Sub-THz Technologies State-of-the-Art

Yevhen Yashchyshyn, Anna Urzędowska, Konrad Godziszewski

Abstract - **In this paper the introduction to the sub-THz technologies is presented. Many aspects of the sub-THz measurement techniques are reviewed and compared. A unique laboratory of Institute of Radioelectronics at Warsaw University of Technology equipped with the VNA with Frequency Extenders up to 500 GHz is demonstrated.**

Keywords – **sub-THz frequency band, measurement technologies.**

I. STATE-OF-THE-ART

In recent years the attention of scientists is focused on researching in the very high frequency band ranging up to terahertz frequencies. This is related to the enormous possibilities offered by this range of the electromagnetic spectrum including research areas as imaging, material characterization, quality of goods, security systems or high data rate transmission systems [1, 2, 3]. There are already known commercial solutions such as terahertz scanners at airports which allow to detect objects hidden under clothing (especially hazardous to human health and life). If the objects are made of non-metallic materials, they are impossible to be detected by conventional metal detectors. But when a passenger is illuminated by terahertz radiation, they can be completely recognized and visualized with high resolution. In addition, preliminary studies have shown no harmful effects of such waves on living organisms (terahertz radiation is non-ionizing). From the standpoint of the theory of the universe, detection and analysis of residual radiation also becomes important. Maximum energy density of the radiation occurs at a wavelength of 1.1 mm (300 GHz – sub-terahertz range). A key aspect is the ability to design very sensitive and low-noise receivers of this radiation with special emphasis on the terahertz antennas.

The considered areas of application of terahertz waves directly result from their specific and unique properties [4, 5]. Waves in the band between the optical and radio range penetrate through e.g. synthetic materials, textiles, paper. However many biomolecules, proteins, explosives, drugs and water, absorb certain frequencies, creating characteristic absorption lines, so called "spectral lines". Strong absorption of terahertz waves by water vapor on the one hand limits the transmission range, on the other enables accurate and precise measurement of humidity. Liquid water is even stronger absorber for considered electromagnetic spectrum. To make advantage of the radiation of terahertz waves efficient techniques for generation and detection of these waves are required. The two main methods of generation of terahertz radiation are: solid-state electronics method and optical method [4, 6]. In the solid-state electronics to produce an efficient source of terahertz radiation, it is necessary to use semiconductor with specific parameters such as: high electron mobility, high breakdown voltage, low dark current and fast recombination of carriers. Only a few of the available semiconductors meet these requirements. Therefore, the most commonly used are multi-layer structures. In addition, transmitters are mostly equipped with a focusing lens. In the case of optical methods primarily phenomena occurring in nonlinear crystals are used. One possibility is a frequency mixing of two beams of monochromatic radiation. This method allows the generation of terahertz radiation in continuous mode, but requires the use of two lasers. These lasers must have narrow spectral lines and work on stable and controlled frequencies. The second way is an optical rectification, which is based on the use of very short pulses focused in the crystal structure [7]. This solution is easy to implement, but due to the pulse operation the radiation has limited power and a broad spectrum. In the case of detection of terahertz signal we can distinguish two main methods: coherent and incoherent. Coherent methods are closely associated with generation techniques and allow measuring both amplitude and phase. However incoherent methods only allow detecting the amplitude of the signal. Specific solutions for incoherent detection are Schottky diodes or thermal sensors such as bolometers well known from the lower frequency bands [8].

An essential part of any transmitter or receiver in every wireless system is antenna. There are lots of structurally different antenna solutions for a range of terahertz waves known from the literature [9]. Widely used types of antennas are planar antennas constructed on a dielectric substrate. The main reasons for this are their small size, light weight and easy integration with transmitter or receiver circuits. The problem arises when we need to verify the designed antennas' parameters. Most publications on this topic are based only on the electromagnetic simulation results due to lack of suitable measuring equipment [10]. Simulating dielectric planar antennas for very high frequencies may be inadequate to the real conditions, since it does not take into account e.g. heterogeneity of material, whose size may be comparable with the operating wavelength. Another problem with experimental verification of designed antennas is related to effective transmission of electromagnetic waves between the waveguide, which is provided in most high frequency measuring equipment, and feeding line of the traditional microstrip antenna [11, 12, 13]. It can be solved by designing appropriate transitions between waveguides and those transmission lines. There are many different solutions described in the literature, but there are no comprehensive studies on the behavior of such structures in a wide frequency range.

It is also necessary to provide new methods and use appropriate measuring equipment in the field of radiation of terahertz waves [14, 15]. Metrological aspects in a given

---

Yevhen Yashchyshyn, Anna Urzędowska, Konrad Godziszewski – Warsaw University of Technology, Nowowiejska 15/19, 00-665 Warsaw, Poland. E-mail: {e.jaszczyszyn, a.urzedowska, k.godziszewski} @ire.pw.edu.pl

band can be divided into three main groups: power measurements, measurements of scattering matrix parameters and measurements of antennas [16, 17, 18]. In some applications the power measurements are sufficient. More advanced systems, however, require the measurement of both amplitude and phase of the transmitted signal. For this purpose it is necessary to use e.g. a Vector Network Analyzer (VNA). Commercially available analyzers do not allow for direct work with signals in the terahertz band. However, frequency range can be extended by using frequency extenders designed for standardized bands of metallic waveguides.

A number of antenna metrology difficulties are present in the sub-THz frequency range. The reason is the lack of high power sources, high noise level receivers and high free space propagation losses. Both microwave and quasi-optical methods can be suitable at the sub-THz band. In general, the sub-system for antenna measurement should be consisted of high-stability sub-THz source of sufficient power and low-noise receiver. The mentioned receiver very often is built either as a direct detector or as a heterodyne one. The sub-system can operate at narrowband or broadband depends on appropriate sub-THz sources. In case when used sub-THz sources are unmodulated then either an external mechanical chopper or internal Dicke switch should be used at the very front end. Antennas designed for millimeter and sub-terahertz range are often integrated with electronic elements on a dielectric substrate and fed by planar lines (microstrip, coplanar, SIW). To experimentally verify the performance of manufactured antenna, it is necessary to develop transitions between these lines and rectangular waveguides used in measuring equipment.

Institute of Radioelectronics at Warsaw University of Technology has an anechoic chamber equipped with necessary devices for measurements at frequencies up to 50 GHz. It allows carrying out measurements of the spatial distributions of electromagnetic field, scattering matrix measurements and antenna parameters in this spectral range. Since recently, the Institute has been equipped in a unique test set consisting of a VNA *PNA-X* from *Agilent Technologies*, with 6 pairs of VDI frequency extenders [19]. The VDI's VNA Extenders expand the range of current commercial 4-port VNAs to the 500 GHz range while maintaining high dynamic range (100 dB). The frequency multipliers and frequency mixers are the key technology. These VNA extenders allow to design systems and make measurements that were scarcely possible recently.

II. CONCLUSION

In this paper the introduction to the many aspects of the sub-THz measurement technologies are presented. A unique laboratory of Institute of Radioelectronics at Warsaw University of Technology equipped with the VNA with Frequency Extenders up to 500 GHz is also discribed.

REFERENCES

[1] S. Dexheimer: "Terahertz Spectroscopy: Principles and Applications", CRC Press, 2008.

[2] M. C. Kemp, P. F. Taday, B. E. Cole, J. A. Cluff, A. J. Fitzgerald, W. R. Tribe, "Security applications of terahertz technology", in *Conf. Proc. Terahertz for Military and Security Applications*, 21 Apr., 2003, pp. 44-52.

[3] P. U. Jepsen, D. G. Cooke , M. Koch: "Terahertz spectroscopy and imaging – Modern techniques and applications", *Laser Photonics rev. 5*, no. 1, pp. 124–166

[4] Y-S. Lee: "Principles of Terahertz Science and Technology", Springer, 2009.

[5] X-C. Zhang, J. Xu: "Introduction to THz Wave Photonics", Springer, 2010.

[6] J. Hesler, D. Porterfield, W. Bishop, T. Crowe, A. Baryshev, R. Hesper, J. Baselmans, "Development and Characterization of an Easy-to-Use THz Source", *16th Int. Symp. Space Terahertz Techn.*, 3 May, 2005.

[7] N. C. J. van der Valk: "Towards terahertz microscopy", Ph.D. Thesis, Delft University of Technology, 2005.

[8] J. L. Hesler, L. Liub, H. Xub, Y. Duana, R. M. Weikle: "The Development of Quasi-Optical THz Detectors", in *Conf. Proc. IRMMW-THz*, 15-19 Sep. 2008, pp. 1-2.

[9] D. Liu, B. Gaucher, U. Pfeiffer, J. Grzyb: "Advanced Milimiter-wave Technologies", Wiley, 2009.

[10] Z. Lukes, J. Lacik, Z. Raida: "Linearly Tapered Slotline Antenna Array for Quasi-optical Molecular Spectroscopy", *Microwave and Optical Technology Letters*, vol. 52, no. 5, May 2010, pp. 1043-1046.

[11] K. Seo, A. Nakatsu, K. Sakakibara, N. Kikuma: "Via-hole-less planar microstrip-to-waveguide transition in millimeter-wave band", in *Microwave Conf. Proc. CJMW*, 20-22 Apr. 2011, pp. 1-4.

[12] L. Lin, C. Xiaoping, R. Khazaka, W. Ke: "A transition from substrate integrated waveguide (SIW) to rectangular waveguide", in *Microwave Conf. Proc.* , 7-10 Dec. 2009, pp. 2605-2608.

[13] L. Yuan, P. Bo, M. M. Tentzeris, J. Papapolymerou: "A Fully Micromachined W-Band Coplanar Waveguide to Rectangular Waveguide Transition", in *Proc. of IEEE/MTT-S International Microwave Symposium*, 3-8 June 2007, pp. 1031-1034.

[14] Z. Popovic, E. N. Grossman: "THz Metrology and Instrumentation", *IEEE Transactions on Terahertz Science and Technology*, vol. 1, no. 1, Sep 2011, pp. 133-144.

[15] D. S. Kurtz, T. W. Crowe, J. L. Hesler, D. W. Porterfield: "Frequency Domain Terahertz Spectroscopy", in *Conf. Proc. IRMMW-THz*, 19-23 Sep. 2005, pp. 76-77.

[16] K. Moon, E. Jung, M. Lim, Y. Do, and H. Han: "Terahertz Near-Field Microscope: Analysis and Measurements of Scattering Signals", *IEEE Transactions on Terahertz Science and Technology*, vol. 1, no. 1, Sep. 2011, pp. 164-168.