Phase Synchronization of BWO SubTHz Frequency Range, Applying Superlattice Harmonic Mixer

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***Abstract*— We report generation of a signal of 667-857 frequency range by means of a synthesizer of 15-20 GHz frequency range. Frequency of the reference is multiplied 30-45 times by means of mixer based on superlattice structures. The mixer is used at the room temperature.**

***Index Terms*—THz frequency range, phase synchronization, superlattice structures, diode**

I. Introduction

THE great interest to the THz frequency range is caused by new possibilities for investigations, first of all, in high resolution microwave spectroscopy. These investigations substantially stimulate a lot of researches, for example radio-astronomical ones [1].

However, this region is one of the least explored ranges. Until recently, it was difficult to efficiently generate and detect THz radiation. Most THz sources were either low-brightness emitters such as thermal sources, or cumbersome, single-frequency molecular vapor lasers. The only source of wide-range coherent THz radiation – backward wave oscillator (BWO) – generates till 1200 GHz. Recently, however, there has been a progress in THz technology due to the using of optical techniques such as femtosecond laser [2]. Application of such sources, based on femtosecond lasers, allow to create THz spectrometers [2], which are capable to solve various problems, for instance studying of biological molecules [3], liquids [4,5] and solids [6,7]. Although it is worth pointing out, that spectral resolution is worse than 1 cm^{-1}. It is insufficient for the high resolution spectroscopy naturally. Necessary condition of high spectral resolution is a source having narrow line and accurate control of frequency. Spectroscopic requirements to frequency parameters and spectrum of the high quality source are usually determined by necessity of resolving of Doppler broadened lines (~10^{-6}) and finding of frequencies and its displacement to within ~10^{-8}÷10^{-10}.

Usually such a system - frequency synthesizer – represents a system of proportional multiplication (based on phase lock of generators of various ranges) of reference synthesizer frequency (as a rule of centimeter range). This system fulfils the requirements described above. Its frequency stability is near 3x10^{-10} c^{-1}, comparative spectral width is about 3x10^{-10} at l =1 mm. The first frequency synthesizer, described in [8], had 6 multiplication rings. In general, as nonlinear element in harmonic mixers of GHz frequency range planar semiconductors Schottky diodes (SD) are used [9-15]. However application of these diodes in the THz region requires increase of limiting frequency of the diode, f_p, (a frequency which determines the upper limit of working range of diode). Unfortunately it is quite difficult due to some restrictions. On the one hand the limiting frequency is given by peculiarities of processes in semiconductors, particularly by inertness of flight of electrons (for Schottky barrier). Time of flight for the best SD is about 1 ps [14]. On the other hand, the limiting frequency is specified for the most part by influence of parasitic capacitance of diode, C, and series resistance, R_s ($f_p = 1/2pR_sC$). The latter consists of resistance of semiconductor thickness, contact junction and outputs of diodes. Capacity of Schottky diode, which active area is several mkm, is not less than 3 fF [12-14]. Decrease of the series resistance by increasing of alloyage is restricted to the concentration of 5×10^{17} ?? $^{-3}$ [13, 14].

More short response time and lesser capacities can be obtained by making planar diodes based on semiconductor superlattice structures (DSS) [16,17]. Current-voltage characteristic of the superlattice structures has negative differential conductivity till to several THz [11,12]. All these peculiarities of the superlattice structures make them attractive for investigations, since generators, mixers, detectors based on these structures, can be used for elaboration of new sources and detectors of THz radiation.

In the paper [21] there was done a comparison between planar diodes based on the superlattice structures and planar

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Schottky diodes. To do it a special method was applied [22], which allows managing without THz detectors. According to the method a diode is treated with signals of two mm sources, which have different frequencies F_s and F_p. Low-frequency signal of beating, f_{if}, (between harmonics mF_s and nF_s, where m,n are integers) is intensified by low-noise amplifier and observed on a screen of a spectral analyzer. Tuning the frequencies F_s and F_p and observing displacement of f_{if} on the screen of analyzer, one can determine harmonic numbers m, n, appearing in the diode. For studying diode's characteristics in the mm frequency range, the diodes were put into metallic single-mode waveguides of 80 ÷120 GHz. Block diagram includes two synthesizers (80 ÷120 GHz and 115÷150 GHz), set of attenuators, low-noise amplifier of 1÷2 GHz frequency range, spectral analyzer of 0.1÷2 GHz and constant-current source. Maximal harmonic frequency observed for diodes based on superlattice structures was 3000 GHz, but for SD it was 1800 GHz. Experimental dependence of signal strength of beating on the harmonic's number was approximated by a power polynomial with index of power -5.3. For DSS the index of power was -3.6 (see Fig1).

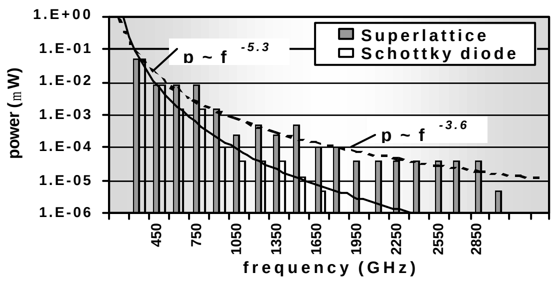

Fig. 1. Experimental dependence of the signal power on the harmonic's number for Schottky diode and diode based on superlattice structures. It was approximated by a power polynomial.

Therefore, planar diodes based on alloyed superstructures can be used for construction of THz sources. Let us consider application of amplifiers based on DSS for stabilization of subTHz generator.

At present phase lock systems of BWO utilizing harmonic mixers based on SD with automatic tuning with respect to reference source of frequency range 8÷18 GHz. In this system phase lock is realized on 16 ÷26 harmonics of reference synthesizer HP 8673 E with output power 20 mW. In the phase lock systems of BWO of frequency range 380÷1000 GHz harmonics 4 ÷10 of synthesizers (78 ÷118 GHz and 118÷178 GHz) are used.

II. Experiment

Below we describe phase lock loop system of 526 ÷714 GHz frequency range of BWO OV-80 and phase lock loop system of 667 ÷ 857 GHz of BWO OV-81, where harmonic mixer based on DSS was applied. In latter phase lock synchronization is fulfilled with respect to 30[th] and 44[th] harmonics of reference synthesizer of 8 ÷20 GHz frequency range. Beforehand we measured characteristics of multipliers, based on DSS to use them as THz sources till 2.5 THz. Also there were done measurements (till 1 THz) of characteristics of harmonic mixers based on DSS for the phase lock of BWO. Earlier measurements of the properties of multipliers based on DSS shown, that necessary power of input signal must be 12 ÷20 mW. To optimize a work of DSS, we investigated possibility of operation of multipliers, based on DSS, under voltage. To study dependence of characteristics of DDS on voltage there was used frequency synthesizer (of 8 ÷18 GHz, with output power to 100 mW) as an input signal source. Application of such a synthesizer allowed comparing characteristics of DDS in two different regimes: with and without bias.

As a result of the experiment we established that supply of bias causes decrease of necessary power of input signal, but the noise of output signal increases and some points of frequency range have frequency modulation of output signal. The latter indicates a bad balancing of reference generator's channel and input of multiplier based on DSS. We carried out qualitative measurements of noises of harmonic mixers on DSS in channel of intermediate frequency. The results shown that if a commercial amplifier M42136 "Saljut" (with noise coefficient k =2 dB at t=25^{0}C) is used as intermediate-frequency amplifier, mixer's noise is higher than one of the multiplier per 5 dB. The measurements were done by Hewlett Packard E4402B. Conversion ratio of harmonic mixer of input signal (power 0.5 mW, frequency 844 GHz) with 44[th] harmonic of reference generator (power 20 mW, frequency 19.175 GHz) is 80 dB.

Block diagram of the BWO phase-lock loop system for OV-80 and OV-81 is shown on pic.2.

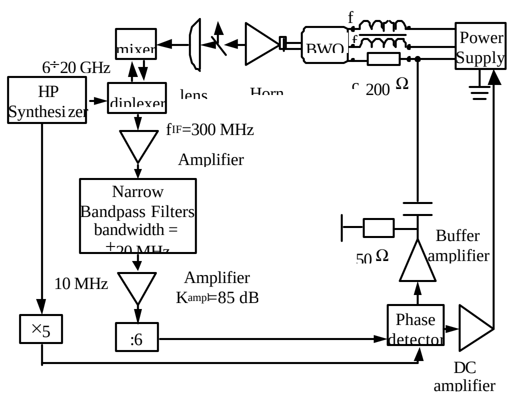

Fig. 2. Block diagram of the BWO phase-lock loop system

As a reference generator we apply a synthesizer of frequency range 0.01 ÷20 GHz in the set-up. In the frequency range of 667 ÷857 GHz synchronization is obtained at the 37[th] and 44[th] harmonics of reference synthesizer. The intermediate frequency channel consists of three multipliers M42136 and band-pass filter with bandwidth 40 MHz at the frequency 300 MHz. The total gain constant of intermediate-frequency amplifier is 85 dB. To improve a noise-to-signal ratio incoming to the frequency-phase detector, the bandwidth of intermediate frequency channel is chosen as narrow as possible, but it is taken into account bandwidth of signal, which is generated by BWO freely. This bandwidth is 20 MHz. Control of the BWO frequency is done by two-channel scheme.

Command of frequency-phase detector is divided on two channels: low-frequency one (0-40 kHz) and high-frequency channel (higher than 40 kHz). Frequency-phase detector is built on a chip PE3236 of Peregrine with reference frequency 50 MHz. Control of BWO frequency at low-frequency channel is realized by high-voltage power supply. Command of high-frequency channel is given to a cathode of BWO trough disjunctive capacity. Such a control scheme of BWO let one obtain maximum broad synchronization range of 5 MHz.

Spectral analysis of characteristics of PLL BWO is done at the signal of intermediate frequency. On fig.3 the spectrum of signal of intermediate frequency (at a frequency 300 MHz) of BWO output signal (on a frequency 844 GHz) is presented. The measurements are done by spectrum analyzer ROHDE SCHWARZ 1093.4495.30.

Our results of investigation of the BWO synchronization and characteristics of harmonic mixers based on DSS give a possibility to obtain BWO synchronization (till 1 THz), applying the presented method.

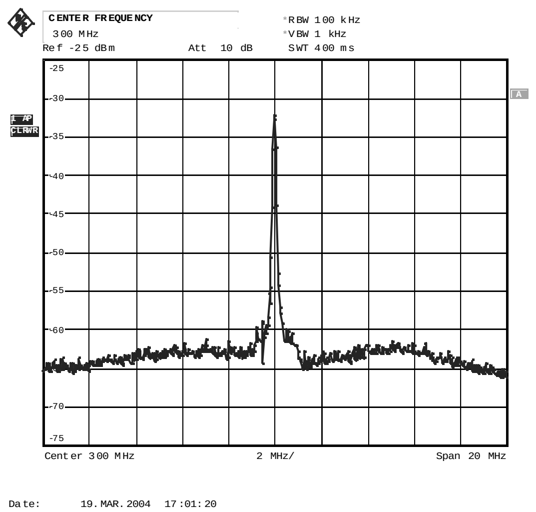

Fig.3. Line shape of PLL spectral power density. Center frequency is 300 MHz, Ref is -25 dBm, Att. is 10 dB, RBW is 100 kHz, VBW is 1 kHz, SWT is 400 ms.

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