Power Coupling

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Outline

Basic concepts

coaxial/waveguide couplers
magnetic/electric coupling
coupling coefficient

Couplers for Standing Wave Normal Conducting Cavities

Couplers for Traveling Wave Structures

Couplers for Superconducting cavities

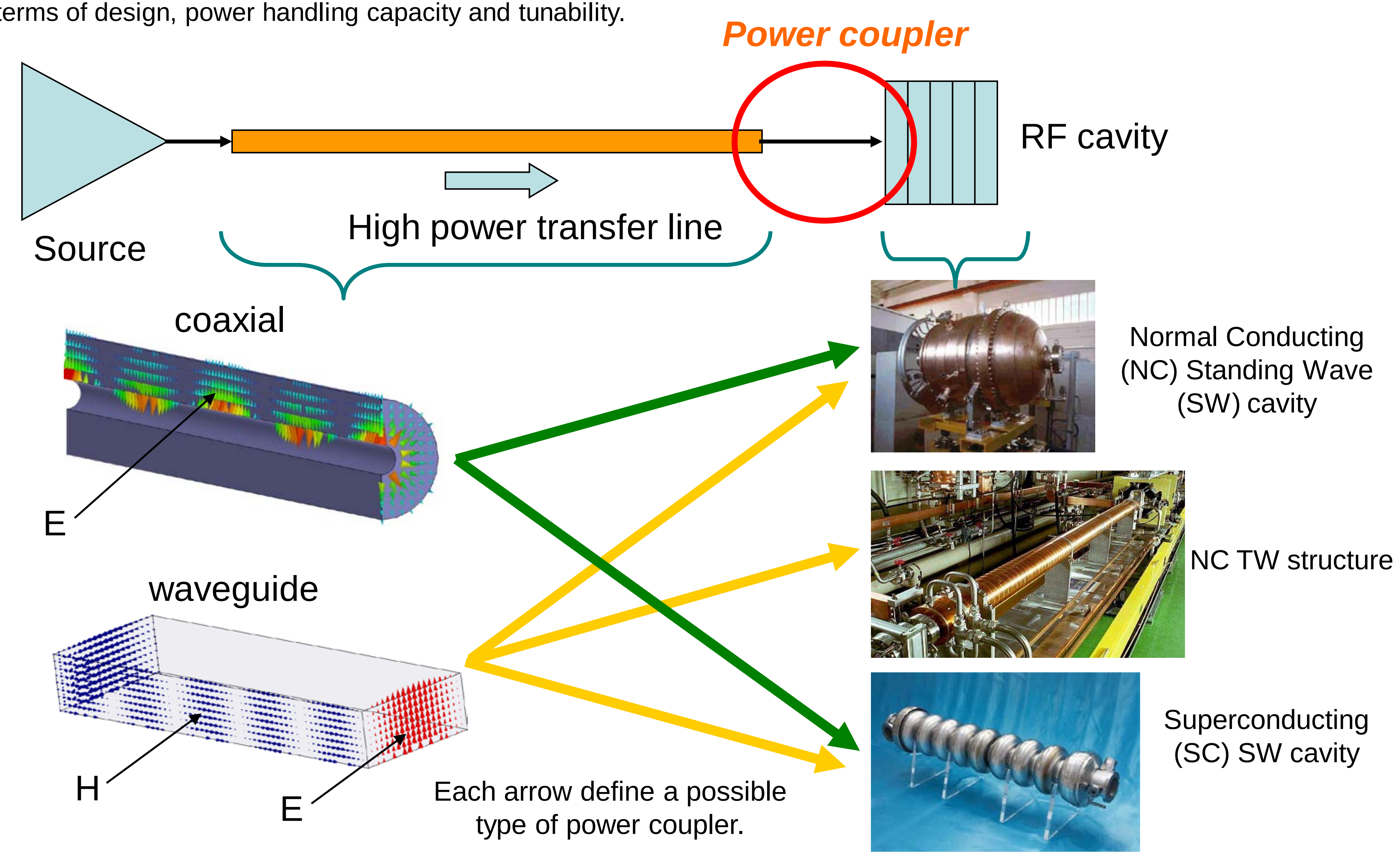
A lot of material (pictures, photos, drawings) has been taken from papers and presentations reported in the final references.

I would like to thank all authors for their help and contribution.

Introduction: what is a coupler

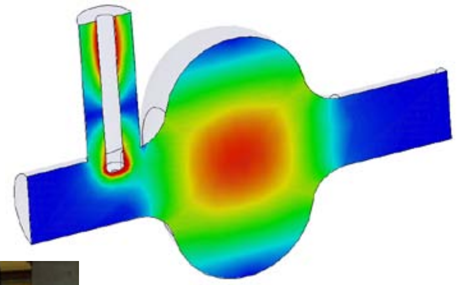
Power couplers transmit the power generated by the source to the cavity with a proper rate of energy. They are passive impedance matching networks designed to efficiently transfer power from an RF power source to a beam-loaded cavity operating under ultra-high vacuum conditions.

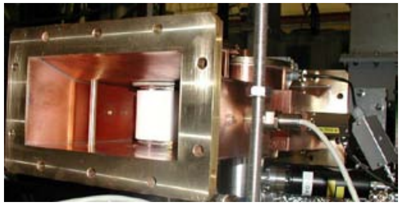
Two types of couplers can be used: ***waveguide*** type and ***coaxial*** type. Both have some advantages and disadvantages in terms of design, power handling capacity and tunability.



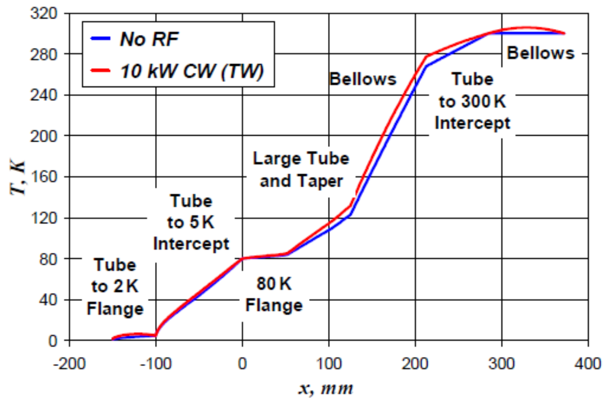
Introduction: important aspects in coupler design

1) In recent years the RF design of the couplers has been enormously aided by ***computer codes*** (such has HFSS, MAFIA, CST microwave studio). This codes allow complete modeling the field distribution of the coupler/cavity minimizing the cut-and–try design technique used at origin.

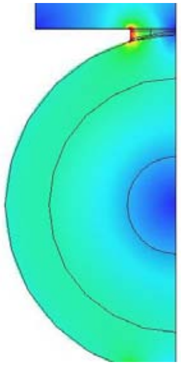




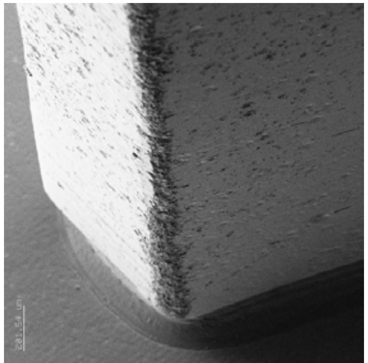
2) As transmission lines, coaxial or waveguide, are usually filled with gas, couplers have to incorporate ***vacuum barriers*** (***RF windows)***.



3) For ***superconducting cavities*** an input coupler must serve as a ***low-heat-leak thermal transition*** between the room temperature environment outside and the cryogenic temperature (from 2 to 4.5 K). Thermal intercepts and/or active cooling in the coupler design might be necessary.

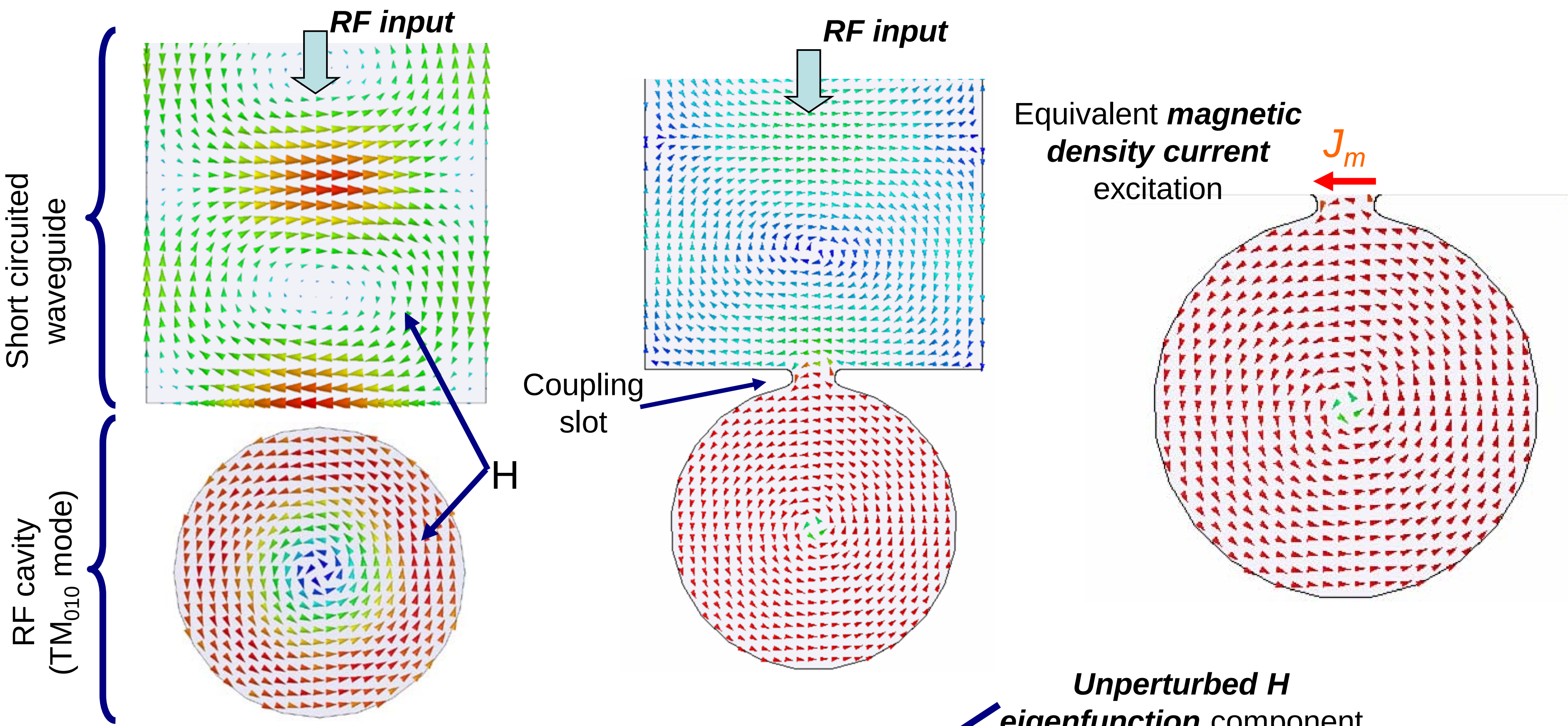


4) The coupler introduces an ***asymmetry*** in the electromagnetic field distribution which can deteriorate the beam quality. Special measures, such as using double couplers or compensating stubs, may be required.



5) Input couplers should be designed taking into consideration ***pulsed heating*** and ***multipacting*** phenomena.

Magnetic coupling: slots on waveguides



Amplitude of the excited mode in the cavity

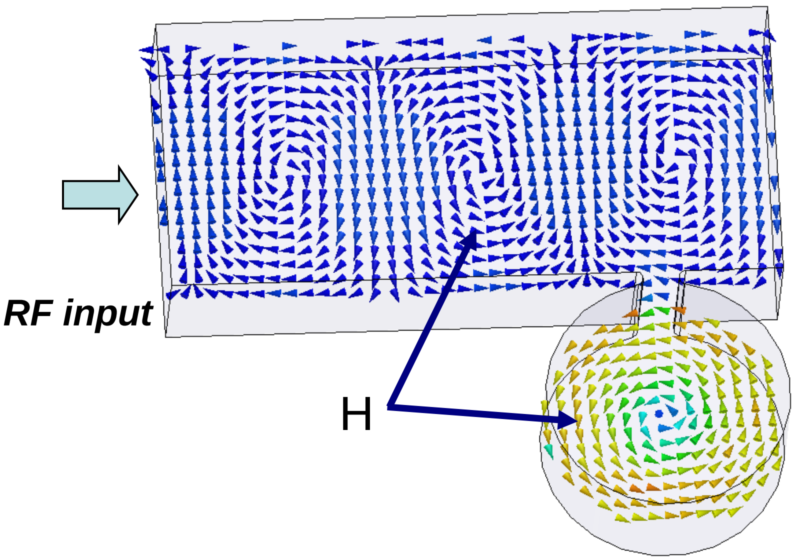
$$A_H \propto \int_{\substack{coupling\\volume}} \overrightarrow{H} \cdot \overrightarrow{J}_m \, dV$$

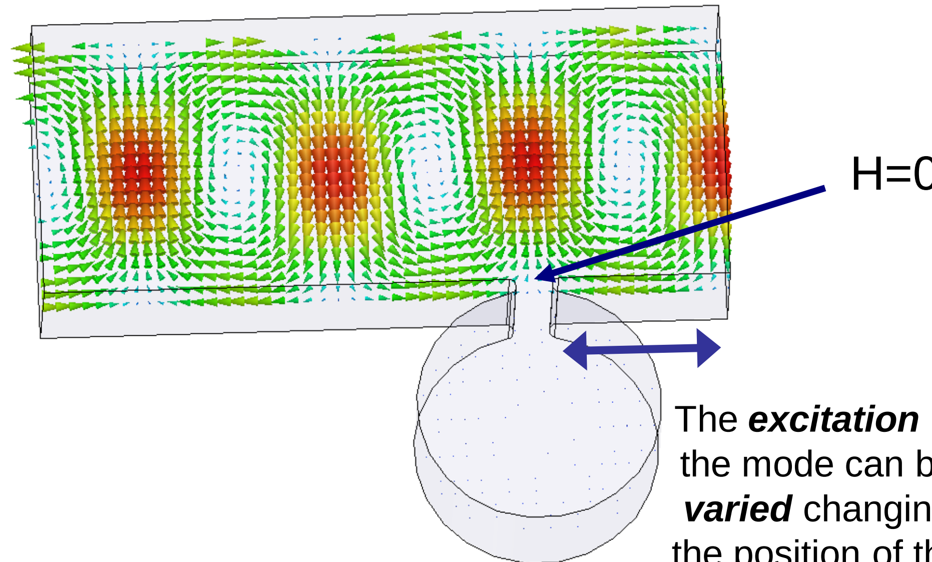
Unperturbed H eigenfunction component of the excited mode in the coupling area

Equivalent magnetic density current of the waveguide in the coupling area

Both H and J_m should be different from zero and non orthogonal in order to have excitation of the mode

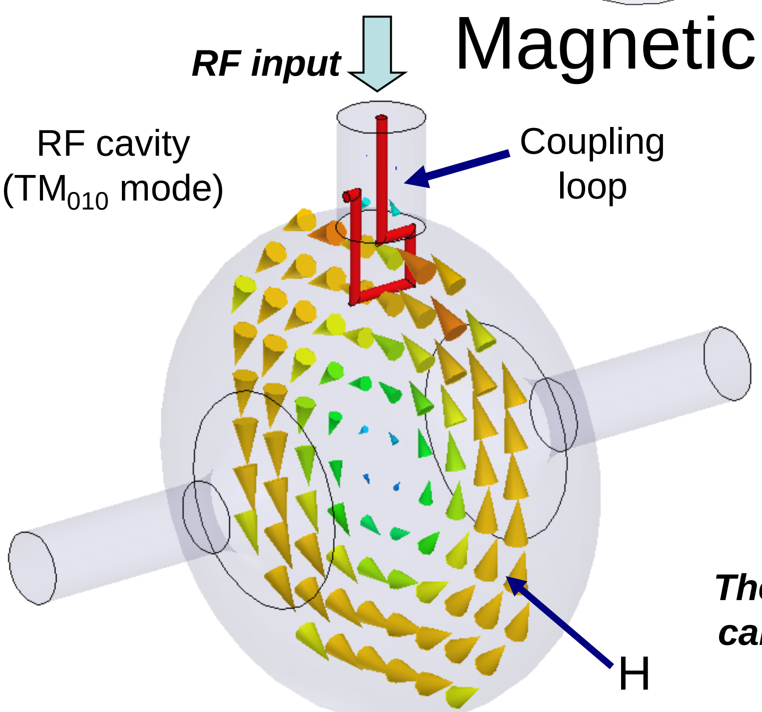
Magnetic coupling: longitudinal slots on waveguides





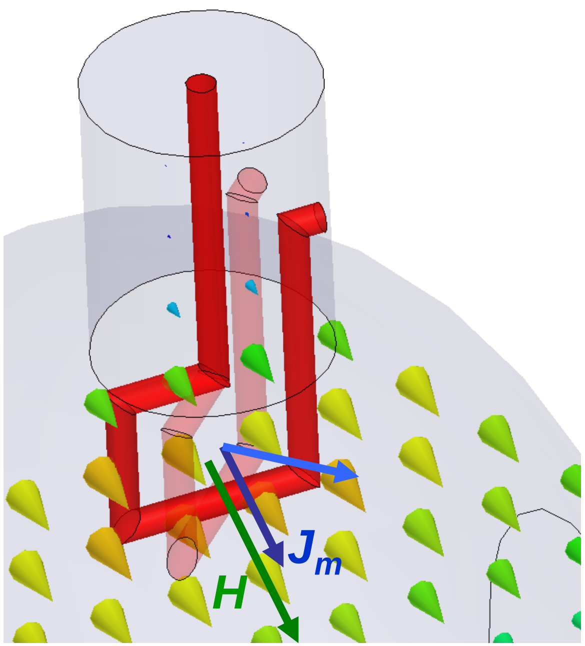
The ***excitation*** of the mode can be ***varied*** changing the position of the short circuit plane

Magnetic coupling: loop

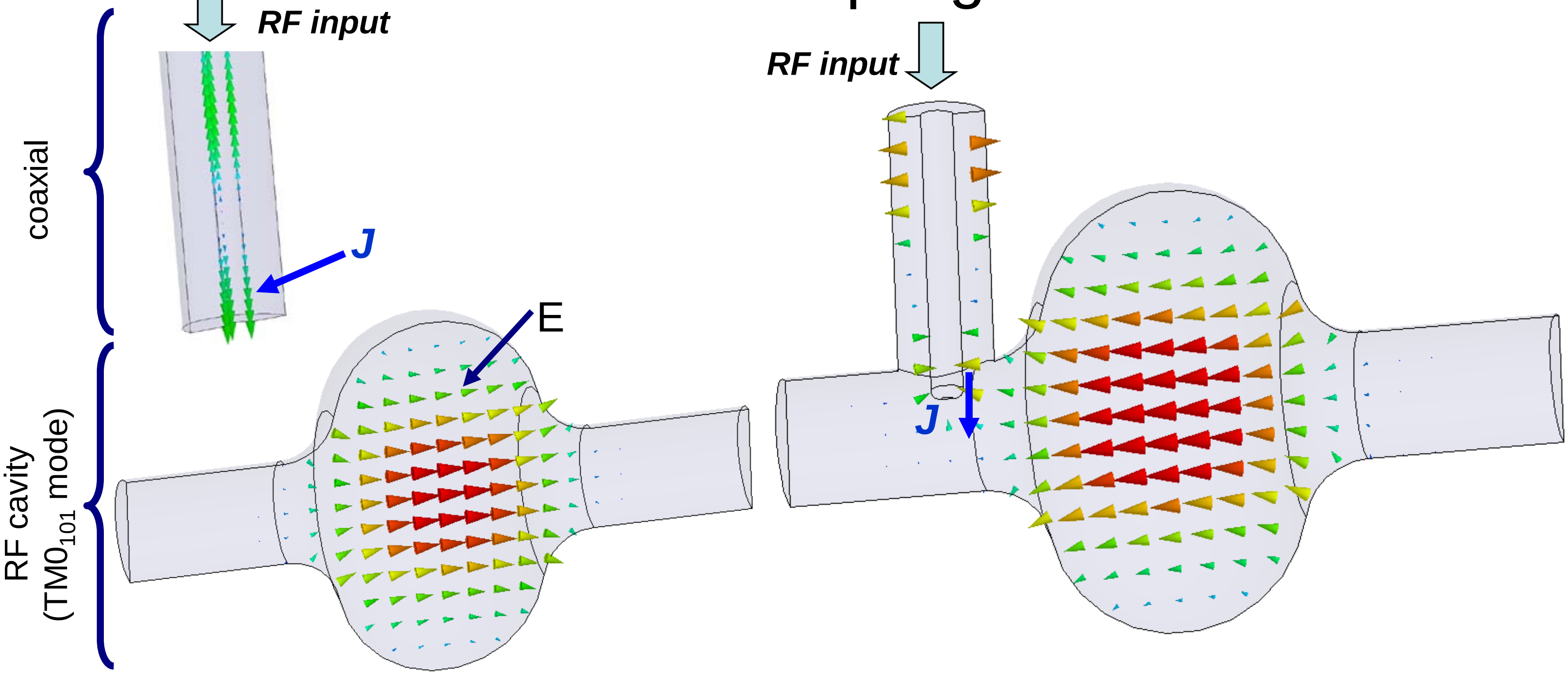


$$A_H \propto \int_{\text{coupling volume}} \overrightarrow{H} \cdot \overrightarrow{J_m} \, dV$$

The excitation of the mode can be varied changing the orientation of the loop



Electric coupling: antenna



Amplitude of the excited mode in the cavity

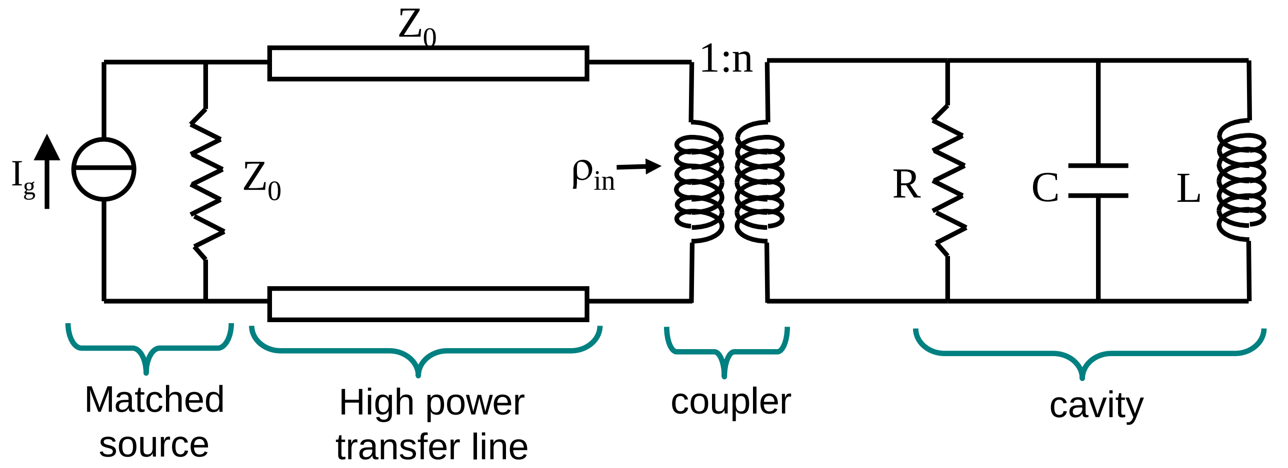
Unperturbed E eigenfunction component of the excited mode in the coupling area

$$A_E \propto \int_{\text{coupling volume}} \vec{E} \cdot \vec{J} \, dV$$

Equivalent electric density current of the waveguide in the coupling area

Both E and J should be different from zero and non-orthogonal in order to have excitation of the mode

Circuit model coupler-SW cavity: coupling coefficient



Resonant frequency of the cavity $f_{res} = \frac{1}{2\pi\sqrt{LC}}$ $\left(\omega_{res} = 2\pi f_{res}\right)$

Average dissipated power in the cavity P_{cav}

Average dissipated power in the source load P_{ext}

Coupling coefficient $\beta = \frac{P_{ext}}{P_{cav}} = \frac{R}{n^2 Z_0}$

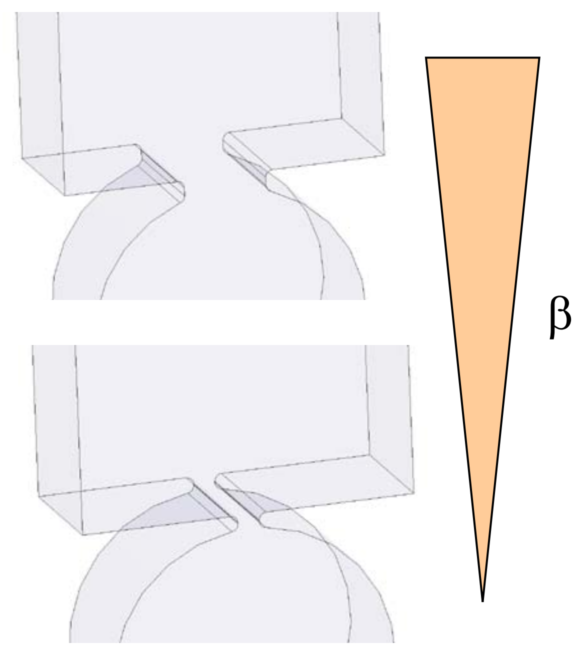
Unloaded quality factor $Q_0 = \frac{\omega_{res} W_{cav}}{P_{cav}}$

External quality factor $Q_E = \frac{\omega_{res} W_{cav}}{P_{ext}}$

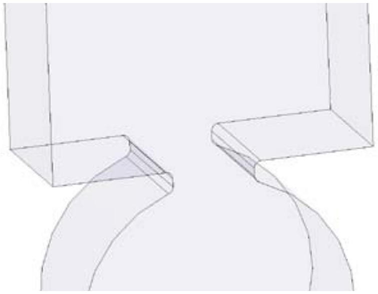
Loaded quality factor $Q_L = \frac{\omega_{res} W_{cav}}{\underbrace{P_{cav} + P_{ext}}_{P_{tot}}} = \frac{Q_0}{1+\beta}$

$$\rho_{in} = \frac{\beta - 1 + jQ_0\delta}{\beta + 1 + jQ_0\delta}$$

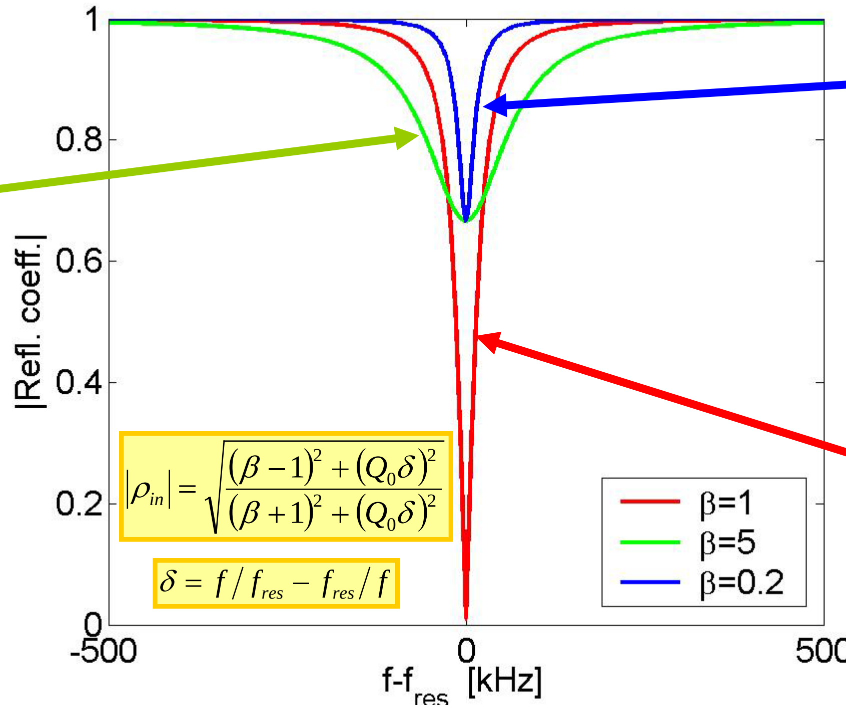
The coupling fixes the reflection coefficient at input port, the resonance bandwidth and the ratio between the power dissipated into the cavity and external load.

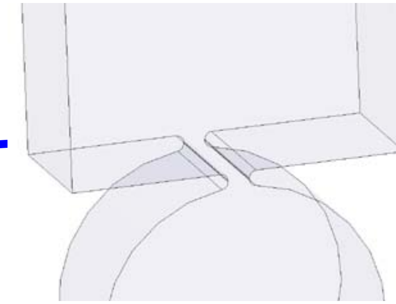


Coupling coefficient

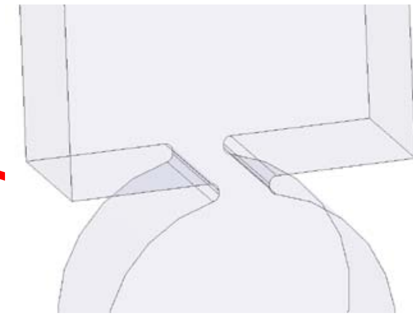


β>1 over coupling





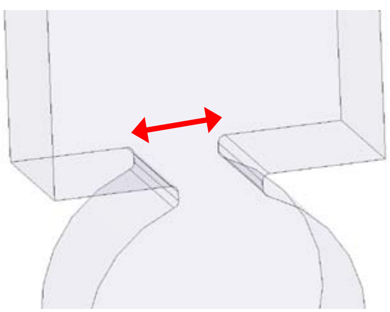
β<1 under coupling



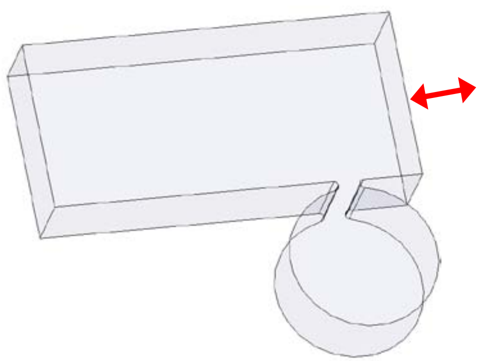
β=1 critical coupling

The choice of the coupling depends on the cavity operational condition with beam.

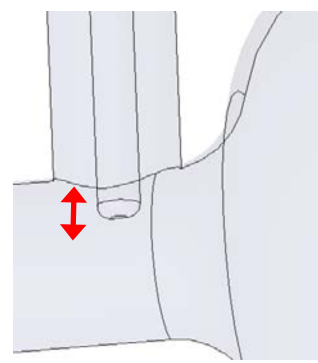
slot



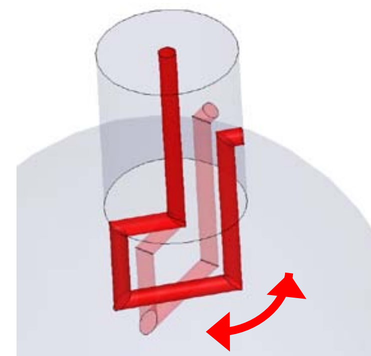
Longitudinal slot



antenna



loop



The coupling is fixed once we have construct the cavity

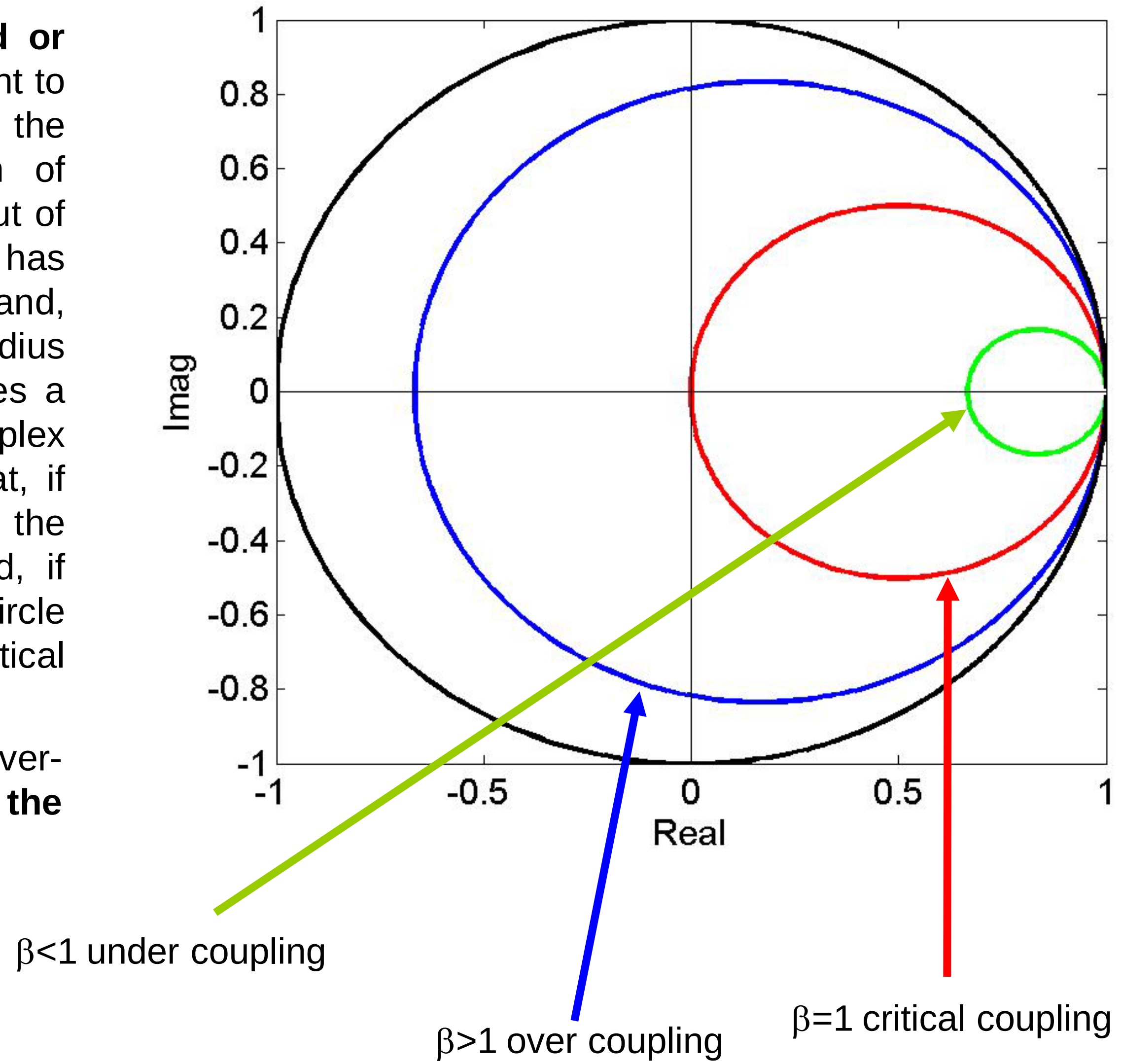
It is possible to ***change the coupling*** changing the position of the short circuit plane, the antenna penetration or the loop orientation

Design/calculation of coupling coefficient

In the design of a coupler (by, as example, an electromagnetic code) it is important to calculate and tune the coupling coefficient. To calculate it is enough to:

1) **establish if we are under-coupled or over-coupled**. To do this it is sufficient to look at the reflection coefficient at the coupler input port (as a function of frequency) in the ***complex plane***. Out of resonance the reflection coefficient has an absolute value equal to 1 and, therefore, it stay on a circle with radius equal to 1. At resonance it describes a circle towards the origin of the complex plane. It is easy to demonstrate that, if the circle include the origin of the complex plane we are over-coupled, if not we are under-coupled. If the circle cross the origin we are in critical coupling.

2) Once we have established if we are over- or under-coupled, **we can calculate the coupling by the formulae**:



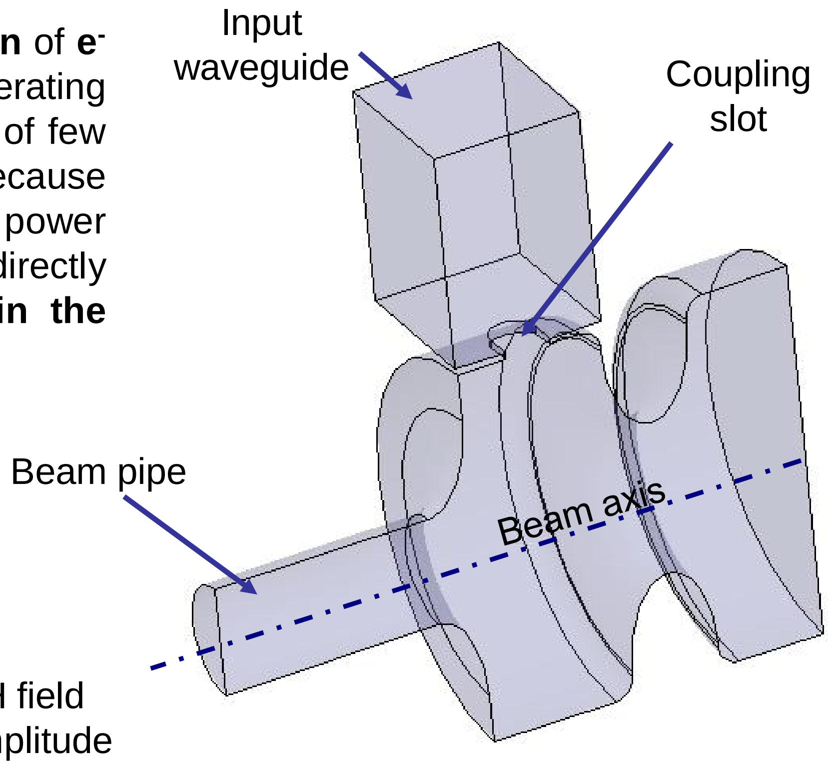
$$\beta = \frac{1+|\rho_{in}|}{1-|\rho_{in}|} \quad \text{(overcoupled)}$$

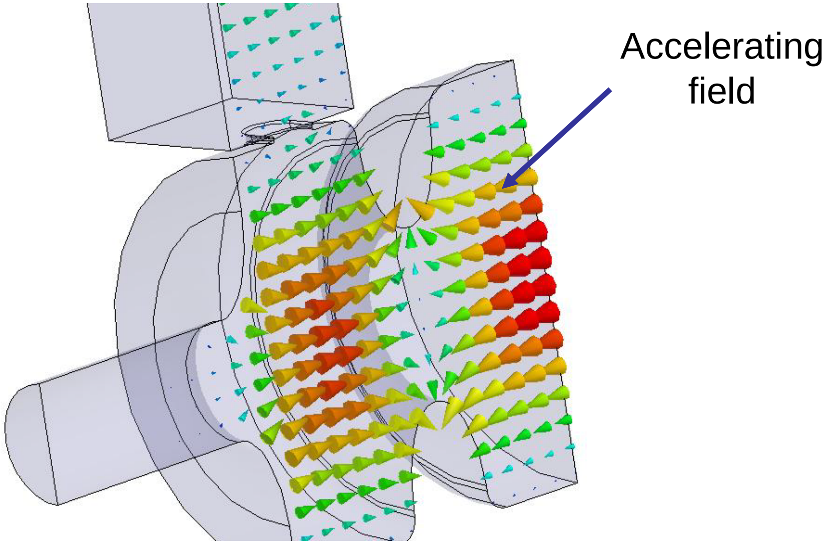
$$\beta = \frac{1-|\rho_{in}|}{1+|\rho_{in}|} \quad \text{(undercoupled)}$$

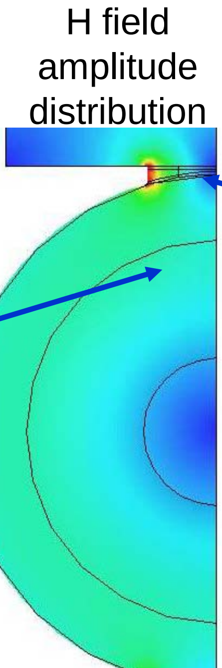
Where $|\rho_{in}|$ is the absolute value of the reflection coefficient at resonance

Waveguide couplers for NC SW cavities: RF guns

Normal Conducting **RF guns** are the **first stage of acceleration** of **e⁻** in the LINACs for FEL. They are, in general, 2-3 cell SW accelerating structures operating on the π mode at frequencies of the order of few GHz. Required coupling coefficients β are between 1 and 2. Because of the high accelerating gradient (~50-100 MV/m), high input power (~10 MW) operation and fixed coupling, the structure are fed directly by waveguides and the **coupler is realized by one slot in the waveguide**.







<u>FIELD DISTORTION</u>

Because of the relatively low energy of the electron beam (few MeV) the accelerating field has to have an excellent uniformity to preserve the beam quality. "Standard" coupling slots introduce a distortion in the field distribution and a **dipole and quadrupole component of the field** can apper strongly affecting the beam dynamics.

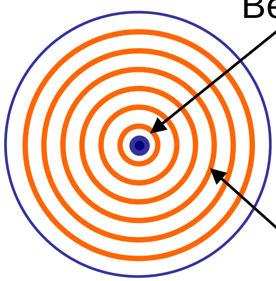
<u>HIGH DISSIPATION IN THE SLOT</u>

In the **slot region there is an high dissipation due to the high surface density currents** related to the high magnetic field. The high losses can create hot spots in the coupling region damaging of the coupler itself.

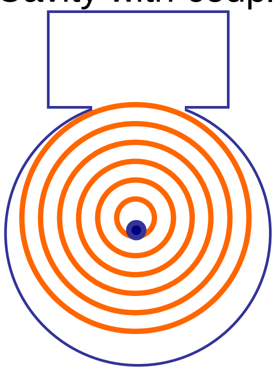
Compensation of the field distortions

DIPOLE COMPONENT

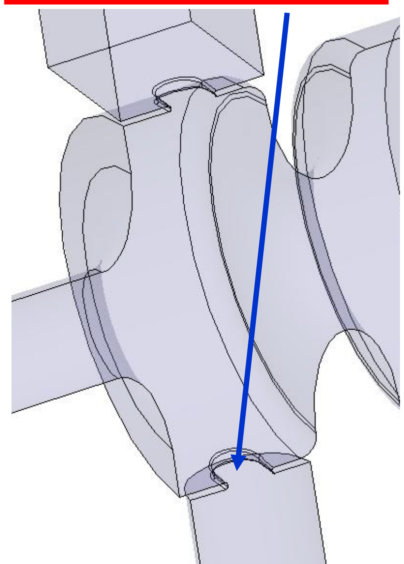
Ideal cavity



Cavity with coupler

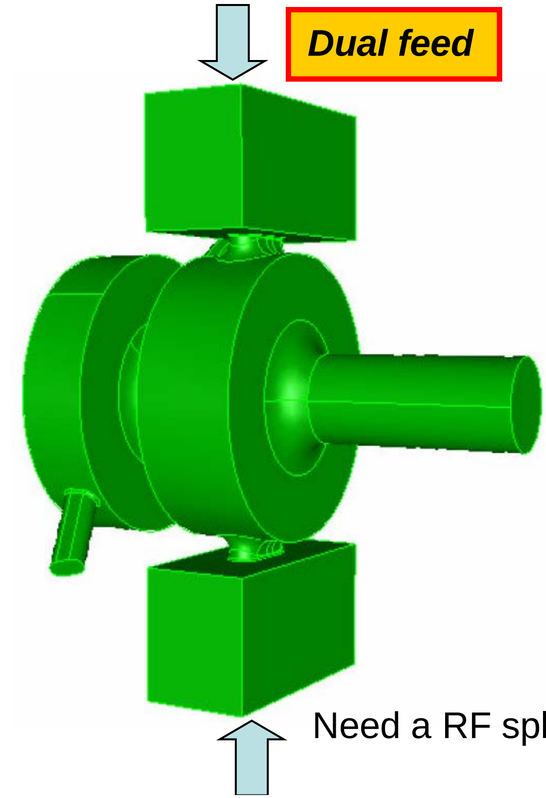


Compensating slot



Used for pumping

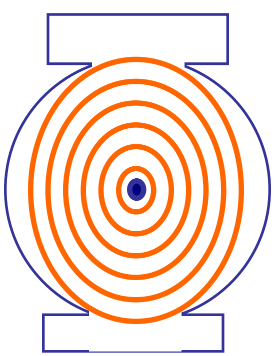
Dual feed

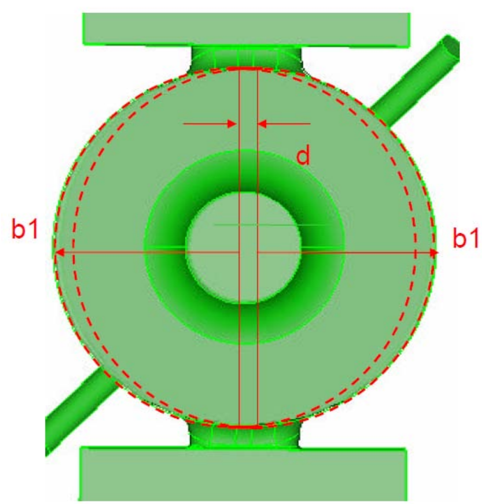


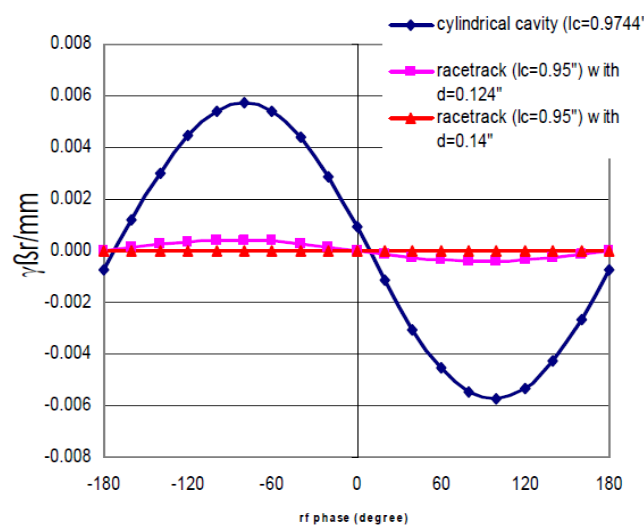
Need a RF splitter

QUADROPOLE COMPONENT

Racetrack profile







Pulsed heating in couplers

RF power enters the structure through the slots. The **rf surface currents flow along the edges of the slots** and, therefore, this edge, is a place where **local rf currents are significantly amplified**. The pulse temperature rise ΔT *(D.P. Pritzkau)* is given by:

If this pulsed heating exceed ~100 C one can have serious damages of the coupler itself.

Magnetic field (calculated by e.m. codes)

RF pulse length

$$\Delta T = \frac{|H_{||}|^2\sqrt{t}}{\sigma\delta\sqrt{\pi\rho' c_\epsilon k}}$$

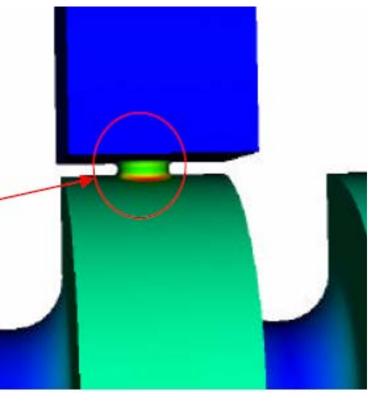
thermal conductivity

specific heat

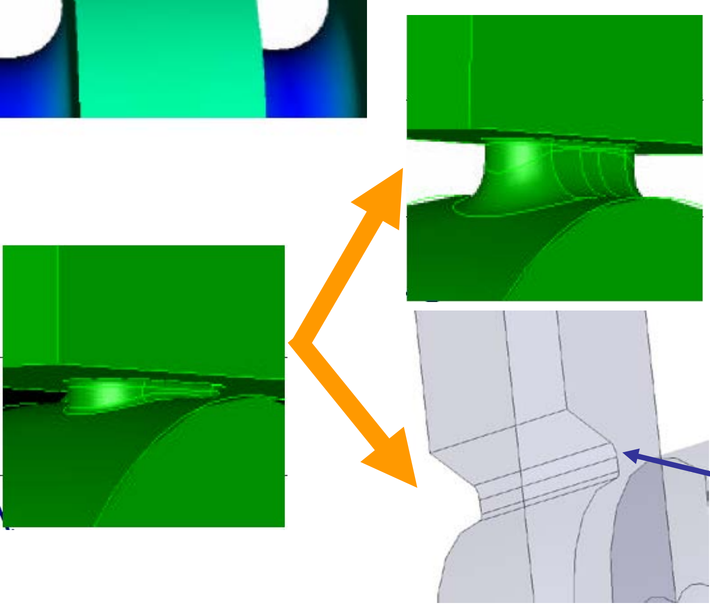
material density

electrical conductivity

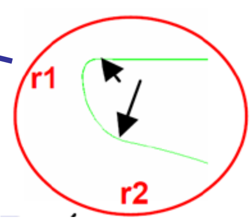
skin depth

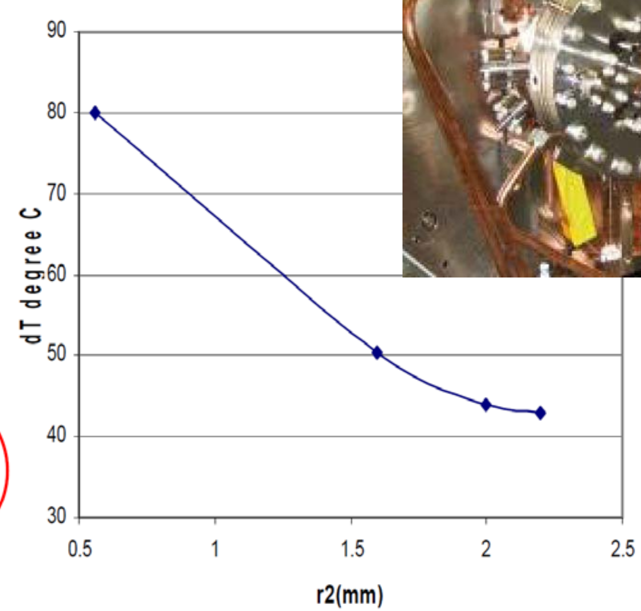


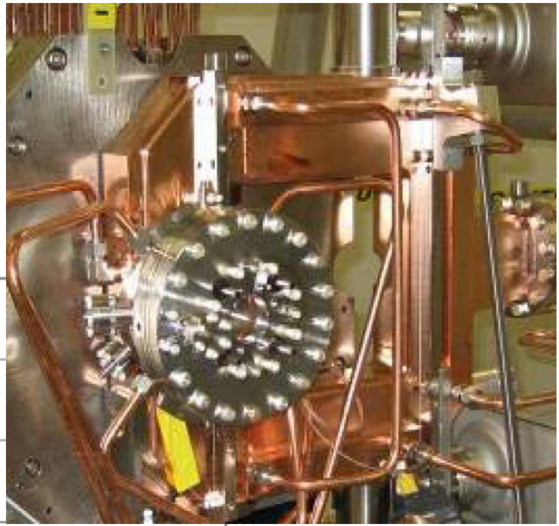
Reduction of the pulsed heating



z-coupling







LCLS gun
f_{RF}=2.856 GHz
t=3 μs
E_{acc}=120 MV/m
Symmetric
z-coupling

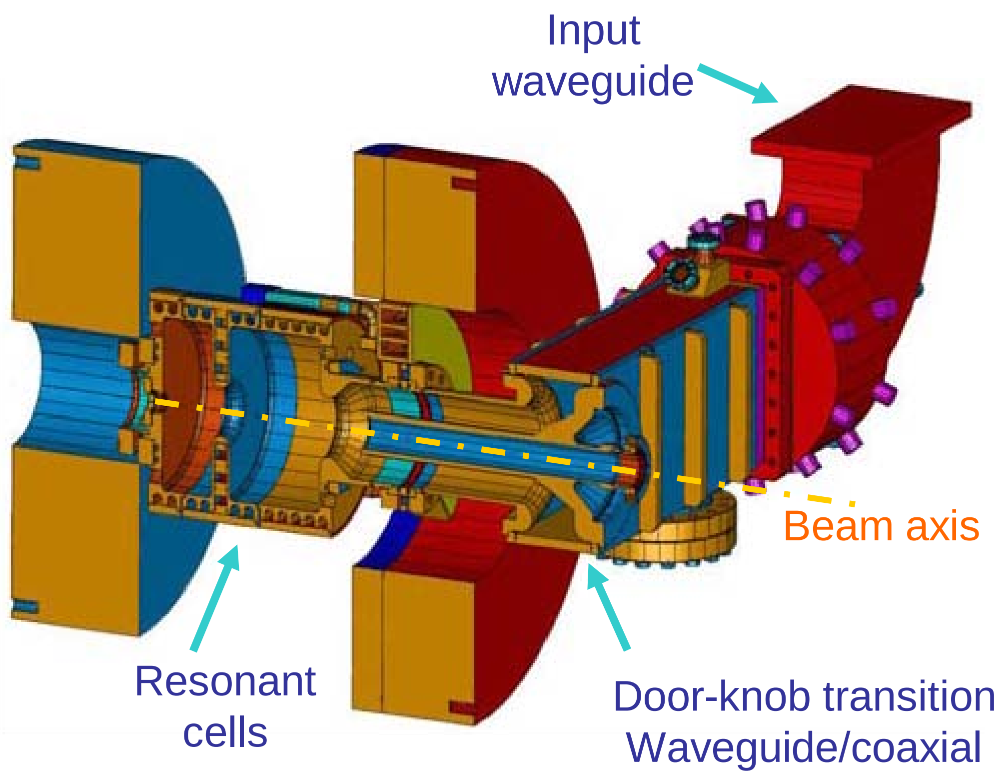
Coaxial power couplers for RF guns

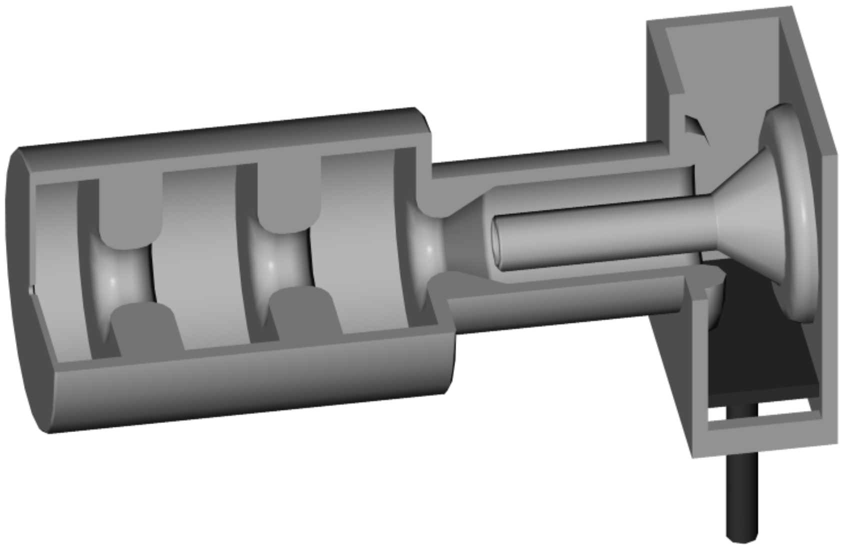
In order to avoid emittance growth due to field asymmetries introduced by the coupler an alternative **idea is to use a coaxial input coupler** that couples to the cavity on the cavity axis *(F.B. Kiewiet, K. Flottmann,…)*.

Asymmetric mode configurations are strongly suppressed since the symmetry of the cavity is not disturbed.

Dipole modes which can be generated at the Door-knob transition are in addition damped in the coaxial line.

This scheme also reduces the pulsed heating in the coupler region.



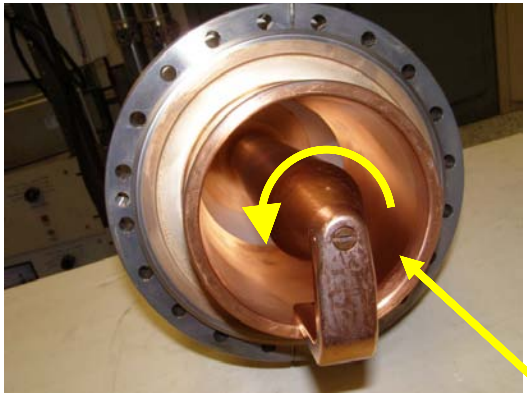


The guns of the Free Electron Laser in Hamburg (**FLASH**) and the Photoinjector Test Facility at DESY in Zeuthen (**PITZ**) are based on this principle.

RF parameters of the gun cavity

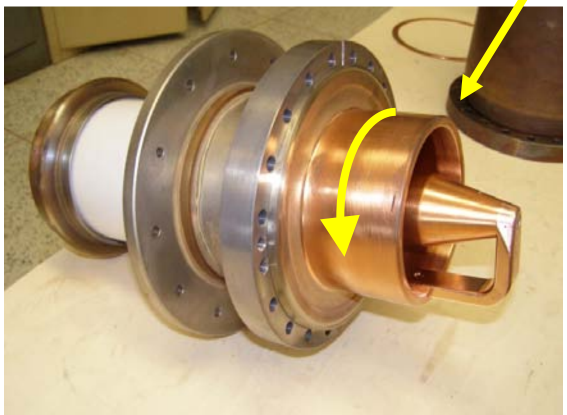
Input power	4.5 MW
Resonance frequency	1.3 GHz
Q value	21 500
Max. gradient on the cathode	50 MV/m
Max. energy gain for a particle starting with $\beta = 0$ on the cathode	5.6 MeV

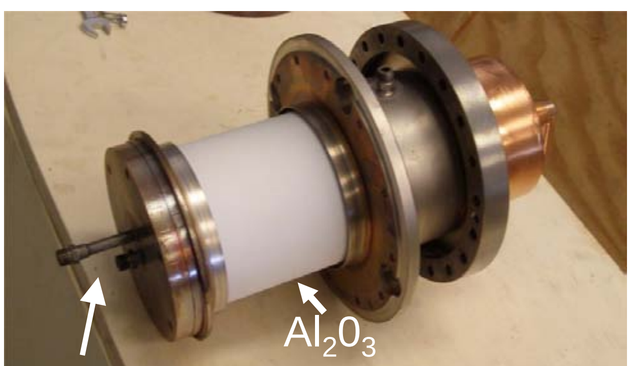
Coaxial-loop couplers for SW NC cavities: DAΦNE cavity

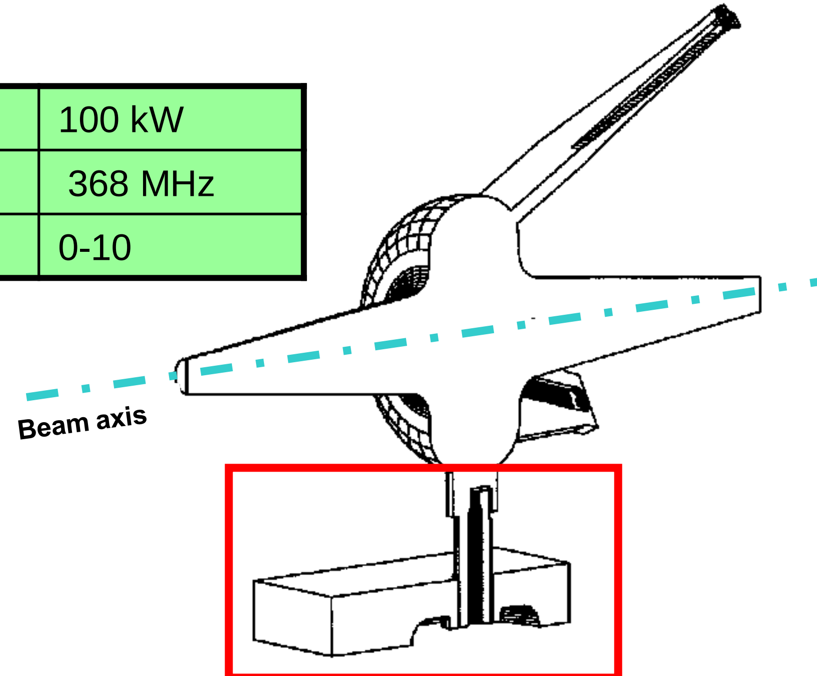


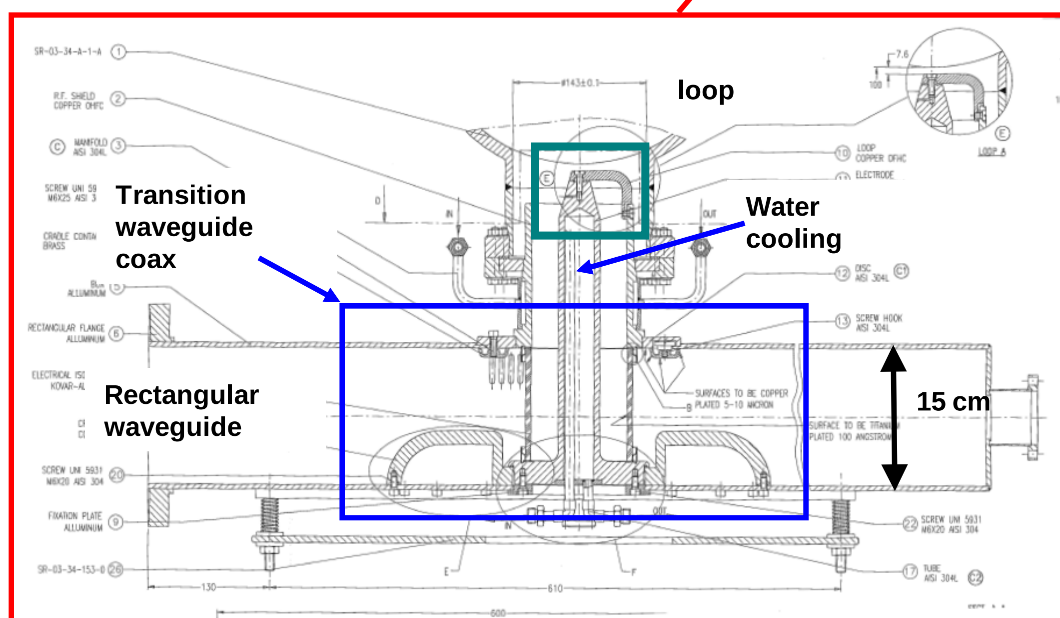
Max input power (CW)	100 kW
Frequency	368 MHz
Couplin β	0-10

The loop can be rotated changing the coupling from 0 to 10







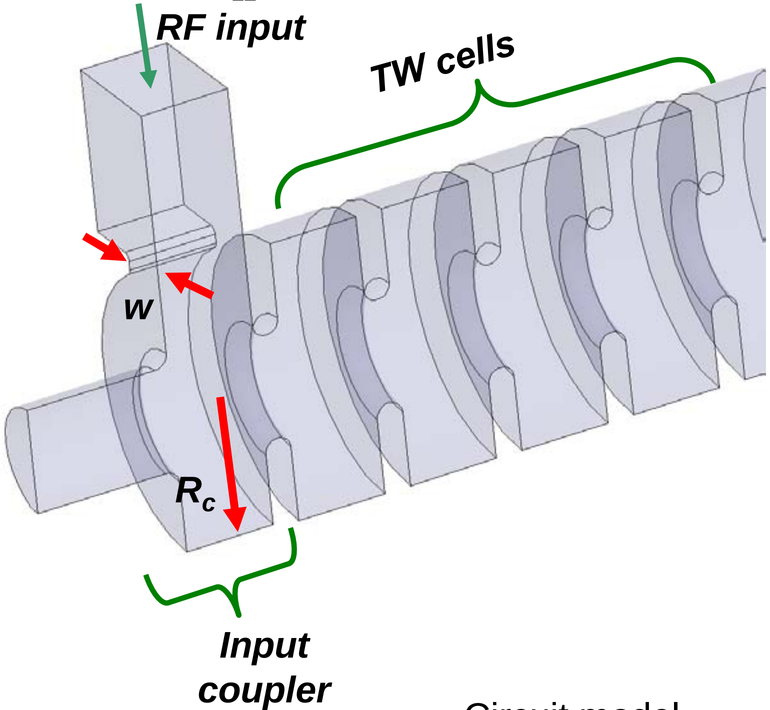


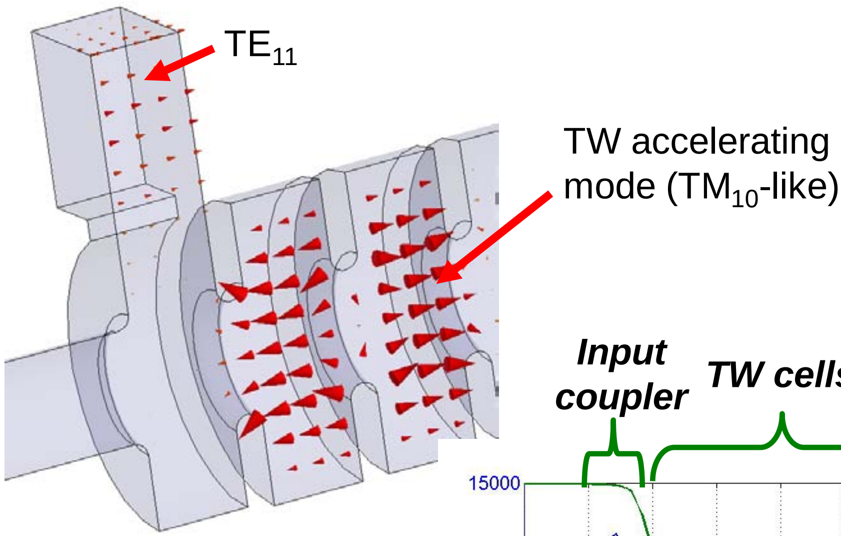
Couplers for Traveling Wave structures

Traveling wave structures are ***normal conducting structures*** used for electron acceleration. They have an input coupler, many accelerating cells (~80), and an output coupler.

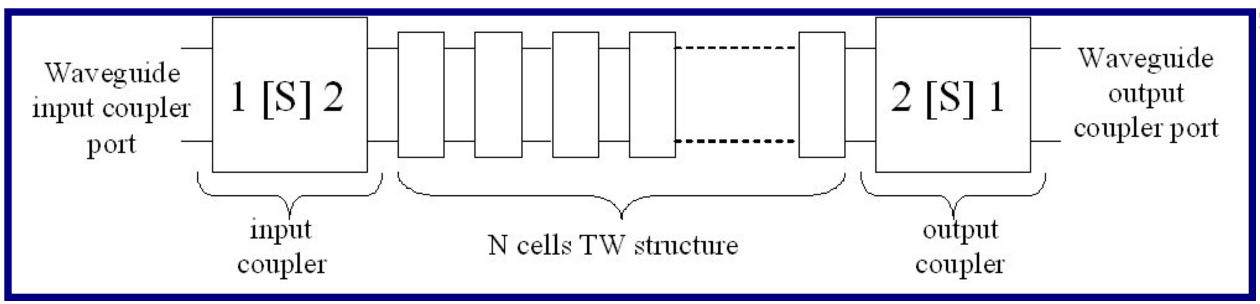
Because of the high gradient (~20-40 MV/m) and high input power (~100 MW) **the structures are fed by waveguides**.

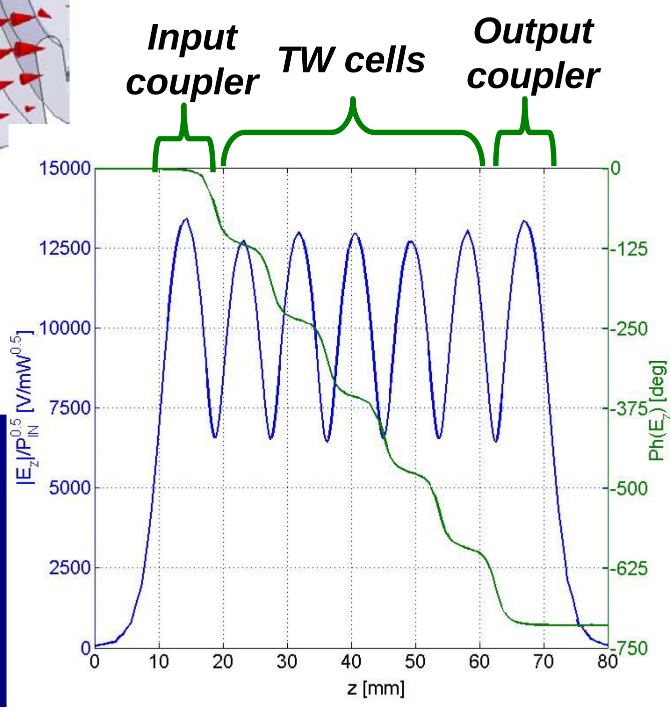
The coupler is realized, in this case, by a ***slot in the waveguide*** and the radius of the first accelerating cell (R_c) together with the slot aperture (w) are tuned to not have reflections at the waveguide input port. This coupler match the TE_{11} mode of the waveguide with the traveling wave mode (TM_{01}-like).





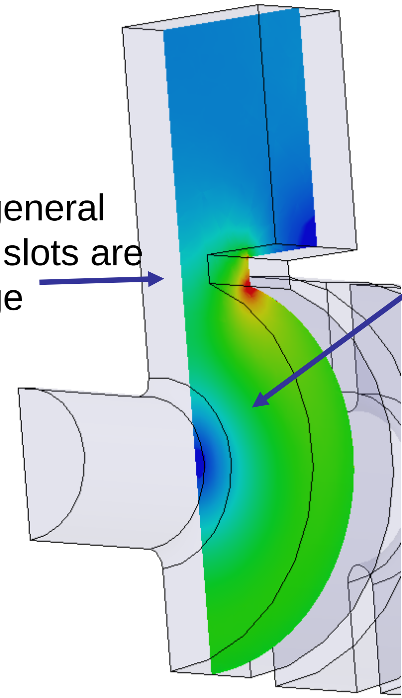
Circuit model





Field distortions introduced by the couplers in the coupler cell

In general the slots are large

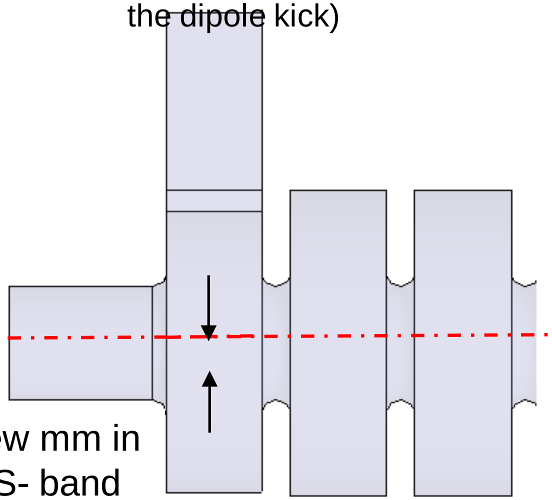


distortion in the field distribution: ***dipole*** and quadrupole components.

Compensation of the dipole field

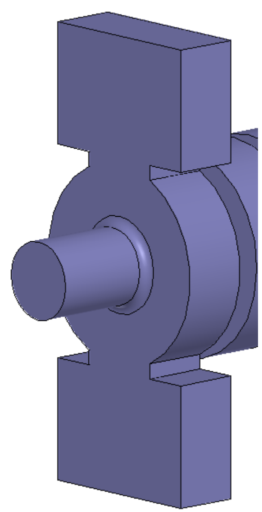
There are several techniques to compensate the dipole component.

Transverse offset of the coupler
(does not give a total compensation of the the dipole kick)

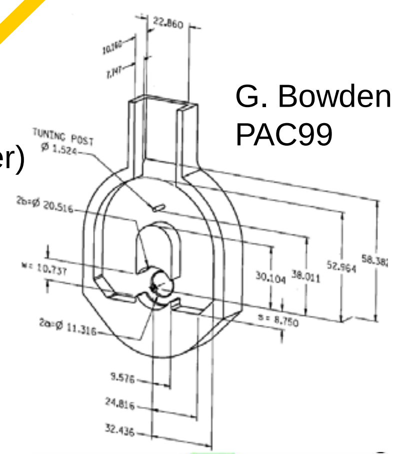


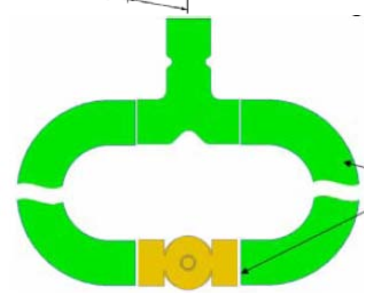
few mm in S- band

Dual feed
(it needs a splitter)

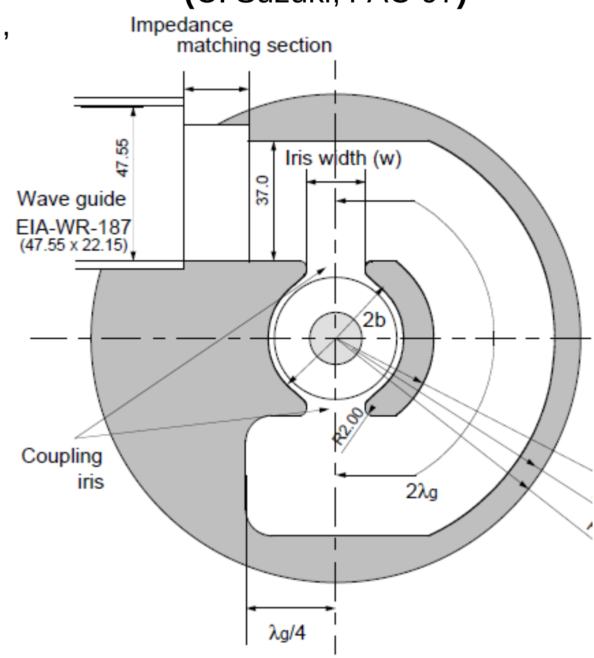


G. Bowden, PAC99



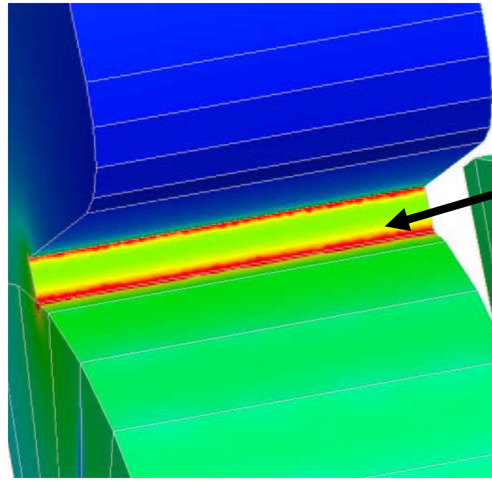


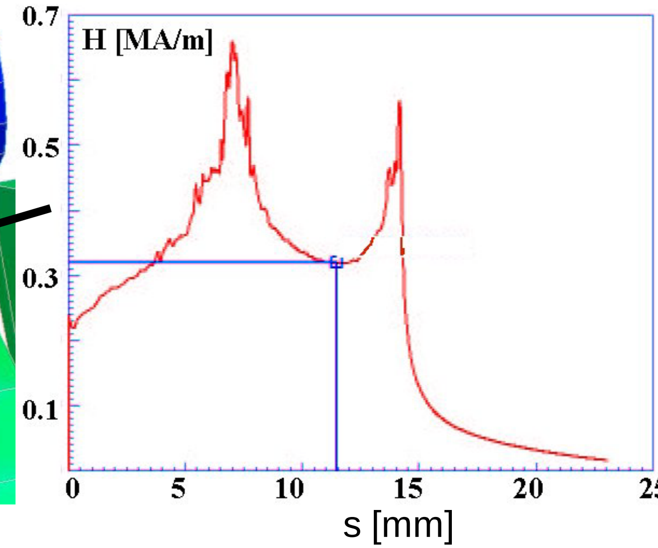
J-type coupler
(C. Suzuki, PAC 97)

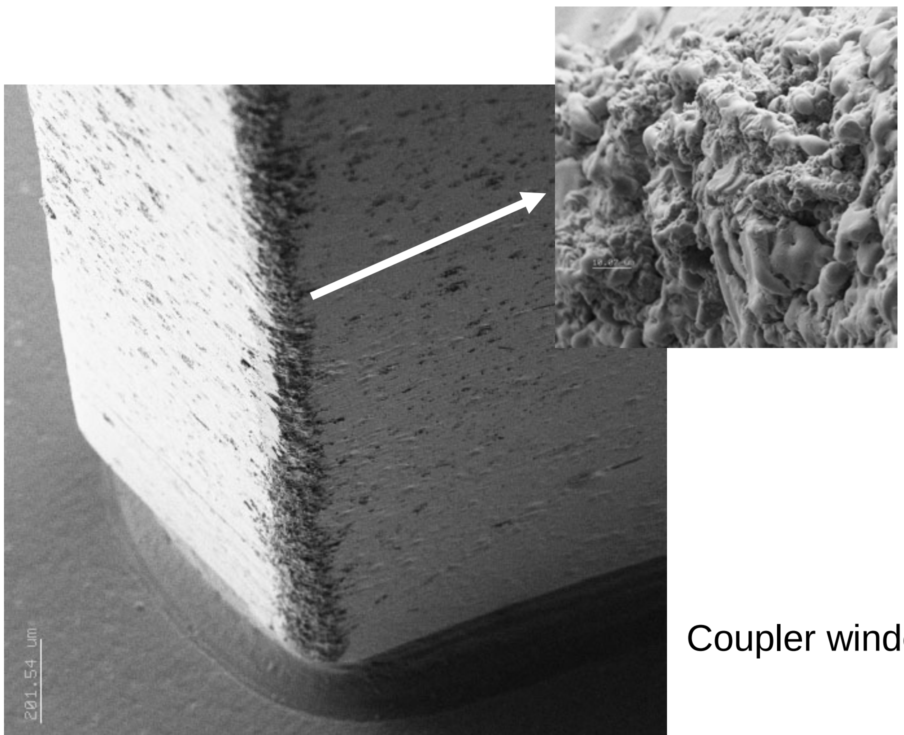


Couplers for high power-high gradient applications

In TW (or SW) **high gradient LINAC** (typically C/X-Band structures for linear collider) the magnetic field in the coupler region can reach very high values. This give a local pulsed heating (with ΔT>100ºC) that **can feed breakdown phenomena in the coupler itself**.

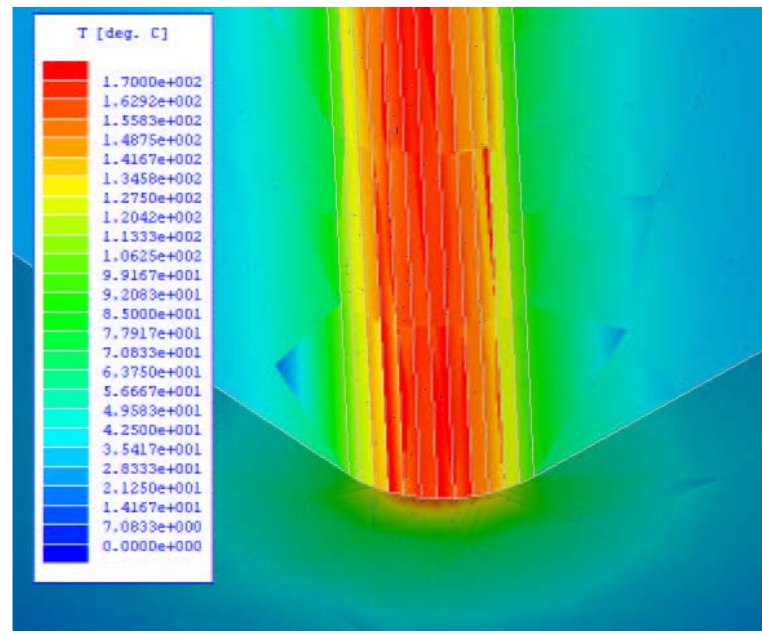






Coupler window

(courtesy V. Dolgashev)

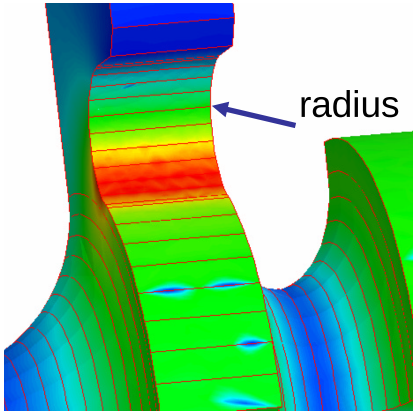


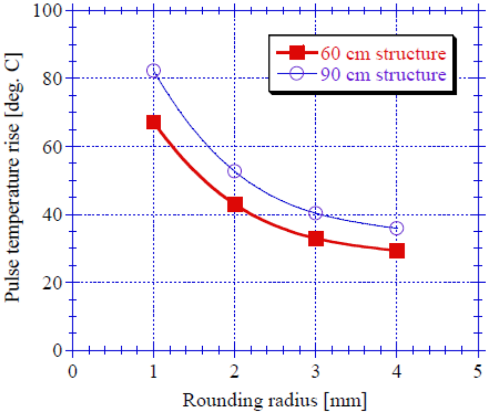
Surface temperature distribution (400 ns pulse, 82.5 MW, maximum temperature 166ºC)

Low field couplers for high gradient applications

Rounded couplers

The magnetic field can be reduced **increasing the radius of the coupling slot**.



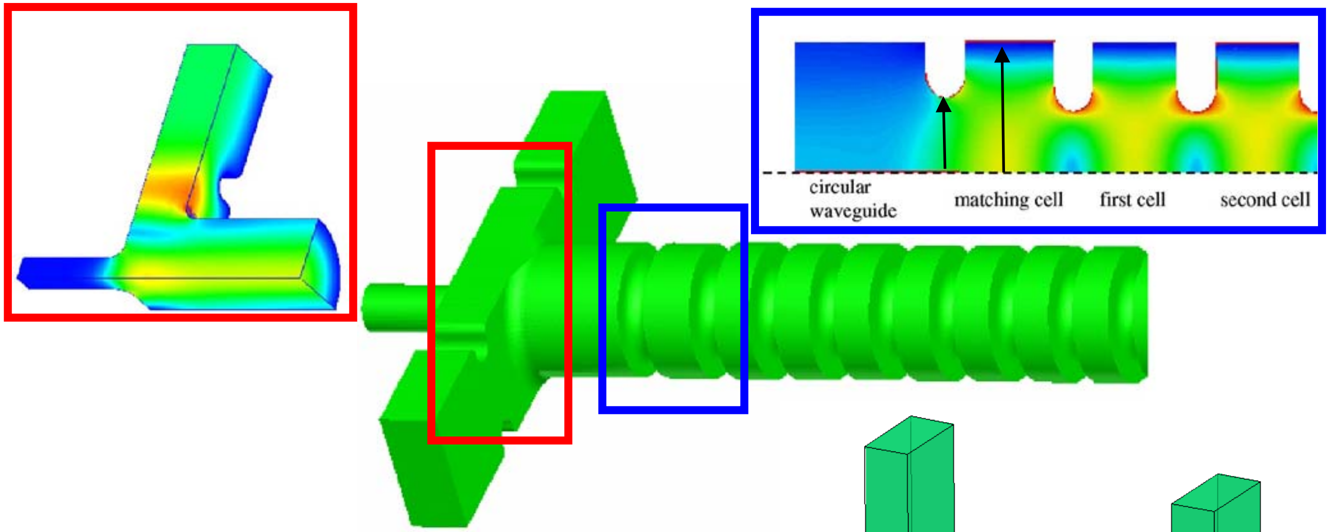


Mode-launcher coupler

The coupler is divided in two parts:

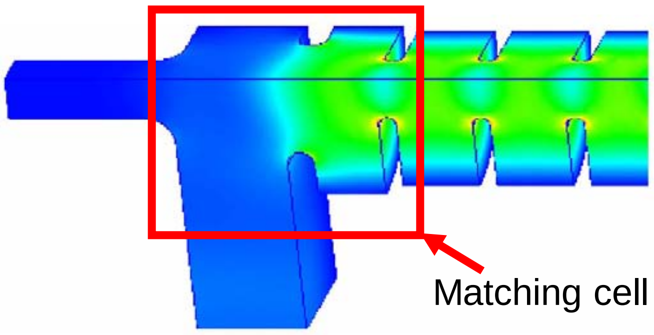
-the first one is a **mode converter TE_{11}** (rectangular) to TM_{01} (circular)

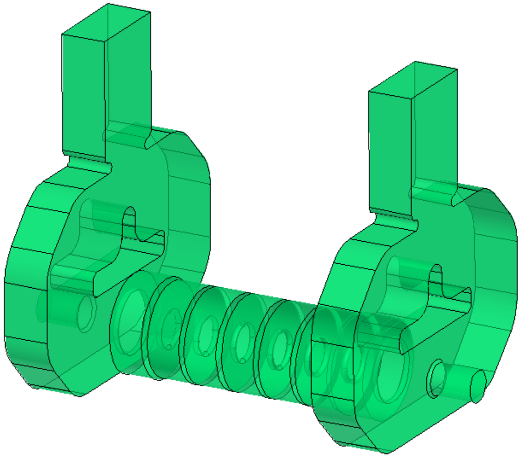
-the second one is a **matching coupler** between the TM_{01} mode of the circular waveguide and the TM_{01}-like accelerating mode



Waveguide coupler

Similar to the mode-launcher coupler but the mode converter and the matching cell are **compacted** in a single cell. In this case the integration of a splitter in a compact geometry is easier because of the dimensions of the coupler itself (C. Nantista, et al., PRST-AB, 2004)



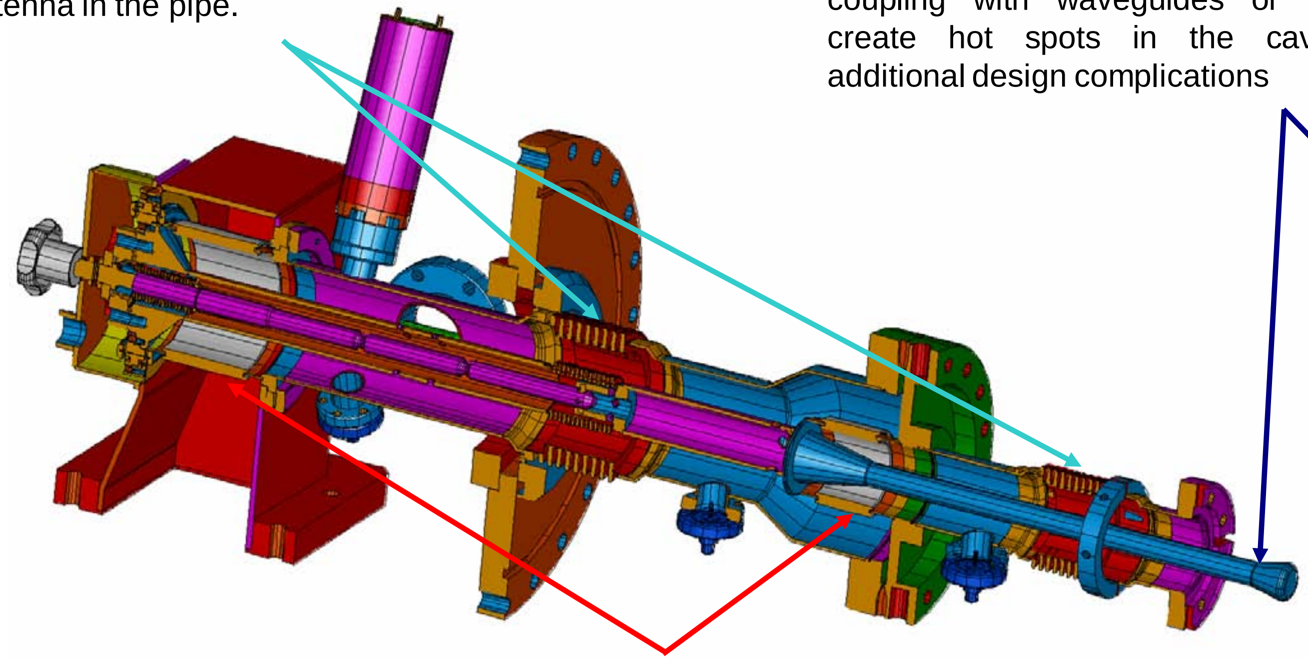


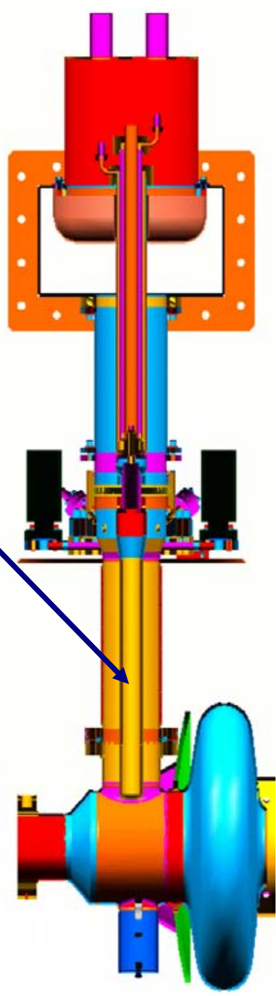
Couplers for superconducting cavities

Superconducting cavities ⇒ extremely low surface resistance (about 10 nΩ at 2 K).
Quality factors of normal conducting cavities are 10^4-10^5 ⇒for sc cavities they may exceed 10^{10}: only a tiny fraction of the incident rf power is dissipated in the cavity walls, most of it is either transferred to the beam or reflected into a load.

Bellows for Q_{EXT} tunability. For many accelerators it is necessary to tune the coupling changing the penetration of the antenna in the pipe.

Coaxial-type electric couplers have the widest applications, because magnetic coupling with waveguides or loops can create hot spots in the cavities with additional design complications



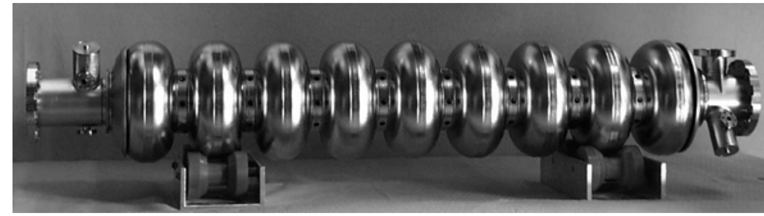


Vacuum barriers (windows). They prevent contamination of the SC structure. Obviously these barrier are necessary also in normal conducting accelerators but the demand on the quality of the vacuum and reliability of the windows are less stringent. The failure of a window in superconducting accelerator can necessitate very costly and lengthy in repart. They are made, in general, in Al_2O_3. Ceramic material have a high Secondary Emission Yield (SEY) that stimulates the multipacting activity. Ti-coating can reduce this phenomena. To reduce the risk of contamination two RF windows, warm and cold, are advisable.

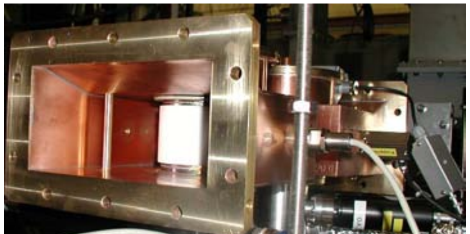
Thermal barrier: The RF power must be fed into the cold superconducting cavity and in the coupler we cross the boundary between the room temperature and the low-temperature environment (usually 2-4.5 K).

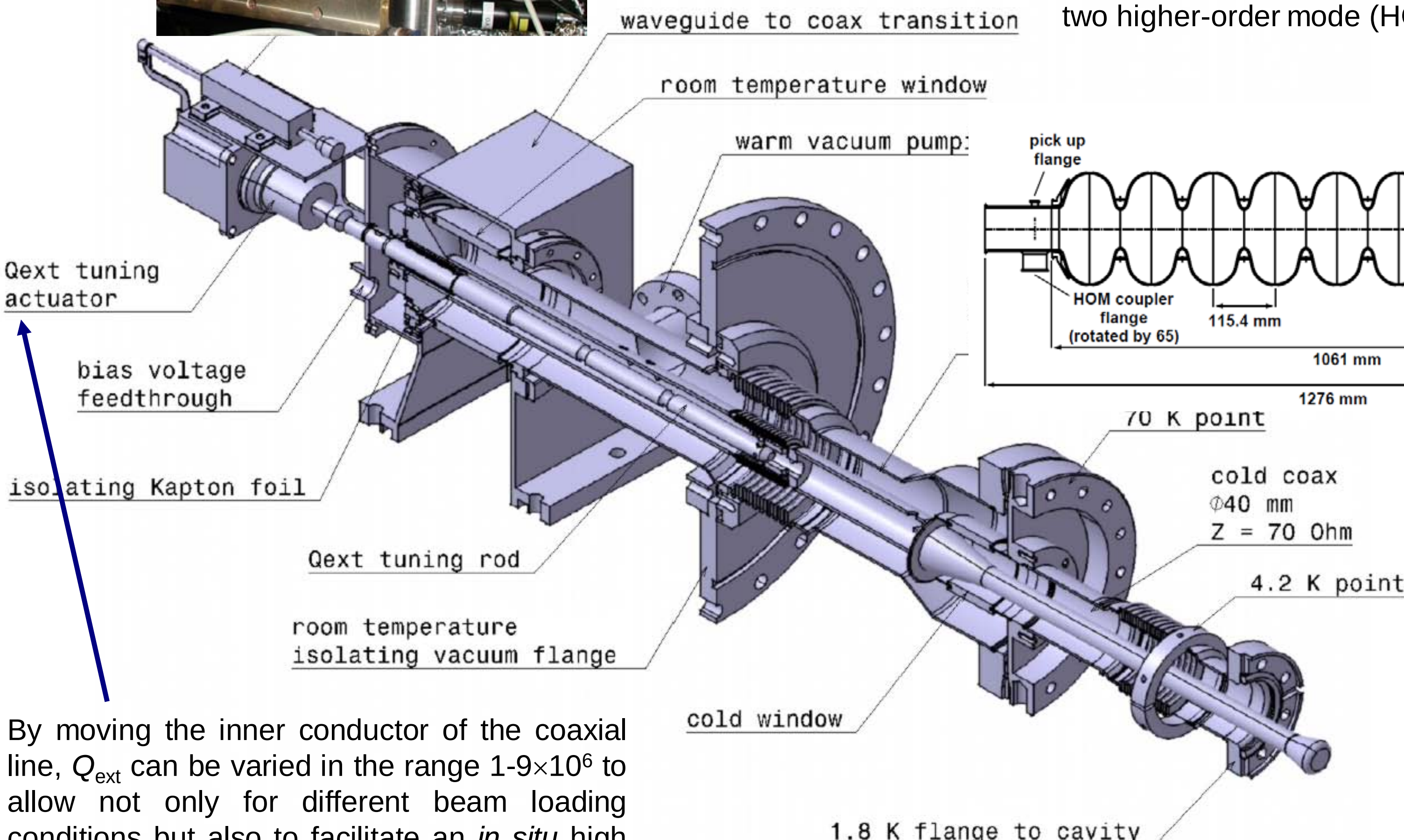
Example of couplers for superconducting cavities: TESLA

As an example of superconducting cavities we consider the TESLA Test Facility (TTF) cavities. The TTF cavity is a 9-cell standing wave structure of about 1 m length whose lowest TM mode resonates at 1300 MHz. The cavity is made from solid niobium and is cooled by superfluid helium at 2 K.



Each 9-cell cavity is equipped with its own titanium helium tank, a tuning system driven by a stepping motor, a coaxial rf power coupler capable of transmitting more than 200 kW, a pickup probe, and two higher-order mode (HOM) couplers.

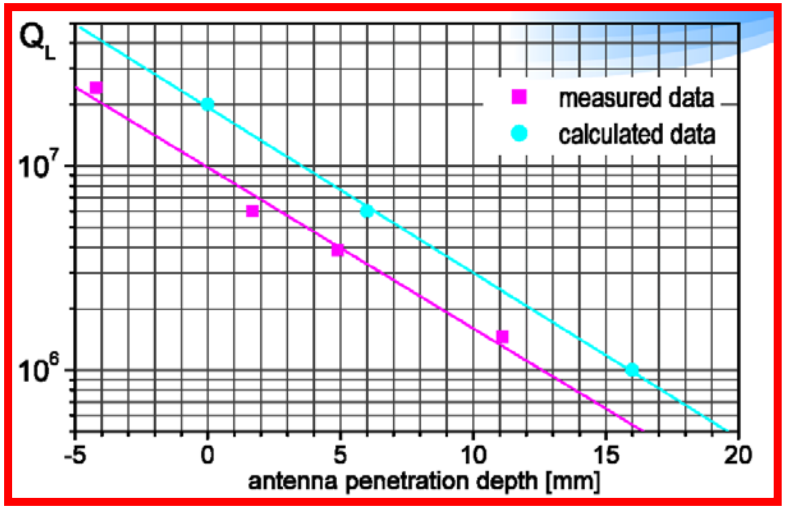




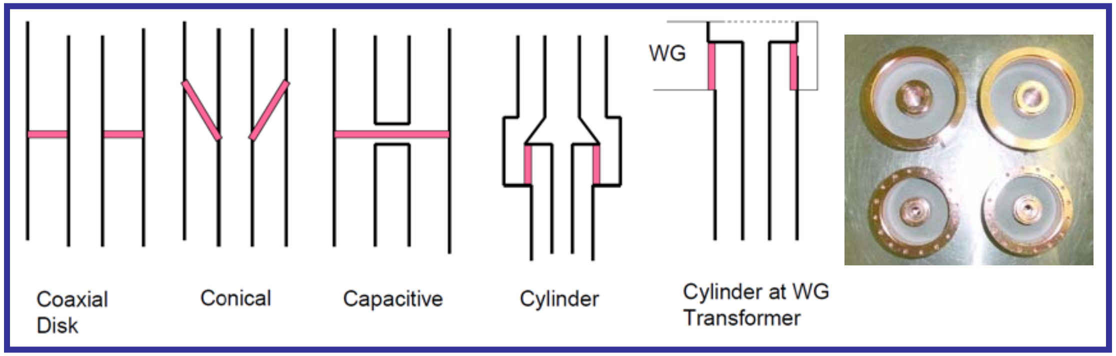
By moving the inner conductor of the coaxial line, Q_{ext} can be varied in the range 1-9×10^6 to allow not only for different beam loading conditions but also to facilitate an *in situ* high power processing of the cavities.

Other aspects of couplers for superconducting cavities

Q_{ext} tuning

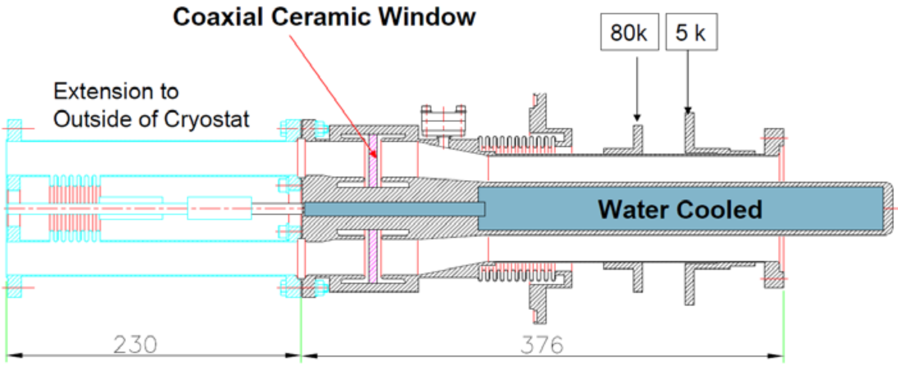


Ceramic Windows geometries



CW couplers

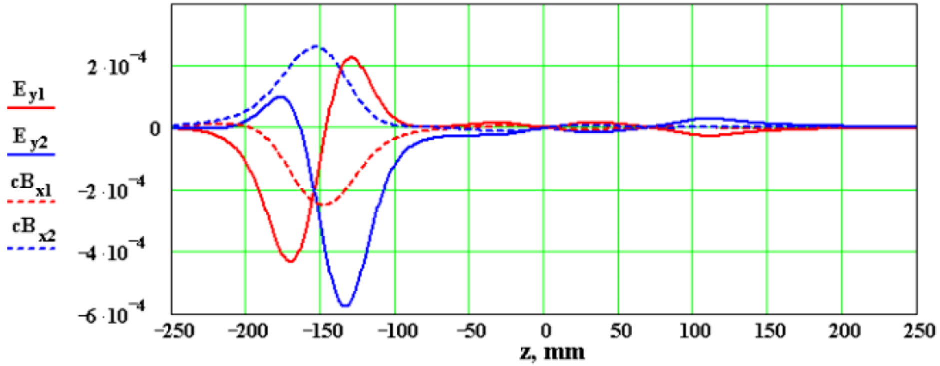
For CW couplers the high requirements in average power are demanding for the design of a cooling system. Usually the central antenna and the bellows can be water, gas or air cooled. Attention must also be paid to the thermal characteristics of the gaskets if the flange region proves to be a “hot zone”. For certain materials (like Aluminium for example) it is possible to have vacuum leaks starting from ~ 150 degrees. In this case copper gaskets are recommended.



Beam dynamics

Another important parameter associated with the particle beam in the coupler design is the transverse kick.

The coupler insertion being asymmetric with respect to the cavity axis, a dipolar electric field component appears to have the effect of a beam kick in the transverse plane. This can be evaluated by integrating the equation of motion taking into account the simulated electromagnetic field on the beam axis. The remedy is to compensate this effect by alternating the coupler insertion on both sides of the beam propagation axis and, in the design phase, reducing the ratio between the coupler and the cavity diameter.



Multipacting in High Power Couplers

Multipacting is a phenomenon of ***resonant electron multiplication***. ***Electrons are emitted*** from the walls because of the presence of high electric field. A a specific level of input power (field) the electrons can be accelerated, can hit another wall (or the same wall) and force the emission of more electrons (if the Secondary Emission Yield-SEY is bigger than 1). Therefore a ***large number of electrons can build up an electron avalanche***, leading to remarkable ***power losses*** *and* ***heating of the walls***, so that it becomes impossible to increase the cavity fields by rising the incident power.

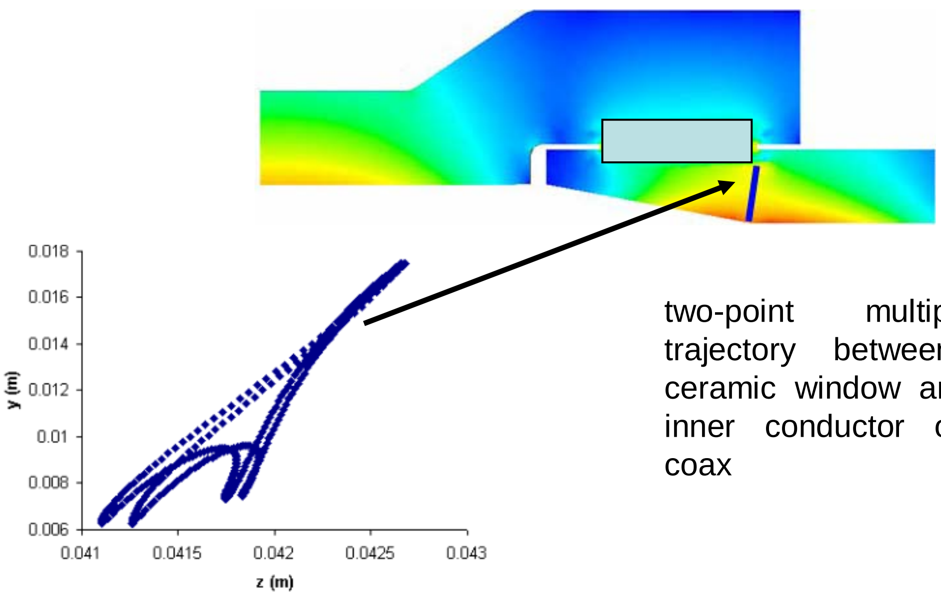
Multipacting electrons can strongly affect the electromagnetic design since the low order power thresholds must be carefully assessed to avoid sparks and coupler damage already during the conditioning process at some specific levels of input power.

The ***multipactor threshold*** varies following a $(f\,D)^4$ or a $Z\,D^4$ laws where f is the frequency, Z is the coaxial impedance D external diameter of the coaxial coupler. This formulae can also help in designing the coupler.

Multipacting is strongly enhanced in couplers by the presence of the ***ceramic windows*** that usually present a ***high SEY*** and of ***bellows with very high field zones***.

Shifting of the resonant condition can be achieved by applying a ***bias voltage on the central antenna in the coaxial couplers***. In the ***waveguide*** option the same effect is obtained by applying a ***magnetic field***.

Concerning the ceramic emission, a ***coating*** (of some tents of nm) with a low SEY material (usually Ti or TiN) is mandatory.



two-point multipacting trajectory between the ceramic window and the inner conductor of the coax

Example of coupler for superconducting structures (CW)

CW input couplers

Facility	Frequency	Coupler type	RF window	Q_{ext}	Max. power
LEP2 / SOLEIL	352 MHz	Coax fixed	Cylindrical	2×10^6 / 1×10^5	Test: 565 kW 380 kW Oper: 150 kW
LHC	400 MHz	Coax variable (60 mm stroke)	Cylindrical	2×10^4 to 3.5×10^5	Test: 500 kW 300 kW
HERA	500 MHz	Coax fixed	Cylindrical	1.3×10^5	Test: 300 kW Oper: 65 kW
CESR (Beam test)	500 MHz	WG fixed	WG, 3 disks	2×10^5	Test: 250 kW 125 kW Oper: 155 kW
CESR / 3rd generation light sources	500 MHz	WG fixed	WG disk	2×10^5 nominal	Test: 450 kW Oper: 300 kW 360 kW
TRISTAN / KEKB / BEPC-II	509 MHz	Coax fixed	Disk, coax	1×10^6 / 7×10^4 / 1.7×10^5	Test: 800 kW 300 kW Oper: 400 kW
APT	700 MHz	Coax variable (±5 mm stroke)	Disk, coax	2×10^5 to 6×10^5	Test: 1 MW 850 kW
Cornell ERL injector	1300 MHz	Coax variable (15 mm stroke)	Cylindrical (cold and warm)	9×10^4 to 8×10^5	Test: 61 kW
JLAB FEL	1500 MHz	WG fixed	WG planar	2×10^6	Test: 50 kW Oper: 35 kW

Example of coupler for superconducting structures (Pulsed)

Pulsed input couplers

Facility	Frequency	Coupler type	RF window	Q_{ext}	Max. power	Pulse length & rep. rate
SNS	805 MHz	Coax fixed	Disk, coax	7×10^5	Test: 2 MW Oper: 550 kW	1.3 msec, 60 Hz 1.3 msec, 60 Hz
J-PARC	972 MHz	Coax fixed	Disk, coax	5×10^5	Test: 2.2 MW 370 kW	0.6 msec, 25 Hz 3.0 msec, 25 Hz
FLASH	1300 MHz	Coax variable (FNAL)	Conical (cold), WG planar (warm)	1×10^6 to 1×10^7	Test: 250 kW Oper: 250 kW	1.3 msec, 10 Hz 1.3 msec, 10 Hz
FLASH	1300 MHz	Coax variable (TTF-II)	Cylindrical (cold), WG planar (warm)	1×10^6 to 1×10^7	Test: 1 MW Oper: 250 kW	1.3 msec, 10 Hz 1.3 msec, 10 Hz
FLASH / XFEL/ ILC	1300 MHz	Coax variable (TTF-III)	Cylindrical (cold and warm)	1×10^6 to 1×10^7	Test: 1.5 MW 1 MW Oper: 250 kW	1.3 msec, 2 Hz 1.3 msec, 10 Hz 1.3 msec, 10 Hz
KEK STF	1300 MHz	Coax fixed (baseline ILC cavity)	Disks, coax (cold and warm)	2×10^6	Test: 1.9 MW 1 MW	10 μsec, 5 Hz 1.5 msec, 5 Hz
KEK STF	1300 MHz	Coax fixed (low loss ILC cavity)	Disk (cold), cylindrical (warm)	2×10^6	Test: 2 MW 1 MW	1.5 msec, 3 Hz 1.5 msec, 5 Hz

Summary waveguide/coaxial couplers

Parameter	Waveguide	Coaxial	Notes
Dimensions	larger	Smaller	At low frequencies the coaxial are preferred
Power handling capacity	Higher	Lower	At high frequency and for high gradient/power structures the waveguide couplers are preferred
Attenuation	lower	higher	
Vacuum/ pumping speed	better	worst	
Variable coupling	Difficult to realize	Easy to make it	
Cooling	better	worst (inner)	

Design techniques for input couplers of TW structure (1/2)

Coupler design is performed using ***3D electromagnetic codes***.

The coupler cell dimensions have to be designed in order to minimize the reflected power at the waveguide input/output ports.

Technique 1

Since, with e.m codes, it is not possible to consider an infinite number of TW cells, to design the single couplers we have to consider a ***TW structure with input and output couplers and a few cells***. In this case it is possible to design the couplers by changing their dimensions minimizing the reflection coefficient at the waveguide input port and verifying that also the phase advance per cell in the TW structure is constant and equal to the nominal one. This procedure is, in general, very time consuming.

Technique 2

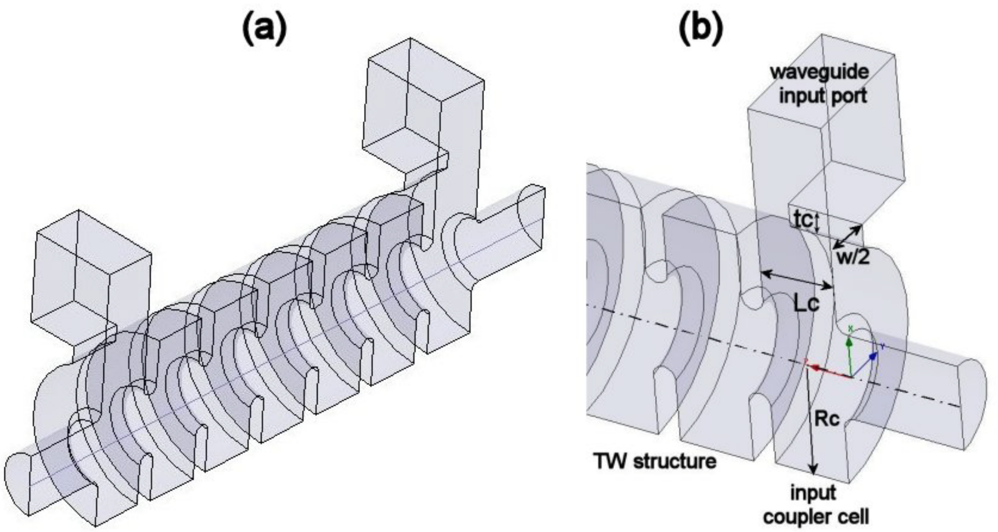
It is based on the following theorem:

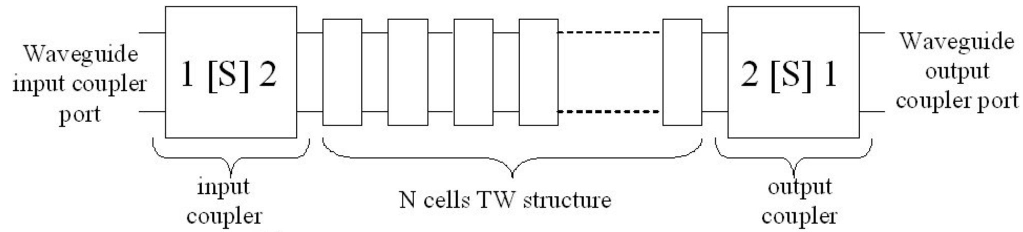
$$S_{11}=0 \Leftrightarrow \frac{\Gamma_s(n+2)}{\Gamma_s(n+1)}=\frac{\Gamma_s(n+1)}{\Gamma_s(n)}=e^{-j2\phi} \quad (with \quad |\Gamma_s(n)|=1)$$

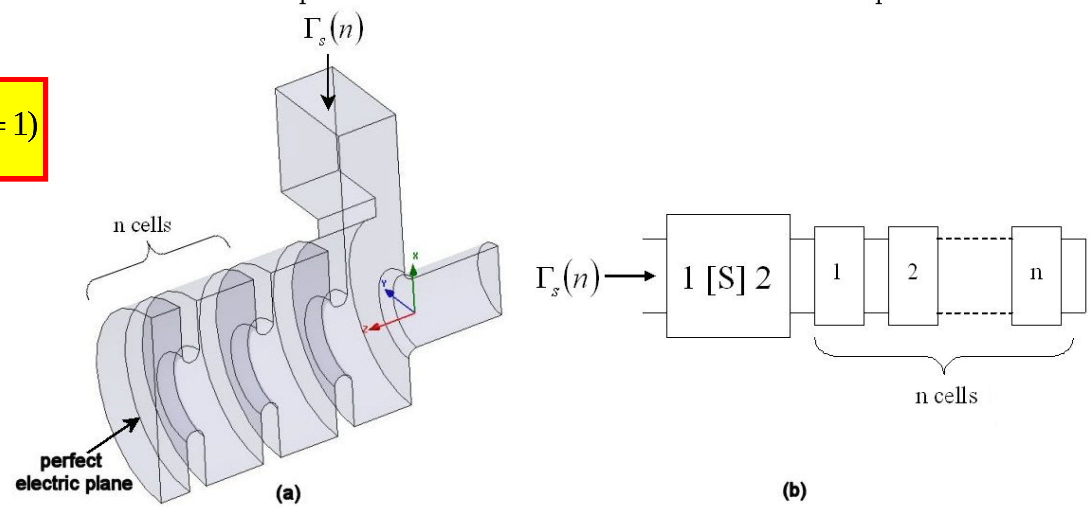
S_{11} is the first element of the coupler scattering matrix

$\Gamma_s(n)$ is the reflection coefficient at the coupler waveguide when the structure is short circuited (*n* is the position of the short circuited cell)

$-\phi$ is the phase advance per cell in the TW structure







Design techniques for input couplers of TW structure (2/2)

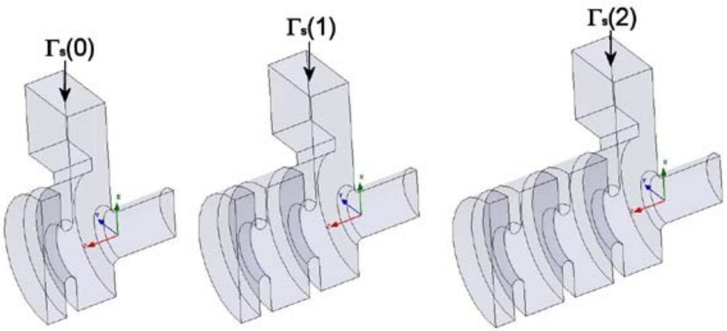
If we consider the three cases to n=0, n=1 and n=2, the $|S_{11}|$ is given by:

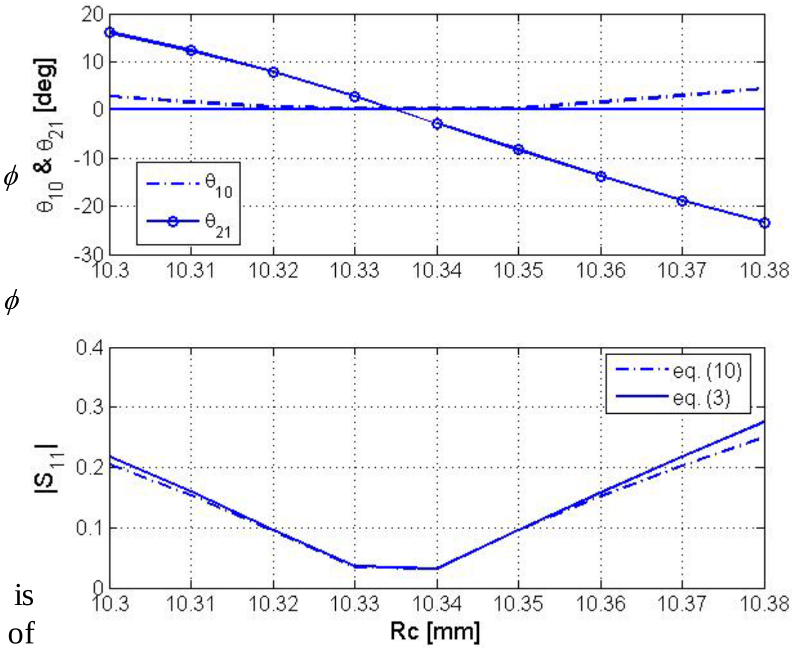
$$|S_{11}| \cong \frac{1}{2(\sin\phi)^2}\sqrt{\frac{(\vartheta_{21}+\vartheta_{10})^2}{4(\cos\phi)^2}+\vartheta_{10}^2-\vartheta_{10}(\vartheta_{21}+\vartheta_{10})}$$

where:

$$\vartheta_{10}=\frac{\angle\left[\frac{\Gamma_s(1)}{\Gamma_s(0)}\right]}{2}+\phi$$

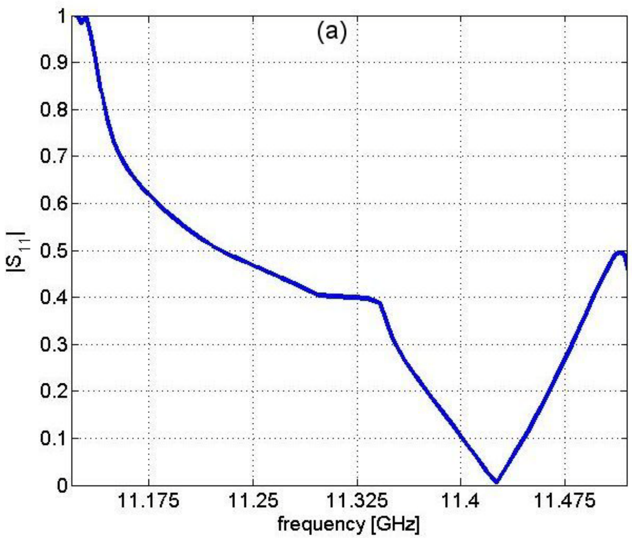
$$\vartheta_{21}=\frac{\angle\left[\frac{\Gamma_s(2)}{\Gamma_s(1)}\right]}{2}+\phi$$



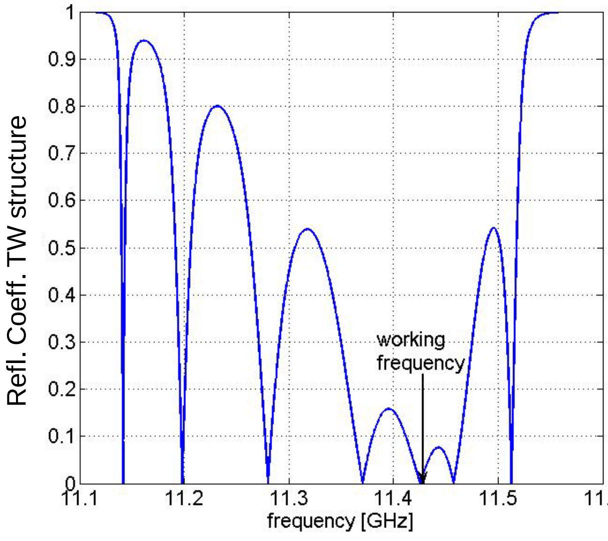


To tune the coupler it is enough to vary only two of the input coupler dimensions (two parameters) until the residual $|S_{11}|$ value is within the specified range. By simulations it is possible to show that the most sensitive parameters are w and Rc while the length Lc and the thickness tc can be kept fixed.

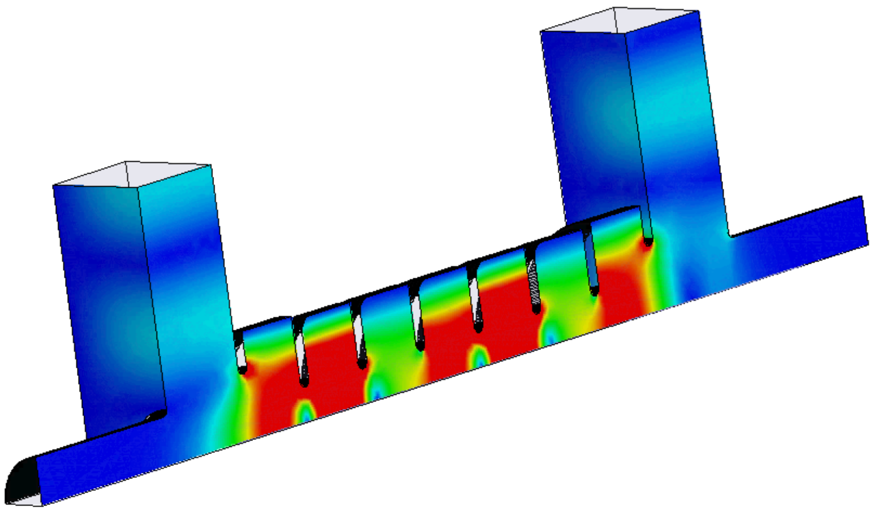
Calculated amplitude of the S_{11} element of the coupler scattering matrix as a function of frequency

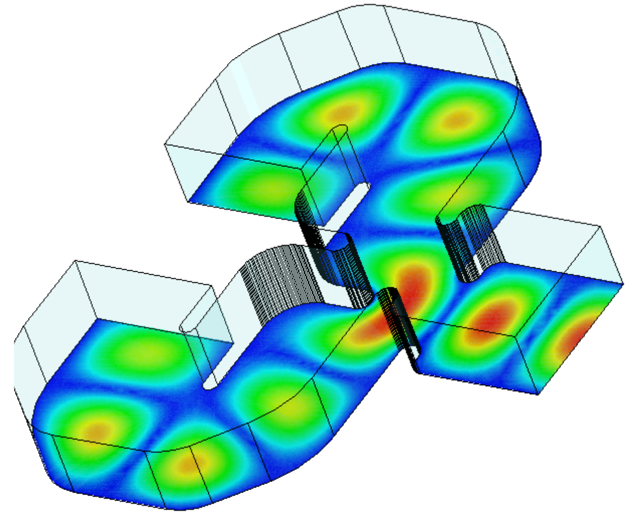


Reflection coefficient at the coupler waveguide as a function of frequency in the case of a 7 cell structure

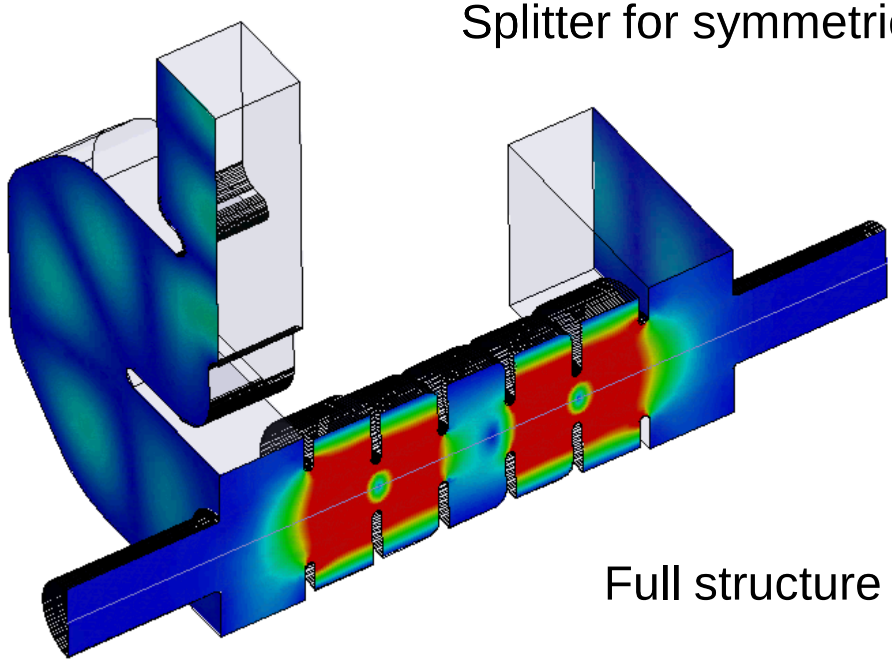


HFSS Examples





Splitter for symmetric feed



Full structure

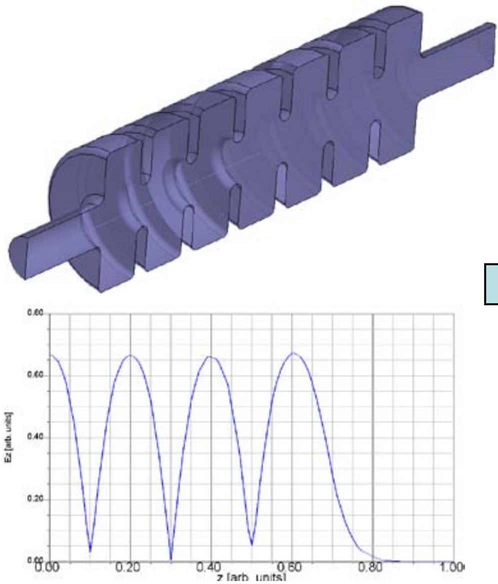
Design techniques for input couplers of NC SW structures

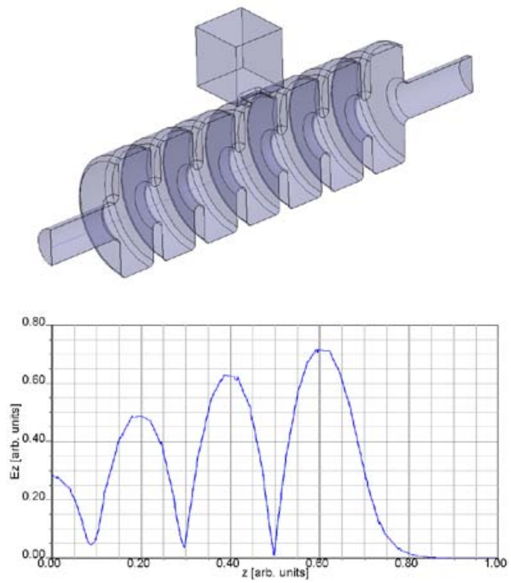
In this case one has to design the ***coupling slot in order to obtain the desired coupling coefficient without modifying the accelerating field distribution and the resonant frequency of the structure***.

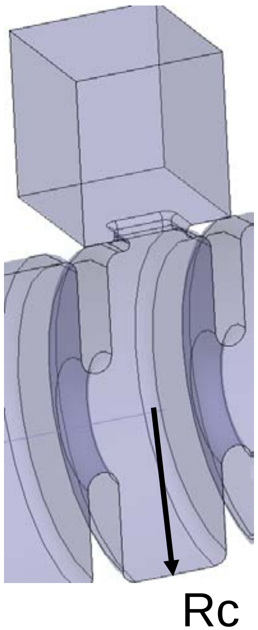
The insertion of the waveguide input coupler, in fact, ***detune the coupler cell*** because it increases its volume.

This ***gives a shift of the resonant frequency*** of the working mode and detune of the field flatness with respect to the structure without input coupler.

To retune the coupler one has to tune (reduce) the radius of the cell itself. It is not possible to evaluate the coupling coefficient before the retuning of the coupling cell since it depends on the field level into the structure.







To coupler design follows therefore an ***iterative procedure***:

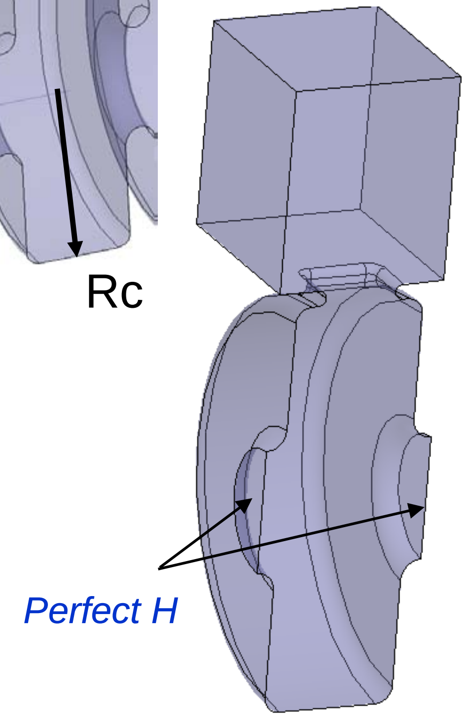
1)We fix the ***slot dimension***

2)We ***retune the coupler cell***

3)We ***calculate the coupling coefficient***

4)If the coupling is not the desired one we have to return to the point 1).

To simplify the design it is possible to simulate the coupler cell only with the proper boundary conditions (perfect H for π mode). In this case one has to tune the slot and the radius of the cell in order to have a coupling coefficient equal to N times (N=total number of accelerating cell in the full structure) the desired coupling coefficient and the resonant frequency exactly equal to the resonant frequency of the structures without coupler.



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Thank you for your attention