RF System Overview

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KEK

KEKB Machine Advisory Committee
Feb. 11, 2000

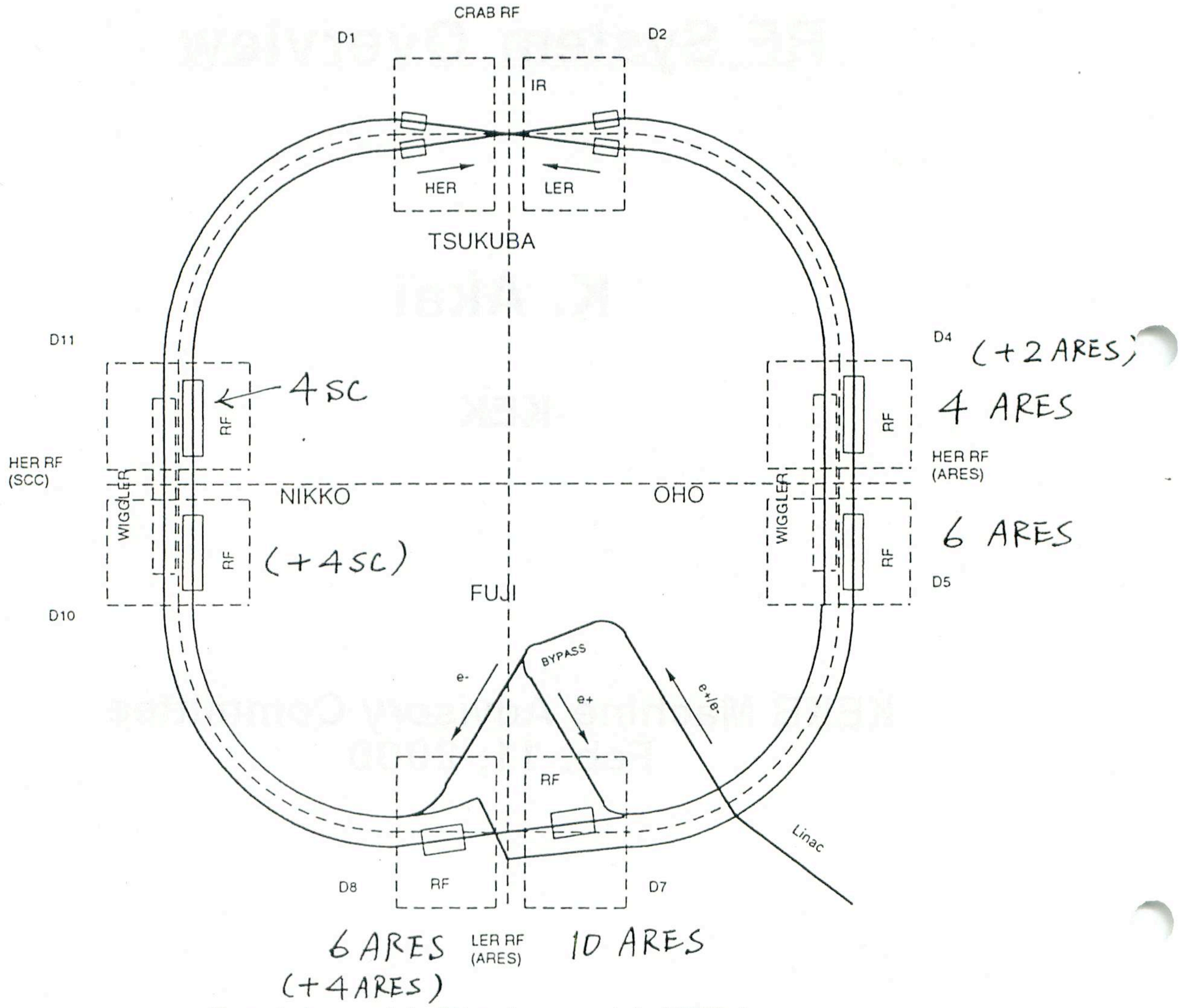
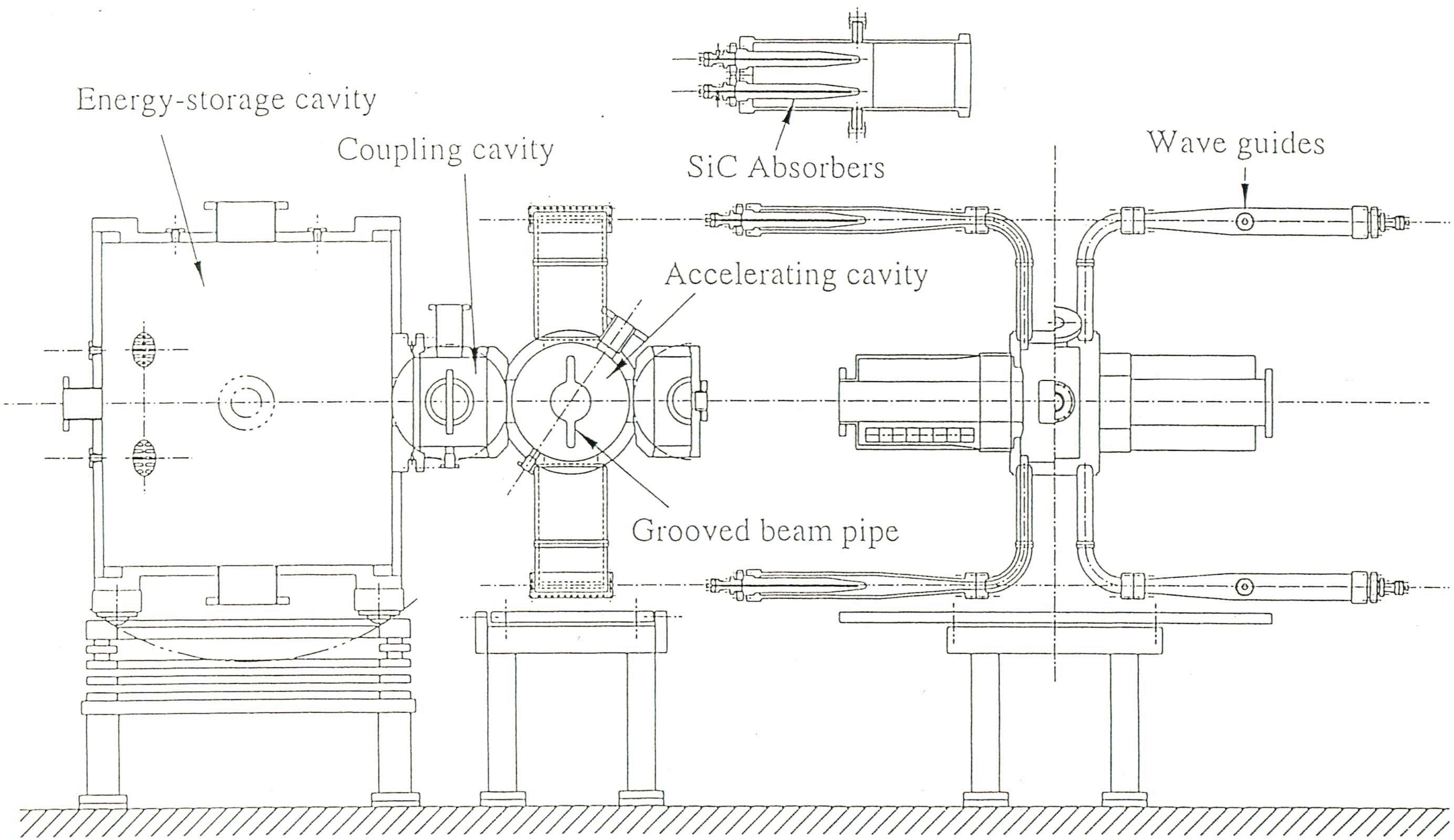
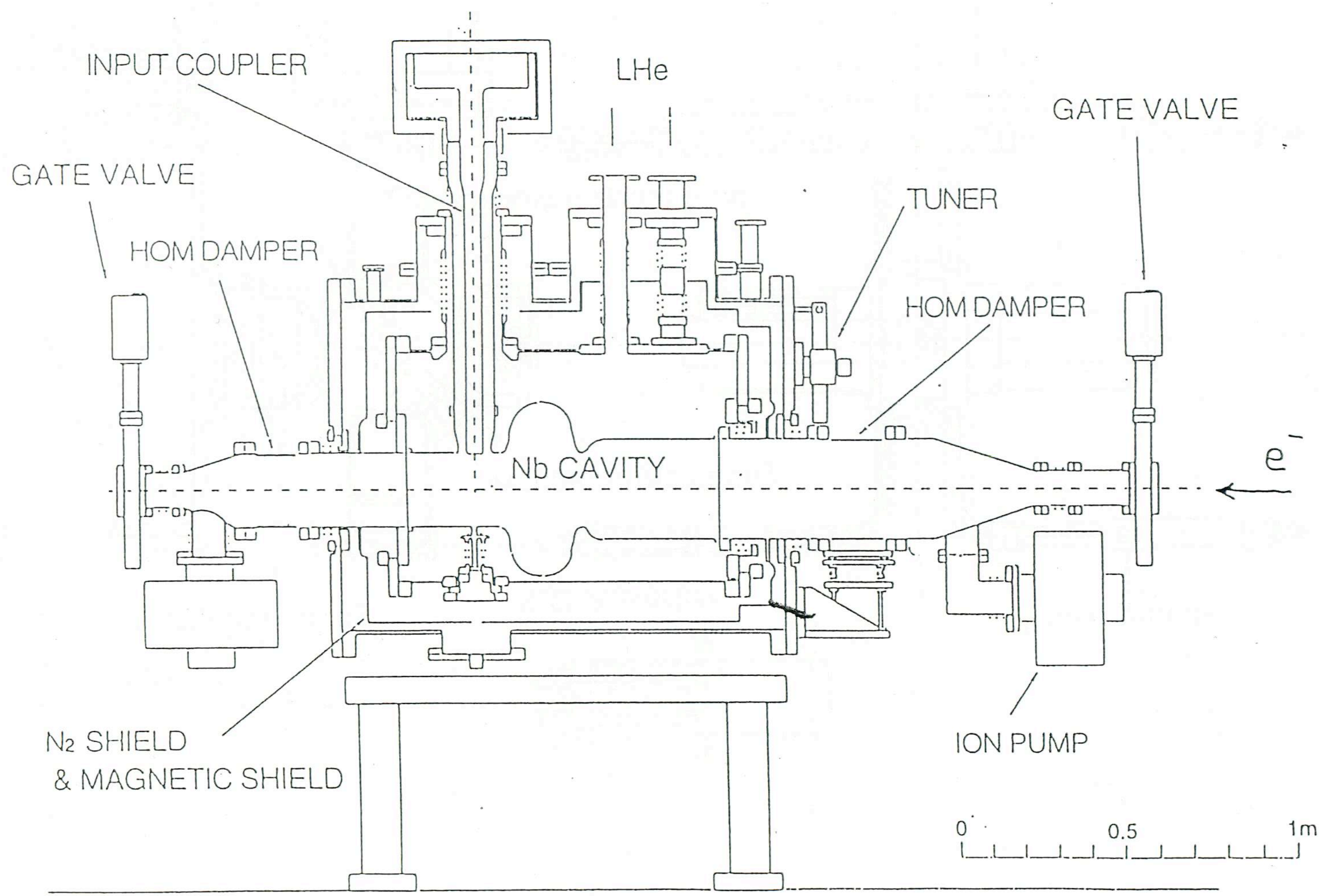


Figure 1: Layout of the RF stations around the KEKB ring.



ARES cavity for KEKB



Superconducting Cavity for KEKB

RF-related Machine Parameters

	LER	HER	
Beam energy	3.5	8.0	GeV
Beam current	2.6	1.1	A
Bunch length	4	4	mm
Synchrotron tune	0.01 - 0.02	0.01 - 0.02	
RF voltage	4.9 - 9.4	8.7 - 16.2	MV
RF frequency	508.887		MHz
Energy damping time	43 / 23*	23	ms
Radiation power	2.1 / 4.0*	3.8	MW
HOM loss	0.57	0.14	MW
Total beam power	2.7 / 4.5*	4.0	MW

*with wigglers for LER

Example of RF Parameters

Ring		LER w/wiggler	HER hybrid
Cavity		ARES	SCC+ARES
Relative phase	deg.	-	10
RF voltage	MV	10	17.9
Number of cavities		20	8 + 12
R/Q	Ω	14.8	93 / 14.8
Q_0		1.1×10^5	$>1 \times 10^9$ / 1.1×10^5
Q_L ($\times 10^4$)		3.0	8.0 / 3.0
Input coupling		2.7	- / 2.7
Cavity voltage	MV/cav.	0.5	1.5 / 0.5
Input power	kW/cav.	375	250 / 340
Wall loss	kW/cav.	154	- / 154
Beam power	kW/cav.	221	250 / 250
Number of klystrons		10	8 / 6
Klystron power	kW	~810	~270 / ~740

Number of Accelerating Cavities

revised, Jan. 2000

Ring	Dec.'98 ~Jul.'99	Oct.'99 ~Jan.'00	Feb.'00 ~Jul.'00	Oct.'00 ~ plan 1	Oct.'00 ~ plan 2 (full spec)
LER					
Fuji (ARES)	12	16[1]	16	16	20
Operating Vc	4 MV	5 MV	5~6 MV	6~7 MV	8~9 MV
HER					
Oho (ARES)	6	10	10	10	12
Nikko (SCC)	4	4	4	8	8
Operating Vc	8MV	9 MV	11 MV	~ 16 MV	~ 18 MV

(1) Two cavities were not operated in 1999.

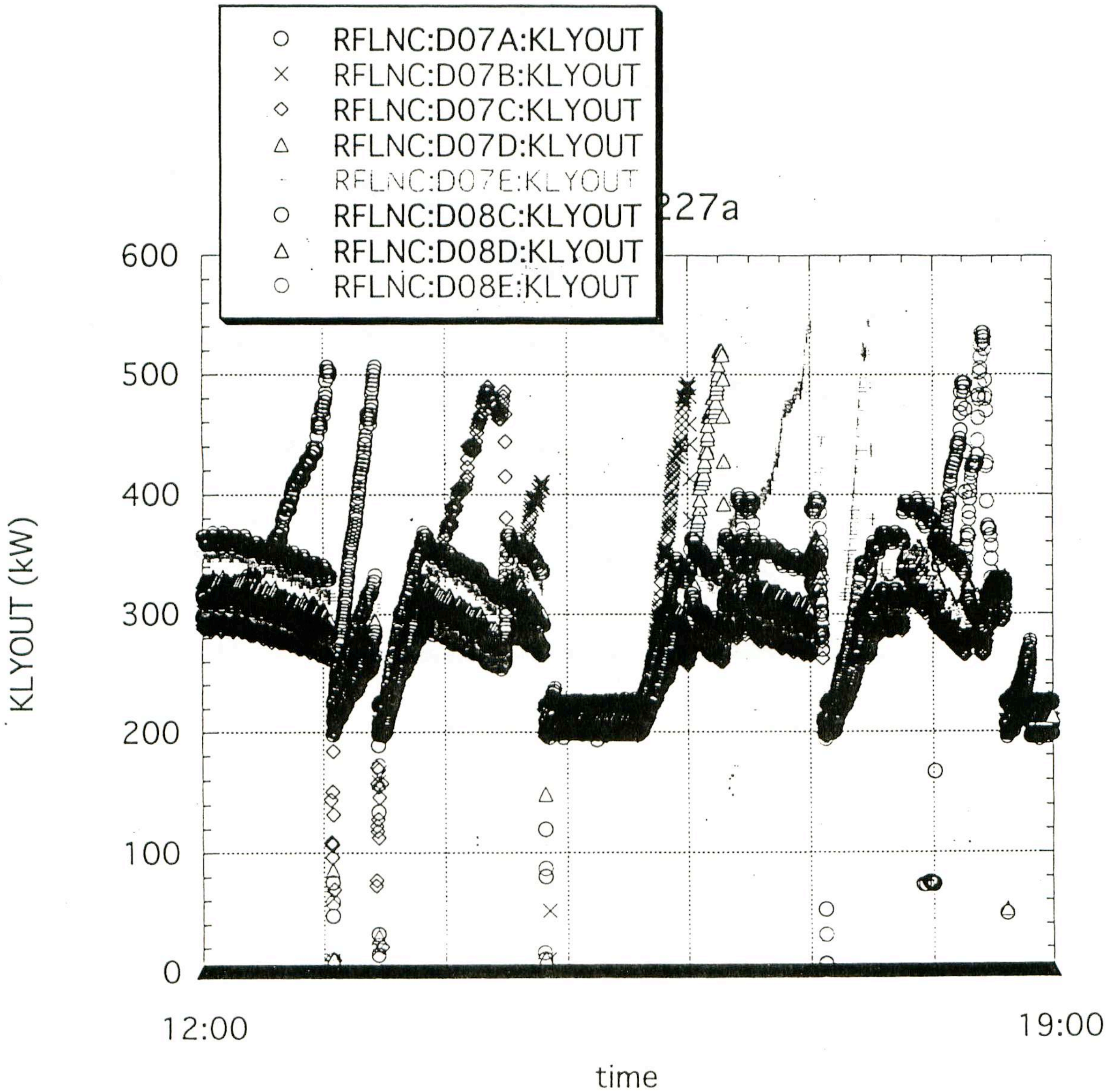
Design value of Vc/cavity is 0.5MV/ARES and 1.5MV/SCC.

Operating status

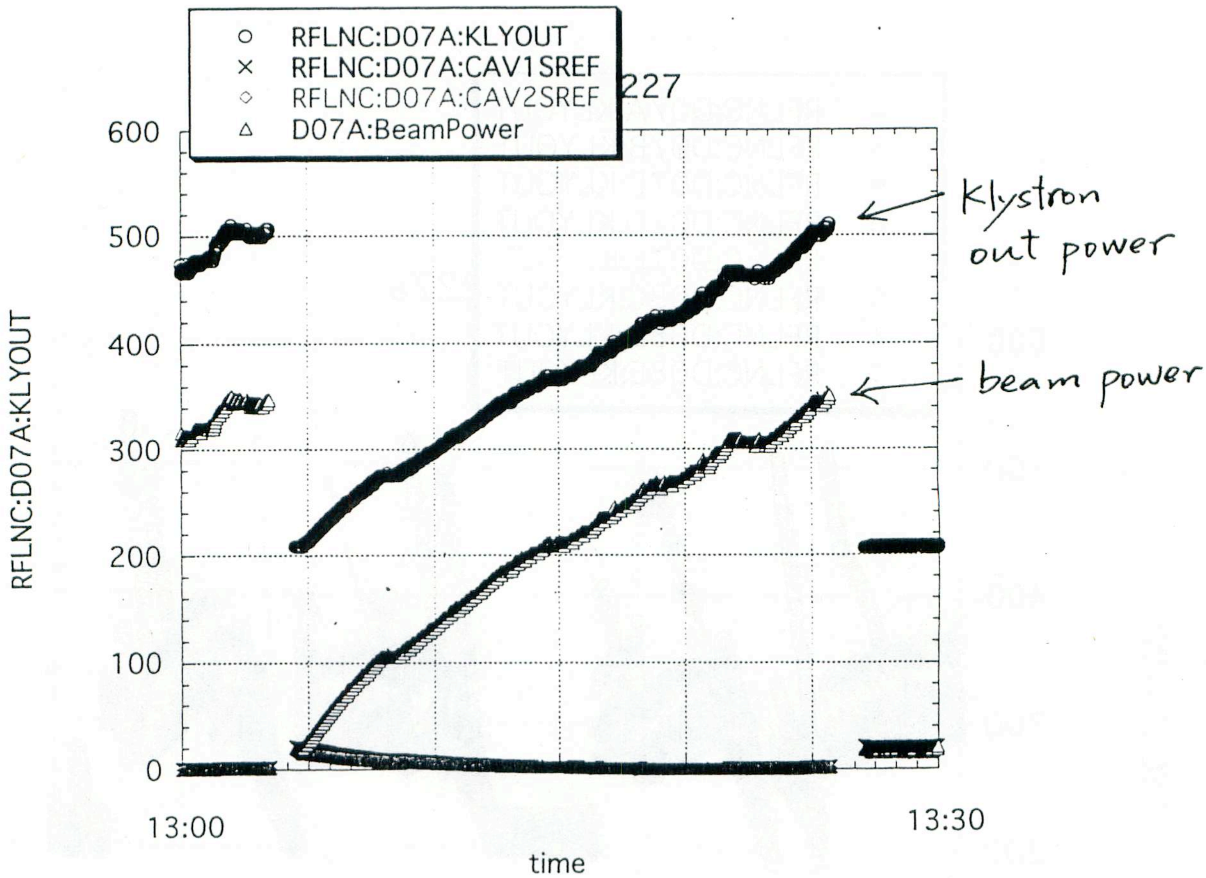
(～Feb. 2000)

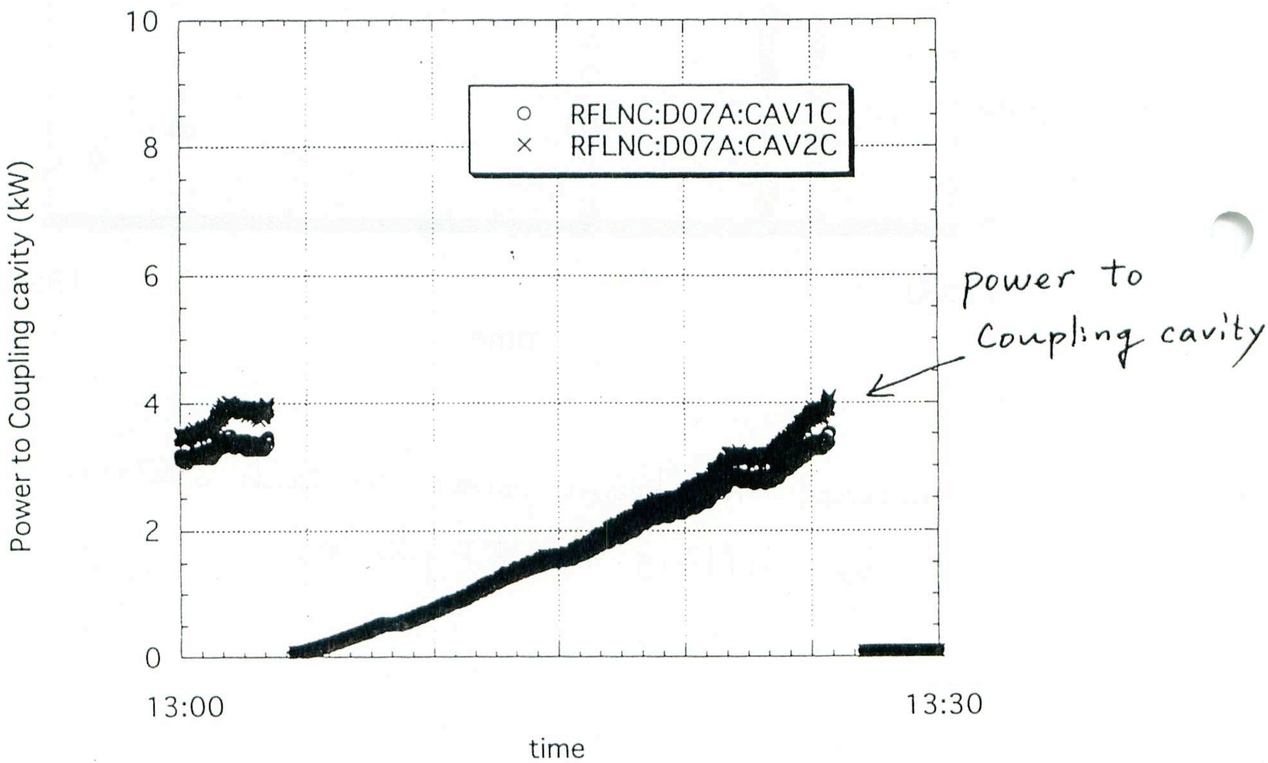
	LER	HER
Beam current (mA)	600 (2600)	514 (1100)
Operating Vc (MV) NC/SC	5 (5-10)	11 (10-16) 4.2 / 6.8
No. of cavities	16 (20)	NC: 10 (12) SC: 4 (8)
Operating Vc / cavity (MV)	0.31 (0.5)	NC: 0.42 (0.5) SC: 1.7 (1.5)
Conditioned up to (MV)	0.4 (0.5)	NC: 0.45 (0.5) SC: >2.2 (1.5)
Total Beam power (MW) NC/SC	1.0 (4.5)	2.1 (4.0) 0.7 / 1.4
Beam power / cavity (kW)	64 (225)	NC: 130 (170) SC: 380 (250)
Beam power / cavity (kW) (by shifting RF phase)	170 (225)	
HOM power / cavity (kW)	>0.5	SC: 2.6 (5.0)

Numbers in ( ) is design values.



Increase the beam power in each station by shifting the RF phase.


RFLNC:D07A:KLYOUT
RFLNC:D07A:CAV1SREF
RFLNC:D07A:CAV2SREF
D07A:BeamPower
227
600
500
400
300
200
100
0
RFLNC:D07A:KLYOUT
13:00
13:30
time
Klystron out power
beam power


10
8
6
4
2
0
Power to Coupling cavity (kW)
RFLNC:D07A:CAV1C
RFLNC:D07A:CAV2C
13:00
13:30
time
power to Coupling cavity

Operation for Physics Run

- 1999 Jul.～Aug. (12 days, 25 pb-1)
- 1999 Oct.～2000 Jan. (34 days, 450 pb-1)

Here, the physics run from Oct.1999 to Jan.2000 is summarized.

■ Typical parameters

	LER	HER
(Oct.-Dec. 1999)		
Beam current	400mA	250mA
No. of bunches	～870	～870
Total RF voltage	5MV	9MV
(Jan. 2000)		
Beam current	550mA	350mA
No. of bunches	～1000	～1000
Total RF voltage	5MV	9MV

■ Loss time due to RF troubles

• SCC quench (3 times)	1.5 hours
• ARES water flow interlock (twice)	3.5 hours
• 1MW dummy load trouble	2.0 hours
• Klystron PS crawbar work (twice)	1.0 hours
• Control modules troubles	2.0 hours

Total loss time due to RF is only 10 hours in 34 days physics run operation.

■ Other faults (No beam loss is caused.)

• Coupler arc and/or vacuum interlock in ARES.

→ Several-hour conditioning during machine maintenance reduces the fault rate in steady operation below 0.1 /cavity/day.

• When a high current beam is aborted, some RF stations trip:

(i) nearby arc sensors work due to noise.

→ Noise protection was effective to some extent.

→ Inhibit gate during the beam abort solved the problem.

(ii) One SC station (D11-D) trips by breakdown detector due to transient response to beam abort.

→ Trying to solve by changing transient response of the system.

■ No beam loss even when RF trips

• Even one or two ARES stations trips, no beam is lost in most cases.

This is because:

(i) Sufficiently high voltage is provided by other stations.

(ii) Resonant frequency of tripped cavities is controlled at a safe frequency so that it causes neither instability nor large beam-induced power.

(iii) Our RF control system allows the tripped stations, after the cause is solved, to smoothly switch-on without losing the high current beam.

■ Keeping the longitudinal collision point

- Error in the relative RF phase between the two rings shifts the collision point.

- RF phase of whole ring is stabilized within 1 degree.

- The change of synchronous phase due to the change of bunch current or bunch gap transient is estimated to be about 2~3 degree for the design current.

- Shift of synchronous phase due to a change of RF voltage can be compensated by changing the ring phase.

- **Belle detector data shows no big shift of longitudinal collision point throughout the physics run.**

■ Zero-mode oscillation damper

- Longitudinal beam oscillation can reduce the luminosity.

- **Before summer 1999, we observed the 0-mode synchrotron oscillation of about ±0.5 degree (±0.8mm) even at a small current.**

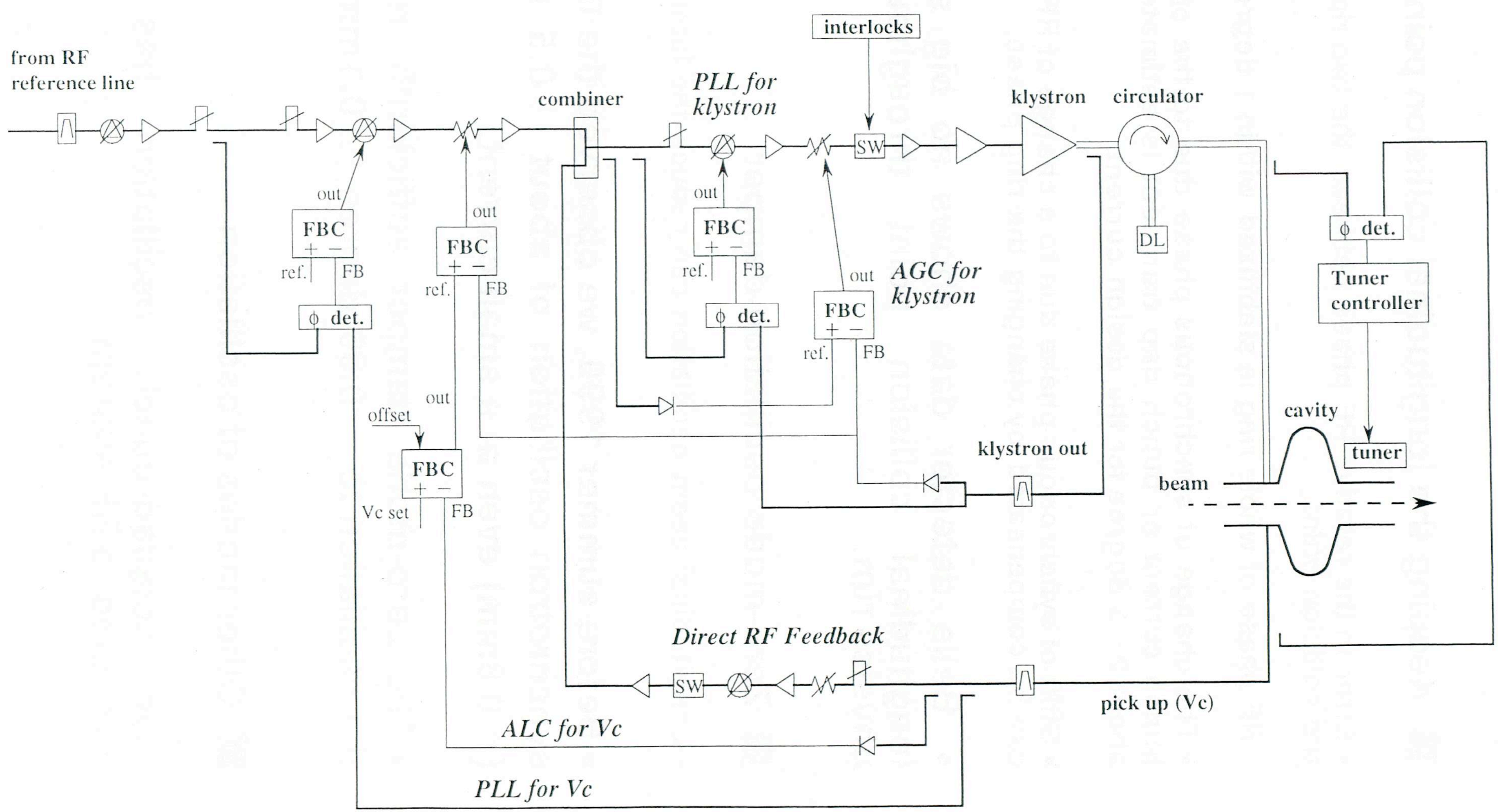
- The zero-mode damper sufficiently reduced the oscillation to ±0.06 degree (±0.1mm).

■ Other modes of oscillation

- No coupled-bunch oscillation has been attributed to RF system.

RF System for KEKB Superconducting Cavity

K. AKAI



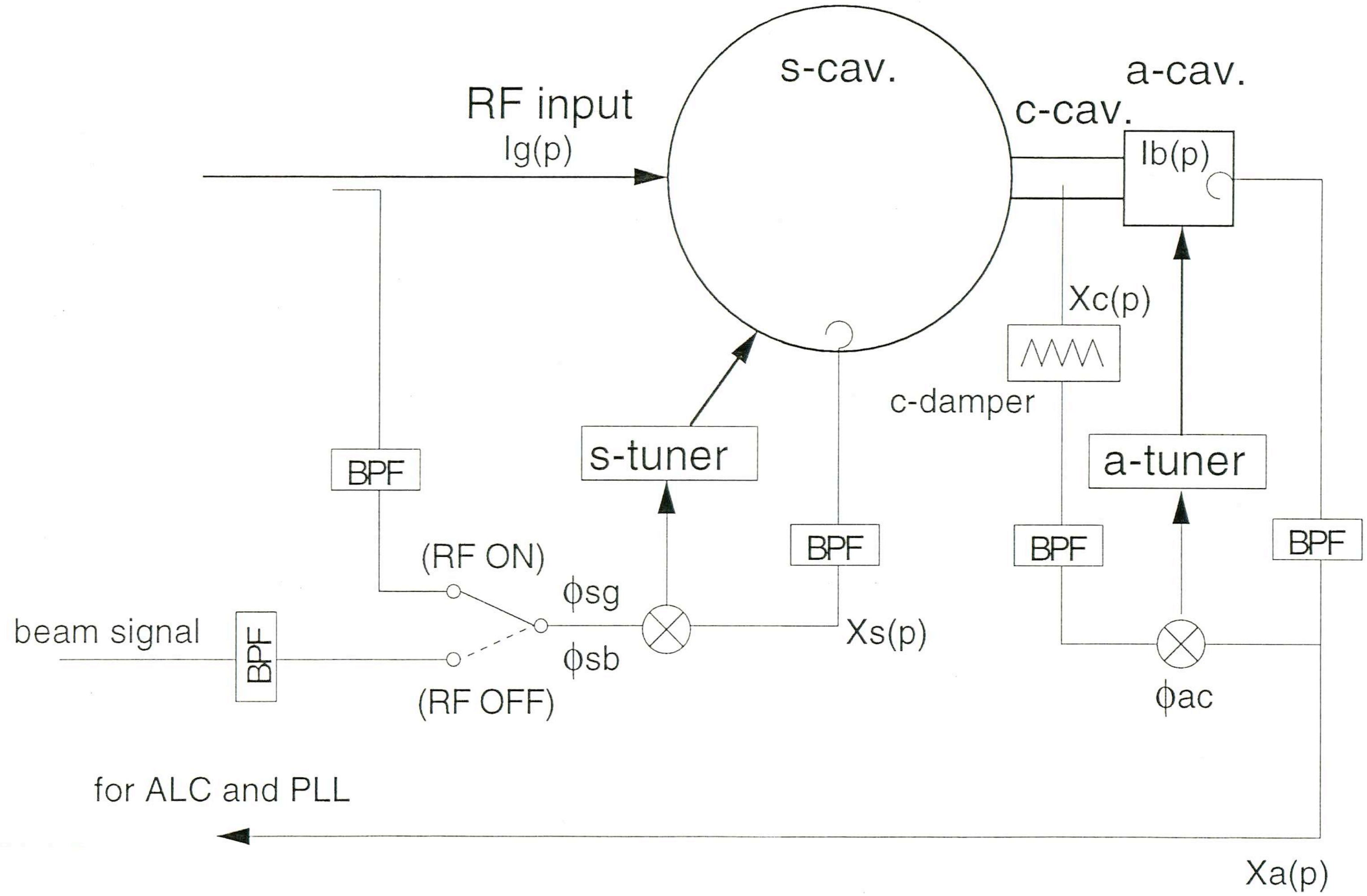
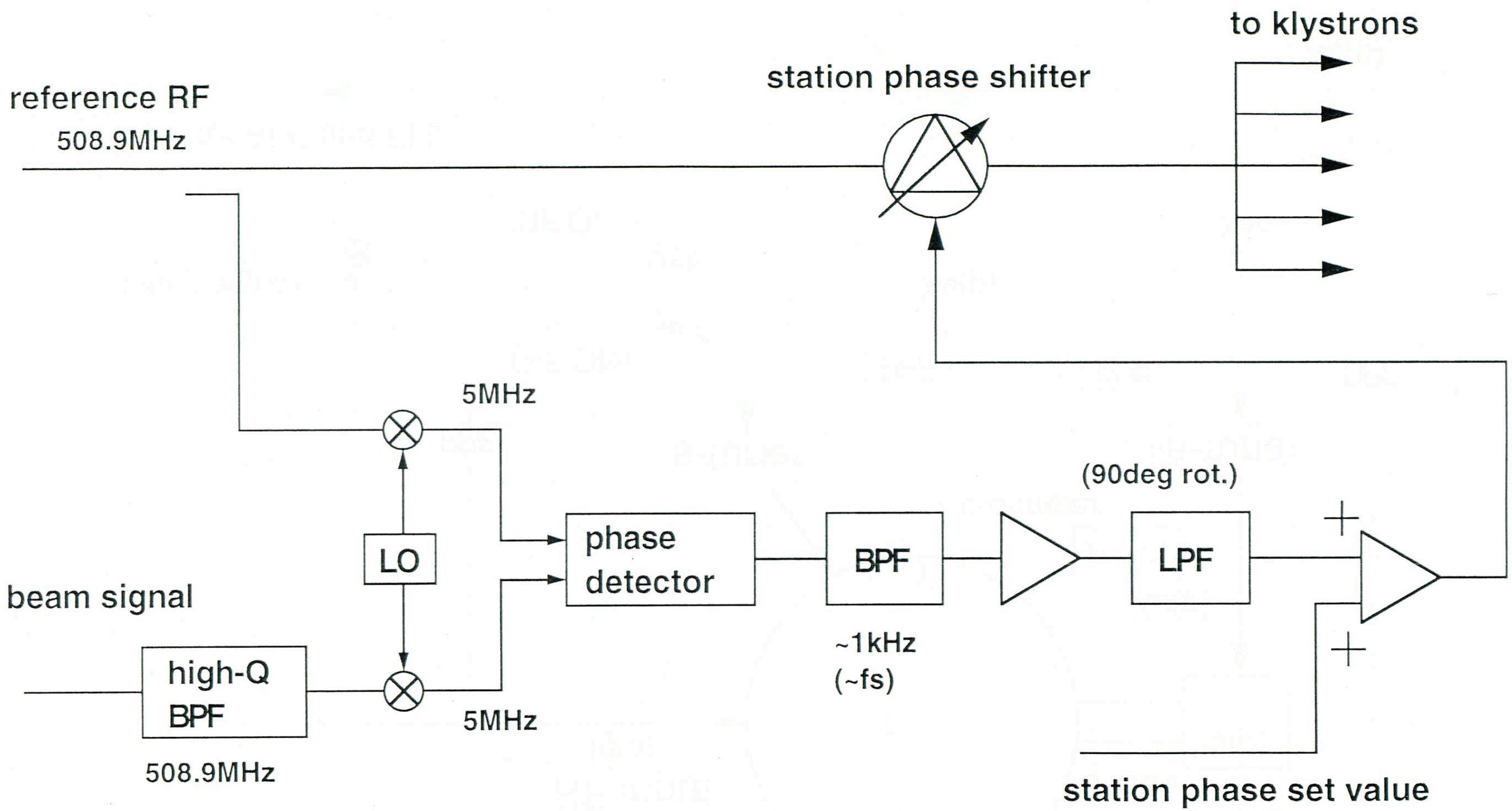
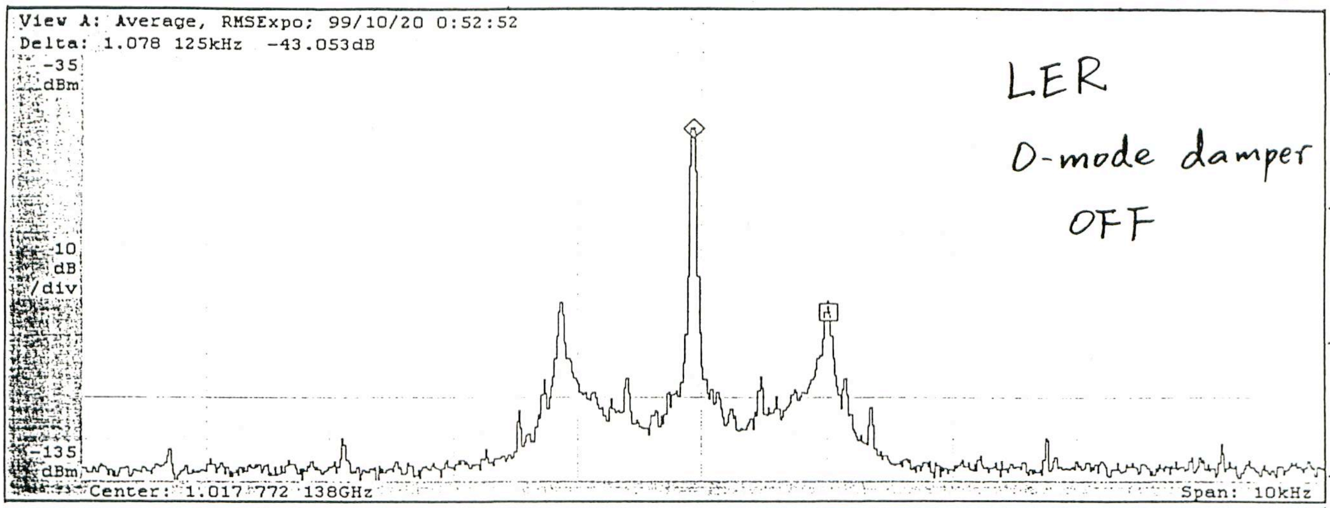
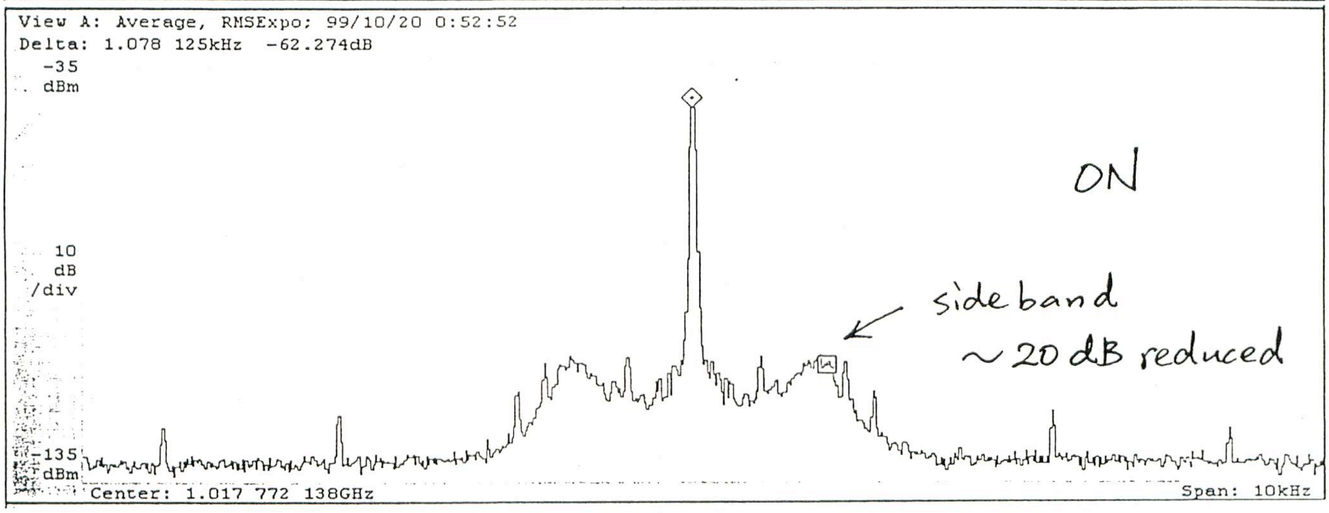


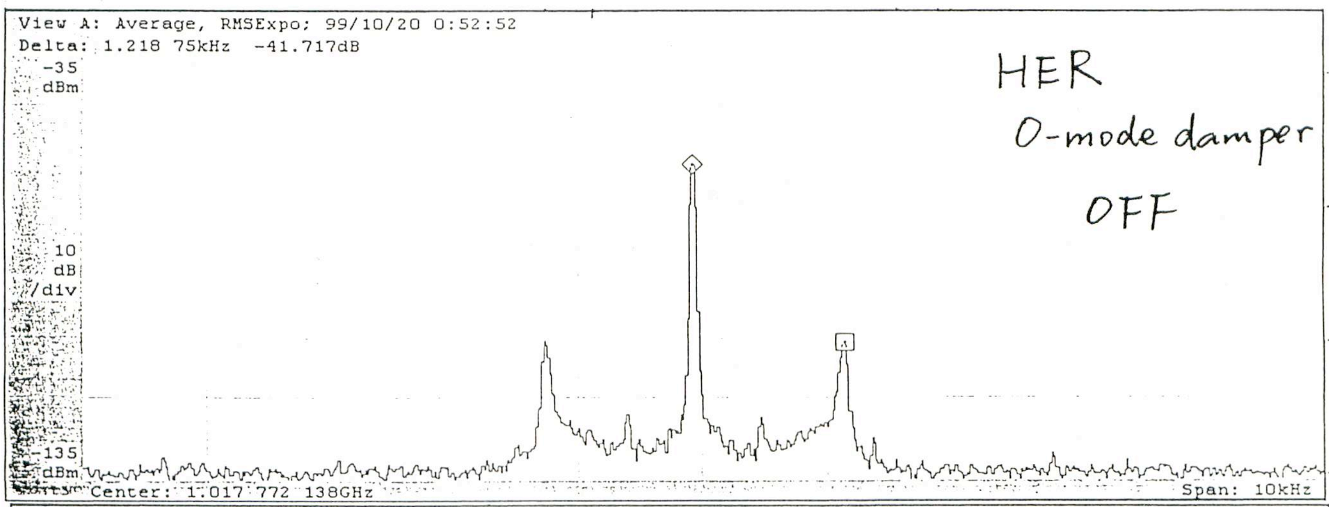
Figure 2: Block diagram of the tuning control system for ARES.

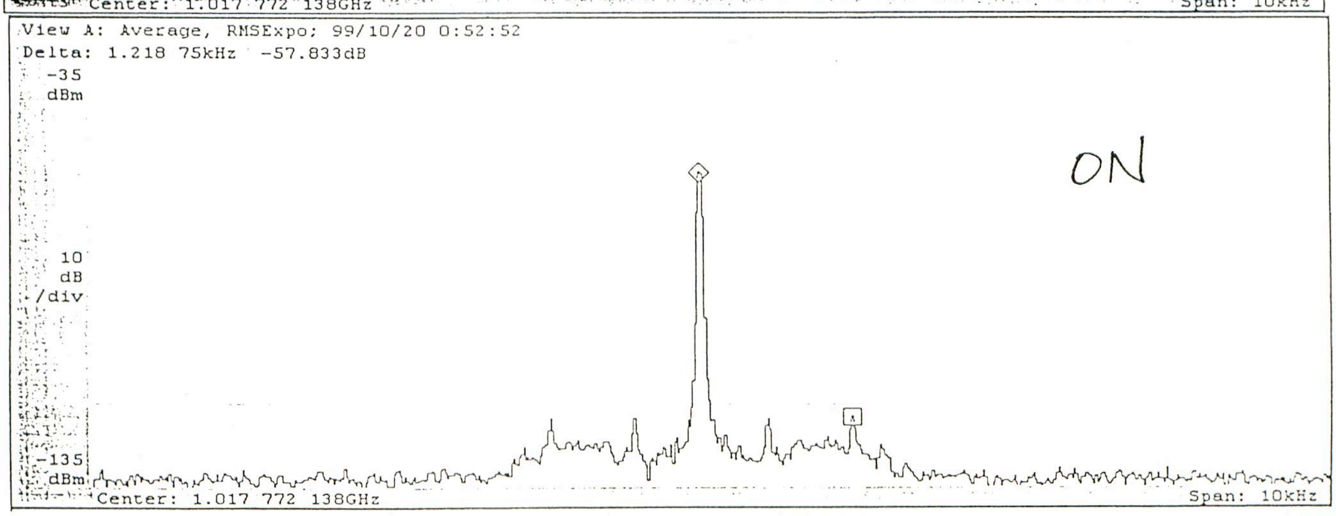


Block diagram of the 0-mode damper for KEKB RF


View A: Average, RMSExpo; 99/10/20 0:52:52
Delta: 1.078 125kHz -43.053dB
-35
dBm
10
dB
/div
-135
dBm
Center: 1.017 772 138GHz
Span: 10kHz
LER
0-mode damper
OFF


View A: Average, RMSExpo; 99/10/20 0:52:52
Delta: 1.078 125kHz -62.274dB
-35
dBm
10
dB
/div
-135
dBm
Center: 1.017 772 138GHz
Span: 10kHz
ON
side band
~20 dB reduced


View A: Average, RMSExpo; 99/10/20 0:52:52
Delta: 1.218 75kHz -41.717dB
-35
dBm
10
dB
/div
-135
dBm
Center: 1.017 772 138GHz
Span: 10kHz
HER
0-mode damper
OFF


View A: Average, RMSExpo; 99/10/20 0:52:52
Delta: 1.218 75kHz -57.833dB
-35
dBm
10
dB
/div
-135
dBm
Center: 1.017 772 138GHz
Span: 10kHz
ON

Major troubles (since last MAC: Mar. 1999)

■ **The rubber vacuum seal at the flange connection between the storage and coupling cavity of ARES was burned.**

→ Detuned until the storage cavity was replaced in the next shut down.

In summer shut down in 1999, every ARES cavity in LER was vacuum-sealed by welding the stainless steel lips at the flange connection after removing the rubber seal.

6 cavities for HER still have the rubber seal. They will be removed in summer 2000.

■ **Vacuum trouble in a ARES cavity (D8-D#2). Plating solution trapped near surface leaked out.**

→ Detuned from Oct. to Dec. 1999. After baking in winter shut down, it returned to operation.

■ A door-knob transformer at the input coupler was burned. (Caused by bad brazing?)

■ Two klystrons were damaged.

■ Some troubles in other components. (dummy loads, control modules, etc)

RF system upgrade in summer 2000

(1) Stored beam current
- So far, beam current has NOT been limited by RF system.
- Maximum current by RF system is approximately proportional to number of cavities (i.e., beam power to be delivered).
- 1.5A (LER) and 0.7A (HER) can be supported by present RF system.
- Upgrade is necessary for much higher current.

(2) Required RF voltage
- At present, luminosity is NOT clearly limited by RF voltage.
- Higher Vc may be needed? - In particular, in view of photo-electron related instabilities in LER: A simulation showed larger νs and short σz reduce the growth rate.

(3) Margin
- For stable operation, it is desired to have sufficient margin to cover troubles in one or two RF stations.

(4) Cavities for upgrade
- ARES's have been manufactured and high-power processed. They can be installed in tunnel in summer 2000 on demand.
- SCC's are in preparation on schedule. In view of the term of validity (Sep. 2001) regarding examination, it is strongly desired to install them in summer 2000.
- Adding SCC's in D10, where radiation is stronger than D11, may give useful information for crab cavities.

(5) High power and low-level RF system
- Most of high power components are available. Both high power and low-level systems can be constructed in summer shut down to meet the upgrade plan.

(6) Other things
- About 2.5 months shut down is required for the RF upgrade.
- Cost and available budget

We can upgrade the RF in this summer, if budget allows.

Summary

• RF system has been operating very stably. Loss time due to all RF troubles is small (for example, 10 hours in 34-days physics run).

• The cavity performance of ARES and SCC is excellent. In particular, trip rate of SCC is only twice /month.

• No sign of HOM-induced beam instabilities has been observed.

• Collision point is kept stable.

• The zero-mode synchrotron oscillation was sufficiently reduced by the zero-mode damper.

• Up to now, the RF system has limited neither stored beam current, nor luminosity.

• Upgrade of RF system is scheduled in summer 2000.