KEKB Accelerator Review
23-25 January 1997

BUNCH FEEDBACK SYSTEMS [1)]

E. KIKUTANI
(菊谷英司)
KEK

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[1] Major changes in the design since the design report
[2] The signal process board
[3] Feedback experiments in AR
---- Measurement of the shunt imp. of the drift tube kicker
---- Systematic study of the feedbacks with the 2-tap filter
---- Multibunch feedback experiments
[4] A plan for near future (DAΦNE kicker)
[5] Related systems

[1)] This report is based on the works by E. Kikutani, M. Tobiyama and Y. Minagawa with the help of the KEKB accelerator staffs.

Main Features of KEKB Feedback Systems

- A 2 GHz component of the beam signal is used to detect the bunch position (transverse, longitudinal) . The band pass filters are made of cables/combiners.

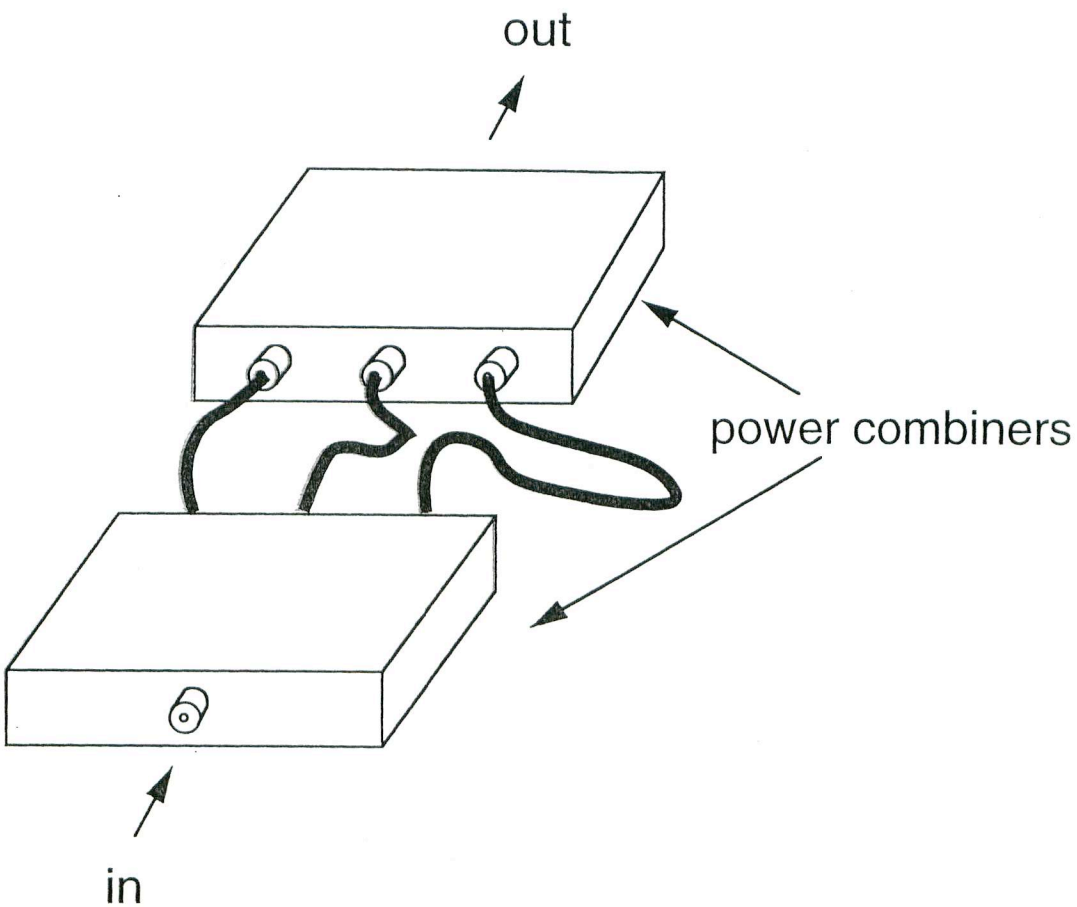
- Signal processing is done with a digital process board with very fast de-multiplexers and multiplexers. These (de-)multiplexers are realized as custom GaAs LSI's.

A Cable-Combiner Bandpass Filter

(an analog FIR filter)

low-Q

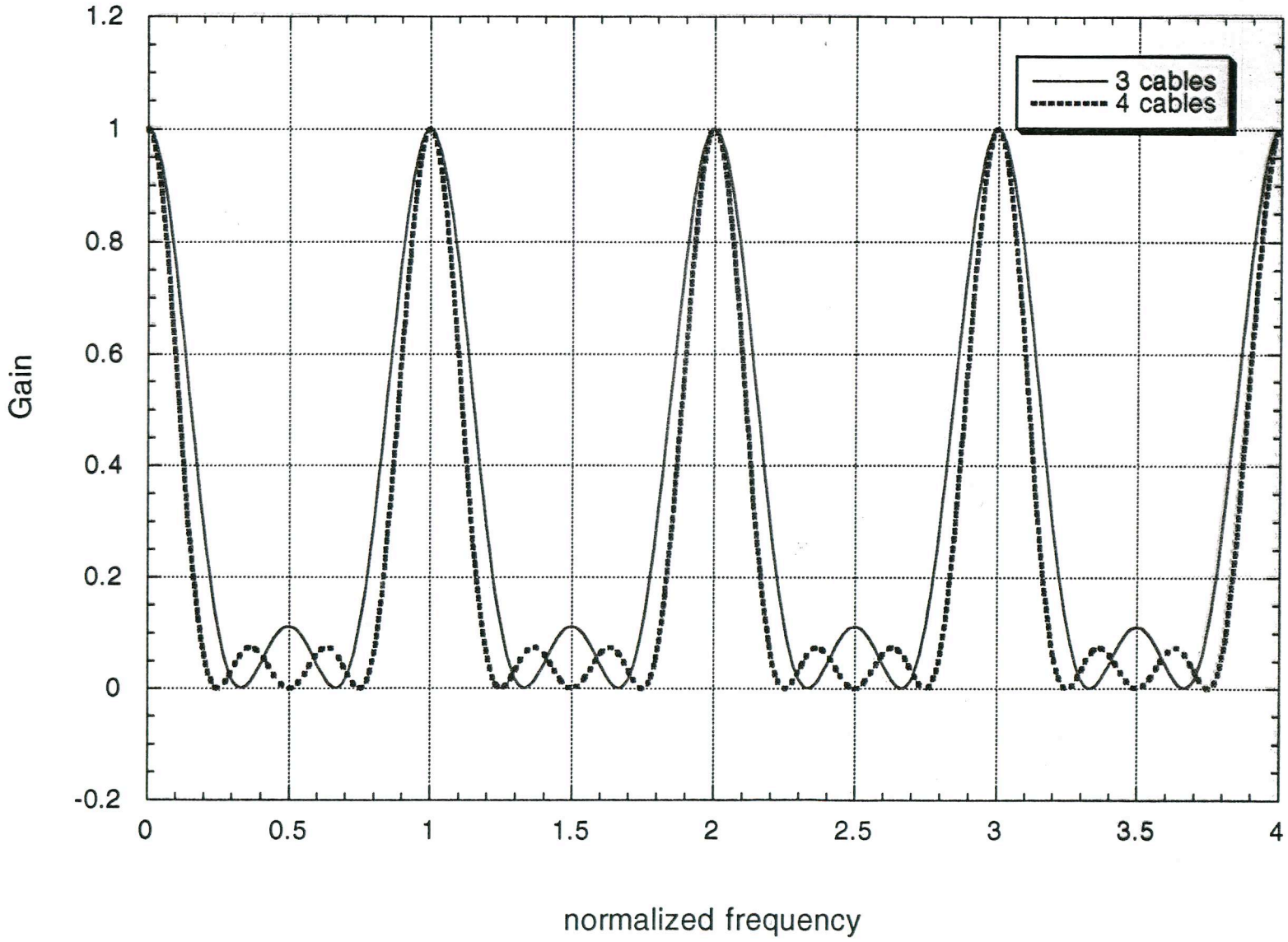
completely ringing free

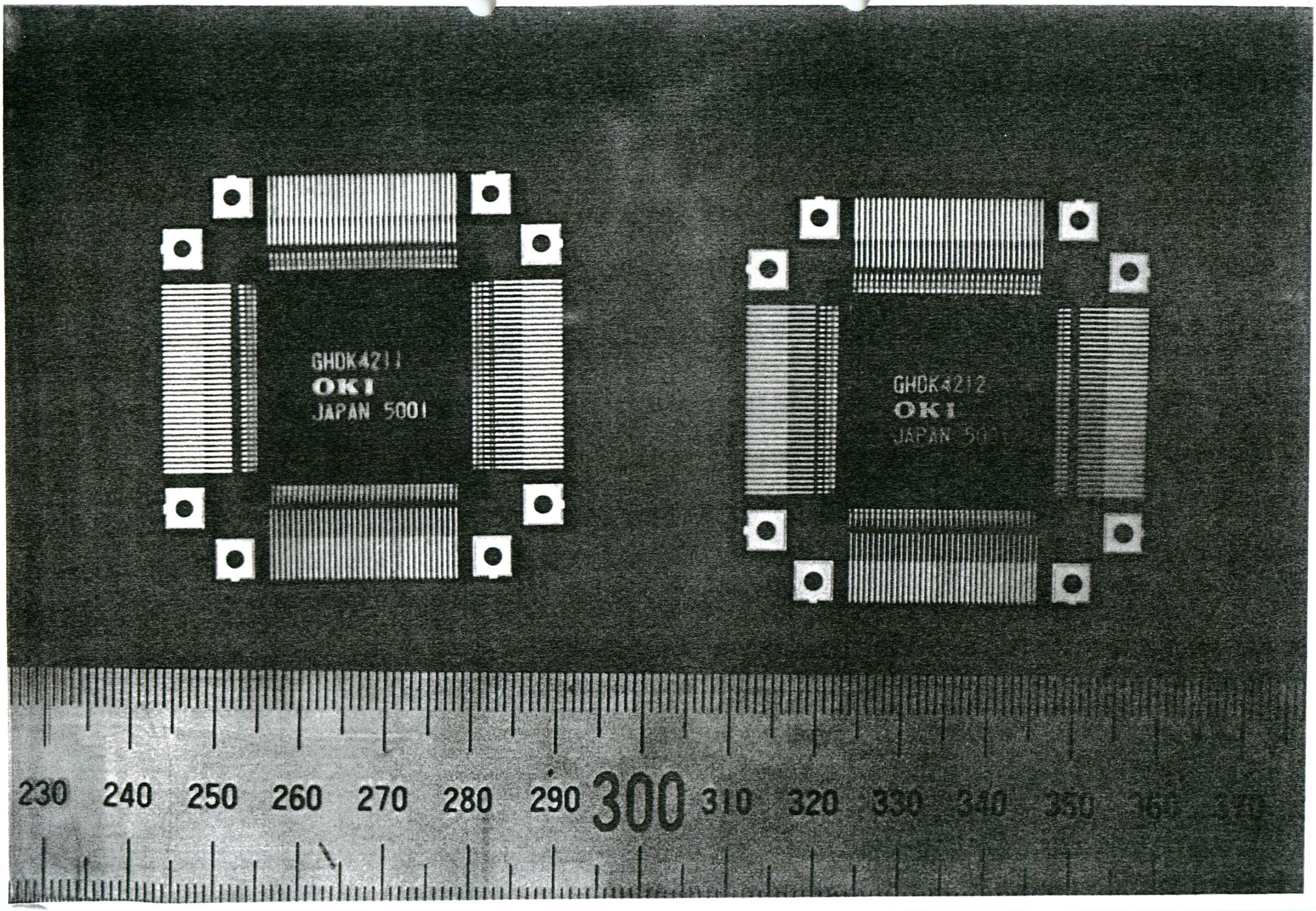


Lengths of the cables : a_i

$$a_i = \text{constant} + \lambda \times i$$

Gain of the Cable-Combiner Filter




GHDK4211
OKI
JAPAN 5001
GHDK4212
OKI
230 240 250 260 270 280 290 300 310 320 330 340 350

Major Changes since the Design Report

- Transverse front-end electronics

  AM/PM ————————> with Hybrid (direct subtract)

- Signal delay (1 turn or *n* turn)+ betatron phase adjust

  2 tap filter only ⟶ { 2 tap filter + combine of signals of 2 bpms

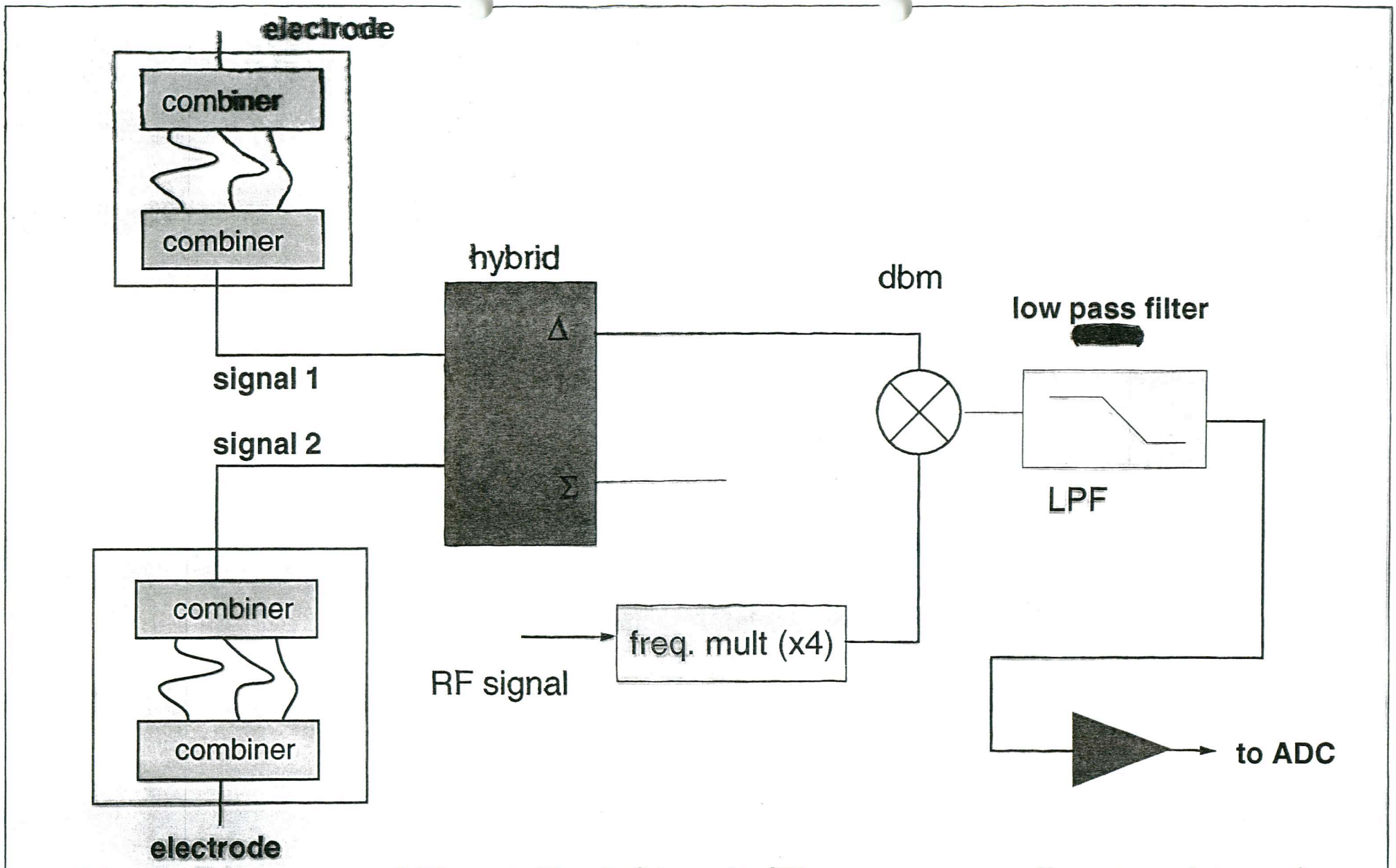
Front-end Electronics for the Transverse Position Detection

In the Design Report, our plan was to use the AM/PM detector for the transverse.

AM/PM	Hybrid (direct subtract)
output $\propto$ (bunch current)^2	output $\propto$ (bunch current)
not depend on long. oscillation	depend on on long. oscillation
not simple	simple

The (bunch current)^2 dependence is very inconvenient for the feedback systems. We have tried limiting amplifiers. But they introduced the reduction of S/N.

Then we decided to use the hybrid method.



Block Diagram of Front-End Circuit (Transverse, direct subtract)

KEKB

Signal Delay Schemes

In the Design Report, our plan was to use the 2-tap filter system for the 1-turn delay (or *n* turn delay) and betatron phase adjustment

But after the design report, we found that

"the 2-tap filter scheme might not work

with very strong beam-beam collisions

and

with the tune not convenient for this scheme."

Then we modified the design to use 2-bpm (with an adjustable combiner) schemes in parallel with the 2-tap filter scheme.

However, this does not mean that we abandon the 2-tap scheme thoroughly. If the tune is not bad for our system, the 2-tap scheme can work very well.

Comparison of the signal delay schemes

2-monitor scheme	*2-tap filter scheme*
double front-end elec. + adjustable combiner	single front-end elec.
analog DC suppress	digital DC suppress by the 2-tap filter
analog delay adjust	digital delay adjust by the 2-tap filter
less sensitive to the tune	often sensitive to the tune (need careful adjust of the tap)
can work under strong strong beam-beam interaction	sometimes, less powerful under strong beam-beam interaction

The Signal Process board

★ A one-board digital-signal-process system is used.

ADC, de-multiplexer,
memory +ALU,
multiplexer, DAC

★ The board is applicable to both the longitudinal and transverse planes.

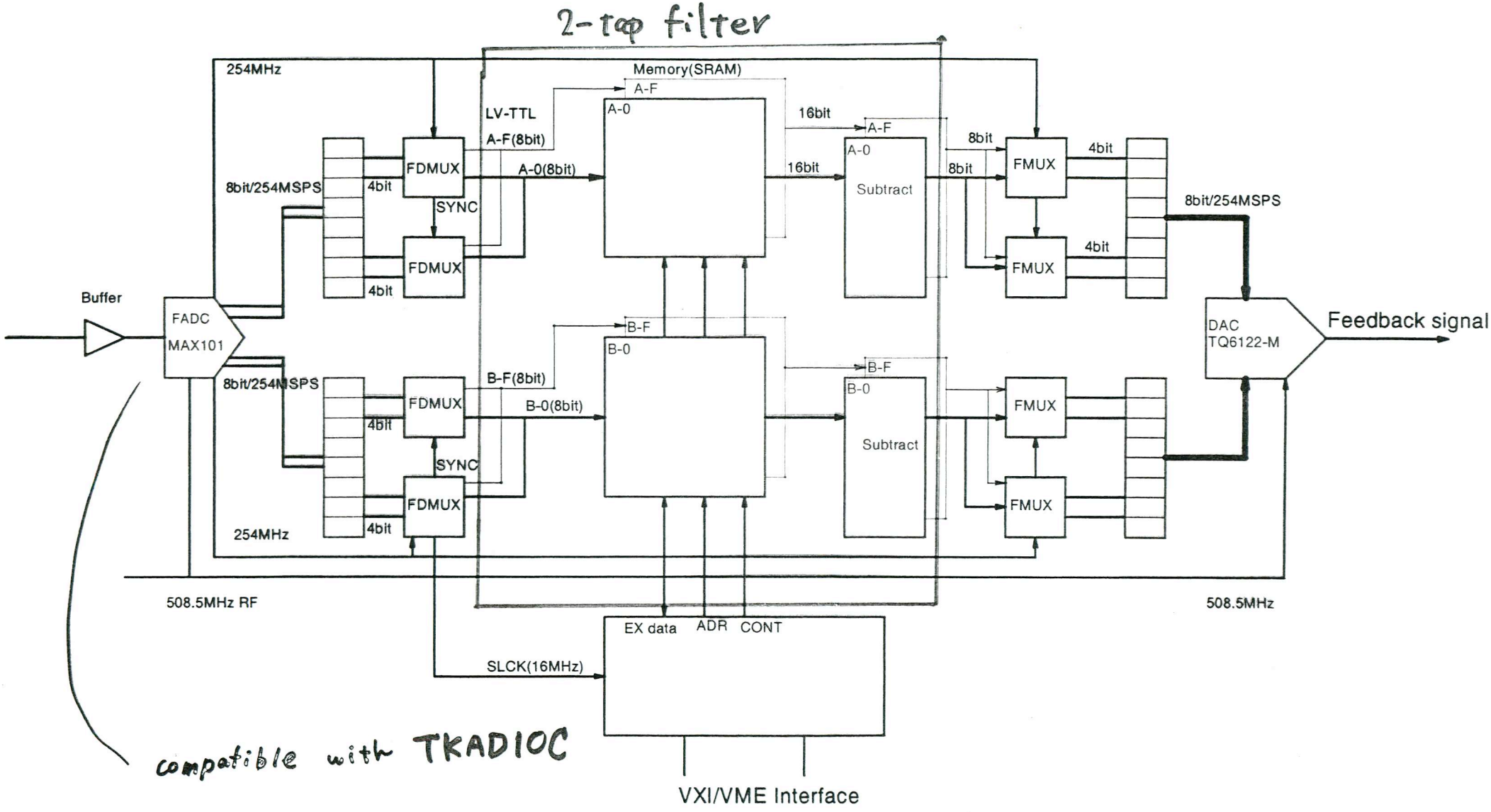
★ Very fast de-multiplexers/multiplexers (GaAs custom LSI) are used to be able to treat all the bunches with the spacing of 2ns. The memory chips are CMOS which are not extremely fast.

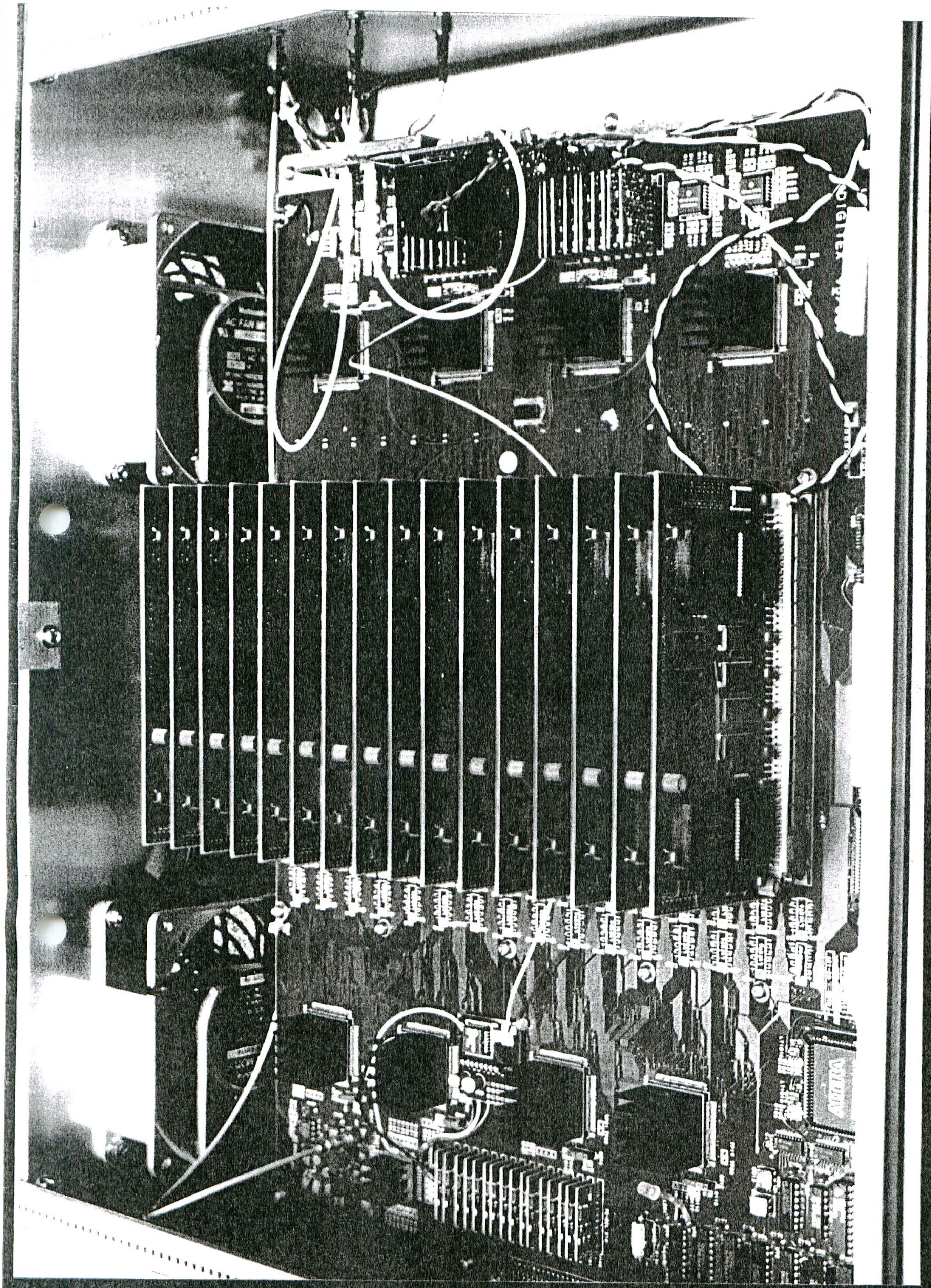
all the bunches + all the turns = no down-sampling

★ A large memory can store 5120x128 data. (5120 is the maximum number of the bunches)

★ It works either as the 2-tap FIR filter or as a simple digital delay.

★VME interfaced. The switching between delay/filter and tap-postions are set through the interface.


2-tap filter
254MHz
Memory(SRAM)
A-F
LV-TTL
A-F(8bit)
A-0
16bit
A-F
8bit
4bit
FDMUX
A-0(8bit)
16bit
A-0
8bit
FMUX
8bit/254MSPS
4bit
SYNC
Subtract
8bit/254MSPS
FDMUX
4bit
FMUX
4bit
Buffer
FADC
MAX101
B-F
B-0
DAC
TQ6122-M
Feedback signal
8bit/254MSPS
B-F(8bit)
B-F
B-0
FDMUX
4bit
B-0(8bit)
Subtract
FMUX
SYNC
FDMUX
FMUX
254MHz
4bit
508.5MHz RF
508.5MHz
EX data
ADR
CONT
SLCK(16MHz)
compatible with TKADIOC
VXI/VME Interface



Beam Experiments in AR

(1) A practical estimation of the shunt impedance of the drift-tube longitudinal kicker (4 inner electrodes)

(2) Systematic studies of the transverse feedback systems based on the 2-tap filter.

(3) Multi-bunch (high current) experiments.

A practical Estimation of the shunt impedance of the drift-tube kicker

★ beam

AR, 2.5GeV, a few milli amperes, ν_s=0.03

★ Tools

button pick-ups + front-end,
2-tap filter board (version 0, CAMAC)
kicker (version 0, 4 inner electrodes, screw-connected),
amplifiers (500 W x 2)

★ Method

-- To use the feedback system as a "positive feedback" system, namely, an exciter.

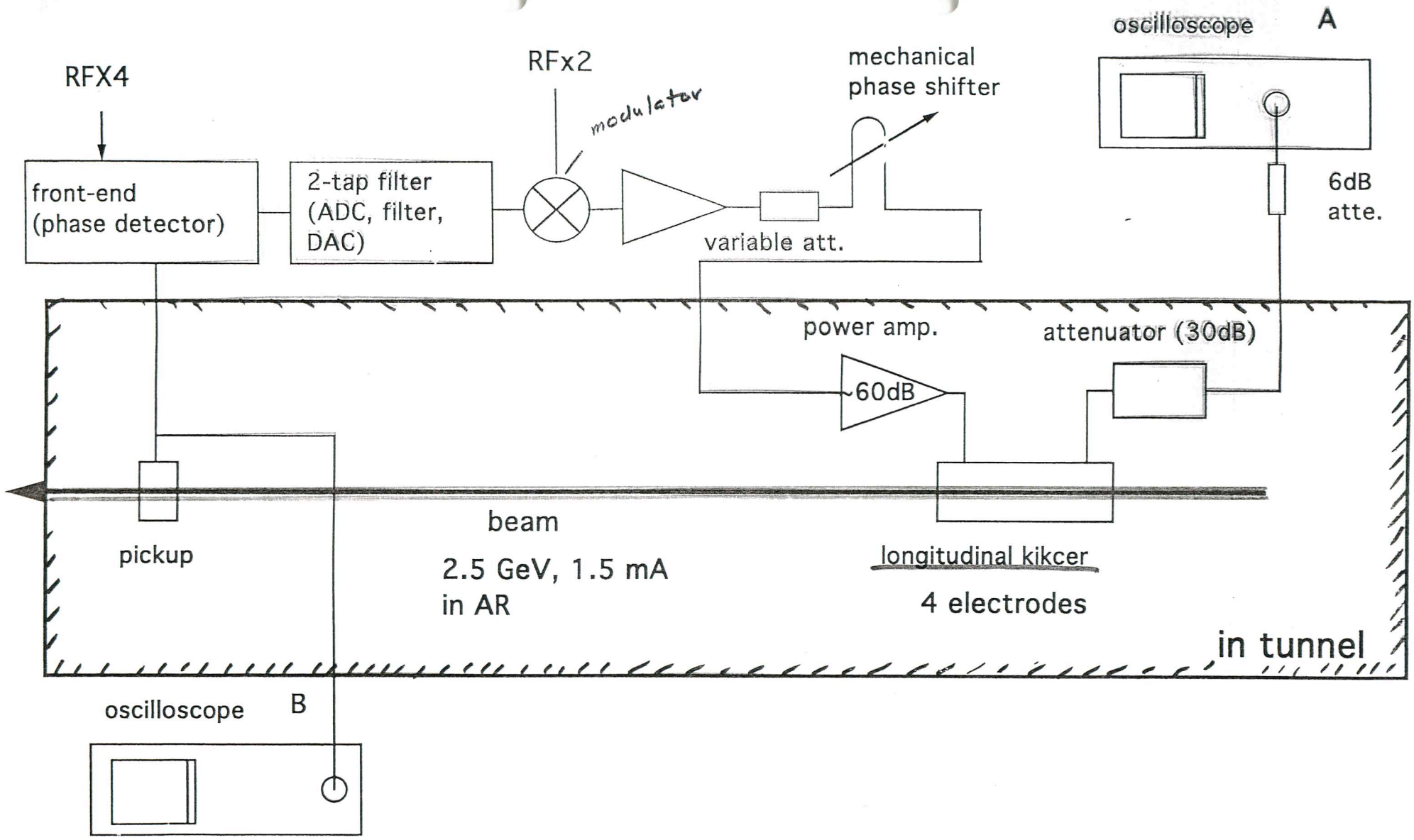
-- The beam oscillation goes to an equilibrium state:

excitation=Natural damping

then record the *power* and the *amplitude*

-- Then turn off the feedback and measure the natural damping time mainly due to the Robinson damping

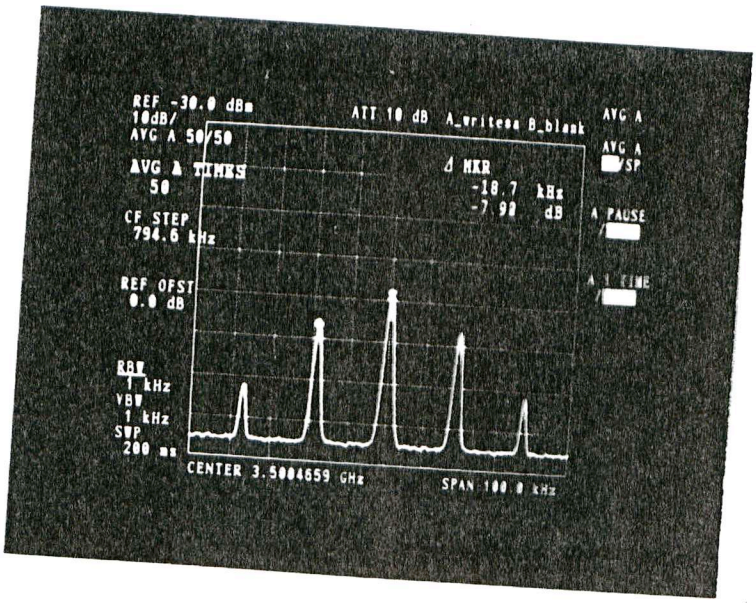
-- Estimate the shunt impedance from the data (oscillation amplitude, power fed to the kicker, natural damping time]



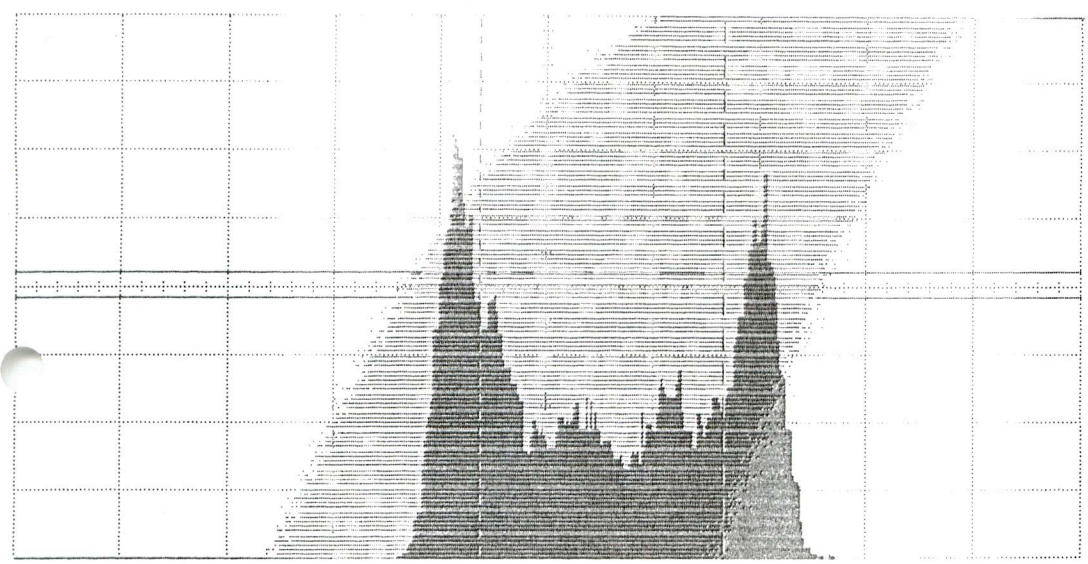
The setup of the longitudinal feedback experiment in AR

23.34

tap = (23, 49)



~ 60ps



0 - Xing Histo.

24.2110 ns 24.3110 ns 24.4110 ns

Ch. 2	=	10.00 mVolts/div	Offset	=	-375.0 uVolts
Timebase	=	20.0 ps/div	Delay	=	24.3110 ns
Delta Windo=		3.7500 mVolts			
Window 1	=	1.7187 mVolts	Window 2	=	-2.0312 mVolts
Delta %	=	49.69 %			
Upper	=	74.74 %	Lower	=	25.04 %
Delta T	=	45.7 ps			
Start	=	24.3442 ns	Stop	=	24.2985 ns
# Samples	=	10000			
Mean	=	24.3214 ns	Sigma	=	22.8 ps

Trigger on External at Neg. Edge at -40.50 mVolts

Result

Amplitude of the oscillation	± 30 ps
Power fed to the kicker	640 Watts
Effective voltage of the natural damping	1300 volts

Then the shunt impedace is

$$Z_s=(1300)^2/(2x640)=1300\ \Omega$$

This is about 80 % of the ideal one.

A systematic studies of the feedback system based on the 2-tap filter in transverse plane

Tools

- AR, 2.5 GeV, a few milli amperes
- with the version 0 of the 2-tap filter (CAMAC)
- the pickups and the kickers are the usual ones
- horizontal feedback, by kicking the beam by the injection kicker and damp the oscillation with test feedback system

Goals

- measure the damping rate
  - -- as a function of the tune for fixed tap-position
  - -- as a function of the tap-position for fixed tune

- check the behavior of the beam under the feedback with the large taop-positon

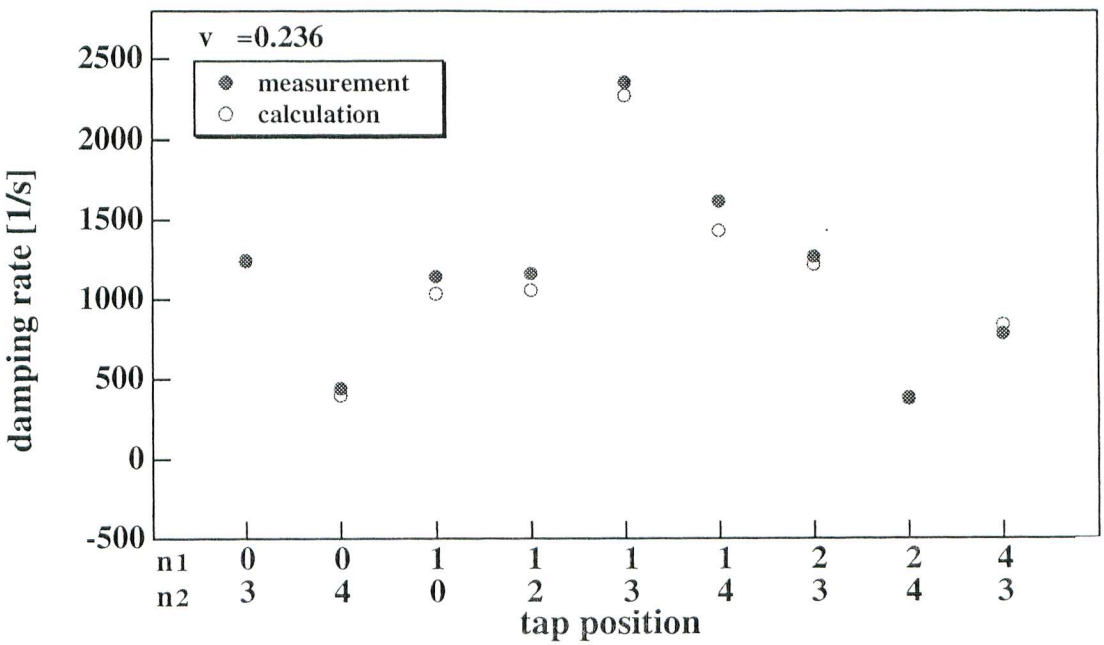


Figure 3.11: The damping rates with $\nu = 0.236$.

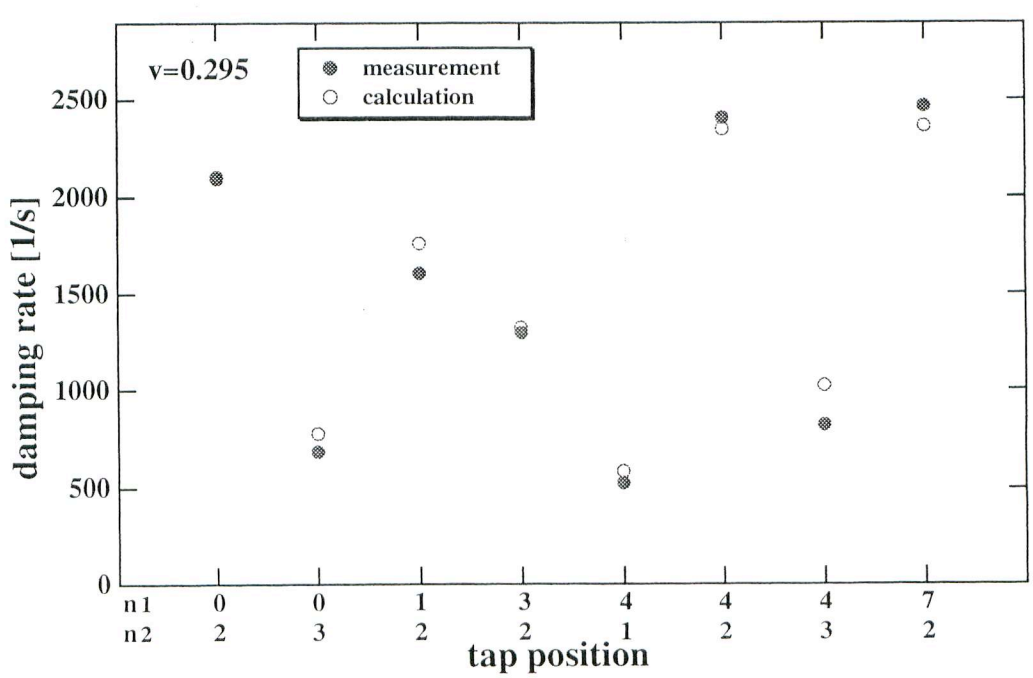


Figure 3.12: The damping rate with $\nu = 0.295$.

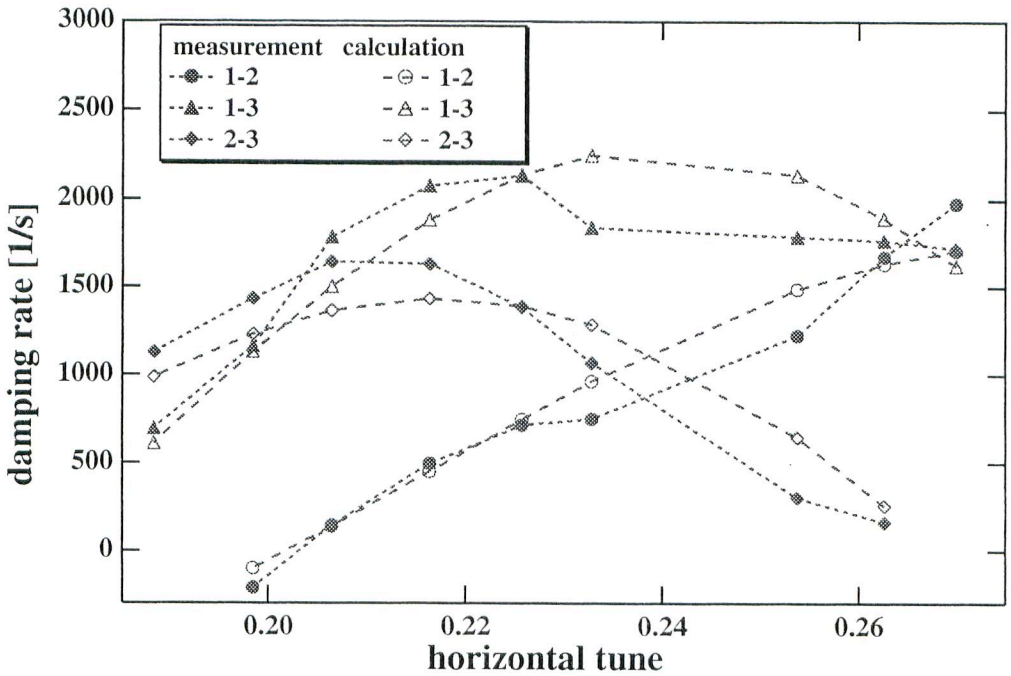


Figure 3.15: The damping rates as functions of tunes around $\nu = 0.235$.

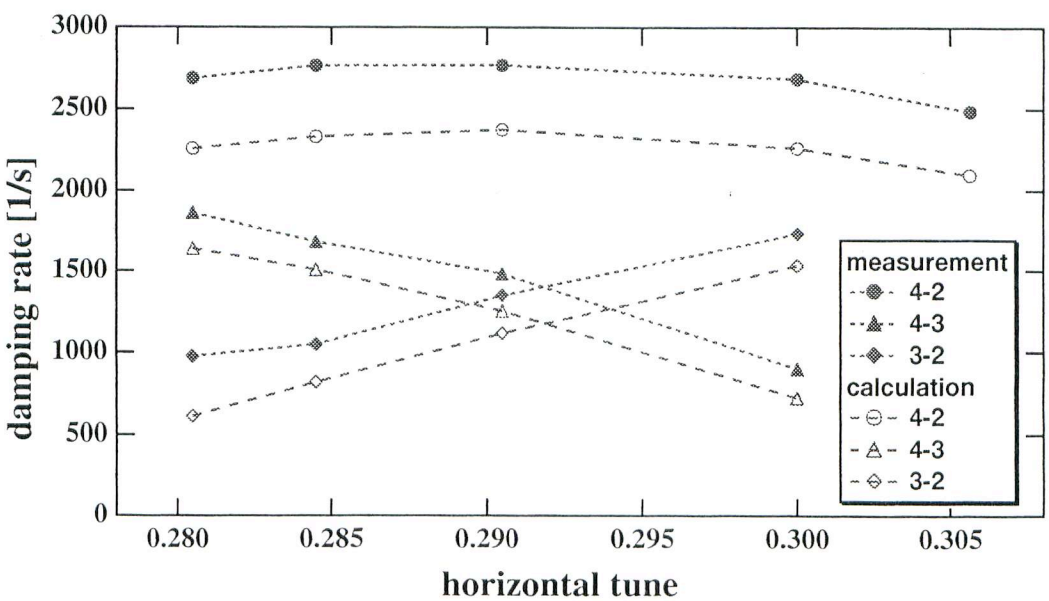


Figure 3.16: The damping rates as functions of tunes around $\nu = 0.295$.

Results of the feedback experiments based on the 2-tap filter

(1) The damping rates observed agreed very well with the calculated one within the measurement error.

(2) The tap positions less than 10 can cover the practical tune range. The large tap positions, namely taps>50, in the 2-tap filter are not preferable because the feedback is not reliable.

(3) In conclusion, we can use the 2-tap filter for the feedback system if there is no strong perturbing source which can shift the betatron phase drastically

Multibunch (High current) Experiments in AR

(1) Transverse feedbacks with analog delay
(horizontal, vertical)

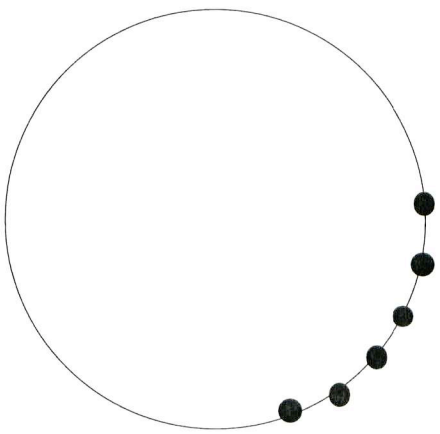
(2) Longitudinal feedback with the 2-tap filter
(2-tap filter version 1, can treat 2ns spacing)

tools

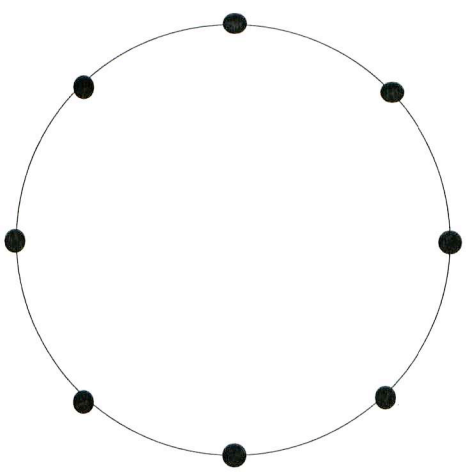
-- button pickups specially made for this experiment
-- two tap filter board (version 1)
-- transverse kicker (striplines)
-- longitudinal kicker (version 1)
-- power amplifiers

The memory in the two-tap filter can store the data of 1600 tunrs/bunch.

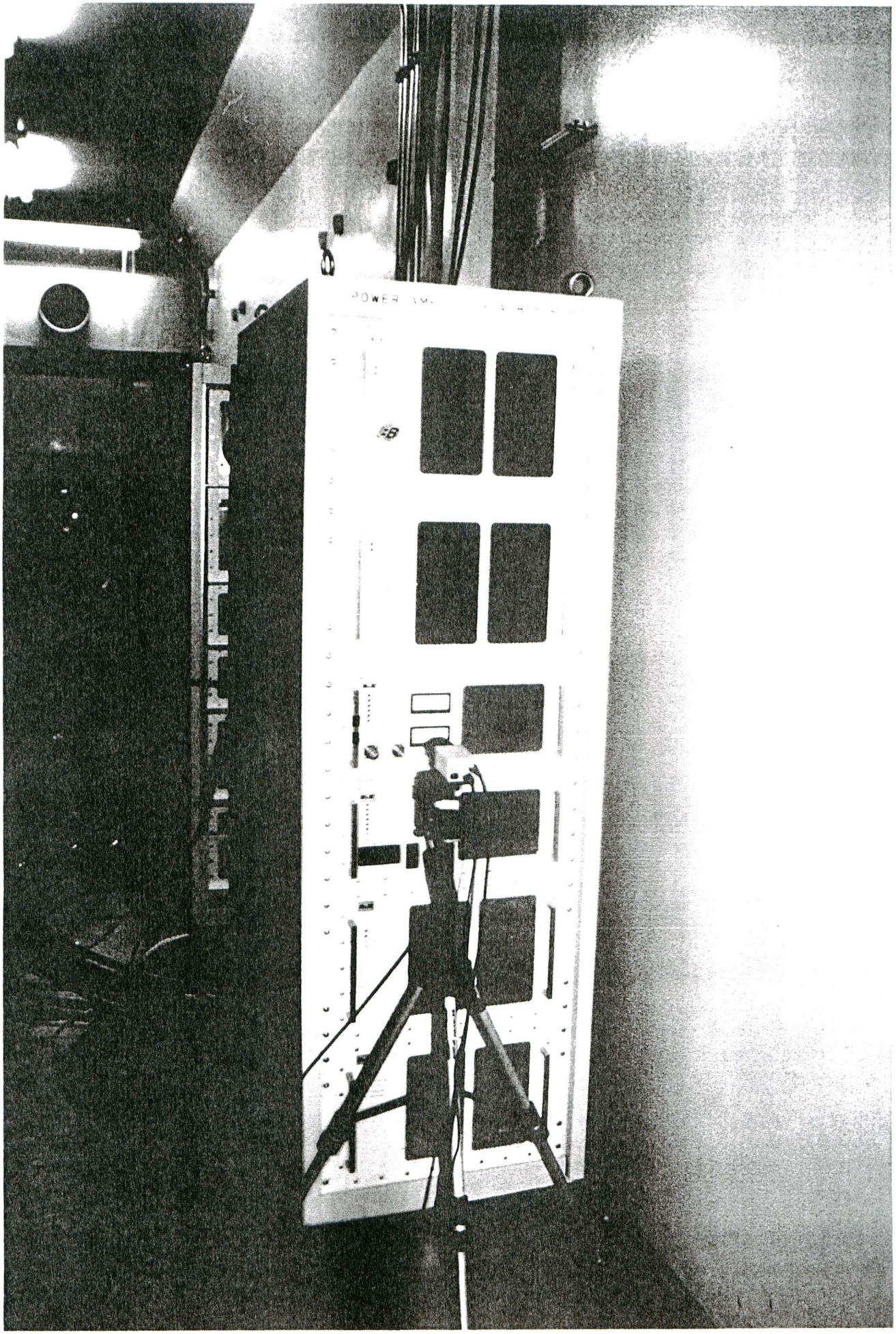
Patterns of the bunch storage



bunch-train storage

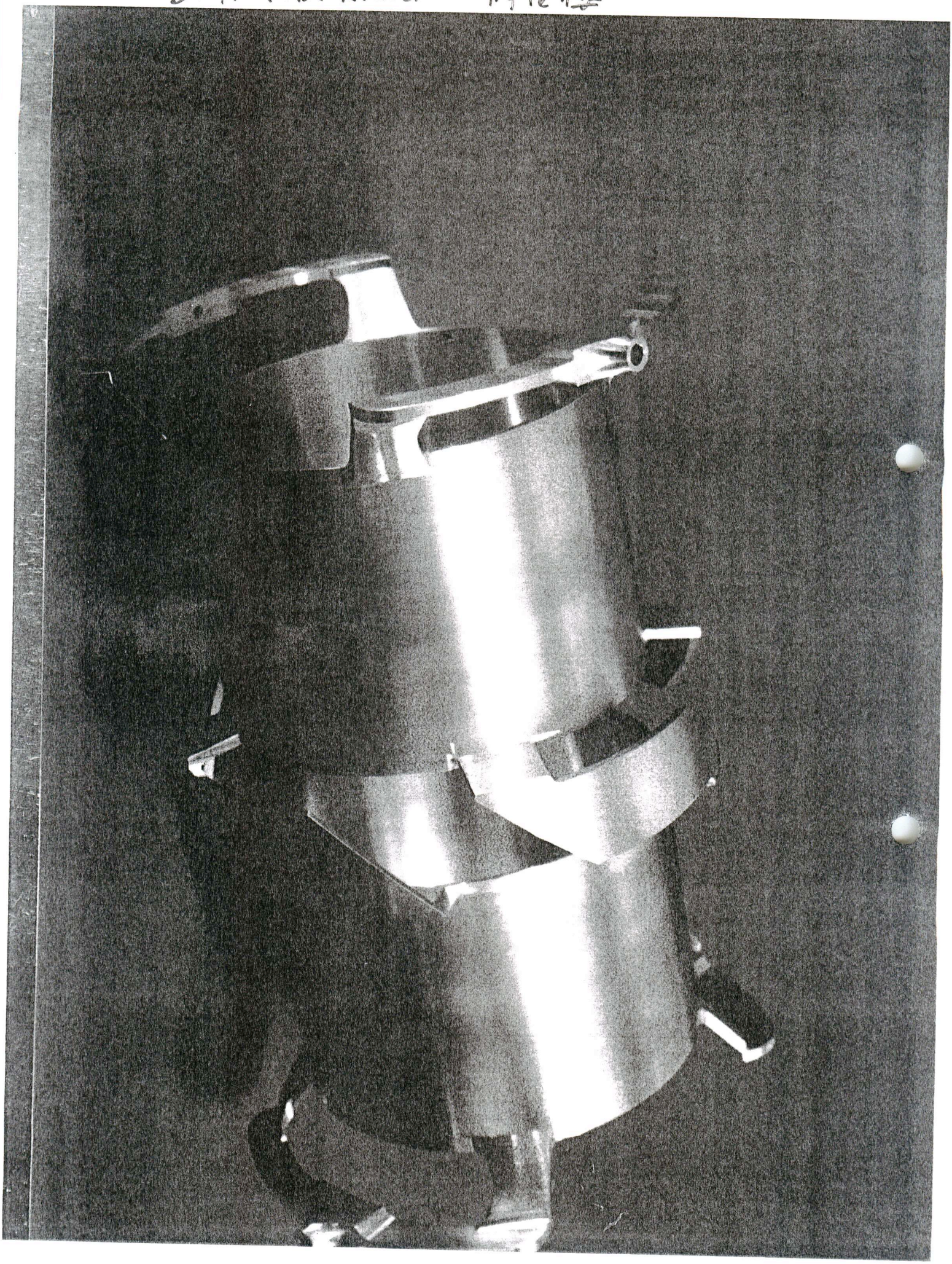


equally-spaced storage

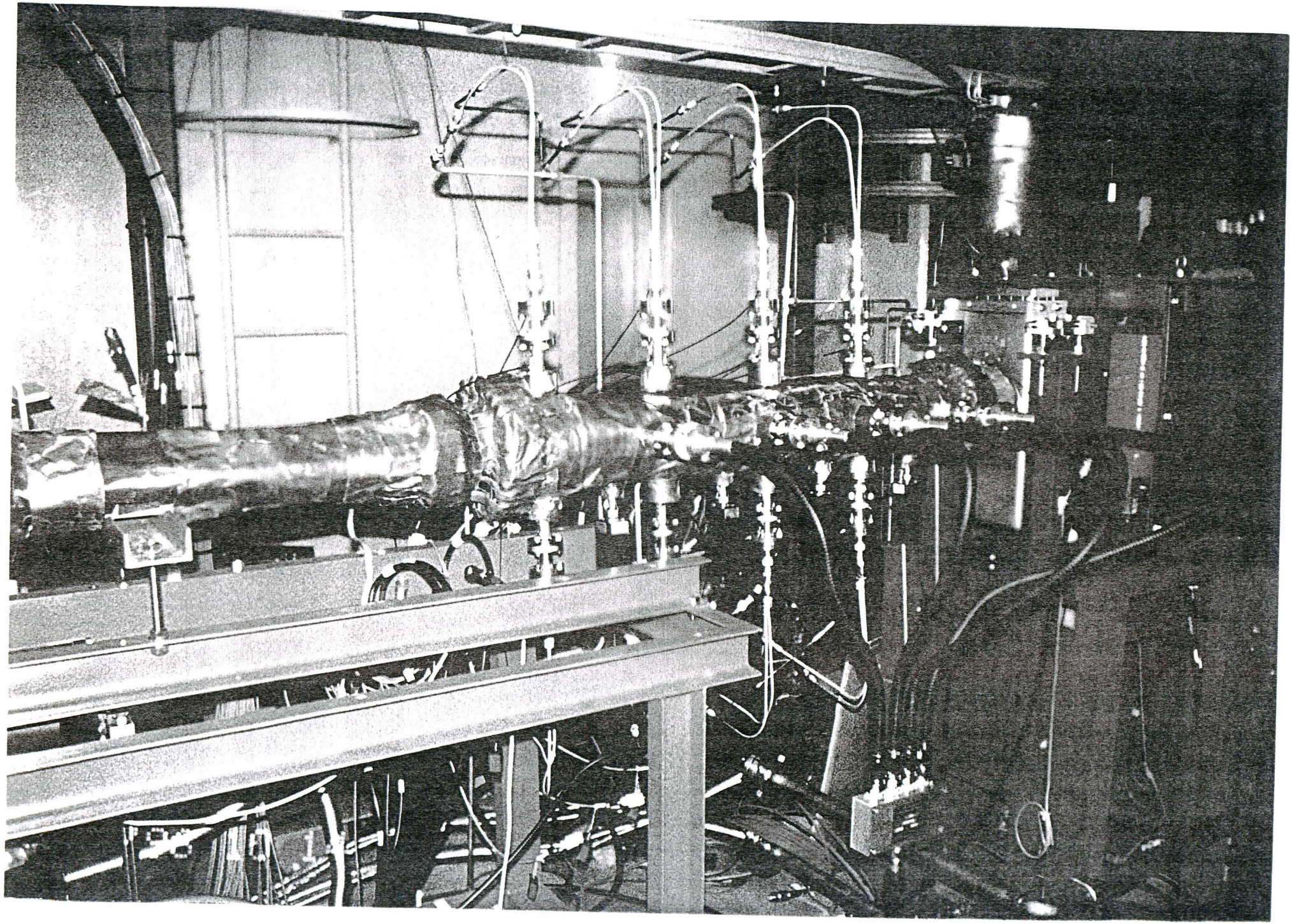


Amplifier for longitudinal feedback
500 W, 1 GHz ± 125 MHz. 60 dB

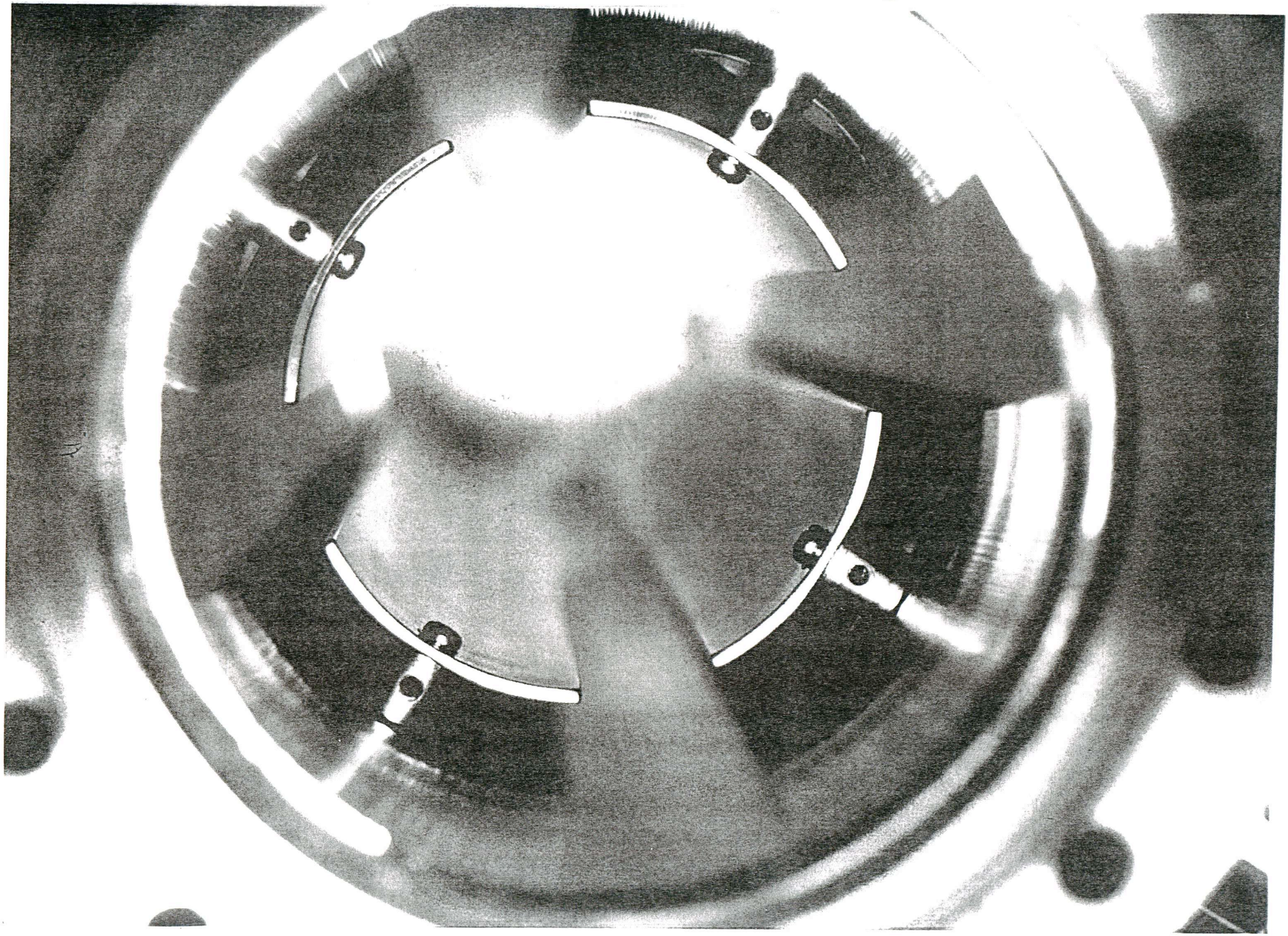
Drift tube kicker 内電極



longitudinal kicker in AR 2×4 electrodes



Transverse kicker in AR



Power Amplifiers for Longi. Feedback

by R&K Company, Japan

Output power	500 W
Center freq.	1 GHz
Bandwidth	250 MHz
Gain	>60 dB

class A
air-cooled

GaAs transisters (FUJITSU FLL120MK x 328)

a kicker is fed by 2 sets of these amplifiers.

~ $ 210,000/2 sets

Effect of the transverse feedbacks

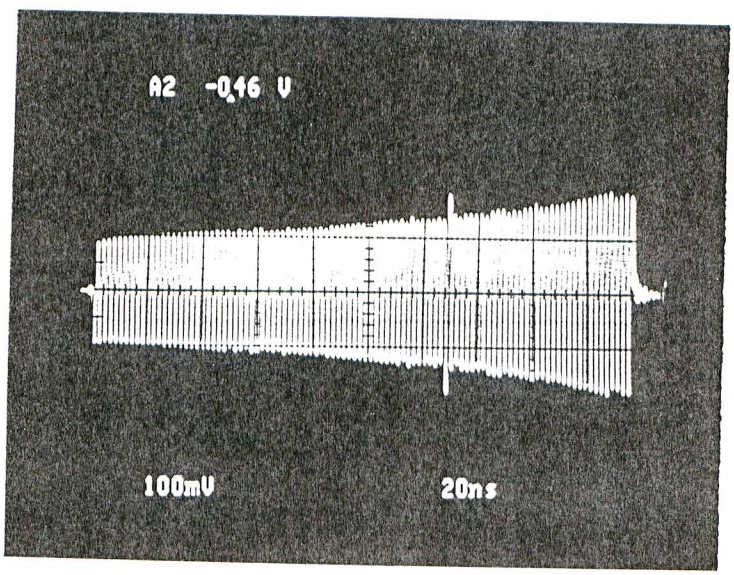
(1) Max. # of bunches in a train (bunch spacing 2ns)

	transverse feedback on/off			
I_{bunch}	H&V off	H on	V on	H+V on
1 mA	18	20		> 300
2 mA	20	20	70	~170
4 mA	25	25	25	> 100

(2) Maximum storable current

I_{bunch}	spacing	# of bunches	max. current
1 mA	2 ns		>300mA
2 mA	2 ns	160	320 mA
4mA	2 ns	100	376 mA
3mA	8ns	104	290 mA
2mA	10ns	94	180 mA

Oscilloscope photo of the signal from a button pickup

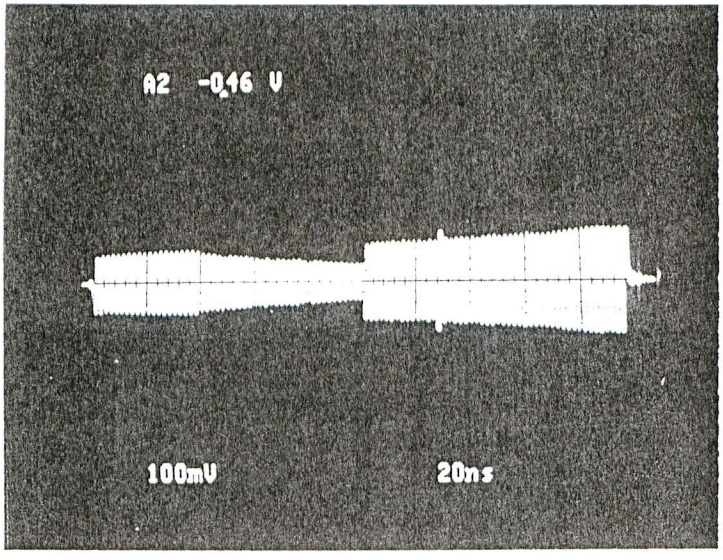


~4mA/bunch with 2ns spacing

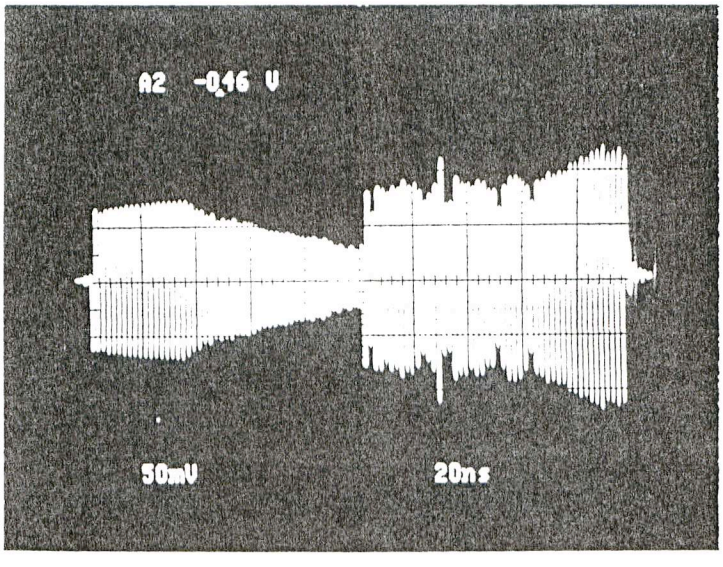
# of bunches is about 100

376 mA in total

What happen to the bunches when the feedback was turned off

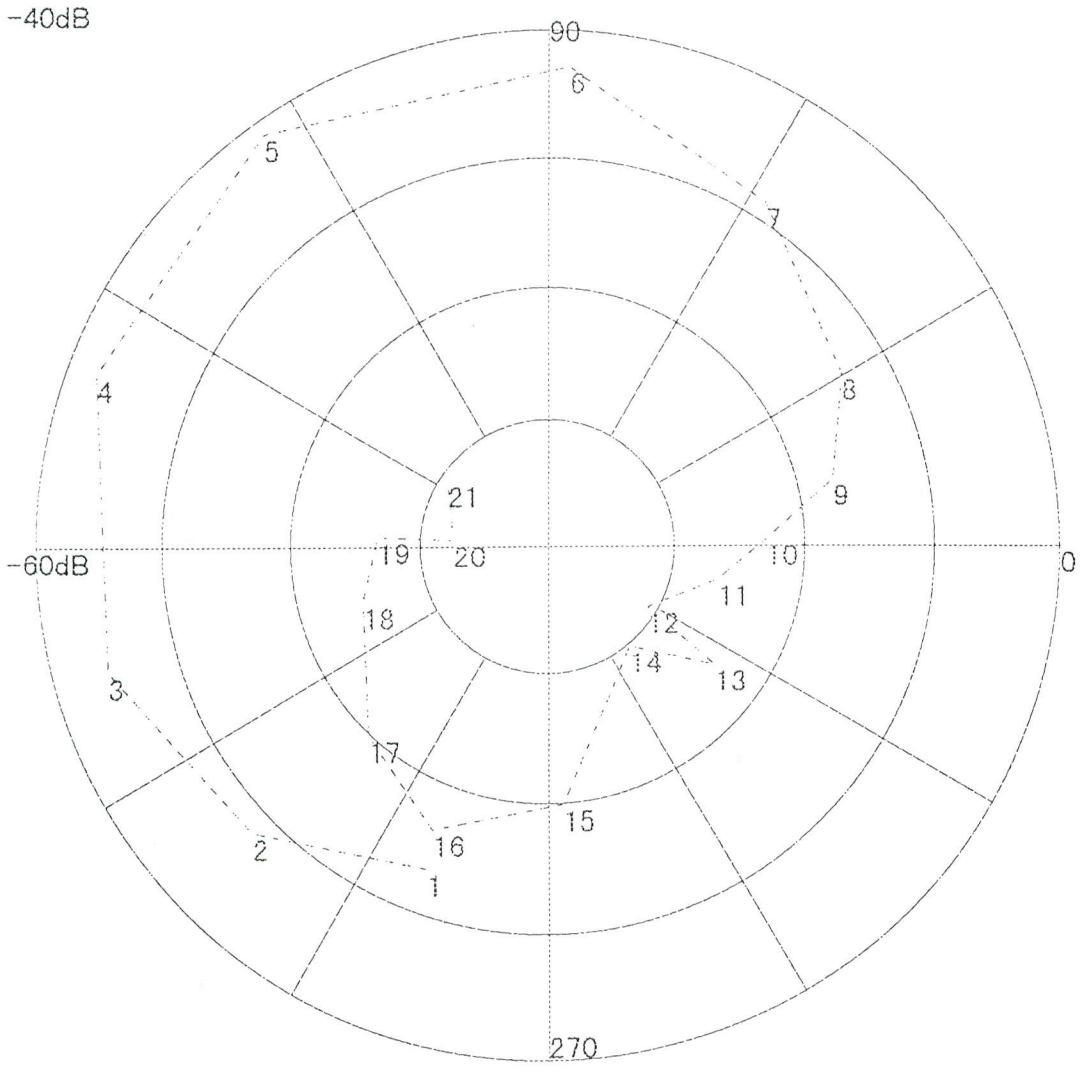


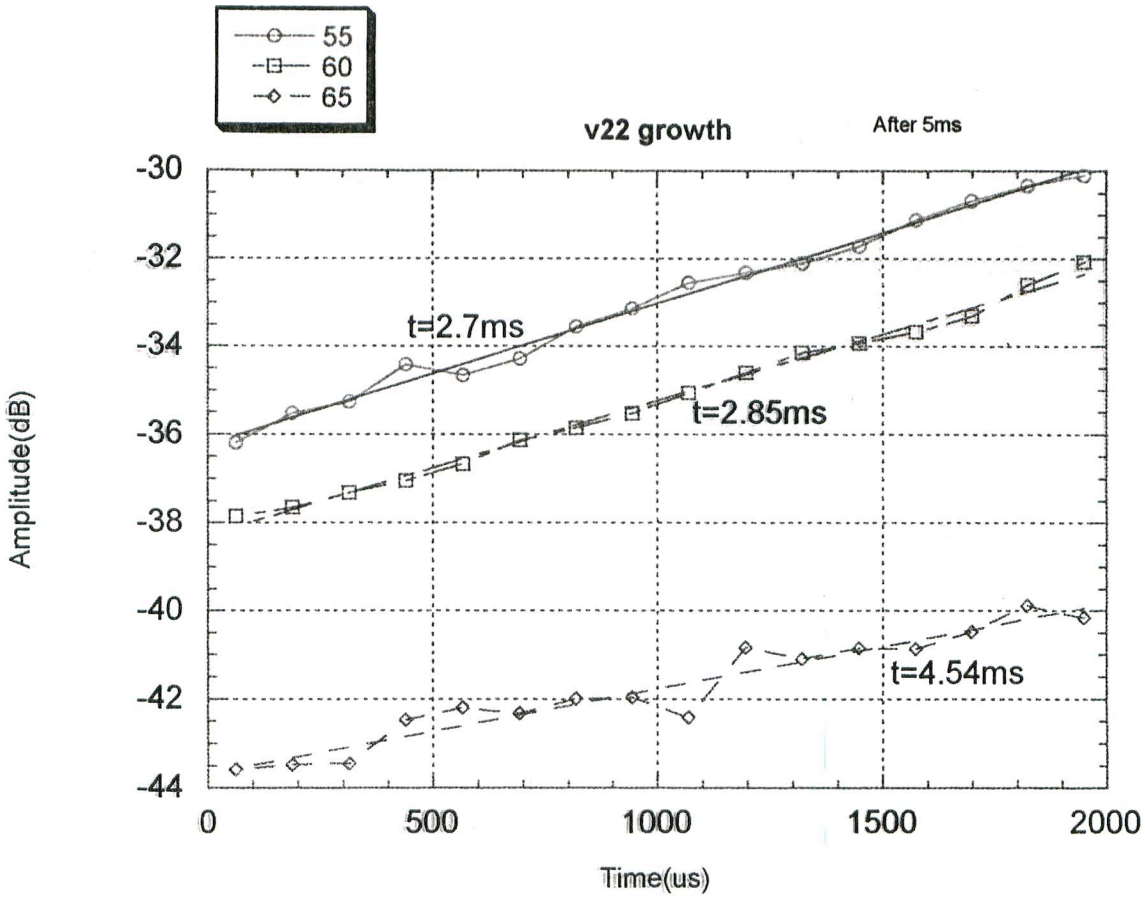
horizontal feedback on /vertical off (100mV/div)

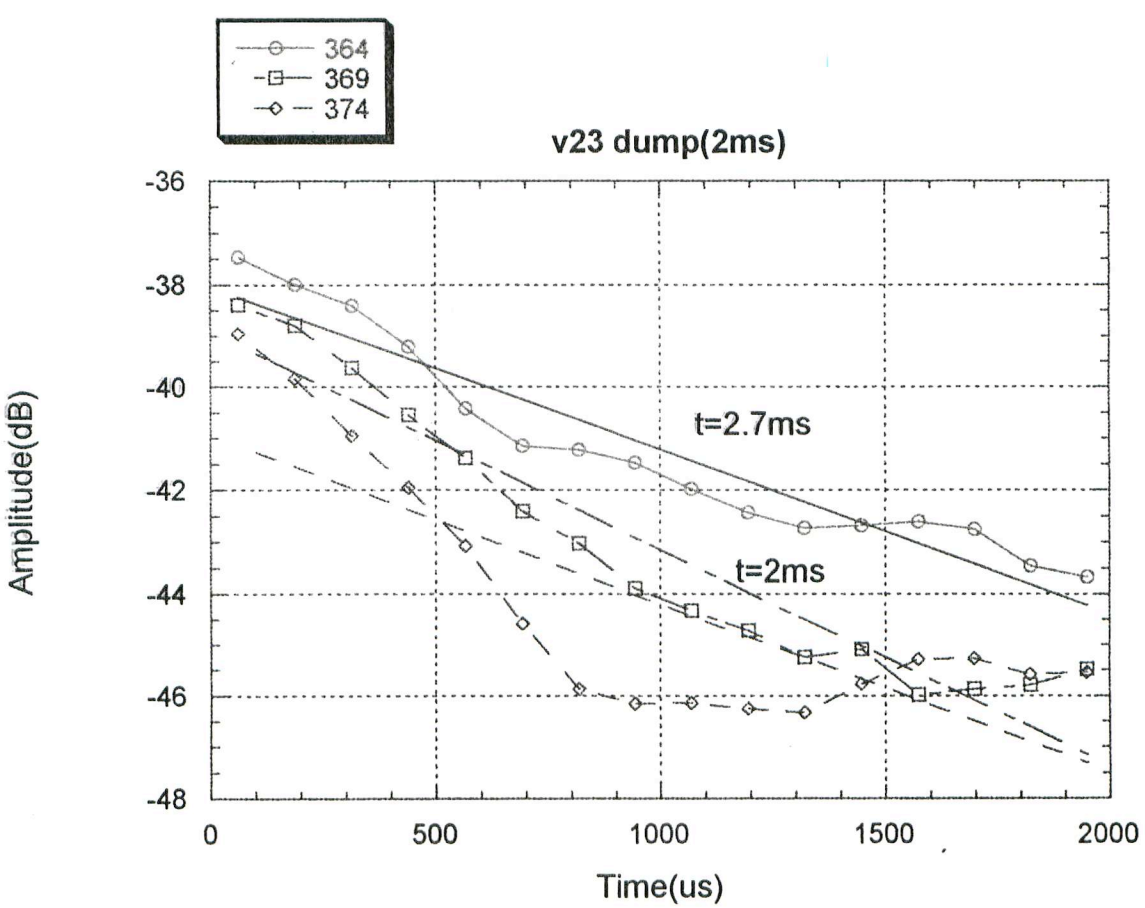


both horizontal and vertical off (50mV/div)

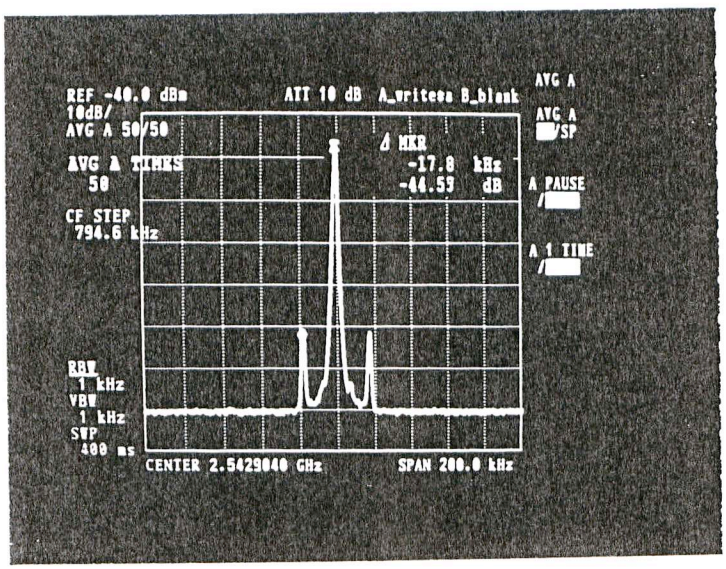
An example of modal analysis of the multi-bunch oscillation based of the date stored in the memory of the 2-tap filter.



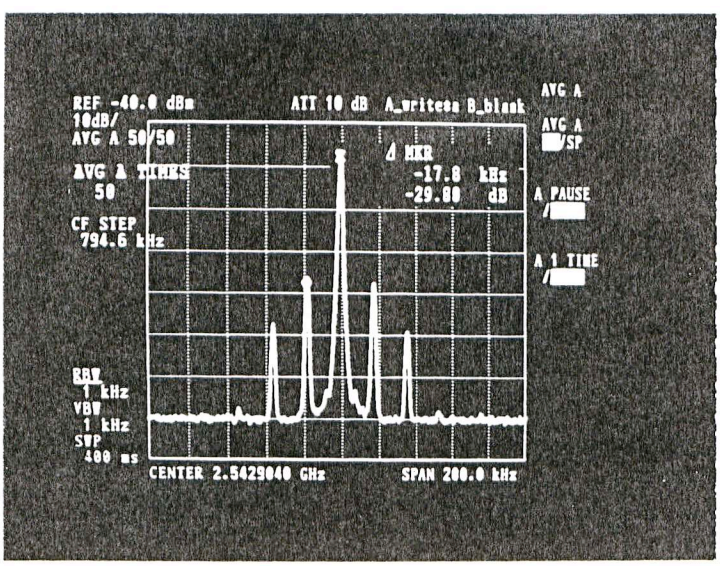

55
60
65
v22 growth
After 5ms
-30
-32
-34
-36
-38
-40
-42
-44
t=2.7ms
t=2.85ms
t=4.54ms
0
500
1000
1500
2000
Amplitude(dB)
Time(us)


364
369
374
v23 dump(2ms)
-36
-38
-40
-42
-44
-46
-48
t=2.7ms
t=2ms
0
500
1000
1500
2000
Amplitude(dB)
Time(us)

Effects of the longitudinal Feedback System



feedback on



feedback off

2ns spacing 2mA x 5 bunches

Photographs of a spectrum analyzer. The center peak corresponds to a multiple of the revolution . We can see the synchrotron side bands. With the feedback on, power of the side bands are reduced by about 15dB.

Summary of the AR Multibunch (High Current) Experiments

For the feedback systems

★ The 2-tap filter version 1 (it works with 2ns bunch spacing) worked and longitudinal feedback system succeeded in suppressing oscillation.

★ The transverse feedback system based on the analog delay worked very well. The maximum storable current was drastically increased with the systems.

In general

★ Some unexpected instabilities occurred in both the transverse and longitudinal planes. The growth rate of these instabilities were rather large.

★ Some machine-physics experiments were carried out. The feedback system was able to contributed to these machine studies.

★ From the memory of the 2-tap filter, bunch oscillation data were stored. These data are very important to analyze the bunch oscillation in time domain.

Studies on the DAΦNE kicker

★ The shunt impedance of the longitudinal kicker might be the key to the successful longitudinal damping.

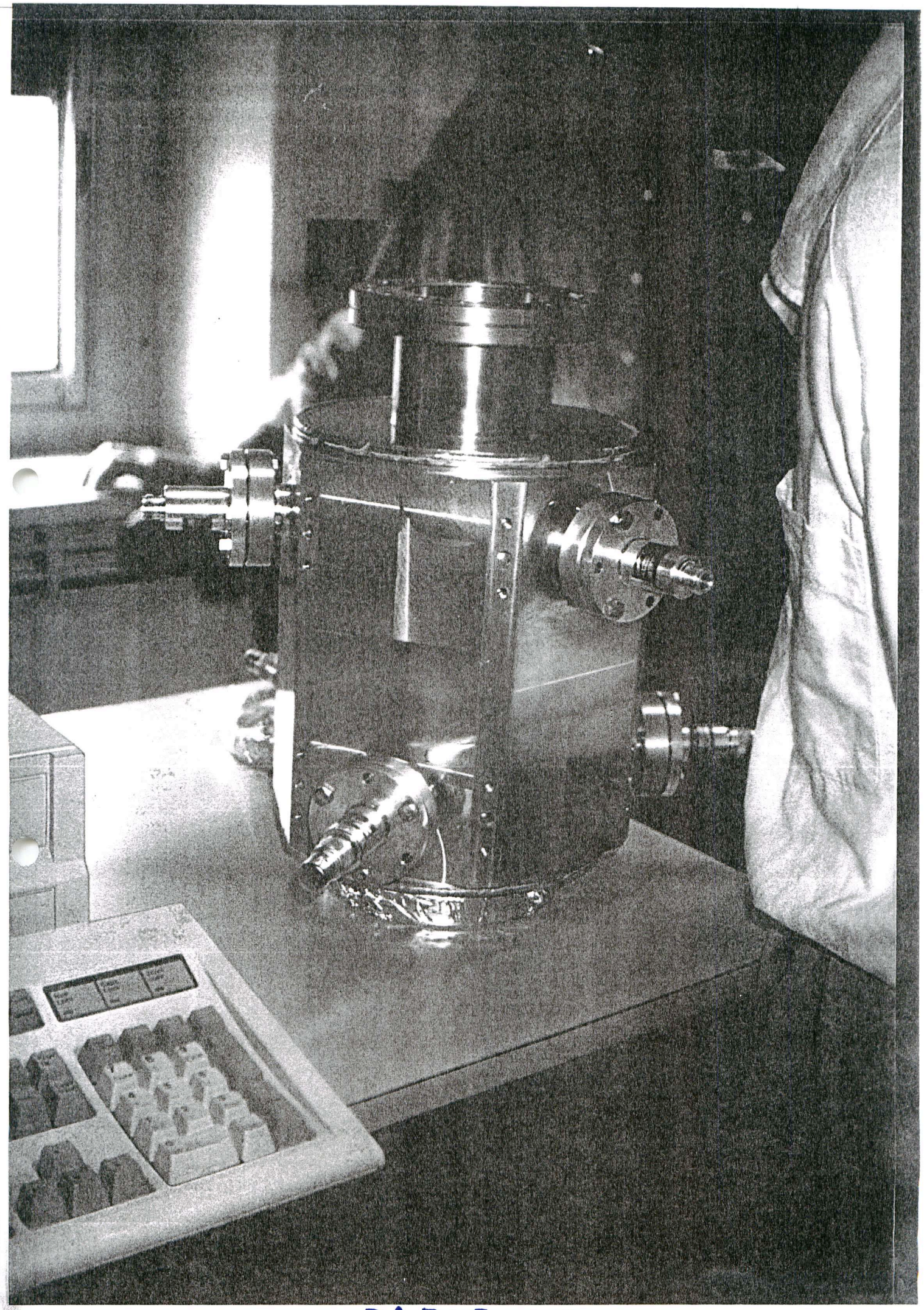
★ We have made R+D of the drift-tube kicker. It will be the first candidate of the longitudinal kicker of KEKB.

★ But some resonator-type kickers may have more shunt impedance than the drift tube kicker.

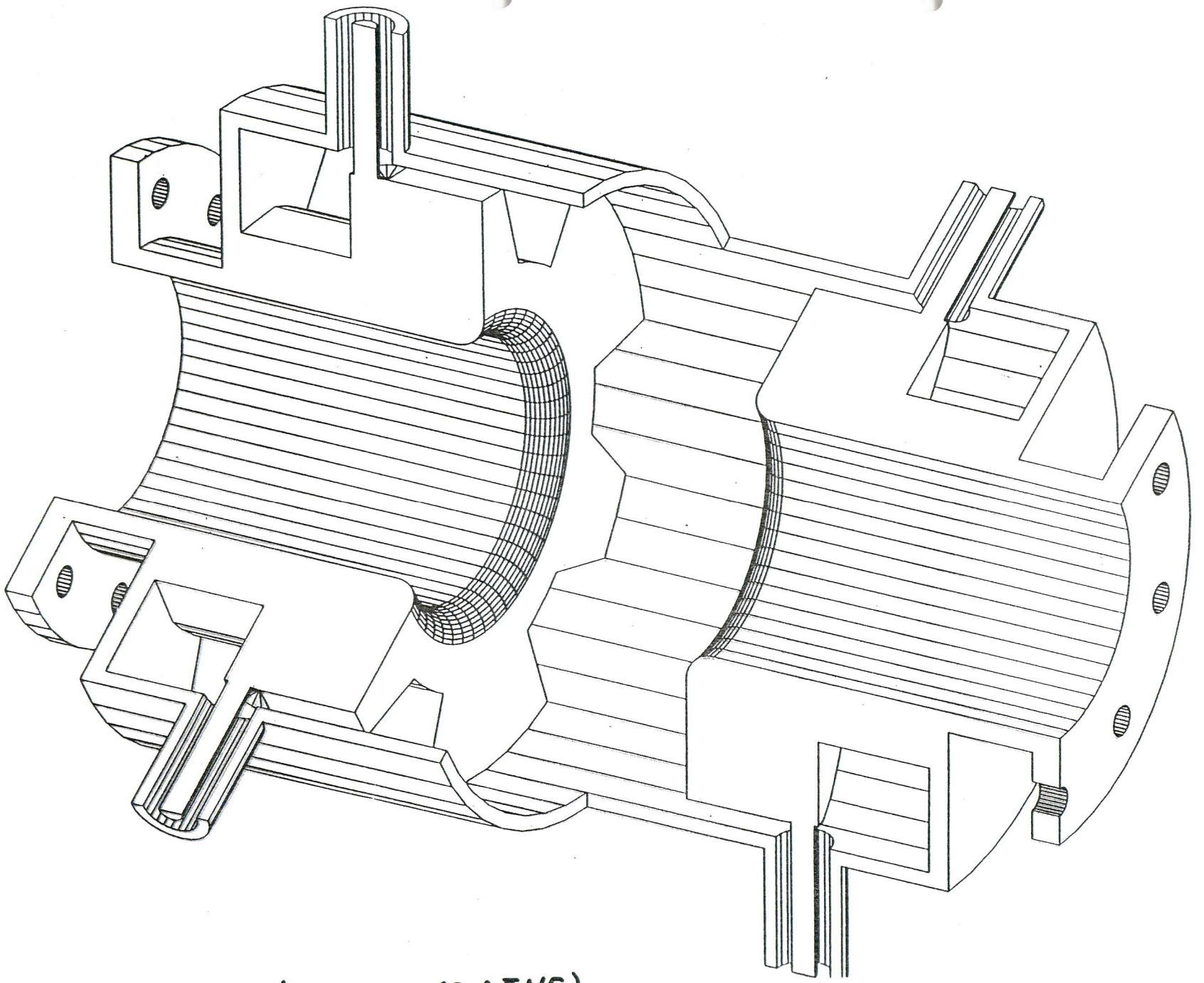
★ One of the such kickers, the DAΦNE type, is the second candidate for the KEKB longitudinal kicker.

Comparison of the longitudinal kickers

	drift tube(2 inner elec.)	DAΦNE
shunt imp.	$\sim 360\Omega$	about 700Ω
band width	very wide	wide
cooling	not easy	easy
circulators	not necessary	necessary
ope. experience	yes (at ALS)	no



DAΦNE kicker



longitudinal kicker (DAΦNE)

Feedback-Related Systems

(1) The memory board
(2) Tune meter
(3) Bunch current monitor

《The memory board》

The *memory board* is a widely applicable transient memory, that can store 5120x4096 data.
It consists of

☆ 500 MHz ADC,
☆ de-multiplexer,
☆ memory chips.

Its mother board is common to the 2-tap filter board.

The tune meter and the bunch current monitor are based on this memory board. It can also be used as a powerful tool of machine experiments.

The version 0 completed recently.

Tune meter

★*While a single bunch is stored,*
a traditional method,
《a tracking analyzer + kicker》
will be used .

★*While multiple bunches are stored and the feedback system works,*
the oscillation of the bunches are stored in the memory board and the fft analysis gives the tune in bunch by bunch manner.

Bunch Current Monitor

The front-end electronics of the bunch current monitor is essentially the same as the longitudinal front-end electronics. Only the phase of the reference signal should be shifted by 90 degrees.

The output of the front-end electronics is digitized and stored in the memory board.

Summary

◆ Some changes have been made since the Design Report:

---- transverse front-end

---- *n* turn delay and betatron phase-adjust

◆ The signal process board (two-tap filter board) completed. And it worked in the AR experiment.

◆ Shunt impedance of the drift tube kicker (version 0) was estimated with beam experiment.

◆ The feedback systems in AR worked in both the transverse and longitudinal directions under the multi-bunch environment.

◆ The DAΦNE kicker will be constructed and be checked.

◆ Development of the feedback-related systems (the memory board, tune meter, bunch current monitor) are in progress.