RF Feedback

· Purpose

To prevent the coupled-bunch instabilities caused by the accelerating mode of detuned cavities.

· Principle

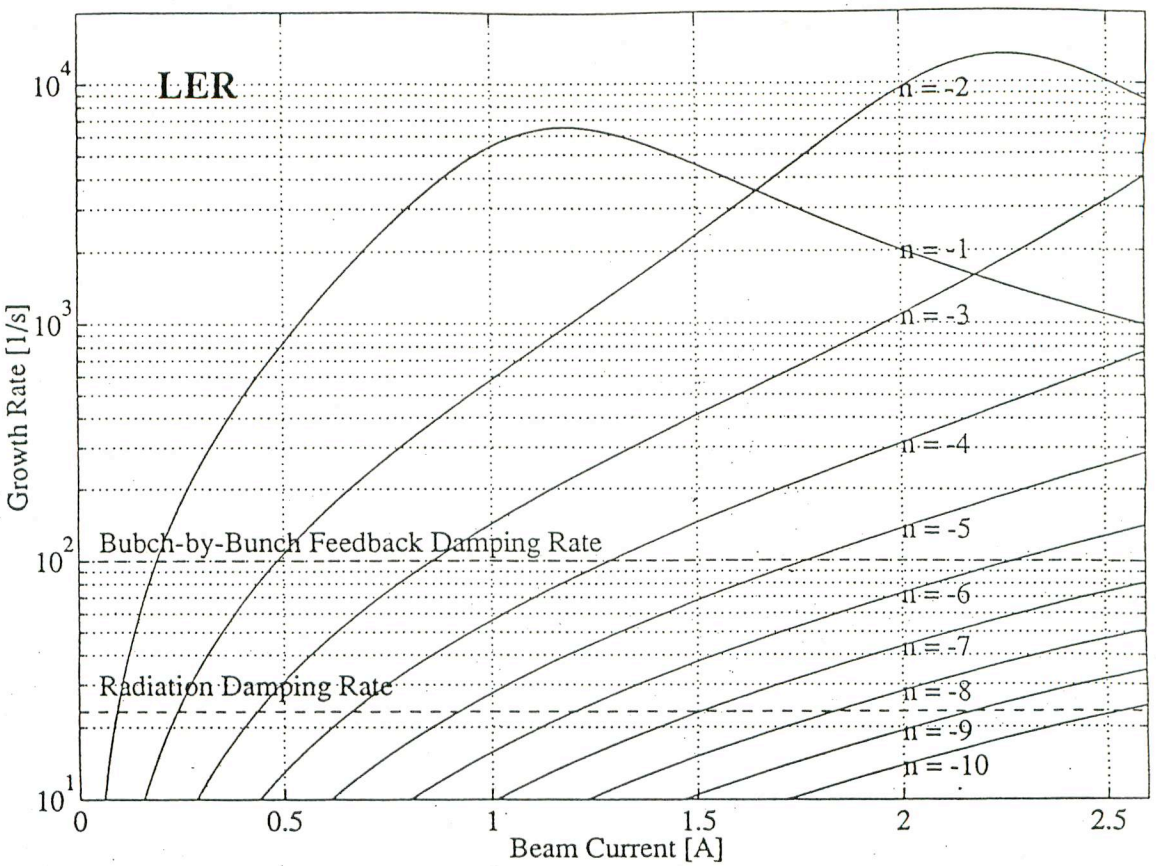
To reduce the effective cavity impedance, which is the cause of the instabilities, by an RF feedback around the klystron and cavity.

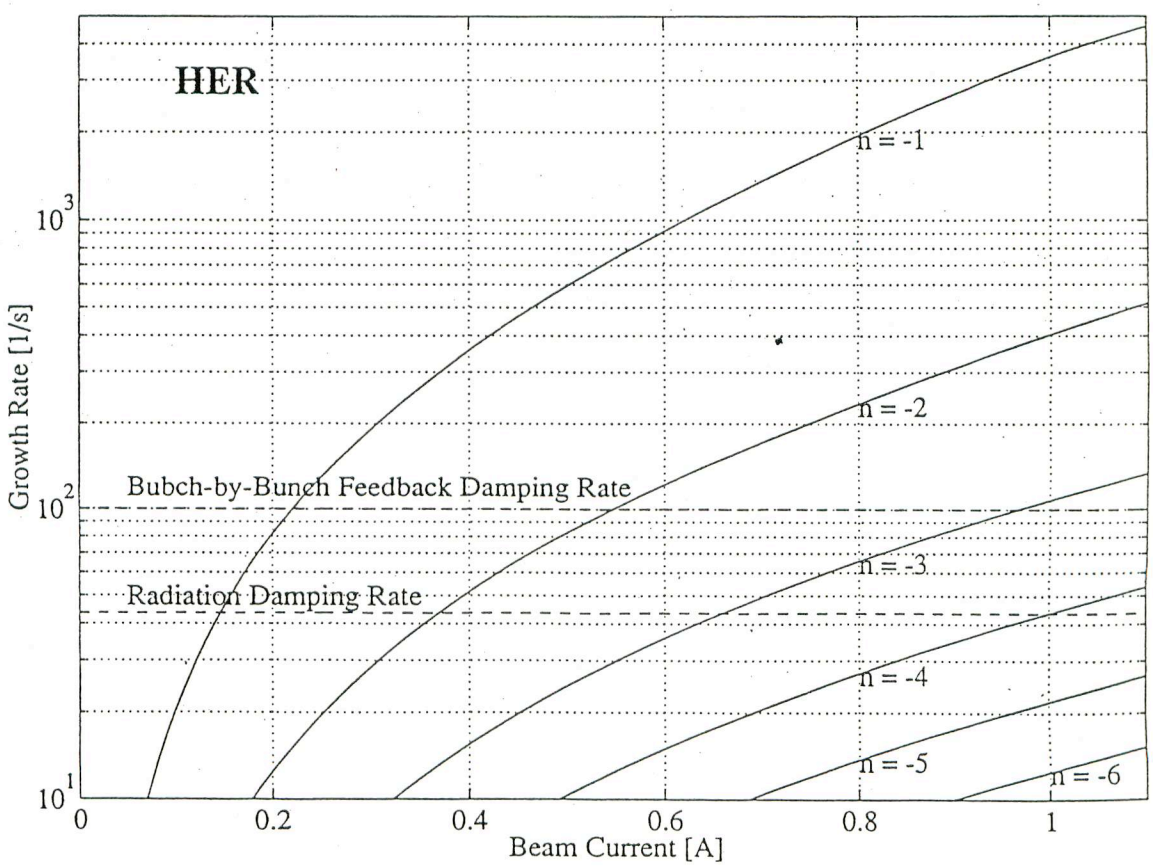
· How much must the impedance be reduced ?

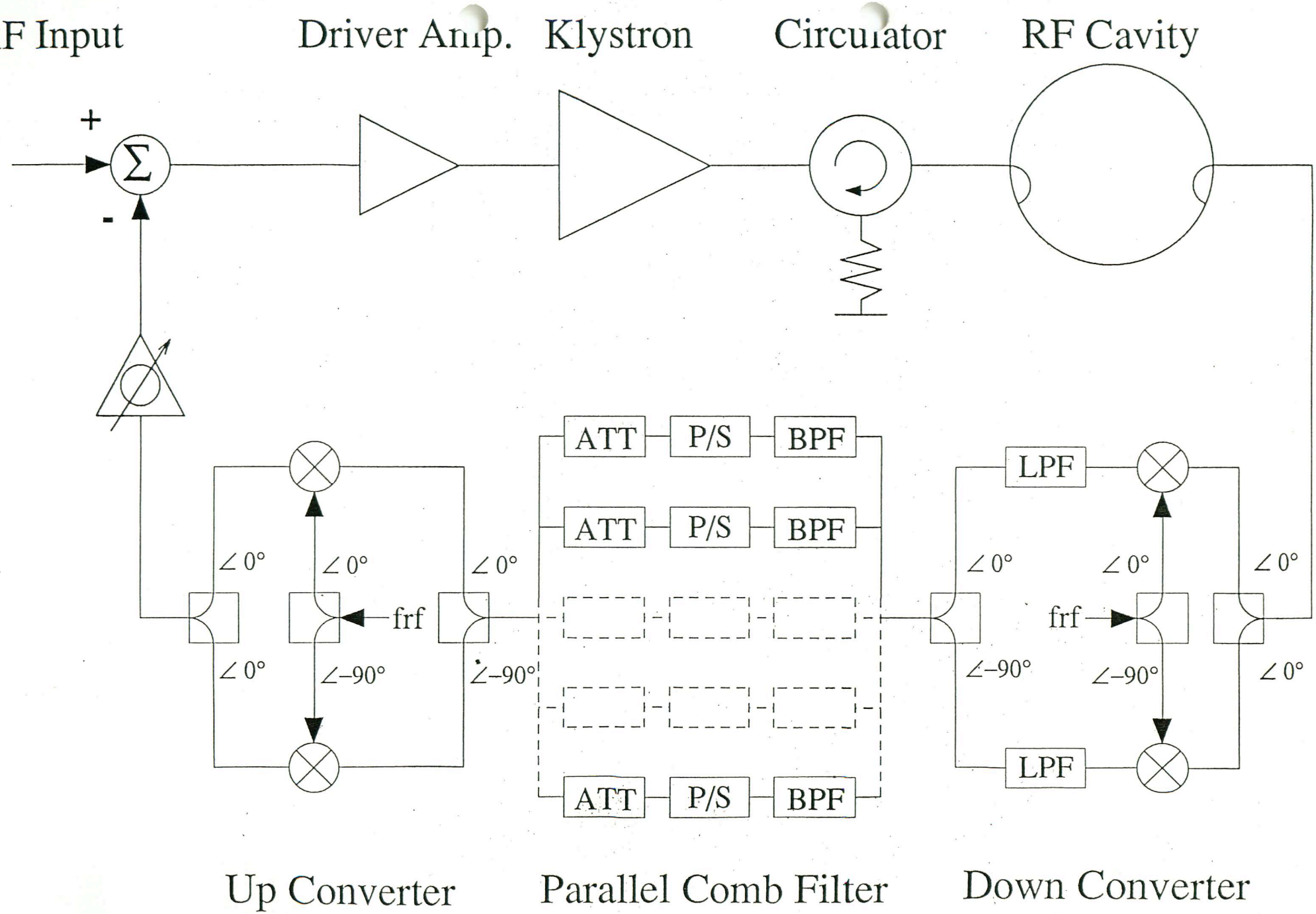
	expected growth time		Re[Z] must be
	LER	HER	reduced to
ARES	30~50 ms	100~180 ms	1/1
SCC	0.3~14	23~54	≒ 1/20
CMC (choke-mode cavity)	0.05~0.2	0.1~0.3	≒ 1/100
Bunch-feedback damping time	10 ms	10 ms	
Radiation damping time	43(23) ms	23 ms	

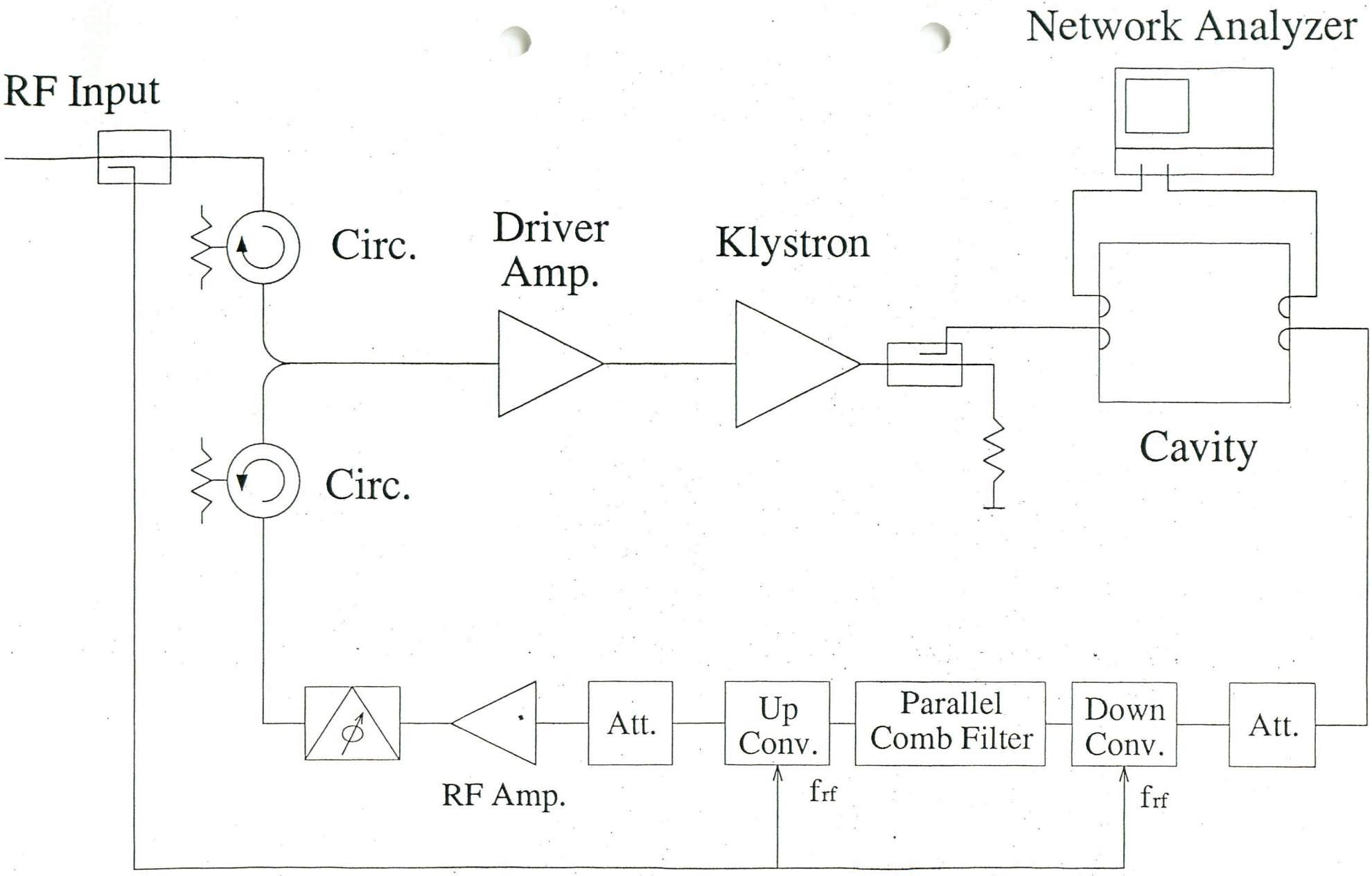
Table 1.1: Parameters used in the instability calculations

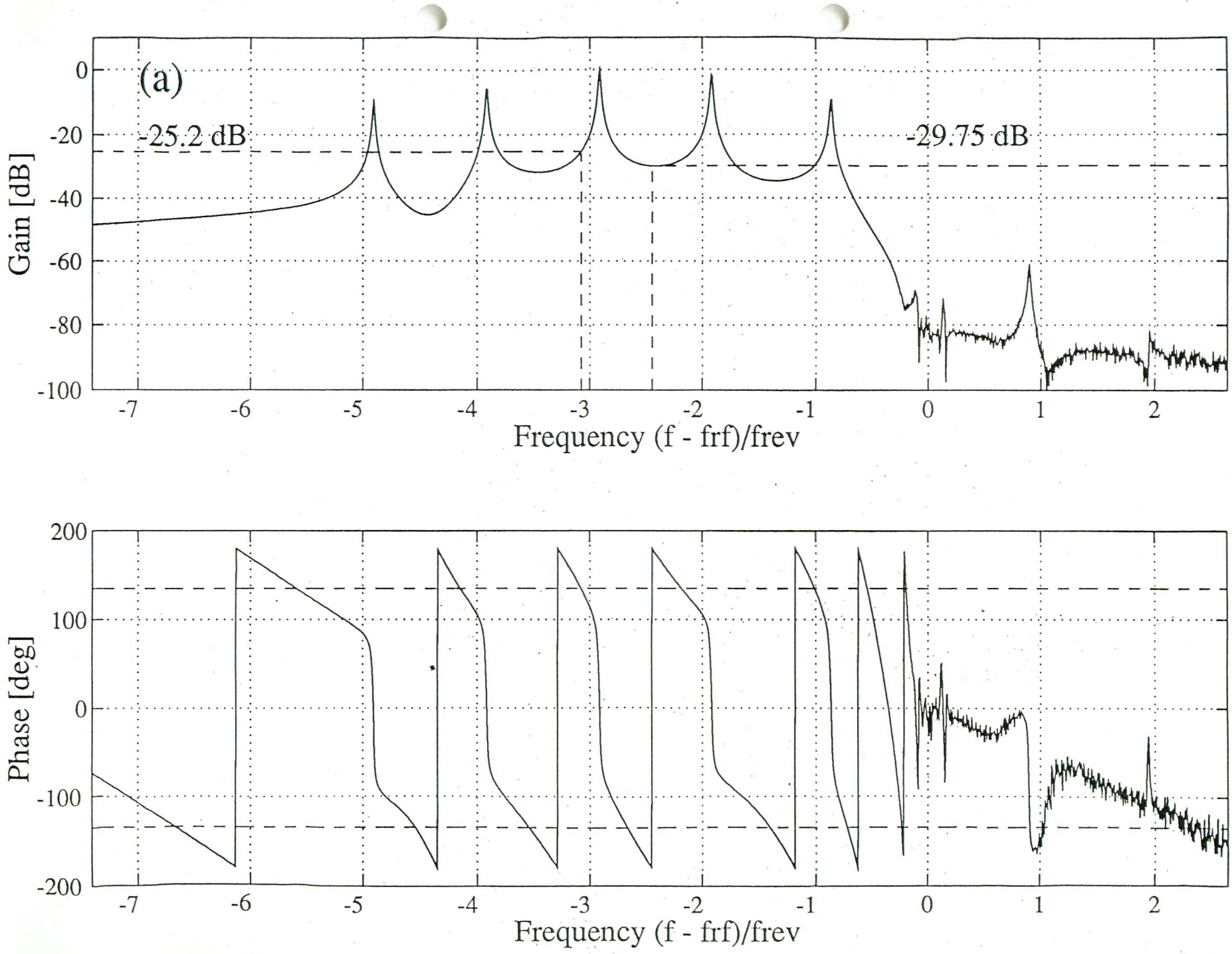
		LER	HER	
Type of cavity		accelerating cavity of ARES		
Total cavty voltage	V_c	8.6	15.7	MV
Number of cells	N_c	20	32	
Cavity voltage/cell	V_c/cell	0.43	0.49	MV/cell
Shunt impedance/cell	$R_{\rm sh}$	5.3		MΩ
Unloaded Q	Q_0	35000		
R/Q		147		Ω
Maximum frequency detuning	Δf	−232	−82	kHz
Synchrotron frequency	f_s	1.7	1.6	kHz
Energy loss/turn	U_0	0.81	3.5	MeV

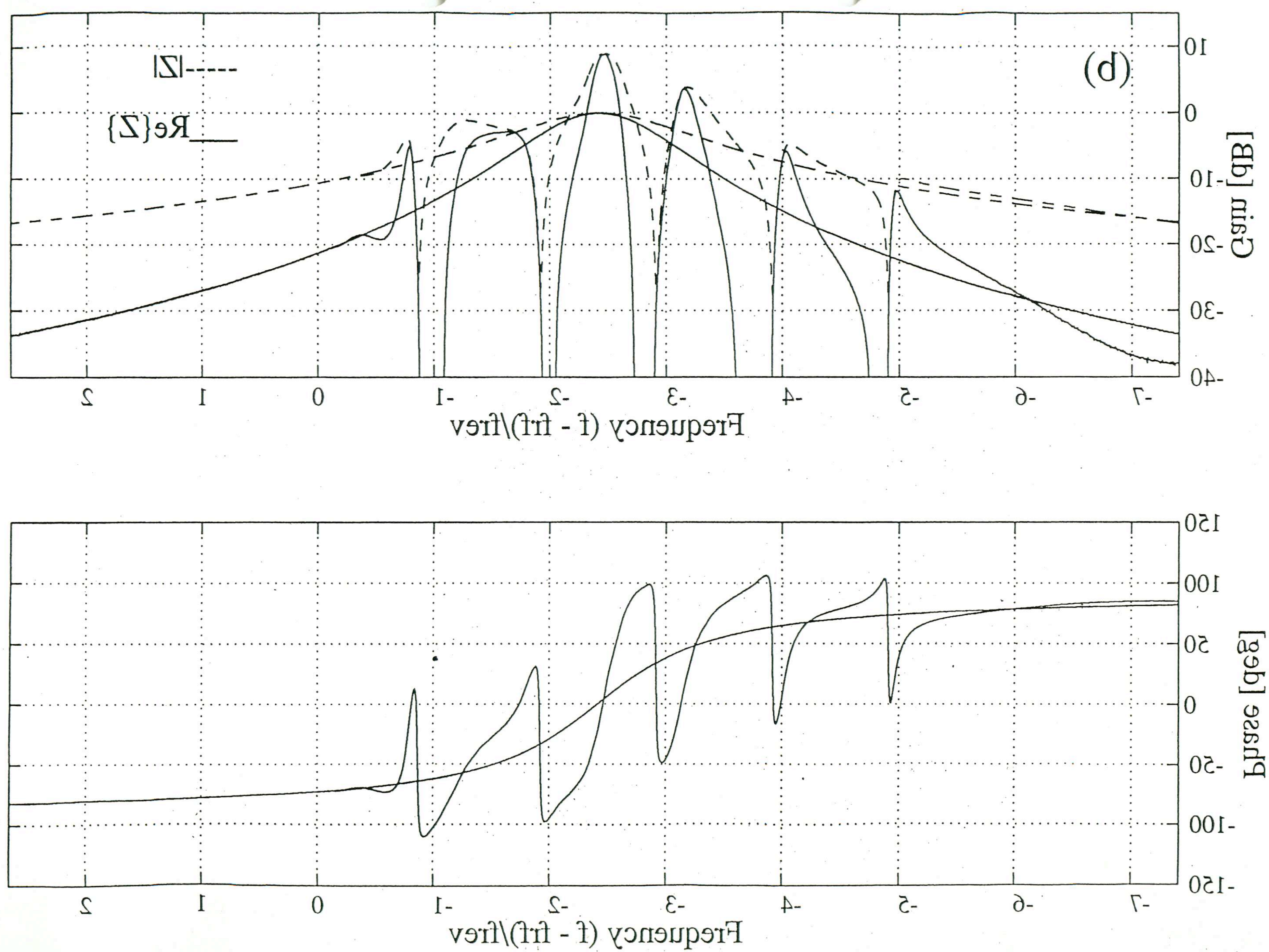

LER
Growth Rate [1/s]
Beam Current [A]
Bubch-by-Bunch Feedback Damping Rate
Radiation Damping Rate
n = -1
n = -2
n = -3
n = -4
n = -5
n = -6
n = -7
n = -8
n = -9
n = -10


HER
Growth Rate [1/s]
Beam Current [A]
Bubch-by-Bunch Feedback Damping Rate
Radiation Damping Rate
n = -1
n = -2
n = -3
n = -4
n = -5
n = -6


RF Input
Driver Amp.
Klystron
Circulator
RF Cavity
+
Σ
-
ATT
P/S
BPF
ATT
P/S
BPF
ATT
P/S
BPF
LPF
LPF
∠ 0°
∠ 0°
∠ 0°
frf
∠ 0°
∠–90°
∠–90°
∠ 0°
∠ 0°
∠ 0°
frf
∠–90°
∠–90°
∠ 0°
Up Converter
Parallel Comb Filter
Down Converter


Network Analyzer
RF Input
Circ.
Driver Amp.
Klystron
Cavity
Circ.
Att.
Up Conv.
Parallel Comb Filter
Down Conv.
Att.
RF Amp.
frf
frf


(a)
-25.2 dB
-29.75 dB
Gain [dB]
0
-20
-40
-60
-80
-100
-7
-6
-5
-4
-3
-2
-1
0
1
2
Frequency (f - frf)/frev
Phase [deg]
200
100
0
-100
-200
-7
-6
-5
-4
-3
-2
-1
0
1
2
Frequency (f - frf)/frev


(b)
|Z|-----
Re{Z}___
Gain [dB]
Phase [deg]
Frequency (f - frf)/frev
Frequency (f - frf)/frev

The real part of the impedance and growth time of coupled bunch instabilities with / without parallel comb feedback

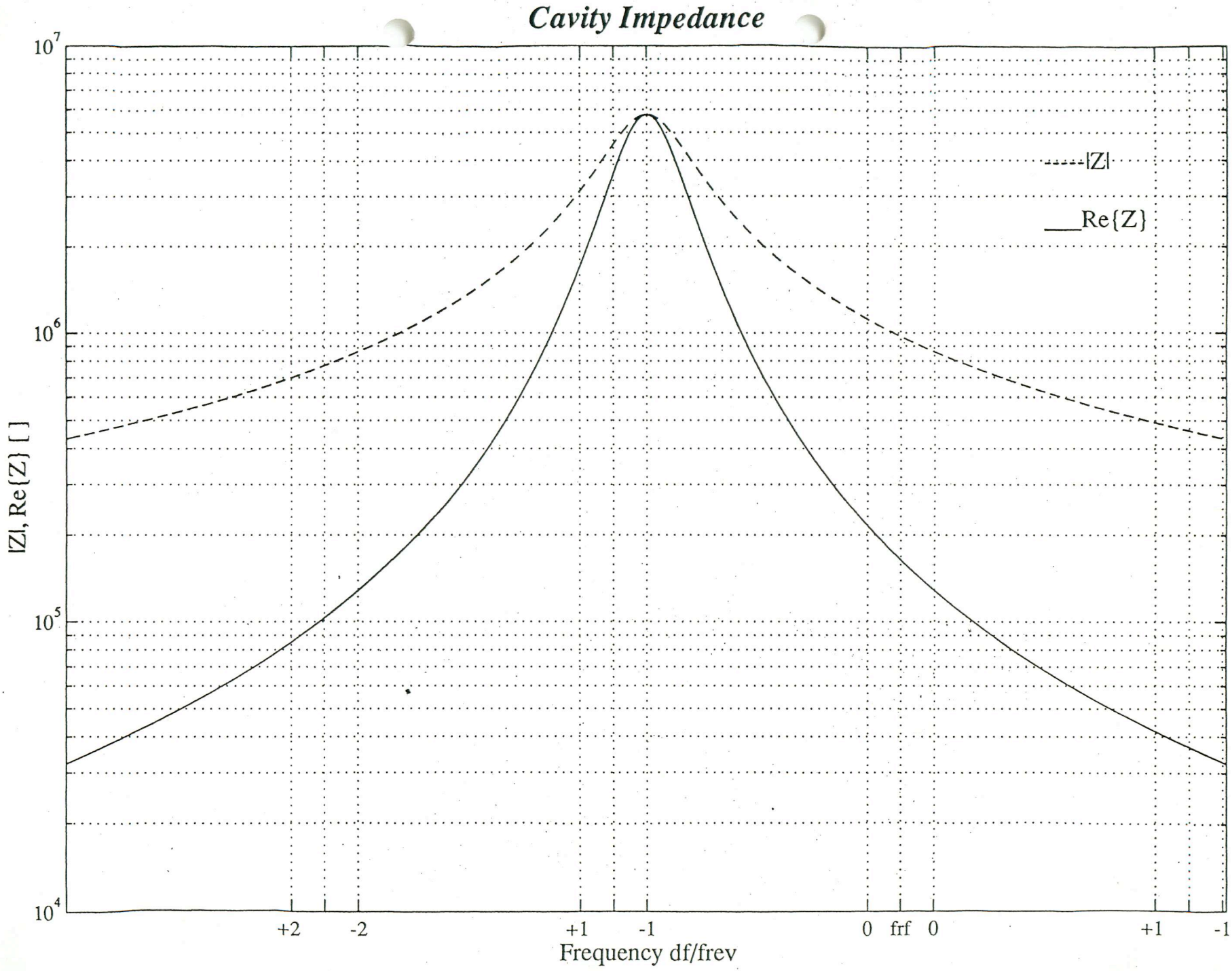
Mode	without feedback			with feedback		
	$Re\{Z_+\}$ [kΩ]	$Re\{Z_-\}$ [kΩ]	Growth Time [ms]	$Re\{Z_+\}$ [kΩ]	$Re\{Z_-\}$ [kΩ]	Growth Time [ms]
-1	60.36	12.76	0.63	11.27	12.76	-20.16
-2	211.46	7.73	0.15	17.23	7.73	3.15
-3	163.33	5.16	0.19	10.63	5.16	4.48
-4	48.18	3.69	0.67	6.08	3.69	12.55
-5	20.56	2.76	1.68	3.43	2.76	45.18

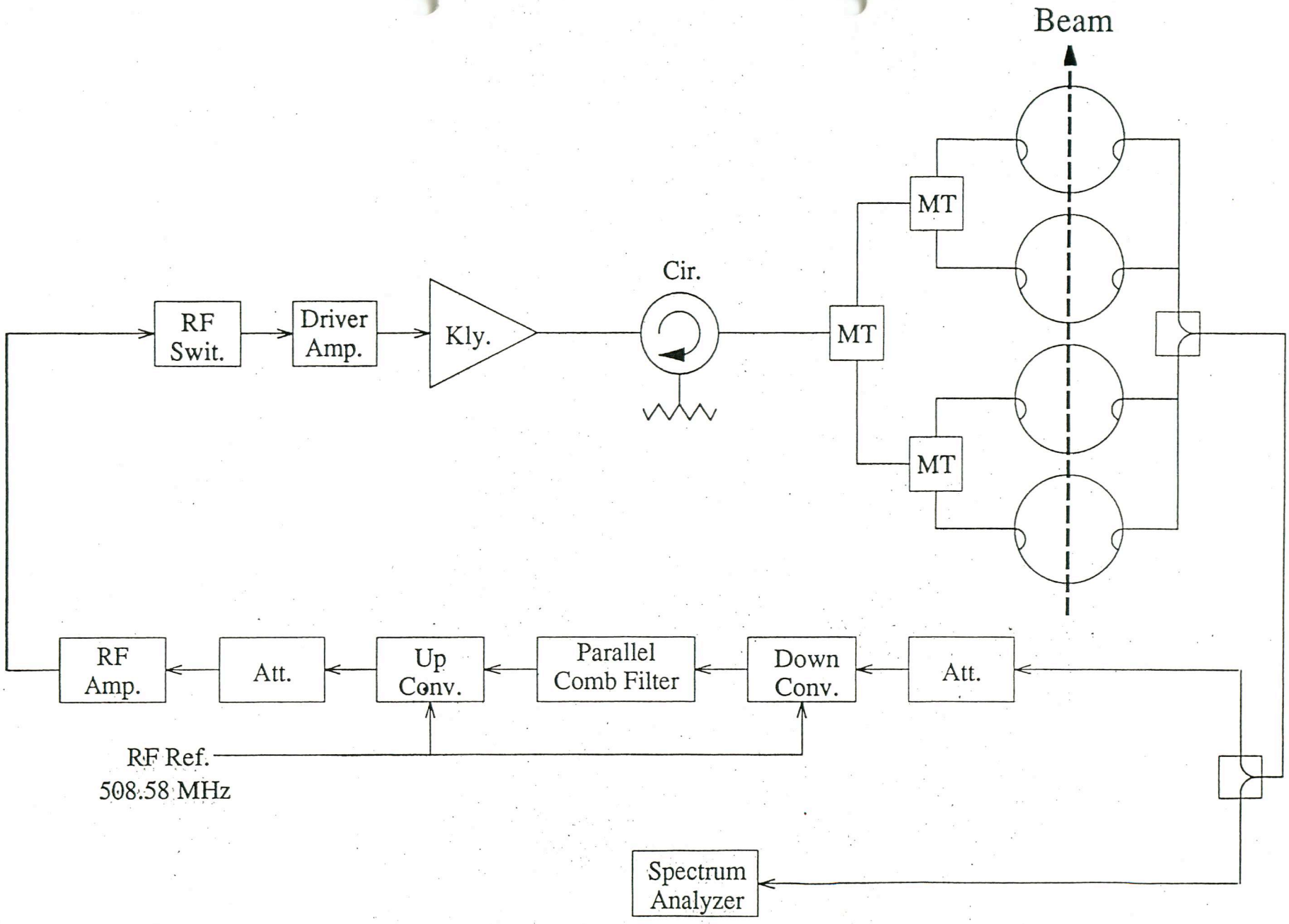
Beam test of RF Feedback in TRISTAN MR

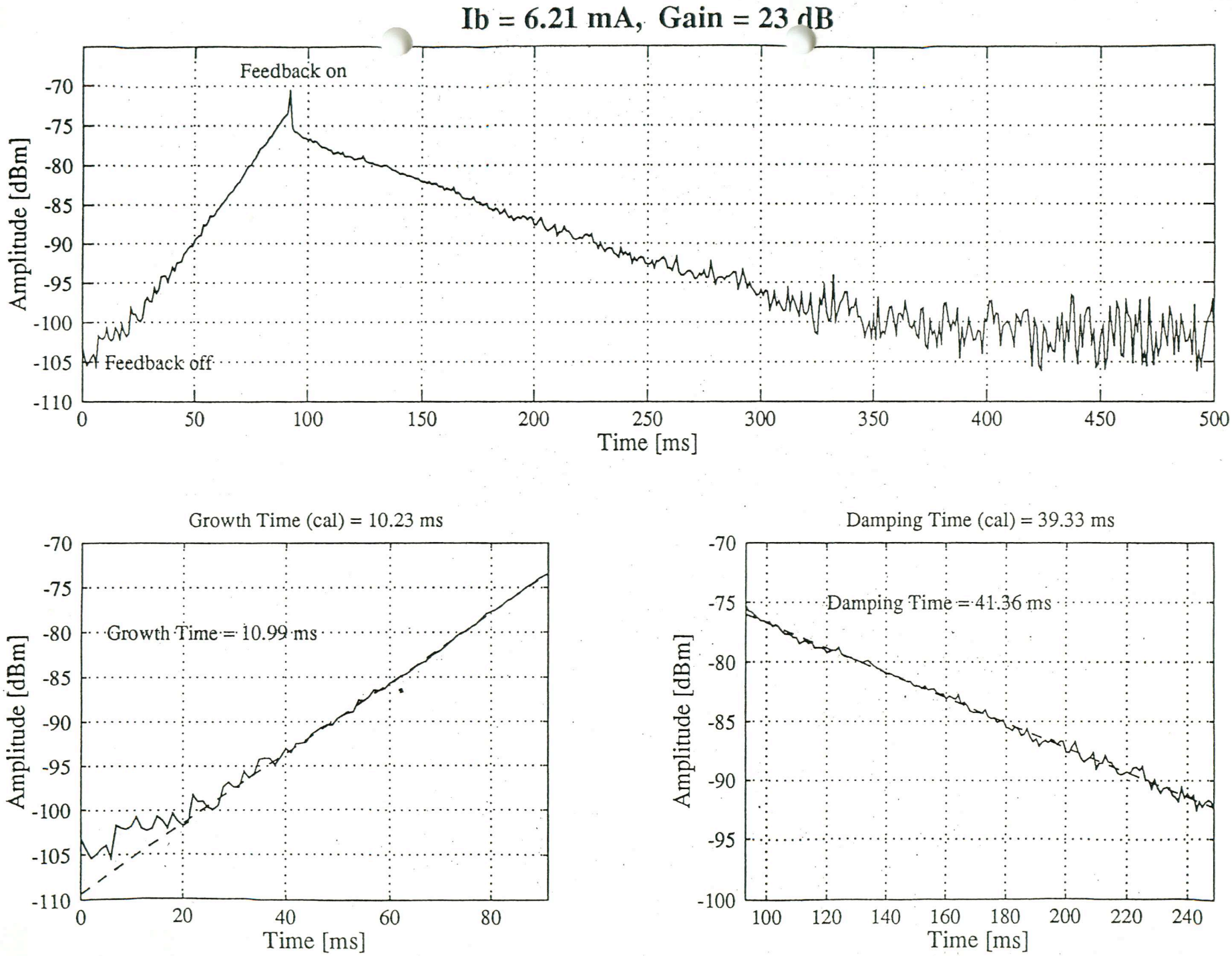
- Four idling 9-cell cavities were detuned by 88 kHz(=frev-fs) to excite -1 mode.
- The estimated growth time of -1 mode is 6.8 ms, while the radiation damping time is 20 ms.

[parameters]

e^- beam energy	8	GeV
e^- beam current	6	mA
number of bunches	4	
RF frequency	508.6	MHz
Revolution frequency (frev)	100	kHz
Synchrotron frequency (fs)	11.6	kHz
Detuning frequency (Δf)	-87.7	kHz
Shunt impedance of 4 cavities	239	MΩ
Coupling factor	1.3	
Growth time of -1 mode	6.8	ms
Radiation damping time	20	ms


Cavity Impedance
10^7
10^6
10^5
10^4
|Z|, Re{Z} [ ]
|Z|
Re{Z}
+2
-2
+1
-1
0
frf
0
+1
-1
Frequency df/frev


Beam
MT
MT
MT
Cir.
RF
Swit.
Driver
Amp.
Kly.
RF
Amp.
Att.
Up
Conv.
Parallel
Comb Filter
Down
Conv.
Att.
RF Ref.
508.58 MHz
Spectrum
Analyzer


Ib = 6.21 mA, Gain = 23 dB
Feedback on
Feedback off
Amplitude [dBm]
Time [ms]
-70
-75
-80
-85
-90
-95
-100
-105
-110
0
50
100
150
200
250
300
350
400
450
500
Growth Time (cal) = 10.23 ms
Growth Time = 10.99 ms
Amplitude [dBm]
Time [ms]
0
20
40
60
80
Damping Time (cal) = 39.33 ms
Damping Time = 41.36 ms
Amplitude [dBm]
Time [ms]
100
120
140
160
180
200
220
240

Summary of RF feedback

1.System

- RF feedback with comb-filter will be prepared as a backup scheme of ARES.
  (1) Parallel comb-filter (an array of resonators), each resonator of which is tuned at $nf_{rev}+f_s$, is used to compensate long group delays.
  (2) Feedback is done only in the lower side of f_{rf} to make the system simple.
  (3) As an instability-signal source, either cavity voltage or bunch signal is used.
  (4) Picked-up voltages at nf_{rev} are not fed back to avoid the increase in peak klystron power.

- Direct RF feedback only around f_{rf} will be used to ease the beam loading effects on the fundamental mode operation.

2. Work to be done in a few years

(1) Impedance reduction test on the cavity under high power operation.
(2) Development of a new parallel comb-filter.
(3) Improvement of the loop gain.
(4) Development of a digital parallel comb-filter.
(5) Simulation of RF feedback including the beam and klystron.
(6) Beam test of RF feedback in TRISTAN Accumulation ring.
(7) Others