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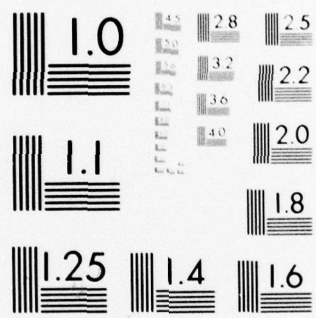

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UNSTABLE RESONATORS FOR ARMY LASER DESIGNATORS (U)

JUN 1978

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1. Introduction

The objective of this program was to investigate optical resonator properties relevant to the improvement of laser systems suitable for military designator/rangefinder applications. A study of the particular characteristics of a negative-branch, unstable resonator laser was performed. Laboratory experimentation revealed unique aspects which offer a new approach to solutions of existing technological problems of: beam quality, operational efficiency and reliability, and boresight stability.

In an initial effort to extend the results of the laboratory experimentation, an existing "Handheld Laser Designator" (HLD) was retrofitted with an unstable resonator laser module. A performance evaluation, and comparison with the standard unit using a conventional resonator system, revealed particular advantages in this preprototype design.

The conclusions drawn from this investigative effort highlight the unique characteristics of this new approach and offer insight to possible techniques for improving reliability of laser designator systems.

2. Technical Background

The primary function of a laser resonator is to maintain, through multiple reflection, the high intensity internal field necessary for the stimulated emission process. A fortunate by-product of this process is the formation of a coherent, monochromatic, narrow beam of radiation which is the hallmark of a laser and distinguishes it from all other known sources of radiation.

However, this statement is only qualitative in nature, and it is not until the actual performance of real lasers is measured against specifications for real applications that the quantitative shortcomings of state-of-the-art systems can be appreciated. Military applications, in fact, probably generate the most stringent requirements and specifications.

Army or Tri-Service applications for lasers range from very small rangefinder units, lightweight handheld target designators to larger, sophisticated units which may be tripod or vehicle mounted and have multi-functional capabilities. Although these systems may be very different in operating characteristics, due to their different design requirements, they share common problem areas in which improvement is necessary. The areas to be covered in this work are those which specifically require advances or improvements in laser resonator technology.

Military designator/rangefinder systems which employ flashlamp excitation and crystalline laser media (such as neodymium-YAG), are typically Q-switched and generate pulses of radiation with megawatts of peak power in approximately 10-20 nanoseconds duration. They must be capable of reliable repetitive pulse operation, as well as single-shot, from a "cold" start through a continuous time period dictated by mission requirements. The problem areas generated by these operational characteristics, which still confront current laser systems, are identified in the following list and will be addressed in the text. (a) Overall operating efficiency: This factor is important for all systems but especially for lightweight units with limited power resources. (b) Beam Quality: This term encompasses not only far-field beam divergence, but must also be concerned with near-field spatial coherence and freedom from spurious radiation. This factor determines the facility by which the "raw" laser beam emitted from the oscillator can be subsequently optically processed and implies the degree to which the resonator discriminates against unwanted modes of oscillation. Resonator mode discrimination is important since spurious internal radiation can cause not only a loss in true operating efficiency, but also produce "hot spots" within the resonator which can exceed materiel damage thresholds and thus deteriorate optical components within a short operating time span. (c) Initial expense and long-term reliability: These factors are related not only to fabrication quality, but also to inherent

superiority and simplicity of design, since improvement may sometimes be accomplished by merely reducing the number of components, if a superior design eliminates unnecessary complication required by an inherently more sensitive optical configuration.
(d) Maintenance of accurate boresight: This factor is critical for military applications and represents a primary area of consideration for improvement by resonator technology. (e) Overall performance over temperature change: This factor encompasses the totality of performance of the individual operating characteristics of the laser system and represents a major challenge in meeting rigorous military specifications. Ideally, lasers designed for field application should be operable over a relatively large ambient temperature range and/or over an extended operating time with minimum deterioration of output energy, beam quality, or boresight accuracy. The degree to which a laser system has these qualities is related to the relative sensitivity of the resonator design to optical misalignment caused by thermal variation.

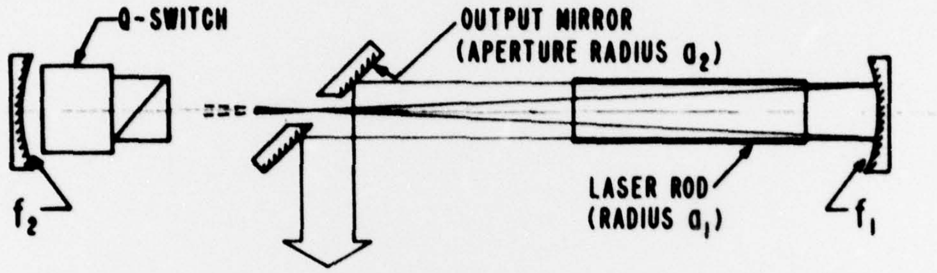
3. Technical Approach

This work was specifically concerned with improvement of the performance characteristics of Q-switch neodymium-YAG lasers operating in an energy category and repetition-rate suitable for designator/rangefinder applications.

Based on previously successful experience (1) with rhodamine 6G dye lasers, the negative-branch form of confocal, unstable resonator was investigated for use with the crystalline system. Although numerous publications describing unstable resonators have been presented in recent years, (2) their primary application has been virtually restricted to large-bore gas lasers - exploiting the inherent feature of arbitrarily large mode volume. However, more important to our interests, we found that the unstable resonator has the additional beneficial capacity of producing near diffraction-limited beam quality in short pulse-duration, high-gain lasers (3, 4, 5). An important consideration which particularly motivated the choice of the negative-branch configuration was provided by its unique feature of relatively large misalignment tolerance. Unstable resonator laser performance was not significantly degraded by mirror misalignment far beyond the point where laser action completely ceased with a conventional plane mirror-porro prism resonator (3).

4. Experimental Results

Figure 1 schematically illustrates the arrangement of optical components for the laboratory experimentation. Pertinent design parameters and formulas are defined (2,3). A 1/4 x 2 1/2 in. neodymium-YAG laser rod was pumped by a linear flashlamp in an elliptical pump cavity. Q-switching was accomplished with either a Pockels cell or a plastic sheet saturable absorber. Output coupling corresponding to an optical magnification of m = 2 was found to be optimum.



OUTPUT COUPLING FRACTION $c = 1 - 1/m^2$

OPTICAL MAGNIFICATION $m = f_1 / f_2$

CONFOCAL RESONATOR LENGTH $L = f_1 + f_2$

OUTPUT MIRROR APERTURE RADIUS $a_2 = a_1 / m$

Figure 1. Physical arrangement of the negative-branch, unstable resonator laser and definition of pertinent parameters.

4.1 Beam Quality Measurements

Figure 2 shows the quasi-far-field intensity profile of the laser beam as detected by a linear array of pyro-electric elements at a distance of 17 m. At this distance, the Fresnel Number is about 0.33, and the array pattern describes the far-field distribution with reasonable accuracy. A Fraunhofer pattern is clearly evident, and the diffraction angles to the first and second minima were immeasurably close to the theoretical values of 0.174 and 0.405 mrad, respectively.

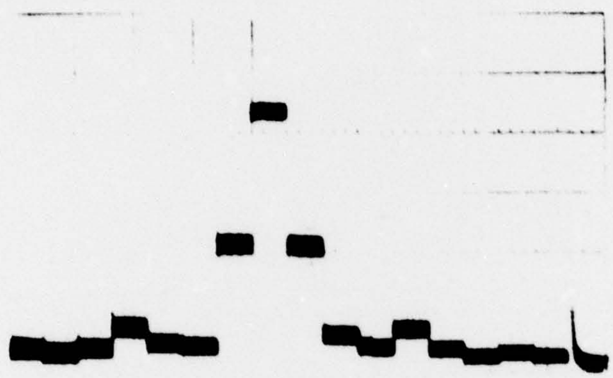


Figure 2. Far-field intensity profile of the unstable resonator laser beam as detected by a linear array of pyro-electric elements.

Figure 3 shows examples of laser burn patterns that were produced on Polaroid prints at various distances. In general, they were well resolved and clearly traced the evolution of the beam through the Fresnel diffraction regime. These observations implied that the output beam had excellent spatial-coherence characteristics and beam quality.

Figure 3. Laser burn patterns at 0.25 m, 1.7 m, and 7.2 m from the laser. A Fraunhofer pattern was observed to occur at a distance approximately 6 m, corresponding to diffraction theory.

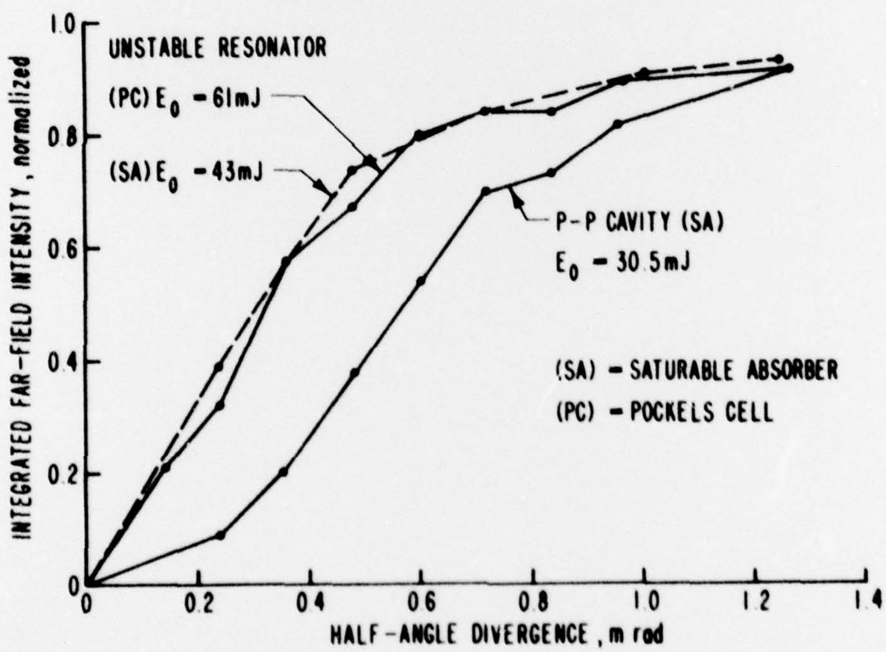


Figure 4. Comparison of energy distribution measurements for the laser with either an unstable or parallel-plane resonator.

Quantitative measurements of the emitted energy distribution were made by measuring the fractional transmission through apertures placed at the focal plane of a well-corrected plano-convex lens. Figure 4 shows the results of such measurements using either a Pockels cell or saturable absorber Q-switch. The results of corresponding measurements made with a parallel-plane mirror resonator are shown for comparison.

This data graphically illustrates the superior "brightness" achieved in the far-field beam by the unstable resonator. Note that although the divergence angle for the 90% energy distribution is only slightly less than that for the conventional resonator, the 20-70% energy points are achieved at significantly smaller angles.

4.2 Misalignment Tolerance

4.2.1 Since the optical axis defines the orientation of the resonator mode, it may be expected that angular mirror misalignment will result in beam steering. If the short focal length end mirror is misadjusted by an angle θ so that the optical axis makes some angle ϕ with respect to the geometrical axis of the resonator, the rate of beam steering is given by simple geometrical calculations to be $\phi/\theta = 2/(m + 1)$. It was found that actual laser performance closely concurred with the results predicted by these geometrical considerations. The beam steering rate was measured to be 0.61 mrad/mrad while the above equation gives the value 0.67. Over a measured range of θ as large as 4.5 mrad, output energy diminished by only about 1/3. Beam divergence characteristics changed significantly only when misadjustment was so severe that internal vignetting was eventually produced.

4.2.2 Actual resonator length was empirically determined by adjustment for optimum beam collimation. In general, length misadjustment was found to be not critical and a change up to about one-half percent produced no discernible difference in either output energy or beam divergence.

With respect to the radially expanding, outgoing wave, the resonator appears to be an expanding telescope. Changing its length merely focuses or defocuses the radiation. Consequently, this feature may be used as a simple form of adaptive optics that can compensate for thermal "lensing" of the laser rod or other such thermal effects in the resonator.

4.2.3 The major significance of these observations is that angular or length misalignment produces effects which can be explained by a simple geometric model and can be corrected by correspondingly simple means. For example, by readjusting only the short focal length mirror, both bore-sighting and col[illegible]ation adjustments can be performed without necessity for additional adjustment in the other resonator optics and without loss in operating efficiency.

5. Packaged, Fieldable Prototype

The [illegible]ective of this extension program was to investigate the characteristics of the unstable resonator design in an actual, packaged laser designator. An existing "Handheld Laser Designator" (HLD), shown in Figure 5, was retrofitted with the unstable resonator and a hybrid form of pump cavity (in which the flashlamp is conduction cooled, with the jacketed laser rod liquid cooled). The original HLD utilizes a conventional laser resonator and gas cooled pump cavity.

Figure 6 is a schematic illustration of the optical configuration actually packaged in the laser module. The raw beam from the laser module is directed through a pair of optical wedges, for boresight adjustment, to the standard HLD six-power telescope. Because the resonator module was retrofitted to an existing unit, physical constraints prevented realization of the new design concept for alignment optimization as described in the previous section. However, it was expected that this retrofitting would provide a fair comparison with conventional engineering approaches and thus strenghten the technological base for future development.

Table I summarizes the results of a performance comparison with a standard HLD unit. Both units were operated at 10 pulse/sec. In general, it is seen that the unstable resonator version produced superior beam radiance and equaled the standard version in operating efficiency.

Figure 7 shows a plot of beam divergence variation with pulse repetition frequency (PRF) for the raw beam output of the laser module. Comparison is made with a conventional resonator which employed an intracavity compensating lens necessary to reduce thermally induced deteriorating effects. Although the unstable resonator was fixed in adjustment and employed no explicit compensating elements, it gave a clearly superior performance and demonstrated its inherent misalignment insensitivity.

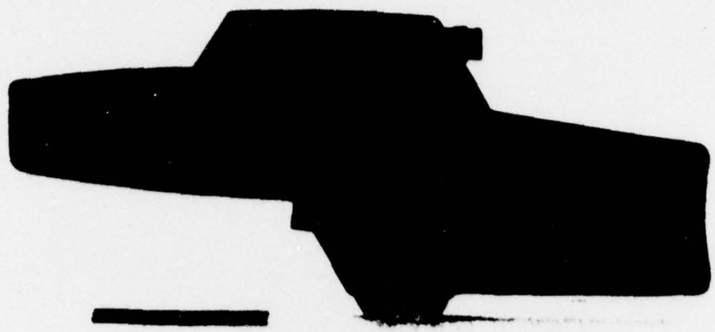


Figure 5. Handheld Laser Designator (HLD).

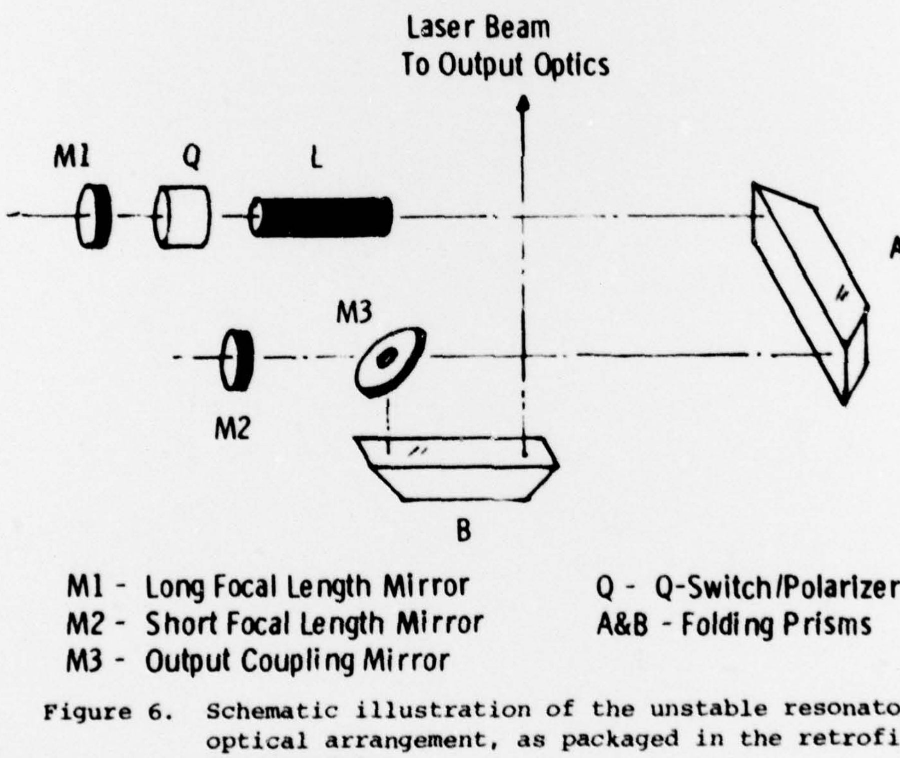


Figure 6. Schematic illustration of the unstable resonator optical arrangement, as packaged in the retrofitted laser module.

Table 1. Performance comparison of standard HLD Designator with retrofitted Unstable Resonator/Hybrid Pump cavity version.

	HLD	Unstable Resonator
Energy/pulse	58 mJ	60 mJ
Pulse Duration (FWHM)	22 ns	14 ns
Peak Power	2.6 MW	4.3 MW
Full-Angle Beam Divergence		
50% Energy	0.39 mrad	0.37 mrad
75% Energy	0.58 mrad	0.48 mrad
90% Energy	0.82 mrad	0.65 mrad
Shot-to-Shot Amplitude Stability	± 10%	± 1%

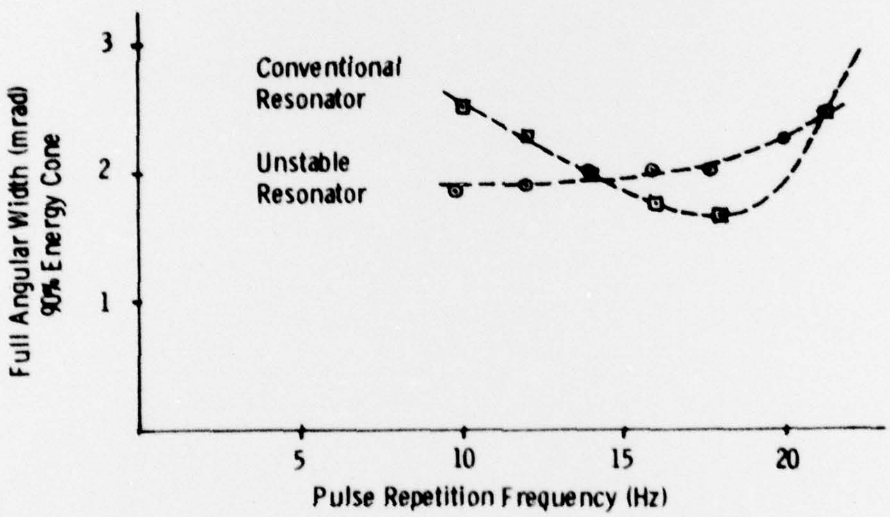


Figure 7. Comparison of "raw" beam divergence from the unstable resonator and the compensated conventional resonator as a function of pulse repetition frequency.

6. Conclusions

Experimental results of a Q-switched, neodymium-YAG laser in the designator energy category have been presented. A performance comparison between an unstable resonator, retrofitted designator and a conventional unit has been described. The experience and information gained have shown that the unstable resonator system can have a significant impact on laser technology in the following areas:

a. Beam quality: Improved beam divergence and high radiance can be achieved. Both of these parameters are important for improvement of designator target discrimination characteristics.

b. Resonator Mode Discrimination: This factor is important in producing good output beam quality. In addition, the dominant character of the internal flux reduces spurious oscillation which can produce "hot spots" responsible for both short and long term deterioration of optical components, with consequent loss of reliability.

c. Performance insensitivity to misalignment: It has been shown that the unstable resonator has inherent qualities which reduce sensitivity of output energy or beam divergence to optical misadjustment. Furthermore, because the confocal unstable resonator has focusing properties inherent to its configuration, it is feasible that this feature could be directly employed as an efficient mechanism for correcting beam divergence and output variation typically induced by either ambient or dynamic thermal variation. The approach presently employed to perform these tasks in conventional resonators is to introduce additional, corrective, intracavity optical elements. The problems associated with this approach might be obviated by the focusing characteristics of the unstable resonator.

d. The feasibility of extending the unstable resonator design concept to large bore, high Fresnel Number lasers operating to wavelengths as far as the submillimeter range would appear to have an established technological basis.

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