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PHASE LOCK-IN OF MM/SUBMM BACKWARD WAVE OSCILLATORS: DEVELOPMENT, EVOLUTION, AND APPLICATIONS

A. F. Krupnov

Institute of Applied Physics of Russian Academy of Sciences
46 Uljanova Str., Nizhnii Novgorod 603600, Russia
E-mail: kru@appl.sci-nnov.ru, http://www.appl.sci-nnov.ru/mwl/index.htm

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Abstract

The development and evolution of a Phase-Lock Loop (PLL) system up to the highest frequencies of Backward Wave Oscillators (BWO) is considered starting from the first submillimeter BWO PLL in 1970. Improvements and increase of working range near to Terahertz are followed. Development of the series of commercial BWO - based millimeter wave frequency synthesizers, extension of the BWO PLL beyond Terahertz as well as recent progress in fast millimeter wave frequency synthesizers are described. Applications of BWO PLL systems for physical and technical measurements are discussed and some proposals for the next generation of BWO – based synthesizers are presented.

Keywords: millimeter, submillimeter, backward wave oscillator, phase lock – in.

1. Introduction

Backward-wave oscillators (BWO) of the type first described in [1] still are an exceptional type of microwave tunable oscillators which continuously cover the millimeter (mm) and submillimeter (submm) - wave bands up to approximately 1.2 Terahertz. This range exceeds many times all the summary range of microwaves actively used at the present time. For realization of all the advantages of coherent microwave methods in this whole range the extension of the most precise phase lock—in technique to this broad mm and submm band appeared to be necessary. We started this process in 1970 [2]. Microwave spectroscopy was historically the first in the mastering of increasingly shorter wavelengths by microwave methods [3], and first our systems were also developed for microwave spectroscopic use. However, the development of BWO PLL systems is also of general physical and technical importance, and the

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results obtained in this field can also be applied in other areas of science and technology. The objective of the present paper is short following of the development of the high - frequency BWO PLL, evolution of them up to the highest frequencies, exceeding Terahertz at the present time, their significant improvements such as broad (hundreds of GHz) single computerized scans and fast (200 ns) synthesizer frequency switching, and mentioning some physical and engineering applications of such systems, including unique series of commercial millimeter wave frequency synthesizers developed and now widely used throughout the world. Further improvement of BWO PLL systems which can lead to new generation of the mm and submm synthesizers is suggested in Discussion. A large contribution to this field was given by specialists from Nizhnii Novgorod, later in a collaboration with many laboratories abroad. Without going into details, we will give references for the reader willing to gain more information on the subject.

2. Shortest history of the beginning

In the seventies, the idea and basic scheme of PLL were the common knowledge. However, the transition to higher frequencies also meant the transition to a different type of electron oscillators. The reflex klystrons employed in the first microwave PLL circuits [4] were closest to being defined as "voltage-controlled oscillators". Backward wave oscillators have even a broader range of the electron frequency control through the high voltage of the slow wave system but it means also control of perceptible currents. This required the development of powerful and fast enough control elements for assuring of stable operation of the BWO PLL system. Necessary for realization of the submillimeter BWO PLL also was development of the source of the reference signal continuously covering very broad frequency range through tuning of the microwave or millimeterwave synthesizer feeding frequency multiplier with possibility to use several harmonics. About octave tuning is necessary for single BWO, but for convenience it was very desirable to cover bands of several BWO's by a single and nontunable multiplier, just changing of the harmonics used. For continuous BWO tuning the PLL system must be efficient over a large dynamic range to withstand numerous frequency dependencies of BWO, tract interference, detector characteristic etc.

The operation of the first PLL system up to submm wave BWO's of the type [1] up to approximately 350 GHz frequencies was achieved by us in 1970 [2]. For comparison, described in 1971 Western BWO - based frequency synthesizer [5] reached at that time range up to only 40 GHz (characteristi - cally, it was developed basically for microwave spectroscopy use also). At a later time, the lock - in range of BWO was extended by us to the continuous range of frequencies up to 500 GHz.

The first submillimeter digital BWO scan is presented in Fig. 1 [7]. This system in more details was described in [8]. Appearance of such instrument as

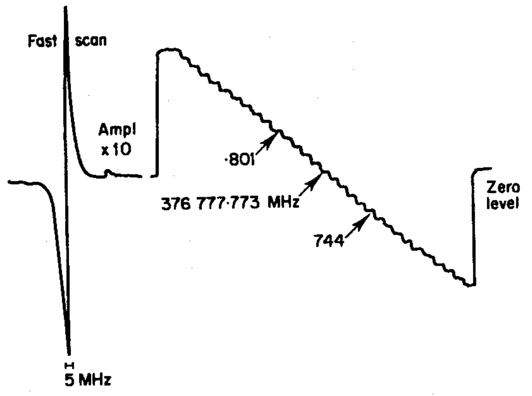

Fig. 1. First digital scan of submm BWO PLL. Line J = 15 - 14 of N_2O near 377.8 GHz is recorded in the form of first derivative of absorption profile using FM. Left: forward scan. Right: backward scan through the line center with amplification increased ten times and scan speed reduced about thousand times. One step corresponds to 5.672 kHz, i.e., about 1.5×10^{-8}. Frequencies are marked in the Figure.

submm BWO PLL was noticed in [9]. The first submillimeter wave synthesizer [7, 8] had flywheel 200 MHz oscillator locked against harmonic of 50 MHz RF synthesizer, and consecutive PLLs of 3 - cm and 4 - mm BWOs. With this system BWO PLL frequencies as high as 600 GHz in 1978 [7] and then 820 GHz in 1984 [10] were reached. Further improvements of the multiplier-mixer and IF amplifier permitted to abandon stage of 4 - mm BWO PLL up to frequencies about 500 GHz. The development of PLL systems for submm wave BWOs was also started in France in 1982 - 1984 [11, 12] on the basis of Thomson - CSF carcinotrons (up to 480 GHz). Applications of the technique developed at that stage to the microwave spectroscopy are described in the books (e.g., [13]) , review papers [6, 7, 8, 14, 15] and in a large number of original papers. In the following chapters we will discuss in more details methodics and applications which are used and actively being developed at the present time: commercial mm wave frequency synthesizers up to 178 GHz; Terahertz broadband PLL BWO scanning; role of BWO PLL in extension of the microwave spectroscopy range up to 1.5 THz by frequency multiplication; "sum" frequency sources using stabilized FIR laser with BWO frequency added up to 1.9 THz; "fast" mm - submm frequency synthesizer with 200 ns switching time; and some applications of the methodics developed.

3. Development of the commercial millimeter wave frequency synthesizers

The development of laboratory BWO PLL systems also led to their "technical" improvement and development of frequency synthesizers on their basis. Stages of development of mm - wave frequency synthesizers from laboratory to commercial ones can be seen from [16, 17, 18]. The first joint paper with KVARZ Institute of Electronic Measurements (also in Nizhnii Novgorod), containing the main features of a mm-wave synthesizer (a microwave synthesizer of 10-12 GHz, a mixer-multiplier, and a PLL of a mm-wave BWO) was published in 1985 [16]. In 1990, we described already first mm-wave commercial synthesizer and a laboratory BWO PLL system of up to 370 GHz close to a synthesizer [17]. In 1994, the researchers of KVARZ finished the development of a family of commercial frequency synthesizers with continuous coverage of frequencies from 53 to 178 GHz (units 53–78, 78–118,

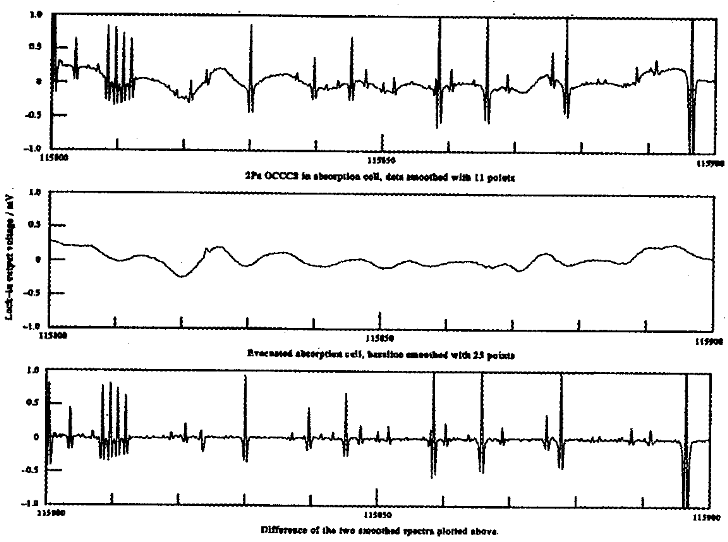

Fig. 2. Part of the record covering 100 MHz of the full scan length 40 GHz of the OCCCS molecule spectrum obtained in automatic regime by 78 - 118 GHz BWO - based frequency synthesizer. Upper record - spectrum of OCCCS in absorption cell filled by 2 Pa pressure of the gas investigated. Middle record - evacuated (empty) cell record few hours later. Lower curve - result of subtraction of the second curve from the first. Frequencies are plotted in the Figure. Full record contains thousands of spectral lines of OCCCS molecule.

and 118–178 GHz) with the frequency step from 100 Hz and digital control by a computer through standard interface bus or by built – in microprocessor [18]. The appearance, block - diagram and description of a mm-wave synthesizer of 118-178 GHz are presented in [18]. These synthesizers do not have foreign analogues and at the present time are used in many laboratories of USA, Germany, Japan, France, Italy, China, Canada etc. We cannot follow the large number of publications of these laboratories produced with the use of mm wave synthesizers. Synthesizers operated at still higher frequencies on the basis of BWO PLL systems are also under development at present.
Example of the small part of the scan of the OCCCS molecule spectrum (100 MHz from 40 GHz scan) produced by mm wave synthesizer as radiation source is presented in Fig. 2. Fig. 2 also illustrates reproducibility of the synthesizer output, permitting to subtract baseline after several hours of spectra recordings. Spectral purity of the synthesizer output can be illustrated e.g., by observation of the Lamb dip on the Doppler spectral line having relative width of the order of 10-7 [18].

4. The Terahertz BWO PLL

The next significant step in BWO PLL, which allowed us to master the Terahertz region, was made after the development by us the mm - wave commercial synthesizers [18] giving convenient powerful enough and fully computer - controlled fundamental reference source, and broadband multiplier - mixer, first described in [19]. In 1994, together with the University of Cologne, we mastered at first a range of up to 970 GHz [19] (see also [20]) and demonstrated the possibility of a single scan with a length of up to 200 GHz in the phase - locked mode of a BWO. The scheme of a BWO PLL system first used in [19, 20] and improved in [21] is given in Fig. 3. The main features of a typical BWO PLL system Fig. 3 for stabilization and scanning of all BWOs, including the highest frequencies, are as follows.
The master oscillator is a computer - controlled mm - wave synthesizer of type [18], clock of which is often stabilized by the quantum frequency standard. The broadband mixer-multiplier developed by us has the quasioptical construction with a planar Schottky diode placed at the end of a ridged waveguide from lower – frequency side and in a focal point of a semi – parabolic mirror from higher – frequency side. This combination of powerful tunable phase - locked mm - wave source and maximally frequency – independent construction of the mixer - multiplier produced the reference signal permitting to operate BWO PLL circuits just by computer control of the synthesizer frequency without additional tuning of the mixer - multiplier within the whole frequency range from 200 GHz to 1.2 THz. The intermediate-frequency amplifier (IFA) with total gain about 80 dB works in the 350 MHz region, has an effective automatic level control system and often HEMT non - cooled preamplifier with noise

temperature about 40 K. Amplifier is followed by digital IF divider (DFD) by ten and a digital phase - frequency detector (DPFD) operated at a 35 MHz frequency range. Output video amplifier (VA) has bandwidth about 3 MHz and controls currents up to 50 mA. The synchronizer is controlled by logical circuits (LC). High voltage BWO supply is usually varied from 500 to 5 500 V for different types of BWO. The steepness of the BWO characteristic is of the order of 50-100 MHz/V. The operation of the setup is described e.g., in [19, 20, 21, 22]. In 1997 Terahertz BWO PLL of the type [19 - 22] was reproduced in Japan [23].

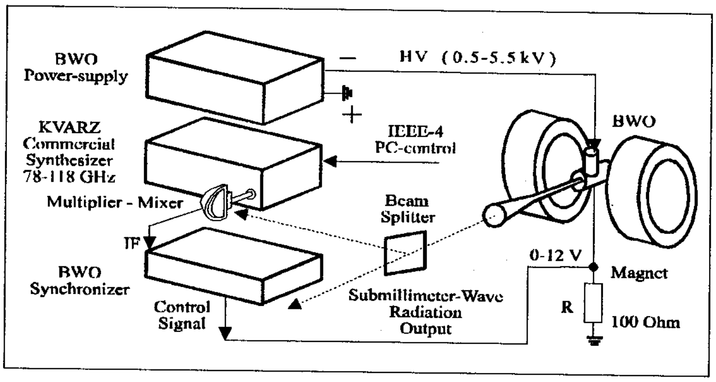

Fig. 3. Schematic of BWO PLL working up to the Terahertz range. To the BWO frequencies about 500 - 700 GHz the permanent magnets are used, for the higher frequencies electromagnet is used. Reference source is millimeter wave BWO - based frequency synthesizer. Multiplier - mixer on the planar Shottky diode has quasioptical construction and works without tuning from 200 GHz to 1200 GHz. Synchronizer has 350 MHz IF center frequency, digital phase/frequency detector and 3 MHz output bandwidth amplifier.

By our opinion, the most instructive example of the new quality of investigation with BWO PLL system may be comparison of the microwave record of e.g., portion of the HSSH molecule spectrum with the record produced by one of the best FIR Fourier - transform spectrometer where ranges of both devices overlap - near 978 GHz - presented in Fig. 4. The Q - branch spectral feature of HSSH molecule is presented in the records [20]. It is worth to remember, that each "microwave" line in the Fig. 4 can be resolved as, e.g., lines in Fig. 2 and further. Fig. 4 shows also scanning possibilities of the microwave methods developed. Earlier the only spectrometers able to cover continuously a broad spectral range were the "infrared" type (Fourier or grating) spectrometers using non - coherent radiation sources, resolution of which may be compared with microwave in Fig. 4.

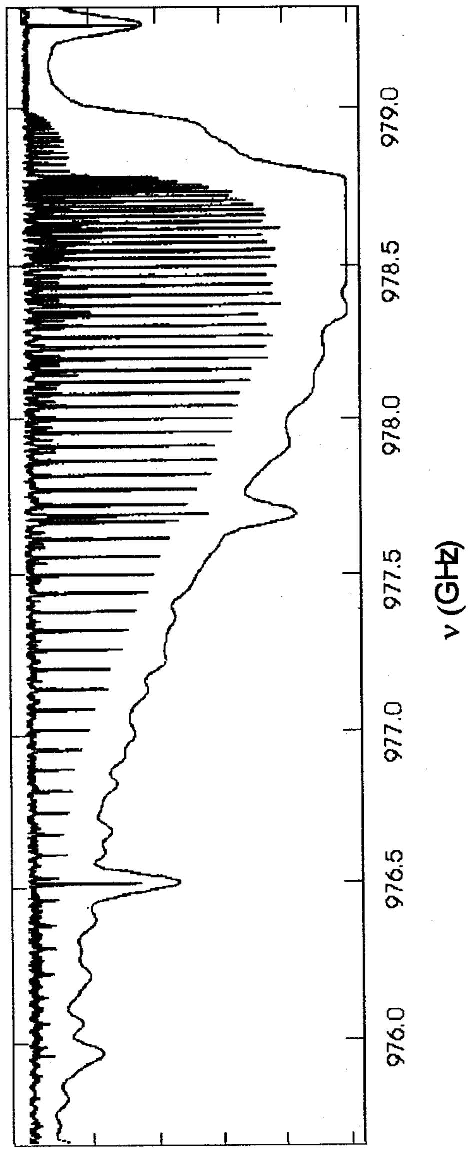

Fig. 4. Digital scanning of the part of HSSH spectrum around 976 - 979 GHz by BWO (upper trace). For comparison Fourier - transform spectrometer record of the same part of the spectrum is presented (lower trace). Each microwave line can be expanded to its Doppler width (~ 10^{-6} relative units).

Some results and applications of the technique described one can find in reviews [24, 25, 26] and constant flow of original papers. Applications for the microwave spectroscopy stretch from the mass investigations of the rotational molecular spectra (peak of intensity of which is situated in submillimeter region) to the more special cases such as study of the so – called "forbidden" spectra, first microwave spectra of the negative molecular ions (separated by their Doppler effect), observation of the large (up to 40% of the broadening) collisional line shifts etc which became accessible with new technique.

Described in this chapter BWO PLL also forms the basis of further extension of the frequency range of microwave methods by BWO frequency multiplication and "sum frequency" sources using non - tunable far infrared laser and scanned BWO, described in Chapters 5 and 6.

5. Phase - locked BWO frequency multiplication beyond the Terahertz

Reaching of the highest frequencies by microwave methods always were done by frequency multiplication [3]. We first used submillimeter BWO as tunable fundamental source for multiplication. Frequency multiplier developed by us on the planar Shottky diode had similar to the quasioptical construction described in the preceding section as PLL mixer and differed only by (smaller) dimensions of the input ridged waveguide. Harmonics produced by quasioptical multiplier on a planar Shottky diode were received by opto - acoustic detector with rarefied gas as absorber of radiation in numerous absorption lines. Pioneering works are described in [27, 28] - first to 1.3 THz [27], then up to 1.524 THz [28]. Here we would like to point out the role of BWO lock — in not only in identification of harmonics observed, but also in investigation of the frequency multipliers characteristics, namely quantitative measurements of multiplication efficiency for each harmonic separately. From the very beginning of penetration into submm range by frequency multiplication the spectral lines were used as convenient frequency markers spreading many octaves in frequency and surely being identified by their frequency measured [3]. Without PLL it is difficult, e.g., to distinguish weak line observed in lower harmonic from strong line observed in higher harmonic, nothing to say about assignments of the spectral lines, and moreover, about measurements of conversion losses into each harmonic separately. Measurements of the conversion losses are based on independence of the sensitivity of the opto - acoustic detector on frequency, and easy calculable intensities of rotational molecular lines. Details of simple methodic are presented in [29]. So real – time comparison of conversion losses (e.g., in the process of multiplier tuning) is always possible. Measurements are done without any changes in the setup even in the case of simultaneous emission of all harmonics including the fundamental in a frequency range up to 1 THz and well above - up to 1.5 THz (e.g., [30]).

F_f (GHz)	F_h (GHz)	N	FCL (dB)
230.5	230.5	1	0
230.5	461.0	2	-23
230.5	691.5	3	-27
230.5	921.8	4	-33
259.2	1 036.9	4	-40
230.4	1 152.0	5	-43
253.4	1 267.0	5	-52
230.3	1 382.0	6	-49
249.5	1 496.9	6	-52

Table 1. Example of the measured Frequency Conversion Losses (FCL) for each harmonic of submm BWO frequency multiplication . F_f – fundamental frequency, F_h – frequency of radiation in harmonic, N – harmonic number.

Example of practically measured conversion losses are shown in the Table 1. The output power on each harmonics produced by the multiplier was measured separately; passing from one harmonic to another is done just by small tuning of the fundamental frequency. In this way, e.g., the 2-nd, 3-rd, 4-th, 5-th and 6-th harmonics of 230 GHz BWO [29] were measured up to 1.4969 THz upper frequency range. Thus measuring technique primarily developed for high resolution microwave spectroscopy can be used for general purpose microwave measurements.

Quality of these works is demonstrated by their successors [31] though without references to [27 - 30]. Use in [31] special powerful BWO, construction of multiplier, specially developed planar Shottky diode and LHe - cooled bolometer (instead of thermal room-temperature receiver – acoustic detector – in [27, 28], i.e., 70 times gain in the thermal noise level) led to increase of the frequency of lines observed only from 1.524 THz in [28] to 1.593 THz in [31], i.e., somewhat less than by 5 % . We think that full possibilities of this work are not yet realized.

6. Sideband or "sum frequency" sources with scanned phase – locked BWO

"Sideband spectrometers" using one non - tunable (laser) and one tunable (MW synthesizer) sources mixed at nonlinear element to obtain tunable sidebands at higher frequencies are well known [32]. But their variant for the Terahertz range can be also named as "sum frequency" sources because orders of frequencies of FIR lasers and BWOs are practically the same, so often only their sum frequency sideband is of interest. The first use of a BWO – based synthesizer as a tunable source of reference signal for frequency stabilization was achieved in our experiments [33, 34, 35]. Again the similar construction of the multiplier – mixer as described in previous sections was used as a mixer in a FIR laser sideband spectrometers up to 2.5 THz [33, 34, 35]. Main cause of the frequency error in sideband sources is connected with the drift of the non - stabilized laser frequency within the laser line (about 1 MHz). For reduction of this error the laser frequency stabilization is needed. As the first step to the more accurate frequency measurements the counting of the beats between harmonic of the mm wave synthesizer and laser frequency was done in [34]. This immediately reduced error limits from 0.4 MHz down to 78 kHz [34]. Then frequency stabilization of FIR laser against the harmonic of synthesizer was achieved [35]. With frequency stabilized FIR laser frequencies of the spectral lines were measured with 25 kHz accuracy [36]. Without stabilization BWO + FIR laser spectrometer (e.g., [37]) has accuracy ~0.5 MHz. Everywhere in the works mentioned the described in the Section 4 BWO PLL was used. The next necessary stage should be phase lock – in also FIR laser frequency to match the synthesizer frequency stability.

7. "Fast" synthesizers and modern resonator spectroscopy

We met the problem of desirability of fast frequency scanning in BWO PLL when developing modern millimeter wave resonator spectroscopy [38, 39]. The essence of the resonator spectroscopy is measurement of the widths of the resonance curves of empty and loaded resonator from which the losses introduced by the sample can be determined. Importance of this kind of spectroscopy is in its universality, i.e., applicability to very broad class of the objects measured, including gas, solid and liquid states of samples. The main source of error in measurement of the resonance width is the drift of the central frequency of resonance during the time of measurement. To minimize this error one has to measure the resonance curve as fast as it is physically possible. Response time of the resonator used by us itself $\tau_{res} = 1/\pi\Delta f \approx 2$ microseconds. For precision measurement the observation time should be increased, say, ten times, i.e., up to ~ 20 microseconds. But microwave and millimeter wave synthesizers commonly used for spectroscopy employ indirect frequency synthesis and so have commonly ~ (10 - 50) milliseconds switching time (the fastest indirect microwave synthesizers e.g.. [40] have ~ 0.5 millisecond switching time). This circumstance prevents the fast scanning of the resonance curve. When tuned by digital switching of such fundamental frequency reference source BWO PLLs are "slow". This often limits the parameters of the devices using such synthesizers.

Frequency range of the fast frequency synthesizers using direct frequency synthesis is limited by much lesser frequencies than discussed by us. Direct frequency synthesizer with up - converters HP 8791 Model 21 [41] has frequency range up to 18 GHz and 100 ns switching time. Weight of the device nears 400 kg [41]. Further order of magnitude extension of the frequency range of such fast — switching direct frequency synthesizers with up - converters at least demands significant efforts.

For our purpose we used fast DDS RF synthesizer as source of reference signal for phase detector. The two possibilities of frequency control - through high frequency reference and through phase detector reference - was pointed out even in the first MW PLL work [4]. Slow switching is often due to losing the phase lock regime during the building of the new reference signal and then gaining it again after search and lock of VCO frequency. Tuning of the locked BWO can be much faster considering output amplifier range about 3 - 5 MHz and 50 – 100 MHz/V steepness of BWO characteristic mentioned before. But for this in particular one has to use reference signal tuned without loss of phase, without "phase jumps" which can produce losing of phase lock - in.

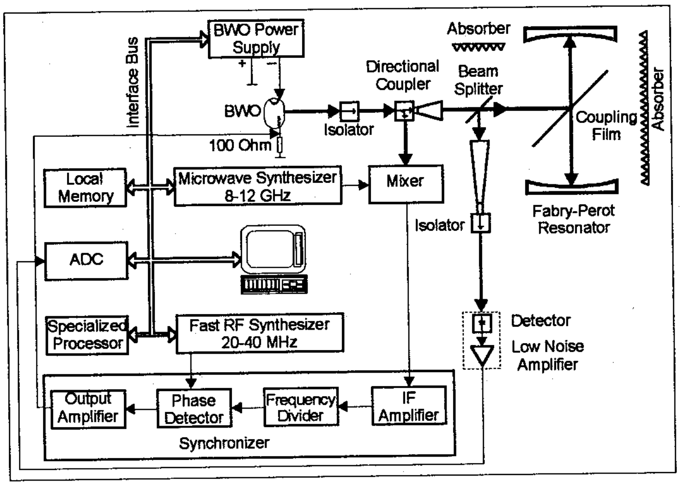

Fig. 5. Block - diagram of the improved BWO PLL able to fast scan around the central frequency defined by microwave synthesizer harmonic shown in installation for use in resonator spectroscopy with Fabry – Perot open resonator. Time of switching of the BWO frequency within 200 MHz constitute 200 ns with discreteness 0.3 Hz. Note digital frequency divider of IF frequency and direct digital synthesizer as a reference source for phase detector. Both synthesizers are controlled by computer. Principal concept of this BWO PLL can be used for the development of the next generation of mm / submm frequency synthesizers with broad fast scanning possibilities.

Block - diagram of the device used by us is presented in Fig. 5, where BWO PLL is shown in the installation for the use in resonator spectroscopy. The synthesized frequency radiation source employ BWO [1] stabilized by PLL with the use in this case of two reference synthesizers: one microwave (MW) synthesizer (8 - 12 GHz) defining central frequency of the BWO as described above, and fast radio frequency (RF) synthesizer (20 - 40 MHz) for precision fast scanning of the BWO frequency around the chosen central frequency. Radio frequency synthesizer provides frequency scanning without loss of the phase of oscillations. Both synthesizers are computer—controlled. As a result, BWO frequency was defined as

$$f_{BWO} = n\,f_{MW} \pm m\,f_{RF}\,,$$

where n varied from 4 to 20, and m in [39] was equal to 10, so phase detection was done at 10 times digitally divided intermediate frequency (IF) which was about 350 MHz. Fast direct radio frequency synthesizer with switching time ~ 200 nanoseconds was used in [39] as a source of reference signal for phase detector in the lock-in loop. Thus precision and fast scanning of the BWO radiation frequency within ~ 200 MHz around the central frequency defined by microwave frequency synthesizer had been performed. Scanning without loss of phase permits to near physical limits of the resonance observation time and reduces the source phase noise. The passed through resonator radiation was received then by low-barrier Schottky diode detector. The precision frequency control, signal acquisition and processing were done by the combination of computer, additional specialized processor and local memory as it is shown in Fig. 5. Results of each scan were recorded and processed separately. In Fig. 6 the example of resonance curve record of the Fabry - Perot resonator near 85 GHz is shown. Highest - to - date accuracy 20 Hz in measurement of the width of the resonance 164 728 (20) Hz at 85 GHz is obtained in this experiment what corresponds to the minimal detectable absorption coefficient 4.10^{-9} cm^{-1} or 0.0018 dB/km. Introduction of the fast frequency scanning permitted to increase more than by an order of magnitude the sensitivity of resonator spectroscopy and leave behind most part of systematic errors. Applications of the modern resonator spectroscopy technique may include atmosphere monitoring, technological processes monitoring, material characterization including best CVD diamonds films, surfaces of the metals etc. Some of them will be discussed in Conclusion.

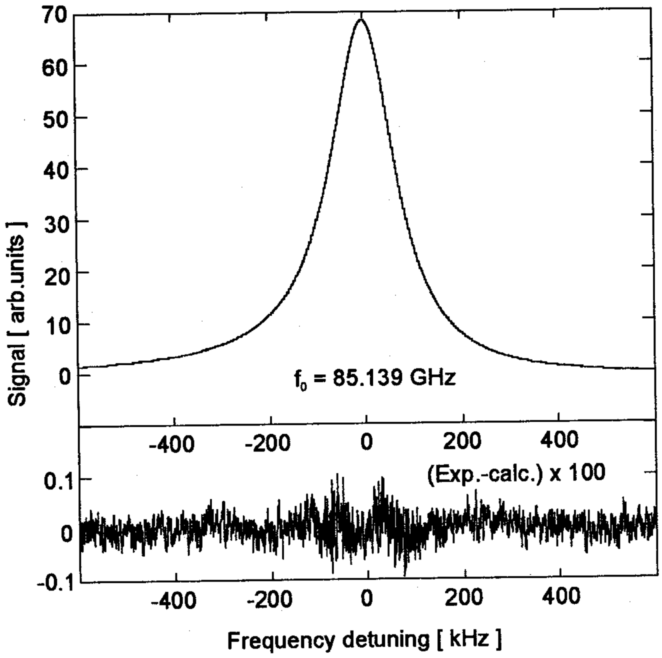

Fig. 6. Record of the resonance curve of the high - quality (Q ~ 600000) Fabry - Perot resonator done by fast frequency scanning of BWO PLL. Highest - to - date accuracy 20 Hz in measurement of the width of the resonance 164 728(20) Hz at 85 GHz is obtained, what correspond to the minimal detectable absorption coefficient 4×10^{-9} cm^{-1} or 0.0018 dB/km.

8. Some future prospects

Terahertz range is practically mastered by the devices described. But significant further improvements are possible in the BWO - based synthesizer construction described in the previous section with some changes of its parameters. Fast frequency switching in much broader range can be achieved by using higher IF, broadband enough IFA, frequency dividers with increased division coefficient (*m* factor in the formula above), possibly higher – frequency DDS without phase jumps and "always locked" regimes. Let us remind that fast frequency switching described above is practically independent on the frequency range of the synthesizer. The necessary millimeter or submillimeter wave range may be divided into parts each of which would be covered by the fast lock-in system of the type described in [39] and presented in Fig. 5 with improvements mentioned. Increase of divider range (*m* factor) and increase of phase detector (and DDS) frequency change the roles of two synthesizers used, giving possibility to produce most part of the frequency scanning by the fast synthesizer used as a reference for the phase detector. Existence of DDS with frequencies higher than used by us [42] (at least 240 MHz [43]), digital frequency dividers up to 69 GHz [44] (up to 750 GHz in cryogenic variant [45]), IF amplifiers with frequencies and bandwidths up to 40 GHz [46] makes practical the development of mm / submm synthesizers frequency of which can be fast controlled within the ranges of the order of ten(s) of GHz at least, working always in the locked regime. Only change of harmonic (or frequency) of the slow microwave synthesizer will produce one slow step after scanning of ten(s) of GHz order range. Limits of this approach are defined by the spectral purity of the reference signal. Of course, this approach gives fast tuning not in the full BWO range, but by the order of magnitude fast scanning range may be hopefully comparable to the whole range of the fast synthesizer with up - converters mentioned [41] but at much higher frequencies and in a more compact device. So practically a new type of submillimeter BWO - based device can be expected which can suite to a very broad class of applications.

9. Conclusion

Even with the understandable trend to use solid - state sources in e.g., transportable, specialized etc devices such as scientific space project [47], modulation / demodulation of light in multi - channel optical fiber transmission lines, local networks, car radar [48], communications [49] etc BWO with continuous coverage of all microwave band up to Terahertz range stays as very convenient if not the only solution for many investigations, developments, measurements, characterization of materials etc. For example, for construction of the fast broadband frequency synthesizers in mm / submm range as it is mentioned above, the BWO – based device looks as only possible way at the moment. Existing BWO - based commercial mm wave frequency synthesizers are very close to the submm wave band. Further developments permit to cover the whole mm / submm bands also by the fast frequency synthesizers. So standard microwave measurements with the help of BWO PLL become possible in the whole continuous range up to Terahertz. Use of the methods described for covering of the most intense part of the rotational spectra of molecules by precise microwave spectroscopy were mentioned above. Use of the fast frequency synthesizers permitted to develop universal highly sensitive methods of the modern resonator spectroscopy. Resonator spectroscopy permits to overcome limitation of common microwave spectroscopy by low pressure region and to observe molecular lines up to atmospheric pressures without loss of sensitivity. Precise broad lines measurements by the modern resonator spectroscopy methods made possible real - time atmosphere and technological processes monitoring just in the open air (or other gas at atmospheric pressure) thus greatly expanding number of the possible applications of microwave methods. As an example the lowest air / gas humidity measurements can be pointed out which often are of the primary importance for science (e.g., higher atmosphere humidity) and technology (work with dry materials, gas precursors in optical fiber or polymers fabrication etc). It is well known that good part of the purification of many substances are based on rectification processes which include the gas phase state to which the described methods can be applied with advantages of universal quantitative analysis. Sensitivity of measurements can be increased another orders of magnitude by passing to the stronger submm lines. E.g, in water vapor intensity of 556 GHz water line exceeds of the intensity of the 183 GHz one by three orders of magnitude. Also precise characterization of solid and liquid samples become possible by the methods described. One characteristic example can be measurement of the quality of intensely investigated now CVD diamond samples: higher sensitivity permits to measure losses in thinner samples (practically films), i.e., significantly reduce the time of growing of one sample (measured by micrometers per hour) giving possibility to study dependencies of diamond parameters on the fabrication methods in a lesser time. Another example can be measurement of the dependence of the surface conductivity of metals on the method of preparation making resonator mirrors from the samples investigated. We do not touch here large field of the solid state submillimeter dielectric spectroscopy [50] in which modern resonator spectroscopy methods described here open completely new possibilities of studies. So area of applicability of the high precision methods developed is large enough and there are hopes for further extension of it in the future. Obviously, the constant desire to extend the frequency range employed in science and engineering will increase still further the role of high - precision coherent methods for the maximum use of all the possibilities of the vast frequency bands being reached now.

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