TRIPLE M — 'MOTIVATING MICROWAVE MAESTRO'

IN

TRIPLE S — 'SIDDHI SADHAN SWARUP'

A Tribute

by

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Moradabad-244 001

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Banaras Hindu University-221 005

I most humbly dedicate this presentation

to

Dr. GS Sidhu

Dear Dr. Basu, 17th April 2009

Thank you Dr. Basu for doing this honour to me. I wish I could attend the function but my handicap prevents me from doing so.

I would like to point out one omission in the text of your paper. Dr. Deb was the project leader of Magnetron project when this development work was being carried out at RPE in the Mid fifties.

Your paper gives an excellent overview of the field of Microwave Tubes in the country. It is very apt tribute to Dr. S.S.S Agarwala for the service he has done to this field.

Our Colleagues in the MWT Group will continue to benefit from tradition of discipline, dedicated work, honest and realistic approach which he has given to the group.

I am still benefiting from these in my present work.

Thanks and regards,

G. S. Sidhu

I worked at

- Defence Electronics Research Laboratory, Hyderabad
- Regional Institute of Technology, Jamshedpur
- Central Electronics Engineering Research Institute, Pilani
- Banaras Hindu University

I continued to receive the encouragement and support in terms of literature and research facilities from SSS even when I was no longer an employee of CEERI

- Distinguished Visiting Scientist Scheme of CSIR

- Adoption as the third partner in a programme under ALIS originally between CEERI and Lancaster University

- Honour of being offered the huge stock of IEEE journals from the personal library of SSS

"*Every so often, it still happens that someone tells me that there is an irreconcilable conflict between teaching and research, that dedicated teachers do not do research because it takes away time that they could be spending on their teaching, or that serious research physicists cannot afford to devote significant amounts of time and effort to teaching. As a generalization, this has always struck me as ludicrous.*"

— Robert H. Romer, Editor, American Journal of Physics, from "Teaching or research, research or teaching? - Thoughts about Edward M. Purcell," Am. J. Phys. vol. 65, 689 (1997)

(cited by Edl Schamiloglu in New Mexico University Website)

SSS and the tradition that he established supported academia in carrying out research in the area of microwave tubes

- Centre of Research in Microwave Tubes, Banaras Hindu University
- Burdwan University
- IIT-Roorkee
- Devi Ahilya Vishwavidyalaya, Indore

M. Tech students of Burdwan University who have carried out their M. Tech thesis work at CEERI, Pilani in the areas of direct relevance to the ongoing sponsored projects on microwave tubes (The list is not complete)

1. Debojoity Chaudhary (1996)
2. Mrinal (1997)
3. Arindam Chakraborty (1998)
4. Sivendra Maurya (1999)
5. Gautam Sarkar (1999)
6. Ayan Banerjee (2000
7. Hasibur Rahaman (2000)
8. Anirban Bera (2001)
9. Shiv Chadan (2001)
10. Raudra Gatak (2001)
11. Amitavo Roy Chaudhary (2002)
12. Promod Kumar (2002)
13. Shalabh Gunjan (2002)
14. Maifuz Ali (2002)
15. Sarbani Basu (2002)
16. Shiv Kumar (2003)
17. Shubhamaya Bose (2003)
18. Intekhab (2004)
19. Indrajit Banerjee (2004)
20. Asim Biswas (2004)
21. Anal Hembram (2004)
22. Aritra Bhaumik (2004)
23. Pranab (2004)
24. Raju Manna (2005)
25. MitraBarun Sarkar(2005)
26. Naru Gopal Nayek (2005)
27. Narendranath Mukherjee (2005)
28. Pampa Debnath (2005)
29. Deblina basudhar (2005)
30 Debashish Pal(2005)
31. Tanuja (2005)
32. Santanu Mandal (2006)
33. Partha sarathi Nandi (2006)
34. Anirban Karmakar (2006)
35. Tanima Giri (2006)
36. Maria Rosi
37. Jyotirmoy Koner (2007)
38. Rezoul Karim (2007)
39. Joydeep Banerjee (2007)
40. Dipankar Mondal (2007)
41. Anujit Adhikari (2007)

…. ……..

A journey from the magnetron to the gyrotron

Where do we stand in the historical timeline of the development of microwave tubes?

1921-1940

Smooth-wall magnetron — 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 — Hull and Williams (1926)

Beam diffraction oscillogram
(beam and helix-wave interaction) — Haeff (1933)

Cavity magnetron — Posthumas (1935), Randall and Boot (1939)

Linear beam microwave tube theory — Oskar and Heil (1935)

Magnetron: Institute of Radiophysics and Electronics, Calcutta University

Professors S. K. Sen, H. F. Steyskal, BN Das, NB Chakrabarty (late 1950's).

CU Annual Report : 1956-57 published in 1958

“RPE

C. Electron Tubes

“Work on electron tubes has been intensified since Spt 156, 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 upto 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

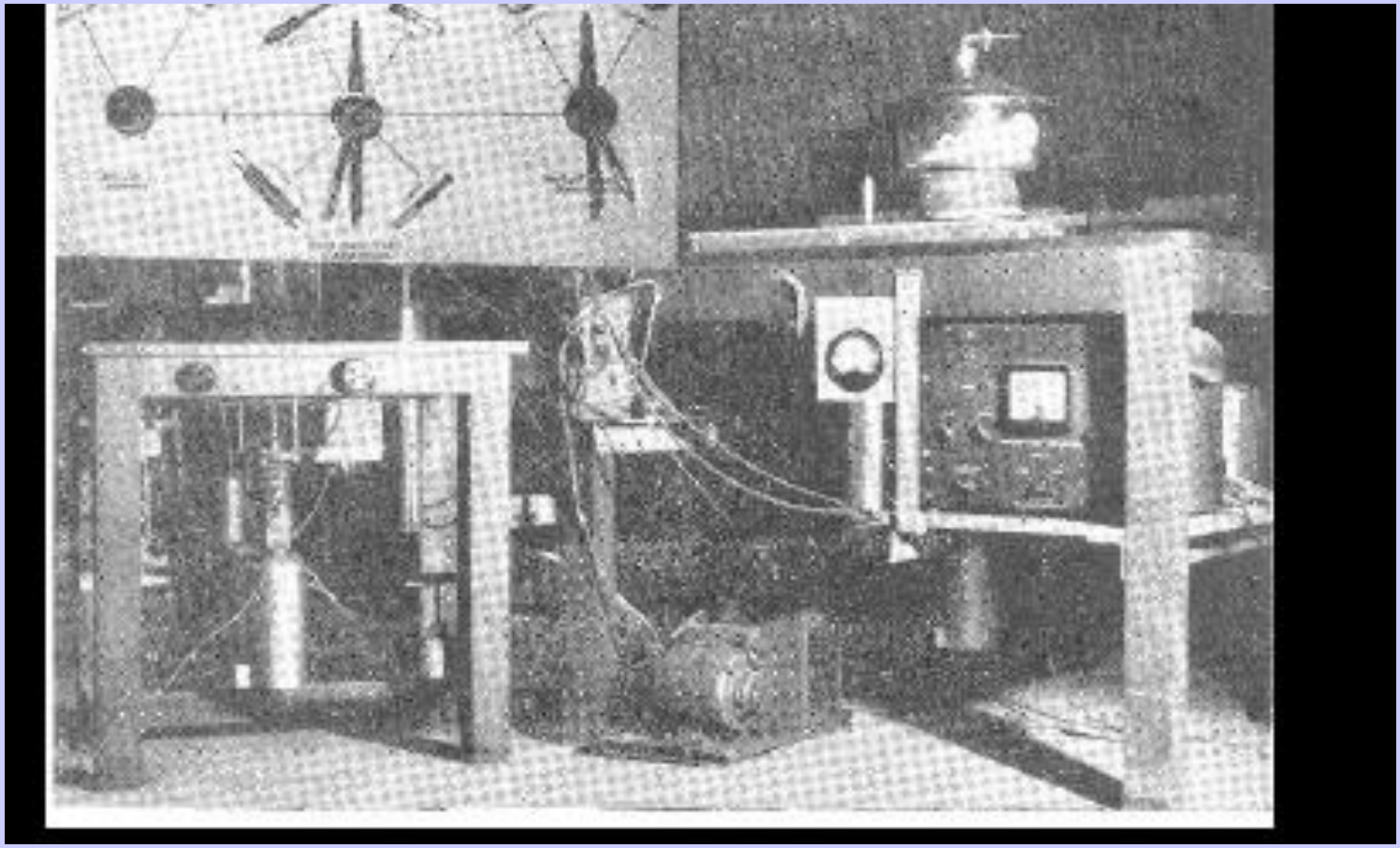
(e) Electron Tubes and Plasma Electronics

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

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

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

Professor N. B. Chakraborty directed me to join CEERI where I received tutelage from 'SSS' whom I describe as 'MMM' — Motivating Microwave Maestro!



Set up (1056) at Institute of Radiophysics and Electronics, Calcutta University

Magnetron activities at NPL and CEERI

Dr. Amarjit Singh

Dr. NC Vaidya

and others

Production: CEL, Sahibabad, BEL, Bangalore

Klystron — Metcalf and Hahn (1936)

Klystron — Russel and Siguard (Varian brothers) (1937)

Cavity magnetron — Randall and Boot (1939)

Travelling-wave tube (TWT) — N. E. Lindenblad (1940)
(PM series focusing, helix pitch tapering)
(U. S. Patent 2,300,052, filed on **May 4, 1940** issued on October 27, 1942)

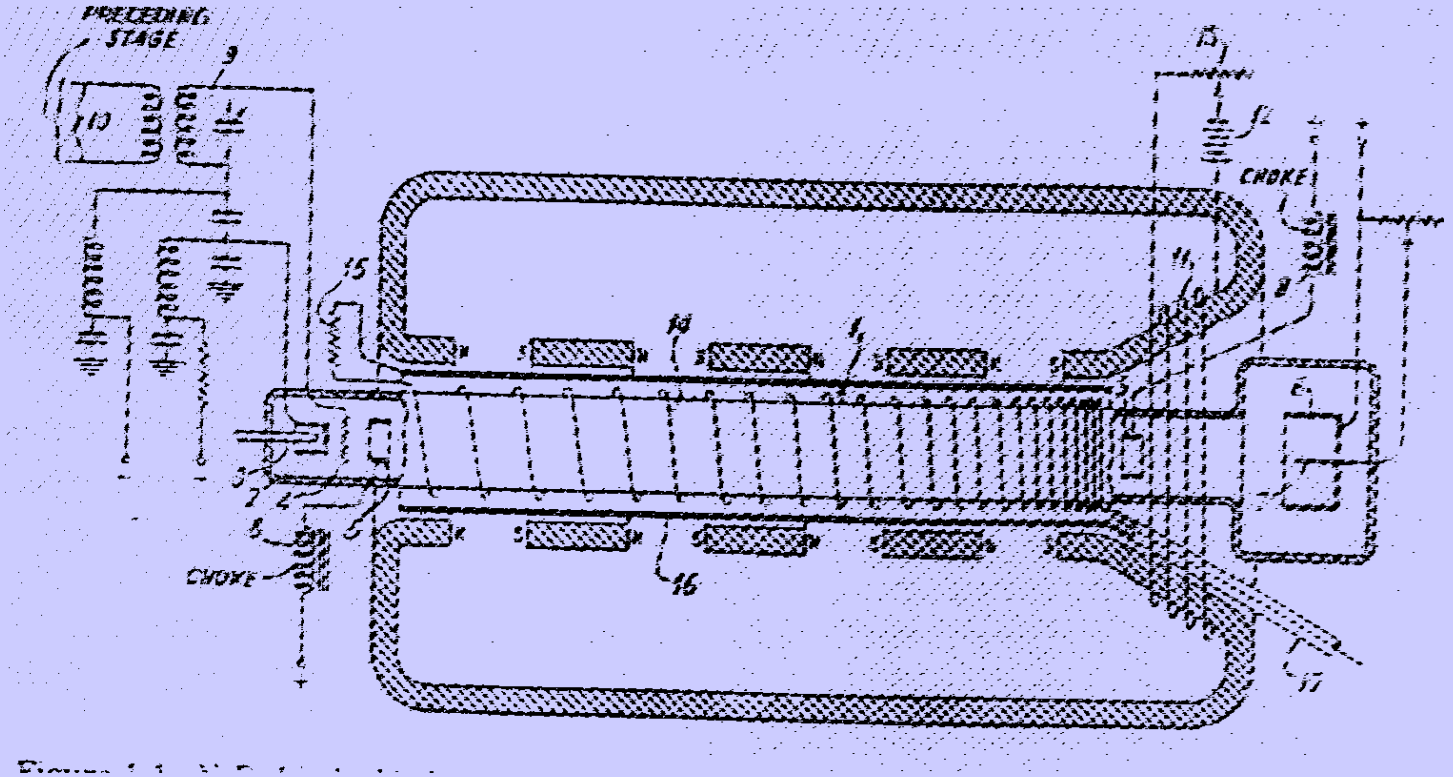
First ever TWT in India: 1977 at CEERI, Pilani (SSS Agarwala, SN Joshi)

1941-60

Travelling-wave tube — **Kompfner (1942)**
— Field (1946) (U. S. Patent 2,575,383)
— Pierce (1946) (U. S. Patent 2,602,148)

Maser — Gordon (1954)

ECM interaction theory — J. Schneider (1957)
— R. Twiss (1958)
— A. Gaponov (1959)



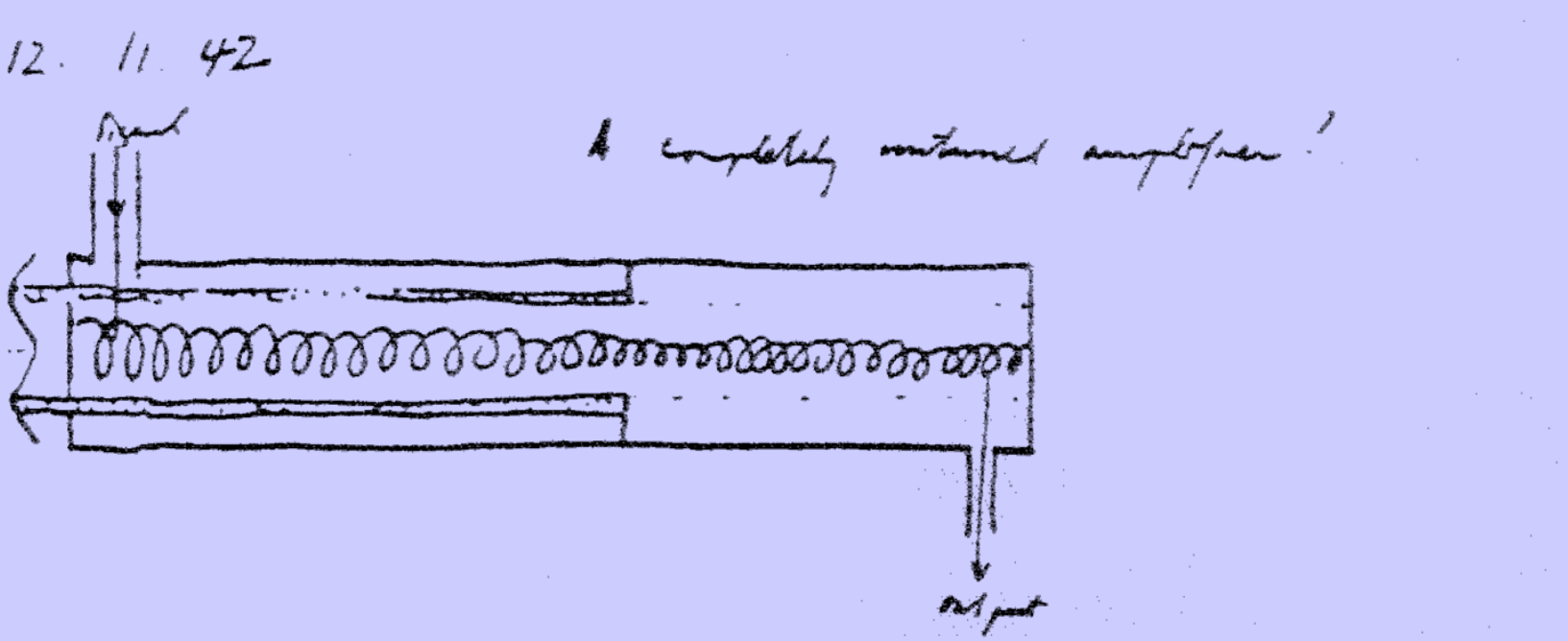
Lindenblad's travelling-wave tube amplification at 390 MHz over a 30 MHz band (U. S. Patent 2,300,052, filed on May 4, 1940 issued on October 27, 1942)

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



Sketch of the travelling-wave tube from Kompfner's note book

1961 onwards

Earliest version of gyrotrons in Russia (1965)

Proposals on JET and ITER (1980 onwards)

Modern gyrotron technology (1990 onwards):

IAP, Russia; FZK, Germany; JAERI, Japan; Toshiba, Japan; CPI, USA; TTE, France; CRPP, France, MURI, USA, and so on

Development of **magnetrons, klystrons and TWTs** at CEERI, Pilani (Dr. Amarjit Singh, Dr. O. P. Gandhi, Dr. S. S. S. Agarwala, Dr. R. P. Wadha, Dr. G. S. Sidhu, Mr. H. N. Bandopdadhya, Dr. S. N. Joshi, and others)

Establishment of a dedicated Centre at BHU (Professor N. C. Vaidya)

Participation of Burdwan University M. Tech students (Professor BN Biswas)

Establishment of MTRDC (DRDO) (Dr. Raj Narayan and Mr. K. U. Limaye, Dr. Lalit Kumar, and others)

Production of microwave tubes at BEL and the contribution of Mr. T. R. K. Janardan

Contribution of Professor K. P. Maheswari at Devi Ahilya Vishwavidyalaya, Indore in the area of relativistic tubes

Microwave tubes is a subject of applied electromagnetics — microwave engineering

Time-independent fields:

- Formation of an electron beam — electron guns
- Confinement of an electron beam — focusing structures

Time-dependent fields:

- Interaction structures
- Beam-wave interaction

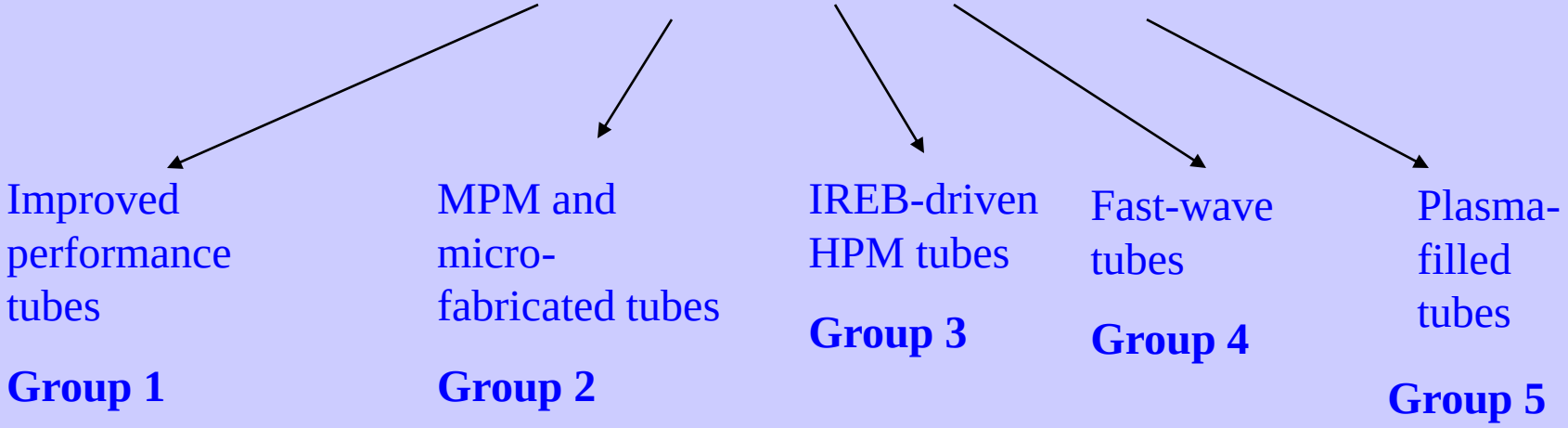
'SSS' encouraged us to develop the understanding of microwave tubes from first principles using electromagnetic analysis

Classification of microwave tubes

(based on the mechanism of electron beam bunching and conversion of beam energy into electromagnetic energy)

- O- and M-types (O standing for TPO — tubes à propagation des ondes, and M for TPOM — tubes à propagation des ondes à champs magnetique)
- Kinetic energy and potential energy conversion types
- Longitudinal space-charge-wave, transverse space-charge-wave, and cyclotron-mode interaction types
- Distributed and localised interaction types
- Slow-wave and fast-wave types
- Non-relativistic and relativistic bunching types
- Cerenkov, transition, and bremsstrahlung radiation types
- CRM instability and Weibel instability types

Trends in microwave tubes



Grouping of microwave tubes

Group 1	Improved performance conventional microwave tubes: TWT (ultra-wide bandwidths, high efficiency); Klystron (EIK — wider bandwidths, higher power, EIO — millimeter-wave, low-power, MBK (large beam current, low beam voltage, high power, compact); Magnetron (oven, millimeter wave radar, relativistic — high power, long pulse).
Group 2	MPM and microfabricated tubes: 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); Microfabricated tubes: Triode, Klystron, Klystrino, FW-TWT (folded waveguide TWT), etc.
Group 3	HPM Tube driven by IREB: 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, plasma-filled BWO/ PASOTRON, etc.
Group 4	Fast-wave tubes: Gyrotron (high-harmonic, low-magnetic field, 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.
Group 5	Plasma-filled tubes: Pasotron (BWO) (IREB-driven Group 3), Coupled-cavity TWT (Group 2), Gyrotron (Group 4) (Plasma filling for large beam transport, relaxation of magnetic field, larger structure cross section, etc.)

Recent microwave tube activities at CEERI include

Klystrons

TWTs

Plasma-Assisted Devices

Magnetrons

Gyrotrons

Electron guns

Cathodes

Interaction structures and RF couplers

Innovative interaction structures

Slow-wave structures for wideband TWTs: Dispersion-controlled helical structures

- Inhomogeneous loading — by shaping dielectric helix-supports
- Anisotropic loading — by using an angularly periodic metal envelope (vane/segment loading)

- Ring-and-bar structures for high power TWTs
- Structure losses (structure material and attenuator coating)
- Fast-wave structures
  - — Mode selective structures for gyrotrons: coaxial cavity, photonic band-gap cavity, etc.)
  - — Dielectric and disc loaded structures for wideband gyro-TWTs

Wideband multi-octave TWTs

Zero-to-slightly-negative-dispersion structure for wideband performance:

Negative dispersion ensures the constancy of Pirece's velocity synchronization parameter *b*

Anisotropically loaded helix:

Metal vane/ segment loaded envelope

Inhomogeneously loaded helix:

Helix with tapered geometry dielectric supports such as half-moon-shaped and T-shaped supports

Multi-dispersion, multi-section helix for wideband performance:

The value of *N* in the gain parameter *CN* depends on both the frequency and the interaction helix length.

One positive-dispersion helix section of length l_1 is synchronous only at lower frequencies and the other no-dispersion helix section of length l_2 is synchronous both at lower and higher frequencies.

Causes an increase in effective length to $l_1 + l_2$ at lower frequencies and a decrease in effective length to l_2 at higher frequencies

Reduction of length at higher frequencies prevents oscillation at higher frequencies

Dr. SSS Agarwala's doctoral work at the University of London in 1958

SSS carried out research in the area of slow-wave structures (non-reciprocal structures) at the University of London

From the letter sent by Dr. Amarjit Singh to Dr. SN Joshi on 14th April 2009

…….“I had known him from the mid nineteen fifties, when we were colleagues in NPL. Sent from there, as a Visiting Scientist to UK, he had worked on Traveling Tubes, with non reciprocal attenuation, provided in the middle region of the helix, by use of ferrites. As such he was uniquely qualified to lead the R and D on TWT’s at CEERI. He did this with great distinction, so that CEERI continues to be a pioneer in this field in India, to this day. As Area Leader for Vacuum Devices at CEERI, he provided judicious guidance to colleagues working on various projects in the Area. The achievements of the Vacuum Tubes group over the years, are in no small measure due to his professional competence, clear vision, and personal qualities as a leader.”

……. “His meticulous approach towards everything that his touched, was truly remarkable.”

‘SSS’ motivated us to work in the area of helical slow-wave structure

Two Internal Reports at CEERI on electromagnetic analysis of helical slow-wave structures were brought out in quick succession in 1978 under the guidance of Dr. SSS Agarwala

One based on

- **field analysis** and the other on
- **equivalent circuit analysis**, both yielding the same dispersion relation

Issues involved: sheath-helix boundary conditions, number of boundary conditions to be handled at a time, interaction impedance, characteristic impedances, and dispersion relation

The manuscripts of the reports were thoroughly edited by ‘SSS’

Incidentally, who were the ‘authors’ of these reports?

One of the reports were handwritten by Dr. SN Joshi, subsequently later, typewritten by Professor PK Jain.

Extension of the theory that was developed at CEERI under the guidance of ‘SSS’

- Inhomogeneous and anisotropic helix-loading (AK Sinha, SK Ghosh)
- Asymmetry of dielectric helix supports (AK Sinha, SK Datta)
- Helix finite resistivity and attenuator coating (PK Jain, SK Datta)
- Unconventional dielectric helix supports (SK Ghosh)
- Tape-helix model (AK Sinha, SK Ghosh)

….. to mention a few

Sharing my experience with the following, which 'SSS' stood for:

- Extension of all technical support to genuine researchers
- No compromise on discipline
- Recognition of work

An anecdote:

Measurement of AM-to-PM conversion coefficient of the first ever TWT built in the country required by ISRO in connection with the funding of a project to CEERI

Today, we are honouring the entire microwave tube community by honouring

‘SSS’ synonymous with

‘MMM’ —‘Motivating Microwave Maestro’

who, however, always distanced himself from such honours!

I am grateful to CEERI and VEDA Society to give me this opportunity to pay my tribute to Dr. SSS Agarwala!

Thank you!