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FREQUENCY SYNTHESIZERS UP TO 370 GHz

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A new generation of frequency synthesizers up to 370 GHz is described. The main parts of them are microwave frequency synthesizer covering 11-15 GHz band, effective frequency multipliers-mixers using an opposite pair of planar Shottky diodes and a lock-in loop of a backward-wave oscillator tube covering millimeter and longer part of submillimeter wave bands with tens of milliwatts of output power. The ways of further increase in the operating frequency of such synthesizers are discussed.

Key words: millimeter waves; submillimeter waves; frequency synthesizers

1. Introduction

Papers (1, 2) describe millimeter wave synthesizers covering 55-80 GHz and 40-60 GHz bands correspondingly based on a backward wave oscillators (BWO) of millimeter band and microwave frequency synthesizers. Paper (3) describes a frequency synthesizer up to 110 GHz with a solid-state source of mmw radiation; however, as far as we know at present time there are no such solid-state synthesizers which can reach more shortwave

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millimeter and submillimeter regions. This paper describes further development of the direction of (1, 2) which yielded a unified system of frequency synthesizers covering millimeter and longer part of the submillimeter wave bands approximately up to 370 GHz with a continuous coverage up to 100 GHz in the high-frequency band and tens of milliwatts of the output power. The synthesizers consist of a basic microprocessor-controlled microwave synthesizer of the 11-15 GHz band, an effective frequency multiplier-mixer using an opposite pair of planar Shottky diodes in the high-frequency region and a stage of the phase/frequency control of the corresponding millimeter or submillimeter BWO. The general view of the typical millimeter wave frequency synthesizer is given in Fig. 1 and the submillimeter frequency synthesizer in Fig. 2. In this paper the laboratory submillimeter frequency synthesizer is mainly described. A commercial version of the millimeter synthesizer will be described elsewhere.

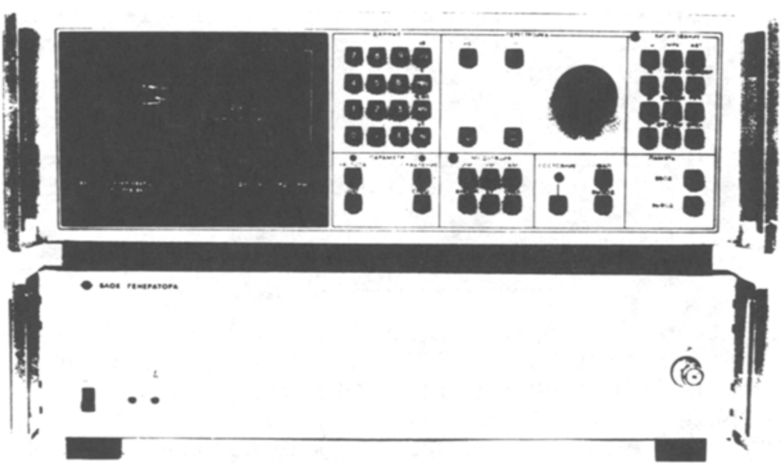

Figure 1. Typical millimeterwave synthesizer. Waveguide output is seen at lower right.

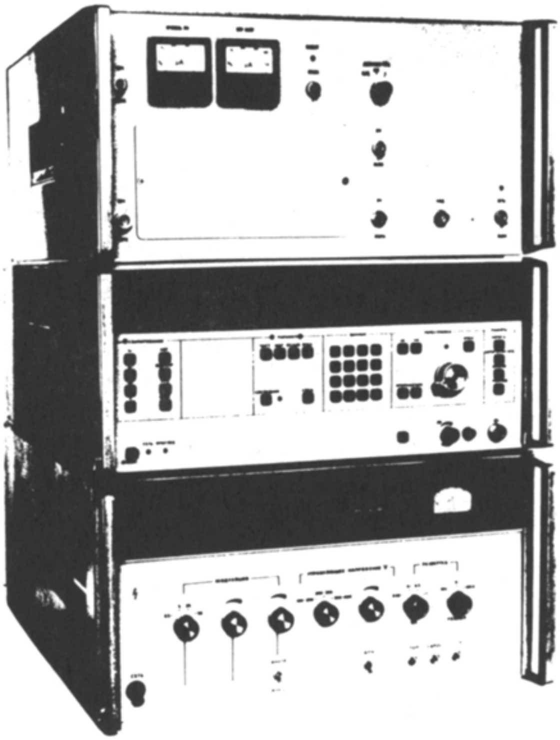

Figure 2. Submillimeter frequency synthesizer. Lower unit - BWO power supply, middle - MW frequency synthesizer, upper - submm BWO and its lock-in loop circuit. Oversized waveguide output is seen at the left side, output frequency range 180-260 GHz or 260-370 GHz depending on BWO installed.

2. A Block Diagram of the Submillimeter Frequency Synthesizer

A simplified block diagram of the submillimeter frequency synthesizer is given in Fig. 3. A source of the submillimeter radiation is BWO of the type (4) in a compact permanent magnet and its frequency is controlled by the phase lock-in loop using the reference signal obtained by frequency multiplication of the microwave synthesizer. The BWO is fed by high-voltage (up to 1.5 kV in the millimeter range and up to 3.7 kV

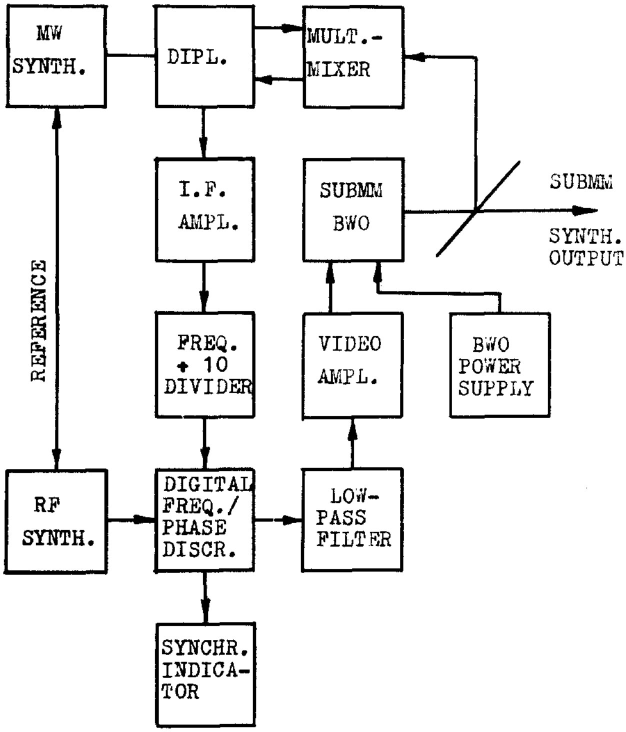

Figure 3. Submm synthesizer structure

in the submillimeter range) power supply; the BWO body is isolated from the ground and is connected with it by the 100 Ohm resistor, which is the load of the power amplifier of the signal controlling the BWO's frequency. The inside view of BWO ; unit is given in Fig. 4.

To obtain the controlling signal, the output signal of the microwave synthesizer in the region 11-15 GHz is directed through a high-frequency arm of the diplexer to the frequency multiplier-mixer based on a pair of Shottky diodes, to which also a part of the output power of the submillimeter BWO is picked off by a directional coupler. The beats between the corresponding (of the order of 20-30) harmonic of the microwave synthesizer frequency and BWO frequency appear

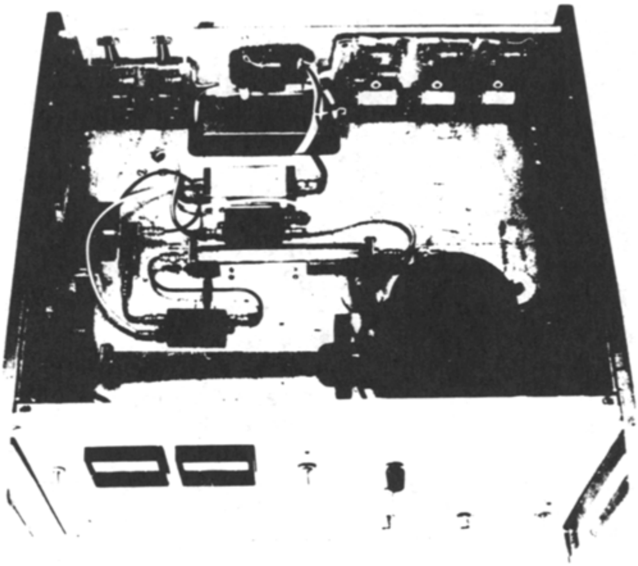

Figure 4. Inside view of submm BWO and its lock-in loop circuit unit. BWO in a permanent magnet is seen at the right side, beamsplitter, frequency multiplier-mixer and diplexer - at the left side, I.F. amplifier and filter - in the middle.

from the low-frequency arm of the diplexer and are directed to the intermediate frequency amplifier. The intermediate frequency amplifier consists of two amplification modules between which a band-pass filter with a 266-444 MHz transmission band is situated. The transmission band of this filter defines both the maximal bandwidth of the capture of the phase-lock system and the range of the BWO tuning by the tuning of the phase detector reference signal. The signal of the intermediate frequency amplified up to the level not less than 200 mV comes to the tenfold frequency divider, whose output signal starts the digital frequency/phase discriminator; the signal of the radio-frequency synthesizer serves as the reference one. The output voltage of the frequency/phase discriminator is the signal which (after being filtered and amplified) controls the BWO frequency. The low-pass filter (Cauer filter of the fifth order, producing the phase shift 18° at 1.7 MHz) serves for filtering the output signal of the frequency/phase discriminator from the reference frequency and its harmonics. The video amplifier containing additional RC filters has 30 MHz bandwidth at 20 dB amplification coefficient. Amplitude of the output voltage at 100 Ohm load reaches 20 V at 0.5 MHz frequency and the phase shift of the output signal does not exceed 14° at 5 MHz.

The regime of the phase synchronization of BWO is indicated by the light drived by the logical circuit, controlling the presence of the reference signal, intermediate frequency signal and zero beats in the frequency phase discriminator.

The millimeter wave frequency synthesizers mentioned in this paper are fully controlled by the microprocessor. Now BWO in a submillimeter wave synthesizer is tuned to lock-in regime manually; however, a continuous frequency tuning of BWO at one harmonic of the microwave synthesizer may exceed 10 GHz and to pass to another harmonic of the microwave synthesizer one should only tune the BWO frequency to the region required by changing the supply voltage. The synthesizer shown in Fig. 2 covers the ranges 180-260 GHz or 260-370 GHz depending on the BWO installed and provides the output power of several tens of milliwatts in the entire range mentioned.

3. Frequency Mixer-Multiplier

The scheme of the mixer-multiplier is analogous to that described in (5). Its construction is given in Fig. 5; it comprises a pair of opposite diodes placed in E-plane of the 0.3×2.4 mm waveguide connected by Chebyshev transformer with a 0.3×2.4 mm waveguide which in turn is connected with the horn leading to the beamsplitter. The signal from the microwave frequency synthesizer is directed to the diodes via coaxial line which is used also for transmitting the IF signal via diplexer. The signal from the submillimeter BWO comes from the beamsplitter

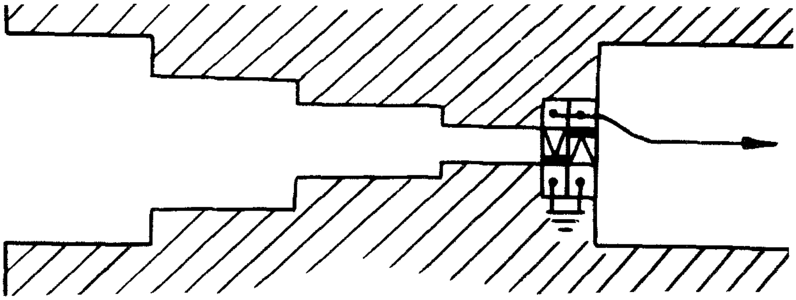

Figure 5. Multiplier-mixer on the pair of opposite Shottky diodes. Waveguide 1.2 x 1.2 mm is at the left, Chebyshev transformer in the middle, pair of planar Shottky diodes and coaxial line - at the right side.

mentioned. The diode pair consists of arsenide gallium Shottky diodes with lowered height of the barrier. Shottky diodes are formed on the 10 μm poly-imide film base so their stray capacitance is less than 5 fF; the full capacitance of the pair of the diodes does not exceed 30 fF, and series loss resistance of each diode is 20 ÷ 30 Ohm.

4. Microwave Synthesizer

The structure of the basic microwave frequency synthesizer is presented in Fig. 6. Depending on the range of the output frequencies of millimeter and submillimeter synthesizers, this scheme may vary. E.g., in the synthesizer of Fig. 1 the internal microprocessor controls also the BWO stabilization loop, and control and indication are performed directly in the terms of the frequency of the output millimeter wave signal.

To achieve the low level of the phase noise and discrete nonharmonic spectral components in the spectrum of the microwave synthesizer, a three-loop structure of frequency synthesis is used. Two phase lock-in loops are used in the 80-120 MHz and 350-395 MHz synthesizers to obtain small and large steps of reference frequencies and the third output phase lock-in loop stabilizes the frequency of the tunable Gunn oscillator by the harmonics of the 350-395 MHz synthesizer and the fourth subharmonic of the

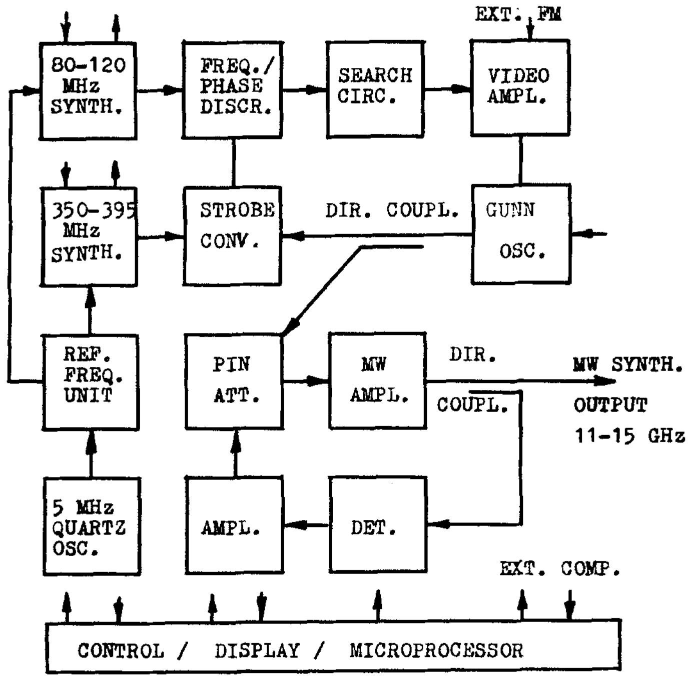

Figure 6. MW Synthesizer structure.

80-120 MHz synthesizer. A large value of amplification in the output phase lock-in loop required for decreasing the level of phase noise down to minus 70-75 dB/Hz at 10 kHz detuning from the carrier frequency, the frequency switching of the Gunn oscillator in a wide range of frequencies can lead to the operation of the phase lock-in loop at the image intermediate frequency where the phase synchronization process cannot be stable. To avoid this, the searching device is introduced to the system of the phase synchronization which in the absence of synchronization shortens the control signal circuit for 15 ms. This time is enough for the frequency of the synchronizing Gunn oscillator to be set with enough accuracy to avoid the operation of the phase stabilization system at the image channel.

To achieve the optimal operation of the frequency mixer-multiplier at the output of the microwave synthesizer, it is desirable to have the microwave power of the order of 30 mW. This level of power is provided by adding a microwave amplifier on a miniature travelling wave tube. The output power of the synthesizer then is leveled by the system of automatic power control, consisting of the directional coupler, microwave detector, D.C. amplifier and pin-attenuator at the input of the TWT.

5. Phase Noise in the Submillimeter Synthesizer

The spectral characteristics of the submillimeter synthesizer are measured using the second microwave synthesizer and the second frequency multiplier-mixer for obtaining the beats between the oscillations of the submillimeter synthesizer and the harmonic of the second synthesizer, which were analyzed by the spectrum-analyzer. Table 1 gives the results of measurements of the relative spectral power density of the phase noise of the output signal of the submillimeter synthesizer operating at frequencies near 280 GHz (the second microwave synthesizer operated at frequencies near 14 GHz) in one sideband. For comparison in Table 1 also the da-

Table 1. Relative spectral power density of phase noise of the output synthesizer signal at 280 GHz frequency in one sideband.
The reference synthesizer frequency is 14 GHz.

Detuning from the carrier frequency	Noise level of mw synthesizer dB/Hz	Noise level of submillimeter synthesizer dB/Hz
80 Hz	- 46	- 20
1 kHz	- 56	- 30
10 kHz	- 71	- 45
100 kHz	- 99	- 73
1 MHz		- 76
5 MHz		- 89
10 MHz		- 92

ta on the phase noise of the microwave synthesizer are given. The comparison of the results of the measurements taking into account the multiplication coefficient with the standard values of the microwave synthesizer phase noise shows that the spectrum of the submillimeter synthesizer is defined practically by the spectrum of the microwave synthesizer.

Conclusion

The experience of the development of the frequency synthesizers described in this paper shows that the reference signal enough for the BWO phase stabilization can be, evidently, obtained up to frequencies 500 GHz only by improving the tract and the submillimeter wave receiver and by perfecting the construction and the regimes of the frequency multiplier-mixer. For covering the most high-frequency region of BWO (6), the millimeter synthesizer Fig. 1 combined with a multiplier diodes with a low barrier height can be used as a source of the reference signal. Of course, constructions of the higher-frequency BWO phase stabilization systems by necessity will be more complicated and spacious. For practice at present time the most important, probably, are relatively compact and convenient synthesized sources of signals with enough for many purposes radiation power continuously covering millimeter and longer part of submillimeter wave bands, including all the atmospheric windows in this region, represnting the unified series of devices suitable for commercial production, described in this paper.

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