SUNRAY-1D and SUNRAY-2.5D Codes for Large-Signal Analysis of a Space TWT

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Abstract: *One-dimensional (SUNRAY-1D), and two and half dimensional (SUNRAY-2.5D) codes are developed for accurate, fast and reliable multi-signal large signal analysis of a complete helix-type space TWT. Detailed beam and rf field parameters including inter-modulation components and higher-order time harmonics are simulated accurately for a high efficiency space TWT. The spent electron beam data of SUNRAY-2.5D code is used successfully for design of beam refocusing section and multi-stage depressed collectors for various space TWTs. Space TWTs of different frequencies (C-band, Ku-band, Ka-band and W-band), and of different power levels have been designed successfully.*

Keywords: Space TWT, Large-signal model, Multi-signal analysis, I/M components, Satellite communication.

Introduction

Space TWTs are continuously being upgraded for satellite communication of higher and higher efficiency with high linearity, reliability, reduced weight and size. This requires improved design, upgraded technology, and new materials. Large-signal analysis of beam-wave interaction is essential for optimizing design of a space TWT operating under multiple input signals as well as varying output powers. Multi-signal effects for higher order harmonics and inter-modulation components are analyzed by suitably defining the rf circuit fields in terms of a base frequency. Base frequency is defined as the greatest common factor of all signals frequencies to be analyzed. All the signals are then considered as higher-order time harmonics of the base frequency. In the large-signal analysis, one rf wavelength of the electron beam (in terms of the base frequency) is represented by a certain number of charged particles (electrons) and these electrons are tracked in small distance steps of forward integration along the tube by numerically solving the relativistic Lorentz force equations under the influence of the rf circuit field, the space charge field and the magnetic focusing field. Mutual beam-wave coupling parameters, namely the rf current induced on the beam by the rf circuit field and the rf voltage induced onto the circuit by the modulated beam, are calculated at each step of forward integration along the tube. Electron beam is represented in disc form, in ring form, and in sectorial form, respectively in 1-D, 2-D, 3-D analysis, as shown in Fig.1.

SUNRAY-Codes

SUNRAY-1D and SUNRAY-2.5D codes are developed for accurate, fast and reliable multi-signal large signal analysis of a complete space TWT. For 2.5-D analysis, rings are considered with varying azimuthal velocity. Both the models are optimized for detailed analysis of beam-wave interaction for all the input signals with improved speed, accuracy and self consistency. Simulated results for a high efficiency space TWT for a MPM are shown in Figs.2-5. Fig.2 shows power transfer curves for 2 simultaneously fed input signals with their 3rd-order I/M components. Fig.3 shows transfer characteristic curves for the input signals with their 5th-order I/M components. Fig.4 shows results for Carrier to 3rd I/M level (C/3IM) versus number of representative electrons. Fig.5 shows results for (C/3IM) and efficiency versus drive power for both the input signals. Fig.6 shows electrons (discs) velocities along the tube length simulated using SUNRAY-1D code for a space TWT operating at saturated drive power. Fig.7 shows electrons (rings) radial positions along the tube length simulated using SUNRAY-2.5D code for a space TWT operating at saturated drive power. Both SUNRAY-1D and 2.5D codes are used successfully for design of space TWTs of different frequencies (C-band, Ku-band, Ka-band and W-band), and power levels. Fig.8 shows schematic diagram of a space TWT designed using SUNRAY codes. Table-I shows minimum number of discs that are required for accurate simulation of I/M components with approximate simulation time on a standard PC. Minimum 24 discs and 16 integration steps in the highest frequency are generally required for self-consistent results. The simulation time is less than a minute for a single-signal analysis. Since more than 240,000 discs are required for multi-signal analysis of a Ku-band TWT with separation of 1MHz in input signals, the computing time is 100's of hours on a standard PC. Table II and Table III show comparison of simulated results with the experimental results for 3rd and 5th I/M products for a high efficiency TWT. SUNRAY-2.5D code is used successfully for design of low-weight PPM-focusing for electron beam flow without any beam interception. Spent beam data of SUNRAY-2.5D code is used successfully for design of beam refocusing section and high efficiency multi-stage depressed collectors for various space TWTs.

Both the codes are also used for the beam-wave interaction analysis of other TWTs like multi-octave broadband TWTs, folded waveguide TWTs, sheet beam and multi-beam TWTs, and coupled-cavity TWTs with fairly good accuracy. Parallel process algorithm is being developed for faster computation of multi-signal analysis of simultaneously fed input signals with frequency separation less than 10MHz.

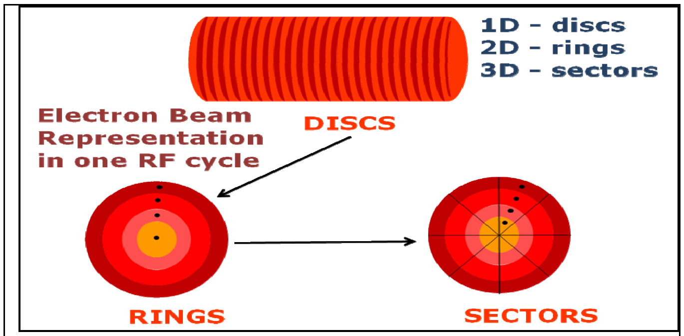

Fig.1: Electron beam representation in large signal analysis

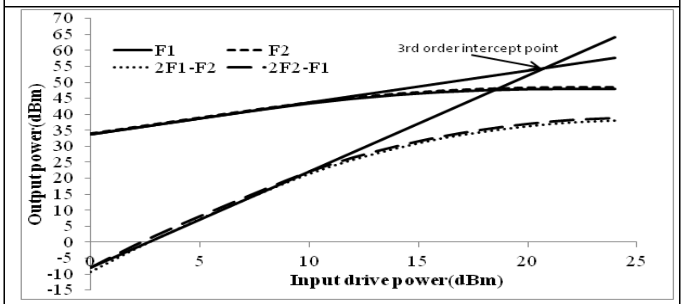

Fig.2: Two input signals with 3rd I/M components

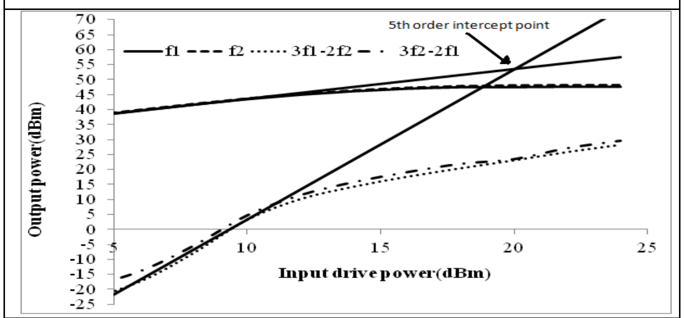

Fig.3: Two input signals with 5th I/M components

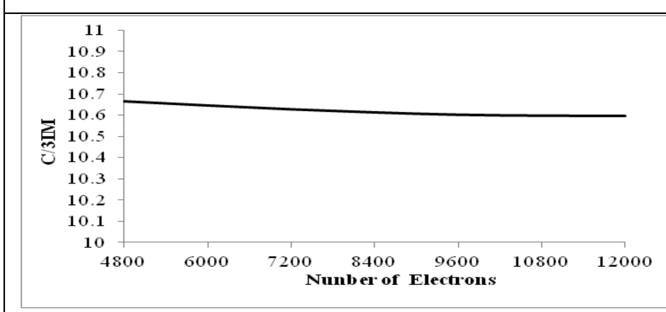

Fig.4: C/3IM versus number of electrons

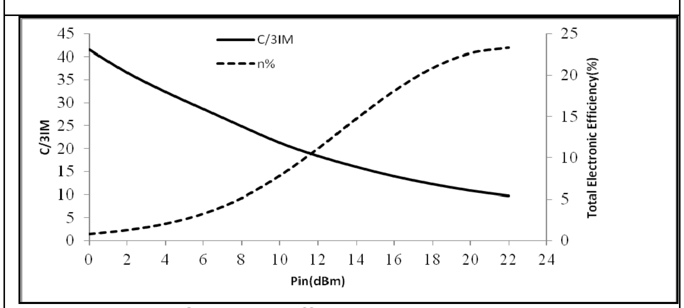

Fig.5: C/3IM and efficiency versus drive power

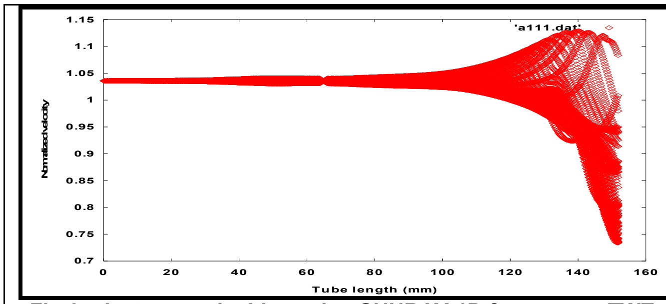

Fig.6: electrons velocities using SUNRAY-1D for a space TWT operating at saturated drive power

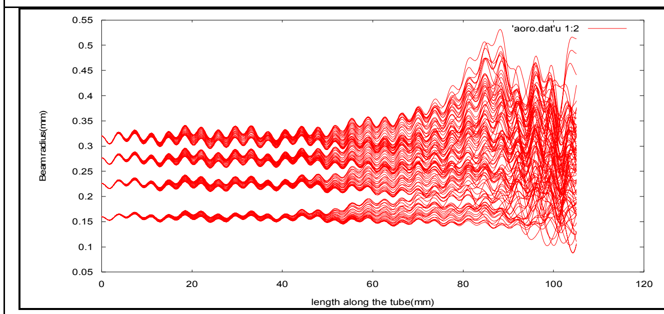

Fig.7: Radial positions of 96 rings along a high efficiency TWT operating at saturated drive power

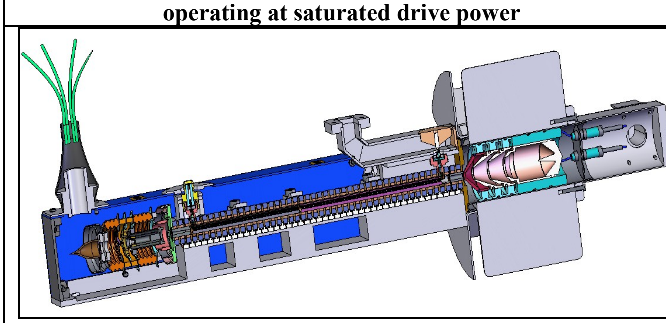
Fig.8: Systematic diagram of a high efficiency space TWT

Table-I: No of electrons & CPU time for I/M simulation (F1, F2 for signals #1, #2; F0-base frequency)

F1(GHz)	F2(GHz)	F0 (GHz)	Electrons	Time (hours)
11.100	11.101	0.001	240000	100
11.10	11.11	0.01	24000	1.0
11.10	11.20	0.1	2400	0.1

Table-II: 3rd order I/M components at saturation

Freq. (GHz)	Simulated (dBc)	Expt. (dBc)
F1	-12.8	-11.7
F2	-12.9	-12.1

Table-III: 5th order I/M components at saturation

Freq. (GHz)	Simulated (dBc)	Expt. (dBc)
F1	-26.4	-25.7
F2	-27.1	-26.1

Acknowledgements

Thanks are due to Dr Chandrashekhar, Director, CSIR-CEERI; all MWT division colleagues; Director and scientists from MTRDC, Bangalore; CMMACS, Bangalore; and BEL, Bangalore for their full supports.