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Using Large Signal Code TESLA for Wide Band Klystron Simulations

Alexander N. Vlasov, Igor A. Chernyavskiy
Science Applications International Corporation
11710 SAIC Drive, McLean, VA, USA, 22102 (alexander.n.vlasov@saic.com)

Thomas M. Antonsen Jr.
Institute for Research in Electronics and Applied Physics
University of Maryland
College Park, MD, USA, 20742

Dean E. Pershing
Mission Research Corporation
Newington, VA, USA, 20375

Khanh T. Nguyen
Beam Wave Research, Inc.
Silver Spring, MD, USA, 20901

Simon J. Cooke and Baruch Levush
Naval Research Laboratory
Washington DC, USA, 20375

Abstract: *Large signal klystron simulation code TESLA has been developed to be suitable for simulations of wide band klystrons with two-gap two-mode resonators. The results of TESLA simulations for NRL S-bans MBK with extended bandwidth have been compared with predictions of electromagnetic code HFSS and PIC code MAGIC.*

Keywords: klystrons, large signal simulations, multi-gap multi-mode resonators.

Introduction

TESLA (Telegraphist's Equations Solution for Linear beam Amplifiers) is a hybrid code designed to simulate linear beam vacuum electronic devices with cavities, such as klystrons, extended interaction klystrons, twystrons, and coupled cavity amplifiers. The model includes a self-consistent, nonlinear solution of the three-dimensional electron equations of motion and the solution of time-dependent field equations. The model differs from the conventional Particle in Cell approach in that the field spectrum is assumed to consist of a carrier frequency and its harmonics with slowly varying envelopes. Also, fields in the external cavities are modeled with circuit like equations and couple to fields in the beam region through boundary conditions on the beam tunnel wall. The model in TESLA is an extension of the model used in gyrotron code MAGY [1] developed at University of Maryland and Naval Research Laboratory (NRL). TESLA has been verified by comparisons with the PIC code MAGIC [2] and validated by comparison with measured performance of high power klystron [3].

Wide band klystrons very often employ resonators with several gaps for wide band operation. The multi gap resonators have several eigenmodes with closely spaced resonance frequencies. Each mode can interact effectively with an electron beam at each frequency inside operating bandwidth.

TESLA Model Extension

The TESLA model for electromagnetic fields is based on decomposition of simulation region into an external cavity region and a beam tunnel region. The regions are coupled through coupling gaps where the field continuation boundary conditions are applied. Eigenmodes of external cavity are found as a solution of homogeneous Maxwell's equations with the perfect conducting boundary conditions on metal surfaces and the perfect magnetic boundary conditions on the coupling gap at $r=r_w$ where r_w is radius of the beam tunnel. As a result, the TESLA resonator eigenmodes are different from the real eigenmodes of a resonator.

$$\frac{dV_s}{dt} = -i\omega_s I_s + i\omega V_s - \omega_s \int_{z_{\min}}^{z_{\max}} \sum_k K_{s,k}^{res} I_k dz -$$

$$\omega_s \frac{4\pi}{c} \int_{z_{\min}}^{z_{\max}} dz \int_{S_\perp} \mathbf{j}_\omega \cdot \mathbf{e}_s^{*\,\mathrm{gap}} dS + \omega_s \sum_{s'} C_{s,s'}^{self} V_{s'},$$

$$\frac{dI_s}{dt} = -i\omega_s V_s + i\omega I_s - \omega_s S^{hole} - \omega_s \sum_{s'} L_{s,s'} I_{s'}$$

TESLA resonator equations include eigenfrequencies ω_s and matrix of losses $L_{s,s'}$ which should be determined. Tuning procedure has been developed to choose parameters of TESLA eigenmodes to be consistent with the real eigenmodes in resonant frequency, quality factor and *R/Q*. After the tuning procedure TESLA simulates accurately actual eigenmodes of the structure as a solution of the coupled field equations.

Basic TESLA model allows to model extended interaction klystrons under assumption that modes are orthogonal inside beam tunnel when $C_{s,s'}^{self}$ is diagonal matrix. This assumption is good for eigenmodes which are symmetrical with respect to center plane of the resonator.

However, resonators' eigenmodes might become non-orthogonal inside beam tunnel due to substantial non-symmetric loading by input/output waveguides, by lossy elements, and also due to different design of individual gap.

TESLA model has been extended to allow modeling of klystrons with non-symmetrically loaded multi gap resonators. Tuning algorithm in TESLA has been modified to provide additional adjustment for non-orthogonal TESLA modes properties.

TESLA Simulations of S-band NRL MBK

New algorithm has been implemented into TESLA code and verified by comparison with HFSS calculations for electromagnetic fields and MAGIC calculations for electron beam bunching in NRL S-Band MBK [5,6]. To extend bandwidth of MBK the input and idler cavities built as two partial resonators coupled through large slots with two gaps for interaction with an electron beam. Two modes (odd π and even 2π) with closely spaced resonant frequencies exist in two-gap resonators.

Input and idler resonators of the NRL MBK have been selected for TESLA verification because these resonators have an non-symmetric elements: non-symmetric waveguide connection in input resonator and lossy cylinder located inside second partial resonator of idler resonator. As a result, the resonator modes become non-orthogonal inside the beam tunnel.

An example of modified TESLA calculations for the idler resonator of NRL S-Band MBK [6] is presented in Fig.1 where shown how two non-orthogonal modes are excited. There are extra local maximums for both modes due to fact that modes are non-orthogonal.

The results of TESLA calculations of resonant frequencies and quality factors for two modes of the idler two-gap resonator are summarized in Table 1. Extended TESLA code can predict very well resonant frequencies, quality factor and R/Q for two-gap two-mode resonators.

Table 1. Resonant frequencies and quality factors for π 2π modes of idler two-gap resonator

	HFSS	TESLA
$F_{res,1}$ [GHz]	3.348	3.348
$F_{res,2}$ [GHz]	3.596	3.596
Q_1/Q_2	61.0/73.0	61.0/72.0

Further TESLA simulations for the two-gap two mode input resonator also shown good agreement with HFSS in frequency dependence of gap voltages and with MAGIC in frequency dependence of a bunching factor.

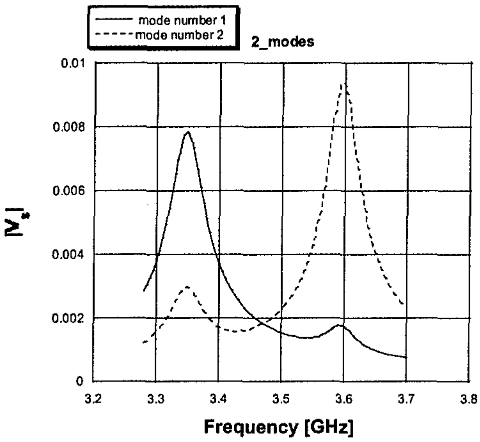

Figure 1. TESLA calculations for two modes (π and 2π types) in two-gap resonator

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