NEWSLETTER

of the International Consortium "Development of High-Power Terahertz Science & Technology"

June 2018 № 9

CONTENT

EDITORIAL: HOW TO CONTRIBUTE TO THE NEWSLETTER

Dear Reader,

We are inviting contributions to the following rubrics:

- Research highlights (annotations) presenting the projects pursued by the members of the Consortium.
- Short regular papers.
- Proposals for collaborative research work.
- News from the participating institutions.
- Information about conferences, symposia, workshops, seminars.
- Programs and frameworks for an exchange of visits and mobility of researchers. Job opportunities (especially for young researchers, e.g. postdoctoral positions, specializations, internships).
- Annotations of books, conference proceedings, software and internet resources. Additions to the list of the recent scientific publications and conference reports at the website of the Consortium (http://fir.ufukui.ac.jp/Website_Consortium/publist.html).
- Information and announcements about awards and nominations.
- Short presentations of laboratories and research groups belonging to the participating institutions.

Please submit your contributions to the Newsletter as well as requests for information to:

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ACCELERATING THE INTERNATIONAL COLLABORATION

A Successful Implementation of the Cross-Appointment Scheme at FIR UF

M. Tani[1], M. Glyavin[2], T. Idehara[3]

[1]*Director of the FIR UF Center, Fukui, Japan*
[2]*Deputy Director of the IAP-RAS, N. Novgorod, Russia*
[3]*Supervisor of International Collaboration and Facilitator of the International Consortium*

The longstanding and fruitful collaboration between IAP RAS and FIR UF started in the distant 1999 when an agreement was signed and the first visits of IAP RAS staff to FIR UF were accomplished. Such common research was supported by the Visiting Professor program, and many researchers, including Profs. Vladimir Bratman, Vladimir Zapevalov, Mikhail Glyavin, Drs. Andrey Kuftin, Yuri Kalynov, Alexey Fedotov participated in such activity with a leading role of Prof. Toshitaka Idehara. The main goals were focused on the development and applications of high-power sub-THz radiation sources – Gyrotrons. As a result of the joint efforts, several projects were successfully finished. Among them were gyrotron based systems for material processing (24 GHz/3 kW/CW and 28 GHz/15 kW/ CW); large orbit gyrotron (LOG) with a permanent magnet system, operated at high (up to 5) cyclotron harmonics; first powerful CW sub-THz tube (300 GHz/ 2.5 kW/ CW - gyrotron FU CW I). At the same time, investigation of the advanced device such as QO-gyrorotron and peniotron was realized, modern electron-optical systems have been developed and a detailed analysis of mode excitation has been carried out. All such projects were supported by an international research team with an active participation of Profs. Svilen Sabchevski, Olgierd Dumbrajs, and Gregory Nusinovich.

In 2017, Prof. Masahiko Tani proposed and established the new system – “Cross Appointment” (CA) for enhancing personnel exchange of academic staff in the International Division of the Research Center for Development of Far-Infrared Region of the University of Fukui (see the table below). Under the cross-appointment system, staff members of IAP RAS are employed as a staff at FIR UF while his/her position is retained by the institution he/she currently belongs to, and he/she works for both institutions based on the employment ratio. The implementation of such system during the first academic year immediately demonstrated its merits: (i) increase the number of participants in the collaboration (including invitation of Ph.D. students); (ii) open more contacts between people and give a chance for young scientist to work together with other visiting professors at FIR UF; (iii) broaden the time horizon of the collaboration allowing the planning of long-term collaborative works and projects.

The first researcher working in the framework of the CA system was Prof. Irina Zotova (the first female Visiting Professor at the FIR FU Center) followed by Prof. Naum Ginzburg, Prof. Andrey Savilov, Svilen Sabchevski (from IE-BAS), and Dr. Andrey Fokin. The main activities of their team were focused on the theoretical and experimental investigations of the novel gyro devices, with a goal to achieve a CW generation at frequencies above the symbolic threshold of 1 THz. For such a purpose, several concepts were analyzed, in particular, multi-beam gyrotron, complex cavity gyrotron, frequency multiplication as well as the development of physical models and computer codes for their analysis and computer-aided design.

Visiting Professor and Cross-Appointment Scheme at FIR UF for FY2017

	Visiting Prof/Assoc Prof	Cross-Appointment (New)
Position/Title	Visiting Professors/Assoc Professors	Specially Appointed Professors/Assoc Professors
Memorandum of Agreement	Not necessary	Necessary (Annex is supplied for specification of working conditions of Cross-Appointed researchers)
Qualification	Having equivalent position in his/her mother institute, or having equivalent achievements suitable for the position as visiting or specially appointed Professor/Assoc Professor	
Term	3 months (Apr – Jun, Jul –Sep, Oct – Dec, Jan –Mar)	1-12 months (selectable)
Working condition or duty	1) Joint research	1) Joint research (multiple years) 2) Teaching duty (not heavy)
Advantages	1) Simple procedure	1) Flexible term 2) Multi-year project 3) Budget for research activities and for inviting post-doc researcher (graduate students)
Disadvantages	Fixed term	Complicated procedure

The work carried out by the cross-appointed and visiting researchers, has been presented in an annual report (70 pages altogether) which includes 6 short papers, 4 reprints of selected recently published papers presenting the results of the collaboration, a list of 5 common reports to be presented at IRMM-THz 2018 Conference (Nagoya, Japan) and 6 photos (see the collage below). The report is available upon request from Prof. M. Glyavin.

We are completely satisfied with the outcome of the first year of the new CA program and express our gratitude to all members of the collaborative team looking forward to future achievements.


T. Idehara and M. Glyavin


I. Ogawa and A. Fokin


A. Fokin at FIR UF seminar


T. Idehara and A. Fokin

I. Zotova


M. Glyavin and S. Sabchevski

SHORT INVITED PAPER

High-power sub-terahertz gyrotron with a record frequency stability at up to 1 Hz

Mikhail Glyavin, Andrey Fokin, German Golubiatnikov, Lev Lubyako, Mikhail Morozkin, Alexander Tsvetkov, and Gregory Denisov

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Abstract: Many state-of-the-art fundamental and industrial applications require the use of terahertz radiation with high power and small line width. Gyrotrons as radiation sources provide the desired level of power in the sub-THz and THz frequency range but have substantial free-running frequency fluctuations of the order of 10^{-4}. Here, we demonstrate that a precise frequency stability at high-power levels of a sub-THz gyrotron can be achieved by a phase-lock loop in the anode voltage control. The relative width of the frequency spectrum and the frequency stability obtained for a 0.263THz/100W gyrotron are 4×10^{-12} and 10^{-10}, respectively, and these parameters are better than those demonstrated so far by other high-power sources by almost three orders of magnitude. Such breakthrough results confirm the potential of the realized approach and open the road to its implementation in the radiation sources for ultra-high precision spectroscopy as well as in the development of sources with large-scale radiating apertures, and other new projects.

In recent years, precise spectroscopy based on the high-power microwave sources becomes more and more actual. Microwave driven DNP experiments are now recognized as the most effective and versatile methods of enhancing signals in solid-state and solution NMR and imaging. DNP improves the sensitivity of NMR spectra by about a factor of 100, thus reducing the acquisition time in multidimensional NMR. Currently, the most widespread devices in the THz frequency range are backward-wave oscillators (BWOs) that provide an output power of a few milliwatts in the CW regime at the highest admissible frequencies with a half-power bandwidth of spectral distribution less than 100 mHz (a relative resolution of about 10^{-13}). The devices based on multiplication of a signal from solid-state sources[6] with relative linewidths of about 10^{-12} produce subterahertz and terahertz radiation at a power level from hundreds of microwatts to a milliwatt. In contrast with sources mentioned above, gyrotrons can produce the power higher by many orders of magnitude.

From the theory of gyrotron operation it is well-known, that the output power and frequency depend on a number of parameters, including the magnetic field, the accelerating voltage, the beam current, and the electron pitch factor (velocity ratio); thus, the stability of the output parameters depends predominantly on the inevitable fluctuations caused by the high-voltage power supply. In IAP RAS experiment, the anode voltage variation was used as a way of frequency control and stabilization, since a low anode current reduces the power supply requirements and a small capacitance of the modulating anode relative to other electrodes increases the speed and performance of the control system.

The experiment on frequency stabilization was carried out using a continuous-wave (CW) gyrotron for spectroscopy and various media diagnostics operating at a frequency of 263 GHz and an output power of up to 1 kW with an electron beam formed by a triode-type magnetron injection gun and having an accelerating voltage of 15 kV and current of 0.4 A, respectively. The gyrotron was designed for operation with, a liquid helium-free cryomagnet (JASTEC JMTD-10T100), at the $TE_{5,3}$ mode of a cylindrical cavity. The internal mode converter transforms the operating mode into a Gaussian beam. A simplified experimental scheme is presented in Fig. 1.

The electron beam current chosen for the experiment was 0.2 A and the magnetic field was adjusted so as to set the output power at a level of 100 W as required by the envisaged spectroscopic technique. In the experiment, a phase-locked loop (PLL) method (Fig.2) has been used against the reference oscillator in order to control the gyrotron modulating anode voltage. A specially designed fast voltage control unit performed voltage modulation in a range of 1 kV with a speed better than 1 kV/μs. The voltage drop on the active element of the unit is proportional to the external control signal. Preliminary testing of the control system showed a modulation bandwidth of 150 kHz, defined by the time constant of the modulating anode circuit.

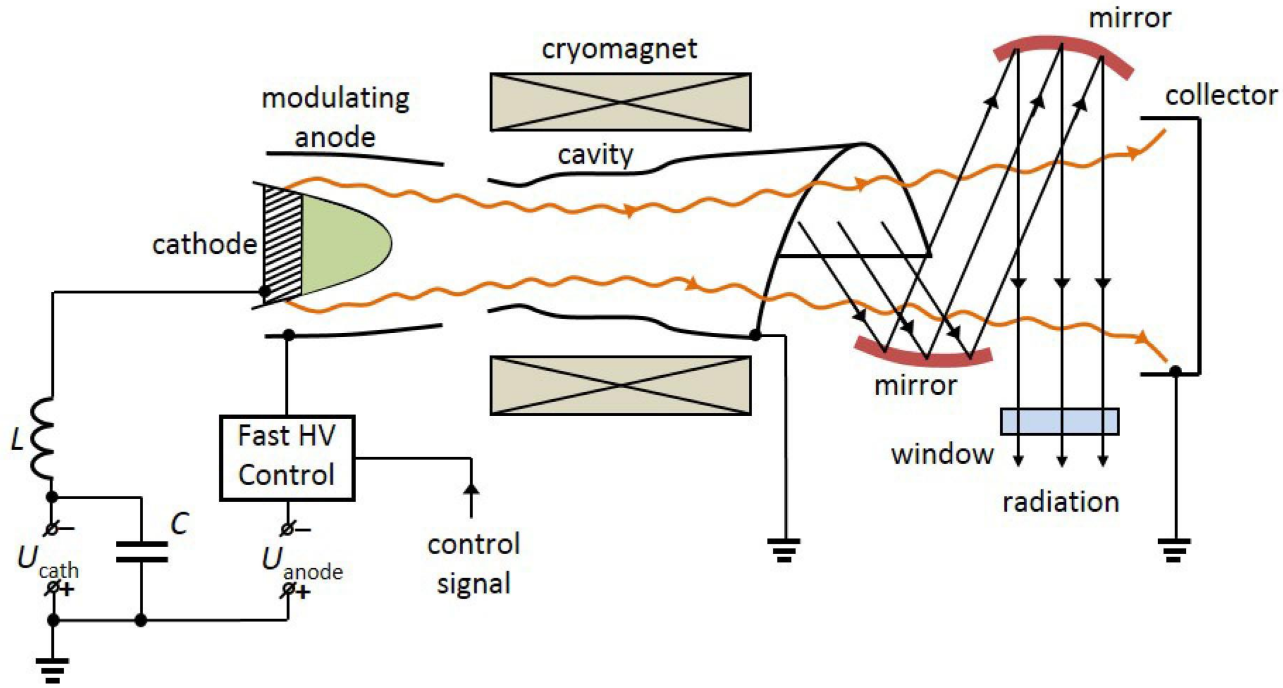


Fig.1. Scheme of the gyrotron and power supply connections

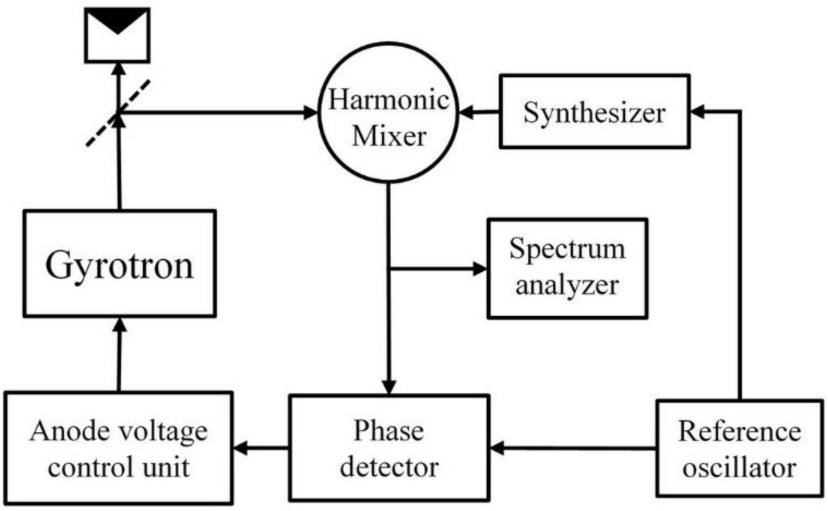


Fig.2. Block diagram of the phase-locked loop units for a sub-THz gyrotron

After applying the phase-locked loop, the width of the frequency spectrum was decreased from 0.5 MHz for a free-running gyrotron down to 1 Hz for the stabilized gyrotron, measured at the intermediate frequency IF = 350 MHz, which corresponds to $\Delta f\ /\ f\ = 3*10^{-12}$ with a measurement time of a few seconds (Fig. 3). The observed single-sideband (SSB) phase noise in the range 10-1000 Hz demonstrates a flat dependence on the offset and does not exceed -60 dBc.

The long-term frequency drift is defined by the stability of the reference oscillator ($\delta f/f \sim 10^{-9}$ for the quartz clock employed in the experiment) and can be improved by using another reference oscillator with better parameters (for example, a rubidium clock with $\delta f/f \sim 10^{-12}$). The output power fluctuations due to a change in the beam pitch factor by the modulating anode voltage were less than the uncertainty of the calorimetric system, and are at a level of $\Delta P\ /\ P = 1\%$.

In the experiment, we used the well-known principle of frequency stabilization. Although the concept of the stabilization scheme is similar to that employed in low-power devices such as a BWO, its realization is essentially different. In a BWO, the usual method of frequency control is based on the variation of the accelerating voltage, which for high-power devices like gyrotrons is a complex and rather slow method. The direct control of the cathode potential (as in a BWO) is impeded by the need to vary the parameters of the power supply with both a high voltage and a high current. Variation of the body voltage is slowed down by the relatively high capacitance of the gyrotron cavity relative to other parts; thus, such a method (Idehara, T., Mitsudo, S. & Ogawa, I. Development of High-Frequency, Highly Stable Gyrotrons as Millimeter to Submillimeter Wave Radiation Sources. *IEEE Trans. Plasma Sci.* **32,** 910–916 (2004)) has a significantly lower bandwidth.

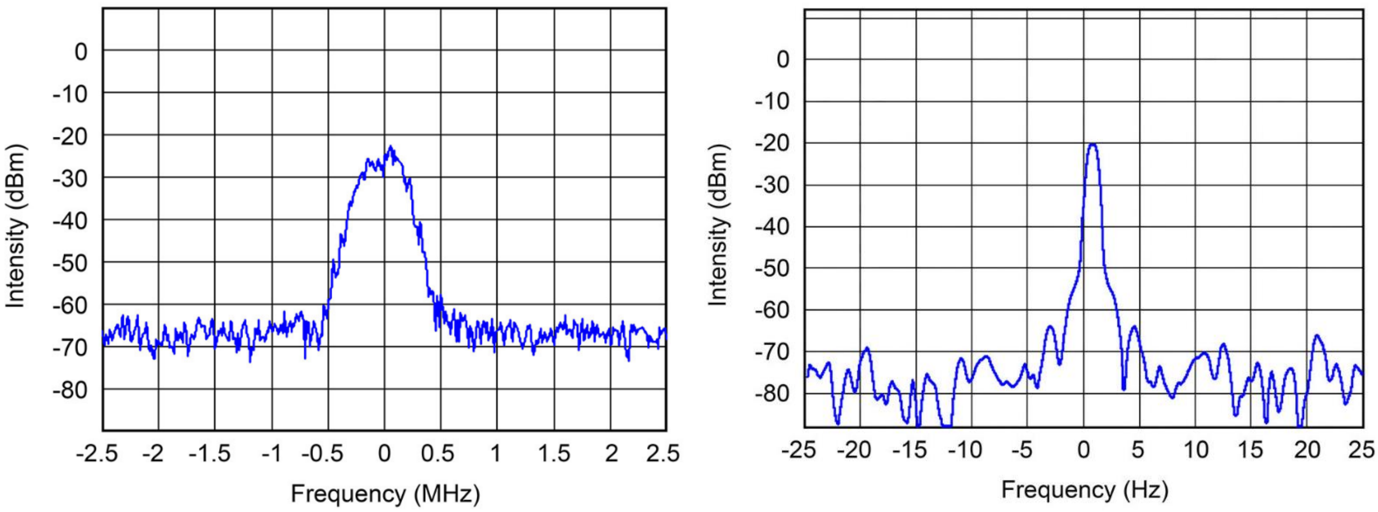


Fig.3. Experimental frequency spectrum of the free running gyrotron (left) and with phase-locked loop at an intermediate frequency with spans of 60 Hz (right)

To conclude, a phase locking of a 263 GHz gyrotron has been achieved with an output power of 100 W and a linewidth of 1 Hz, defined mostly by the bandwidth of our spectrum analyzer, for a PLL control bandwidth of 150 kHz. The technique takes advantage of the dependence of the resulting gyrotron frequency on the parameters of the electron beam modulated by an additional low-current anode and has no apparent limiting factors in terms of output power. From the point of view of the intended applications, we believe that such a spectral purity and low phase noise opens new prospects for using THz gyrotrons as new standard sources for spectroscopy. The capability of both the frequency and phase modulation of the stabilized gyrotron is appropriate also to other new applications, such as telecommunications and synchronization of a large number of high-power THz gyrotrons.

Acknowledgements

The source development and the arrangement of the experimental tests were supported by the Russian Science Foundation (RSF) under Project No. 14-12-00887.

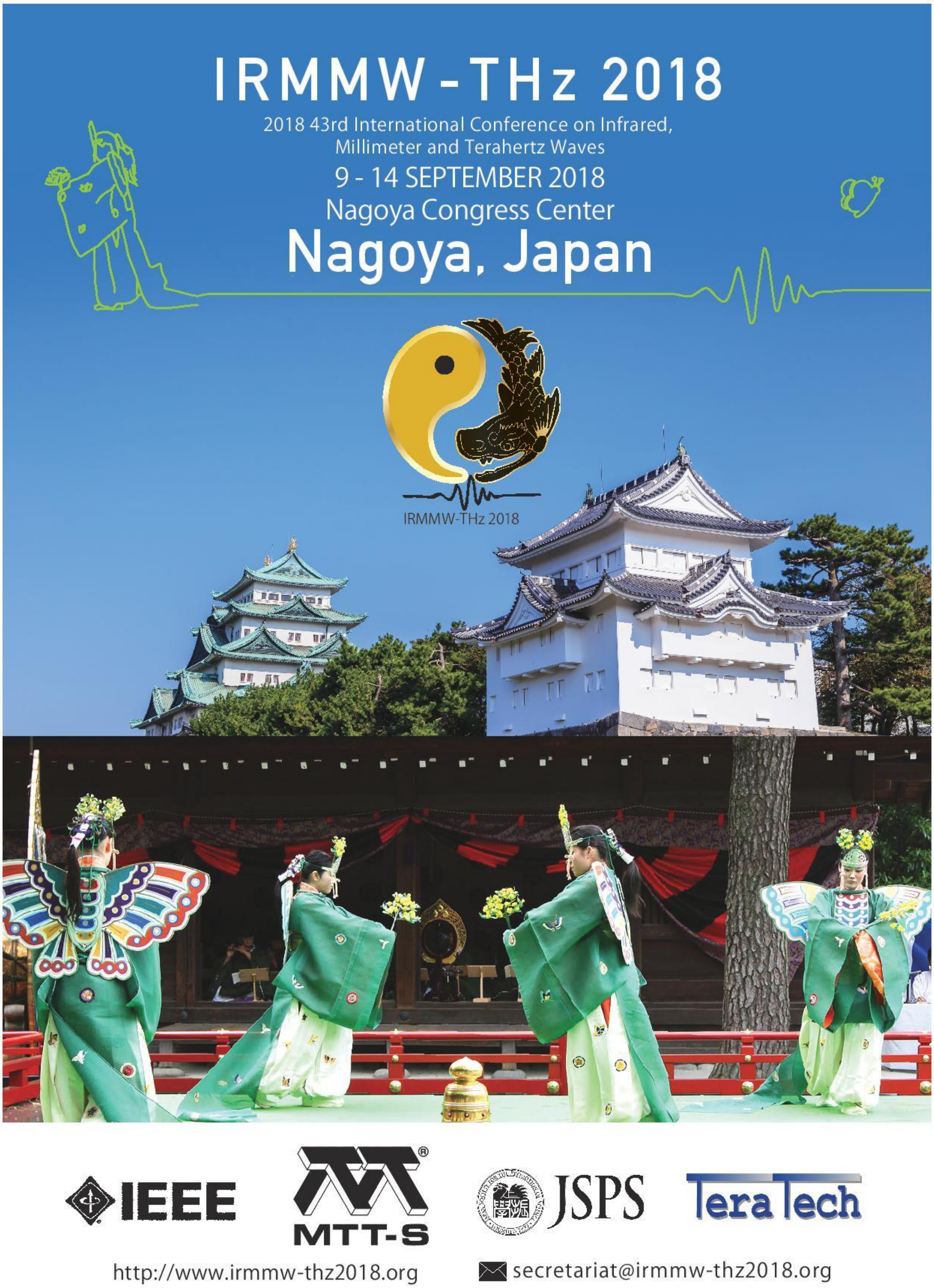
For additional information, please see the paper:

Fokin, M.Glyavin, G.Golubiatnikov, L.Lubyako, M.Morozkin, B.Movschevich, A.Tsvetkov, G.Denisov, “High power sub-terahertz microwave source with record frequency stability up to 1 Hz,” Scientific Reports 8, 4317 (2018) DOI:10.1038/s41598-018-22772-1.

This Open Access paper is available at the following link:

https://www.nature.com/articles/s41598-018-22772-1

NEXT IRMMW-THz CONFERENCE



For up-to-date information, registration, etc. follow the link to the website of [IRMMW-THz 2018]

IRMMW-THz 2018

2018 43rd International Conference on Infrared, Millimeter and Terahertz Waves

9 - 14 SEPTEMBER 2018

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OTHER CONFERENCES

TERA 2018

3rd International Conference

Terahertz and Microwave Radiation: Generation, Detection and Applications

http://tera2018.ipfran.ru

October 22 – 25, 2018

Institute of Applied Physics of the Russian Academy of Sciences
46 Ulyanov Street · 603950 · Nizhny Novgorod · Russia

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TERA-2018 conference is devoted to the discussion of fundamental and applied problems related to the generation and detection of terahertz and microwave radiation as well as its interaction with matter.

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Sections

- **Electronic sources of THz & MW radiation, synchrotron radiation, free-electron lasers.**
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- **Generation of THz radiation by intense laser pulses.**
- **Quantum cascade lasers.**
- **Detection of THz & MW radiation. Metrology in THz frequency range.**
- **Study of materials (including nano- and metamaterials) with the help of THz & MW radiation. Time-domain and CW spectroscopy.**
- **Interaction of high-power THz and MW radiation with matter. Application of THz radiation for the research and control of ultrafast process in physics, chemistry and biology.**
- **Terahertz & microwave imaging: tomography, holography and near-field microscopy.**
- **Systems of security and non-destructive control using THz and MW radiation. Remote sensing with THz radiation. Communication in THz frequency range.**
- **Medical and biological applications of THz radiation.**

Institute of Applied Physics RAS
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For more information please visit the site of the conference here

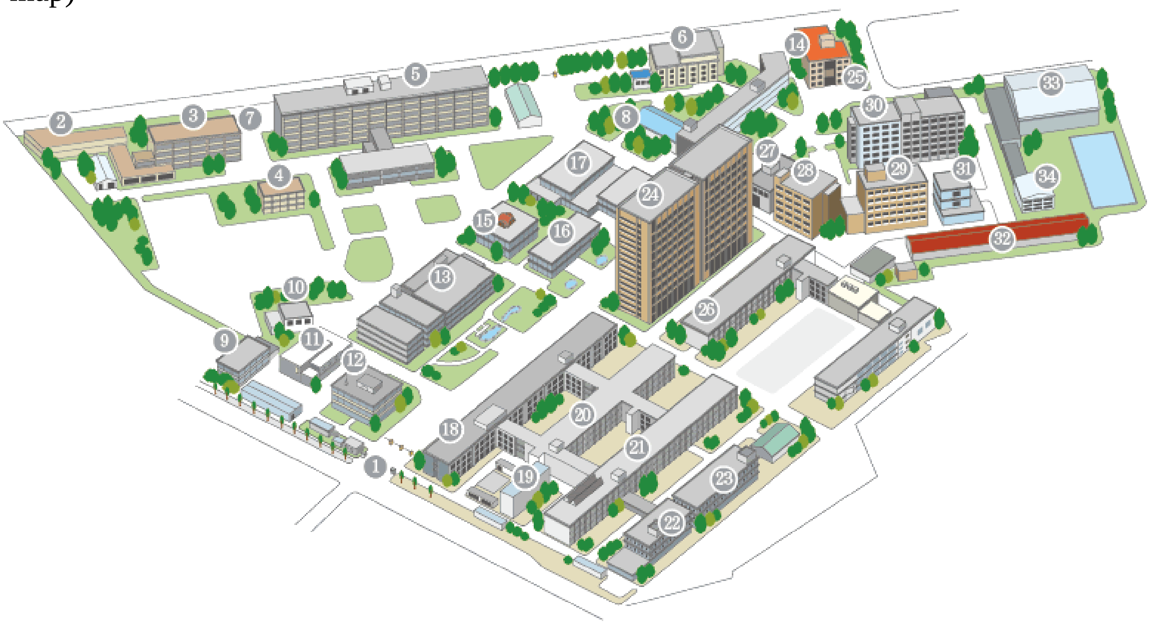
IW-FIRT 2019

The 7th International Workshop on Far-Infrared Technologies (IW-FIRT 2019)
(5-7 March, 2019, University of Fukui, Fukui, Japan)

The International Workshops on Far-Infrared Technologies (IW-FIRT) has been held six times in the past from 1999 to 2017. In these workshops it was aimed to discuss the recent development and future directions of far-infrared and terahertz science and technologies with a special emphasis on high power radiation sources in this frequency region and their applications. We feel that it is the time to organize the next IW-FIRT to update our knowledge and understanding in this rapidly developing field. Therefore, we organize the Seventh International Workshop on Far-Infrared Technologies (IW-FIRT 2019).
The workshop consists of invited talks, oral presentations and a poster session with the following scope of topics:
1) Development of high power radiation sources in the far-infrared region,
2) Application of high power terahertz technologies especially to the following topics
  2-1) Terahertz spectroscopy,
  2-2) Magnetic resonance phenomena in the far-infrared region,
  2-3) Material development with high-power FIR sources, and
3) Other subjects related to the far-infrared region.

Past Workshops of IW-FIRT and DHP-TST:
6th IW-FIRT 2017 and DHP-TST 2017, 5th IW-FIRT 2014, 4th IW-FIRT 2012, 3rd IW-FIRT 2010, and DHP-TST 2013.

Venue: Bunkyo Campus, University of Fukui (Fukui, Japan). Main conference room and poster session: On the 13th floor of the Science Tower I (No.24 in the campus map). Workshop banquet: At the academy hall (No.11 in the campus map)



For up-to-date information please visit the link.

LIST OF SELECTED RECENT PUBLICATIONS

Bibliography and links to selected recent publications on topics related to the research field of the International Consortium and published after February 2018, i.e. after issuing the previous Newsletter #9. This cumulative list is in chronological order as collected from various bibliographical and alert services

A. Publications by authors from the institutions participating in the International Consortium

Abubakirov E.B., Guznov Y.M., Kuzikov S.V., Shevchenko A.S., Vikharev A.A., Zapevalov S.A., "Quasi-Optical Input Mode Coupler for a Ka-Band Multimegawatt Gyroklystron," IEEE Trans. on Microwave Theory and Techniques, (2017) pp. 1-6. DOI:10.1109/TMTT.2017.2772917.

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Radiation sensor apparatus
Inventors: Vadim Yevgenyevich Banine, Gerrit Jacobus Hendrik (BRUSSAARD) Willem Jakobus Cornelis (KOPPERTOtger), Jan Luiten Han-Kwang (NienhuysJob) Beckers Ruud Martinus (VAN DER HORST)
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Publication date: 1 Mar 2018
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Inventor: Martin Hempstead
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Publication date: 22 Mar 2018
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Inventor: Edl Schamiloglu, Mikhail I. Fuks
US20180082817A1 Application
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MAS stator of an NMR probe head with optimized microwave irradiation
Inventor: Armin Purea, Arndt von Bieren
US20180113183A1 Application
Publication date: 26 Apr 2018
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Control of microwave source efficiency in a microwave heating apparatus
Inventor: Ulf Nordh, Hakan Carlsson, Olle Niklasson, Fredrik Hallgren
US20180132311A1 Application
Publication date: 10 May 2018
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Inventor: Yu.V. Rodin, A.V. Palitsin
№218.016.413b (Russian patent)
Publication date:10 May 2018
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Method and system for generating and detecting centimeter, millimeter or sub-millimetre electromagnetic waves and especially terahertz electromagnetic waves
Inventor: Al Hadi, Richard (Ramonville-Saint-Agne, FR)
United States Patent Application 20180128900
Publication date:10 May 2018
http://www.freepatentsonline.com/y2018/0128900.html
Apparatus and method for providing terahertz waves
Inventor: Kyung Hyun Park, Il Min LEE, Eui Su LEE, Ho Jin Lee, Sang Pil HAN, Hyun Soo Kim, Ki Won Moon, Dong Woo Park
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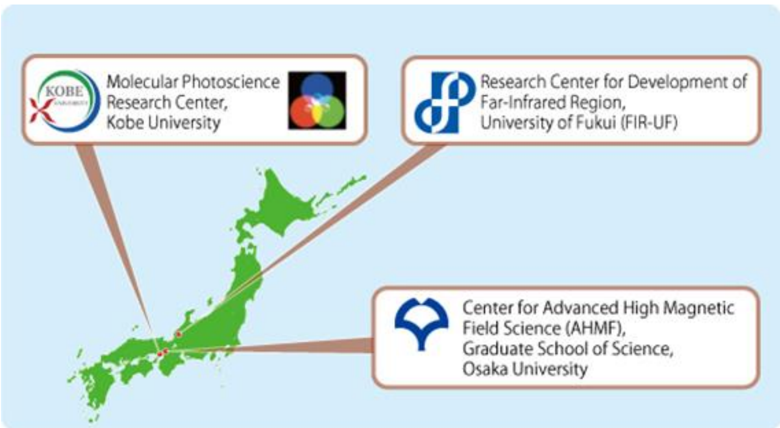
RECENT ACTIVITIES OF COFUC

COFUC Network is a Center of Excellence (COE) in western part of Japan (Kobe・Osaka・Fukui), which aims to enhance the research on pulsed high magnetic field. It has been established by the Molecular Photoscience Research Center (Kobe University), the Center for Advanced High Magnetic Field Science (Osaka University), and the Research Center for Development of Far-infrared Region (University of Fukui).



The 4th Introductory Workshop for High Magnetic Field Experiments was held on 18 May 2018 at Machikaneyama Facility （Toyonaka Campus), Osaka University. The opening and the closing talks have been presented by Professor Seitaro Mitsudo from the FIR UF Research Center. The program of the workshop is available at the following link.

NEWS FROM THE NET (OUR BROADER HORIZONS)

RECENT PROGRES ON THE DEVELOPMENT OF GYROTRONS FOR FUSION

The year of the gyrotron

Powerful (megawatt class) gyrotrons are being developed for electron cyclotron resonance heating (ECRH) of magnetically confined plasma, electron cyclotron resonance current drive (ECRCD), plasma initiation (startup) as well as for plasma diagnostics and stabilization in various reactors for controlled thermonuclear fusion (most notably for ITER and its successor DEMO). On 26 Feb, 2018 Krista Dulon posted a note in the ITER NEWSLINE that proclaims the current year as "The year of the gyrotron". The rationale for this is the remarkable resent progress in the development of gyrotrons in the framework of the European gyrotron program, which is focused on the production of 1 MW prototype for the second plasma phase at ITER, where a total power of 20MW of injected power is required. For First Plasma in 2025, the installed ECRH system will include eight gyrotrons (four from Japan and four from Russia) and 4 sets of high-voltage power supplies (two from Europe and two from India).

European gyrotron (1 MW prototype) for ITER (Image courtesy ITER)

The European 1 MW prototype (pictured above) operates routinely at a frequency of 170 GHz for periods of 1000 seconds. From the Radio Frequency Building where the gyrotrons are located, the generated microwave beams will be transmitted through a 160 meters long microwave waveguides to launchers at the equatorial and upper levels of the vacuum vessel.

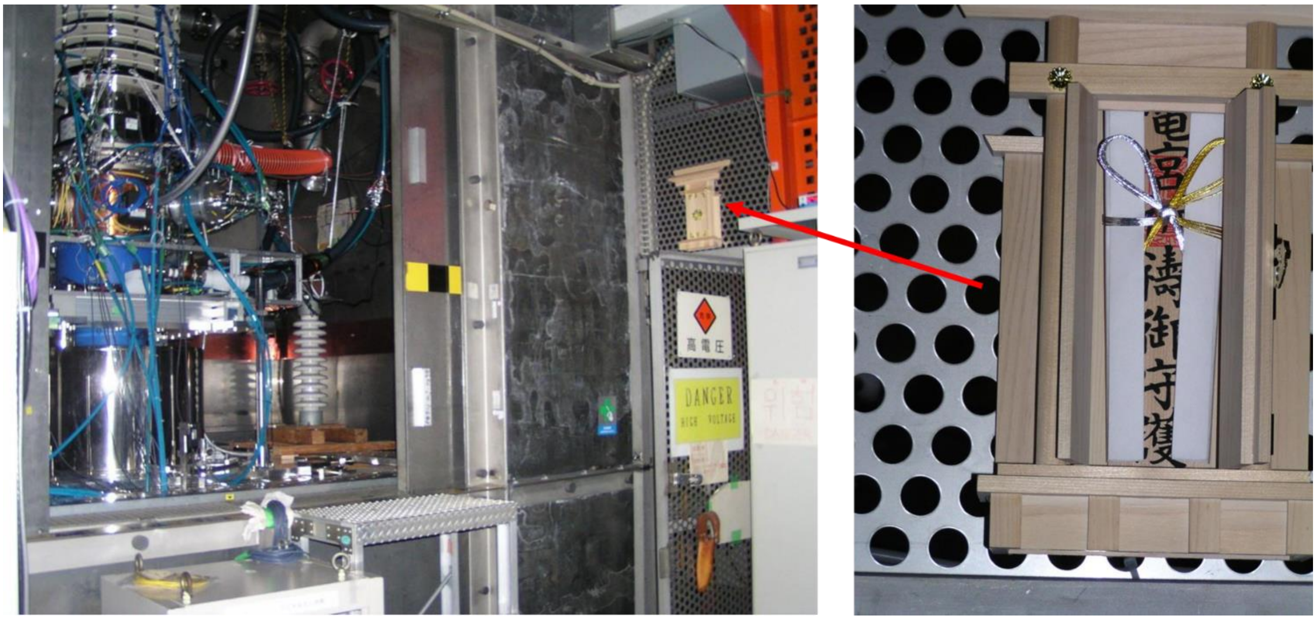
The first gyrotron units have already been completed in Japan and Russia and final testing is underway. By the end of 2018 factory acceptance tests will have concluded on two gyrotron units in Japan, two units in Russia, and power supplies in Europe. The Russian gyrotron (shown in the photo below) is installed at the gyrotron test bench of the Swiss Plasma Center in Lausanne, Switzerland. Equivalent to the gyrotrons manufactured in Russia for ITER, the production module was purchased by Europe to test upper launcher components and is available to other ITER partners for testing waveguide components.

Five ITER members are participating in the procurement of the electron cyclotron system at ITER: Europe (6 gyrotrons, 12 power supplies, 4 upper launchers), India (2 gyrotrons, 4 power supplies), Japan (8 gyrotrons, 1 equatorial launcher), Russia (8 gyrotrons), and the United States (all transmission lines). Installation activities are planned to start in 2020 for the eight gyrotron units needed for ITER's First Plasma; (16 others units will be installed at a later assembly phase).

Russian 1 MW gyrotron at Swiss Plasma Center (image courtesy ITER)

This first Russian gyrotron unit is one of two undergoing factory acceptance testing at GYCOM, in Nizhny Novgorod. After the tests conclude in 2018, the units will be stored until the Radio Frequency Building is ready to receive them.

The Japanese Domestic Agency will supply a total of eight gyrotron units to ITER. Contractor Toshiba has manufactured the two first production units, which are undergoing testing now at The National Institutes for Quantum and Radiological Science and Technology (QST).



Japanese ITER gyrotron and its God blessing (original images courtesy ITER)

In her posting, Krista Dulon tells the following interesting story: “Prior to starting the Toshiba gyrotron at QST, one scientist visited a local Shinto shrine to receive the blessing from the patron saint of radio frequency devices. The blessing is manifested in the above plaque that is kept near the gyrotron test stand at all times.” (You can also see it also in the left image if you look carefully.)

Please visit the original article of the ITER Newsline following the link.

Gyrotron power supplies pass muster in Europe

The ITER Newsline of 9 April 2018 reports that the first power supply units produced in Europe for ITER's microwave plasma heating system have successfully passed factory acceptance tests. In ITER, 12 high voltage power supplies will convert grid voltage to the high voltage levels required by ITER's electron cyclotron heating system (ECRH). Europe, which is responsible for the supply of eight of these, has contracted with the Swiss company Ampegon for the design and fabrication of the equipment. Ampegon will produce eight main high voltage power supplies (55 kV/110 A) and 16 body power supplies (35 kV/100 mA).

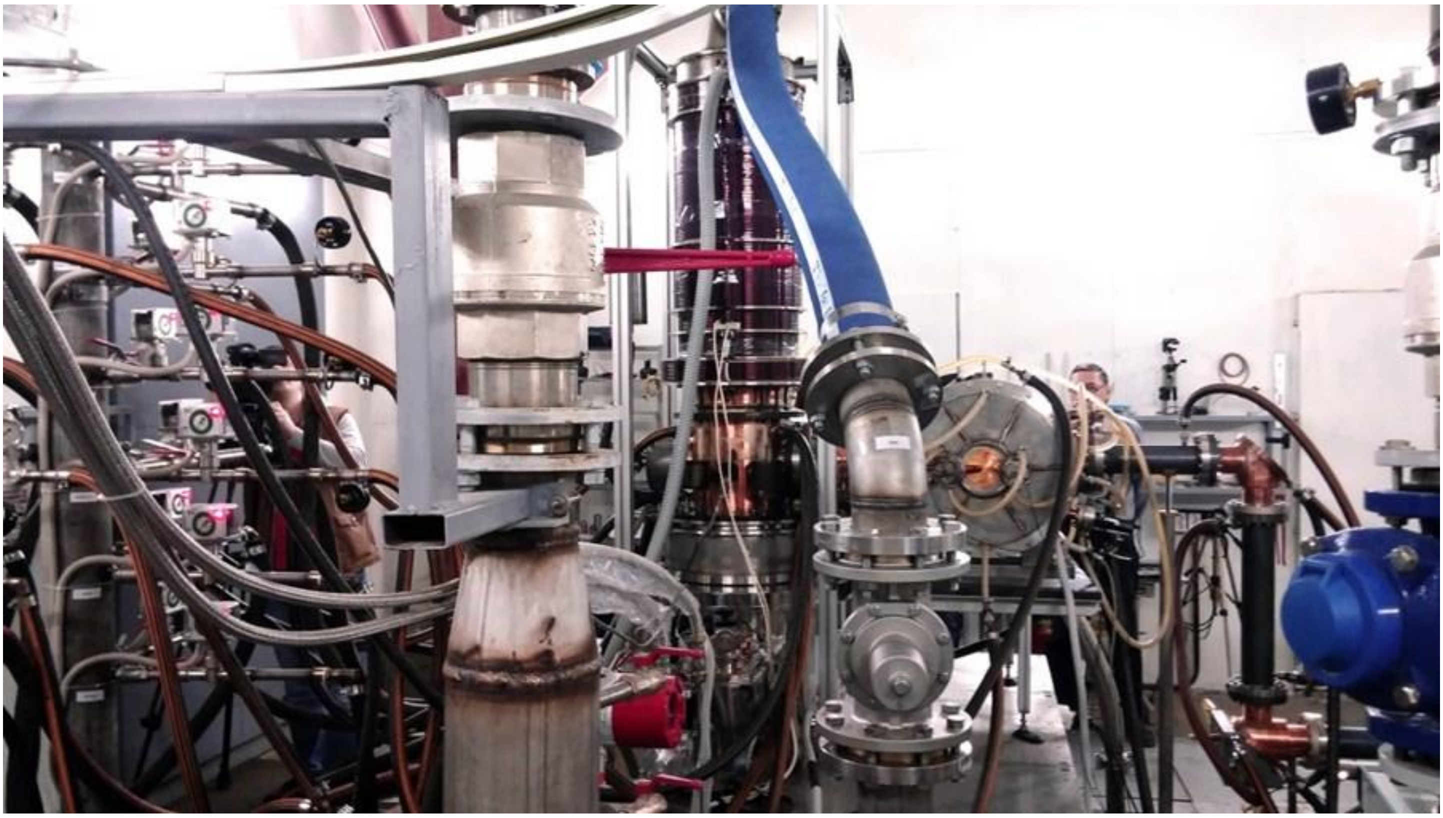
Factory acceptance tests of the high-voltage power supply systems (image courtesy to ITER)

The high voltage supply units are powerful indeed. The eight units alone could provide sufficient household electricity for a city of 270,000 inhabitants. The electricity generated by these units will feed into the ECRH, which is one Plasma heating of three external heating systems that will bring the ITER plasma to temperatures allowing for fusion to occur. The 24 gyrotrons at the core of the ECRH system will generate strong electromagnetic waves—not unlike a powerful microwave oven—which will be guided to the vacuum chamber, where they transfer their energy to the plasma particles and heat them. During the factory acceptance tests the power supply units exceeded expectations, according to Ferran Albajar, who is in charge of gyrotrons at the European Domestic Agency. The production of the remaining units will be completed in 2020.

Please visit the original article of the ITER Newsline following the link.
Please see the full report on the European Domestic Agency website.

Successful acceptance tests of the second Russian ITER gyrotron

In the ITER Newsline of 4 June 2018, Alexander Petrov (ITER Russia) reported that in mid-May, factory acceptance tests were successfully carried out on the second gyrotron of the Russian procurement program by specialists at the Institute of Applied Physics and GYCOM Ltd.



The second Russian gyrotron for ITER during the acceptance tests (image courtesy ITER)

The author of the report recollects that the first gyrotron was developed at the Institute of Applied Physics (Russian Academy of Sciences) back in 1964, generating 6W at 10 GHz for continuous operation. Since then, scientists around the world have steadily increased gyrotron output power and, today, ITER needs are driving the program. The tests conducted on the second gyrotron manufactured in Russia demonstrated full compliance with ITER Organization technical requirements (1 MW power at the required 170 GHz in continuous mode).

Please visit the original issue of the ITER Newsline following the link.

Electromagnetic doughnuts - short bursts of electromagnetic energy propagating in free space at the speed of light

In a recent paper by N. Papasimakis et al., published in Phys. Rev. B, the authors have proposed a metamaterials-based scheme to realize flying electromagnetic doughnuts, a theoretical solution to Maxwell's equations that's never been achieved experimentally. Besides the well-known plane-wave solutions to the Maxwell's equation there are also rather exotic solutions (obtained theoretically more than 20 years ago) in the form of short pulses with a toroidal, or doughnut-like, shape that would propagate in free space, and that include a strong electromagnetic-field component in the direction of propagation rather than transverse to it (as in the ordinary transverse electromagnetic waves).

For a popular description of the promising features of the electromagnetic doughnuts and their expected application please read the article "A Recipe for Flying Electromagnetic Doughnuts" by Stewart Wills, at the website Optics&Photonics News following the link.

Papasimakis N., Raybould T., Fedotov V., Tsai D., Youngs I., Zheludev N.I., “Pulse generation scheme for flying electromagnetic doughnuts,” Phys. Rev. B, vol. 97, n. 20 (2018) 201409. DOI:10.1103/PhysRevB.97.201409.

The original paper is available at: https://journals.aps.org/prb/abstract/10.1103/PhysRevB.97.201409

Manipulating all kinds of waves by metamaterials

In an article published on 5 March 2018, the scientists from Duke’s Center for Metamaterials and Integrated Plasmonics (CMIP) discuss a number of amazing properties of novel metamaterials that can be used for manipulation of various waves. They explain several projects in which such metamaterials are used to manipulate electromagnetic waves in the terahertz region of the spectrum. Among the foreseen applications are imaging devices that can identify thousands of plants and minerals, diagnose cancerous melanomas and predict weather patterns, simply by the spectrum of light they reflect. Moreover, the Duke’s researchers have shown that metamaterials can be used not only for manipulation of electromagnetic waves but of acoustic waves as well, i.e. to control the propagation of sound. The team even built a wall of such blocks carefully tailored to sculpt a sound wave into an arbitrarily shaped hologram, a shaped sound.

Please read the original article entitled “Metamaterials bend waves of all kinds” at this link.

Simple and efficient approach to the visualization of terahertz radiation

Recently, L.L. Slocombe and R.A. Lewis have compared in detail two methods, namely electrical and optical, of detecting THz radiation using neon lamps. They are based on the fact that the terahertz radiation impinging on a lit neon tube causes additional ionization of the encapsulated gas. As a result, the electrical current flowing between the electrodes increases and the glow discharge in the tube brightens. The authors show that these dual phenomena suggest two distinct modes of terahertz sensing. The electrical mode simply involves measuring the electrical current while the optical mode involves monitoring the brightness of the weakly ionized plasma glow discharge. These two detection modes are compared directly under identical experimental conditions measuring 0.1 THz radiation modulated at frequencies in the range 0.1–10 kHz, for lamp currents in the range 1–10 mA. It has been found that electrical detection provides a superior signal-to-noise ratio while optical detection has a faster response. Either method serves as the basis of a compact, robust, and inexpensive room-temperature detector of terahertz radiation.

L.L. Slocombe, R.A. Lewis, “Electrical Versus Optical: Comparing Methods for Detecting Terahertz Radiation Using Neon Lamps,” Journal of Infrared, Millimeter, and Terahertz Waves (published online on 18 May 2018). DOI: 10.1007/s10762-018-0495-1.

The original paper is available here.

Plasmon Enhanced Terahertz Electron Paramagnetic Resonance — PETER

A new Horizon2020 project, which is described as highly original, visionary, essential for society's needs and development has just been started by an international scientific consortium. With a budget of 2.89 mil. EUR the project will focus on the unique innovation of electron paramagnetic resonance (EPR) also known as electron spin resonance (ESR). The goals of the project are: (i) establishing a brand novel terahertz-frequency EPR micro-spectroscopic technique based on a combination of plasmonic-based magnetic field enhancement and scanning probe microscopy; (ii) Realization of THz EPR micro-spectroscope that offers unprecedented sensitivity (several orders higher than conventional EPR instruments) and spatial resolution below 1 μm (approx. 1/300th of used wavelength).

In contrast to usual THz plasmon-enhanced spectroscopy of nonmagnetic materials, the novel approach is based on magnetic plasmonic resonances. This presents unprecedented implementation of plasmonic phenomena into EPR technique. In particular, this project introduces for the first time plasmonic effects into the THz EPR.

It is expected that such advanced technique will open new possibilities to in-situ study of wide variety of materials for scientific, technological and medical purposes.

For more information on the project please visit the link.

Damage in a Thin Metal Film by High-Power Terahertz Radiation

Researchers from the Russian Joint Institute for High Temperatures of the Russian Academy of Sciences (JIHT RAS) were the first in the world to conduct an experiment in which the destruction of a thin metal film was observed under the influence of a strong terahertz radiation with a wavelength of the order of fractions of a millimeter. A unique terahertz laser was used to create an electromagnetic field with an intensity of up to 100 million volts per centimeter. The electromagnetic waves of the terahertz range decay very rapidly in the metal, so it is very difficult to destroy any metal in this way. In the experiment, the researchers used a thin metal film of aluminum and sent single terahertz pulses to the plate, gradually increasing their power. When a certain threshold value is reached, a high-power pulse has made a through hole in the metal. Additionally, they have found that multiple irradiation with pulses with a power less than the threshold value did not penetrate the metal, however, cause damage, the nature of which remains to be studied. Such amazing results were observed for the first time. The authors believe that their results will open the way for new experimental and theoretical studies on the interaction of strong THz waves with different metallic materials and to new applications in photonics, biology, medicine, and materials science.

M.B. Agranat, O.V. Chefonov, A.V. Ovchinnikov S I. Ashitkov, and V. E. Fortov, “Damage in a Thin Metal Film by High-Power Terahertz Radiation,” Phys. Rev. Lett., vol. 120 (2018) 085704. DOI: 10.1103/PhysRevLett.120.085704.

The above paper is available at the link.