupler *6*, as well as the cable *10* with the coaxial-to-waveguide adapters *9*, was injected to the rf port of the heterodyne receiver *11*, *12*, *13*. Here, the microwave signal could be additionally attenuated to the necessary extent by an attenuator *11* with electric control when a control voltage U_a was applied to it with a current I_a, after which the signal was injected to the input of the mixer *12*. The other port of the mixer received the signal of the local oscillator *13*. The intermediate frequency (IF) signal from the output of the mixer *12* entered an oscilloscope for digitizing and Fourier transform.

To supply the control voltage of the electronic attenuator *11* and the power of the local oscillator *13* a sources of the type Rigol DP832A or sources with similar specifications could be used.

TABLE I. MAIN SPECIFICATIONS OF THE HETERODYNE RECEIVER

Parameter name	Parameter value
Input signal frequency range	35.6–37 GHz
Local oscillator frequency	35.44 GHz
Microwave input power (continuous)	not more than 50 mW
Conversion losses for the current $I_a = 0$ mA	not more than18 dB
Conversion losses for the current $I_a = 5$ mA	not less than 43 dB
Conversion losses for the current $I_a = 10$ mA	not less than 50 dB
Control voltage U_a for the current $I_a = 5$ mA	1.35 V
Control voltage U_a for the current $I_a = 10$ mA	1.57 V
LO voltage U_{LO}	12 ± 0.5 V
LO current I_{LO}	not more than 300 mA

TABLE II. MAIN SPECIFICATIONS OF THE ADDITIONAL ELEMENTS OF THE MEASURING CIRCUIT

Parameter name	Parameter value
Input frequency range	35.0–37.0 GHz
Receiving cross section of the waveguide antenna 1, Fig. 2	0.29 ± 0.025 cm^2
Effective area of the horn antenna 3, Fig. 2	1.9 ± 0.26 cm^2
Coupling coefficient of the input directional coupler 2 (No. 1), Fig. 2	35.2 ± 0.9 dB
Coupling coefficient of the input directional coupler 2 (No. 2), Fig. 2	26.5 ± 0.15 dB
Coupling coefficient of the input directional coupler 2 (No. 3), Fig. 2	13.6 ± 0.4 dB
Coupling coefficient of the additional directional coupler 6, Fig. 2	20.8 ± 0.7 dB
Insertion loss of the cable 7, Fig. 2	59.6 ± 1.2 dB

The operability of the described circuit was tested in [9]. In these experiments, the circuit was used to measure the spectral characteristics of high-power nanosecond pulses of microwave radiation of the relativistic Cherenkov oscillator in the Ka-band.

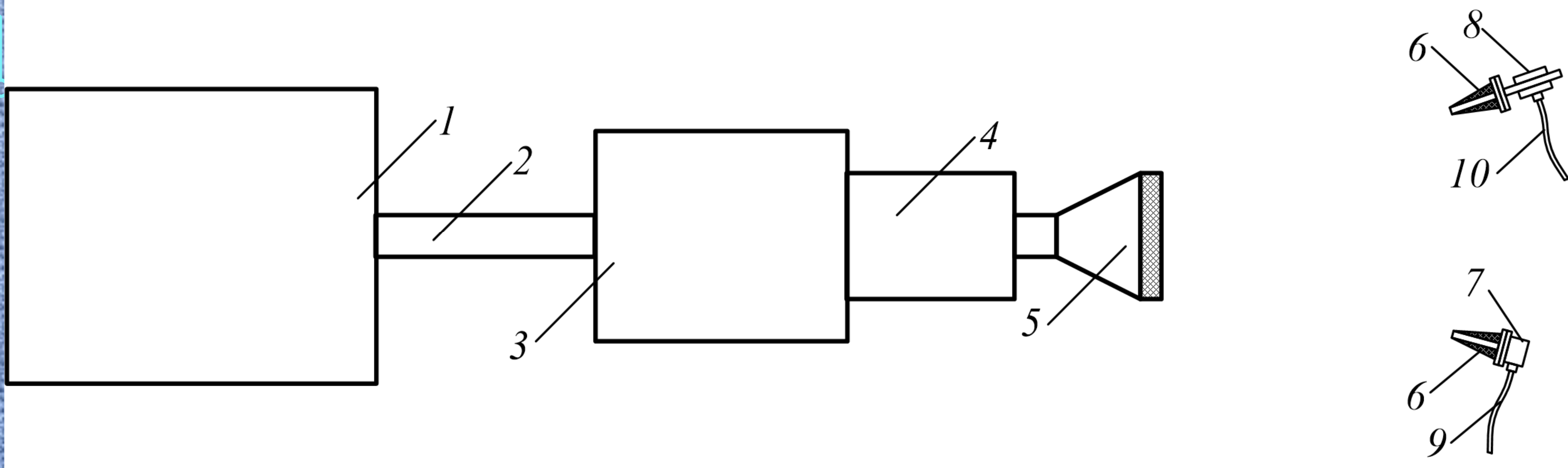

Fig. 3. Scheme of the experiments [9] using a high-current nanosecond accelerator of the SINUS-200 type [10]: *1* – pulser based on the Tesla transformer [11] built into coaxial line filled with transformer oil, *2* – transmitting coaxial line, *3* – accelerating tube, *4* – magnetic system with a slow wave system of Cherenkov microwave oscillator [9] inside, *5* – transmitting horn antenna, *6* – Ka-band receiving waveguide antennas like [8], *7* – coaxial-to-waveguide adapter, *8* – detector on hot carriers like [7] *9* – coaxial cable to the heterodyne receiver, *10* – coaxial cable to the oscilloscope.

At the accelerator diode voltage amplitude of 350 ± 10 kV, which corresponded to an amplitude of the electron beam current of 2.9 ± 0.2 kA with 2.5 T magnetic field, single microwave pulses with a duration of ≈ 3 ns and a power amplitude of 400 ± 100 MW were generated. Under these conditions, the carrier frequency was about 36.4 GHz. The corresponding oscillograms are presented in Fig. 4.

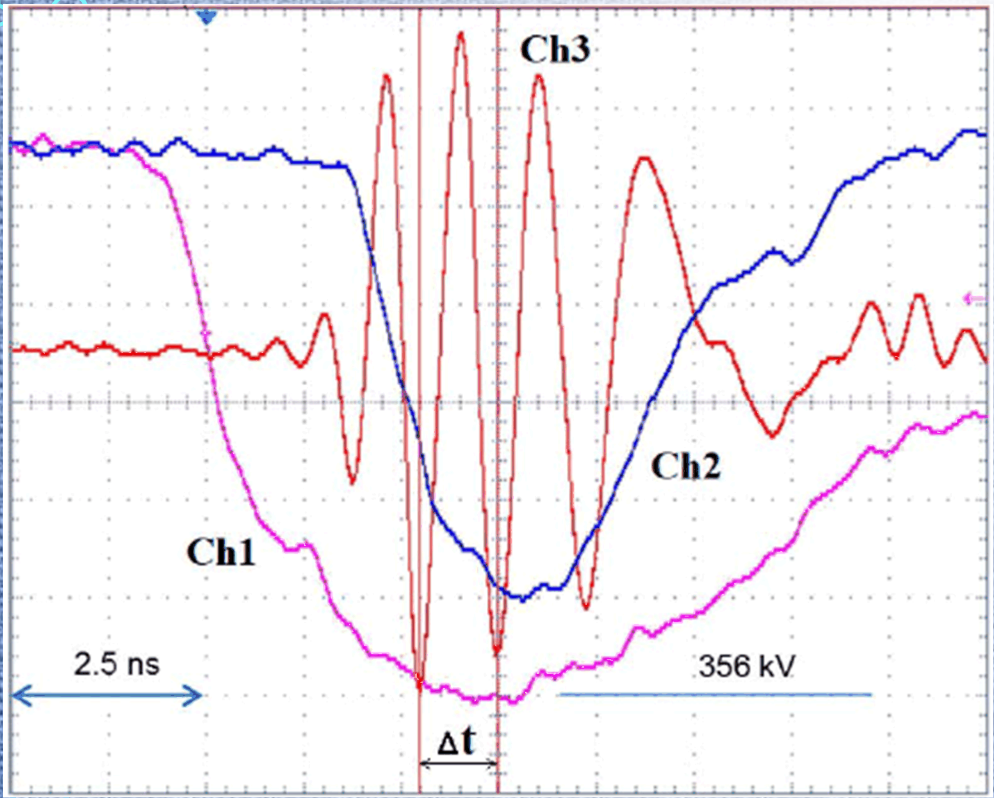

Fig. 4. The oscillograms from [9]: diode voltage (Ch1), detected microwave signal (Ch2), and intermediate frequency signal (Ch3) for single pulse. The heterodyne frequency is f_h=35.4 GHz. Carrier frequency is $f_0 \approx f_h + 1/\Delta t$, $1/\Delta t \approx 1$ GHz.

This work was funded by the Russian Foundation for Basic Research and the Government of the Tomsk Region of the Russian Federation, grant No. 18-42-700012.

REFERENCES

[1] J. Benford, J. A. Swegle, and E. Schamiloglu, High power microwaves, New York–London: Taylor & Francis, 2007, pp. 214–222.

[2] Teledyne Lecroy: Products: Oscilloscopes: WaveMaster 830Zi-B, http://teledynelecroy.com/oscilloscope/wavemaster-sda-dda-8-zi-b-oscilloscopes/wavemaster-830zi-bJ.

[3] L. M. Earley, W. P. Ballard, L. D. Roose, and C. B. Wharton, “Comprehensive approach for diagnosing intense single-pulse microwave sources,” Rev. Sci. lnstrum., vol. 57, no. 9, pp. 2283–2293, September 1986.

[4] A. A. El’chaninov, A. I. Klimov, K. I. Kurkan, “Heterodyne meter of spectral characteristics of high-power nanosecond X-band microwave pulses,” Instrum. Exp. Tech., vol. 43, no. 1, pp. 88–90, 2000.

[5] M. S. Gusyatiner, A. I. Gorbachev, Semiconductor microwave diodes, Moscow: Radio and Communication, 1983, pp. 60–89. (In Russian: Poluprovodnikovyye sverkhvysokochastotnyye diody, Moscow: Radio i svyaz’, 1983).

[6] V. I. Belousov., G. Yu Golubyatnikov, A. V. Morev, et al., “Geterodinnaya sistema izmereniya spektra moshchnogo nanosekundnogo sverkhvysokochastotnogo impul'sa” (“Heterodyne system for measuring the spectrum of high-power nanosecond microwave pulse”), Prib. Tekh. Eksp., no. 3, pp. 133–136, 1990.

[7] M. Dagys, Z. Kancleris, R. Simniskis, et al., “The resistive sensor: A device for high-power microwave pulsed measurements,” IEEE Ant. Propag. Mag., vol. 49, no. 5, pp. 64–79, October 2001.

[8] A. I. Klimov, O. B. Kovalchuk, V. V. Rostov, and A. S. Sinyakov, “Measurement of parameters of X-band high power microwave superradiative pulses,” IEEE Trans. Plasm. Sci., vol. 36, no 3, pp. 661–664, June 2008.

[9] V. V. Rostov, E. M. Tot’meninov, R. V. Tsygankov, et al., “Two-wave Ka-band nanosecond relativistic Cherenkov oscillator,” IEEE Trans. Elect. Dev., vol. 65, no. 7, pp. 3019–3025, July 2018.

[10] N. S. Ginzburg, I. V. Zotova, A. W. Cross, et al., “Generation, amplification, and nonlinear self-compression of powerful superradiance pulses,” IEEE Trans. Plasm. Sci., vol. 41, no. 4, pp. 646–660, April 2013.

[11] S. D. Korovin, V. V. Rostov, “High-current nanosecond pulse-periodic electron accelerators utilizing a tesla transformer,” Rus. Phys. Journ., vol. 39, no. 12, pp. 1177–1185, 1996.