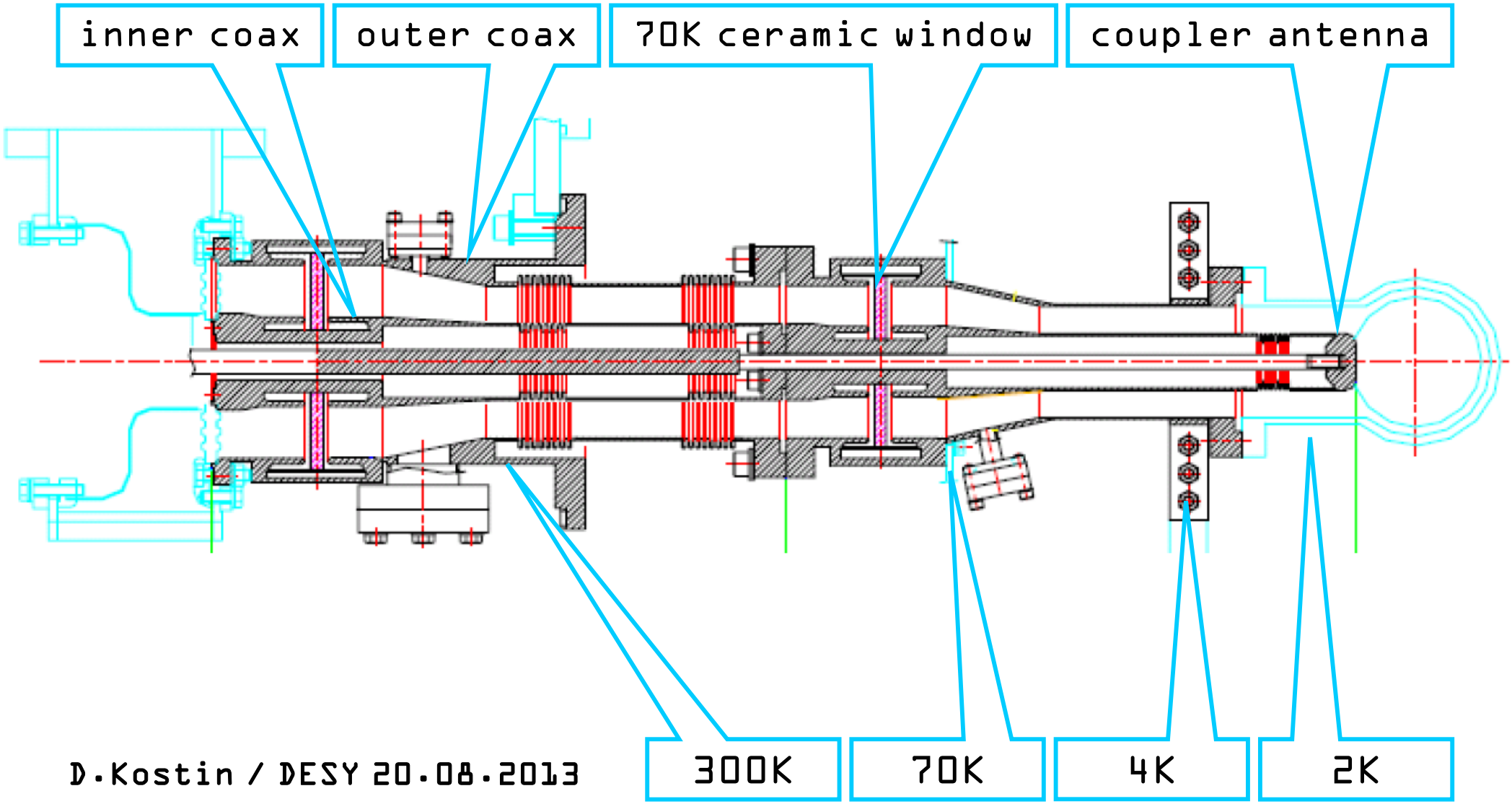
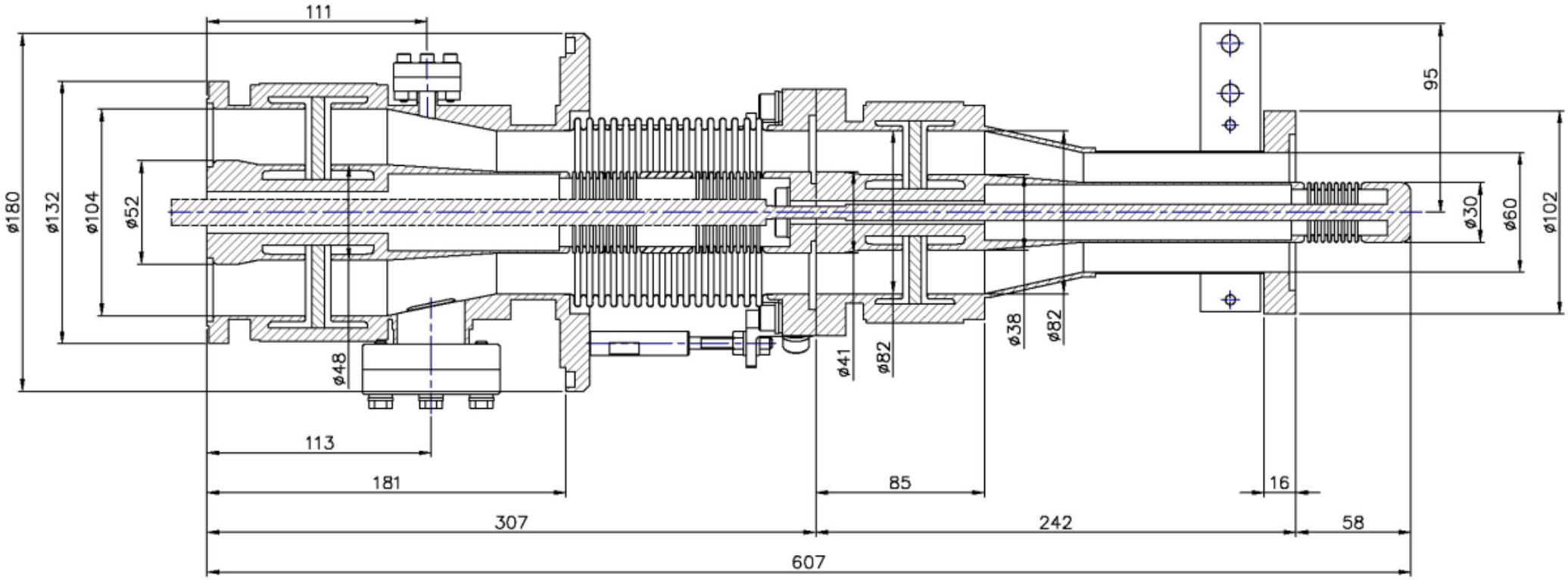
KEK S1-G / STF-2 RF POWER COUPLER THERMAL ANALYSIS



D.Kostin / DESY 20.08.2013

Coupler Dimensions

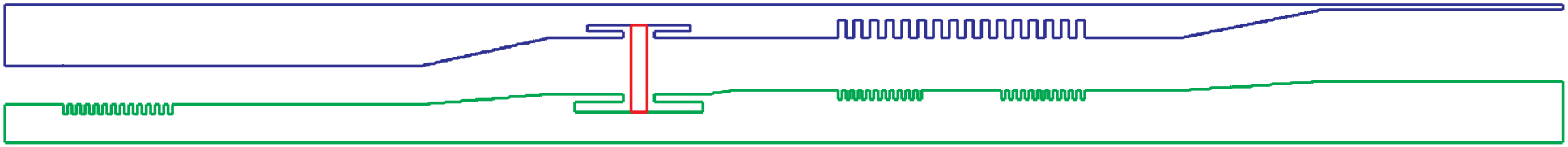


Copper Coating

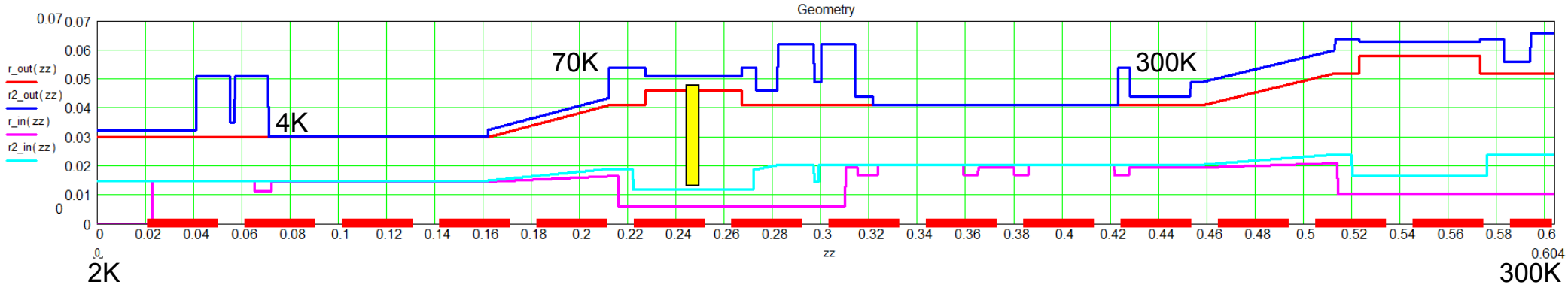
coupler	part	in [μm]	in RRR	out [μm]	out RRR
S1-G	cold	10	5	3	1.5
	warm	10	5	10	5
STF2	cold	25	20	10	5
	warm	25	20	25	20

Coupler Model

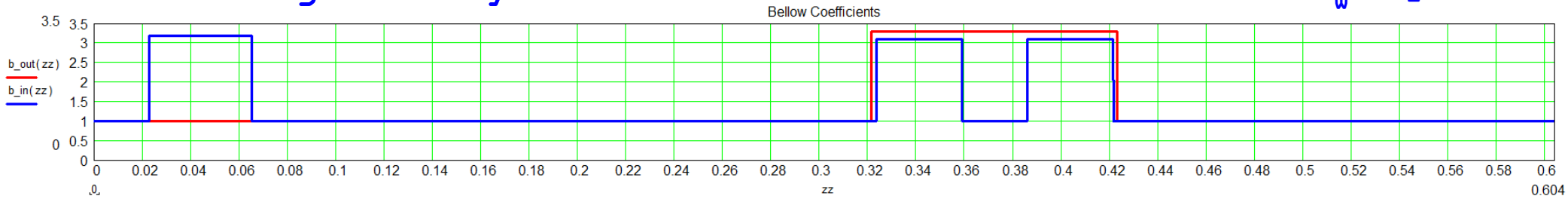
mafia RF losses calculation geometry



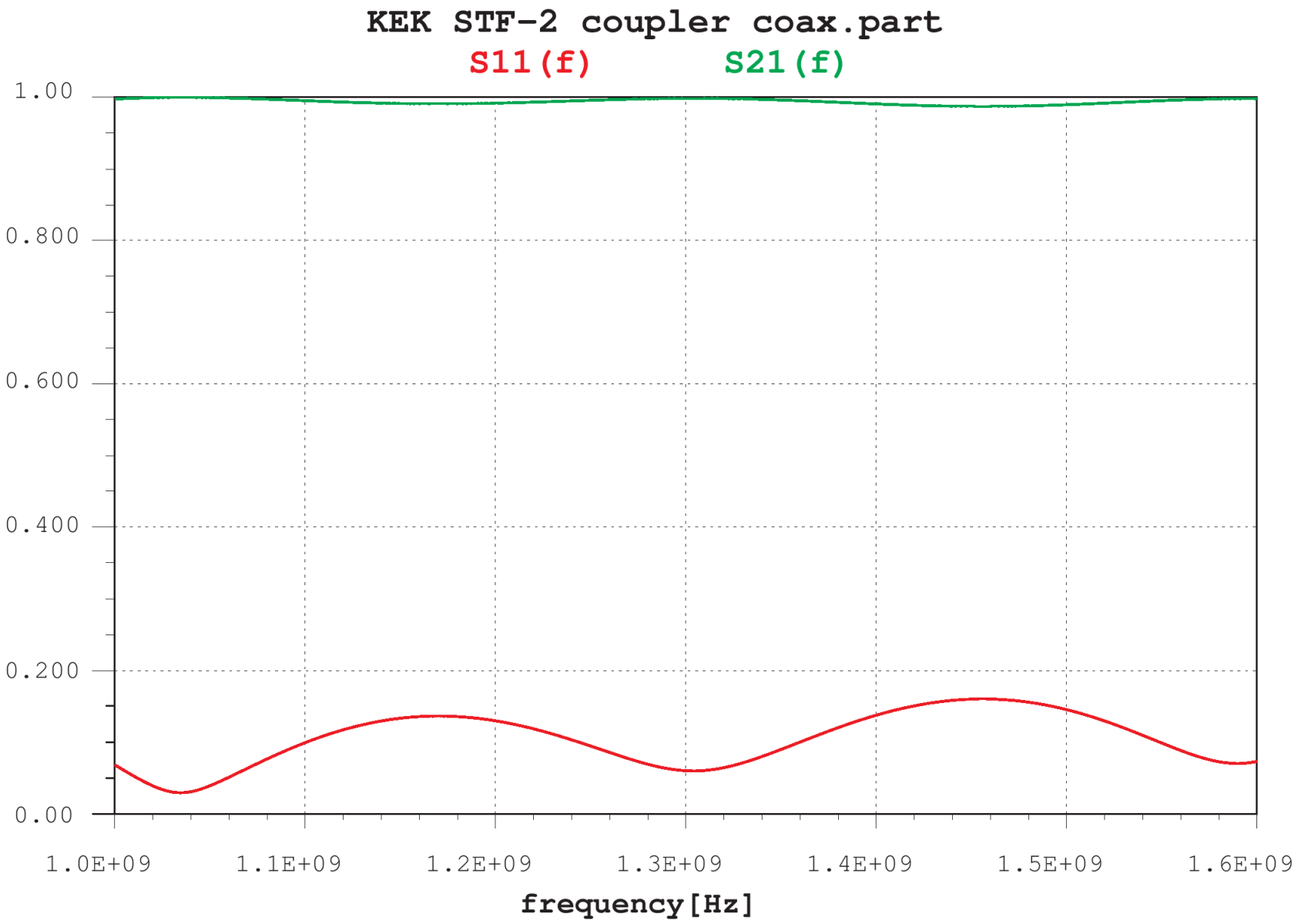
mathCAD thermal analysis geometry



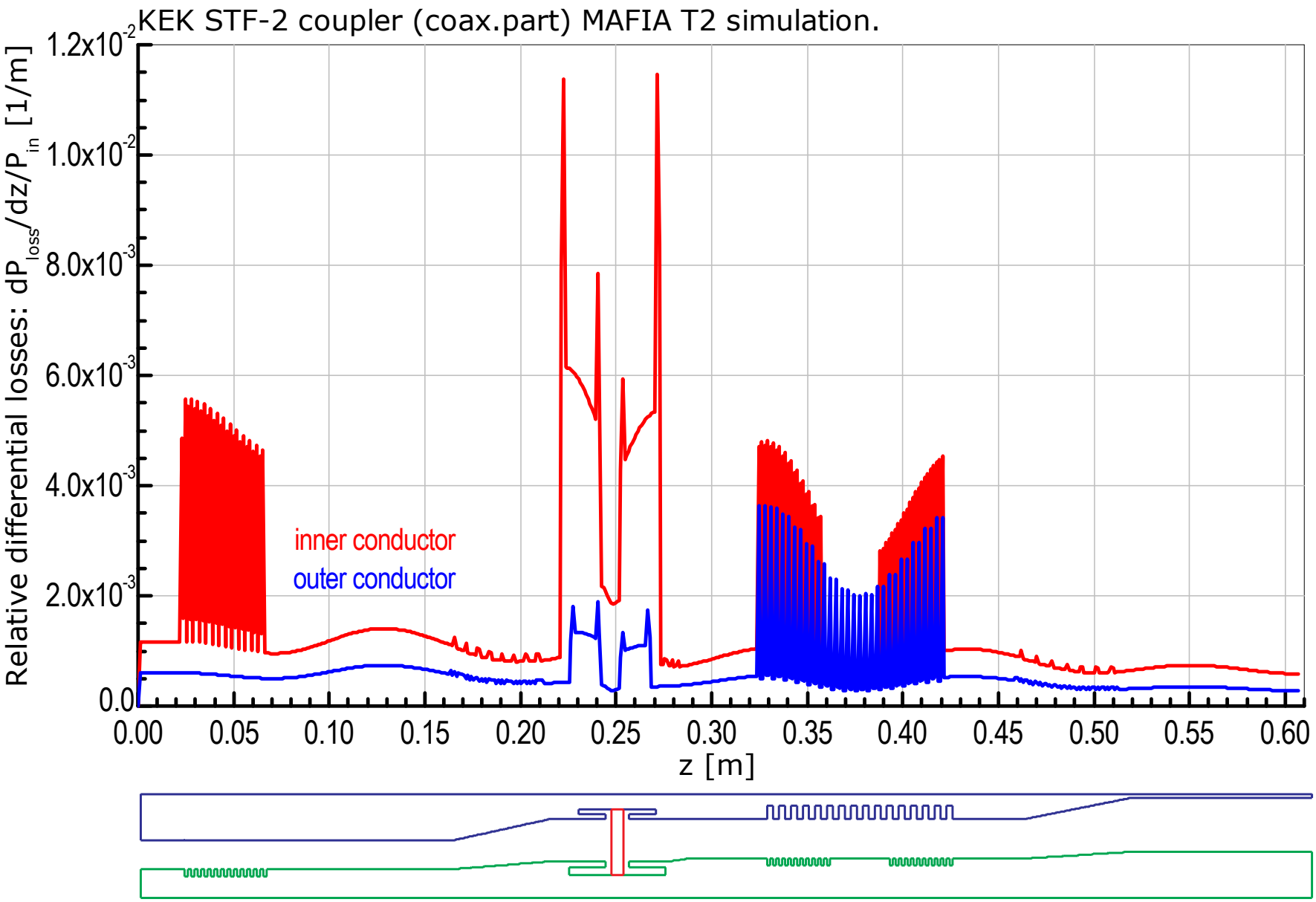
mathCAD geometry: bellows (Bellow coefficient: L_w/L_-)



Mafia calculation: S-parameters

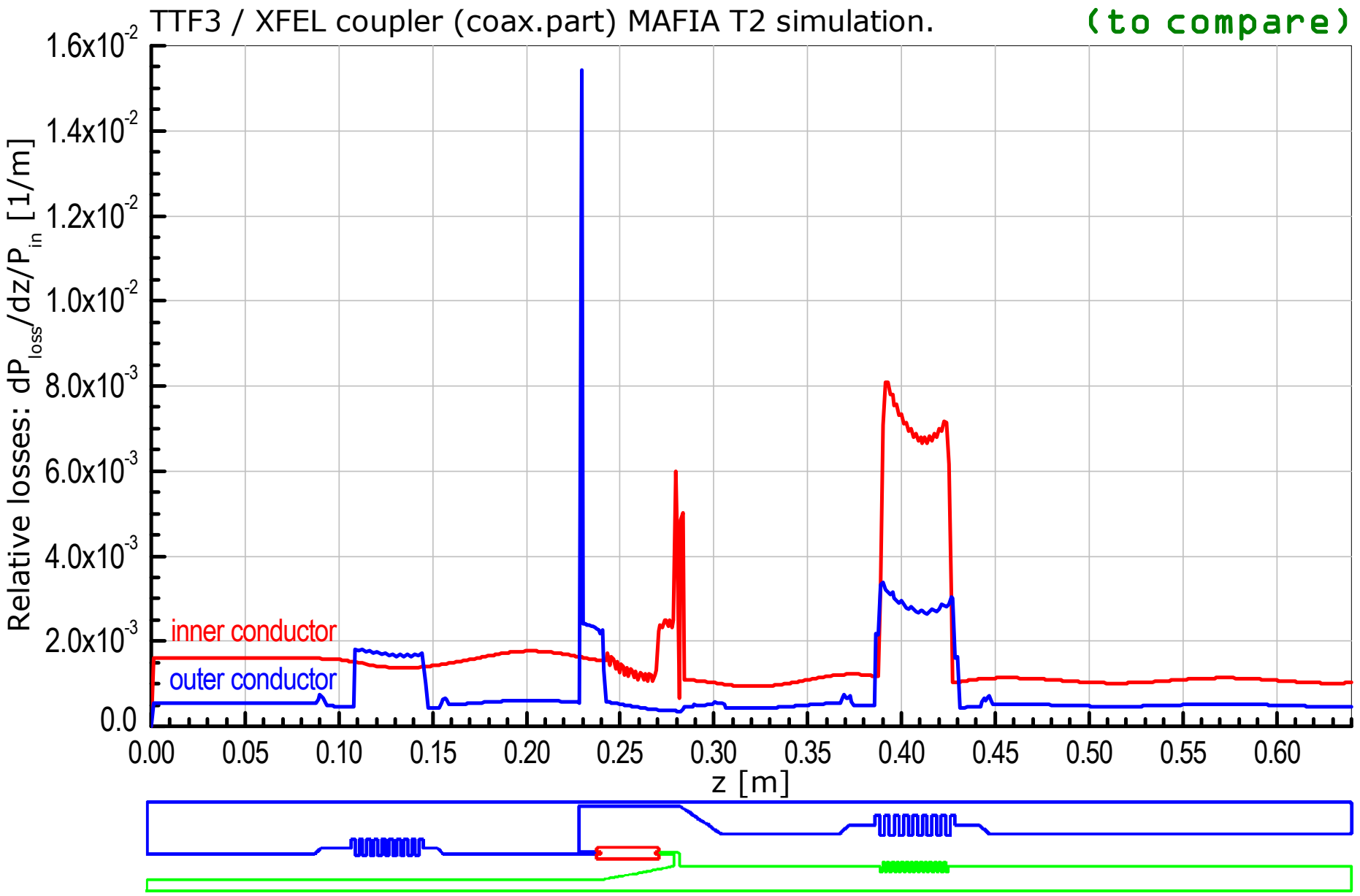


Mafia calculation: RF losses



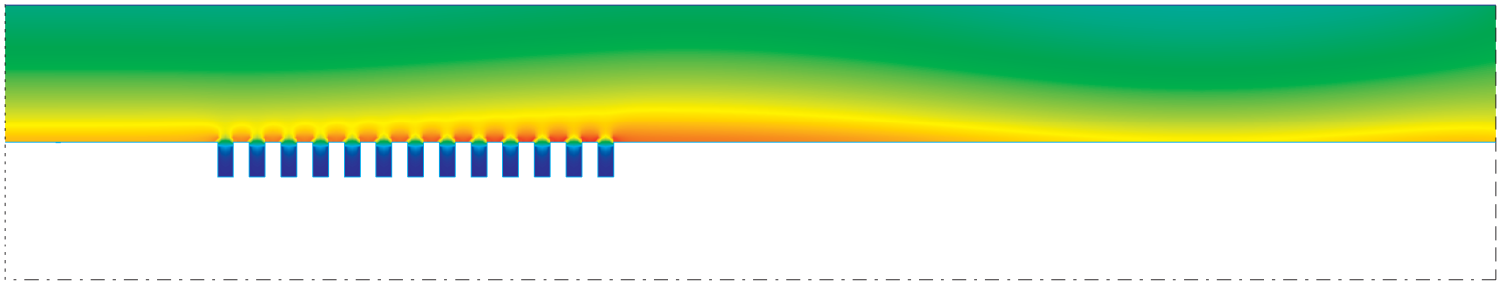
Material: Cu, $\kappa_0=5.8\times10^7$ 1/(Ω×m) (300 K)
Power Losses in the 70K ceramic window
(ε=9.2, tgδ=10^{-4}): $P_{loss.win}/P_{in} = 1.39\times10^{-4}$

Mafia calculation: RF losses XFEL coupler

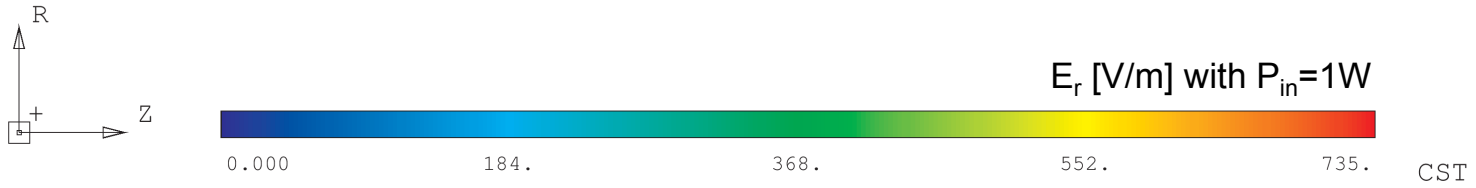


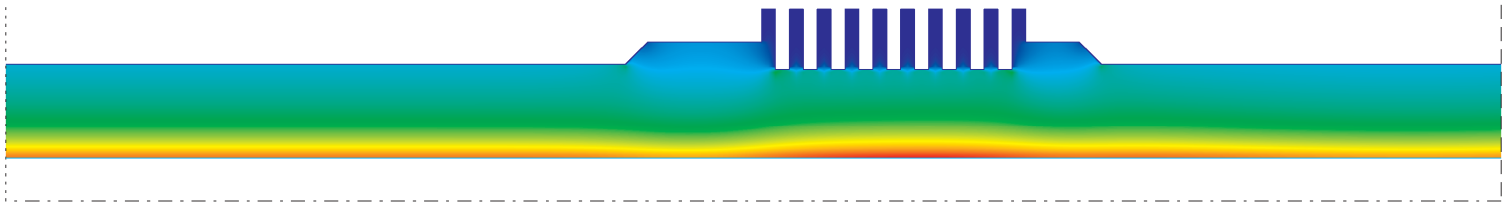
Material: Cu, $\kappa_0=5.8\times10^7$ 1/(Ω×m) (300 K)
Power Losses in the 70K ceramic window
(ε=9.2, tgδ=10^{-4}): $P_{loss.win}/P_{in} = 1.94\times10^{-4}$

Mafia calculation: Fields

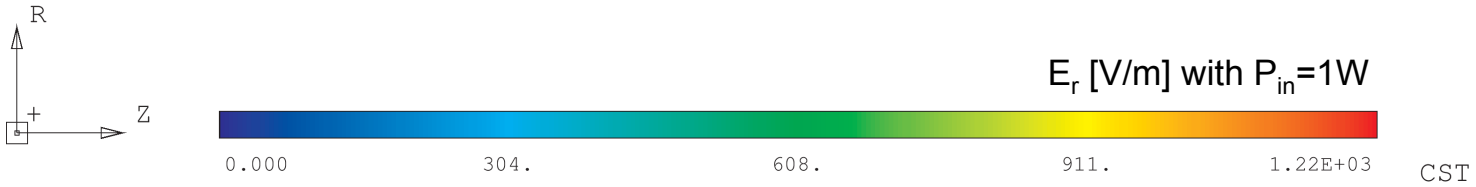


KEK S1G/STF-2 coupler





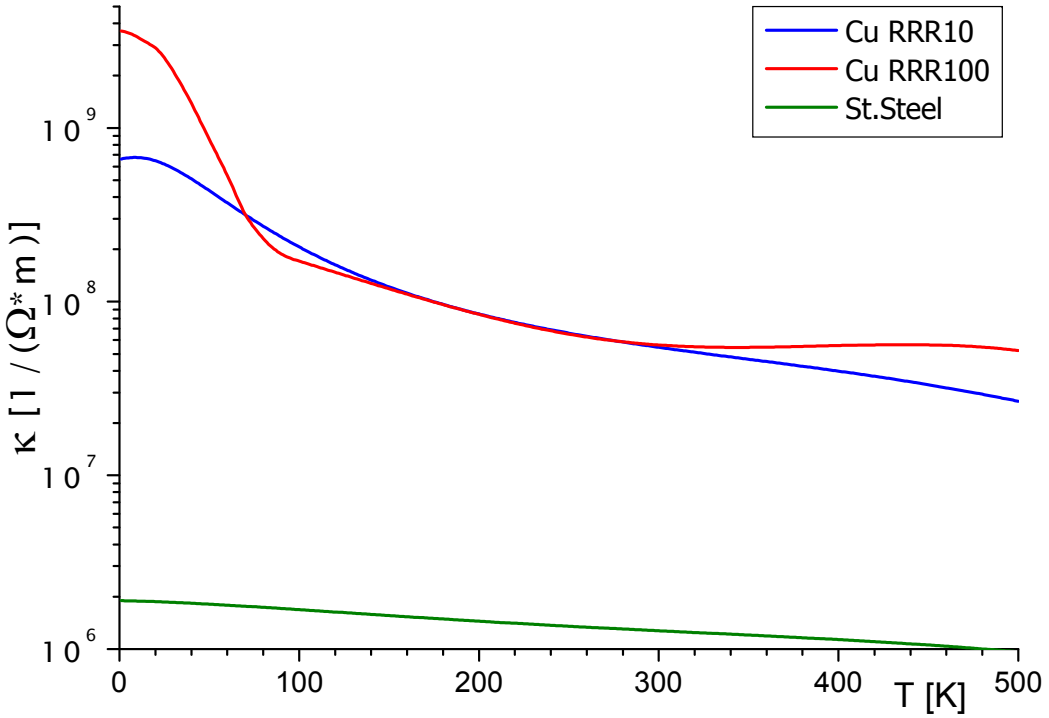
DESY XFEL/TTF3 coupler



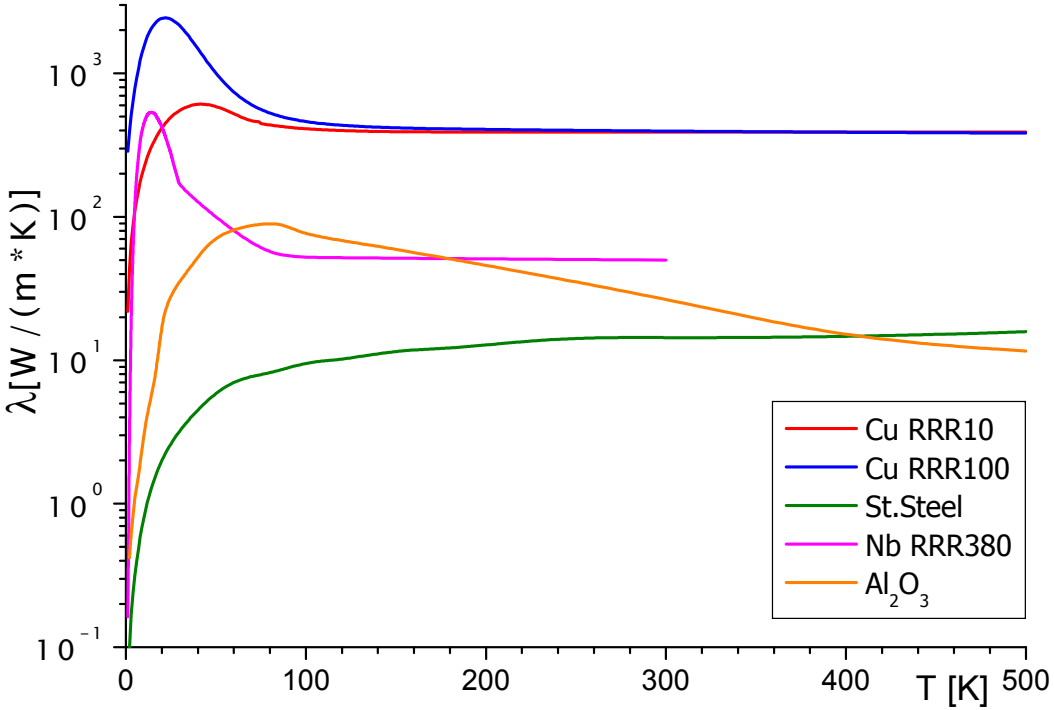
coupler cold part E-field ratio XFEL / KEK = 1.66

Material properties:

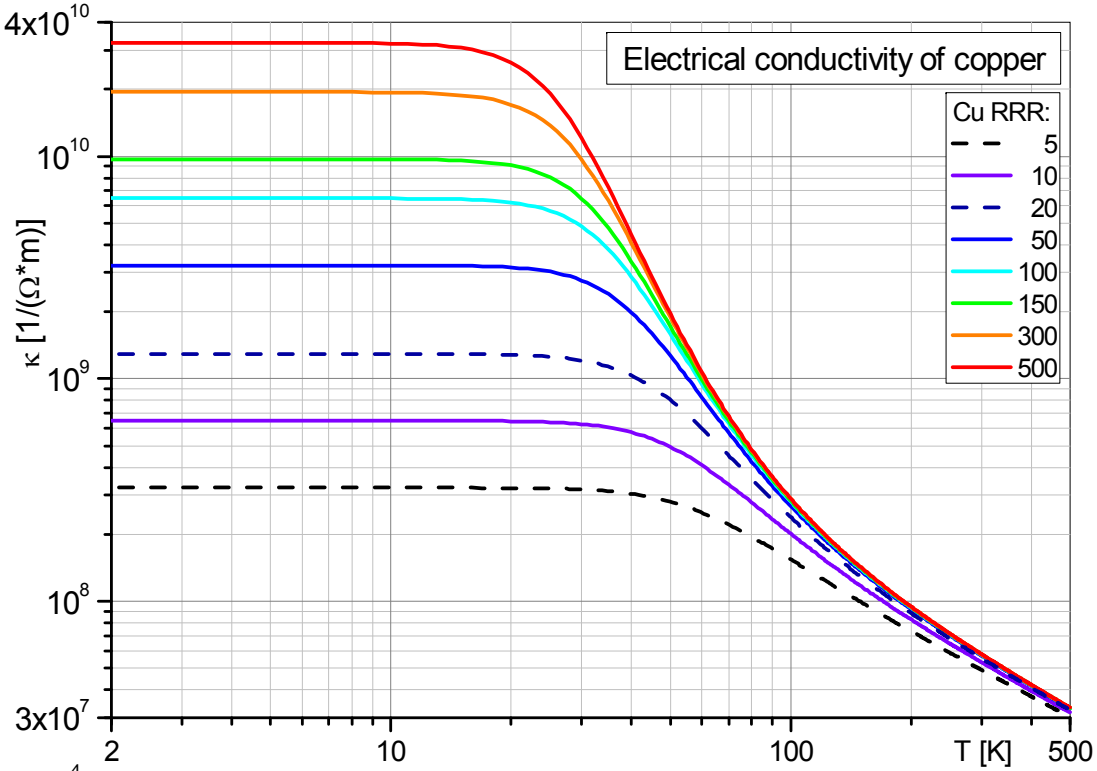
Electrical Conductivity

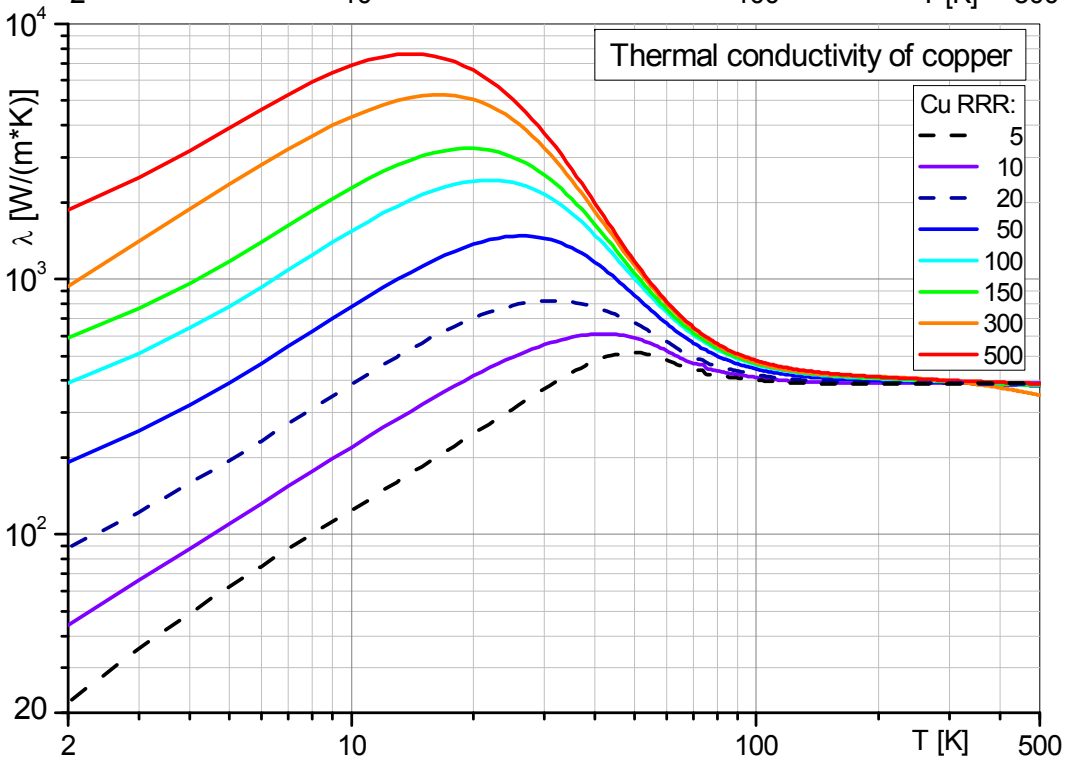


Thermal Conductivity



Material properties: copper





KEK S1-G/STF-2 coupler: coax.part / results

KEK S1-G/STF2 input RF power coupler coax.part

oCu	iCu[um]	Pav[kW]	Ti_ant	Ti_70K	Ti_max[K]	P_2K	P_4K	P70Ki	P70Ko	P70Kc	P70K[W]
S1-G: Cu RRR=5, Cu layer cold/warm out. 3/10um, in. 10/10um											
3	10	0.0	146.7	70.3	300.0	0.013	0.35	0.84	0.65	0.00	1.49
3	10	1.0	221.8	70.5	300.0	0.020	0.38	1.74	0.85	0.14	2.73
3	10	2.0	308.5	70.9	308.5	0.028	0.41	2.78	1.05	0.28	4.11
3	**10**	**2.5**	**350.6**	**71.0**	**350.6**	**0.032**	**0.43**	**3.32**	**1.16**	**0.35**	**4.83**
3	10	3.0	390.0	71.2	390.0	0.035	0.44	3.86	1.26	0.42	5.54
3	10	4.0	460.6	71.5	460.6	0.043	0.47	4.93	1.47	0.56	6.96
3	10	5.0	525.4	71.9	525.4	0.051	0.50	6.00	1.68	0.69	8.37
STF2: Cu layer cold/warm out. 10/25um with RRR 5/20, in. 25/25um with RRR=20											
10	25	0.0	117.0	70.5	300.0	0.026	0.64	1.46	1.40	0.00	2.86
10	25	1.0	160.6	70.7	300.0	0.033	0.68	2.27	1.58	0.14	3.99
10	25	2.0	219.1	71.0	300.0	0.040	0.71	3.22	1.76	0.28	5.26
10	**25**	**2.5**	**250.0**	**71.2**	**300.0**	**0.043**	**0.72**	**3.70**	**1.85**	**0.35**	**5.90**
10	25	3.0	285.0	71.3	300.1	0.047	0.74	4.30	1.95	0.42	6.67
10	25	4.0	354.9	71.7	354.9	0.054	0.77	5.45	2.13	0.56	8.14
10	25	5.0	419.0	72.1	419.0	0.061	0.81	6.60	2.32	0.69	9.61
STF2: Cu layer cold/warm out. 10/25um with RRR 5/20, in. 50/25um with RRR=50											
10	50	0.0	97.1	70.5	300.0	0.026	0.64	1.51	1.40	0.00	2.91
10	**50**	**2.5**	**165.4**	**71.1**	**300.0**	**0.043**	**0.72**	**3.46**	**1.85**	**0.35**	**5.66**
10	50	5.0	280.8	71.9	304.0	0.061	0.81	6.17	2.32	0.69	9.18
10	50	6.0	333.5	72.3	333.5	0.068	0.88	7.40	2.50	0.83	10.73
10	50	7.5	412.0	72.9	412.0	0.078	0.89	9.31	2.79	1.04	13.14
10	50	10.0	526.6	73.9	526.6	0.096	0.97	12.46	3.27	1.39	17.12

XFEL/TTF3 coupler: coax.part (to compare)

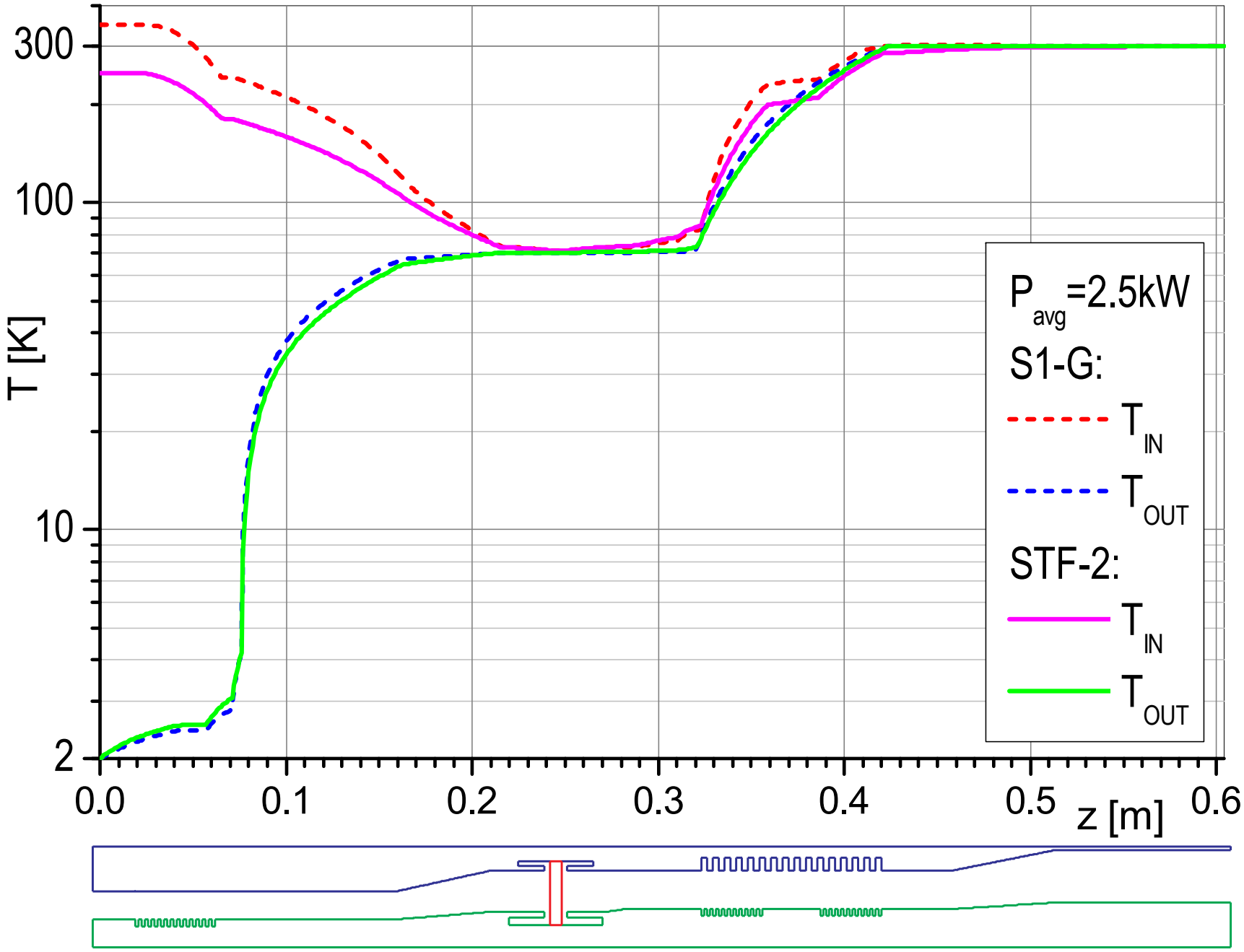
TTF III / XFEL coupler: coax.part. Cu RRR=10

oCu	iCu[μm]	Pav[kW]	Ti_ant	Ti_70K	Ti_max[K]	P_2K	P_4K	P70Ki	P70Ko	P70Kc	P70K[W]
10	30	0.0	70.7	70.7	300.0	0.02	0.20	0.84	1.06	0.00	1.90
10	30	1.0	72.0	71.2	300.0	0.03	0.25	1.57	1.30	0.19	3.06
10	**30**	**1.9**	**73.3**	**71.8**	**303.2**	**0.04**	**0.29**	**2.26**	**1.51**	**0.37**	**4.14**
10	30	3.0	74.9	72.5	320.1	0.05	0.33	3.15	1.78	0.58	5.51
10	30	4.0	76.5	73.1	341.1	0.06	0.38	4.00	2.03	0.78	6.81
10	30	5.0	78.2	73.8	364.9	0.07	0.43	4.88	2.28	0.97	8.13
10	30	6.0	79.8	74.5	390.9	0.075	0.47	5.81	2.54	1.16	9.57
10	30	7.0	81.6	75.3	420.2	0.08	0.52	6.78	2.81	1.36	10.95
10	30	8.0	83.4	76.1	453.0	0.09	0.57	7.80	3.07	1.55	12.42
10	30	9.0	85.3	76.9	490.1	0.10	0.62	8.88	3.35	1.74	13.97
10	30	10.0	87.3	77.9	533.1	0.11	0.68	10.05	3.63	1.94	15.62
10	5	1.9	72.8	71.3	332.6	0.04	0.29	1.68	1.51	0.37	3.56
10	10	1.9	73.0	71.4	322.1	0.04	0.29	1.82	1.51	0.37	3.70
10	20	1.9	73.1	71.6	309.5	0.04	0.29	2.05	1.51	0.37	3.93
10	**30**	**1.9**	**73.3**	**71.8**	**303.2**	**0.04**	**0.29**	**2.26**	**1.51**	**0.37**	**4.14**
10	40	1.9	73.5	71.9	300.5	0.04	0.29	2.45	1.51	0.37	4.33
10	50	1.9	73.6	72.0	300.0	0.04	0.29	2.62	1.51	0.37	4.50
5	30	1.9	73.3	71.8	303.2	0.03	0.20	2.26	1.29	0.37	3.92
10	**30**	**1.9**	**73.3**	**71.8**	**303.2**	**0.04**	**0.29**	**2.26**	**1.51**	**0.37**	**4.14**
20	30	1.9	73.3	71.8	303.2	0.05	0.45	2.26	1.94	0.37	4.57
30	30	1.9	73.3	71.8	303.2	0.06	0.60	2.26	2.36	0.37	4.99
40	30	1.9	73.3	71.8	303.2	0.075	0.76	2.26	2.77	0.37	5.40
50	30	1.9	73.3	71.8	303.2	0.09	0.91	2.26	3.17	0.37	5.80

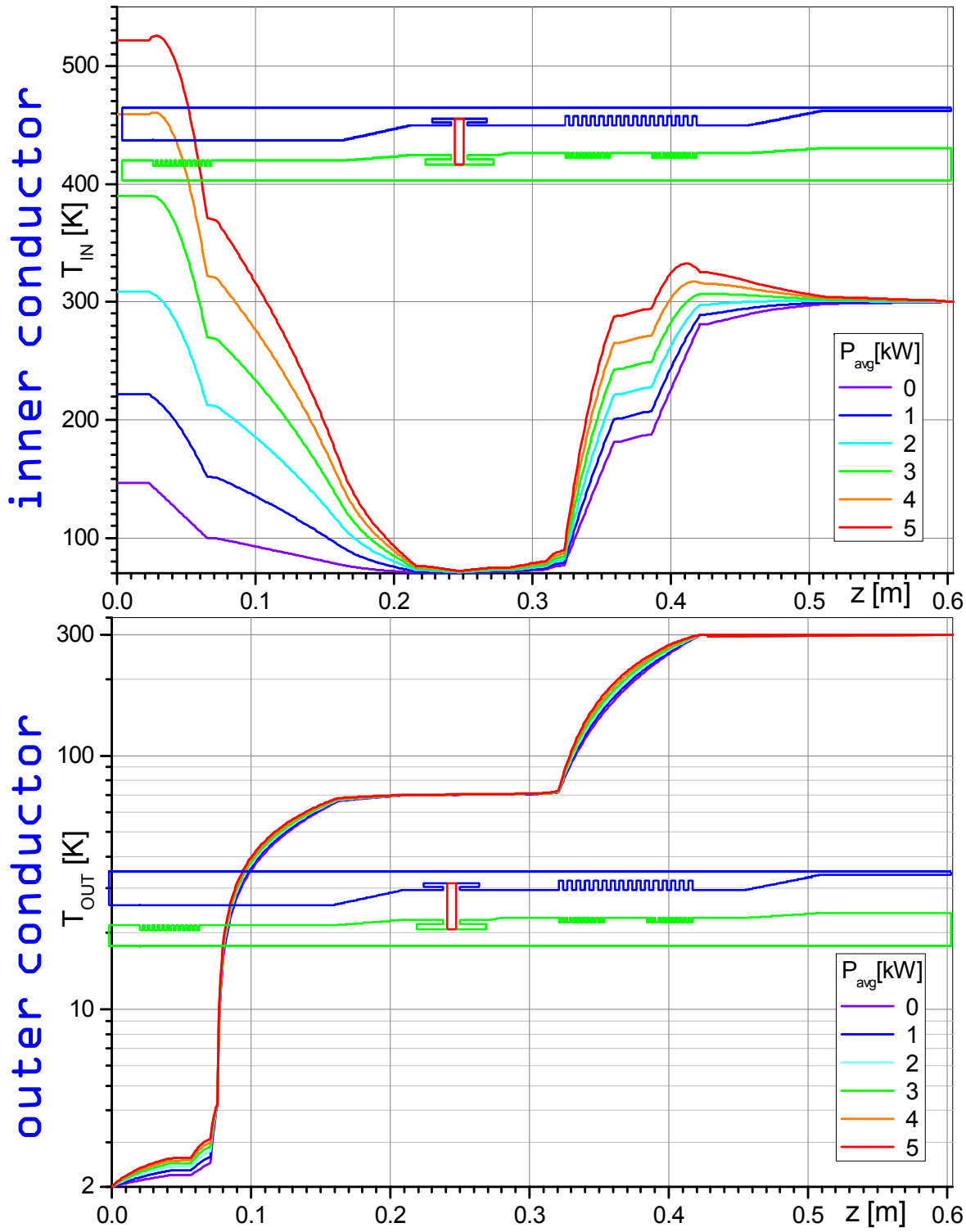
TTF III / XFEL coupler: coax.part. Cu RRR=50

10	**30**	**1.9**	**72.9**	**71.6**	**302.5**	**0.10**	**0.54**	**2.32**	**1.15**	**0.37**	**3.84**
10	30	6.0	78.7	74.2	376.0	0.11	0.63	5.88	2.12	1.16	9.16
10	30	10.0	85.4	76.9	457.9	0.13	0.73	9.70	3.13	1.94	14.77

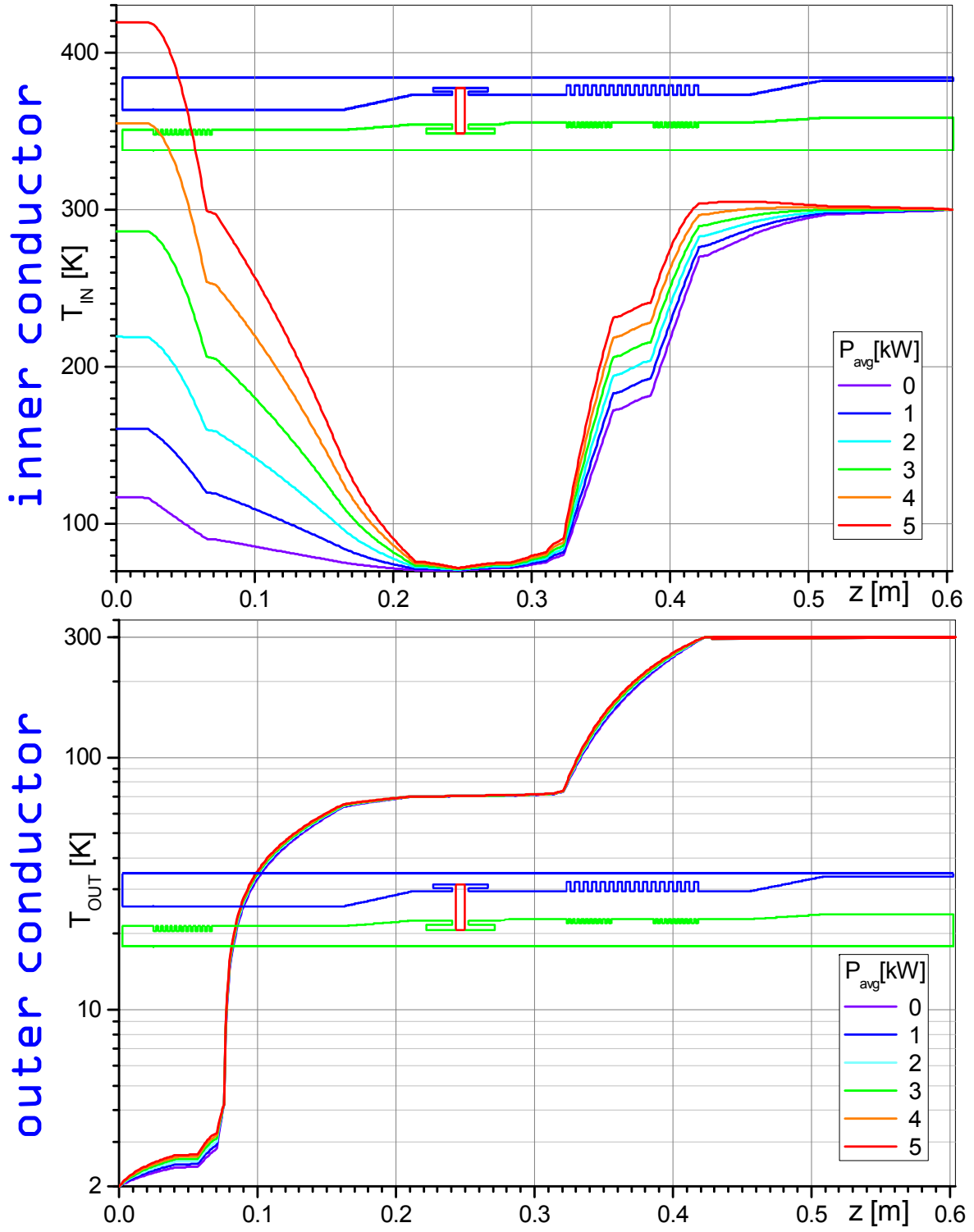
KEK coupler: Temperature distribution



Temperature distribution: SL-G coupler

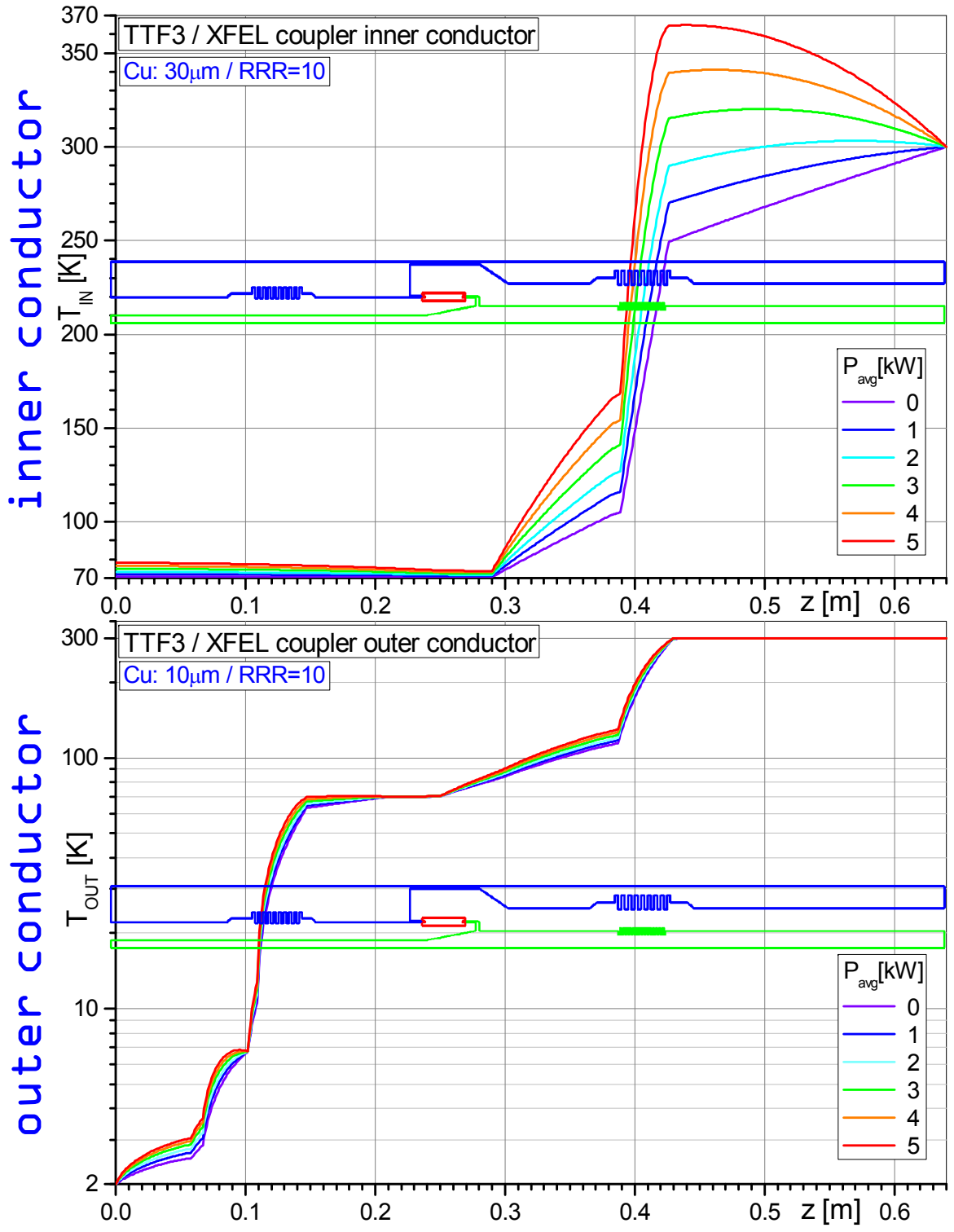


Temperature distribution: STF-2 coupler



Temperature distribution: XFEL coupler

(to compare)



SUMMARY:

1. KEK S1-G and STF-2 couplers thermal analysis done with mafia / MathCAD simulation codes using simplified 2D model of the coaxial part. Simulations assume perfect connection to 4K and 70K for the outer conductor. Antenna tuning rod connection to 300K was simulated. Inner conductor is connected to the 70K through the ceramic window.
2. RF power simulated up to 5 kW (effective average CW power). For the ILC coupler the effective average CW power is 2.5 kW, with accelerating gradient 40 MV/m, rep.rate 5 Hz, pulse length 1.65 ms, beam current 6 mA and control margin of 25%. For the XFEL the effective average CW power is near 2 kW.
3. Material properties data for the thermal conductivity are taken from NIST Cryogenics Technologies Group data base at http://cryogenics.nist.gov/.
4. KEK S1-G and STF-2 couplers are compared to TTF3 / XFEL coupler. Analysis shows, that the designs are very close by cryogenic losses. STF-2 coupler has increased static crygenic losses compared to S1-G, but lower antenna operating temperature. RF simulation shows 5% less total RF losses for the KEK coupler and 25% less RF losses on the ceramic window compared to TTF3 DESY design.
5. KEK coupler has a hole antenna design in contrast to XFEL one with a solid copper antenna. This results for KEK coupler in the coupler antenna temperature increase. Increasing the copper thickness on the antenna for the KEK coupler helps to resolve this issue. In the simulation for STF-2 coupler 25μm and then 50μm were used as an example.