37th ICFA Advanced Beam Dynamics Workshop on Future Light Sources

Cavity Beam Position Monitors in the LCLS

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Introduction

- Measuring beam position from electrode pickups requires subtraction of two large numbers, even when the beam is on axis.
  - Limited by signal to noise ratio and ADC resolution
- SLAC striplines limited to ~5µm/nC
- LCLS undulator requires 1 µm at 200 pC

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X-Band Cavity BPM for the LCLS Undulator

- Dipole mode signal is proportional to beam offset
  - Not necessary to difference large numbers
  - Providing we exclude monopole mode from couplers
- Resolution improves with increasing cavity frequency and shrinking cavity dimensions
  - History: S-band ➡C-band ➡X-band
- X-band cavity is compact, has adequate stay clear for spontaneous radiation from undulator and electronics available in this band

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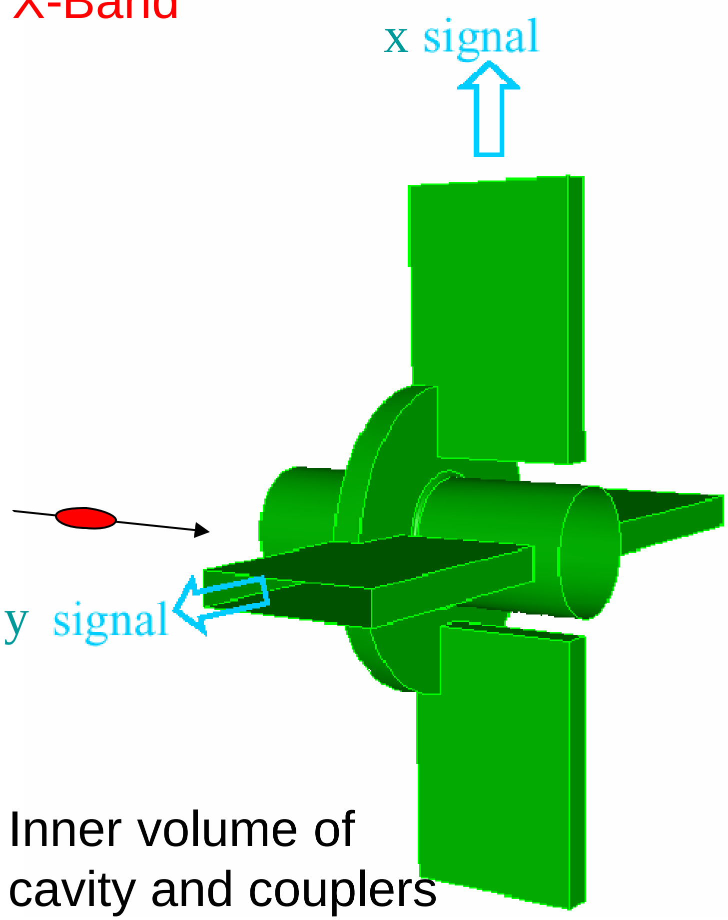
Cavity BPM with TM_{11} mode Selective Coupler

X-Band



Inner volume of cavity and couplers

- Dipole mode:
  - TM_{11}
- Dipole mode frequency:
  - 11.424 GHz
- Coupling to waveguide:
  - magnetic
- Horizontal beam offset
  - couples to vertical port
- Waveguide does not couple to fundamental TM_{01} mode
- Sensitivity
  - 1.6 mV/nC/mm

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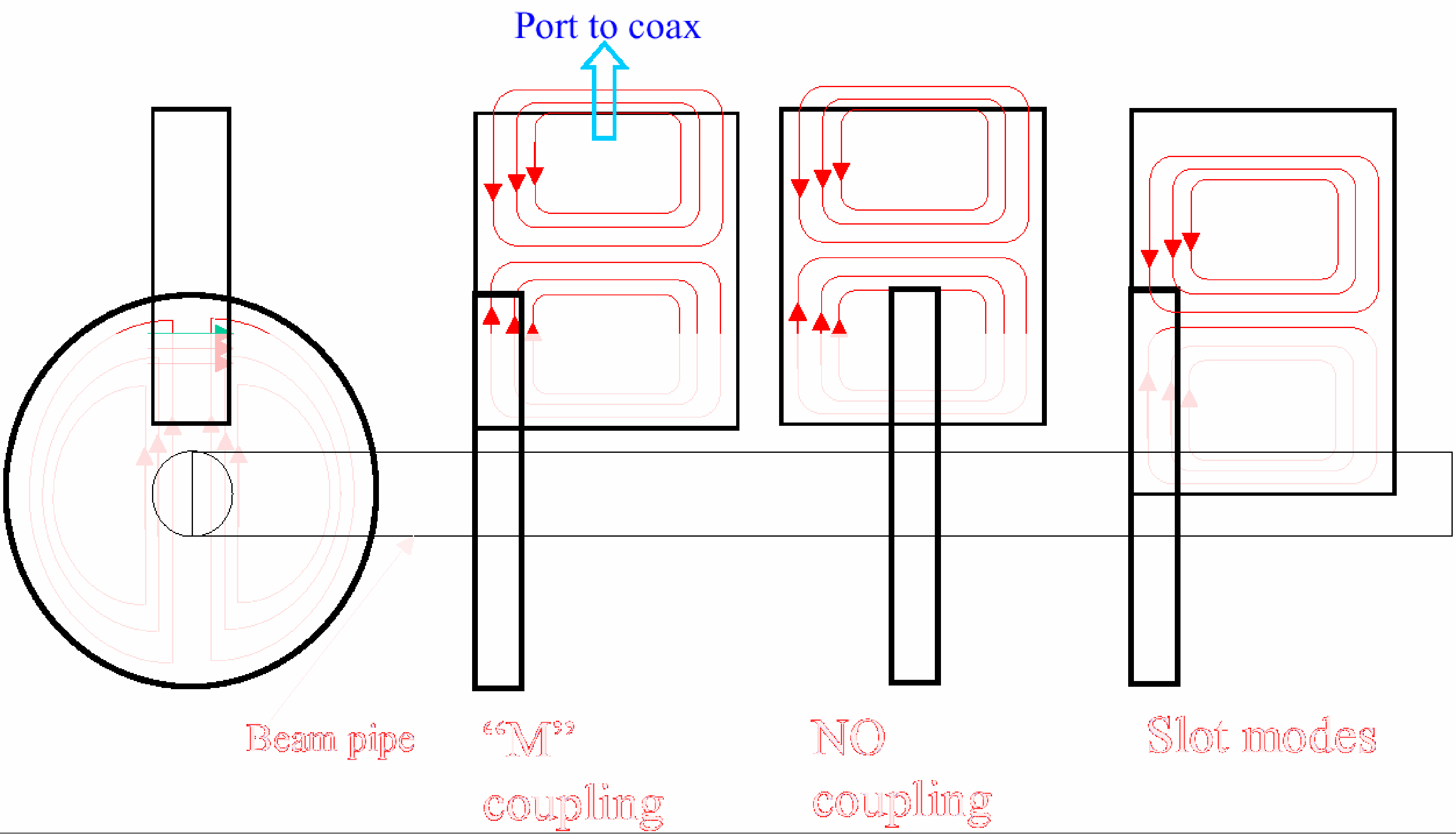
TM_{11} Selective Coupling Scheme



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Intrinsic Resolution

- Resolution limited signal to noise ratio
  - Energy loss from the beam and external coupling give

$$V_{beam}(q,x)=\sqrt{q^2 Z_0 \frac{b}{1+b}\frac{w_0 k_{loss} x^2}{Q_L}}$$

  - Thermal noise determined by temperature and BW

$$V_{noise}=\sqrt{Z_0 kT\Delta F}$$

- Ratio independent of BW
- Theoretical resolution limit at room temperature
  - 0.1 nm/nC

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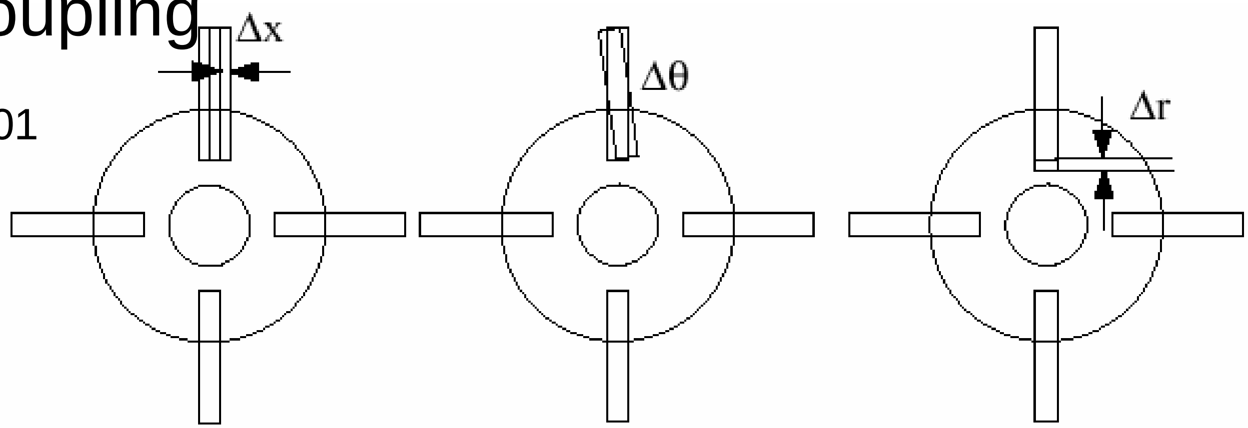
Sensitivity to Fabrication Errors

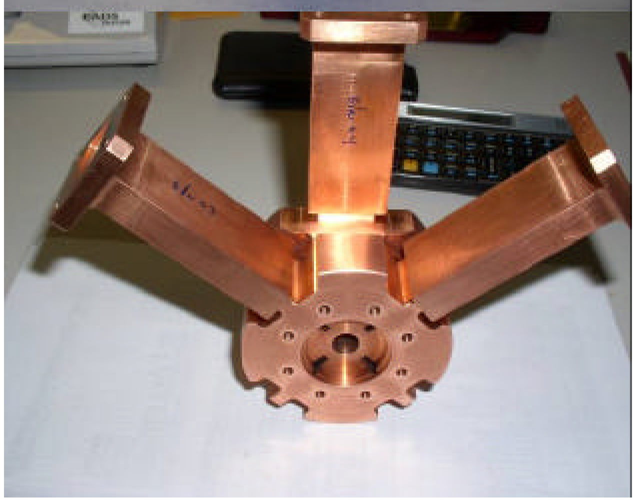
- Frequency dependence
  - -0.7 MHz/μm in cell radius
  - 0.1 MHz/ °C
  - Need to stay within receiver BW ~10 MHZ
  - No (symmetrical) tuners are included
- Offset errors due to coupling slot misalignment
  - Introduce x-y coupling
  - Leakage of TM_{01}

Δx of 100 μm
gives 1 nm offset

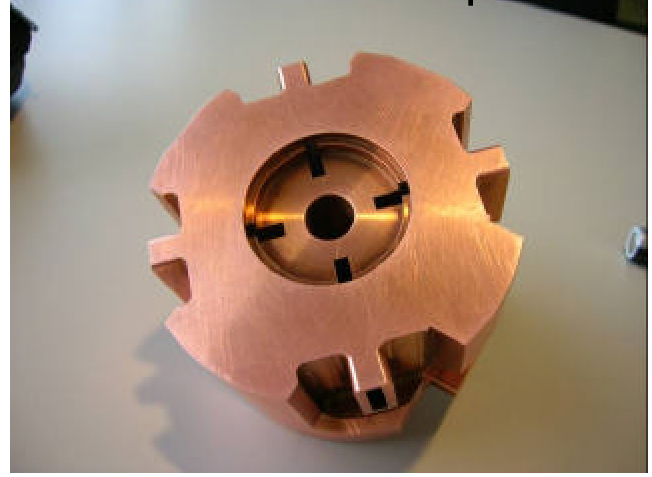


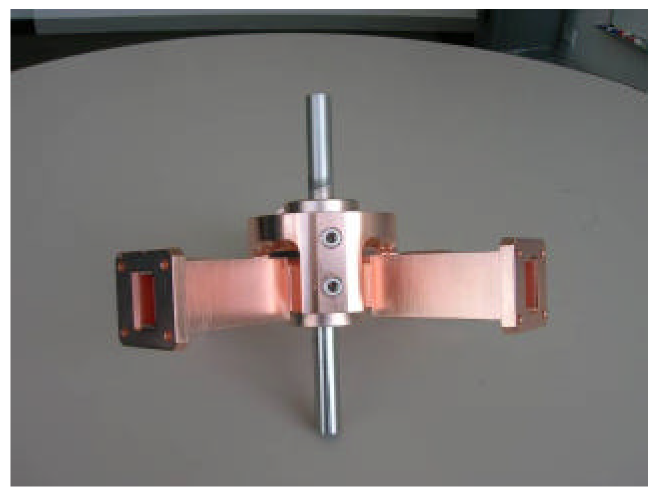
ANL Prototypes for the LCLS Undulator

Bolted end caps



Brazed end caps





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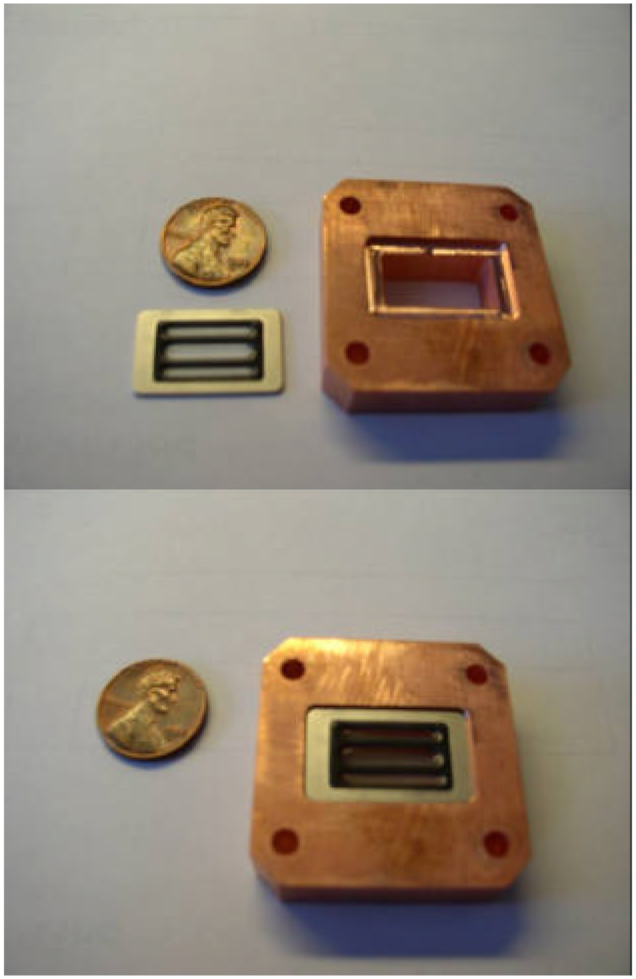
Vacuum Window Prototype

- Utilized standard CPI WR-75 window
- Silver plated Kovar/Glass vacuum seal
- Window cost $100 vs. $ 218 for Kaman coax feed thru
- Insertion Loss < 0.2 dB
- Return loss -20dB



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ANL Prototype Dipole Cavity Data

Parameter (500 micron offset)	Predicted Value	Measured prototype # 1 Bolted end caps	Measured prototype # 2 Brazed end caps
Frequency (TM010)	8.262 GHz	8.271 GHz	8.243 GHz
Coupling (TM010)	-53 dB	-69 dB	-62 dB
Frequency (TM110)	11.364 GHz	11.344 GHz	11.357 GHz
Coupling (TM110)	-32 dB	-28 dB	-24 dB
Q (loaded) (TM110)	2704	2086	2391
Isolation X/Y (TM110)	-26 dB	-33 dB	-23 dB
Isolation monopole to dipole cavity	< -80 dB	< -85 dB	< -89 dB
Frequency (TM020)	15.825 GHz	15.767 GHz	15.785 GHz
Coupling (TM020)	-78 dB	-64 dB	-50 dB

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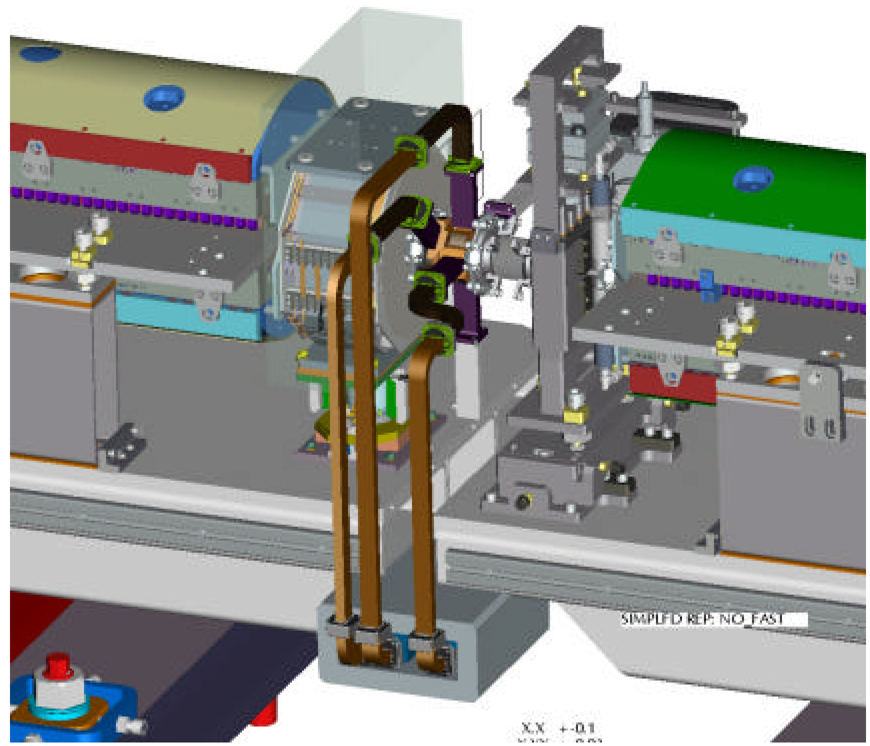
LTU and Undulator Planning

- Receiver and LO housed in shielded enclosure below girder 20 watt power dissipation maximum
- Presently BPM output on wall side
- BPM output flexible waveguide section allows movement for alignment



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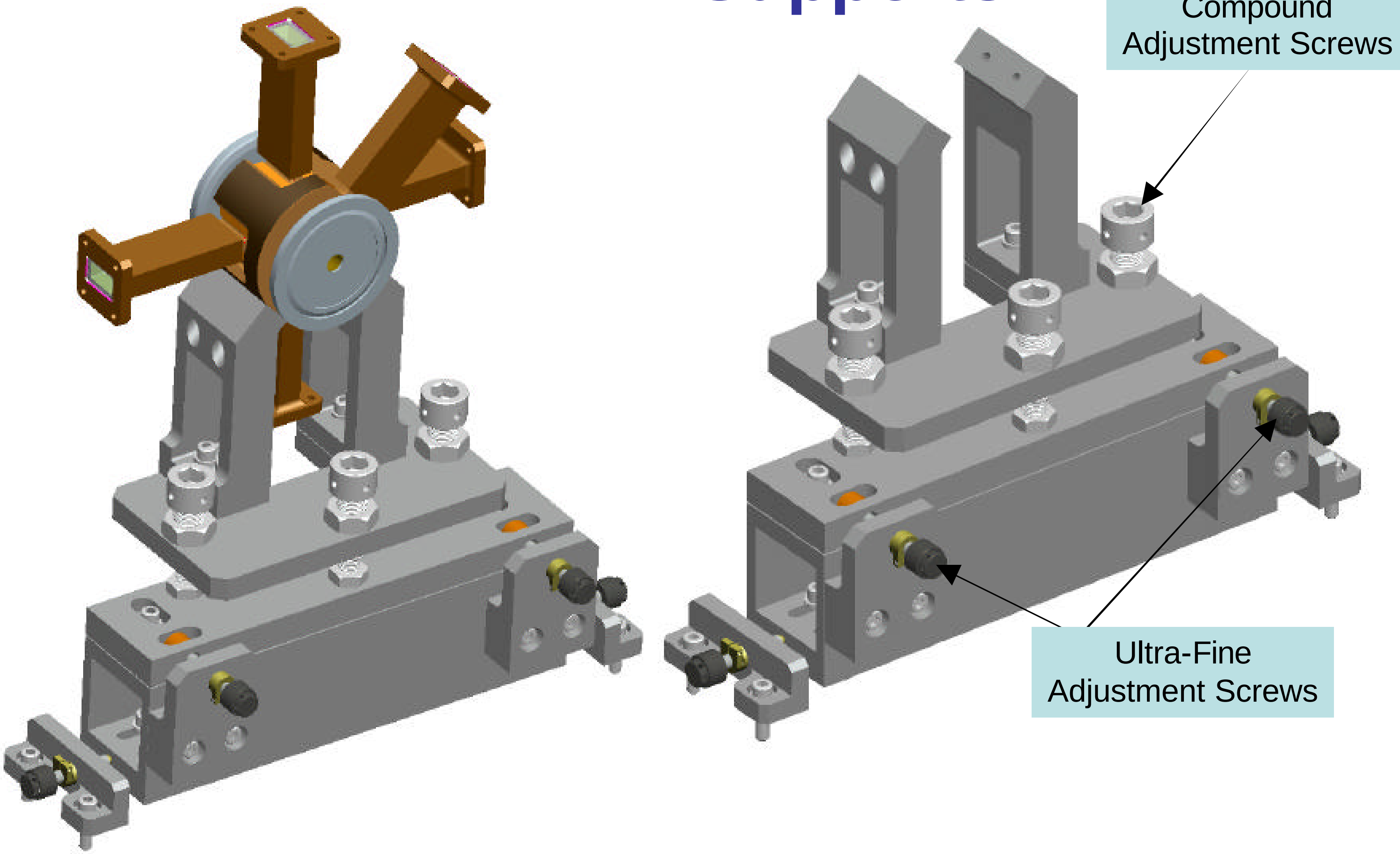
Mechanical Supports



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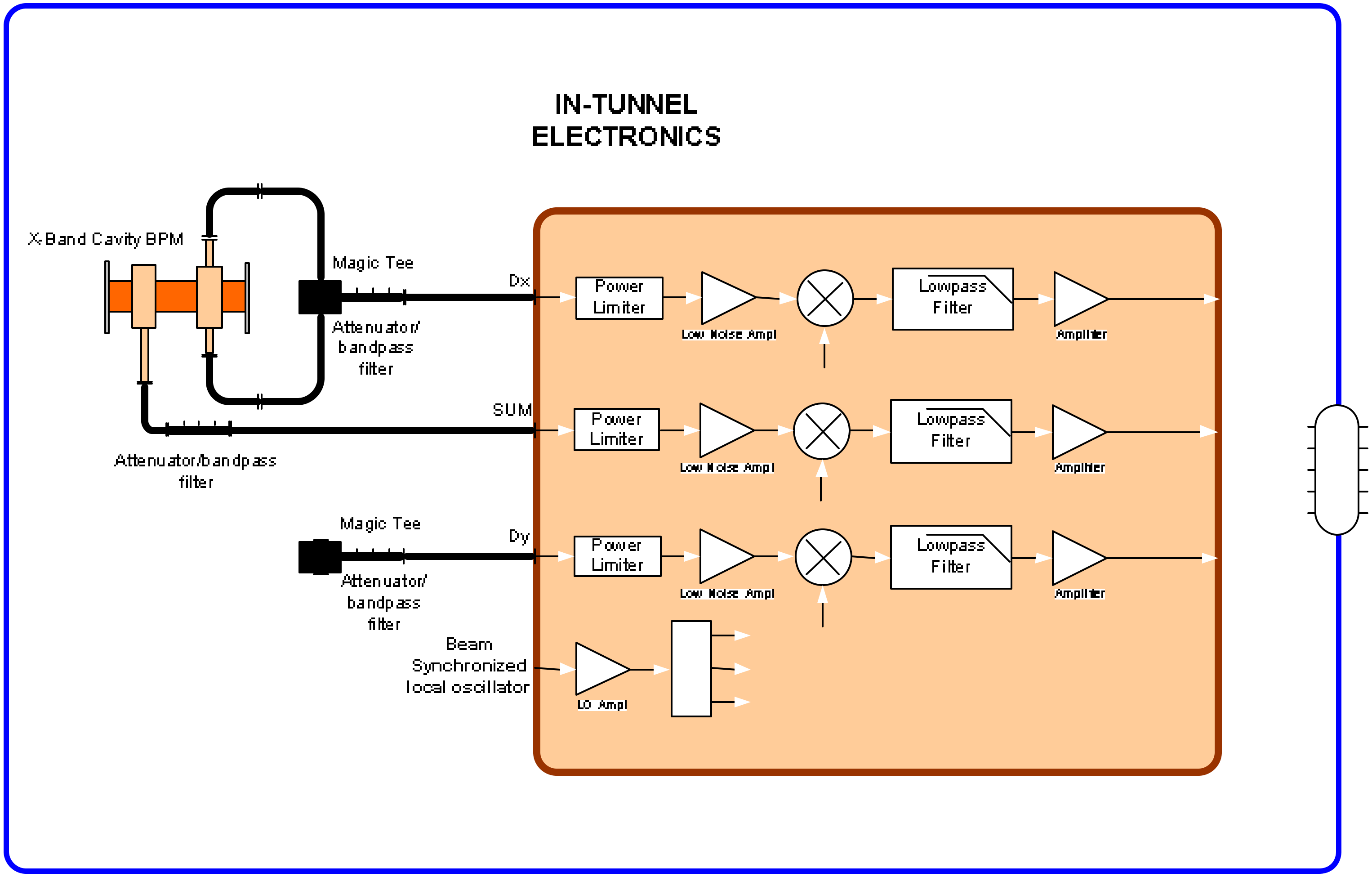
In-Tunnel Electronics Block Diagram



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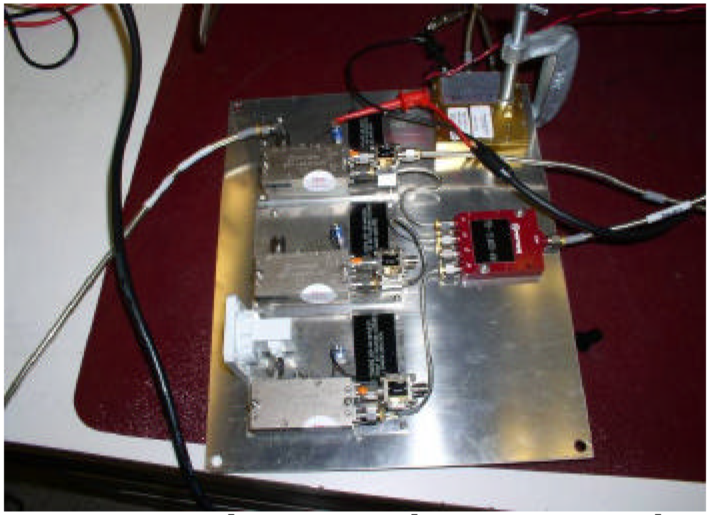
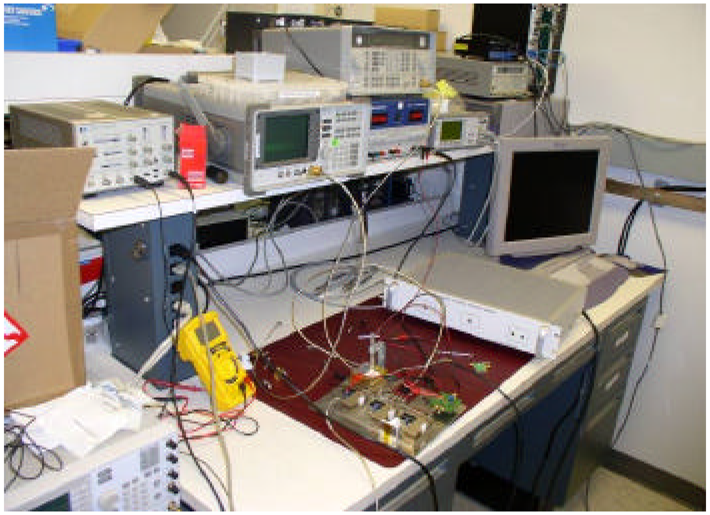
Prototype X-Band Low Noise Receivers





- Conversion gain 27.5 dB
- Over 60 dB dynamic range
- Noise Figure 2.5 dB
- IF bandwidth 40-80 MHZ
- Ready for ITS Installation

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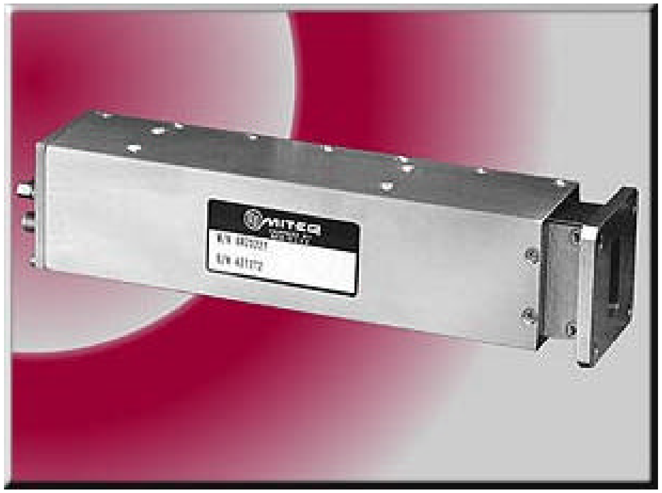
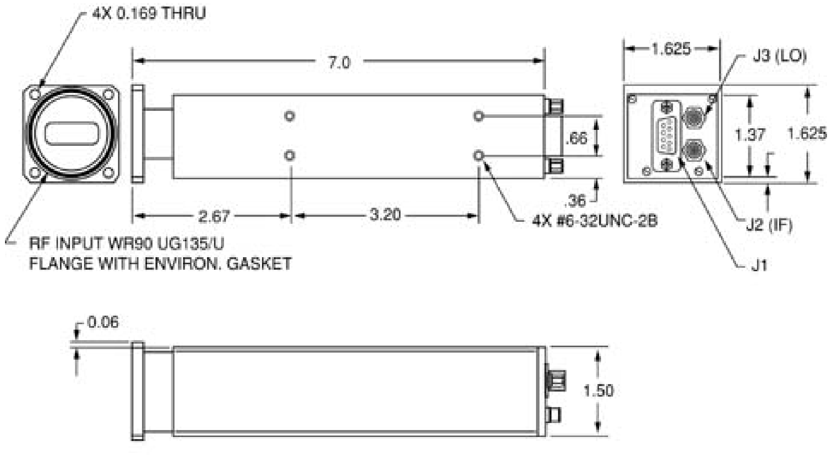
Miteq X-Band Low Noise Receiver





- Existing product line
- WR 75 Waveguide Interface
- Low Noise Figure (2.7 dB)
- Budgetary price for (3 channels) $6500.00

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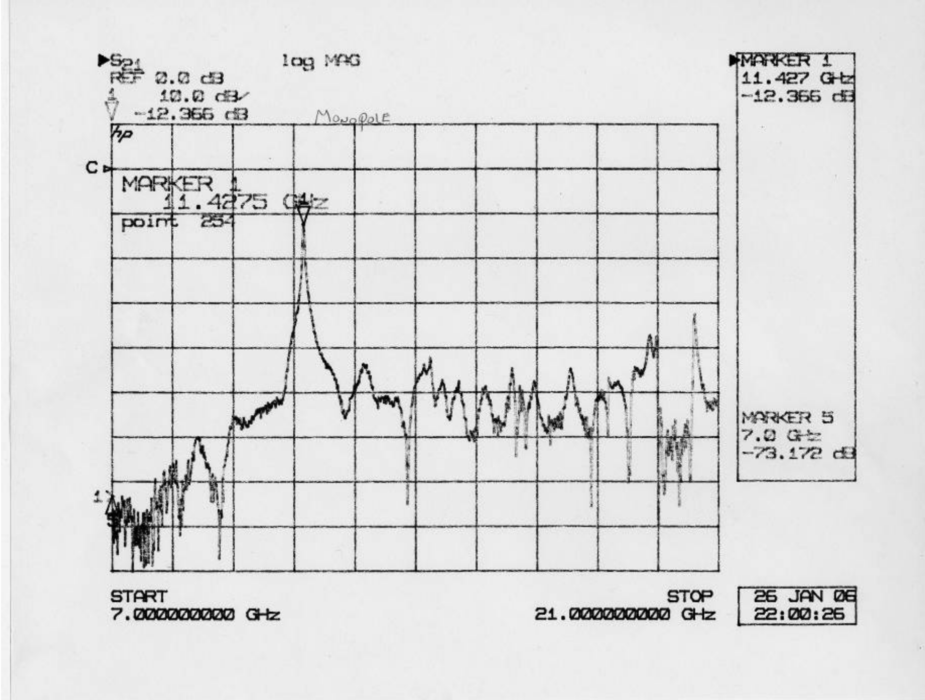
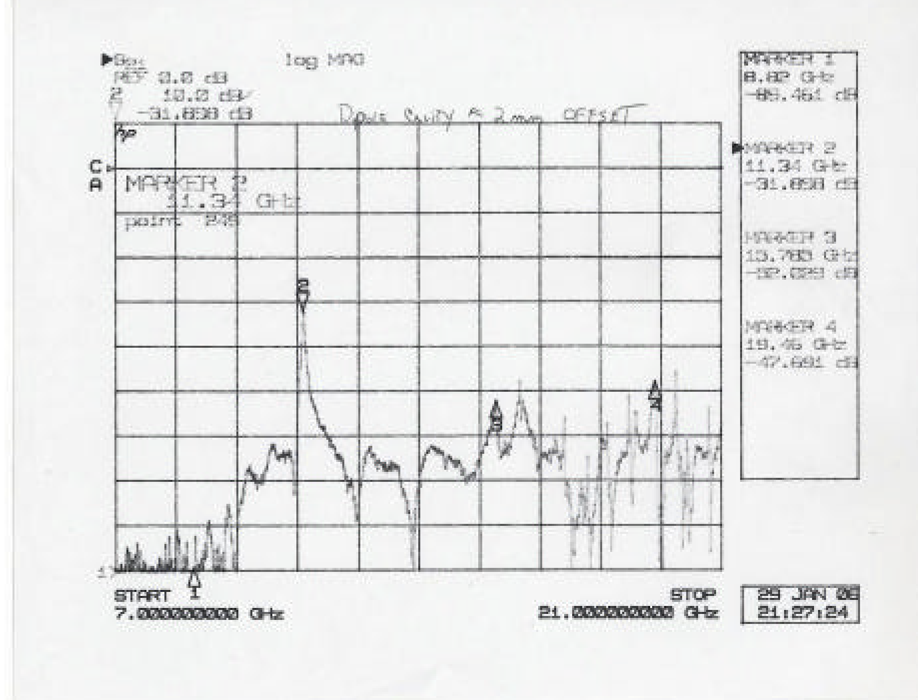
Monopole and Dipole Wideband Sweep Bolted End Caps

Monopole Cavity



Dipole Cavity antenna offset 2 mm



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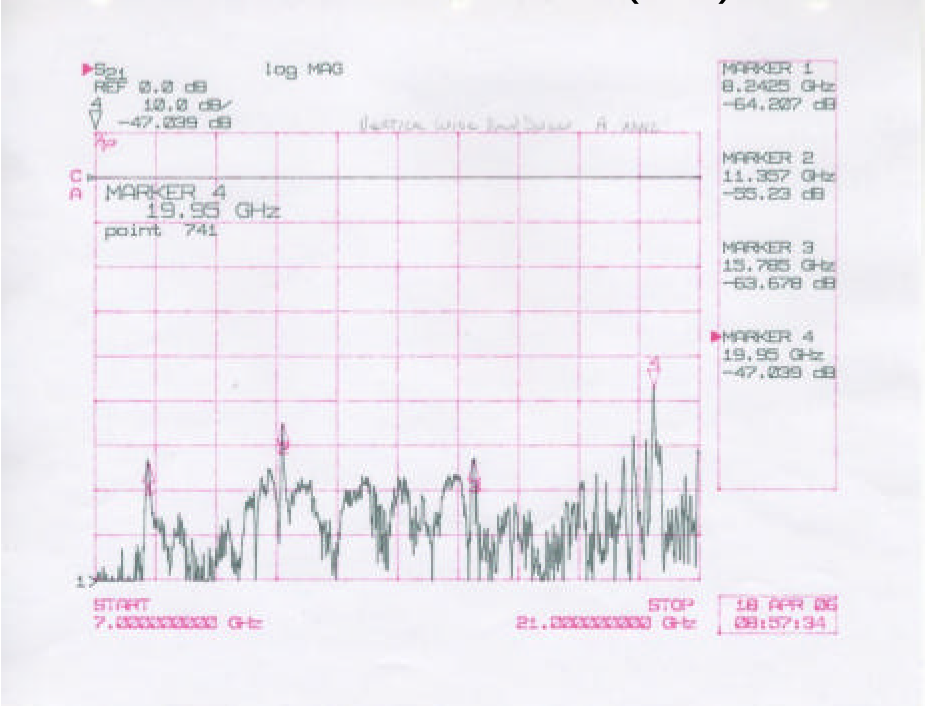
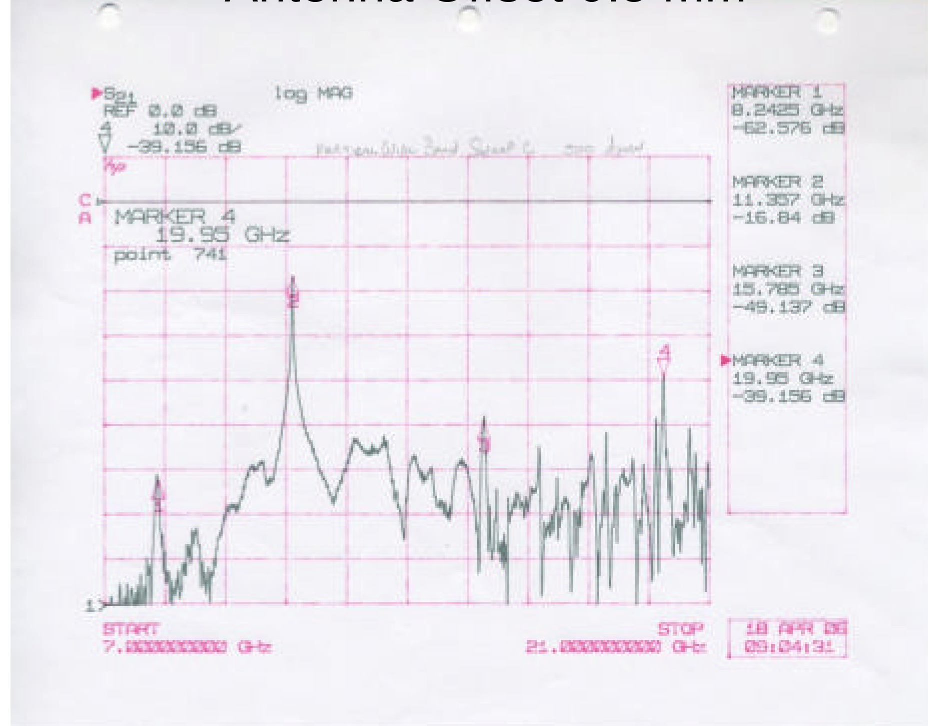
Dipole Wideband Sweep
Brazed End Caps

Antenna Centered (null)



Antenna Offset 0.5 mm



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Conclusions

- X-band cavity design should easily meet LCLS resolution requirements
- Cavity BPMs moving beyond proof-of principal systems to integrated systems
- Much detail involved in integration with undulator mechanical design
- X-band waveguide mixer in the tunnel
- Remote digital signal processing

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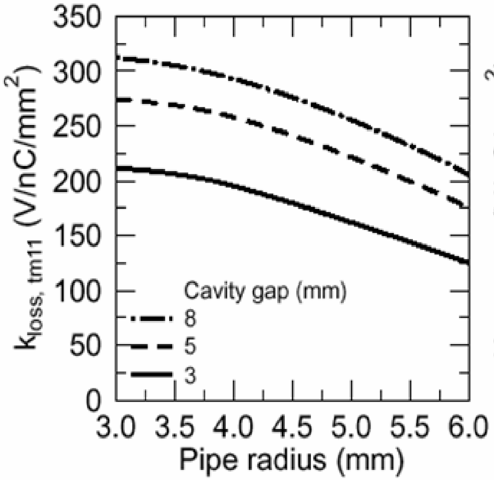
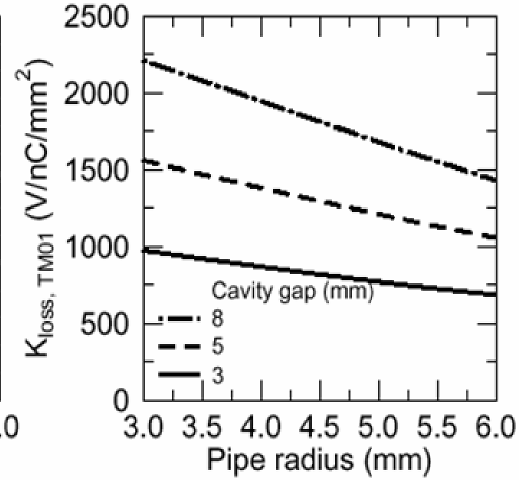
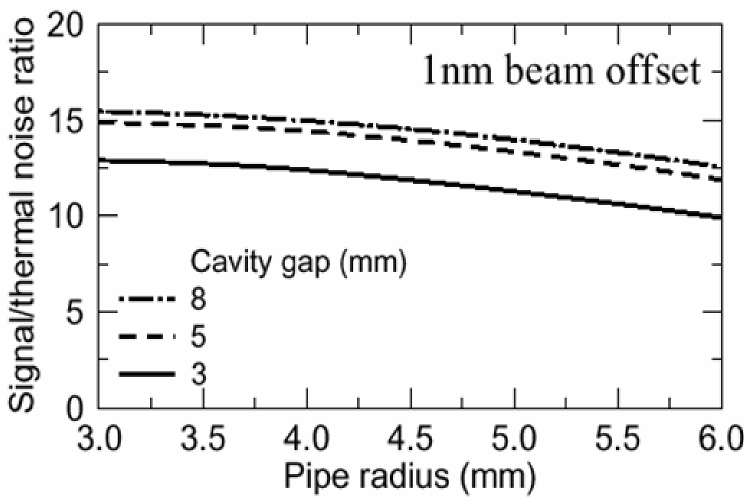
Energy loss from the beam versus pipe radius







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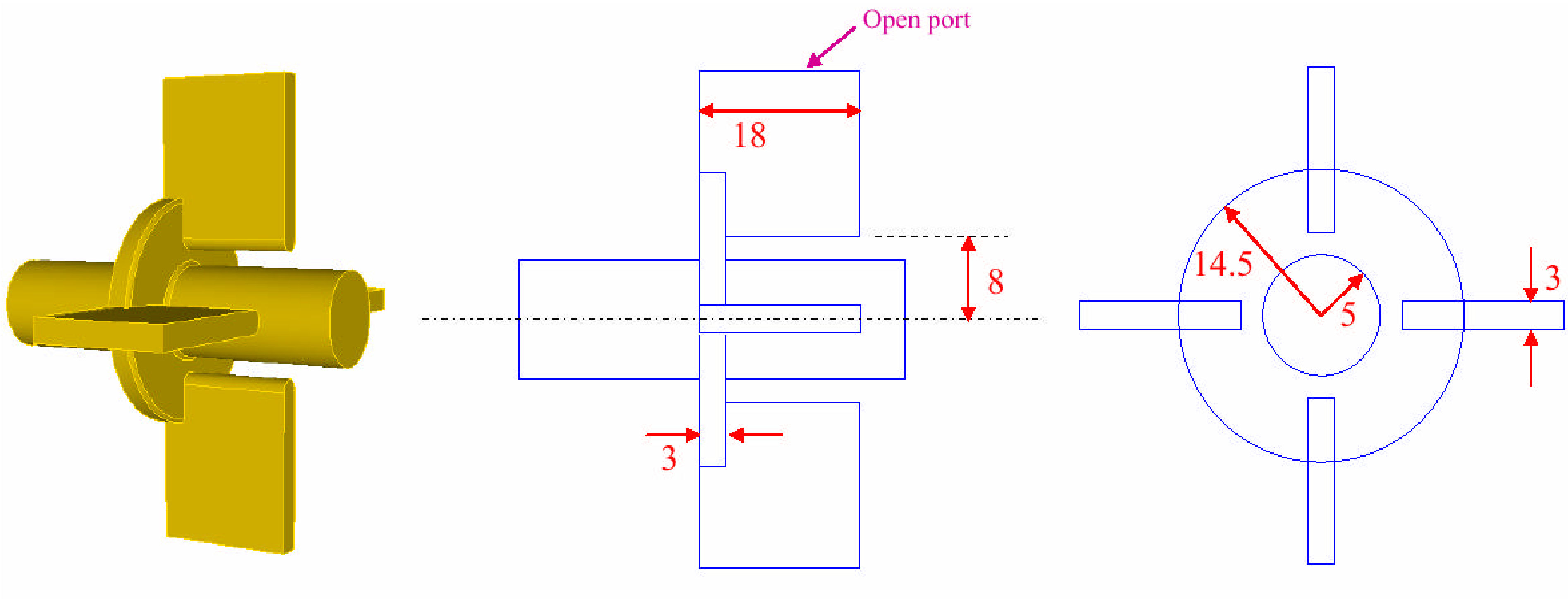
X-Band Cavity Dimensions



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