SPX Workshop

Prelude to Discussion on Error Budgets

July 18, 2011

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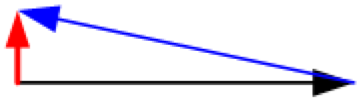
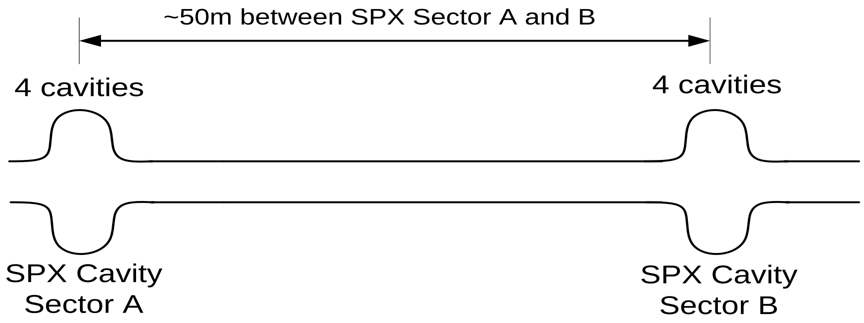
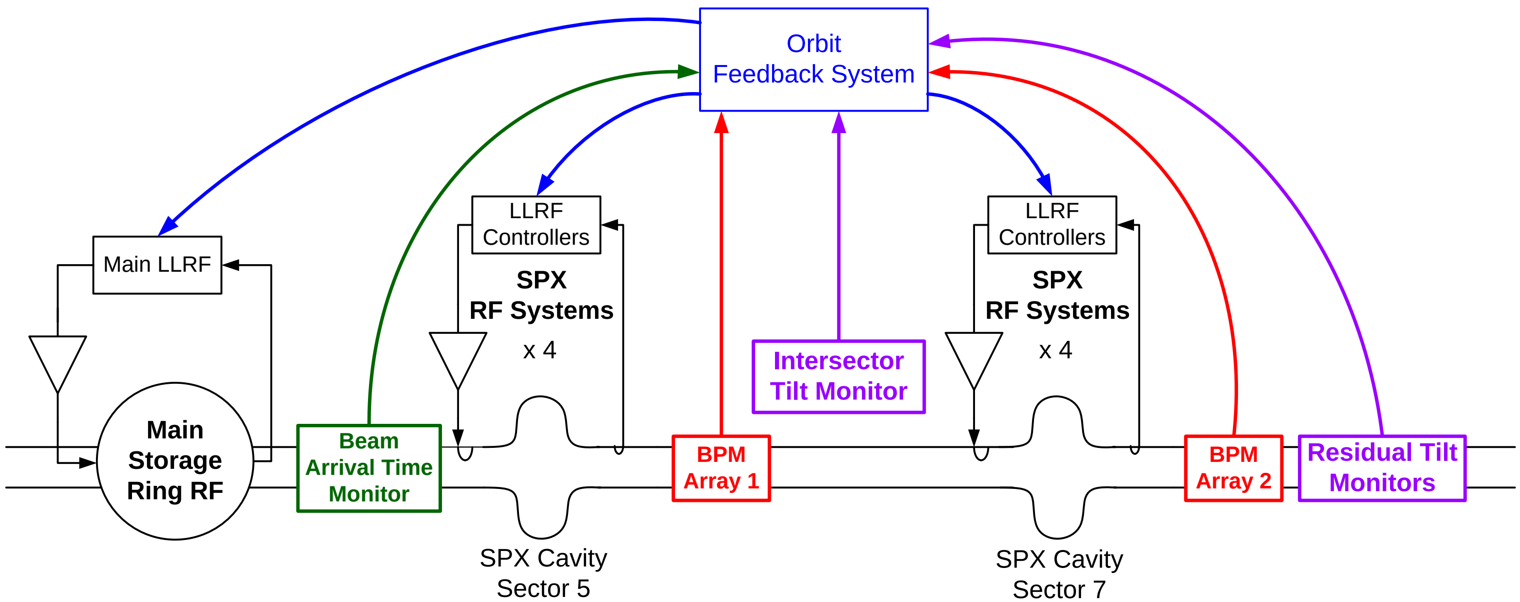
Performance Requirements

	Specification name	Rms Value	Driving requirement
Common Mode	Common-mode voltage variation	$< 1\%$	Keep intensity and pulse length variation under 1% rms
	Common-mode phase variation	$< 4.0^{\circ}$	Keep intensity variation under 1% rms
Differential Mode	Voltage mismatch between sectors	$< 1.1\%$	Keep rms emittance variation under 10% of nominal 40 pm
	Phase error between sectors	$< 0.18^{\circ}$	Keep rms beam motion under 10% of beam size/divergence





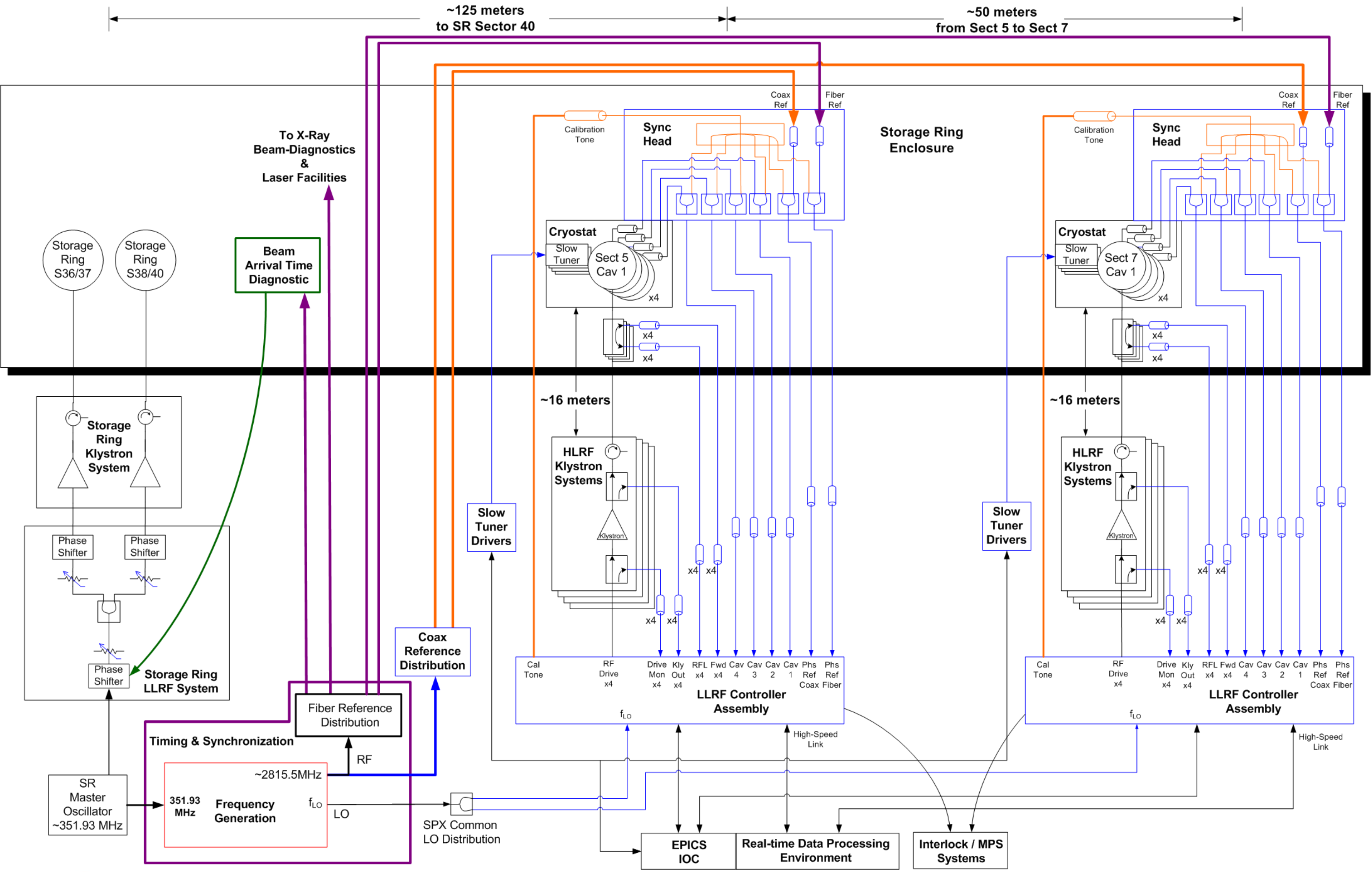


BPM Array 1: sets phase of Sector 5
BPM Array 2: sets phase of Sector 7

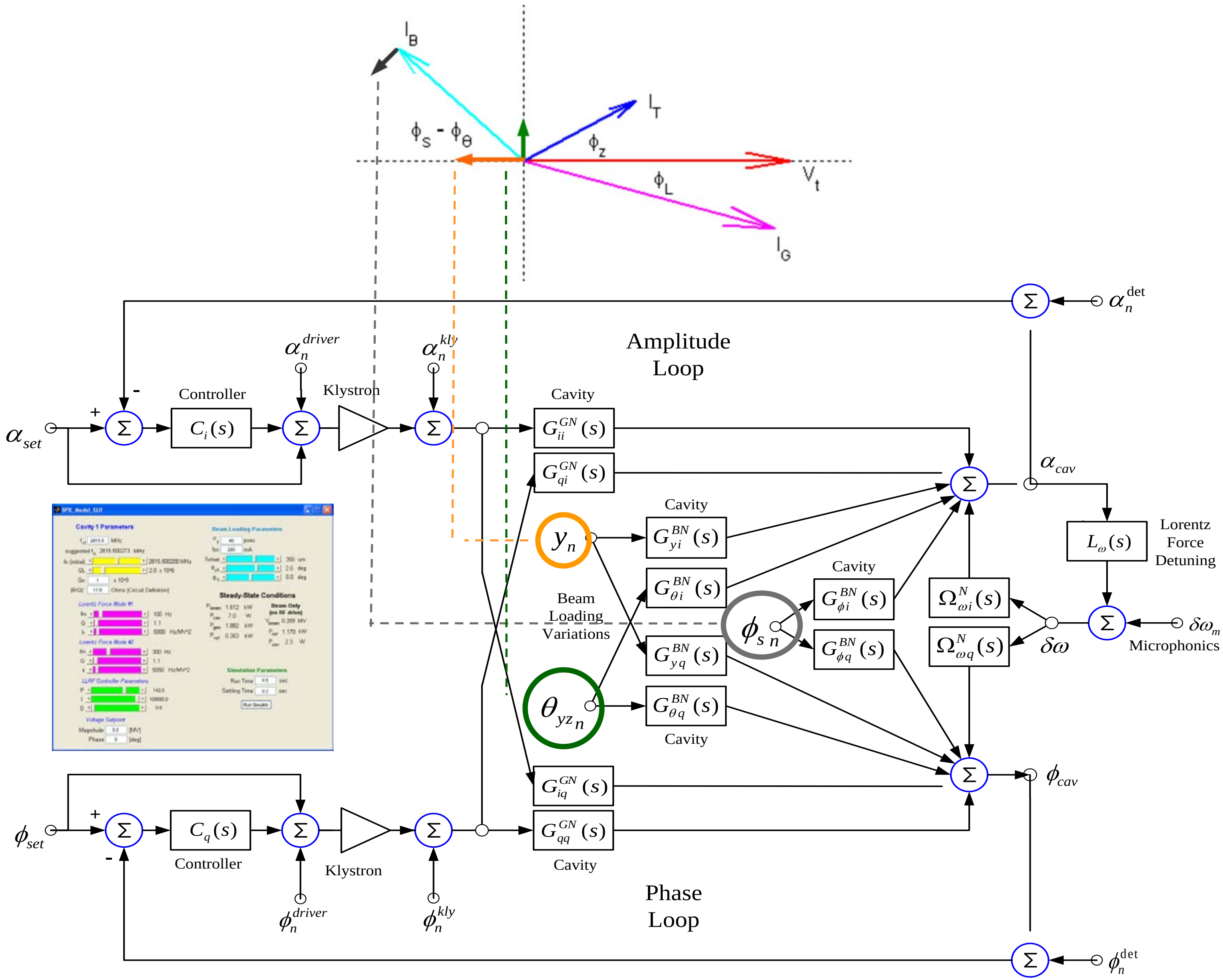
Intersector Tilt Monitor: sets amplitude of Sector 5
Residual Tilt Monitors: sets amplitude of Sector 7

Beam Arrival Time Monitor: sets phase of Main Storage Ring RF

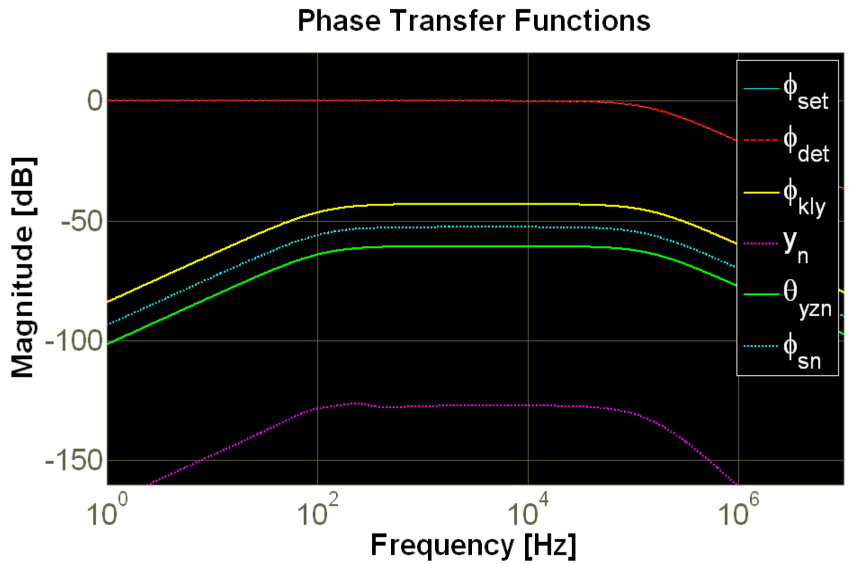
Production System Concept (2 Sectors, 4 cav/sector)

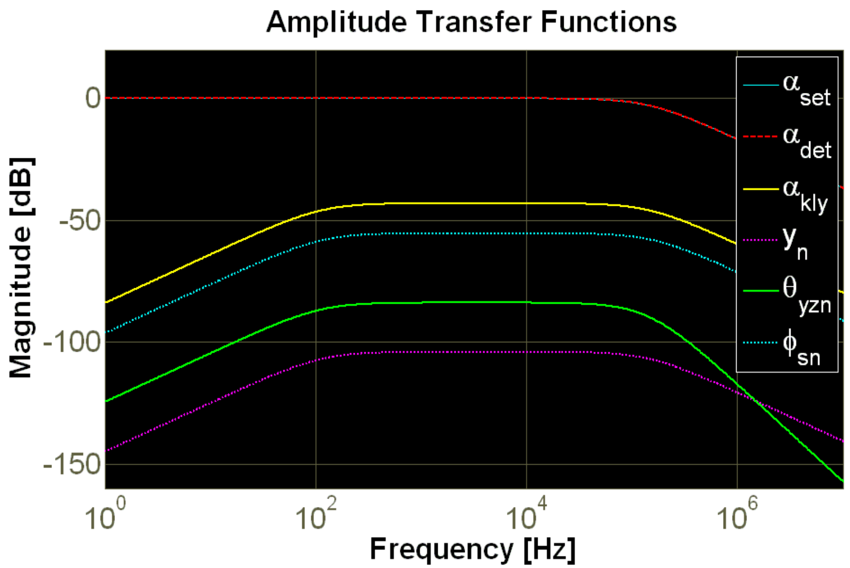


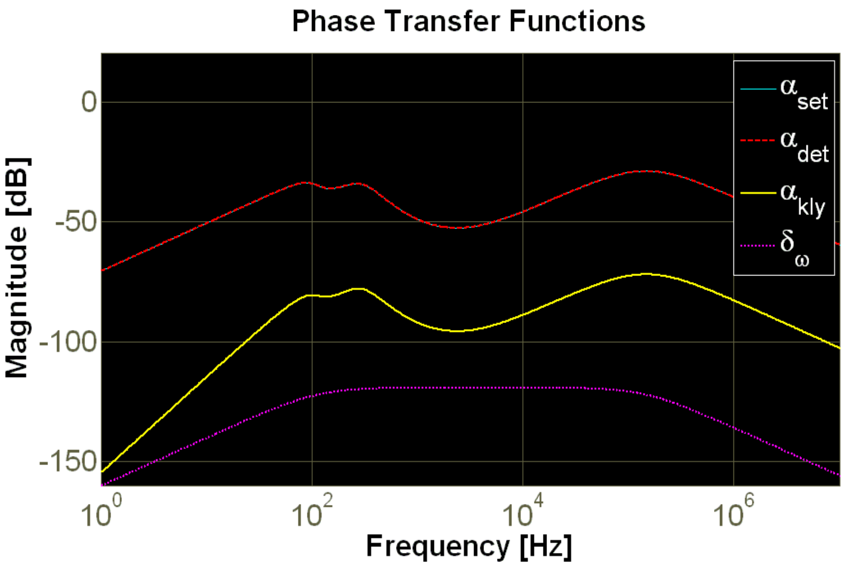
- Dynamic small signal model for individual crab cavity

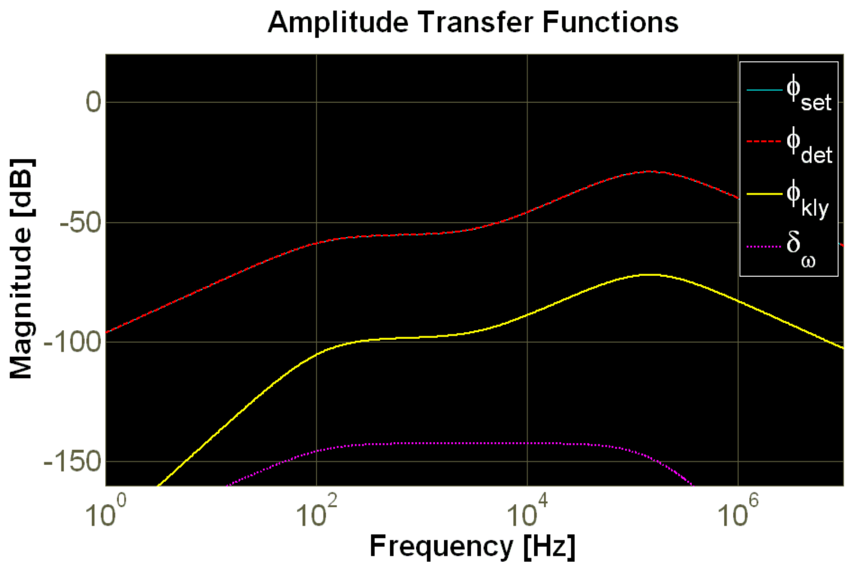


- Example Transfer Functions from single cavity small signal model

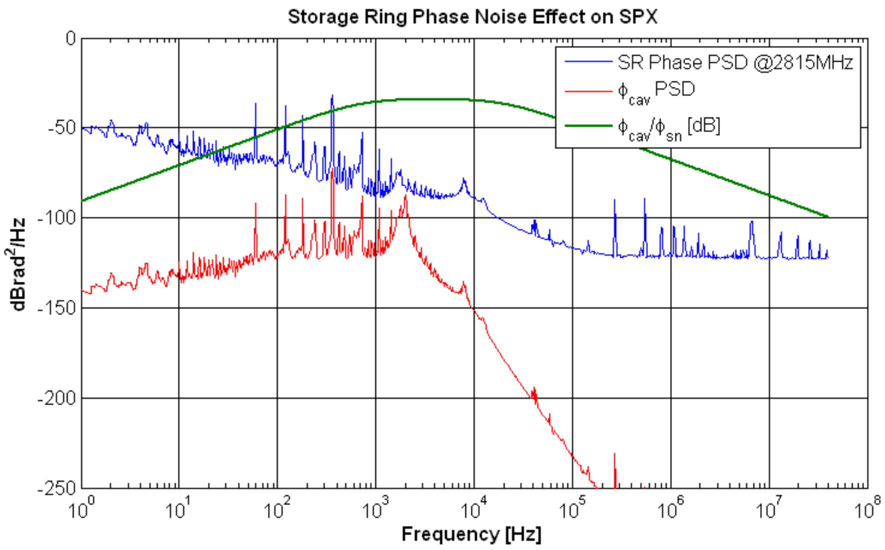








Motivation for Cavity Electrical Alignment Adjust



Beam Loading is proportional to offset

Cavity-to-cavity alignment errors cause **differential beam-loading** that will lead **to differential phase noise**

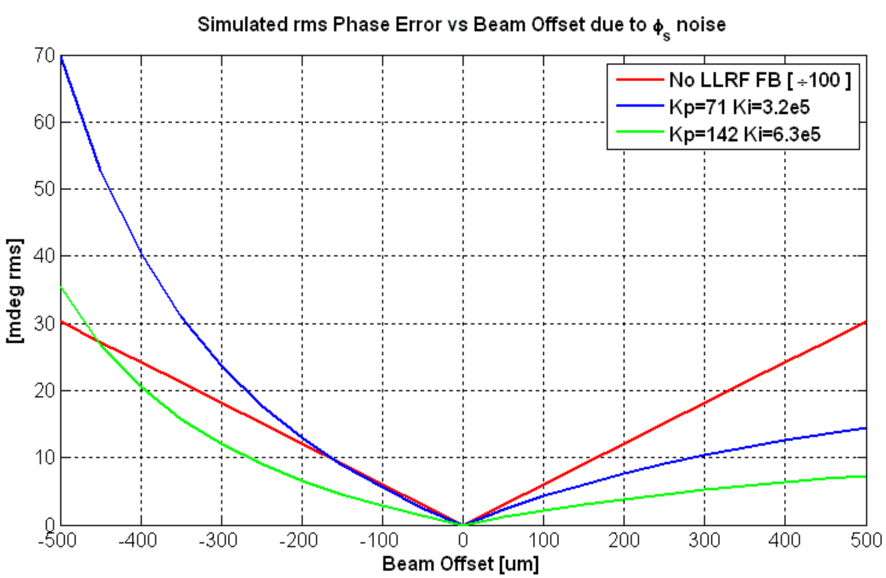
Standard cavity-to-cavity alignment = 500um

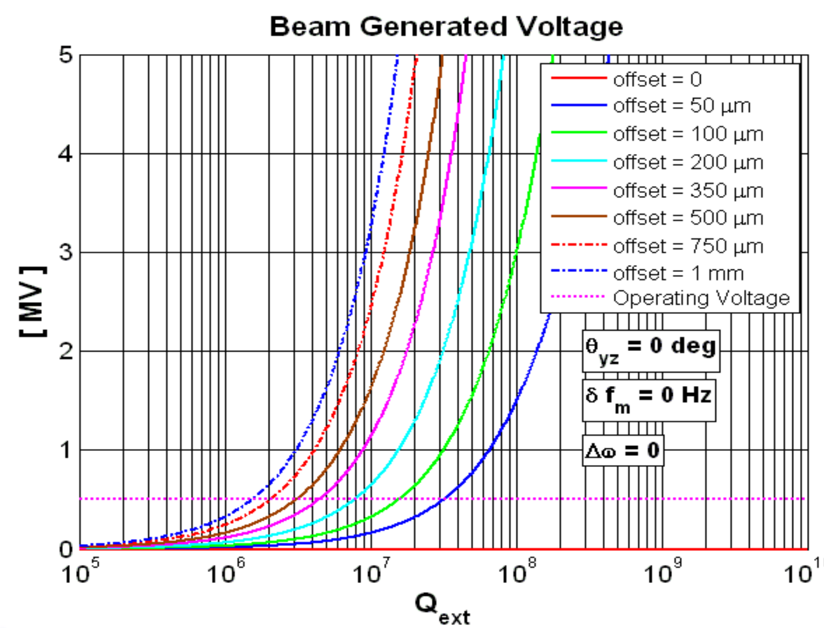
Beyond APS-U, 4MV => 0.07deg spec

Need measurements of beam jitter at 150mA

Means to reduce effect:

improve cavity alignment, go to lower QL, reduce Storage Ring AM & PM noise





Initial Error Budgeting

$$\sigma_{tot} = \sqrt{\sigma_1^{\,2} + \sigma_2^{\,2} + \ldots}$$

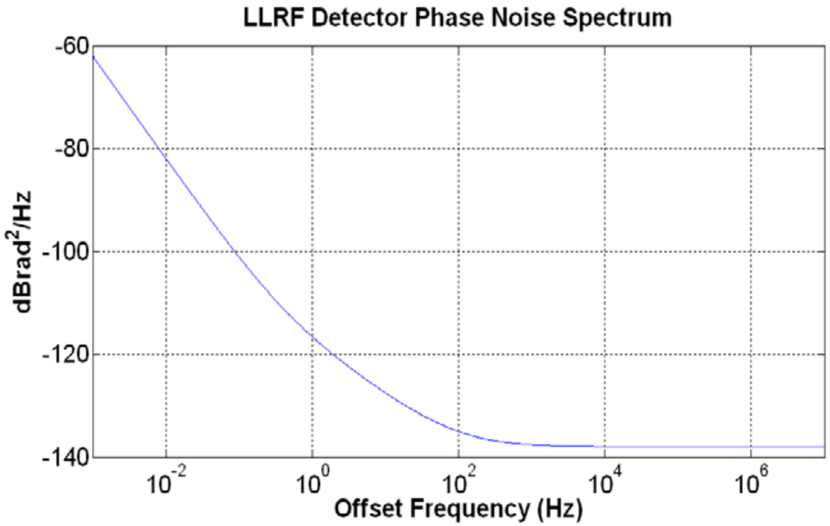
$$\sigma_n^{\,2} = \int_{f_{\min}}^{f_{\max}} S_n(f)\left|H_n(f)\right|^2 df$$

		PHASE				AMPLITUDE			
		Common Mode [deg rms]		Differential [deg rms]		Common Mode [% rms]		Differential [% rms]	
	Total Budget	4		0.18		1		1.1	
		2.31	3.27	0.10	0.15	0.58	0.82	0.64	0.90
	Error/Noise Source [4]	< 10Hz [deg rms]	[10Hz-200kHz] [deg rms]	< 10Hz [deg rms]	[10Hz-200kHz] [deg rms]	< 10Hz [% rms]	[10Hz-200kHz] [% rms]	< 10Hz [% rms]	[10Hz-200kHz] [% rms]
1	SPX Frequency Generation Chassis		0.5097		0.039		0.226		0.249
2	Phase Ref. Distribution		0.5097		0.039	[redacted]	[redacted]	[redacted]	[redacted]
3	LO Distribution		0.5097		0.039		0.226		0.249
4	LLRF Controller		0.5097		0.040		0.226		0.249
5	Cavity Field Probe Cabling		0.5097		0.039		0.226		0.249
6	Klystron + Driver Amp		0.5097		0.040		0.226		0.249
7	Microphonics		0.5097		0.039		0.226		0.249
8	Beam-Loading Offset Noise		0.5097		0.039		0.226		0.249
9	Beam-Loading Tilt Noise		0.5097		0.039		0.226		0.249
10	Storage Ring Beam Jitter		2.7		0.039		0.226		0.249
11	Beam-Loading Synchronous Phase Noise (other than Storage Ring beam jitter ??)		0.5097		0.039		0.226		0.249
12	Beam Arrival Time Feedback Process		0.5097		0.039		0.226		0.249
13	AM-to-PM Cross Modulation		0.5097		0.039	[redacted]	[redacted]	[redacted]	[redacted]
14	PM-to-AM Cross Modulation	[redacted]	[redacted]	[redacted]	[redacted]		0.226		0.249
15	Orbit Feedback Process [outside SPX zone] (differential phase correction)	[redacted]	[redacted]		0.039	[redacted]	[redacted]	[redacted]	[redacted]
16	Orbit Feedback Process [inside SPX zone] (common mode phase correction)		0.5097	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
17	Residual Tilt Feedback [outside SPX zone] long-term differential amplitude correction	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]		0.249
18	Intersector Tilt Feedback Process [inside SPX zone] common mode amplitude set-point	[redacted]	[redacted]	[redacted]	[redacted]		0.226	[redacted]	[redacted]
	# of processes	14		14		13		13	

Example Calculation for a Single Line Item

$$S_{\phi}^{cav}{}_{effective}(f) = S_{\phi}^{LLRF} \cdot \left| N_{RTFB}(s) \cdot \beta_N(s) \right|^2$$

Beam Orbit Transfer Function



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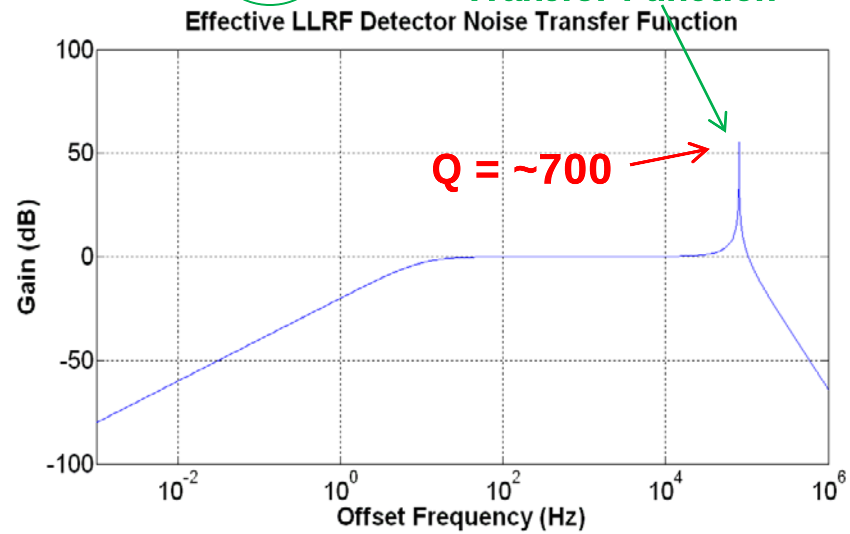

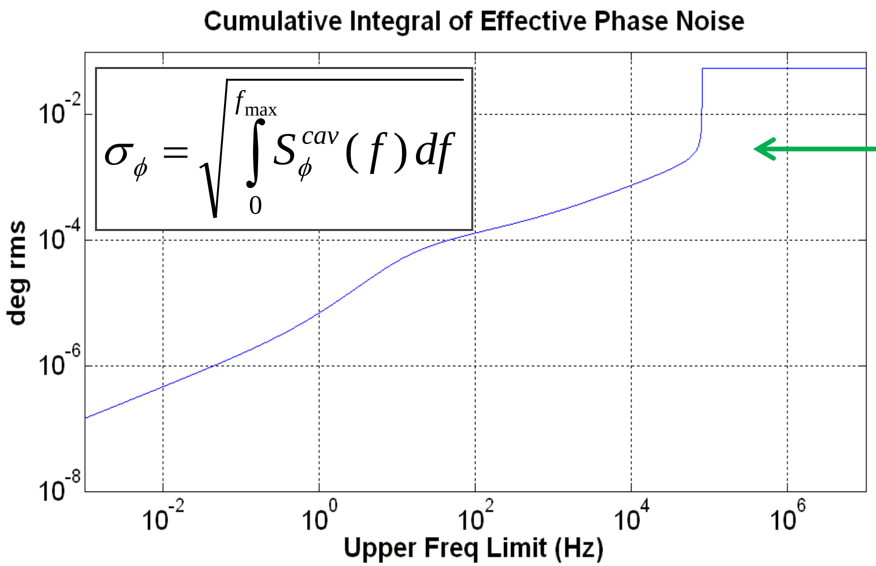

$$\sigma_{\phi} = \sqrt{\int_0^{f_{max}} S_{\phi}^{cav}(f)\,df}$$

0.054 deg RMS w Betatron Tune

0.0034 deg RMS w/o Betatron Tune

Expect lower Q when including existing transverse feedback system

Will study the need for:

- narrow-band beam-based feedback near the betatron resonance

Potential Topics To Discuss...

- Identify additional processes and noise sources
- Ways to a practical allocation of error budgets across frequency bands and systems
- Cavity alignment tolerance
- Interaction with orbit feedback and influence of bunch by bunch feedback on betatron tune Q

Blank Worksheet

		PHASE				AMPLITUDE			
		Common Mode [deg rms]		Differential [deg rms]		Common Mode [% rms]		Differential [% rms]	
	Total Budget	4		0.18		1		1.1	
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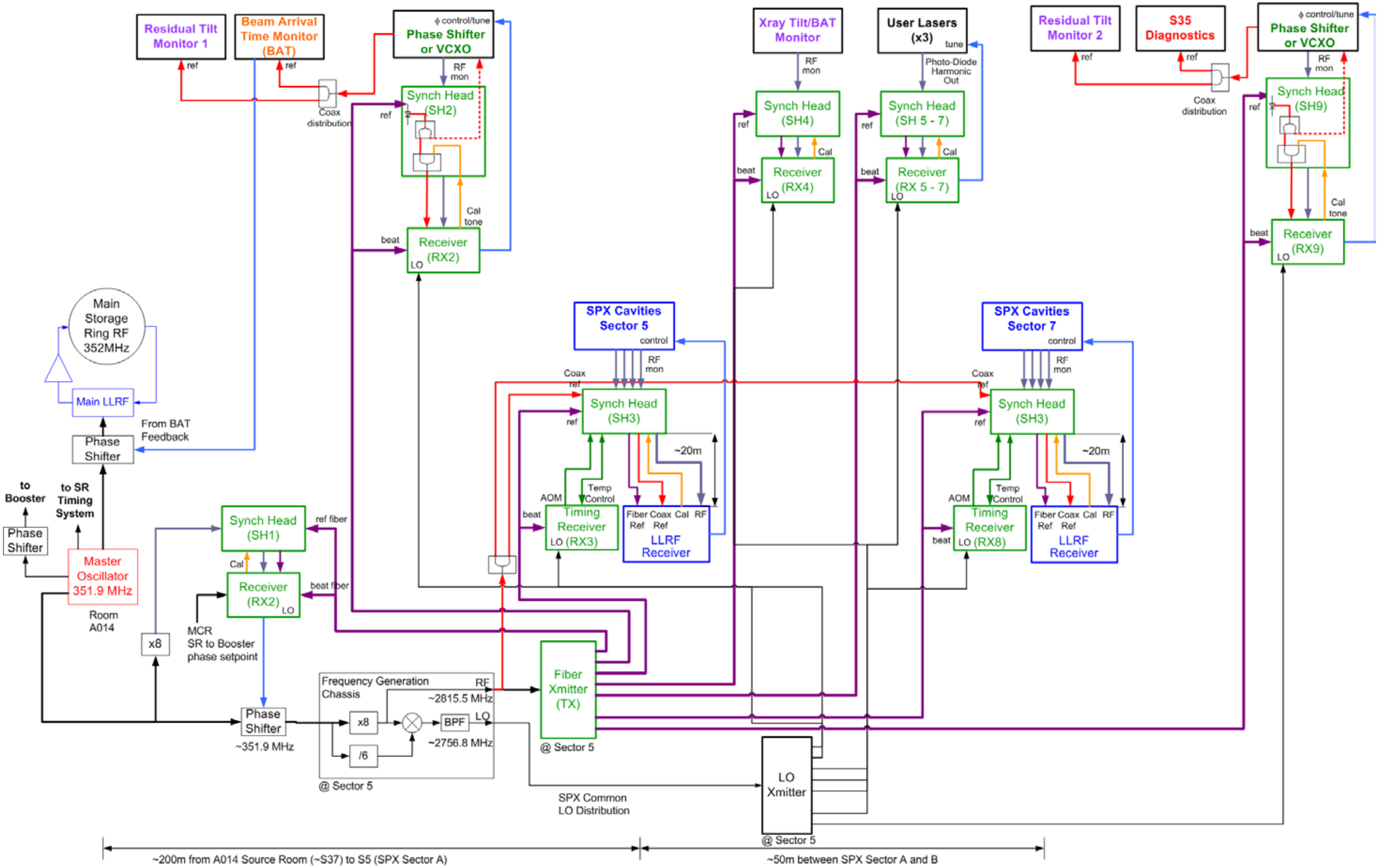
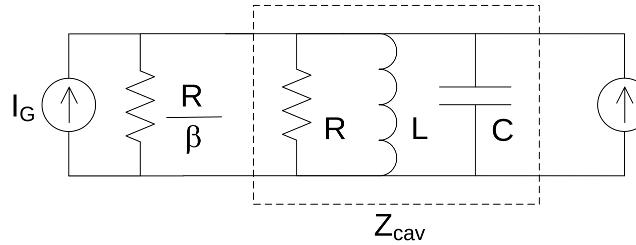
12	Beam Arrival Time Feedback Process								
13	AM-to-PM Cross Modulation					N/A	N/A	N/A	N/A
14	PM-to-AM Cross Modulation	N/A		N/A					
15	Orbit Feedback Process [outside SPX zone] (differential phase correction)	N/A				N/A	N/A		
16	Orbit Feedback Process [inside SPX zone] (common mode phase correction)					N/A	N/A		
17	Residual Tilt Feedback [outside SPX zone] long-term differential amplitude correction	N/A		N/A		N/A			
18	Intersector Tilt Feedback Process [inside SPX zone] common mode amplitude set-point	N/A		N/A					
	# of processes	14		14		13		13	

Backup Slides



Residual Tilt Monitor 1
Beam Arrival Time Monitor (BAT)
Phase Shifter or VCXO
ϕ control/tune
RF mon
Synch Head (SH2)
Coax distribution
ref
Cal tone
beat
Receiver (RX2)
LO
Xray Tilt/BAT Monitor
User Lasers (x3)
tune
Photo-Diode Harmonic Out
Synch Head (SH4)
Synch Head (SH 5 - 7)
Cal
Receiver (RX4)
Receiver (RX 5 - 7)
Residual Tilt Monitor 2
S35 Diagnostics
Synch Head (SH9)
Receiver (RX9)
Main Storage Ring RF 352MHz
Main LLRF
Phase Shifter
From BAT Feedback
to Booster
to SR Timing System
Master Oscillator 351.9 MHz
Room A014
x8
Synch Head (SH1)
ref fiber
Receiver (RX2)
beat fiber
MCR SR to Booster phase setpoint
SPX Cavities Sector 5
control
Coax ref
Synch Head (SH3)
~20m
AOM
Temp Control
Timing Receiver (RX3)
Fiber Ref
Coax Ref
LLRF Receiver
SPX Cavities Sector 7
Timing Receiver (RX8)
Frequency Generation Chassis
~2815.5 MHz
x8
/6
BPF
~2756.8 MHz
@ Sector 5
~351.9 MHz
Fiber Xmitter (TX)
LO Xmitter
SPX Common LO Distribution
~200m from A014 Source Room (~S37) to S5 (SPX Sector A)
~50m between SPX Sector A and B

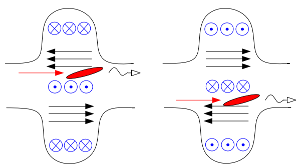
Deflecting Cavity Beam Loading



$$i_o \kappa_o \left(y + j \cdot \theta\, \omega_o c\, \sigma_t^{\,2} \right) \cdot e^{-j(\pi+\phi_s)}$$

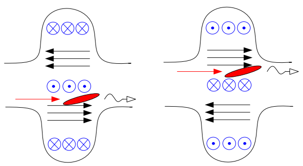
$$i_o = 2 I_{dc} \cdot e^{-\frac{1}{2}(2\pi f_o \sigma_t)^2}$$

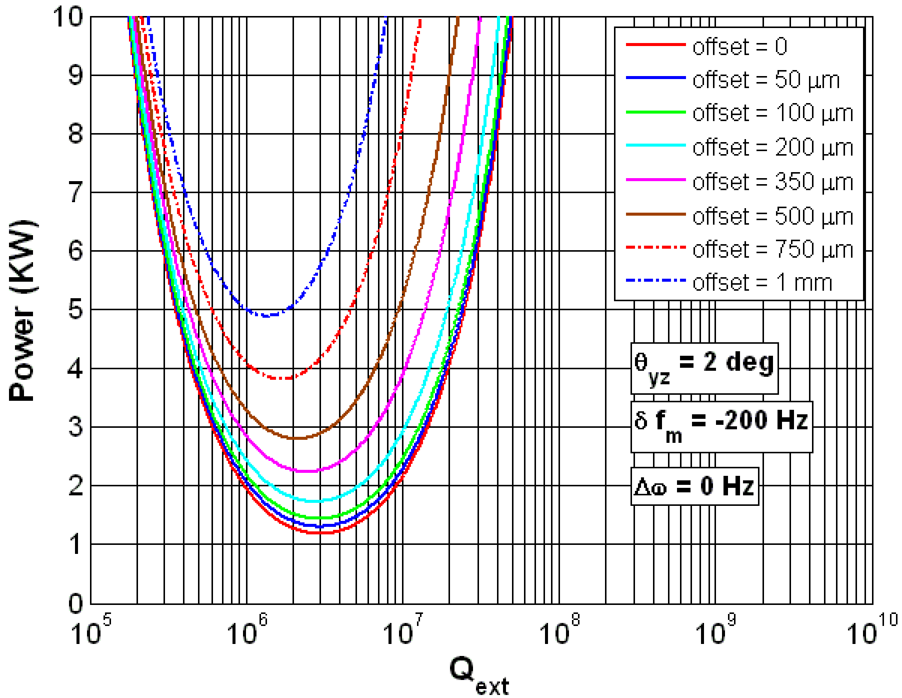
$$P_g^{\,+} = \frac{V_t^{\,2}}{8\beta\,(R/Q)'\,Q_o} \cdot \left[\left(\beta + 1 + \frac{P_B}{P_{cav}} \right)^2 + \left(2Q_o \frac{(\cancel{\Delta f} + \delta f_m)}{f_r} + \frac{P_B}{P_{cav}} \tan\phi_s \right)^2 \right]$$

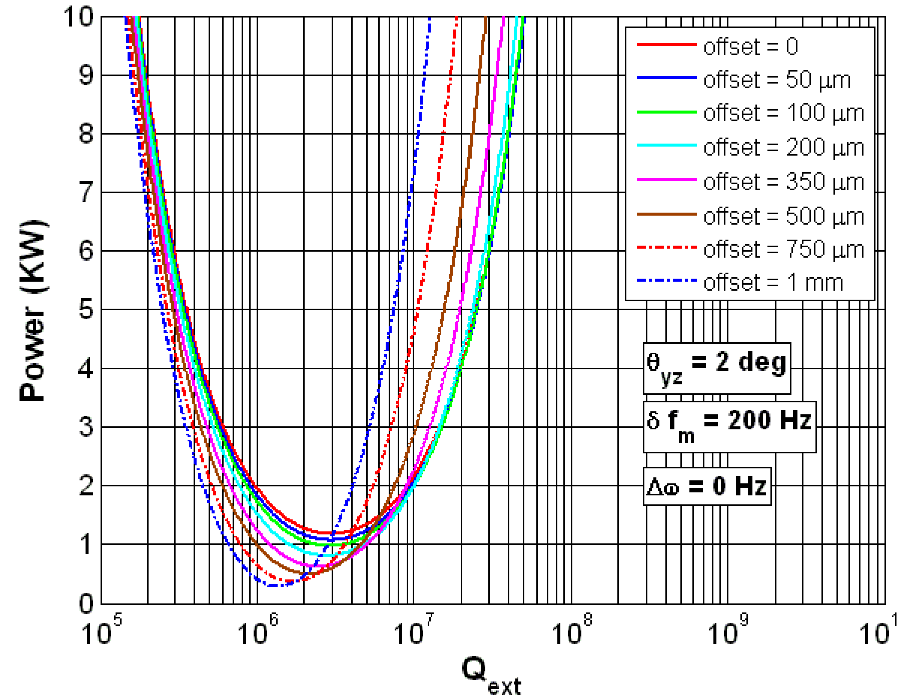


$$V_t \cdot y > 0$$

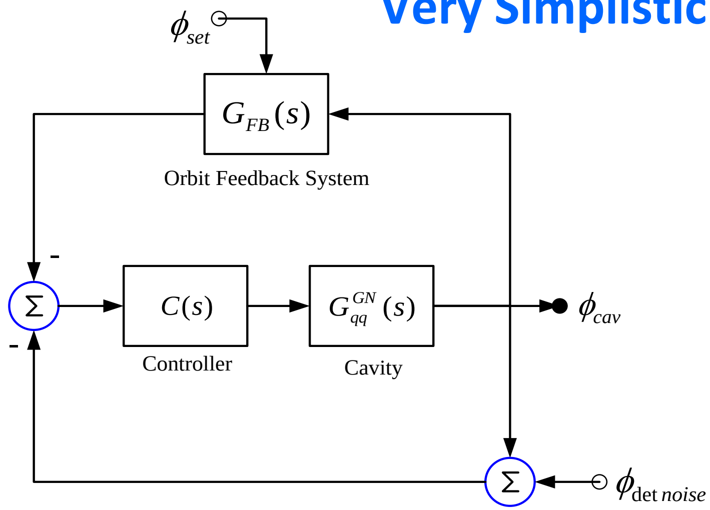
$$V_t \cdot y < 0$$







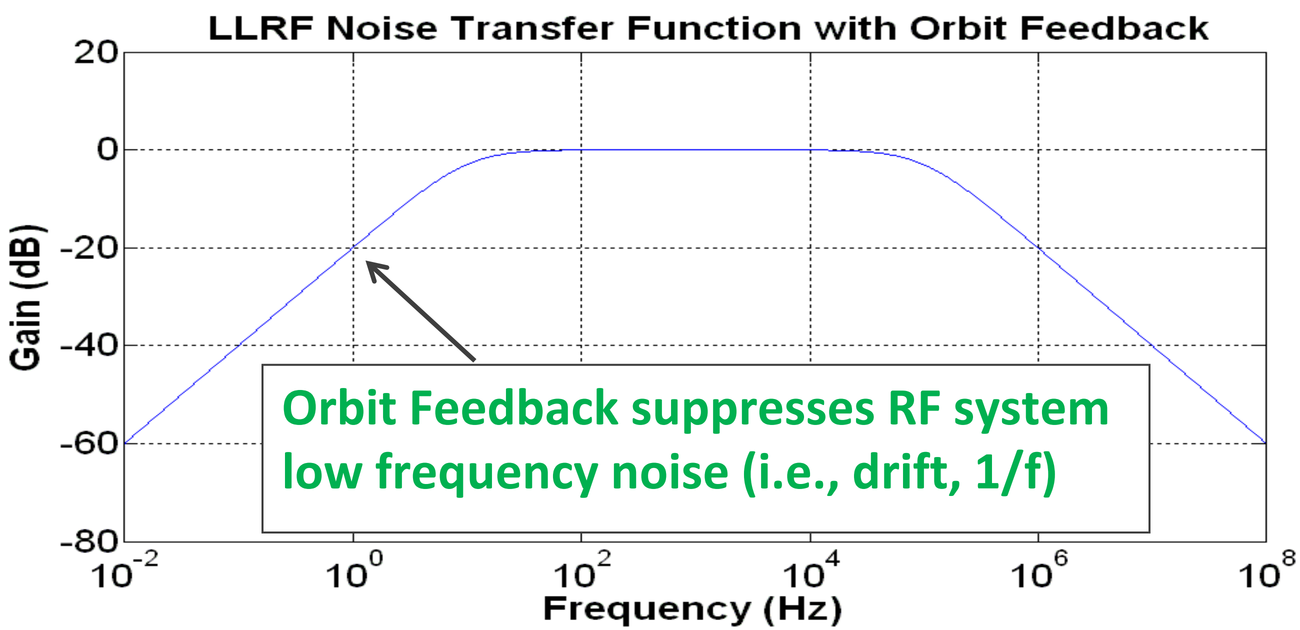
Very Simplistic First Order Orbit Feedback concept



Assume: $$G_{FB}(s) = \frac{K_p^{RTFB}\sigma_{RTFB}}{s}$$

$$N_{FB}(s) = \frac{\phi_{cav}(s)}{\phi_{\det noise}(s)} = \frac{C(s)G_{qq}^{GN}(s)}{1 + C(s)G_{qq}^{GN}(s)\left[1 + G_{FB}(s)\right]}$$

$$= \frac{K_p\sigma_{cav}\, s}{s^2 + K_p\sigma_{cav}\, s + K_p^{RTFB}K_p\sigma_{RTFB}\sigma_{cav}}$$



How to achieve 0.18° rms Differential Phase ??

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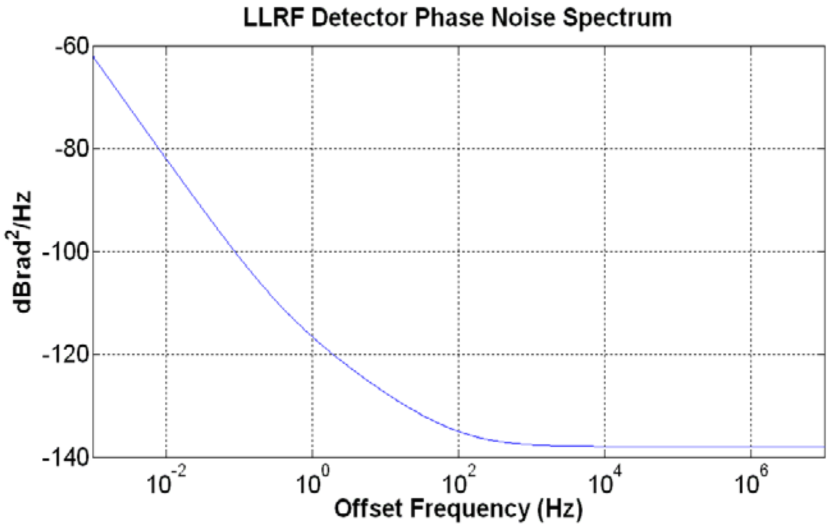
Beam Orbit Transfer Function



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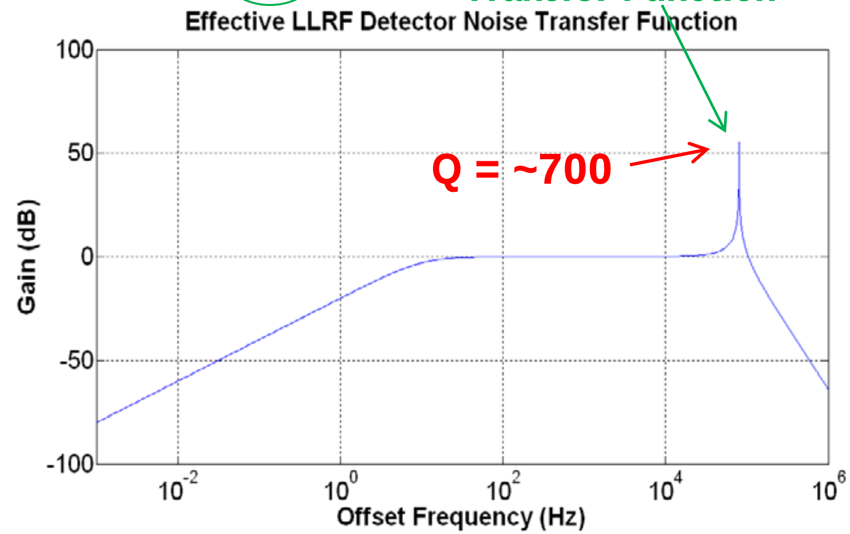

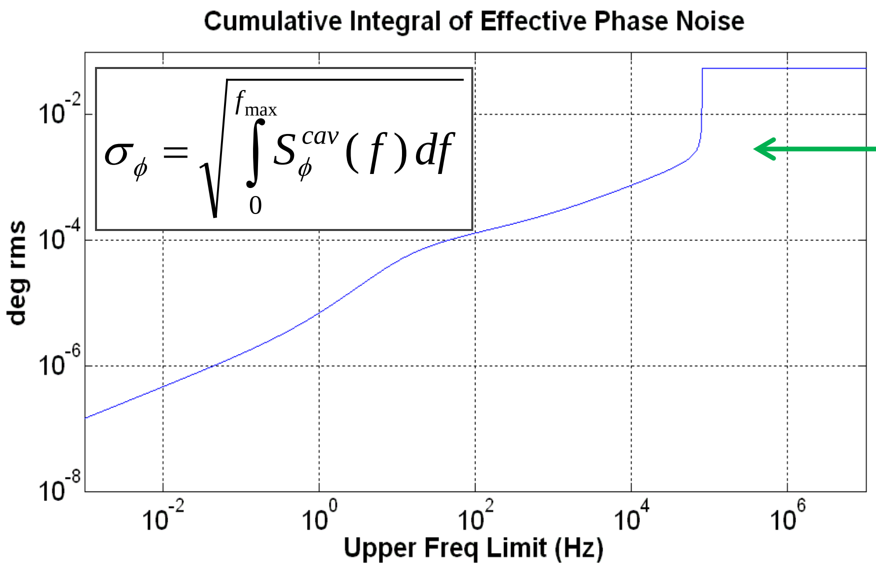

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