

Validation Study for the Large-signal Code TESLA-CC Based on Experimental Ka-Band Coupled-Cavity TWT

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Abstract: *The 2.5D large-signal code TESLA-CC is a modification of the well-established klystron code TESLA to make it suitable for the 2D modeling of Coupled-Cavity Traveling-Wave Tubes (CCTWTs) by adopting the Curnow-circuit model for representation of the fields of an external coupled-cavity structure. We report the results of TESLA-CC modeling for an experimental Ka-band broadband CCTWT, called here as NRL-1. Performed in this work comprehensive numerical simulations and their wide comparisons with the measurements can be considered as a validation study for the code TESLA-CC.*

Keywords: coupled-cavity traveling-wave tube; broadband amplifier; large-signal code; 2D modeling.

Introduction

In a few recent years a series of Ka-band coupled-cavity TWTs have been successfully developed, built and tested at CPI [1] in collaboration with the NRL and SAIC. This activity gave impulse to the new code development in NRL [2, 3] to provide computational tools capable on a more efficient and more accurate modeling of the CCTWTs, including the wide improvement and optimization in their output parameters and overall efficiency.

The generally used in these devices non-uniform PPM focusing magnetic field makes it largely important to take into account effects of the 2D dynamics of the beam, what requires fully 2D simulations for more accurate modeling of such CCTWTs. To address this issue we have performed wide modeling of experimental CCTWTs by using the recently developed 2.5D code TESLA-CC [3]. For the purposes of the code's TESLA-CC validation, a very detailed study was completed for the so called NRL-1 tube [1]. Here we present the results of TESLA-CC modeling of NRL-1 CCTWT and their wide comparison with the measurements.

Study of electromagnetic properties of CCTWT

To check and potentially to increase an accuracy of the used in the TESLA-CC modeling Curnow circuit parameters, we first completed the detailed study of electromagnetic (EM) properties of the experimental coupled-cavity structure by using EM code Analyst (STAAR/AWR). As a result of this study it was found that

the predicted by EM code frequency dependent Kino-impedance Z_{kino} is different from the theoretical one, computed by help the well-known Curnow formula. To match the predicted by Analyst impedance Z_{kino} , it was imported into and used by the code TESLA-CC for corresponding corrections in the initially computed Curnow circuit parameters L's and C's at every frequency across the working band. Additional correction factor was introduced in the gap-field computations by TESLA-CC to ensure its full matching with the axial profile of the Ez-field predicted by the EM code inside the beam tunnel.

Results of TESLA-CC simulations

Using corrected values for the Curnow circuit parameters we then have performed TESLA-CC modeling of NRL-1 tube in a wide frequency range and for the different regimes of its operation. Additional care was taken to choose the proper injection conditions for an electron beam for its balanced transport in the PPM focusing magnetic field.

To overcome limited accuracy of the experimental measurements and an existed level of uncertainty in some parameters of the experimental device, we have performed sensitivity study to find out the impact of possible variations in the main set of its physical parameters, including the values of the beam-voltage, residual magnetic flux on a cathode, injection radius of the beam, amplitude of the PPM focusing field, properties of the sever sections of the tube and more.

As one can expect, the value of the beam-voltage has a biggest impact on a slope of the predicted in simulations frequency band. Indeed, it was found that good agreement with measurements can be achieved by using in simulations beam-voltage, which is on 250 V lower than its "nominal" value $V_b=16.48$ kV (what is in a good agreement with the suggested initial drop on 250 V in the beam-voltage for this device, discussed in more details in the Ref. 2). The results presented on Fig.1 show that once adjusted, the same value for the beam-voltage $V_b=16.23$ kV used in TESLA-CC simulations allows to reach good agreement between the predicted and measured frequency band in both, small-signal and large-signal regimes of the device's operation. As expected, 2D code can provide better agreement with the experiment, than the 1D code does [2, 3].

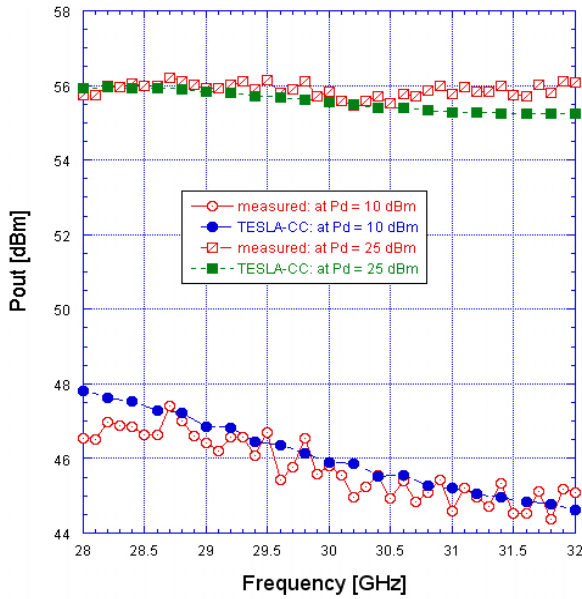


Figure 1: Comparison between the measured and computed by TESLA-CC small-signal (lower curves) and large-signal (upper) bandwidth of the NRL-1 CCTWT.

Another important result of the current study is the finding in simulations much bigger, than expected, role of the additional drift tube presented inside the sever section of the experimental CCTWT. According to the TESLA-CC simulations, taking into account such drift becomes especially important near the tube's saturation: its introduction leads to an additional de-bunching of the beam (Fig.2) and can highly impact an overall performance and operation of the device.

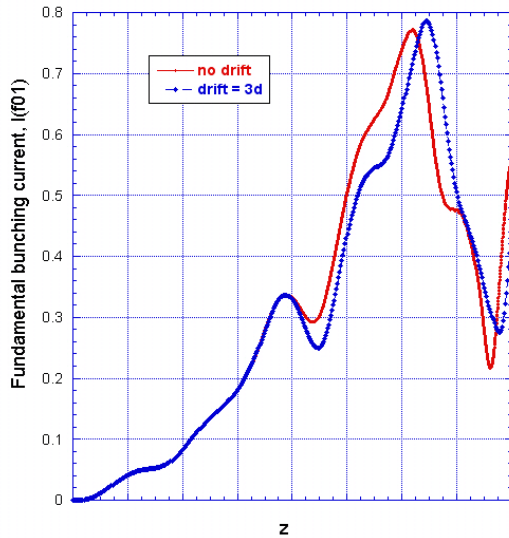


Figure 2: Computed by TESLA-CC fundamental bunching current in NRL-1 CCTWT depending on the length of the drift inside the sever section of the device ($P_d = 28$ dBm).

An importance of taking into account the 2D dynamic of the beam becomes especially obvious in the large-signal regime of the device's operation: Fig.3 illustrates very active transverse motion of the particles and big change in the average beam-radius observed near the end of the device. Finally, the result of the performed by us wide sensitivity study allowed to find an impact of variations in the many other physical parameters and helped to make an additional "fine" tuning in the TESLA-CC simulations to reach a better agreement with the full set of available to us experimental data.

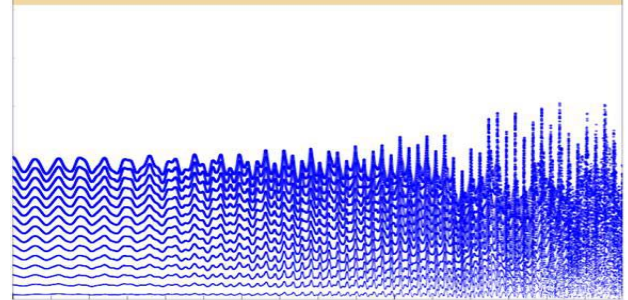


Figure 3: Computed by TESLA-CC particles trajectory (R versus Z) along the NRL-1 tube on a large-signal regime of its operation.

Conclusion

We completed wide modeling of an experimental NRL-1 CCTWT by using the large-signal 2.5D code TESLA-CC, including the detailed sensitivity study of the code's predictions depending on a main set of the physical parameters of the device. As a result of this comprehensive study it was shown that code is capable to provide good agreement with the measured data across its whole working band and for all regimes of its operation.

Acknowledgements

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