Mechanical Measurements of Laser Pulse Duration

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Laser pulse width measurement Methods (1)

Streak Camera

- Precise
- Delicate to use
- Needs an optical delay line (clumsy)
- Very expensive
- Resolution limited by optoelectronical conversion
- Can work at extremely low light levels (MCP)

Laser pulse width measurement Methods (2)

Autocorrelator

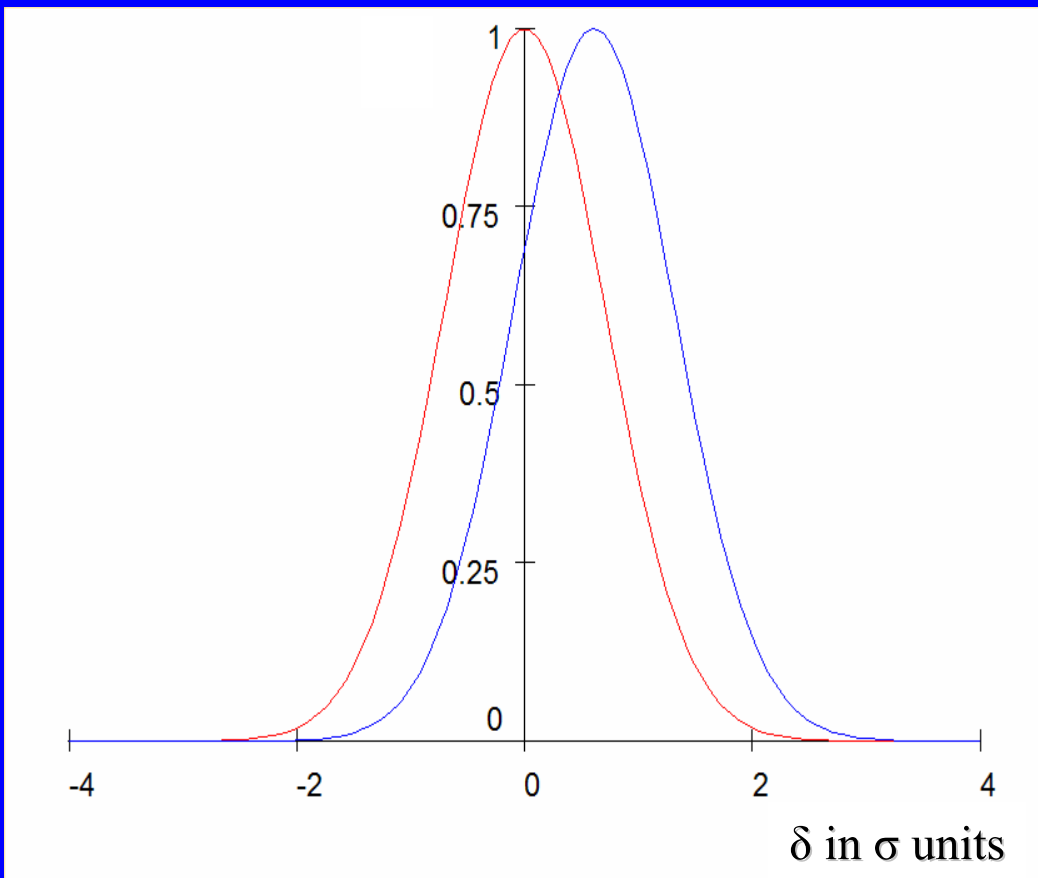
- Statistical : needs a lot of pulses for one measure
- Cheaper than Streak Camera but still expensive
- Multiplicative, non-linear : needs high power density for operation

Laser pulse width measurement Methods (3)

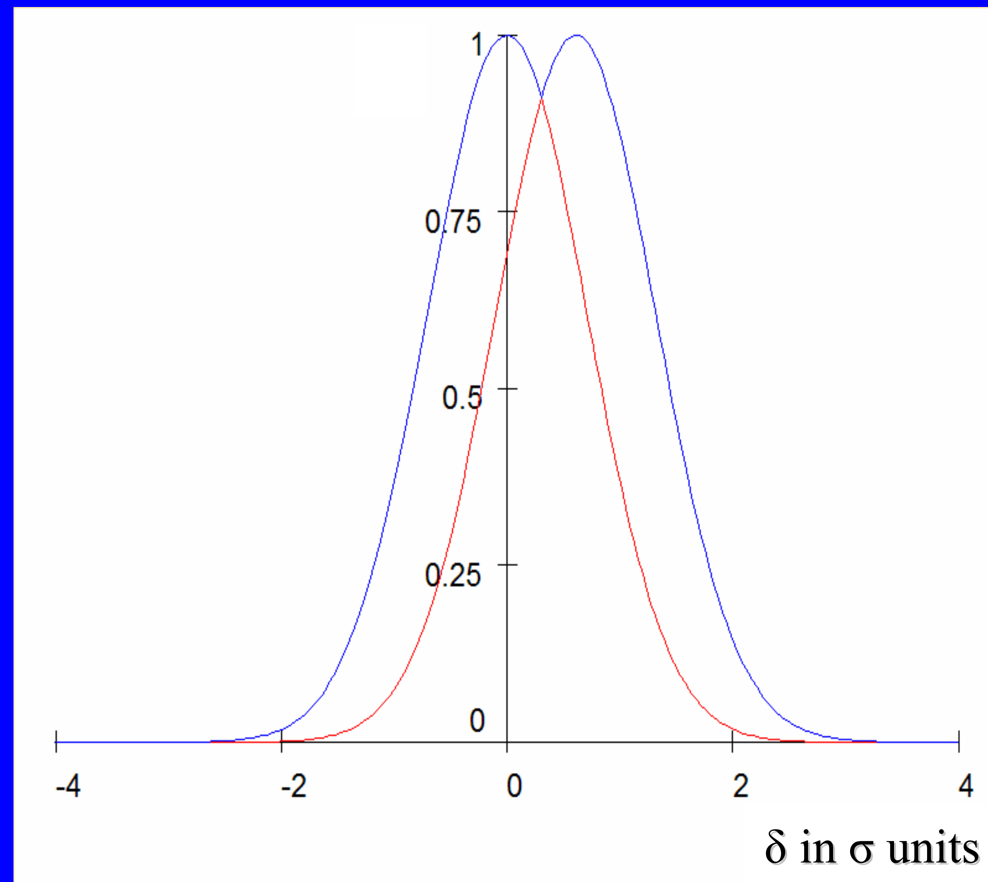
Interferometry

- Additive, linear : can be used at low light levels
- Standalone operation or CCD + computer assisted image processing for more precision
- Statistical mode give partly access to pulse shape information
- Very cheap design

Principle of Operation (1)

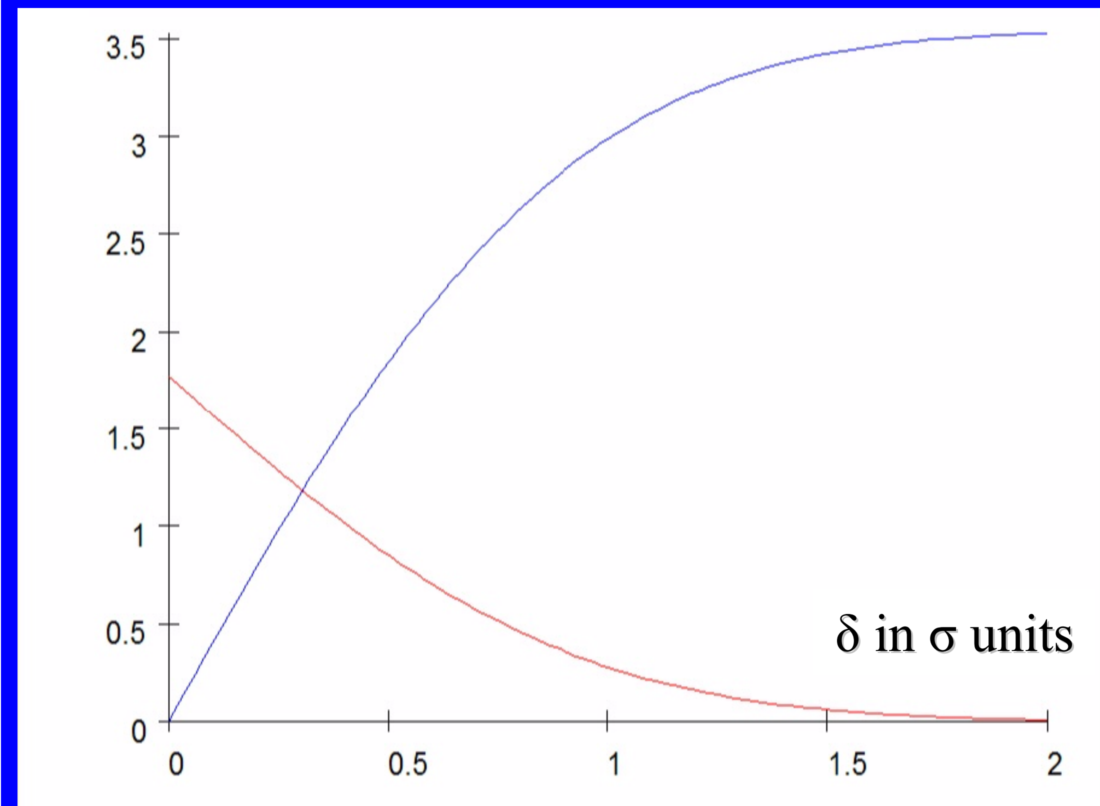


Reference and Delayed Gaussian pulses



Intersection & Union of two pulses

Principle of Operation (2)



Area of the Intersection of the two Gaussians:

$$-\sigma\cdot\sqrt{\pi}\cdot\left(\operatorname{erf}\left(\frac{\delta}{\sigma}\right)-1\right)$$

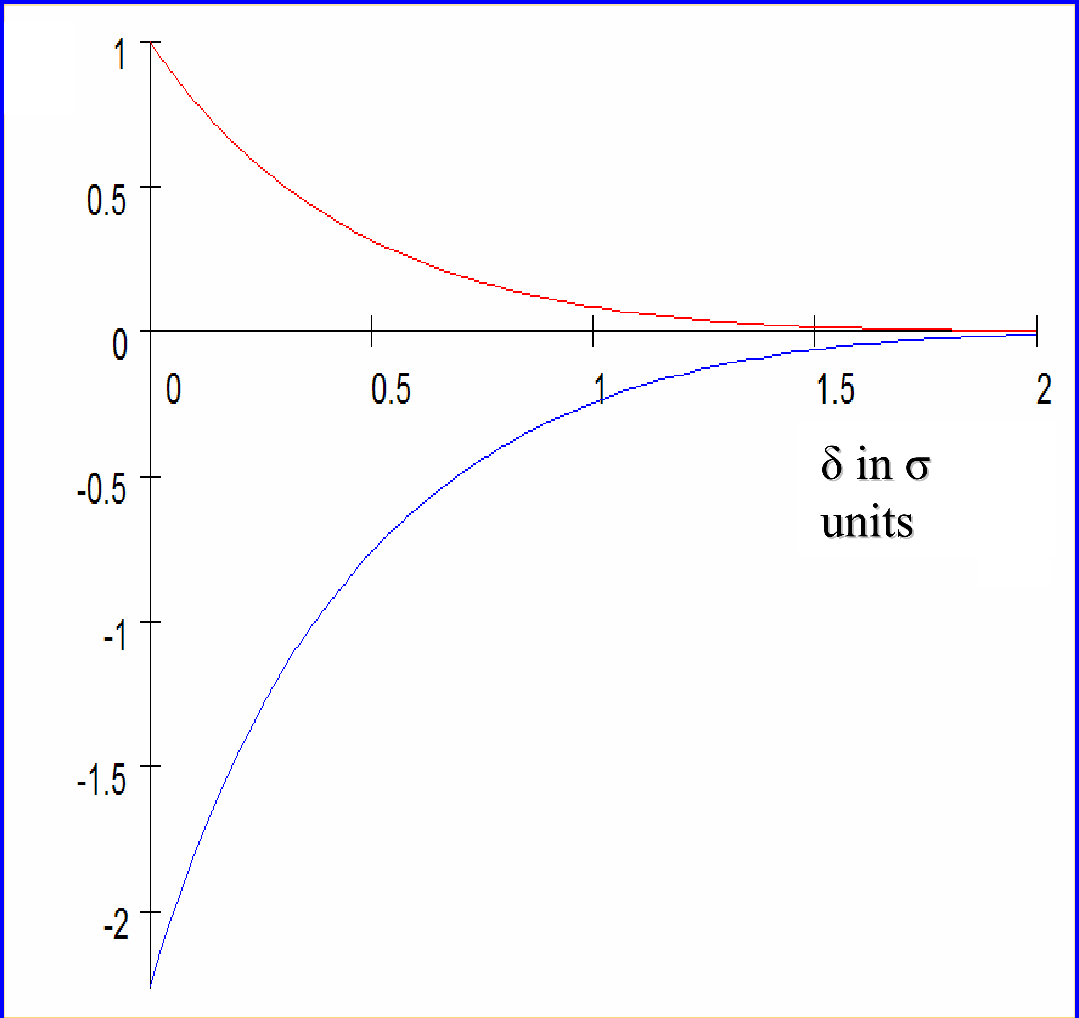
Area of the Union, excluding Intersection, of the two Gaussians:

$$2\cdot\operatorname{erf}\left(\frac{\delta}{\sigma}\right)\cdot\sigma\cdot\sqrt{\pi}$$

Areas of Intersection and Union (excluding Intersection) vs. path difference in σ units

Areas of Intersection & Union (excluding Intersection) of the two pulses

Principle of Operation (3)



$$-\frac{\operatorname{erf}\left(\frac{\delta}{\sigma}\right)-1}{\operatorname{erf}\left(\frac{\delta}{\sigma}\right)+1}$$

First derivative of the fringe contrast:

$$-\frac{4\cdot e^{-\frac{\delta^2}{\sigma^2}}}{\left(\operatorname{erf}\left(\frac{\delta}{\sigma}\right)+1\right)^2\cdot\sqrt{\pi}\cdot\sigma}$$

- Contrast of fringes (top) = (Intersection area)/(Union area)
- First derivative of contrast (bottom)

Principle of Operation (4)

Evaluation of the Fringe Contrast

- Difficult to estimate absolute contrast
- Easier to estimate relative contrast using known reference
- Null path difference interferometer with density in one arm gives known contrast

- A density d leads to a contrast C:

$$C = 10^{-2d}$$

- For a contrast of 50 %, one needs a density:

$$d = 0.1505$$

Interferometer Requisites ?

- Wide field : non-critical alignment
- Easy path difference adjustment over a wide span without needing realignment
- Near achromatic design
- Good stability

Michelson Interferometer (1)

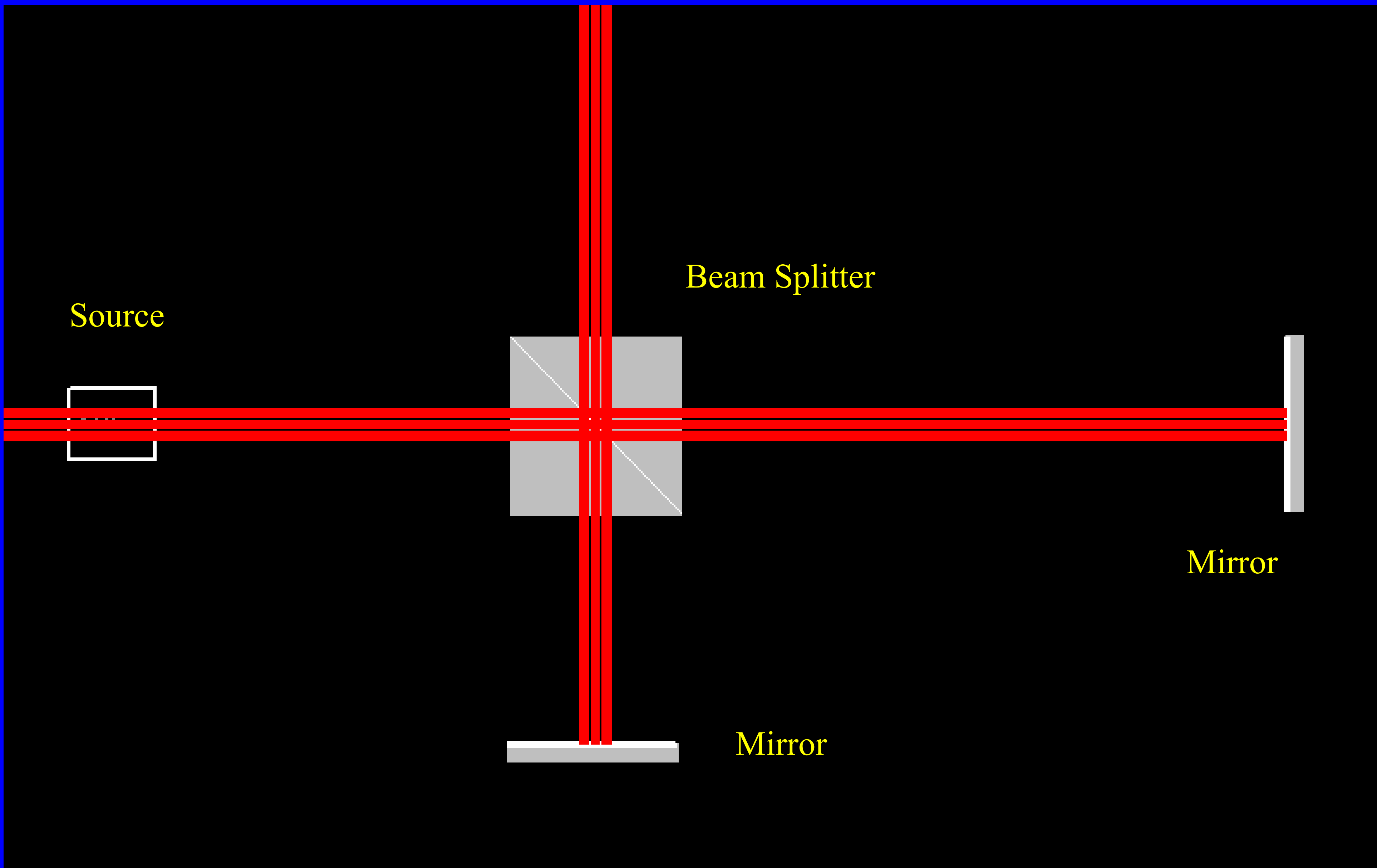
Pros

- Simple
- Adjustable path difference without additional optics

Cons

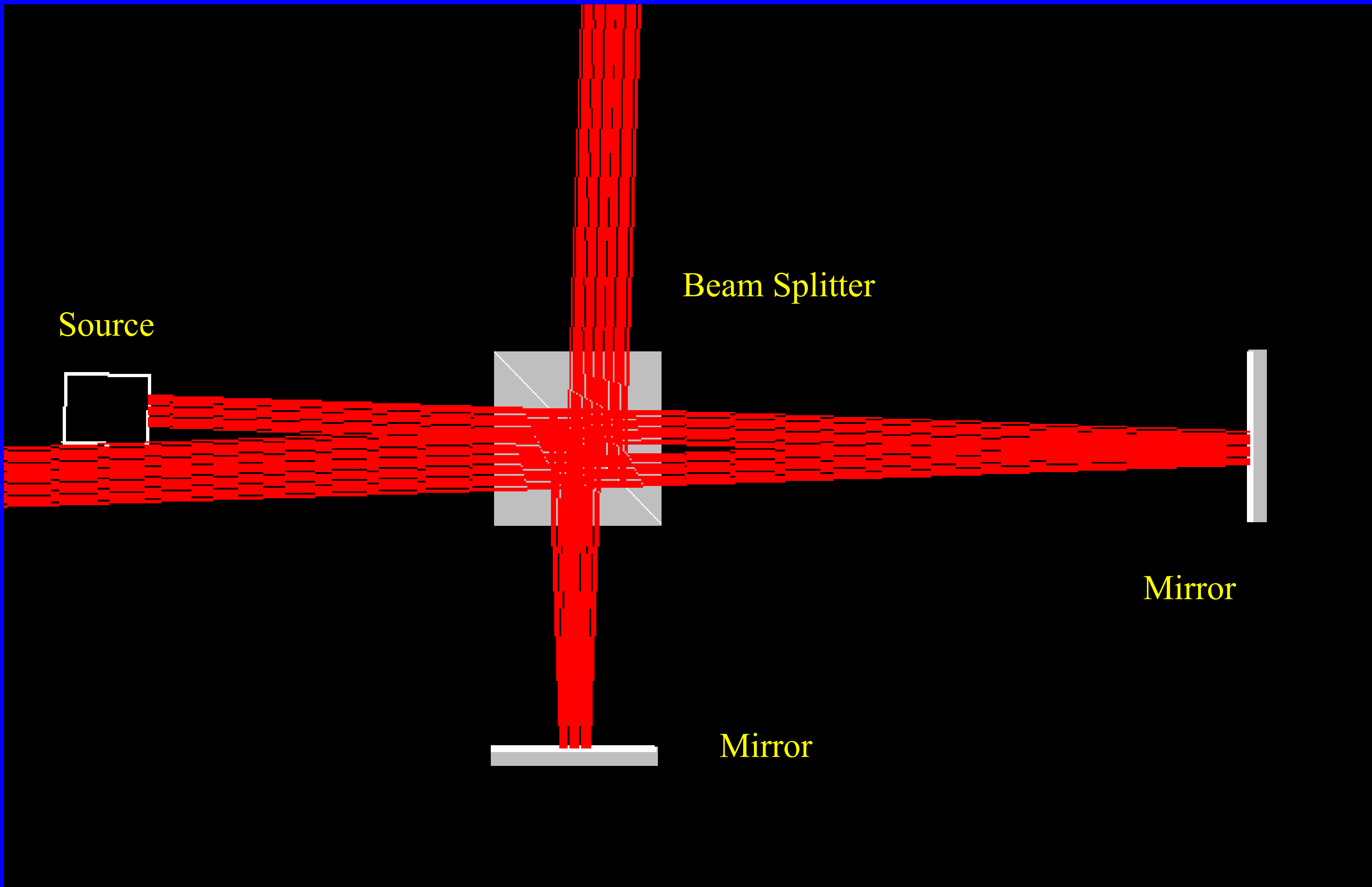
- Delicate alignment
- Narrow field

Michelson Interferometer (2)



Michelson Interferometer (3)

unbalanced and off-axis



Sagnac Interferometer (1)

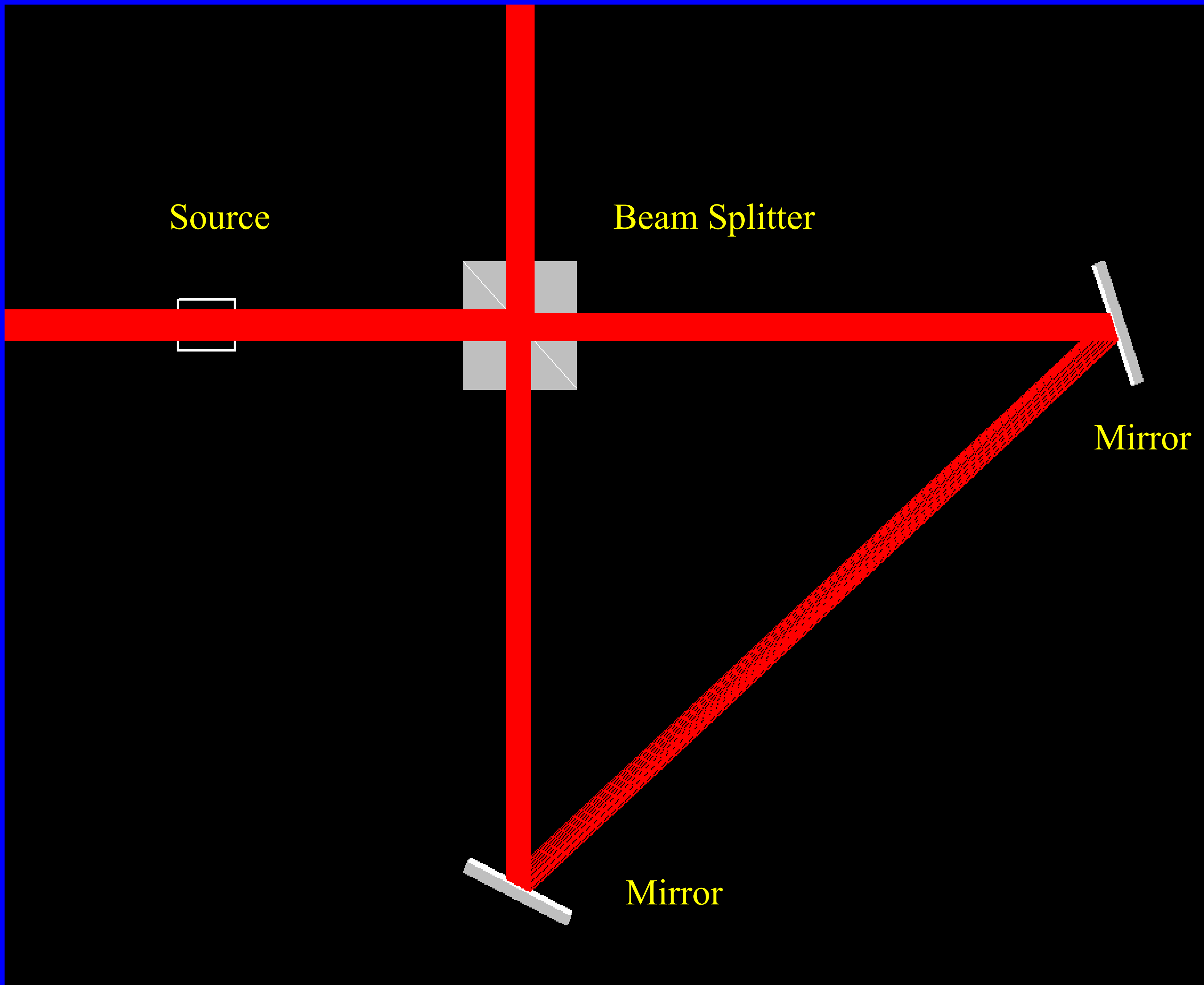
Pros

- Extreme simplicity

Cons

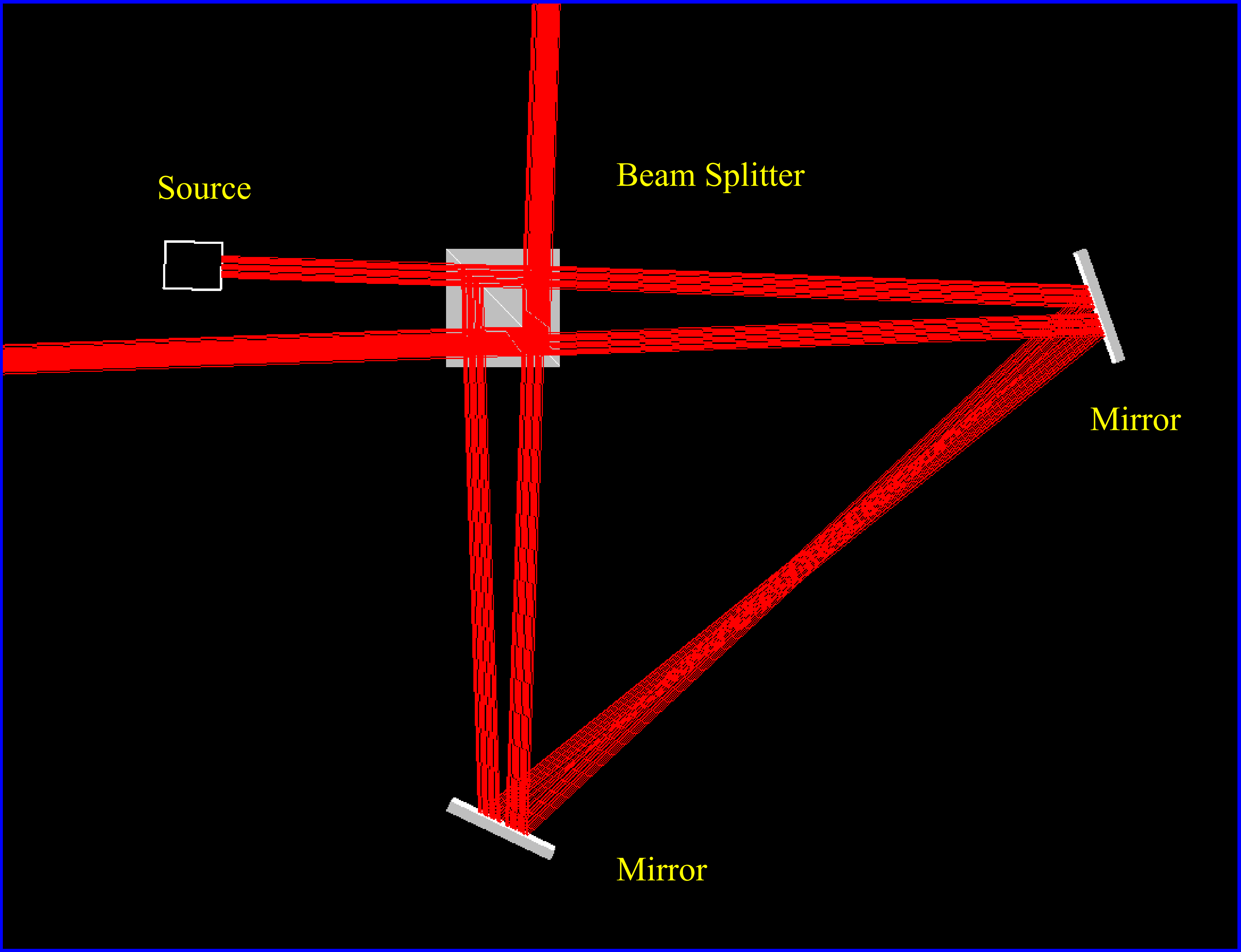
- Path difference always null (all paths are shared)
- Rather sensitive to mis-alignment

Sagnac Interferometer (2)



Sagnac Interferometer (3)

off-axis



Mach-Zehnder Interferometer (1)

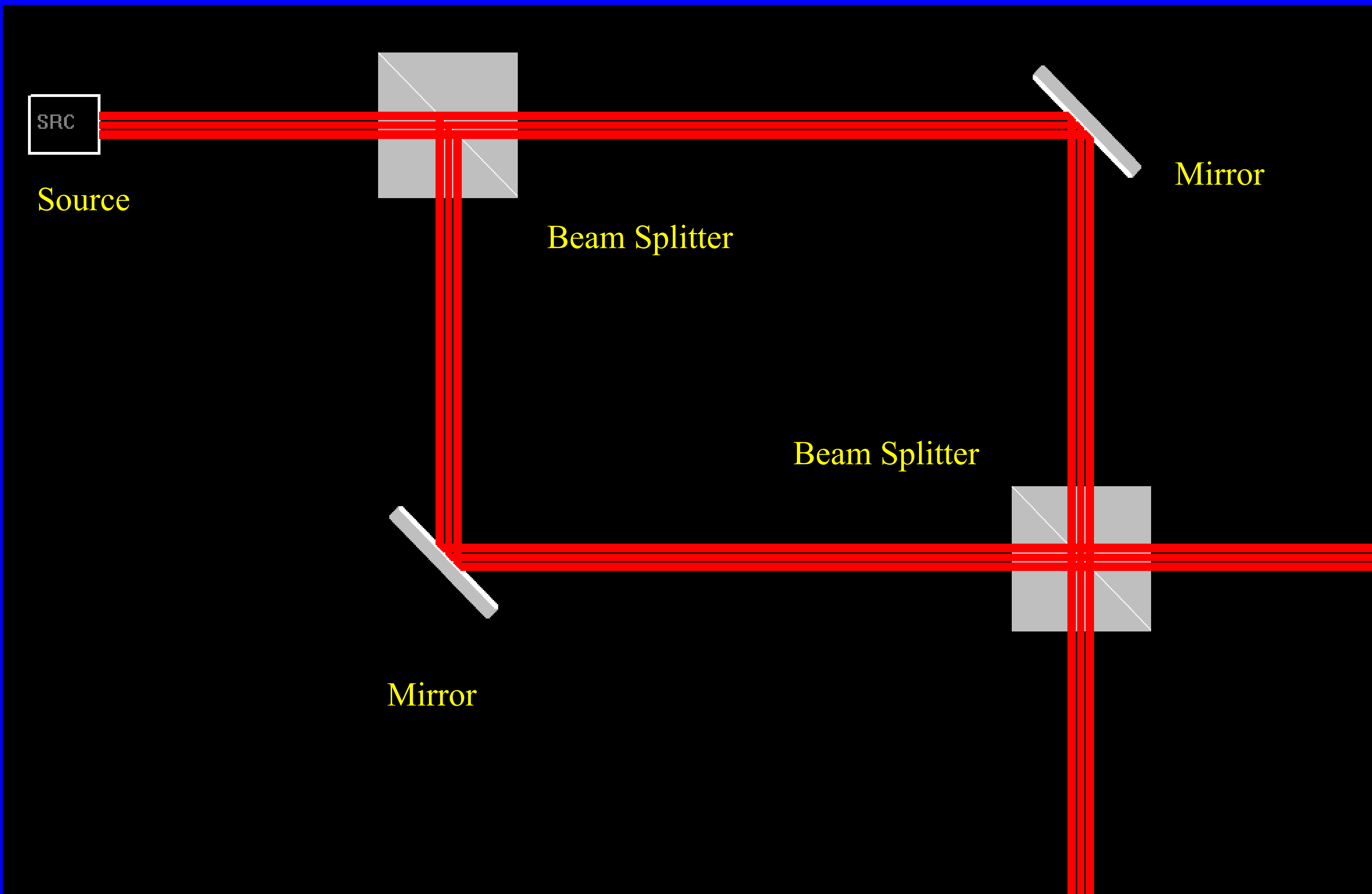
Pros

- Wide field

Cons

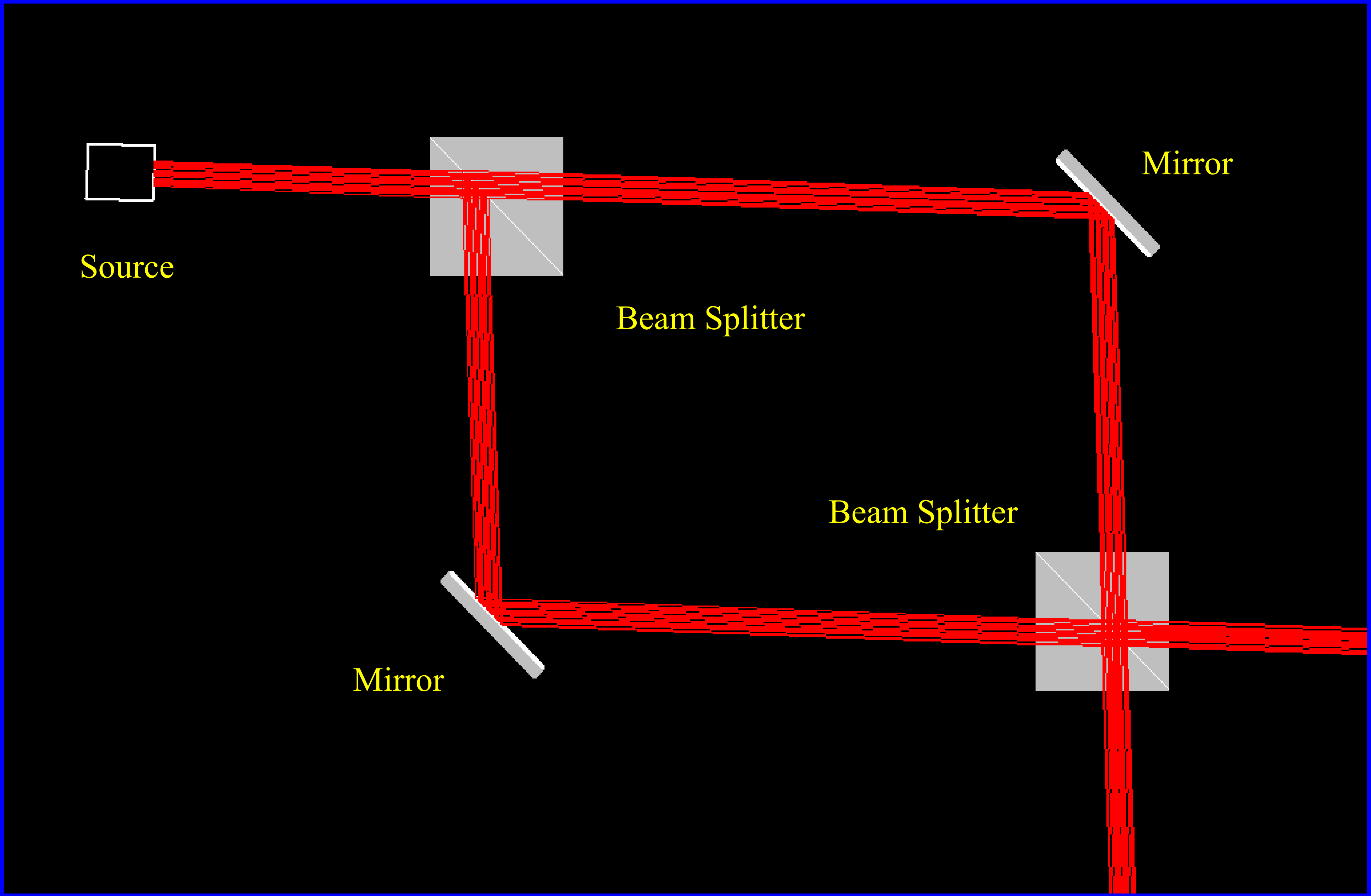
- needs a delay line to vary easily the path difference
- the delay line can be a source of stability problems

Mach-Zehnder Interferometer (2)



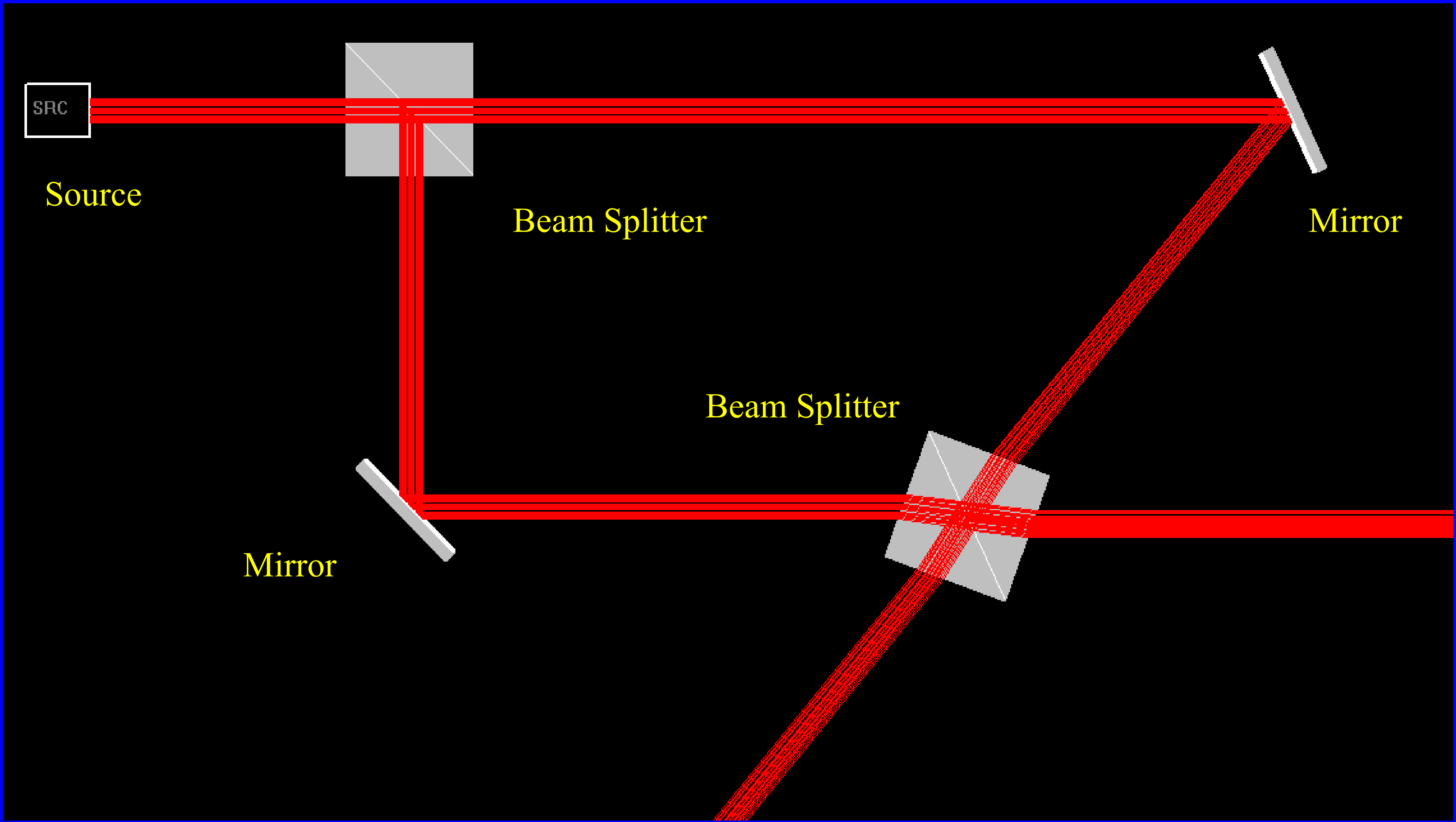
Mach-Zehnder Interferometer (3)

balanced, off-axis



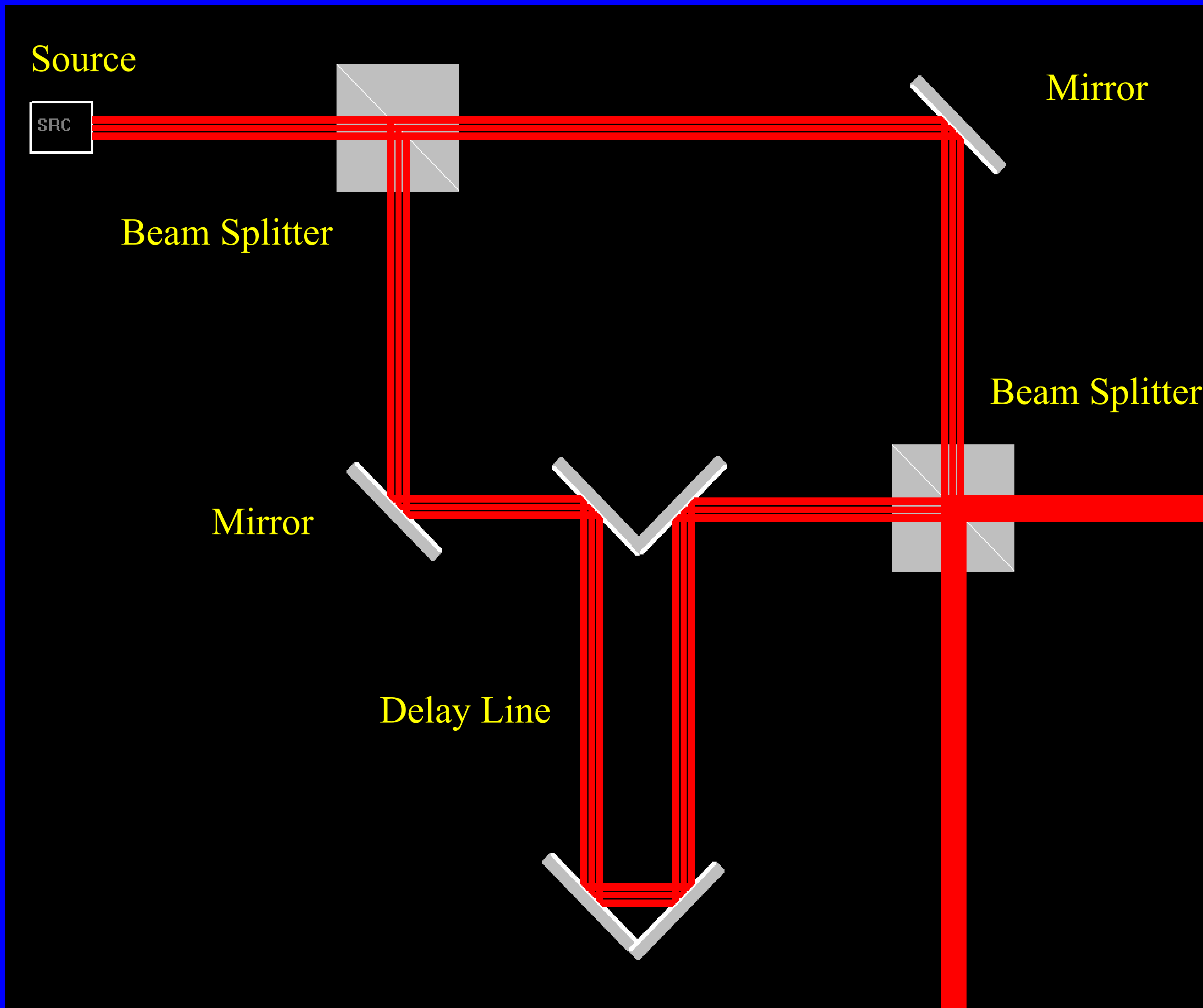
Mach-Zehnder Interferometer (4)

unbalanced without delay line



Mach-Zehnder Interferometer (5)

unbalanced with delay line



Modified Mach-Zehnder Interferometer (1)
(MMZI)

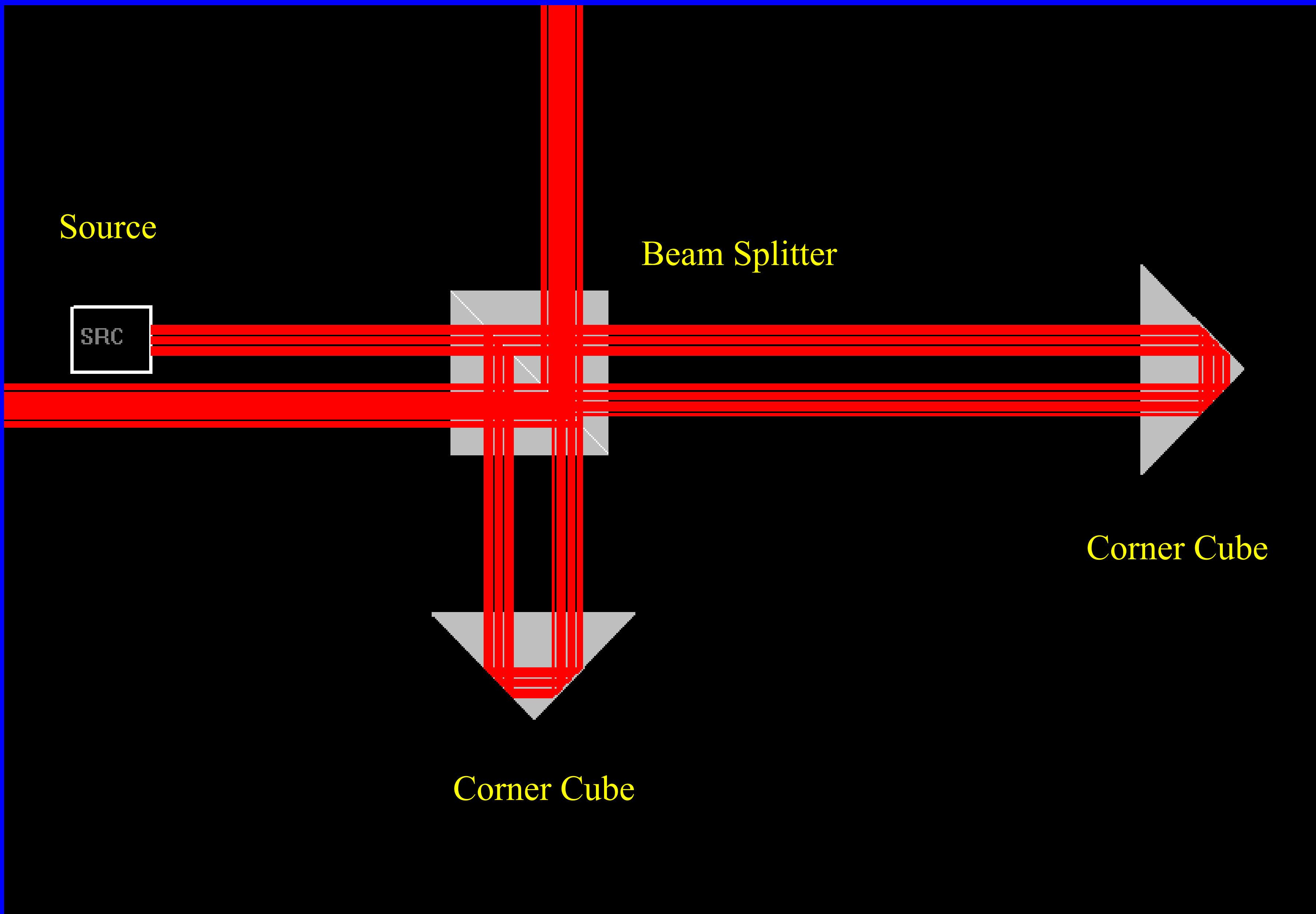
Pros

- Almost as simple as Michelson
- Auto-aligning setup
- Wide field
- Variable delay without additional optics
- High stability design

Cons

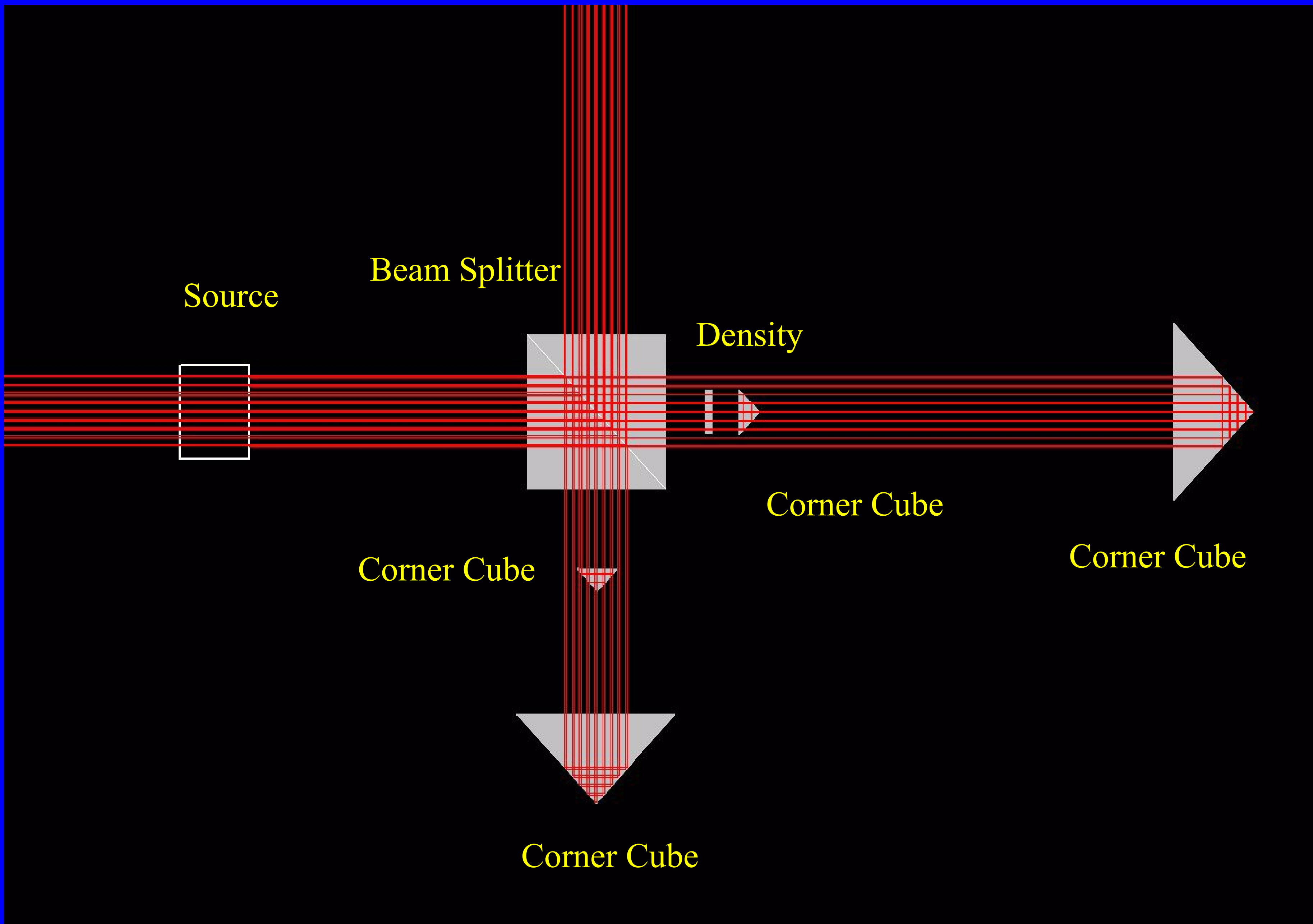
- Almost none

Modified Mach-Zehnder Interferometer (2)

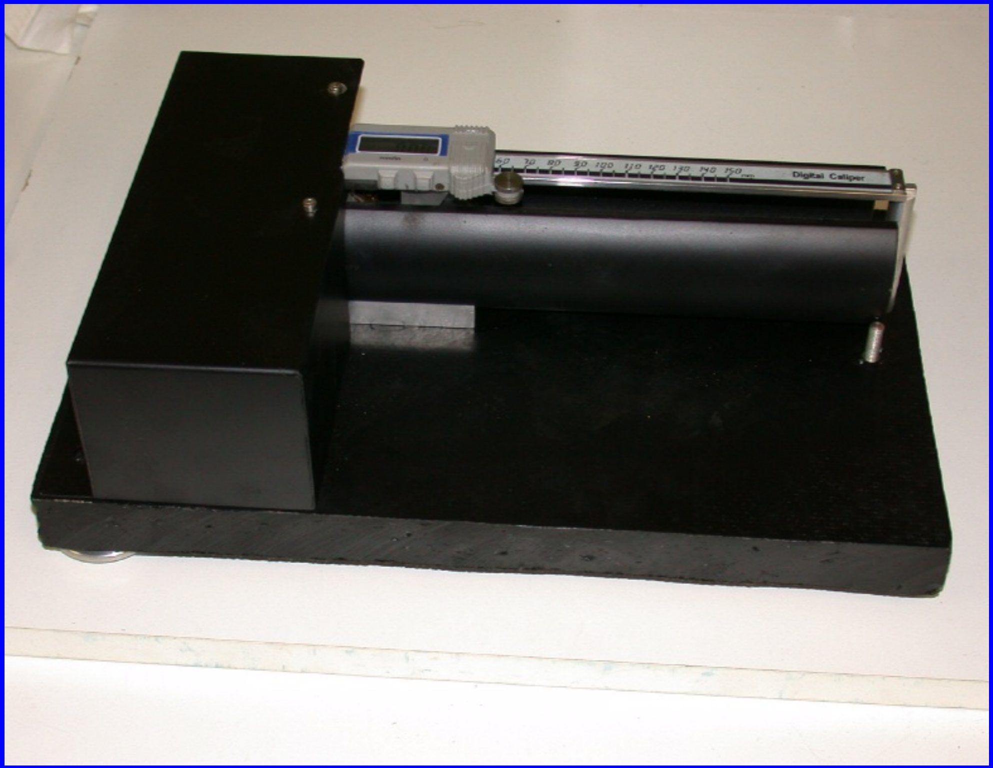


Modified Mach-Zehnder Interferometer (3)

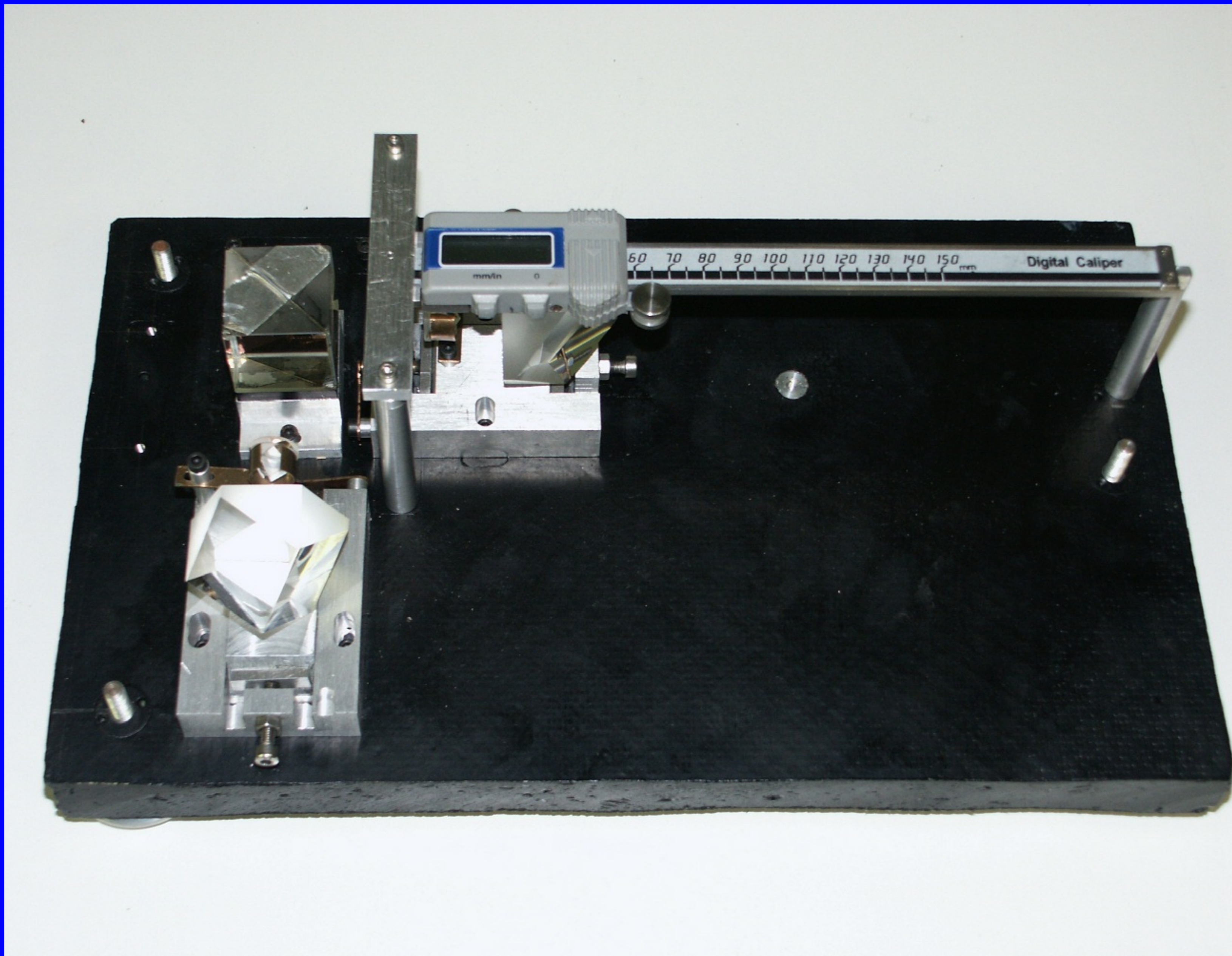
with contrast reference (null path difference with density Interferometer)



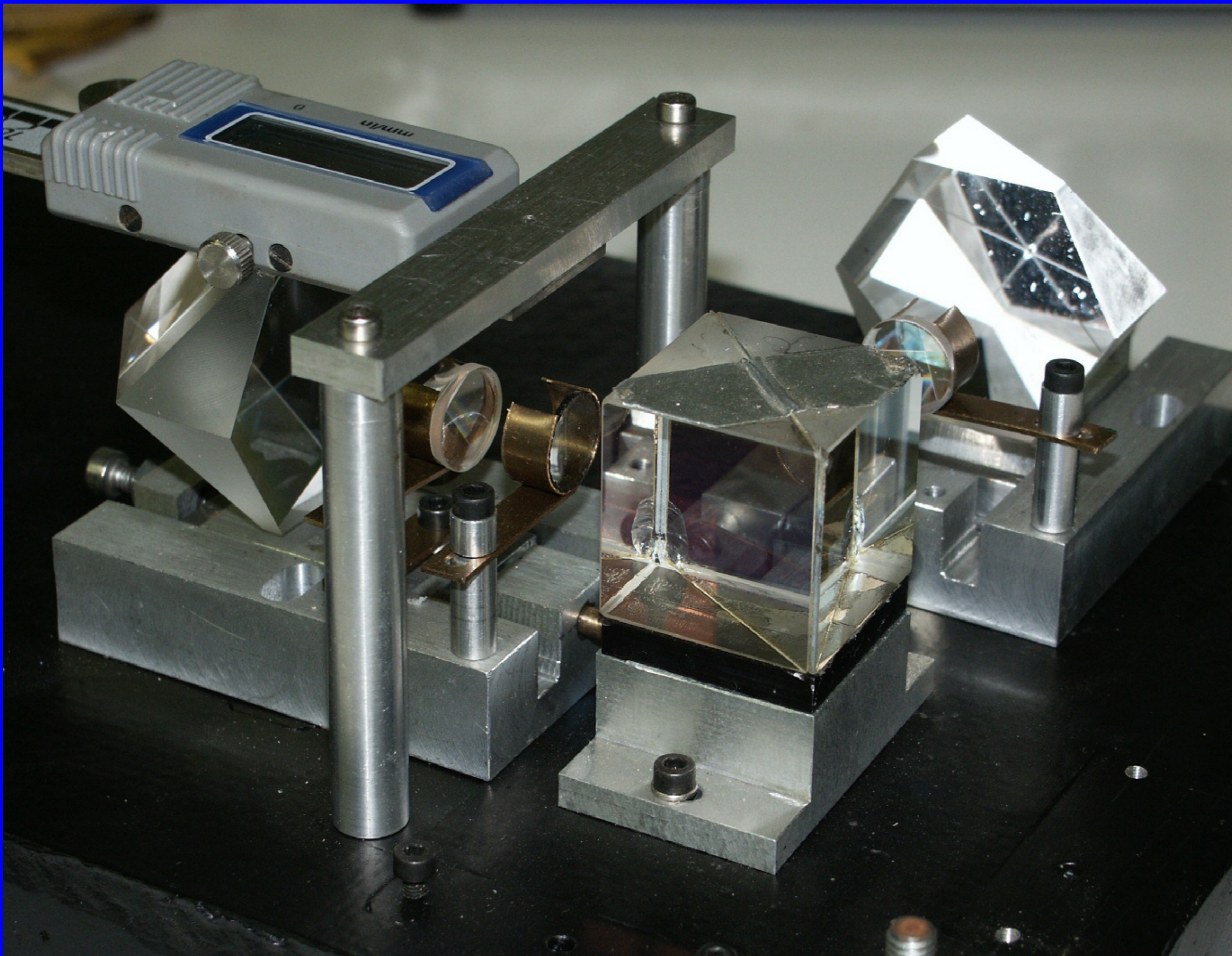
MMZI prototype (patent pending)



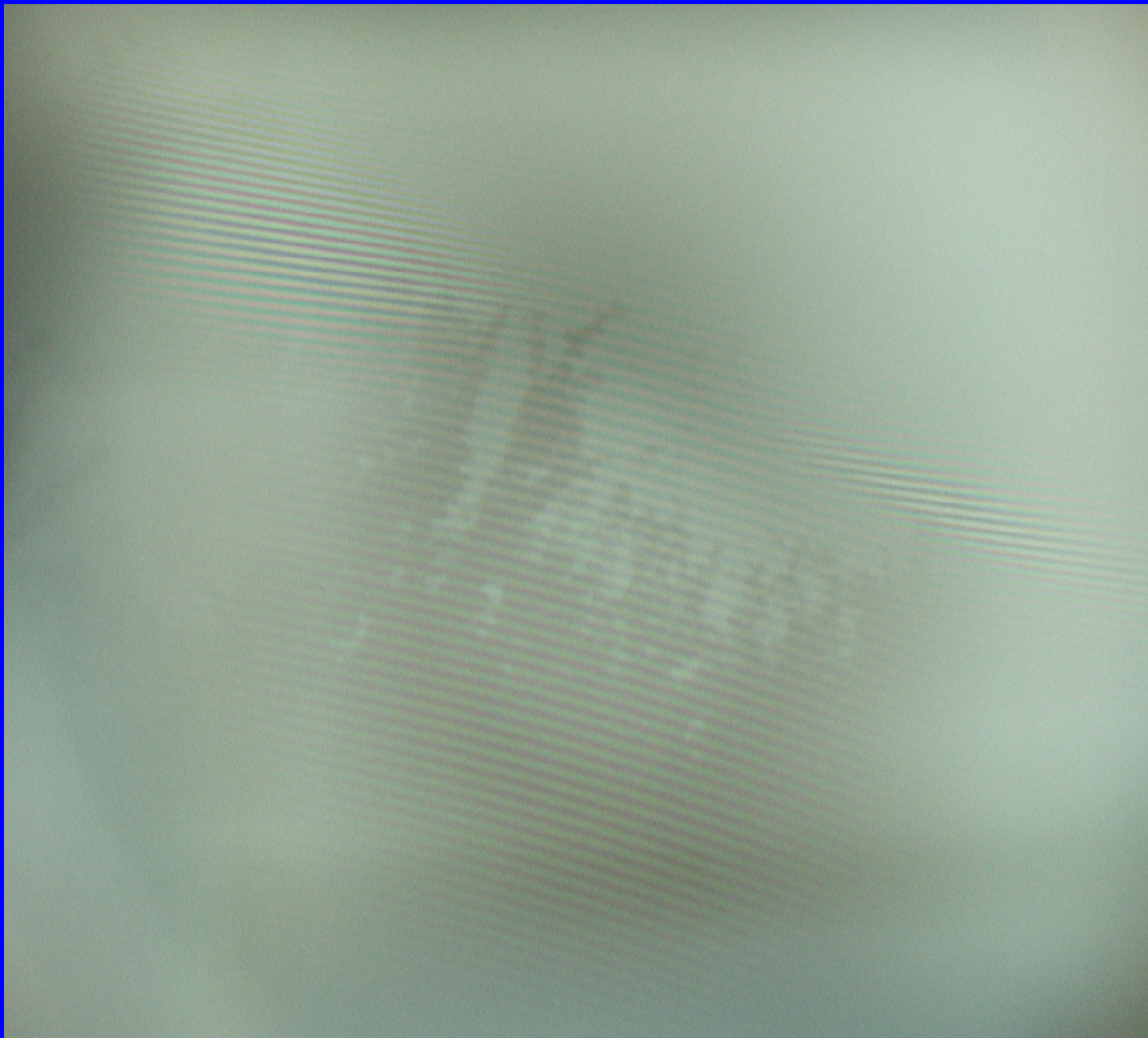
MMZI Prototype (details) (1)



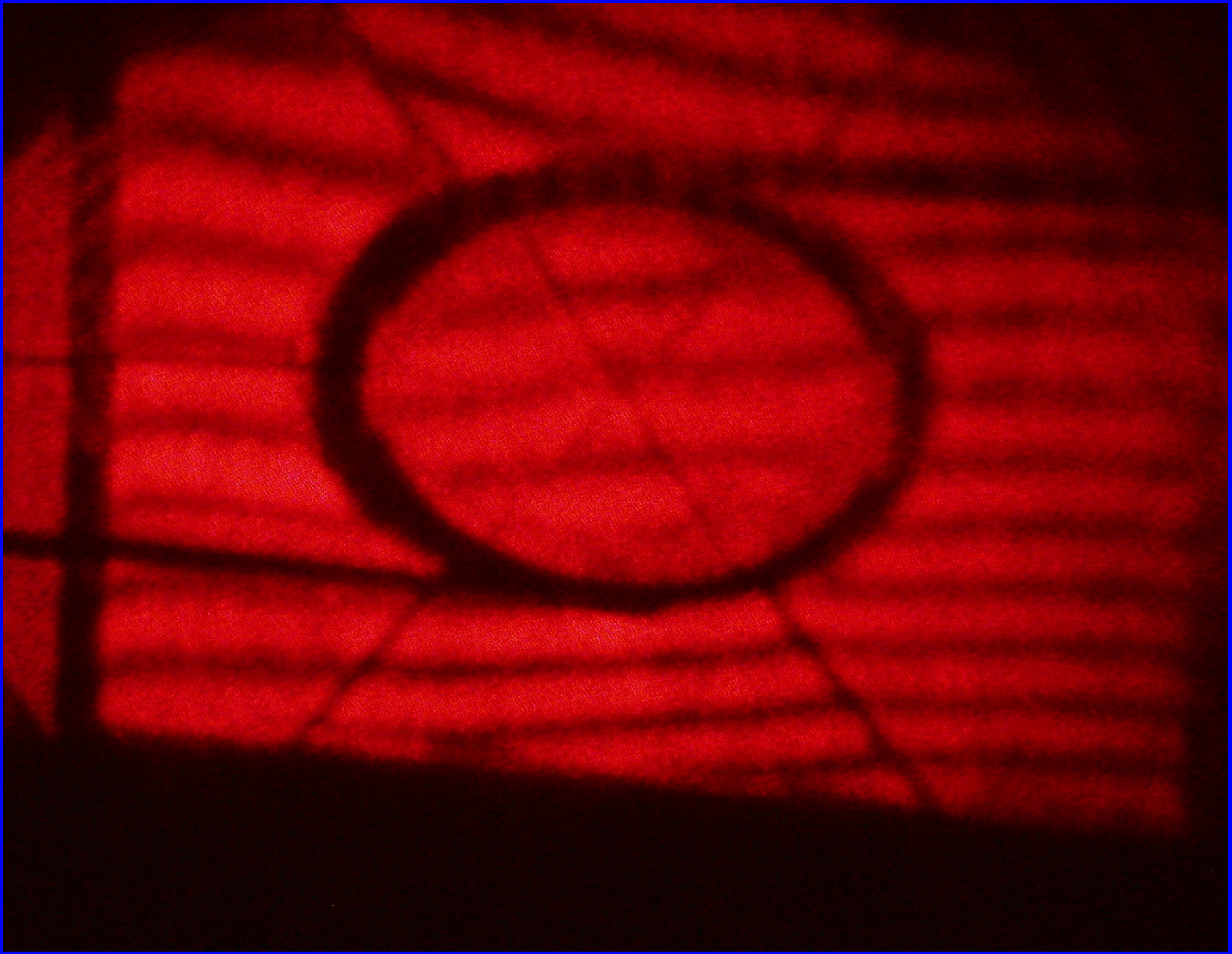
MMZI Prototype (details) (2)



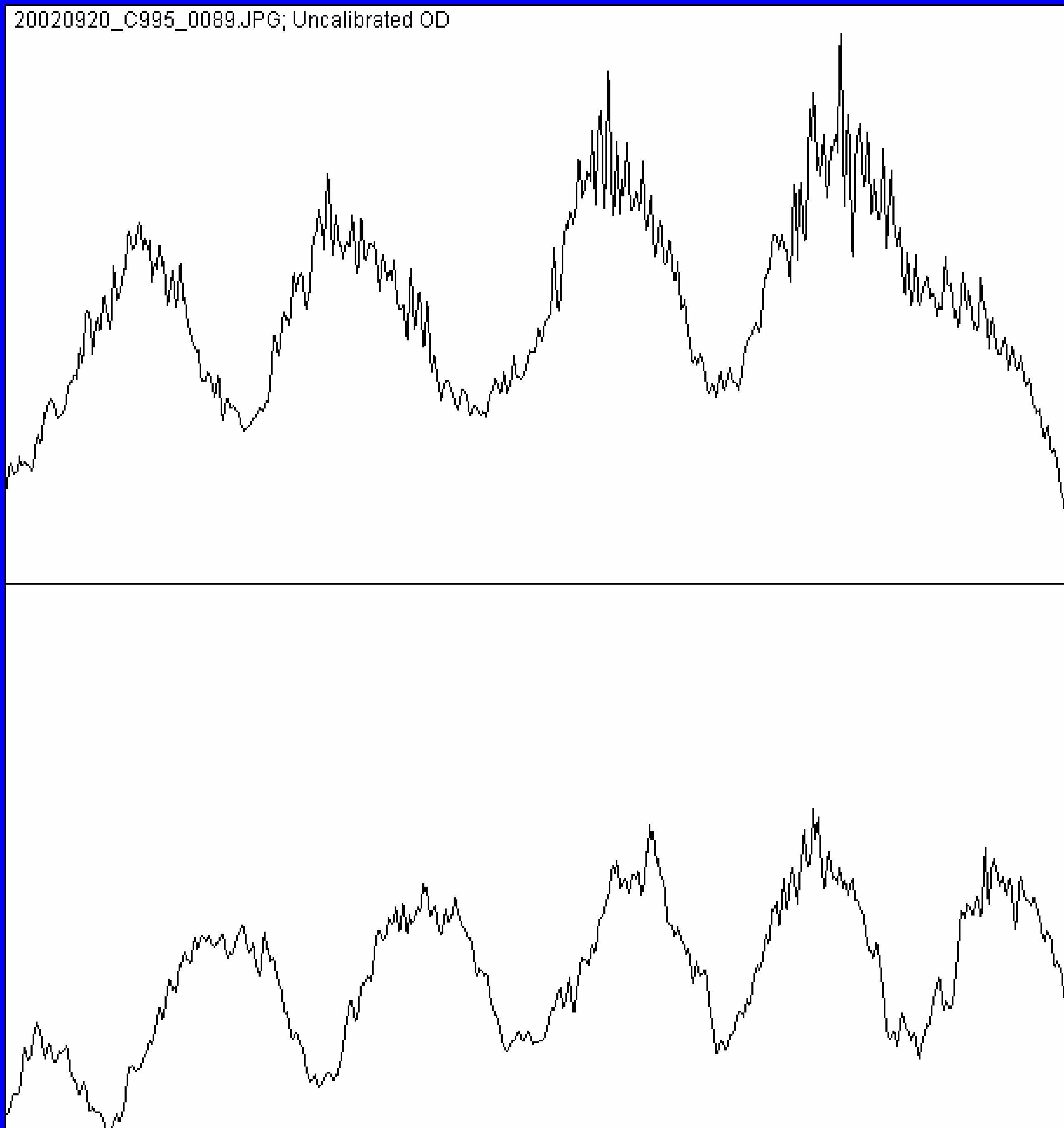
White light fringes (null path difference)



Continuous He-Ne Laser fringes



Continuous He-Ne Laser Fringes

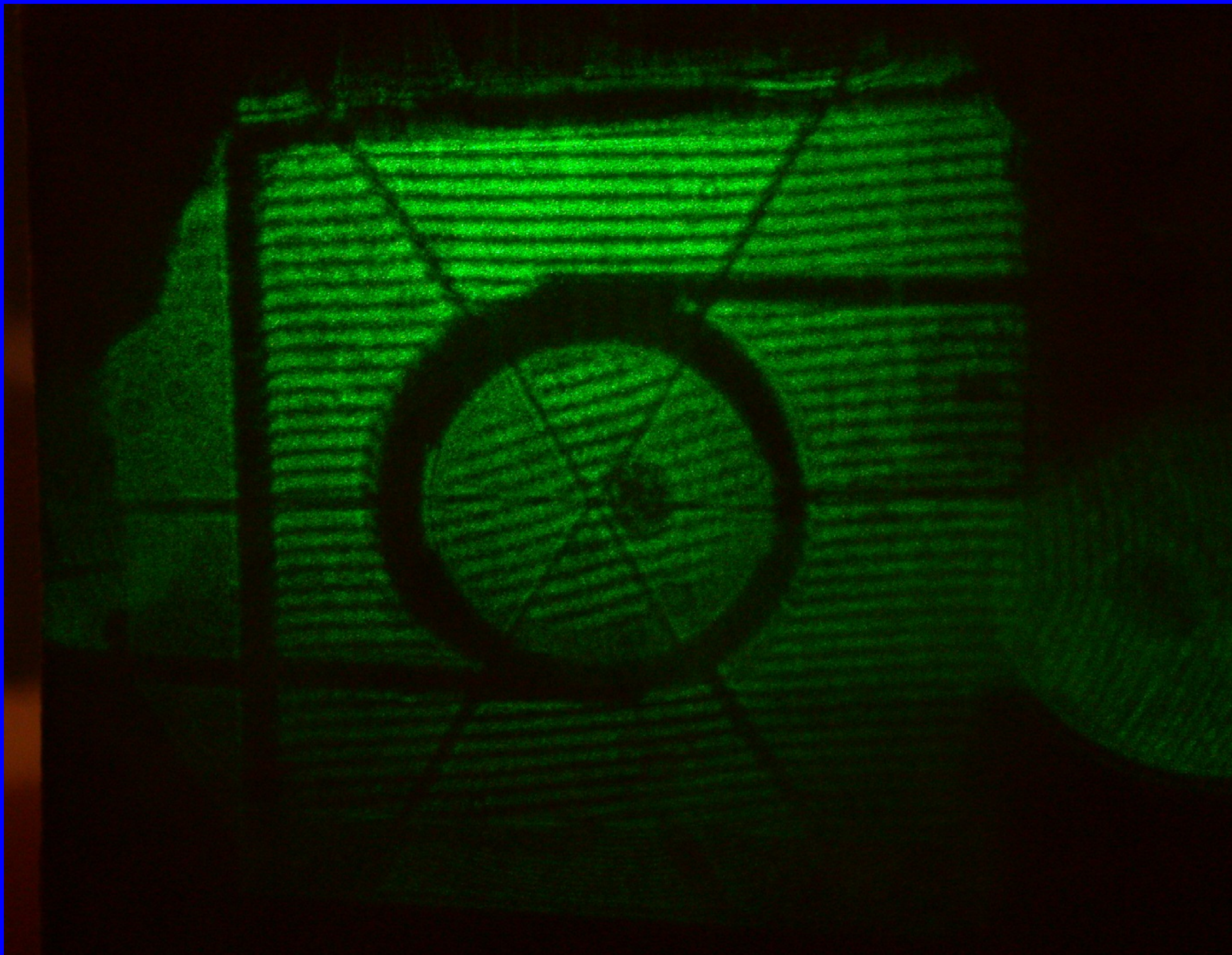


50% reference

~100% measured

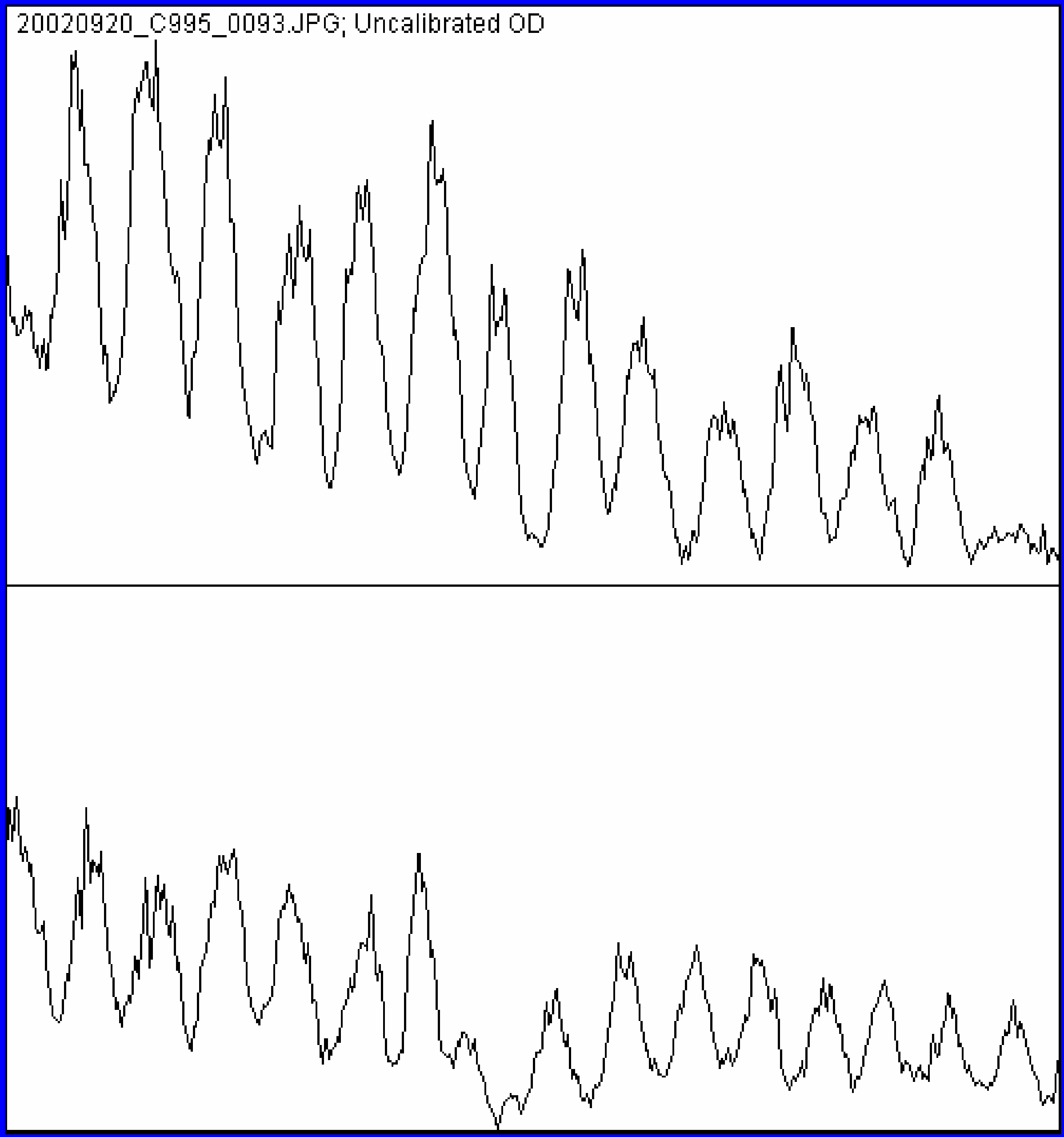
Relaxed doubled Nd:YAG Laser fringes

(null path difference)



Relaxed doubled Nd:YAG Laser fringes

(null path difference)

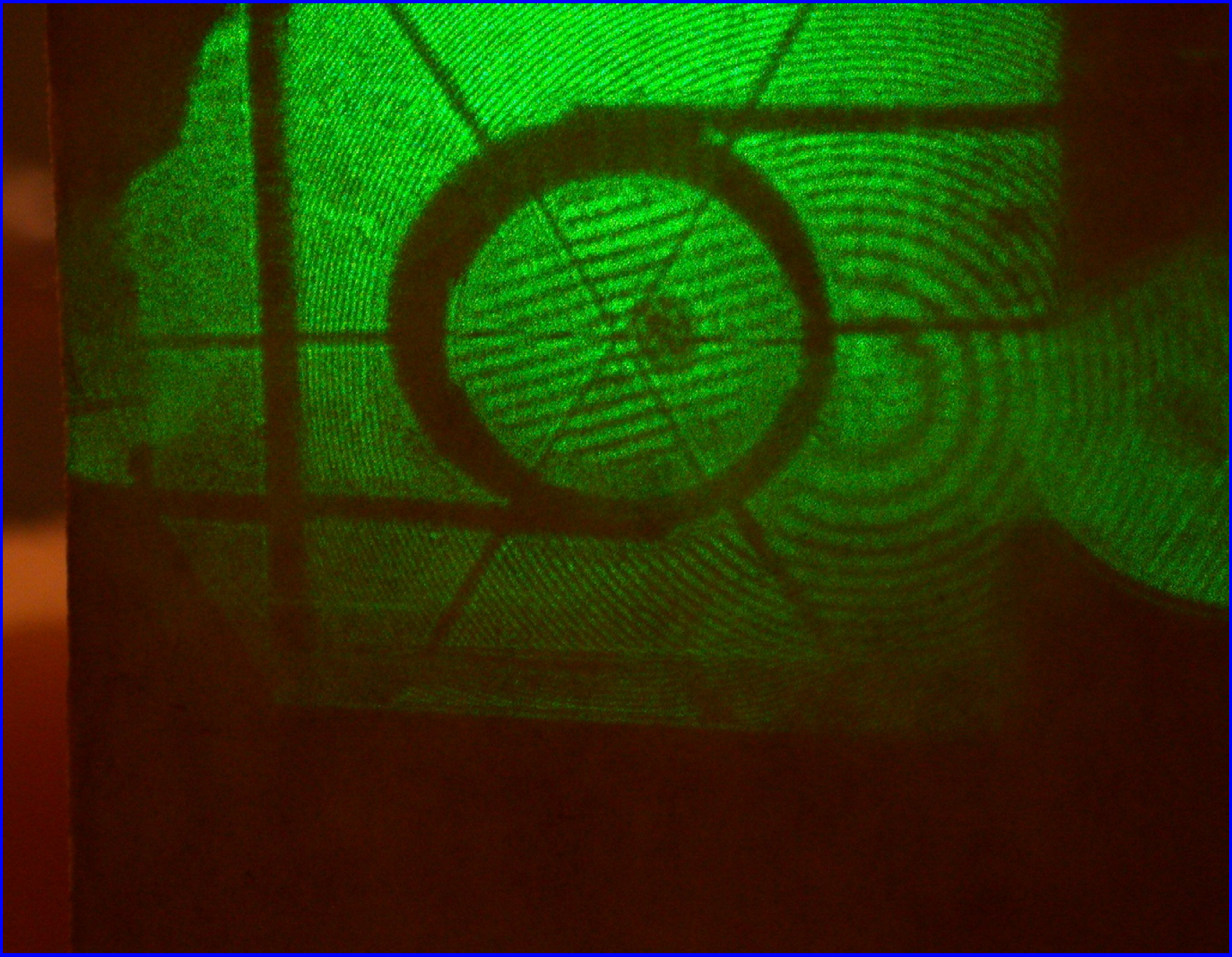


50% reference

~100% measured

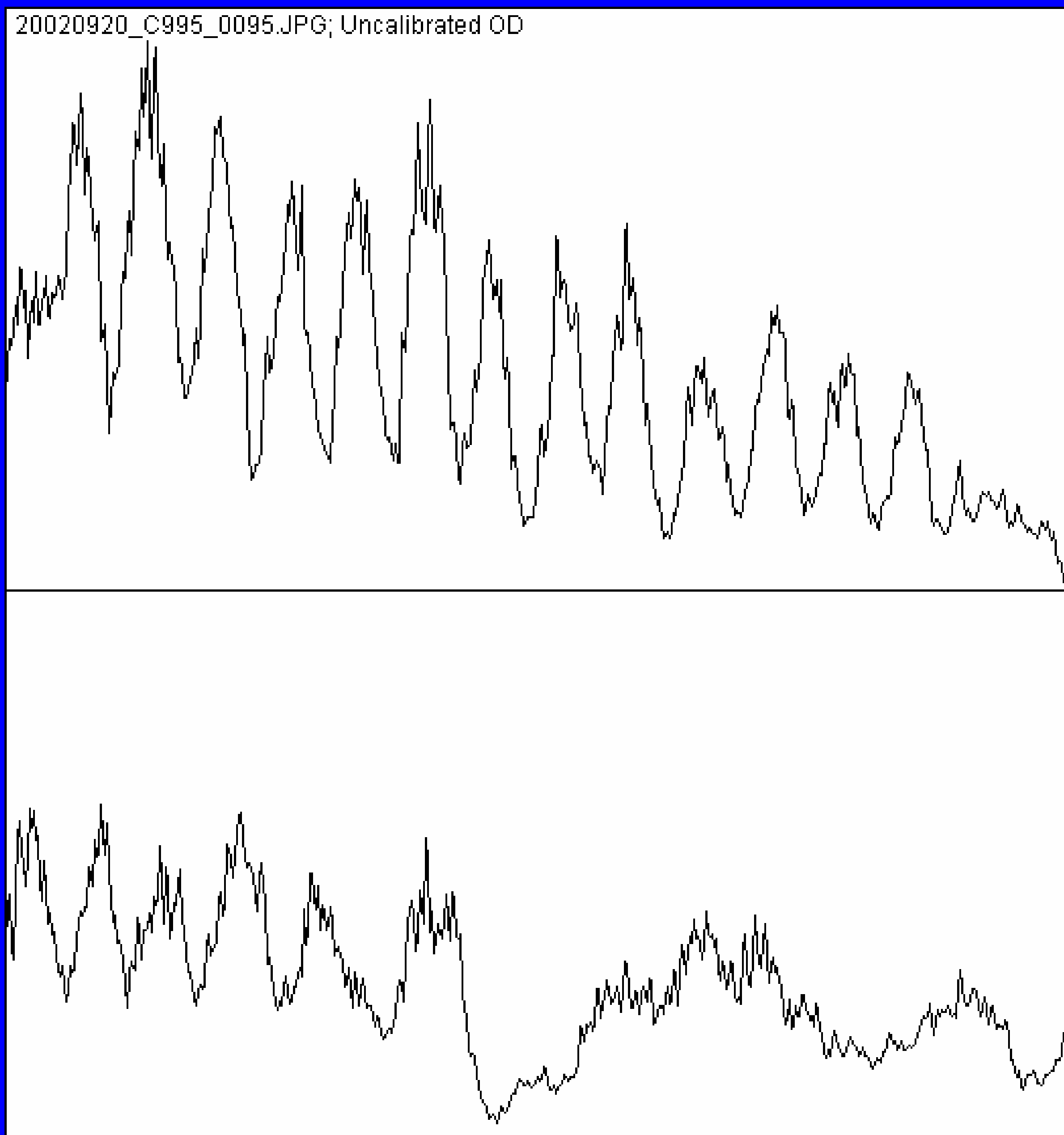
Relaxed doubled Nd:YAG Laser fringes

(equal contrasts path difference)



Relaxed doubled Nd:YAG Laser fringes

(equal contrasts path difference)

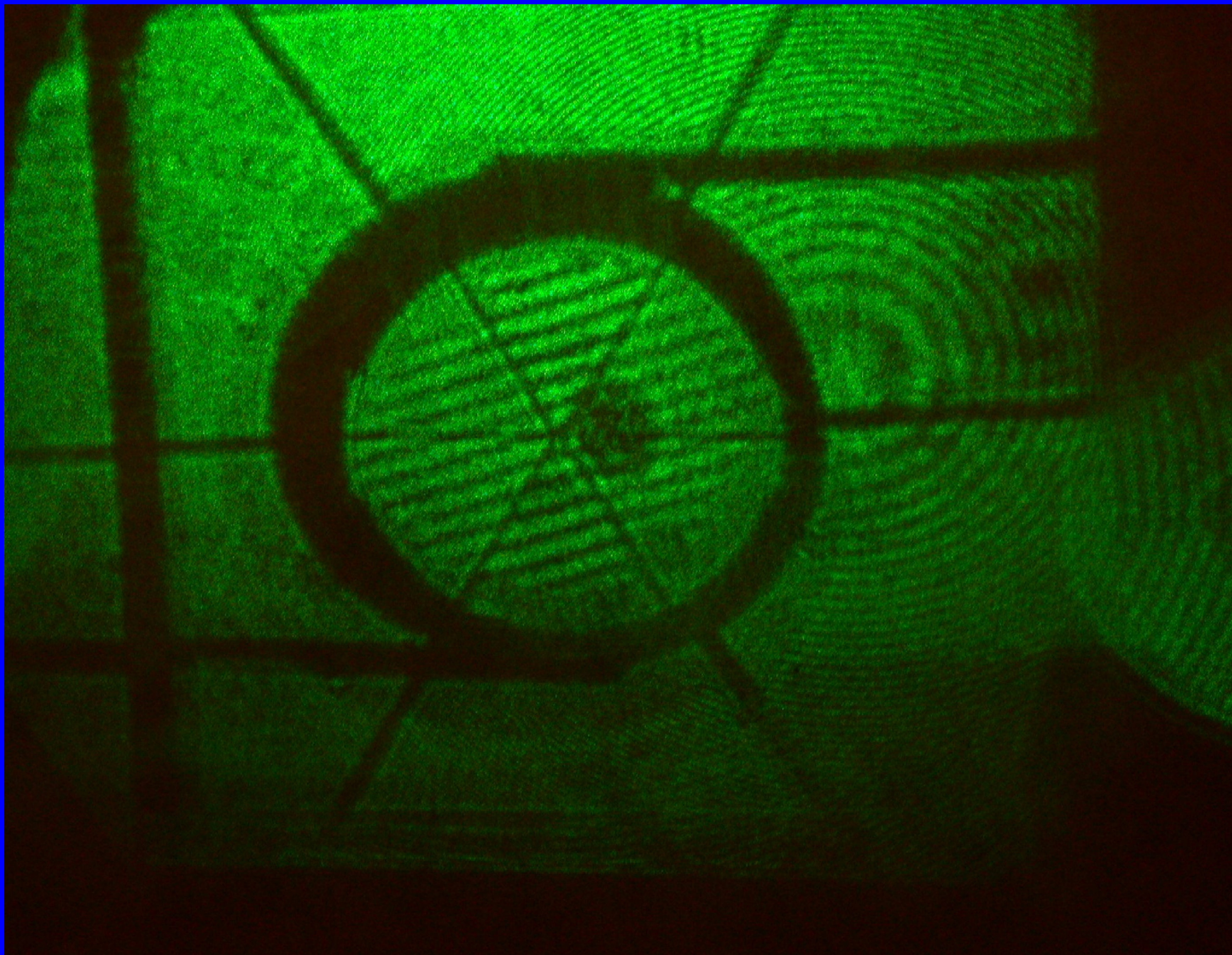


50% reference

~50% measured

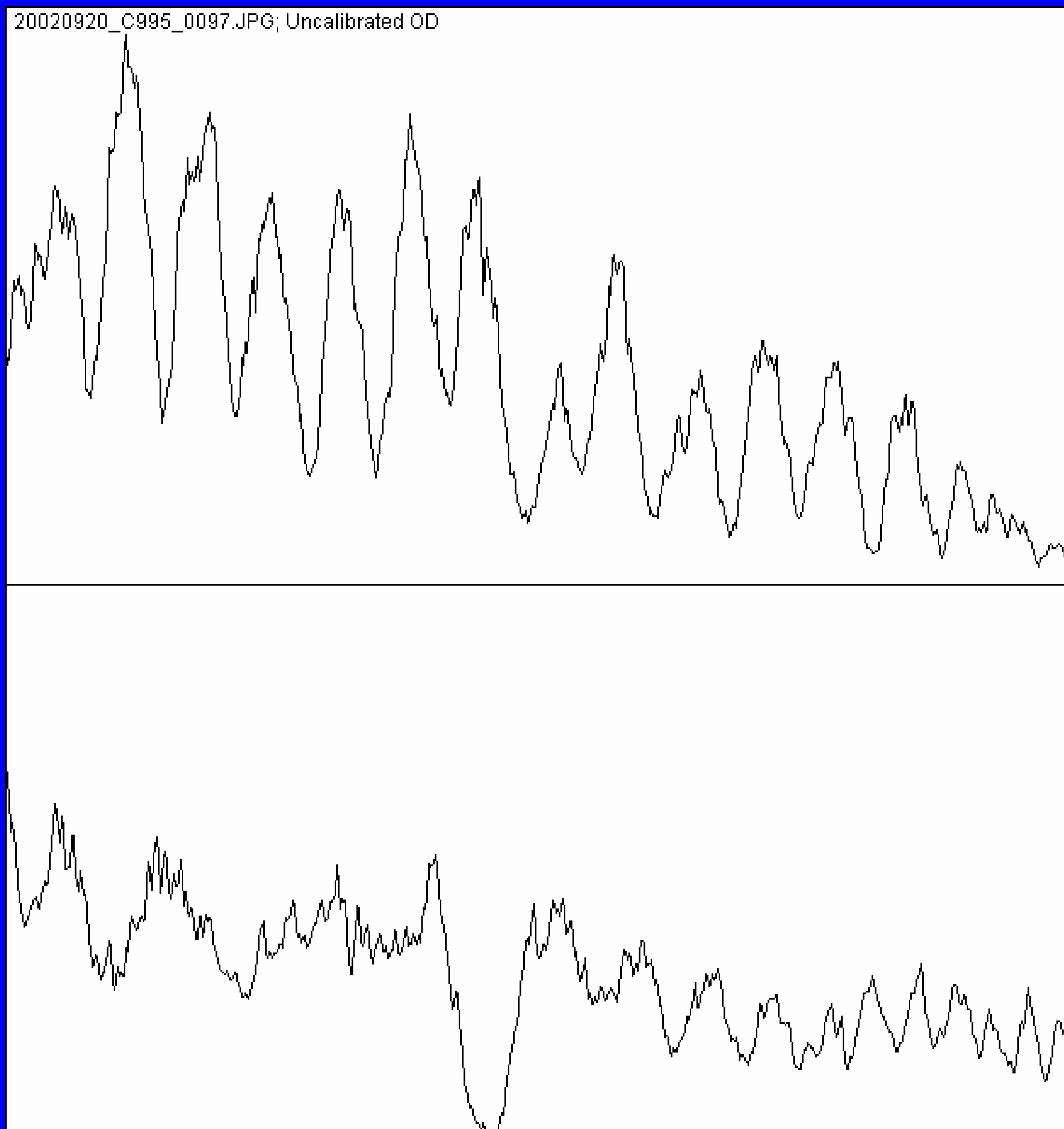
Relaxed doubled Nd:YAG Laser fringes

(too large path difference)



Relaxed doubled Nd:YAG Laser fringes

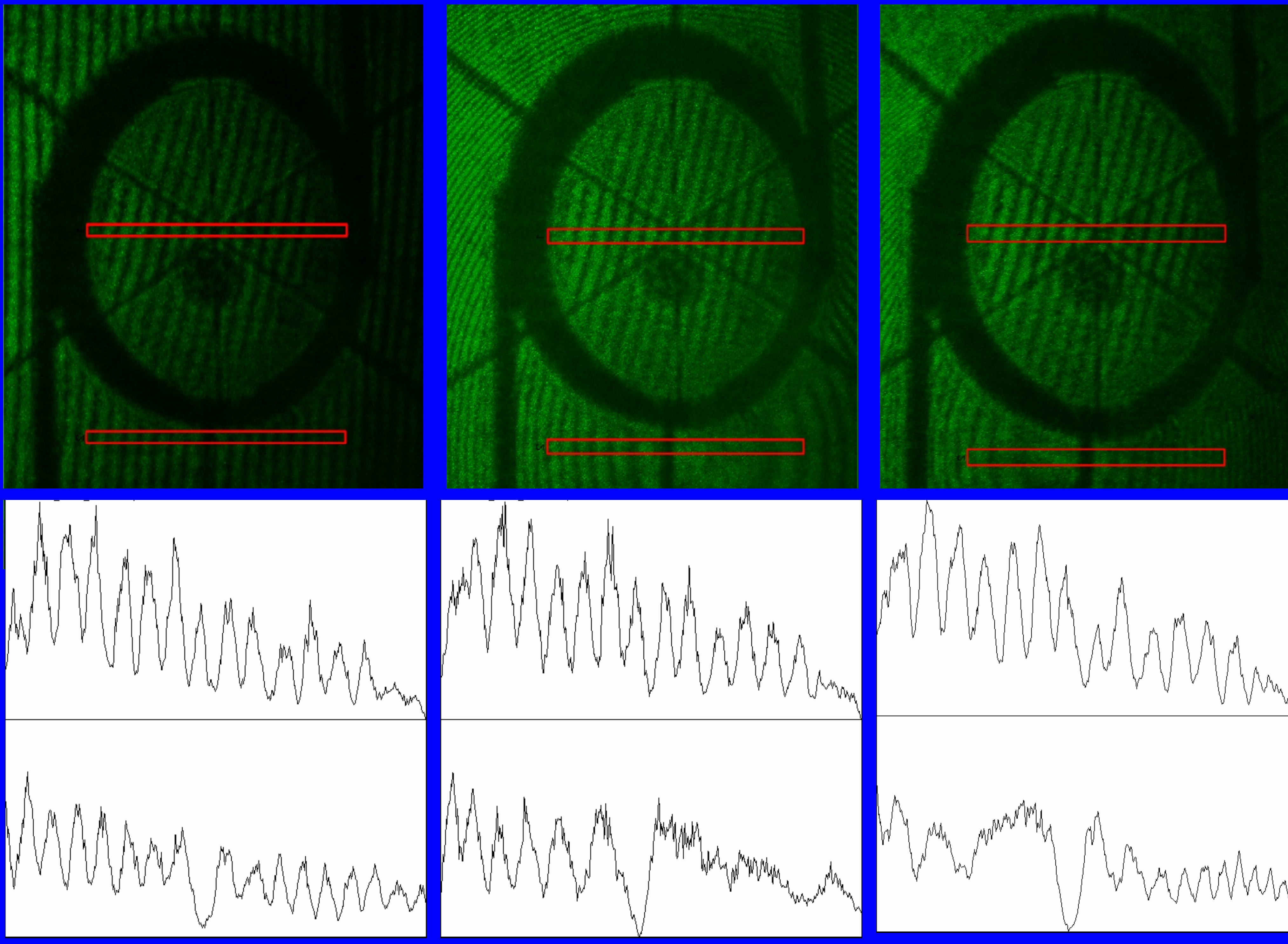
(too large path difference)



50% reference

< 50% Measured

Evolution of Fringe Contrast for increasing path differences



Conclusion

- Precision limited by:
  - value of density
  - appreciation of contrast
- Pulse shape not directly accessible
- Result shape dependant: needs assumption to deduce pulse width
- Density can be calibrated with another method
- Could be improved by use of a CCD/Image processing system
- Whole C(δ) curve leads to shape under correct assumptions

But, in many situations, the easy of use and low cost should overcome the limitations of this method