Indian Efforts in Vacuum Electron Devices: Organisations and Persons Caught in My Glimpse

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It is always a pleasure to write something for Vacuum Electronic Devices and Application Society, India. I do not intend to list the vacuum electron devices developed by the various organisations in the country nor enumerate the achievements of these organisations. I would like to present some points in my own perspective. I am likely to miss many a point and fail to mention the names of significant 'contributors'. For such inadvertent lapses I may please be pardoned. VEDAS is not responsible for the facts and opinions presented here by me.

Creation of VEDAS:

During a Workshop organised as part of the celebration of MTRDC Annual/Foundation Day held at Begaluru in the year 2004, the idea emanated from Dr. Lalit Kumar, the erstwhile Director of Microwave Tube Research and Development Centre (MTRDC), DRDO, that those working in the area of microwave tubes and their applications in India should have a society of their own. In the conference room of MTRDC, we took part in a discussion to coin a suitable name for the society. Besides MTRDC scientists, the scientists of Central Electronics Engineering Research Institute (CEERI), CSIR including Dr. SN Joshi and Dr. LM Joshi took part in the discussion. Dr. SK Datta of MTRDC was writing all the potential names suggested on a board, and finally 'VEDA' Society, suggested by me for our society name, was found 'catchy' and unanimously accepted (the acronym VEDA standing for Vacuum Electronic Devices and Application). Subsequently, Dr. Lalit Kumar took help of his colleagues including Dr. SK Datta of MTRDC to complete all the formalities for the official registration of VEDAS at Bengaluru.

Applications of Vacuum Electron Devices:

Vacuum electron devices in the form of microwave tubes have applications in defence, including radar, missile guidance and tracking, electronic warfare, directed energy weaponry, etc. They have applications in industry and material processing, too. In the domestic sector, the use in microwave ovens is well known. They are also used in radars in civilian sector encompassing communication including satellite/space; weather prediction; under-earth life detection in hazards; civil, mining and public health engineering including breaking of rock and concrete, tunnel boring and soil treatment; and environment control including waste remediation and ozone generation as well as atmospheric purification of admixtures that destroy ozone layer. They are also used in charged particle accelerators. Microwave tubes have medical applications, too, including diagnosis and treatment such as hyperthermia. They are also in demand for futuristic generation of power including satellite power station and fusion plasma heating for thermonuclear energy. They are needed to artificially create ionized layers for the extension of radio range, city lighting, and nitrogen fertilizer-raining on the earth, and so on. A short review of applications of and trends in vacuum electron devices/microwave tubes can be found in a write up due to Dr. SK Datta of MTRDC and the present author in the Guest Editorial of the Special Issue of an international journal [1]. Also, Dr. V Kesari of MTRDC and the present author have presented such a review in a book, dedicated to Professor NC Vaidya, who founded

Centre of Research in Microwave Tubes (CRMT) at Banaras Hindu University (BHU), the latter being enriched with a foreword due to Pofessor Edl Schamiloglu of University of New Mexico [2].

***Early Work at Calcutta University*:**

Efforts in vacuum electron devices started at the Institute of Radiophysics and Electronics (INRAPHEL) at Calcutta University in 1950's, as can be seen in a historical document of the University [3][]. The activities in this area at INRAPHEL were led by Professor SK Sen (who taught us microwave engineering at INRAPHEL in B Tech and M Tech programmes). These activities there were intensified by Dr. H. F. Steyskal (UNESCO Expert), who at a later date visited CEERI and extended his expertise there too. Professor NB Chakaraborty at INRAPHEL developed the understanding of electron beam parametric amplifier in the late 1950's [4,5]. Later on he taught me, at IIT-Kharagpur during my doctoral study, the application of nonlinear Eulerian hydrodynamic analysis in the understanding of harmonic generation and frequency mixing in double-stream and beam-plasma amplifiers. Dr. SK Datta of MTRDC during his postgraduate study at BHU-CRMT followed this approach to study nonlinear effects in TWTs. Even though it cannot take into account the effect of electron overtaking unlike the Lagrangian approach, Dr. Datta, inspired by Dr. RG Carter of University of Lancaster, dared to take the Eulerian hydrodynamic approach in his doctoral work, while he was at MTRDC, to study harmonic generation and intermodulation distortion in helix TWTs under backed-off conditions. He used this approach in the work embodied in his doctoral thesis at BHU as well as in his publications.

[] **CU Annual Report:**

1956-57

(c) Electron Tubes

"Work on electron tubes has been intensified since Sept 1956, when the UNESCO Expert, Dr. H. F. Steyskal joined the Institute. The aim of the work was to improve the research facilities of the existing electron tube laboratory and to develop various special processes involved in the electron tube making, especially with regard to all metal tubes, including microwave tubes, e.g., magnetron. The equipment in the lab has been enriched by the following items:

Two high vacuum pumping units with provision for measuring pressures of 10-7 mm Hg. A Tubular Hydrogen Furnace for temperatures up to 1000 C. A large chamber for heat treatment in protective atmosphere at temperatures upto 1200 C. A strain viewer for glass ware. A ball Mill for powdering chemicals. An apparatus for spraying insulating coatings and emission pastes. An Electrolytic trough for investigation of potential fields. A 6 KW RG heating unit (Gift fro UNESCO). A glass lathe (Gift from UNESCO).

Furthermore, the following practical processes have been developed:

Manufacture of graded glass seals and tubular seals between glass and metals like copper and Kovar; vacuum tight brazing of metals in protective atmospheres and in vacuum; fabrication of special brazing alloy, electroplating, precision machining of magnetron parts., and of plane and cylindrical oxide cathodes and their appropriate filaments. Finally the properties of self made oxide cathodes and the activation schedule of thoriated tungsten cathodes were investigated and satisfactory results obtained.

1958-59

(c) Electron Tubes

A programme of work on parametric amplifiers has been started. This includes both electron beam type and the semiconductor diode type of parametric devices.

Work on beam type largely centred round the design of a low voltage electron gun. The various electrode structures required have been worked out. With regard to semiconductor diode a cavity simultaneously resonant to the pump and the signal frequency for the degenerate mode of operation has been designed. Its electrical response characteristics are being measured.

1961-62

(e) Electron Tubes and Plasma Electronics

Work is also in progress towards better design and performance of 10 cm multicavity CW magnetron.

***Activities at CEERI, Pilani*:**

In the late 1950's, R&D activities in magnetrons started at National Physical Laboratory, New Delhi of CSIR with the initiative of Dr. Amarjit Singh and Professor NC Vaidya. Both of them later shifted these activities to CSIR-CEERI, Pilani. Dr. Singh nourished as Director of the Institute its Vacuum Tube Division and focussed its R&D on crossed-field tubes including magnetron and M-carcinotron. Some of the stalwarts who worked with him in the area are Professor OP Gandhi, Professor NC Vaidya, Dr. RP Wadhwa, and Dr. GS Sidhu. Later on Dr. JL Bahri, Dr. HS Diwan, Dr. V. Srivastava, Mr. Ram Naresh, Mr. Sharda Prasad and Dr. VVP Singh contributed to this area. At present, Dr. S Maurya with his deep understanding of both theoretical and experimental aspects of crossed-field tubes leads the activities in this area. Professor Gandhi has analysed vacuum electron devices in-depth in his book on microwave engineering [6]. For instance, from the analysis presented by him in his book [6] I learned that the beam-present or hot attenuation in a TWT is finite even if the beam-absent or cold attenuation caused by a built-in attenuator in the device is infinite and subsequently I myself presented this understanding in one of my books [7].

Dr. Vaidya also worked in the area of electron lens/electron microscope. Mr. HN Bandyopadhyay under the guidance of Dr. Sidhu started R&D activities in the area of klystrons. Dr. Sidhu after leaving CEERI established Pilani Tubes and Devices Ltd. at Sangrur, Punjab. Later on Dr. LM Joshi took the responsibility of klystron activities at CEERI and established a collaborative link of CEERI with RRCAT, BARC and IPR. Now, Dr. A K Bandyopadhyay leads these activities with Dr. Dabashis Pal and others.

Dr. SSS Agarwal, who was heading the microwave tube activities at CEERI, guided Dr. SN Joshi who in turn led a team to develop the first ever TWT in the country, and incidentally I was fortunate to be one of his team members. Subsequently, Dr. Joshi at CEERI under the guidance of Dr. Agarwal carried out R&D in TWTs for both defence and space sectors. Under the guidance of Dr. Agarwal and with the support of Dr. Joshi, I wrote in 1977 two internal reports at CEERI one on equivalent circuit analysis (co-authored by Dr. Joshi) [8] and the other on field analysis [9], both of helical slow-wave structures of TWTs. I dedicated my book on Technical Writing (Prentice-Hall of India) [10] to Dr. Agarwal.

Dr. V Srivastava significantly contributed to the area of both helix and coupled-cavity TWTs through his large-signal analysis. His code SUNRAYS is extensively used in the design of TWTs in India. Dr. RS Raju and Mr. RK Gupta also took part in the progress of this area. The activities in the area of TWTs of wide bandwidths for electronic warfare as well as of high efficiency, lightweight and long life for space applications are now being led by Dr. SK Ghosh at CEERI. He developed the code GANGA, which is extensively used in the design of helix TWTs in the country. Dr. Ghosh as well as Dr. Sinha added a rigor to the analysis of a helical slow-wave

structure by considering the variation of the radial propagation constant over the cross section of the model of a discrete dielectric helix supports smoothed out into a number of equivalent dielectric tubes of the model. Dr. Amarjit Singh motivated us to investigate into the band gap in □-□ dispersion characteristics caused by the asymmetry of dielectric helix-supports. Dr. AK Sinha succeeded in developing the analysis with our Seoul National University (SNU) collaborators. Subsequently, Dr. SK Datta also added rigour to the stop-band analysis and published the work in IEEE-TED and International Journal of Infrared and Millimeter Wave. Dr. Sinha further established a heuristic tape-helix model that made it simple to obtain the dispersion relation of a 'loaded helix' in the 'tape-helix model' by combining the dispersion relation of a 'loaded helix' obtained by the simpler 'sheath-helix model' with the dispersion relation of a 'helix in free-space' obtained by the 'tape-helix model' available in text books. Dr. Ghosh has validated the heuristic tape-helix model against the rigorous Sensiper's tape-helix model analysis of a loaded helix. Dr. Lalit Kumar suggested a suitable model of a vane-loaded helical slow-wave structure of a wideband TWT that made it easier to analyze the structure doing away with involved field analysis that needs to take into account the azimuthal harmonics due to the angular periodicity of vanes. Dr. Lalit Kumar developed the code PIERCE for the design of electron guns and focusing structures.

The activities of the Plasma Group of CEERI were led by Dr. HK Dwivedi and later by Dr. Ram Prakash and Dr. Udit N Pal. Dr. Hasibur Rahman, Dr. Niraj Kumar, Mr. RP Lamba among others contributed to the area. The activities of this group focused on high power plasma switches (thyratron and pseudospark), DBD based non-thermal plasma and VUV/UV sources, EUV/Soft X-ray sources, and plasma cathode electron gun. I suggested Dr. Dwivedi to take up the development of the plasma-assisted slow-wave oscillator (pasotron). Later Dr. Udit N Pal and his team including Dr. Niraj Kumar developed the first ever pasotron in the country.The group successfully developed thyratrons for BARC, Mumbai and RRCAT, Indore. They have strong collaborative linkages with Friedrich-Alexander-University (FAU), Erlangen, and also University of Frankfurt in Germany; Institute of High Current Electronics RAS, Tomsk, Russia; and University of Strathclyde, Glasgow, UK.

The self reliance of vacuum electron devices greatly depends on the capability of indigenously developing cathodes for both the conventional, terahertz and MPM tubes. The activities of CEERI in the area of developing cathodes owe to the initial effort of first Mr. AK Chopra and then Dr. RS Raju. Now, Dr Ranjan Barik is spearheading these activities with the support of his team member including Mr. Sushil Kumar, Mr. Asish Singh and others. The group is collaborating with MTRDC in this area and is also being supported by Vikram Sarabhai Space Centre of ISRO in the development of ion thrusters.

The Gyrotron lab of CEERI after contributing to its success to the first ever gyrotron in the country has now focussed on the design and development of the various other types of gyrotrons. Following Dr. AK Sinha, Dr. Anirban Bera has taken the leadership of the gyrotron activities including those under an ITER-India project. His team comprises Dr. Hasina Khatun, Dr. Nitin Kumar, Dr. Vishant Dwivdi, Dr. M Alaria, Mr. Om Ranjan, and others.

Further, newer areas are being given attention to including multi-beam klystron and inductive output tube at CEERI. Recently, Dr. N Purushottaman and Mr. Raktim Guha are exploring the new field of metamaterial assisted vacuum electron devices based on the work initiated by Dr. SK Datta at MTRDC.

While at BHU I became closely associated with CEERI as Distinguished Visiting Scientist of CSIR that gave me an opportunity to establish a close collaborative link between CRMT and CEERI in academics and research. Dr. Agarwal, Dr. Joshi, Dr. V. Srivastava and Dr. RK Sharma, while spearheading the R&D activities in vacuum electron device/microwave tube area at CEERI supported our work in the area at BHU. Quite a good number of scientists of CEERI obtained their PhD degree from CRMT (BHU) as external candidates of the University.

***R&D at Banaras Hindu University*:**

Professor NC Vaidya left CEERI to join Department of Electronics Engineering, BHU. There he founded Centre of Research in Microwave Tubes (CRMT) under the aegis of UGC while executing, in the year 1979, a DOE-sponsored project in the area of TWTs in the area of microwave tubes encompassing TWT and klystron. The TWT group was led by Professors ML Sisodia, who joined CRMT on lien from University of Rajasthan, Jaipur. DS Venkateswarlu, who joined CRMT from BEL via CEERI, led the klystron group. Dr. PK Jain and I worked with Professor ML Sisodia. Mr. R Patnaik, who later moved to BEL, Bengaluru, had been with Professor Venkateswarlu. Dr. Anima Chatterjee also worked with Professor Venkateswarlu in the area of cathodes. Dr. B Jha was responsible for microwave measurement related activities at CRMT. Later on Professors RK Jha, SK Srivastava, DS Venkateswarlu, I and PK Jain successively became the Coordinator of CRMT. Professor Srivastava also encouraged the microwave tube activities of CRMT under Centre of Advanced Study of UGC in BHU. Professor Jain, who is presently the Director of NIT, Patna on deputation from IIT-BHU, worked at CRMT in the area of TWTs. His analysis of helical structures could take into account the effect of loss due to the attenuator coating and lossy dielectric helix-supports. Later Dr. Jain along with his students explored the high power domain of high power (HPM) microwave tubes encompassing gyro-devices and MILO. I profoundly acknowledged Professor Jain for his immense support and inspiration in writing my book on electromagnetic theory and its applications in beam-wave electronics published by World Scientific, in ‘Special Acknowledgement’ section of the book [7]. Professor A Lakhtakia of Pennsylvania State University, who was classmate of Professor Jain in his undergraduate class at BHU (now IIT-BHU), during one of his visits to BHU picked up the manuscript of the book from the table of Professor Jain. He found it worth recommending the book to World Scientific for publication. The book has two parts. The second part of the book deals with beam-wave electronics emphasizing on growing-wave devices, while the first part of the book deals with electromagnetic theory as the prerequisite of the book. Incidentally, later on I wrote a separate memoir on electromagnetic theory for undergraduate students under the imprint of Universities Press [11]. Again due to the initiative of Professor Lakhtakia, it was possible for Dr. Kesari of MTRDC and me to write a book on high power microwave tubes for Institute of Physics [2]. In the early period, many students greatly contributed to the area of vacuum electron devices. In the undergraduate programme of BHU, Dr. Sirigiri Jagadishwar Rao (who later joined MIT and founded Bridge 12 Company in USA) set up the non-resonant perturbation technique for the measurement of the dispersion and interaction impedance versus frequency characteristics of helical slow-wave structures of a TWT. He as well as Dr. Mukul Agrawal (who later joined Stanford University) worked in the area of gyro-devices. Similarly, Dr. Y Murlidharan (who later joined Maryland University) contributed to this area during his study at BHU in the postgraduate programme. Professor Ghanshyam Singh, Dr. Vishal Kesari, Dr. Kalpana Singh and Dr. Ashutosh Singh also contributed to this area under doctoral programme and/or in sponsored projects. I mentioned the names of only those who were with us in our initial efforts at CRMT. Later on many other students contributed to this area. Following

the footstep of Professor PK Jain, now Professor M Thottappan is significantly contributing to this area with a good number of his students of IIT-BHU.

I left Regional Institute of Technology (RIT) (now known as NIT, 'N' standing for 'National'), Jamshedpur to join CRMT, BHU on lien on invitation from Professor Vaidya. In fact, while visiting CSIR-NPL at Jamshedpur, Professor Vaidya came down to see me at my residence at Jamshedpur to know if I was interested to join BHU. I did not know him then. I guess he might have read me in journals on the subject of the analysis of helical slow-wave structures of TWTs. I guided Dr. AK Sinha, who later joined CEERI, to carry out his doctoral work in this area at RIT. Dr. Amarjit Singh, Dr. SSS Agarwal and Professor SN Joshi from CEERI inspired us. Dr. RS Raju, also from CEERI, with whom later I authored several papers in the area of helical slow-wave structures, had helped Dr. Sinha and me in checking our hand-calculated results using the CEERI computer while both of us were at RIT, Jamshedpur. Similarly, Dr. SK Ghosh analysed these structures in depth in his doctoral work at BHU and later joined CEERI to continue working in this area.

While at CRMT I worked as Distinguished Visiting Scientist of CSIR at CEERI. During my stay at CRMT and also after superannuating from CRMT, I worked with CEERI and MTRDC scientists and co-authored research papers with them in the area of vacuum electron devices. I also co-authored papers with Professor Gun-Sik Park of SNU, South Korea and his group and Professor Zhaoyun Duan of University of Electronics Science and Technology of China (UESTC), Chengdu and his group.

I was attached to CRMT both professionally and emotionally so much so that I did not wish to leave CRMT and did not give my consent to Dr. MD Raj Narayan and Sri KU Limaye, the erstwhile Directors of MTRDC, when they at different times asked me to give my consent if they had proposed my name for a DRDO Chair Professorship in Microwave Tubes at IISc, Bangalore.

It is the need of the hour to emphasize on vacuum electron devices in the university curriculum. In the Special Issue of Journal of Electromagnetic Waves and Applications edited by me with the support from Dr. SK Datta [1], the great scientist Dr. AS Gilmour (internationally acclaimed for his three books on vacuum electron devices) expressed his concern over the existing large gap between the needs of universities and industries and brought out the necessity of bridging this gap. However, at the instance of the erstwhile DOE, the contents of the postgraduate course in Microwave Engineering discipline of BHU were modified to encompass vacuum electron devices to a great extent. CSIR in its programme 'Academy of Scientific and Innovative Research' has also emphasized on this area in its curriculum at CSIR-CEERI.

After superannuating from CRMT, I worked first at IFTM, Moradabad, UP and then at SKFGI, Mankundu, West Bengal. I organized VEDA Conference at IFTM, Moradabad when I was myself the President of VEDAS. While serving these institutions (IFTM-Moradabad) and SKFGI-Mankundu) I continued to remain in collaborative link with CEERI, MTRDC, UESTC (Chengdu) and SNU (Seoul). Dr. SN Joshi, Dr. Chandra Shekhar, Professor Gun-Sik Park and I served a pivotal role in establishing MOUs between BHU and CSIR-CEERI; SNU and CSIR-CEERI; and SKFGI and CSIR-CEERI to serve the cause of VEDAS. It is very much worth mentioning that Mr. Amit K Varshney, one of the young faculty members of SKFGI, Mankundu and two postgraduate students of the same institute Mr. Subhradeep Chakraborty and Mr. Raktim Guha contributed to the area of vacuum electron devices as evidenced by their publications. In their academic pursuit they were guided by CEERI and MTRDC scientists (Dr. SK Datta, Dr. SK

Ghosh, Dr. AK Sinha, Dr. A Bandyopadhyay, Dr. Hasina Khatun and others). The student trainees at CEERI and MTRDC from the various other institutions such as Banasthali Vidyapith and Burdwan Universities have also greatly contributed to the various sponsored projects in this area.

The work of Professor N Kalyansundaram and his students including Dr. G Naveen Babu at Jaypee Institute of Information Technology, Noida in the analysis of helical slow-wave structures as well as in the small-signal/large-signal analysis of conventional and gyro-TWTs is internationally regarded. Quite a good number of students of Professor MV Kartikeyan are contributing to the area of gyro-devices at IIT-Roorkee. The students of Professor K. P. Maheshwari and Professor Y Choyal are contributing greatly to the area of relativistic vacuum electron devices (such as backward-wave oscillator) at Devi Ahilya Vishwavidyalaya, Indore.

***Foundation of MTRDC*:**

MTRDC was established in 1984 in Bharat Electronics (BEL) Complex at Jalahalli, Bangalore. In the initial stage of the development of MTRDC, Mr. AN Murthy of DLRL during his visits to BHU-CRMT used to discuss with me about the approaches to carrying out the programme in the upcoming MTRDC. Later on Dr. MD Raj Narayan invited me good number of times to MTRDC. I have seen Dr. Raj Narayan develop MTRDC brick by brick; Dr. Sudhir Kamath, who was our student at BHU-CRMT, was with him in this effort. Later on our student Dr. SK Datta also joined MTRDC. Subsequently, Sri KU Limaye, Dr. Lalit Lumar, Dr. Sudhir Kamath, , and now Dr. SUM Reddy became the successive Directors of MTRDC. Quite a good number of scientists of MTRDC obtained their PhD degree from CRMT (BHU) as external candidates of the University. Incidentally, after superannuating from MTRDC, Dr. Lalit Kumar served DRDO as the Chairman of Centre for Personnel Talent Management (CEPTAM). Further, of very much relevance to VEDAS, Dr. Lalit Kumar is Editor of IEEE Transaction on Electron Devices. Dr. Sudhir Kamath continues to serve DRDO as Director General of Cluster on Microelectronic Devices and Computational Systems (MED & CoS).

MTRDC developed collaborative link with various organisations in the country and abroad and developed a large number of tubes and tubes based systems of strategic importance. I have seen Dr. KS Bhat developed its cathode lab to a great height. Dr. M Ravi now leads the activities in the area of cathodes. Similarly, Dr. P Sidharthan significantly contributed to the development of the electronic power conditioner lab at MTRDC. Dr. Santanu Karmakar along with Dr. Vishal Kesari along with other scientists of MTRDC is working in the area of fast-wave tubes. The areas of TWTs (wideband and space-qualified), klystrons and its variants including MBK, HPM tubes including relativistic magnetron and MILO, etc. have been enriched by the contributions of the acclaimed scientists including Dr. L Christie, Dr. R Seshadri, Mr. S Raina, Mr. AK Agrawal, Dr. M Santra, Dr S Chhotray, Dr. M Sumathi, Dr. V Nallasamy, and others. Dr. Lalit Kumar, while he was a member of Vacuum Electronics Technical Committee (VETC) from India of IEEE Electron Devices Society (EDS), taking help of his colleagues of MTRDC, set a milestone by organising IVEC-2011 as its General Chair. The event was jointly organized by IEEE-EDS and VEDAS. Incidentally, I was the first to be member of VETC of IEEE-EDS. Successively, Dr. SN Joshi, Dr. Lalit Kumar and now Dr. MV Kartikeyan became the member of VETC of IEEE-EDS from India.

***Production at BEL*:**

A range of vacuum electron devices catering to the need of defence and space sectors are manufactured in BEL. These devices also include microwave tubes produced jointly with CEERI and MTRDC designed and developed respectively by them. Shri BS Venugopalan, Mr. TRK Janardan and Mr. BG Satyanarayana have been felicitated by VEDAS with Lifetime Achievement Award for their role in the development of vacuum electron devices in the country. Mr. Janardan and his successors Mr. Venkatesh Murthy, Mr. SF Thangaraj, Mr. RR Patnaik, Mr. RP Rajagopalan and Mr. Srinivas Prasad took a key role in establishing a close linkage of BEL with MTRDC and CEERI. BEL has also joined CEERI-Pilani and SAC Ahmedabad in developing space-TWTs.

SAMEER-CHMTCT, IIT-Guwahati:

Society for Applied Microwave Electronics Engineering and Research (SAMEER) established Centre for High Power Microwave Tube and Component Technology (CHMTCT) at IIT-Guwahati. Dr. T Tiwari, Programme Director In Charge along with his team comprising Mr. N Nayek, Dr. S Vyas, Mr. N Shekawat and others, has taken up the development of microwave components such as circulator, isolator and load as well as magnetrons, the latter for medical 'linacs'. Recently, Dr. Tiwari organised, jointly with IIT-Guwahati, VEDA-2018 conference under the chairmanship of Professor PK Jain of CRMT, now deputed as the Director of NIT-Patna, who is going to organise VEDA-2019 at NIT-Patna.

***Multi-Institutional Project on the Development of Gyrotron*:**

While as scientist at CEERI, I along with my colleague Dr. Lalit Kumar attended a lecture on the basics of gyrotrons by Dr. Amarjit Singh at BITS, Pilani perhaps in the year 1978 under the aegis of the Pilani chapter of IETE. We were enthused by the lecture of Dr. Singh. Later on Dr. Lalit Kumar as well as Mr. HN Bandyopadhyay initiated research in the area of gyrotrons at CEERI. Dr. Lalit Kumar had passed on the hard copies of a few key papers on gyrotrons to me while I was shifting from CEERI to RIT, Jamshedpur. Similarly, I passed on the copies of these papers on gyrotrons to Dr. AK Sinha at RIT when I was myself shifting from RIT, Jamshedpur to BHU-CRMT. Dr. Sinha told me that he had read and appreciated those papers. However, at that time he was more involved in writing his Ph D thesis at RIT on the analysis of helical slow-wave structures. Dr. Sinha later joined CEERI and I considered him to be the right person at CEERI to pursue R&D in the area of gyrotrons. Subsequently later Professor RK Jha, while he was Coordinator, CRMT, placed before DST a proposal which I prepared for him on the development of the first ever gyrotrons in the country. This led to a DST-sponsored multi-institutional project for the development of a gyrotron for electron cyclotron resonance heating of fusion plasma at Institute for Plasma Research (IPR), Gandhinagar. I became one of the steering committee members of the project. The helms at CEERI including Dr. SN Joshi accepted my suggestion as to opt Dr AK Sinha as the project leader of CEERI, one of the participating organisations of the project and chosen as the 'nodal centre' of the project by DST, the remaining four participating organisations being Society for Applied Microwave Electronics Engineering and Research (SAMEER), Mumbai, IIT-Roorkee, BHU-CRMT, Varanasi, and IPR, Gandhinagar. Dr. SN Joshi became the overall project leader of the project and Dr. AK Sinha the project leader of CEERI. The first ever gyrotron was developed in the country in this project by the joint effort of the five participating organisations. The development of the gyrotron window by Dr. Subrata Das, the Coordinator of the project at SAMEER, and his team made a significant contribution to the

success of the gyrotron development. The gyrotron developed is now being tested at IPR. While executing this project, Dr. AK Sinha with the support from Dr. Chandra Shekhar, the erstwhile Director of CEERI and Dr. SN Joshi established the Gyrotron Lab at CEERI. An important aspect of the project is that the designs carried out by the participating organisations had been cross-checked and validated by Dr. MV Kartikeyan and his team at IIT-Roorkee, Professor PK Jain and his team at CRMT, and Dr. AK Sinha and his team at CEERI including Dr. Dr. Nitin Kumar, Dr. U Singh, Mr. Vishant Dwivedi and others. Dr. B Jha was involved with Professor Jain at CRMT in the cold measurement on the cavity and the nonlinear taper designed at CRMT and cross-checked at IIT-Roorkee. I have seen the project leaders at CEERI Dr. AK Sinha and his successor Dr. Anirban Bera were supported by Mr. Vishant Dwivedi, Mr. N Shekawat, Mr. A Mishra and others. Dr. Hasian Khatun, Dr. M Alaria and others helped them tube-process the gyrotron. During the fabrication stage I have seen Mr. Vishant Dwivedi use the facilities at RRCAT, Indore. The present project leader Dr. Bera has immensely contributed to the testing of the gyrotron at IPR, Gandhinagar taking help of Mr. K Satyanarayan, Mr. D Rathi, Mr. Atul Bora, Rajan Babu and others at IPR. Obviously, the end user of this project being IPR, all work related to power supply, plumbing line, magnetic field profiling, tube characterisation, etc. was taken care of by IPR. Dr. SV Kulkarni led the activities at IPR, and the scientists Mr. K Satyanarayan, Dr. BK Shukla, Mr. D Rathi, Mr. A Vora and many others assisted him with the immense support from Dr. Dhiraj Bora and Dr. Shashank Chaturvedi, the erstwhile and the present Directors of IPR, respectively. A separate gyrotron lab has been set up at IPR for the testing of the gyrotron.

***Position Paper on the Requirement of Microwave Tubes*:**

Dr. Chandra Shekhar, the erstwhile Director of CEERI, along with Dr. SN Joshi, organized 'Technical Meet' of all concerned R&D, academia, production, and user organisations on April 10, 2006 at CSIR Vigyan Kendra, New Delhi to generate 'Position Paper on the Requirement of Microwave Tubes and Their Development for the Coming Ten Years'. There the requirements of the organisations such as ISRO, RCI, LRDE, DLRL, MTRDC, DEAL, ADA, RRCAT, IPR, SAMEER, BEL, and BARC were projected. VEDAS can perhaps take an initiative in organizing such Technical Meets to review the scenario of the country's requirement from time to time.

***List of VEDAS Symposia and Workshops*:**

VEDAS has been organizing every year symposium/workshop since 2004. In 2011, besides the regular event (VEDAS Workshop), the VEDA Society jointly with IEEE-ED Society has organized the International Conference IVEC-2011 at Bangalore.

VEDA 2004 Symposium: MTRDC, Bangalore (30 & 31 October 2004)

VEDA 2005 Workshop: CRMT-BHU, Varanasi (18 & 19 January 2006)

VEDA 2006 Symposium: CEERI, Pilani (CSIR) (11-13 October 2006)

VEDA 2007 Workshop: SAMEER, Mumbai (22 & 23 November 2007)

VEDA 2008 Workshop: MTRDC, Bangalore (DRDO) (8-10 January 2009)

VEDA 2009 Symposium: CRMT-BHU, Varanasi (30 & 31 October 2009)

VEDA 2010 Workshop: CET, Moradabad (18 & 19 November 2010)

VEDA 2011 Workshop: RKGIT, Ghaziabad (18 & 19 November 2011)

IEEE-EDS IVEC-2011: Organized in Bangalore jointly with VEDA Society

VEDA 2012 Symposium: CEERI, Pilani (CSIR) (21-24 September 2012)

VEDA 2013 Workshop: IIT-R, Roorkee (18-20 October 2013)

VEDA 2014 Workshop: DAVV, Indore (20 & 21 March 2015)

VEDA 2015 Conference: MTRDC-DRDO, Bangalore (3-5 December 2015)

VEDA 2016 Conference: IPR-DAE, Gandhinagar (16-18 March 2017)

VEDA 2017 Symposium: IIT-R, Roorkee (17-19 November 2017)

VEDA 2018 Symposium: IIT-G, Guwahati (22-24 November 2018)

VEDA 2019 Workshop/ Symposium: NIT-Patna (dates yet to be announced)

***Mid-Carrier Awardees*:**

VEDAS takes the honour of felicitating the achievers in its annual workshops/symposia. Dr. M Santra of MTRDC in 2017 and Mr. Mukesh K Alaria in 2018 have been felicitated by Mid-Carrier Award by VEDAS for their outstanding achievements.

Lifetime Achievement Awardees:

1	Dr. Amarjit Singh	2006	Former Director, CEERI, Pilani
2	Dr. RP Shenoy	2006	Former Director, LRDE, Bangalore
3	Prof. Bharti Bhat	2007	Former Professor, IIT-Delhi
4	Dr. RVS Sitaram	2007	Former Director, SAMEER, Mumbai
5	Dr. SSS Agarwala	2008	Former Scientist, CEERI, Pilani
6	Shri V Narayana Rao	2008	Former Director, DLRL, Hyderabad
7	Prof. RK Jha	2008	Former Professor, IT- BHU, Varanasi
8	Dr. MD Rajnarayan	2009	Former Director, MTRDC, Bangalore
9	Shri BS Venugopalan	2009	Former Group General Manager, BEL, Bangalore
10	Dr. GS Sidhu	2010	Former Scientist, CEERI, Pilani
11	Prof. OPN Calla	2010	Former Scientist, ISRO
12	Prof. ML Sisodia	2010	Former Director, UGC Staff College, Jaipur
13	Dr. E Bhagiratha Rao	2011	Former Director, DLRL,

			Hyderabad
14	Prof. DS Venkateswarlu	2011	Former Professor, IT- BHU, Varanasi
15	Prof. BN Biswas	2012	Former Professor, Burdwan University
16	Prof. KP Maheshwari	2012	Former Professor, DAVV, Indore
17	Shri TRK Janardan	2012	Former General Manager, BEL, Bangalore
18	Shri NP Ramasubbarao	2013	Former Director, LRDE-DRDO, Bangalore
19	Shri V Sreenivasa Rao	2013	Former General Manager, CEL, Sahibabad
20	Shri Trilok Singh Syunry	2013	Former Program Director, SAMEER, Mumbai
21	Prof. BN Basu	2014	Former Professor and Head, IT-BHU, Varanasi
22	Shri N Divakar	2014	Former Director of DLRL-DRDO
23	Dr. PI Biradar	2015	Former Additional General Manager, BEL Bangalore
24	Professor PK Kaw	2015	Former Director IPR-DAE, Gandhinagar
25	Dr. Surendra Pal	2017	Former Scientist, ISRO, Bangalore
26	Dr. SN Joshi	2018	Former Scientist, CEERI Pilani

Conclusion:

I have narrated as a founder member of the Society how VEDAS came into being. I have in brief mentioned the application of vacuum electron devices. In the historical timeline, the early work at Institute of Radiophysics and Electronics of Calcutta University and CSIR-NPL comes in the forefront before the activities were shifted to CSIR-CEERI, Pilani. From my personal acquaintance with CEERI, I tried to narrate the pioneering activities of CEERI and their contributors in the various types of devices. The foundation of CRMT at BHU in academics sector and subsequently that of DRDO-MTRDC in defence sector were the two significant landmarks in the progress of R&D in vacuum electron devices. BEL, the manufacturers of vacuum electron devices, has joined with CEERI, MTRDC and ISRO in developing vacuum electron devices. A milestone in the progress was the success of the DST-sponsored multi-institutional project on the development of the first gyrotron in the country for fusion plasma heating. Some other points which I have encompassed in this article are the necessity of bringing out from time to time the position paper on the requirement of microwave tubes in the country; the symposia and workshops organized by VEDAS; and the mid-term and lifetime achievement awards of VEDAS to honour the achievers.

The narration of the activities concerning CEERI, MTRDC, ISRO and BEL is based on my own acquaintances with these organisations, and under proprietary constraints obviously it avoids enumerating the ranges and specifications of the tubes developed in these organisations. I have in brief presented an account of the efforts in our country in R&D in vacuum electron devices of interest to VEDAS. It is based on my own perspective and on my association with the activities and concerned contributors whom I have come across. Certainly it is not a full account and there must be many lapses and missing points to be borne with.

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