Fully Three-Dimensional Helical RF Field Effects on TWT Interaction

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Introduction

The phenomenal growth of the satellite communications industry has created a large demand for traveling wave-tubes (TWTs) operating with unprecedented specifications requiring design and production of many novel devices in record time. To achieve this, the TWT industry heavily relies upon computational modeling. However, there is a need for improvement in the TWT industry's computational modeling capabilities as there are often discrepancies between measured TWT data and that predicted by conventional two-dimensional helical TWT interaction codes. This severely limits the analysis and design of novel devices or TWTs with parameters differing from what is conventionally manufactured. In addition, the inaccuracy of current computational tools limits achievable TWT performance because optimized designs require highly accurate models. In particular, collector efficiency, which significantly affects overall TWT efficiency, is difficult to optimize unless extremely accurate spent beam data is predicted by the interaction code.

A fully three-dimensional (3D), time-dependent, helical TWT interaction model has been developed using the electromagnetic particle-in-cell (PIC) code MAFIA (Solution of MAxwell's equations by the Finite-Integration-Algorithm) [1, 2]. The model includes a short section of helical slow-wave circuit with excitation fed by RF input/output couplers, and electron beam contained by periodic permanent magnet (PPM) focusing. A cutaway view of several turns of the 3D helical slow-wave circuit with input/output couplers is shown in Figure 1. All components of the model are simulated in three dimensions allowing the effects of the fully 3D helical fields on RF circuit/beam interaction to be investigated. The development of the MAFIA interaction model will be presented. Additionally, predicted TWT performance using 2.5D (radial (r) and longitudinal (z) RF field components, and r and z beam motion with azimuthally symmetric angular velocity) and 3D models will be compared to investigate the effect of conventional approximations used in TWT analyses.

The growth of the communications industry has also imposed a demand for increased data rates for transmission of large volumes of data. This requires minimum distortion of the modulated signal as it is passed through the TWT. To successfully minimize intersymbol interference, it is critical to correlate the quality of the transmitted data with TWT parameters. Unfortunately, limited experimental testing is available to perform this correlation, and until now a computational model did not exist. The time-domain helical TWT interaction model reported on here, however, provides the capability to establish this computational test bench where signal integrity or bit error rate can be measured as a function of TWT operating parameters and component geometries, such as coupler configurations. Intermodulation products, harmonic generation and backward waves can also be monitored with the model for similar correlations.

The advancements in computational accuracy and capabilities, and corresponding potential improvements in TWT linearity and efficiency may prove to be the enabling technologies for realizing unprecedented data rates for near real time transmission of increasingly larger volumes of data demanded by planned commercial and government satellite communications applications.

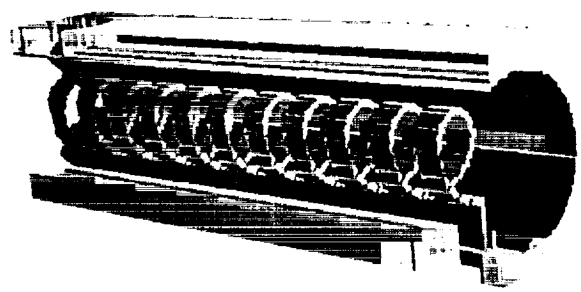

Figure 1 Cutaway of several turns of the helical slow-wave circuit with input/output couplers

Simulation Results

An accurate 3D helical cold-test model [3] (no electron beam present) was used to investigate standard approximations currently used in 2.5D helical TWT interaction codes [4]. These conventionally used approximations were found to be in significant error, and it was shown in [4] that the error increases with increasing beam diameter. Accordingly, if the approximations in question have a significant effect on TWT interaction, we would expect them to appear as a discrepancy between 2.5D and 3D codes, increasing with increasing beam diameter and increasing RF input drive power (where the relative RF field strength is also increasing).

The effects of approximations made in typical 2.5D helical interaction codes on RF circuit/beam interactions were investigated by comparing 3D MAFIA simulations to the conventional 2.5D interaction code TWA3 [5]. The TWT used as a model is a 40 Watt, 18-40 GHz TWT for the millimeter-wave power module (MMPM) designated the Hughes 8916H. Equivalent helical length, phase velocity, interaction impedance, attenuation (assumed to be zero), focusing conditions and RF drive were used in the 2.5D TWA3 and 3D MAFIA models. An 81 mA, 7600 V beam and a 29 GHz excitation signal were used for all simulations.

Results from these simulations showed an increasing difference between 2.5D and 3D codes with increasing beam diameter as shown in Figure 2 where simulated gains are compared as a function of beam diameter for a 20 helical turn model (b and a are the beam and average helix radii, respectively). Results also showed an increasing difference between codes with increasing RF input power as shown in Figure 3 where simulated gains for a 40 helical turn model are compared. These results imply that the conventional approximations made in helical interaction codes are responsible for the discrepancies. Additionally, the 2.5D TWA3 simulations consistently predicted gains lower than those predicted by the 3D model, and since there is also a general tendency for 2.5D codes to underestimate saturated gain compared to experiment [6], this further supports the presumption that the fully 3D model is more accurate than conventional models. The CPU time for each 40 helical turn simulation was about 36 hours on a Sun Ultra 60 workstation.

Additional comparisons will be presented including percent transmission, percent ripple, beam profiles, efficiency and gain as a function of beam radius and input power.

For the purpose of this work, a 3D model without any simplifications was necessary; however, the computational intensity limited the modeled length of the slow-wave circuit. In the future, the model will be simplified, allowing the length of the structure to be increased to experimental TWT length so that simulations can be compared to measured data.

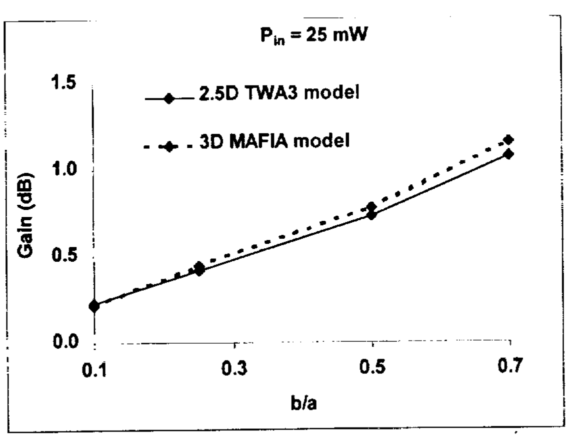

Figure 2 Gain as a function of beam radius for TWA3 and MAFIA 20 helical turn models with P_{in} = 25 mW

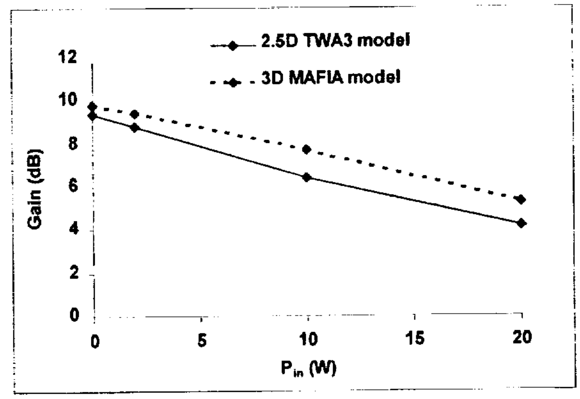

Figure 3 Gain as a function of input drive power for TWA3 and MAFIA 40 helical turn models with b/a = 0.5

References

1] T. Weiland, On the numerical solution of Maxwell's equations and applications in the field of accelerator physics, *Part. Accel.*, Vol. 15, pp. 245-292, 1984.

2] T. Weiland, On the unique numerical solution of Maxwellian eigenvalue problems in three dimensions, *Part. Accel.*, Vol. 17, pp. 227-242, 1985.

3] C. L. Kory and J. A. Dayton, Jr., Accurate cold-test model of helical TWT slow-wave circuits, *IEEE Trans. on Electron Devices*, Vol. 45, No. 4, pp. 966-971, April 1998.

4] C. L. Kory and J. A. Dayton, Jr., Computational investigation of experimental interaction impedance obtained by perturbation for helical traveling-wave tube structures, *IEEE Trans. on Electron Devices*, Vol. 45, No. 9, pp. 2063-2071, September 1998.

5] D. M. MacGregor, Two-dimensional nonlinear multisignal helix traveling-wave tube amplifier computer program, Volume 1: User Manual, Electrocon International, Inc., Ann Arbor, Michigan, April 1993.

6] Personal communication with Jeff Wilson of NASA Glenn Research Center, February 2000.