DIODE LASER TEMPERATURE STABILIZATION AT 3 10^{-5} K LEVEL

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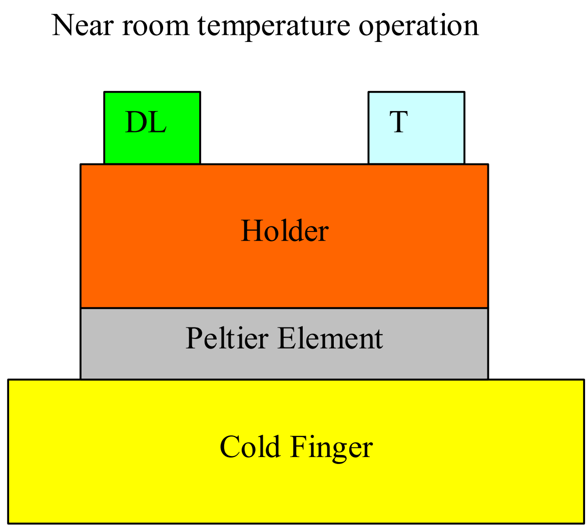
Abstract

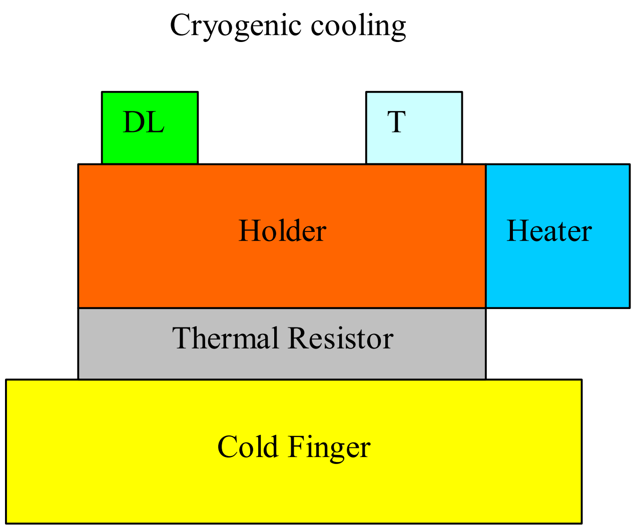
Quality of Diode Laser (DL) temperature stabilization is important for many DL applications. Typical values reported in literature are about 1 mK. Following theory of regulation operation of our system was optimized (details can be found in [1]) and temperature stabilization was significantly improved.

In present paper we report temperature stability at 0.03 mK level. Comparison of several commercially available DL modules (Sensors Unlimited, Laser Components, Anritsu, NOLATEX, etc.) from point of view of temperature stabilization is presented.

[1] A.Nadezhdinskii, Diode laser spectroscopy of polyatomic molecules, Doctor of Sciences Thesis, Moscow, 1986.

Principal Block-Schemes of Diode Laser Module





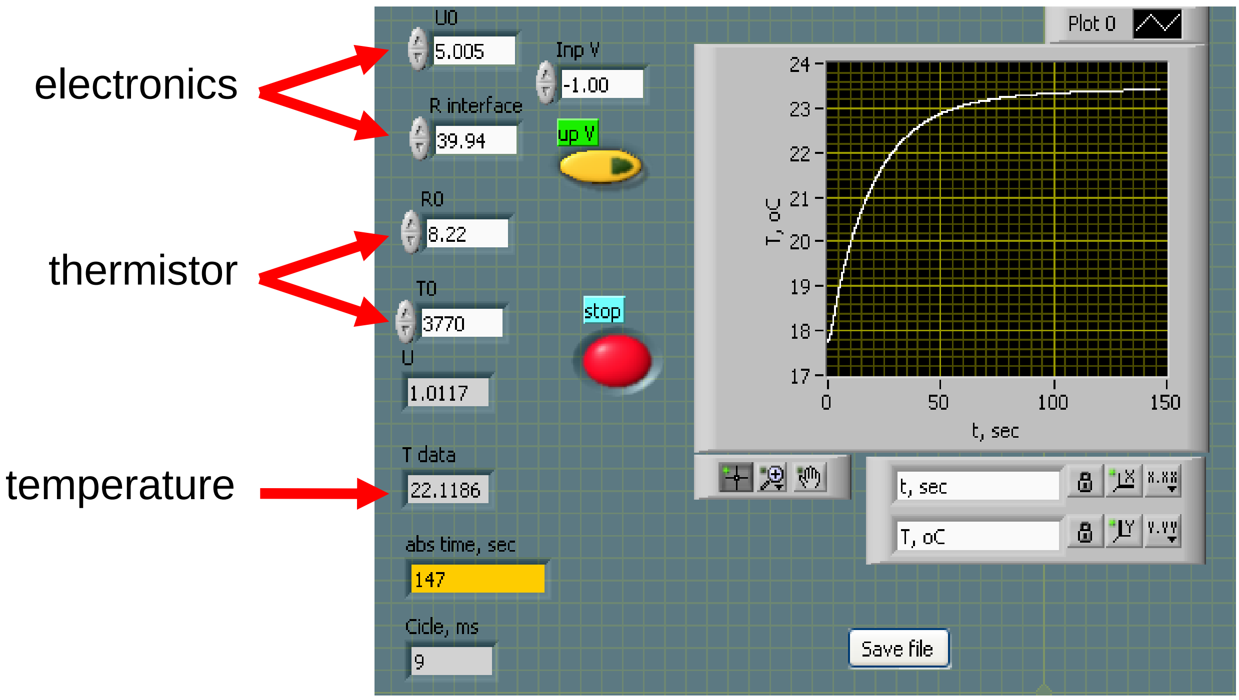
Following equation describes temperature stabilization

$$RC\frac{\partial \Delta T(t)}{\partial t} + \Delta T(t) = R\Delta W(t) - \\ - \alpha\left[\Delta T(t-\tau) + 2\pi\beta\int_{-\infty}^{t}\Delta T(x-\tau)dx\right]$$

C and R thermal capacity and resistance, respectively; τ - delay time; α, β - parameters of PI regulation. The system behavior depends on two parameters: RC and τ.

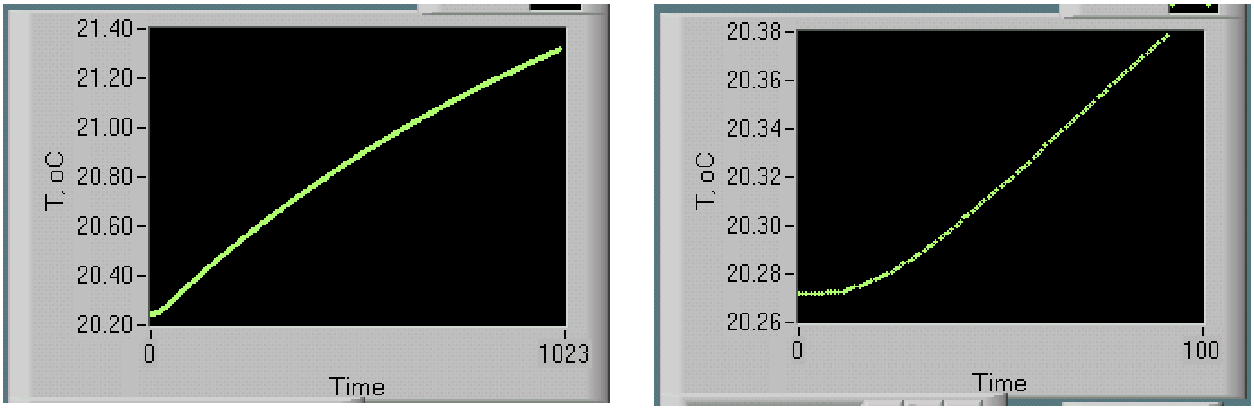
Temperature Measurement

Temperature sensor (thermal diode or termistor) is used. As first step parameters of electronic module and sensor were calibrated separately. This calibration enables us to use the same diode laser module with different electronics with reproducible result.



Example of developed software interface
Temperature measurement after step like current applied to Peltier element.

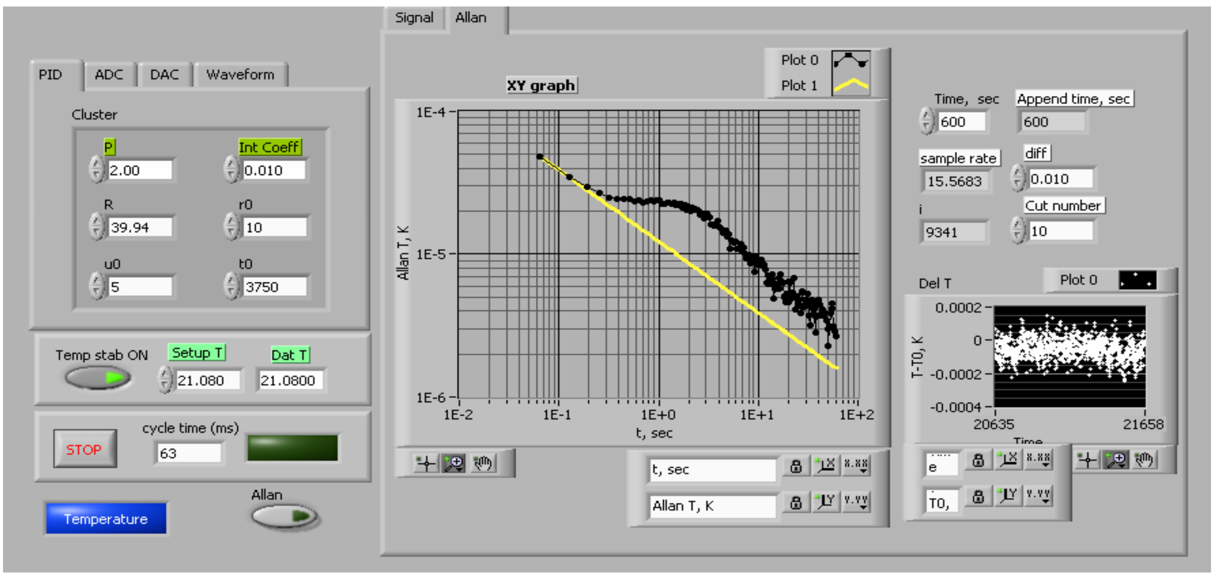
Temperature Transient Processes in Diode Laser Module



Time delay investigation in temperature stabilization system of diode laser module. Time between successive points is equal to 43 msec.

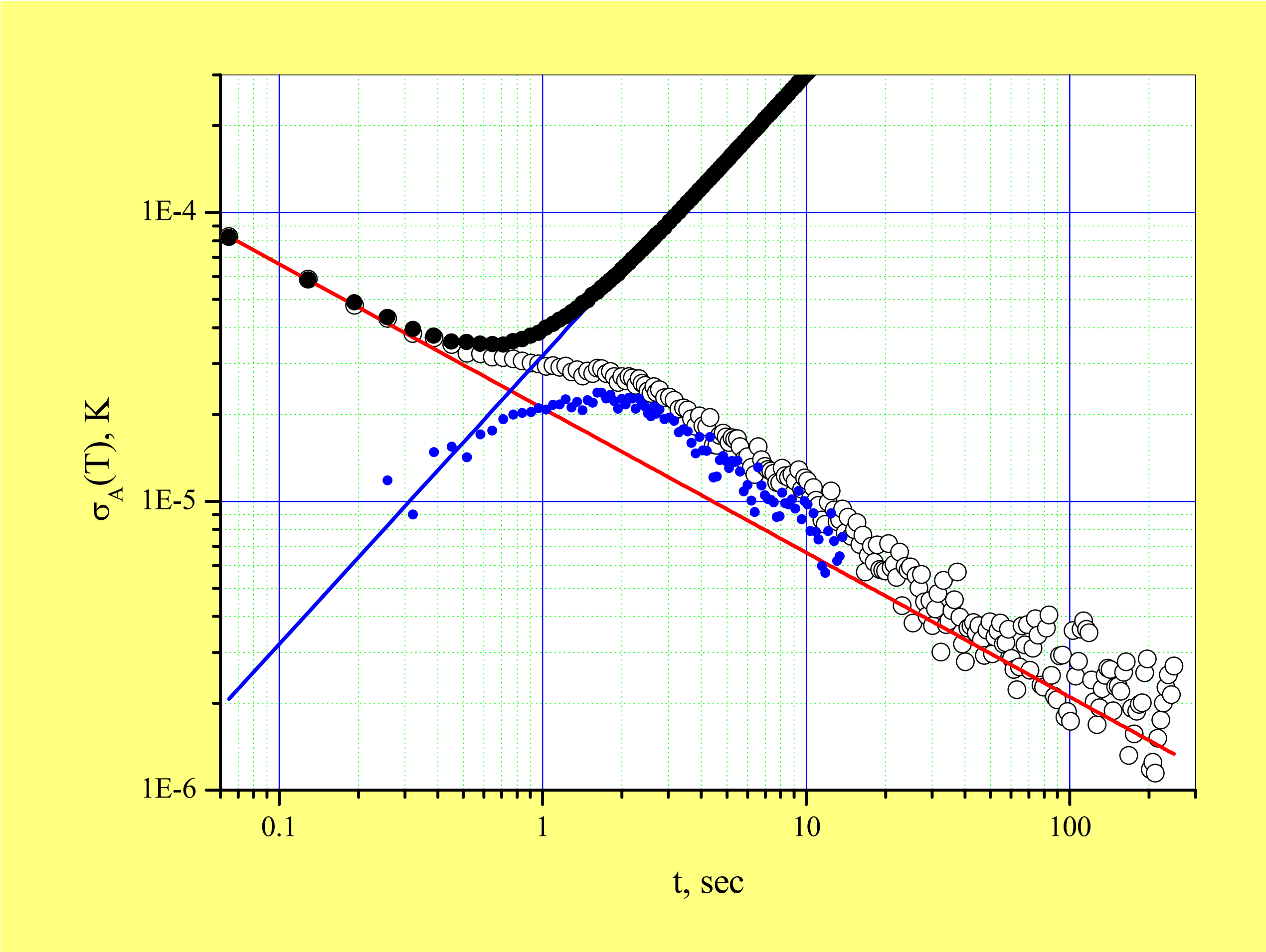
RC = 40 sec, τ = 0.8 sec

Temperature Stabilization



Interface of software developed to investigate quality of temperature stabilization

Temperature Stabilization



Allan plot of temperature measured by termistor with temperature stabilization off (black solid cycles) and on (black open cycles).

Red line corresponds to ADC noise of data acquisition board in use. When this noise was subtracted, temperature instability was obtained (blue cycles). Blue line describes temperature drift.

From this picture one can see maximum near 2 sec with value 2.5 10-5 K,

RC = 30 sec, τ =0.5 sec.

Temperature Stabilization Transfer Function

From temperature stabilization equation

$$RC\frac{\partial \Delta T(t)}{\partial t} + \Delta T(t) = R\Delta W(t) -$$

$$-\alpha\left[\Delta T(t-\tau) + 2\pi\beta\int_{-\infty}^{t}\Delta T(x-\tau)dx\right]$$

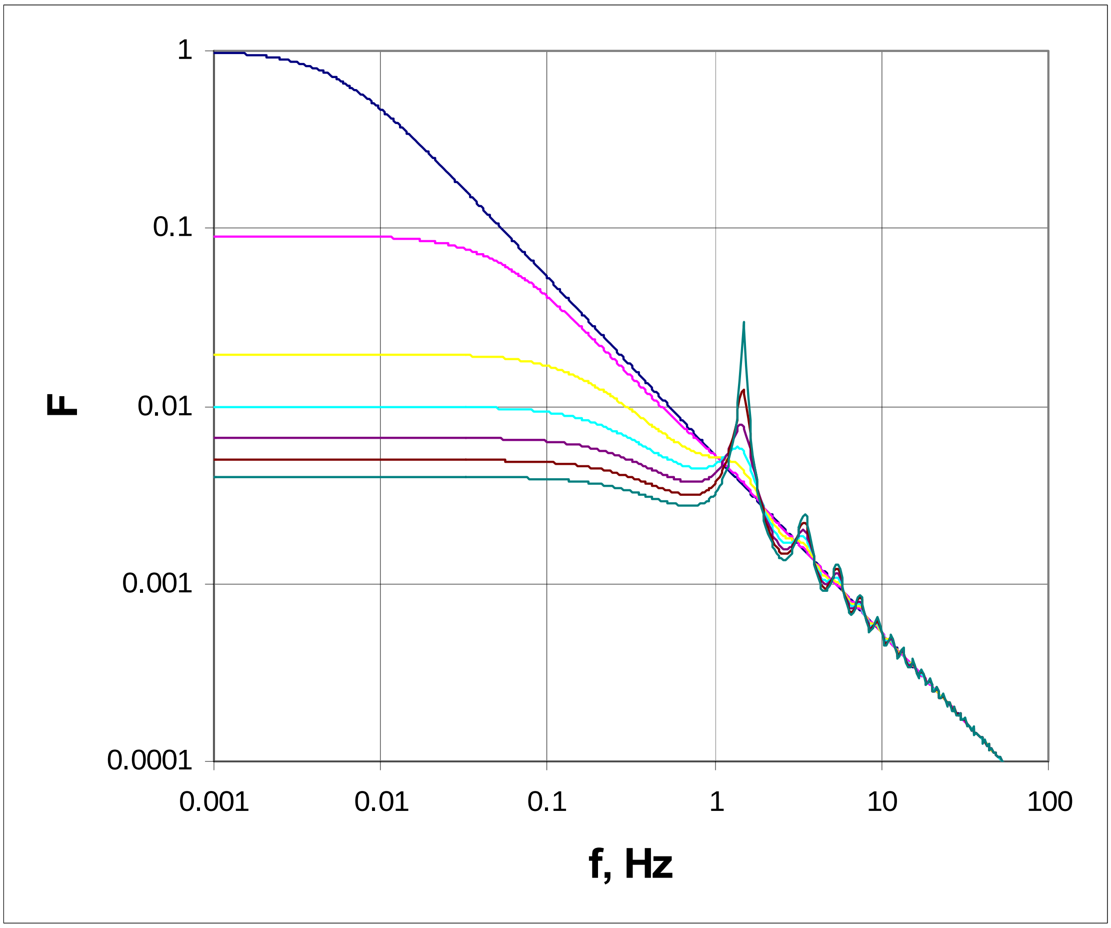
From this equation transfer function in frequency domain - F(f) can be obtained

$$\Delta T(f) = F(f)R\Delta W(f);$$

$$F(f) = \frac{1}{i2\pi fRC + 1 + \alpha\left[1 + \frac{i\beta}{f}\right]\exp(i2\pi f\tau)}$$

Proportional regulation

$$F(f) = \frac{1}{i2\pi fRC + 1 + \alpha \exp(i2\pi f\tau)}$$



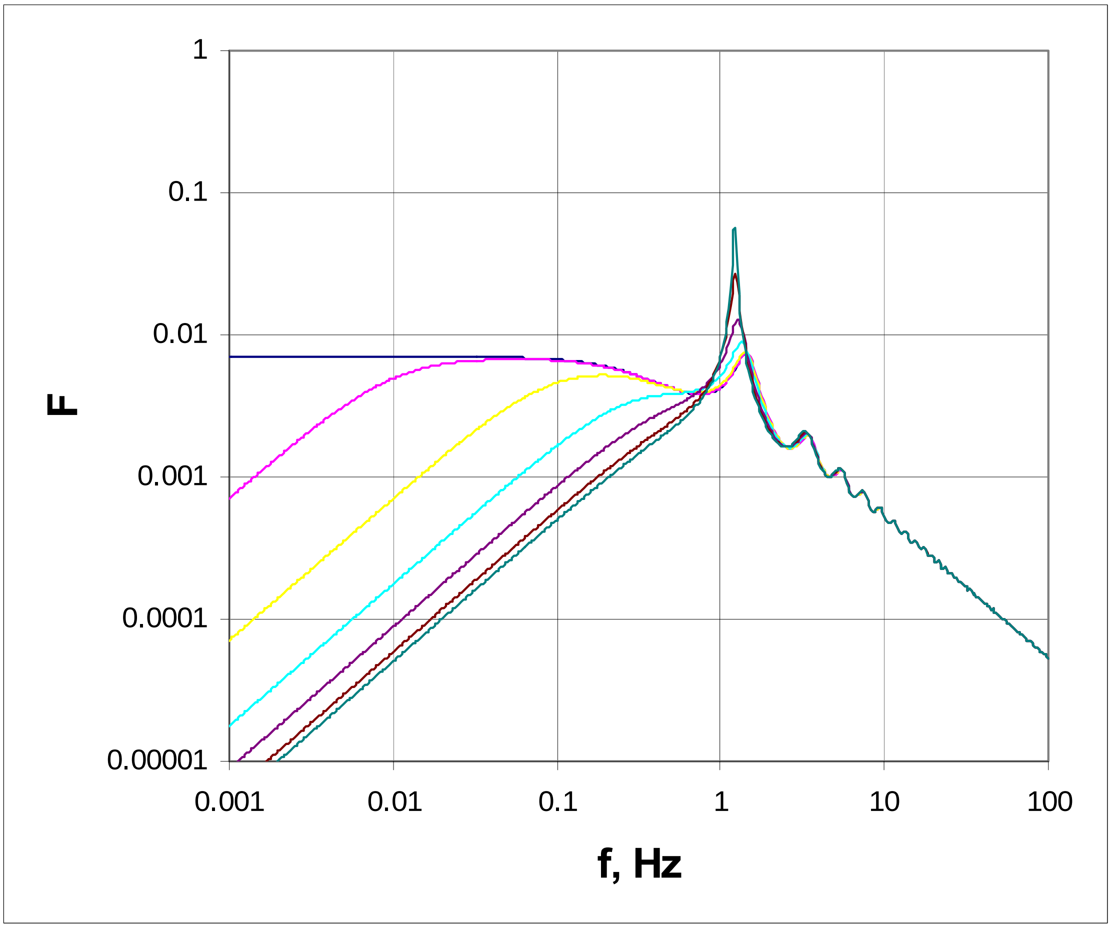
Transfer function of temperature stabilization F(f) for proportional regulation (from up to down α = 0, 10, 50, 100, 150, 200, 250)

From analysis of this curves one can obtain frequency of resonance peak and optimal value of proportional coefficient

$$f_{osc} = \frac{3}{4\tau}; \quad \alpha_{opt} = \frac{3\pi RC}{\tau}$$

PI regulation

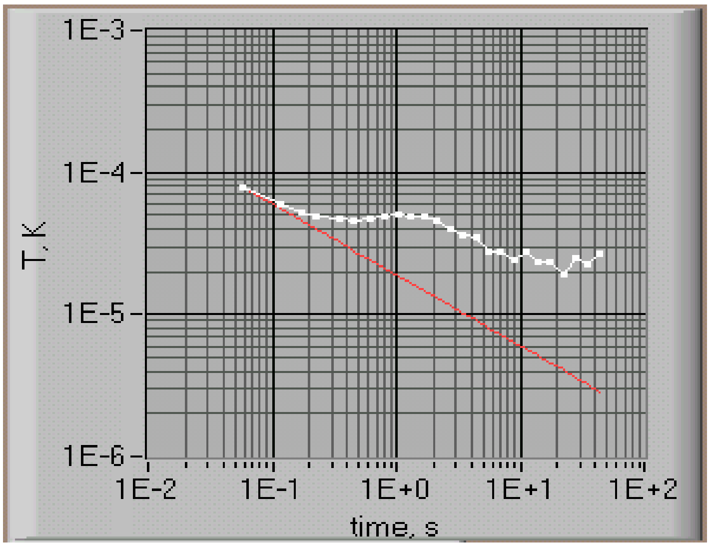
$$F(f)=\frac{1}{i2\pi fRC+1+\alpha_{opt}\left[1+\frac{i\beta}{f}\right]\exp(i2\pi f\tau)}$$



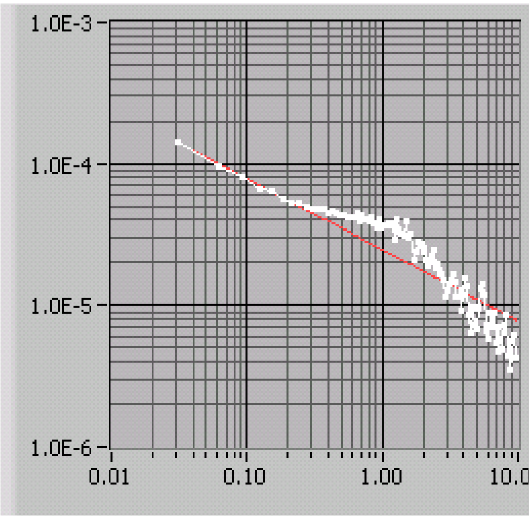
Transfer function of temperature stabilization F(f) for PI regulation (α=αopt; from up to down β = 0, 0.01, 0.1, 0.4, 0.8, 1.2, 1.4 Гц).

From analysis of this curves one can obtain optimal value of integral coefficient

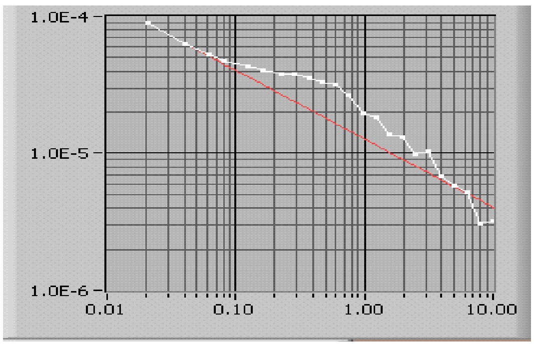
Examples of temperature stabilization with different diode laser modules



Sensors Unlimited
τ = 0.8сек



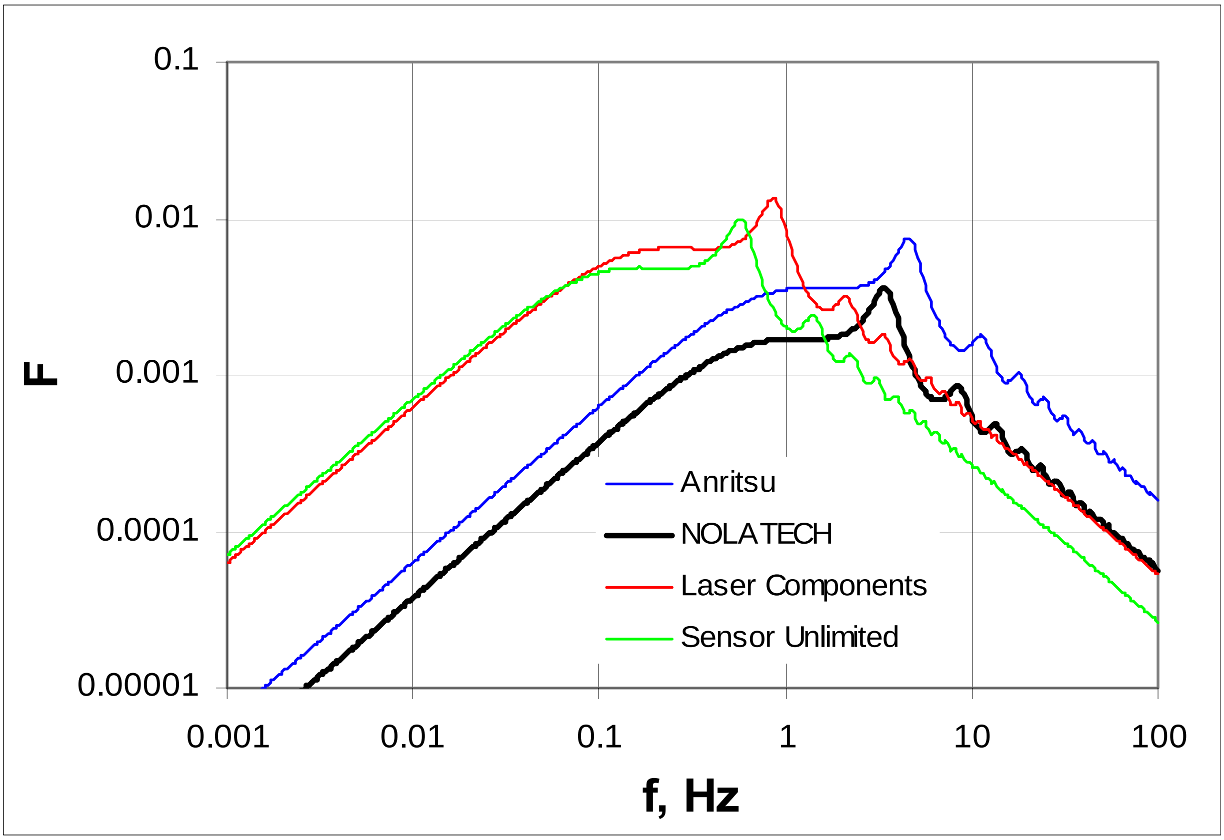
Laser Components
τ = 0.5 сек



NOLATECH
τ = 0.2 сек

Optimization of diode laser module

As it was mentioned above there are three parameters characterizing temperature stabilization of diode laser module: thermal capacity and resistance C and R, respectively and delay time - τ. Their choice is subject of optimization



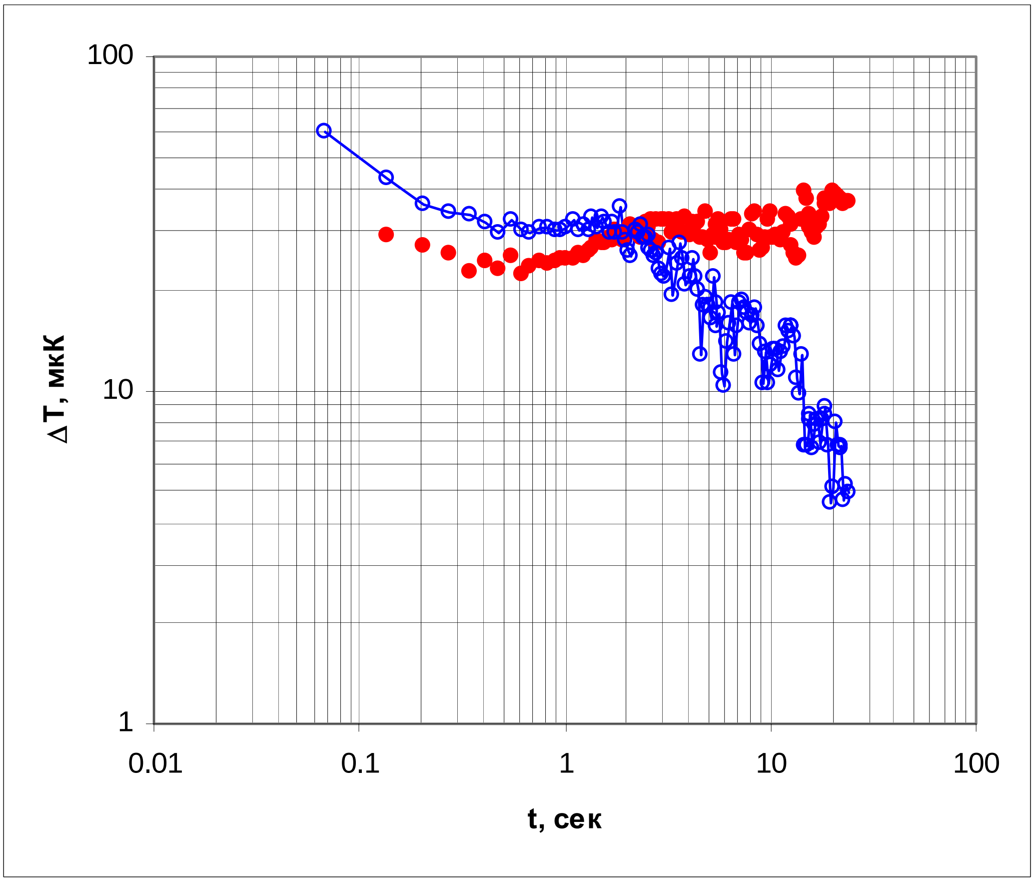
Comparison of optimal transfer function for several tested diode laser modules.

Presented curves are subject for future diode laser modules optimization.

Temperature and DL frequency instability

For different DL application its frequency stability plays key role.

Because of DL frequency temperature dependence spectral line can be used as temperature sensor. Modified software was able to analyze simultaneously temperature variations measured by termistor and with help of reference spectral line. For this purpose DL temperature tuning coefficient was determined independently.



Allan plot of instability of temperature measured by termistor (blue open cycles) and with help of reference spectral line (red solid cycles) as function of averaging time t. Diode laser temperature stability at 0.03 mK level was achieved. Presence of diode laser frequency flicker noise and shift can be observed.