Gratitude to the Revered Jury for Selecting me for the 2023 *John R. Pierce Award* for Excellence in Vacuum Electronics of IEEE Electron Devices Society

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Gratitude to the Revered Jury

My greetings to one and all!

I thank *Dr. Monica Blank* for her kind introduction.

I am the first from India to receive the John R. Pierce Award for Excellence in Vacuum Electronics of IEEE Electron Devices Society.

My receiving this award will immensely inspire the students, researchers and teachers devoted to the area of vacuum electronics in India.

I am very much grateful to the revered proposer and referees of my nomination. I express my gratitude to the revered Jury.

I take the 2023 John R. Pierce Award for Excellence in Vacuum Electronics of IEEE Electron Devices Society with humility!

Gratitude to the Revered Jury

24th International Vacuum Electronics Conference

I am indebted to the *NOMINATOR* and *REFERENCES* of my nomination.

NOMINATOR

Prof. Claudio Paoloni

REFERENCES

Prof. Gun-Sik Park

Prof. Yubin Gong

Dr. Jinjun Feng

Prof. MV Kartikeyan

Dr. Baruch Levush

My Regards to the Past Recipients

24th International Vacuum Electronics Conference

2022 – Keishi Sakamoto (Japan);
2021 – Gun-Sik Park (Republic of Korea);
2020 – John H. Booske (USA);
2019 – Jinjun Feng (China);
2018 – Alexander Scott Gilmour (USA);
2017 – Yue-Ying Lau (USA);
2016 – Thomas M. Antonsen (USA);
2015 – Kevin Felch (USA);
2014 – Dan M. Goebel (USA);
2013 – Carter Amstrong (USA);
2012 – Neville C. Luhmann (USA);
2011 – Michael I. Petlin (Russia);
2010 – Richard True (USA);
2009 – Richard Carter (UK);
2008 – Manfred Thumm (Germany);
2007 – Baruch Levush (USA);
2006 – Jim Dayton (USA);
2005 – Joe Saloom (USA);
2004 – Georges Fleury (France);
2003 – George Caryotakis (USA);
2002 – Armand Straprans (USA)

Salutation to J. R. Pierce

- ✓ My salutation to J. R. Pierce – John Robinson Pierce – J. J. Coupling!
- ✓ J. R. Pierce, wrote, "Rudy Kompfner invented the traveling-wave tube, but I discovered it."
- ✓ In 1950's, the traveling-wave tube used to be called as the 'Kompfner tube'.
- ✓ No doubt, Pierce discovered the traveling-wave tube. The question is whether Kompfner invented the traveling-wave tube. The historical timeline shows that A. V. Haeff invented the traveling-wave tube in 1933.

I acknowledge

i. **Professor N. B. Chakrabarty**, who at the Indian Institute of Technology, Kharagpur, India, mentored my doctoral research in the area of nonlinear Eulerian hydrodynamic analysis of double-stream amplifier (Haeff tube) and beam-plasma amplifier.

ii. **Dr. James A. Dayton, Jr.**, the Founder of IVEC, who inspired me by his invitation to serve the very first Technical Committee on Vacuum Devices of IEEE-EDS as a member of the Committee, which I served from 1998 to 2003. Dr. Dayton received J. R. Pierce award in 2006.

iii. **Dr. Amarjit Singh**, the erstwhile Director of CSIR-Central Electronics Engineering Research Institute (CEERI), Pilani, who encouraged me to join CEERI and work in the area of VEDs.

I acknowledge

iv. **Dr. S. S. S. Agarwala**, Ex-Scientist, CSIR-CEERI, Pilani, for guiding me and our team to develop the first TWT in India.

v. **Professor N. C. Vaidya**, who invited me to join and nurture the Centre of Research in Microwave Tubes in the Electronics Engineering Department of Banaras Hindu University, Varanasi, India.

vi. **Dr. D. T. Swift-Hook**, former Head of Research Division of Central Electricity Generating Board, London, (a) who through a letter suggested me how I could use tapered-cross-section dielectric helix-support rods to implement my idea of surrounding a helix by a number of dielectric tubes of different optimally increasing permittivity values in the radially outward direction, for dispersion-shaping a helical slow-wave structure for the purpose of widening the bandwidth of a TWT, and (b) who has esteem for me because, in my publication, I cited maximum number of times in the world to one of his papers (Swift-Hook, D. T., 1958, "Dispersion curves for a helix in a glass tube," IEE, vol. 105B, pp. 747-755).

I acknowledge

vii. Professor Alexander Scott Gilmour, Jr., who responded to my request and authored a paper entitled "An overview of my efforts to bridge the gap in the microwave tube area between what universities provide and what the industry needs" in the Special Issue on "Microwave Tubes and Applications" in the Journal of Electromagnetic Waves and Applications (Taylor and Francis) (issue 17, vol. 31, 2017), which I guest-edited. Dr. Gilmour is the recipient of J. R. Pierce award in 2018.

viii. Professor R. G. Carter, who invited me in 1993 to the Lancaster University in an academic link and interchange scheme of the British Council, as the adopted third partner with the original two partners: Central Electronics Engineering Research Institute, Pilani, India and Lancaster University, UK, where I developed an improved theory of measurement on helical slow-wave structure of a TWT based on non-resonant perturbation technique. Dr. Carter is the recipient of J. R. Pierce award in 2009.

I acknowledge

ix. Professor Gun-Sik Park, who has been in close interaction and collaboration with me since 2001 when he started his R&D activities at Seoul National University (SNU), Republic of Korea in the area of VEDs as evidenced by my joint publications with him and his team as well as an MOU between SNU, Republic of Korea and CSIR-CEERI, Pilani India in the development of which I took a key role. Professor Park is the recipient of J. R. Pierce award in 2021.

x. Professor Manfred Thumm, who provided his immense conceptual support to us during our effort to develop the first gyrotron in India, and who invited me to visit Karlsruhe Institute, Germany, when he was the Director of the Institute. Both Professor Thumm and I delivered tutorial lectures in the areas of gyrotrons and TWTs, respectively, in 2003-IVEC held at Seoul which was general-chaired by Professor Gun-Sik Park.

On my request Professor Thumm delivered a webinar lecture on the platform of the *Group of VED Thinkers*, which I established in India.

Professor Thumm is the recipient of J. R. Pierce award in 2008.

I acknowledge

xi. Professor John Jelonnek, who was the Director of Karlsruhe Institute of Technology (KIT), Germany, when I visited the Institute in November 2011 for academic interactions and when Professor Manfred Thumm had just handed over the charge as the Director of the Institute to Professor Jelonnek. On the invitation of Professor Jelonnek, I delivered two lectures—one on some broadbanding aspects of slow-wave and fast-wave traveling-wave tubes on November 15, 2011 and the other on the scenario of the development of microwave tubes in India on November 17, 2011.

On my request Professor Jelonnek delivered a webinar lecture on the platform of the Group of VED Thinkers, which I established in India.

xii. Professor Edl Schamiloglu, (a) who presented me the hard copy of the book entitled 'High Power Microwaves' authored by him and his co-athors James Benford and John A. Swegle, and (b) who wrote his scholarly 'Foreword' of the book entitled 'High Power Microwave Tubes: Basics and Trends' authored by Vishal Kesari and me.

I acknowledge

xiii. Professor Zhaoyun Duan of University of Electronic Science and Technology of China (UESTC) at Chengdu in China, who interacted with me in 2005 through email, and jointly authored a research paper on accurate tape-helix model of analysis of attenuator coated helical slow-wave structure in 2006. Five years later we met at Bangalore IVEC-2011.

On invitation from Professor Duan, I spent the summer of 2018 delivering lectures to the PhD students of UESTC. Thereafter we have been carrying out collaborative research until today and jointly authored a good number of research papers.

Striving for Being a Good Teacher

I will consider myself to be a good teacher if I teach my students for a year and thereafter I learn from them for the rest of my life.

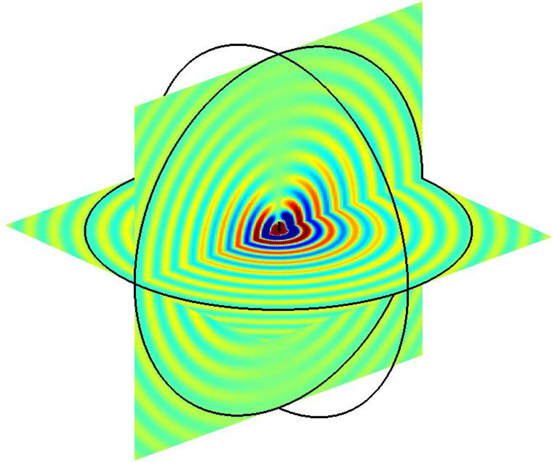
Also, I believe in the following quote from Swahili's Collected Works, vol. IV, p. 183:

"The only true teacher is he who can immediately come down to the level of the student, and transfer his soul to the student's soul and see through the student's eyes and hear through his ears and understand through his mind. Such a teacher can really teach and none else."

Kindly permit me to describe

Indian Scenario of Vacuum Electron Devices Research and Development

Indian Scenario of Vacuum Electron Devices Research and Development



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Historical Timeline

1901-1920

Fleming valve (vacuum tube diode)	John Ambrose Fleming	1904
First rudimentary radar	C. Hülsmeyer	1904
Audion or triode valve	Lee DeForest	1906
Physics of electric oscillation and radio telegraphy	G. Marconi and K. F. Braun (Nobel prize)	1909
Magnetron in early form	H. Gerdien	1910
Commercial electron tube	Radio Corporation of America (RCA)	1920

Historical Timeline

IVEC
24th International Vacuum Electronics Conference

1921-1940

Smooth-wall, split-anode magnetrons	A. W. Hull	1921
Tube scanning system for television	Philo T. Farnsworth	1922
Iconoscope or cathode-ray tube and kinescope	Vladimir K. Zworykin	1923
Tetrode valve	Albert Hull & N. H. Williams at General Electric and Bernard Tellegen at Phillips	1926
Travelling-wave tube	A. V. Haeff	1933
Beam diffraction oscillogram (beam and helix-wave interaction)	A. V. Haeff	1933

Historical Timeline

IVEC
24th International Vacuum Electronics Conference

1921-1940

Multi-cavity magnetron	K. Posthumas, H.E. Hollmann	1935
Linear beam MWT theory	Oskar Heil	1935
Klystron	George F. Metcalf and William C. Hahn	1936
Klystron	Russel Varian and Siguard Varian	1937
Improved cavity magnetron for radar	J. T. Randall and H. A. H. Boot	1939
Traveling-wave tube	N. E. Lindenblad (US patent 2,300,052 filed on May 4, 1940	1940

Historical Timeline

24th International Vacuum Electronics Conference

1941-1960

Traveling-wave tube	Rudolf Kompfner	1942
Traveling-wave tube	Lester M. Field	1946
Traveling-wave tube	J. R. Pierce	1946
Generation of microwaves by rotational energy of helical electron beam	H. Kleinwachter	1950
Maser	James P. Gordon	1954
Electron cyclotron maser interaction theory	J. Schneider R. Twiss A. Gaponov	1957 1958 1959

Historical Timeline

24th International Vacuum Electronics Conference

1961-1980

Gyrotrons (earliest version) in Russia (1965)		1965

1981-1990

Gyrotron in JET and ITER

1990 Onwards

Modern gyrotron technology

IAP, Russia; Gycom, Russia; FZK, Germany; JAERI, Japan; Toshiba, Japan; CPI, USA; TTE, France; CRPP, France; MURI, USA; CSIR-CEERI, India; DRDO-MTRDC, India; and so on

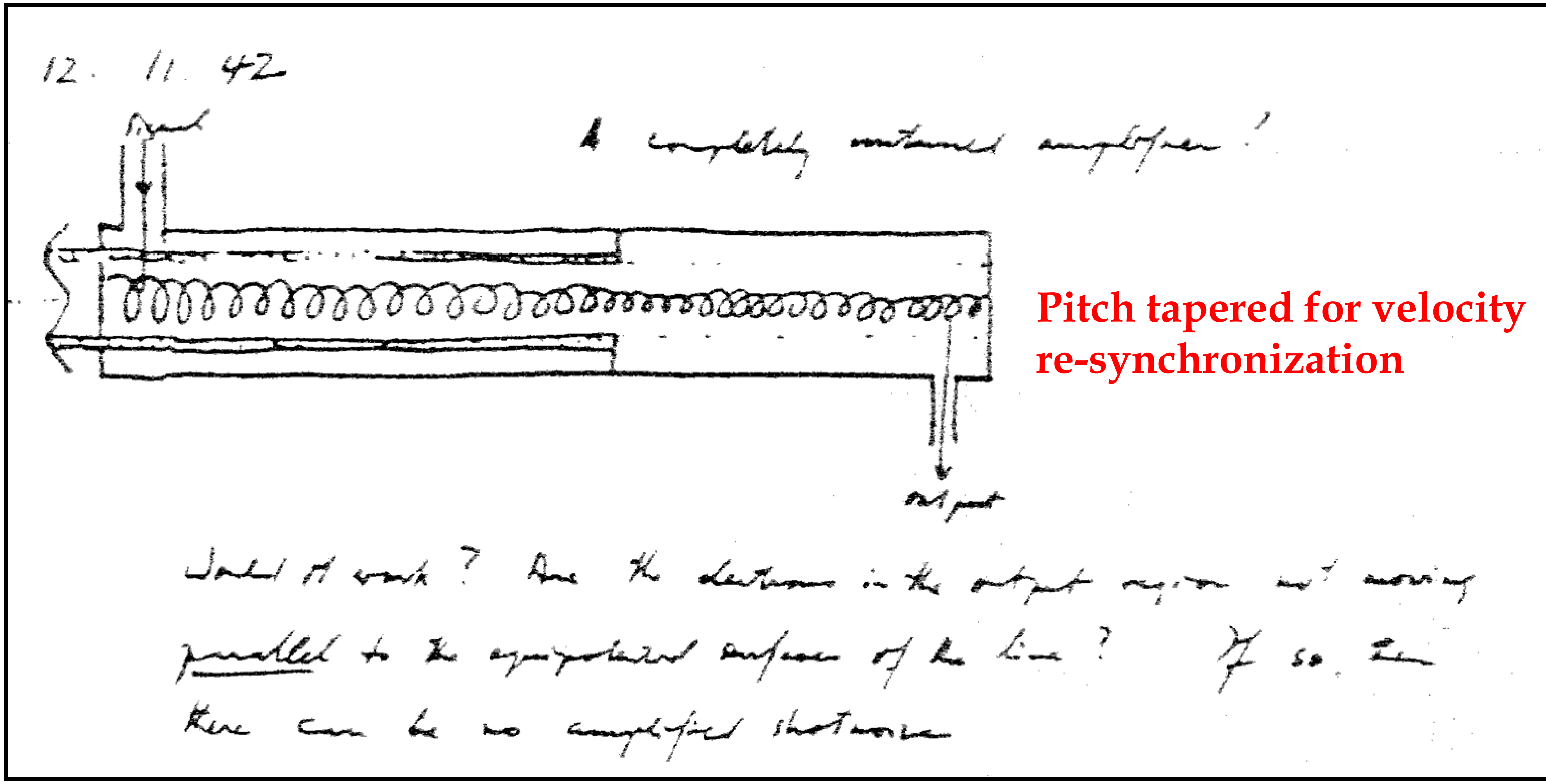
HPM-DEW

UNM, USA; DRDO-MTRDC, India; CSIR-CEERI, India; IIT-BHU, India; DAVV, India

Historical Timeline

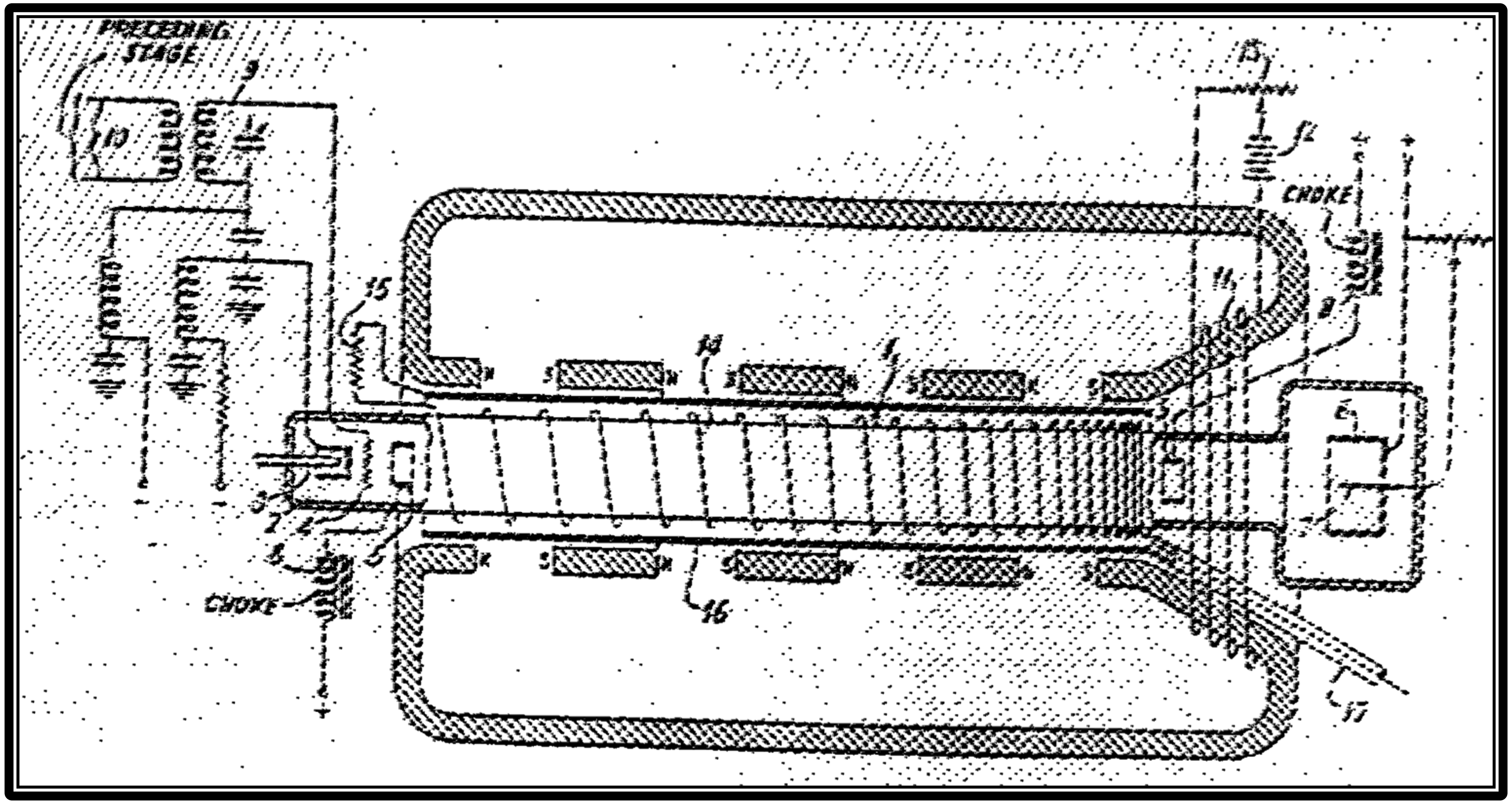
In the historical time line we like to know who invented what.

"Success has many fathers, but failure is an orphan."



Sketch of the travelling-wave tube from R. Kompfner's note book (1942)

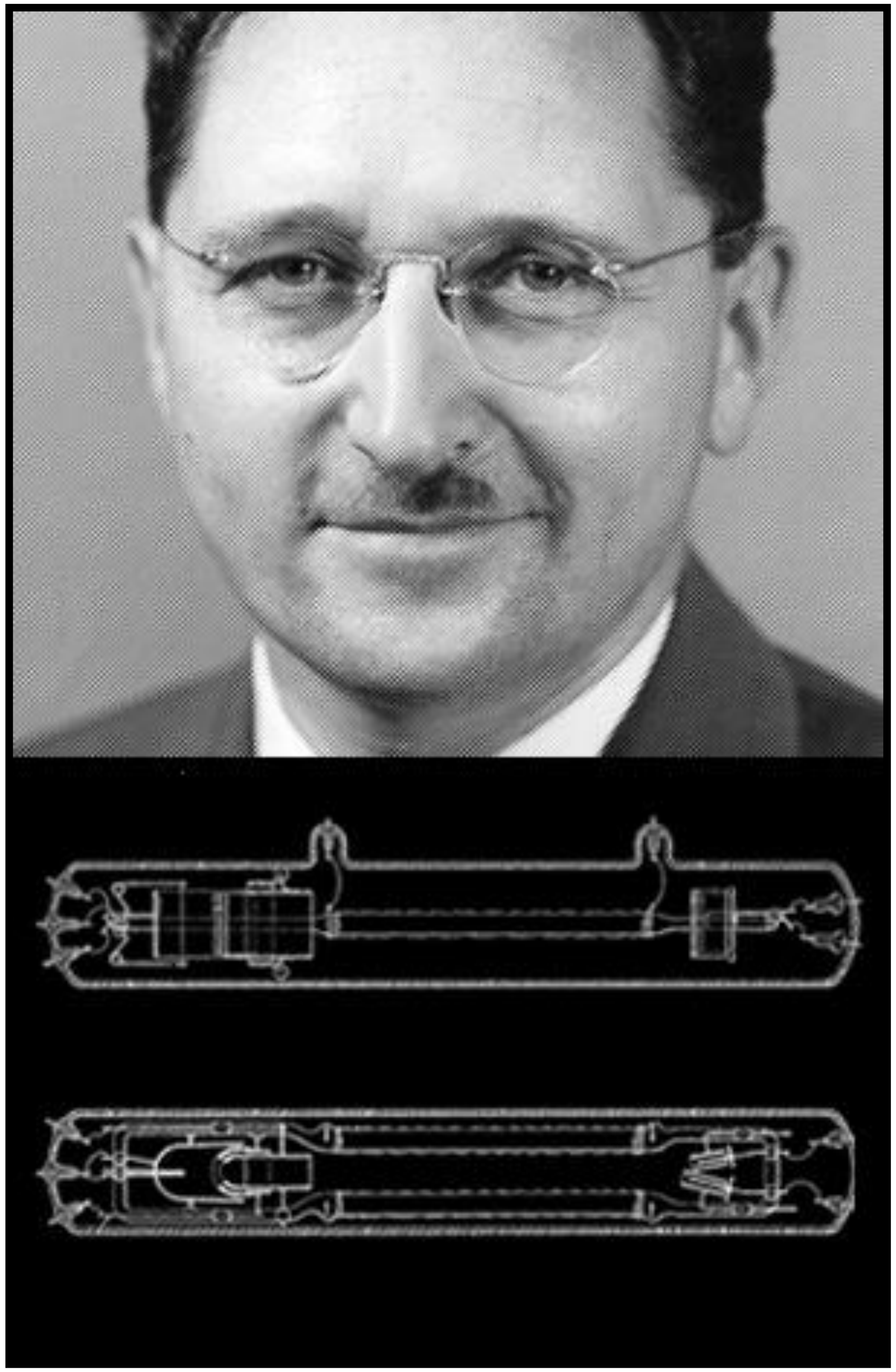
(Fig. 12.2 of the book: A.S. Gilmour, "Klystrons, Traveling Wave Tubes, Magnetrons, Crossed-Field Amplifiers, and Gyrotrons," (Artech House, Norwood, 2011))



N. E. Lindenblad's travelling-wave tube amplification at 390 MHz over a 30 MHz band (U. S. Patent 2,300,052, filed on May 4, 1940

(Fig. 12.1 of the book: A.S. Gilmour, "Klystrons, Traveling Wave Tubes, Magnetrons, Crossed-Field Amplifiers, and Gyrotrons," (Artech House, Norwood, 2011))

Helix wound around the outside the glass envelope. Signal applied to the grid of the electron gun (also applied to the helix in other experiments). Series of permanent magnets (non-periodic). Pitch tapered for velocity re-synchronization



"The patent *Andrei Haeff* filed in *1933* for a primitive type of traveling-wave tube has been largely ignored."

Courtesy: SK Datta (MTRDC)

Some relevant sources:

- R. Kompfner, The Invention of the Traveling Wave Tube, San Francisco, CA: San Francisco Press, 1963.
- J. R. Pierce, and L. M. Field, “Traveling-wave tubes,” Proc. IRE, Vol. 35, No. 2, 1947, pp. 108–111
- R. Kompfner, “Travelling wave valve,” Wireless World, Vol. 52, No. 11, 1946, pp. 369–372.
- R. Kompfner, “The traveling-wave tube as amplifier of microwaves,” Proc. IRE, Vol. 35, No. 2, 1947, pp. 124–127.
- J. R. Pierce, and L. M. Field, “Traveling-wave tubes,” Proc. IRE, Vol. 35, No. 2, 1947, pp. 108–111.
- J. R. Pierce, “High-frequency amplifier,” U.S. Patent 2602148, 1952.
- L. M. Field, “High-frequency amplifying device,” U.S. Patent 2575383, 1951,

- Haeff invented TWT in 1933.
- Lindenblad invented TWT in 1940.
- Kompfner invented TWT, however, not before 1943.
- Pierce and Field significantly contributed to the development of the TWT, however, not before 1947.
- Haeff also invented the double-stream amplifier (Haeff tube), in which two electron beams with slightly different DC velocities are intimately mixed such that the slow space-charge wave of the faster beam couples to the fast space-charge wave of the slower beam resulting in growing waves.

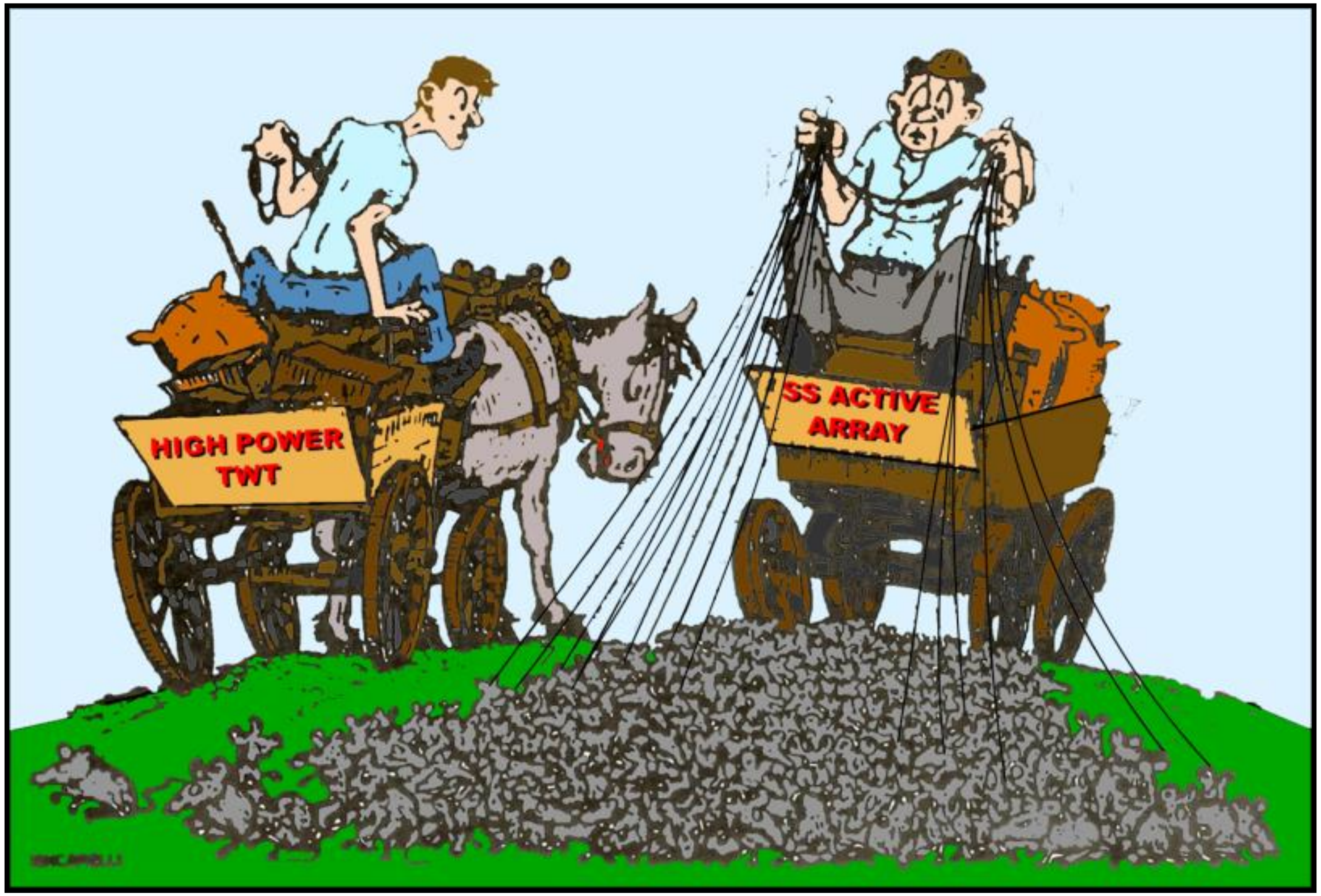
Superiority of VEDs over Their Solid State Counterparts

- Vacuum electronic devices enjoy the superiority over their solid state counterparts with respect to having
  - ✓ Lesser heat generated due to collision in the bulk of the device
  - ✓ Higher breakdown limit on maximum electric field inside the device
  - ✓ Smaller base-plate size (determined by the cooling efficiency)
  - ✓ Higher peak pulsed-power operability
  - ✓ Ultra-bandwidth (three-plus octave) performance above a gigahertz
  - ✓ Inherently hardened against radiation and fairly resistant to temperature and mechanical extremes (being fabricated out of metals and ceramics)

Professor Edl Schamiloglu wrote in the Foreword of the book authored by V. Kesari and myself entitled *High Power Microwave Tubes: Basics and Trends*:

"Vacuum electron devices (VEDs) have played a central role in electrical engineering almost since the birth of the profession near the end of the nineteenth century. However, despite all the successes of VEDs, including the Voyager twin spacecraft, which are still chugging along, logging 35 000 miles an hour as they zoom farther and farther into the cosmos, forty years after their launch, VEDs are still cast in a negative light. Recall Senator Lloyd Bentsen's comments on NBC's program Meet the Press during the 1988 United States Presidential Campaign as Michael Dukakis's candidate for Vice President: 'You can't compete if you build vacuum tubes in a solid-state world.'

“Of course, nothing can be further from the truth. Although solid-state microwave devices are making progress in achieving higher output power levels, they have important limitations (electrons transport in a solid-state medium in solid-state devices, whereas electrons are ‘free’ in vacuum in VEDs) that will prevent them from overtaking VEDs. VEDs play essential roles in communications, manufacturing, healthcare, homeland security, defense, food industry, and in many other areas.”



"Why use a thousand mice when one horse can do the job?"
(From Rodney Vaughan, Litton [Courtesy: A.S. Gilmour]

A.S. Gilmour (Jr.), "An overview of my efforts to bridge the gap in the microwave tube area between what universities provide and what the industry needs, *"Journal of Electromagnetic Waves and Applications, Vol 31, 2017, pp. 1775-1785, Special Issue on Microwave Tubes and Applications (Guest Editor: B.N. Basu)*

Indian Efforts

ORGANISATIONS HAVING INTEREST IN USING AND/OR DEVELOPING VACUUM ELECTRONIC DEVICES IN INDIA ARE LISTED IN THE FOLLOWING COUPLE OF SLIDES.

Indian Efforts

- CSIR (Council of Scientific and Industrial Research), Ministry of Science and Technology, Government of India
- DRDO (Defence Research and Development Organisation), Ministry of Defence, Government of India
- DOS (Department of Space), Government of India
- DAE (Department of Atomic Energy), Government Of India
- ISRO (Indian Space Research Organisation) (DOS) (Bengaluru)
- VSSC (Vikram Sarabhai Space Centre) (DOS) (Thiruvanthapuram)
- SAC (Space Application Centre) (DOS) (Ahmedabad)
- CEERI (Central Electronics Engineering Research Institute) (CSIR) (Pilani)
- MTRDC (Microwave Tube Research and Development Centre) (DRDO) (Bengaluru)
- CHESS (Centre for High Energy System and Sciences (DRDO) (Hyderbad)

Indian Efforts

- LRDE (Electronics and Radar Development Establishment) (DRDO) (Bengaluru)
- DLRL (Defence Electronics Research Laboratory) (DRDO) (Hyderabad)
- RCI (Research Centre Imarat) (DRDO) (Hyderabad)
- ADA (Aeronautical Development Agency) (DRDO) (Bengaluru)
- DEAL (Defence Electronics Application Laboratory) (DRDO) (Dehradun)
- CASDIC (Combat Aircraft Systems Development and Information Centre) (DRDO) (Bengaluru)
- BARC (Bhaba Atomic Research Centre) (DAE) (Mumbai)
- RRCAT (Raja Ramanna Centre for Advanced Technology) (DAE) (Indore)
- SAMEER (Society for Applied Microwave Electronics Engineering and Research (Mumbai, Guwahati) (Ministry of Electronics and Information Technology)
- IPR (Institute for Plasma Research) (Ministry of Electronics and Information Technology) (Gandhinagar)
- Bharat Electronics Limited (Indian Government Owned Public Sector Undertaking)
- Pilani Electron Tubes and Devices (Private Limited Company) (Bengaluru, Sangrur, and Mohali)

First Indian Efforts in the Development of Vacuum Electronic Devices in India

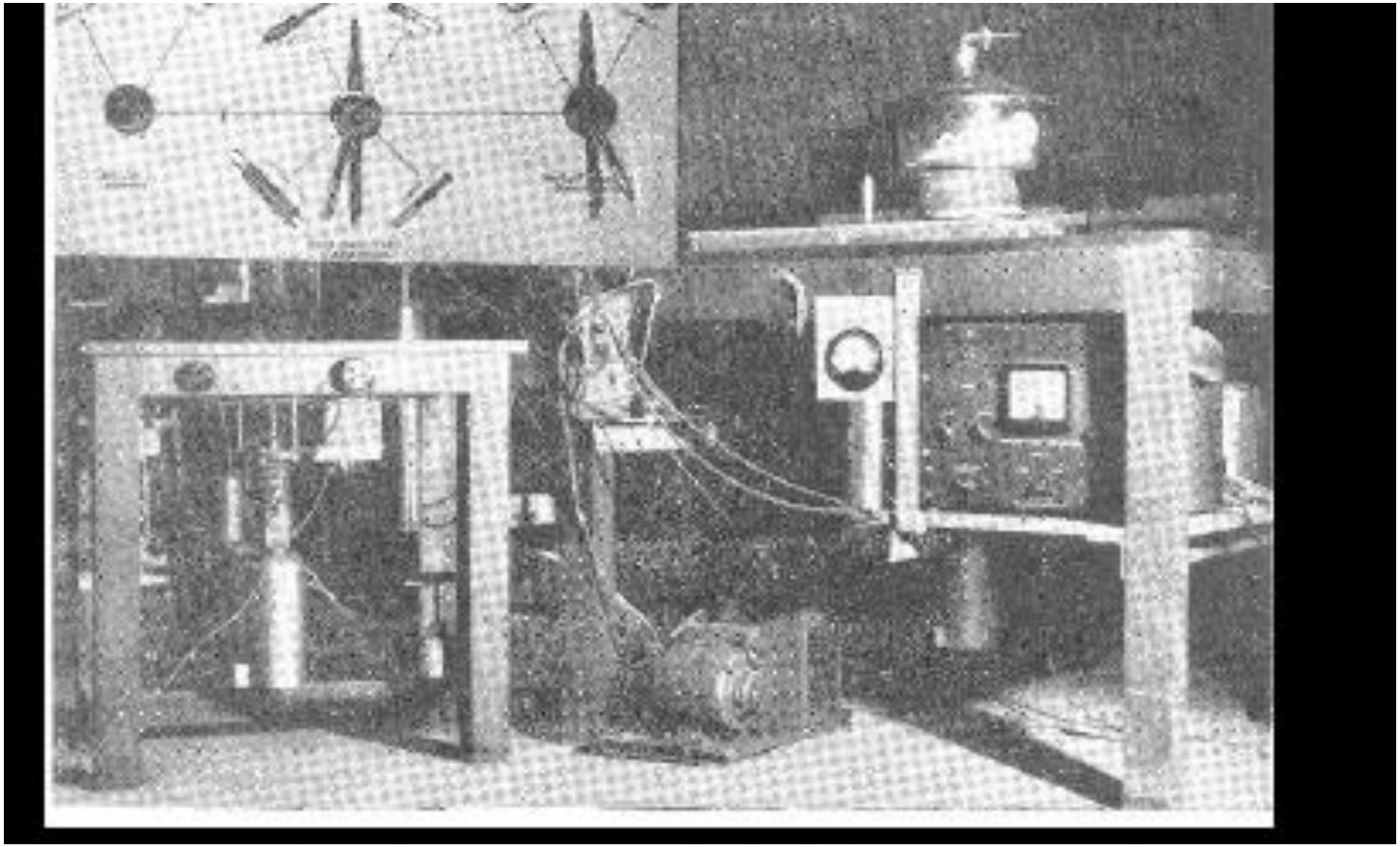
24th International Vacuum Electronics Conference

In 1956, Institute of Radiophysics and Electronics (RPE), Calcutta University (CU), Kolkata developed first in India the facilities for developing vacuum electronic devices encompassing the magnetron (both C-band and X-band). The facilities were augmented with the support from United Nations Educational, Scientific and Cultural Organization (UNESCO) and Dr. H. F. Steyskal, UNECO expert, joining the Institute of RPE, CU.

The institute of RPE stared research in the area of electron beam parametric amplifier as well.

N. B. Chakrabarty, "Lower frequency pumping of electron beam parametric amplifiers," ***Int. J. Electron.***, **vol. 8, no. 3, 161-165 (1960).**

N. B. Chakrabarty, "Analysis of fast-wave amplifiers for transverse field parametric amplifiers," ***Int. J. Electron.***, **vol. 10, no. 2, 147-151 (1961).**



Setup (1956) at Institute of Radiophysics and Electronics, Calcutta University

Courtesy: PK Basu (Calcutta University)

First Indian Efforts in the Development of Vacuum Electronic Devices in India

In early 1957, with the initiative of Dr. Amarjit Singh the activities of the development of the magnetron started at the National Physical Laboratory, New Delhi of CSIR, which however soon shifted to the Central Electronics Engineering Research Institute, Pilani of CSIR.

Subsequently, the magnetron laboratory developed by Dr. Singh and his team developed the magnetrons of different powers and frequencies to be described later in this presentation.

India among Some Typical Companies Manufacturing Microwave Tubes

- **USA: Litton, CPI**
- **Germany: Siemens, AEG, Philips**
- **Russia: ISTOK, ALMAZ**
- **France: Thales (Formerly Thompson-CSF)**
- **Italy : Electronica**
- **Japan: Toshiba, NEC**
- **China: BVERI**
- **India: Bharat Electronics (Bengaluru), Pilani Electron Tubes and Devices (Bengaluru, Sangrur, and Mohali)**

Information to be updated

Courtesy: SN Joshi (CEERI)

Sponsors supporting microwave tube R&D activities in India

- **DAE** (Department of Atomic Energy)
- **DST** (Department of Science and Technology)
- **DBT** (Department of Biotechnology)
- **BRNS** (Board of Research in Nuclear Sciences)
- **AERB** (Atomic Energy Regulatory Board)
- **ARDB** (Aeronautics Research and Development Board)
- **DRDO** (Defence Research and Development Organisation)
- **CSIR** (Council of Scientific & Industrial Research)
- **UGC** (University Grant Commission)
- **ISRO** (Indian Space Research Organization)
- **MeitY** (Ministry of Electronics and Information Technology)

Courtesy: Udit N Pal (CEERI)

Groups of VEDs in which Indian R&D is focused

24th International Vacuum Electronics Conference

Group 1: **Improved performance conventional VEDs**

TWT (ultra-wide bandwidths for EW, high efficiency, lightweight, long life for space application) (requiring innovative tube- envelope/tapered dielectric helix-support/pitch profiling/depressed collection)

Klystron (high-power klystron, EIK— wider bandwidths, higher power, EIO — millimeter-wave, low-power

MBK (large beam current, low effective beam perveance, low beam voltage, tube compactness at higher RF powers), etc.

Group 2: **VEDs accruing the advantages of SSDs and microelectronics**

MPM (ground and air-borne platforms, ECM and towed decoys, phased-array and power-combined EW, mobile and satellite communication, missile seeker and surveillance radar);

Micro-fabricated tubes: triode, klystron, FW-TWT (folded-waveguide TWT), terahertz generation, batch production. etc.

Groups of VEDs in which Indian R&D is focused

Group 3: IREB-driven HPM tubes

VIRCATOR (no magnetic fields), BWO, orotron (RDG), MWCG (multi-wave Cerenkov generator)

MWDG (multi-wave diffraction generator)

MILO (magnetically insulated line oscillator (no external magnetic field, magnetic insulation)

relativistic klystron, RELTRON, relativistic magnetron, relativistic BWO

E-bomb using a magnetic flux compression generator (FCG) in conjunction with a VIRCATOR etc., HPM/DEW/ information warfare application

Group 4: Fast-wave gyro-VEDs

Gyrotron (high-harmonic, low magnetic fields, large-orbit, vane-loaded, coaxial-cavity, quasi-optical, etc.)

gyro-TWT (dielectric-loaded, disc-loaded, frequency multiplying, etc.)

gyro-klystron

gyro-twystrons,

PHIGTRON (phase-coherent, harmonic multiplying, inverted gyro-twystron); gyro-BWO; CARM; SWCA; Peniotron, etc.

Groups of VEDs in which Indian R&D is focused

Group 5: Plasma-assisted VEDs

Plasma-assisted VEDs (plasma-filled for large beam transport, relaxation of magnetic field, larger structure cross section, etc.)

Pasotron (BWO), plasma-filled coupled-cavity TWT, plasma-filled helix TWT, plasma-filled gyrotron (Group 4)

Group 6: Metamaterial assisted VEDs

TWT, BWO, backward-wave amplifier, klystron, MBK, resistive-wall amplifier, etc

Efforts of CRMT, IIT-BHU, Varanasi

IVEC
24th International Vacuum Electronics Conference

- Centre of Research in Microwave Tubes (CRMT), Department of Electronics Engineering, Banaras Hindu University (BHU), Varanasi
  - Field and equivalent circuit analyses of helical slow-wave structures for travelling-wave tubes
  - Modelling of helix thickness, discrete dielectric helix-support rods, and metal envelope of helical slow-wave structures of TWTs
  - Anisotropic helix loading (metal vane/segment loading) for widening the bandwidth of a TWT
  - Inhomogeneous helix loading (using tapered-geometry dielectric helix-support rods) for widening the bandwidth of a TWT
  - Experimental characterization of helical structures by non-resonant perturbation technique
  - Nonlinear hydrodynamic analysis of helix TWTs for the estimation of harmonic content and intermodulation distortion
  - Synthesis of Pierce electron guns

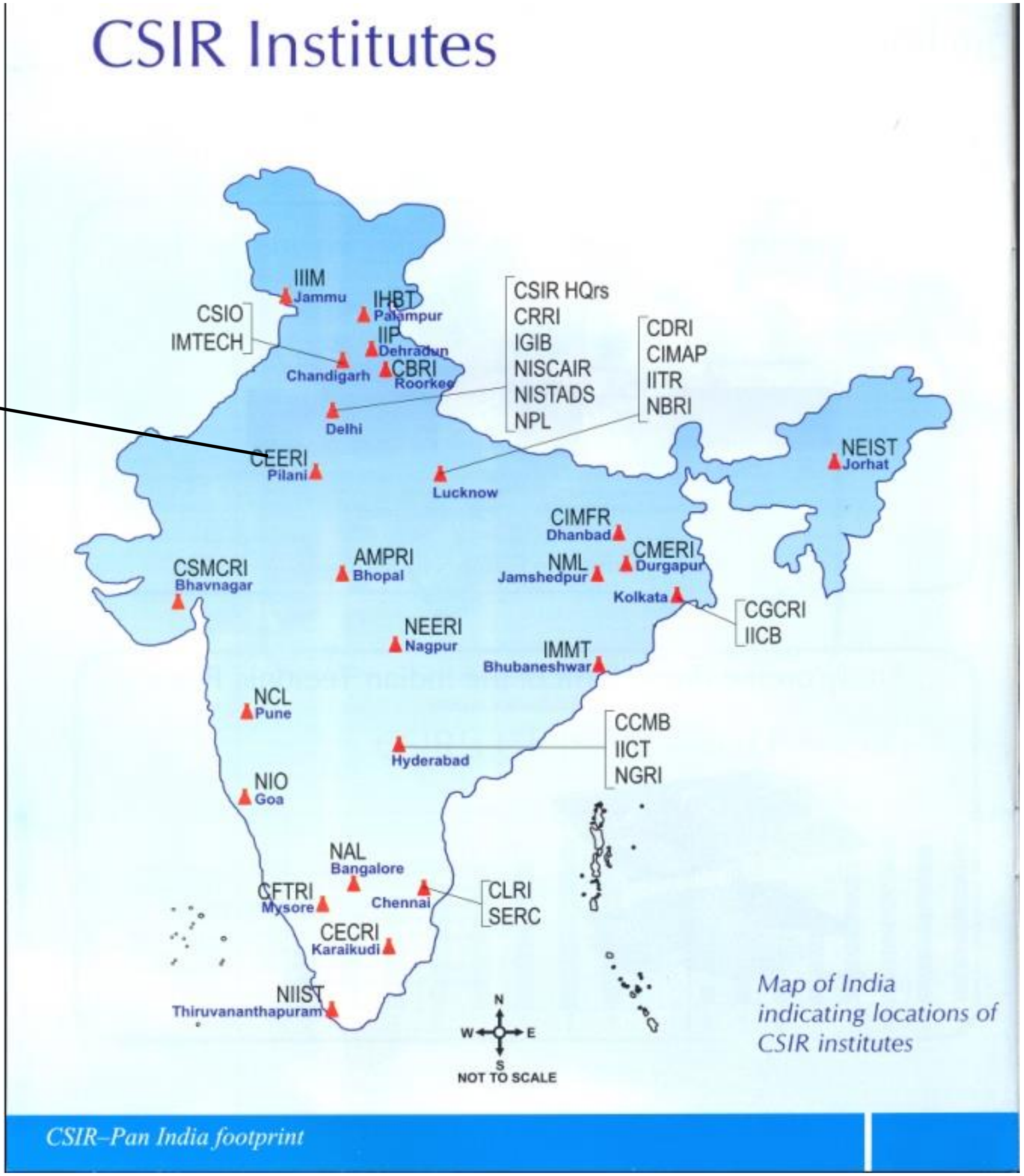
Efforts of CRMT, BHU, Varanasi

- **Centre of Research in Microwave Tubes (CRMT), Department of Electronics Engineering, Banaras Hindu University (BHU), Varanasi**
  - Cold and hot (small-signal) analysis of a vane-loaded gyrotron for mode selectivity
  - Analysis of a tapered-cross section, corrugated coaxial-cavity gyrotron for mode rarefaction
  - Cold and hot (small-signal) analysis of a dielectric-loaded gyro-TWT for wide bandwidths
  - Analysis of a tapered cross-section gyro-TWT for wide bandwidths
  - Analysis of a disc-loaded gyro-TWT for wide bandwidths
  - Simulation of and measurements on gyrotron cavities and nonlinear taper
  - Large-signal analysis and simulation of gyrotrons, gyro-TWTs, and gyro-klystrons, gyro-twystrons, relativistic BWO and MILO, etc.

Efforts of Central Electronics Engineering Research Institute, Pilani (CSIR), Ministry of Science and Technology, Government of India

24th International Vacuum Electronics Conference

CEERI



CSIR Institutes/Labs

Information to be updated

Efforts of CSIR-CEERI, Pilani

CSIR-CEERI TWTs

- **Developed the first ever helix TWT in India (1977): S-band, 2 W (CW) helix-TWT (helix closely fitting in a glass tube, with contra-wound helical couplers and attenuators)**
- **Developed the first ever space-qualified TWT in India: C-band, 60 W (CW), in collaboration with BEL, Bangalore. The flight models were handed over to ISRO**
  - ✓ C-band, 20 W (CW) TWT
  - ✓ S-band, 30 W (pulsed) TWT
  - ✓ X-Ku-band, 40 W (CW) Mini-TWT
  - ✓ C-band, 60 W (CW) TWT
  - ✓ Ku-band, 140 W (CW) TWT
  - ✓ X-Ku band, 40 W CW mini-TWT
  - ✓ Ku-band,140W short length space-TWT
  - ✓ C-band, 70 kW pulsed CC-TWT
  - ✓ Ku-band, 40 W (CW) (Ku-band) space-TWTs
  - ✓ Ka-band, 100 W (CW) space-TWTs
  - ✓ Development of lab prototype W-band (94 GHz) folded-waveguide TWT

Information to be updated

Efforts of CSIR-CEERI, Pilani

CSIR-CEERI Crossed-Field Tubes (Magnetrons and Carcinotrons)

- **Development of magnetrons using the hole-and-slot-type cavities and echelon- or ring-type strapping:**
  - ✓ S-band, 500 kW magnetron
  - ✓ S-band,1.0 MW magnetron
  - ✓ S-band (tunable), 800 kW magnetron
  - ✓ S-band, 2 MW and 3 MW magnetron
  - ✓ S-band,10 kW CW magnetron
  - ✓ Limited production of S-band, 2 MW magnetron)
  - ✓ S-band 200 W and 400 W carcinotron (BWO)

Courtesy: SN Joshi (CEERI)

- **Technology development for RF windows for (i) 170 GHz, 1 MW, long-pulse and (ii) 4 MW S-band tunable pulse magnetrons**

Recent R&D on magnetrons:

Information to be updated

- ✓ S-band, 5.0-7.5 MW-peak magnetron development using the hole-and-slot-type cavities and echelon-type strapping
- ✓ S-band,15 kW CW magnetron using the vane-type, double-ring strapping
- ✓ Exploration of space-harmonic magnetron with cold cathode planar structure configurations for higher frequencies

Courtesy: SN Joshi (CEERI)

Efforts of CSIR-CEERI, Pilani

CSIR-CEERI Klystrons

- D/E-band, 1 kW CW klystron
- S-band, 5 MW (peak), 5 kW (average) klystron
- 2856 MHz, 6 MW peak, 24 kW average power klystron (for cargo scanning)*
- KU/J-band, 300 W CW klystron
- 350 MHz, 100 kW CW klystron
- 5 GHz, 250 kW CW klystron (for ITER lower hybrid current drive, under development)

- **Related design and developmental activities:**

19-beam electron gun for MBK; Low-power air-cooled RF coupler (for low-energy, high-intensity proton accelerator); High-power water-cooled coaxial RF coupler (for low-energy, high-intensity proton accelerator); High-power water-cooled iris coupled RF coupler (for low-energy high-intensity proton accelerator); 64-channel rectangular RF window (for IPR-Aditya TOKAMAK, lower hybrid current drive)

Information to be updated

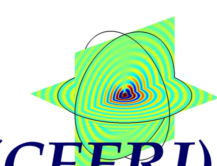
Courtesy: A Bandyopadhay, LM Joshi (CEERI)

Efforts of CSIR-CEERI, Pilani

CSIR-CEERI Cathodes

- ✓ 20 A/cm2, >8 yr (extrapolated) B-type dispenser cathode
- ✓ > 100 A/cm2, >12 yr (extrapolated) alloy-coated dispenser cathode
- ✓ Technology development for reliable long-life dispenser cathodes
- ✓ Surface analytical studies on dispenser cathode
- ✓ Development of large-area dispenser cathodes for high-power microwave tubes: M-type cathode, ~3.1 mm cathode diameter, >20 A per square cm current density, 1000 C operating temperature
- ✓ Development contract for triple-alloy coating
- ✓ Development of graphene-based field emitters
- ✓ Design and development of high current density (> 100 A/cm^2) thermionic cathode for terahertz devices application
- ✓ Design and development of the work function measurement setup at elevated temperatures of thermionic cathode
- ✓ Design and development of thermionic emitter for electric propulsion (ion thruster) system
- ✓ Design and development of multi-beam cathode for multi beam klystron
- ✓ Design of sheet beam electron gun for THz vacuum electron devices
- ✓ Numerical design of vacuum micro-electronics devices using AI algorithm

Information to be updated



Courtesy: Ranjan Barik (CEERI)

Efforts of CSIR-CEERI, Pilani

CSIR-CEERI Gyrotrons

- **Design and development of MIG, beam tunnel, cavity, nonlinear taper, collector of a gyrotron**
- **Analysis of after-cavity-interaction in a gyrotron**
- **Design and development of 42 GHz, 220 kW CW gyrotron (for fusion plasma heating) (carried out under a DST-sponsored multi- institutional project)**
- **Design and development of 170 GHz, 1MW (short pulse) gyrotron**
- **EM simulator for gyrotrons**

Information to be updated

Courtesy: Anirban Bera and AK Sinha (CEERI)

Efforts of CSIR-CEERI, Pilani

CSIR-CEERI Plasma Based Devices and Systems

- Plasma Cathode Electron (PCE) Guns: High density and energetic short pulsed electron beam generation for microwave, THz and surface modification applications
  - Electron Beams: ~35 kV(energy), ~5.0kA(peak current), ~104 A/cm2(Current density)
- Plasma assisted microwave sources: PASOTRON (X-band, 0.5 MW) and THz sources (0.1 1THz) for High Power NDE Application
- UV/VUV (vacuum UV) excimer sources based on DBD for Biomedical, Surface treatment, Water purification (jointly with CSIR-NEERI), Ozone Generation applications
- High power plasma switches: cold cathode Pseudospark Switch (PSS) and hot cathode Thyratron for fast pulsed power applications
  - Thyratrons: 25 kV/1 kA, 35-40 kV/3 kA for BARC, Mumbai and RRCAT, Indore)
  - Pseudospark switches (40 kV/5 kA, 50-70kV/10kA and 20 kV/100 kA)
- Cold atmospheric pressure plasma devices and technologies for food, biomedical, and plasma medicine applications: Cold Atmospheric Plasma (CAP) Jets and Large Volume Plasma Source (LVPS)
- Portable and tunable extreme ultraviolet (EUV)/soft X-ray sources for surface modification of biomaterials and radiography
- Micro-hollow cathode discharge devices for intense VUV/UV and Ozone generation

Courtesy: Udit N Pal, Niraj Kumar (CEERI)

Efforts of DRDO-MTRDC, Bengaluru

DRDO-Microwave Tube Research and Development Centre (MTRDC), Bengaluru (Bangalore)

MTRDC is a constituent R&D laboratory of Defense Research & Development Organisation (DRDO), Ministry of Defense. It was established in 1984, with an aim to develop advanced types of microwave tubes to meet the present and futuristic needs of the country and establish self-reliance in this strategic area.

Efforts of DRDO-MTRDC, Bengaluru

IVEC
24th International Vacuum Electronics Conference

DRDO-MTRDC Helix-TWTs

- **X-Ku band, 200 W (CW) helix-TWT**
- **X-Ku band, 2 kW (pulsed) helix-TWT**
- **X-Ku band, 300 W (CW) helix-TWT**
- **K-Ka band, 40 W (CW) helix-TWT**
- **C-X-Ku band 100 W (CW) helix-TWT**
- **C-X-Ku band 200 W (CW) helix-TWT**
- **C-X-Ku band 1.5 kW (CW) helix-TWT**

Information to be updated

Courtesy: SUM Reddy (MTRDC)

Efforts of DRDO-MTRDC, Bengaluru

Lalit Kumar and KU Limaye, "Review of progress in indigenous design, development and production of microwave vacuum-electronic devices," IETE Technical Review, Vol. 20, No 2, pp 75-93 (2003)

TABLE 1a Parameters and features of indigenously developed CW helix TWTs

DESCRIPTION	CW HELIX TWTS								
FREQUENCY BAND	S	C	X-Ku	C	C	C	C	X-Ku	K-Ka
Power(W)	2	20	40	80	125	400	60	300	40
Gain(dB)	20	45	40	50	50	50	50	35	36
Vacuum envelope	GM	GM	CM	CM	CM	CM	CM	CM	CM
Beam control	-	BFE	BFE	-	-	-	-	BFE	BFE
Focusing	Solenoid	PM	PPM	PPM	PPM	PPM	PPM	PPM	PPM
Application	Exptl	Satellite Earth Station	ECM	Satellite uplink	Satellite uplink	Satellite uplink	G-SAT	ECM	ECM
Agency	CEERI	CEERI / ISRO	CEERI / BE	BE	BE	BE	CEERI / BE	MTRDC/ BE	MTRDC
Current status	Completed	Completed	Completed	Completed	Completed	Completed	Continued	Continued	Continued

GM – Glass-Metal; CM – Ceramic-Metal; BFE – Beam Focus Electrode, PPM – Periodic Permanent Magnet; PM – Permanent Magnet; ECM – Electronic Counter Measure; Exptl – Experimental, G-Sat – Geo stationary satellite

Efforts of DRDO-MTRDC, Bengaluru

Lalit Kumar and KU Limaye, "Review of progress in indigenous design, development and production of microwave vacuum-electronic devices," IETE Technical Review, Vol. 20, No 2, pp 75-93 (2003)

TABLE 1b Parameters and features of indigenously developed pulsed helix TWTs

DESCRIPTION	PULSED HELIX TWTs			
FREQUENCY BAND	S	X-Ku	X-Ku	Ku
Peak power output (W)	30	200	2000	2500
Gain(dB)	40	35	45	65
Vacuum envelope	CM	CM	CM	CM
Beam control	IG	BFE	IG	IG
Focusing	PM	PPM	PPM	PPM
Application	3D static radar airforce	Exptl	ECM	ECM
Agency	CEERI / BE	MTRDC	MTRDC / BE	BE
Current status	Completed	Completed	Completed	Completed

CM – Ceramic-metal; IG – Intercepting grid; BFE – Beam focus electrode; PM – Permanent magnet; PPM – periodic permanent magnet; ECM – Electronic counter Measure; Exptl - Experimental

Efforts of DRDO-MTRDC, Bengaluru

DRDO-MTRDC Power Booster Helix-TWTs for MPMs

	MCH-3550	MCH-3553	MPH-4052	MPH-5055
Band	C-Ku	C-Ku	X	Ku
Bandwidth (GHz)	12	12	1	2
Duty	CW/Pulsed	CW/Pulsed	Pulsed	Pulsed
Peak power (W)	100	200	180	375
Focussing	PPM	PPM	PPM	PPM
Cooling	Cold plate	Cold plate	Cold plate	Cold plate
Weight (gm)	540	800	500	500

Information to be updated

Courtesy: SUM Reddy (MTRDC)

Efforts of DRDO-MTRDC, Bengaluru

DRDO TCHNOLOGY FOCUS: JUNE 2015
— a useful document which was brought out by the initiative of Dr. Lalit Kumar, the erstwhile Director of DRDO-MTRDC

DRDO Technology Focus: June 2015

Features of DRDO MPMs

Characteristics	Model No.			
	MCS-3549	MCS-3550M	MPS-4051	MPS-4051M
Application	EW	EW	Radar	Radar
Frequency band	C-Ku	C-Ku	X	X
CW/ Pulsed	CW/ Pulsed	CW/ Pulsed	Pulsed	Pulsed
Output Power (W)	80	100	120	120
Input voltage (V DC)	270	270	270	270
Prime power (W)	430	430	170	170
RF input connector	SMA(F)	SMA(F)	SMA(F)	SMA(F)
RF output connector	TNC(F)	TNC(F)	TNC(F)	TNC(F)
Cooling	Cold plate (external)	Cold plate (external)	Natural air (integrated heatsink)	Natural air (integrated heatsink)
Dimension (mm^3)	310×280×40	296×280×40	345×325×70	345×325×70
Weight (kg)	4	4	12	12

DRDO Technology Focus: June 2015

Features of MMP-based transmitters

Characteristics	Model No. MCS-3547	MCS-3552	MPS-3560	MCS-5050	MCS-5051
Application	EW	EW	EW	Communication	Communication
Frequency band	C-Ku	C-Ku	C-Ku	Ku	Ku
CW/ Pulsed	CW/ Pulsed	CW/ Pulsed	Pulsed	CW/ Pulsed	CW/ Pulsed
Output Power (W)	50	150	1000	100	120
Input Voltage	270 V DC	115 V, 400 Hz, 3-Phase AC	115 V, 400 Hz, 3-Phase AC	28 V DC	28 V DC
Prime Power (W)	560	2800	850	430	570
RF input conn.	TNC(F)	TNC(F)	SMA(F)	SMA(F)	SMA(F)
RF output conn.	TNC(F)	WRD-650	WRD-650	N(F)	N(F)
Cooling	Forced air (external)	Forced air (external)	Forced air (external)	Forced air (external)	Forced air (integrated fan and heatsink)
Dimension (mm^3)	390×210×150	570×270×195	465×165×130	320×160×150	280×300×160
Weight (kg)	19	30	< 15	<9	10

Efforts of DRDO-MTRDC, Bengaluru

DRDO-MTRDC Coupled-Cavity (CC) TWT

- Ku-band, 10 kW (pulsed) CC-TWT
- X-band, 6.5 kW (pulsed) CC-TWT
- S-band, 130 kW (pulsed) CC-TWT

Related Technologies Developed, Collaboration, and Technology Transfer

- Fabrication of shadow-gridded electron gun
- Distributed-loss and resonant-loss loading of cavities
- Development of Samarium Cobalt magnets with good homogeneity
- Thermal management
- Collaboration with ISTOK, Russia on joint development of X- and Ku-band CC-TWTs
- Qualified tubes delivered for multimode radar
- Technology for production of the X-band and S-band CC-TWTs transferred to BEL resulting in limited series production

Information to be updated

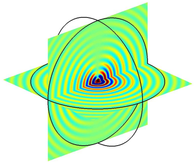
Courtesy: SUM Reddy (MTRDC)

Efforts of DRDO-MTRDC, Bengaluru

DRDO-MTRDC Dispenser Cathodes

- **> 50 A/cm^2 Os-coated cathode**
- **30 A/cm^2, >20,000 hr Lithium oxide MM cathode**
- **> 50 A/cm^2, >45,000 hr W-Ir MM cathode**
- **> 40 A/sq cm, >40,000 hr W-Re MM cathode**
- **35,000 hr Scandate cathode**
- **>360 A/cm^2 PZT based ferroelectric cathode**

Information to be updated



Efforts of BEL, Bengaluru

Bharat Electronics Limited (BEL), Bengaluru (Bangalore)

BEL (a public-sector organization) was established at Bangalore, India, by the Government of India under the Ministry of Defence in 1954 to meet the specialized electronic needs of the Indian defence services. Over the years, it has grown into a multi-product, multi-technology, multi-unit company serving the needs of customers in diverse fields in India and abroad.

"Good service is when the customers come back and the goods don't."

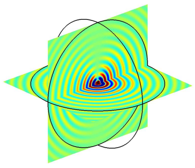
Efforts of BEL, Bengaluru

BEL Tubes (Typical)

- L-, C-, K- and Ku-band, 400 W – 1.0 MW (pulsed) conventional/coaxial magnetrons
- L-, S-, C-, X- and Ku-band, 1.0 W – 400 W (CW); 1 kW to 6 kW (pulsed) helix TWTs
- X-, S band CC-TWTs
- L-, S-, and C- band Klystrons
- (BEL also manufactures other electron tubes such as power triodes and tetrodes)

(BEL takes technology know-how, as and when necessary, for manufacturing MWTs from CSIR-CEERI, Pilani; DRDO-MTRDC, Bangalore; Philips, EEV, UK; VARIAN (now CPI), USA; Thomson-CSF (now Thales), France; ISTOK, Russia, etc.

Information to be updated



Efforts of BEL, Bengaluru

BEL TWTs

- **BEL6242:** L-Band, 200 W (CW), 35 dB (3.9 kV, 525 mA)
- **BEL6252:** S-Band, 200 W (CW), 37 dB (4.2 kV, 430 mA)
- **BTC401:** C-Band, 400 W (CW), 50 dB (9.6 kV, 350 mA)
- **BTC6262:** C-Band, 200 W (CW), 37 dB (9.0 kV, 300 mA)
- **BTU5191:** X-Ku Band,1 kW (pulsed; 4% duty), 50 dB (11.5 kV, 1.8 A)
- **BEL mini-TWT:** 7.5-18 GHz, C-X-Ku Band, 80 W (CW), 50 dB (4.2 kV, 175 mA)
- **BEL CC-TWT (BCCT 2000X):** X-Band, 120 kW (pulsed; 0.5% duty), 50 dB (45 kV, 14 A)
- **BTC60 (Space-TWT):** S-C band, 60 W (CW), 50 dB (3.2 kV, 80 mA)
- **BTU140:** X-Band, 140 W (CW), 50 dB (6.2 kV, 120 mA)

Information to be updated

Efforts of BEL, Bengaluru

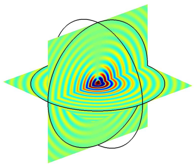
BEL Klystrons

- **BEL 4K3SL3:** L-S Band, 1 kW (CW) (7 kV, 650 mA)
- **BEL 4K3SL3:** L-S Band, 12 kW (CW) (20 kV, 3 A)
- **BEL 888E: BEL 888E:** C-Band, 1.4 kW (CW) (8.5 kV, 600 mA)

BEL Magnetrons

- **5J26:** L-Band, 600 kW (pulsed, 0.25%) (34 kV, 55 A)
- **BEL 200 MX:** C-X Band, 200 kW (pulsed, 0.11%) (23 kV, 12 A)
- **BEL 512 cm:** X-Band, 200 kW (pulsed, 0.11%) (23 kV, 30 A)

Information to be updated



Requirement of MWTs in the country for coming ten years

Requirement of microwave tubes has been estimated by CEERI, Pilani (CSIR) based on the deliberation at the Technical Meet of all concerned R&D, academia, production, and user organisations held 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'.

A great initiative was taken up by Dr. Chandra Shekhar, the erstwhile Director, CSIR-CEERI, Pilani in preparing this position paper.

The requirements of vacuum electronic devices such as the magnetron, klystron, traveling-wave tube, and gyrotron were placed by the various organizations in the country.

However, the document needs to be updated from time to time.

Consortium for the Execution of Multi-institutional Project

Consortium for the development of the first ever gyrotron in the country for the IPR tokamak executed in a multi-institutional DST-sponsored project

42-GHz, 200-kW (CW or long pulse); 1.6-1.62 Tesla; 65-70 kV, 10-15 A; TE_{03} mode

Participating organizations (Coordinator: Dr. SN Joshi of CEERI, Pilani)

1. **CEERI, Pilani** — Electron gun and beam tunnel, Collector, Fabrication of all parts, Assembly/Integration of parts, Processing, Testing, and Coordination with the other participants of the project working as the Nodal Centre of the project (Leader: Dr. AK Sinha)
2. **IIT-Roorkee** — Analysis and simulation of beam-wave interaction and design of specific modules for the design and development of the device besides extending design validation to all the participants as and when required (Leader: Professor MV Kartikeyan)
3. **SAMEER, Mumbai** — Window (Leader: Dr. S Das)
4. **IPR, Gandhinagar** — Magnetic focusing structures, Thermal management, Power supply and Plumbing line (Leader: Dr. SV Kulkarni)
5. **BHU** — Cavity and Nonlinear taper (Leader: Professor PK Jain).

Academic Institutions

Academic institutions (to mention a few) which offer postgraduate and doctorate degrees in RF/Microwave Engineering involving research in microwave tubes and related areas

- IIT-BHU, Varanasi
- IIT-Roorkee, Roorkee
- CSIR-Academy of Scientific and Innovative Research (AcSIR), New Delhi
- Burdwan University, Burdwan, West Bengal
- Banasthali Vidyapith, Rajasthan
- Supreme Knowledge Foundation Group of Institutions, Mankundu, West Bengal
- Devi Ahilya Bai Vishwavidyalaya, Indore, Madhya Pradesh

VEDA Society

Vacuum Electronic Devices and Applications (VEDA) Society

Organises every year workshop/symposium/conference in India

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 Symposium: NIT-Patna (21-23 November 2019)
VEDA 2022 Conference: MTRDC-DRDO, Bangalore (19-21 January 2023)

TOPICS ON WHICH LECTURES WERE DELIVERED IN THE VEDA 2022 CONFERENCE: DRDO-MTRDC, BANGALORE (19-21 JANUARY 2023)

Tutorial Theme Setting Lecture: High power microwave and THz technologies and applications

Tutorial-1: Present and future trends in THz devices and technologies

Tutorial-2: HPM sources, diagnostics and facilities, and antennas for high power microwave applications

Plenary Talk-1: Future trends in microwave-terahertz-wave vacuum electronic devices—an Indian perspective

Plenary Talk-2: Implementation of electromagnetic environmental effects and high power electromagnetics in electronic system design

Plenary Talk-3: DEW system based high power laser—challenges and perspectives

TOPICS ON WHICH LECTURES WERE DELIVERED IN THE VEDA 2022 CONFERENCE: DRDO-MTRDC, BANGALORE (19-21 JANUARY 2023)

1. Acute high-power millimetre-wave exposure instigates thermal responses in rat skin
2. Analysis and characterization of Kr/Cl2 based 222 Nm far UV-C excimer source
3. Analysis of non-thermal atmospheric pressure plasma source based plasma activated water for agriculture application
4. Analysis of folded-waveguide TWT for efficiency enhancement at W-band
5. An equivalent circuit analysis of a coaxial double-reentrant cavity for klystrons
6. An S-band metamaterial backward-wave oscillator for HPM application
7. A rectangular waveguide slow-wave structure for W-band travelling-wave tube amplifier for security systems and udestroyed explosive detection
8. Beam-wave interaction simulations for a 7 MW peak power S-band klystron
9. Cassegrain reflector antenna for high power microwave applications
10. Commissioning of new 42GHz-500kW gyrotron and experiments on the effect of high power microwave in plasma and in seed germination

TOPICS ON WHICH LECTURES WERE DELIVERED IN THE VEDA 2022 CONFERENCE: DRDO-MTRDC, BANGALORE (19-21 JANUARY 2023)

11. Comparative analysis and future trends of high voltage EPCs of CW and pulsed TWTs DEW system based on high power lasers — challenges and perspectives
12. Designing of SWS for a planar high power THz BWO using multi-sheet electron beams
13. Design, analysis and experimental evaluation of electron gun and PPM focusing recent trends in microwaves and tera-wave vacuum electronic devices in india
14. DC and RF breakdown analysis a helix-TWT
15. Design of electron optics for W-band TWT
16. Design and development of thermally stable dual anode electron gun for space applications
17. Development of cold atmospheric pressure plasma jet sources for biomedical application
18. Design and simulation of dual-band RBWO with azimuthally splitted slow-wave structure

TOPICS ON WHICH LECTURES WERE DELIVERED IN THE VEDA 2022 CONFERENCE: DRDO-MTRDC, BANGALORE (19-21 JANUARY 2023)

19. Development and switching characterization of high power pseudospark switches for fast pulsed power applications
20. Development and characterization of psuedospark discharge based plasma cathode electron (PD-PCE) high density and energetic e-beam generation for pulsed power applications
21. Development of liquid stub tuner and liquid phase shifter for antenna-plasma coupling impedance matching for high power rf experiments
22. Design and simulation of dual-band RBWO with azimuthally splitted slow-wave structure
23. Development of X-band, 3.5W TWT for radar applications latest trends in high power microwaves and system
24. Development of demountable high power microwave device for single-shot applications

TOPICS ON WHICH LECTURES WERE DELIVERED IN THE VEDA 2022 CONFERENCE: DRDO-MTRDC, BANGALORE (19-21 JANUARY 2023)

25. Design of a **94 GHz PBG-based multi-beam EIK**
26. Design of **field emission electron gun** for photonic crystal based **W-band source**
27. Development of 150W **compact Ka-band helix-TWT**
28. Design and development of modified designing of SWS for **planar high power THz BWO using multi-sheet electron beams**
29. Development of **pull type micro broaching tool** for making slots in **SWS of TWT**
30. Design and PIC simulation of periodic dielectric loaded millimeter-wave **gyro-twystron**
31. Design of 28GHz, 15 KW **gyrotron for industrial applications**
32. Design and development of multiple-beam cavity for Ku-band **multiple-beam klystron**
33. Design of the **radio-frequency section** of a 3.7 GHz klystron for **plasma heating applications**
34. Development of a 150MHz, pulsed, Ku-band **multiple beam klystron**

TOPICS ON WHICH LECTURES WERE DELIVERED IN THE VEDA 2022 CONFERENCE: DRDO-MTRDC, BANGALORE (19-21 JANUARY 2023)

IVEC 24th International Vacuum Electronics Conference

35. Design of C-band metamaterial for vacuum electron devices
36. Design of a bi-frequency metamaterial for high power microwave sources
37. Design of high-power microwave directional coupler for 28 GHz gyrotron application
38. Development of mode converter for high power microwave source through additive manufacturing
39. Review of HPM based counter UAS systems
40. Dispersion analysis of a wideband staggered double-vane slow-wave structure for V-band amplifier
41. Development of Planar Schottky Barrier Diode Technology for THz Applications
42. Development of slit-wire scanner based emittance scanner for ion beam emittance measurement
43. Development of an X-band MPM for airborne radar
44. Design and development of C-X-Ku-band MPM for ECM application
45. Design of a magnetic focusing structure for multiple-beam klystron for space transmitter

TOPICS ON WHICH LECTURES WERE DELIVERED IN THE VEDA 2022 CONFERENCE: DRDO-MTRDC, BANGALORE (19-21 JANUARY 2023)

IVEC
24th International Vacuum Electronics Conference

46. Design of electronic power conditioner for space imaging application
47. Design of an photonic crystal based X-band cavity for accelerator
48. Design and PIC simulation of klystron-like RBWO with dual extraction cavity
49. Experience of testing 1 MW, 352 MHz klystron RF system for 20 MeV DTL of LEHIPA
50. Feasibility of predistortors for frequency hopped Ku-band communication
51. Graphene-based field emitter for high performance X-ray tubes
52. GaN amplifier: a viable TWTA contender for next generation defence technologies
53. Investigation of MIG for a 95 GHz, second harmonic gyrotron
54. Large volume plasma device-upgrade: a versatile plasma system for electron emitter, beam and wave based diagnostics
55. Optimization of 16-slot anode block of magnetron using the backtracking search algorithm
56. Overview of STARC facilities for fabrication of vacuum microelectronic devices
57. Parametric retrieval of metamaterial supports of helix slow-wave structure

TOPICS ON WHICH LECTURES WERE DELIVERED IN THE VEDA 2022 CONFERENCE: DRDO-MTRDC, BANGALORE (19-21 JANUARY 2023)

58. Prediction of temperature distribution in integrated assembly of TWT
59. Progress of high power gyrotrons research at IITR: 2022 edition
60. Parametric studies of a quasi-optical launcher for a DEMO-class gyrotron
61. Planar transmission lines for millimeter waves—a journey for space applications
62. Reliability prediction of traveling-wave tube for space transmitter
63. Realization of dual-band MILO with axially partitioned interaction structure
64. Study and simulation of 3.5-Watt 1 THz BWO driven by 5mA sheet electron beam
65. Space-charge limiting current of an electron beam drifting through a metal envelope
66. Simulation studies of nonlinear transmission lines using varactor diodes for RF generation
67. Simulation of high frequency short pulse excitation of coaxial xenon excimer source for the generation of 172 nm radiation
68. Systematic performance study of a three-stage clustered buncher cavity gyro-klystron amplifier

TOPICS ON WHICH LECTURES WERE DELIVERED IN THE VEDA 2022 CONFERENCE: DRDO-MTRDC, BANGALORE (19-21 JANUARY 2023)

69. Successful commissioning of 1MW, 170 GHz gyrotron test facility at ITER-India
70. Study on waveguide cavity based microwave pulse compression system
71. Smart materials for thermal energy harvesting in multi-stage depressed collectors
72. Structure for Ku-Band 210W space-TWT
73. Studies on travelling-wave antenna for current drive applications
74. Study of characteristics of plasma antenna: an emerging technology
75. Swap optimized L-band power amplifier for airborne applications
76. Theoretical investigation on impact ionization of argon gas filled cavities
77. Thermal design and experimental evaluation of large sized dispenser cathode
78. Use of conformal cooling towards better thermal management of travelling wave tube
79. Virtual prototyping and particle-in-cell simulation of a rising sun magnetron
80. X-band backward wave oscillator operating with a Marx generator

ORGANIZATIONS OF THE SPEAKERS DELIVERING TALKS IN THE CONFERENCE

1. Academy of Scientific and Innovative Research (AcSIR), Ghaziabad
2. Accelerator and Pulse Power Division, Bhabha Atomic Research Centre, Mumbai
3. Andhra Electronics Limited, Kakinada
4. Bhabha Atomic Research Centre, Mumbai
5. Birla Institute of Technology and Science-Pilani, Hyderabad
6. Centre for High Energy System and Science, Hyderabad
7. Centre of Research in Microwave Tubes, Department of Electronics Engineering, Varanasi
8. CSIR-Central Electronics Engineering Research Institute, Pilani
9. Department of ECE, University of New Mexico, Mexico
10. Department of Physics, Banasthali Vidyapith, Banasthali

ORGANIZATIONS OF THE SPEAKERS DELIVERING TALKS IN THE CONFERENCE

11. DRDO Industry Academia Centre of Excellence, Indian Institute of Science, Bengaluru
12. DRDO-Microwave Tube Research and Development Organisation, Bengaluru
13. DRDO-Electronics and Radar and Development Establishment, Bengaluru
14. DRDO-Defence Electronics Applications Laboratory, Dehradun
15. Department of Electrical and Electronics Engineering BITS Pilani Hyderabad Campus
16. Gallium Arsenide Enabling Technology Centre (GAETEC), Hyderabad
17. Homi Bhabha National Institute, Anushaktinagar, Mumbai
18. Indian Institute of Science, Bengaluru
19. Indian Institute of Technology-BHU, Varanasi

ORGANIZATIONS OF THE SPEAKERS DELIVERING TALKS IN THE CONFERENCE

20. Indian Institute of Technology-Guwahati, Guwahati
21. Indian Institute of Information Technology, Design and Manufacturing, Kancheepuram
22. Institute for Plasma Research, Gandhinagar
23. Indian Institute of Technology-Roorkee, Roorkee
24. Lancaster University, Lancaster
25. National Institute of Technology Andhra Pradesh, Tadepalligudem
26. National Institute of Technology, Patna
27. National Institute of Technology, Silchar
28. RF Systems Division, RRCAT, Department of Atomic Energy, Indore
29. School of Automation Banasthali Vidyapith Banasthali

ORGANIZATIONS OF THE SPEAKERS DELIVERING TALKS IN THE CONFERENCE

30. School of Electronics Engineering, Vellore Institute of Technology, Chennai
31. School of Physics, Devi Ahilya University, Indore
32. Semiconductor Technology and Applied Research Centre, Bengaluru
33. Space Applications Centre, ISRO, Ahmedabad
34. Supreme Knowledge Foundation Group of Institutions, Mankundu
35. Vellore Institute of Technology, Chennai
36. VIT-AP University, Amaravati

BUSINESS ORGANIZATIONS/COMPANIES/SPONSORS PARTICIPATING IN THE CONFERENCE

1. ASTRA microwave products limited, Hyderabad (strategic electronics: radar electronics, space electronics, MMIC, radar systems)
2. ARS audio visual, Chennai, Pune, etc. (projection mapping, active LED screen, video walls for monitoring, conferencing solutions, interactive signage system, etc.)
3. CARBORUNDUM universal limited, Chennai (metallized ceramics)
4. DASSAULT systems, HQ: velilizy-Villacoublay, France (realistic simulation for product, nature and life)
5. ENTECH advanced technologies limited, Bengaluru (cooling units, dryers, shelter AC, for applications in TWT, antenna, cold plates, electron tubes, PCBs, etc.)
6. NAVANEETH Inc., Bengaluru (computer and IT products, CCTV and security products, etc.)
7. GROWCONTROLS, Hyderabad (power supply, frequency converter, induction heating system, electromagnetic forming machine, magnetron modulator, etc.)

BUSINESS ORGANIZATIONS/COMPANIES/SPONSORS PARTICIPATING IN THE CONFERENCE

8. **LOTUS microwave technologies private limited, Hyderabad and Bengaluru (antennas, amplifiers, transmit receive modules, exciters, up/down converters, RF over fibre kink, high power cable assemblies, radomes, etc.)**
9. **NEXGEN electric and cable company, Kolkata (high voltage power supply, RF window, thyratrons, ignitron, high voltage connector, probe and divider, etc.)**
10. **PILANI electron tubes and devices, Bengaluru, Sangrur, and Mohali (transmitting tubes, magnetron, VED parts, and brazing (metal-ceramic, metal-metal) in UHV/inert atmosphere), etc.)**
11. **SENESAN technology private limited, Coimbatore (antenna, duplexer, RF components, flow sensors, IOT based energy monitoring system, etc.)**
12. **VERSABYTE data systems private limited, Bengaluru (Converters: AC/DC, DC/AC, SMPS, EPCs and HVPS for TWT and MBK based radar and EW transmitters, MPM, reconditioning of TWTs, etc.)**

WHATSAPP GROUP: THINKERS IN VACUUM ELECTRONIC DEVICES

During the pandemic Covid this WhatsApp group was established with my initiative. Subhradeep Chakrabarty of CSIR-CEERI, Pilani and Debasish Mondal, Professor MV Karthikeyan's PhD student at IIT-Roorkee, helped me to start the group. There are 211 members of the group from all walks of the VED community constituted by the vice-chancellors, directors, professors and students from academia; the directors and scientists of national laboratories from the science, defence and space sectors; and the entrepreneurs and engineers from the industrial sector. The problems and challenges faced by the group members in the area of VEDs are shared in the group for solution. The group has organized 13 webinar events so far. The Proceedings of the webinar events prepared by us have been edited by Dr. Vishal Kesari.

WHATSAPP GROUP: THINKERS IN VACUUM ELECTRONIC DEVICES

First Webinar: Recent Trends and Challenges in Vacuum Electron Devices in Indian Scenario: 1 Aug 2020

Speaker: BN Basu (founder of the WhatsApp group): Proposal of the Objective of the WhatsApp group formed vis-à-vis the topic of the webinar

Experts from different organizations representing academia, national laboratories and industries commenting on the objective proposed: Dr. Lalit Kumar, Dr. Chandra Shekhar, Dr. P C Panchariya, Dr. S N Joshi, Dr. R R Patnaik, and Dr. K S Bhat

Second Webinar: Vacuum Electronic Devices: 5 Sep 2020

Speakers:

Dr. S Mourya: Past and Present Status of the Magnetron Development in the Country and the Efforts at CSIR-CEERI Leading to the Product Development for the Users;

Dr. Manpuran Mahto: Compact and Efficient High Power Microwave Source – Reltron;

Dr. Mumtaz Ansari: RF Pulse Shortening Studies of High Power Relativistic BWO Using MAGIC-PIC Simulation

Third Webinar: Vacuum Electronic Devices : 7 Nov 2020

Speakers:

Dr. SN Joshi: First TWT Built in India;

Dr. Richards Joe Stanislaus: Large-Signal Analysis of Helix-TWT; and

Dr. S. Yuvaraj: Recent Trends in Millimeter/THz Wave Vacuum Electron Beam Devices

Fourth Webinar: New Frontiers of Sub-THz Wireless Communications Enabled by Travelling Wave Tubes:

Speaker: Professor Claudio Paoloni

Fifth Webinar: Cathodes/HPM VEDs and Components: 13 Mar 2021

Speakers:

Dr. RS Raju: Some Aspects of the Development of Cathodes for Microwave Tubes;

Dr. Vikram Kumar: Sectoral Waveguide HPM Mode Converters;

Dr. Ajith Kumar MM: Application of Planar Helix Slow-Wave Structure in Backward-Wave Oscillator

WHATSAPP GROUP: THINKERS IN VACUUM ELECTRONIC DEVICES

24th International Vacuum Electronics Conference

Sixth Webinar: VEDs/Plasma Devices: 8 May 2021

Speakers:

Professor KP Maheshwari: High Power Microwaves at 50 Years Encompassing Relativistic Backward Wave Oscillator;

Dr. Varun: Analysis of Pseudo-spark Discharge Based Plasma Cathode Electron Source

Seventh Webinar: Challenges in Manufacturing VEDs and VED Components: 10 Jul 2021

Session 1: Inaugural Remarks: Dr. SN Joshi, Dr. SUM Reddy, Dr. LM Joshi, Dr. KS Bhat, Dr. RS Raju

Session 2: Challenges Faced By Manufacturers: Speakers: Shri Guriqbal Singh, Dr. Alok Gupta, Rahul Dinkar Patil, Dr. Santanu Mandal, and Dr. Tarun Sharda

Session 3: Panel Discussion: Speakers: Dr. SK Ghosh, Dr. T Tiwari, and Dr. S Maurya

Eighth Webinar: Gyrotrons and Gyro-Amplifiers: Natural Sources of High-Power, High-Order, Orbital-Angular-Momentum Millimeter-Wave Beams: 4 Sep 2021

Speaker: Professor Dr. Manfred Thumm

Ninth Webinar: Indigenous Development of Simulation Tools for Vacuum Electronic Devices: Challenges and Opportunities: 27 & 28 Nov 2021

Speakers:

Dr. SK Ghosh: Introduction;

Shri V Bhanu Naidu: Software used in the Design of Microwave Tubes;

Dr Udaybir Singh: Simulation of Magnetron Injection Gun;

Dr G Naveen Babu: Code LS2.5ADTD for Helix-TWT;

Dr A Mercy Latha: Simulation of Multi Stage Depressed Collector;

Swapnil Gaul: TaraNG Software at NUMEREGION

Tenth Webinar: Metamaterials and Their Applications Encompassing Assistance in Microwave Tubes: 15 Jan 2022

Speakers:

Professor Subal Kar: Metamaterial and Metasurfaces: An Emerging Field of Research in Microwave and Photonics;

Dr N Purushothaman: Scope of Metamaterials in Microwave Tubes

WHATSAPP GROUP: THINKERS IN VACUUM ELECTRONIC DEVICES

Eleventh Webinar: Gyrotron: Basics and Trends: 26 Mar 2022

Speaker: Professor Dr -Ing. John Jelonnek (Karlsruhe Institute of Technology)

Twelfth Webinar: Plasma Science & Technology/ Vacuum Electron Devices: 12 Jun 2022

Speakers: Dr Debjyoti Basu (University of Maryland, USA)/ Rupa Basu (Lancaster University)

Thirteenth Webinar: RF/Microwave to THz: Education for the Next Generation: 17 Oct 2022

Speakers: Professor RK Shevgaonkar, Professor V Subramanian, Professor Subal Kar, Professor Chandra Shekhar

Panellists: Dr Harshita Tolani, Dr Richards Joe Stanislaus, Dr Vishant Gahlaut, Dr Runa Kumari, Dr Aviraj Jadhav, Surya Teja, Akshaya

Science, Engineering and Technology—All in VEDs

"There is only one nature — the division into science and engineering is a human imposition, not a natural one. Indeed, the division is a human failure; it reflects our limited capacity to comprehend the whole." — ***Sir William Cecil Dampier***

Eventually, we realize: "Science is the rule of the game, engineering is playing the game and technology is the tits and bits to win the game."

We have science, engineering and technology—all in VEDs.

Epilogue

Concluding Remarks

A glimpse of the progress of R&D in VEDs in India vis-à-vis global trends has projected the strength of India in the area. It is hoped this document will strengthen the collaboration between the vacuum electron device researchers and developers in India and abroad. The area being of strategic importance, the self reliance in the area is very much called for.

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Thank You!