National Vacuum Electronics Conference

25th June 2013

Queen Mary, University of London

PROGRAMME

&

ABSTRACTS

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Programme

8:30-9:00  Morning tea/coffee, Registration, Posters session

9:00-9:10  NVEC 2013 Opening, Introductory Remarks

9:10-10:25  Oral session – 1
  Chaired by Mr Richard Patrick

9:10-9:35  Vacuum tubes for Terahertz power generation

  M. Mineo and C. Paoloni*
  Department of Engineering, Lancaster University, Lancaster, LA1 4YR, United Kingdom
  * and Cockcroft Institute, Daresbury, WA4 4AD, United Kingdom

9:35-10:00  200 GHz Signal Generation from a Pseudospark-Driven Backward Wave Oscillator

  D. Bowes¹, H. Yin¹, A.W. Cross¹, W. He¹, G. Liu¹, K. Ronald¹, A.D.R. Phelps¹, D.Li² and X. Chen²
  ¹Department of Physics, SUPA, University of Strathclyde, Glasgow, UK
  ²School of Electronic Engineering & Computer Science, Queen Mary, University of London, London E1 4NS, UK

10:00-10:25  Numerical simulation and experimental design of a mm-wave BWO utilising a structurally-induced surface field

  A.R. Phipps¹, A. J. MacLachlan¹, C. W. Robertson¹, I. V. Konoplev², A. D. R. Phelps¹ and A. W. Cross¹
  ¹Department of Physics, SUPA, University of Strathclyde, Glasgow, G4 0NG, Scotland, UK.
  ²JAI, Department of Physics, University of Oxford, Oxford, OX1 3RH, England, UK.

10:25-10:45  Tea/coffee break, Poster session

10:45-12:25  Oral session – 2
  Chaired by Prof Philip Burrows

10:45-11:10  Optimisation of the 3-Stub Tuner for Matching the Diamond SCRF Cavities

  Shivaji Pande
  Diamond Light Source

11:10-11:35
Design of a Transverse Deflecting Cavity for the longitudinal measurement of electron bunches on VELA

Louise Cowie
STFC Daresbury Laboratory
11:35-12:00

Coherent Smith-Purcell radiation for femtosecond electron bunch diagnostics


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b/ Instituto de Física Corpuscular IFIC, E-46071 Valencia, Spain
c/ LAL, University Paris-Sud XI, 91898 Orsay, France
d/ LANL, Los Alamos, NM, 87545, USA
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f/ SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, CA 94025, USA
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h/ Tech-X Corporation, 5621 Arapahoe Ave, Suite A, Boulder, CO 80303, USA

12:00-12:25

Beam-based stabilisation and control for future colliders

Glenn Christian
University of Oxford

12:25-13:20 Lunch, Poster session

13:20-15:00 Oral session – 3
Chaired by Dr Yasir Alfadhli

13:20-13:45 Workflow of a 3D Magnetron Simulation with CST STUDIO SUITE™

Monika Balk
CST

13:45-14:10 3D spatial harmonic magnetron – a contender for compact high power THz source

Jiandong Lang, Xiang Li, Yasir Alfadhli and Xiaodong Chen
Queen Mary University of London, UK

14:10-14:35 A screen-printed carbon nanotube-based field emission device

Edward Boughton, Wenhui Song, Benjamin Jones, Robert Bulpett, Hugh Levinson, Geoff Sheehy, Michael Waite
Observation and Study of Low-Frequency Oscillations in a 1.5-MW 110-GHz Gyrotron

Jonathan Smith
Tech-X UK Ltd

15:00-15:20 Tea/coffee break, Poster session

15:20-17:00 Oral session – 4
Chaired by Prof Alan Phelps

Non-linear efficiency enhancement for cyclotron maser amplifiers

K. Matheson¹, A. R. Young¹, A. D. R. Phelps¹, A. W. Cross¹, I. V. Bandurkin², A. V. Savilov² and K. Ronald¹
¹SUPA and the Department of Physics, University of Strathclyde, Glasgow, G4 0NG, UK
²Institute of Applied Physics, Russian Academy of Science, Nizhny Novgorod, 603950, Russia

15:45-16:10
Study of starting process of oscillation in a gyrotron using 3D PIC simulation

Xiang Li, Jiandong Lang, Yasir Alfadhl and Xiaodong Chen
Queen Mary, University of London

16:10-16:35
Design of a G-band Sheet Beam Backward Wave Oscillator with Double Staggered Metallic Rod Array

Guo Liu¹,², Wenlong He¹, Adrian W. Cross¹, Huabi Yin¹
¹Department of Physics, SUPA, University of Strathclyde, Glasgow G4 0NG UK
²School of Physical Electronics, University of Electronic Science and Technology of China, Chengdu 610054 China

16:35-17:00
Design and testing of the four rod crab cavity for the HL-LHC upgrade

Ben Hall
Lancaster University

17:00-17:10 NVEC2013 closing remarks - announcement for NVEC2014
Vacuum tubes for Terahertz power generation

M. Mineo and C. Paoloni*
Department of Engineering, Lancaster University, Lancaster, LA1 4YR, United Kingdom
* and Cockcroft Institute, Daresbury, WA4 4AD, United Kingdom

Recent technological advancements in the realization of high aspect ratio micrometric structures lead to a renewed interest in Vacuum Electron Devices for terahertz frequencies. Terahertz sources based on vacuum electronic principles are a viable solution for generating power at THz frequencies. In particular, backward wave oscillators (BWOs) represent one of the most viable solutions to realize THz sources. Due to the reduced wavelength and consequently the reduced geometrical dimensions that terahertz regime imposes, only a limited number of realizable slow-wave structures (SWSs) can support this range of frequency. Corrugated Rectangular Waveguides have been proved to be a suitable solution as SWS for sub-millimeter wavelength range and can be realized by high-aspect ratio fabrication processes such as DRIE, LIGA or UV-SU8. Due to the electromagnetic field distribution, located over the corrugation, a sheet beam has to be chosen for the best interaction effectiveness. In this work, a BWO designed assuming the corrugation narrower than the waveguide enclosure width, to make the assembling simpler and reducing the effect of fabrication errors, is proposed and compared to a Corrugated Rectangular Waveguide BWO for 1 THz oscillation frequency. The better output power performance, together with the advantages from the point of view of fabrication and vacuum pumping, demonstrated the validity of the choice. The high level of output power and the frequency range of tuning confirm the BWOs based on corrugated waveguides as promising sources for generation of power at terahertz frequencies.

200 GHz Signal Generation from a Pseudospark-Driven Backward Wave Oscillator

D. Bowes1, H. Yin1, A.W. Cross1, W. He1, G. Liu1, K. Ronald1, A.D.R. Phelps1, D.Li2 and X. Chen2

1Department of Physics, SUPA, University of Strathclyde, Glasgow, UK
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The pseudospark low-pressure discharge has long been of interest for high-speed switching applications but its production of a high current density, high brightness electron beam makes it highly suitable for the purposes of high-frequency signal generation, while the formation of an ion channel following the pseudospark anode focuses the beam and eliminates the need for a guiding magnetic field.

At the University of Strathclyde, a backward wave oscillator utilising a sinusoidally-rippled wall slow-wave structure has been designed and modelled using the PIC code MAGIC, before being constructed by means of the electrodeposition of copper on a precision-machined aluminium mandrel. The simulation and construction of this device shall be presented here, as well the results of its subsequent operation using a four-gap pseudospark discharge as an electron beam source.

References:
Numerical simulation and experimental design of a mm-wave BWO utilising a structurally-induced surface field

A.R. Phipps¹, A. J. MacLachlan¹, C. W. Robertson¹, I. V. Konoplev², A. D. R. Phelps¹ and A. W. Cross¹

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Cherenkov emission occurs when a charged particle propagating through a dielectric medium has an axial velocity greater than the phase velocity of light in the same medium, such that \( v > v_{ph} \). Since the phase velocity of the electromagnetic field is decreased by the repeated absorption and re-emission within the dielectric, the electrons do not therefore travel faster than \( v_g \), the group velocity and so the principles of special relativity remain intact. In this particular case we create a ‘virtual’ dielectric using a Slow Wave Structure (SWS) [1]. Such a structure can be created by machining sinusoidal perturbations on the inside of a section of cylindrical waveguide. The reduced velocity of the wave allows the relativistic electrons to give some of their kinetic energy to the wave by way of the Cherenkov emission process at the operating frequency of the device, which in this case is 100 GHz (W-band: 75-110 GHz). In this way, a novel type of maser can be produced [2]. This process is demonstrated numerically using CST Microwave Studio and Magic 3D to model the mode coupling within the SWS cavity [3] and the wave-beam interaction [3] respectively. Results from both codes confirm the successful interaction between beam and wave, as predicted analytically [4] and hence an initial experimental design is proposed.

Optimisation of the 3-Stub Tuner for Matching the Diamond SCRF Cavities

Shivaji Pande
Diamond Light Source

The Super Conducting RF cavities of the Diamond Storage Ring are aperture coupled resulting in a fixed external Q. This results in the cavities being matched under certain conditions depending on the loss per turn, the beam current and the accelerating voltage. Operationally, there are advantages to limiting the accelerating voltage to improve reliability and lifetime, which at high beam current results in a mismatch and high reflected power. To match the cavities under such non-optimum operating conditions we use 3-stub tuners in the waveguide feeds. It has been observed, that certain configurations of the 3-stub tuners can improve the match of the cavity, but this can result in strong heating of the waveguide in the cryostat. Numerical simulations of the cavity along with the coupling waveguide and 3-stub tuners have been carried out using CST Studio for different beam loading conditions to optimise the 3-stub tuners for acceptable match and heating. In this paper we present the results of our simulations and comparisons with measurements for operation with different beam currents and cavity voltages.

Design of a Transverse Deflecting Cavity for the longitudinal measurement of electron bunches on VELA.

Louise Cowie
STFC Daresbury Laboratory

VELA at Daresbury Laboratory will provide short, low energy bunches of electrons for both industrial and scientific research users. In order to measure the longitudinal profile of these bunches a transverse deflecting cavity will be inserted into the beamline. The cavity will cause a transverse kick of around 5 MV, rotating the bunch and converting the longitudinal profile to a transverse profile which can be imaged with a YAG screen. A 9-cell design was chosen, with shortened end cells to minimise unwanted beam displacement. A side coupler into the centre cell was used for the RF input to avoid exciting some higher order modes, and a dummy port was added to symmetrise the centre cell.

Coherent Smith-Purcell radiation for femtosecond electron bunch diagnostics.


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There is a significant interest in the development of compact particle accelerators within research areas including X-ray and THz (T-ray) sources of radiation, particle physics and medical sciences. To support the progress in these areas, non-invasive, electron beam diagnostics that are capable of measuring a single femtosecond electron bunch are required. At the current stage such beam diagnostics for femtosecond-long electron bunches are still not available. The goal of the work presented is to understand the characteristics of coherent Smith-Purcell radiation to enable its quick and reliable interpretation to enable the longitudinal profile reconstruction of femtosecond electron
bunches. The research presented comprises results from theoretical and experimental studies. We discuss the radiated spectra dependence on the electron bunch profile and analyse the results. We also discuss the experimental data and compare it with theoretical predictions.

This work performed [in part] under DOE Contract DE-AC02-7600515

 Beam-based stabilisation and control for future colliders

Glenn Christian
University of Oxford

Beam-based feedback and feedforward systems will be employed at future high energy physics facilities, such as the International Linear Collider (ILC) and the Compact Linear Collider (CLIC), to stabilise beam properties, such as the beam orbit in the transverse plane, and phase longitudinally. One such system that will be essential for maintaining the luminosity at such facilities, will be the interaction point (IP) feedback system. Several prototype IP feedback systems have been demonstrated at the KEK Accelerator Test Facility in Japan, and the current FONT5 system is being used to aid in the stabilisation of the ultra-low spot size beams as part of the ATF2 project. Another application of similar technology is in the drive beam phase stabilisation for CLIC. In the CLIC design a low-energy high-current drive beam is used to transfer power to accelerate the low-current main beam, which goes on to produce collisions. The arrival time of the drive beam at the power transfer structures must be accurately matched to that of the main beam for efficient acceleration, and a feed-forward correction system is envisaged to stabilise the phase of the drive beam with respect to the main beam. A prototype feedforward system to demonstrate the phase stabilisation is being developed at the CLIC Test Facility (CTF3). Details of the instrumentation for both systems will be given, and recent results from the feedback tests at ATF and plans for the system demonstration at CTF3 will be presented.
Workflow of a 3D Magnetron Simulation with CST STUDIO SUITE™

Monika Balk
CST

A magnetron shows a fairly complex particle-field interaction. The understanding of this process has been supported by simulations since the last decades. Thus, simulations have gained an increasing importance in this field.

This talk shows the different steps of a magnetron analysis within CST STUDIO SUITE™. First the resonance frequency of the 3D geometry is found by means of an eigenmode solver run. Then a particle in cell simulation is performed to obtain the true resonance frequency of the magnetron including the particles inside the structure. In addition, the formation of the space charge wheel is shown. Different excitation options of the simulation are compared with respect to the start up process of the magnetron. Finally, the possibility to speed up such a normally time consuming simulation using a graphic processing unit will be illustrated.

3D spatial harmonic magnetron – a contender for compact high power THz source
Jiandong Lang, Xiang Li, Yasir Alfadhl and Xiaodong Chen
Queen Mary University of London

Magnetrons with their intrinsic advantages of high efficiency and low cost are widely used in domestic and industrial heating, particle accelerators, radars and other applications. However, a conventional π-mode magnetron has several difficulties in operating in the millimetre-wave band. Firstly, the anode structure becomes so small – being difficult to be fabricated and also can’t stand electron bombardment. Secondly, the electron back-bombardment on the cathode is so intense that the lifetime of the thermionic cathode becomes too short for any practical application. Finally, the magnetic field needs to be quite high to maintain an efficient operation at a high frequency.

A spatial harmonic magnetron (SHM) was first proposed in 1950s [1] and has regained interests lately for its capability of delivering a high power radiation in millimetre-wave bands [2-4]. It utilises a cold secondary emission cathode and the interaction of electrons with the first negative spatial harmonic of the π/2 mode or π/2-1 mode. Therefore, the SHM allows a relatively large cavity dimension and exhibits a good mode separation even the anode is neither strapped nor in a rising-sun structure when operating at high frequency. Our group at Queen Mary has proposed a 3 dimensional (3D) spatial harmonic magnetron to further increase the operating frequency. This talk gives an introduction to SHMs and presents our initial modelling work on the 3D spatial harmonic magnetron.

A screen-printed carbon nanotube-based field emission device

Edward Boughton\textsuperscript{1,2,3}, Wenhui Song\textsuperscript{1}, Benjamin Jones\textsuperscript{2}, Robert Bulpett\textsuperscript{2}, Hugh Levinson\textsuperscript{3}, Geoff Sheehy\textsuperscript{3}, Michael Waite\textsuperscript{3}

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Currently, most vacuum electronics technologies use thermionic electron sources, in which a low work function material is heated to high temperature. By contrast, field electron emission is a process by which electrons are able to escape without additional thermal energy. Field emission ordinarily occurs only at very high electric fields. However, around a sharp tip the local electric field may be several orders of magnitude higher than macroscopically. This effect allows field emission to occur from a sharp tip at significantly lower applied fields. The extent to which the required field is lowered is related to the aspect ratio of the tip. Carbon nanotubes (CNTs) are 1-dimensional tubes composed of graphene sheets of hexagonally-arranged carbon atoms. A screen-printing technique has been developed which exploits the high aspect ratio, small size and ballistic conductivity of multiwalled carbon nanotubes (MWNTs) to fabricate a field emission electron source with low turn-on field, a large number of individual emission sites and high current density. The device has the advantage over thermionic cathodes of requiring fewer connections, has no warm-up time and can be fabricated on a number of substrate materials.

Observation and Study of Low-Frequency Oscillations in a 1.5-MW 110-GHz Gyrotron

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We report the observation of low-frequency oscillations (LFOs) in the range 165–180 MHz in a 1.5-MW 110-GHz gyrotron operating in 3-\(\mu\)s pulses. The oscillations have been measured by a capacitive probe located just before the entrance to the cavity. The LFOs are observed only in a narrow region of beam parameter space, at voltages between 45 and 60 kV, where no microwave emission occurs. When the gyrotron operates near 96 kV, with high output power, they are not seen. The variation of the frequency of the oscillations with electron beam voltage and magnetic compression was measured, and the results are reported. Time-domain analysis of the probe signal shows the influence of the beam current and cathode voltage on the time of onset of the oscillations. The amplitude of the time-domain signal indicates that the trapped electron current associated with the LFOs represents a few percent of the total electron current.
Non-linear efficiency enhancement for cyclotron maser amplifiers

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Intrinsic properties of conventional cyclotron maser amplifiers, associated with regime of operation, tend to limit their performance. Amplifiers operating with large axial wavenumbers (k₂), namely cyclotron autoresonance maser amplifiers, are susceptible to beam velocity spread with gyro-travelling wave amplifiers (gyro-TWAs) typically operating in a regime susceptible to both this and spurious oscillations. One possibility to circumvent this regime in a gyro-TWA is to introduce a perturbation along the inner wall surface of the interaction waveguide in the form of a helical corrugation. This serves to modify the wave dispersion which can then be matched to the electron beam over an increased bandwidth in a region of small k₂. Devices which utilise helical interaction waveguides have been shown to achieve an efficiency of ~30% at X-band¹. It is anticipated that by integrating a section into the interaction circuit which is tapered along the axis of propagation², one may improve device efficiency. Tapering key parameters (here the waveguide radius and corrugation amplitude) alters the associated characteristic dispersion curves for such amplifiers to hold the interaction resonance at a given frequency for the entire device length, irrespective of the increase in gyro-frequency of beam electrons as they lose kinetic energy. This paper will present particle-in-cell simulations of such an enhanced amplifier.


Study of starting process of oscillation in a gyrotron using 3D PIC simulation

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In this paper, the starting process of oscillation in a 42 GHz gyrotron is simulated and analyzed using CST Particle Studio. The similar simulation work is firstly reported by Ashutosh in Reference [1] with a specially arranged emission base to generate gyrating electron beam. This paper is further focused on the mode competition and building up of oscillation to give a 3D time-dependent view of gyrotrons’ operation. The dependence of gyrotron operation on the electron beam current and positioning will be also investigated.


Design of a G-band Sheet Beam Backward Wave Oscillator with Double Staggered Metallic Rod Array

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In this paper, a G-band (140-220GHz) sheet beam backward wave oscillator (SB-BWO) based on a novel proposed double staggered metallic rod array as slow wave structure is investigated and presented. The slow wave structure can extend the beam-wave interaction area effectively for the sheet beam with a more uniform electric field in the beam cross-section. This could alleviate beam instability problems in the sheet beam transportation and avoid many potential parasitic oscillations.
Moreover, a relatively broad bandwidth can be achieved due to its special dispersive properties. Particle-in-cell simulation predicted that the G-band sheet beam BWO can achieve output power of over 90W in a continuous frequency tuning range (187GHz-230GHz) of relative bandwidth 20% with tunable voltage 20kV-40kV. In order to fabricate it with the existing techniques easily, a compact double staggered grating waveguide is utilized instead of the double staggered metallic rod array, which is on the way to be manufactured. For the beam source, pesudospark discharge will be used in our initial hot experiment.

**Keywords:** G-band, Sheet beam backward wave oscillator (SB-BWO), Double staggered metallic rod array (DSMRA), Pesudospark discharge

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**Design and testing of the four rod crab cavity for the HL-LHC upgrade**

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The High luminosity upgrade to the LHC calls for crab cavities to reduce the luminosity loss due to the crossing angle. A TEM-type four rod crab cavity similar to the CEBAF deflector has been modified to meet the LHC requirements. Due to the need for CW operation the cavity must be superconducting. The space restrictions of the LHC tunnel impose a limitation on the maximum size of the cavity; as such a non-traditional shape is required.

A compact crab cavity has been designed and optimised to fulfil the requirements of the HL-LHC upgrade. An aluminium prototype was manufactured and tested to ensure transverse field flatness. A niobium prototype was then manufactured and cold testing has been performed at CERN up to a voltage of 1.4 MV.

The design, optimisation and results of the testing are presented.