Development of the Model of a Self Excited Loop

Introduction

Development of model in digital domain

- **RF Power System**
- **Limiter**
- **Controller**
- **Loop Phase Shifter**
- **Test Results**

Initial Experiments

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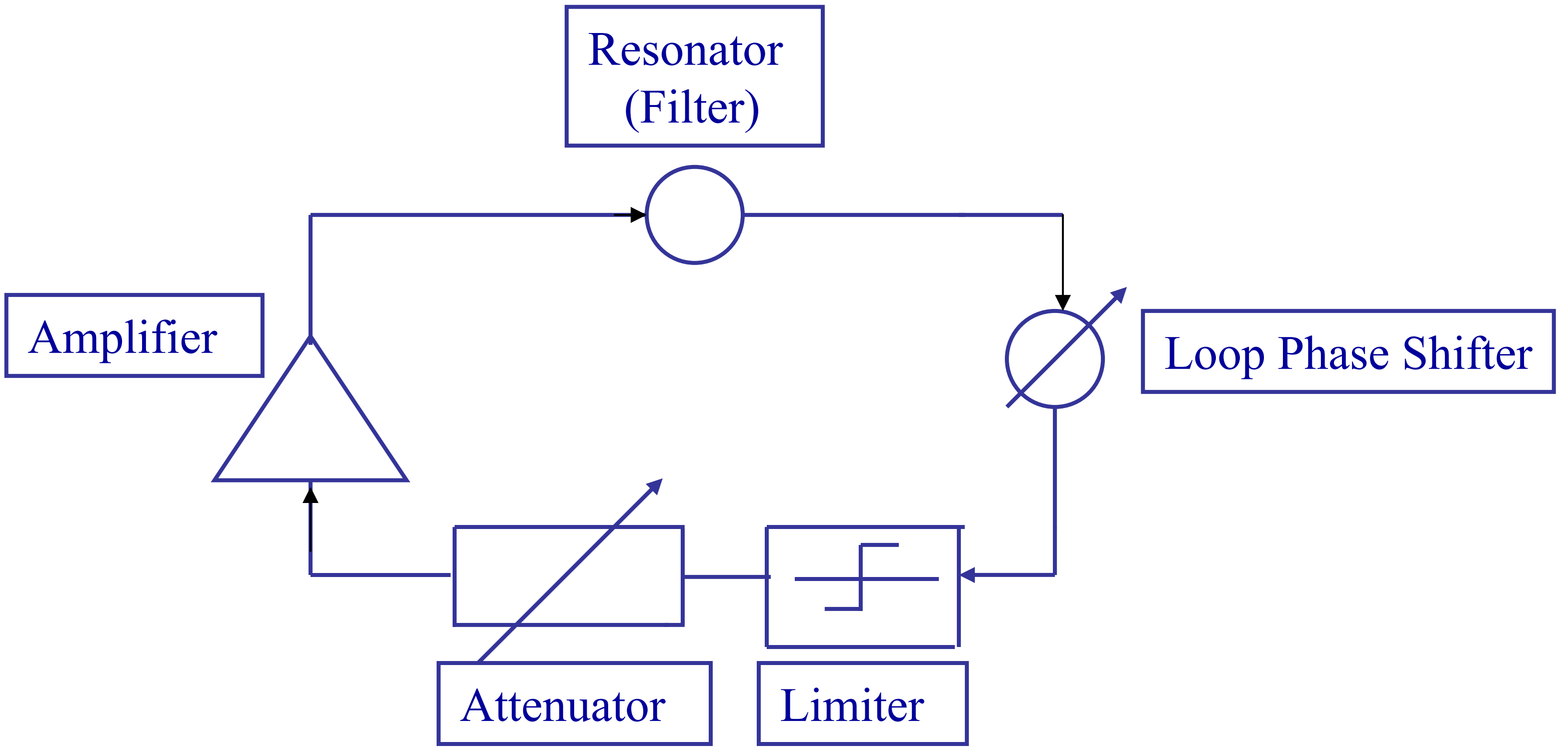
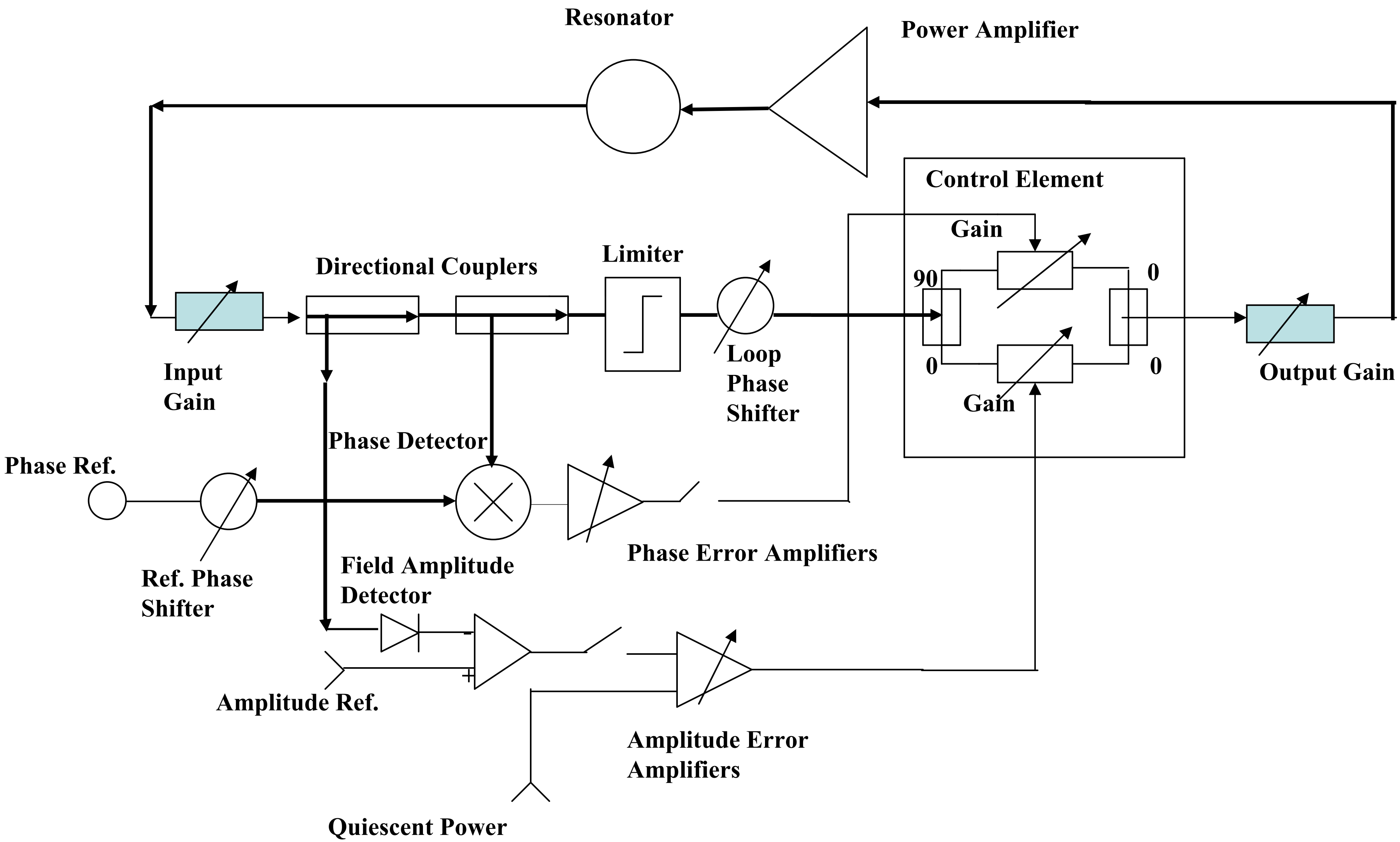


ELEMENTS OF A SELF EXCITED LOOP

A convenient starting point for subsequent amplitude and phase locking:

- Smooth adjustment across the resonance curve using the Loop Phase Shifter.
- Immune to electro-mechanical instability



SEL WITH AMPLITUDE & PHASE LOCK

SEL

- **A number of implementations exist-**
  with low level signal processing in analog domain
- **At BARC-TIFR**

  development of SEL based LLRF for three Super-conducting heavy ion LINACs

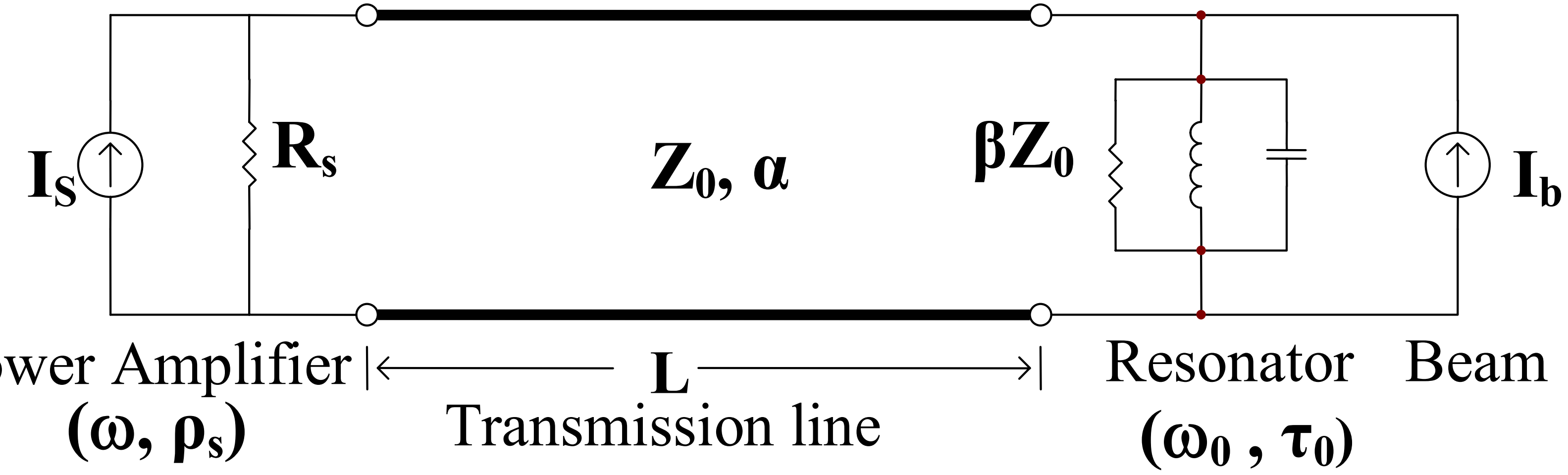
  - **Pelletron Linac Facility, Tata Institute of Fundamental Research, Mumbai (150 MHz, Quarter wave, Pb on copper)**
  - **Inter University Accelerator Centre, New Delhi (97 MHz, Quarter wave, Nb)**
  - **Australian National University, Canberra (150 MHz, Split-loop, Pb on copper)**

  Self Excited Loop based on digital technology - under development

  First step: develop a computer model

MODEL DEVELOPMENT
RF Power System

Equivalent Circuit



Resonator field amplitude 'V'

V=(I,Q) ; complex phasor

High-Q; $\Delta\omega = (\omega_0 - \omega) << \omega_0$

$$\tau_0 \frac{dV}{dt} + (1 + j(\omega - \omega_0)\tau_0)V = V_{ext}$$

$$\frac{dI}{dt} = -\frac{1}{\tau} I - \Delta\omega\, Q + \frac{1}{\tau}\frac{\beta}{\beta+1}(2V_{fi} + Z_0\, I_{bi})$$

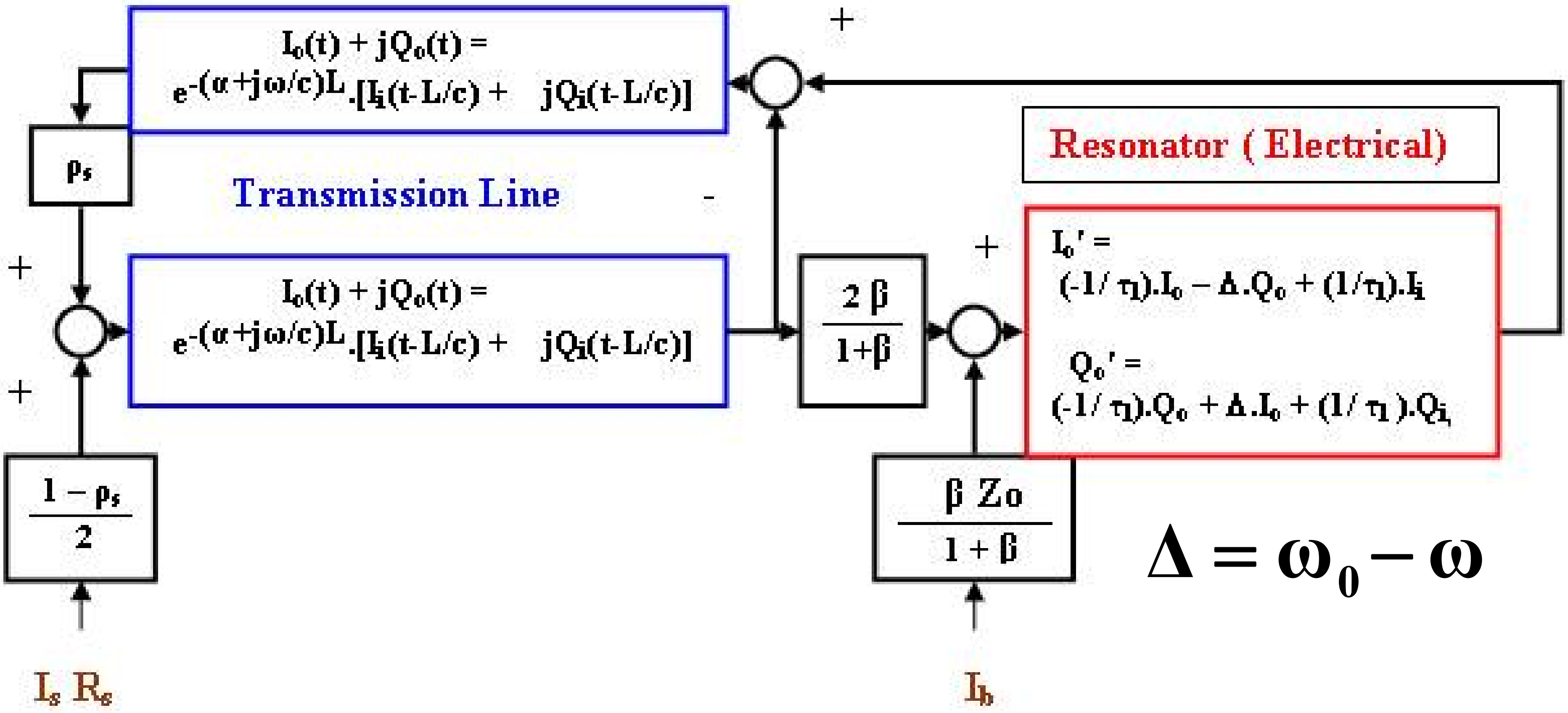
$$\frac{dQ}{dt} = -\frac{1}{\tau} Q + \Delta\omega\, I + \frac{1}{\tau}\frac{\beta}{\beta+1}(2V_{fq} + Z_0\, I_{bq})$$

1) high power RF amplifier

transmission line

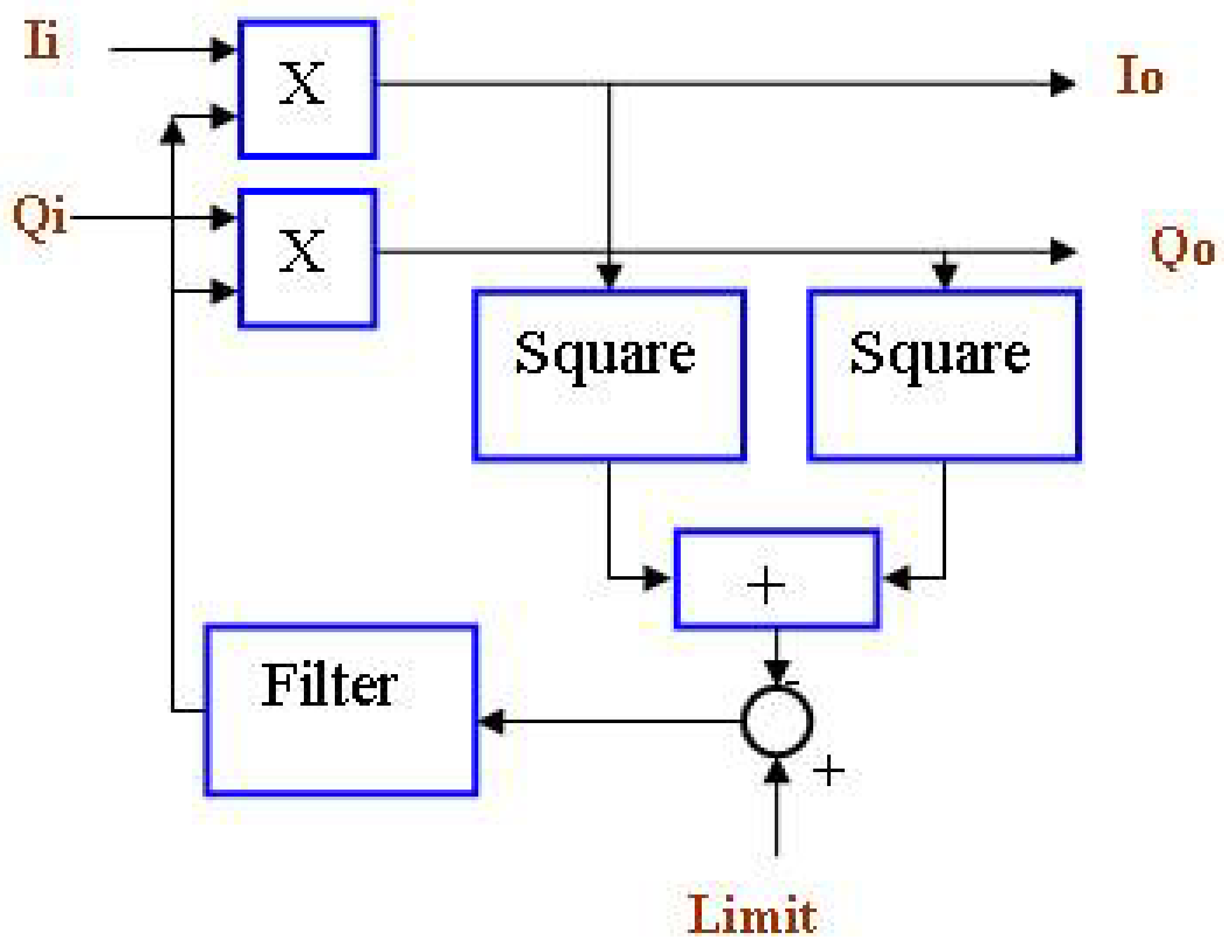
2) beam current

Model - RF Power System



Limiter

Modeled as a Feedback loop



Limiter

Choice of compensator- main design issue

Concern

Good steady-state and transient response

Two loops – free running SEL
Outer loop – low pass filter
Limiter inner loop – high pass filter
Composite system – Gain < unity at all frequencies

Adequate band-width with high enough steady state gain

Solutions

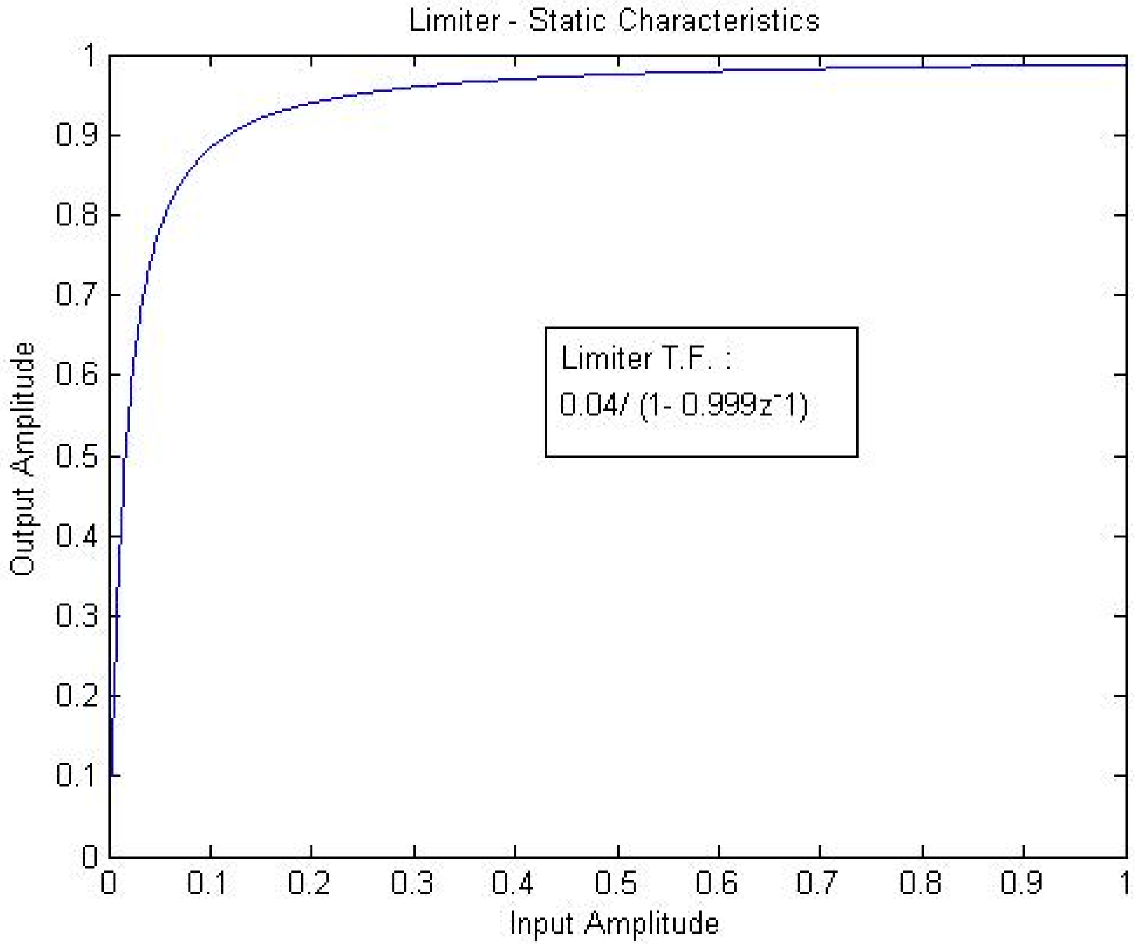
Fast and precise signal processing

FPGAs

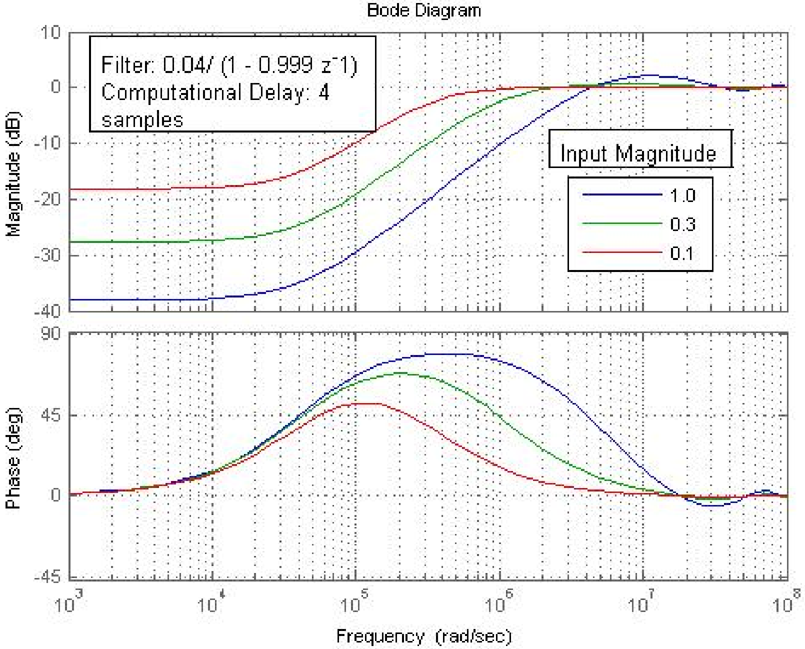
Fast- Faster devices, Parallelism (25ns)
Precise- Bus-widths as per the requirement (56bit)

Limiter: For its simplicity, we have chosen

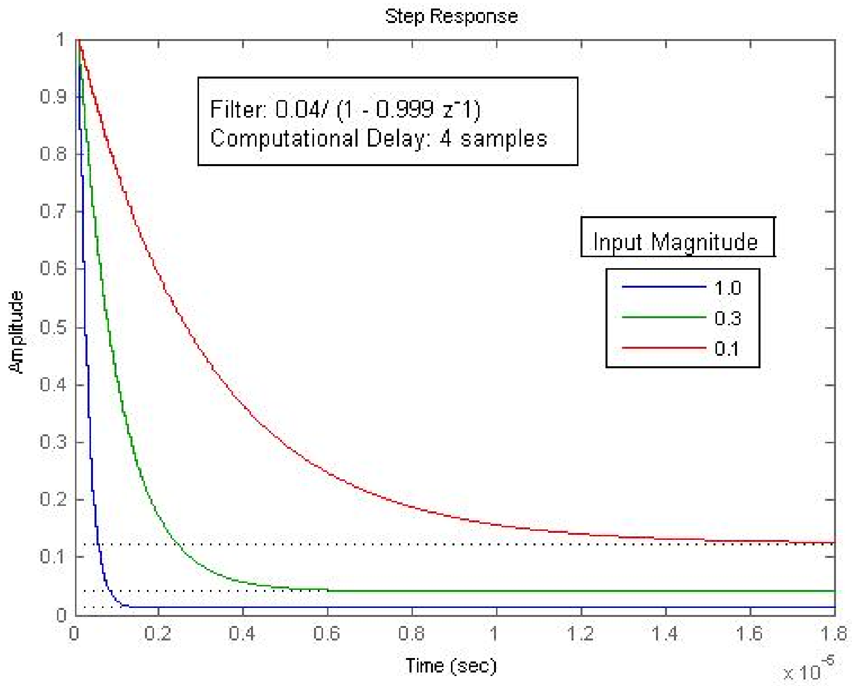
$$\frac{K}{1 - a z^{-1}}$$ as compensator



Linearised System

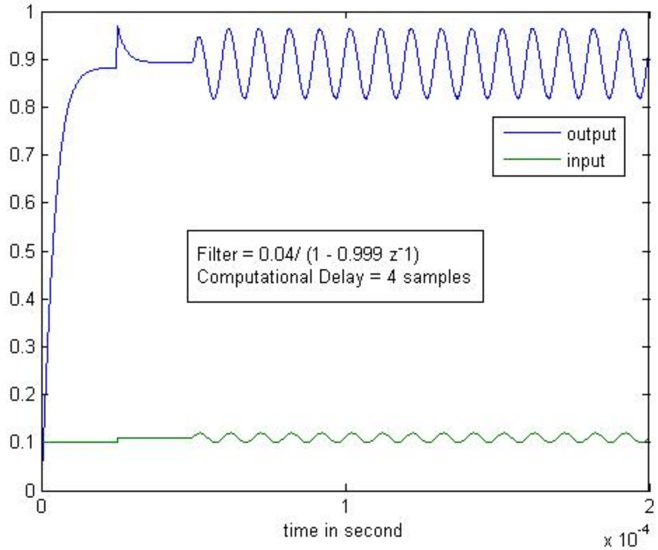


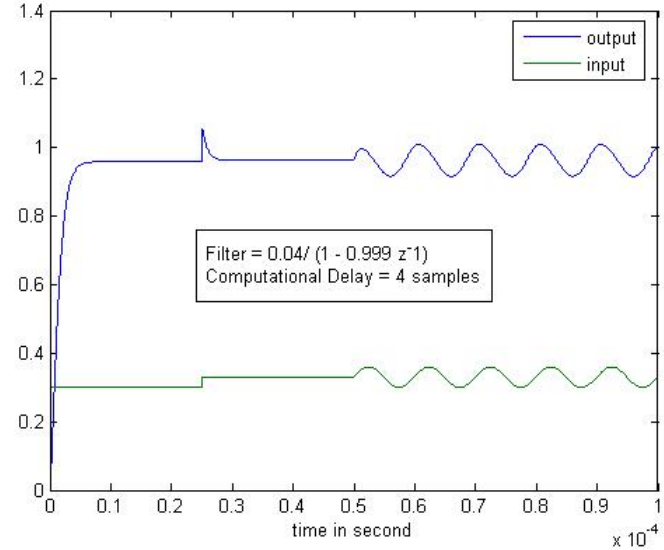
Frequency Response

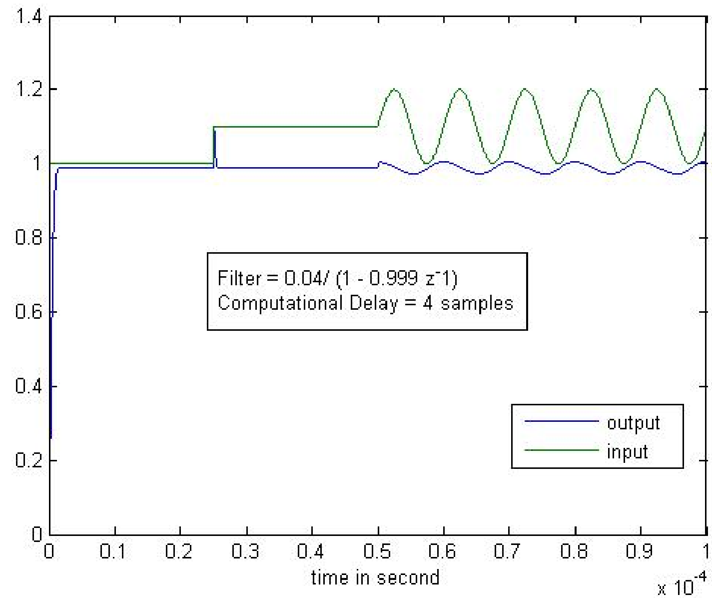


Pulse Response

Limiter: Dynamic







Controller

SEL dynamics:

$$\tau \frac{dV}{dt} + V = \text{in} - \text{phase} \quad \text{Drive}$$

$$\tau(\omega - \omega_0)V = \text{quadrature Drive}$$

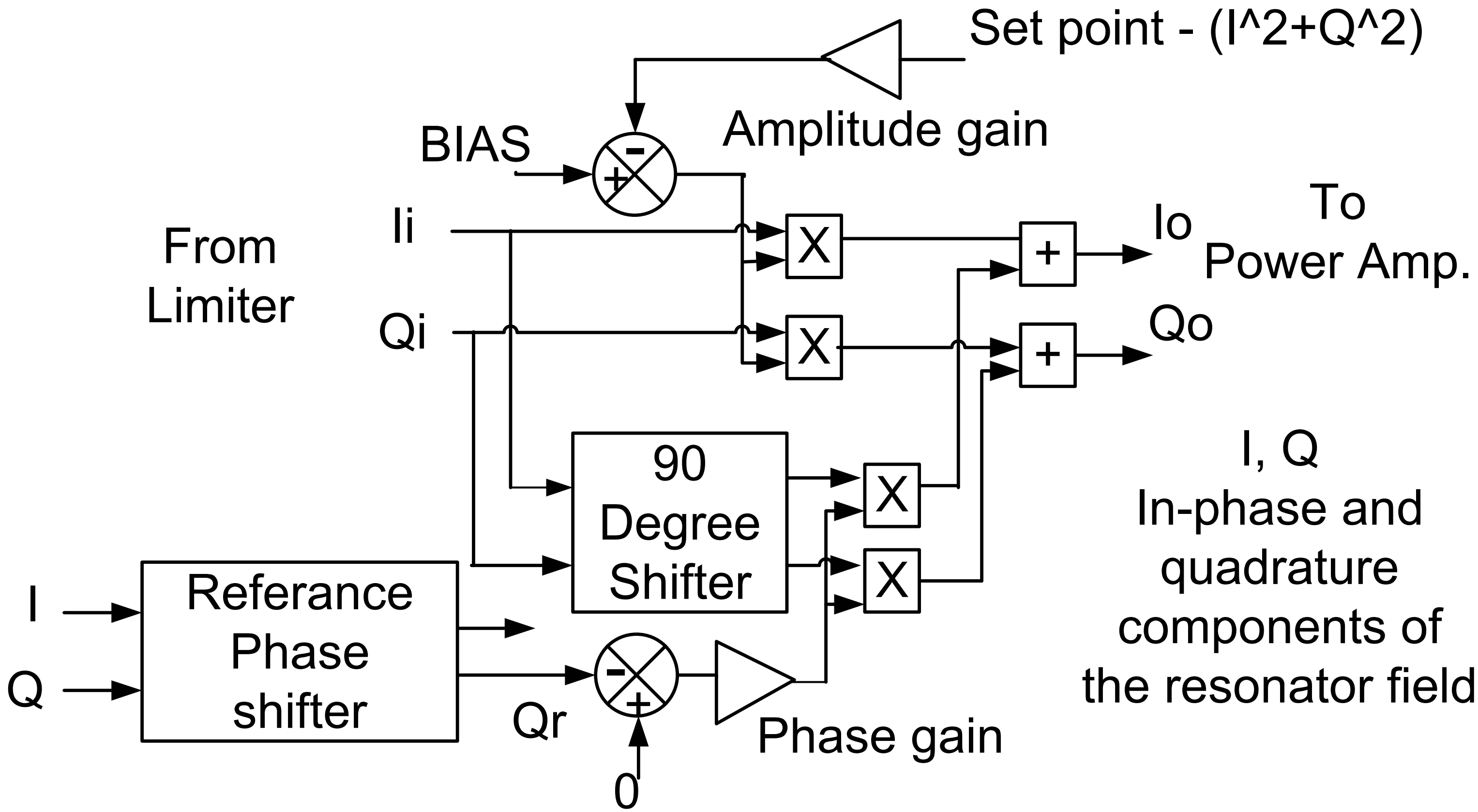
V: amplitude of RF in the resonator

1. Phase Control - modulation of Quadrature drive
2. Amplitude control - modulation of In-phase drive

Low beam current machines

Variation of ω_0 – dominant disturbance
ensure electromechanical stability
counteract cross-couplings

Controller


Set point - (I^2+Q^2)
Amplitude gain
BIAS
-
+
From
Limiter
Ii
Qi
X
X
+
+
Io
Qo
To
Power Amp.
90
Degree
Shifter
X
X
I, Q
In-phase and
quadrature
components of
the resonator field
I
Q
Referance
Phase
shifter
-
+
Qr
0
Phase gain

Phase Shifter

Co-ordinate Rotation

$$I_o = I_i \cos(\phi) - Q_i \sin(\phi)$$
$$Q_o = I_i \sin(\phi) + Q_i \cos(\phi)$$

ϕ - the phase shift across the phase shifter

Resonator Model: Electro-mechanical

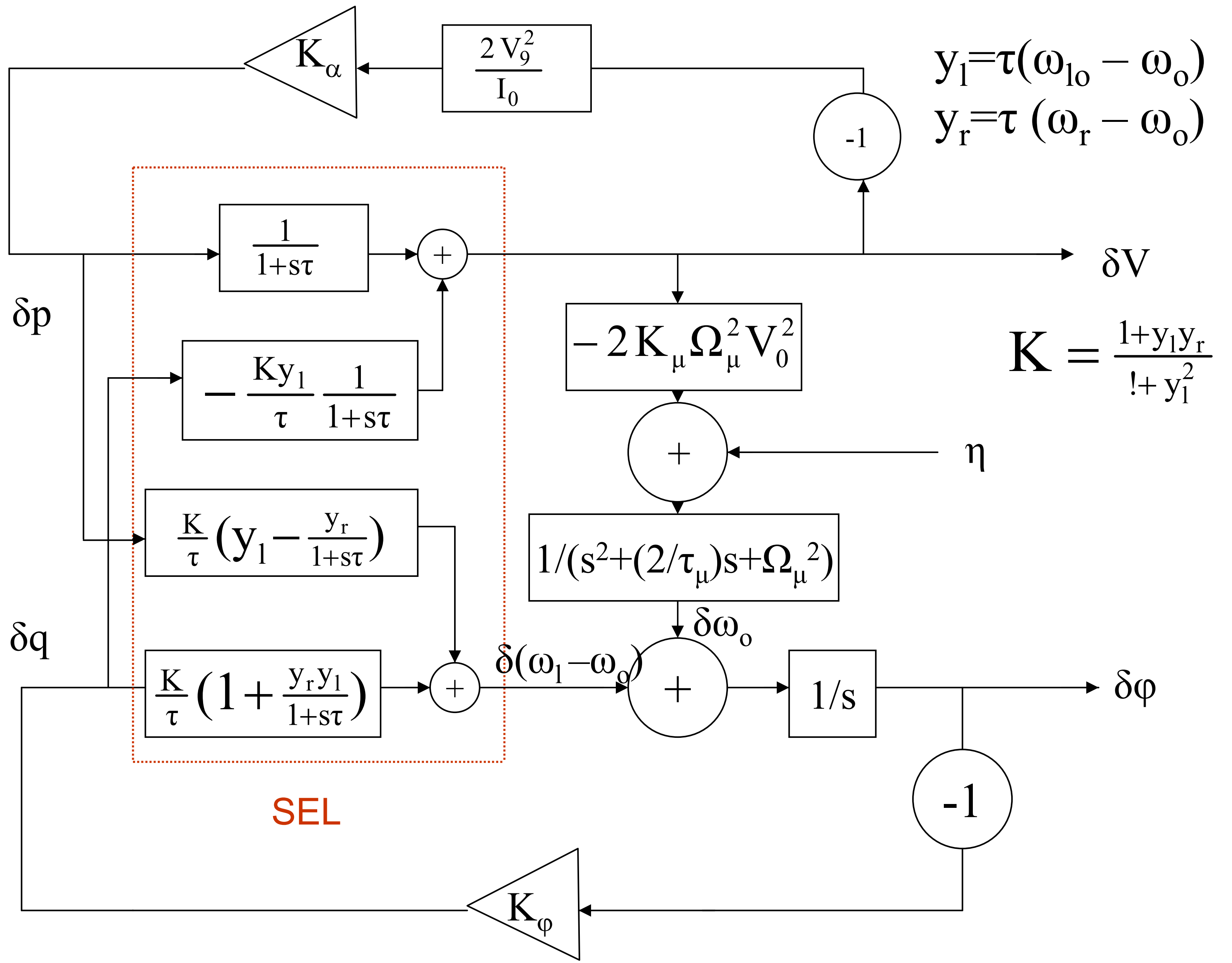
Electro-mechanical modes excited by: resonator field and micro-phonics

$$\frac{d^2\omega_\mu}{dt^2} + \frac{2}{\tau_\mu} \cdot \frac{d\omega_\mu}{dt} + \Omega_\mu^2 \omega_\mu = -K_\mu \Omega_\mu^2 VV^* + \eta(t)$$

Where, $VV^* = I^2 + Q^2$

Instantaneous Resonant Frequency $\omega_c = \omega_{co} + \sum \omega_\mu + \omega_{ex}$

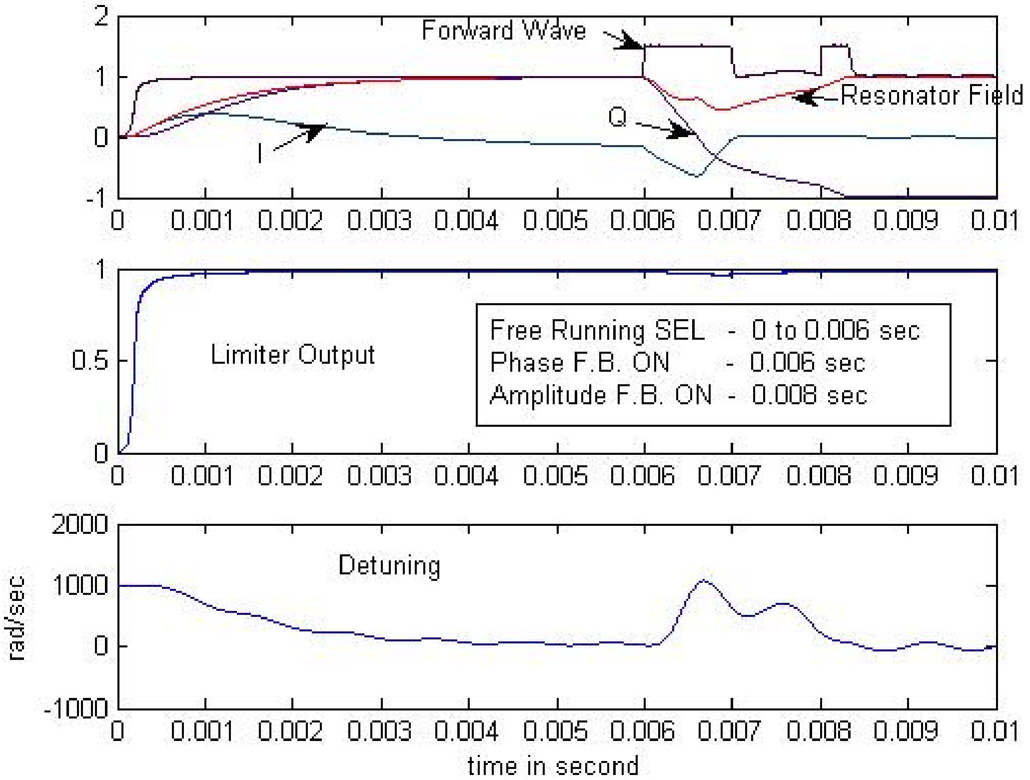
Detuning $\Delta = \omega_c - \omega$



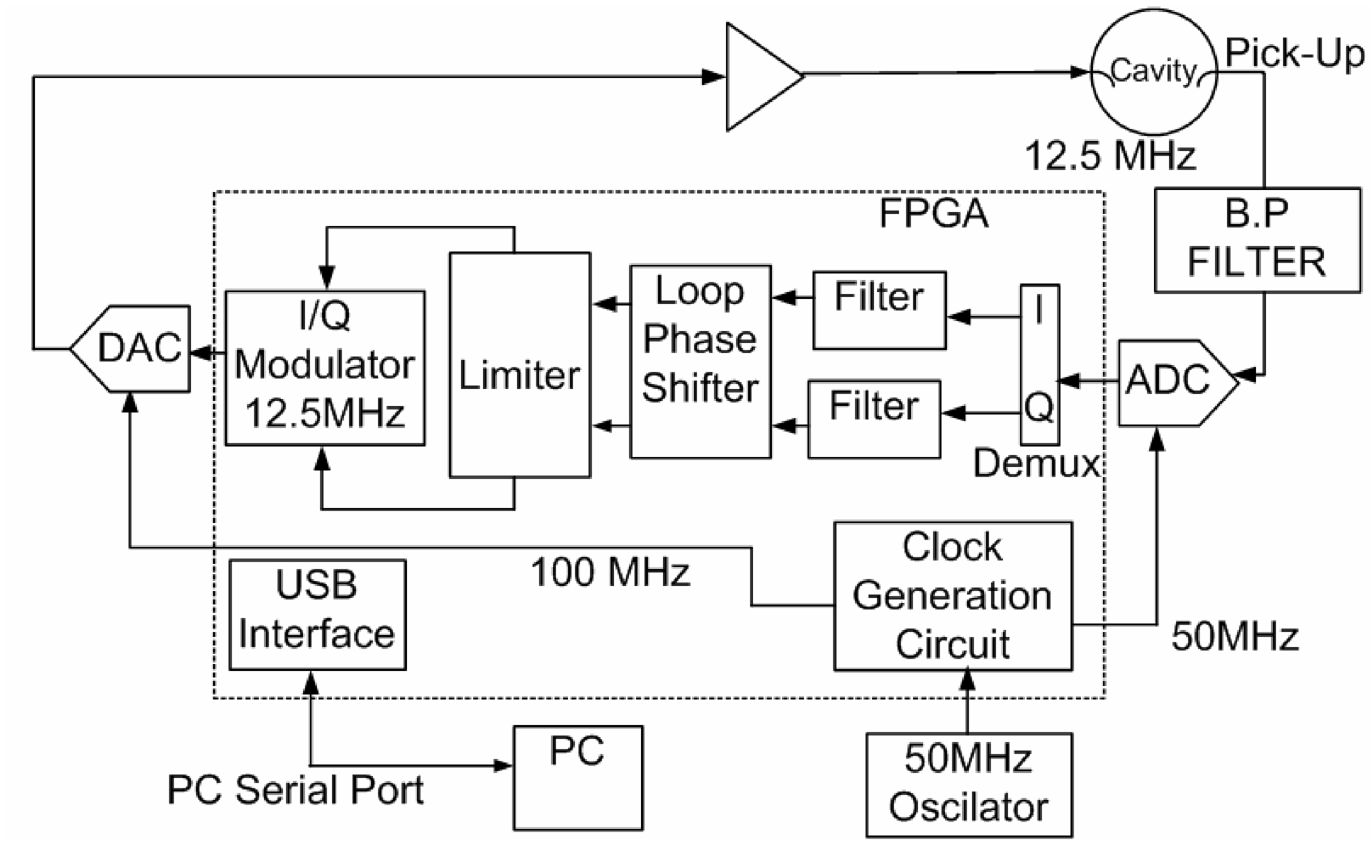
Low Frequency System Model: Linearized

Mathlab/Simulink: A sample run

the compensator in the limiter loop = .04/ (1 – 0.999 z^{-1}),
the computational delay in the feedback loop of limiter = 4 samples,
sampling time= 25 nano-seconds



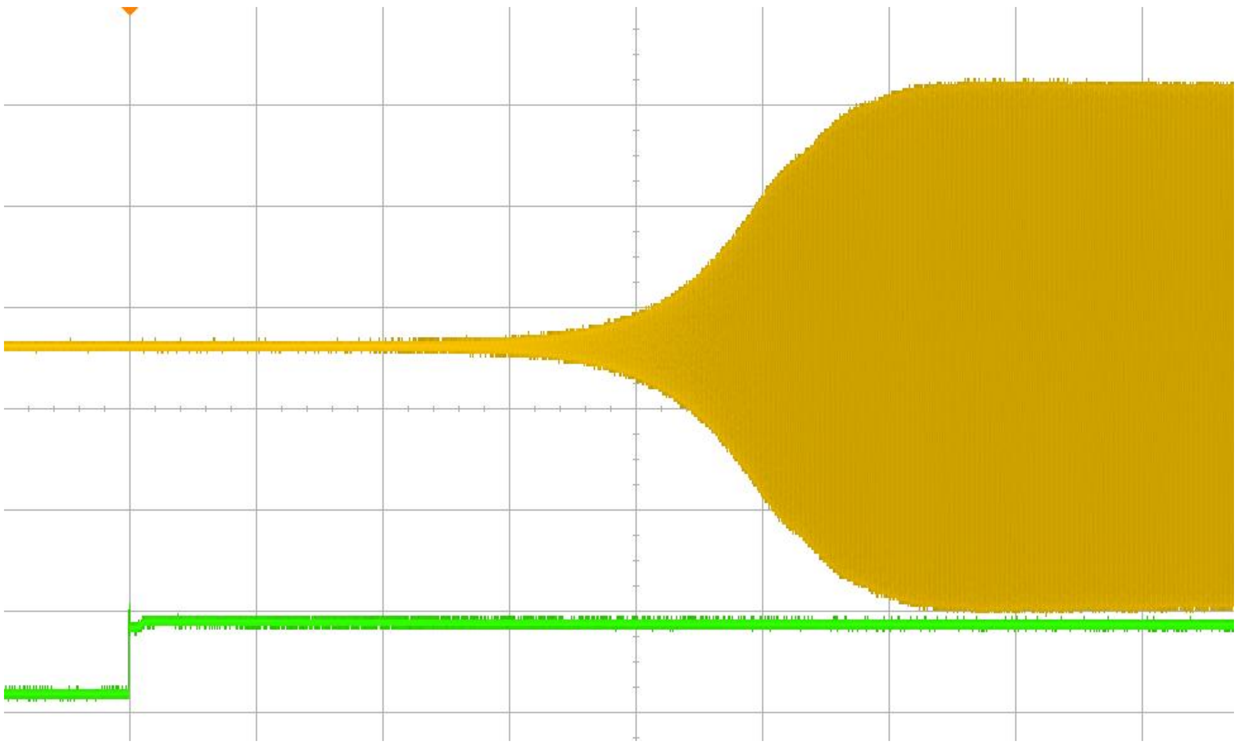
Initial Experiments



SEL realised using An FPGA development Kit: Altera Cyclone III

With a normal conducting resonator: loaded $\tau = 12\mu sec$

Self-Excited Oscillations



Horizontal-axis: 10 μsec/div

Green trace: system reset
Yellow trace: resonator pick-up

Conclusion

The model – simulation useful to understand the behaviour of an SEL and feedback control

The results obtained from the model and initial experiments are encouraging

Processing speed and precision

Development and implementation of a SEL based control in digital domain

Thanks!

ACKNOWLEDGEMENTS

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