325 MHz coupler review

S. Kazakov

02/02/2012
Agenda

S. Kazakov:
• Coupler requirements
• Electrical coupler parameters
• Thermal coupler parameters
• Possible preliminary tests

S. Cheban:
Air cooling

O. Pronitchev:
Mechanical design of coupler

S. Kazakov
Choice of cavity /line for coupler test
Requirements

Coupler was design to feed SSR coupler family.

Maximum beam power gain per cavity in different projects:

- PXIE: SSR1 ~2 kW
- PX, 1mA: SSR2 ~3.5 kW
- PX, 5mA: SSR2 ~18 kW

With overhead the coupler have to work reliably at power levels:
- ~6 kW for PXIE, PX 1mA
- ~30 kW for PX 5mA

Thermal properties were calculated for power levels:
- 0, 3, 6, 20, 30 kW
Cryogenic losses of SSR cavities at 2K:

SSR0 ~0.2W-1.5W (170W – 1300 W cryo-plant)
SSR1 ~1.5W-1.8W (1300W– 1550W)
SSR2 ~1.6W – 4W (1380W – 3440W)

Coupler should not be main source of cryogenic loss.

SSRx cold flange can sustain power flow >1W, without quench (Serena Barbanotty simulation).

What is a maximum power can be taken by liquid He?
Coupler has to be compatible with already designed SSR1 cavity. (diameter of input port is fixed)

We decided to make a new coupler interchangeable with the old one (Khabibuline-Nicol design)

20kW-30KW operation power will require antenna cooling. Cooling must be an air type.

Possibility to apply HV bias to suppress multipactor

It has to accommodate ~1mm cavity displacement during cool down/warming up

Coupler has to be assembled with cavity in clean room

Standard coaxial input (3-1/8”)
Design approach:

Vacuum part is simple as possible:
One window, no bellows, straight coaxial, no coating if possible.

Common technology and parts with 650 MHz coupler
325 MHz coupler structure
View of 325 MHZ coupler
View of 325 MHz coupler
Main sizes of coupler

Coupler have been designed to be interchangeable with Khabibuolline-Nicol coupler
Electrical parameters of 325MHz coupler

Design CW power $\sim 6\text{kW} \ (30\text{kW})$
(30 kW - with air cooling, copper plated vacuum outer conductor)

Pulse power (breakdown in air) $\sim 0.4\text{MW}$

Multifactor threshold $> 6\text{ kW SW} \ (>25\text{kW TW})$

Pass band ($S_{11} < -20\text{dB}$) $\sim 50\text{MHz}, \ (15\%)$
Matching section

Pass band ~ 15% (-20dB)
Max. E-field, Air breakdown limit ~ 400 kW, TW

Loss (cupper) ~ 0.06%

6kW -> 3.5W, 30kW -> 18W
Bellow section

Copper

Bronze

Al₂O₃, 6mm

S11 is not too sensitive to ceramic dielectric constant
Max. E-field, air breakdown limit > 1 MW, TW

E-field

Loss (copper, bronze) ~ 0.082%  
6 kW -> 5W, 30 kW -> 25W

H-field

Loss in ceramic = 0.4*δ  
δ – loss tan.

δ= 0.001  
6kW -> 2.4W, 30kW -> 12W
Vacuum part

Loss in antenna  \( \sim 0.045\% \), 6kW -> 2.7W, 30 kW -> 13.5W

Loss in outer conductor (no copper coating):
6kW -> 1.2W, 30kW -> 6W

Loss in outer conductor (10um copper coating)
6kW -> \( \sim 0.1W \), 30kW -> 0.5W

Total loss of coupler \( \sim 0.17\% \)

6kW -> 10W, 30kW -> 50W
Multipactor simulation by CST studio

Noticeable multipactor starts at power (TW) > 30 - 50 kW.
Ceramic presence shows small effect in CST studio: E-field is parallel of ceramic surface. But model is not accurate enough. It does not take into account an electric charge at the ceramic surface. Charge causes a perpendicular motion and can generate multipactor. 

Ceramic will be coated by TiN

Hopefully, there will be no multipactor in PXIE and PX 1mA
Thermal properties

New in this design (comparatively with half year ago):

We understood, that thermo-interception is technically not simple task.

To decrease static loss, a thickness of SS tube (outer conductor) was decreased to minimum \(0.4\text{mm}\)

To get realistic cross-section arias of stripes, intercepting temperatures were increased: \(5\text{K} \rightarrow 10\text{K, 15K};\) \(80\text{K} \rightarrow 125\text{K}\)
Outer conductor, 0.4mm SS, no copper coating, interceptors 10K, 125K

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## 10K intercept

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PXIE and PX 1mA do not require a copper coating of 325MHz coupler.

PX 5 mA - It is better to coat

Shell we try both at test stand and PXIE?
Antenna cooling

Antenna – 0.5” tube (12.7mm), wall thickness - 1.57mm, length ~ 330mm (from window to tip)

Temperature distribution (no air cooling):

\[ T_{\text{tip}} = T_0 + dT \quad T_0 \approx 310 \text{ K} (\approx 36.6 \text{ C}) \]

\( P_{\text{in}} = 6 \text{ kW}, dT = 16.7 \text{ K}, T_{\text{tip}} \approx 327 \text{ K} (\approx 54 \text{ C}) \)

\( P_{\text{in}} = 30 \text{ kW}, dT = 83.4 \text{ K}, T_{\text{tip}} \approx 393 \text{ K} (\approx 120 \text{ C}) \)

Thermal radiation:
Antenna radiation length (looks at SC) ~ 70mm
Radiating aria ~ 2800 mm\(^2\)
Emissivity factor ~ 0.05

\( P_{\text{rad}} (6\text{kW}) \approx 0.1\text{W} \)

\( P_{\text{rad}} (30\text{kW}) \approx 0.2\text{W} \)

It seems coupler can work without air cooling if emissivity factor ~0.05
Emissivity factor ~0.1 requires air cooling for \( P_{\text{in}} = 30\text{kW} \)
Cooling of the antenna by the radiation without RF power

In previous slide:
Ohmic loss at antenna surface for 6kW RF power is about ~2.2W and gives temperature rise ~ 17C.

It means that radiation ~2.2W will decrease a temperature tip ~ 17C. But radiation is not more than 0.1W x 5 = 0.5W (70mm x 5 = 350mm) for emissivity 0.05 and not more 1W for emissivity 0.1.

Temperature of antenna tip will be > 0 C even without RF power.
Thermo-interceptors

It supposes to be two base temperature in cryomodule for interception: “5K” and “80K”. Parameters and ability of “pipes” is not clear yet.

Temperature of coupler intercept points has to be higher then temperature of “pipes” to provide temperature gradient and acceptable cross-section areas of stripes.

Estimation of stripes cross-section areas:

“5 K”
Copper thermo conductivity ~ 700 W/(K*m)
Power ~ 3W
Length ~ 0.3m

Gradient dT ~ 5K \rightarrow S \sim 260 \text{ mm}^2
Gradient dT ~ 10k \rightarrow S \sim 130\text{mm}^2
“80 K” Copper thermo conductivity ~ 400 W/K*m
Power ~ 6W
Length ~ 0.3m

Gradient dT ~ 30K (Pipe in PXIE ~ 95K ?) -> S ~150 mm²

“300 K” Copper thermo conductivity ~ 400 W/K*m
Power ~ 4W
Length ~ 0.3m

Gradient dT ~ 5K -> S ~600 mm²
Gradient dT ~10K -> S ~ 300mm² - quite thick stripes

It is better to keep window warmer then environment to avoid moisture on the surface. The simplest solution is electric heater ~ 10W and temperature control.
Air cooling: Sergey Cheban will make detailed talk.

Short conclusions:
PXIE and 1mA PX do not require air cooling for 325 MHz coupler. Coupler of 5 mA PX has to be air cooled.
Possible diagnostics and interlocks:

• Direct, reflected power

• Temperature monitoring (2K?, 5K? 70K? 300K)

• E-pickup (activity in vacuum part)

• Arc detector

• No vacuum diagnostic – common vacuum with cavity
Preliminary tests we suppose to do:

Antenna assembling

Issues to check:

• Assembling
• Air cooling efficiency (power, temperature, air flow /pressure)
• Air flow noise
• Resonance frequency of antennas (325 MHz and 650 MHz)

Assembling is ordered. Will be ready for measurement at the beginning of March
Measuring of ceramic properties
We can measure ceramic’s properties at 3GHz -5GHz and extrapolate them to operating frequencies 325MHz and 650MHz. It is rather difficult to make high-Q cavity (Q >1E+4) at operating frequencies.
Test procedure:

- Cleaning.
- Assembling pair of couplers (vacuum parts) with test cavity in clean room, vacuum leak check, pumping.
- Transportation to test place.
- Assembling at the test stand.
- Pumping and vacuum leak check.
- Baking.
- Air part assembling and low power RF check.
- Connecting RF parts. Low power measurements with RF parts.
- RF conditioning.
- Disassembling and transportation to clean room.
- Disconnecting test cavity and connecting storing volumes.
- Storing.
Block diagram of 325MHz coupler test stand

90 dgr bend
To Power Meter
Air inlet
HV input
Arc detector
Coupler
Points of temperature measurements
Current detector
Flexible coaxial line
Test coaxial lines
10 kW coaxial water load
Movable plunger
Low vacuum pump
Ion pump
Vacuum gage
Possible geometries of test cavities
Geometry with mechanical contact

~90Lb
(41kg)
**Pro:** Small, simple and cheap

**Cons:** Mechanical contact at tip, multipactor suppression by HV bias (?)

**Note:** Mechanical contact does not change any RF properties of antenna – RF power too small for RF breakdown and multipactor. Only issue is generation of micro-particles. Can we re-clean a tip after test?
Multipactor thrashholde $\sim 6 \text{ kW}$
Pro: no mechanical contact with antenna during test. No multipactor due to big size of coaxial.

Cons: Big sizes, heavier, more expensive.
It seems, there is NO multipactor in slot at interesting power range.
Size comparison

~90Lb (41kg)

~150Lb (68kg)

~30.25” (768.5mm)

Ø13.25” (336.5mm)
Conclusion:

Reviewers will make a conclusion.
Backup
HV bias insulator in 3-1/8” coaxial line
Do we need a good contact of inner conductor?

\[ I = \left(\frac{2P}{Z_{\text{line}}}\right)^{1/2} \quad H = \frac{I}{2\pi R} \quad U \approx \omega abH\mu_0 \]

\[ E \approx \frac{U}{b} = \frac{\omega aH\mu_0}{2\pi R} = \omega a\left(\frac{2P}{Z_{\text{line}}}\right)^{1/2}\mu_0/(2\pi R) = aZ_0\left(\frac{2P}{Z_{\text{line}}}\right)^{1/2}/(\lambda R) \]

a = 1.5mm \quad E(6kW) \approx 1\text{kV/m} \quad E(30kW) \approx 2.3\text{kV/m}

\[ Z_{\text{slot}} (a = 1.5\text{mm}, b = 1\text{mm}) \approx 0.1\text{ Ohm} \]

Slot is acceptable with good ohmic contact.
Do we need a good ohmic contact?

$L = 13.5\text{mm}$

$R = 6.3\text{ mm}$

$G = 0.05\text{mm}$

$C = 95\text{ pF}$

$Z_{(325\text{MHz})} = 5\text{ Ohm}$

$Z_{\text{Line}} = 105\text{ Ohm}$

Reflection $\sim 0.025$ (SWR $\sim 1.05$)

$E$ in the gap: $6\text{ kW} \rightarrow \sim11\text{ kV/cm}, \quad 30\text{ kW} \rightarrow \sim24\text{ kV/cm}$

Conclusion: should be no problem with inner conductor contact