Robust 2070 nm ns Pulsed PM Laser Module
with 250 W Peak Output Power and 12 μJ Pulse Energy

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Executive Summary

- Optical transmitter design based on polarization-maintaining (PM) holmium-doped fiber amplifiers (HDFAs) [1] for medical, sensing, and LIDAR applications [2]
- CW output power $>$ **2.5 W** at wavelength $\lambda =$ **2070 nm**
- Pulse energies of $>$ **12 μJ** and peak powers $>$ **250 W** in sub-μs pulses
- Broad range of available pulse length, $\tau \in [80-500]$ **ns**, and repetition frequencies, **PRF** $\in [85-1000]$ **kHz**
- Controllable linewidth $\Delta\nu \in [15-400]$ **MHz** to suppress stimulated Brillouin scattering (SBS)
- **Pulse pre-shaping** allows for reduction in gain-peaking and improvement of the output pulse shape

Experimental Setup

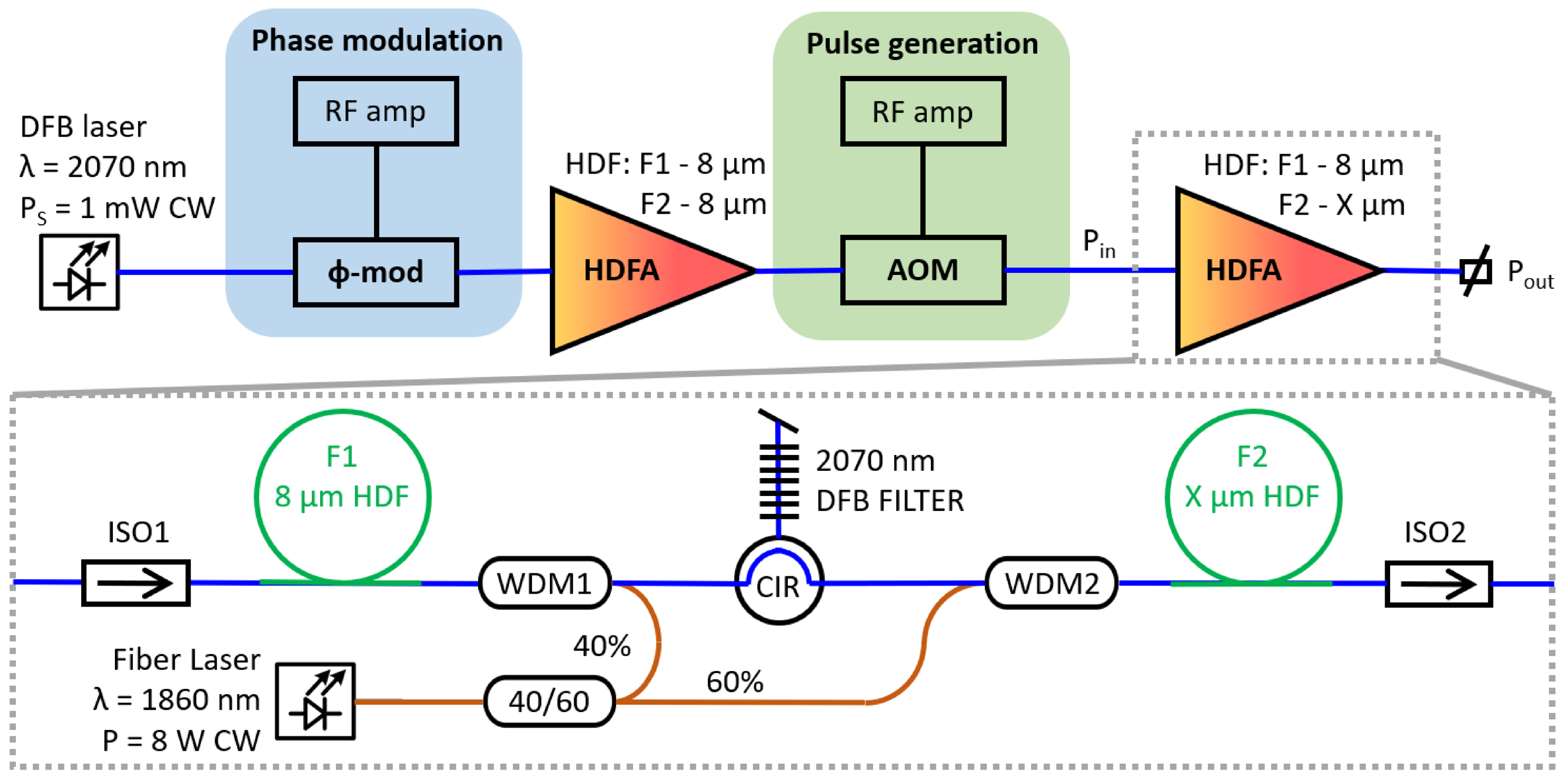

Figure 1: Schematic of the master-oscillator power-amplifier (MOPA) transmitter (top) and the topology of the HDFAs (bottom).

- **Semiconductor seed laser** (Eblana) provides 1 mW of continuous wave (CW) signal at $\lambda_S = 2070$ nm ($\Delta\nu = 15$ MHz)
- **Phase modulator** (iXblue) **broadens the linewidth**, $\Delta\nu \leq 400$ MHz
- **Holmium-doped fiber pre-amplifier** boosts the signal power to up to 1 W CW
- **Acousto-optic modulator** (AOM: G&H) **generates pulses** with $\tau > 50$ ns, peak power $>$ 500 mW and duty cycle DC $<$ 10%
- **Dual-stage HDFA with mid-stage filter**, pumped at 1860 nm used for amplification.
- **Two types of HDFs tested** for booster amplifier stage:
  - with 20 μm core (large mode field to lower peak power and prevent NL effects)
  - with 8 μm core (higher efficiency due to lower ion-pairing)

CW Performance

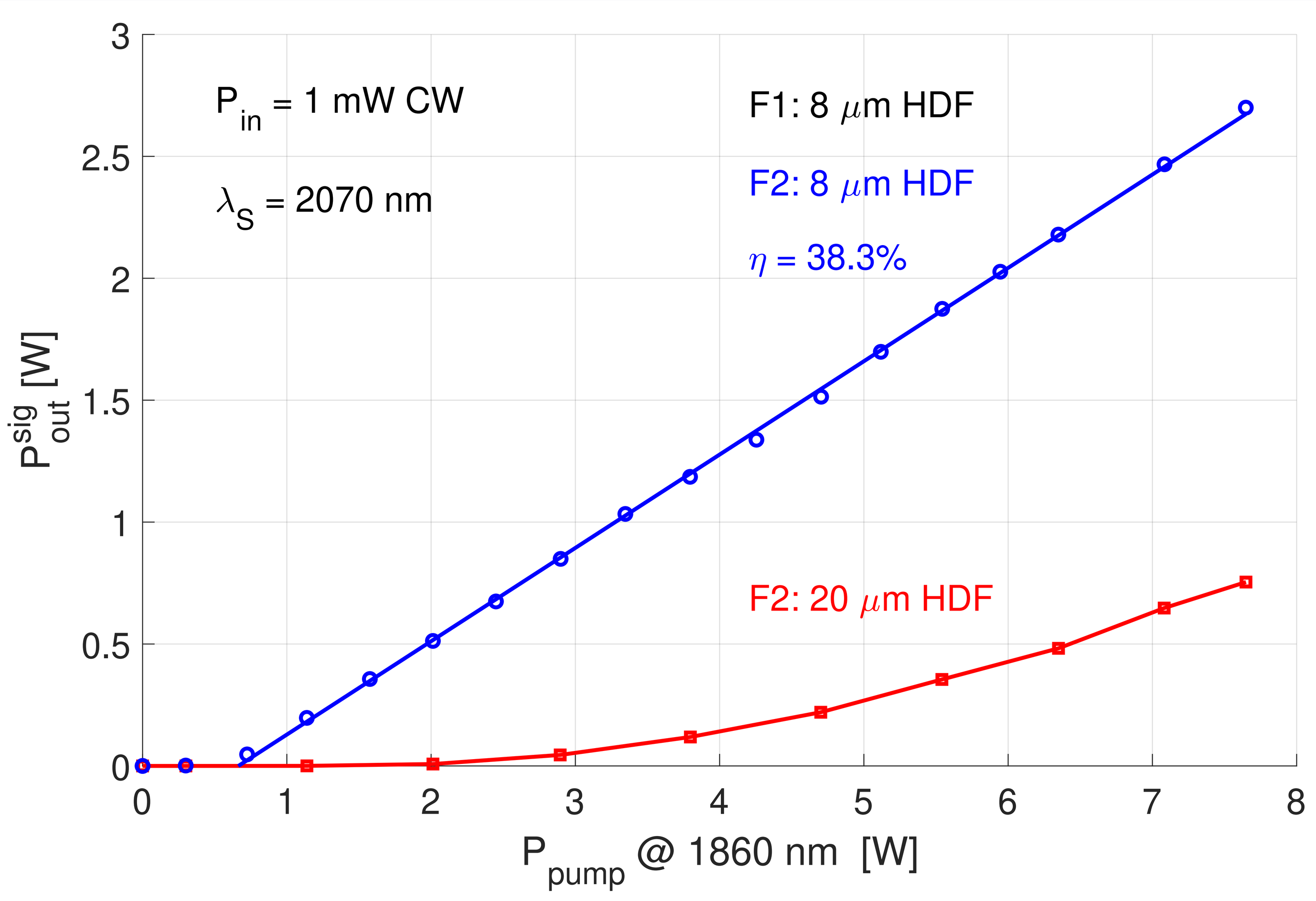

Figure 2: Output signal power of the PM HDFAs as a function of pump power: 8 μm core (blue) and 20 μm core (red). **Output power of $>$ 2.5 W is achieved.**

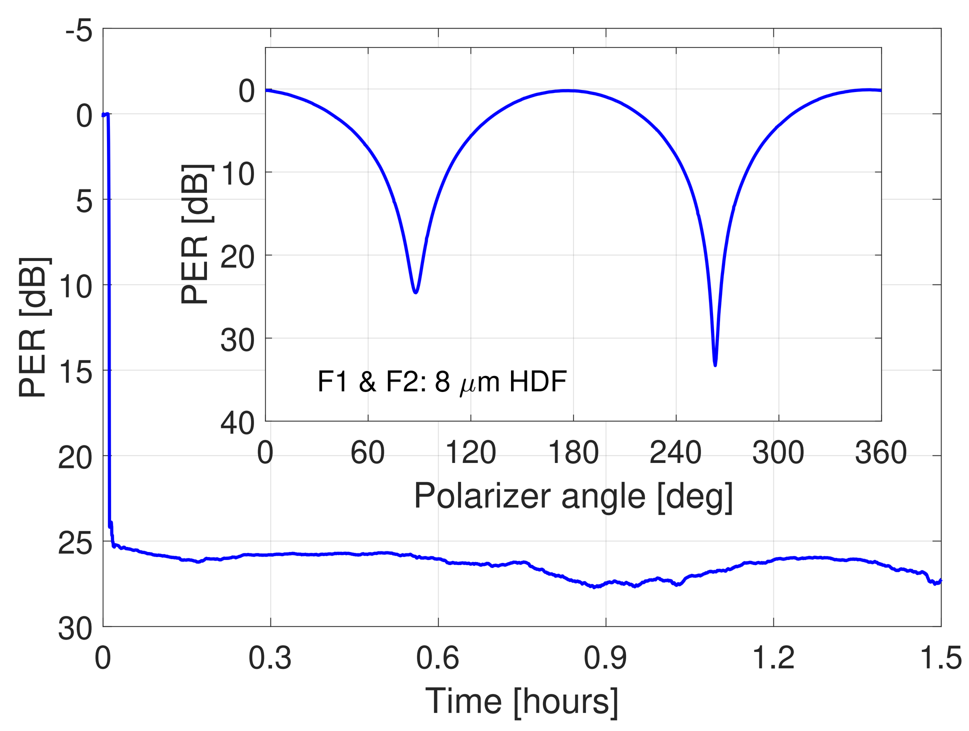

Figure 3: Stability of the polarization extinction ratio (PER) and PER visibility curve (inset) measured at 400 mW of CW output.

The measured **PER** is **$>$ 25 dB**.

Pulsed Performance

(with 8 μm core booster HDF)

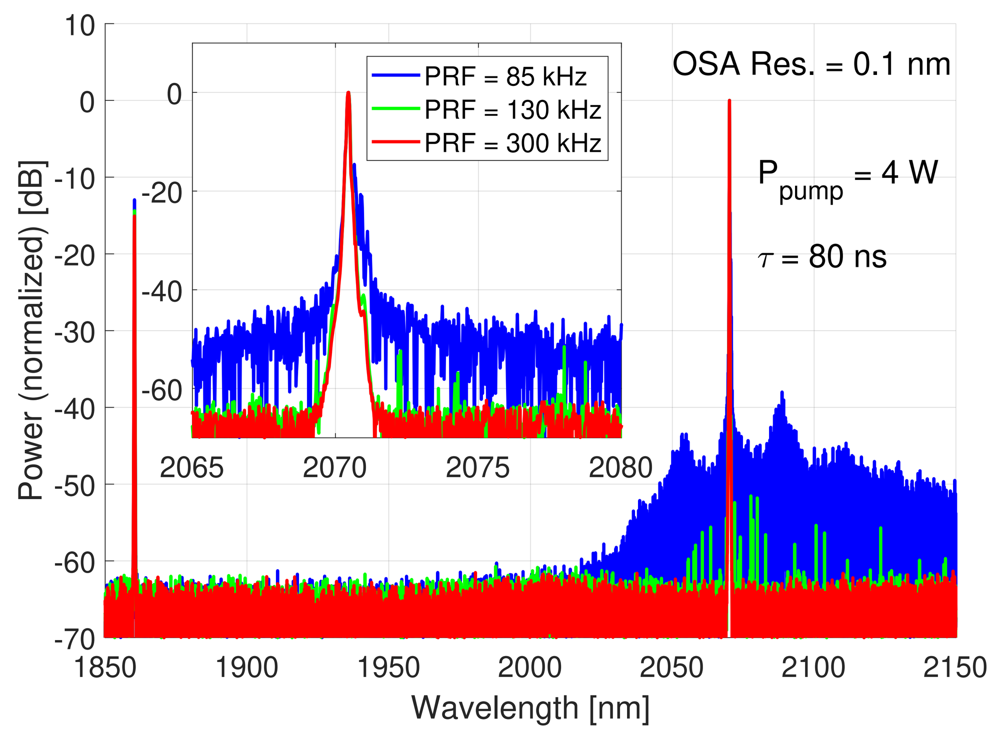

Figure 4: Spectra of the pulsed PM HDFA. The inset shows the spectrum in the vicinity of the signal wavelength.

With increasing peak power, the sidebands generated by the modulation instability (MI) and four-wave mixing become visible.

OSNR is **$>$ 50 dB/nm**.

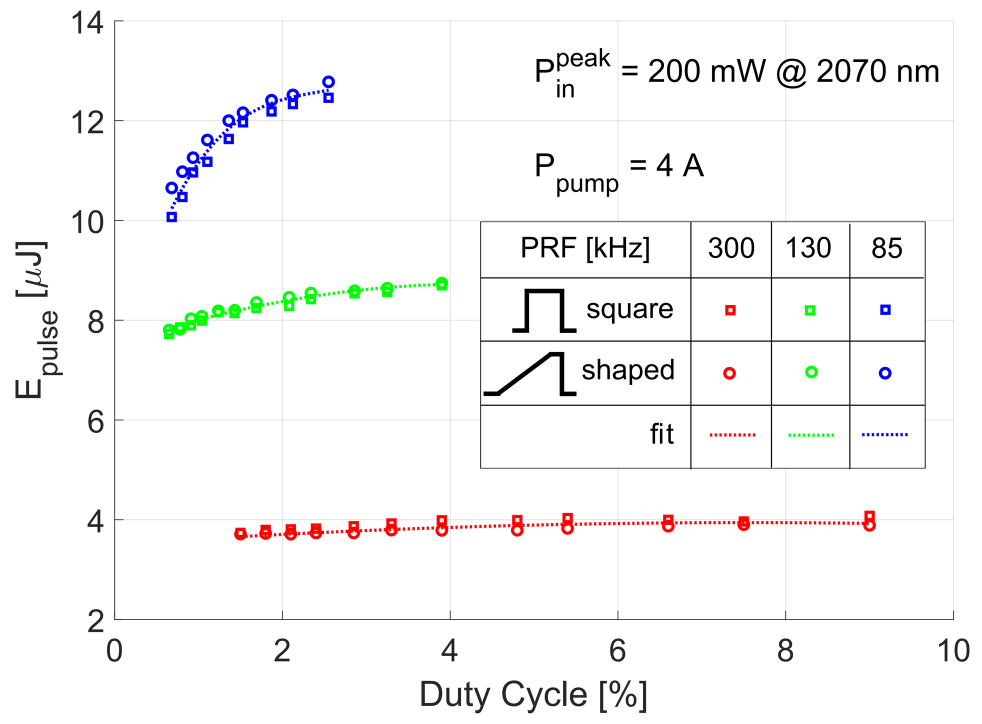

Figure 5: Pulse energy as a function of the signal duty cycle, measured at various PRF, for square (squares) and pre-shaped (circles) input pulses. Pre-shaping preserved the input pulse energy.

Pre-shaping does not affect the output pulse energy.

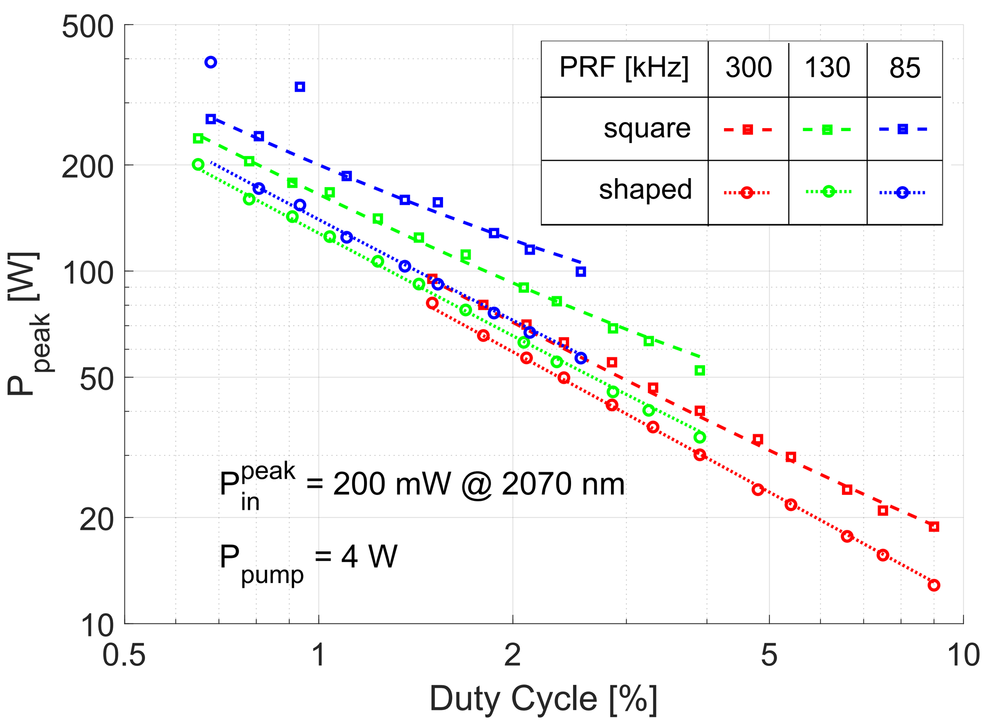

Figure 6: Peak output power as a function of the signal duty cycle, measured at various PRFs.

Pre-shaping allows for significant decrease of the peak output power, in particular for low PRFs.

Peak powers $>$ 200 W are obtained for duty cycles $<$ 1%.

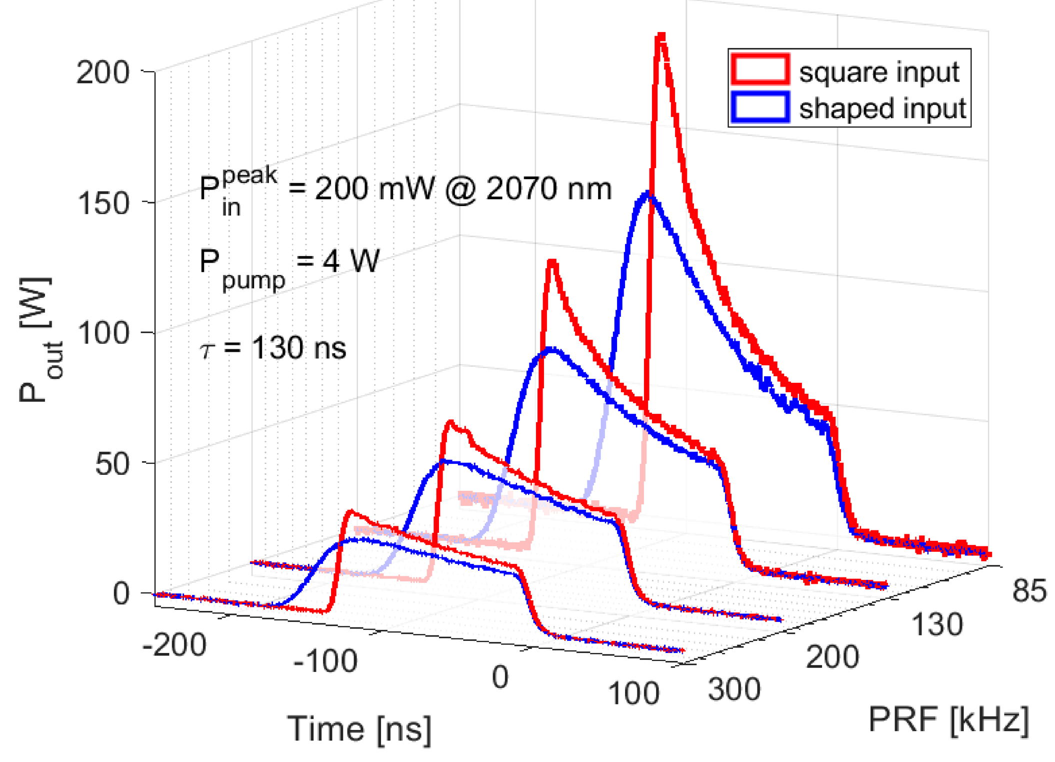

Figure 7: Output pulse shapes measured for 130-ns-long (FWHM) input pulses at different PRFs.

Pre-shaping allows to significantly reduce gain-peaking.

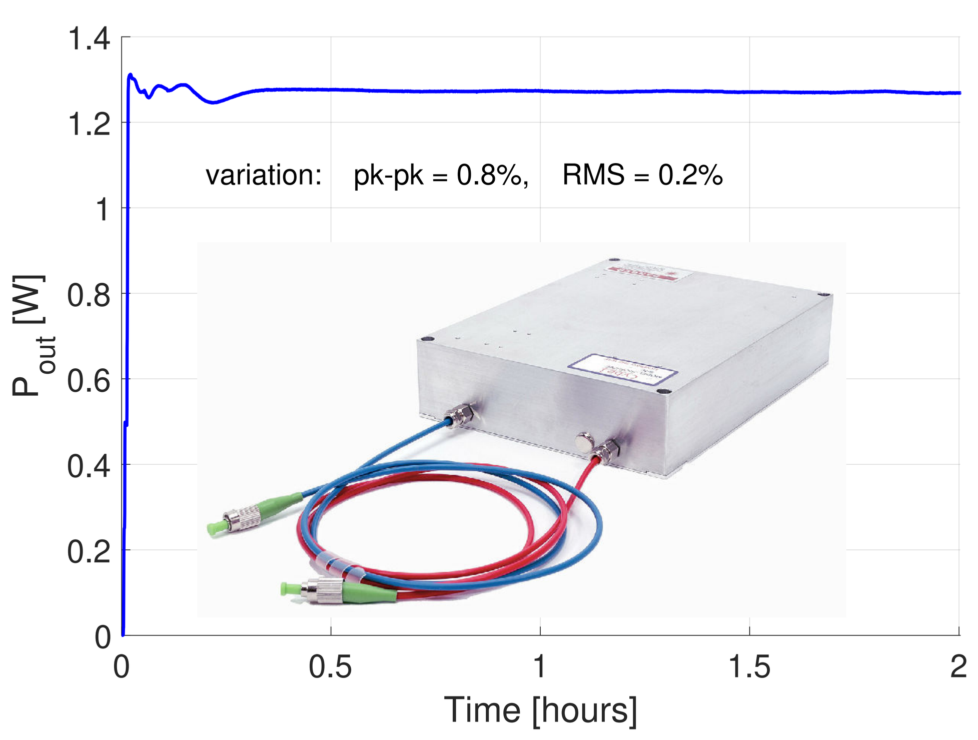

Figure 8: Temporal power stability of the amplifier with power variation of $\boldsymbol{\Delta P_{pk-pk}} < 1\%$ and $\boldsymbol{\Delta P_{RMS}} < 0.5\%$.

Inset shows the $20 \times 15 \times 4.3$ cm^3 OEM package of the HDFA. The package was attached to a heatsink passively cooled with forced airflow.

Parameters: $P_{in}^{peak} = 200$ mW, $\tau = 100$ ns, PRF = 150 kHz (DC = 3%), $P_{pump} = 4$ W.

Future Developement

- Use **wide bandwidth phase modulator** to further **increase SBS threshold**
- Add **electro-optic modulator (EOM)** to generate pulses as short as a **few ns**
- Optimize the configuration with the **20 μm core fiber** for **better power extraction**

[1] W. Walasik *et al.*, J. Lightwave. Technol. **39**, 5126–5133 (2021).
[2] T. J. Wagener *et al.* IEEE Aerosp. Electron. Syst. Mag. **10** 23–28 (1995).