Guest Editorial: Selected papers from the 10th UK-Europe-China Workshop on Millimetre-waves and Terahertz Technologies (UCMMT)

The UK-Europe-China Workshop on Millimetre-waves and Terahertz Technologies (UCMMT) is run annually, alternating between Europe and China. It is now well established and has become a special international forum for exchange of ideas on state-of-the-art research in millimetre-wave and terahertz science and technologies. The 10th UCMMT was organised by the University of Liverpool, UK, co-sponsored by the IET and IEEE (Photonics Society and Microwave Theory and Techniques Society), and held in Liverpool in September 2017. About 100 papers were presented covering a wide range of topics with an attendance of 150 people from 15 countries. Following the successful conclusion of UCMMT 2017, the authors of selected papers were invited to submit their extended papers for inclusion in a Special Section of IET Microwaves, Antennas & Propagation. After a rigorous and independent peer review process, six papers were selected to publish in this Special Section.

Millimetre-wave and terahertz science and technologies have become a very hot topic which has been driven mainly by industrial applications in areas such as space, security and wireless communications (especially 5G mobile communications). This trend is set to continue for the foreseeable future. It is not possible to provide comprehensive coverage of this subject area in this Special Section, but we believe that the six selected papers are a good reflection of the latest technologies, challenges and developments in some particular areas. They include both simulations and measurements, and work at both millimetre-wave and terahertz frequencies. Here we intend to provide a brief overview of these papers and their relevance.

Topic A: Gyro-devices

Gyro-devices are coherent microwave radiation sources based on the cyclotron resonance maser as fast-wave devices. They have superior power capability compared with slow-wave devices and are probably the best high-power sources operating at millimetre and sub-millimetre wavelengths to date. They have been successfully used in radar, telecommunications, plasma diagnostics, electron paramagnetic resonance spectroscopy, electron cyclotron resonance (ECR) heating, and materials processing. The development of various types of high power Ka- and W-band gyro-amplifiers allows high resolution ranging and imaging in atmospheric and planetary science. In the Special Section, we are pleased to present two papers on this topic.

The first paper, by Liang Zhang et al., is entitled ‘Input coupling systems for millimetre-wave gyrotron travelling wave amplifiers’. An input coupling system is very important for a good gyrotron travelling wave amplifier (TWA) since it not only separates the atmosphere from the ultra-high vacuum inside the gyro-TWA but also ensures efficient mode coupling between the rectangular waveguide (TE10 mode) and the circular waveguide (TE11 mode). In this paper, two input couplers for millimetre-wave gyro-TWAs were designed, optimised, constructed and measured. In the first design, a W-band input coupling system was developed with a pillbox window, a smoothly curved waveguide bend, a T-junction and a broadband reflector. An average transmission coefficient of ~2.0 dB over the designed operating frequency range (90–100 GHz) was obtained. In the second design, a higher-frequency input coupler for operation at a centre frequency of 372 GHz was presented based on a multiple-hole coupling configuration. The simulated transmission coefficient was ~0.5 dB, without considering the ohmic loss, which is an excellent performance.

The second paper, by Li Wang et al., is entitled ‘Design of a Ka-band MW-level high efficiency gyrokystron for accelerators’. Gyrokystrons tend to be high-power, narrow-band amplifiers compared to the moderate-power, broad-band gyrotron travelling wave amplifiers but both are members of the gyro-device electron cyclotron maser family. Unlike oscillators such as gyrotrons and gyrotron backward wave ones, their amplitude and phase can be precisely controlled. Therefore, they are attractive in applications such as communications and electron spin resonance spectroscopy. In this paper, the design of a three-cavity Ka-band (around 36 GHz) MW-level gyrokystron operating in the TE02 mode in the output cavity while the input cavity and buncher operating in the TE01 mode is presented. The optimised design of the magnetron injection gun (MIG) and interaction circuit was completed by particle-in-cell simulation and analytically using a MATLAB code. The non-linear theory and PIC simulation were performed for a three-cavity TE01/TE02 beam–wave interaction. The simulation results show that the gyrokystron can deliver an output power of more than 1.5 MW with a gain of >35 dB at 36 GHz. The achieved efficiency exceeds 40% when driven by a 95 kV, 45 A beam. The optimised MIG has a transverse velocity spread of <3% when the velocity ratio is around 1.3. A maximum output power of 1.9 MW, efficiency of 44%, gain of 39 dB, and 3 dB bandwidth of 700 MHz were predicted.

Topic B: Antennas

Antennas are essential devices for wireless millimetre-wave and terahertz systems. The well-known challenges for antennas in these frequency bands are the efficiency and fabrication. Here we have selected two papers to deal with these problems.

The paper by Chao Gu et al. is entitled ‘Wideband high-gain millimetre/submillimetre wave antenna using additive manufacturing’. This antenna is a resonant cavity antenna (RCA) with a partially reflecting surface and three impedance matching layers fed by a waveguide. Additive manufacturing techniques were utilised to fabricate the antenna operating at 30 GHz. Two fabrication techniques were used for printing the antenna. The first technique was based on printing a dielectric material and then fully coating the parts with a metallic layer, while the second technique involved printing the parts in a single process using metal 3D printing. The first technique offers a lightweight solution while the second technique involved printing the parts in a single process using metal 3D printing. The first technique offers a lightweight solution while the second technique can print the whole model in one run. A comparison of both techniques was provided in the paper. The antenna design was investigated by both simulations and experiments. The measured results show a 3 dB gain bandwidth of about 10%, and high gain over 15 dBi for all the three resulting antennas. The antenna can be scaled up to higher frequencies (300 GHz was used as an example), has a low cost and achieved good performance in terms of wide bandwidth and high gain (hence high efficiency), thus it is potentially useful for high-speed wireless communications at millimetre-wave and terahertz frequencies.

The other paper, by Wang Hongjian et al., is entitled ‘Multi-frequency dual polarisation radiometer common aperture antenna'.
feeding system’. The proposed feeding system consists of a corrugated horn, an orthomode transducer (OMT) and two pairs of high-pass filter (HPF) and band-pass filter (BPF). The broadband profiled corrugated horn loaded with teeth (rings) was adopted as the feed of a radiometer. A wide band finline OMT was developed to realise a bandwidth ratio in excess of 2:1. Two different HPFs and BPFs were employed to block and pass waves of different frequencies. The feeding structure was then simulated, fabricated and tested. The measured results showed that the radiation patterns possessed good symmetry at three working frequency bands around 18.7, 23.8 and 37 GHz. Furthermore, the cross-polarisation levels were below −23 dB and voltage standing-wave ratios were less than 1.5 which means that the beam efficiencies should be more than 90% over the working bands – this is essential for an excellent radiometer.

**Topic C: Oscillators**

An electronic oscillator is an electronic circuit that produces a periodic, oscillating electronic signal, often a sine wave or a square wave. It is the source of many electronic systems. The paper entitled ‘Theoretical study of extended interaction frequency-locking oscillator based on carbon nanotube (CNT) cold cathode to overcome locked-frequency limits of the conventional oscillator. Compared with the conventional ones, the oscillation frequency is locked by a modulation electron beam, which can be obtained from a field emission CNT cold cathode electron gun. The frequency-locking signal does not enter the high-frequency system and imposes an additional high-frequency electric field on the cathode surface by a microstrip structure, which consumes considerably less power to lock the oscillation frequency. A ladder structure extended interaction oscillator operating in 2π mode is numerically investigated by 3D Particle-In-Cell (PIC) simulation code. By analysing the impact of different frequency-locking power levels on the locked ranges, the results show that the saturation output power of 35.6 W is achieved at 35.11 GHz when the frequency-locking power consumption is 460 mW. The 3 dB bandwidth of the frequency-locking region reaches 100 MHz. This seems to be an excellent design which is to be validated by experiments.

**Topic D: Terahertz imaging**

Terahertz imaging has attracted a lot of attention due to the promising and unique features of this technology. In this Special Section, we have selected a paper by Hungyen Lin et al. entitled ‘Steps towards numerical verification of the terahertz in-line measurement of tablet mixing by means of discrete element modelling’, which is a highly specialised topic on using terahertz in-line sensing to monitor the film coating thickness of individual pharmaceutical tablets during the coating process. Unlike previous work (where the in-line measurements were verified against off-line measurements of samples from the same population), this work verifies the validity of the terahertz in-line measurement modality using discrete element modelling for an artificial lab-scale tablet mixing process inside a tablet pan coater. By coupling discrete modelling with a ray-tracing method, the authors estimate the cumulative measurements taken, to guide the fine-tuning of the selection criteria as part of measurement analysis. If successful, this could be another real-world application of terahertz imaging technology.

**Summary/Conclusion**

All of the papers chosen for this Special Section have shown some of the latest ideas and developments although they are really just a very small part of the many topics that are being researched at millimetre-wave and terahertz frequencies. We hope that this collection of papers will contribute to the active discussions and collaborations that are taking place among industry, academia, and governmental regulators in this important area of science and technology.

**Guest Editor's Biographies**

Dr Jiafeng Zhou received a Ph.D. degree from the University of Birmingham, Birmingham, U.K., in 2004. His doctoral research concerned high-temperature superconductor microwave filters. From July 1997, for two and a half years he was with the National Meteorological Satellite Centre of China, Beijing, China, where he was involved with the development of communication systems for Chinese geostationary meteorological satellites. From August 2004 to April 2006, he was a Research Fellow with the University of Birmingham, where his research concerned phased arrays for reflector observing systems. Then he moved to the Department of Electronic and Electrical Engineering, University of Bristol, Bristol, U.K until August 2013. His research in Bristol was on the development of highly efficient and linear amplifiers. He is now with the Department of Electrical Engineering and Electronics, University of Liverpool, Liverpool, U.K. His current research interests include microwave power amplifiers, filters, electromagnetic energy harvesting and wireless power transfer.

Prof Nick Ridler is Head of Electrical Science in the Engineering, Materials and Electrical Science Department at the UK’s National Physical Laboratory (NPL). He is also Non-Executive Director of LA Techniques Ltd. He has more than 35 years’ experience working in industrial, academic and government scientific research establishments. His main area of interest is high-frequency precision electromagnetic measurement. He is a Visiting Professor at the University of Leeds (School of Electronic and Electrical Engineering), the University of Liverpool (Department of Electrical Engineering and Electronics) and the University of Surrey (Faculty of Engineering and Physical Science). He is a Fellow of the Institution of Engineering and Technology (IET), a Fellow of the Institute of Physics (IOP), and a Fellow of the Institute of Electrical and Electronics Engineers (IEEE). He is an Associate Editor of the IET’s Microwaves, Antennas and Propagation journal, and, a Past Chairman of the Executive Committee of the IET’s RF & Microwave Technology Network.

Prof Yaochun Shen is a Professor of Electrical Engineering at the University of Liverpool. He has been working on terahertz imaging technology for many years, first as a Research Associate (2001–2004) at the Cavendish Laboratory, University of Cambridge, and then as a Senior Scientist (2004–2007) at TeraView Limited, Cambridge. He served as the TPC Chair of the 10th UK/Europe-China Workshop on Millimetre-Waves and Terahertz Technologies in 2017. Prof Shen has been awarded 7 patents and published 5 book chapters and over 200 journal and conference publications with over 5100 combined citations and an h-index of 38. He is a Fellow of the Institution of Engineering and Technology (IET). His current research interests
include the development of novel terahertz and optical coherence tomography 3D imaging technologies with a focus on the exploitation of their applications in science and industry.

Prof Yi Huang is a Professor in Wireless Engineering, the Head of High Frequency Engineering Group and Deputy Head of Department. Prof Huang has published over 300 refereed papers in leading international journals and conference proceedings, and authored Antennas: from Theory to Practice (John Wiley, 2008) and Reverberation Chambers: Theory and Applications to EMC and Antenna Measurements (John Wiley, 2016). He has received many research grants from research councils, government agencies, charity, EU and industry, acted as a consultant to various companies, and served on a number of national and international technical committees and been an Editor, Associate Editor or Guest Editor of five international journals. He has been a keynote/invited speaker and organiser of many conferences and workshops. He is at present the Editor-in-Chief of Wireless Engineering and Technology, Associate Editor of IEEE Antennas and Wireless Propagation Letters, UK and Ireland Rep to European Association of Antenna and Propagation (EurAAP), a Senior Member of IEEE, a Fellow of IET, and Senior Fellow of HEA. He is a recipient of a number of awards, including BAE Systems Chairman's Award for Innovation in 2017.