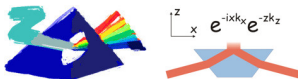


# Stabilizacja częstości laserów — subhercowa dokładność w zasięgu ręki

Tomasz Kawalec

28 listopada 2011

Zakład Optyki Atomowej, Instytut Fizyki UJ



[www.coldatoms.com](http://www.coldatoms.com)

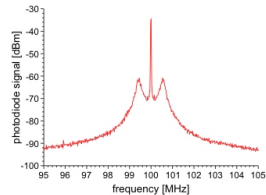
**Wstęp, rozwinięcie, zakończenie**

Bezwzględna stabilizacja częstotliwości

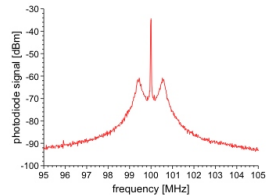
Względna stabilizacja częstotliwości

Interferencja światła z różnych źródeł

- względna stabilizacja częstotliwości laserów diodowych — jak działają detektory fazy i częstotliwości i jak je wykorzystać w optyce



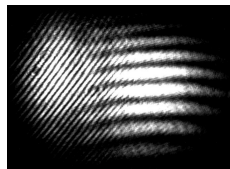
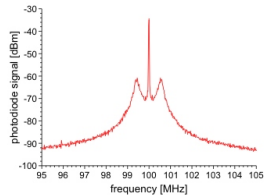
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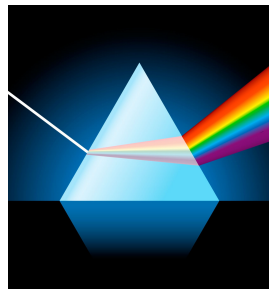
- dygresja o technice radiowej

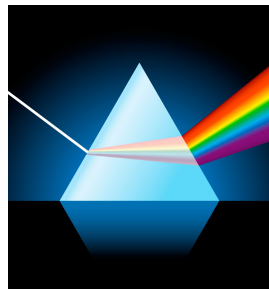
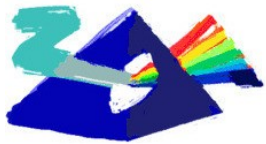


- względna stabilizacja częstotliwości laserów diodowych — jak działają detektory fazy i częstotliwości i jak je wykorzystać w optyce
- dygresja o technice radiowej
- jak zobaczyć interferencję światła pochodzącego z dwóch różnych laserów

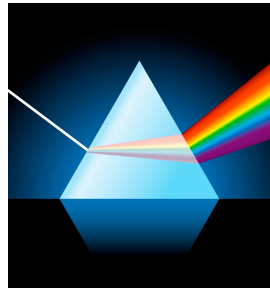
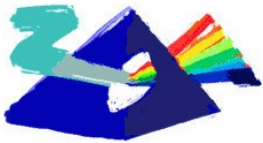












*Optica Applicata, Vol. XXXIV, No. 4, 2004*

## **Stabilization of diode-laser frequency to atomic transitions**

WOJCIECH GAWLIK, JERZY ZACHOROWSKI

Different methods of stabilization of diode lasers are reviewed with the emphasis on stabilization to atomic transitions. The stabilization methods to Doppler-broadened and Doppler-free resonances are presented. A novel method of stabilization using the saturated dichroism of atomic vapours is described. An example of stability transfer from the diode laser onto the reference Fabry-Perot cavity is presented.

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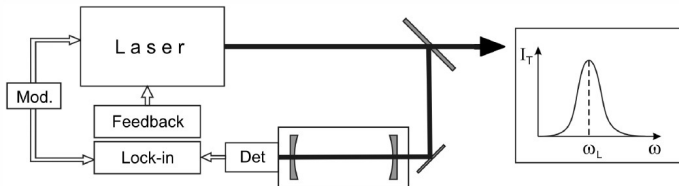


Fig. 2. Center-of-fringe stabilization scheme of the laser frequency to the external Fabry–Perot cavity.

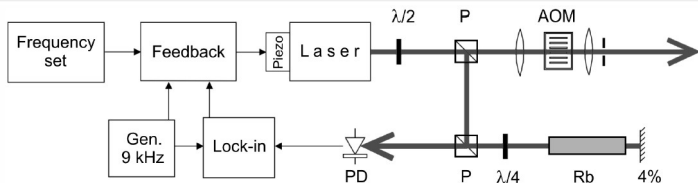


Fig. 4. Scheme of the laser stabilization using the saturated absorption method (P – the polarization beamsplitter, Rb – the atomic absorption cell, PD – the photodiode, and  $\lambda/2$  and  $\lambda/4$  – waveplates, AOM – the acousto-optical modulator used for shifting the laser frequency).

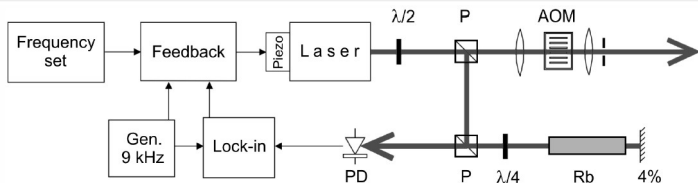


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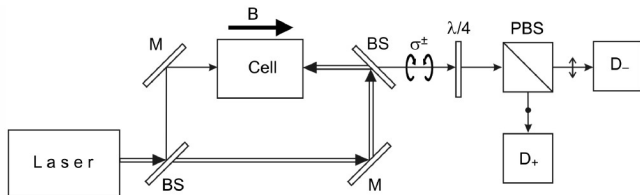
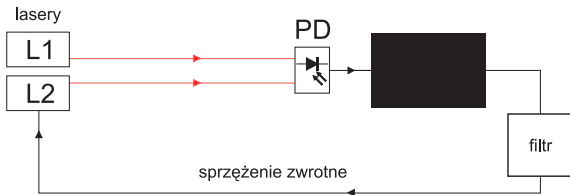
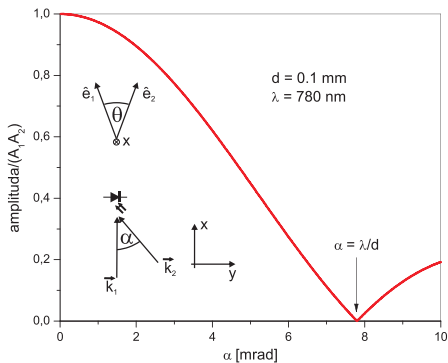


Fig. 7. Scheme of the stabilization system using the Doppler-free magnetic dichroism (the saturating laser beam is shown as a double line, the probe beam as a single line; BS – a beamsplitter, PBS – polarization beamsplitter, M – mirrors,  $\lambda/4$  – quarter-wave plate,  $D_+$  and  $D_-$  – the photodetectors measuring absorption for  $\sigma^+$  and  $\sigma^-$  polarized light).



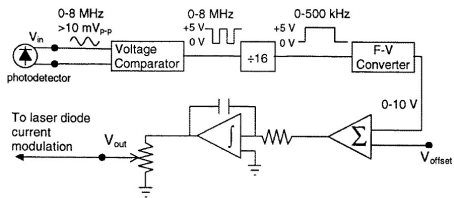
- idea stabilizacji względnej częstotliwości laserów
- czarna skrzynka: detektor fazy, detektor fazy/częstotliwości, filtr górnoprzepustowy,...
- w elektronice — od lat 30 XX wieku; w technice laserowej — od lat 60



$d$  — rozmiar detektora

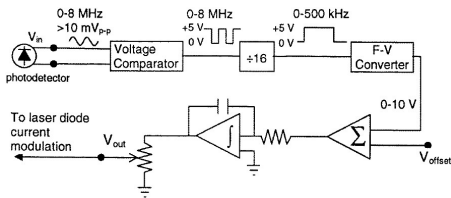
$$\overline{|A_1^2 + A_2^2|^2} = \frac{1}{2} (A_1^2 + A_2^2) + A_1 A_2 \cos \theta \cos \left( (\vec{k}_1 - \vec{k}_2) \cdot \vec{r} - (\omega_1 - \omega_2) t \right)$$

$$\overline{|A_1^2 + A_2^2|^2}_y = \frac{1}{2} (A_1^2 + A_2^2) + \frac{A_1 A_2 \sin \left( \frac{1}{2} dk_2 \sin \alpha \right)}{\frac{1}{2} dk_2 \sin \alpha} \cos \left( \frac{1}{2} dk_2 \sin \alpha + (\omega_1 - \omega_2) t \right), \theta = 0, x = 0$$

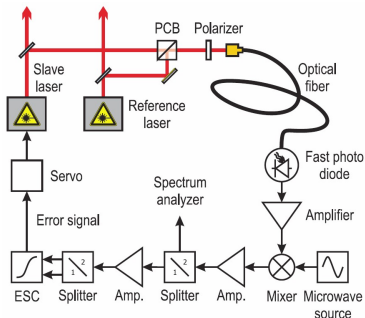


- Meas. Sci. Technol. 9 1635 (1998)





- Meas. Sci. Technol. 9 1635 (1998)



- Appl. Phys B 79 363 (2004)

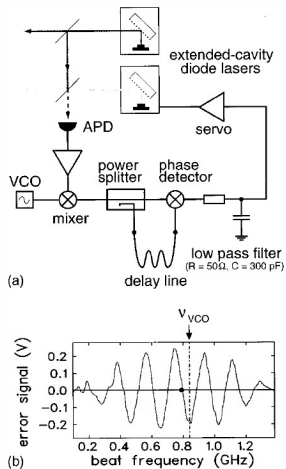
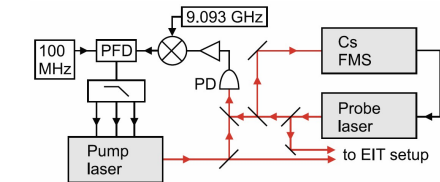
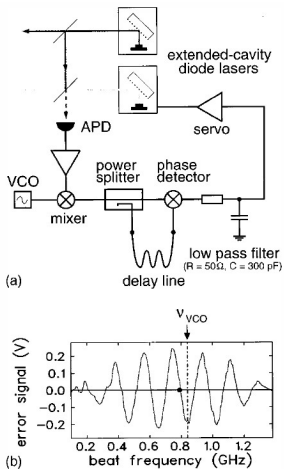


FIG. 1. (a) Scheme of the tunable frequency offset lock. (b) Error signal as a function of beat frequency between the two lasers. The dot indicates one of the locking points of the servo loop, and  $\nu_{VCO}$  denotes the frequency of the rf oscillator used for frequency shifting the beat signal.



• Appl. Phys. B 94 429 (2009)

• Rev. Sci. Instr. 70 242 (1999)

- bramka XOR:

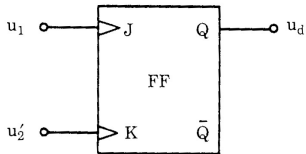


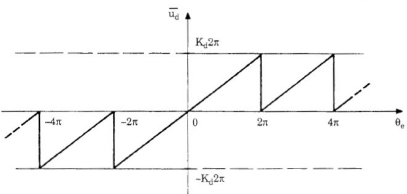
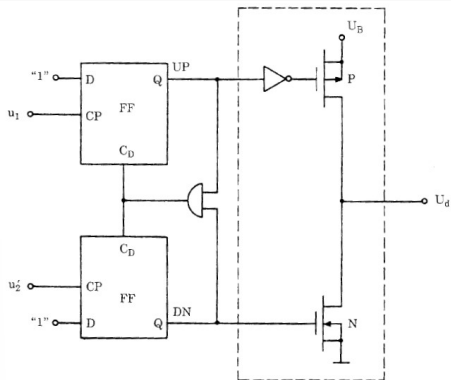
- przerzutnik JK:

- bramka XOR:



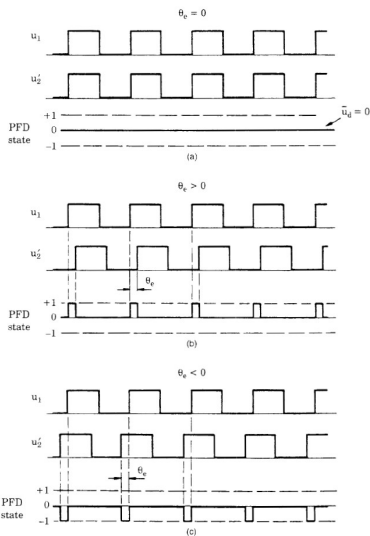
- przerzutnik JK:

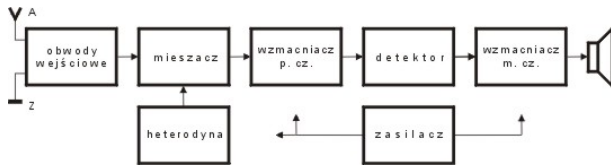




• R. E. Best, Phase-Locked Loops

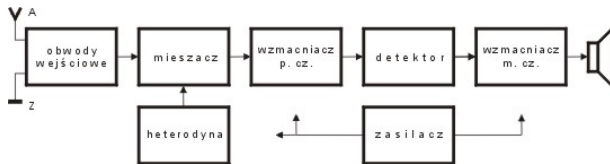
## • PHASE-FREQUENCY DETECTOR





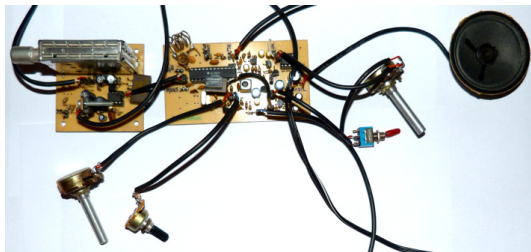
[www.olderadio.pl](http://www.olderadio.pl)

- schemat blokowy typowego odbiornika radiowego

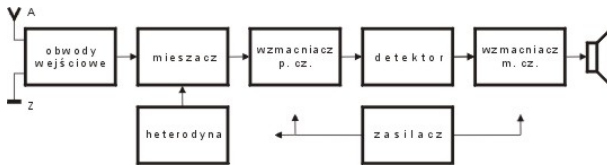


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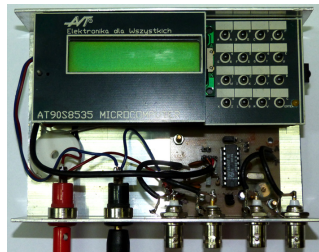
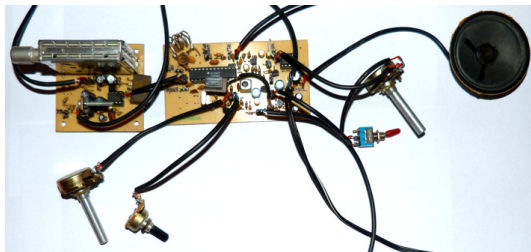




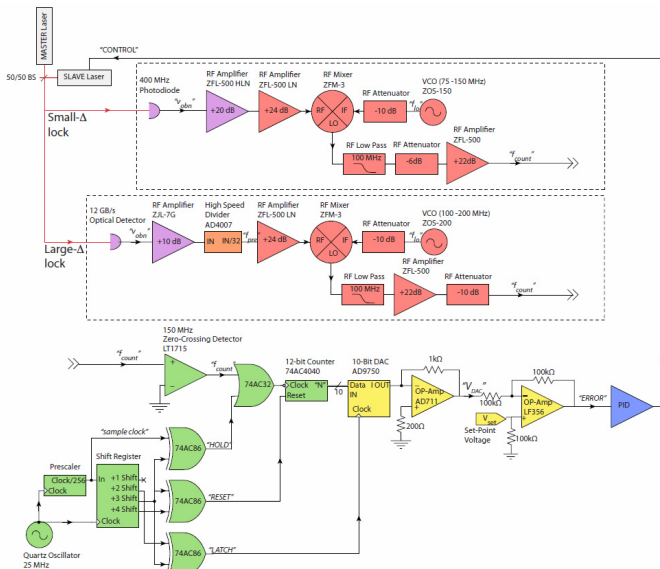


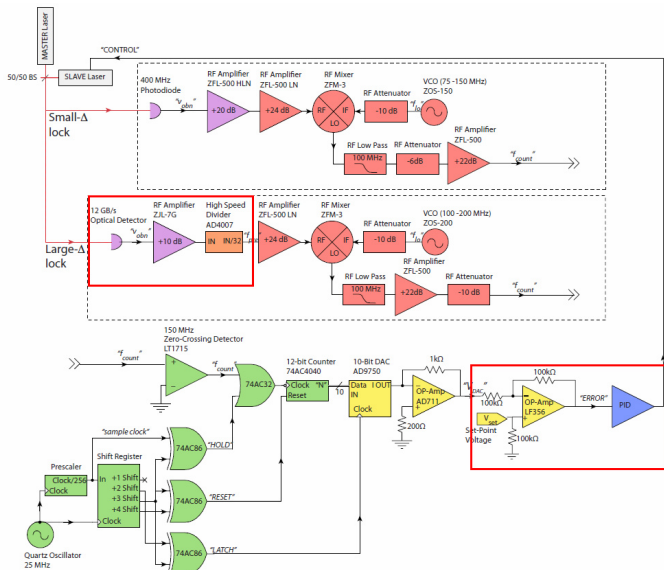
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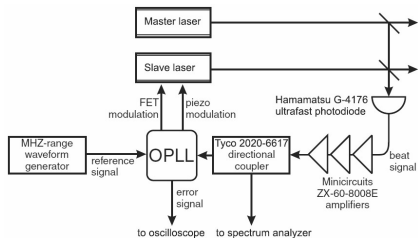
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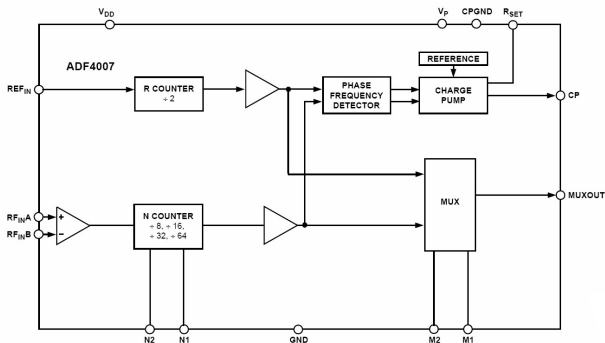


- Meas. Sci. Technol. **20** 055302 (2009)

- ADF4007, ADF4107, ADF4002,...
- zakres od MHz do 7 GHz
- częstotliwość detektora fazy do 120 MHz
- zawierają dzielniki, PFD, pompę ładunkową, układy dodatkowe
- dzielniki N i R do 13-14 bitów
- dostępne układy testowe

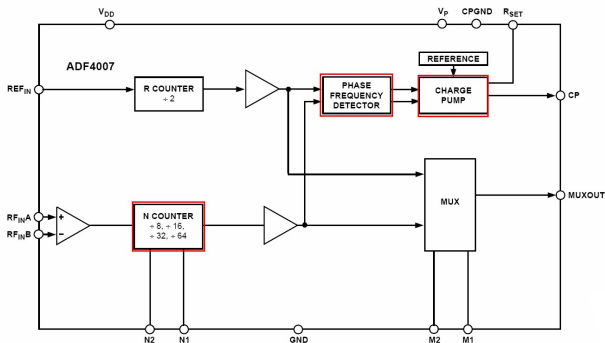
- potrzebne składniki: szybka fotodioda, wzmacniacze w.cz., ADF..., generator referencyjny, wzmacniacz i filtr pętli oraz rozdzielacz piezo/prądowy

### FUNCTIONAL BLOCK DIAGRAM

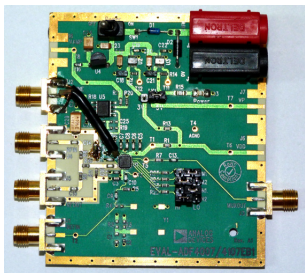


- główne bloki układu ADF4007; MUX = multiplexer

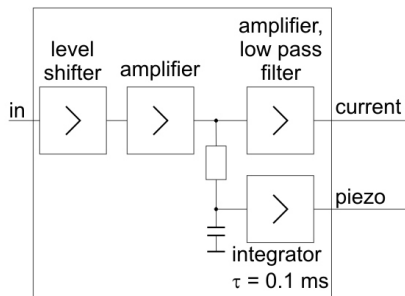
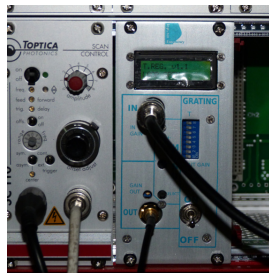
### FUNCTIONAL BLOCK DIAGRAM



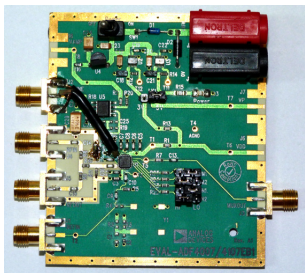
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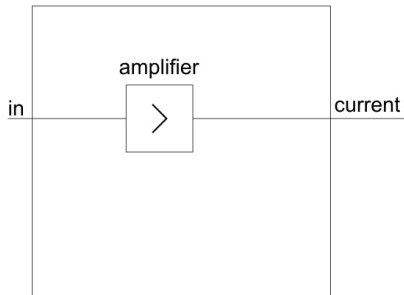
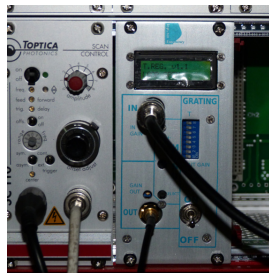
- ADF4007 + ADF4002
- zakres 20 MHz – 7 GHz
- precyzja  $< 1$  Hz

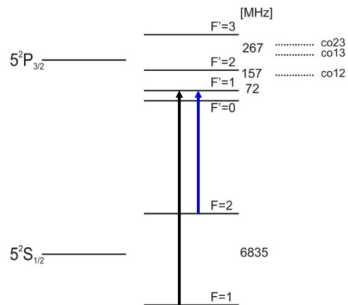
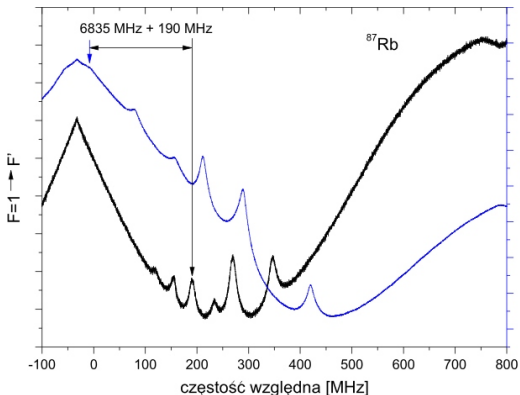




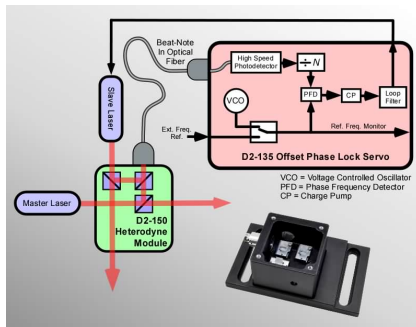


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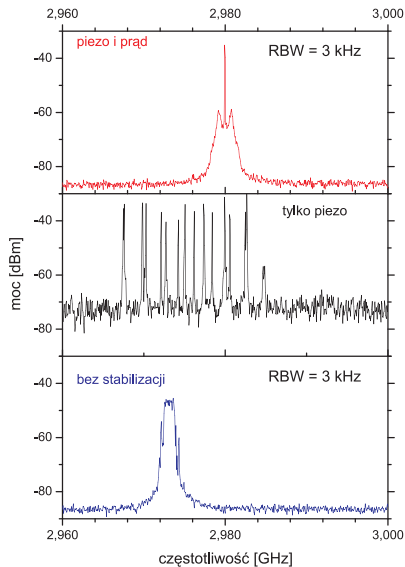




- synchroniczne przestrajanie lasera repompującego z laserem pułapkującym z odstępem 6740 MHz i AOMem 95 MHz

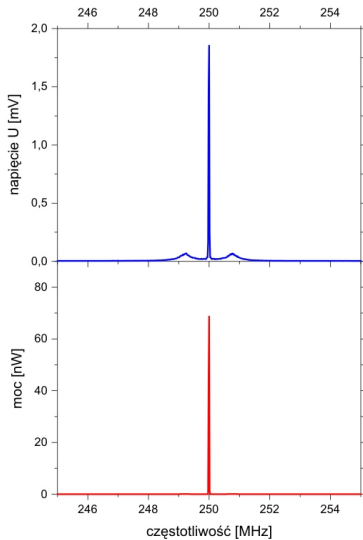
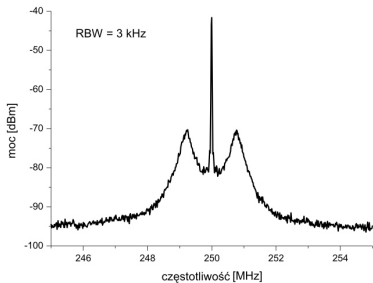


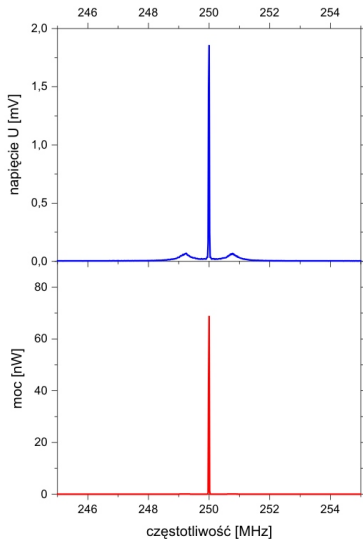
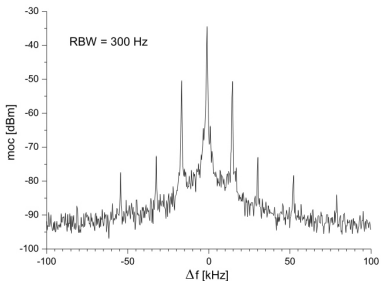
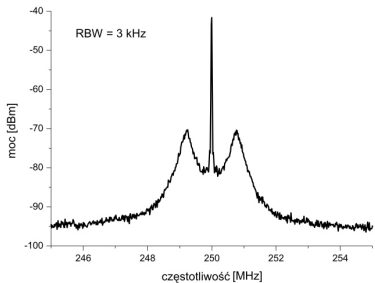
- Vescent Photonics

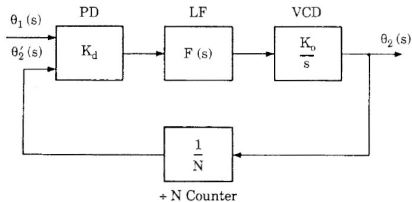


widmo sygnału dudnień:

- z pełną stabilizacją
- z zamkniętą pętlą piezo
- bez żadnej stabilizacji

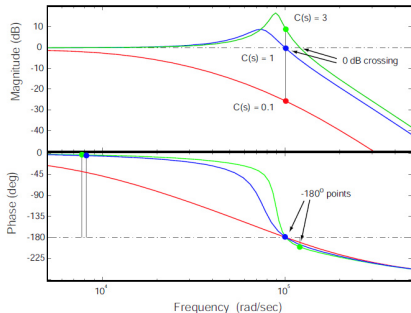






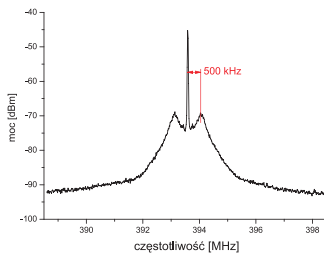
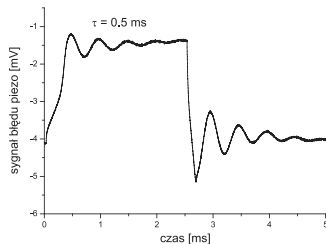
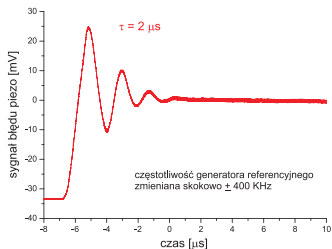
$$F(s) = \int_0^{\infty} e^{-st} f(t) dt$$

$$T(s) = \frac{\Theta_2(s)}{\Theta_1(s)} = \frac{G(s)}{1 + G(s)H(s)}$$



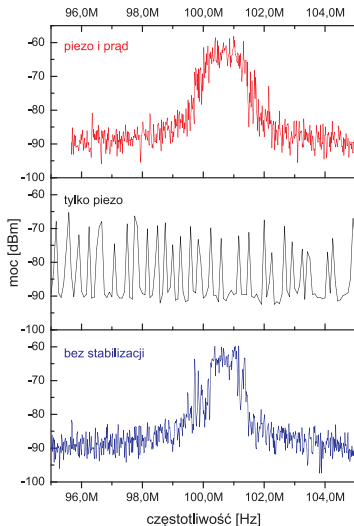
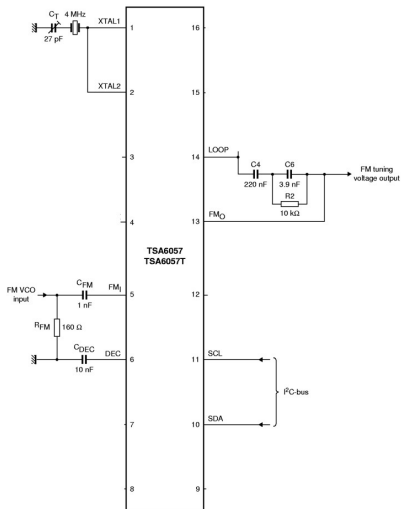
$$T(s) = \frac{K_d F(s) \frac{K_O}{s}}{1 + K_d F(s) \frac{K_O}{s} \frac{1}{N}}$$

$$s = j\omega$$



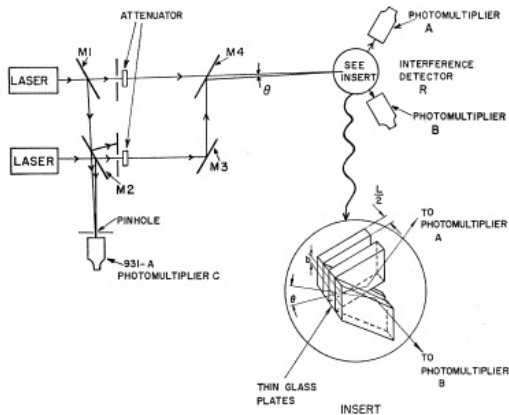
- diagnostyka pętli





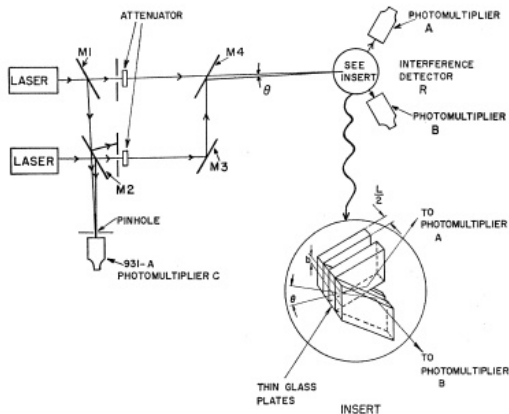
- układ TSA6057 do stabilizacji częstotliwości (bez zawężania linii)

- 1963 — interferencja promieniowania z dwóch niezależnych laserów (zdjęcie)



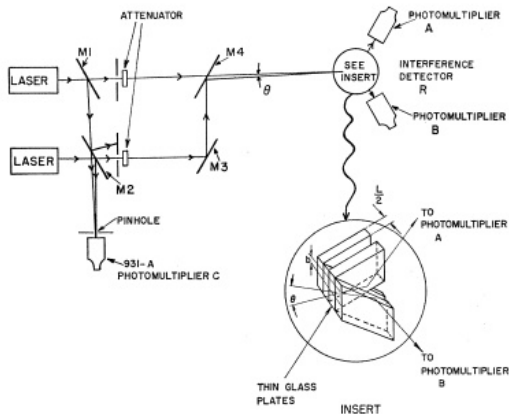
- Phys. Rev. **159** 1084 (1967)

- 1963 — interferencja promieniowania z dwóch niezależnych laserów (zdjęcie)
- 1967 — interferencja dla pojedynczych fotonów (korelacje)

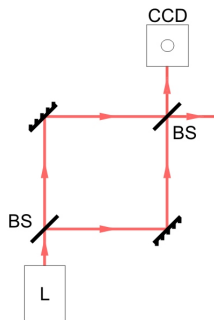


- Phys. Rev. **159** 1084 (1967)

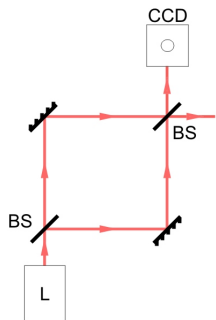
- 1963 — interferencja promieniowania z dwóch niezależnych laserów (zdjęcie)
- 1967 — interferencja dla pojedynczych fotonów (korelacje)
- interferencja światła z: laserów impulsowych (streak camera), stabilizowanych laserów diodowych, He-Ne (korelacje)



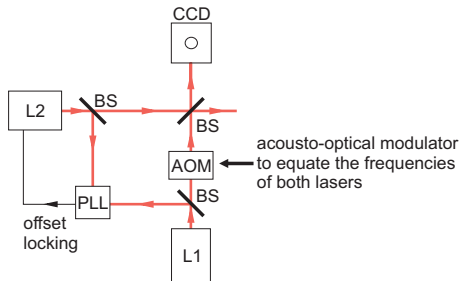
- Phys. Rev. **159** 1084 (1967)



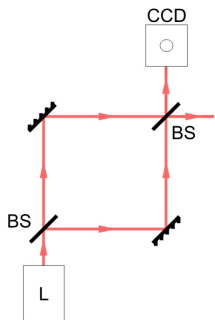
- interferometr Macha-Zehndera



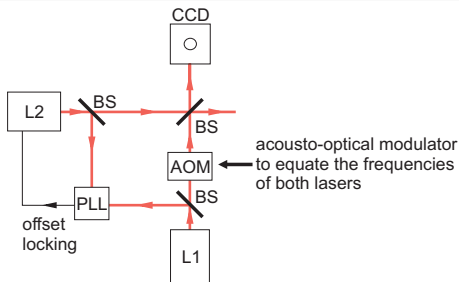
- interferometr Macha-Zehndera



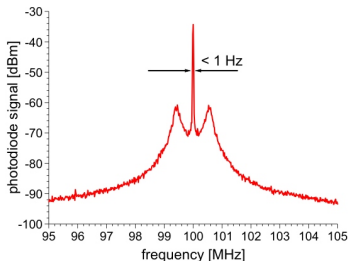
- zmodyfikowany interferometr dla dwóch źródeł

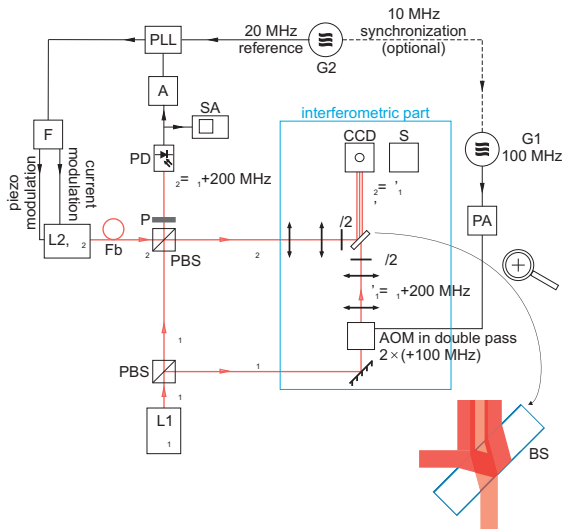


• interferometr Macha-Zehndera



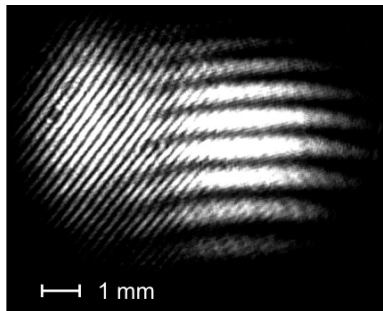
• zmodyfikowany interferometr dla dwóch źródeł



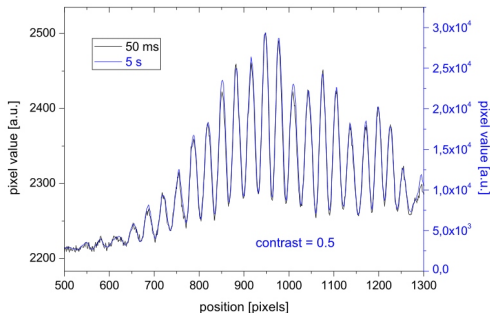
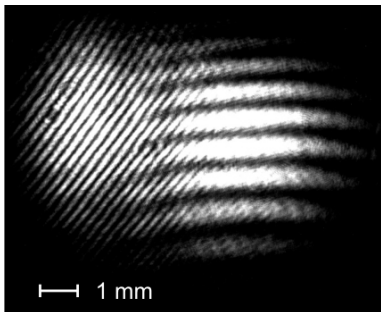


- schemat układu do obserwacji prążków interferencyjnych dla dwóch różnych laserów diodowych





- prążki interferencyjne zarejestrowane bezpośrednio na matrycy CCD



- prążki interferencyjne zarejestrowane bezpośrednio na matrycy CCD
- przekrój przez gęstsze prążki dla czasu naświetlania 50 ms i 5s

DZIĘKUJĘ ZA UWAGĘ

DZIĘKUJĘ ZA UWAGĘ

