Poster Session

Hot-Carrier-Effect-Based Coaxial Broadband Detector of High-Power Nanosecond Microwave Pulses

I.E. Ivanov, P.S. Strelkov*, D.V. Shumeyko**

Prokhorov Institute of General Physics, Russian Academy of Sciences
38, Vavilova str., Moscow, 119991, Russia. Phone: 8-499-1356387, E-mail: iei@fpl.gpi.ru
*E-mail: strelkov@fpl.gpi.ru
**E-mail: shumeyko@fpl.gpi.ru

Abstract – The present report is aimed at investigating the structure and parameters of a liquid-nitrogen-cooled, hot-carrier-effect-based microwave pulse detector for recording electromagnetic radiation in the frequency range 2–10 GHz with a time resolution of at least 1 ns. The coefficient of conversion of the voltage at the entrance cable into the modulated signal amplitude at the exit is $1.2 \times 10^{-2}$. The sensitivity threshold of the detector in terms of the power density of the input signal is 2 W/cm$^2$.

1. Introduction

Although it is a simple matter to record microwave signals by standard microwave detectors, there are problems in measuring high-power (~50 MW and higher) pulses, as is the case, e.g., with vacuum and plasma relativistic microwave devices [1, 2]. In 1975, Raiser and Tsopp [3] proposed to record microwave pulses in relativistic electronics by using so-called hot-carrier-effect-based detectors with semiconductors [4]. The main advantages of such detectors are high-speed operation and high reliability at essentially any level of the pulsed input power. The detectors are known to be used in two versions – with a semiconductor placed in a 3-cm- and a 8-mm-wavelength waveguide – and are devised to record microwave signals at frequencies above 6.5 GHz. In the present paper, results are reported from measuring the parameters of a hot-carrier-based detector placed within a coaxial waveguide. The detector is immersed in liquid nitrogen for supercooling, is equipped with entrance cables, and is aimed at recording signals at relatively low frequencies of 1–5 GHz.

2. Experimental scheme and main results

The objective of the present work was to check how exactly the input signals were recorded: a) Is the shape of the microwave pulse envelope recorded reliably? b) What is the time resolution? c) How does the shape of the pulse at the exit from the detector depend on the broad bandwidth of the input signal? and d) How does the accuracy of recording the pulse shape depend on the duration of the input microwave signal? These questions can be answered by using an oscilloscope the bandwidth of which is broad enough to immediately record the microwave signal that is fed to the entrance of the detector, rather than the signal that has passed through the detector. We used a 4-GHz-bandwidth Tektronix TDS 7404 oscilloscope, which digitized signals to make them suitable for computer processing. By simple computer manipulations, numerical procedures equivalent to recordings were performed and the results of mathematical processing were then compared with the pulses from the hot-carrier-based detector.

As a microwave pulse source, we used a plasma relativistic microwave amplifier [2] with a pulse power of ~50 MW, a duration of ~400 ns, and a frequency of 3.24 GHz. A noisy signal with a frequency spectrum from 2 to 4 GHz, but with a lower integral intensity, can be used for this purpose too. Microwave pulses from a 25-cm-diameter horn were recorded by two side-by-side antennas and were then simultaneously transmitted through two identical cables to a 4-GHz-bandwidth Tektronix TDS 7404 oscilloscope and to a microwave detector. The signals from the detector were then sent to a 300-MHz-bandwidth oscilloscope with a digitization step of 2 ns.

A. Monochromatic signal

The signal that arrived at a high-speed oscilloscope was a 3.24-GHz amplitude-modulated sinusoid, digitized with a time step of 16 ps (Fig. 1, a). The sinusoid was then squared (Fig. 1, b) and smoothed with the time constant $\tau$ (Fig. 1, c). The degree to which the signal under analysis was monochromatic was estimated by Fourier transforming the sinusoid shown in Fig. 1, a. A portion of the spectrum from 150 to 560 ns (with a duration of 410 ns) is shown in the inset to Fig. 1.

The peak in the spectrum in the inset corresponds to the frequency 3.24 GHz of the signal under analysis. In addition, Fig. 1, d shows the “instantaneous frequency” of the input signal. The instantaneous frequency is the reciprocal of the time interval between the successive local maxima of the sinusoid.

It is obvious that, for a monochromatic signal, the instantaneous frequency is simply the frequency.

The signal was transmitted through the second cable to a liquid-nitrogen-cooled crystal, was then fed to

---

1 The work was supported by the Russian Foundation for Basic Research (Project No. 08-08-12184).
High Power Microwaves

Fig. 1. Monochromatic signal: a – signal at a high-speed oscilloscope; b – squared signal; c – squared signal smoothed with the time constant \( \tau = 2 \) ns; d – plot of the instantaneous signal frequency

A signal from the first channel and a signal from the cold detector are shown in Figs. 2, a and b, respectively. For convenience of comparison, the signals are displaced vertically relative to one another. The positions of the peaks in the signals are seen to coincide well over essentially the entire microwave pulse. From the beginning of the pulse up to 450 ns, there is a very close correlation, better than 5%, between the pulses. After 450 ns, the correlation between the pulse shapes is worse: at some instants, the signal amplitudes differ by 40%. The correlation coefficient is 0.96.

B. Broadband signal

As a broadband signal source, we used the same plasma relativistic microwave amplifier, but without sending a microwave signal to its entrance (Fig. 3).
The resulting noisy signal (the Fourier transformed signal in the inset to Fig. 3) was processed as described for the monochromatic signal: it was squared and then smoothed with the time constant $\tau = 2$ ns to be compared with the signal from the detector. Their comparison is illustrated in Fig. 3, which shows (a) a processed signal from a high-speed oscilloscope and (b) a signal from the detector. The signals are seen to correlate fairly closely, even in details. In this case, the correlation coefficient is 0.84.

In order to estimate the possibility of recording at frequencies above 4 GHz, we used a 9–12 GHz plasma relativistic microwave oscillator as an input signal source. In this case, a signal from our cable microwave receiver was compared with a signal from a waveguide detector with a crystal placed within a $23 \cdot 10 \text{ mm}^2$ rectangular waveguide. The signals were also found to correlate well with each other.

3. Conclusions

To conclude, we have proposed the design of a microwave receiver with which it possible to record the shape of microwave signals in the frequency range 2–4 GHz essentially without distortion, as well as to record signals at higher frequencies, up to 10 GHz. We can anticipate that the detector will record microwaves at frequencies below 2 GHz, a possibility that was not checked experimentally, however.

References