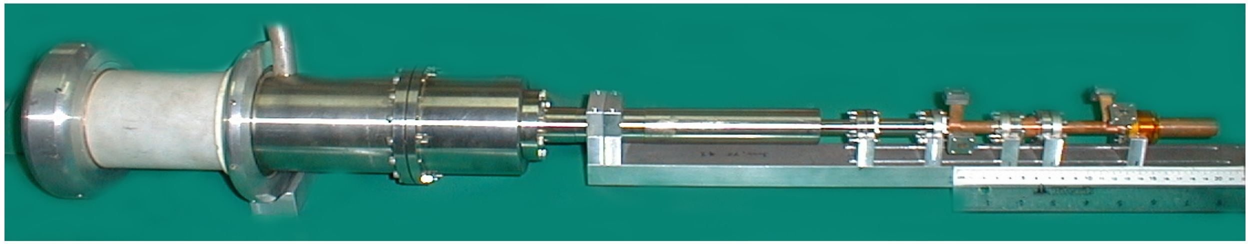
W - Band Second Harmonic TE_{02} Gyrotron Traveling Wave Amplifier



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Introduction to Gyro-TWA

- The high power and broad bandwidth capability of gyrotron traveling wave amplifiers (gyro-TWA) make them attractive sources in the millimeter wave range.

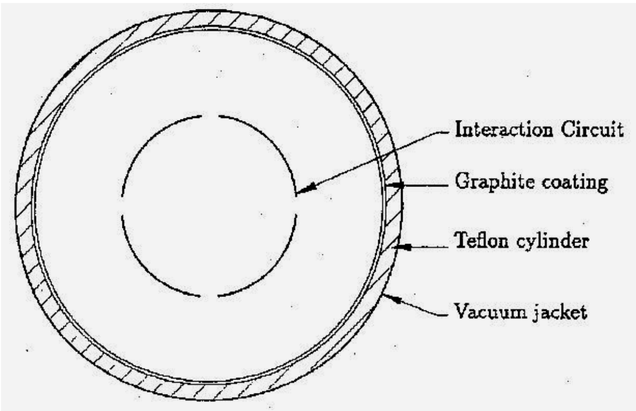
- The property of the TE_{02} mode in the gyro-TWA exhibits the low Ohmic dissipation and lager guiding center radius. The required magnetic field of the harmonic gyro-TWA is then reduced by the harmonic number *s*.

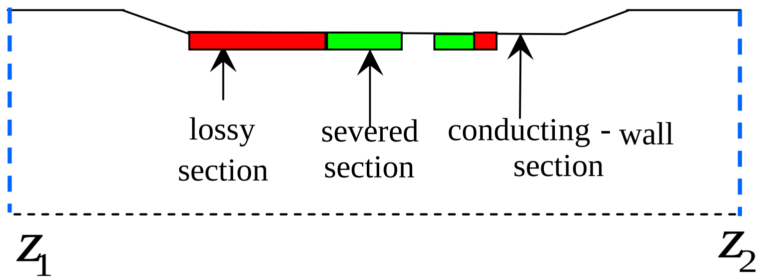
- The performance of the gyro-TWA will be degraded where the absolute instability, gyrotron backward oscillation (gyro-BWO) and reflective oscillation occur to cause mode competition.

Introduction to Gyro-TWA

- The mode-selective interaction circuit may excite the non-operating mode, which can degrade the conversion efficiency .

- The multi-stage gyro-TWA with distributed-loss and severed structure seem to increase effectively the start-oscillation currents of the absolute instability, gyro-BWO, and reflection oscillation.





Ref.[1]

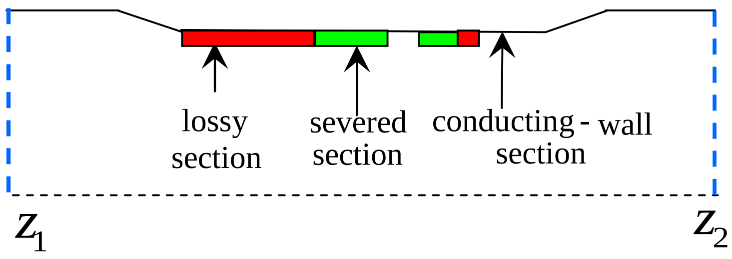
Computer Models of Nonlinear Simulation Code

1. Fields of the circularly polarized TE_{mn} mode

$$B_z = k_{mn}^{\ 2} f(z) J_m(k_{mn} r) e^{-i(\omega t - m\theta)}$$

2. Field equation

$$\left(\frac{d^2}{dz^2} + k_z^2\right) f(z) = i \frac{8|I_b|}{x_{mn}^2 K_{mn} \omega} \sum_{j=1}^{N} W_j \frac{\boldsymbol{v}_j(z) \cdot \boldsymbol{E}^*(r_j, \theta_j, t_j, z)}{\boldsymbol{v}_{zj}(z) f^*(z)}$$



3. The relativistic equation of montion

$$\frac{d}{dt}\boldsymbol{P} = -e\boldsymbol{E} - \frac{e}{c}\boldsymbol{v} \times (\boldsymbol{B}_{ext} + \boldsymbol{B})$$

4. Boundary conditions (gyro-TWA)

$$f'(z_1) = ik_z (f_+ e^{ik_z z_1} - f_- e^{-ik_z z_1})$$

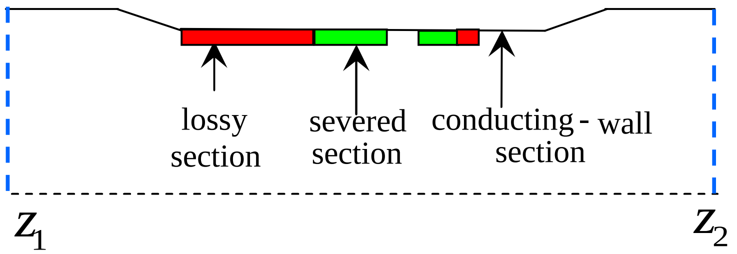
$$f(z_1) = f_+ e^{ik_z z_1} + f_- e^{-ik_z z_1}$$

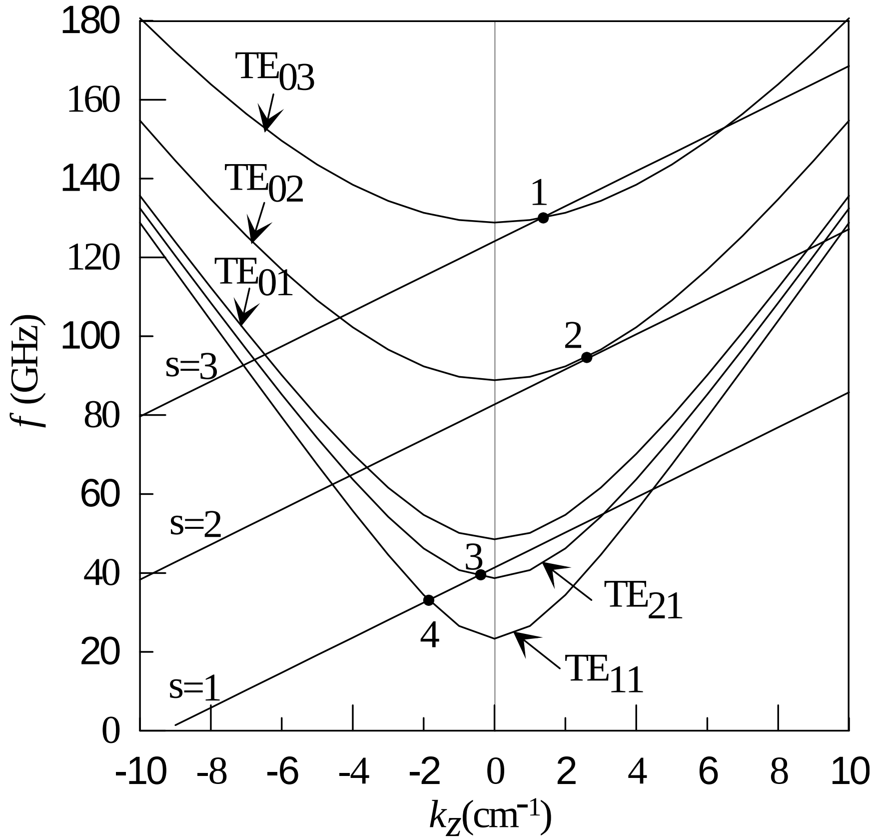
$$f'(z_2) = ik_z f(z_2)$$

Ref.[2]

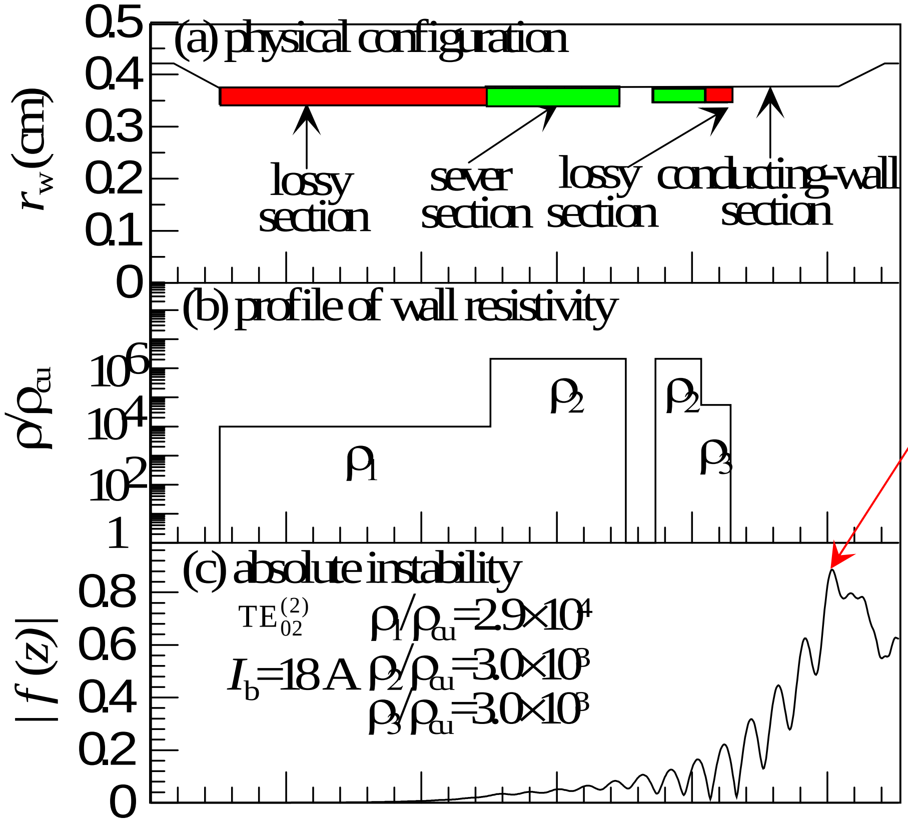
Self – Excited Oscillations

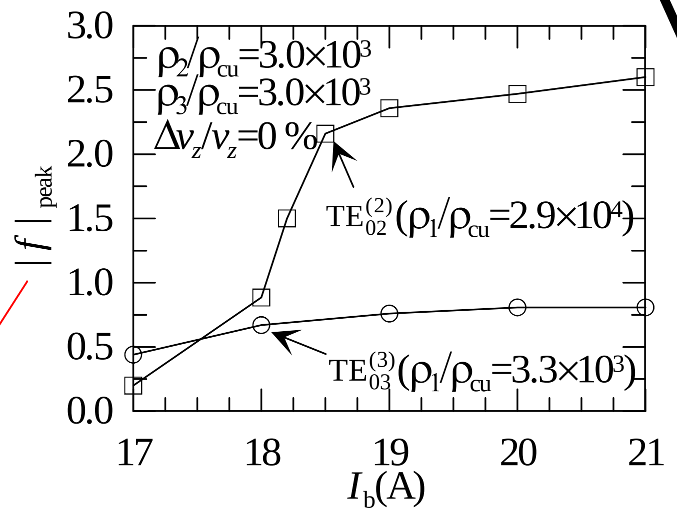
- Absolute instability-the interaction in the forward wave region (points 1 and 2).
- Gyrotron backward oscillation-the interaction in the backward wave region (points 3 and 4).
- Reflective oscillation-the oscillations take place in the sever-wall junction on the left and the output structure on the right.

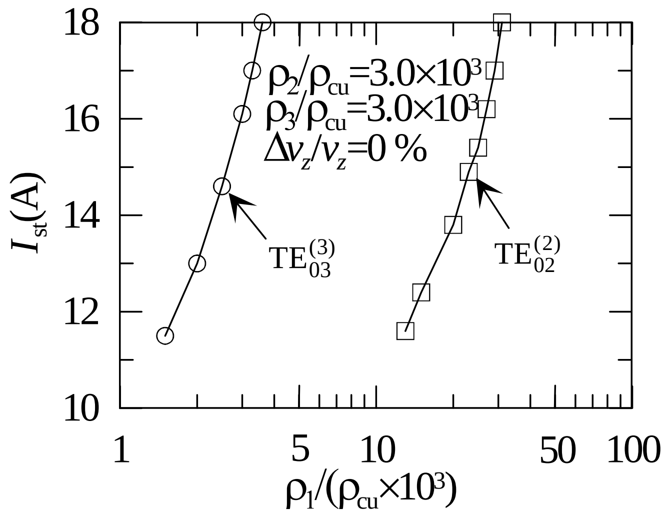




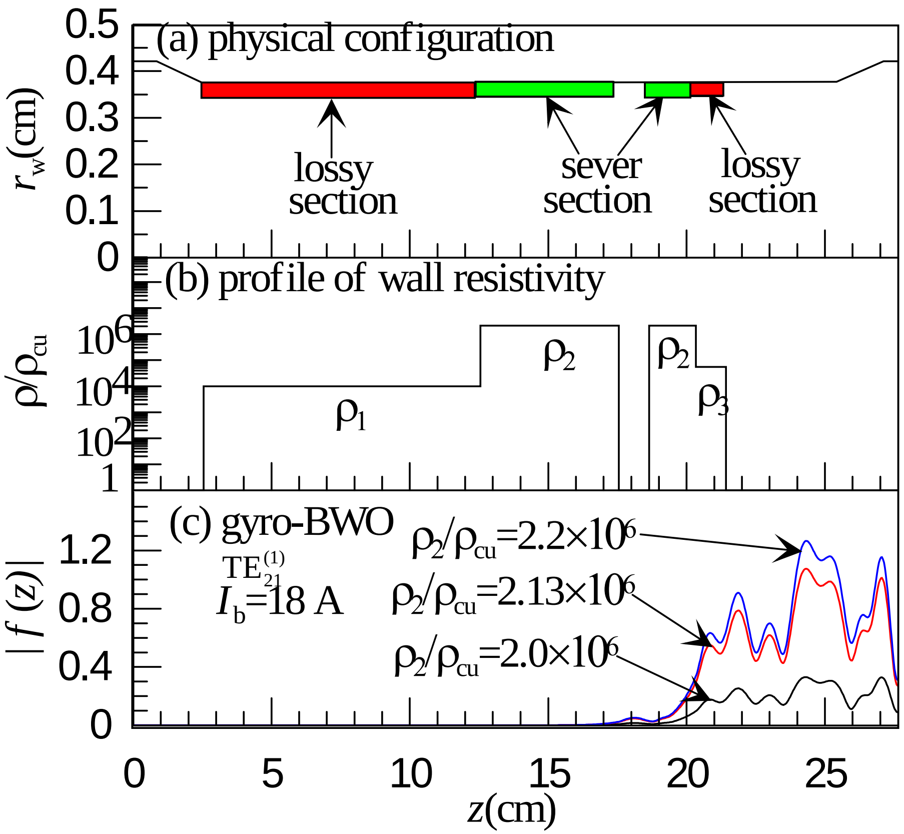
Absolute Instability

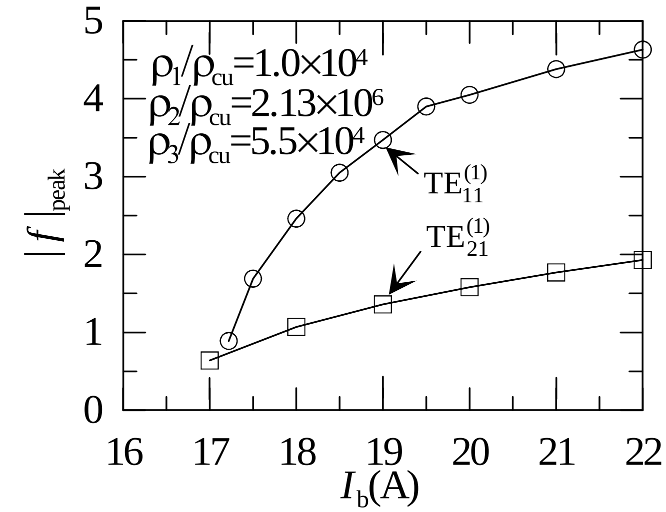


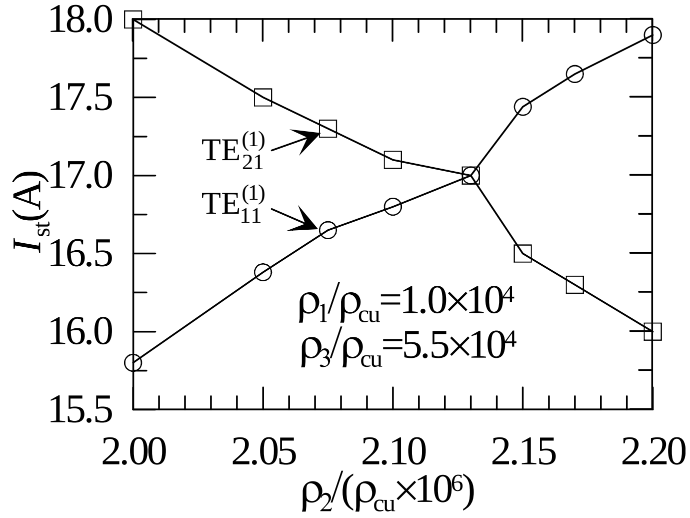




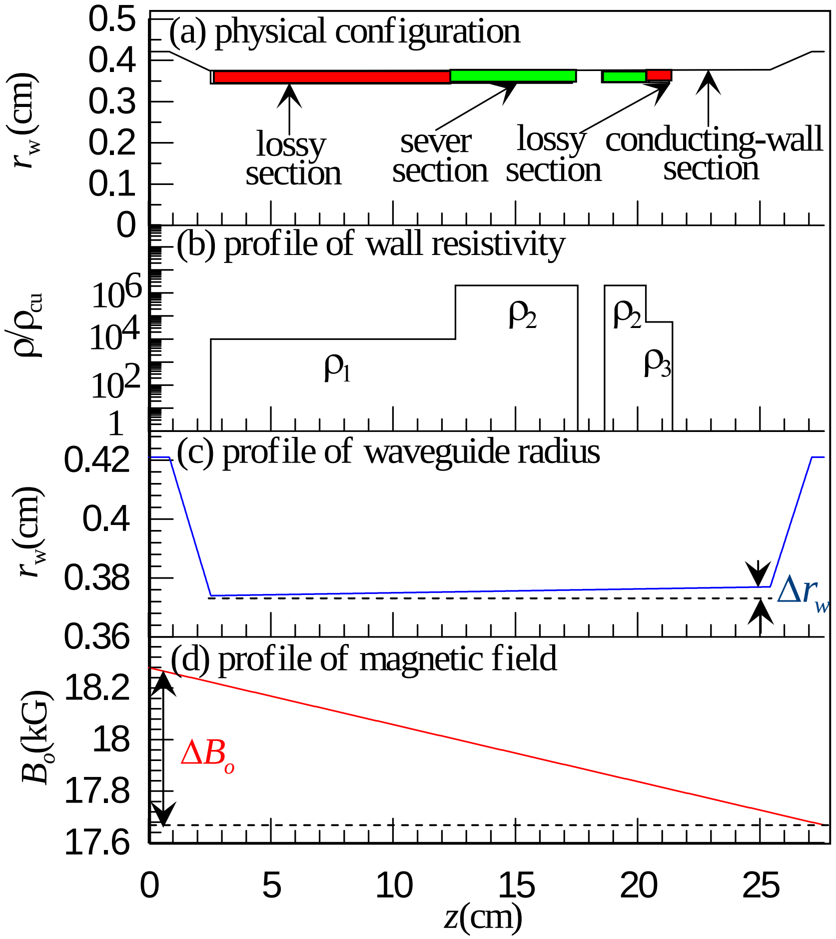
Gyro - BWO


(a) physical configuration
r_w(cm)
0.5
0.4
0.3
0.2
0.1
0
lossy section
sever section
lossy section
(b) profile of wall resistivity
ρ/ρ_{cu}
10^6
10^4
10^2
1
ρ_1
ρ_2
ρ_2
ρ_3
(c) gyro-BWO
$TE_{21}^{(1)}$
I_b=18 A
$\rho_2/\rho_{cu}=2.2\times10^6$
$\rho_2/\rho_{cu}=2.13\times10^6$
$\rho_2/\rho_{cu}=2.0\times10^6$
$|f(z)|$
1.2
0.8
0.4
0
0
5
10
15
20
25
z(cm)

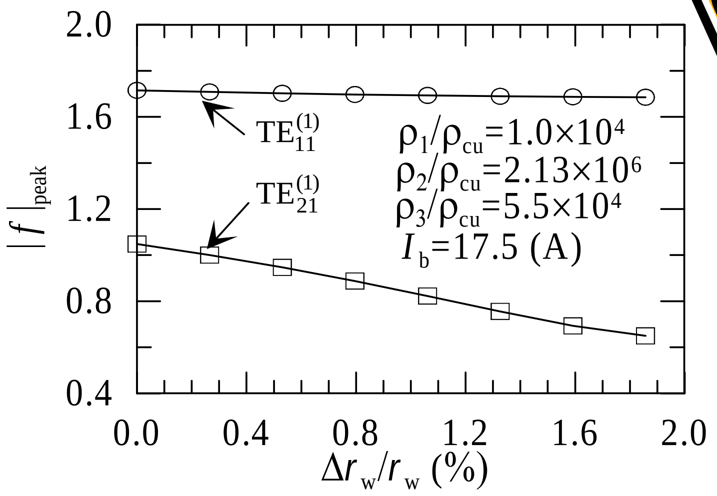

$\rho_1/\rho_{cu}=1.0\times10^4$
$\rho_2/\rho_{cu}=2.13\times10^6$
$\rho_3/\rho_{cu}=5.5\times10^4$
$TE_{11}^{(1)}$
$TE_{21}^{(1)}$
$|f|_{peak}$
5
4
3
2
1
0
16
17
18
19
20
21
22
I_b(A)


I_{st}(A)
18.0
17.5
17.0
16.5
16.0
15.5
$TE_{21}^{(1)}$
$TE_{11}^{(1)}$
$\rho_1/\rho_{cu}=1.0\times10^4$
$\rho_3/\rho_{cu}=5.5\times10^4$
2.00
2.05
2.10
2.15
2.20
$\rho_2/(\rho_{cu}\times10^6)$

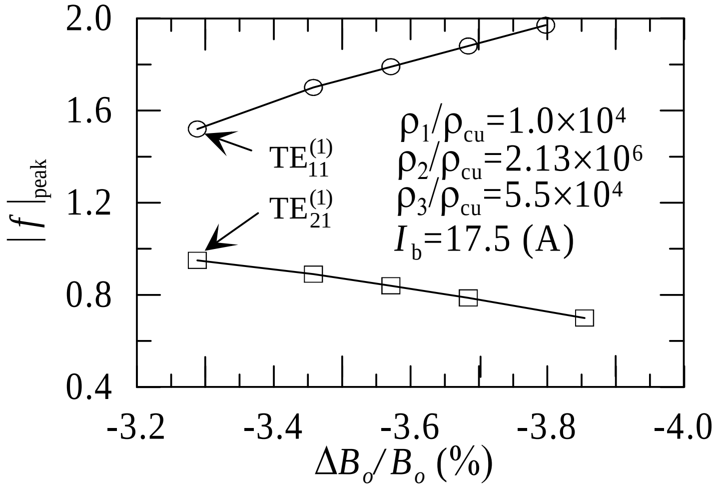
Gyro - BWO



(a) physical configuration
lossy section
sever section
lossy section
conducting-wall section
r_w(cm)
(b) profile of wall resistivity
ρ/ρ_{cu}
ρ_1
ρ_2
ρ_2
ρ_3
(c) profile of waveguide radius
r_w(cm)
Δr_w
(d) profile of magnetic field
B_o(kG)
ΔB_o
z(cm)

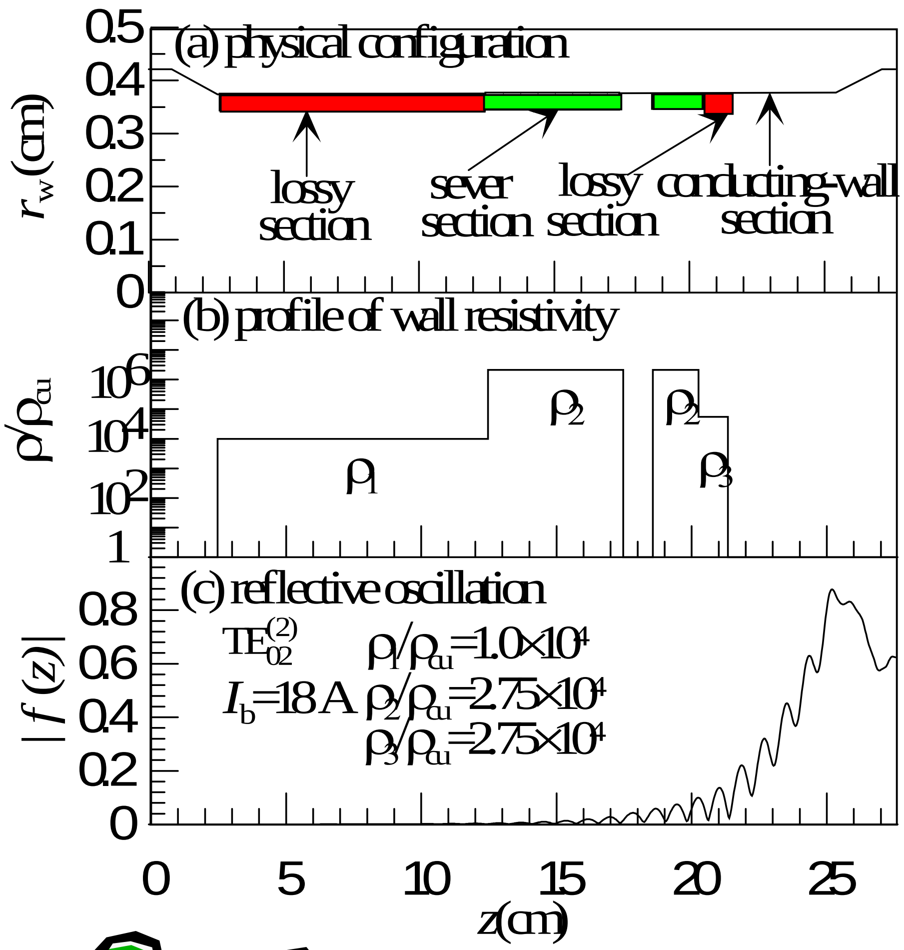


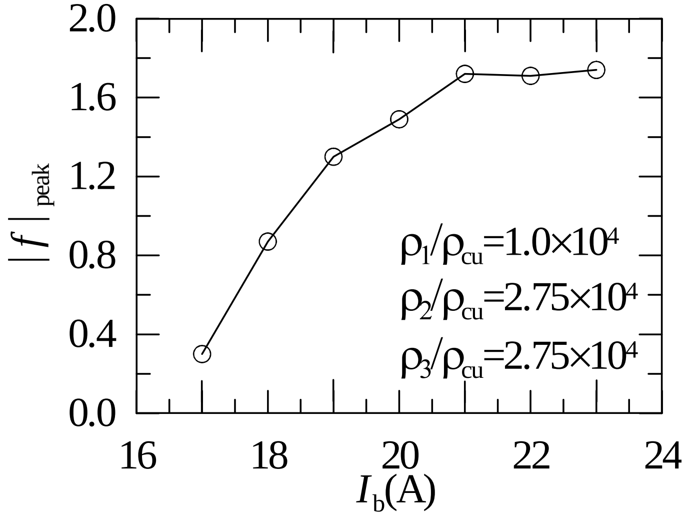
$TE_{11}^{(1)}$
$TE_{21}^{(1)}$
$\rho_1/\rho_{cu}=1.0\times10^4$
$\rho_2/\rho_{cu}=2.13\times10^6$
$\rho_3/\rho_{cu}=5.5\times10^4$
$I_b=17.5$ (A)
$|f|_{peak}$
$\Delta r_w/r_w$ (%)

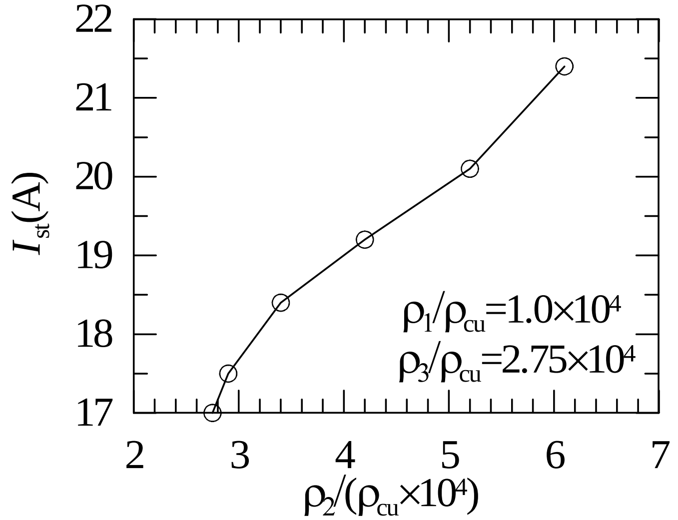


$TE_{11}^{(1)}$
$TE_{21}^{(1)}$
$\rho_1/\rho_{cu}=1.0\times10^4$
$\rho_2/\rho_{cu}=2.13\times10^6$
$\rho_3/\rho_{cu}=5.5\times10^4$
$I_b=17.5$ (A)
$|f|_{peak}$
$\Delta B_o/B_o$ (%)

Reflective Oscillation







Performance of the Gyro-TWA

Operating current : 15 A

Center frequency : 91 GHz

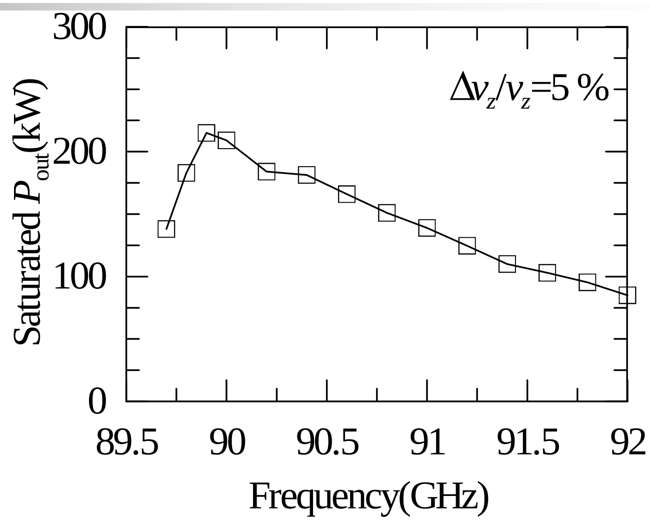
Peak power : 215 kW at 89.9 GHz

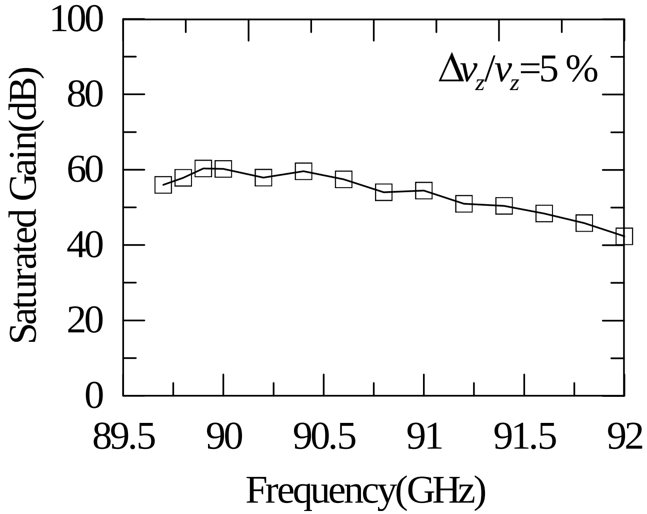
Saturated gain : 60 dB

Saturated efficiency : 14.3 %

Bandwidth : 1.7 GHz

Velocity spread : 5 %





Conclusions

- A multi-stage gyro-TWA design with distributed-loss and severed structure is proposed to stabilize the amplification.

- The multi-stage gyro-TWA has a positively tapered waveguide radius and a negatively tapered applied magnetic field to suppress the gyro-BWO and increase the bandwidth of the gyro-TWA.

- The multi-stage structure gyro-TWA for a 15 A electron beam predicted to yield a peak output power of 215 kW at 89.9 GHz with an efficiency of 14.3% , a saturated gain of 60 dB and a bandwidth of 1.7 GHz with an axial velocity spread $\Delta v_z / v_z = 5\%$.

References

[1] K. R. Chu, L. R. Barnett, H. Y. Chen, Ch. Wang, Y. S. Yeh, Y. C. Tsai, T. T. Yang, and T. Y. Dawn, "Stabilizing of absolute instabilities in gyrotron traveling wave amplifier," *Phys. Rev. Lett.*, vol. 74, no. 7, pp. 1103-1106, 1995.

[2] K. R. Chu, H. Y. Chen, C. L. Hung, T. H. Chang, L. R. Barnett, S. H. Chen, T. T. Yang, and D. J. Dialetis, "Theory and experiment of ultrahigh-gain gyrotron traveling wave amplifier," *IEEE Trans. Microwave Theory Tech.*, vol. 27, no. 2, pp. 391-404, 1999.

[3] A. T. Lin, K. R. Chu, C. C. Lin, C. S. Kou, D. B. Mcdermott, and N. C. Luhmann, Jr., "Marginal stability design criterion for gyro-TWT and comparison of fundamental with second harmonc operation," *Int. J. Electron.*, vol. 72, no. 5, pp. 813-885, 1992.

[4] K. R. Chu, Y. Y. Lau, L. R. Barnett, and V. L. Granatstein, "Theory of a wide-band distributed gyrotron traveling-wave amplifier," *IEEE Trans. on electron devices*, vol. 28, no. 7, 1981.

[5] Q. S. Wang, H. E. Huey, D. B. McDermott, Y. Hirata, and N. C. Luhmann, Jr., "Design of a W-band second-harmonic gyro-TWT amplifier," *IEEE Trans. Plasma Sci.*, vol. 28, no. 6, pp. 2232-2237, 2000.

References

[6] Q. S. Wang, D. B. McDermott, C. K. Chong, C. S. Kou, K. R. Chu, and N. C. Luhmann, Jr., "Stable 1 MW, third-harmonic gyro-TWT amplifier," *IEEE Trans. Plasma Sci.*, vol. 22, no. 5, pp. 608-615, 1994.

[7] Y. S. Yeh, T. S. Wu, Y. T. Lo, C. W. Su, and S. C. Wu, "Stability analysis of TE_{01} gyrotron travelling wave amplifiers," *Int. J. Electron.*, vol. 90, no. 8, pp.517-532, 2003.

[8] Y. S. Yeh, Y. T. Lo T. S. Wu, and C. W. Su, "Nonlinear analysis of absolute instability in gyrotron traveling wave amplifiers, " *in Proc. Fourth IEEE International Vacuum Electronics Conference*, 2003.