Couplers for Project X

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Requirements to RF coupler for ProjectX:

❑Couplers have to provide reliable operations superconductive accelerating cavities in CW regime of following frequencies and powers:

Section	Energy range MeV	β	Number of cavities	Type of cavities	Maximal power per cavity*, kW
SSR0(βG=0.11)	2.5-10	0.073-0.146	16	Single spoke cavity.	0.8
SSR1 (βG=0.22)	10-32	0.146-0.261	18	Single spoke cavity.	1.5
SSR2 (βG=0.4)	32-160	0.261-0.52	44	Single spoke cavity.	3.2
650 MHz (βG=0.6)	160-500	0.52-0.758	35	Elliptic cavity	11.5
650 MHz (βG=0.9)	500-2000	0.758-0.95	92	Elliptic cavity	18.5
1300 MHz (βG=1)	2000-000	0.95-0.97	64	Elliptic cavity	16

* Without overhead, only beam power.

- **Couplers have to allow make assembling accelerating cavities with coupler in clean room and to be installed in cryomodules then.**

- **Couplers should not increase noticeably the heat load of cavity.**
  (Heat load of cavities is estimated as about 20W per cavity at 2K).

- **Couples have to be comparable with present 1.3 GHz cavities, ILC-type cryomodules and SSR1 cavities.**

- **Cooling of the couplers, if it is necessary, has to be air-type.**

- **Maximum unification of couplers parts.**

Important questions:

- How many windows coupler has to have, one or two?
- Has coupler to be tunable or with fixed coupling ?
- Is HV bias necessary?

Two window (cold and warm) or one window (warm)?

Two window

Pros: cold window can be placed closer to structure.

- **It simplifies cryomodule-cavties assembling**
- **Higher reliability (?)**

Cons: complicity and price.

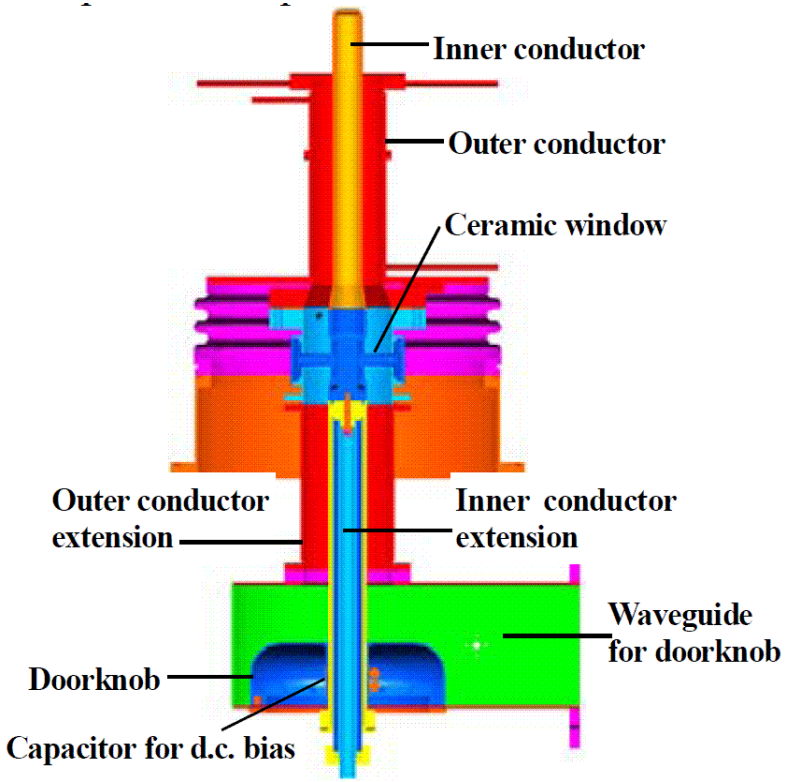
What previous experience says?

All facilities in Solar System except ILC-like (FLASH, TTF, STF, improved TTF-III couplers supposed to be used in Cornell ERL) use single window couplers .

Examples of single-window couplers for SC cavities (S. Belomestnyhk)

Facility	Frequency	Coupler type	RF window	Q_{ext}	Max. power	Comments
LEP2 [4,5,6]	352 MHz	Coax fixed	Cylindrical	2×10^6	Test: 565 kW 380 kW Oper: 100 kW	Traveling wave Stand. wave@ Γ=0.6
LHC [5,7]	400 MHz	Coax variable (60 mm stroke)	Cylindrical	2×10^4 to 3.5×10^5	Test: 500 kW 300 kW	Traveling wave Standing wave
HERA [8,9]	500 MHz	Coax fixed	Cylindrical	1.3×10^5	Test: 300 kW Oper: 65 kW	Traveling wave
CESR [10,11] (Beam test)	500 MHz	WG fixed	WG, 3 berillia disks	2×10^5	Test: 250 kW 125 kW Oper: 155 kW	Traveling wave Standing wave Beam test
CESR [12,13]	500 MHz	WG fixed	Disk WG	2×10^5	Test: 450 kW Oper: 300 kW 360 kW	Traveling wave Beam power Forward power
TRISTAN [14]	509 MHz	Coax fixed	Disk coax	1×10^6	Test: 200 kW Oper: 70 kW	
KEK-B [15,16]	509 MHz	Coax fixed	Disk coax	7×10^4	Test: 800 kW 300 kW Oper: 380 kW	Traveling wave Standing wave
APT [17]	700 MHz	Coax variable (±5 mm stroke)	Disk coax	2×10^5 to 6×10^5	Test: 1 MW 850 kW (fixed coupler)	Traveling wave Standing wave
JLAB FEL [18]	1500 MHz	WG fixed	Planar WG	2×10^6	Test: 50 kW Oper: 35 kW	Very low ΔT

SNS - example of successful usage of single window couplers in superconductive linac:



SNS coupler (805MHz):

Single planar window

Tested (TW) 750kW x 1.3ms x 60pps (58.5kW average)

2MW x 0.65ms x 60pps (78kW average)

Tested (SW) 600kW x 1.3ms x 60pps (46.8kW average)

Average power density through ceramic ≈ 0.9 kW/cm2

Most powerful examples: of CW couplers/windows:

APT coupler (700MHz):
Single planar window with intercooling (cooling air two ceramic windows)
Tested power 1 MW (TW), 850 KW (SW)
Average power density through ceramic ≈ 2.3 kW/cm2

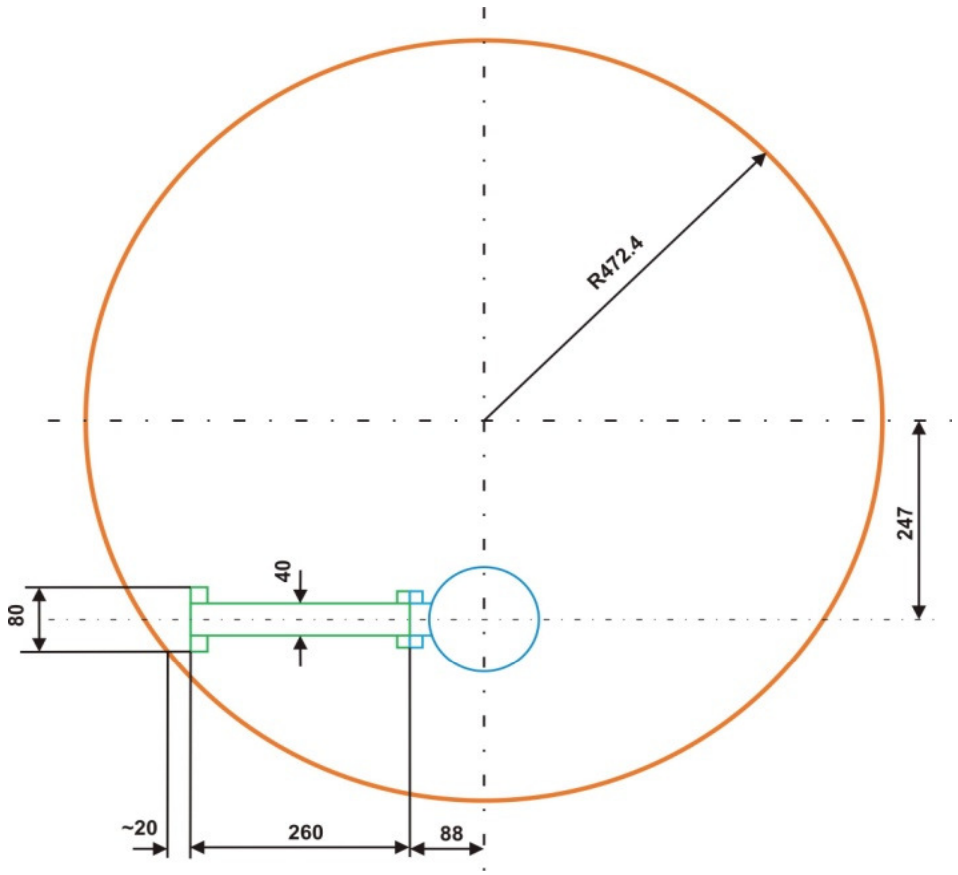
Super-KEKB ARES:
Single planar window
Tested 950 kW CW (supposed operating power 800 kW)
Average power density through ceramic ≈ 4.4 (3.7) kW/cm2

Toshiba 1MW CW 508 MHz klystron:
Single coaxial planar window
Tested power 1.2 MW CW
Average power density through ceramic ≈ 5.6 kW/cm2

Parameters of Project X couplers:

1.3 GHz
Coaxial planar window.
Outer diameter - 41.15 mm
Inner diameter – 12.7 mm
Power 20 - 30 kW CW
Average power density through ceramic 1.7 – 2.5 kW/cm2

325 MHz, 650 MHz
Coaxial planar window.
Outer diameter - 72.9 mm
Inner diameter – 12.7 mm
Power 5 - 30 kW CW
Average power density through ceramic 0.13 – 0.74 kW/cm2



We can install the present 1.3 GHz cavity with RF window in existing ILC-type cryomodule if length from cold flange till window flange is less then ~260mm. It is enough to provide good thermal properties.

Note,

we do not expect RF breakdown – power is low.

no multipactor for right geometry choice.

only thermal stress is possible reason of window destruction.

Conclusion:

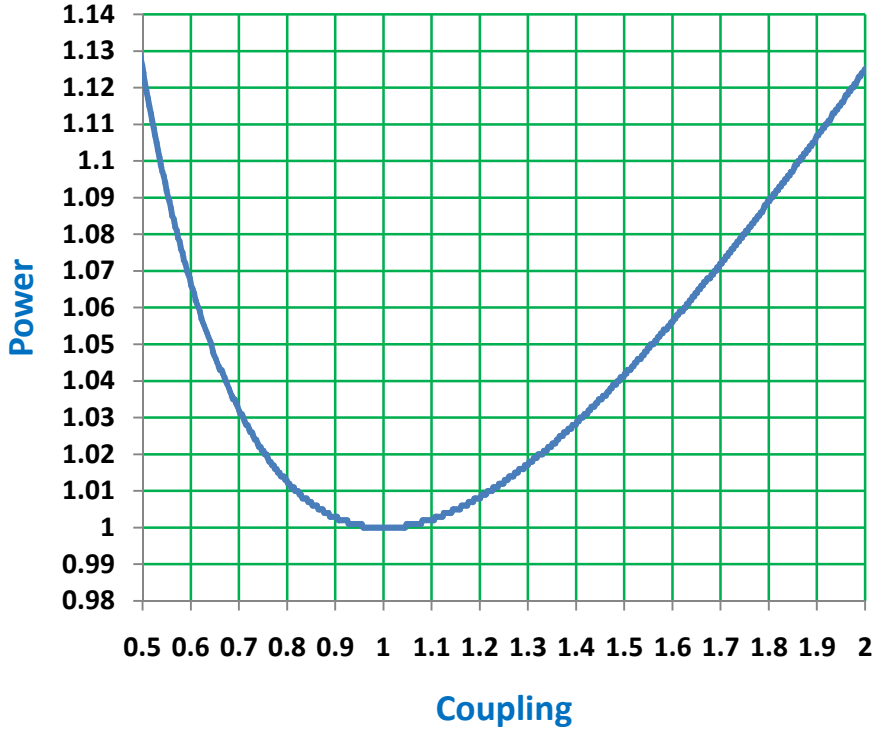
“Entities must not be multiplied beyond necessity”

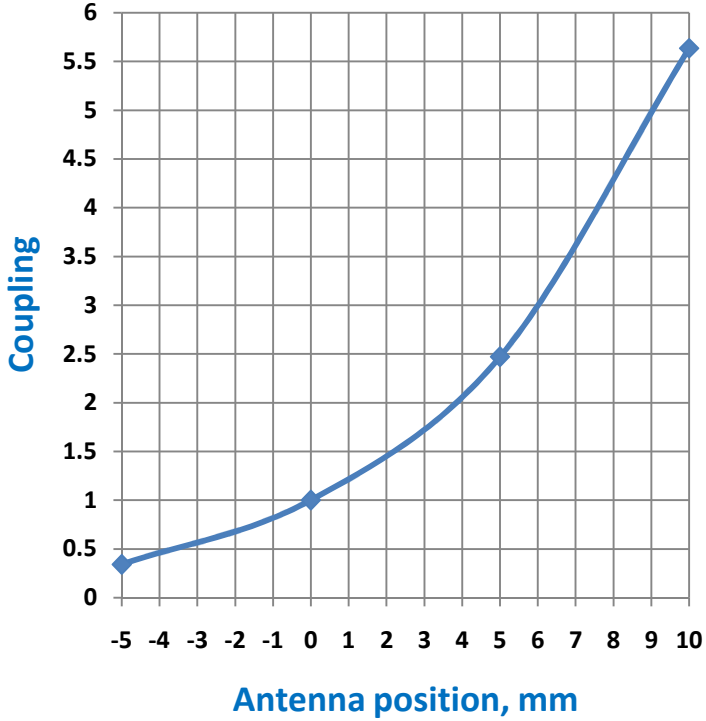
Single-window can be a right choice for Project X.

Experiments with prototypes give us final answer

Fixed coupling

In case of CW steady state operation a payment for wrong coupling is only additional power. But payment is not too big:

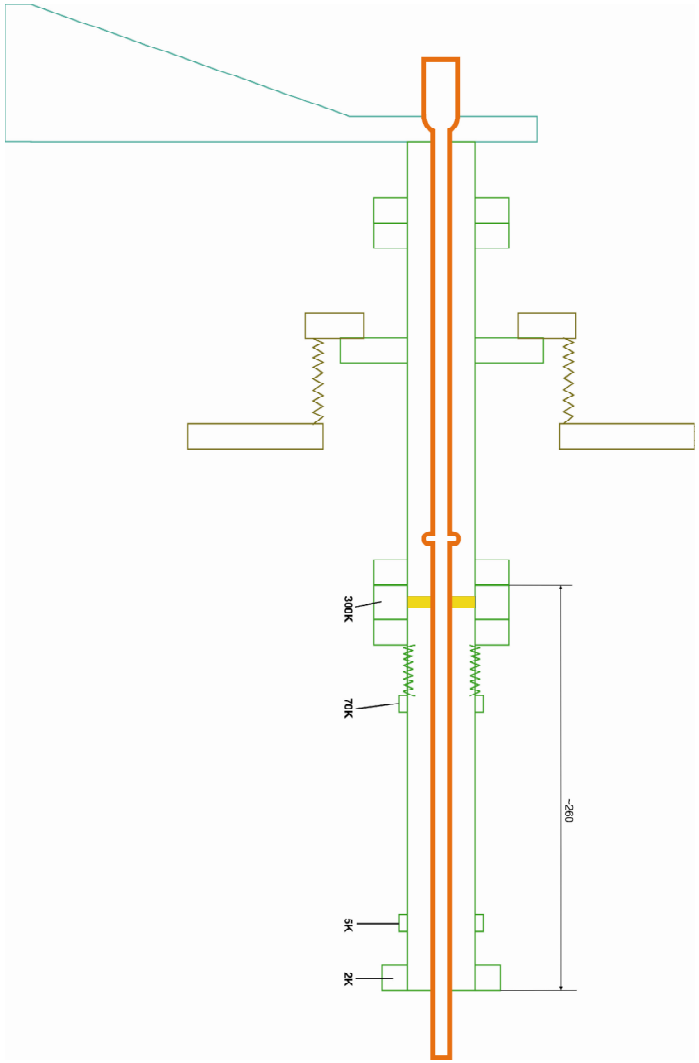


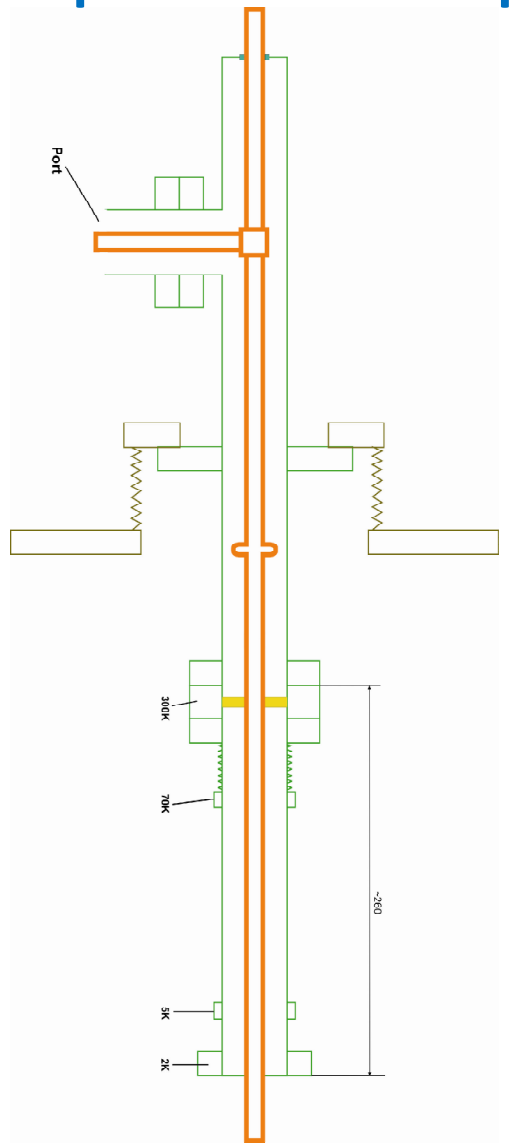


5% extra power corresponds to coupling range $0.64 \le \beta \le 1.56$. If cavity is over-coupled from beginning ($\beta \approx 1.6$) the currant can be increased 2.4 times (1.56/0.64 = 2.4) without changing the coupling and loosing only 5% power.

Antenna position tolerances (5% power) -3 +2 mm

As result , possible configurations of couplers can be simple:





We can expect that price of couplers can be several times less then price of present TTF-type couplers.

Waveguide or coaxial port?

325 MHz – no choice, input is coaxial. Waveguide is too big

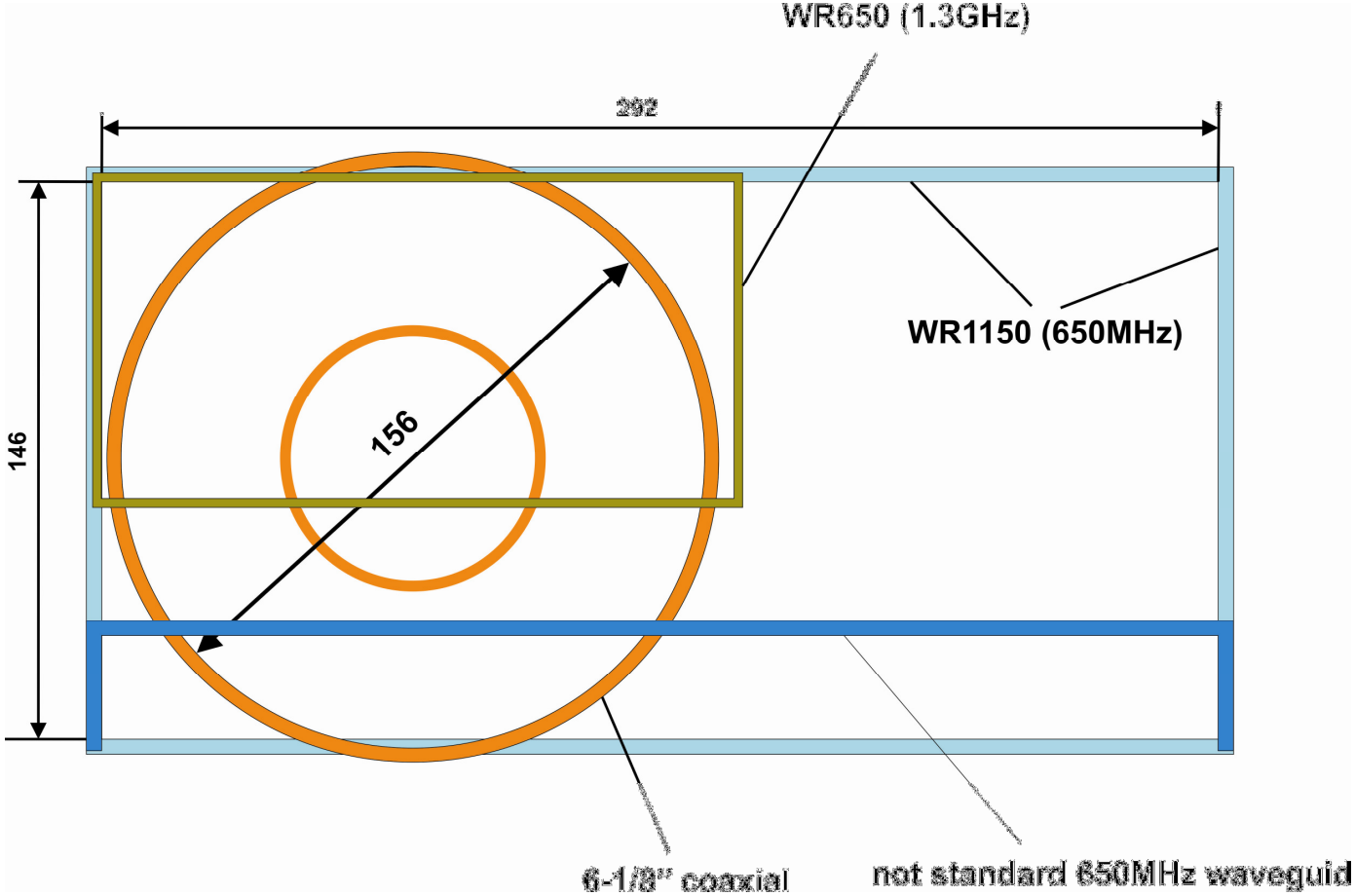
650MHz, 1.3GHz:

RF source will have output power ≈ 30 kW.
coaxial line has to be able to operate at this power level

Standard coaxial lines:
4-1/16”, Max. CW power (650 MHz) - 33kW
6-1/8’’, Max. CW power (650 MHz) - 57 kW

Standard waveguides:
WR 1150, Max. CW power (650MHz) – 650kW
WR 650, Max. CW power (1.3GHz) - ≈ 140kW

Cross-section area of feeding line is important: to minimize penetration area in radiation shield.



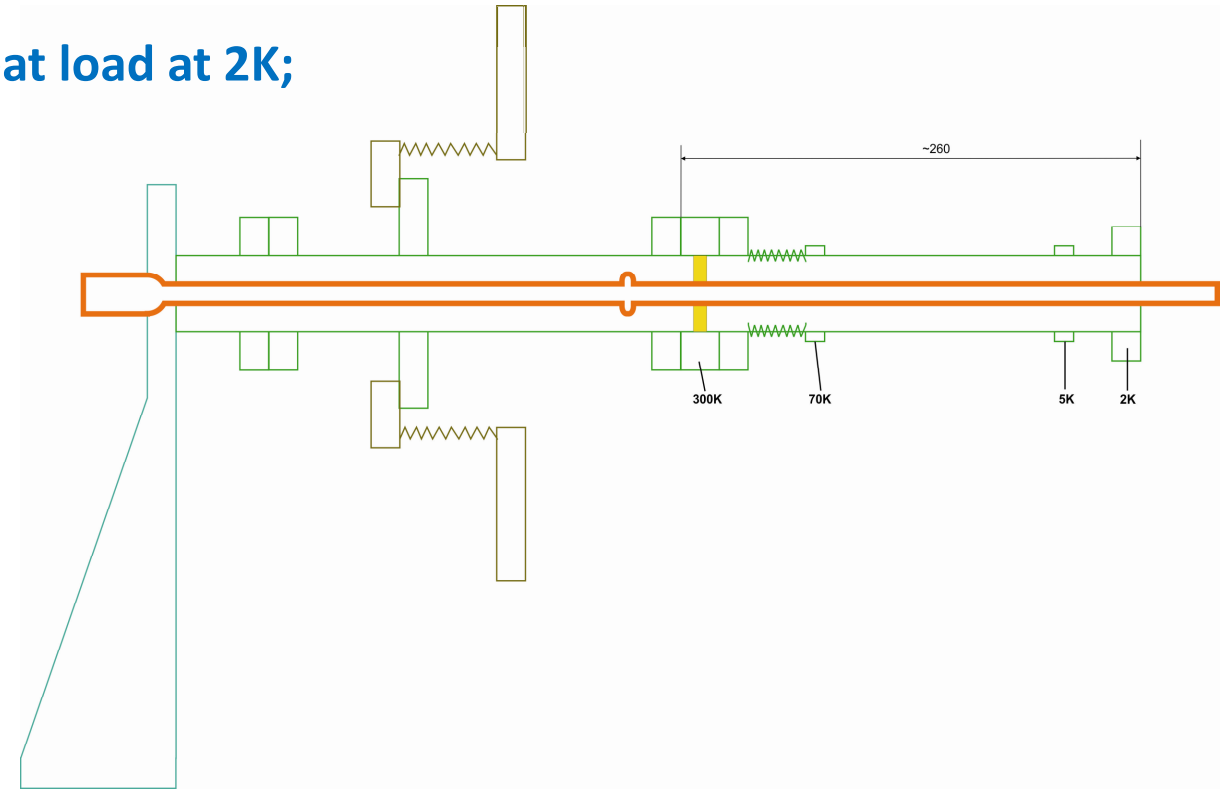
1.3 GHz coupler input port - waveguide

Waveguide with reduced height can be solution for 650 MHz.

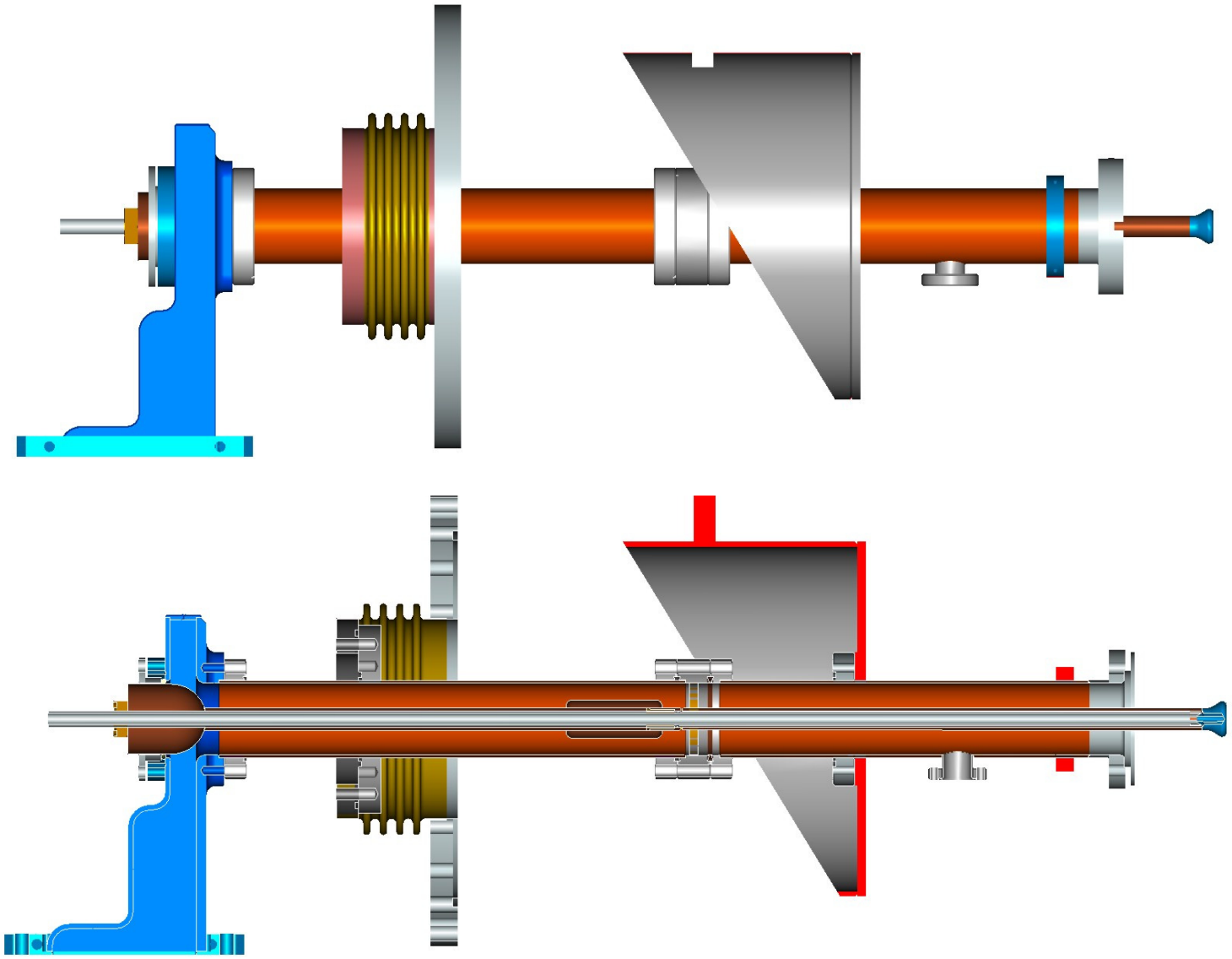
(Waveguide has a lot of advantages comparing with coaxial line: simple topology, higher power, cheaper material and, probably, line, no problem with oxidation)

Boundary conditions for design 1.3 GHz coupler.

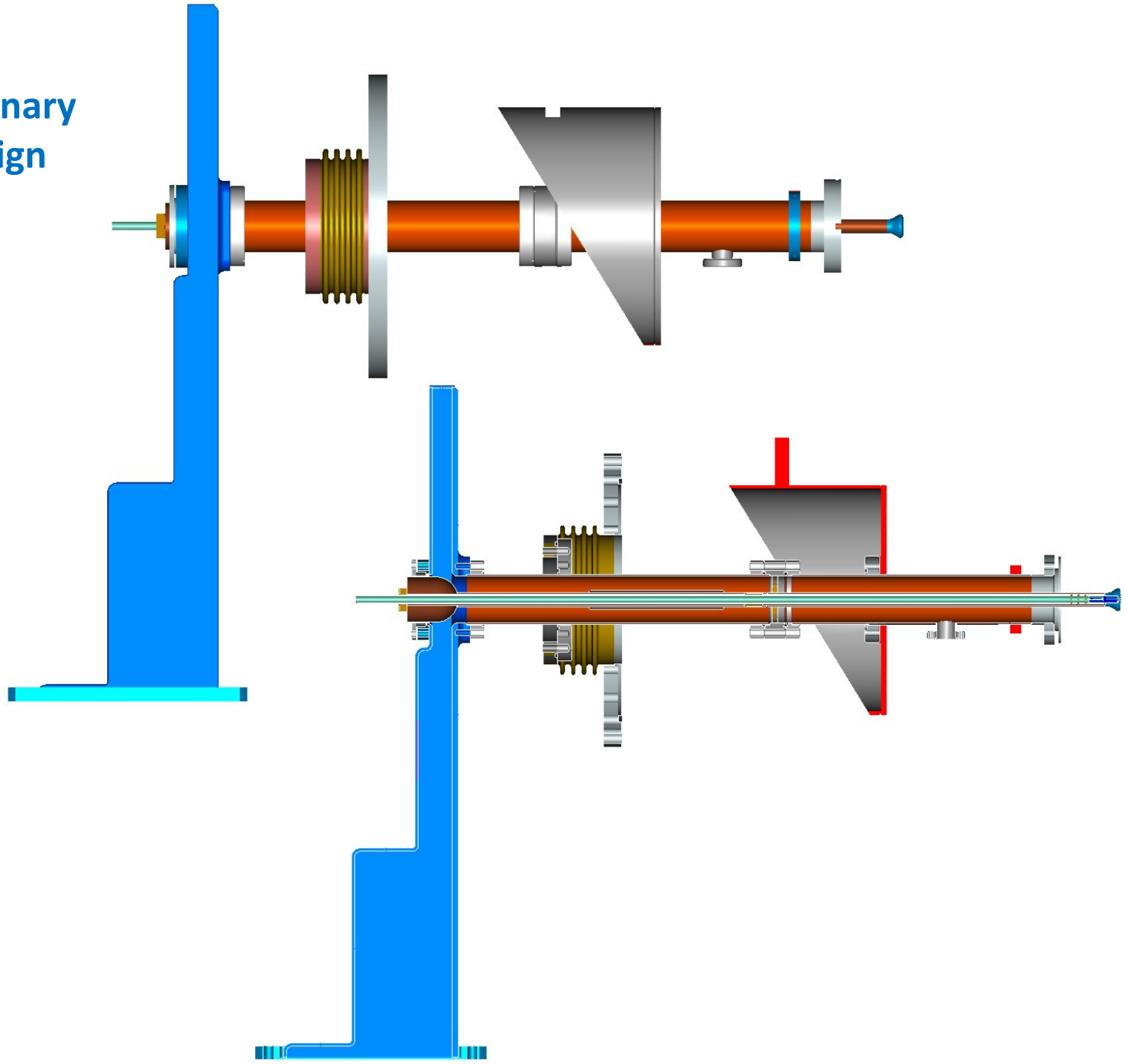
- has to be comparable with present 1.3 GHz cavity (D40mm input);
- has to be compatible with ILC type cryomodule;
- 20-30 kW power level;
- less then ≈ 1W heat load at 2K;
- single window;
- waveguide input;



1.3 GHz coupler, preliminary mechanical design.

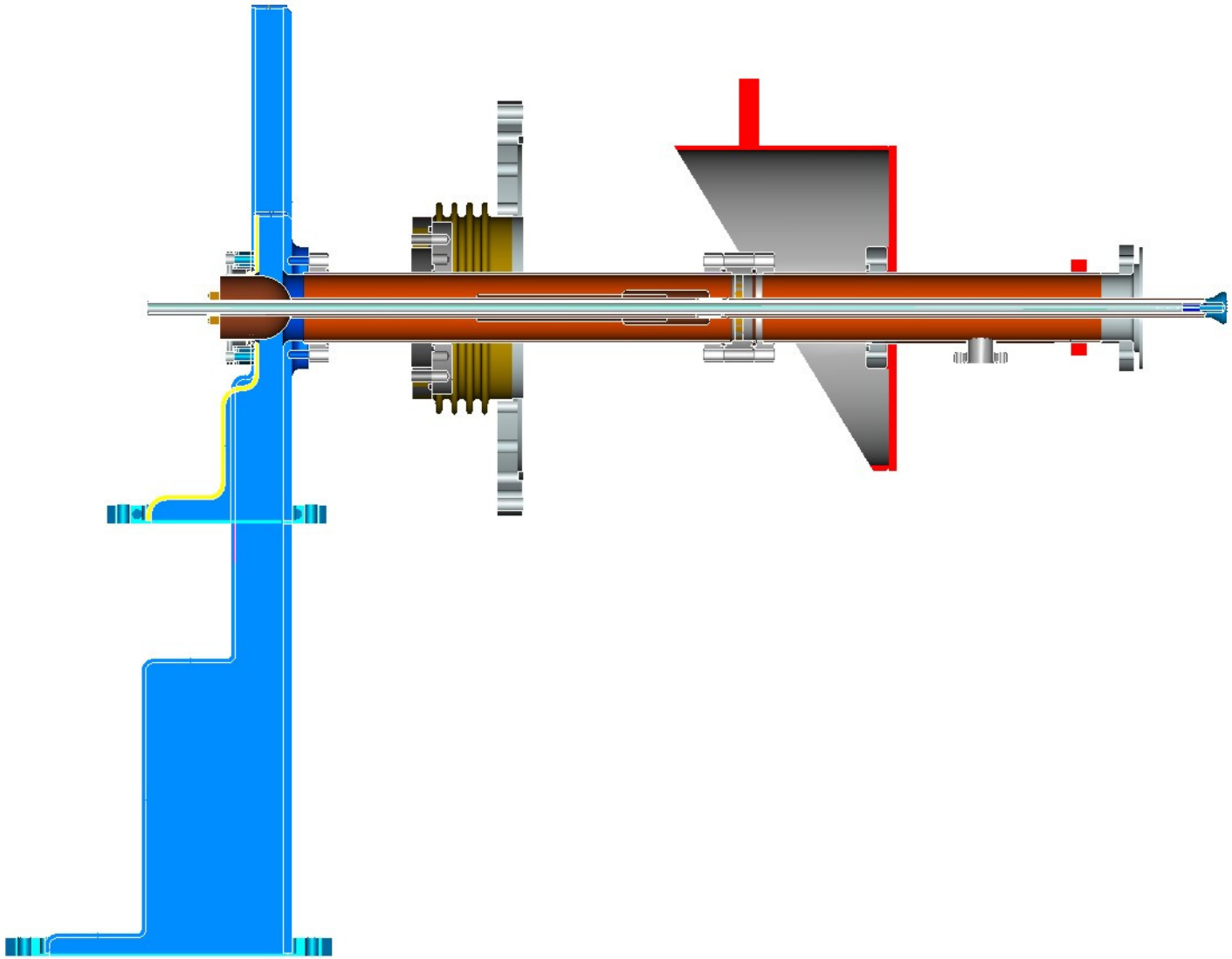


650MHz coupler, preliminary mechanical design



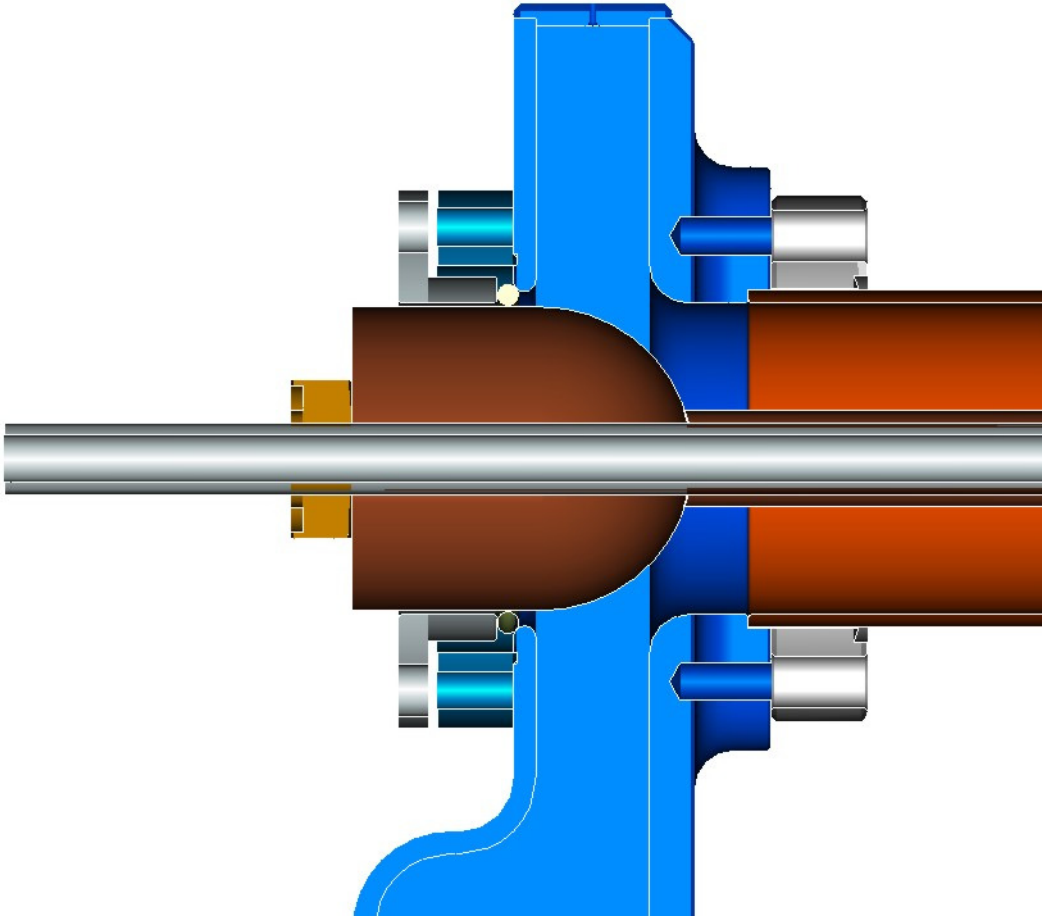
1.3 GHz and 650MHz couplers.

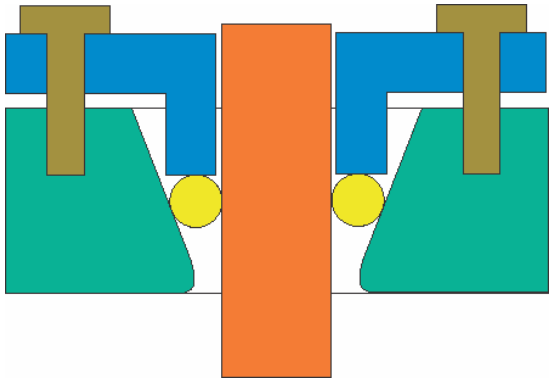
Differences are only two details: waveguide and pipe with matching element!

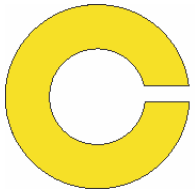


Coaxial-waveguide connection.

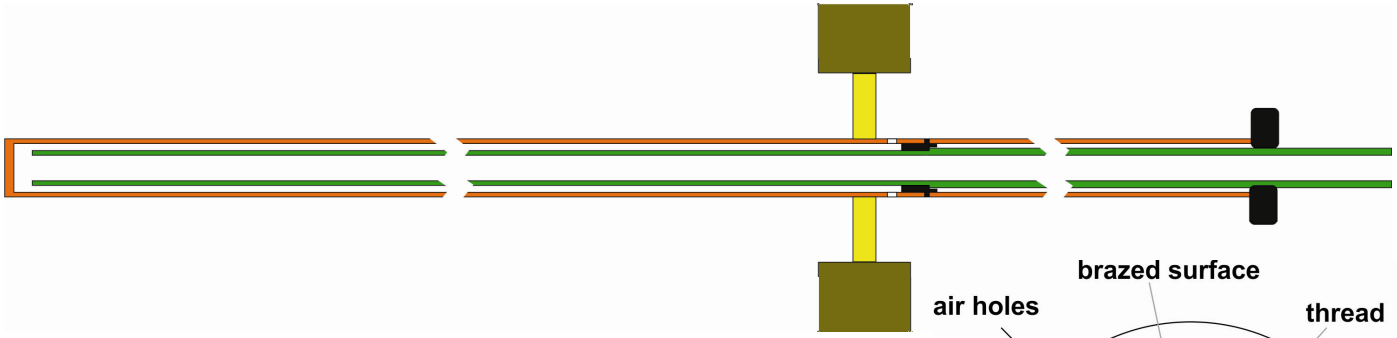
Door knob can have a thin insulator on the surface.
In this case we can apply HV bias to suppress multipactor.

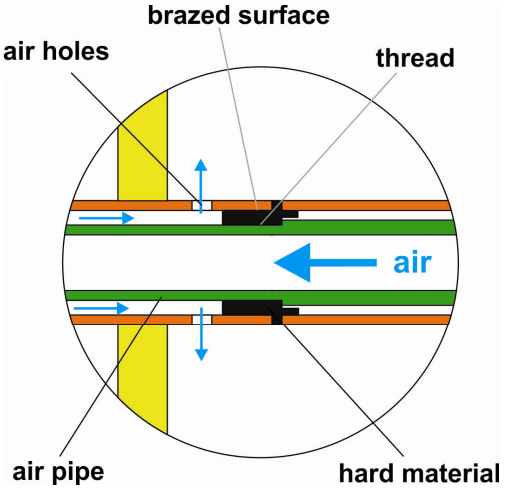


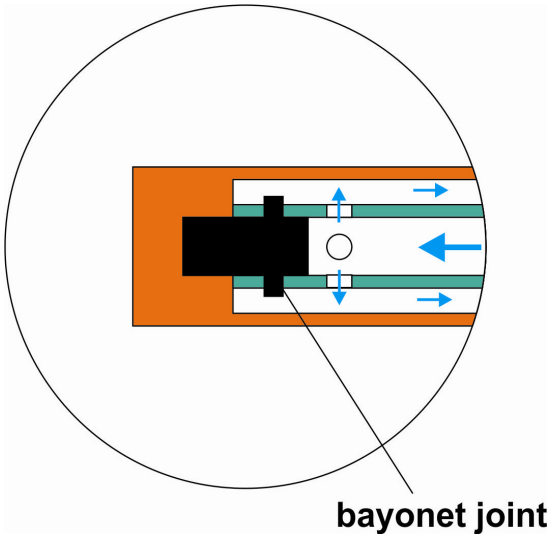


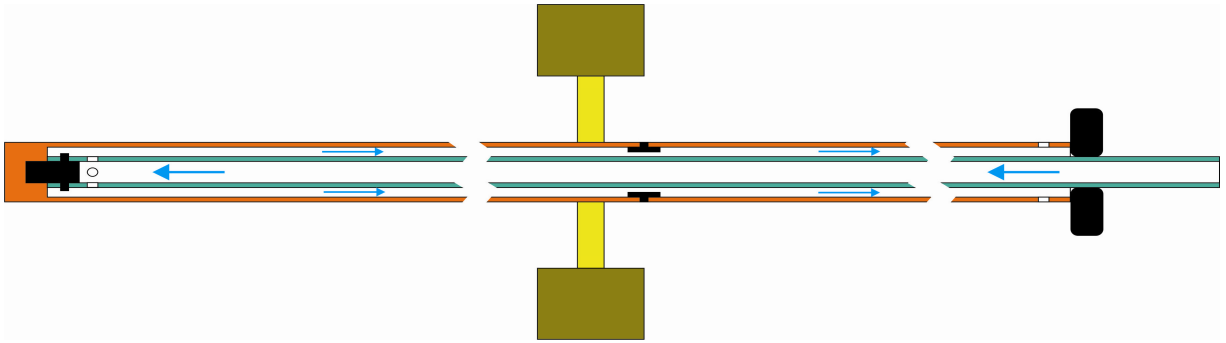


Internal conductor is air-cooled:

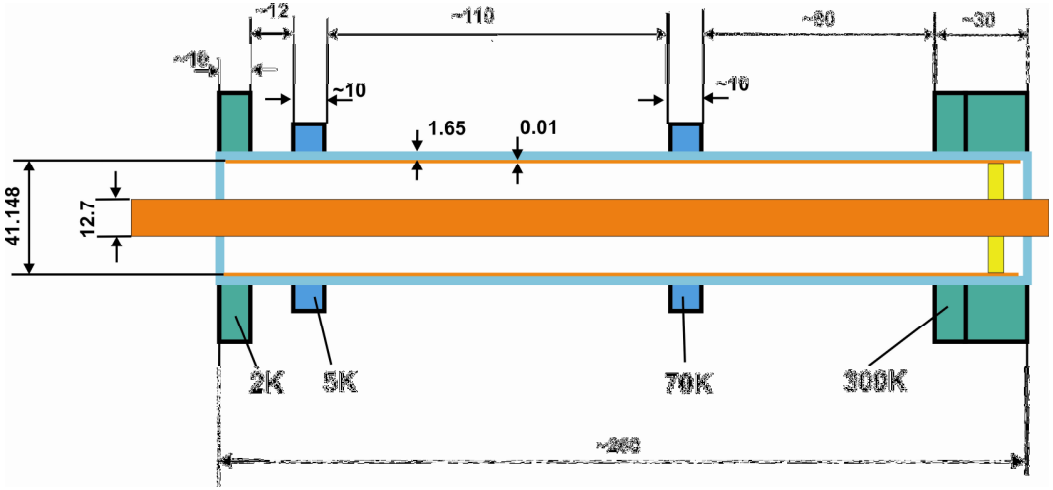








Optimum geometry of “cold” part.



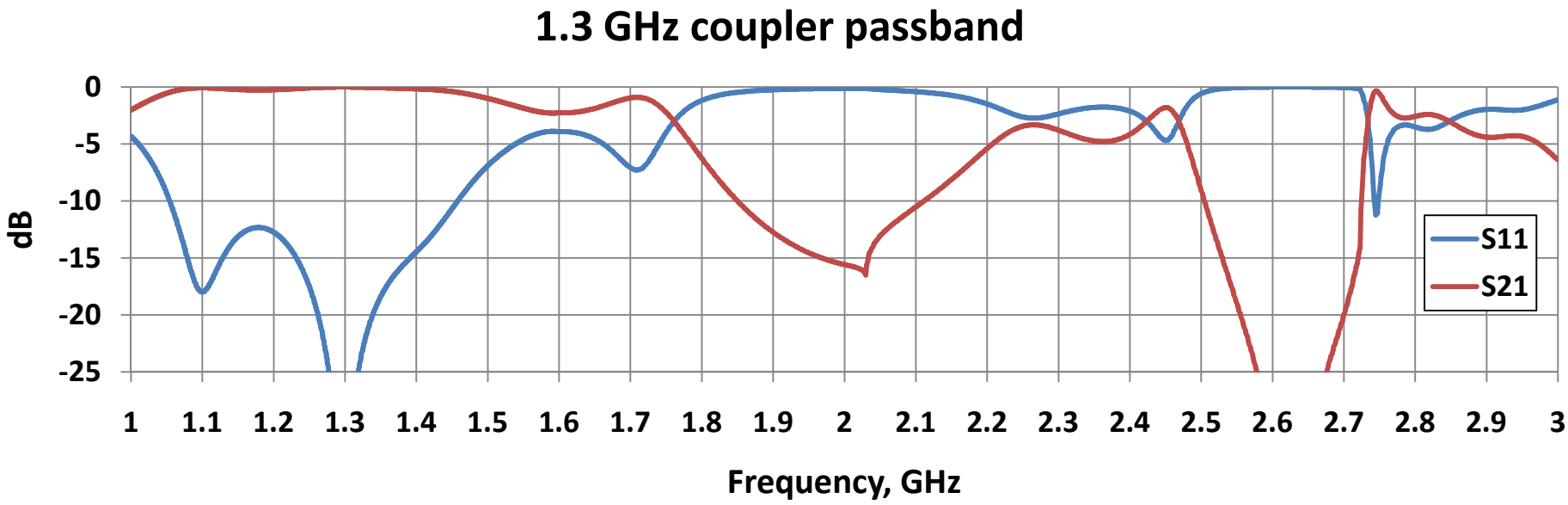
1.3 GHz

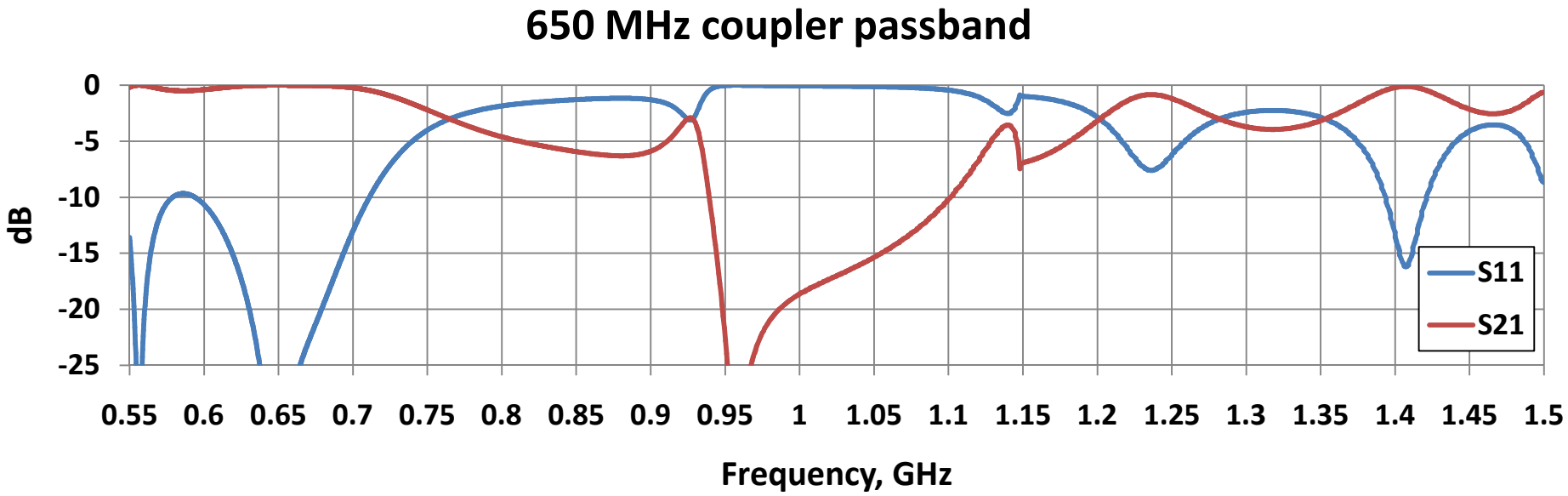
	2K (Flow/Plant),W	5K(Flow/Plant),W	70K(Flow/Plant),W	Total plant,W
RF = 0kW	0.04 / 28.1	0.99 / 196	7.85 / 62.8	287
RF = 20kW	0.075 / 52.7	1.38 / 273.2	8.84 / 70.7	397
RF = 30kW	0.093 / 65.4	1.59 / 314.8	9.36 / 74.9	455

650 MHz

	2K (Flow/Plant),W	5K(Flow/Plant),W	70K(Flow/Plant),W	Total plant,W
RF = 0kW	0.04 / 28.1	0.99 / 196	7.85 / 62.8	287
RF = 20kW	0.065 / 45.7	1.27 / 251.5	8.55 / 68.4	366
RF = 30kW	0.078/ 54.8	1.41 / 279.2	8.87 / 71.0	405

Expected power plant for cavity cooling is ≈20W x 703 ≈ 15kW.
Coupler contribution will be 3-4 % .


1.3 GHz coupler passband
0
-5
-10
-15
-20
-25
dB
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
Frequency, GHz
S11
S21


650 MHz coupler passband
0
-5
-10
-15
-20
-25
dB
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
1.05
1.1
1.15
1.2
1.25
1.3
1.35
1.4
1.45
1.5
Frequency, GHz
S11
S21

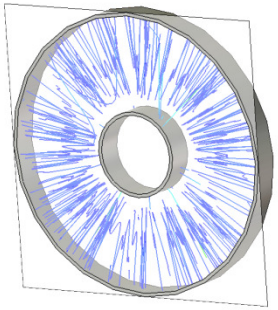
Pulse power limitation

Pulse power limited by breakdown in air.

Max. E_fld in air 3.7 kV/cm for 20 kW (TW)

Expected max. pulse power (20kV/cm) ≈ 150 kW even for SW

Multipactor analysis



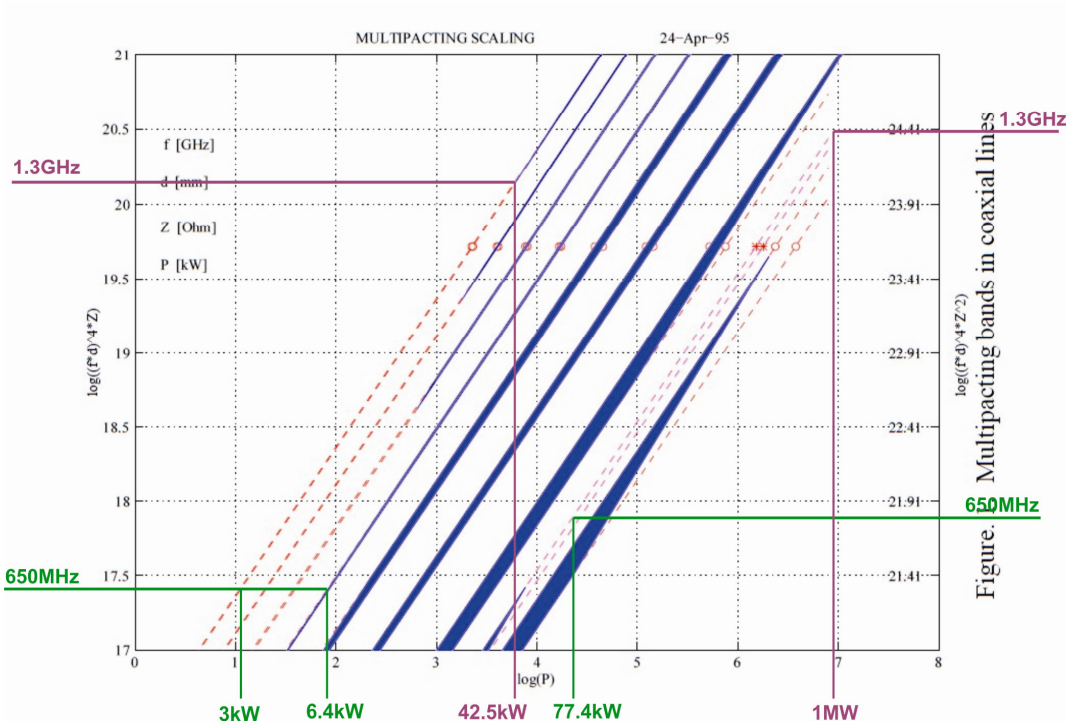
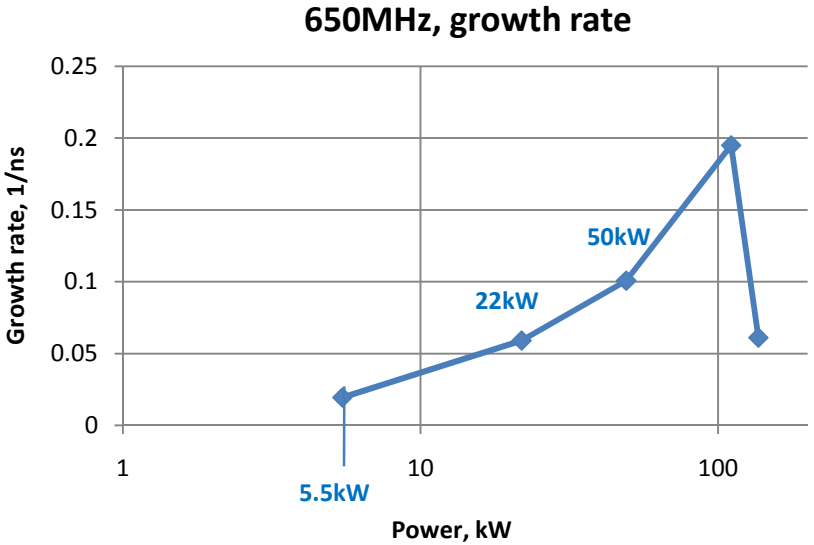
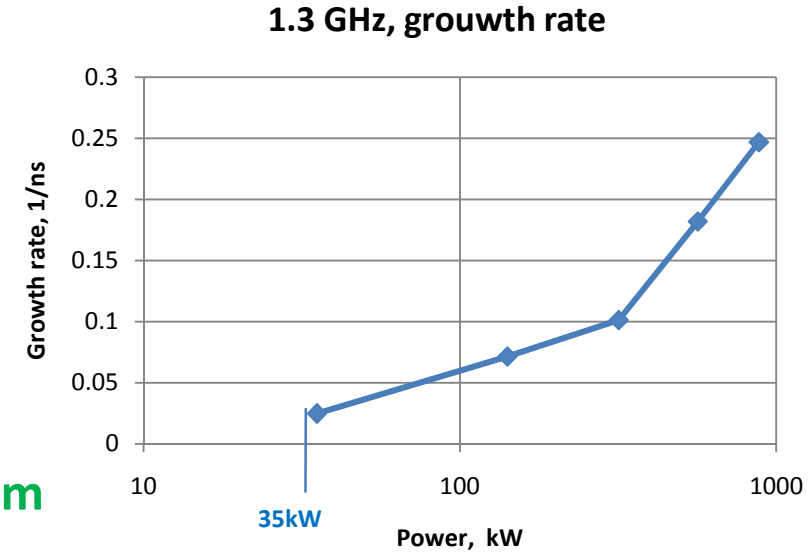


Figure. Multipacting bands in coaxial lines





1.3GHz – mult. threshold P > 40 kW, no problem

650 MHz – mult. threshold P > 6 kW, problem

We need bigger coaxial for 325 / 650 MHz couplers:

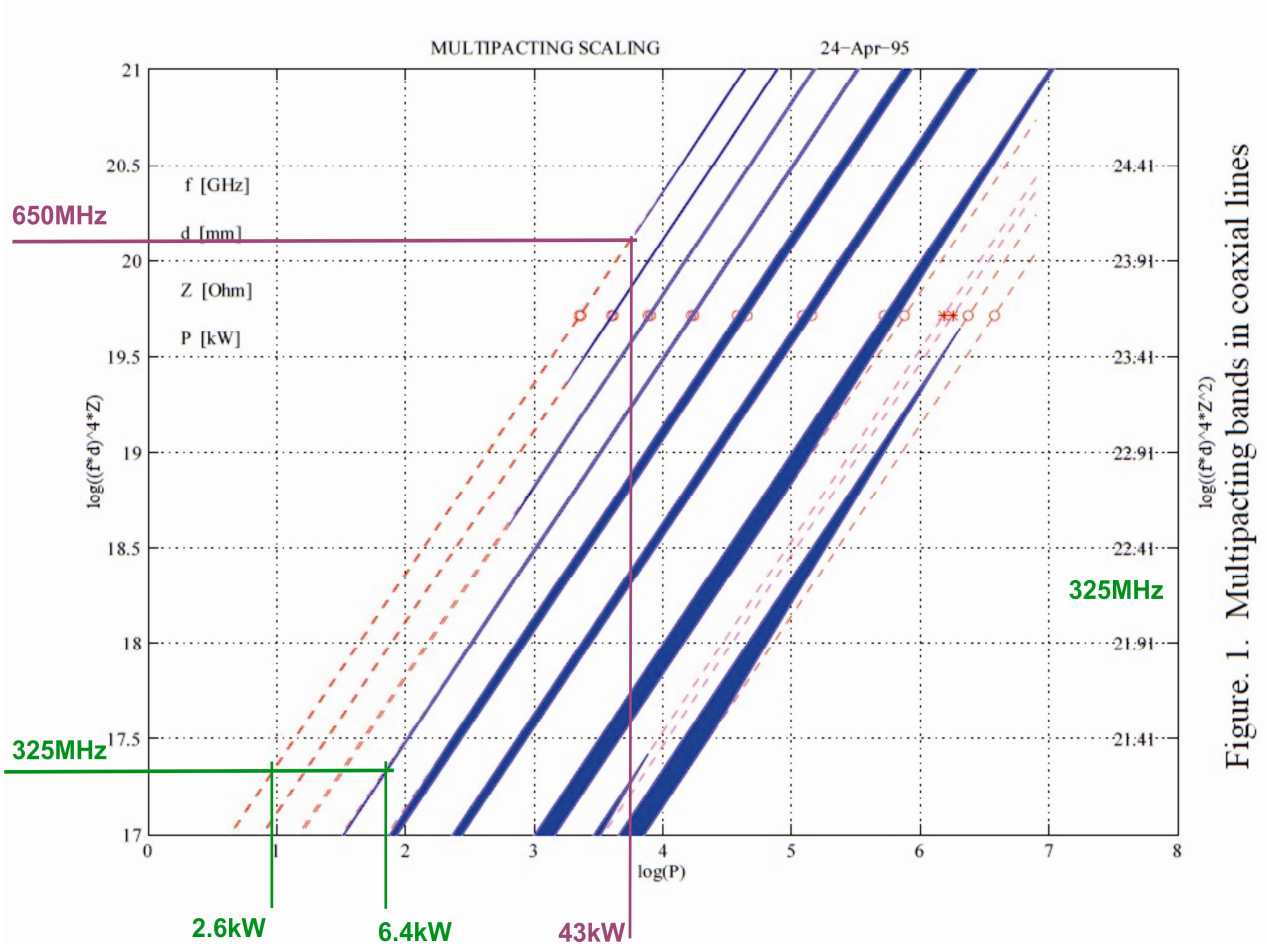


Figure. 1. Multipacting bands in coaxial lines

Coaxial 0.5”/3” (standard copper/stainless steel pipes):

650 MHz – mult. threshold P > 40 kW, no problem

325 MHz – mult. threshold P > 6 kW, no problem

Geometry of vacuum part of coupler is simple and multipactor can be easy simulated.

Proper chose of sizes of coaxial line enables to avoid multipactor without HV bias.

Design allows to use HV bias.

Conclusion:

Parameters of Project X allow to have simple single-window couplers with fixed coupling and without HV bias.

Preliminary design of 1.3GHz coupler is done. Coupler is compatible with present 1.3GHz cavities and cryomodules

Designs of 325MHz and 650 MHz couplers are under way.