A Compact, Totally Passive, Multi-Pass Slab Laser Amplifier Based on Stable, Degenerate Optical Resonators

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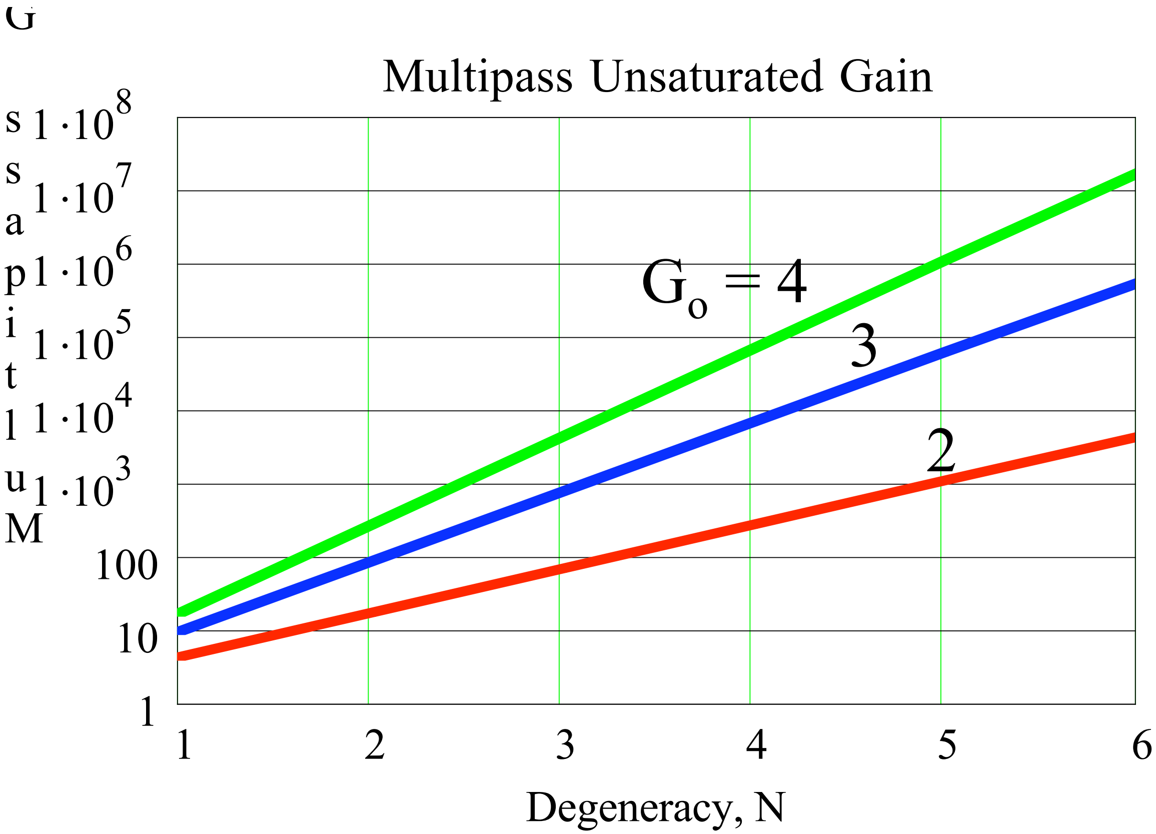
Why do we need compact multipass amplifiers?

- Availability of small, high repetition rate, picosecond pulse sources (e.g microchip and SESAM oscillators) and photon-counting techniques is opening up a wide range of new applications, e.g.
  - compact photon-counting SLR stations (SLR2000)
  - Airborne/spaceborne 3D imaging lidars
  - Lunar and interplanetary transponders
- Most of these applications require pulse energies between 40 and 4000 μJ whereas the oscillators produce sub-μJ (10 ps SESAM) up to 250 μJ (custom 400 psec microchip).
- At several KHz repetition rates with CW diode pumping of the amplifiers, the gain per pass can be relatively low so highly multi-passed amplifiers are desirable and more efficient.

Unsaturated Multipass Gain

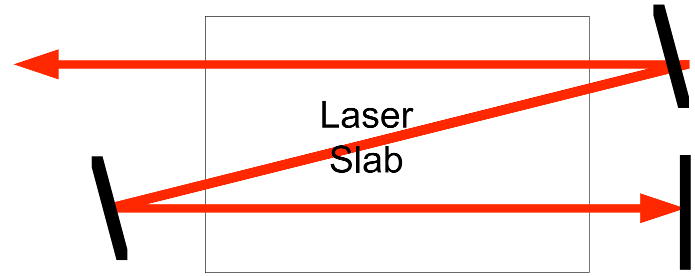


G_o = single pass unsaturated gain

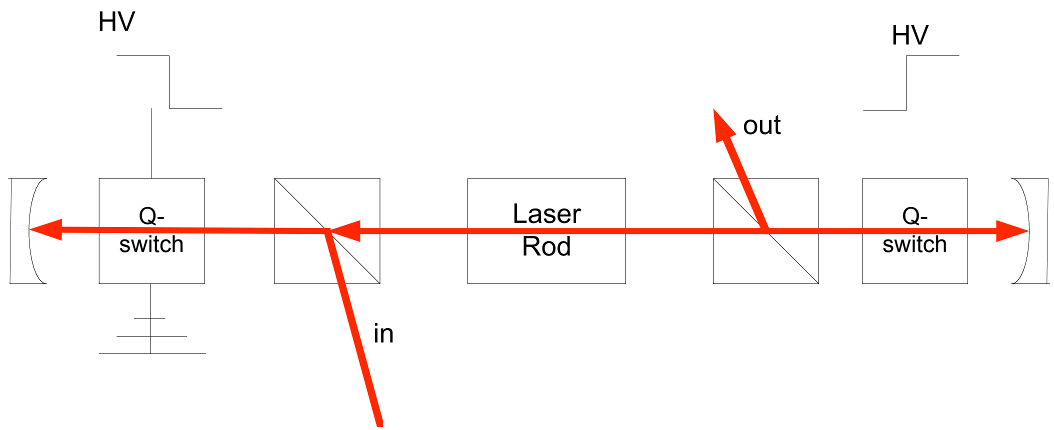
$G_{mp} = G_0^{2N}$ = multipass unsaturated gain

Multipass Amplifier Approaches

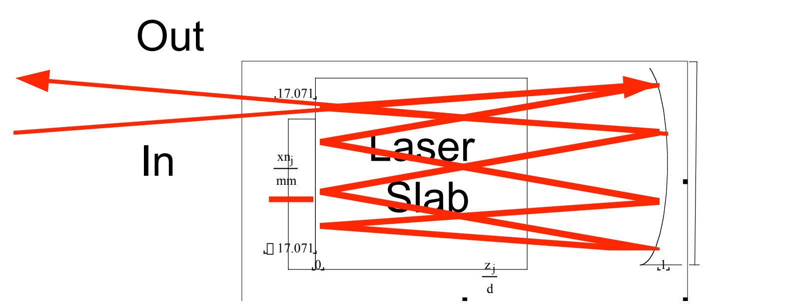
Passive Amplifier/Multiple Mirrors
(e.g. Q-Peak laser in SLR2000)



Regenerative Amplifiers
(e.g. NASA STALAS Laser
or High-Q laser at Graz)



Degenerate Optical Resonators



*Stable Degenerate Resonators**

- A stable optical resonator is defined by two spherical mirrors with radii of curvature, b_1 and b_2, and separated by a distance d such that $0 \leq (1-d/b_1)(1-d/b_2) \leq 1$
- At certain mirror separations, d, the resonator becomes “degenerate”and can be characterized by an integer N
- At a mirror separation with “degeneracy” N:
  - The Hermite-Gaussian resonator modes divide into N discrete frequencies separated by c/2NL where L is the resonator length; thus, N=1 represents the highest degeneracy where all spatial modes oscillate at the same frequency.
  - Hole-coupled lasers exhibit large power losses because the frequency-degenerate modes can couple together to create a low loss composite mode with a null at the coupling hole
  - Ray paths can be defined which repeat themselves after N round trips (useful for multipass amplifiers)

***Reference: I. A. Ramsay and J. J. Degnan, "A Ray Analysis of Optical Resonators Formed by Two Spherical Mirrors", Applied Optics, Vol. 9, pp. 385-398, February, 1970.**

General Resonator

If b_1 and b_2 are the mirror radii of curvature, the degenerate mirror separations are given by

$$d_{\pm}(N,K) = \frac{b_1 + b_2}{2} \pm \frac{1}{2}\sqrt{b_1^2 + b_2^2 + 2b_1 b_2 \cos\left(\frac{2\pi K}{N}\right)}$$

where N is the degeneracy factor, $K = 0$ for $N = 1$, and

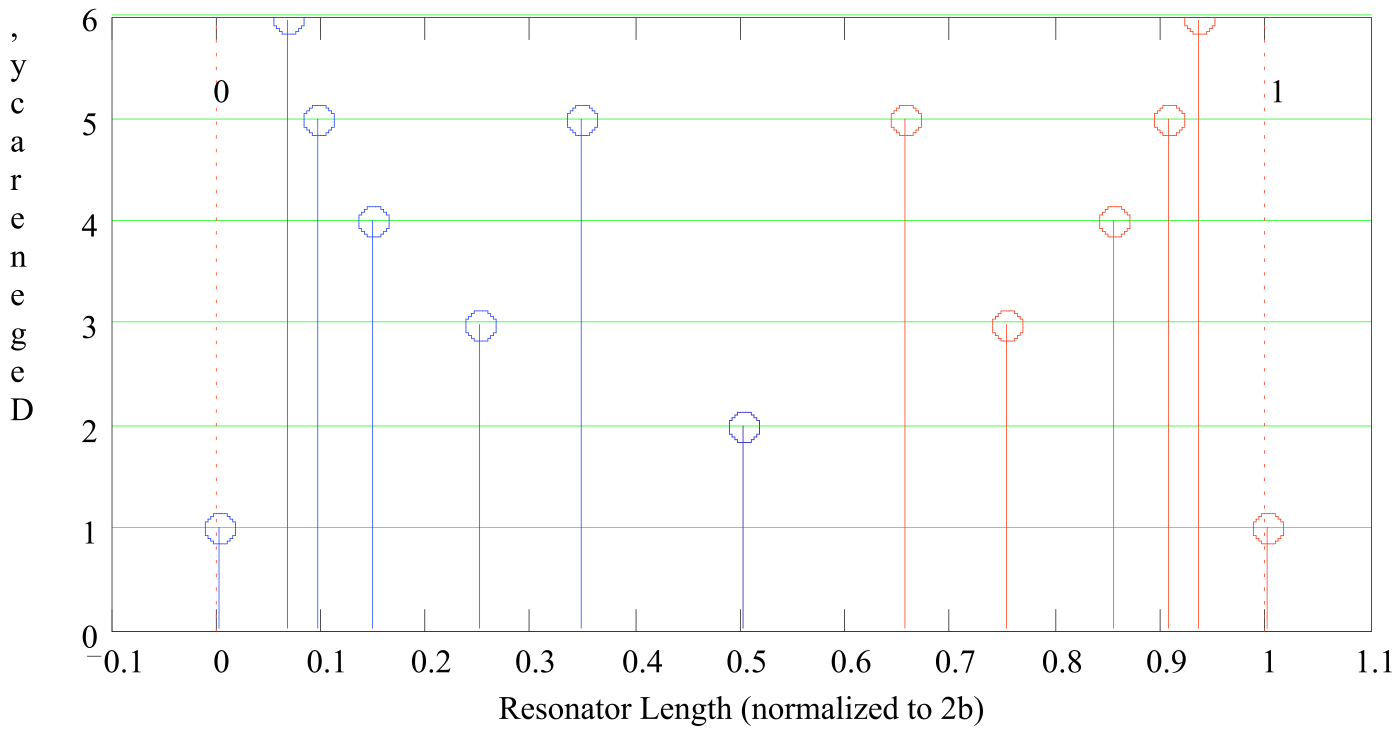
$$1 \le K \le \frac{N}{2}$$ for N > 1 provided K >1 is not divisible into N

N =	1	2	3	4	5	6	7	8
K=	0	1	1	1	1	1	1	1
					2		2	3
							3	

***Reference: I. A. Ramsay and J. J. Degnan, "A Ray Analysis of Optical Resonators Formed by Two Spherical Mirrors", Applied Optics, Vol. 9, pp. 385-398, February, 1970.**

Symmetric Resonator ($b_1 = b_2 = b$)

$$d_{\pm}(N,K) = b\left[1 \pm \cos\left(\frac{\pi K}{N}\right)\right]$$

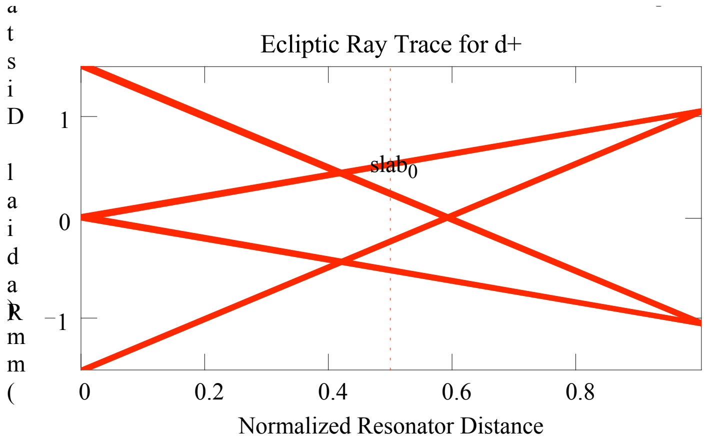


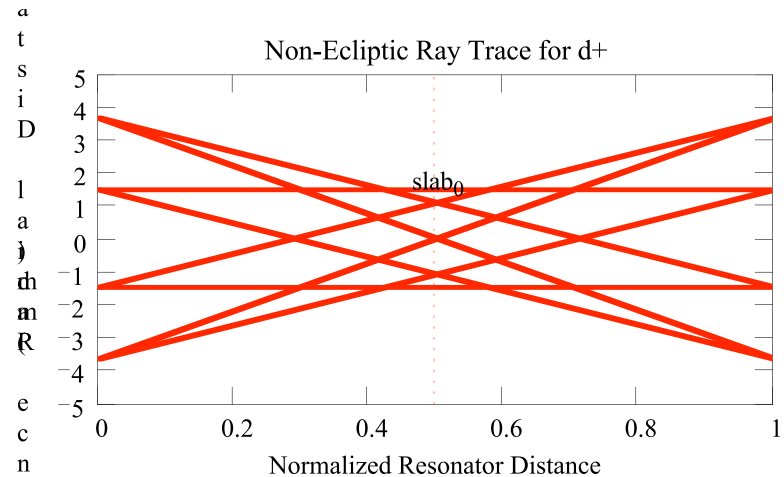
Symmetric Resonator ($b_1 = b_2$)
N=4, K=1

Ecliptic

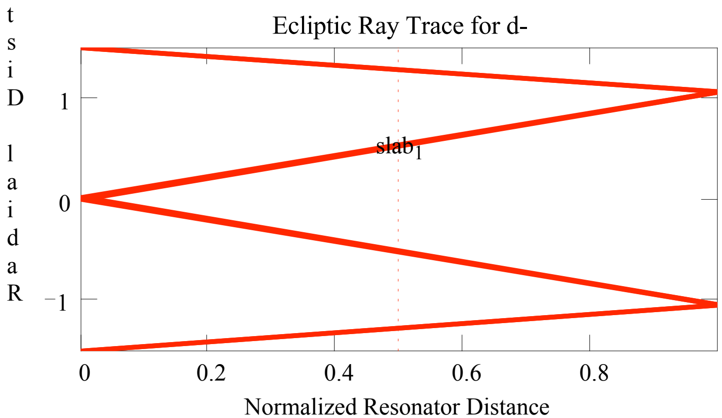
Non-Ecliptic

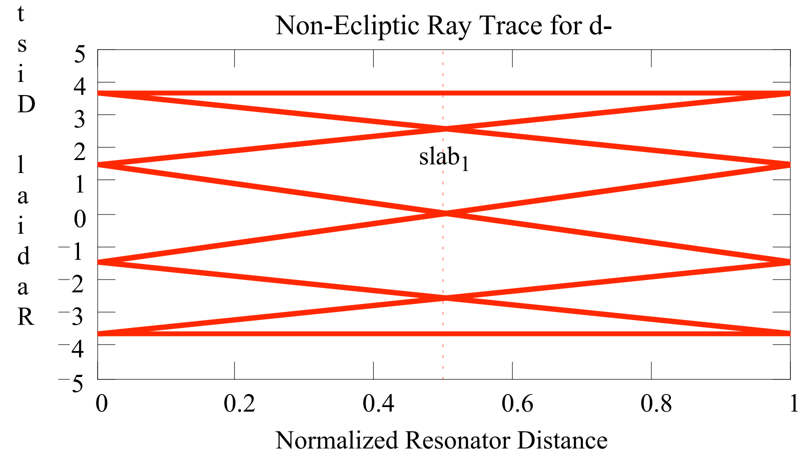
d_+





d_-



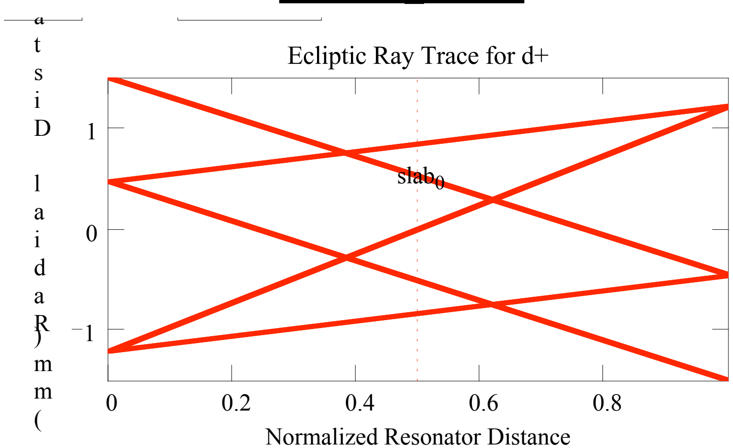


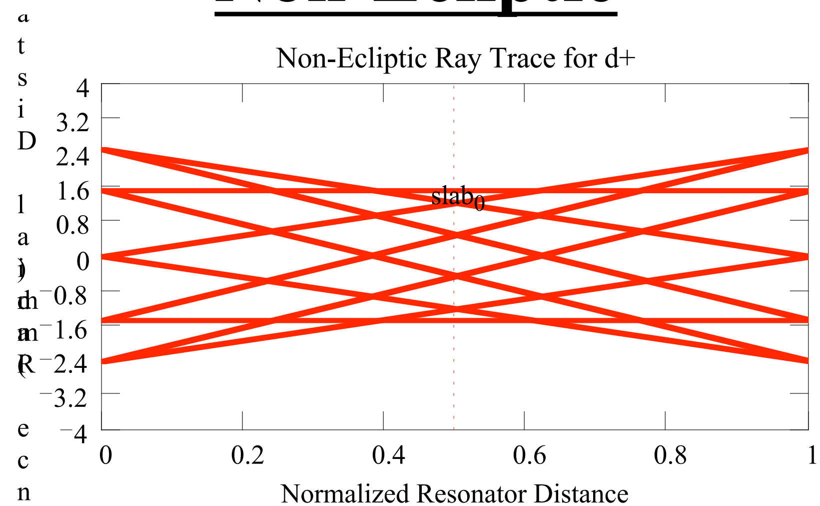
Symmetric Resonator ($b_1 = b_2$) *N=5, K=2*

Ecliptic

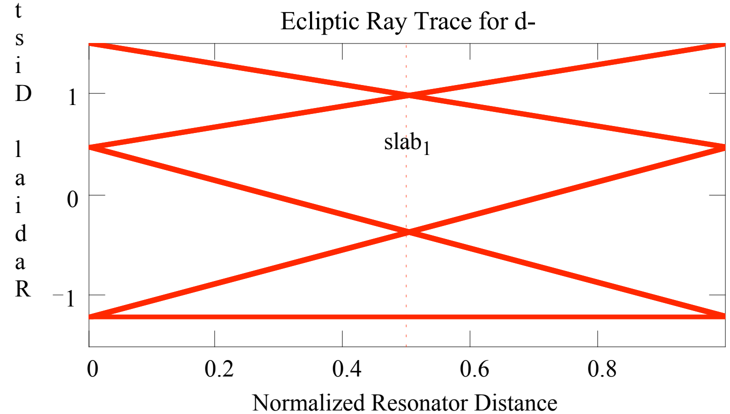
Non-Ecliptic

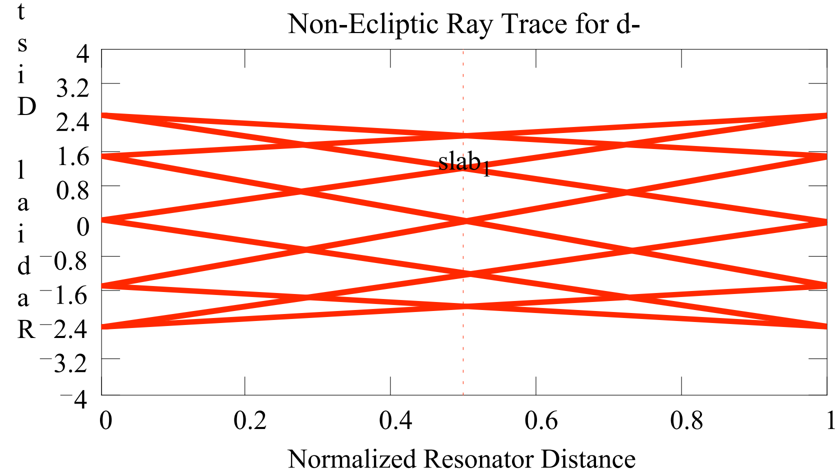
d_+





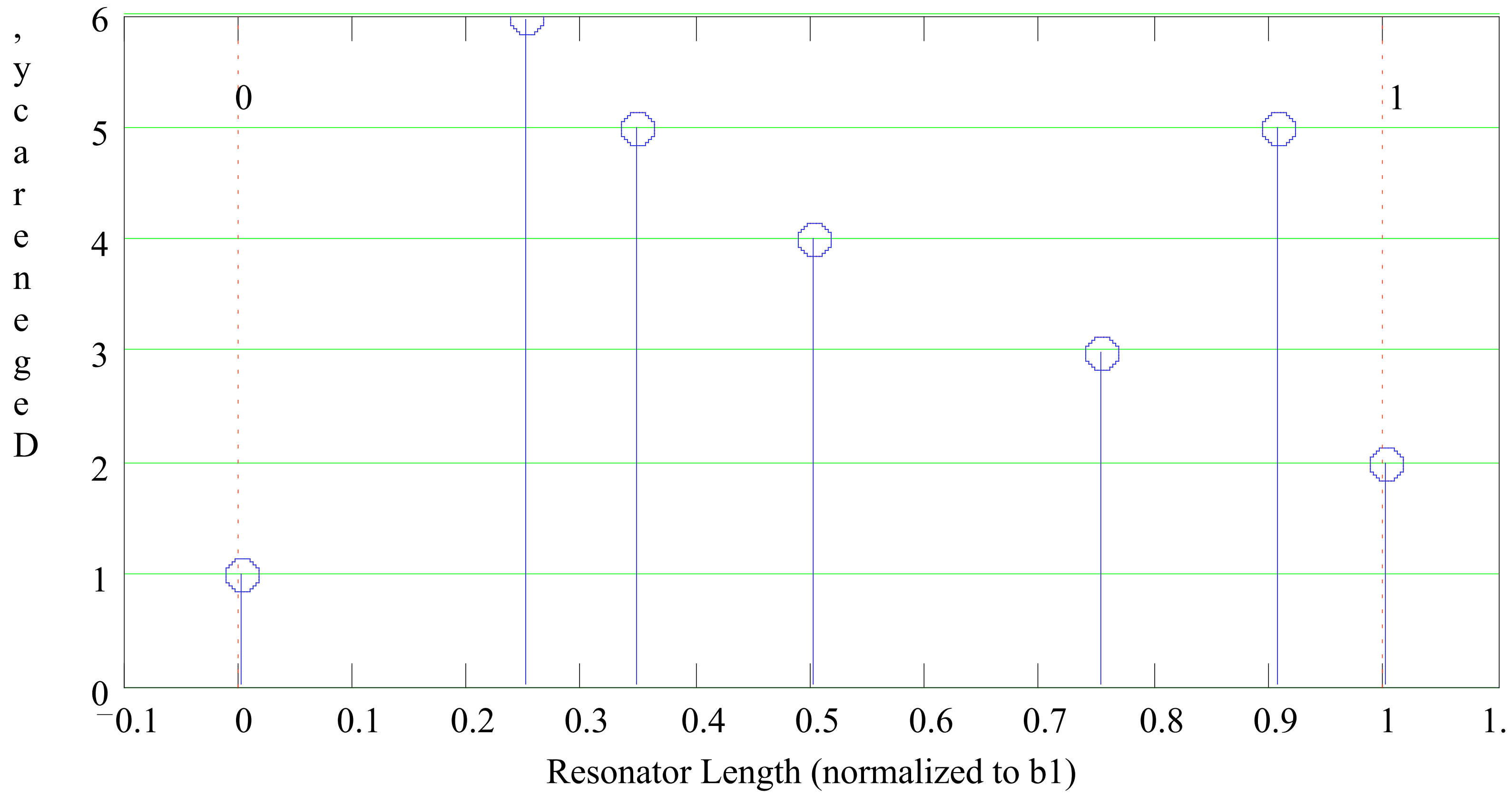
d_-





Flat-Concave Resonator (b_2 =)

$$d(N,K) = \frac{b_1}{2}\left[1 - \cos\left(\frac{2\pi K}{N}\right)\right]$$

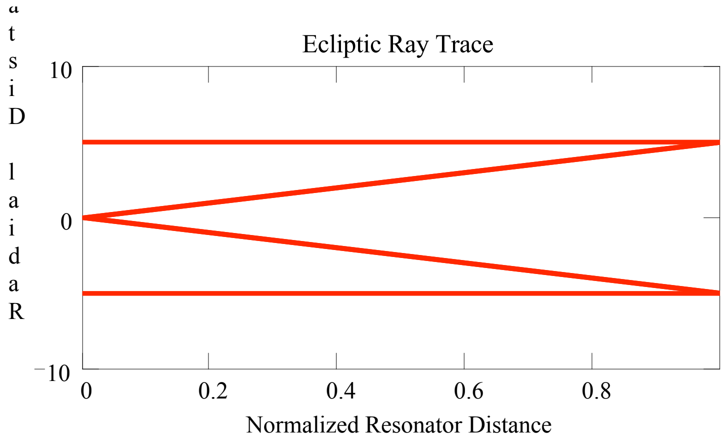


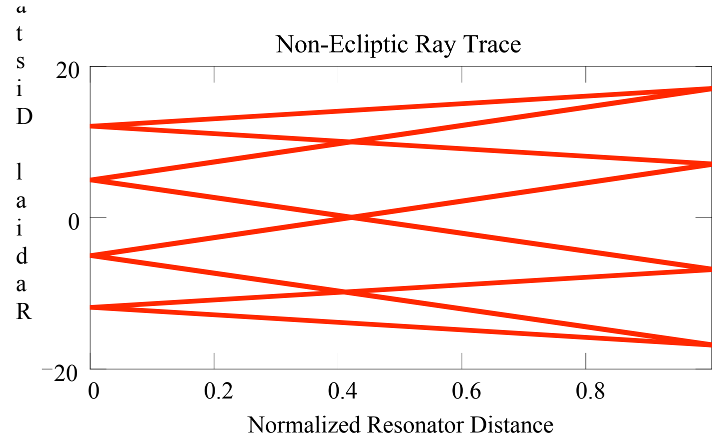
Flat-Concave Resonator (b_2=)

Ecliptic

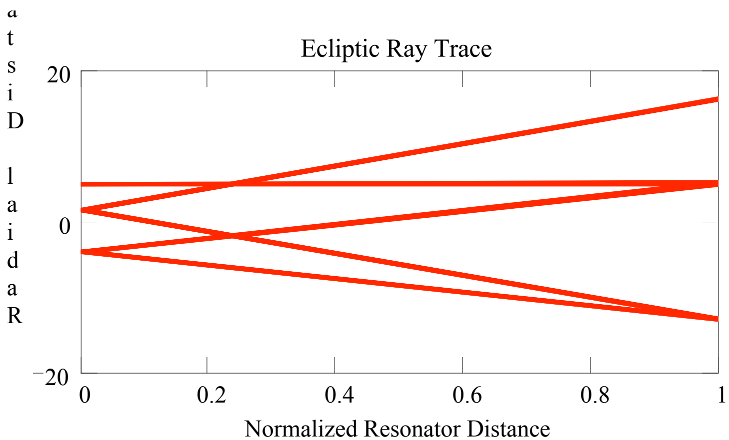
Non-Ecliptic

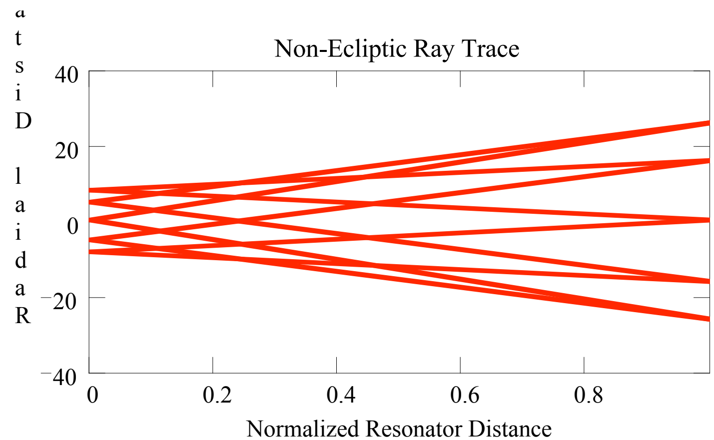
N = 4
K = 1





N = 5
K = 2





Ecliptic vs Non-Ecliptic Amplifiers

<u>Ecliptic</u>

- **Amplifier entrance and exit rays overlap**
  - Requires optical isolation from the oscillator
  - Requires a means to insert and extract the beam (e.g. polarization rotation)
  - Samples less of the laser slab (less efficient extraction?)

- **Generally easier to align since the insertion axis always lies along mirror normal**

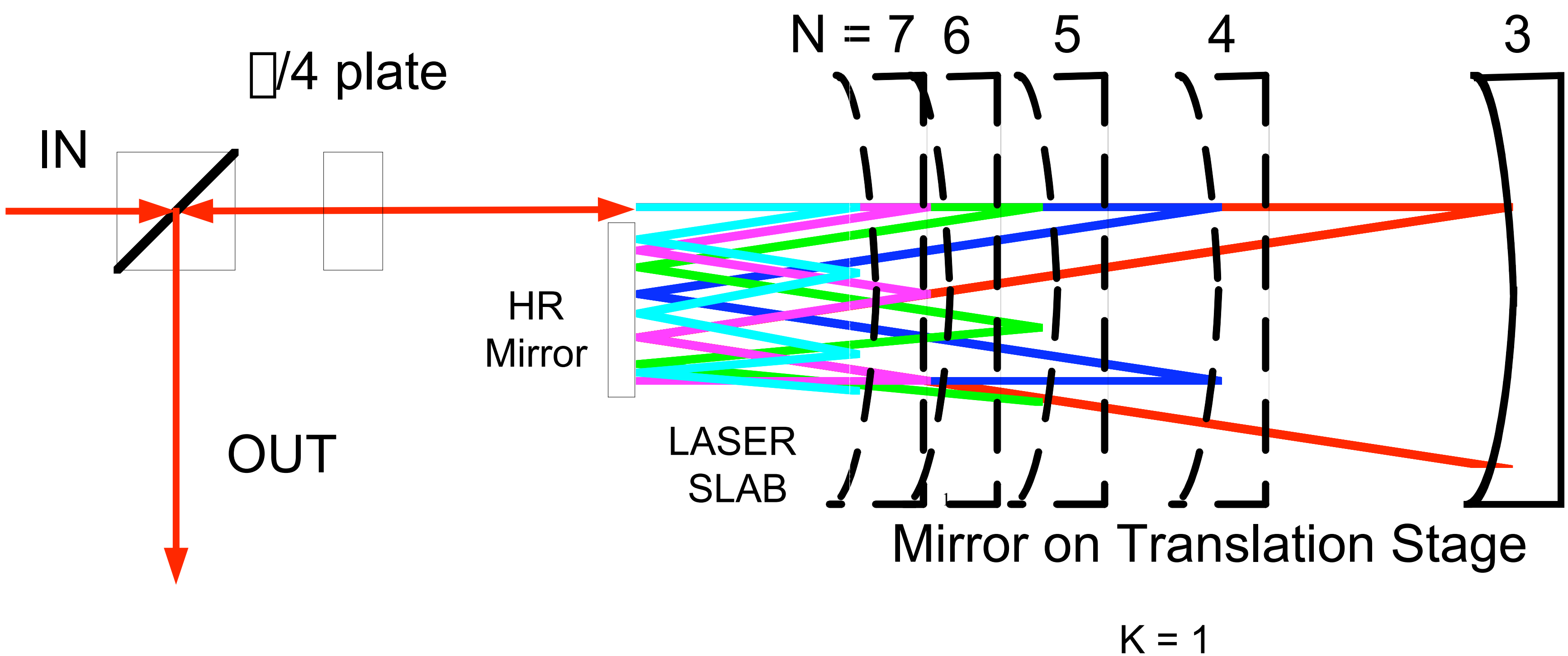
- **With one flat mirror, a variable pass amplifier can be constructed using one translatable mirror.**

<u>Non-Ecliptic</u>

- **Amplifier entrance and exit rays do not overlap**
  - Probably does not require optical isolation from the oscillator
  - Does not require a means to insert and extract the beam (e.g. polarization rotation)
  - Samples more of the laser slab (more efficient extraction?)

- **Generally more difficult to align since the insertion angle varies with degeneracy N.**

Ecliptic Variable Pass Amplifier



Excellent Beam Control: Collimated beam in, same size collimated beam out!

Summary

- **Microchip and SESAM oscillators can generate picosecond pulses at multi-KHz rates but at low single pulse energies (microjoules or less)**
- **Many airborne and spaceborne applications require amplifications of 10 to 10^3 in a compact, efficient, diode-pumped package.**
- **Since CW-diode pumped amps typically have low single pass gains, many passes through the amplifier may be required to reach the required pulse energies and to extract the stored energy efficiently**
- **Degenerate resonator multipass amplifiers can provide :**
  - **high multipass gain in a compact, easily aligned package**
  - **A fair amount of isolation from the oscillator and reduced internal feedback for suppressing self-oscillations**
  - **Variable number of passes with one translating mirror which can be set for optimum performance or compensate for a degradation in oscillator power**
  - **Excellent beam control since it preserves the gaussian parameters of the input beam at the output due to periodic refocusing**