International Journal of Infrared and Millimeter Waves, Vol. 15, No. 10, 1994

COMMERCIAL FREQUENCY SYNTHESIZER OF 118 GHz–178 GHz RANGE

A. F. Krupnov[1] and O. P. Pavlovsky[2]

[1]*Applied Physics Institute of Russian Academy of Sciences*
46 Uljanova st, 603600 Nizhnii Novgorod GSP-120, Russia

[2]*Institute of Electronic Measurements KVARZ*
176 Gagarin Ave, 603600 Nizhnii Novgorod, Russia

Received July 22, 1994

1 Abstract

This paper is concerned with description of development of commercial millimeterwave frequency synthesizer promised by authors in previous paper [1]. Synthesizer described has highest for commercial synthesizers at the moment frequency range 118 GHz – 178 GHz and due to the use in it of Russian - made Backward Wave Oscillator (BWO) radiation source of the [2] type has continuous tunability range as broad as 60 GHz and significant - from 3 to 10 mW - output power in the whole range covered. Minimal frequency step is 100 Hz. Synthesizer is fully microprocessor - or PC - (through IEEE-488) controlled. Mentioned are other members of this synthesizer family (37 - 53 GHz, 53 - 78 GHz, 78 - 118 GHz) also now in production (general information about development of Russian frequency synthesizers from 1.07 GHz up to 118.1 GHz can be found in [3]). Possibility of further extension of frequency range up to 256 GHz in serial and up to 1 THz in laboratory versions (see [4]) is considered.

Keywords: BWO, millimeterwave, frequency, synthesizers.

0195-9271/94/1000-1611$07.00/0

2 Introduction

Existence of frequency synthesizers as radiation sources is one of the most important criteria of availability of the frequency region considered for extensive uses and applications.

Until the present time most of the efforts in development of millimeterwave synthesizers were directed to the use in them radiation sources based on solid state devices. But during the years of developments increase of the both frequency range and output power of solid state oscillators met significant difficulties, and commercial synthesizers range was limited by 110 GHz with output power of the order of one milliwatt (obtained for covering broad enough frequency band by the use of several generator units) [5]. Use of combination of centimeter wave range synthesizers and frequency multipliers met the same difficulties in the same frequency and output power ranges [6]; also for covering broad enough frequency band several multiplier units are used.

Principal decision made by authors in Nizhnii Novgorod millimeterwave synthesizers development was changing from solid state devices to the vacuum tubes, Backward Wave Oscillators (BWO's) [2], which cover with vide (almost octave) tunability, powers from milliwatts up to big tens of milliwatts and pure spectrum frequency region up to Terahertz [4]. In millimeterwave region considered here sizes and supply voltages of BWO's [1] permitted to construct whole synthesizers in the dimensions closely resembling common lower - frequency synthesizers to which users are aquainted.

In Figure 1 a general view of 118 - 178 GHz synthesizer is presented.

This decision permitted now to cover continously in four units frequency range from 37 GHz up to 178 GHz (37 -53 GHz, 53 - 78 GHz, 78 - 118 GHz and 118 - 178 GHz) with minimal frequency step 100 Hz with clear perspective of further extension of frequency range. Now the next member of the family of synthesizers is conceived covering 178 - 256 GHz.

Common uses of synthesizers in microwave region as crucial parts of test equipment, communications systems, local oscillators etc

[1]BWO mentioned here [2] are developed and produced by ISTOK Research and Production Company at Fryazino, Moscow Region

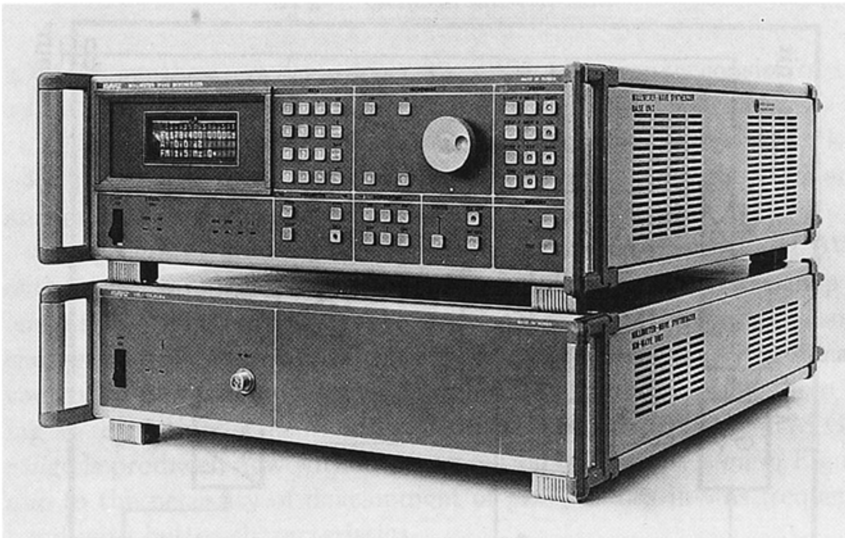

Figure 1: **A General View of 118 – 178 GHz Synthesizer.**

are widely known. Well known is also use of them for microwave spectroscopy of high resolution. Now synthesizers covering 53 - 78 GHz, 78 - 118 GHz and 118 - 178 GHz are already implemented for high resolution spectroscopy purposes in several laboratories in the world, including Division of Molecular Physics, National Institute of Standards and Technology, Gaithersburg, Md, USA, Department "G. Ciamician", Bologna University, Italia, I. Physical Institute of University of Cologne, Germany, and Institute of Physical Chemistry of Giessen University, Germany. Here and in some conference reports and published papers cited examples of uses of developed millimeterwave synthesizers for high resolution spectroscopy - directly on the synthesizer frequency or using millimeterwave synthesizers as reference sources for phaselock of higher - frequency BWO's - are presented [7], [8], [9], [10].

3 Block – Diagram

Block - diagram of 118 - 178 GHz synthesizer is presented in Figure 2.

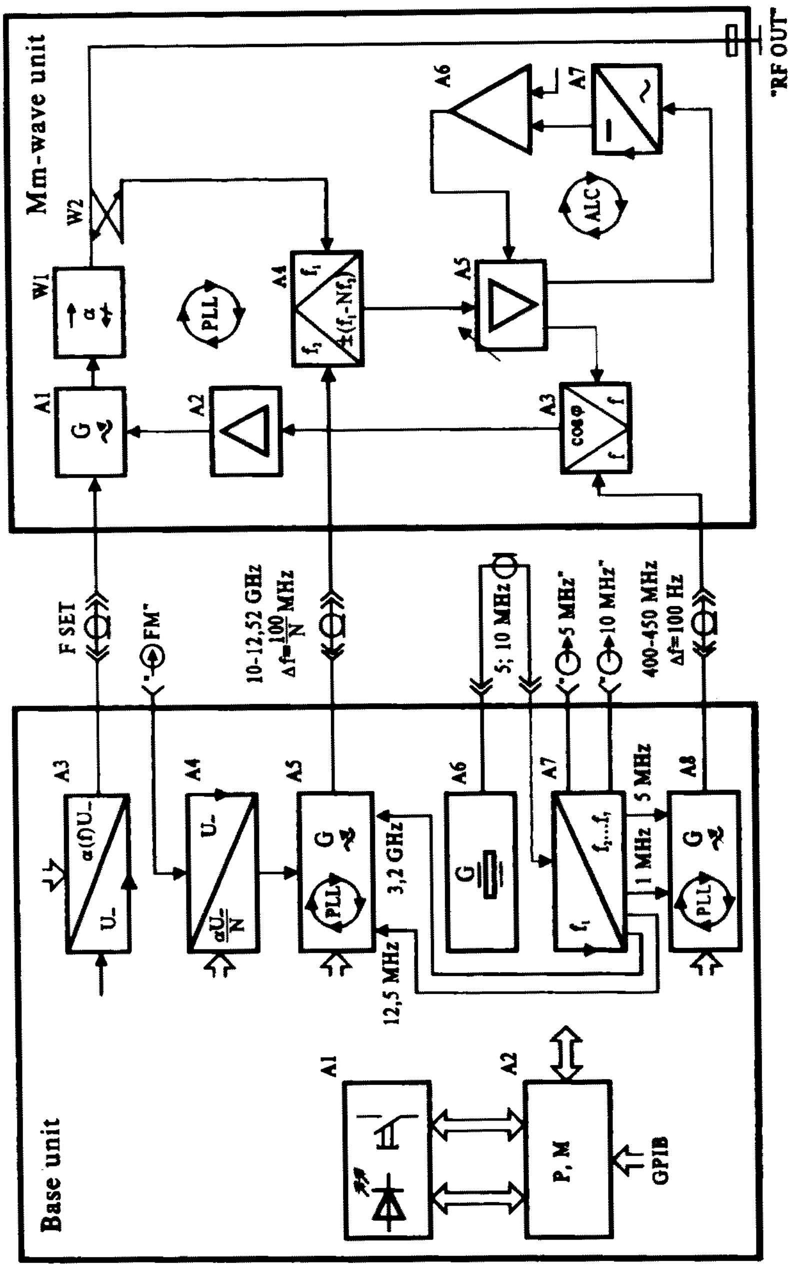

Figure 2: **Block – Diagram of 118 – 178 GHz Synthesizer.**

3.1 General Description

KVARZ synthesizers [2] covering 37 – 178 GHz range consist of two units:

base unit containing keyboard, indicators, microprocessor, IEEE - 488 input, quartz oscillator and common elements of high - frequency and microwave synthesizers, and

generator unit containing specific for the frequency band BWO with power supply, waveguide elements, and BWO's lock - in loop elements and electronics. Synthesizers up to 118 GHz contain also in the generator units as options output power - leveling, electronically controlled power attenuator and amplitude modulator, all of them using as regulation elements *pin* - diodes. Synthesizer in 118 – 178 GHz range is produced now without these options, as can be seen in Figure, due to the necessity of development of *pin* - diodes in this frequency band with better characteristics.

Both units have built - in power supply. Plugging into AC base unit switches on quartz reference oscillator which can work continuously.

Output power level of 118 – 178 GHz synthesizer varies with frequency from 3 up to 10 milliwatts with BWO's power from 10 up to 50 milliwatts due to the losses in 1.6 mm x 0.8 mm cross - section waveguide elements including ferrite unidirectional element, directional coupler etc; this power level has to be increased in the next version by improving, simplifying and shortening of the waveguide tract on the fundamental mode. Use of waveguide fundamental mode simplifies matching of synthesizer with other devices; but quite possible that the next 178 - 256 GHz synthesizer will have oversized waveguide output.

Base unit includes keyboard and indication board A1, microprocessor unit A2, reference quartz oscillator A6, frequency of which is equal to 5 or 10 MHz, unit forming reference frequencies for all units of synthesizer A7, microwave frequency synthesizer A5 (10 GHz - 12.52 GHz), high frequency synthesizer A8 (400 MHz - 450 MHz), circuit forming settings of power supply voltage, i.e, initial settings of millimeterwave BWO frequency A3, FM voltage forming circuit A4.

Microprocessor unit A2 receiving new frequency value (from

[2] parameters described are basic; in each case parameters of synthesizers can be changed in accordance with the customer demand.

keyboard or interface) gives command to unit A3 to form out voltage controlling BWO power supply using approximation function of BWO frequency *vs* high voltage supply (proportional to control voltage) s-tored in microprocessor. Also commands go to microwave synthesizer A5 forming reference signal with 100 MHz steps at millimeterwave frequencies and high frequency synthesizer forming signal with frequency steps 100 Hz (or multiples of 100 Hz) at millimeterwave frequencies. Forming of three signals mentioned gives possibility of realization of the BWO phase lock - in at the frequency needed. Block - diagram Fig. 2 is simplified; real lock - in circuit includes quadrature phase detector [11], [12] and automatic frequency search circuit with digital phase detector [13] [3]. After successful search and lock - in BWO frequency is set on necessary value. The cycle of frequency switching takes no more than 40 ms; typical transient time of frequency switching is 10 - 20 ms.

Generator unit includes BWO with power supply A1, ferrite ventil W1, directional coupler W2, stroboscopic mixer A4, phase detector A3, IF amplifier A5, BWO driver amplifier A2 and IF levelling circuit elements detector A7 and amplifier A6.

3.2 Frequency Characteristics

Frequency band covered by synthesizer considered mainly in this paper is stretching from 118.1 GHz up to 178.4 GHz; this entire band can be scanned continuously with smallest frequency step equal to 100 Hz.

Internal quartz reference oscillator has limits of instability: $\pm 3.10^{-7}$ /year; $\pm 5.10^{-9}$/day after 72 hours of working; $\pm 5.10^{-10}$/day after 30 days of working.

External reference signal (e.g, atomic frequency standard output) should have frequency error no more than $\pm 5.10^{-7}$, and rms voltage on 50 Ohm load 0.6 - 1.8 V.

In the first studies of the molecular spectra with millimeterwave synthesizers serving as radiation source in microwave spectrometer [7], [8] frequency of millimeterwave synthesizer has been digitally scanned by computer; computer also was used for spectrometer signal processing. Radiation passed through quasioptical cell three meters long and

[3]all modified according to the specifics of millimeterwave lock - in; detailed description of these and other millimeterwave components will be given separately.

was received then by InSb liquid Helium cooled bolometer. Source frequency modulation was used and spectrometer signal on second harmonic of modulation frequency was registered, so spectral lines were recorded as second derivative of absorption profile. Digital scan for, e.g, OCCCS molecule spectrum study [7] covered continuously 40 GHz (78 - 118 GHz synthesizer was used); examples one can see in [8].

For some illustrations small portion of OCS molecule spectrum record obtained by this spectrometer is demonstrated in Figure 3; it covers only 100 MHz (from 97 250 MHz to 97 350 MHz) for clarity of the picture. Lines assignment is shown in the Figure. Strong lines are limited by the dynamic range with amplification used to show weak lines of the spectrum.

Observation of lines with absoption coefficient of the order of 10^{-7} cm-1 with time constant 120 milliseconds [4] shows high sensitivity of spectrometer and demonstrates, by the way, absence of any additional noise coming to the receiver e.g, from radiation source.

Stability and reproducibility of the synthesizer output signal over hours led to an unexpected but highly welcomed feature: the whole spectrum record lasted several hours; after recording of the spectrum of OCS cell was evacuated and the recording was repeated; subtraction of the two spectra gave a surprisingly flat baseline which can be seen in the Figure 3. This result shows level of accuracy of measurements, in fact, of amplitude *vs* frequency characteristics, achievable with the use of synthesizers described.

3.3 Spectral Characteristics

Synthesizer described has: harmonics level - no more than - 25 dB; combination frequencies level - no more than - 50 dB; spectral density of power of phase noise (SSB) - no more than - 55 - - 60 dB at 10 kHz detuning from carrier frequency and no more than - 75 - - 80 dB at 100 kHz detuning.

One more spectral characteristic of the synthesizer output radiation from the point of view of high - resolution spectroscopy is presented in Figure 4: whereas records of spectral lines of gases at Doppler (or near - Doppler) resolution were demonstrated in [7], [8], [9], here

[4] Well - known OCS spectrum often serves as "etalon" for such calibrations

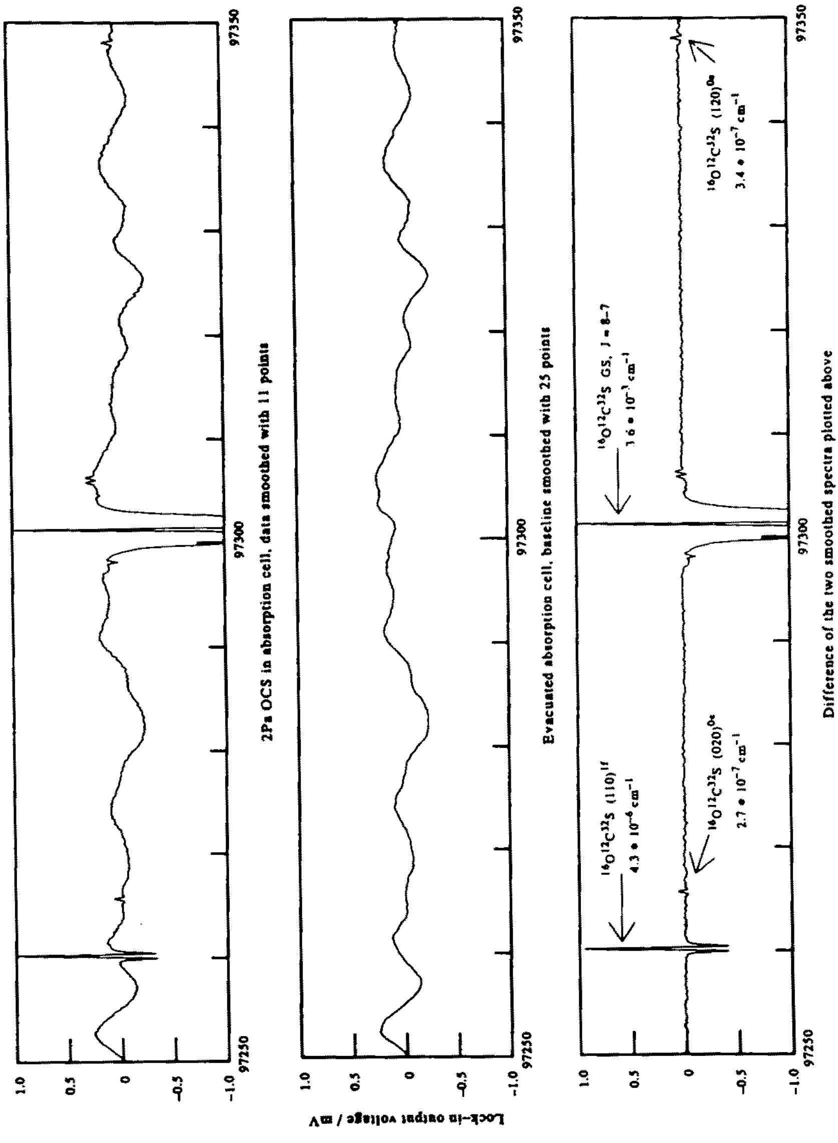

Figure 3: **Example of OCS Molecule Spectrum Record.**

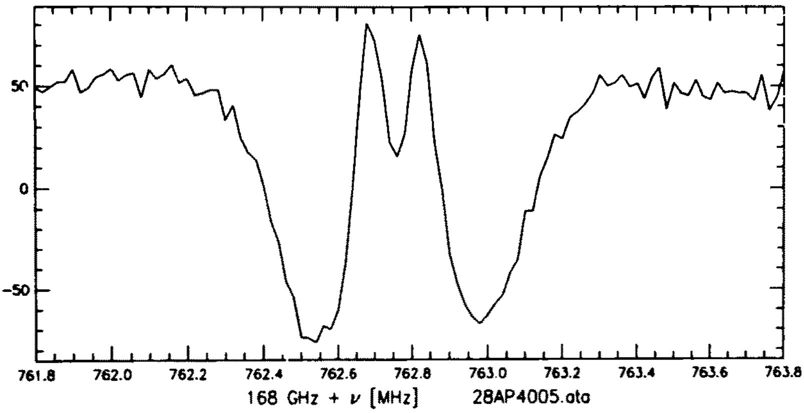

Figure 4: **Lamb Dip Record of H_2S $1_{0,1}$ – $1_{1,0}$ Line Near 168 GHz Using 118 – 178 GHz Synthesizer As Radiation Source**

we present the first record of spectral line at sub – Doppler resolution obtained with synthesizer described on the University of Cologne spectrometer and kindly supplied to us by Professor G. Winnewisser to whom authors express their deep gratitude. In the Figure 4 the Lamb dip on the 168 GHz H_2S $1_{0,1}$ – $1_{1,0}$ line is presented; HWHM of Lamb dip profile constitutes approximately 32 kHz or $1.9.10^{-7}$ of the line frequency. Undistorted Lamb dip is evidence of possibility of the use of synthesizer described also for sub – Doppler spectroscopy.

3.4 Power characteristics

As was said earlier, power level of synthesizer output is no less than 3 mW (10 mW at the peak).

3.5 Modulation Regimes

As was said in general description, this highest - frequency synthesizer has only external FM with characterisrics: modulation frequency from 0.001 MHz up to 5 MHz; frequency deviation from 0 up to 1 MHz by steps of 0.1 MHz.

3.6 Regimes and Parameters of Digital Sweep

Of course, in the regime of PC control of the synthesizer digital sweep parameters can be choosed by the operator; in this section only regimes from front - panel controls through microprocessor (without necessity of PC use) are described.

Digital sweep can be choosed as:

– automatic non - periodic from any frequency with frequency step ordered from 100 Hz up to the whole bandwidth of synthesizer every 0.3 seconds; sweep can be interrupted and started again;

– automatic periodic or single from start frequency to the stop frequency ordered; symmetrically from central frequency ordered within frequency band ordered; in these regimes minimal sweep width is 10 kHz, number of steps 100; time of sweep from 10 s to 99 s $\pm$ 1 s; steps from 100 Hz (to cover 10 kHz range) up to one - hundredth of the whole frequency band (placing start frequency at the beginning and stop frequency at the end of the frequency band; such regimes can be very convenient e.g, for equipment testing);

– manual.

3.7 Programming Characteristics

Computer control of the all regimes of synthesizer is realized through standard IEEE - 488 interface with functions: SH1, AH1, T6, L3, SR1, RL2, DC1, DT1, PP1, CO.

3.8 Exploitation Characteristics

Power supply: AC 182 - 252 V or 90 - 126 V; AC frequency 48 - 66 Hz. Power consumption: base unit 250 VA, generator unit 250 VA.

Working temperature interval: 5 - 40 ^{0}C (room temperature). Weight and dimensions: base unit 177 x 488 x 595 mm, 28 kG; generator unit 137 x 488 x 595 mm, 21 kG.

4 Conclusion

Successive development of the unique serie of 37 - 53 GHz, 53 - 78 GHz, 78 - 118 GHz and now 118 - 178 GHz commercial frequency synthesizers and their successful exploitation now by several Laboratories showed possibility of further extension of the frequency range of these devices. At the present time plans are existing to start development of the next 178 - 256 GHz synthesizer equipped by specially developed by ISTOK Research and Development Company packetized BWO with similar to the previous dimensions, voltages and characteristics.

Moreover, recent demonstration of the workability of the precise (phase lock - in) higher - frequency BWO's frequency control up to frequency range 1 THz using frequency multiplied signal of millimeterwave synthesizer as reference, in which multi - GHz scans were demonstrated and e.g, BWO frequency stabilization signal was not lost during continuous digital scanning over 200 GHz without any additional frequency tuning [4] shows that in this development principal problems of high - frequency BWO stabilization and control are solved, and limiting factors now are rather technical (sizes, power consumption, water cooling of BWO's in electromagnet, higher supply voltages etc). We can state here that in laboratory version our Institutes now are able to develop and deliver BWO - based radiation source at least up to 1 THz with phase stabilized and computer controlled BWO frequency. These developments of course form also the base for further extension of the range of commercial (serial) frequency synthesizers.

5 Acknowledgements

Studies described in this paper were supported in part by Deutsche Forschungsgemeinschaft, Russian Fund for Fundamental Studies by Grant N 94-02-05424-a, Ministry of Science and Technical

Politics of Russia in the frame of State Program on Fundamental Metrology, and International Science Foundation by Grant R8I000 to all of whom the authors express their deep gratitude.

Authors express their gratitude to Director General of Institute of Electronic Measurements KVARZ Dr. A.A. Uljanov and Director of Physical and Engineering Department of Institute of Applied Physics Dr. B.G. Eremin for constant attention to the work.

Authors express their gratitude to Professor G. Winnewisser for presenting the picture of Lamb dip record obtained by the use of synthesizer described for illustration of its spectral characteristics prior to publication of H_2S molecule spectrum studies [14].

References

[1] Yu.I. Alekhin, G.M. Altschuller, O.P. Pavlovsky, E.N. Karyakin, A.F. Krupnov, D.G. Paveliev, A.P. Shkaev, *Int. J. of Infrared and Millimeter Waves* **11**, 961–971 (1990).

[2] M.B. Golant, R.L. Vilenkin, E.A. Zulina, Z.F. Kaplun, A.A. Negirev, V.A. Parilov, T.B. Rebrova, V.S. Saveliev, *Pribory i technika eksperimenta*, **4**, 136 (1959); M.B. Golant, Z.T. Alekseenko, Z.S. Korotkova, L.A. Lunkina, A.A. Negirev, O.P. Petrova, T.B. Rebrova, V.S. Saveliev, *Pribory i technika eksperimenta*, **3**, 231 (1969).

[3] O.P. Pavlovsky, *Radio Measurements and Electronics (Rus)*, IEM KVARZ, N 2, 19 - 23 (1993).

[4] G. Winnewisser, A.F. Krupnov, M.Yu. Tretyakov, M. Liedtke, F. Lewen, A.H. Saleck, R. Schieder, A.P. Shkaev, S.A. Volokhov, *J. Molec. Spectrosc.* **165**, 294–300 (1994).

[5] Hughes Aircraft Company Catalog, (1983), p.23;
Hughes Millimeter-Wave Products for 1987/1988, pp. 10 - 11.

[6] Hewlett - Packard Test and Measurements Catalog, (1990), pp. 405 - 406.

[7] V. Wagener, M. Winnewisser, A.A. Uljanov, O.P. Pavlovsky, G.M. Altshuller, O.G. Anikin, A.F. Krupnov, E.N. Karyakin, V.P. Kazakov, *48th Ohio State University International Symposium on Molecular Spectroscopy*, Paper WF 05, Columbus, Ohio, 1993.

[8] A.F. Krupnov, *Infrared Phys. Technol.* **35**, 267–276 (1994).

[9] E.N. Karyakin, G.T. Fraser, R.D. Suenram, *Mol. Physics* **78**, 1179–1189 (1993).

[10] S.P. Belov, M. Liedtke, Th. Klaus, R. Schieder, A.H. Saleck, J. Behrend K.M.T. Yamada, G. Winnewisser, A.F. Krupnov, Precision measurement of the $^{r}Q_2$ at 700 GHz and $^{r}Q_3$ branch at 980 GHz of HSSH, *J. Molec. Spectrosc*, accepted for publication.

[11] M.P. Fortunato, K.Y. Ishikava, *Microwaves*, **21**, 119 - 124 (1982),

[12] K.Y. Ishikava, C.T. Hsieh, *Microwave and RF*, **22**, 103 - 109 (1983).

[13] A.V. Ryzhkov, *Electro Communications (Rus.)*, N 10, 68 - 70 (1975).

[14] G. Winnewisser, private communication.