

Simultaneous AM and Harmonic FM Modelocking of a Nd:YAG Laser

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ABSTRACT

Into a fundamentally AM modelocked Nd:YAG laser, we incorporate an electro-optic phase modulator driven at the 22nd harmonic (1.76 GHz). With only 0.6 Watts of RF power we obtain 17 ps pulses at 80 MHz and 8.0 Watts average optical power.

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Both AM and FM modelocking have been studied and applied extensively to many different laser systems.^{1,2} Analysis shows that the optical pulsewidth for either process depends on the modulation depth and frequency according to

$$\tau_p \propto \left(\frac{1}{\delta}\right)^{1/4} \left(\frac{1}{f_m}\right)^{1/2}, \quad (1)$$

where δ is the modulation index and f_m is the modulation frequency. Clearly, to obtain shorter pulses, raising the frequency f_m provides a more rapid rate of return than increasing δ . But, for lasers that are limited to constant average output power, the peak power is reduced at a rate $\propto f_m^{-1/2}$. There are many applications where this tradeoff is undesirable (e.g. harmonic generation).

However, if two modelocking mechanisms are combined such that one operates at the fundamental frequency and one at a harmonic, the benefits of shorter pulses at low repetition rates will be preserved.^{3,4} Towards this end we report here on simultaneous modelocking; fundamental AM and harmonic FM.

We constructed an electro-optic phase modulator (FM modelocker) with a LiNbO₃ crystal in a resonant microwave cavity ($f_m = 1.76$ GHz, $Q_L = 1500$, $\eta = 0.59$ rad/ $\sqrt{\text{Watt}}$ single pass).⁵ The modulator was placed inside an AM modelocked Nd:YAG laser (Coherent Antares), 15 cm from the output coupler. The 1.76 GHz drive signal was phaselocked

to the 40 MHz acousto-optic modelocker signal. This ensured that the phase modulation was synchronized to the AM modelocker.

Simultaneous AM-harmonic FM operation was studied under constant AM modulation conditions. Fig. 1 shows the variation in pulsewidth as a function of phase modulator drive power along with a trend line denoting the $-1/8$ slope dependence predicted by the theory (cf. Eq. (1) and recall that $\delta \propto \sqrt{P_m}$). At very low phase modulator drive power, laser operation is dominated by the AM modelocking mechanism. However, with remarkably low power levels, the FM modelocking process begins to dominate. With as little as 15 milliwatts (0.072 radians), the pulsewidth was halved to 40 ps. Raising the modulator power to 0.63 Watts (0.68 radians) reduced the pulsewidth to 17 ps.

Using AM modelocking alone, we routinely obtain 75 ps pulses with an average optical power of 24 Watts (≈ 4 KW peak). With the phase modulator inserted in the cavity, the average power dropped to about 6 Watts and the laser was somewhat noisy, with occasional self-Q switching. We attribute both the loss and instability to imperfect antireflection coatings and the photorefractive effect in LiNbO_3 which may be causing intensity dependent “waveguiding” and spatial mode instability. Nonetheless, we measured a “typical best” pulse of 17 ps at an average optical power of 8 Watts which corresponds to a peak power of 5.9 KW; a 47% increase.

The great utility of simultaneous fundamental and harmonic modelocking is that the pulse repetition rate remains that of the fundamental. Thus, for constant average laser power, the peak power increases linearly with the reduction in pulsewidth. Fig. 2 verifies the fundamental pulse rate when both modelockers are running. Turning off the AM modelocker resulted in the repetition rate rising to 1.76 GHz, as expected.

This technique should be broadly applicable to many laser systems. There are new, subtle, and interesting effects that the combination of AM and harmonic FM modelocking produce and these will be presented.

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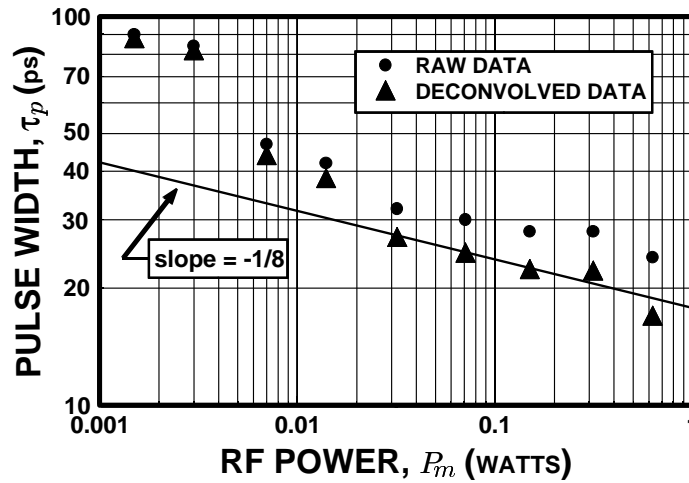


Figure 1. Optical pulsewidth vs. phase modulator drive power ($\eta = 0.59 \text{ rad}/\sqrt{\text{Watt}}$ single pass). Deconvolution applied to data because of photodiode’s 17 ps impulse response.

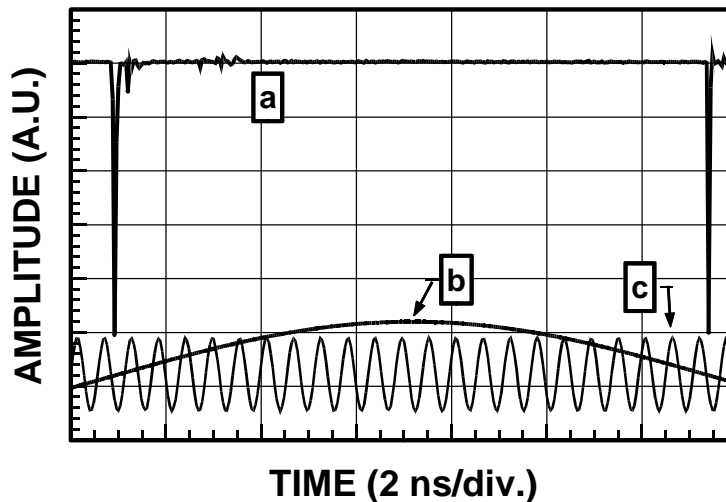


Figure 2. Verification of fundamental pulse repetition rate. (a) Modelocked pulse train (12.5 ns separation/80 MHz). (b) 40 MHz AM modelocker drive signal. (c) 1.76 GHz FM modelocker drive signal. The signals are displayed with arbitrary relative phases.