Research on Gyrotron Traveling Wave Amplifier with Lossy Dielectric-Load Waveguide

NaLiu*
School of Physical Electronics, University of Electronic Science and Technology of China, Chengdu, Sichuan610054, China,
* Contact: 635733312@qq.com

Abstract—Gyrotron traveling wave tubes (gyro-TWTs) are ofconsiderable interest for high-power millimeter and submillimeter radiation sources. Lossy dielectric waveguide to improve the stability of the cyclotron traveling wave tube amplifiers and other properties have a positive effect. The combined appropriate selection of the lossy waveguide thickness, permittivity, voltage, the applied magnetic field and the velocity ratio can effectively give attention to bandwidth and instability to ensure the stable operation of the gyrotron traveling wave amplifier. It is revealed that due to the lossy property of the dielectric, the energy in the dielectric slots is absorbed effectively and the high order Bloch harmonics induced by the periodicityof the structure are suppressed, which changes the discrete spectrum under lossless condition into a continuous one .

INTRODUCTION

As a high power broadband millimeter wave sourceGyrotron amplifier is the inevitable choice for the next generation high power millimeter wave imaging radar transmitter. Gyro-TWT with high average power capacity, high efficiency, high gain and wide bandwidth and other characteristics，can be applied in high resolution radar and high capacity intensive communication systems, but an actual gyro-TWT interaction system is highly susceptible to potential absolute instabilities, which bring up oscillations and spread out in the entire interaction system. The National Tsing Hua University reported that an ultra-high gain gyro-TWT amplifier employing distributed wall losses produced 93 kW peak power, with 70 dB saturated gain, 26.5% efficiency and a -3 dB bandwidth of 8.6% (Chu, Chen, Hung, Chang, and Barnett1998; Chu et al. 1999).Recently, a new type of distributed loss scheme has been employed by NRL for high average power applications. A Ka-band TE11 mode gyro-TWT loaded with high thermal conductivity ceramic elements produced 78 kW power, 60 dB saturated gain and 19% efficiency with a 3 dB bandwidth of 17.1%.This paper aims to reach an interaction structure with distributed loss for gyro-TWT， which demonstrates that loading lossy dielectric is excellent to stabilize the spurious oscillations. Furthermore, the designs of magnetron injection gun, interaction circuits, and input and output structures are also achieved to satisfy the requirements.

STRUCTURE AND ANALYSIS OF DISPERSION

In our gyro-TWT research, we employed a long loaded section of constant radius which consists of lossy ceramic rings spaced with metal rings to provide controlled loading of the fundamental TE01 mode. The scheme of periodical dielectric loaded waveguide and normalized radical E-field are described in Fig.1 and Fig.2.

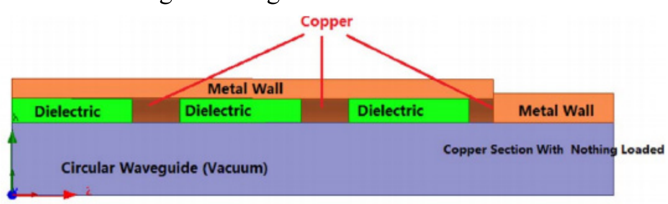

Fig. 1. Schematic view of the simulation model for gyro- TWTinteraction structure.

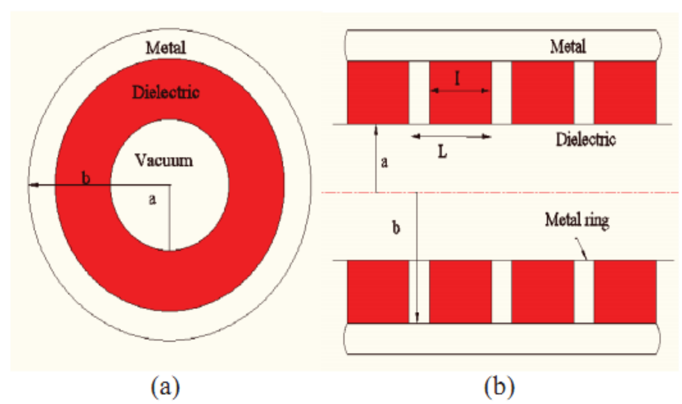

Fig. 2. (a) Transverse structure of the dielectric-loaded metal cylindrical waveguide. (b) Periodical dielectric loaded waveguide for gyro-TWT.

The interaction circuits are structured with a lossy section (AlN-SiC) followed by a copper section. The nonlinear highest power portion of the amplification occurs in the short conducting wall section at the end of the interaction region.The dispersion diagram of TE_{01}gyro-TWT interaction circuits with unloaded structure is shown in Fig. 3.

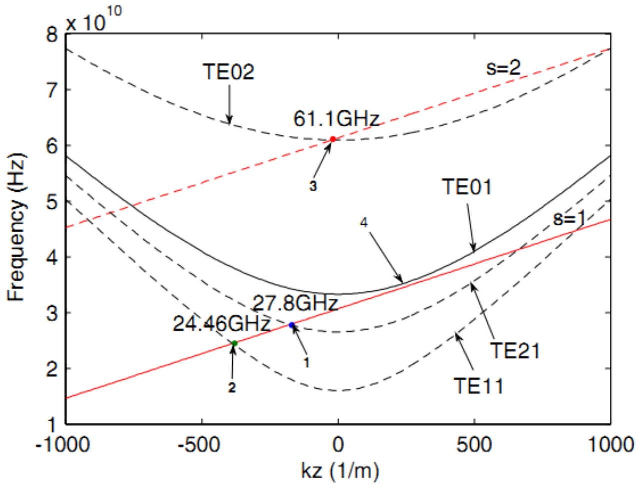

Fig. 3. Dispersion diagram of TE_{01} gyro-TWT

Small-signal analysis is the foundation of gyro-TWT beam-wave interaction analysis andgives a clear physical interpretation to the amplification and self-induced oscillation ofgyro-TWT. Taking advantage of the small-signal analysis, start current and start length oprimary modes in smooth and dielectric-loaded waveguide arecalculated. According to actual gyro-TWT parameters such as operating band and outputpower et al. and to the status of our high power Gyrotron hot test Lab, essential parametersof distributed-loss loading circuit of Ka-band gyro-TWT including beam voltage, current,velocity ratio, waveguide and guiding center radius are determined.

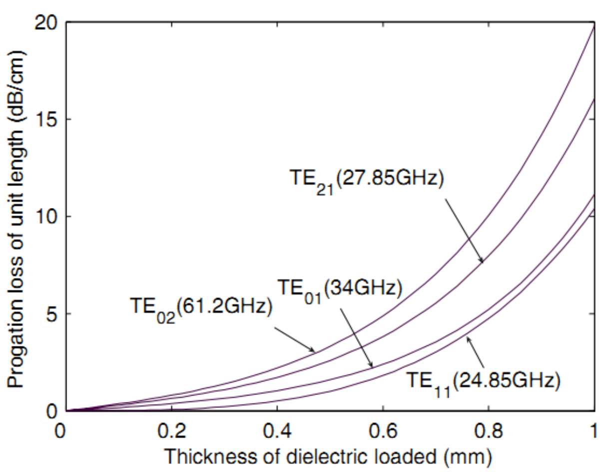

Fig. 4 Propagation loss of unit length vs. thickness of loss layer d=0.07 cm (relative permittivity ξ''=11−6j, waveguide radius rw=0.56cm).

Whenbeam current I_b=10 A, even the most susceptible oscillation mode TE_{02} whose start lengthin lossless circuit is 4 cm, longer than designed lossless circuit length 3.5 cm. Hence, thedielectric loading scheme is capable of suppressing oscillation of both operation andparasitic modes (Fig. 4).

CONCLUSION

The theoretical predictions ofa Ka-band TE01 gyro-TWT has been presented. Distributedloaded lossy dielectric rings are introduced to suppress theunwanted modes TE_{11},TE_{21}, and TE_{02}. The performanceresulted by loss wall plays an important role for the gyro-TWT oscillation stability. Dielectric loading results in reducing of operating mode gain of unit length. Adjustment of interaction section structure is necessary.

ACKNOWLEDGMENT

The authors would like to thank Dr. D. K. i, Dr. Y. R,and Prof. L. Y. for many useful discussions aboutan interaction structure with distributed loss fora Ka-band gyro-TWT and calculation of gyro-TWT.

REFERENCES

H. H. Song et al., “Theory and experiment of a 94 GHz gyrotrontraveling-wave amplifier,” Phys. Plasmas, vol. 11, no. 5, p. 2935,May 2004.

C. H. Du and P. K. Liu, “Linear full-wave-interaction analysis of agyrotron-traveling-wave-tube amplifier based on a lossy dielectric-lined circuit,” IEEETrans.Plasma Sci., vol. 38, no. 6, pp. 1219–1226, Jun. 2010.

R. Yan, Y. Luo, G. Liu, and Y. Pu, “Design and experiment of a Q-bandgyro-TWT loaded with lossy dielectric,” IEEE Trans. Electron Devices,vol. 59, no. 12, pp. 3612–3617, Dec. 2012.

K. T. Nguyen, J. P. Calame, D. E. Pershing, B. G. Danly, M. Garven, B. Levush, and T. M. Antonsen,“Design of Ka-band gyro-TWT for radar applications,” IEEE Trans. Plasma. Sci., vol. 48,pp. 108–11,Jan.2001

D. E. Pershing et al.,“ATE11 Ka-band gyro-TWT amplifier withhigh-average power compatible distributed loss,” IEEE Trans. PlasmaSci., vol. 32, no. 3, pp. 947–956, Jun. 2004.

B. T. Liu, J. J. Feng, E. F. Wang, Z. L. Li, X. Zeng, L. J. Qian, andH. Wang, “Design and experimental study of a Ka-band gyro-TWT withperiodic dielectric loaded circuits,” IEEE Trans. Plasma Sci., vol. 39,no. 8, pp. 1665–1672, Aug. 2011.

J. P. Calame, M. Garven, B. G. Danly, B. Levush, and K. T. Nguyen,“Gyrotron-traveling wave-tube circuits based on lossy ceramics,” IEEETrans. Electron Devices., vol. 49, no. 8, pp. 1469–1477, Aug. 2002.

H. Wang, H. Li, Y. Luo, and R. Yan, “Theoretical and experimentalinvestigation of a Ka-band gyro-TWT with lossy interaction structure,”J. Infr. Millim. Terahertz Waves, vol. 32, no. 2, pp. 172–185, Feb. 2011.

D. E. Pershing, J. P. Calame, K. T. Nguyen, B. G. Danly, and B. Levush, “A distributed loss technique for high average power gyro-TWT’s,” Proceedings of the 2nd International Vacuum Electronics Conference, Noordwijk, The Netherlands, p.145,2001.

Y. S. Yeh, C. L. Hung, C. W. Su, T. S. Wu, Y. Y. Shin, and Y. T. Lo, “W-band second-harmonic gyrotron traveling wave amplifier with distributed-loss and severed structures,” Int. J. Infrared Millim. Waves, vol. 25, no. 1,pp. 29–42, Jan. 2004.

Chu, K.R., Lau, Y.Y., and Barnett, L.R. (1981), ‘Theory of a Wideband Distributed GyrotronTraveling Wave Amplifier’, IEEE Transactions on Electron Devices, 28(1), 866–871.

C. H. Du and P. K. Liu, “A lossy dielectric-ring loaded waveguidewith suppressed periodicity for gyro-TWTs applications,” IEEE Trans.Electron Devices, vol. 56, no. 10, pp. 2335–2342, Oct. 2009.

Garven, M., Calame, J.P., Danly, B.G., Nguyen, K.T., Levush, B., Wood, F.N., and Pershing, D.E.(2002), ‘Experimental Studies of a Gyro-TWT Amplifier with a Lossy Ceramic InteractionRegion’, IEEE Transactions on Plasma Science, 30, 885–893.