Three-Dimension Software Cold-Test Simulation of Coupled Cavity Slow-Wave Circuit*

Lei Wenqiang Yang Zhonghai Gao Yuanci
(College of Physical Electronics，UEST of China Chengdu 610054)

Abstract The software cold-test method simulating to obtain high frequency characteristic data including dispersion, interaction impedance and attenuation of coupled-cavity slow-wave circuit by MAFIA simulation is discussed considering effect of tube-envelop in the TWT. The precision of dispersion is increased to 0.29%. Then the simulation result is obtained more consistent with experiment data than the method that ignoring effect of tube-envelop. It is proved that computer cold-test simulation method may replace the experiment method.

Key words software cold-test; MAFIA simulation; effect of tube-envelop; high frequency characteristic data

耦合腔慢波电路的三维软件冷测模拟*

雷文强** 杨中海 高源慈
(电子科技大学物理电子学院 成都 610054)

【摘要】 讨论了在考虑行波管管壳影响的情况下，使用MAFIA模拟软件软件的冷测方法模拟耦合腔慢波电路的高频特性参数，包括色散特性、耦合阻抗和衰减特性，使色散特性精度提高到0.29%，其模拟结果比忽略管壳影响下的计算值更加接近实验数据，也证明了计算机模拟冷测方法可以取代实验测试方法。

关 键 词 软件冷测； MAFIA模拟； 管壳影响；高频特性参数

中图分类号 TN124

In the course of traditional design, the method that coupled-cavity slow-wave characteristic data gained by cold-test experiment is called hardware cold-test, while by software simulation is called software cold-test. Software cold-test method may reduce the time and cost of Traveling-Wave Tube research and manufacture, and design some novel slow-wave structure to avoid costly hardware cold-test and shorten development periods.

The slow-wave characteristic data includes high-frequency dispersion characteristic、interaction impedance and attenuation characteristic. In the hardware cold-test experiment, dispersion curve is gained by resonance method testing resonance frequency point per cavity phase shift. Interaction impedance is calculated using a special calculation equation expression by perturbation method testing resonance

Received on April 27, 2002
2002年4月27日收稿
* The project is supported by the National Ddfence Research Found
国防预研基金资助项目
** 男 30岁 博士生

frequency shift.

So far many papers discuss the method by software simulation obtaining such characteristic data. Three-dimension electromagnetism software-MAFIA 4.1 releases is the tool software of simulation cold-test data. After thinking over existed simulation method by MAFIA software, we find that existed simulation often ignored effect of tube-envelop, and directly set electric wall boundary condition in the structure boundary. The simplification method cannot accord with the fact condition. Now the paper improve simulation method by considering effect of tube-envelop, then making the result more consistent with hardware cold-test experiment data than the method that ignoring effect of tube-envelop.

1 Coupled Cavity Structure model

The paper models the 961HA couple cavity TWT slow-wave circuit which parameter is gained in the paper[1]. The 961 HA couple cavity TWT is used in the intersatellite communications which performance is 70 w and 59~64 GHz, a very important device in millimeter waveband TWT. The main view and cross section view of the slow-wave circuit is displayed figure 1.

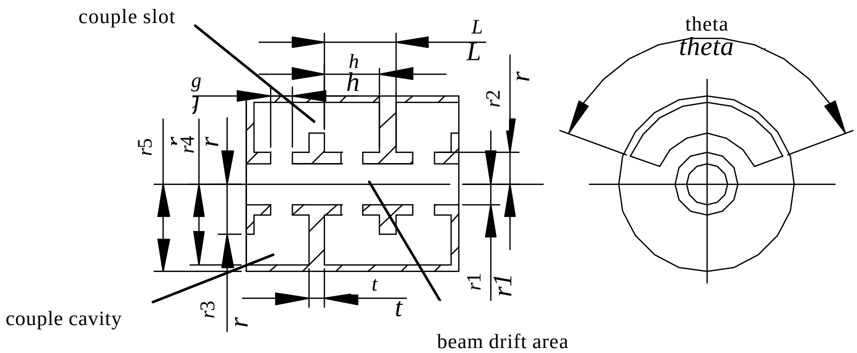

Figure 1 Coupled cavity slow-wave structure plane view

Three cavity structure of the 961 HA coupled-cavity slow-wave circuit is modeled in Cartesian coordinate system by M module in MAFIA, then set 530 000 meshpoint and mesh three-dimension element using automesh function. The structure is set more meshpoint, the software simulation is more accurate.

2 Simulation and Result

2.1 Electric field Distribution

The both ends of the circuit is separately set different boundary condition by E module in MAFIA after automesh. After the circuit is solved by the E-solver, we may obtained eigen-frequency and electromagnetic field distribution corresponding to different boundary condition. The full of course simulating three kind of different boundary condition spend 3 hour and 12 minute using digital 400i workstation.

Electric field distribution for cavity mode in couple cavity simulating by MAFIA software is the same as that of kantrowitx.F’s paper[2]. The relationship of phase shift per cavity with eigen-frequency is gained by different electric field distribution, then data of couple cavity dispersion characteristic is gained by the frequency-phase relationship. The contrast figure of electric field distribution for cavity mode in kantrowitx.F’s paper with MAFIA simulation result is displayed in figure 2.

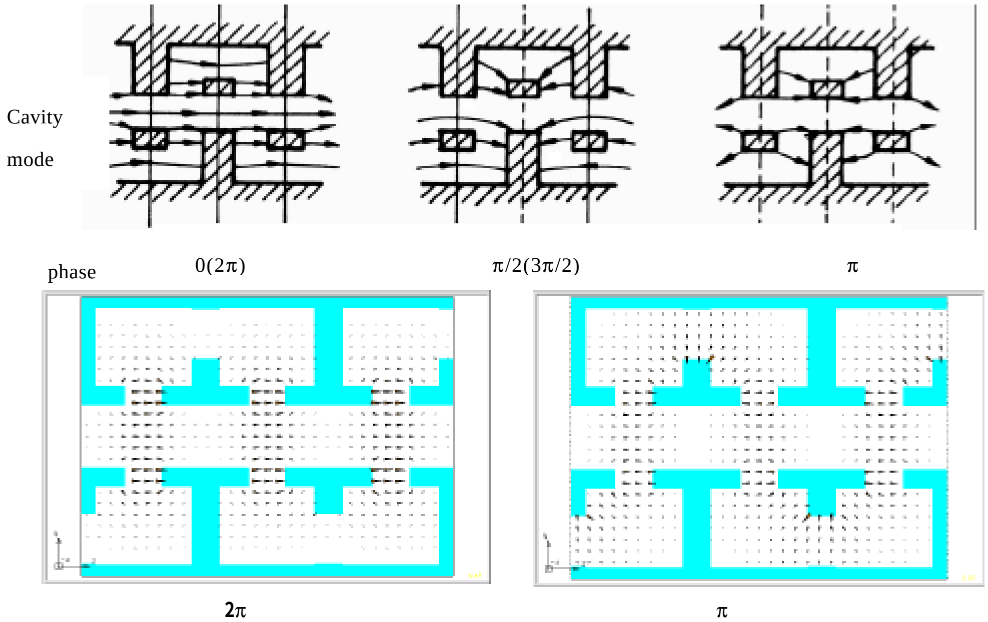

Fig 2 The contrast view of electric field distribution

2.2 Dispersion Characteristic

When three cavity structure of couple cavity is simulated, the both ends of cavity is separately set electric or magnetic wall boundary condition, seven eigen-frequency point relating to phase shift per cavity is obtained by this method. Then dispersion curve is plot in figure 3 by the frequency-phase relationship. The MAIFA simulation result receive more consistent with experimental data, and compared with experimental data precision reach 0.29%. So it is very important that eigen-frequency of couple cavity is simulated considering effect of tube-envelop.

2.3 Interaction Impedance

The method of MAFIA simulation interaction impedance is the same as the experiment method. Making use of perturbation theory, a cylindrical dielectric rod is placed on the central axis of cavity. Then the resonance frequency shift of perturbed cavity is simulated and gained, then interaction impedance is calculated by a special equation expression. The modal with perturbed rod is plot in figure 4.

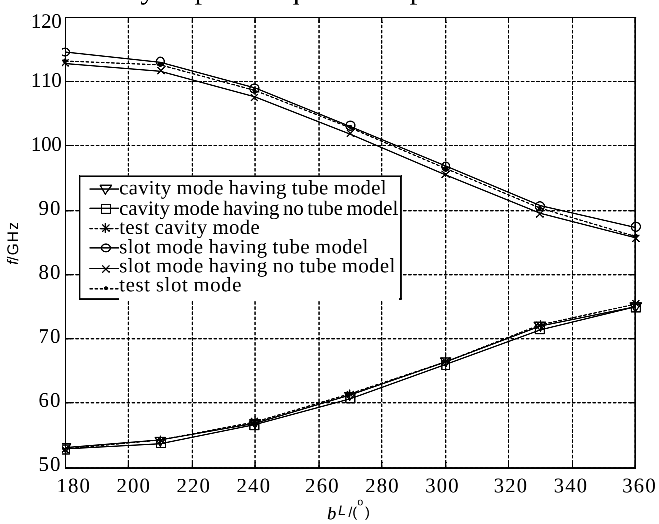

Figure 3 Comparison of dispersion curve by MAFIA simulation with experiment

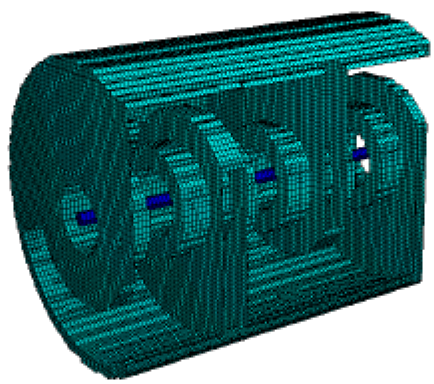

Figure 4 MAFIA 3－D view of couple cavity slow wave circuit with perturbing rob

D.J.Connolly provided a equation expression of calculating couple cavity interaction impedance using perturbation theory in his paper[3], based on the primary expression of interaction impedance

$$K_n = \frac{E_{zn}^2}{2b_n^2 P_{RF}} \tag{1}$$

where E_{zn} is the longitudinal electric field magnitude of the nth axial space harmonic, P_{RF} is the time averaged RF power flow and b_n is the axial propagation constant of the nth space harmonic define by $b_n = b_0 + 2\pi n/L$, where b_0 is the fundamental phase constant, L is a period of couple cavity.

In the couple cavity slow wave circuit, the beam is synchronous with only first RF space harmonic. So interaction impedance for the first forward space harmonic of the couple cavity slow wave circuit is calculated from the equation expression of interaction impedance in the D.J.Connolly's paper[3].

$$K_1 = \frac{2Dw}{w\pi b^2 (e_r - 1) e_0 |b_1|^2 v_g} \tag{2}$$

where b is the rod radius, e_r is the dielectric constant of rod, Δw is frequency shift, v_g is group speed calculated from dispersion curve's slope, b_1 is the axial propagation constant of the first space harmonic.

Then frequency shift of MAFIA simulation after perturbation of cavity are placed in the equation(2), the interaction impedance curve is obtained by the calculation equation expression and is plot in figure 5. The MAIFA simulation result receive more consistent with experimental data, and compared with experimental data precision reach 5.5%.

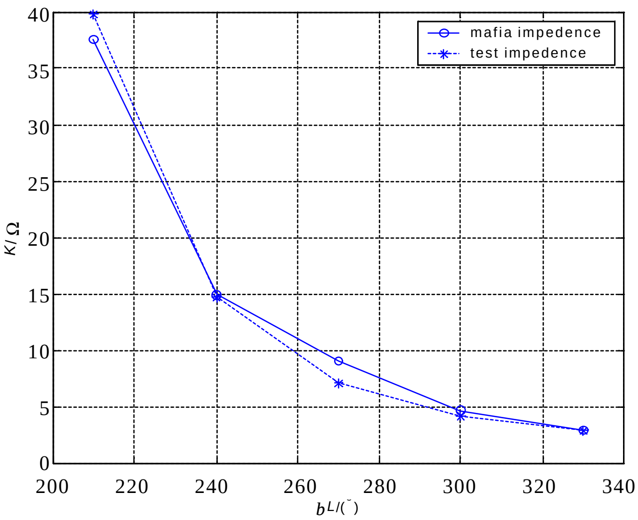

Figure5　Comparison of interaction impedance by MAFIA simulation with experiment data

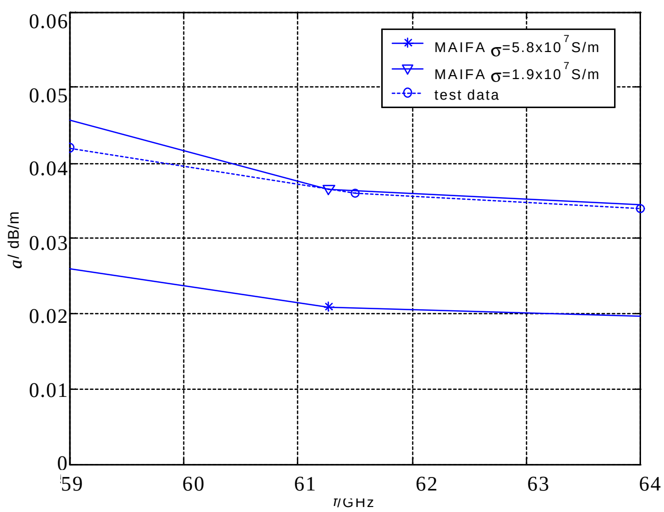

Figure6　Comparison of attenuation constant by MAFIA simulation with experiment data

2.4　Attenuation Characteristic

Simulation of attenuation constant of couple cavity is gained by the given equation expression of calculating attenuation constant, which calculating parameter is obtained by MAFIA Post module. The primary equation of calculating attenuation constant:

$$a = 8.686 \frac{P_L}{2P_{RF}} \tag{3}$$

where P_L is the total power loss for a traveling wave in N cavities. P_{RF} is the time averaged RF power flow.

The paper[1] provided the given equation expression of calculating attenuation constant:

$$a = 4.343\frac{P_{LS}L}{W_s v_g} \tag{4}$$

where P_{LS} is the total power loss for a standing wave, W_s is total time-averaged electromagnetic field energy for a standing wave. These parameters are calculated by MAFIA Post module, then attenuation constant curve is obtained after these parameters are placed in the equation(4).

This attenuation constant curve include two kind of material: $s = 5.8\times10^{7}\,\mathrm{S/m}$, $s = 1.9\times10^{7}\,\mathrm{S/m}$, and are plot in figure 6. The MAIFA simulation result receive more consistent with experimental data, and compared with experimental data precision reach 2%.

3 Conclusion

In this paper's simulation, considering effect of tube-envelop make simulating data more consistent with experiment data, and give very good result. Many data that experiment cannot be obtained is obtained by making use of MAFIA software to cold-test for coupled cavity circuit, and these simulation data is more consistent with experimental data, instructing the design and research of couple cavity traveling-wave tube, saving on time and cost in the course of research and manufacture, improving the work efficiency of design and research.

References

1 Kory C L, Wilson J D. Three-dimensional simulation of traveling-wave tube cold-test characteristics using MAFIA. NASA Technical Paper 3513 , 1995: 1-26

2 kantrowitx F, Tammaru I, Three-dimensional simulations of frequency-phase measurements of arbitrary coupled-cavity RF circuit. IEEE Trans. Electron Devices, 1988, 35(11): 2 018-2 026

3 Connolly D J. Determination of interaction impedance of coupled cavity slow wave structure. IEEE Trans. Electron Devices, 1976, 23(5): 491-493

· 科研成果介绍 ·

强电流铁电陶瓷材料研究

主研人员：张树人 付应泉 郭曙光 钟朝位 周晓华 蔡雪梅 余昌奎 黄富钊 韩 冬 杜广山

强电流铁电陶瓷是一种组成结构为铁电相与反铁电相共存，而极化后为铁电相和亚铁电相的特种功能材料。

该项目在四种材料中优选出一种缺位型新材料，采用等静电成型，极化前高温退火及高温极化工艺技术，制备了平行发射和垂直发射的铁电阴极样品，通过对电极边缘的绝缘保护处理增大了激励场强，提高了发射电流强度。通过SEM、XRD及晶胞参数测定等微观结构分析，验证了快极化反转引起电子发射机理的正确性，研究了结构缺陷、局部相变与电子发射特性的关系，为铁电阴极材料的开发应用提供了理论基础。

·渠 涌·