Beam Stability Measurement

Beam position measurement techniques

- Charged particle beam pickup electrode types

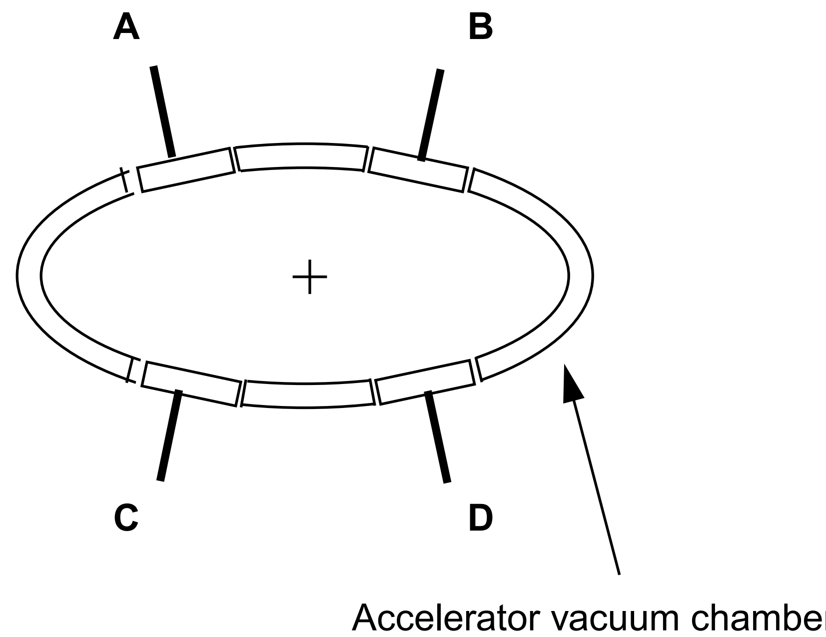
- Analog processing techniques

- Photon beam position monitoring

Charged Particle Beam Pickup Electrodes

Capacitive buttons

- Broadband, up to > 10 GHz
- Most effective when button diameter is comparable to the bunch length
- Minimal wakefield interaction with beam



$$X = K_x \frac{A-B+C-D}{A+B+C+D}$$

$$Y = K_y \frac{A+B-C-D}{A+B+C+D}$$

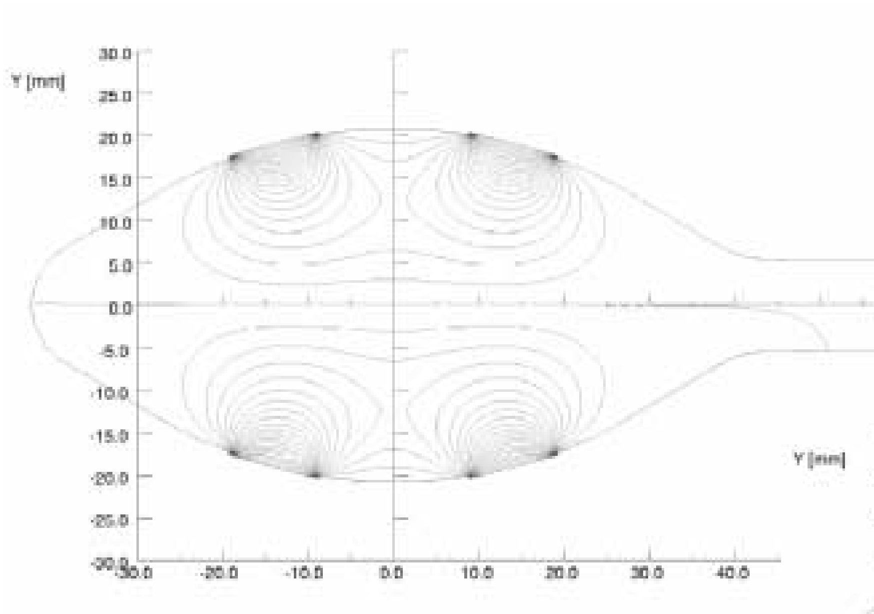
e.g. for round buttons of radius a in round pipe of radius r

$$Z_t(\omega) = V_p / I_b = \frac{a^2 \omega}{2 r \beta c} \quad \frac{R}{(1 + j\omega RC)}$$

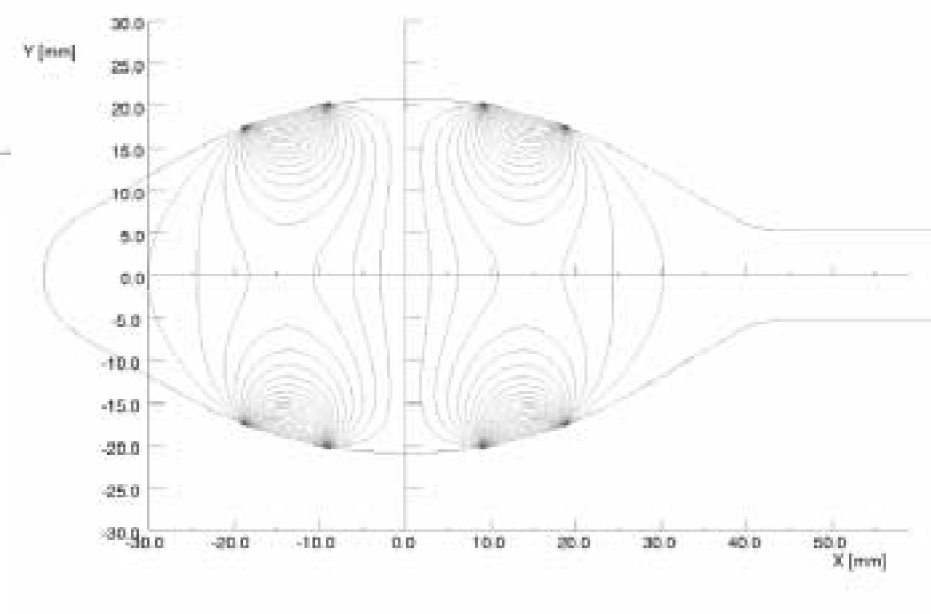
where $\beta = v / c$,
R = Transmission line impedance,
C = Button capacitance

Equipotentials from APS Button Sensitivity Calculation

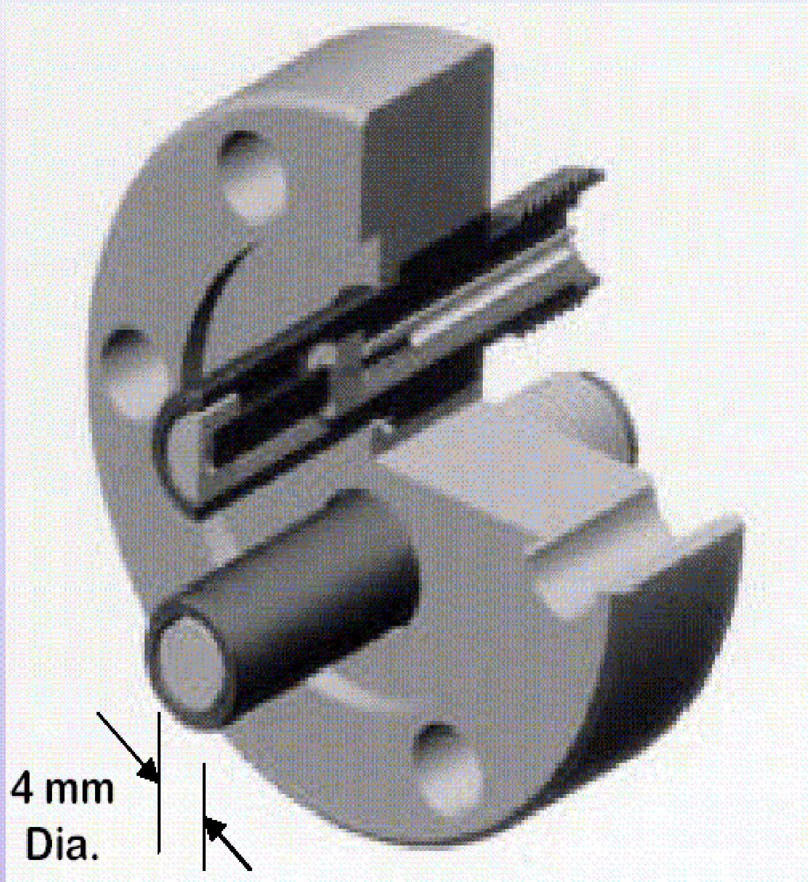
Vertical: Contours of constant $\frac{T - B}{T + B}$



Horizontal: Contours of constant $\frac{L - R}{L + R}$



Capacitive- Button Pickup Electrode / Feedthrough Assembly
Double- button Configuration for APS
Small- Aperture Insertion Device Vacuum Chamber



Drawing courtesy J. Hinkson ALS

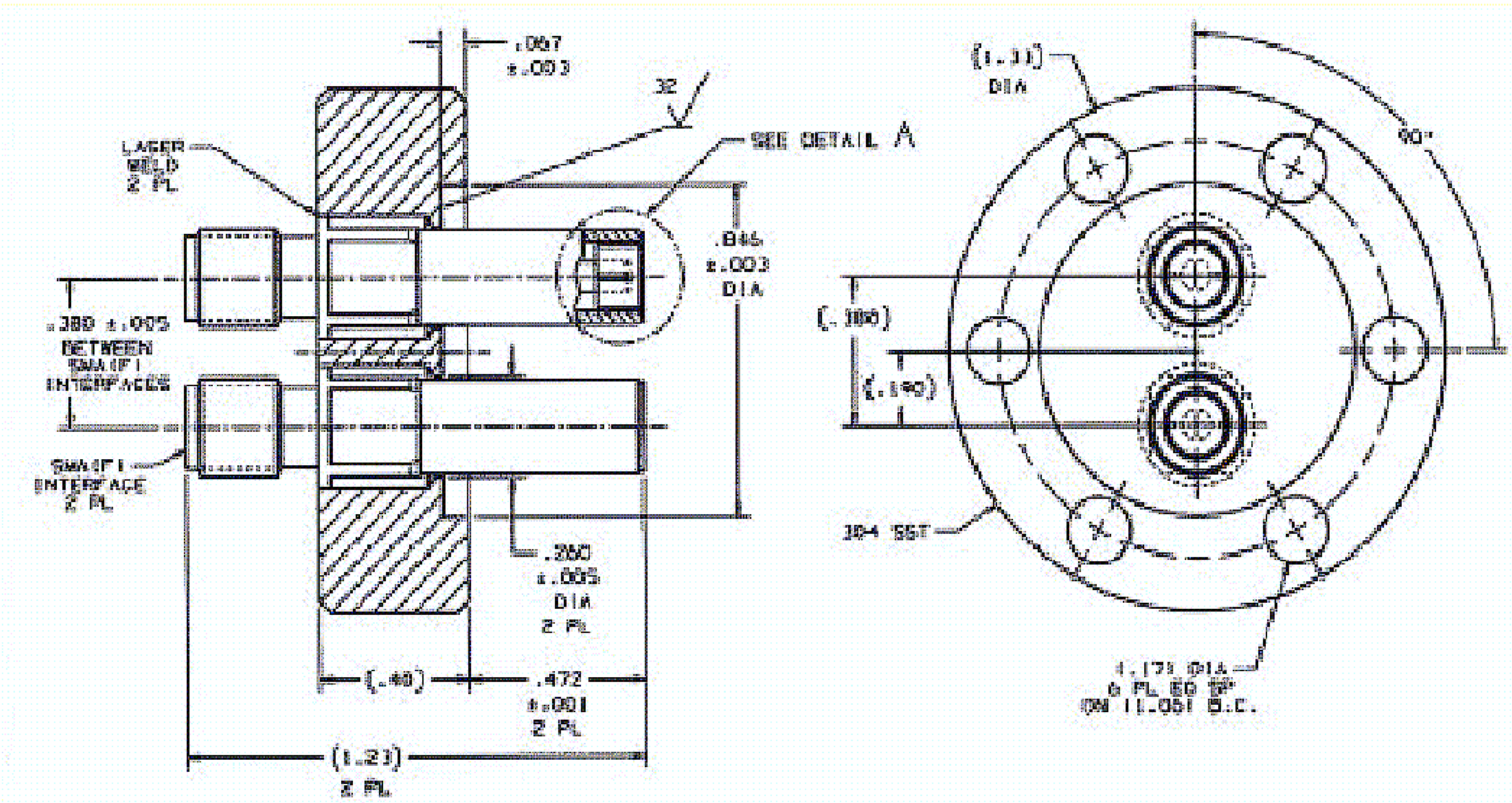
Electrical Specifications:

Frequency: DC to 20 GHz
Impedance: 50 ohm nominal, terminated by a capacitive button
Capacitance: 4.8 pF nominal
VSWR: 1.03:1 max. to 3 GHz, 1.15:1 to 20 GHz
Insertion loss: 0.1 db max. to 3 GHz, 0.5 db max. to 20 GHz
Matching: +/- 0.5 ohm in impedance, and +/- 0.1 pF in capacitance.
Connector: SMA female ,hermetically sealed with glass insulator.
Dielectric Strength: >1500 V at 50/60 Hz
Leakage Resistance: > 10^{13} ohm, from center conductor to outer housing

Mechanical Specifications:

Diameter: 4 mm
Materials: As per Kaman P/N 853881-001
Hermeticity: <10-11 cc He/sec
Radiation: >200 megarads gamma

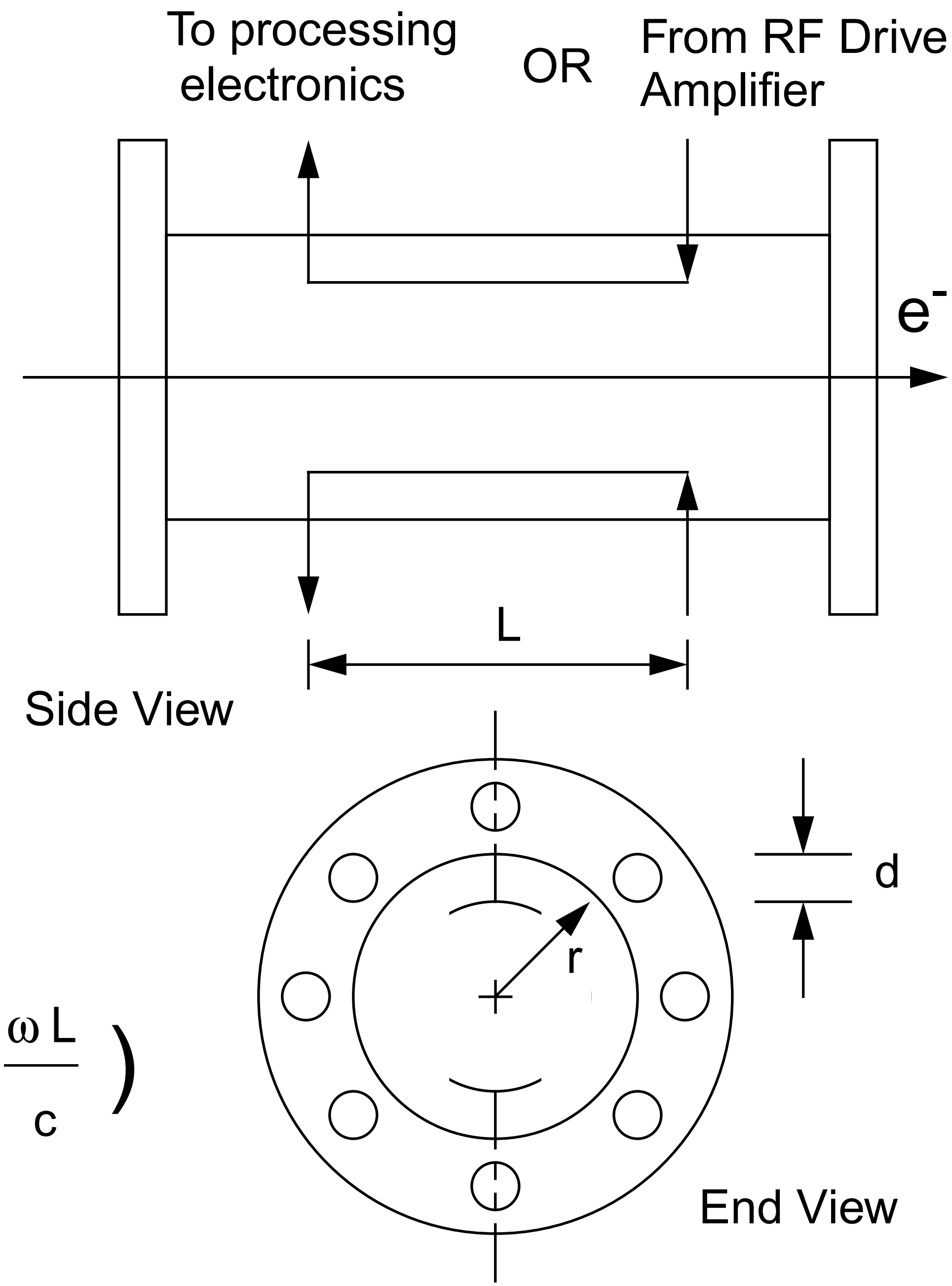
Mechanical Drawing of Double-Button



Charged Particle Beam Pickup Electrodes (cont'd)

Stripline pickup

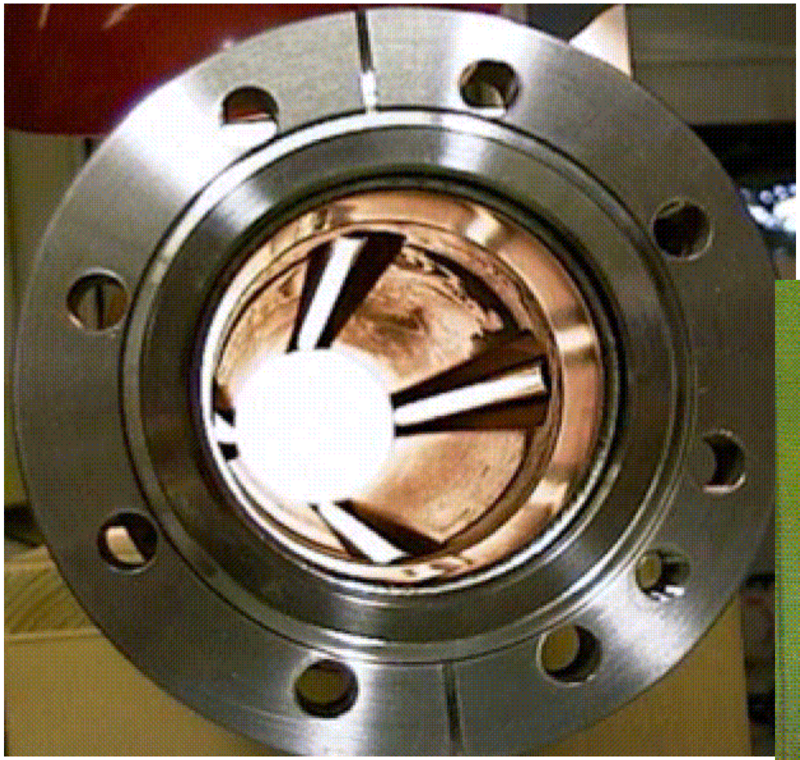
- Also known as directional coupler
- Can be used either as pickup electrode or rf frequency kicker.
- Originally designed to differentiate signals from counter-rotating beams in colliders.
- Strong coupling to the beam
  - Large signal strength
  - Larger wakefield effects than for button pue's
- To save money on feedthroughs, can short one end (it doesn't matter which)
- Typical length chosen is one quarter wave-length at storage ring rf frequency



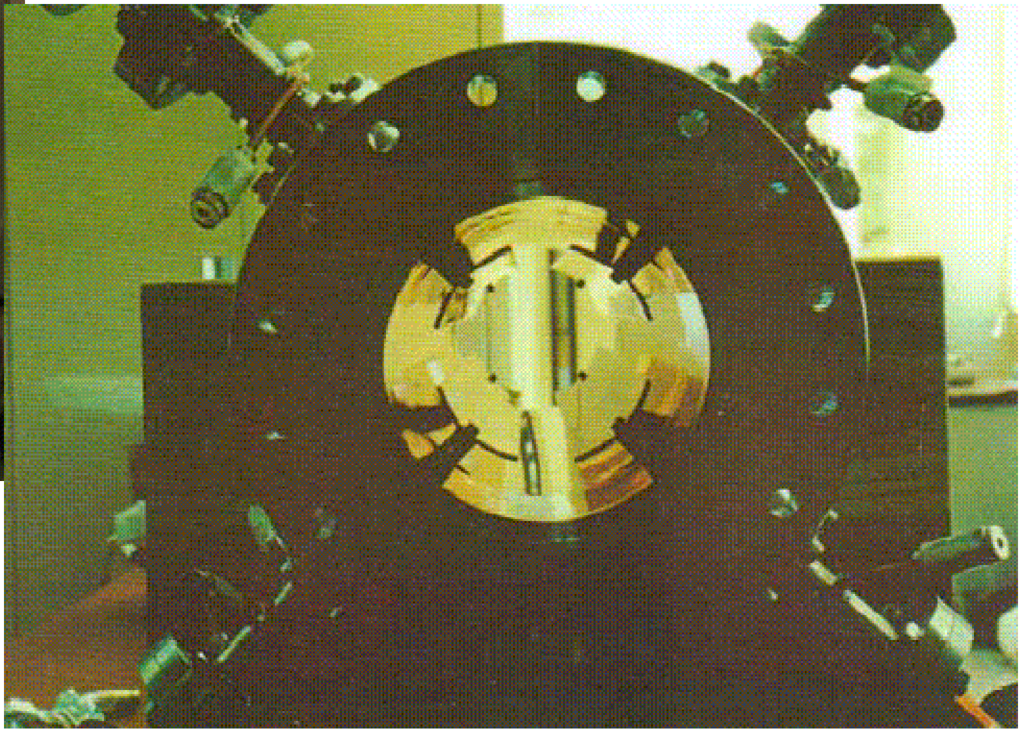
$$Z_t(\omega) = V_p / I_b = 60 \ln\left(\frac{r}{r-d}\right) \sin\left(\frac{\omega L}{c}\right)$$

G. Lambertson, AIP Proc 153. V2 (1985)

Examples of Stripline Pickups

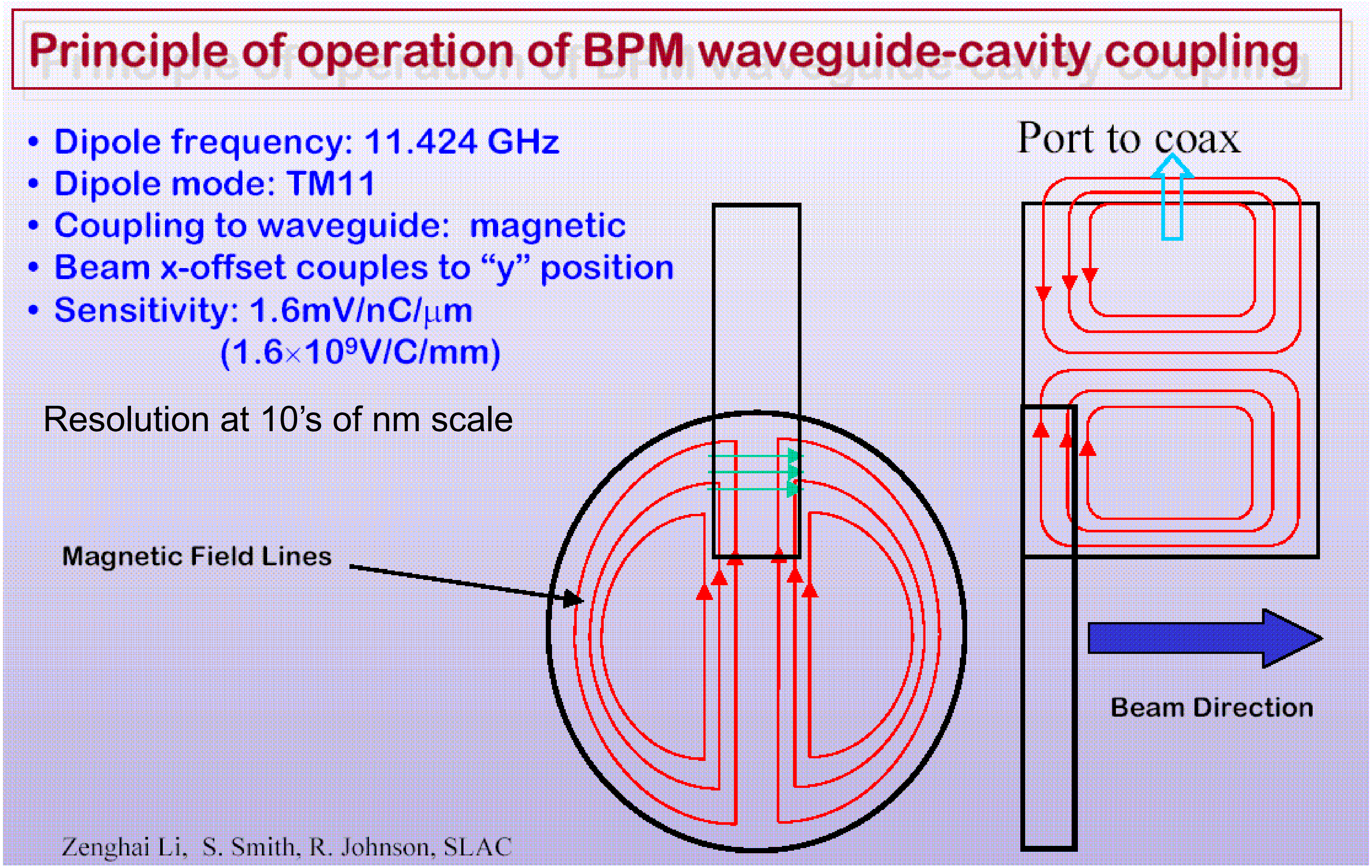


M. Wendt, DESY



M. Tobiyama, KEK

Resonant Cavity-Style BPM

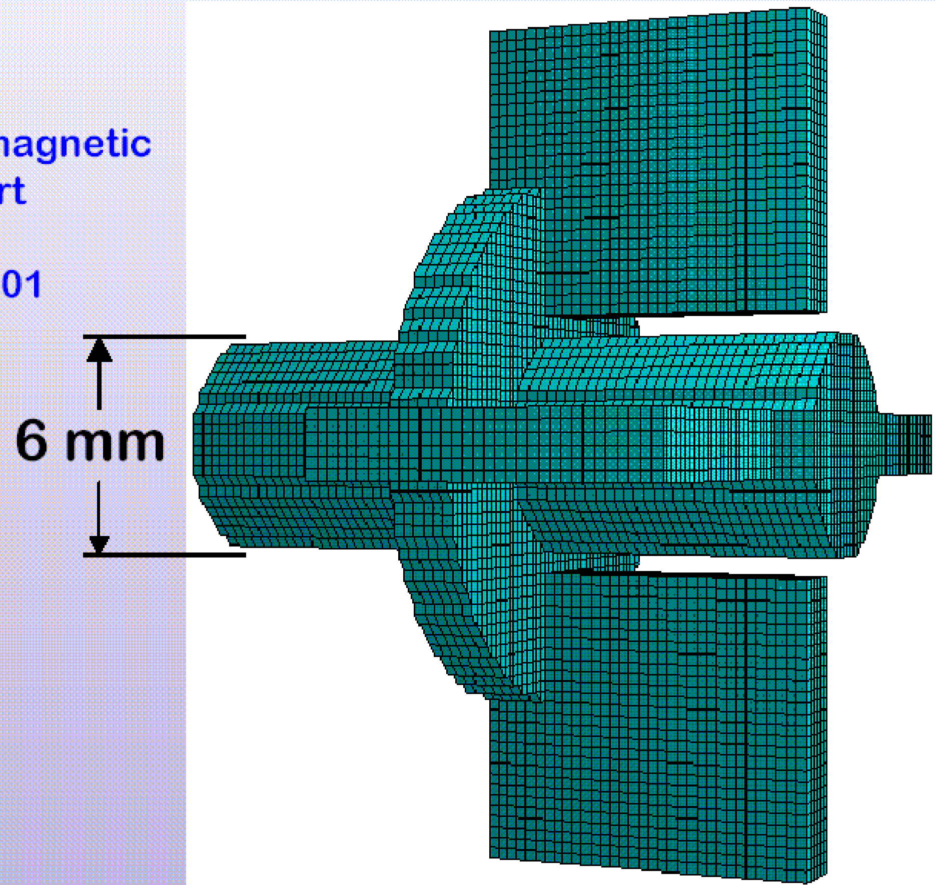


Numerical Model of Cavity BPM

Waveguide-Coupled Cavity-Based BPM Model

- Dipole frequency: 11.424 GHz
- Dipole mode: TM11
- Coupling to waveguide: radial magnetic
- Beam x-offset couples to "y" port
- Sensitivity: 1.6mV/nC/μm
- Explicitly does not couple to TM01

Cavity height	*3mm*	
Guide height	*3mm*	
Guide R pos	*7mm*	*8mm*
Pipe radius	*6mm*	
Q_{dipole}	*450*	*1050*
W_L *amplitude*	*1.3E12*	



Zenghai Li, S. Smith, R. Johnson, SLAC

Beam Position Monitor Analog Signal Processing

Purpose: To process pickup electrode signals to make them suitable for interfacing with a data acquisition and control system.

Challenges:

1) To stretch rf frequencies down to video or base band.

2) To band limit signals to avoid aliasing.

3) Normalization

- Analog addition, subtraction, and even multiplication are reasonably straight forward. Not so for division.

- Digital arithmetic is easy, but perhaps not fast enough for some applications.

RF Beam Position Monitor Analog Signal Processing

Three techniques are common:

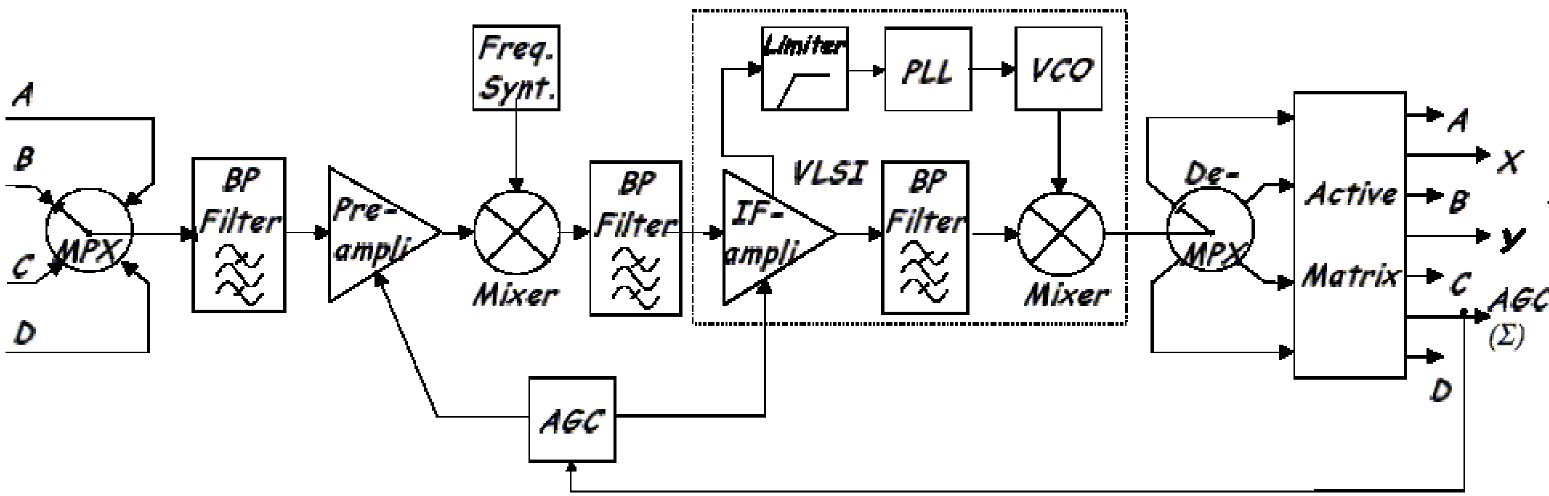
1) Bittner / Biscardi / Galayda multiplexed narrowband receiver

2) Amplitude Modulation -> Phase Modulation (AM/PM) techniques (R. Shafer, R. Webber etal.)

3) Log Ratio

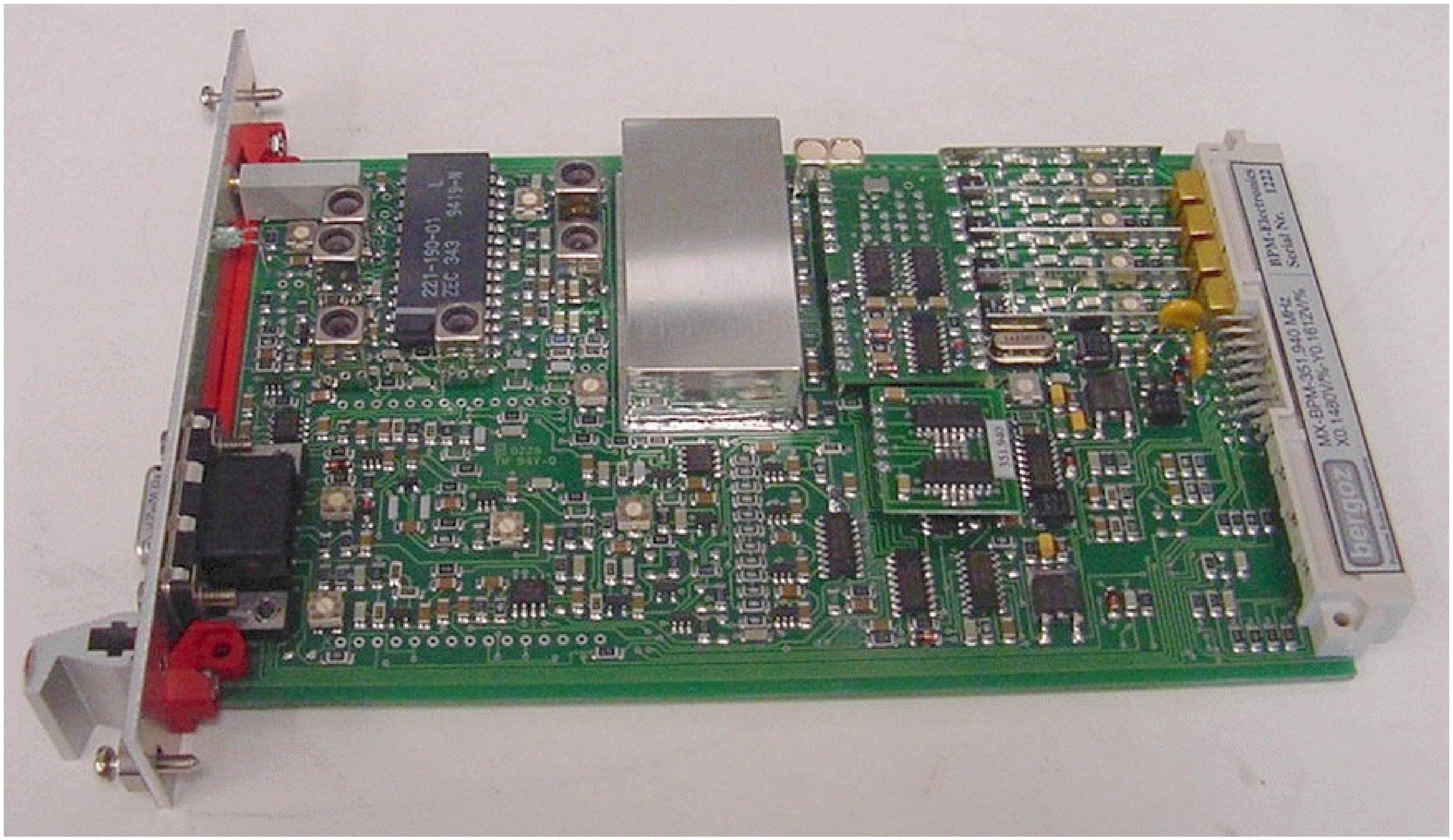
Bittner / Biscardi / Galayda / Hinkson/ Unser / Bergoz Narrowband Receiver

Normalization accomplished via multiplexing plus automatic gain control (AGC)*:



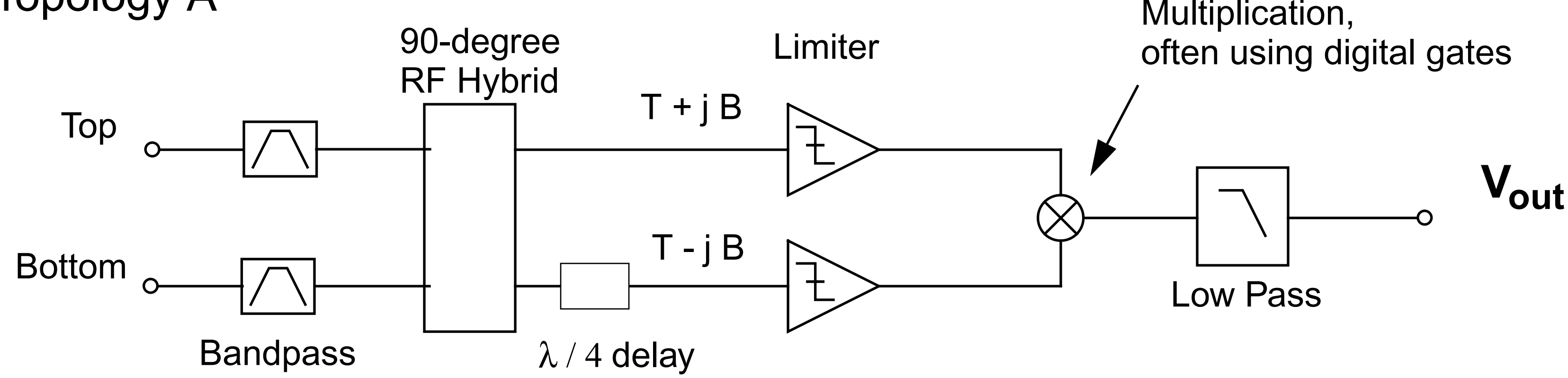
* G. Vismara, DIPAC '99 http://srs.dl.ac.uk/dipac

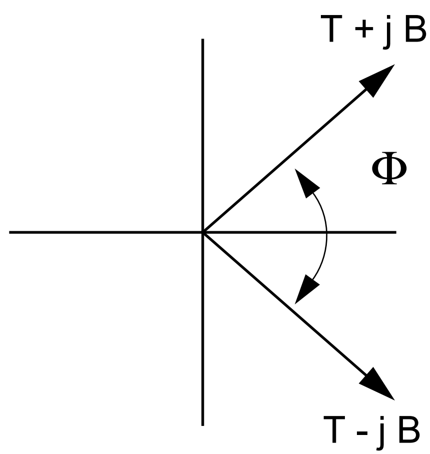
Commercially Available Multiplexed Receiver

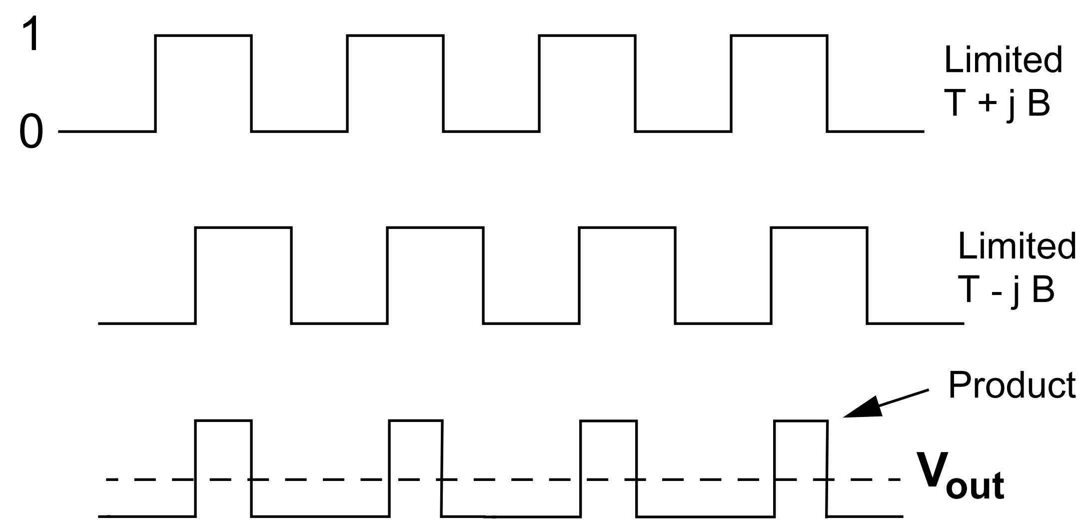


Amplitude-to-Phase Conversion

Topology A







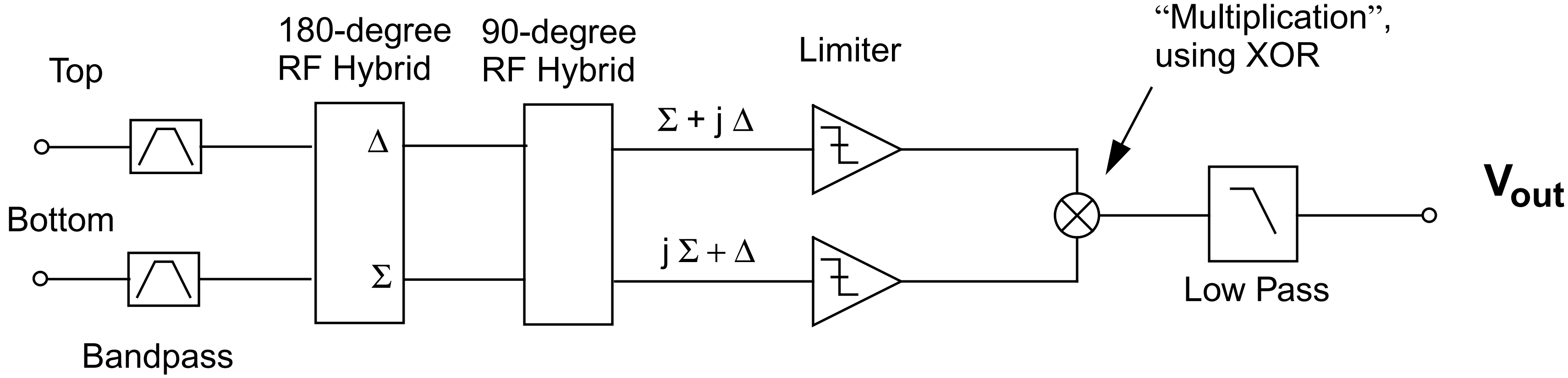
$$\Phi = 2\,\mathrm{Tan}^{-1}(B/T)$$

$$V_{out} = \frac{T^2 - B^2}{T^2 + B^2} = \left[\frac{(T + B)^2}{T^2 + B^2}\right] \frac{(T - B)}{(T + B)}$$

* R. Shafer, BIW ‘89 AIP Conf. Proc. 212

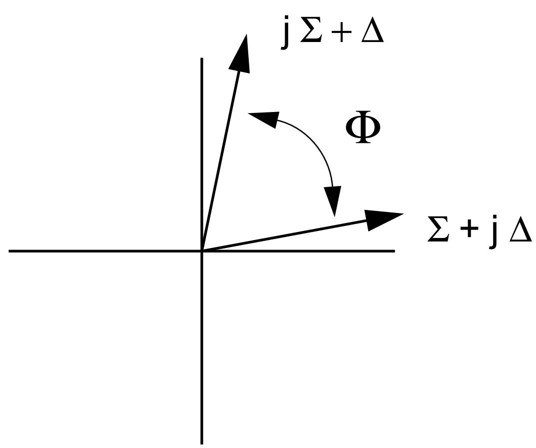
Amplitude-to-Phase Conversion

Topology B



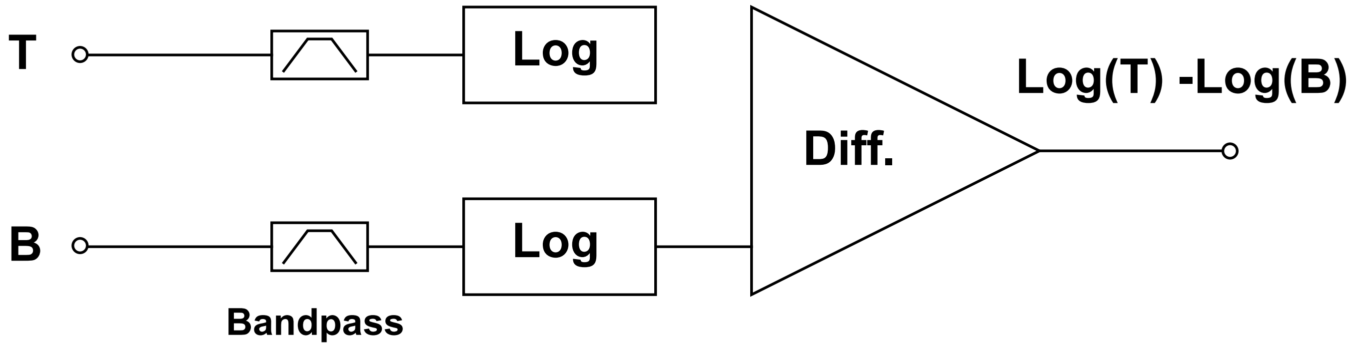
Δ = Top - Bottom

Σ = Top + Bottom



$$V_{out} = K \,\mathrm{Tan}^{-1}(\Delta/\Sigma) = K \frac{\Delta}{\Sigma} + \mathrm{Order}\left(\frac{\Delta^3}{\Sigma^3}\right)$$

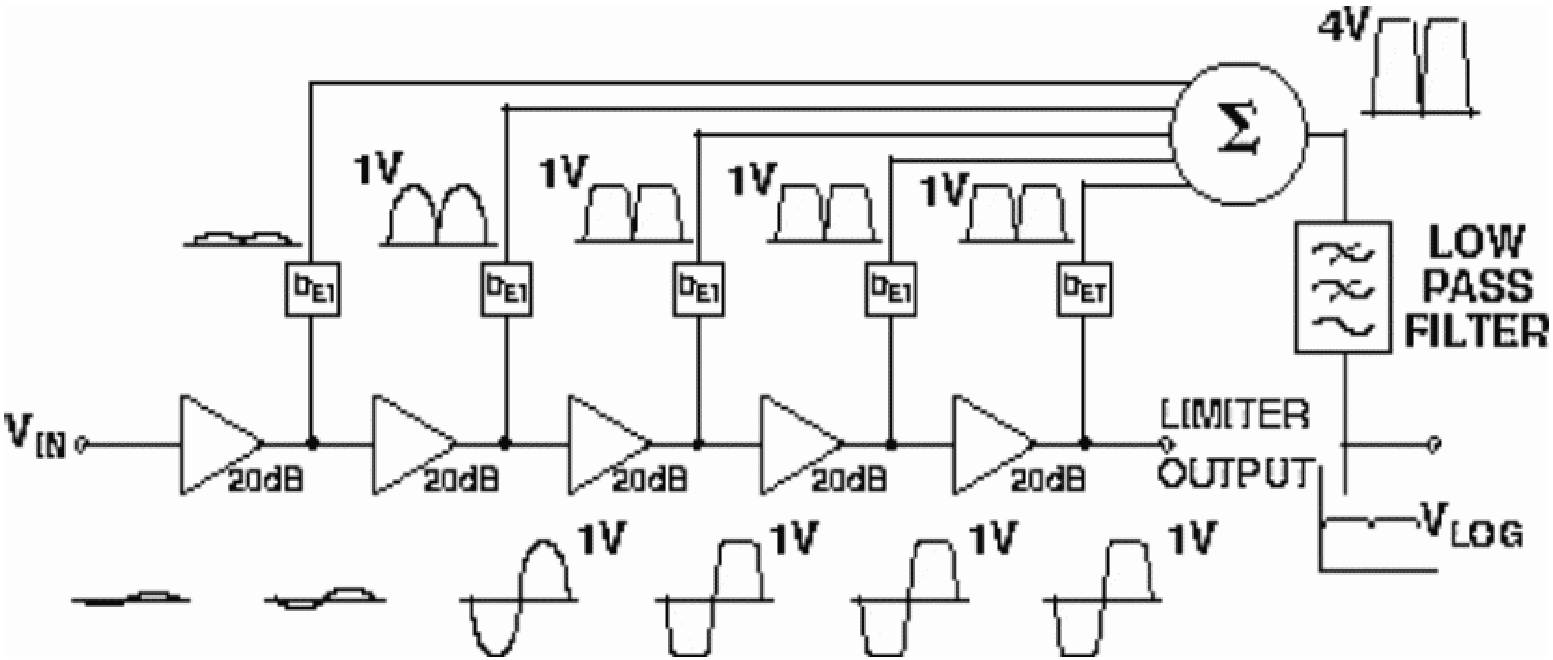
Log-Ratio Processing



$$\text{Log}(T) - \text{Log}(B) = \text{Log}(T/B) = 2\,\text{Tanh}^{-1}\left[\frac{(T - B)}{(T + B)}\right]$$

Logarithmic Amplifier Properties

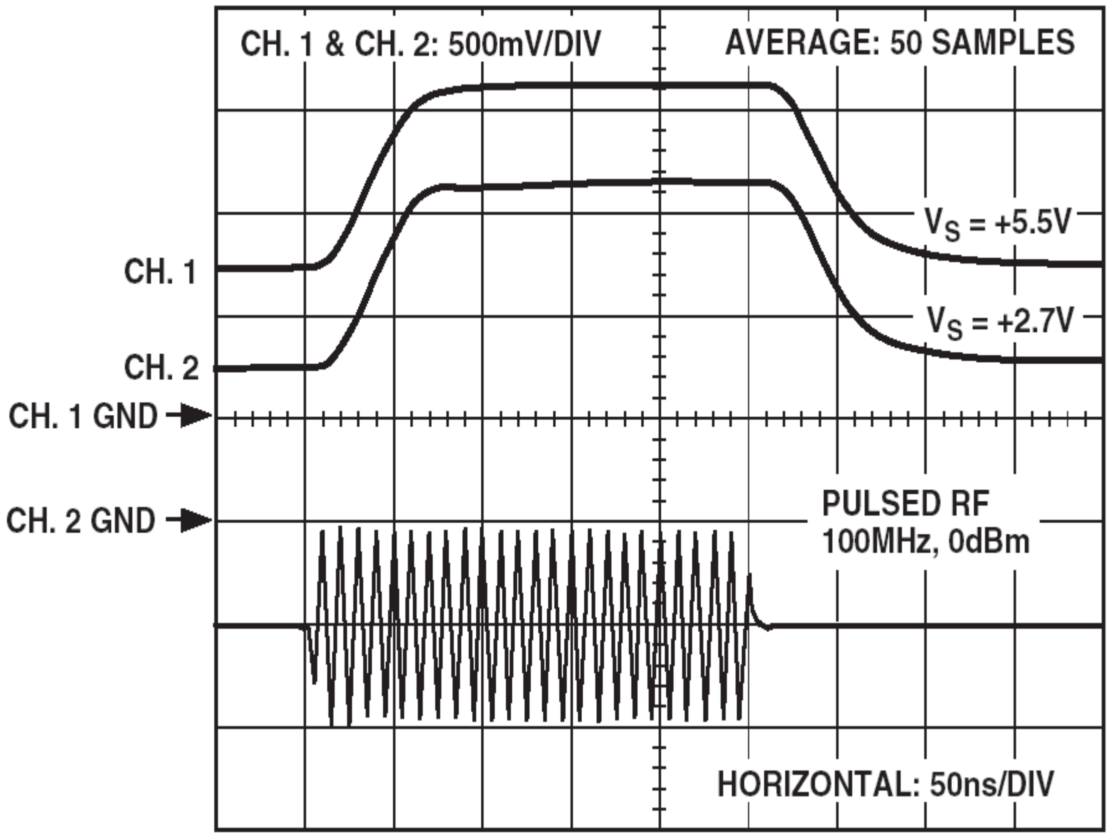
- Inexpensive Log Amps are available up into s-band (> 2.5 GHz)
- Developed to provide rf power measurements in dBm



http://www.analog.com/library/analogDialogue/archives/33-03/ask28/index.html

Logarithmic Amplifier Properties

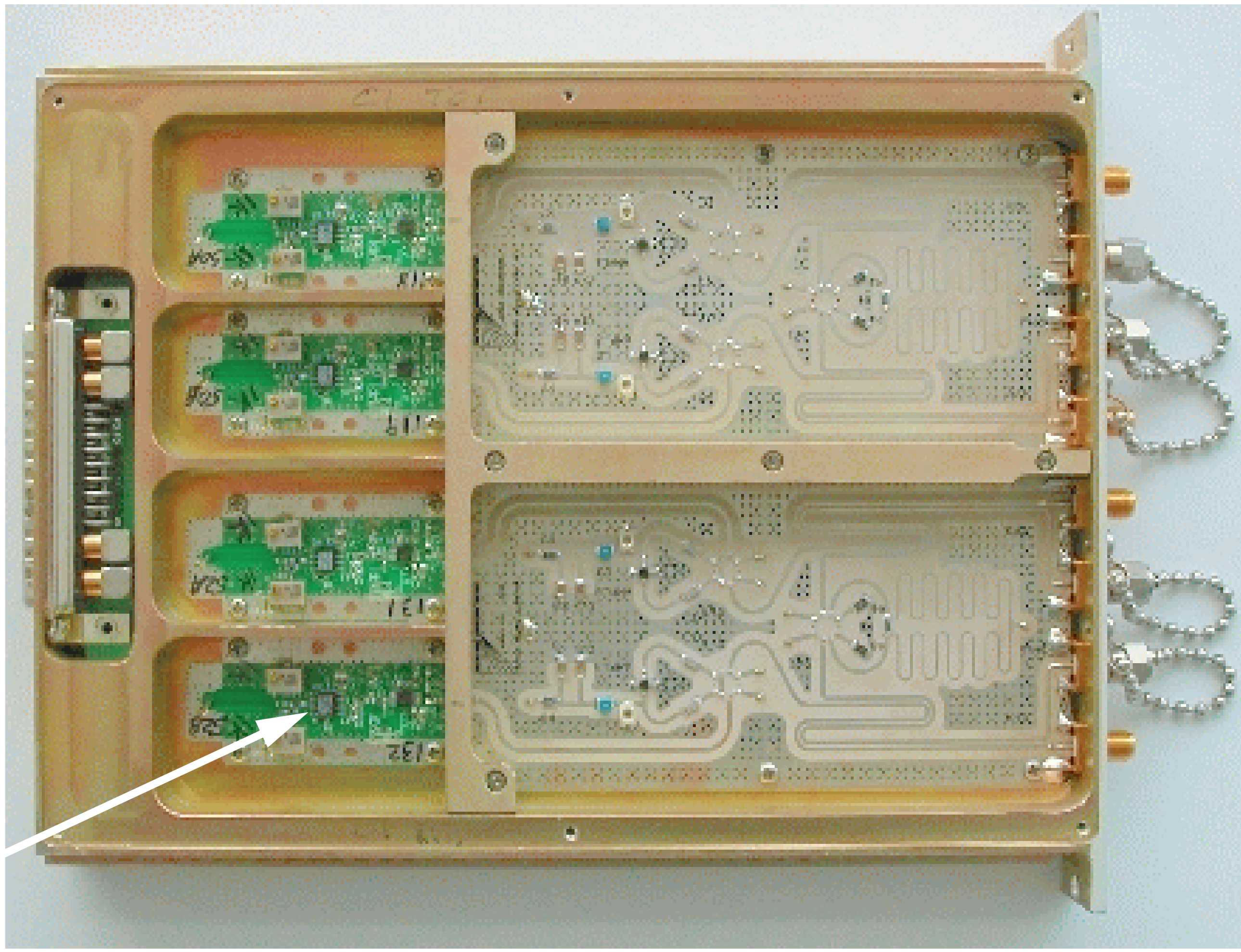
Analog Devices AD8313



TPC 16. Response Time, No Signal to 0 dBm

Log Amp in Practice

Four channels
352 MHz Center Frequency



X-ray / UV Beam Pickup Electrodes

Sensitive to UV radiation / photoelectric effect

Bending magnet radiation excellent for vertical detection

CVD Diamond has excellent thermal conductivity,

Metal cladding is source of photocurrent

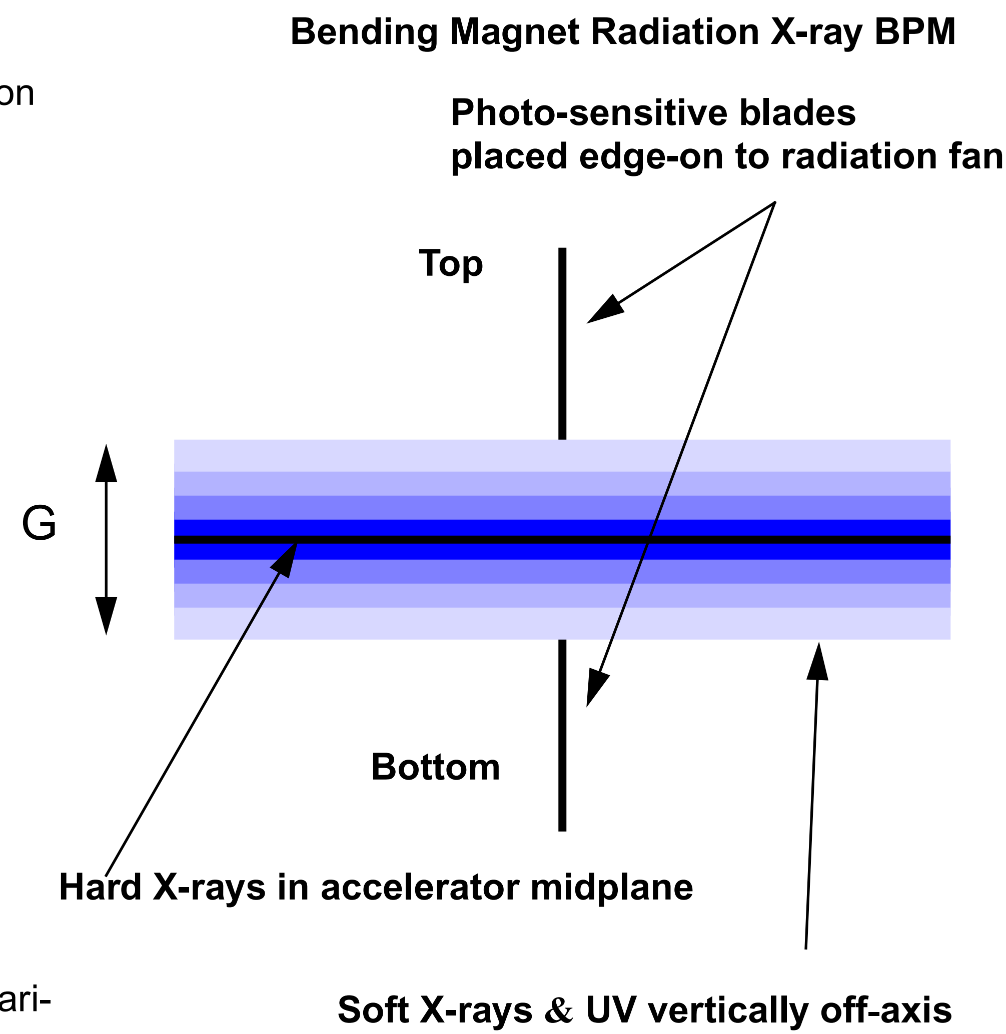
$$Y = K \frac{\text{Top - Bottom}}{\text{Top + Bottom}}$$

Calibration factor K proportional to gap G, usually equal to it, within a factor of two or so.

Mechanical translation stage most reliable method for determination of K

Cross-calibration with rfbpm's straddling the BM source point is a lot cheaper.

Can be located very far from the source point in comparison to rf bpm's - excellent for pointing stability (microradians)



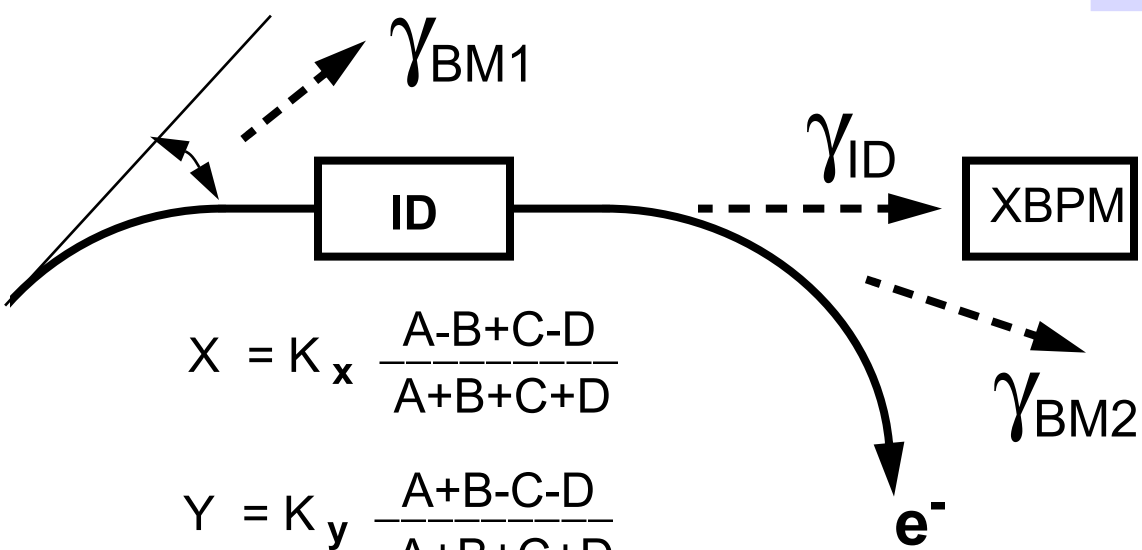
X-ray / UV Beam Pickup Electrodes

Mechanically very similar to BM x-bpm's

Several geometries possible. That shown at right minimizes contamination from adjacent bending magnet sources, best for undulators.

Systematic effects legion
- Insertion device gap
- Stray UV radiation from main dipoles, quadrupoles, sextupoles, and steering corrector magnets
- Cal. factors K_x , K_y depend on insertion device gap

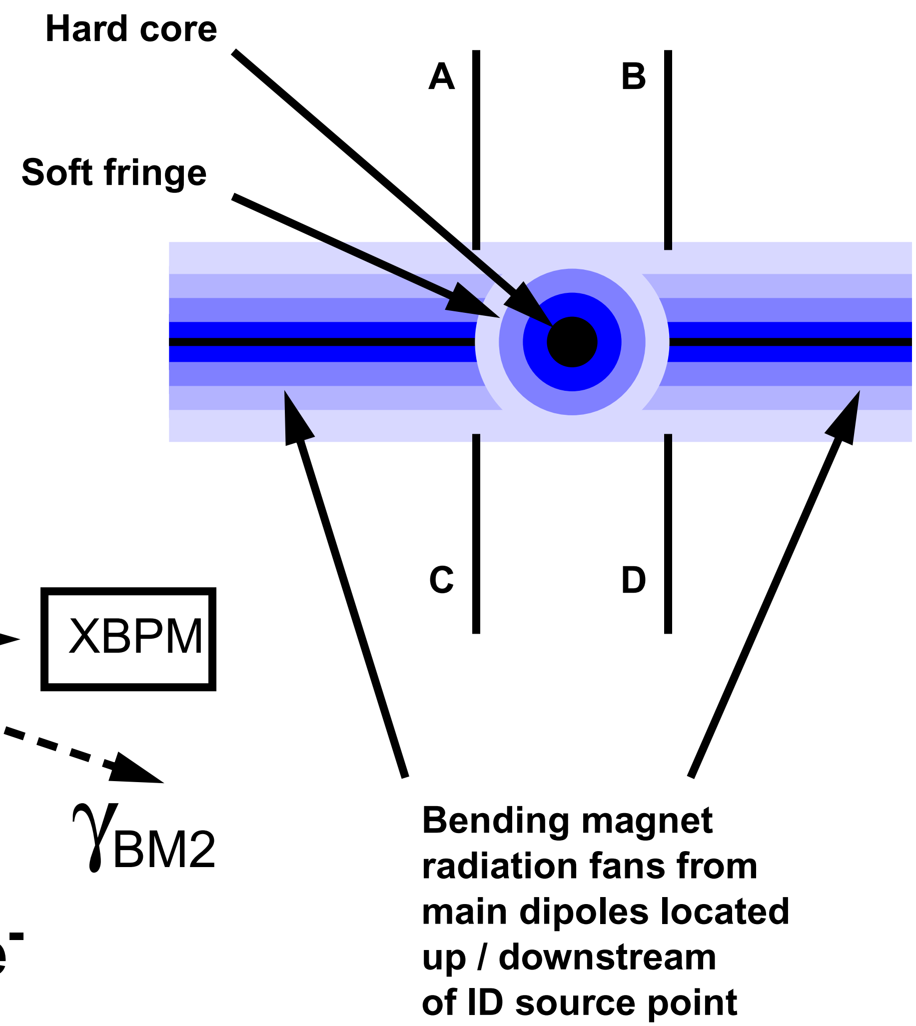
Different types of ID's, e.g. wigglers, helical, electro-magnetic each require special consideration.

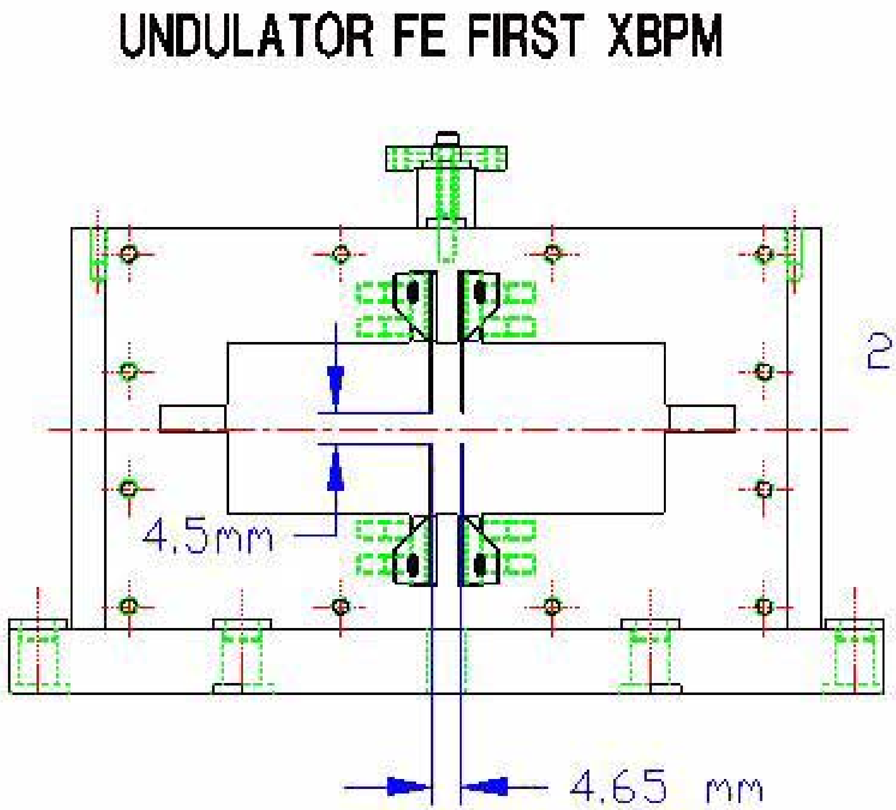


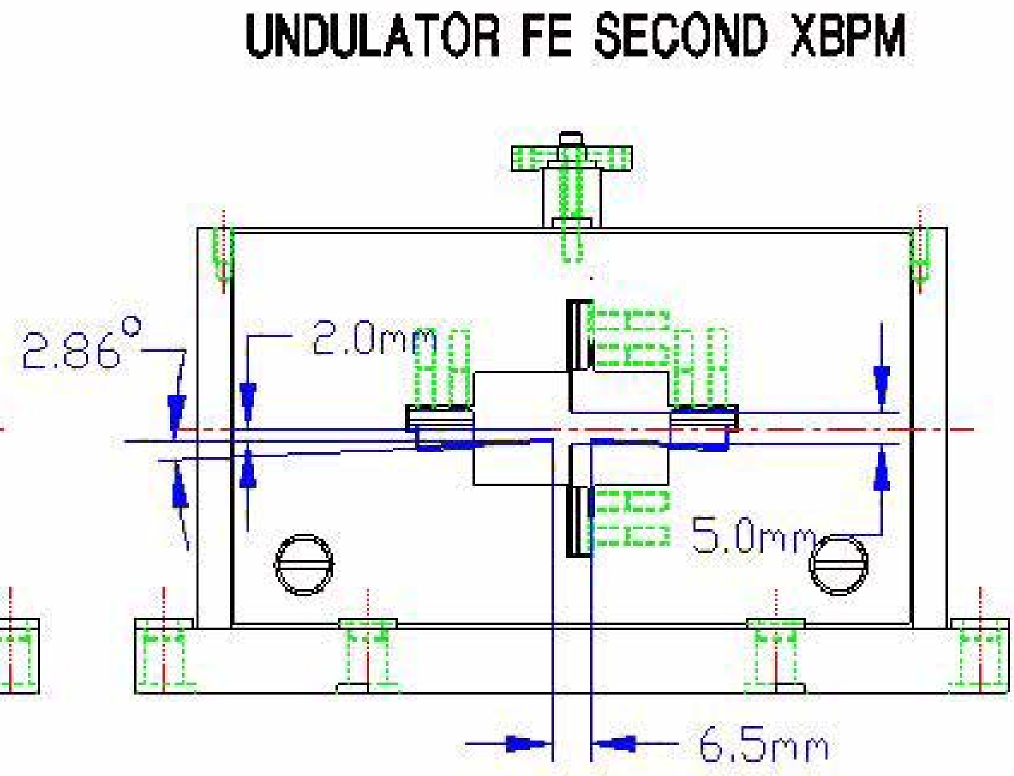
$$X = K_x \frac{A-B+C-D}{A+B+C+D}$$

$$Y = K_y \frac{A+B-C-D}{A+B+C+D}$$

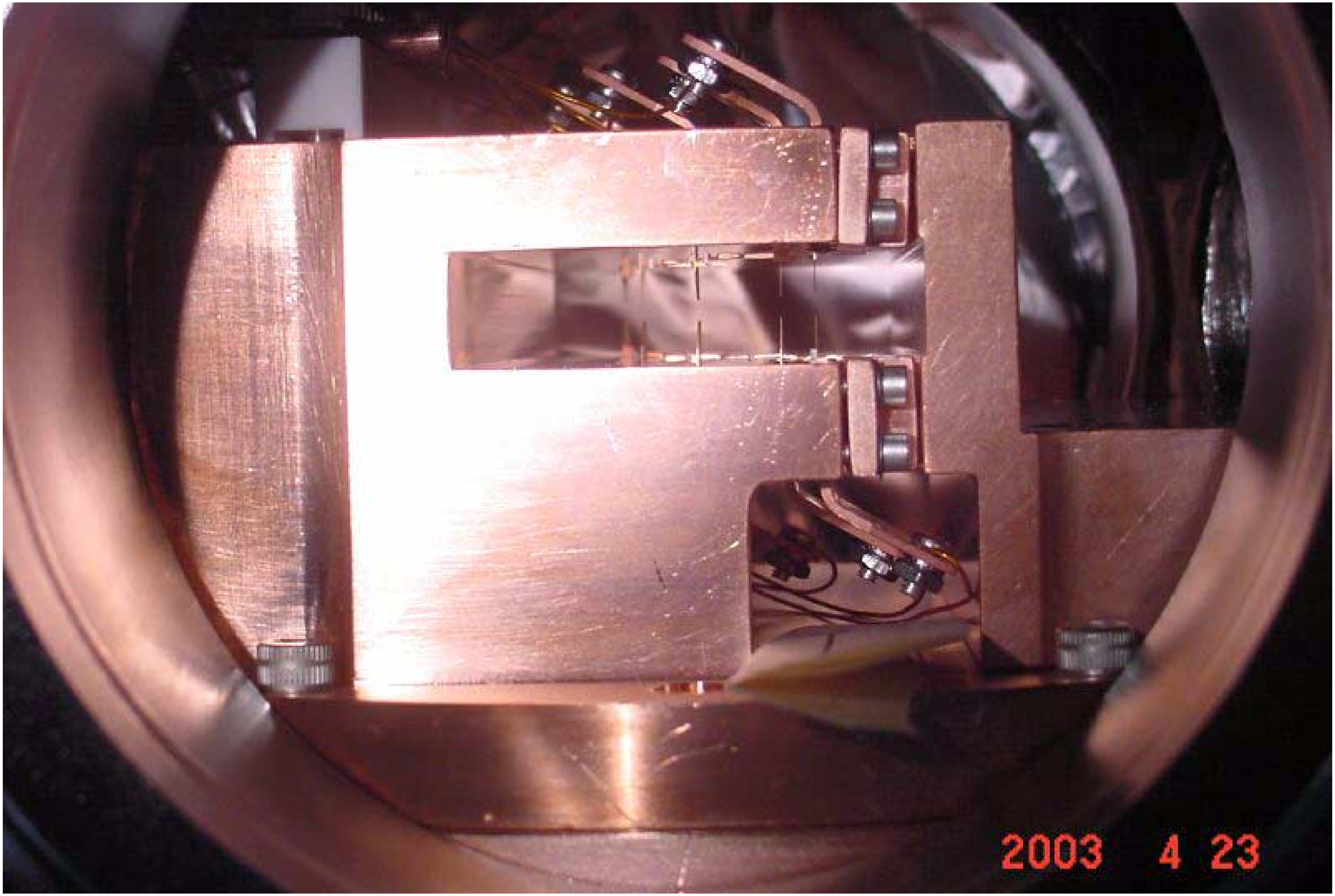
Insertion Device Radiation X-ray BPM




UNDULATOR FE FIRST XBPM
4.5mm
4.65 mm


UNDULATOR FE SECOND XBPM
2.86°
2.0mm
5.0mm
6.5mm

Ten-Blade X-ray BPM, Installed in APS Sector 23-ID



Geometry for BPM Calibration