ANNEX II

Numerical code (*Complex Fishbone*) for the calculation of TE, TM and hybrid waves in a corrugated waveguide with losses

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Abstract

A numerical code (*Complex Fishbone*) has been developed to calculate the characteristics of a gyrotron beam tunnel. The latter is considered as a waveguide with non-periodic corrugations filled with a lossy material. The code offers the capability to calculate the dispersion relation, the quality factor, and the electromagnetic field distributions for all kind of propagating modes (TE, TM and hybrid). We compare our results with those obtained by other numerical codes and the agreement is excellent for all cases presented here.

Numerical Code and Results

The geometry of a cylindrical waveguide with non-periodic corrugations filled with lossy material as well as the major part of the corresponding numerical code is similar to that described in previous Annex. Furthermore, the field analysis has been described in previous period's annex. Therefore, they are omitted here.

The main difference of this code is the location of the complex roots. For this reason, we have used a method adapted to our problem [1]. The method consists of scanning an area of the complex plane with a square of small size to locate the region, where the real and imaginary parts of the complex function studied simultaneously nullify each other [Fig. 1a]. The possible changes of sign in the function are not detected between the segment extremities (classical bisection method), but in between the vertices of a square [Fig. 1b]. If two changes of sign are detected for the real part as well as for the imaginary part of the function, a square four times smaller than the previous one is defined around the point of intersection of the segments [Fig. 1c]. The process goes on until a precise value is reached for the dimensions of the square. Once a root is located, the search for other solutions continues. The calculation stops when the number of solutions is reached.

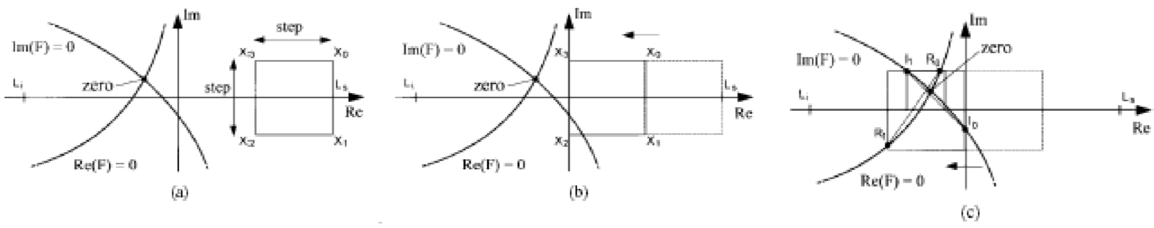


Figure 1

The results of the *Complex Fishbone* code are tested with those obtained by the *Cascade* [2]. In Fig. 2 we give the dispersion relation of the first TM mode for the periodic geometry given in Table 1. Obviously, the agreement between the two codes is excellent. For the same geometry but with ε = 7-j0.5, the real part of the frequency of the first TM mode is given in Fig. 3, from where it is evident the identical results obtained by *Complex Fishbone* and *Mafia* [3]. In addition, the agreement between the two codes is also excellent for the imaginary part of the frequency as well as for higher order TM, TE and hybrid modes, as well as for the field distributions. Next, we present results for the non-periodic geometry given in Table 2. The results obtained by the *Complex Fishbone* for the dispersion relation for all kind of modes are close to those obtained by *Mafia*.

Finally, for the non-periodic geometry given in Table 3, we present results for the field distributions of the first TE mode. From Figs. 7 and 8, it is evident the excellent agreement between *Complex Fishbone* and *Mafia*.

Table 1

α (mm)	D (mm)	b (mm)	L (mm)
6	14	3	6

Table 2

α (mm)	D_i	b_i (mm)	L_i (mm)	ε_i
6	13	3	6	7-j0.5
6	11	4	6	7-j0.5
6	17	2	3	7-j0.5

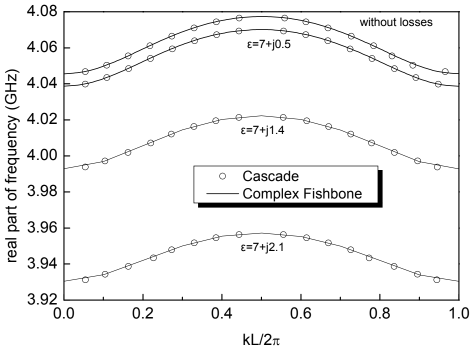


Figure 2: Real part of the frequency of the first TM mode for the periodic geometry given in Table 1.

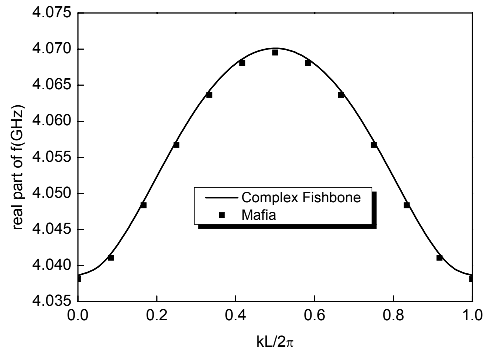


Figure 3: Real part of the frequency of the first TM mode for the periodic geometry given in Table 1 with ε = 7-j0.5.

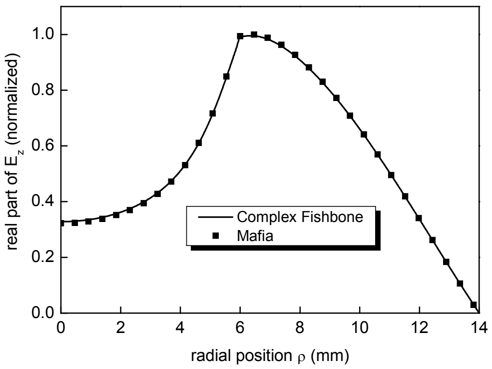


Figure 4: Variation of E_z with ρ at z = 1.55 mm for $kL/2\pi$ = 0.25 of the first TM mode for the periodic geometry given in Table 1 with ε = 7-j0.5.

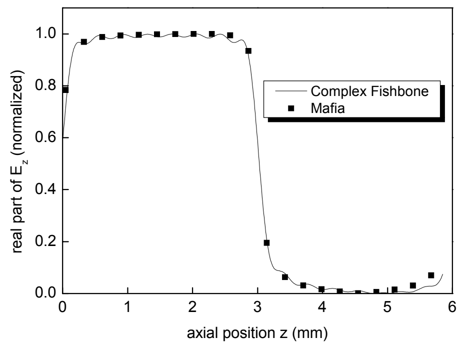
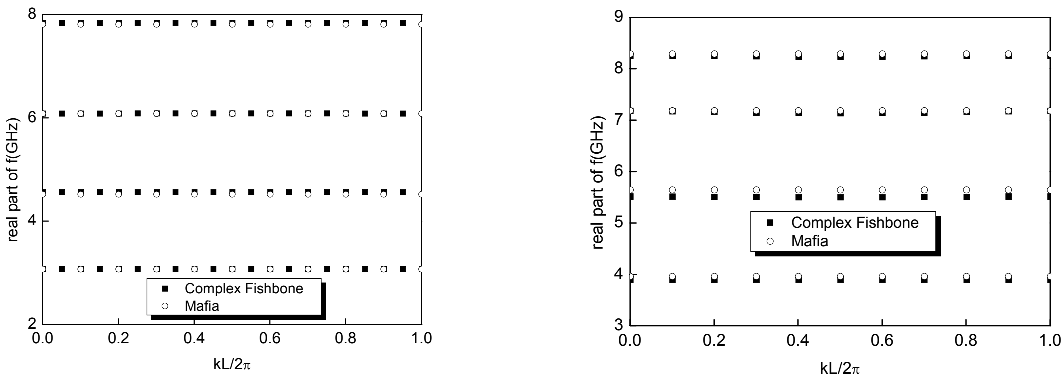


Figure 5: Variation of E_z with z at ρ = 5.9077 mm for $kL/2\pi$ = 0.25 of the first TM mode for the periodic geometry given in Table 1 with ε = 7-j0.5.



(a) (b)

Figure 6: Spectrum of TM (a) and hybrid modes with m=1(b) for the non-periodic geometry given in Table 2.

Table 3

α (mm)	D_i (mm)	b_i (mm)	L_i (mm)	ε_i
6	14	1	4	8-j0.4
6	16	4	6	7.5-j0.6
6	18	2	4	10-j0.1
6	20	7	10	9-j0.8

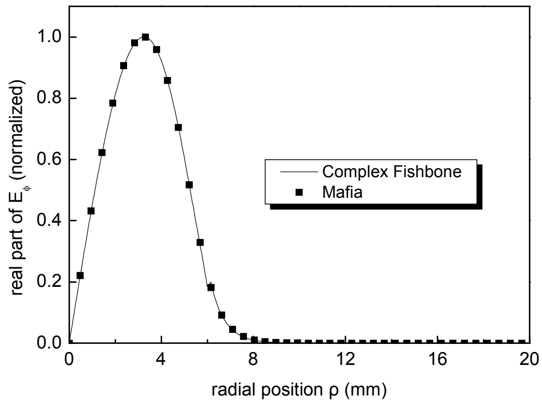


Figure 7: Variation of E_φ with ρ at z = 11 mm for $kL/2\pi$ = 0.25 of the first TE mode for the geometry given in Table 3.

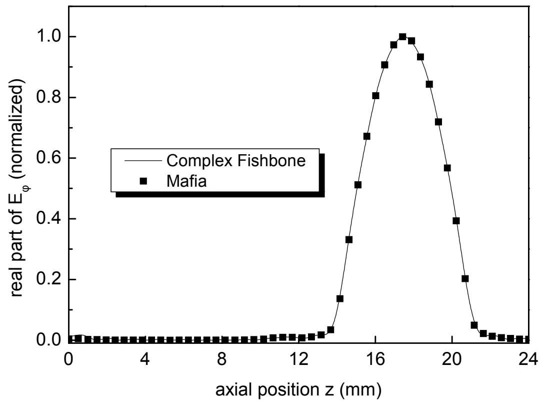


Figure 8: Variation of E_φ with z at ρ = 5.8421 mm for $kL/2\pi$ = 0.25 of the first TE mode for the geometry given in Table 3.

In conclusion, it has been found that the agreement between the three codes (*Complex Fishbone*, *Cascade* and *Mafia*) is excellent in all cases, for both the dispersion relation curves and the field components distributions. Of course, the most significant feature of our code is the very fast calculation of the dispersion relation with just a few harmonics, which results to a significant reduction to the CPU time needed.

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References

[1] P. Queffelec, M. Le Floc'h and P. Gelin, ″Nonreciprocal cell for the broadband measurement of tensorial permeability of magnetized ferrites: direct problem″, IEEE Trans. Microwave Theory Techniques, Vol. 47, No. 4, pp. 390-397, 1999.

[2] W. G. Lawson and P. E. Latham, ″The scattering-matrix formulation for overmoded coaxial cavities″, IEEE Trans. on Microwave Theory and Techniques, vol. 40, pp. 1973-1977, 1992.

[3] T. Weiland, et al.: Mafia Version 4, Proc. of the Computational Accelerator Physics Conference (CAP), 1996, Williamsburg, Virginia, pp. 65-70.