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Linearity of the Transverse Field Interaction in a Traveling Wave Tube*

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The operation of all conventional traveling wave tubes is fundamentally based on the interaction of an electron beam with the axial RF electric field of a traveling circuit wave; transverse electric fields play only a secondary role in the dynamics. It has long been known, however, that a TWT could be designed to exploit certain advantages inherent in the interaction of an electron beam with a *transverse* electric circuit wave. In 1960 Siegman [1] published a detailed small signal analysis of the interaction of a filamentary beam with a traveling transverse wave, and found that positive gain could indeed be obtained from this interaction, which produces no longitudinal bunching of the beam. In a transverse interaction, energy is extracted from the axial motion of the beam, as in the longitudinal interaction case, but in such a way that all particles lose the same amount of energy, independent of their location (phase) within an RF period. This result holds strictly speaking only for a filamentary beam. Briggs et.al. [2] were able to estimate the energy spread of a beam of finite radius and to use this estimate to bound the attainable efficiency of a transverse TWT.

The Moscow State University group, in collaboration with Istok Corp. and Tory Corp. [3], has been successfully designing, developing, and marketing various types of microwave amplifiers and receiver protectors based on the transverse interaction. As of 2002, however, they were reporting only limited experimental success with transverse TWT's. This may be at least partly due to problems associated with the design and fabrication of a suitable slow wave circuit, which are not simple matters.

The basic features of the transverse interaction immediately suggest that a TWT based on this interaction may be both (1) highly efficient, due to the ease of recovering energy from the nearly monoenergetic spent beam, and (2) highly linear, due to the absence of longitudinal non-linear coulomb de-bunching forces, which increase in strength in a conventional TWT as the bunches become tighter, and which therefore contribute to saturation.

Using a specially modified version of the CHRISTINE 3D large signal TWT simulation code, we have compared the spent beam distributions and linearity properties of a

transverse TWT with those of a comparable conventional tube. The large signal simulations include the effects of a finite beam size, which is allowed to vary self-consistently as the beam propagates along the interaction space. The DC beam power was constrained to be the same (646 W) in both designs, and each was separately optimized for maximum output power by choosing the optimum values of beam voltage and RF drive power. Both designs used the same values of the respective beam-wave interaction impedance. The computed spent beam distributions and the C3IM intermodulation levels were then compared.

Figures 1a, b show the spent beam distributions at maximum output power, as computed by CHRISTINE 3D for the optimized longitudinal and transverse interaction TWT designs used in the study. Note that the width of the spent beam energy distribution in the transverse interaction case is less than 1/3 of that of the conventional design. Specifically, if we compute the means and standard deviations of the distributions, we find that $\sigma_E / \bar{E} = 0.42$ for the longitudinal case, while $\sigma_E / \bar{E} = 0.13$ for the transverse case, in this example.

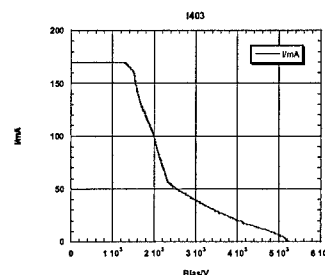


Figure 1a: Spent beam distribution at maximum power for longitudinal interaction

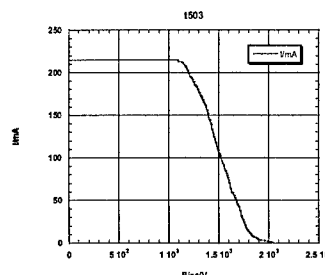


Figure 1b: Spent beam distribution at maximum power for transverse interaction

Figures 2 and 3 illustrate the levels of the third order intermod at saturation and for 3 dB backoff, as computed by CHRISTINE 3D. While at saturation the C3IM levels are about the same (-10dB) in the two designs, at 3dB backoff the C3IM level in the transverse TWT is nearly -30dB from the carrier, compared with -18dB in the conventional tube. Said another way, the onset of nonlinear behavior is seen to be much more sudden in the transverse TWT than in the conventional TWT, as the drive power is increased, in accordance with intuition based on the absence of longitudinal de-bunching forces in the transverse TWT.

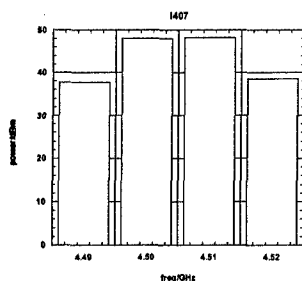


Figure 2a: Output spectrum at saturation for longitudinal interaction

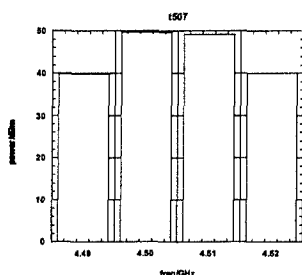


Figure 2b: Output spectrum at saturation for transverse interaction

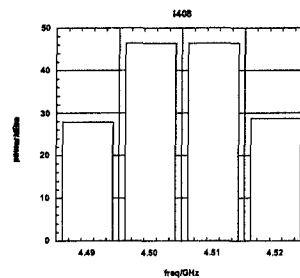


Figure 3a: Output spectrum for 3dB backoff for longitudinal interaction

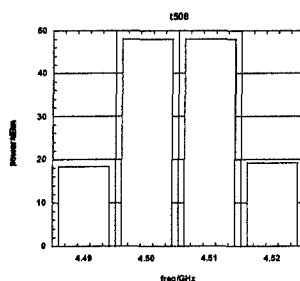


Figure 3b: Output spectrum for 3dB backoff for transverse interaction

These large signal results support one's physical intuition based originally on small signal theory. If a suitable slow wave structure can be devised, they suggest that a transverse TWT may more easily meet today's demanding requirements for high efficiency and linearity in high data rate communications and other applications.

References

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