The ATLAS Fast Tuner Design

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Fast Tuner Development Participants

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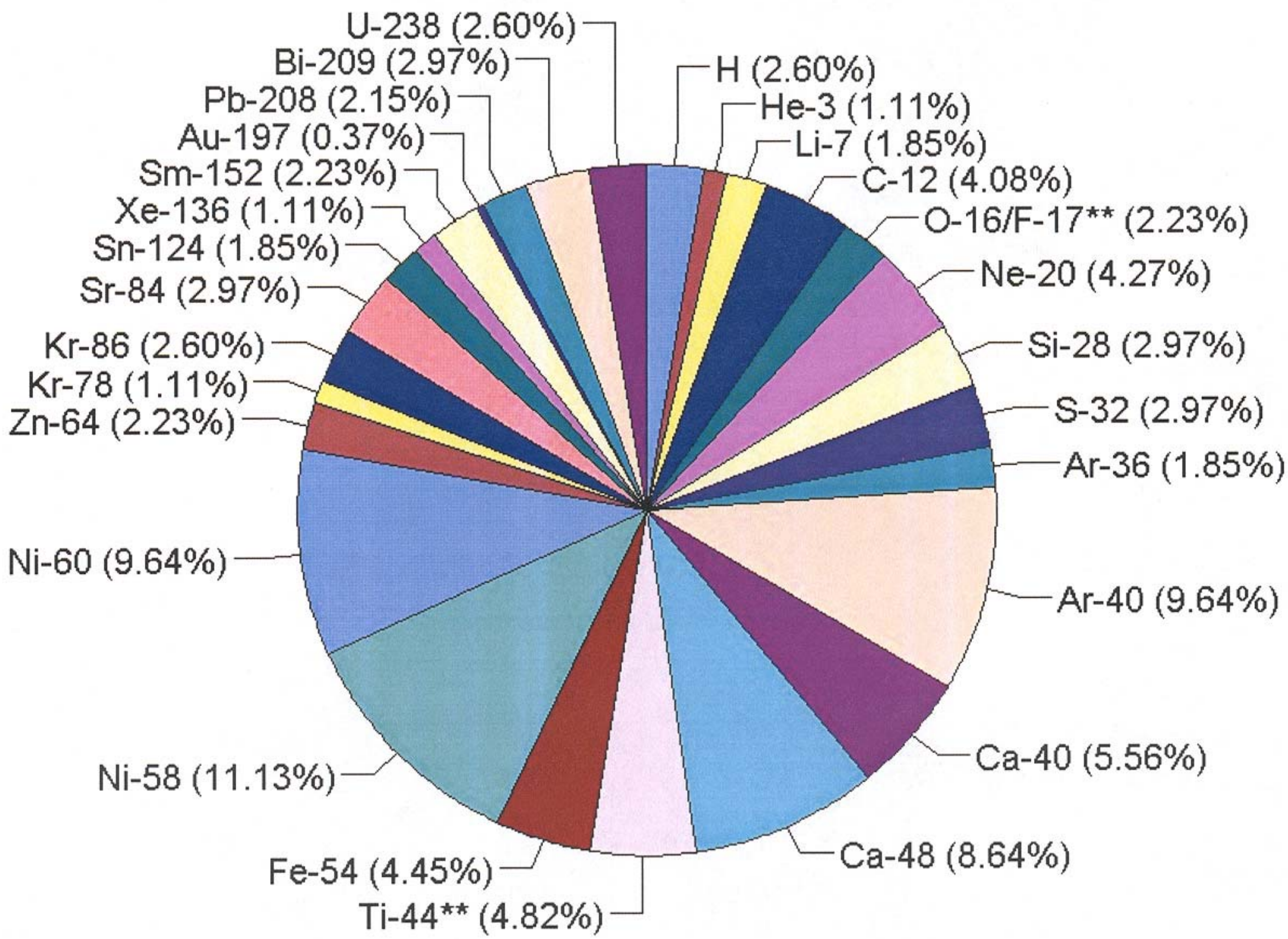
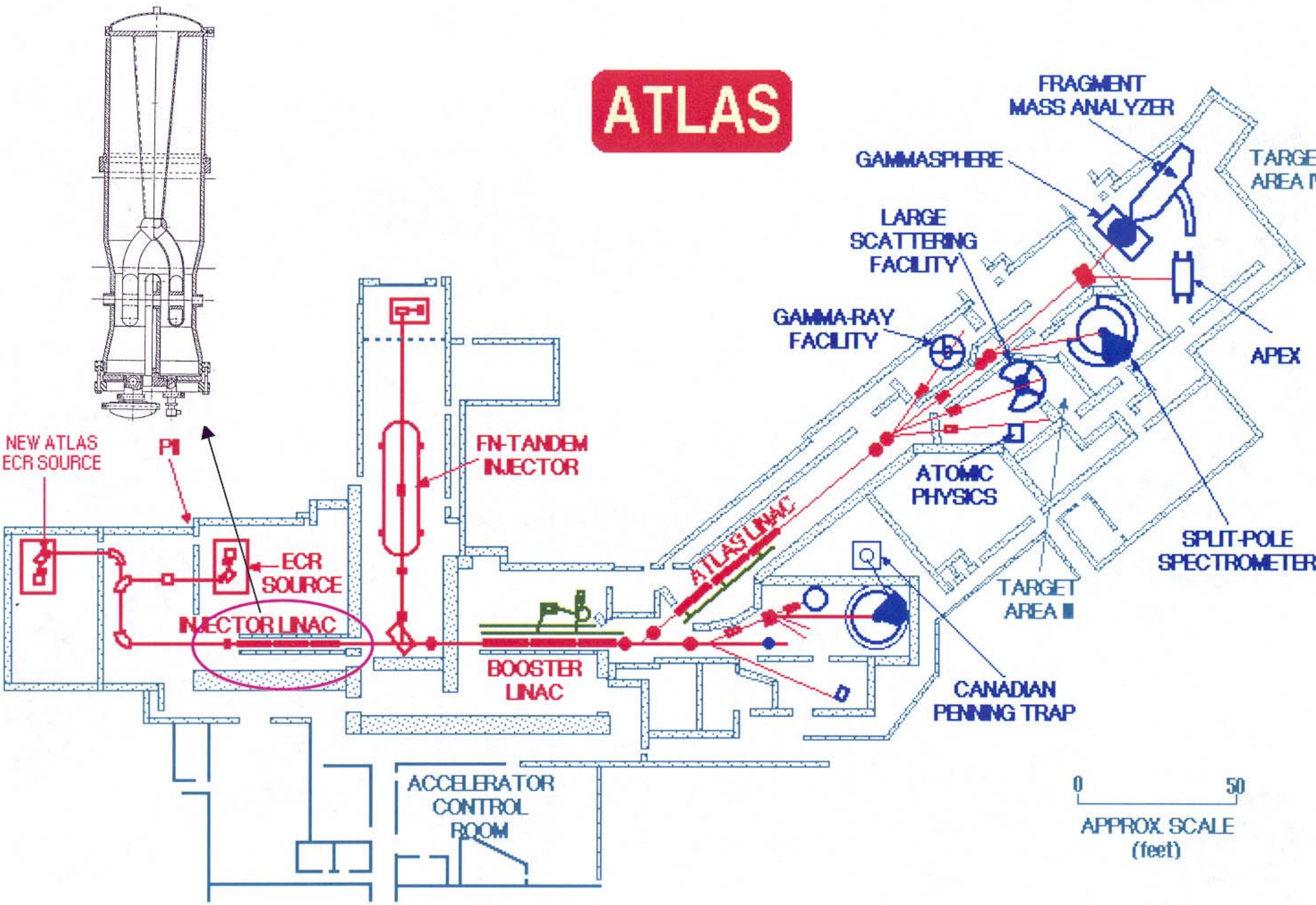
ATLAS

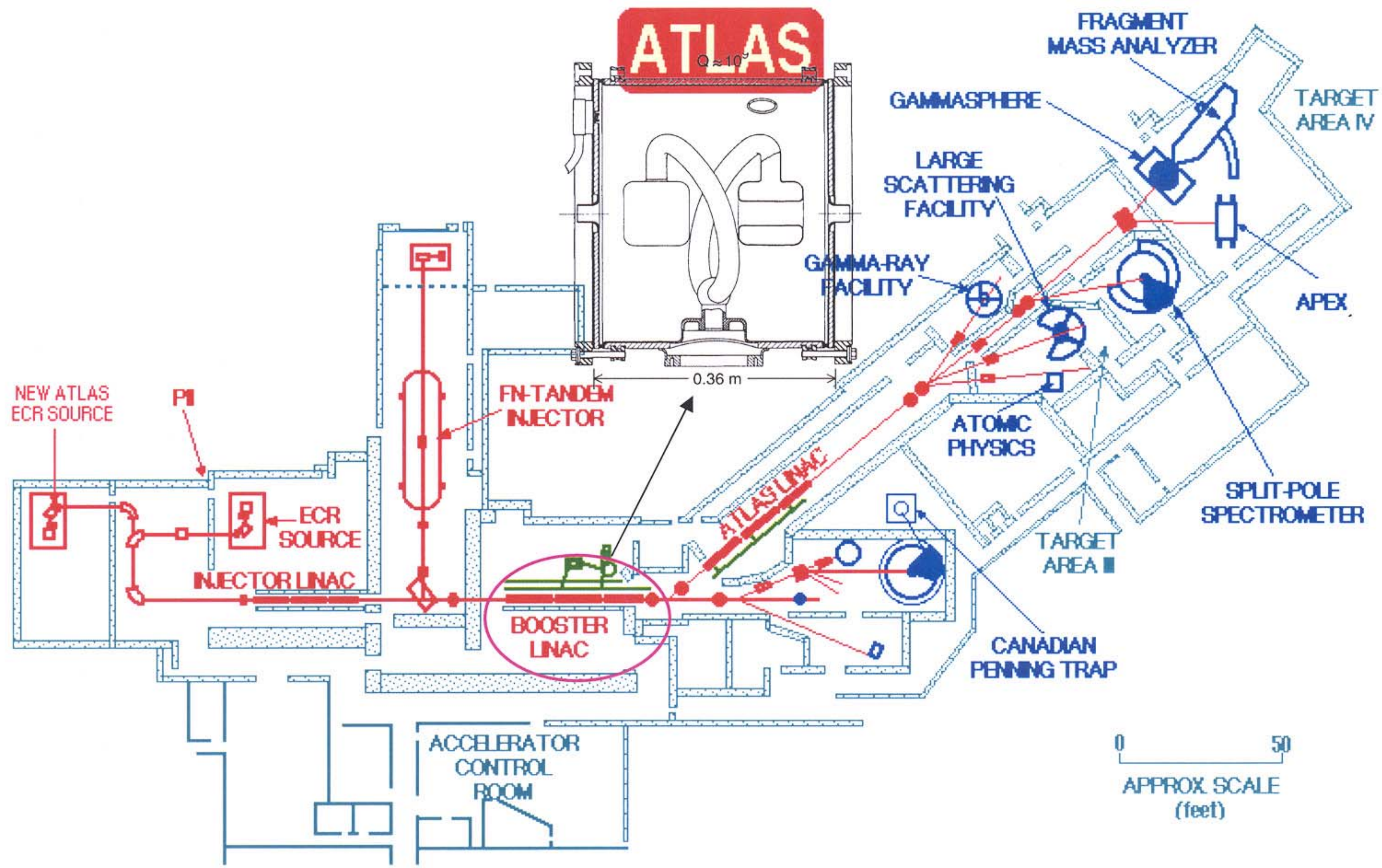
Argonne Tandem Linac Accelerator System

- Medium energy heavy-ion accelerator
  - Elements from A = 1 to A = 238
  - Energy range variable up to ~10 MeV/A
- Comprised of superconducting split-ring and inter-digital accelerating cavities
- Cavity frequencies range from 48.5 MHz to 97 MHz
- Typical operation of 6000 hours beam on target per year
- DOE national user facility

ATLAS BEAMS FY2000




ATLAS
FRAGMENT MASS ANALYZER
GAMMASPHERE
TARGET AREA IV
LARGE SCATTERING FACILITY
GAMMA-RAY FACILITY
APEX
NEW ATLAS ECR SOURCE
PII
FN-TANDEM INJECTOR
ATOMIC PHYSICS
ATLAS LINAC
SPLIT-POLE SPECTROMETER
ECR SOURCE
TARGET AREA III
INJECTOR LINAC
BOOSTER LINAC
CANADIAN PENNING TRAP
ACCELERATOR CONTROL ROOM
0
50
APPROX. SCALE (feet)


ATLAS
0.36 m
FRAGMENT
MASS ANALYZER
GAMMASPHERE
TARGET
AREA IV
LARGE
SCATTERING
FACILITY
GAMMA-RAY
FACILITY
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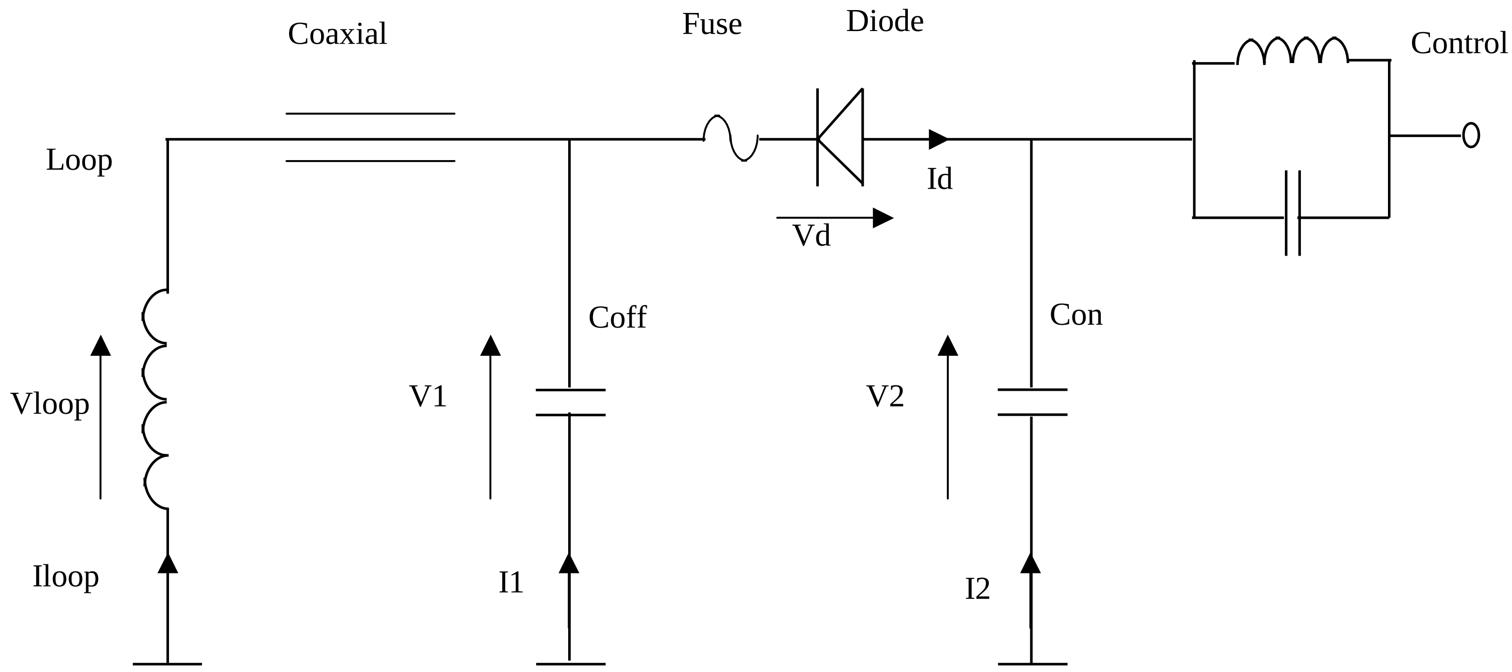
ACCELERATOR
CONTROL
ROOM
0
50
APPROX. SCALE
(feet)

Fast Tuner Description

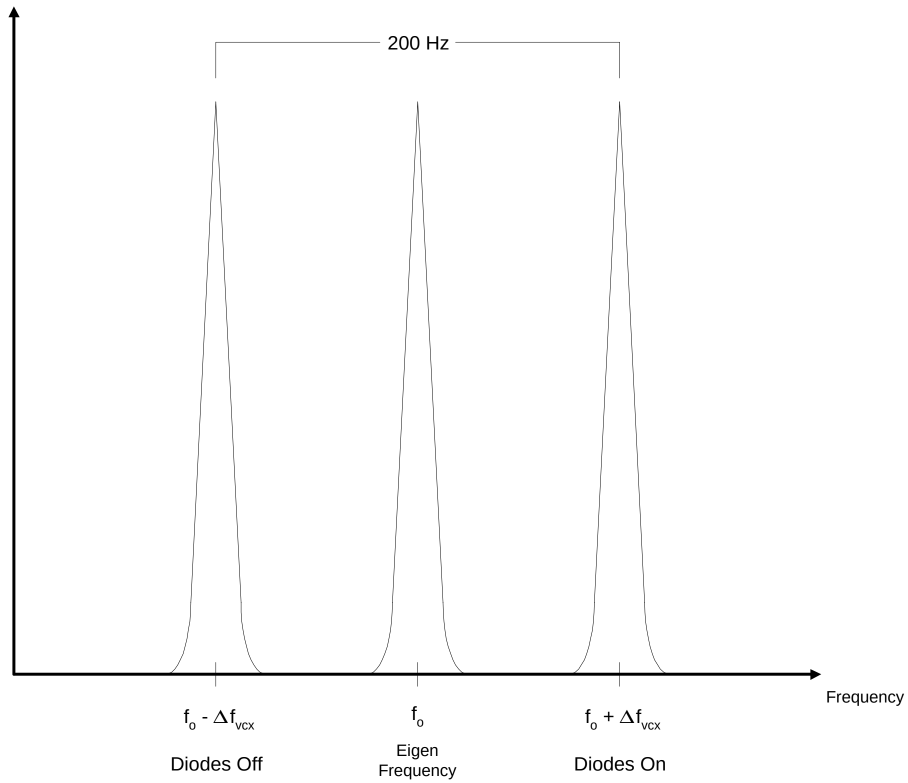
- The fast tuner's function is to electronically cancel the effects of mechanical vibration on the eigen frequency and control of the RF phase with respect to a master oscillator.
- The system consists of three separate components:
  1. 77K PIN Diode Unit
  2. PIN Diode Drive Module
  3. A section of the RF Control Module

Simplified Equivalent Diagram of Fast Tuner

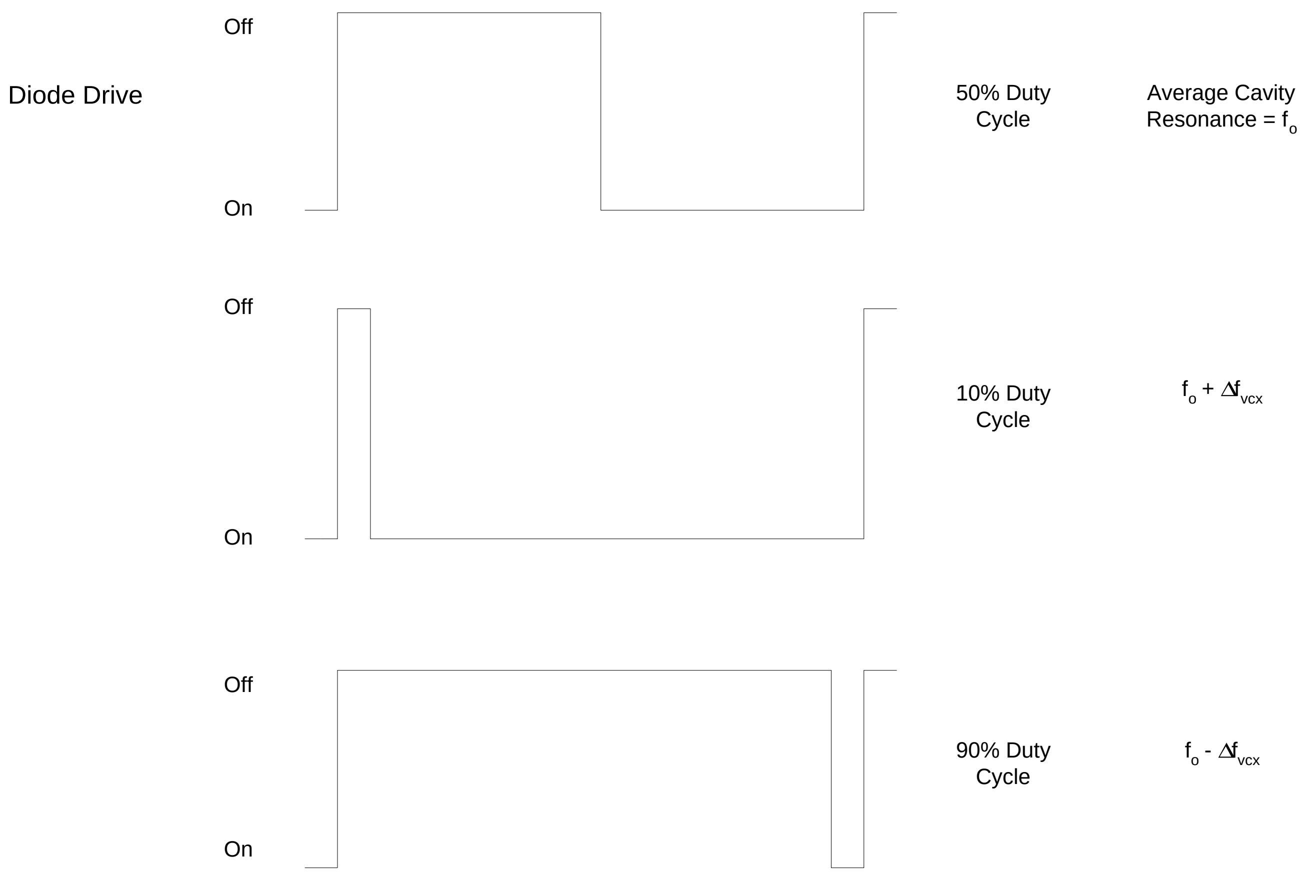


77 K PIN Diode Unit

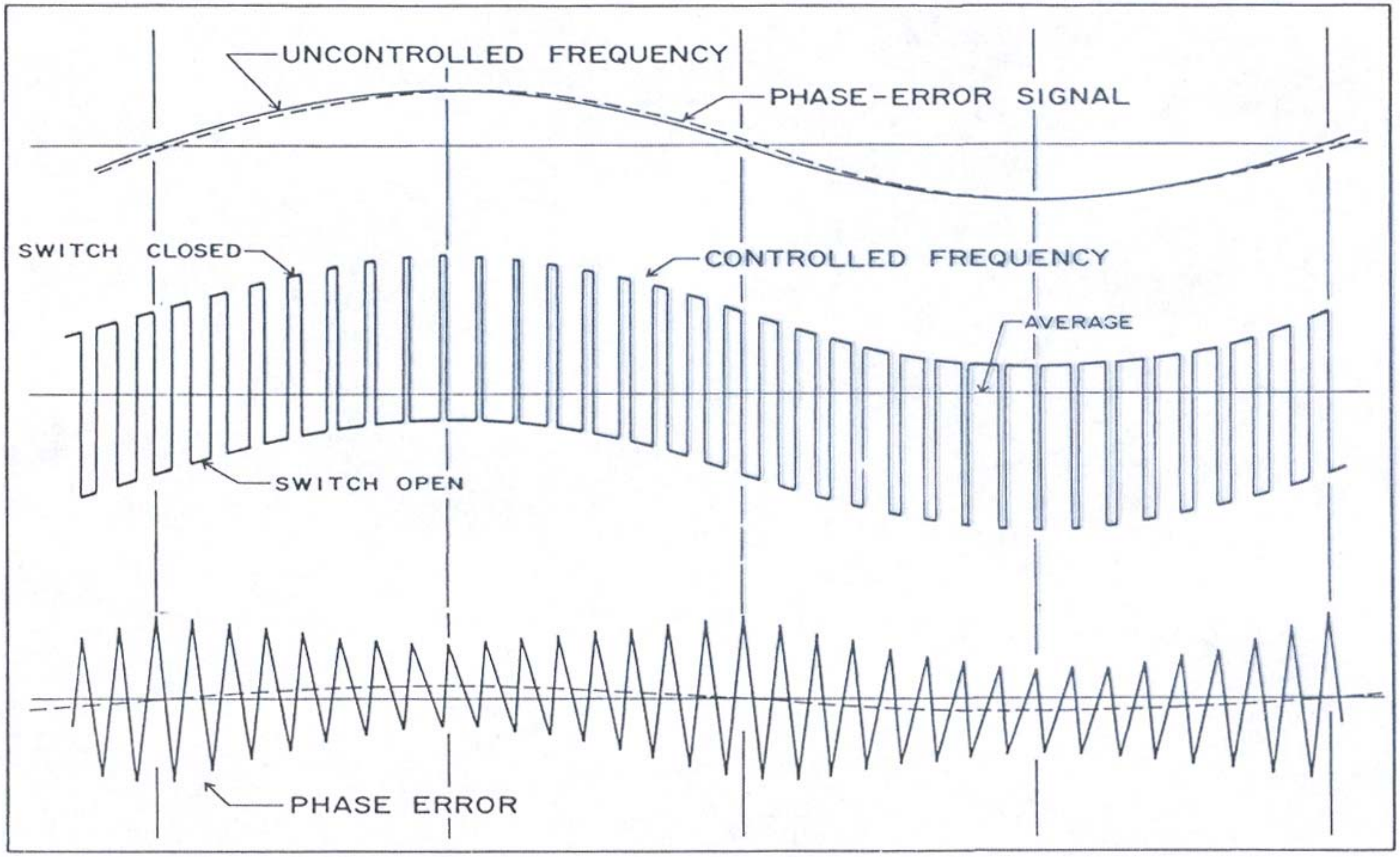
- When the diodes are switched between the on and off states, the eigen frequency shifts typically 200 Hz.



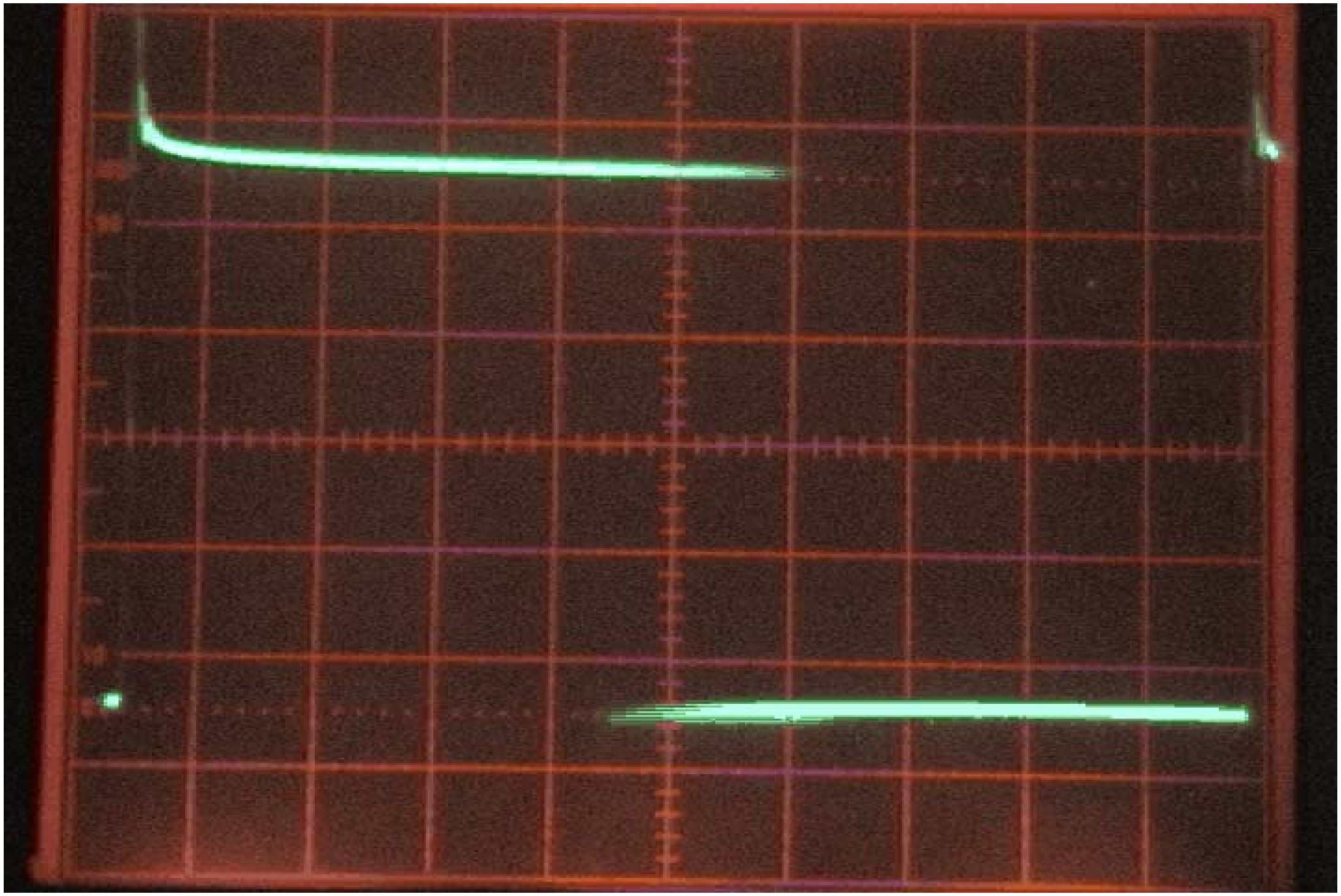
PIN Diode Switching Waveform



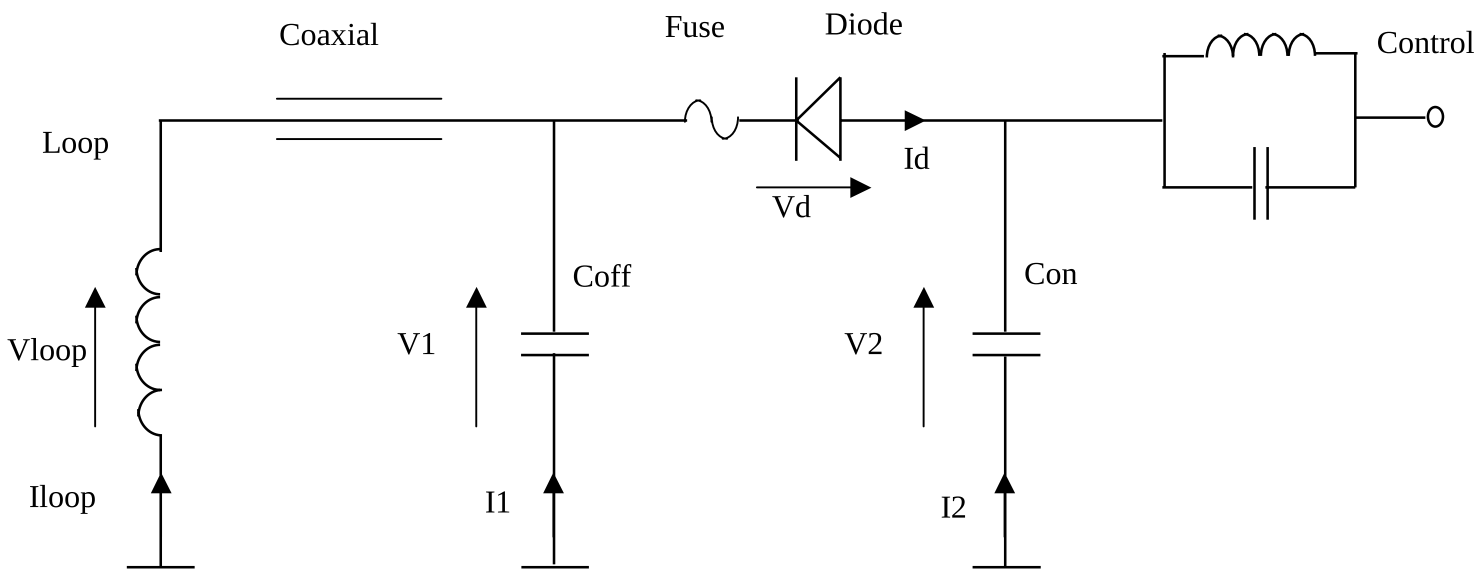
Phase Control



$\theta_{rad} = 2\pi\ (\delta f_{vcx})\ (1/2 \text{ switching period})$

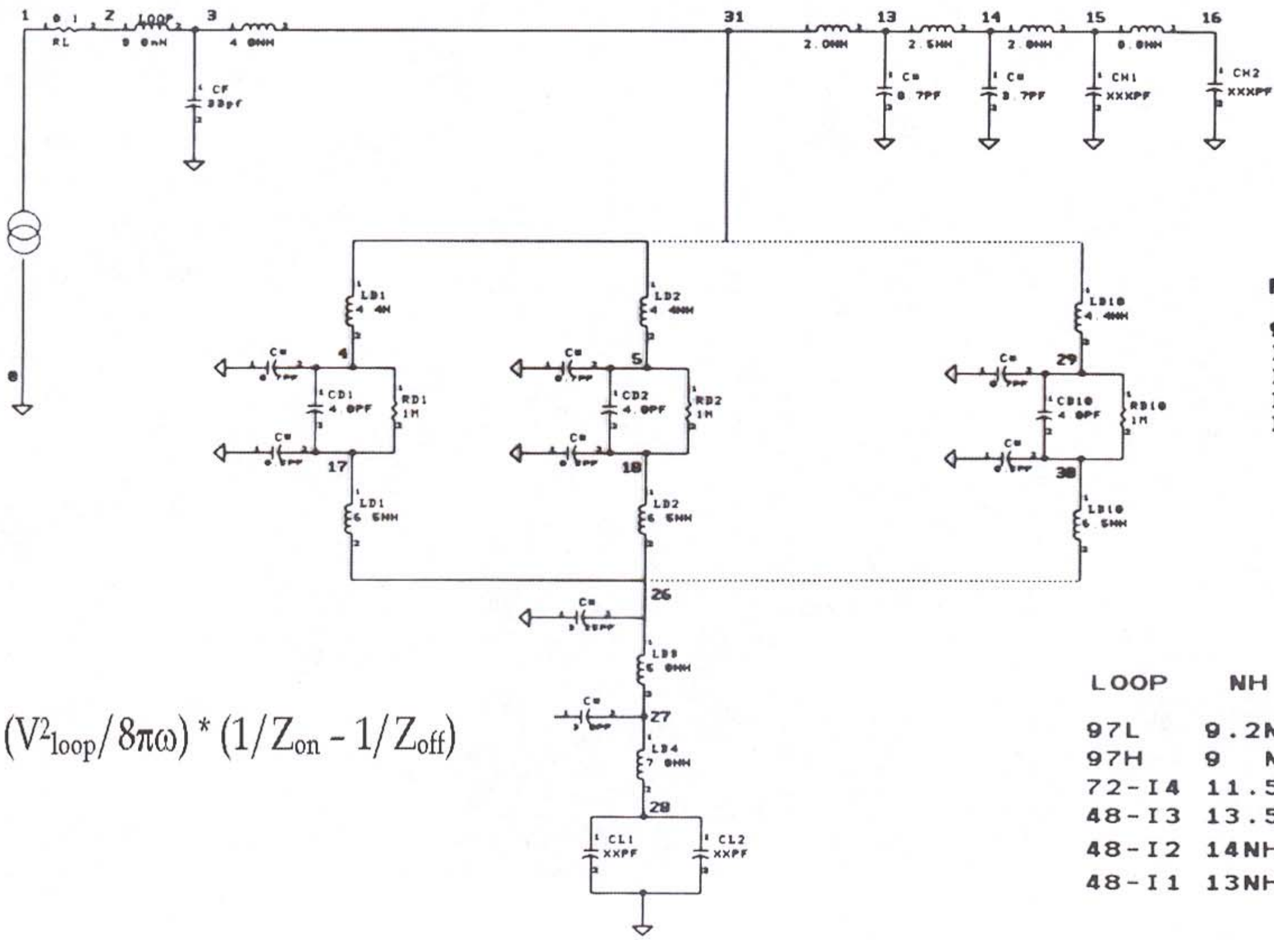


Simplified Equivalent Diagram of Fast Tuner



Nodal Schematic

LOOP VCX NOVA NODAL DIAGRAM

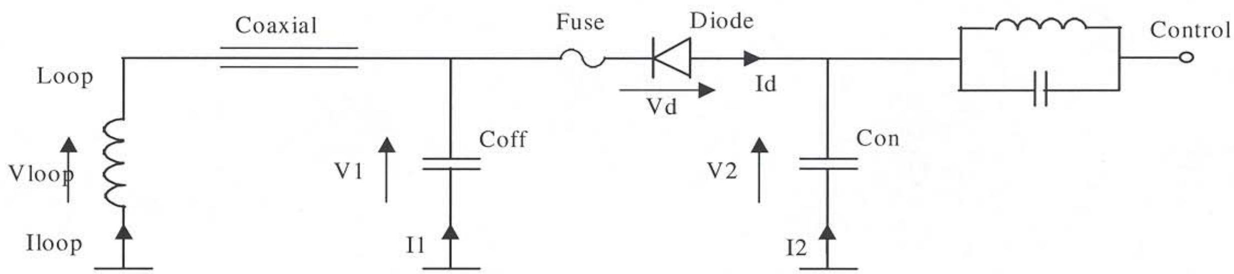


FREQ	CH	CL
97F	11.	166
I1A	166,83	455
I2A	83,83	455
I3	34,34	505
I4	40,40	192

$$\Delta f = (V^2_{loop}/8\pi\omega) * (1/Z_{on} - 1/Z_{off})$$

LOOP	NH	VOLTS	
97L	9.2NH	41.4	0.080j
97H	9 NH	60.0	0.159j
72-I4	11.5NH	45.0	0.141j
48-I3	13.5NH	61.0	0.185j
48-I2	14NH	38.8	0.1026j
48-I1	13NH	25.8	0.0367j

Simplified Equivalent Diagram of Fast Tuner

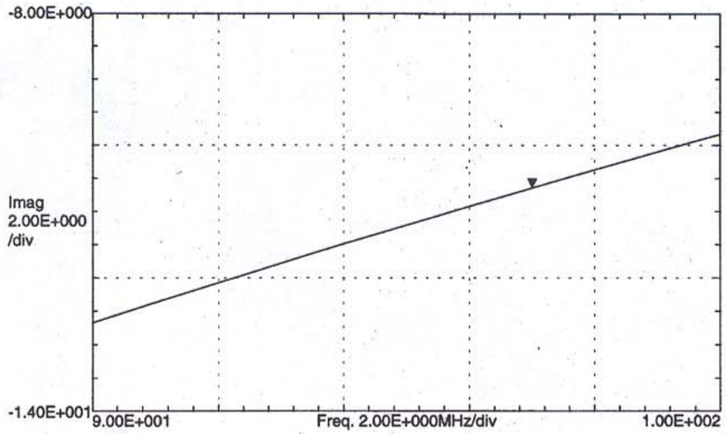


Example of 97H Resonator. Vloop = 60V Peak @ 1MV/m, Stored Energy W=0.159J.

Iloop,A	Ploop react.,W	Ploop act.,W	Vd,V	Id,A	Pd react.,W	Pd act.,W	V1,V	I1,A	V2,V	I2,A	State
9.4	564	5.1	6.25	9.4	58	0.44	16.6	0.19	89.4	9.3	**On** 1MV/m
5.8	347	1.9	95.9	2.9	275	0	105.2	1.1	23.1	2.4	**Off** 1MV/m
Reactive Switching Power **14576** W			Reverse Voltage **384** V Reactive Power **4400 W**				React. Power **1852** W		React. Power **13303** W		**Max** 4MV/m

$Z_{on} = 0.11{+}j6.16$ $\quad Z_{off} = 0.1{-}j10.65$ $\qquad \delta F = \frac{V_{loop}^{2}}{8\pi W}[\frac{1}{\operatorname{Im} Z_{on}} - \frac{1}{\operatorname{Im} Z_{off}}] = 230.6$ Hz

Reactive Switching Power $P_{react} = 8\pi\delta FWE^{2} = V_{loop}^{2}E^{2}[\frac{1}{\operatorname{Im} Z_{on}} - \frac{1}{\operatorname{Im} Z_{off}}] = 14746$ W.



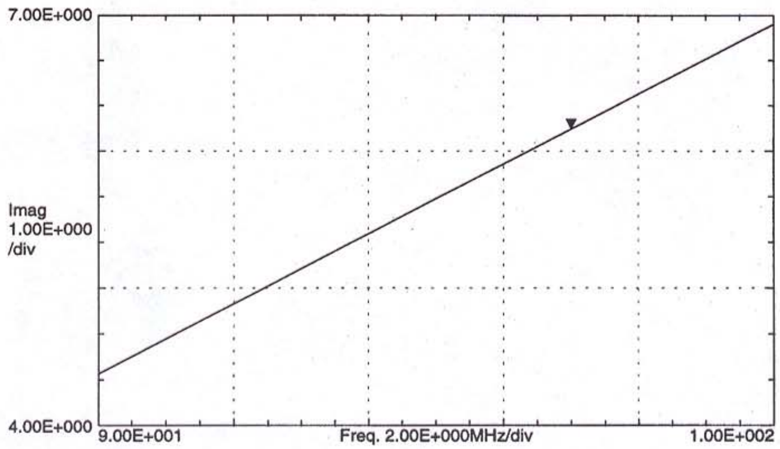
OFF Impedance

Source Simulation

Z_0 = 50.0 Ohms

Zs = 50.0 + j 0.00 ohms

Zin = 0.1029 – j 10.646



ON Impedance

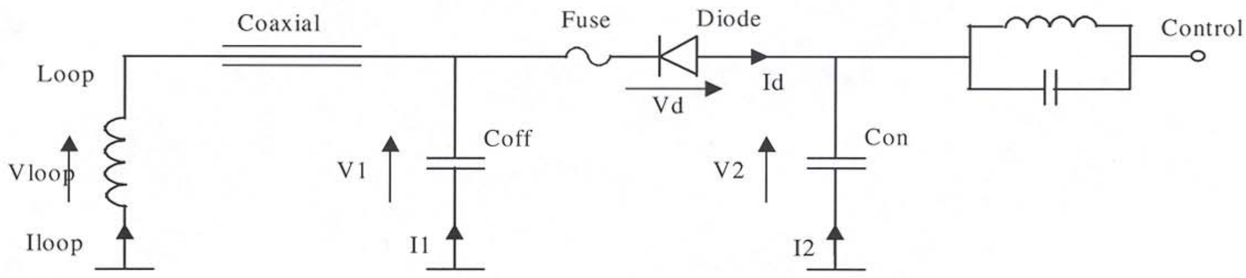
Source Simulation

Z_0 = 50.0 Ohms

Zs = 50.0 + j 0.00 ohms

Zin = 0.1097 + j 6.1604

Simplified Equivalent Diagram of Fast Tuner



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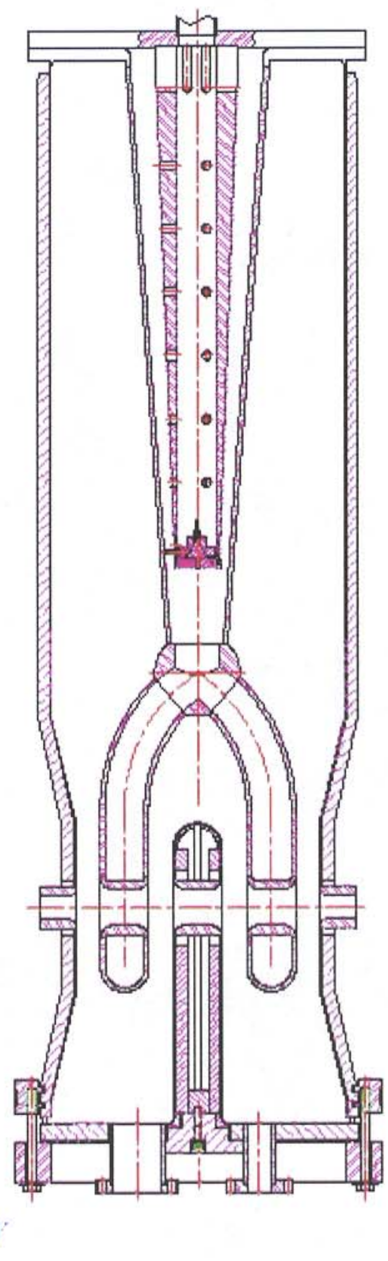
$Z_{on} = 0.11+j6.16$ $Z_{off} = 0.1-j10.65$

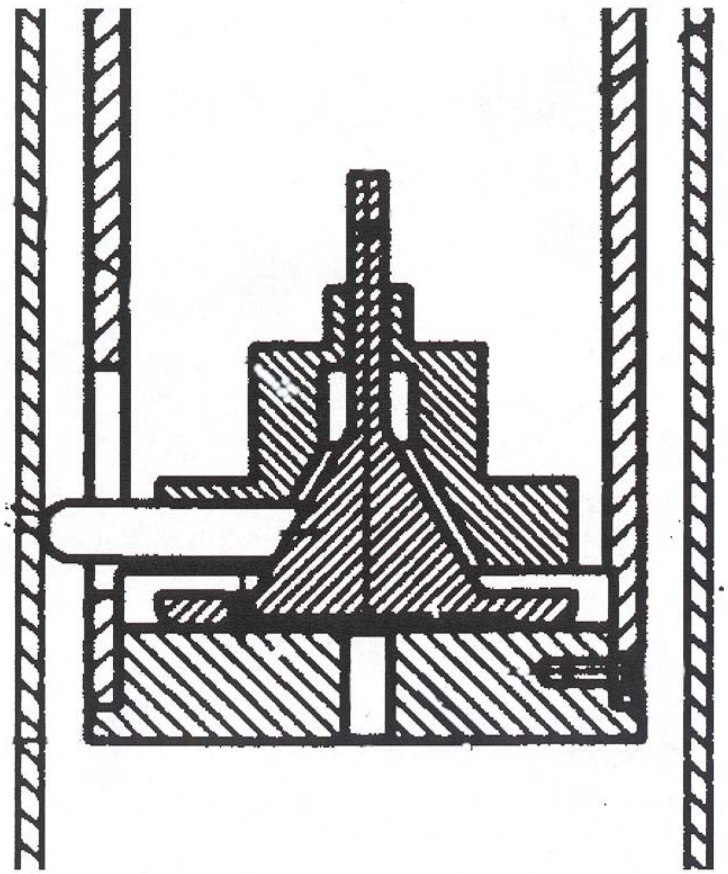
$$\delta F = \frac{V_{loop}^2}{8\pi W}\left[\frac{1}{\operatorname{Im} Z_{on}} - \frac{1}{\operatorname{Im} Z_{off}}\right] = 230.6 \text{ Hz}$$

Reactive Switching Power $P_{react} = 8\pi\delta FWE^2 = V_{loop}^2 E^2\left[\frac{1}{\operatorname{Im} Z_{on}} - \frac{1}{\operatorname{Im} Z_{off}}\right] = 14746$ W.

Damper Assembly

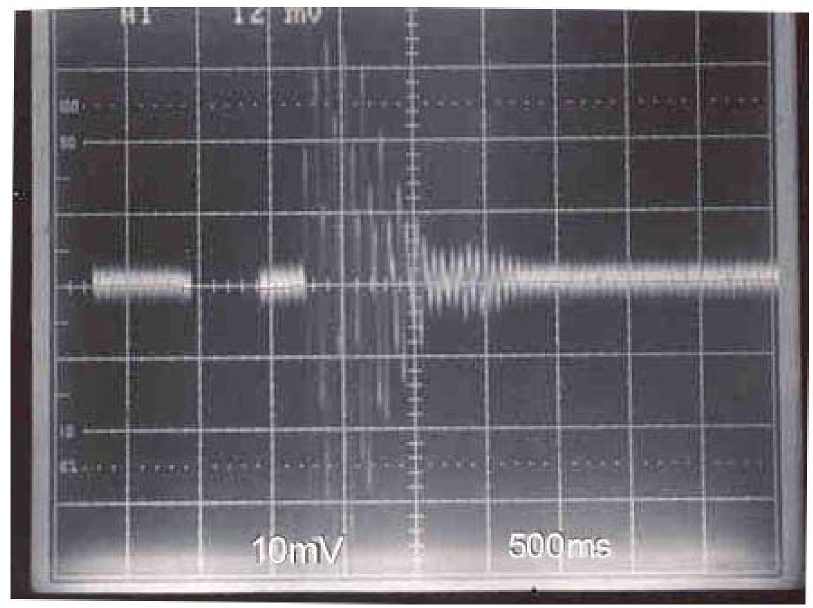


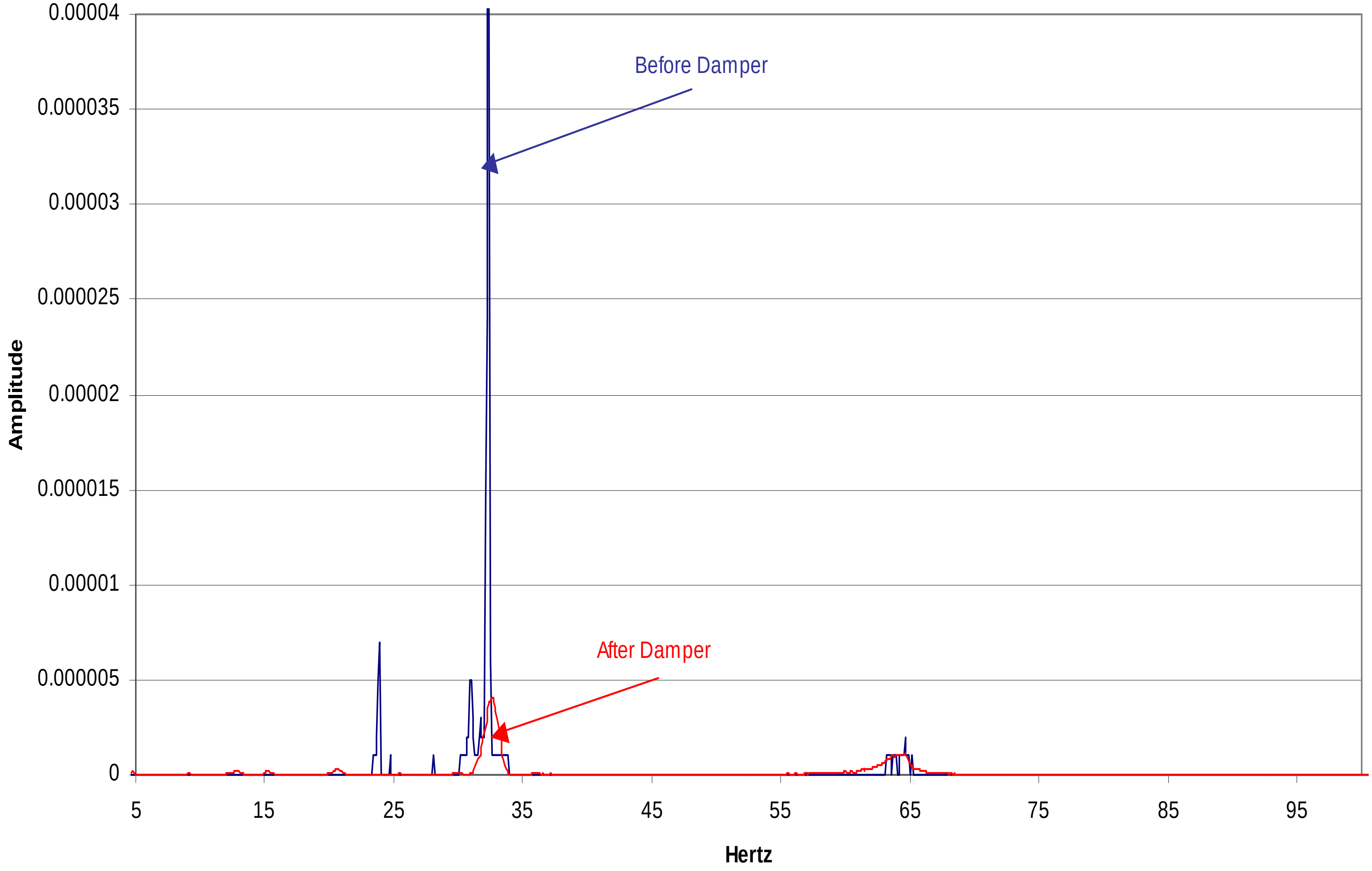
Damper Details



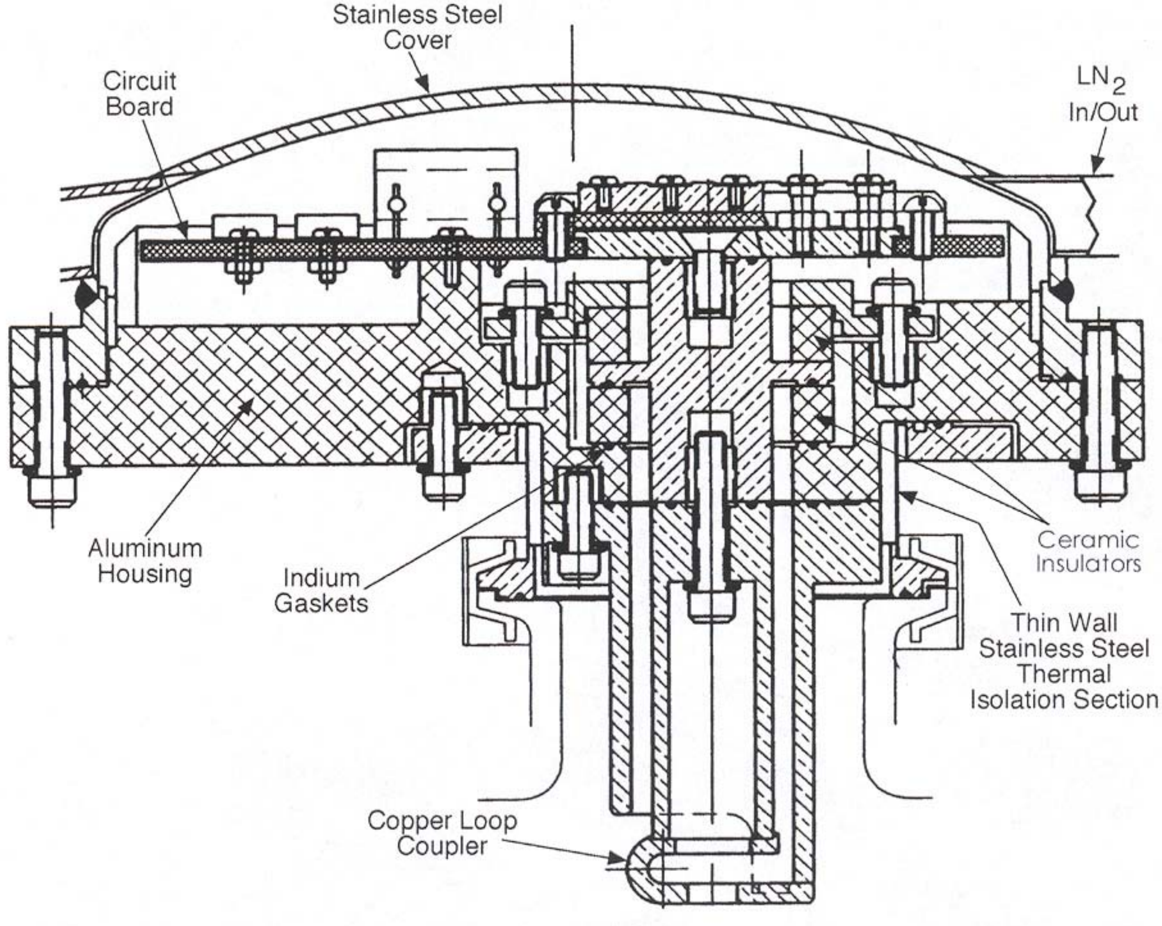
Mechanical Damping Results

- Vibration decay time without damper = 28sec
- Vibration decay time with damper = .5sec




Before Damper
After Damper
Amplitude
Hertz
0.00004
0.000035
0.00003
0.000025
0.00002
0.000015
0.00001
0.000005
0
5
15
25
35
45
55
65
75
85
95

Fast Tuner Mechanical Diagram



PIN Diode Drive Requirements

- Square wave switching must occur at a fast enough rate that resonator phase wobble is acceptable.

$\phi = 2\pi \, (F_{window})$ (1/2 switching period)

$$\phi = \left[2\pi \frac{\text{Radians}}{\text{Cycle}}\right]\left[250 \frac{\text{Cycles}}{\text{Second}}\right](1/2)(4\times10^{-5} \text{ second})$$

$\phi = 0.0314$ radians = 1.8 degrees

Window = 250 Hz
Diode switching Period = 4×10^{-5} sec 25 KHz

This means that resonator phase deviation, per PIN diode switching cycle, can be as large as ±0.9 degrees.

- PIN diodes must be driven to a sufficiently high reverse bias (OFF) that coupled resonator fields do not cause forward bias to occur. Typically, 675 volts of reverse bias is used.

- PIN diodes must be driven into sufficient forward bias (conduction) that coupled resonator fields do not remove the stored charge. (If forward bias is not sufficiently large, the diodes behave as lossy switches.) Approximately 2.0 amperes of forward bias current is used (9 diodes).

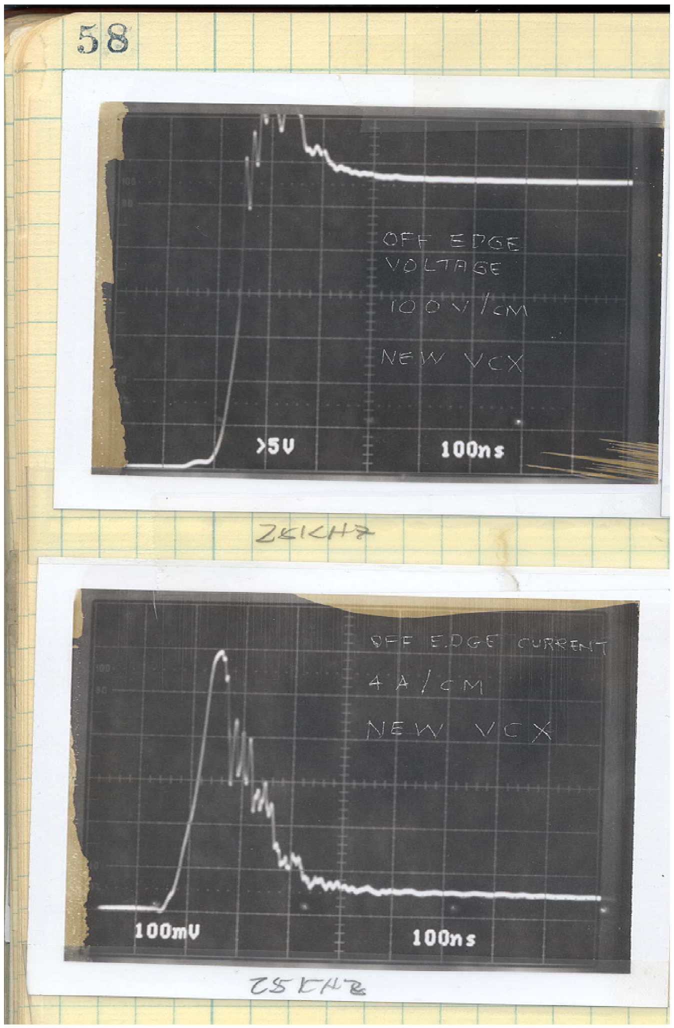
- Transitions of PIN diode bias must occur in 100 nanoseconds or less.

  <u>This means</u> ON → OFF
  <u>and</u> OFF → ON.

This requirement is necessary because, as the diodes switch states, a region of impedance is traversed where maximum RF energy is coupled into the VCX.

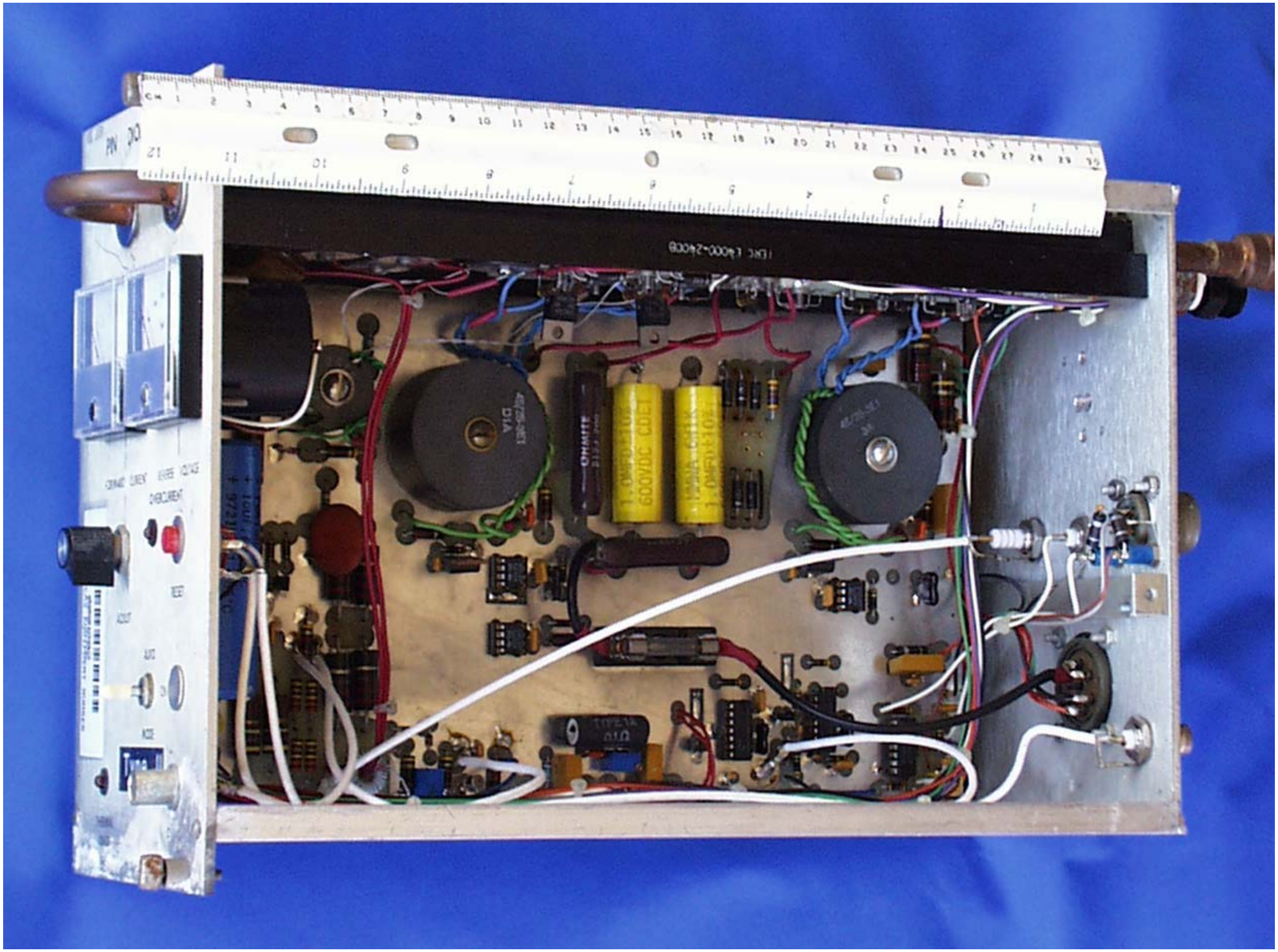
The region must be crossed as quickly as possible to avoid excessive RF energy dissipation.

Switching Rise Time



Off edge voltage
100 V/cm
~ 75 ηsec rise time

Off edge current
4 A/cm



Summary

Cavity Frequencies	48.5 MHz to 97 MHz
Typical on-line windows	200 to 500 Hz
Max. Tested Reactive Power	30KVA
Measured heat load into resonator at 30KVA	2 watts
Typical PIN Diode Stored Charge	85nC
Typical Diode Switching Losses	15 Watts
Typical RF Loss into LN2	150 to 200 Watts
Total System Costs	$7,000.00