Unstable Resonators

In a stable resonator the radiation is confined between the surfaces of the resonator mirrors. In order to produce a diffraction-limited output beam from a stable resonator, the Fresnel number must be on the order of unity or smaller, otherwise sufficient discrimination against higher order modes cannot be achieved. For practical resonator lengths, this usually limits the diameter of the TEM_{00} mode to a few millimeters or less.

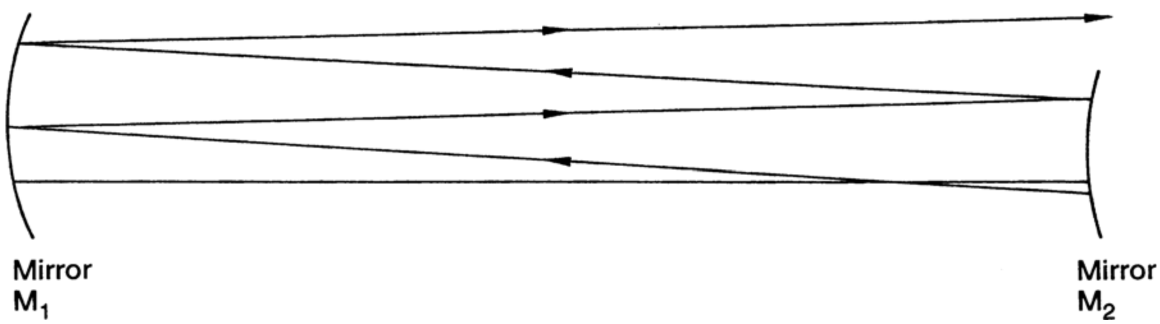


Fig.1. Light ray in an unstable resonator

About 10 years after its discovery, Byer and coworkers applied the unstable resonator concept for the first time to a Q-switched Nd:YAG oscillator/amplifier system. They did achieve a marked improvement in Nd:YAG output energy in a diffraction-limited mode.
However, only recently has the unstable resonator found applications in commercial lasers, mainly as a result of the availability of the variable reflectivity output mirror which provides a smooth and uniform output beam from an unstable resonator. Output coupling via such a mirror provides an elegant solution in overcoming the beam profile issue.

The most useful form of an unstable resonator is the confocal unstable resonator. A primary advantage of this configuration is that it automatically produces a collimated output beam; this also means that the final pass of the beam through the gain medium is collimated.

Confocal Positive-Branch Unstable Resonator

The confocal positive-branch unstable resonator is the most widely used form of the unstable resonator for solid-state lasers because it does not have an intra-cavity focal point that could lead to air breakdown or could cause damage to optical components.

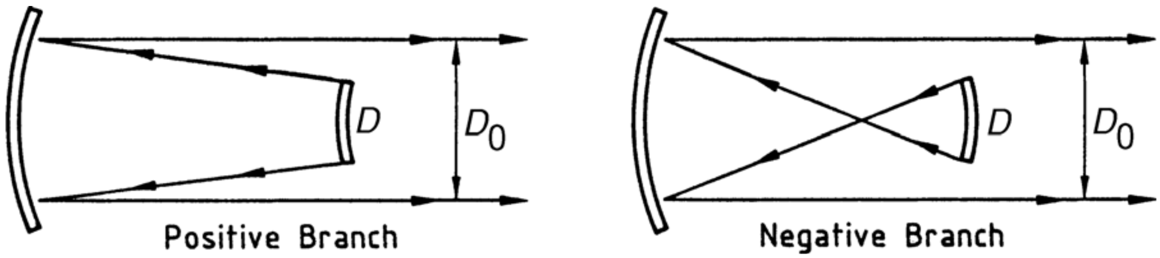


Fig.2 Positive and negative-branch confocal unstable resonator

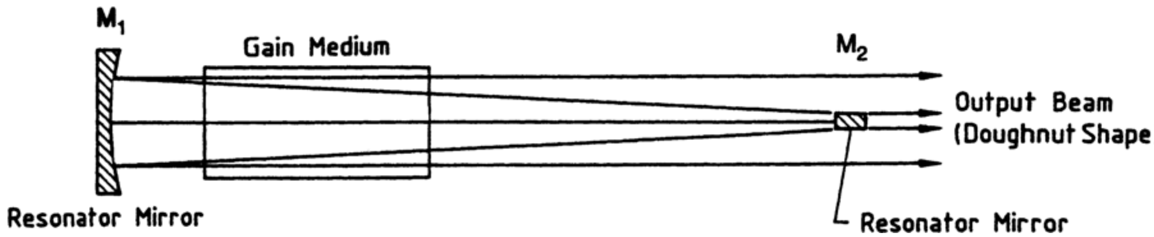
If we insert the gain medium between the mirrors, the loss in energy has to be made up by the gain of the laser.

For a confocal resonator, the mirror radii are given by

$$R_1 = \frac{-2L}{M-1}, \qquad R_2 = \frac{2ML}{M-1} \quad \ldots (1)$$

Where L is the length of the resonator and R_1 and R_2 are the output and back-cavity mirror curvatures. Note that the output mirror has a negative curvature and thus is convex, while the rear mirror has a positive curvature and is concave.

The design depicted in Fig. 3 consists of a concave mirror M1 and a convex output mirror M2, both of which are totally reflecting. The dot mirror M2 is a small circular dielectrically coated area of radius d centered on a glass substrate.



Negative-Branch Unstable Resonator

Fig.3 Small-mirror out-coupling scheme in a confocal, positive-branch unstable resonator

Because of the presence of an intra-cavity focal point, the negative-branch resonator has been neglected in practical laser applications. Despite the potential problem of air breakdown this resonator merits consideration owing to its unique feature of relatively large misalignment tolerances.

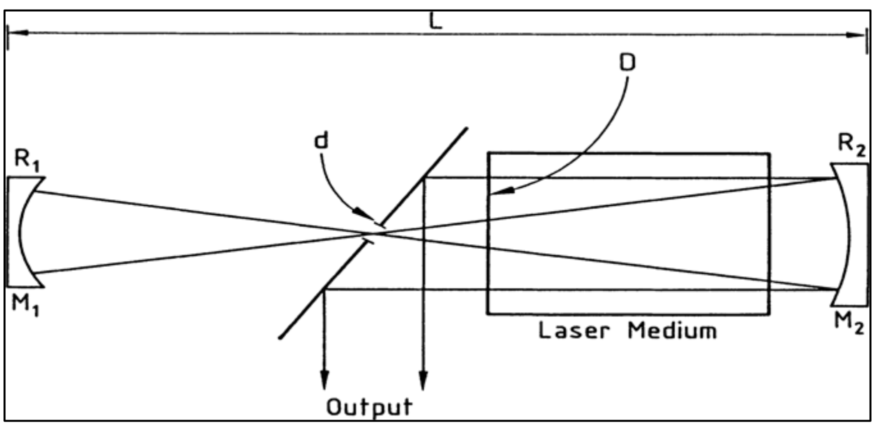


Fig.4 Arrangement of a typical negative-branch unstable resonator

The design parameters for a negative-branch resonator of the type shown in Fig. 6 are

$$R_1 = \frac{2L}{(M+1)} \qquad \text{and} \qquad R_2 = \frac{2ML}{(M+1)} \quad \dots (2)$$

where L is the confocal resonator length and M is the optical magnification defined before.

Variable Reflectivity Output Couplers

One of the major disadvantages of an unstable resonator, namely the generation of an annular output beam containing diffraction rings and a hot spot in the center, can be eliminated by employing a partially transparent output coupler with a radially variable reflectivity profile.

In such a mirror, reflectivity decreases radially from a peak in the center down to zero over a distance comparable to the diameter of the laser rod. Such a resonator is, in principle at least, capable of sustaining a single transverse mode of a very large volume and with a smooth, uniform spatial profile. Whether a large volume can be realized in a practical system depends on the gain of the system.

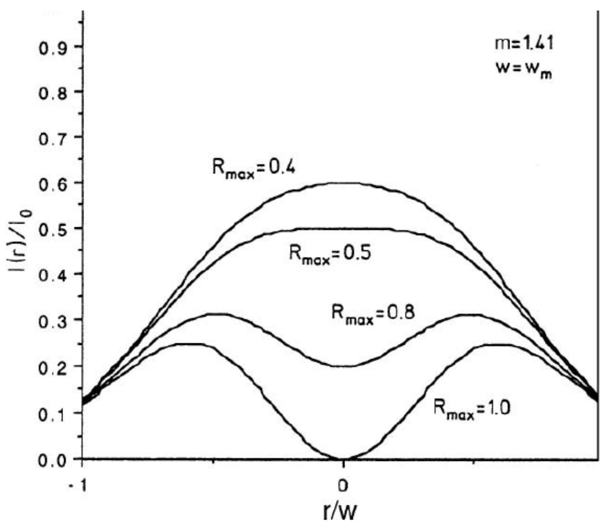


Fig.8 Profile of the output beam for various reflectivities of the mirror