Addressing SRF Input Coupler Design Challenges

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- **RF coupler** is one of the critical components of the cryomodule. Its design and properties affect the cavity performance, beam dynamics, cryogenic system behavior, operational machine cost and overall cost of the project.

- **RF input couplers** are passive impedance matching networks designed to efficiently transfer RF power from a power source to a beam-loaded cavity operating under UHV conditions.

- **RF couplers** separate gas-filled transmission lines from UHV environment of accelerating cavities; therefore they incorporate RF-transparent vacuum barriers (RF windows).
Other Coupler Features

- RF couplers are thermal bridges between room temperature and cryogenic cold mass and should be designed for lowest possible heat leak to cryogenic parts of the cryomodule.

- RF couplers should conform to clean cryomodule assembly procedures to minimize risk of contaminating the superconducting cavity.

- RF couplers should minimize cavity field perturbations that can deteriorate beam or cavity performance.

- RF couplers may provide a variable coupling for different operating modes. That can be achieved by a more sophisticated coupler design or by three-stub waveguide tuners outside the cryomodule.

- RF couplers should be designed taking into consideration the multipacting phenomenon: ideally to be multipacting-free or provide cures such as a DC bias voltage or other mitigating measures.

- RF couplers should have mechanical flexibility to accommodate relative movement of cold part due to shrinkage during cavity cool down.
**Waveguide**
- Simpler design
- Lower RF losses
- Lower surface electric field
- Easier to cool but higher thermal radiation

**Coaxial**
- More compact
- Smaller heat leak
- Easier to make variable
- Easier to handle multipacting

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**CEBAF coupler**

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**X-FEL coupler**
In many coupler designs cold RF windows are used.

- Cold windows are assembled to superconducting cavities in clean rooms and protect cavities from contaminations.
- They also protect cavities from contaminating during coupler processing.
- Cold windows significantly increase cavity protection from vacuum failures.
- Couplers with cold windows have smaller heat leaks.
- Using cold windows is advisable for high-field applications.
- Couplers with cold windows have more sophisticated design and are more expensive.
- It seems it is very difficult or even impossible to build L-band couplers with cold windows that can operate at RF power above 100 kW.
Couplers usually need conditioning for many hours for outgasing and processing multipacting. Coupler bake helps to shorten the processing time.

Processing Time for Couplers of Cornell ERL Injector Cavities (up to 25 kW SW per Coupler):
Each ERL machine includes:

- Electron gun (DC or RF)
- Injector linac
- Main linac

Accelerating structures and modes of operation of these machine parts are different. Requirements for couplers of those structures are also different.
- **Injector:**
  
  High beam current, low beam energy.
  That leads to high RF power, strong coupling and requirements of minimal field perturbations due to couplers. High RF power delivered to the beam is the most challenging factor.

- **Main Linac:**
  
  Very low beam current, high beam energy.
  That leads to low RF power, weak coupling and weak restrictions on field perturbations due to couplers. Cost factor is an issue due to large number of couplers.
For minimizing perturbation of beam motion, couplers should be placed symmetrically (in pairs) or compensating stubs should be used. For very low energy, dipole symmetry might be not sufficient.
For main linac, RF power requirements are determined by microphonics (+ possible beam loss, beam return time errors, etc.)
Cornell ERL Injector Coupler

Frequency: 1.3 GHz
RF power: 60 kW CW
$Q_{ext}$ : $9 \times 10^4$ to $8 \times 10^5$
Input Coupler for KEK ERL Injector

- Frequency: 1.3 GHz
- Input power: 170 kW CW
- Coupling: $Q_{\text{ext}} = 1.7 \times 10^5$
- No cold window
- Water cooling of inner conductor

Tristan-type Ceramic Window
BNL ERL Coupler

SNS coupler is used. SNS coupler is based on KEKB coupler design.

- Frequency: 704 MHz
- Peak power: 550 kW
  (tested up to 2 MW)
- Average Power: 50 kW
- 300 K window
- Cooling:
  - Inner conductor extension: water
  - Inner conductor: conduction cooling
  - Outer conductor: GHe flow
JLab High-Power WG Coupler for Use in Injector for Present FEL

- Frequency: 1.5 GHz or 1.3 GHz
- FWD RF power: 50 kW CW (100 kW max) (Prototype tested to 60kW CW limited by available klystron)
- Sustain local peak RF power of 200 kW (400 kW max)
- 300 K window
- Cooling:
  - Window: water
  - WG transition: GHe flow
- Dogleg or bend (not shown) to avoid exposure to beam
Cornell ERL
Main Linac Coupler

- Frequency: 1.3 GHz
- Input power: 5 kW CW
- $Q_{\text{ext}}$: $2 \times 10^7$
- Gas cooling of inner conductor
Input Coupler for KEK ERL Main Linac

- Frequency: 1.3 GHz
- Gradient: 20 MV/m max
- Input power: 20 kW CW
- Coupling: $Q_{\text{ext}} = 5 \times 10^6$ to $2 \times 10^7$
- Forced air cooling of inner conductor
Many couplers have been designed for different ERL cryomodules.

Many coupler designs were based on successful existing designs (TTF-III, TRISTAN coupler) though often with necessary upgrades or modifications.

Requirements for injector couplers are the most challenging due to high power that has to be delivered to the beam.

Couplers for main linacs are much easier to build. Their design should be cost efficient.
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