2nd UK/Europe-China Workshop on Millimetre Waves and Terahertz Technologies

第二届英国/欧洲-中国毫米波与太赫兹技术研讨会

19th-21st October, 2009
Rutherford Appleton Laboratory, UK

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Contents

Full papers that were submitted to us are provided on the accompanying memory stick along with a digital version of this booklet.

Registration

All attendees should go to the RAL reception building on arrival where they will be issued with badges and a directed to the conference buildings.

Coach times

Monday 19th October:
07.15 - Best Western Linton Lodge Hotel, Oxford
07.20 - Cotswold Lodge Hotel, Oxford
07.30 - Central Oxford, High Street (Bus Stop L1)

Collection at RAL at 17:45 pm for transport to the Bodleian Library for the dinner reception.

Tuesday 20th October:
07.15 - Best Western Linton Lodge Hotel, Oxford
07.20 - Cotswold Lodge Hotel, Oxford
07.30 - Central Oxford, High Street (Bus Stop L1)

Collection at RAL at 17:45 pm for transport to St Mary's Church on High Street, Oxford.

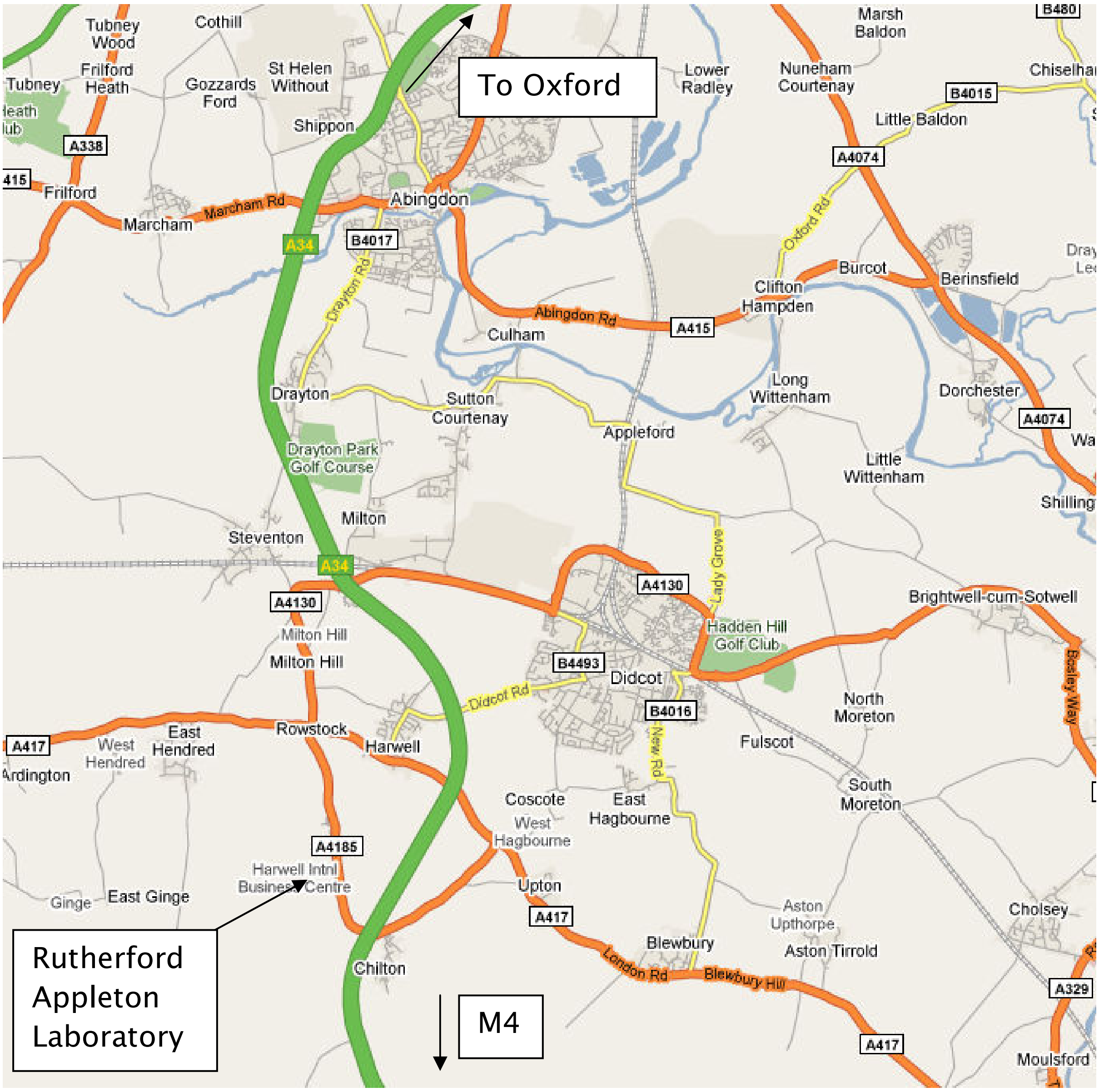
Wednesday 21st October: (Note the later start)
08.00 - Best Western Linton Lodge Hotel, Oxford
08.05 - Cotswold Lodge Hotel, Oxford
08.15 - Central Oxford (Bus Stop L1)

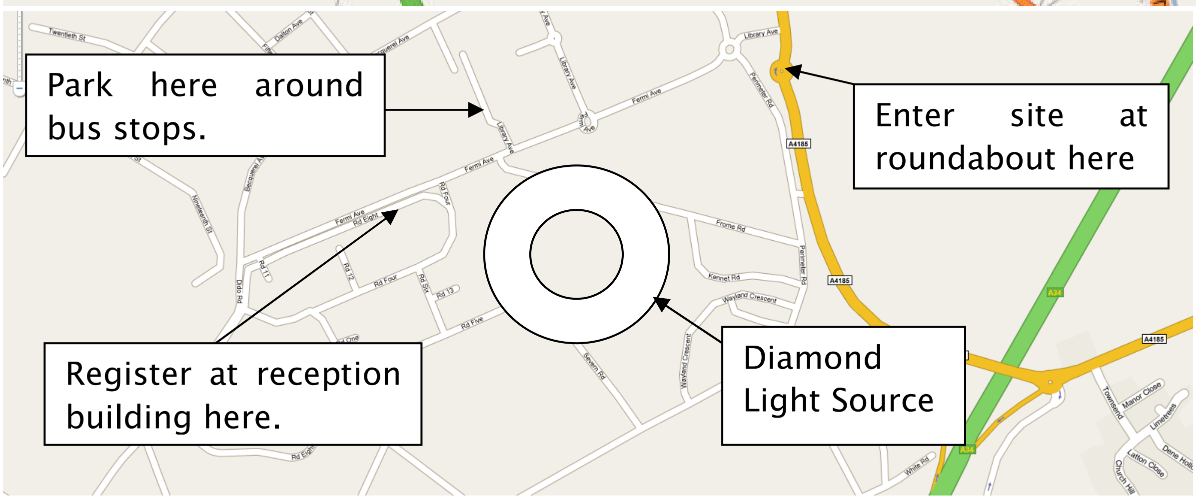
Collection at RAL at 11:30 am for transport to Blenheim Palace. The bus will stay at Blenheim so luggage can be left on the coach.

Collection at Blenheim Palace at 15:30 pm for return to RAL via Oxford train station.

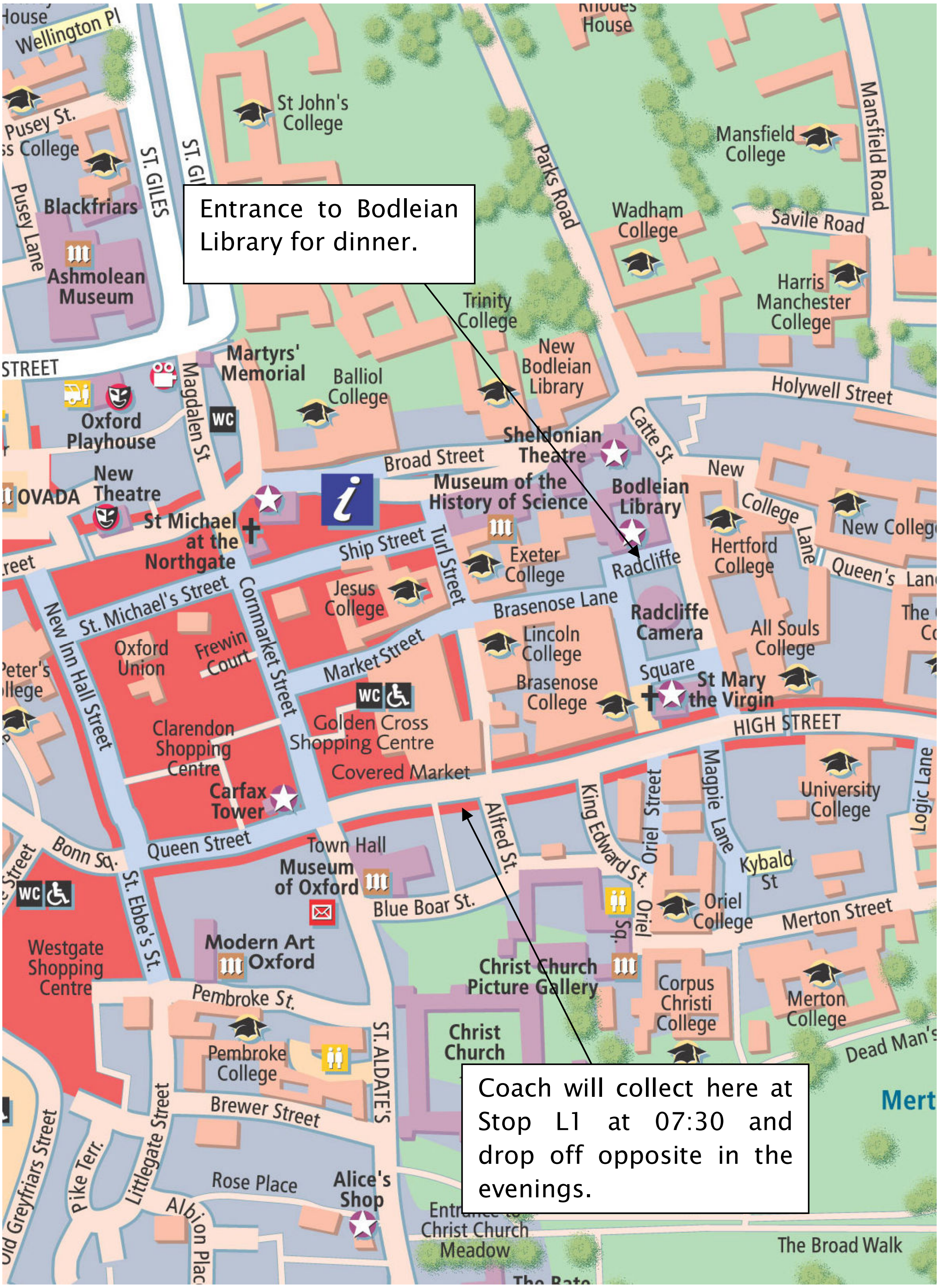
Car Information
A basic map and where to park are shown on the next page. RAL is signposted from the A34 and information boards will direct you to the event car park. The post code for RAL is OX11 0QX.

Rutherford Appleton Laboratory





Central Oxford



Monday 19th October, 2009

Registration	08:00 onwards		
Session 0	09:00	Welcome address	
Session I	09:15	Invited talk	**"Silicon Based Millimeter and Submillimeter Wave Integrated Circuits."** Wei Hong SouthEast University, Nanjing, China
Chair: Shenggang Liu (UESTC) - Alan Phelps (Strathclyde)	09:45	Talk 1	**"The SPIRE Instrument for Herschel: spaceborne THz imaging photometry and spectroscopy."** Matt Griffin Cardiff University, UK
	10:15	Invited talk	**"What determines the size/scale of a high-performance mm-wave/terahertz optical system?"** Derek Martin Queen Mary University of London, UK
Coffee Break	Coffee Break 10:30 - 11:00		
Session II Astronomy and Quasi-Optical Techniques	11:00	Talk 2	**"Space-qualified mid- to far-infrared thermal illumination sources."** Peter Hargrave Cardiff University, UK
Chair: Junsheng Yu (BUPT) - Derek Martin (QMUL)	11:15	Talk 3	**"A novel unilateral SIS finline mixer for sensitive cosmology instruments."** Yangjun Zhou, Ghassan Yassin, Paul Grimes, Jamie Leech University of Oxford, UK
	11:30	Talk 4	**"High performance quasi-optical Faraday rotators for millimetre wave and sub-millimetre wave applications."** R.I. Hunter, D.A. Robertson, G.M. Smith University of St Andrews, UK
	11:45	Talk 5	**"Modulating polarization in the Terahertz Region."** G.Savini University College London, UK

	12:00	Talk 6	**"Ultra-high performance corrugated feedhorns for Gaussian beam mode optics."** D. A. Robertson, P. N. Marsh, P. A. S. Cruickshank and G. M. Smith University of St Andrews, UK
Group photo and lunch	Lunch Break 12:15 - 1:30		
Session III Quasi-Optical Filters & Imaging and Applications I ***Chair:*** ***Yong Fan*** ***(UESTC)*** ***-*** ***Peter Huggard*** ***(RAL)***	1:30	Talk 7	**"Study on Terahertz Transmission Spectra of Metallic Mesh Structures."** Guozhong Zhao(1), Yan Zhang(1), Cunlin Zhang(1) and Guozhen Yang(1,2) (1) Capital Normal University, Beijing, China (2) Chinese Academy of Sciences, Beijing, China
	2:00	Talk 8	**"Frequency-Selective Surfaces for Submillimetre and THz Applications."** R. Dickie(1), J. Sanz-Fernandez(2), R.Cahill(1), R. Cheung(2), G. Goussetis(1), H. Gamble(1), V. Fusco(1), M. Henry(3), M. Oldfield(3), P. Huggard(3), P. Howard(4), N. Grant(4), Y. Munro(4), P. de Maagt(5) (1) Queen's University Belfast, UK (2) The University of Edinburgh, UK (3) STFC - Rutherford Appleton Laboratory, UK (4) EADS Astrium, Portsmouth, UK (5) European Space Agency, The Netherlands
	2:15	Talk 9	**"Experimental Assessment of Periodic Method of Moments Design Accuracy for Quasi Optical Networks."** Hansheng Su(1), Xiaoming Liu(1), Liang Xu(1), Daohui Li(1), Xiaodong Chen(1), C. Rieckmann(1), R. Donnan(1), C. Parini(1), Junsheng Yu(2), and Jungang Miao(3) (1) Queen Mary University of London, UK (2) Beijing University of Posts and Telecommunications, Beijing, China (3)Beihang University, Beijing, China

	2:30	Talk 10	**"An Artificial Dielectric Using Embedded Metal-Mesh."** Jin Zhang(1), Peter Ade(1), Philip Mauskopf(1), Giorgio Savini(2), Lorenzo Moncelsi(1), Nicola Whitehouse(1) (1) Cardiff University, UK (2) University College London, UK
	2:45	Talk 11	**"REconfigurable Terahertz INtegrated Architecture (RETINA)."** Stepan Lucyszyn and Yun Zhou Imperial College London, UK
	3:00	Talk 12	**"Superconducting THz imaging detector arrays."** Philip Mauskopf Cardiff University, UK
Coffee Break	Coffee Break 3:15 - 3:45		
Session IV Imaging and Applications II ***Chair:*** ***Caidong Xiong (UESTC)*** ***-*** ***Clive Parini (QMUL)***	3:45	Talk 13	**"Terahertz Tomograph"** R E Miles(1), M R Stringer(1), Y Zhang(2), J Young(3), P Wright(3), K Ozanyan(3), A Malinowski(4), D Richardson(4) (1) University of Leeds, UK (2) School of Mechanical, Aerospace and Civil Engineering, University of Manchester, UK (3) School of Electrical and Electronic Engineering, University of Manchester, UK (4) University of Southampton, UK
	4:00	Talk 14	**"Combined Active and Passive Measurements Using the AVTIS Millimetre Wave Volcanic Imager."** D.G. Macfarlane, D.A. Robertson University of St Andrews, UK
	4:15	Talk 15	**"The Development of a Millimetre Wave Imaging System."** L. Zhang , Y. Hao, and C. G. Parini Queen Mary University of London, UK
	4:45	Talk 16	**"Novel Antenna Technology Using Freeformed Ceramic Metamaterials At Millimetre-Wave Bands."** Yoonjae Lee, Yang Hao, and Clive G. Parini Queen Mary University of London, UK

	5:00	Talk 17	**"Full Downlink Transmission using a Millimeter-wave over Fiber System for Indoor Pico-cellular Network Coverage."** X. Liang, P. Shen, J. James, A. Nkansah, and N. J. Gomes University of Kent, UK
	5:15	Talk 18	**"Millimetre Wave over Fiber Phase Reference Distribution System with Ultra Low Phase Drift through fiber network."** P. Shen(1), W. P Shillue(2) and N. J. Gomes(1) (1) University of Kent, UK (2) National Radio Astronomy Observatory, USA
	Session closure 5:30		
Workshop Dinner	6:30 Reception / 7:30 seating		

See map on Page 5 for location of dinner.

Tuesday 20th October, 2009

Morning coffee	8:30 onwards		
Session V ***Chair:*** ***Hong Wei*** ***(SEU)*** - ***Stephan Lucyszyn*** ***(Imperial College)***	9:00	Invited talk	**"Terahertz Radiation: An Appropriate Probe of Structure and Dynamics in Biology."** Martyn Chamberlain Durham University, UK
	9:30	Invited talk	**"The electron beam-wave interaction in subwavelength holes array for THz radiation generation."** Liu Shenggang University of Electronic Science and Technology of China, Chengdu, China
	10:00	Talk 19	**"THz Applications."** Jesse Alton TeraView Ltd, UK
	10:15	Talk 20	**"Schottky diode technology at the Rutherford Appleton Laboratory."** B. Alderman(1), H. Sanghera(1), M. Henry(1), H. Wang(1) P. Wilkinson(2), D. Williamson(1), M. Emery(1), and D. N. Matheson(1) (1) STFC - Rutherford Appleton Laboratory, UK (2) University of Leeds, UK
Coffee Break	Coffee Break 10:30 - 11:00		
Session VI National Standards and Electronic Devices ***Chair:*** ***Xian Gao*** ***(CAS)*** - ***Yi Huang*** ***(Liverpool)***	11:00	Talk 21	**"Recent and Future Developments in Millimetre and Sub-millimetre Wavelength Measurement Standards at NPL."** David B. Adamson, John Howes, Nick M. Ridler National Physical Laboratory, UK
	11:15	Talk 22	**"Progress in Superlattice Electronic Devices as Millimeter-Wave Sources."** Heribert Eisele, Suraj P. Khanna, and Edmund H. Linfield University of Leeds, UK

	11:30	Talk 23	**"Schottky Barrier Heights on AlGaN/GaN Heterojunctions and Their Effect on High-Performance GaN TUNNETT Devices."** Wei Lun Oo(1), Heribert Eisele(1), George I. Haddad(2), Yuh-Renn Wu(3), Roger D. Pollard(1) (1) University of Leeds, UK (2) University of Michigan, USA (3) National Taiwan University, Taiwan
	11:45	Talk 24	**"High Performance Quantum Cascade Lasers Operating between 2.7 and 4 THz."** Mohammed Salih, Suraj P. Khanna, Lianhe Li, Paul Dean, John Cunningham, A. Giles Davies, and Edmund H. Linfield University of Leeds, UK
	12:00	Talk 25	**"Laterally Contacted Schottky Diodes for THz Applications."** L.Floyd and J.Pike, Tyndall National Institute, Ireland
	12:15	Talk 26	**"Schottky diode membrane technology for terahertz applications."** Steven Davies University of Bath, UK
Lunch	Lunch Break 12:30 - 1:30		
Session VII High Power Sources ***Chair:*** ***Yubin Gong (UESTC)*** ***-*** ***Martyn Chamberlin (Durham)***	1:30	Talk 27	**"Recent Progress in High Power Millimetre-wave Sources at Strathclyde University."** Alan D.R. Phelps, A.W. Cross, K. Ronald, W.He, I.V. Konoplev, H.Yin, C.G. Whyte, A.R. Young, C.W. Roberston, D.C. Speirs, C.R. Donaldson, S.L. McConville, L. Fisher, P. MacInnes, F. Li. K.M. Gillespie, M. McStravick, L. Zhang, D. Constable, D. Bowes, and K.A. Matheson University of Strathclyde, UK

	2:00	Talk 28	**"High power pulsed electron paramagnetic resonance spectroscopy at 94GHz."** P. A. S. Cruickshank, D. R. Bolton, R. I Hunter, D. A. Robertson, H. El Mkami and G. M. Smith University of St Andrews, UK
	2:15	Talk 29	**"A Novel Co-Harmonic Gyrotron."** D.A. Constable(1), K. Ronald(1), A.D.R. Phelps(1), W. He(1), and A.W. Cross(1), A.V. Savilov(2), V.L. Bratman(2) and I.V. Bandurkin(2) (1) University of Strathclyde, UK (2) Russian Academy of Science, Russia
	2:30	Talk 30	**"W band Gyro-devices using helical interaction waveguides and cusp guns."** W. He, C. R. Donaldson, A. D. R. Phelps, A. W. Cross, F. Li, K. Ronald, C. W. Robertson, C. G. Whyte, A.R. Young and L. Zhang University of Strathclyde, UK
	2:45	Talk 31	**"Mode evolution in an FEM with 2D distributed feedback."** I.V. Konoplev, P. MacInnes, L. Fisher, A.W. Cross, W. He, A.D.R. Phelps, C.G. Whyte, K. Ronald and C.W. Robertson University of Strathclyde, UK
	3:00	Talk 32	**"Numerical Investigation of Pseudospark Discharge Based on Electron Beam Source for Terahertz Generation. "** D. Li(1), J. Zhou(1), X. Chen(1), H. Yin(2), D. Bowes(2), W. He(2), A. W. Cross(2), K. Ronald(2), and A. D. R. Phelps(2) (1) Queen Mary University of London, UK (2) University of Strathclyde, UK
Coffee Break	Coffee Break 3:15 - 3:45		

Session VIII THz diagnostics and photonic and linac sources ***Chair:*** ***Xiaobo Yang (UESTC)*** ***-*** ***Peter Hargrave (Cardiff)***	3:45	Talk 34	**"Investigation of THz technology and FIR laser diagnostics on EAST tokamak."** X.Gao, Y.X.Jie, Y.Yang, E.H.Wang, N.Shi, Z.X.Liu and Y.F.Cheng Institute of Plasma Physics, Chinese Academy of Sciences, China
	4:00	Talk 35	**"THz Light from Alice – the superconducting RF Linac at Daresbury."** G Holder(1), P Harrison(1), A Schofield(1), P Weightman(1), M Surman(2), MA Bowler(2), I Burrows(2), G Stokes(2), B Shepherd(2), NR Thompson(2), B D Fell(2), D G Stokes(2), S F Hill(2), Y M Saveliev(2), P Huggard(3), M L Oldfield(3) and J J Spencer(3) (1) The University of Liverpool, UK (2) STFC - Daresbury Laboratory, UK (3) STFC - Rutherford Appleton Laboratory, UK
	4:15	Talk 36	**"Terahertz Generation by Intracavity Optical Parametric Oscillators."** David A Walsh, Caroline L Thomson and Malcolm H Dunn University of St Andrews, UK
	4:45	Talk 37	**"Increasing the Directivity of Photoconductive Antennas."** Di Li(1),Yi Huang(1),Yao-Chun Shen(1), and Anthony Vickers(2) (1) University of Liverpool, UK (2) University of Essex, UK
	5:00	Talk 38	**"Developing the next generation of photovoltaic cells using terahertz based pump-probe techniques on a prototype energy recovery linac."** D. M. Graham(1), B. F. Spencer(1), W. R. Flavell(1), M. A. Bowler(2), M. Surman(2), S. P. Jamison(2) (1) The University of Manchester, UK (2) STFC - Daresbury Laboratory, UK
	5:15	Closing remarks	
	Session closure 5:30		

Wednesday 21st October, 2009

Morning coffee	8:30 onwards	
Laboratory tour	9:00	Tour of Space Science and Technology Department at RAL
Visit to Blenheim Palace	11:30	Bus depart RAL
	11:30	Palace tour and lunch
	3:30	Bus depart Blenheim for Oxford Station and RAL
	4:30	Expected arrival time at RAL
End of Conference		

Posters
19th - 20th October

The exhibition area will be available from 8:30 on Monday 19th October	
Poster 1	**"Development of Advanced Gunn Diodes and Schottky Multipliers for High Power THz sources."** F. Amir(1), C. Mitchell(1), N. Farrington(2) , T. Tauqeer(1), and M. Missous(1) (1) School of E&EE, University of Manchester, UK (2) e2v Technologies (UK) Plc, Lincoln, UK
Poster 2	**"Terahertz radiation generation with a pseudospark-sourced electron beam ."** D. Bowes(1), A.W. Cross(1), H. Yin(1), W. He(1), K. Ronald(1), A. D. R. Phelps(1), D. Li(2), J. Zhou(2), X. Chen(2), J. Protz(2), M. Verdiel(3), M. Reynolds(3), and T. Schuhmann(3) (1) University of Strathclyde, UK (2) Queen Mary University of London, UK (3) Duke University, Durham, NC, USA
Poster 3	**"Design of a 26 GHz Receiver Front-End."** Huifeng Ding and Xiaowei Zhu Southeast University, Nanjing, China
Poster 4	**"Frequency calibration of THz time-domain spectrometers using an etalon."** Mira Naftaly(1), Richard A. Dudley(1), and John R. Fletcher(2) (1) National Physical Laboratory, Teddington, UK (2) University of Durham, UK
Poster 5	**"Low Noise Theory at 2.5 Thz For HEB Mixer."** Di Jiang, ZHANG Yong, and XU Rui-min University of Electronic Science and Technology of China, Chengdu, China
Poster 6	"The design of a 390 GHz gyrotron based on a Cusp electron gun." Fengping Li, Wenlong. He, Alan. D. R. Phelps, Adrian. W. Cross, Craig. R. Donaldson, and Kevin. Ronald University of Strathclyde, UK

Poster 7	**"The Influence of Dichroic on the Performance of a Quasi-optical System."** Xiaoming Liu(1), Hansheng Su(1), Liang Xu(1), Daohui Li(1), Xiaodong Chen(1) , Junsheng Yu(2), Shaohua Liu(2), R. Donnan(1), and C. Parini(1) (1) Queen Mary University of London, UK (2) University of Posts and Telecommunications, Beijing, China
Poster 8	**"Characterization of Terahertz Quantum Cascade Lasers for laser spectroscopy applications."** Neil Macleod (1), and Damien Weidmann (1), Paul Dean(2), and Edmund Linfield(2) (1) STFC - Rutherford Appleton Laboratory, UK (2) University of Leeds, Leeds, UK
Poster 9	**"Research and Analysis of Self-Consistent Nonlinear Theory for a 240 GHz Gyrotron."** Tan Rui-feng, Luo Yong, and Sun Xu University of Electronic Science and Technology of China, Chengdu, China
Poster 10	**"Development of a frequency-domain THz spectrometer based on parametric generation."** Caroline L. Thomson, David A. Walsh, and Malcolm H. Dunn University of St Andrews, UK
Poster 11	**"Transform Limited Terahertz Pulse Generation from an Injection Seeded Intracavity Optical Parametric Oscillators."** David A Walsh, Caroline L Thomson and Malcolm H Dunn University of St Andrews, UK
Poster 12	**"Demonstration of Quasi Phasematching in an Intracavity Terahertz Optical Parametric Oscillator using Orthogonally Poled LiNbO3."** David A Walsh, Caroline L Thomson and Malcolm H Dunn University of St Andrews, UK
Poster 13	**"Micromachined microwave circuits."** Yi Wang, M Ke, N Murad, T Skaik, X Shang, F Huang, and M Lancaster The University of Birmingham, UK
Poster 14	**"Low –loss terahertz dielectric strip waveguide."** WANG Zhi-hui, ZHANG Yong, XU Rui-min, and LIN Wei-gan University of Electronic Science and Technology of China, Chengdu, China

Poster 15	**"The design of a 664 GHz sub-harmonic mixer."** Paul Wilkinson(1), Manju Henry(2), Hui Wang(2), Hoshiar Sanghera(2), Byron Alderman(2), Paul Steenson(1), and David Matheson(1) (1) University of Leeds, UK (2) STFC - Rutherford Appleton Laboratory, UK
Poster 16	**"Transmission Characteristics of Planar Goubau Line at THz Frequencies."** Longfang Ye, Yong Zhang, and Ruimin Xu University of Electronic Science and Technology of China, Chengdu, China
Poster 17	**"Simulation of a Four-stage Depressed Collector for a W-band Gyro-BWO."** Liang Zhang, Wenlong He, Adrian W. Cross, Alan D. R. Phelps, Kevin Ronald, and Colin G. Whyte University of Strathclyde, UK
Poster 18	**"Design of a 225-GHz Fix-Tuned Subharmonically Pumped Planar Schottky Diode Mixer."** Bo Zhang, Yong Fan, F.Q Zhong, and X.F Yang University of Electronic Science and Technology of China, Chengdu, China
Poster 19	**"Novel Single-Mode Bragg Fibres for THz Applications."** Yunhua Zhang and Ian D. Robertson University of Leeds, Leeds, UK
Poster 20	**"Design and Simulation of Spaceborne Imaging Radar System in Terahertz Band."** Jin Li, Rui Min, Xiaobo Yang and Yiming Pi University of Electronic Science and Technology of China, Chengdu, China
Poster 21	**"THz-TDS measurements of sugars and the future prospect."** Kastriot Shala(1), Bin Yang(1), Richard Dudley(2), Tina T. Chowdhury(2), and Robert S. Donnan(1) (1) Queen Mary University of London, UK (2) National Physical Laboratory, UK
The exhibition area will be available until 5pm on Wednesday 21st October	

Session I

The SPIRE Instrument for Herschel: spaceborne THz imaging photometry and spectroscopy

Matt Griffin

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SPIRE, the Spectral and Photometric Imaging Receiver, is one of three scientific instruments on the European Space Agency's Herschel Space Observatory, launched in May 2009 SPIRE contains two sub-instruments: a three-band imaging photometer operating at 250, 350 and 500 microns, and an imaging Fourier Transform Spectrometer (FTS) covering 194-672 microns. The detectors are arrays of feedhorn- coupled NTD spider-web bolometers cooled to 300 mK. The photometer field of view is 4 x 8 arcminutes, observed simultaneously in the three spectral bands. An internal beam steering mirror allows spatial modulation of the telescope beam and will be used to jiggle the field of view in order to produce fully-sampled images. Observations can also be made by scanning the telescope without chopping. The FTS has an approximately circular field of view with a diameter of 2.6 arcminutes, and employs a dual-beam configuration with broad-band intensity beam dividers to provide high efficiency and separated output and input ports. The spectral resolution can be adjusted between 0.04 and 2 cm-1 (lambda/delta-lambda = 20 - 1000 at 250 microns). The instrument design, operating modes, and performance, will be outlined, and some preliminary in-flight results will be presented.

What Determines the size of a high-performance mm-wave/terhertz optical system?

Derek H Martin

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Directed free-space signal-beams, rather than guided-wave modes, are used in the signal-conditioning circuits of mm-wave/terahertz measurement systems to provide high-efficiency and/or large spatial or temporal bandwidths.

The widths, and the separations, of the optical components in such a quasi-optical system must appreciably exceed the signal-beam wavelengths. The size, and the weight, of a measurement system must nevertheless usually be minimized so the designer of such a system must be able to determine with some precision the least size/scale that will allow compliance with the system's performance specifications.

This means finding the size-scale for each signal-conditioning optical component that will sufficiently limit the beam-aberration there. Signal-conditioning components are of three main types:

beam-launching and receiving feed-horns,
collimating and condensing (focusing) reflectors, and
planar dichroics or polarisers,

and I draw attention in this short presentation to the aberrating properties of each of these types (matters that have received less attention in the literature than they deserve) and I indicate the implications for the size/scale of a system containing them. In order to give some context for these remarks I refer in particular to AMSU-B mm-wave radiometers that are in use on several space-borne platforms for determining the global atmospheric water-vapour distribution.

Session II

Astronomy and Quasi-Optical Techniques

Space-qualified mid- to far-infrared thermal illumination sources.

Dr Peter Hargrave,

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I present details of new thermal illumination sources, developed for use on satellite and balloon-borne experiments. Mid-infrared sources have been built and qualified for flight on board JWST-MIRI for operation in the 2-22μm range. These devices typically dissipate around 9mW for an effective black-body temperature of 1000K, and will warm from 4K to 1000K in around 1s.
Far-infrared illumination sources have been built, and are currently flying on board Herschel-SPIRE, having previously flown on the BLAST balloon experiment. These devices, based on a “reverse bolometer” achieve a black-body equivalent temperature of around 50K for 5mW applied power, with an associated time constant of around 80ms.

A novel unilateral SIS finline mixer for sensitive cosmology instruments

Yangjun Zhou, Ghassan Yassin, Paul Grimes, Jamie Leech*

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SIS (superconductor-insulator-superconductor) tunnel junction mixers are the most sensitive coherent detectors in the frequency range of 200-700GHz. They have been thoroughly investigated in the past 15 years and are employed in major astronomical telescopes receivers such as ALMA, Herschel and the JCMT. In this paper, we present a new mixer design at 230GHz that comprises a unilateral finline taper deposited on a 80 microns silicon substrate. Finline mixers have several advantages over conventional designs including an extremely wide RF bandwidth, easy to fabricate mixer block, and fully integrated tuning. The employment of the silicon rather than the commonly used quartz allows the finline taper impedance to be reduced to approximately 30ohms which is ideal for matching the SIS microstrip circuits. The mixer is fed by a corrugated horn which couples into a unilateral finline taper then couples into a microstrip line which contains the tunnel junction. The transition from the unilateral finline to the microstrip is based on the double-stub structure which has been reported in a previous publication [1]. The SIS mixer described above is developed for the CMB cosmology instruments where high sensitivity is essential. The employment of ultra-wide instantaneous IF bandwidth makes the device sensitivity comparable to what can be achieved by superconducting bolometers, with much less RF losses and much simpler cryogenic system and readout. In particular we shall employ this mixer in Oxford single baseline interferometer GUBBINS (220-GHz Ultra-BroadBand INterferometer for S-z effect) which aims at accurate measurement of the zero crossing in the S-Z spectrum. GUBBINS is featured by its high brightness sensitivity in the millimeter band, low to moderate spatial and spectrum resolution with observation target to measure the spectrum of the Sunyaev-Zel'dovich effect in the brightest galaxy cluster. Finally we shall also present preliminary experimental measurements of an SIS mixer using an antipodal finline taper, fabricated on a quartz substrate[2].

Reference:

[1] G.Yassin, P.K. Grimes, O.G. King and C.E. North. Waveguide-to-planar circuit transition for millimeter-wave detectors. Electronics letter 3rd July 2008 Vol.44 No.14

[2] Paul K. Grimes, Ghassan Yassin, Karl Jacobs and Jamie Leech. Design of SIS finline mixers with ultra-wide IF bands. 19th International Symposium on Space Terahertz Technology, Groningen, 28-30 April 20081

* Yangjun Zhou is a PhD student at Oxford Astrophysics department funded by the Chinese Education Ministry-University of Oxford joint scholarship.

High performance quasi-optical Faraday rotators for millimetre wave and sub-millimetre wave applications.

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Permanently magnetised quasi-optical Faraday rotators (QOFRs) are an enabling technology for a wide range of millimetre and sub-millimetre wave applications. They have been used to make circulators and isolators for applications in radar, imaging systems, metrology, spectroscopy and quasi-optical instrumentation in general.

We have recently reported state-of-the-art performance for QOFRs operating at W-band fabricated using both sintered hexaferrite and plastoferrite material for large area applications. Typical performance values for a sintered ferrite QOFRs at 94GHz are 0.3dB insertion loss, effective 60dB isolation at spot frequencies, 30dB isolation over 7GHz bandwidth, >20dB return loss at normal incidence and >80dB return loss when angled at 45 degrees to the beam.

In this paper we will present results indicating the isolation and loss performance of these devices at higher frequencies, the average power handling of these devices at 94GHz (20W average power with no heatsinking) and the isolation performance that can be achieved when cascading multiple QOFRs. (>90dB demonstrated for a cascade of three devices. where higher order mode excitation and leakage of wire grid polarisers limits achievable performance).

We also outline applications where this level of performance is critical.

Modulating polarization in the Terahertz Region.

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Polarization modulation is critical in a variety of astronomical and generally experimental applications. Different techniques adopted are chromatic in nature and usually conned to a specific range of frequencies. I will review some of the recent polarization modulation techniques adopted for astronomical observations and their development in relation to the frequencies studied from 90GHz to 1.2THz and the future extension to higher frequencies. Highlighting the advantages and disadvantages of each method with potential applications
and future developments.

Ultra-high performance corrugated feedhorns for Gaussian beam mode optics.

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Corrugated feedhorns have been the antenna of choice for designers of quasi-optical (QO) systems as they offer a high purity fundamental mode Gaussian beam output where conversion power efficiencies are approximately 98%. However, the remaining 2% is converted into higher order modes, and whilst this appears to be a low level, it can in fact have serious consequences when designing low aberration QO systems or high performance antenna systems. In particular, in low loss QO mirror-based systems, trapped modes can occur which result in significantly deep, narrow nulls in the frequency response and in antenna systems these higher order modes lead to sidelobes in the far field antenna response..

We report on a novel design of corrugated feedhorn developed at St Andrews which reduces the higher order mode impurity level to fractions of one percent, yielding an output beam with much higher Gaussicity (99.5%). This translates to extremely low sidelobes (-40dB), extremely low cross-polar response (-40dB) and, with the careful design of the rectangular-to-circular transition, an input return loss also at the -40dB level. The design is also relatively wideband and leads to a phase centre positioned at the aperture of the horn. When used in low-loss mirror based QO systems, the ultra pure Gaussian beam gives rise to low levels of the trapped modes described above.

Session III

Quasi-Optical Filters

&

Imaging and Applications I

Study on Terahertz Transmission Spectra of Metallic Mesh Structures.

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The terahertz transmission spectra of metallic mesh structures are studied by means of terahertz time-domain spectroscopy (THz-TDS). THz transmission through a thin conducting metal screen perforated with slots has been measured by illuminating the metal mesh structures by the pulsed THz wave with variable frequencies. The frequency selected band-pass and band-stop characteristics have been observed within the range of 0.2 THz to 2.6 THz. The metallic mesh structures with the different shapes and sizes have been fabricated by two methods of the laser cutting and the standard photographic technology. The copper foil of 50 μm thickness is drilled into fractal structures by the YAG laser, or the metallic film about 100 nm deposited on the high resistance silicon wafer is fabricated into the metallic fractal structures and some hole array by the standard photograph technology. The size and polarization dependence of THz transmission of these metallic meshes have been investigated. The experimental results show that the metallic mesh structures propose the obvious frequency selection except its THz transmission is polarization dependent. The metallic meshes can be a candidate of potential THz photonic devices such as THz filter, THz polarizer, THz attenuator, and so on. In the recent years, more and more works is focusing on the THz optical devices which is concerning with many fields such as metamaterial, photonic crystal, and surface Plasmon Polariton.

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Frequency-Selective Surfaces for Submillimetre and THz Applications

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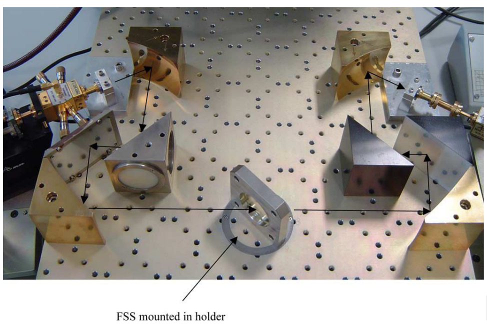
Frequency selective surfaces (FSS) have received significant attention for their use as stop/pass-band filters at infrared frequencies. They offer competitive alternative to thin/thick film filters and dichroics across the submillimeter and THz bands. Recent advances in the design include FSSs with polarisation independent responses or multiple resonant bands. In addition, perturbed FSS have found applications in near-field enhancement, which can be useful for sensing applications. In this work, we will present an overview on recent UK activities in the analysis, design, realisation and testing of FSSs at sub-mmwave and THz. Modelling of the near field of the FSS will be presented and techniques for near-field enhancement will be discussed. The design of multiband FSS at 12 THz band will be described using modelling results and fabricated prototypes. Fabrication techniques will be presented together with experimental results for FSSs at 300GHz as well as 13THz bands, tested using quasi-optical test benches and FTIR equipment respectively.



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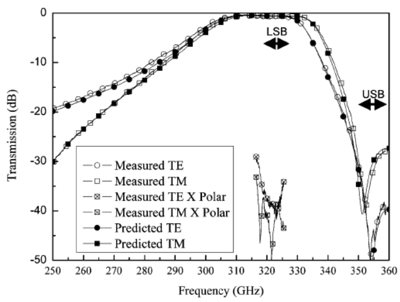

b)

Fig. 1 FSS at 300GHz a) Quasi-optical FSS transmission measurement test bench. b) Measured and predicted copolar and measured cross-polar spectral response of the two layer FSS at 45o incidence for both polarizations.

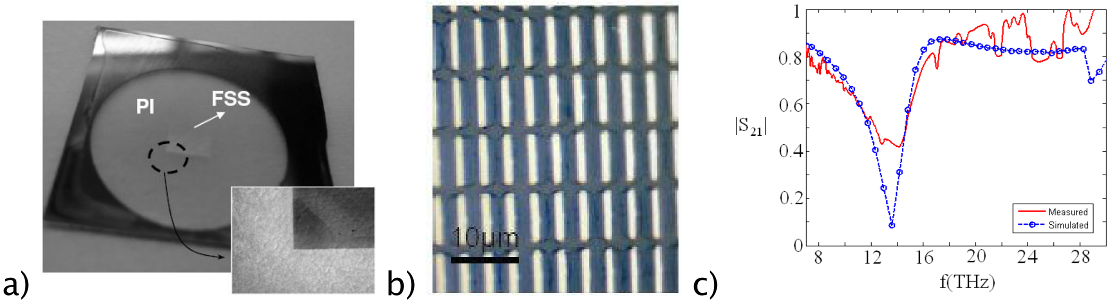

Fig. 2 FSS at 13 THz a) Silicon wafer, b) Optical microscope pictures and c) Simulated and tested results in FTIR equipment

Experimental Assessment of Periodic Method of Moments Design Accuracy for Quasi Optical Networks

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A low-loss and dual-polarised dichroic is designed and tested to check the accuracy of Periodic Method of Moments (PMM) code and assess dichroic performance to fabrication tolerance. The dichroic is designed to transmit at 89 GHz and reflect at 54 GHz in a two-channel multi-reflector quasi-optical network (QON), hence called high-pass dichroic. A copper plate perforated with circular holes on an equilateral triangular lattice was chosen as the final design. The high-pass dichroic shows low insertion loss at 89 GHz. -0.04dB in simulation and -0.27dB in the measurement.

An Artificial Dielectric Using Embedded Metal-Mesh

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Metal mesh technology have been adopted in the millimeter and sub-millimeter wave range as a standard method for providing optical filtering, beam-splitters and diffractive optical elements by fundamental practical purposes. This paper presented a novel artificial dielectric design using metal-mesh technology for the use of millimeter and submillimeter frequency region.

This design has the capability of tuning the refractive index by adjusting the metal-mesh geometry patterns. The fabrication process is hot-pressed thus the material is a solid disc with meshes embedded in, which is robust and gives better performance in thermal cycling. Furthermore, it has a complete control over the thickness and size of the material. These unique advantages potentially lead to a wide range of applications such as anti-reflection coatings (ARC), birefringence dielectric, wave plates, etc.

A prototype device - a broadband ARC has been specifically designed for space experiment BLAST and PILOT over the frequency range of 456-1440 GHz. The device has been fabricated and characterized using a Fourier Transform Spectrometer to explore its frequency behavior. The performance in good agreement with modeling results used finite element analysis is reported with a detailed data analysis.

REconfigurable Terahertz INtegrated Architecture (RETINA)

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A paradigm shift in the way millimetre-wave components and subsystems are conceived is presented with our
REconfigurable Terahertz INtegrated Architecture (RETINA) concept. Here, an entirely new way of implementing *virtual* metal-pipe rectangular waveguides is demonstrated through simulations. Instead of having traditional air-filled structures with solid metal sidewalls, waveguides have photo-induced *virtual* sidewalls within high resistivity silicon. This new technology allows components to be tunable and subsystems to be reconfigurable, by changing light source patterns. A summary of the detailed analysis of wall photoconductivity and electromagnetic simulations is presented here for the first time.

Superconducting THz imaging detector arrays

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We describe the current status of THz imaging systems using superconducting detectors. These systems have been developed primarily for use as THz cameras for astronomical telescopes operating from high altitude ground-based observatories, from balloon-borne platforms and in space. The main type of detector used in these instruments are transition edge superconducting (TES) bolometers which are read out with superconducting quantum interference device (SQUID) cold multiplexing electronics. Instruments currently operating contain 100s to 1000s of pixels with background limited sensitivity.

Future instruments will require even larger format imaging arrays and therefore new detector types and multiplexing techniques are being explored. We present some initial results from a different type of superconducting detector, the kinetic inductance detector
(KID), that is simpler to fabricate than the TES detectors and able to be read out in a frequency division multiplexing system with up to 1000 detectors per cable. We discuss the prospects for scaling these types of detectors up to megapixel arrays and their possible applications in areas other than astronomy.

Session IV

Imaging and Applications II

Terahertz Tomography

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We have developed a fibre laser based THz tomography system, designed for multi-channel simultaneous measurements with a large number (i.e. 32) of independent measurement channels) in 4 projection angles (0°, 45°, 90°, 135°) of 8 channels each. The system has a millisecond image frame rate from each channel and no moving parts. A schematic of the system is shown in Figure 1.

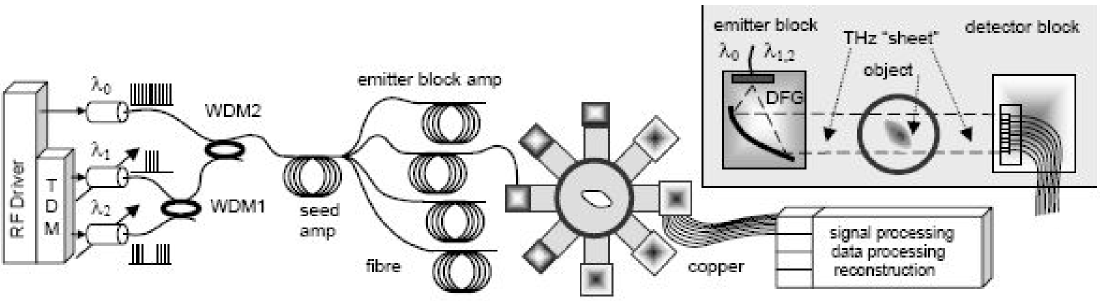


Figure 1. Schematic diagram of the fibre laser tomography system.

The system is specifically designed to study high pressure (> 8 bar) flames as are used in aero engines and gas turbines in power generation. At pressures greater than ~ 8 bar there is considerable soot (i.e. carbon particles formation in a flame which renders it opaque to infra-red light. Combustion efficiency is influenced by these complex processes of soot formation and present day (optical) methods are not capable of complete flame characterization because of the λ^{-4} scattering dependence. Therefore for THz radiation, with its longer λ, scattering is significantly reduced

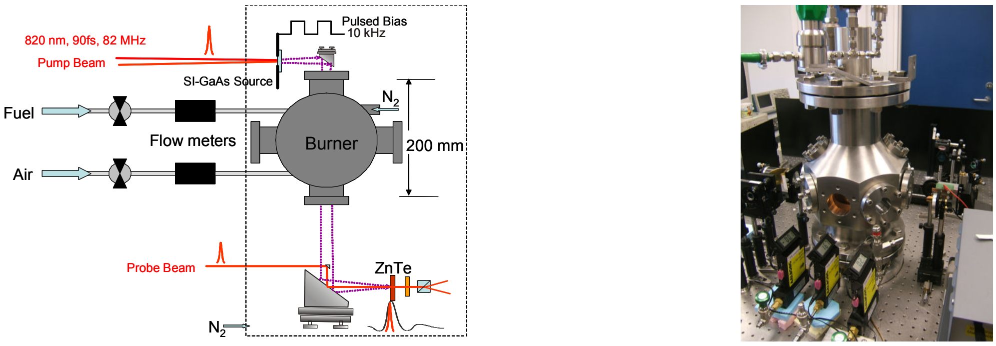
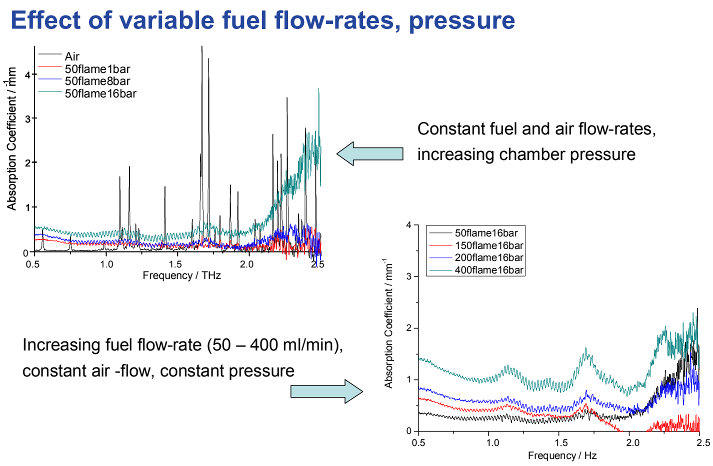


Figure 2. Diagram of high pressure burner used to obtain the THz spectra (left) and the high pressure burner s set up for THz tomography (right)

Not only does terahertz radiation not only pass through the flame but it is also absorbed by many of the chemical products of the combustion process.

Figure 2 shows a diagram of a THz pulsed system used to obtain spectra of high pressure flames and photograph of the high pressure burner tomography apparatus. Figure 3 shows some typical spectroscopy results



that have been obtained.

Figure 3. Spectral information obtained from femtosecond terahertz pulsed spectroscopy (TPS) of a high pressure flame.

The Boltzmann distribution of energy level intensities of the combustion products (e.g. H_2O, CH, NH_3) can be used to estimate flame temperatures. For H_2O temperature mapping, two spectral lines in the laser tuning range (~1 - 2.5 THz) are chosen. These lines must have independence from neighbouring lines (appropriate to the expected laser line-width and/or pressure broadening), sufficient line-strengths and a difference in lower-state energy between lines

The spectral information shown in Figure 3 will be used in the tomography measurements to investigate the geometry, nature of the burning processes and temperature distributions in a high pressure flame.

The authors are grateful for the support of the UK Engineering and Physical Science Research Council (EPSRC) for making this research possible

Combined Active and Passive Measurments Using the AVTIS Millimetre Wave Volcanic Imager

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The AVTIS remotes sensing instrument is a portable 94GHz dual mode imager that has been developed in St Andrews as a practical field tool for round the clock ground based monitoring of volcanoes. AVTIS combines measurements from a heterodyne radiometer with a homodyne, frequency modulated continuous wave (FMCW) radar using a shared antenna to produce a 3D topographic and thermal measurement of volcanic terrain.

Combining active and passive measurements in a single instrument is not straightforward. Despite using non simultaneous data acquisition modes, with active and passive measurements taken sequentially, we have found that radiometric sensitivity can easily be degraded unless careful management of leakage from the radar transmit source to the receiver chain is undertaken.

We will present an overview of the AVTIS dual mode system architecture along with examples of radar and radiometric measurements gathered at active volcanoes. A comparison and analysis of millimetre wave and infrared data gathered in the field will also be presented.

The Development of a Millimetre Wave Imaging System

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INTRODUCTION

The Electromagnetic spectrum has long been exploited to develop imagers for different applications. Research has been focusing on phenomenological study, component design and proof of principle experiments etc. For the particular application of concealed target detection, active imaging is believed to be more effective than passive systems. Recognition of a hand gun size target requires at least 10 mm image resolution and it can be easily achieved by active and coherent system. Passive imaging relies on natural illumination and emission from the target itself, it might fail under circumstances when the temperature of the target and background are very close and/or the natural illumination is not strong enough. Nevertheless, the interaction between the interrogating signal and the target is quite complex, so the targets material phenomenology at the operating frequency must be understood in order to implement the system. At Queen Mary we have done extensive investigations on the material phenomenology at 94 GHz.

Imagers operating at low frequencies have been mature, for example, commercial imaging systems at Q band is already available in the market [1]. For imagers operating at Terahertz frequencies, except TDS (Time Domain Spectrum) 3D imaging approach [2], the research is still largely directed at the component level due to the complexity of the technology and the high cost incurred for manufacturing. For operation at the millimetre band, cheap imaging sensors and arrays are the main focus of the research. At Queen Mary we have validated the use of the low profile EBG woodpile antenna for the imaging purposes.

As for the imager architecture, to keep the system less complex, pupil plane scan scheme is employed rather than focal plane scan so that no collimating devices are required in the imaging system. Image reconstruction algorithms play an important role in the success of microwave, millimetre-wave and THz imaging. The employed algorithms are found to be microwave holography, SAR (Synthetic Aperture Radar) processing, time reversal, tomography, and direct pixel by pixel image formation. In the development of Queen Mary's active imaging system, microwave holographic processing has been adopted.

In the full paper, we will summarize research at Queen Mary in material phenomenology, low profile imaging sensor, array optimum geometry and the application of microwave holographic processing in the concealed target detection.

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Novel Antenna Technology Using Freeformed Ceramic Metamaterials At Millimetre-Wave Bands

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Owing to rapidly increasing demand in high data rate wireless communications, space science and security applications, millimetre-wave and terahertz spectrum is now receiving more attention than ever. The frequency spectrum around 60 GHz is of special interest for high data rate wireless local area network (WLAN) because of the high absorption and attenuation in the atmosphere making this frequency band suitable for short range communications. A point-to-point, wireless communication link at 95 GHz band can provide data transmission rates of more than 1 Gbps at ranges of several miles during normal weather conditions. Non-destructive imaging technology using millimetrewave spectrum is now being extensively experimented for security and healthcare applications. Both active and passive imaging systems are being developed. In recent years, numerous applications based on electromagnetic bandgap (EBG) structures and artificial materials have been demonstrated. Recently, we have demonstrated a direct rapid prototyping method to construct arbitrary three-dimensional (3D) structures (periodic and non-periodic) for millimetre-wave applications, with a possible extension to higher frequencies (terahertz) based on extrusion free-forming of ceramic materials. In this paper, we present several antenna designs using planar and cylindrical woodpile EBG structures for millimetre-wave antennas at 95 GHz. Planar EBG antennas using passive waveguide feed and integrated mixer is presented. Design methodologies based on computer modeling is discussed in detail. A resonator antenna based on the cylindrical EBG structure is demonstrated for short range high data rate communications. The fabricated antennas are characterised and the results are compared with numerical simulations. Experimental results confirmed that the designed antenna showed desirable performances in terms of beamwidth and gain. Relevant technical challenges are also identified.

Full Downlink Transmission using a Millimeter-wave over Fiber System for Indoor Pico-cellular Network Coverage

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Multilevel Quadrature Amplitude Modulation (QAM) data transmissions (64QAM and 16QAM) up to 150 Mbps are successfully demonstrated over a 25GHz millimeter-wave (mmw) over fiber system to a 360 m^2 pico-cell by employing a dual wavelength source. In this system, a dual wavelength source is utilized for generating the mmw carrier by sideband filtering an externally phase modulated optical signal. A sideband filtering technique is implemented by utilizing a thin film dense wavelength division multiplexing (DWDM) de-multiplexing filter [1, 2]. The advantage of such a system configuration is that the phase modulator is free from bias point drift and more robust to temperature change, thereby providing a stable output; and doubling, tripling or quadrupling of the frequency is carried out simply, by selecting the appropriate sidebands of the phase modulated signal.

Millimetre Wave over Fiber Phase Reference Distribution System with Ultra Low Phase Drift through fiber network.

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(2): National Radio Astronomy Observatory, USA

ABSTRACT:

Millimetre wave phase reference distribution system can provide very precise timing signal across the network. This is required in radio astronomy observation, particle accelerators, phased array radar, and frequency and clock signal distribution systems. Optical fiber link has the advantage of very low loss, low cost and can support high frequency, which allows the signal to be delivered over a great distance. Therefore millimetre wave becomes more and more interesting.

This paper demonstrated a millimetre wave phase reference distribution system developed for ALMA (Atacama Large Millimetre Array) project. In the lab, we have demonstrated an 85GHz phase reference signal distributing through a 15km fiber link. We have showed that by serving the fiber length in a closed loop, optimizing the link for reduced polarization noise, and carefully route the fiber over the multiple 19 inch racks, the residual phase drift can be reduce to less than 17fs per 300 seconds, therefore achieve the ALMA specification for the first time. Both phase drift and Allan Variance results are presented.

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Session V

"Terahertz Radiation: An Appropriate Probe of Structure and Dynamics in Biology"

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The ability to grow, reproduce, self-heal and to respond to environmental stimuli are all characteristics of living systems. Crucial to the understanding of such systems are the concepts of structure, dynamics and regulation. Although tremendous advances have been made in understanding structure, through the use of X-ray scattering and other techniques, the general state of knowledge of dynamics in biological systems is less advanced. A fundamental question in biological science is therefore how dynamic processes, such as the molecular dynamics of proteins or the segmental motions of membranes, are organized on a temporal (rather than a spatial) level. Clearly, a wide range of timescales are encountered (from picoseconds through to milliseconds or longer) in biological systems; by the same token, a range of physical probes are needed to explore biological dynamics.

As is well-known, Terahertz (THz) frequency Electromagnetic Radiation (EMR) primarily interacts with groups of molecules. The energy scale of the Terahertz range is typical of the excitation energies for many biological processes, such as: proton tunnelling for enzyme active sites, the collective motion of DNA base pairs along the hydrogen-bonded backbone; protein conformational changes; the vibrational energy of cell membranes; or the nonlinear thermal fluctuations that may be responsible for the initiation of DNA transcription. It is also known that THz EMR can successfully distinguish the disease state of tissues and determine the presence and extent of tumour, so that interaction processes at the level of a few milli-electron volts must also be occurring in organisms of a higher level of complexity.

In this talk I shall explore some of the new Physics and Biology that might be unlocked through the use of Terahertz (THz) frequency techniques. These, it is argued, could be a valuable addition to the physical techniques now available to the biological sciences, providing fresh insights from this hitherto unexplored area of the electromagnetic spectrum.

Interactions of electron beam-wave in subwavelength holes array for THz radiation generation

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Abstract:
The interactions of electron beam-wave in subwavelength holes array (SHA) is one of the promising approaches combining the electronics and photonics to produce THz radiation. The paper deals with these interactions. There are two structures proposed: planar and circular cylindrical SHA. The computer simulations and numerical calculations based on the analytical theory given in the paper show that this proposed approach can produce THz radiation with reasonable efficiency.
A novel mechanism of diffraction radiation has been discovered, it shows that under the excitation of a line current of electron beam, the SHA becomes a diffraction radiation array.

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THz Applications

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Here I will present an overview of terahertz pulsed imaging and spectroscopy applications that TeraView are actively involved in. Applications in the pharmaceutical, non-destructive testing, medical and dental industries will be presented.

Schottky Diode Technology at the Rutherford Appleton Laboratory

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ABSTRACT

Most parts of the electromagnetic spectrum are well understood and exploited, but the terahertz region between the microwave and infrared is still relatively under developed. Potential receiver applications are wide-ranging and cross-disciplinary, spanning the physical, biological, and medical sciences. In this spectral region, Schottky diode technology is uniquely important. InP MMIC amplifiers are generally limited to frequencies less than ~200 GHz, above which their noise performance rapidly deteriorates. Superconducting circuits, which require cooling, may not always be practical. Either as varistor diodes (heterodyne mixing), or varactor diodes (sub-millimetre power generation), Schottky technology underpins terahertz receiver development.

Two important developments have occurred in recent years. First, the underpinning technology base has demonstrably matured. Planar Schottky diode technology has been shown to be practical at frequencies as high as 2,500 GHz, and frequency multipliers have been shown to be capable of generating 100's of mW at frequencies around W-band. Secondly, circuit designs can now be optimised theoretically with CAD electromagnetic structure simulators and non-linear analysis programs. New high-speed computer controlled mills, improved lithographic capabilities and micro-machining techniques also offer exciting new options for cavity and circuit manufacture.

This paper describes the Schottky diode technology currently being developed at the Rutherford Appleton Laboratory. Discrete diode components are described as well as integrated diode/filter circuits. Mixer and multiplier diode structures are reported which include novel substrate transfer techniques to reduce the effects of dielectric loading and self-heating.

Session VI

National Standards and Electronic Devices

Recent and Future Developments in Millimetre and Sub-millimetre Wavelength Measurement Standards at NPL

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INTRODUCTION

With the rapidly growing interest in millimetre-wave and sub-millimetre-wave systems, the lack of traceability for measurements at these wavelengths is becoming ever more of a problem. Making comparable measurements of fundamental parameters, such as power, is very difficult and no proper calibrations traceable to SI realisations are available. At NPL, work undertaken in the 1980s led to the development of the photo-acoustic power meter by QMC, London (now marketed commercially by Thomas Keating) but this does not easily address measurements of power in waveguide. NPL also has comprehensive standards (power, *S*-parameters, noise and attenuation) in waveguide up to 110 GHz but nothing (until recently) at higher frequencies.

There is a clear need to provide standards of measurement for higher frequencies. Members of the UK Millimetre-wave Users Group (www.npl.co.uk/mm-wave) have stated that standards for power and complex-valued *S*-parameters are the most important and should be developed first, followed by noise.

Progress in Superlattice Electronic Devices as Millimeter-Wave Sources

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Abstract

In their seminal paper of 1970, Esaki and Tsu proposed a device structure “with virtually no frequency limitation” where the Bragg reflection of electrons in a semiconductor superlattice (SL) gives rise to minibands and regions of negative differential velocity (NDV) [1]. At a sufficiently high electric field across the SL, traveling domains may then form [2] and cause a negative differential resistance (NDR) to occur between the device terminals. Superlattice electron devices (SLEDs) have received much attention since the 1990s because the underlying physical process, the Bloch effect, has relevant time constants that are much shorter than those of the transferred-electron effect in, for example, GaAs Gunn devices [3], [4]. SLEDs with sufficiently wide minibands in the GaAs/AlAs and InGaAs/InAlAs material systems have been demonstrated successfully as millimeter-wave oscillators [3]–[5]. For example, fundamental-mode operation up to 103 GHz (with an RF power of 0.5 mW) was demonstrated for a GaAs/AlAs SL [3], and a high dc-to-RF conversion efficiency of 5% at 64.4 GHz was obtained with a SLED in a cavity micromachined in SU-8 [5]. More recently, the use of selective etching technologies [6], and improved thermal management with substrateless devices, yielded RF output powers of more than 80 mW and dc-to-RF conversion efficiencies up to 5.1% around 63 GHz [7]. This paper reports on the progress in using SLEDs for high-performance millimeter-wave oscillators above 75 GHz.

Three different SL structures were grown in the Leeds in-house Oxford Instruments V80H molecular beam epitaxy system. Wafer 1 had 120 periods of 12 monolayers (ML) of GaAs and 3 ML of AlAs with a nominal *n*-type doping of 1.5×10^{17} cm^{-3}, wafer 2 had 102 periods of 12 ML of GaAs and 3 ML of AlAs with a nominal *n*-type doping of 1.9×10^{17} cm^{-3}, and wafer 3 had 110 periods of 12 ML of GaAs and 2 ML of AlAs with a nominal *n*-type doping of 1.5×10^{17} cm^{-3}. In all cases, and as before [7], the SLs were sandwiched between graded transition layers on both sides, and an $Al_{0.55}Ga_{0.45}As$ layer was grown between the substrate and the SLED layers to allow complete substrate removal during device fabrication. SLEDs with typical mesa diameters of 30–50 µm were evaluated in WR-15 (50–75 GHz) and WR-10 (75–110 GHz) resonant-cap full-height waveguide cavities, as used previously for GaAs TUNNETT diodes, GaAs and InP IMPATT diodes, and InP Gunn devices [6], [7]. In addition, the highly tunable waveguide mount that previously yielded state-of-the-art results from InP Gunn devices above 180 GHz [8] and from SLEDs [7] was employed. The best results to date from the in-house grown material are 52 mW (4%) at 63 GHz, 42 mW (2.6%) at 78 GHz, 20 mW at 87 GHz, and 11 mW at 105 GHz, all in the fundamental mode, and 5 mW at 151 GHz in a second-harmonic mode. These results are the highest RF powers reported to date from SLEDs and, in particular, the result at 105 GHz demonstrates the highest fundamental frequency for a GaAs/AlAs SLED and a more than twentyfold performance improvement. All results confirm the strong potential of SLEDs as high-performance fundamental sources for millimeter-wave and submillimeterwave frequencies up to 1 THz.

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Schottky Barrier Heights on AlGaN/GaN Heterojunctions and Their Effect on High-Performance GaN TUNNETT Devices

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ABSTRACT: Active microwave devices have been shown to be potential sources for THz frequencies. Experimental results from different types of devices in a wide range of material systems have been reported. To date, no such devices were reported on GaN. Material parameters of GaN are more favourable for high-power and high-frequency devices due to the wide band gap [1]. Therefore, a novel two-terminal transit-time device that utilizes the unique tunnelling properties of a GaN/AlGaN heterostructure was proposed [1]. The AlGaN/GaN heterostructure has a strong piezoelectric effect and a large spontaneous polarization [2]. With the proper choice of AlGaN thickness and composition, undoped junctions can be made with a very high tunnelling probability [2]. The tunnelling properties of the AlGaN/GaN heterostructure were investigated by etching a mesa structure, 32 μm in diameter, and using two Schottky contacts. One contact was deposited on the AlGaN layer at the top of the mesa, and the other is a large area contact on the GaN layer. The devices were char-acterized using static and pulsed measurements where the Schottky contact on the AlGaN layer is reverse biased and the large-area Schottky contact on the GaN layer is forward biased. The dc current-voltage characteristics of Ti, Cr, Ni, Pt, and Pd Schottky contacts on AlGaN/GaN heterostructures grown on GaN, sapphire, and SiC substrates have been meas-ured. Ti and Cr contacts have lower Schottky barrier heights than Pd, Pt, and Ni contacts [3], [4]. It was found that Schottky contacts of the same metal yielded higher current densities on a thinner AlGaN layer at the same applied voltage which agrees with simulated results. Reverse-biased current densities of > 75 $kAcm^{-2}$ were achieved with Ti and Cr con-tacts on 5 nm of AlGaN. Measured contacts that have a low Schottky barrier height of < 1 eV have a linear region with some series resistance at higher voltages. A series resistance significantly reduces the RF performance of the device and a very sharp injected current pulse is required for high performance. Therefore, only contacts with a sharp exponential cur-rent voltage profile were chosen as injector for the RF device design. RF simulations with the measured current-voltage profile of a Cr

contact on an $Al_{0.3}Ga_{0.7}N$/GaN heterojunction show that > 150 mW of RF power can be generated around 180 GHz.

Tab. 1 Barrier heights of Schottky contacts with different metals

Thickness of $Al_xGa_{1-x}N$ $q\Phi B$ *(eV)*

Ti	Cr	Ni	Pt	Pd	
3 nm, *x* = 0.3	*0.8	*0.9	1.2	1.39	1.32
5 nm, *x* = 0.3	1.14	1.10	1.43	1.515	1.37
6 nm, *x* = 0.28	1.00	0.88	1.10	1.18	**
6 nm, *x* = 0.15	1.05	0.92	† 1.23	1.25	**
7 nm, *x* = 0.3	1.03	1.01	**	**	**
7 nm, *x* = 0.15	1.03	0.96	**	**	**

* The measured I-V curves have a linear region with a series resistance at higher reverse-bias voltages.

** The barrier heights for these contacts are currently being determined. † Value similar to [5].

ACKNOWLEDGMENT

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HIGH PERFORMANCE QUANTUM CASCADE LASERS OPERATING BETWEEN 2.7 AND 4 THZ

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We report the performance of three-well, resonant-phonon depopulation, terahertz quantum cascade lasers operating in the frequency range 2.7 – 4 THz. Devices lased up to 113 K in pulsed mode with threshold current densities as low as 845 Acm^{-2}. The effects of the design frequency and laser cavity length on performance were investigated in detail for devices in a surface plasmon waveguide geometry.

Laterally Contacted Schottky Diodes for THz Applications.

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Discrete beam lead GaAs Schottky diodes are routinely flip-chipped into waveguide circuitry for sub-millimeter mixer and multiplier applications. Detrimental consequences include : i. to survive the bonding process the discrete devices need to be fabricated on thick substrates, ii. the air-bridged anode fingers require a minimum diode footprint for robustness, iii. the inevitable bump-bond parasitics.

We have fabricated varactor and varistor diodes using a novel design concept that overcomes these limitations. Conventionally the Schottky contact is formed on a lower doped epilayer grown on the plane of the substrate. Our Schottky contact is made to a lateral epilayer, grown on the highly doped mesa sidewall. With this approach the anode finger remains in contact with the substrate along its length leading to robustness without a minimum junction footprint. The junction area can now be controlled using the submicron accuracy of the grown n^+ active layer thickness. Using GaAs membrane technology the diode (also any filters and matching circuitry) finally remains monolithically on a 3□m thick GaAs membrane which directly mounts into the waveguide block. This represents a potential development of the MOMED technique which has been used successfully at THz frequencies [1], furthermore it allows both varactor and varistor devices to be fabricated on the same membrane. Diode integration into a mixer circuit on a GaAs membrane is described.

The remainder of the paper focuses on the simulation / fabrication / characterisation cycle. A combination of analytic and numerical CAD techniques is used to determine the diode parasitics and SPICE parameters. Comparison is made with measured devices. While the diode performance is principally determined by the epilayer and Schottky contact it can also be significantly affected by the presence of the internal n-n^+ junction. The effects of this iso-junction are illustrated and models including them are presented. Independent Harmonic Balance calculations are compared with results from industry standard simulators and the embedding impedances optimized.

Mixer noise temperature and conversion loss measurements are presented for a 380 GHz sub-harmonic membrane MMIC mixer.

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Schottky diode membrane technology for terahertz applications

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For many applications at millimetre and submillimetre wavelengths, Schottky diode based technology is of key importance in providing both detectors (heterodyne mixers) and sources of power (frequency multipliers). Reducing the parasitic capacitance of the devices is of crucial importance in extending their operation to higher frequenies.

This paper will describe the fabrication of Schottky diode structures on GaAs substrates that have been reduced in thickness to a 5 micron thick membrane. Device structures for submillimetre-wave mixers and frequency multipliers will be described. The device circuits incorporate beam-leads: gold tabs protruding from the edges of the membrane circuit to facilitate mounting of the device circuit in its waveguide cavity and to provide accurate circuit grounding.

Session VII

High Power Sources

Recent Progress in High Power Millimetre-wave Sources at Strathclyde University

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ABSTRACT

Recent progress in research on high power millimetre-wave sources at Strathclyde University is presented.

The study of a coaxial free-electron maser (FEM) based on two-dimensional (2D) and one-dimensional (1D) distributed feedback, driven by a 70 mm diameter, annular electron beam is discussed. A new cavity formed with 2D and 1D periodic lattices, positioned at the input and output of the interaction region, respectively, was used. It has been demonstrated that 2D distributed feedback in the input mirror allowed 8 mm radiation emitted from different parts of the electron beam to be synchronized. The FEM operating in the 35.9–38.9 GHz frequency region generated 65 MW, 150 ns duration millimetre wave pulses which contained ~10 J of energy in the pulse [1].

In addition to studying novel features of laboratory sources of electromagnetic radiation for their own intrinsic interest and for applications the group has also been simulating in the laboratory radiation sources observed in nature such as Auroral Kilometric Radiation. The phenomenon of Auroral Kilometric Radiation arises in the polar magnetosphere in regions of reduced background plasma density called the Auroral Density Cavity where the cyclotron frequency exceeds the plasma frequency by around an order of magnitude. The spectrum of the radiation implies it is due to cyclotron instability in a non-thermal, highly energetic element in the electron population. This population is accelerated towards the auroral zones of the ionosphere and as it descends it acquires an increasing component of rotational momentum due to conservation of the magnetic moment in the increasing magnetic field. A series of publications [2-6] has recently reported the progress in the laboratory experiments and numerical simulations.

A long-standing interest of the group is in methods of generating electron beams for application in a range of millimetre-wave devices. A cusp electron

gun has been studied in recent years and successful results have been reported [7]. A cusp gun uses a non-adiabatic magnetic field reversal to obtain azimuthal motion on an electron beam resulting in an annular shaped, axis-encircling beam. This type of gun is a promising electron beam source for application in millimetre-wave devices.

The pseudospark discharge has been studied by the Strathclyde group for almost 20 years and recently there has been an increased emphasis on employing the electron beam produced by pseudospark discharges for application in high frequency sources. [8] Experimental studies of the production and propagation of an electron beam from a multigap pseudospark discharge have been carried out. From a three-gap pseudospark, a beam up to 680 A has been measured at the anode at an applied dc voltage of 23 kV. This beam can propagate downstream as far as 20 cm in a gaseous environment with no guiding magnetic field, which confirms that the transport of the electron beam was based on the neutralization of the space charge of the electron beam due to the ionization of the gas molecules by the beam itself. The beam is of very small size of 1–3 mm in diameter and is ideal to drive high frequency radiation. Higher energy electron beam pulses were generated using a 14-gap pseudospark discharge powered by a cable pulser capable of producing 120 ns duration and 170 kV voltage pulses. The beam measured had a current of up to 110 A. Interactions between the produced beam and a Ka-band Cherenkov maser and a W-band backward wave oscillator slow wave structure were simulated and designed. Millimetre wave pulses have been detected from the Cherenkov maser and backward wave oscillator beam-wave interaction experiments.

The Strathclyde group is investigating several types of gyro-device to provide millimetre-wave sources. Research has been carried out previously at lower frequencies with a view to then increasing the frequency. For example to realize the full potential of a gyrotron backward wave oscillator (gyro-BWO), an energy recovery system has been designed [9] using Particle-In-Cell (PIC) simulations and optimized using both a genetic algorithm and PIC simulations. Simulations were carried out to optimize a periodic structure for separation of the spent electron beam and the output radiation produced by a gyro-BWO in the 8.0–9.5 GHz frequency range. The spent electron beam can be collected using a multistage depressed collector. The number and electric potentials of the electrodes were optimized to achieve the best overall recovery efficiency for specific parameters of the spent beam. The 3-D PIC code MAGIC was used to simulate the electrons' trajectories and a genetic algorithm was used to refine the electrode shapes for optimum efficiency.

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High power pulsed electron paramagnetic resonance spectroscopy at 94GHz

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Electron paramagnetic resonance (EPR, also known as electron spin resonance, ESR) is a magnetic resonance technique which uses the interaction between unpaired electrons in a magnetic field with a microwave or mm-wave field to yield information about the local magnetic environment of the electron. Most commercial systems work at frequencies around 10 GHz, but moving to higher fields offers more sensitivity and better spectral resolution. Much EPR uses continuous wave illumination, but pulsed techniques are becoming more popular due to some advantage they offer. EPR has been carried out at many hundreds of GHz, but for the high-power operation required to excite wide portions of spectra, 94 GHz is a convenient operating frequency.

We have recently developed a very high performance pulsed EPR spectrometer which offers kW 94 GHz pulses as short as 0.5 ns, as well as continuous wave operation at lower power. This presents significant technical challenges and the instrument uses large quasi-optics to minimise stray reflections in the system and a novel method of generating such short pulses. We will describe the motivation behind constructing such a system, detail the high performance instrumentation involved and introduce it's application to distance measurements in bio-molecules, an area that is attracting increasing interest and application of EPR.

A Novel Co-Harmonic Gyrotron

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Currently, there are few devices capable of generating radiation in the sub-millimetre band, which exploit the electron cyclotron maser instability. Given that there are many potential applications in this regime, significant research is being devoted to novel THz capable sources. However, given the significant cost and bulk of magnetic systems required for a device working at the fundamental harmonic, it is attractive to consider operation at a high harmonic, s, of the electron cyclotron frequency, ω_c. This poses problems however, as the starting current required for a high harmonic will often also satisfy the starting criteria of a lower harmonic.

Therefore, a novel gyrotron interaction cavity has been designed, allowing co-harmonic generation of second and fourth harmonic resonances. Such a process is realised through an azimuthal corrugation of the cavity walls, which allows the frequencies of the two resonances to have an exact integer ratio. Through the use of a specially designed output taper, the resonant second harmonic mode is effectively trapped within the interaction cavity, whilst the resonant fourth harmonic is allowed to propagate into the output region.

The PiC code MAGIC 3-D has be used to examine the proposed geometry. Simulations performed thus far have shown the intended co-harmonic behaviour at the second and fourth harmonics; however, the second harmonic is shown to undergo mode conversion along the output taper, which in turn, dominates the emitted radiation. Current research is focussed on methods of separating the two modes within the output region.

W band Gyro-devices using helical interaction waveguides and cusp guns

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A helically corrugated waveguide has been demonstrated with a wave dispersion that has a near constant group velocity in the region of small axial wave number [1]. This allows broadband microwave amplification to be achieved in a gyrotron travelling wave amplifier (Gyro-TWA) [2, 3] and wide frequency tuning in a Gyrotron Backward Wave Oscillator (Gyro-BWO) [4, 5].
This paper presents the design, simulation and experimental results of a Gyro-BWO and Gyro-TWA based on such a helical waveguide. Both of the devices are for W-band operation and are driven by large orbit electron beams generated from cusp electron guns.
The Gyro-BWO has a 3dB frequency bandwidth of 84-104 GHz, output power of 10kW using a beam of energy 40 keV, current 1.5 A and velocity ratio 1.6. The Gyro-TWA is designed to have a 3dB frequency bandwidth of 90-100 GHz, output power of 5 kW and saturated amplification gain of 40 dB.

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Mode evolution in an FEM with 2D distributed feedback

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The demand for high power radiation sources operating in the millimetre and submillimetre wave regions is steadily increasing. Such sources are important for a number of applications including remote sensing, spectroscopy, material science and security. In order to achieve the desired high power radiation a large diameter high current but low density beam can be used. This has two distinct advantages; firstly the low space charge density avoids the formation of beam instabilities; secondly the electromagnetic power density inside the cavity can be maintained at a level which circumvents electromagnetic field breakdown inside the interaction space. Two dimensional distributed feedback can be used to synchronise the radiation from the oversized electron beam. The effect of the electron beam current density on the operation of the FEM based on 2D distributed feedback will be discussed. The evolution and competition of the modes when the FEM is driven with the high current density (IkA/cm2) electron beam will be presented and compared with numerical modelling. The results will also be contrasted with experimental data obtained for a lower current density (O.3kA/cm2) electron beam.

NUMERICAL INVESTIGATION OF PSEUDOSPARK DISCHARGE BASED ELECTRON BEAM SOURCE FOR TERAHERTZ GENERATION*

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Abstract: Terahertz radiation, which ranges from 0.1THz to 10THz, has received substantial interests in recent years. In order to achieve high power THz source, the conventional vacuum electronics technology has the potential to supply high enough powers to support many exciting and emerging THz applications[1]. Klystrons have been designed to generate THz radiation [2]. This vacuum device requires a very small sized RF circuit and a very thin electron beam with reasonable beam energy. The pseudospark discharge can provide a suitable high current density and small diameter (<1mm) electron beam.

In the study of a pseudospark discharge, we have utilised the physical analysis and numerical simulation technique: electromagnetic particle-in-cell (PIC) simulations with Monte-Carlo collisions (MCC). With a trigger pulse for the pseudospark discharge, the ionisation procedure of the gas in the pseudospark discharge and the dynamics of the charged particles have been studied. The scaling relationship of the electron emission current density corresponding to gas pressure, breakdown voltage, anode-cathode gap distance and cathode materials have been investigated. The PIC numerical simulation has also provided a unique opportunity in the pseudospark discharge research. Through this study, we try to obtain a better understanding of the pseudospark discharge in generating a high current density small diameter electron beam.

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Session VIII

THz diagnostics and photonic and linac sources

Investigation of THz technology and FIR laser diagnostics on EAST tokamak

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A single-channel far-infrared (FIR) laser interferometer was developed for measuring the line averaged electron density in the EAST tokamak as shown in Fig.1. The light source was a THz laser with wavelength of 0.337 mm (HCN laser). The instrument was of the Mach-Zehnder type, with a heterodyne detection system. The modulation frequency (10kHz) was produced by diffraction from a rotating grating. Lower hybrid current drive (LHCD) was the main method to drive currents in the EAST. High power heating of a lower hybrid wave (LHW) was performed (PLHW ~1.2 MW at 2.45GHz) recently in the EAST. Long-pulse (t=60s) plasma discharge was also achieved by LHCD. In plasma density scanning experiment with DN divertor configuration on EAST, we got three regimes of sheath-limited conduction, high-recycling state and detached divertor in the scrape-off layer (SOL). To study the evolution of electron density ne(r) profile and plasma current density j(r) profile, a five channel DCN laser interferometer / polarimeter will be developed in the EAST tokamak.

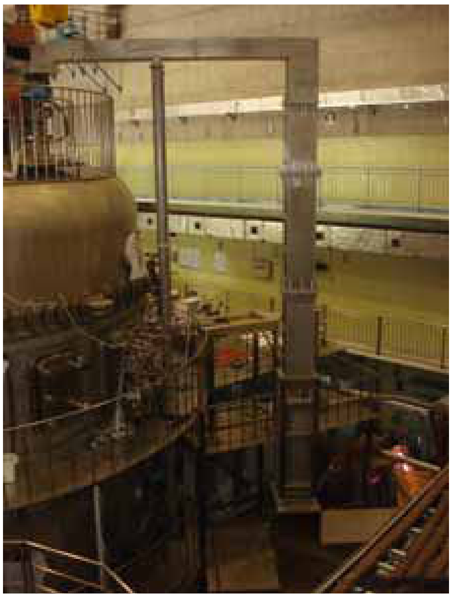

Fig.1 A photo of the HCN laser interferometer on EAST tokamak

THz Light from Alice – the superconducting RF Linac at Daresbury

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The superconducting RF Energy Recovery Linac ALICE started operation in late 2008. Alice consists of a photoinjector , a superconducting booster and linac and dipole chicane to compress the electron bunches. These short electron bunches will provide light from THz to x-ray. High peak power THz radiation is obtained through coherent enhancement of the long wavelength synchrotron radiation., Infrared radiation from a tunable free electron laser and x-rays from Compton scattering a high intensity laser pulse with the electron bunch. These light sources are themselves synchronised and can be synchronised with table top lasers, providing a suite of **A**ccelerator and **L**asers **I**n **C**ombined **E**xperiments.

In this paper we describe the THz beamline which transports the light first to a diagnostics laboratory equipped with a high aperture Martin Puplett interferometer, then on to a dedicated tissue culture laboratory for experiments on living cells.

THz radiation was transported to the diagnostics room in early 2009. We will present the initial commissioning data and modeling of the Alice source.

Terahertz Generation by Intracavity Optical Parametric Oscillators

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The generation of terahertz radiation via parametric techniques is well established, in particular the use of a nanosecond pulse Nd:YAG laser pumping an optical parametric oscillator, or OPO, to produce continuously tunable, narrow bandwidth, pulses in the 1-3 THz range has been shown as a practical, low complexity, generation technique[1]. In St Andrews we have taken this technique and extended it into intracavity devices, where the OPO is situated within the pump laser – directly accessing the higher intensity laser field to reduce threshold energy requirements and increase both efficiency and simplicity[2]. We will describe this technique and present a device generating nanosecond pulses of terahertz radiation with energies up to 20 nJ and tunable from 1 to 3 THz with ~60 GHz linewidth. The properties of the terahertz wave (such as linewidth and frequency) can not only be inferred from the optical wavelengths present in the OPO, but can be controlled by these waves. The primary example of this is how the tuning of the optical wave determines the terahertz frequency generated, but we also demonstrate line narrowing of the terahertz wave by both insertion of etalons within optical waves (<1 GHz)[3], and injection seeding (~100 MHz, transform limited)[4] – both standard techniques for laser line narrowing. Furthermore we will show examples of spectroscopy and imaging performed with our device, and discuss the detector technologies that we have successfully implemented, including bolometric, pyroelectric, and Golay detectors.

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Increasing the Directivity of Photoconductive Antennas

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Terahertz technologies have become an attractive research topic. The antenna, as an essential device for terahertz wave generation and detection, has also drawn a lot of attention. Although the antenna theory for microwave has been well established, it cannot be directly applied to THz band due to the changes in material properties and configurations from lower frequencies to higher frequencies. The most popular THz antenna are photoconductive antennas for this application. The typical configuration of such an antenna consists of a conducting dipole which is fabricated on a semiconductor substrate, and a bias voltage connected to the dipole. However, this kind of antenna has an omni-directional radiation pattern and half of the radiated power is not utilised for most applications, including imaging – the major application of THz to date. To improve the antenna performance and make a better use of the radiated power, some attempts have been made; for example, the size of the gap is optimised, and the shape of the electrodes fabricated on the substrate is changed to a bow-tie structure. This paper will introduce a THz horn antenna with detailed information on how to obtain the optimised parameters of this design. The structure is shown in Fig.1. This new kind of antenna has a uni-directional pattern, which means more power can be radiated to the desired direction thus a better sensitivity can be obtained. By choosing suitable parameters of this antenna, excellent performance can be obtained. The simulation and experimental results are to be presented at the workshop. Fig.2 shows the fabricated horn.

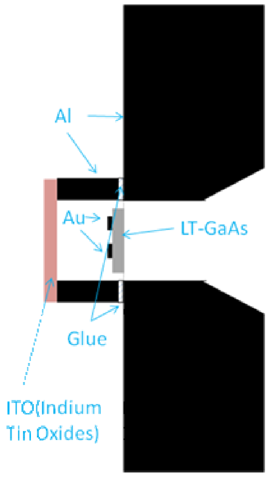

Fig. 1 Cross-section view of the antena

Fig. 2 3D view of the antenna horn part

Developing the next generation of photovoltaic cells using terahertz based pump-probe techniques on a prototype energy recovery linac

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If solar cell technology is to alleviate our current reliance on fossil fuel electricity sources then we need to simultaneously increase device efficiencies and significantly reduce device cost [1]. A potential way forward would be to combine colloidal PbS nanoparticles that have recently revealed a novel multiple exciton generation (MEG) light harvesting mechanism [2], with an anode that can be produced by low cost synthesis, such as ZnO nanorods.
Terahertz radiation based pump-probe techniques can provide insight into the fundamental physics of charge generation and charge transport on ultrafast timescales, which is of crucial importance in the design and development of solar cells. In particular, utilising the intense terahertz radiation from a linac based source may be able to provide insight into the mechanism responsible for the multiple exciton generation. A detailed understanding of the MEG mechanism offers the tantalising possibility of enabling us to exploit the process and harvest the energy of solar photons in excess of the materials bandgap that are normally wasted as heat. In this work we will describe both how be have established laser/accelerator pump-probe based techniques utilising the intense terahertz radiation source from a prototype energy recovery linac and our investigations of PbS nanoparticles as photo-absorbers for solar cells.

Our measurements are carried out using both terahertz radiation generated via optical rectification of 100 femtosecond laser pulses in a <110> ZnTe crystal and ALICE, a prototype 35 MeV energy recovery linac at the STFC Daresbury Laboratory. ALICE is capable of providing intense terahertz radiation from a bending magnet due to coherent enhancement [3]. A high power Ti:sapphire oscillator was synchronised to the 81.25 MHz repetition rate of the long-burst mode of operation of the linac. The terahertz transmission of the samples were measured using electro-optic sampling techniques. The time dependence of the transmission was determined by pump-probe techniques with the use of a laser pump pulse at a controllable delay from the terahertz probe pulse. The time resolution of the experiment was limited only by the 600 fs duration of the terahertz pulses.

In this paper we will also discuss recent progress in laser-pump terahertz-probe measurements on the ultrafast transient photoconductivity in ZnO nanorods and the future possibilities for accelerator based terahertz pump-probe experiments.

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Poster Session

Development of Advanced Gunn Diodes and Schottky Multipliers for High Power THz sources

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This paper presents continuing work on the development of an advanced step-graded Gunn diode using joint modeling-experimental approach. These devices are realized to test GaAs based Gunn oscillators at sub-millimetre wave for use as a high power (multi mW) Terahertz source in conjunction with a multiplier. The mm-wave multiplier, with novel Schottky diodes and Schottky varactors for Terahertz imaging applications will be presented. Concerning the two semiconductor components in a Varactor, the epitaxial growth of both the Gunn diode and Schottky diode wafers are performed at the University of Manchester using an industrial scale Molecular Beam Epitaxy (V100+) reactor. The Gunn diodes are then packaged by e2v Technologies (UK) Plc.

The Gunn diode model has been developed in SILVACO which provides a Virtual Wafer Fabrication (VWF) simulation environment in which two or three dimensional device simulations can be performed using Atlas VWF software. Simulated IV characteristics in forward and reverse bias produced data that was extremely well matched to measured data, thus validating the choice of the physical models and material parameters used. The model was then used to perform predictive modelling for the high frequency and high power devices that will be discussed in detail and presented with measured results. Further work will then be presented on novel self-aligned non-alloyed contact Schottky diodes that will be utilised in the multiplier to generate multi-mW terahertz frequency sources.

Terahertz radiation generation with a pseudospark-sourced electron beam

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A small-scale pseudospark discharge is under investigation for its applications in millimeter wave to terahertz radiation generation. A 10kV voltage was applied to a single-gap pseudospark of configuration: 1mm cathode aperture, 1mm anode aperture and 6mm gap separation. At a pressure of 100mTorr, an output current of 4A was measured which demonstrates a current density of 500 A cm^{-2} and is on a similar scale to that observed in previous 3mm aperture experiments. Based on the pseudospark–sourced electron beam, a 200 GHz microklystron was designed and simulated using the particle-in-cell (PIC) code MAGIC. In a four cavity microklystron, MAGIC-2D results revealed a strong amplification signal with a peak power output of 5 W with a microwave input power of 25 mW when the Q-factors were 730, 1600, 1600 and 1600 for the cavities, respectively. This corresponded to a device gain of 23 dB and an efficiency of 20%. A three-stage energy recovery system has been designed for use with the klystron which will allow for a recovery efficiency of 62 %, giving a total device efficiency of ~40%.

Design of a 26 GHz Receiver Front-End

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ABSTRACT: This paper presents a 26GHz receiver front-end which includes two substrate integrated waveguide (SIW) filters and a low-noise amplifier (LNA). This receiver front-end works at 26GHz with a bandwidth of 4GHz. Measured results indicate that the front-end has a 15.9 dB gain at 26GHz, and a 57dB attenuation at 20GHz.

Frequency calibration of THz time-domain spectrometers using an etalon

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We present an etalon-based method of calibrating the frequency of THz time-domain spectrometers. The method utilizes the etalon effect produced by multiple reflections in non-absorbing wafers or in narrow air-gaps. The technique provides frequency calibration across the measurement bandwidth with uncertainties comparable with the typical THz TDS resolution.

Low Noise Theory at 2.5 Thz For HEB Mixer

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Abstract—In This Paper , We mainly analyse Low Noise Characteristics For Thz hot electron bolometer(HEB) mixer. HEB mixer have many characteristic features not found in other mixer such as Low noise . Low noise receiver based on superconducting niobium nitride and frequency range above 2 THz. The noise temperature of HEB mixer has been analyse at a frequency of 2.5 Thz for room condition.

The design of a 390 GHz gyrotron based on a Cusp electron gun

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Abstract

The design and simulation of a 390 GHz harmonic gyrotron will be present in this paper. The gyrotron is operated on a TE_{71} mode and the 7^{th} cyclotron harmonic of a large orbit electron beam. This beam is produced by a cusp electron gun with a voltage of 40 keV, a current of 1.5 A and an adjustable velocity ratio from 1 to 3. Smooth cylindrical waveguide have been studied and built as the interaction cavity. The relationship between the cavity dimensions and cavity Q values has been studied for optimized output at the designed mode. Both theoretical analysis and numerical simulation results (using the 3D PIC code MAGIC) of this gyrotron will be presented. In the simulation more than 600 W of output power at the designed frequency is predicted. A high frequency (325-500 GHz) VNA was used to measure the microwave properties of the gyrotron cavity and the results will also be presented in this paper.

The Influence of Dichroic on the Performance of a Quasi-optical System

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ABSTRACT: Quasi-Optical techniques have been widely applied in remote sensing and astronomy areas operating in the millimetre wave band and sub-millimetre wave band. The feeding system for Planck mission [1] has operating frequencies even high to the THz range. Other sounding systems such as AMSU-B [2] use Quasi-Optical network to minimise the size and weight to achieve a compact feeding system and satisfy the payload requirements. Dichroic plays an important role in such a Quasi-Optical multipath demultiplexer system, which separates a signal from a main reflector antenna to different frequencies. This can be done by using several dichroics acting as filters. However, the presence and the nonideal performance of a dichroic will cause distortion to the signal and consequently degrade the system performance.

This paper gives a quantitive analysis to the influence brought in by the dichroic based on the measurements of a dual-path Quasi-Optical system. This is done by comparing the measured results with and without the dichroic in place. It is expected that the insertion loss of the dichroic will produce great distortion to the signal. The finite size and the position of the dichroic will also bring in some negative influence due to diffraction. Some other means, including the fabrication method and the optimal position of the dichroic based on the analysis, are also displayed to further reduce the influence by the dichroic component.

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Characterization of Terahertz Quantum Cascade Lasers for laser spectroscopy applications

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The development of compact, high power, single mode laser sources provides the primary tool for high sensitivity molecular sensing across a variety of disciplines including astronomy, atmospheric monitoring and trace detection of illicit materials. Quantum Cascade Lasers (QCLs) [1,2] have proved to be efficient sources of radiation throughout the mid infra-red region (5-15 microns); the combination of compactness, high power, room temperature operation and broad wavelength tuning range provides a formidable spectroscopic and analytical tool, which has enabled the development of high sensitivity molecular sensors operating both in-situ and remotely.

The current challenge is to extend the capabilities of QCLs towards longer wavelengths to cover the far infrared and the terahertz region of the spectrum. Availability of reliable, single mode QCLs in this spectral window (which contains pure rotational transitions) would drive the development of laser-based spectro-radiometers. Molecular trace sensors active in this region would yield lower detection limits, a significant decrease in the noise temperature associated with heterodyne detection systems and high resolution spectroscopic measurements on unstable radicals and weakly bound molecular clusters. [3,4].

In the present work, a number of QCL's were examined with a particular focus on spectral tuning range; it is this characteristic which distinguishes QCL's from other laser sources of terahertz radiation. An optical cavity created between the laser chip and the detector allowed tuning rates of the order of 50-100 MHz/K to be determined. Peak power output in the milliwatt range was observed for operating temperatures up to 100 K giving tuning ranges greater than 0.1 cm^{-1}, which are sufficient to cover entire absorption bands at low pressures where Doppler broadening is dominant. Further characterization of different QCLs was performed, including power, operational parameters, and laser beam spatial profile.

RESEARCH AND ANALYSIS OF SELF-CONSISTENT NONLINEAR THEORY FOR A 240 GHz GYROTRON

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Abstract: In this study, the self-consistent nonlinear theoretical analysis, numerical calculation and particle simulation were carried out for a 240GHz CW technology gyrotron. The result shows that a 240GHz gyrotron operating at the TE_{03} mode and fundamental harmonic can obtain an output power of 57.75kW and efficiency of 33% for beam current 2.5A and beam voltage 70kV. The simulation results of particle simulation software had a basically agreement with the program of the self-consistent nonlinear theory, which can conclude that the program had a very good guide on particle simulation.

Development of a frequency-domain THz spectrometer based on parametric generation

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The development of a THz spectrometer exploiting the novel approach of intracavity parametric generation is described. The THz source is based on a Q-switched, diode-laser pumped Nd:YAG laser, which provides the pump wave for the parametric oscillator. The nonlinear medium, MgO:$LiNbO_3$, is located simultaneously in the pump and idler cavities using a novel intersecting cavity configuration [**1**], and consequently the device is both compact and has a low pump pulse energy threshold (<1 mJ). The device operates in the frequency domain and is tunable over the range approximately 1-3 THz. Tuning of the THz frequency is achieved by altering the angle between the pump and idler beams. In the current configuration the coarse-tuning elements and data logging have been placed under computer control to create a convenient user interface that reliably tunes the THz frequency over the entire operating range. The free-running linewidth of the THz radiation is approximately 50 GHz but the use of solid etalons in the pump and idler cavities results in sub-GHz linewidths [**2**]. Spectroscopic data is obtained using a TIR spectroscopy arrangement that permits the study of highly absorbing liquid and powder samples, several examples of which are presented. Additionally a comparison between several types of detectors has been made including cheap pyro-electric detectors, golay cells, bolometers and electro-optic detectors.

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[**2**] Stothard, DJM., Edwards, TJ., Walsh, D., Thomson, CL., Rae, CF., Dunn, MH., Browne, PG., *Appl. Phys. Lett.*,**92**, (14), pp 141105-141105, 2008.

Transform Limited Terahertz Pulse Generation from an Injection Seeded Intracavity Optical Parametric Oscillators

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One of the features of the intracavity terahertz optical parametric oscillator (OPO)[1] is the ability to infer and/or define the terahertz output frequency and linewidth characteristics via the optical wavelengths involved in the generation process. In the nonlinear optics group at St Andrews University we have put this to good effect by reducing the linewidth of the terahertz output to a level close to the transform limit of the nanosecond pulses it is presented in (i.e. ~100 MHz) via the well known technique of injection seeding[2]. This allows us to continuously tune the OPO over the mode hope free tuning range of the seed laser of ~20GHz at any point in the 1 to 3 THz tuning range of the system. In this poster we will describe the development of our injection seeded system, its characteristics, and illustrate its suitability for spectroscopy with some measurements of the 1.4969 THz carbon monoxide absorption line.

1. T. Edwards, D. Walsh, M. Spurr, C. Rae, M. Dunn, and P. Browne, "Compact source of continuously and widely-tunable terahertz radiation," Opt. Express **14**(4), 1582-1589 (2006).
2. D. Walsh, D. J. M. Stothard, T. J. Edwards, P. G. Browne, C. F. Rae, and M. H. Dunn, "Injection-seeded intracavity terahertz optical parametric oscillator," J. Opt. Soc. Am. B **26**(6), 1196-1202 (2009).

Demonstration of Quasi Phasematching in an Intracavity Terahertz Optical Parametric Oscillator using Orthogonally Poled $LiNbO_3$

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The terahertz optical parametric oscillator typically requires a form of non-collinear phasematching between the three wavelengths involved in the generation process due to the widely different refractive indices of the nonlinear crystal (lithium niobate) between terahertz and visible/infra red regions[1]. This allows rapid side extraction of the terahertz wave, which is important due to a strong absorption in the material caused by a polariton resonance (that also boosts the nonlinear conversion process), and simple tuning via cavity angle adjustment. However this reduces the overlap of the waves, reducing the overall gain of the system. We demonstrate the use of orthogonally periodically poled lithium niobate to form a quasi phasematched device where the optical waves are collinear, overlapping throughout the crystal, and the terahertz wave is still extracted from the crystal's side. At present the terahertz energy produced (5 pJ/pulse) is lower than from the non collinear system, which we believe is due to longer pulse build-up times and diffraction losses incurred by propagating along crystal domain inversion walls, but cascaded generation processes are now observed – indicating that ultimately the efficiency could significantly exceed the Manley-Rowe limit.

1. T. Edwards, D. Walsh, M. Spurr, C. Rae, M. Dunn, and P. Browne, "Compact source of continuously and widely-tunable terahertz radiation," Opt. Express **14**(4), 1582-1589 (2006).

Micromachined microwave circuits

Yi Wang, M Ke, N Murad, T Skaik, X Shang, F Huang, M Lancaster

The dimensional accuracy of millimetre and terahertz passive components is critical to their performance, simple wave guiding structures, need to not only be manufactured accurately, but also be produced of high quality metal to reduce losses. Conventional electroformed components are well developed, but are expensive, and cannot produce complex passive circuits. This poster summarises work on micromachined microwave circuits, where the passive circuits are produced by micromachining of silicon or SU8 photo resist. The work has initially developed square coaxial cable structures at frequencies below 100 GHz. These components include patch antennas, hybrid couplers, filters and a full four element Butler matrix for antenna beam forming. In addition transitions from the square coaxial cable to coplanar line and to ridge waveguide has been produced. The components are made by bonding layers of gold coated micromachined silicon or SU8 together. Both the construction process and the performance of the circuits will be discussed in the poster. The micromachining process is also ideal for waveguide circuits well above 100 GHz, and the poster will discuss the latest work on the development of 300 GHz waveguide circuits.

Low –loss terahertz dielectric strip waveguide

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Abstract —The terahertz (THz) band is one of the late unexplored frontiers in the electromagnetic spectrum. A major stumbling block hampering instrument deployment in this frequency regime is the lack of a low-loss guiding structure. We describe a novel transmission line—dielectric strip waveguide. The dielectric slab-based guide structure is low-loss at the low wave band of terahertz. From 300GHz~600GHz, the attenuation is very low up to 0.001dB/cm.

The Design of a 664 GHz Sub-Harmonic Mixer

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ABSTRACT: This paper presents the design and simulation of a novel fixed-tuned sub-harmonic mixer operating with a central frequency of 664 GHz using a discrete anti-parrallel pair of Schottky diodes fabricated at STFC Rutherford Appleton Laboratory (RAL) and flip-chip mounted onto a quartz based microstrip circuit. A double-sideband (DSB) conversion loss of better than 10dB is simulated with 4.2mW of Local Oscillator (LO) power across an RF range of 650-690GHz with a peak of 8 dB at 663GHz.

Transmission Characteristics of Planar Goubau Line at THz Frequencies

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Abstract: In this communication, the first part will be dedicated to study of Transmission Characteristics of Planar Goubau Line (PGL) at THz frequencies, and the relation between S-Parameter and the main geometrical parameters will also be discussed. For the second part a periodical corrugation of transition between a standard coplanar waveguide (CPW) and PGL is proposed. This novelty structure will greatly reduce the transmission losses and improve propagation characteristics. The results show that this configuration is very well suited for the Terahertz frequency range and the field of biological characterization.

Index Terms: coplanar waveguide, Planar Goubau line, transition, terahertz transmission line.

Some important figures:

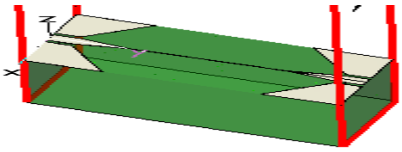
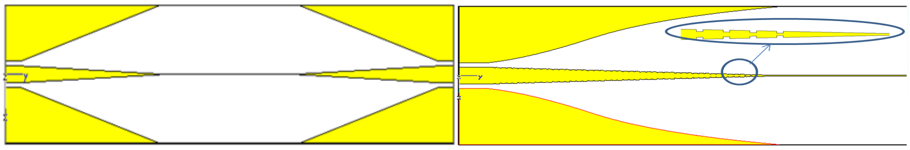


Fig. 1 Planar Goubau line model



(a) Classical structure. (b) Proposed new structure.

Fig.2.Top view of Planar Goubau line

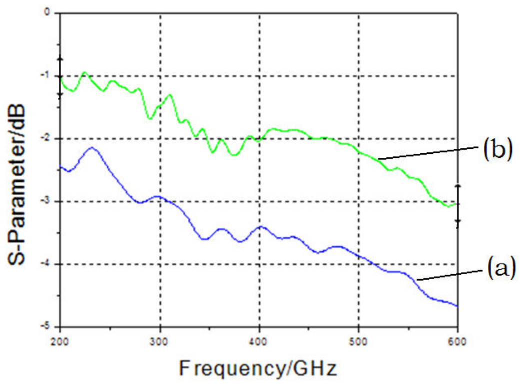


Fig. 2. Simulation results: comparison between Fig.2.(a) and Fig.2 .(b)

Simulation of a Four-stage Depressed Collector for a W-band Gyro-BWO

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Abstract—An energy recovery system using a four-stage depressed collector was designed to realize the full potential of a W-band gyrotron backward wave oscillator (gyro-BWO). The geometry of the depressed collector was optimized using a genetic algorithm to achieve the optimum overall recovery efficiency for specific parameters of the spent beam. Secondary electron emissions were simulated to investigate the effects of the secondary electrons on the overall recovery efficiency and the back-streaming of the electrons from the collector region.

Design of a 225-GHz Fix-Tuned Subharmonically Pumped Planar Schottky Diode Mixer

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Abstract—This paper describes the computer design of a novel subharmonically 225GHz pumped planar schottky diode Mixer for space-borne radiometers . The planar GaAs Schottky diodes found by European company are fully integrated with the RF/IF filter circuitry via the quartz substrate. The GaAs Gunn oscillator is used as the local-oscillator (LO) and this paper also found an innovative nonlinear circuit model for GaAs Gunn diode in oscillator based on the physical mechanism. Its equivalent nonlinear circuit can assist the design of the Gunn LO. A best double-sideband-mixer loss of 8dB was achieved with 12 mW of LO power at 1GHz IF. Over an IF band of 1–2 GHz, the double-sideband loss is below 10dB. The subharmonic mixer is designed as a fix-tuned component with the least number of parts to minimize the cost and maximize its potential for volume manufacture.

Novel Single-Mode Bragg Fibres for THz Applications

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Abstract — This paper presents a novel design of single mode, low loss THz waveguide that uses a Bragg structure. The proposed Bragg structure is designed to be effectively single mode due to its intrinsic polarization filtering effect. Based on the confinement mechanism of Bragg fibres, which is destructive interference in the cladding layers, the Brewster phenomenon can be employed to reduce field confinement. Moreover, the core diameter of Bragg fibres can be chosen so that the angle of incidence of the wave incident on the Bragg cladding lies close to the Brewster angle. In this type of Bragg fibre, only the fundamental HE mode propagates, with the TM and EH modes leaking out. In this paper, polymer Bragg fibres are investigated for THz applications and modelling carried out using the transfer matrix method. It is shown that a single HE_{11} mode of propagation can be sustained over a bandwidth of 200GHz, and the single mode loss can be reduced to as low as 0.3dB/m. Finally, it is shown that the centre frequency can be shifted by core diameter design.

Design and Simulation of Spaceborne Imaging Radar System in Terahertz Band

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ABSTRACT: Terahertz radar is a new system in radar domain, which has been widely used in radar target detection and imaging. Gyrotron is one of the commonly high-power millimeter wave sources, which can provide high power in millimeter band and sub-millimeter band. In this paper, we designed a imaging radar system working in terahertz band based on gyrotron. We demonstrated the key technical indexes of this design and make simulation of imaging to verify the validity of this system.

THz-TDS measurements of sugars and the future prospect

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Abstract
A device for quantifying glucose and cytosine HCL by THz-TDS is described. Absorption spectral data showed concentration-dependent differences in transmittance for glucose and cytosine HCL, making this cuvette design a promising new tool for detecting protein conformations by THz-TDS. Future development of a revised DFTS and generating synthetic spectra of bio-molecules via Langrangian-based equivalent circuit analysis is mentioned.