

ESS DTL

POST-COUPPLERS INSERTION AND TANKS

FREQUENCY, E_0 FIELD VARIATIONS

E_0 FIELD ADJUSTMENT THROUGH FACE ANGLES

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INTRODUCTION

Drift Tube Linac cavities operate in the TM_{010} mode. The fields in all the cells have the same phase, so that the overall cell array operates in a 0 mode. The group velocity of a resonating mode is proportional to the slope of the dispersion curve at that point, being v_g . Since the group velocity of the TM_{010} mode is zero, there is no power flowing along the structure and the field distribution is very sensitive to frequency perturbations of the cells, power losses and beam loading [1]. Post couplers are used to stabilize the accelerating fields of DTLs against tuning errors [1],[2]. In 1967, based on their work on coupled cavity chains, Knapp, Swenson, and Potter, invent a resonant coupling device that they call post-coupler to minimize the sensitivity of the TM_{010} axial electric field mode to tuning errors [3].

When correctly tuned, the post-couplers have their modal spectrum just below that of the accelerating modes. At this point they are in confluence and make the cavity operate in a hybrid $\pi/2$ – type mode [2].

POST COUPLERS FIELD STUDY IN SUPERFISH

Regarding ESS, a stem – insertion study was performed in Superfish and HFSS [4]. In this report, post couplers of length 19 cm and radius 1 cm are introduced in the Superfish simulated tank models, and the deviation of the axial field $E_{0_stems + posts}$ with respect to what found in the models containing only stems (E_{0_stems}), is observed for each tank. PCs exact insertion positions are listed in file “V.84_All_Parameters_15_01_2016”.

In the process of tuning the single cells and subsequently the entire tanks, Superfish simulator calculates two different frequencies: the first is the proper target resonant frequency of the cell (or tank) considered, and the second, named “Cavity frequency corrected for stems and post couplers”, is the resulting resonant frequency when the simulator takes in account the subtracted cavity volume due to the presence of stems and/or Post Couplers. These two numbers can be found in the .SFO file created when the cavity/tank tuning is performed.

Superfish tunes the cells by making a revolution solid, around beam axis, from the 2D cell plot, and then it calculates the corrected frequency, $f_{stems + posts}$, using Slater

perturbation theorem. These calculations are applications of the Slater perturbation theorem using fields calculated by Fish in the region occupied by the stem.

Another way to study the presence and the effects of stems and post couplers on fields and resonant frequency could be the subtraction of a stem-PC proportional volume from the cell volume. By knowing the stem-PC corrected frequency for each cell, this could be done by modifying the geometry of the single cells through subtraction of a volume in the way to tune the cell and reach the stem-PC corrected frequency. Then, the entire tank can be assembled and the frequency, fields can be observed.

Figure 1 shows a detail of tank 1 where triangles subtracted on the tank wall are equivalent to stem-PCs Slater effect, while triangles subtracted on drift tube walls are for stems.

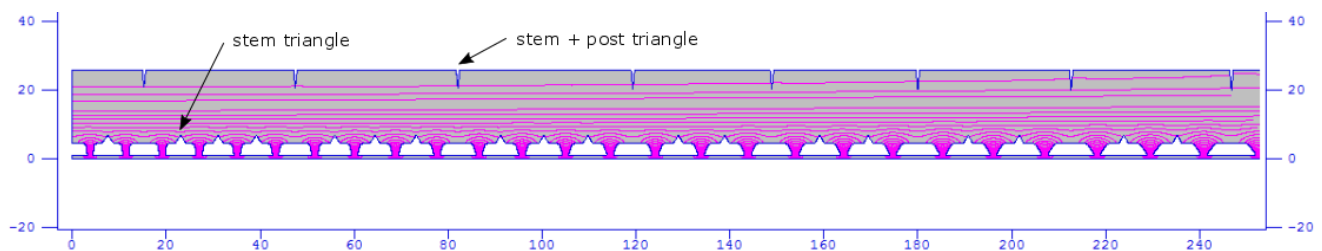


Figure 1 - Detail of Superfish's tank 1 with the area subtraction method applied, to take in account effects of stems and PCs. Bottom triangles are stems', top triangles are stem-PC's.

The following figures 2, 3, 4, 5 and 6 show E_{0i} field plots, for every cell composing each tank, normalized to max value. Values are obtained by the application of the volume subtraction method: each plot is E_{0_stems} vs $E_{0_stems + posts}$, for the five tanks of the DTL. The difference is larger in tank 1 and tank 2 because the number of cells and cell length variation is larger than in the next tanks and, moreover, the post couplers distribution per cell is variable in order to keep the same average distance between posts.

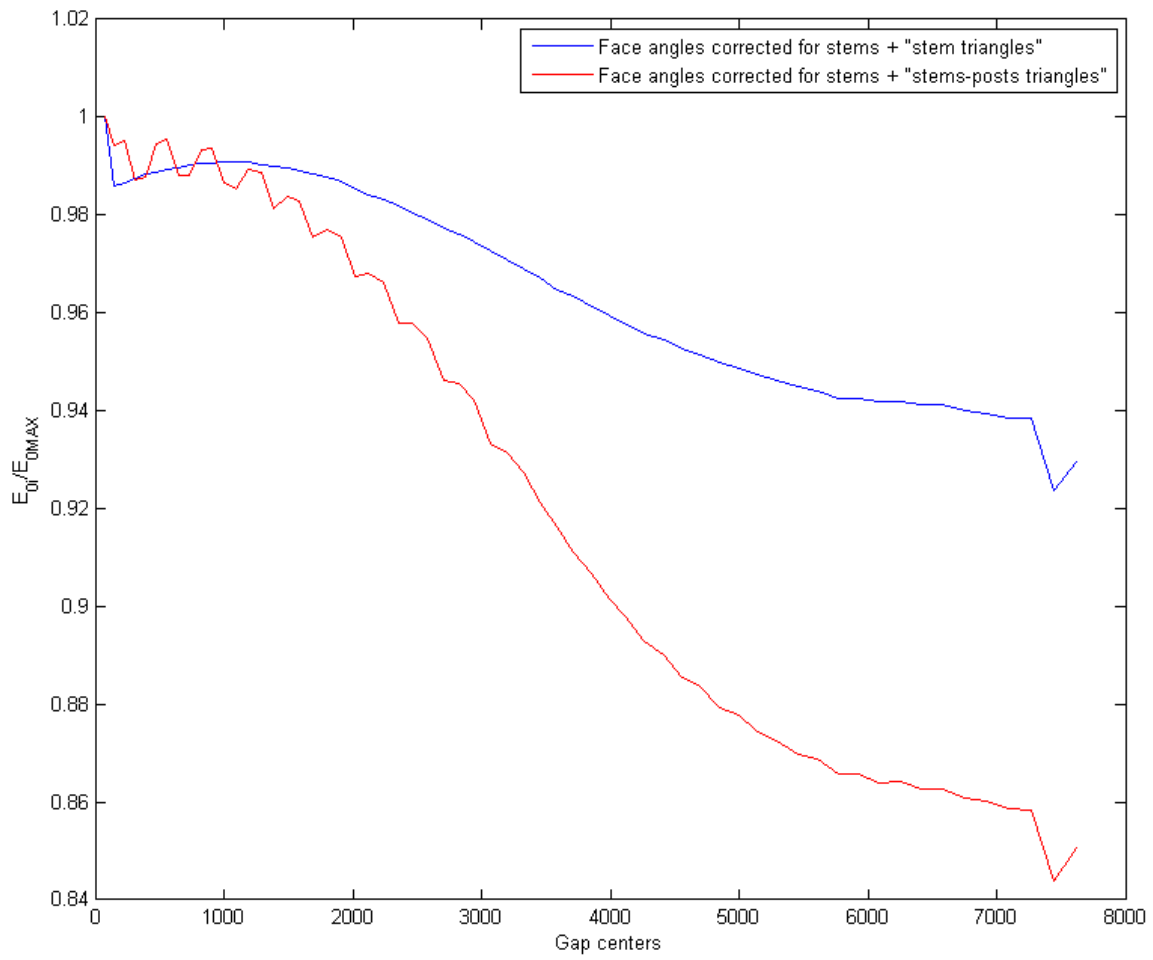


Figure 2 – Values of E_{0i}/E_{0MAX} for tank 1. Blue curve represent the field when only stem areas are subtracted, red curve represents the field when stem and PC areas are subtracted.

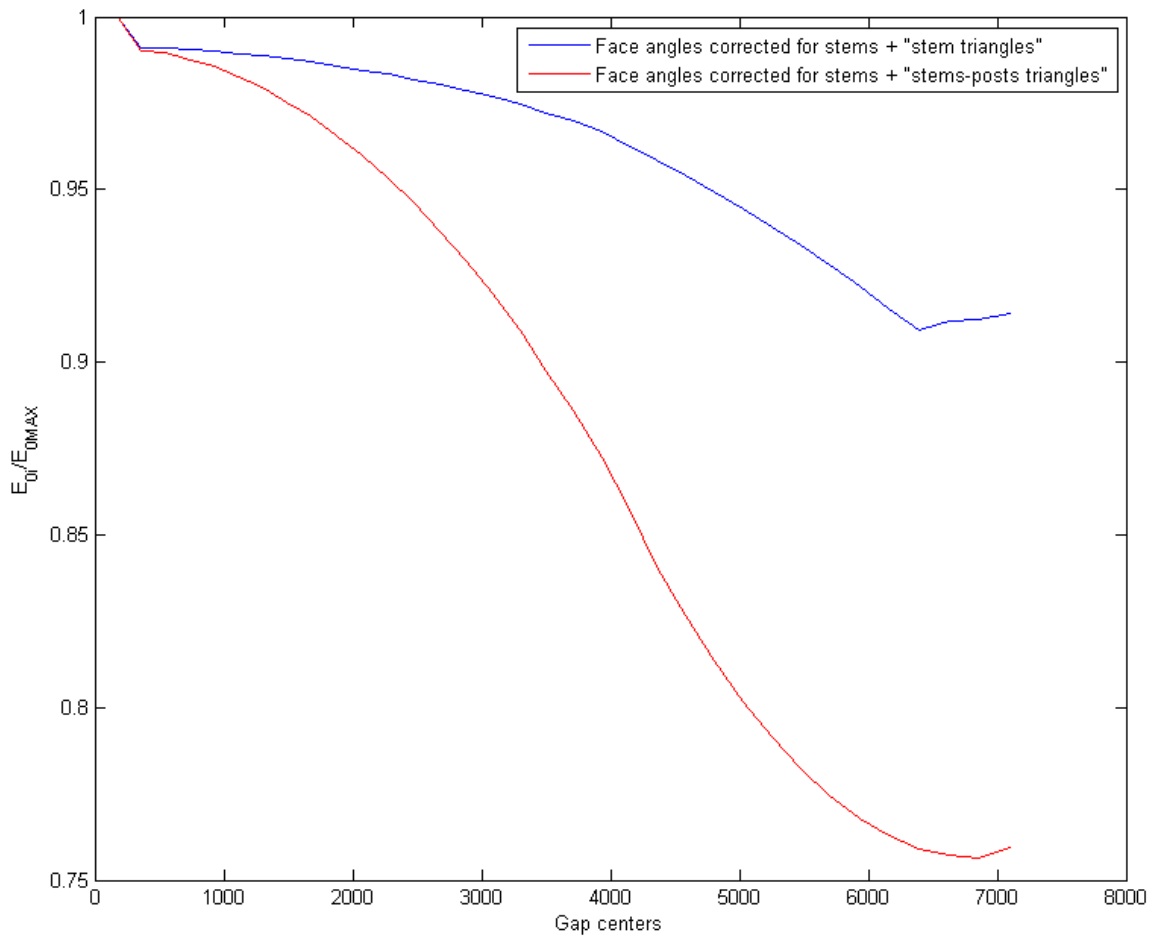


Figure 3 - Values of E_{oi}/E_{0MAX} for tank 2. Blue curve represent the field when only stem areas are subtracted, red curve represents the field when stem and PC areas are subtracted.

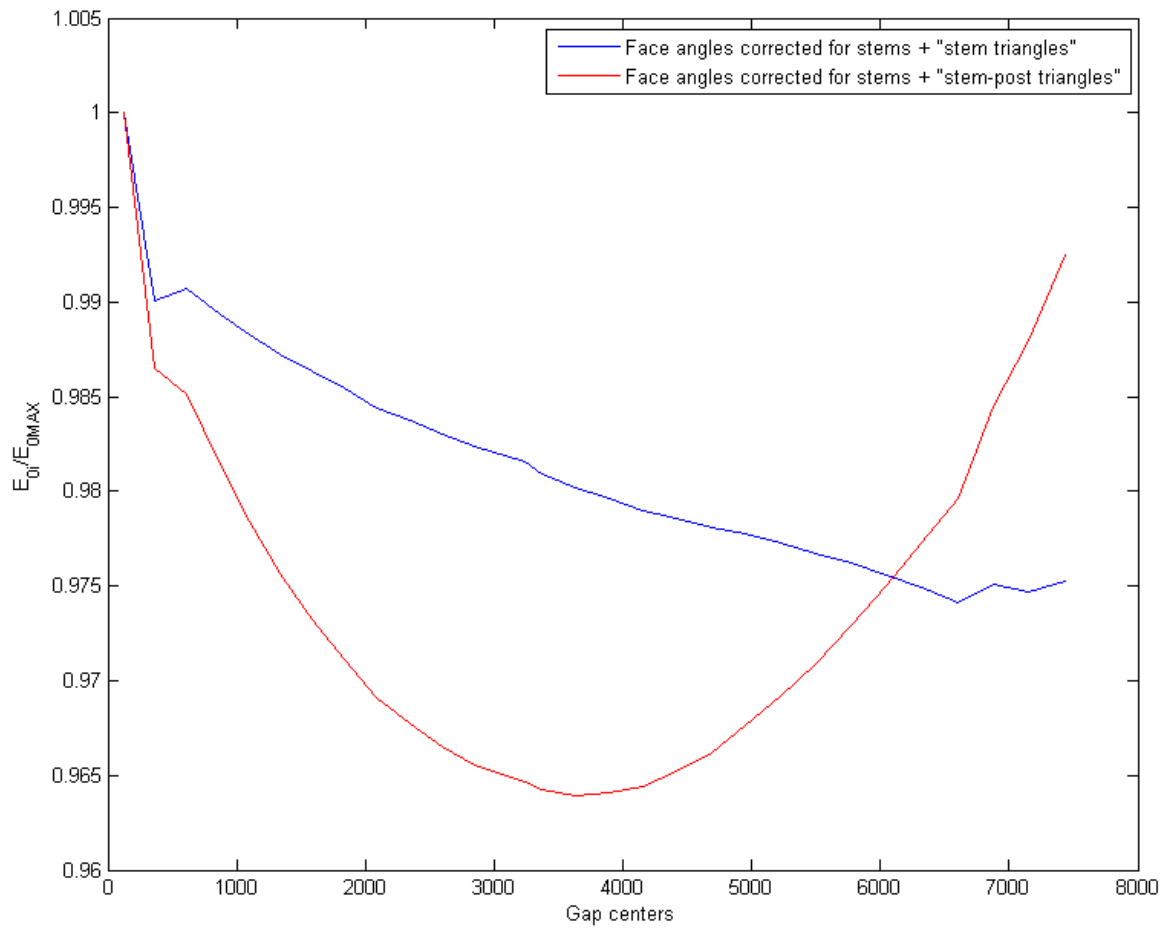


Figure 4 - Values of E_{oi}/E_{omax} for tank 3. Blue curve represent the field when only stem areas are subtracted, red curve represents the field when stem and PC areas are subtracted.

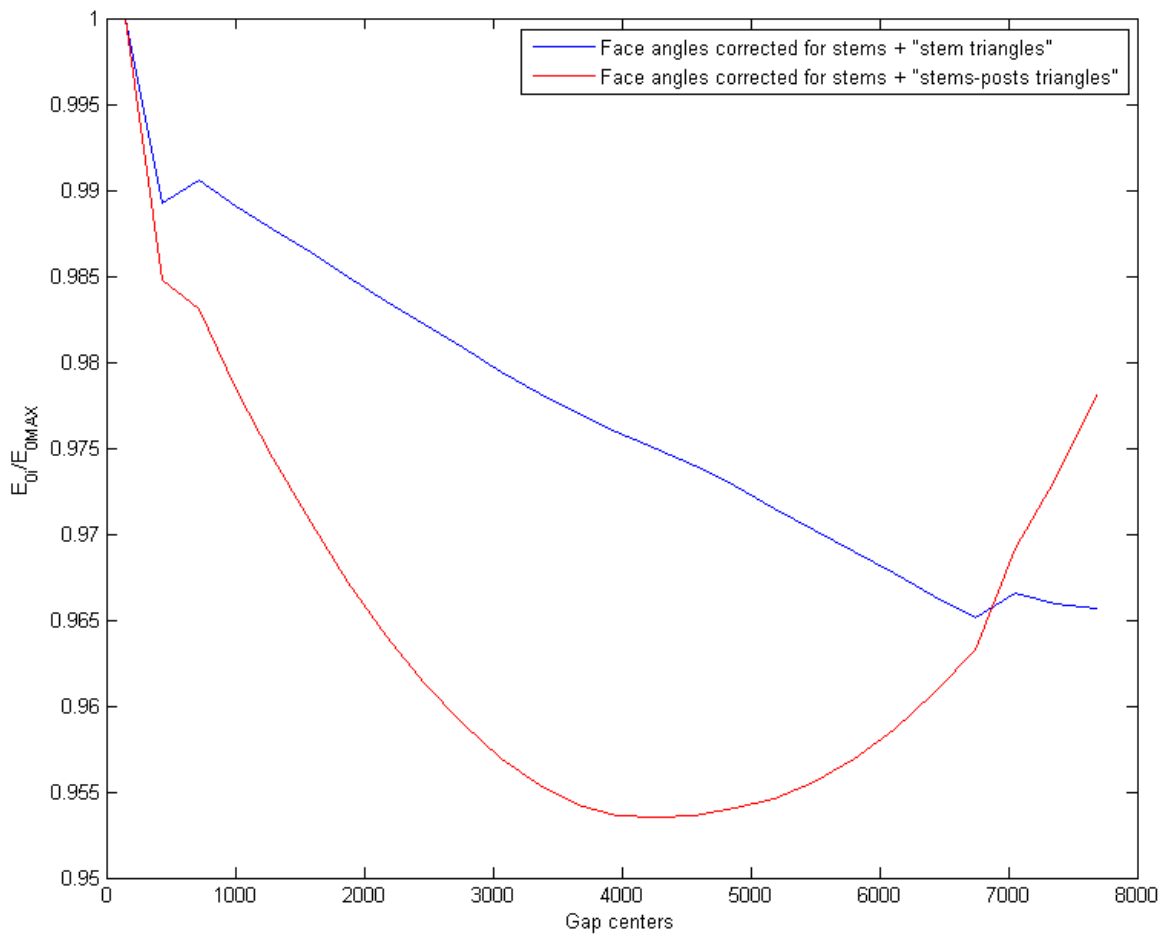


Figure 5 - Values of E_{0i}/E_{0MAX} for tank 4. Blue curve represent the field when only stem areas are subtracted, red curve represents the field when stem and PC areas are subtracted.

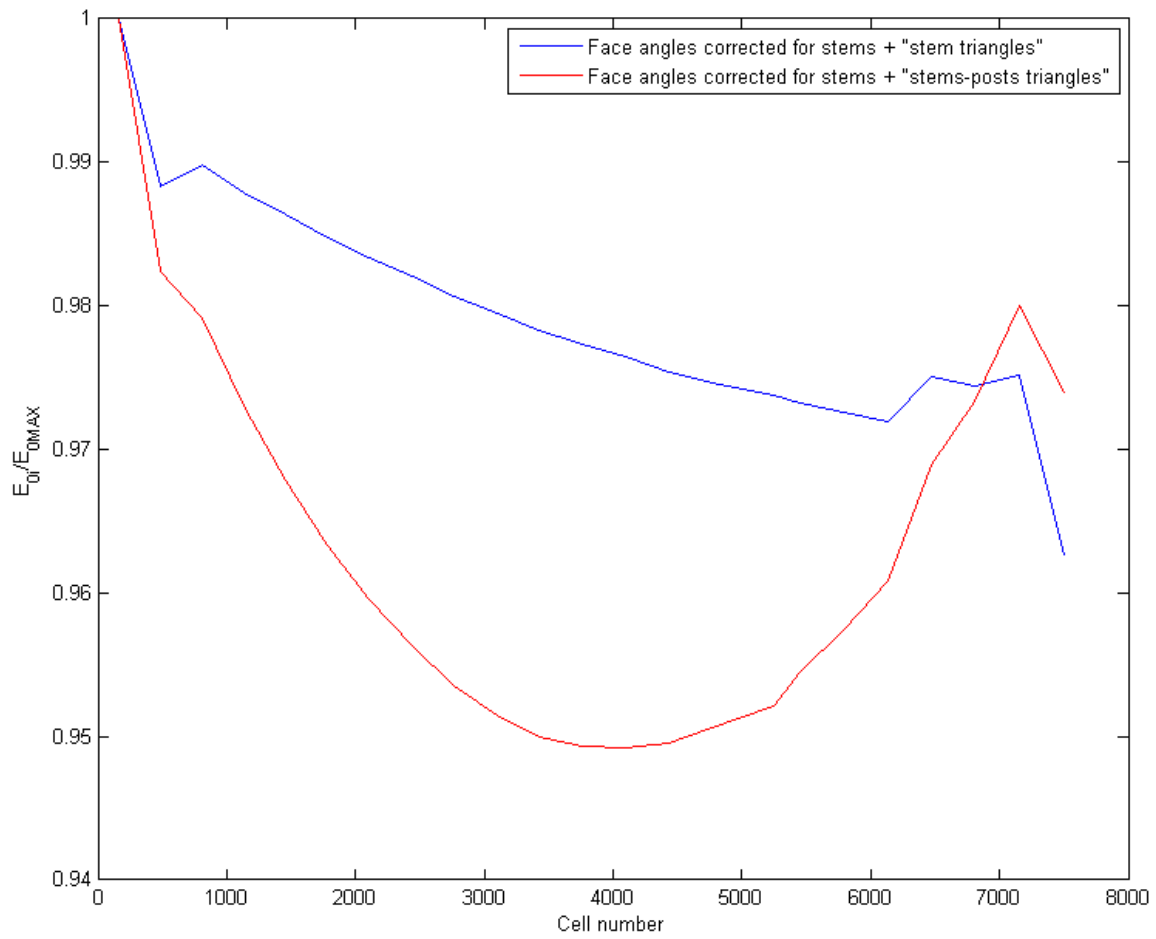


Figure 6 - Values of E_{0i}/E_{0MAX} for tank 5. Blue curve represent the field when only stem areas are subtracted, red curve represents the field when stem and PC areas are subtracted.

TANK RESONANT FREQUENCIES: STEMS vs STEM-PCs

When stems and/or PCs are inserted, the tank resonant frequency shifts. All the five tanks resonant frequencies were observed, using Superfish, with a comparison of two methods:

1. by simple reading the value in the .SFO file, when stem-PCs areas are subtracted from cavity volume (not considering the “cavity frequency corrected for stems and post couplers” value);
2. by creating, through .DTL file, the .MDT and .SEG files for each tank, then modifying the .SEG files in the way to include all stems and PCs and let Superfish calculates the “cavity frequency corrected for stems and post couplers”, with application of Slater theorem, in the lower end of .SFO file.

Results are shown in Table 1, and the agreement is a confirmation of the model goodness.

Table 1 - Tank frequencies obtained in Superfish through the use of the two illustrated methods.

	$f_{\text{stems+PCs}}$ - method 1 (MHz)	$f_{\text{stems+PCs}}$ - method 2 (MHz)
Tank 1	351,48	351,50
Tank 2	351,53	351,53
Tank 3	351,61	351,61
Tank 4	351,60	351,60
Tank 5	351,61	351,60

E_0 FIELD STABILIZATION THROUGH FACE ANGLES MODIFICATION

As one can see from plots in previous section, introducing PCs leads to larger E_0 range, especially for tanks 1 and 2. To obtain good particle acceleration in DTLs, average field flatness is required (E_0 tank value must be as constant as possible). So, the range of values within each E_0 curve swings, must be as small as possible, in the way to assure field flatness inside the tank. Superfish normalizes E_0 values around 1 MV/m, so if the same operation is performed for each tank composing the DTL, it can be seen that the field range for tank 1 is 0.15 and for tank 2 in 0.25, while for the other tanks the difference between maximum and minimum values is small (the field flatness is preserved). Indeed, a field stabilization is required for the first two tanks. One way to do this is through modification of drift-tube's face angles, for each cell composing the tank. This operation can be done in Superfish, by modifying face angles value in the .DTL file and then operate on the tank geometry in the .AM file.

Figure 7 shows a detail of a DTL cell. Face angle α is essentially a tuning parameter: it allows field and frequency adjustments when needed. Also, larger α increases DT “noose”, decreases gap length and thus improves transit time factor T.

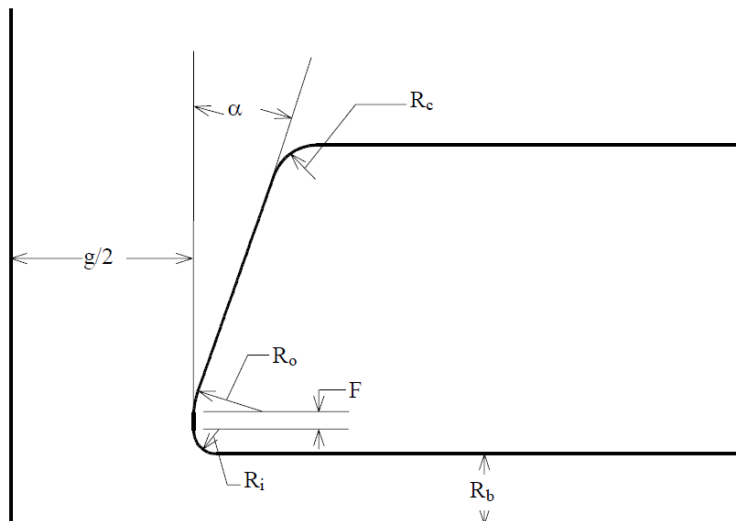


Figure 7 - Detail of a DTL cell.

The optimization procedure was performed on tank 1, tank 2 and tank 4, results are shown in figures 8, 9, 10. Curves are E_{0i} values, for each cell of the considered tank, normalized to max value. Tanks frequency shift is negligible, so it won't be reported.

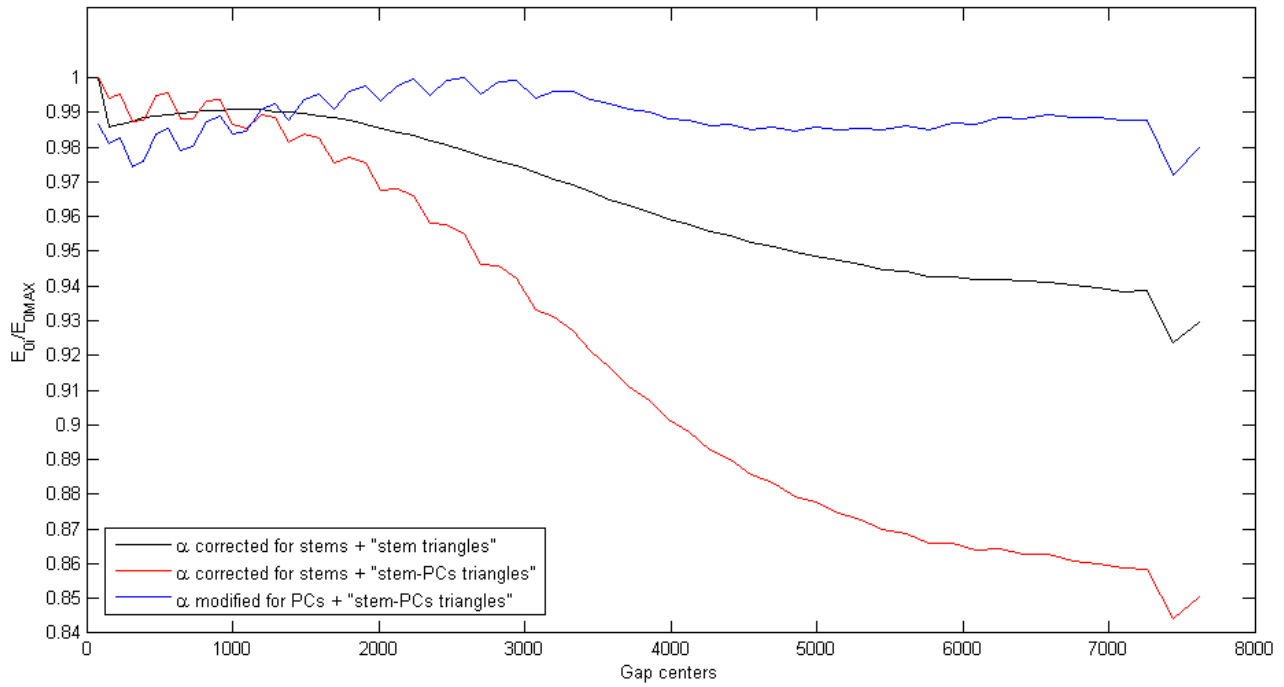


Figure 8 - Stabilization of tank 1 E_0 field through modification of face angles α . Black curve is field when stems are inserted and α corrected for stems are used. Red curve is field when stems and PCs are inserted and α corrected for stems are used. Blue curve is field when stems and PCs are inserted and modified α for PCs are used.

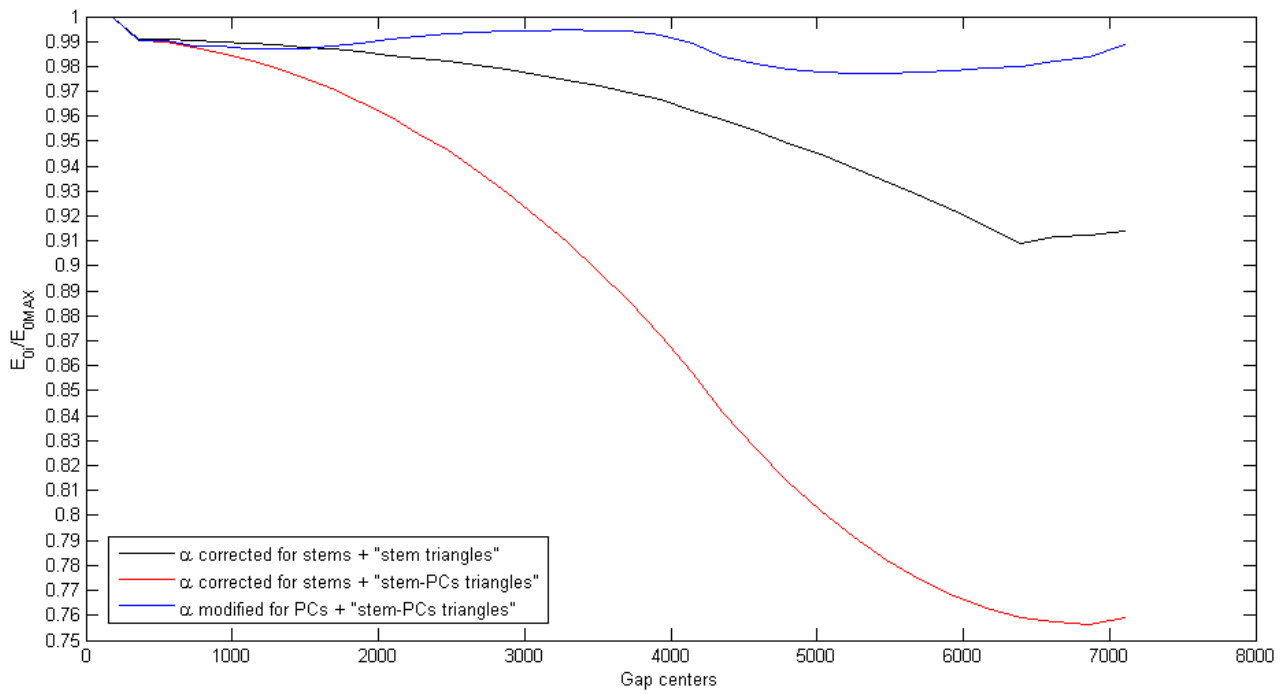


Figure 9 - Stabilization of tank 2 E_0 field through modification of face angles α . Black curve is field when stems are inserted and α corrected for stems are used. Red curve is field when stems and PCs are inserted and α corrected for stems are used. Blue curve is field when stems and PCs are inserted and modified α for PCs are used.

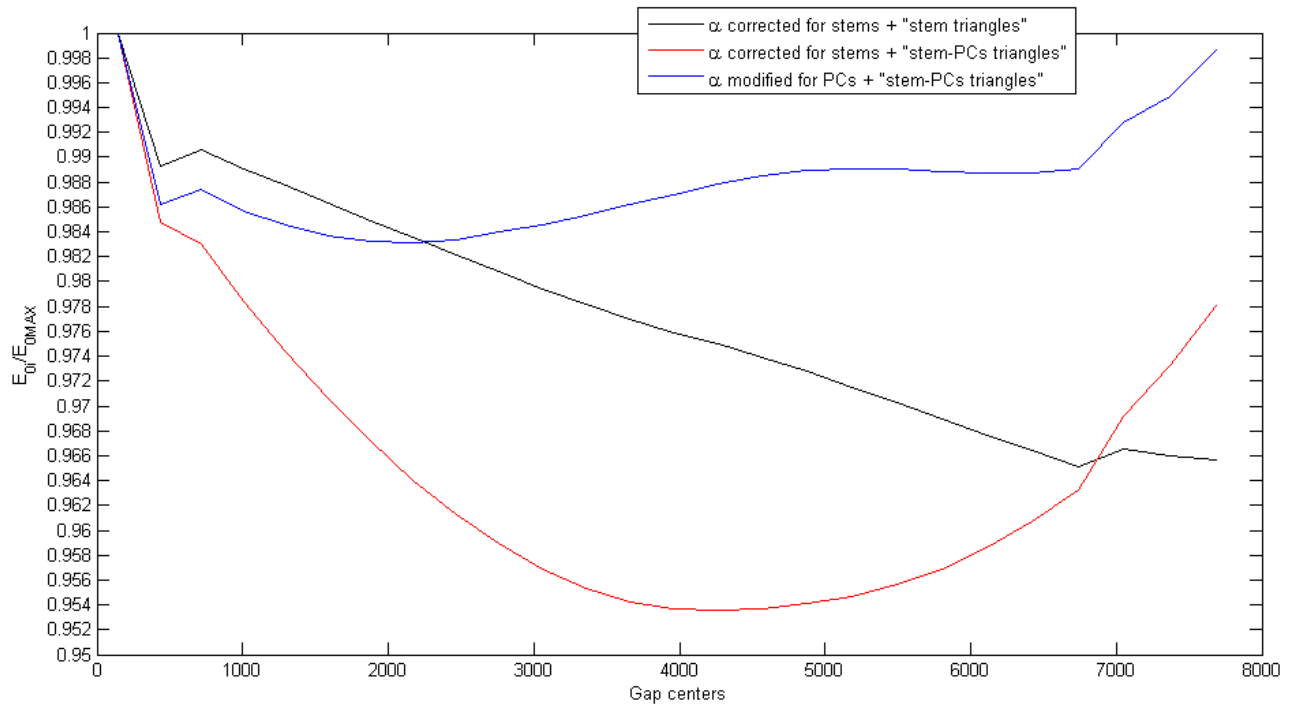


Figure 10 - Stabilization of tank 4 E_0 field through modification of face angles α . Black curve is field when stems are inserted and α corrected for stems are used. Red curve is field when stems and PCs are inserted and α corrected for stems are used. Blue curve is field when stems and PCs are inserted and modified α for PCs are used.

Figures 11 and 12 are face angle plots, for tank 1 and 2: the curves show the difference between original α , α corrected for stems insertion, α modified for stems and PCs insertion.

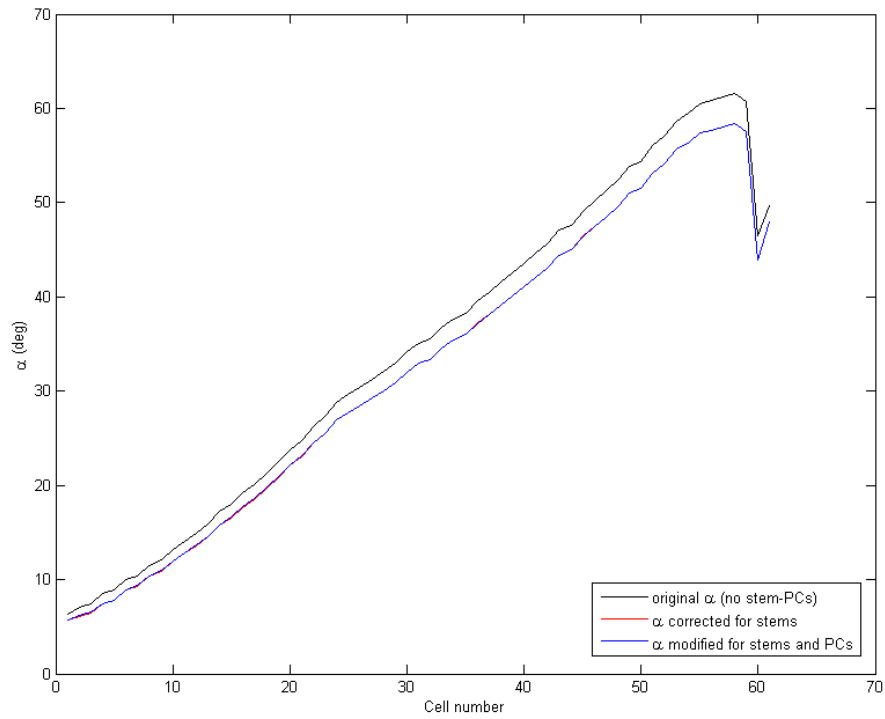


Figure 11 - α plots for tank 1.

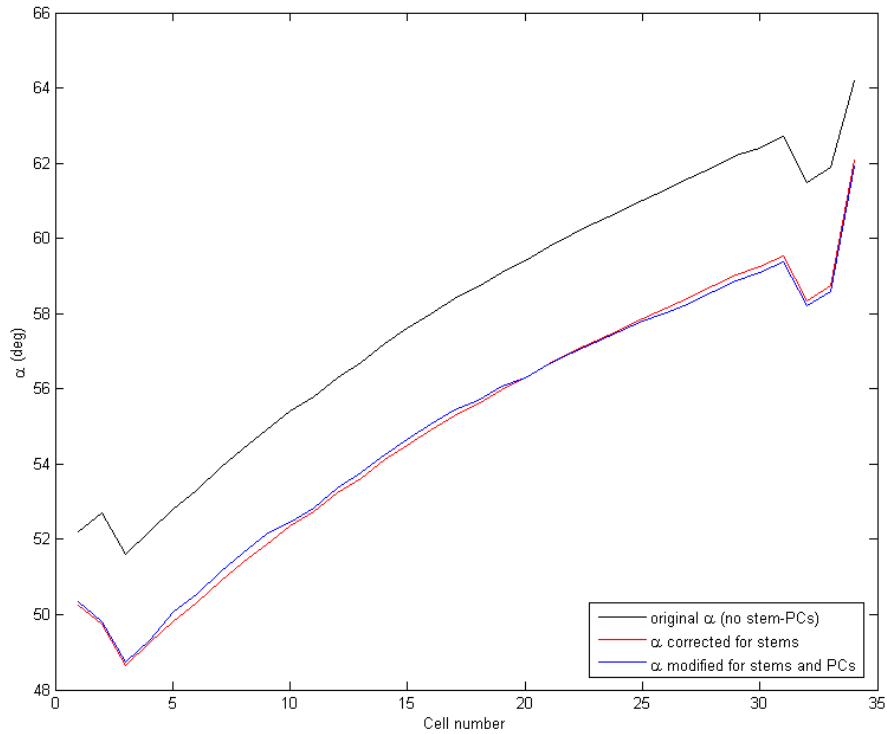


Figure 12 - α plots for tank 2.

Tables 2, 3 and 4 show the difference between face angles corrected for stems and face angles corrected for stem-PCs.

Table 2 - Tank 1: difference between α corrected for stems and α corrected for stem-PCs.

N. cell	α corrected for stems (deg)	α corrected for stem-PCs (deg)	Difference (deg)
1	5.72	5.77	+ 0.05
2	6.10	6.15	+ 0.05
3	6.47	6.52	+ 0.05
4	7.45	7.45	0
5	7.81	7.83	+ 0.02
6	8.88	8.93	+ 0.05
7	9.29	9.34	+ 0.05

8	10.34	10.37	+ 0.03
9	10.91	10.96	+ 0.05
10	11.92	11.98	+ 0.06
11	12.78	12.83	+ 0.05
12	13.61	13.66	+ 0.05
13	14.51	14.56	+ 0.05
14	15.74	15.78	+ 0.04
15	16.54	16.58	+ 0.04
16	17.65	17.69	+ 0.04
17	18.53	18.58	+ 0.05
18	19.73	19.78	+ 0.05
19	20.87	20.91	+ 0.04
20	22.13	22.17	+ 0.04
21	23.08	23.12	+ 0.04
22	24.45	24.48	+ 0.03
23	25.48	25.51	+ 0.03
24	26.94	26.98	+ 0.04
25	27.70	27.71	+ 0.01
26	28.47	28.49	+ 0.02
27	29.26	29.30	+ 0.04
28	30.05	30.05	0
29	30.87	30.88	+ 0.01
30	32.04	32.04	0
31	32.92	32.92	0
32	33.40	33.40	0
33	34.53	34.52	- 0.01
34	35.39	35.39	0
35	36.01	36.01	0
36	37.22	37.21	- 0.01
37	38.14	38.14	0
38	39.17	39.16	- 0.01
39	40.06	40.06	0
40	41.04	41.03	- 0.01
41	42.03	42.03	0
42	43.00	43.00	0
43	44.46	44.45	- 0.01
44	44.99	44.98	- 0.01

45	46.43	46.42	- 0.01
46	47.48	47.47	- 0.01
47	48.47	48.47	0
48	49.55	49.54	- 0.01
49	51.06	51.05	- 0.01
50	51.52	51.51	- 0.01
51	53.17	53.17	0
52	54.04	54.04	0
53	55.65	55.65	0
54	56.35	56.35	0
55	57.35	57.37	+ 0.02
56	57.65	57.66	+ 0.01
57	58.04	58.05	+ 0.01
58	58.42	58.43	+ 0.01
59	57.58	57.59	+ 0.01
60	43.86	43.87	+ 0.01
61	47.93	47.93	0

Table 3 - Tank 2: difference between α corrected for stems and α corrected for stem-PCs.

N. cell	α corrected for stems (deg)	α corrected for stem-PCs (deg)	Difference (deg)
1	50.26	50.34	+ 0.08
2	49.74	49.82	+ 0.08
3	48.66	48.74	+ 0.08
4	49.24	49.31	+ 0.07
5	49.82	50.06	+ 0.24
6	50.31	50.54	+ 0.23
7	50.89	51.12	+ 0.23
8	51.38	51.62	+ 0.24
9	51.87	52.13	+ 0.26
10	52.36	52.44	+ 0.08
11	52.75	52.83	+ 0.08
12	53.24	53.35	+ 0.11

13	53.63	53.76	+ 0.13
14	54.13	54.25	+ 0.12
15	54.51	54.65	+ 0.14
16	54.91	55.05	+ 0.14
17	55.30	55.43	+ 0.13
18	55.59	55.69	+ 0.1
19	55.99	56.08	+ 0.09
20	56.28	56.30	+ 0.02
21	56.68	56.66	- 0.02
22	56.97	56.95	- 0.02
23	57.27	57.24	- 0.03
24	57.56	57.51	- 0.05
25	57.86	57.79	- 0.07
26	58.15	58.01	- 0.14
27	58.44	58.29	- 0.15
28	58.74	58.59	- 0.15
29	59.03	58.88	- 0.15
30	59.24	59.09	- 0.15
31	59.53	59.37	- 0.16
32	58.35	58.20	- 0.15
33	58.74	58.58	- 0.16
34	62.08	61.91	- 0.17

Table 4 - Tank 4: difference between α corrected for stems and α corrected for stem-PCs.

N. cell	α corrected for stems (deg)	α corrected for stem-PCs (deg)	Difference (deg)
1	67.35	67.59	+ 0.24
2	66.22	66.21	- 0.01
3	65.63	65.63	0
4	65.73	65.72	- 0.01
5	65.83	65.82	- 0.01
6	65.93	65.92	- 0.01
7	66.02	66.02	0
8	66.12	66.12	0
9	66.22	66.21	- 0.01
10	66.32	66.29	- 0.03

11	66.32	66.28	- 0.04
12	66.42	66.37	- 0.05
13	66.52	66.47	- 0.05
14	66.61	66.57	- 0.04
15	66.71	66.67	- 0.04
16	66.81	66.76	- 0.05
17	66.91	66.86	- 0.05
18	66.91	66.86	- 0.05
19	67.01	66.96	- 0.05
20	67.10	67.07	- 0.03
21	67.20	67.18	- 0.02
22	67.20	67.19	- 0.01
23	67.30	67.30	0
24	66.53	66.52	- 0.01
25	66.72	66.76	+ 0.04
26	69.03	69.14	+ 0.11

CONCLUSIONS

In this note, a study of stem-PCs tank insertion using Slater theorem through area subtraction method, was performed. Fields and resonant frequencies are reported; the lasts are in good agreement when obtained by the two methods possible in Superfish simulator. Field stabilization for tank 1, 2 and 4 is also performed through face angles modification. Further PCs studies are required.

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