Distributed Optical Fiber Sensor Systems

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Introduction

- Backscattered and Sagnac interferometr systems as a distirbuted sensor has been investigated.
- As matter of fact this presentation will only show an idea of ditributed sensors at all.
- We'll disregard mathematical aspect of problems

Optical Time-Domain Reflectometer

- Orginal objective of OTDR method was examine attenution variations in manufactured and installed lenghts of optical fiber.
- Proposed method for the measurement of temperature (Theocharous, 1983)
- OTDR return signal is differentiated with respect ratio to time, and normalized by division by the instantacous value of the signal, maesure of fiber attenuation is obtained (if fiber with temperature dependent attenuation is used, variations of temperature along the lenght may be monitored!!!)
- Also using OTDR-monitored attenuation variations for distributed radiation dosimetry has also been devised (Geabler and Brauning 1983). In this method, a short section of fiber is exposed to ionizing radiation and suffers excess attenuation, enabling simultaneous detection and location of the radiation exposure.

Variation in Rayleigh backscatter characteristics

- Use of OTDR to monitor fiber attenuation relise on the constatncy of the Rayleigh backscattering cooficient along the lenght of the fiber.
- Form of varibility occurs in monomde fibers, using polarized illumination and polarization-sensitive detection
- Method, know as Polarization Optical Time-Domain Reflectometry (POTDR), suggested by Rogers(1980), realise on the high degree of preservation of polarization exhibited by Rayleigh and Rayleigh-Gans scattered light in silica fibers
- Howevere POTDR, main drawback, as with many potentially useful sensig method, is the variety of parametrs to which it may respond (the sensivity to strain and vibration being particulary trublesome).
- POTDR requires the use of **MONOMODE** fibers!!, which can, when used with narrow-linewidth laser sources, have particular problems due to coherent addition for multpile Rayleigh backscatttering centers

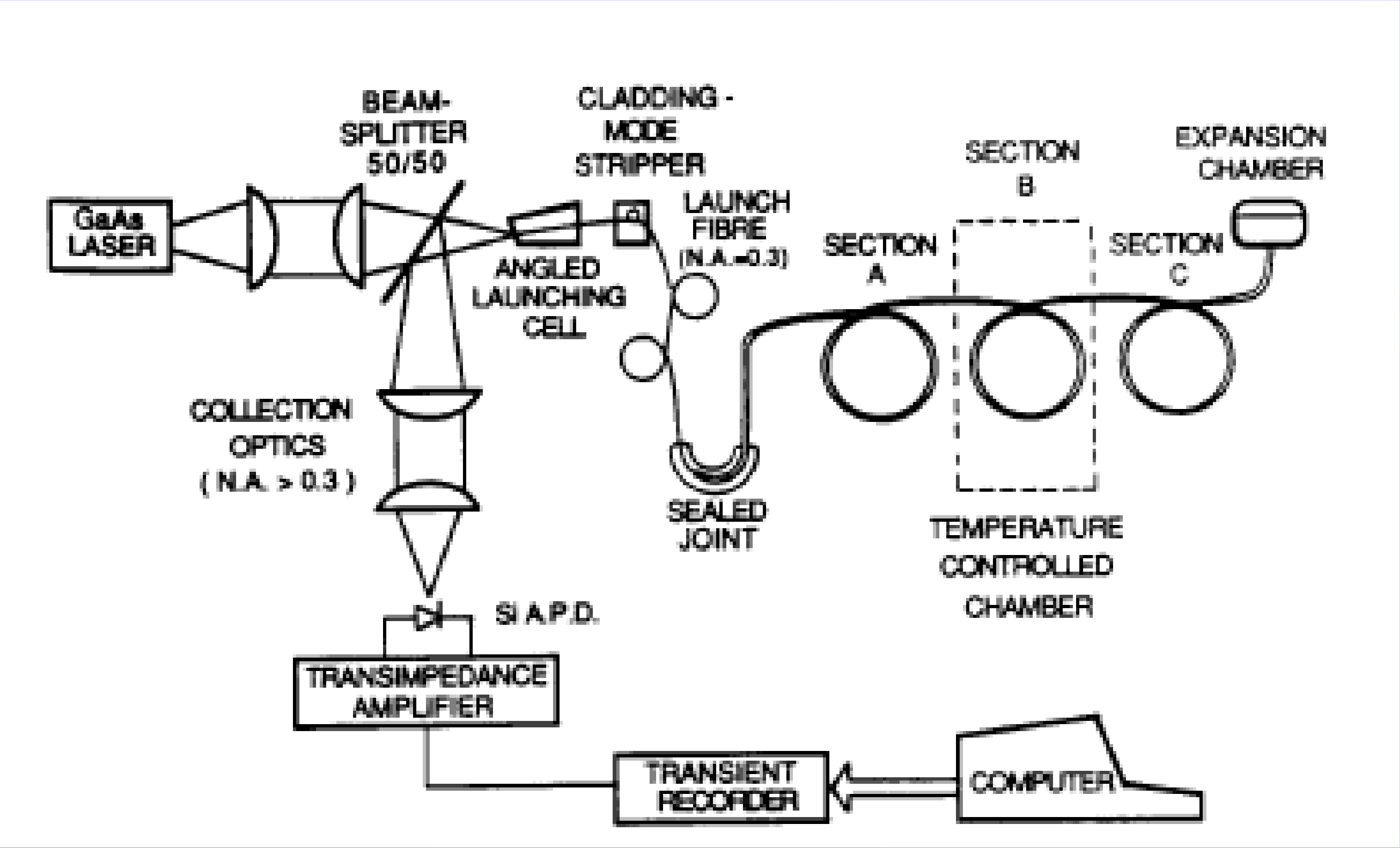


Fig. Rayleigh-scattering temperature profiler using liquid-filled fiber

Distributed anti-Stockes-Raman Thermometry (DART)

The spectral variation of backscattering from a germania-doped silica fibre is examined, it may be seen that there is a strong central line, primarily due Rayleigh (or Rayleigh-Gans) sacttering, but also containing an uresloved contibution from Brillouin scattering!!).

In the Raman case, there are two separate backward attenuations: backward-guided STOKES radiation and anti-STOKES radiation.

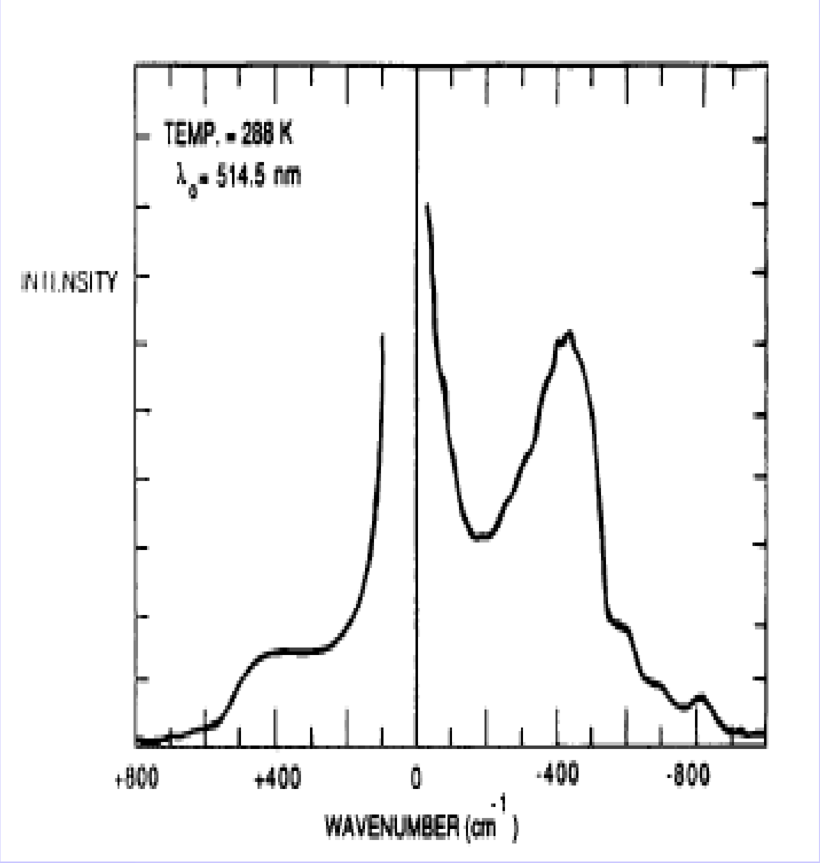


Fig. Raman backscatter spectrum of Ge-doped silica fiber

Measurment of the ratio of Stokes and anti-Stokes backscattered light in fiber should provide an absolute indication of the temperature of the medium, irrespective of the light intesity, the launch conditions, the fiber geometry and even the composition of the fiber.

In practice, small correction has to be made for difference between the back-ward fiber attenuations at the Sotkes and anti-Stokes wavelenghts

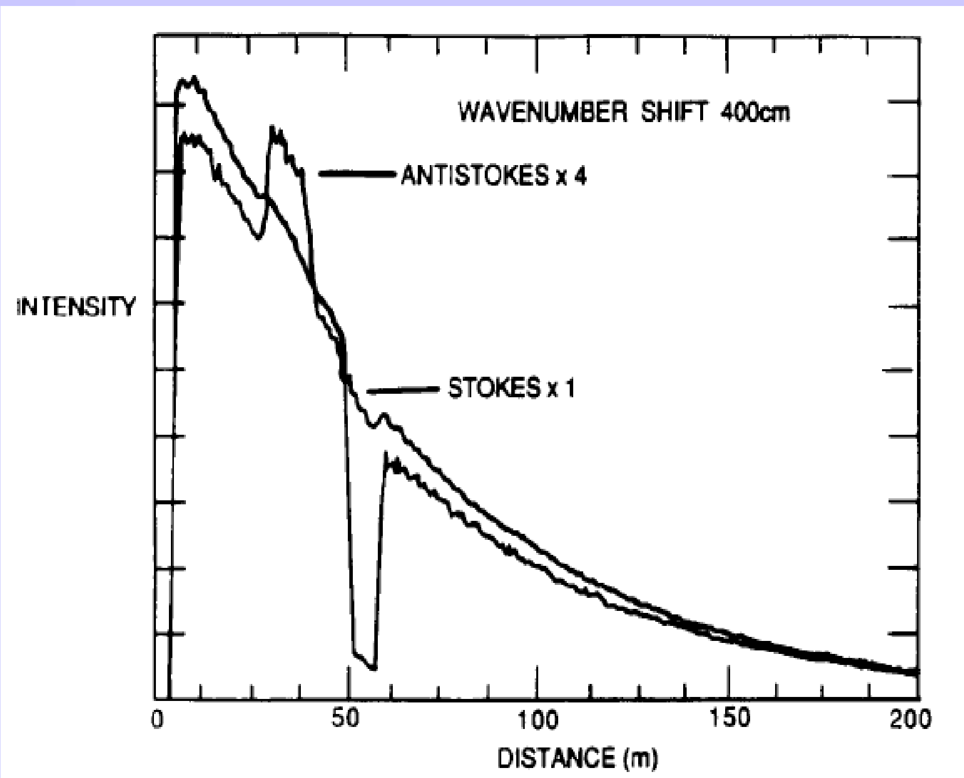


Fig. Raman backscatter signal

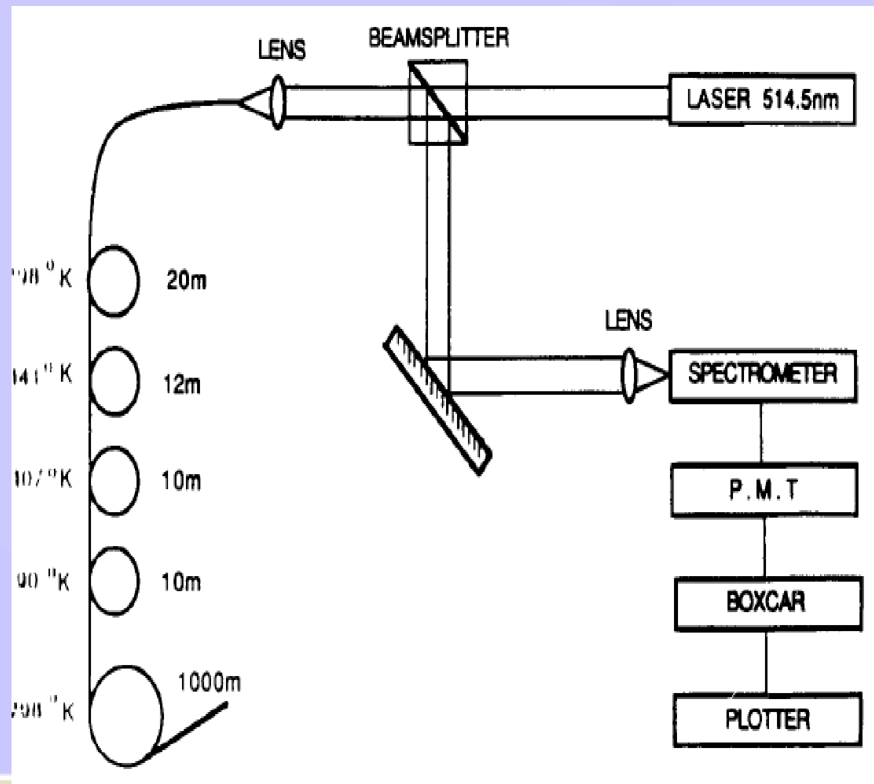


Fig. Raman temperature profile equipment

Frequency Modulated CW Method (FMCW)

- The FMCW method may be used to locate discret points where mode coupling in a fiber has occurred, provided the fiber is capable of suppor-ting two modes with significantly different phase velocities.

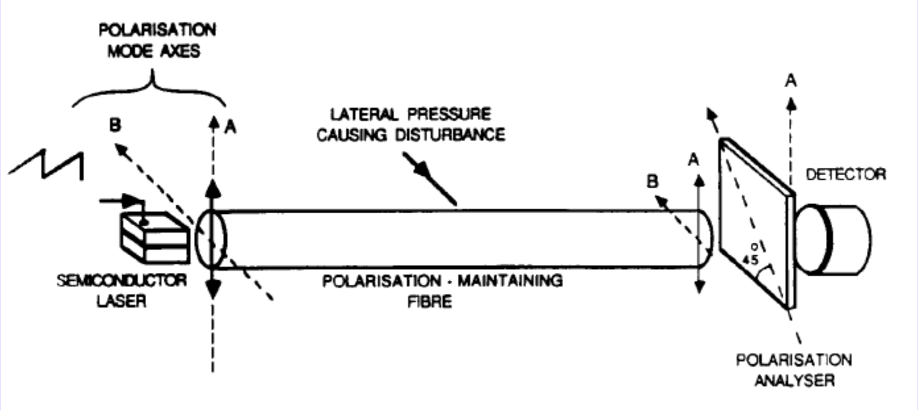


Fig. Transmissive FMCW disturbance location sensor

- Figure show particular implementation used a birefingent fiber, with all transmitted signal energy being launched into only on of two principal polarization modes of the fiber.
- A conveniet attribute of technique is that the relatively close velocity matching between the polarization modes of even high birefrigence fiber allows use of the FMCW techniques over lengths much longer than the coherence lenght of source.

Two potential dificulties :

1. mechanical starins of certain critical magnitudes may cause coupling of power from on polrization mode to the other and then completely back again, resulting in no net beat signal

2. disturbances in the direction along a fiber polarization axis will cause no mode coupling.

The Optical Frequency-Domain Reflectometry (OFDR)

- This method is similar to FMCW technique.
- OFDR system is operated in backscattering mode in a continouous monomode fiber, the beat signal produced at the detector increases in frequency in direct proportion to the distance from which the light is retroscattered.
- If the dected beat signal is displayed on conventional electrionic spectrum analyzer, the power in each frequency increment represents the level of scattered light recived from a short section of fiber situated at a distance corresponding to the frequency offset observed.
- A major potential problem with OFDR is the coherence function of the source!!, which will modulate the recevied spectrum and therefore disort any spatial variation of scattering that it is desired to observe.

Distributed sensing using amplification as a result of a counter-propagation optical pump pulse

- If an optical signal from a steady CW source is transmitted through a fiber to a detection system, the power lever received will be dependent on the total attenuation in the fiber.
- If, however, an intense optical pulse is transmitted in the optical fiber in the opposite direction, the detected signal is affected by any nonlinear gain process which may be created by effects of the pump.

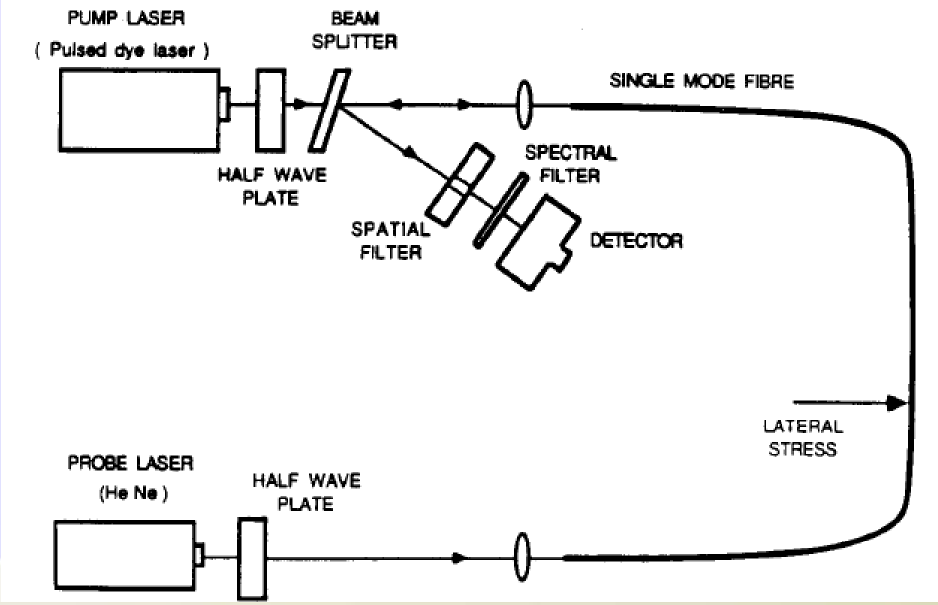
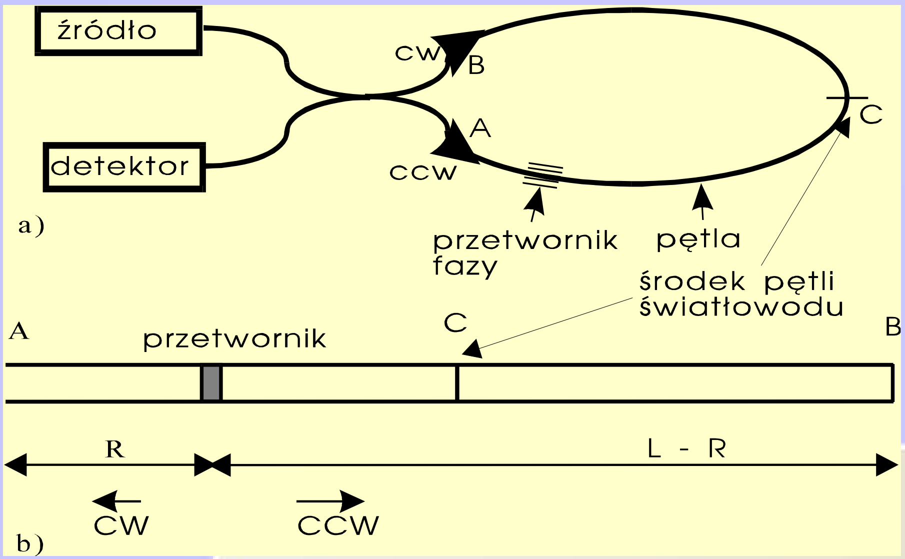


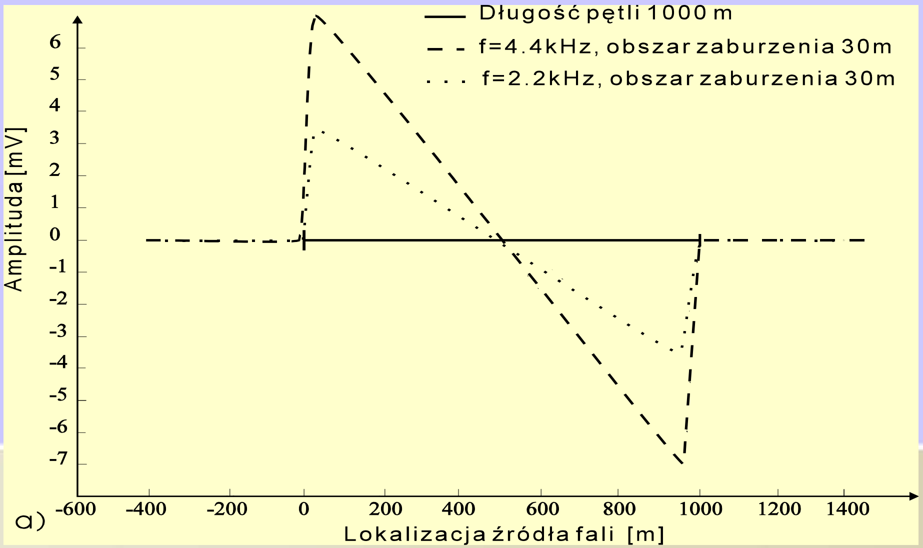
Fig. Experimental arrangement of system for stress location using Raman amplification by counter propagation pump pulse

The Sagnac interferometer

- The fiber optic Sagnac interferometer consist from of a monomode fiber loop and a directional coupler arrangement which allows the launchnig of counterpropagating beams into loop, from common source, and the detection of superomposed waves on a detector coupled to an exit port of the same coupler.
- The difference in phase changes is proportional to product of two factors :

1. rate of change dΦ/dt, of the optical signal, induced at the point P, by external influence,
2. distance Z between point P and the coil center 0





- The quantity of dΦ/dt is not readily measured directly, but by incorporating an additional optical fiber path from the source, together with the path taken by one of the counter-propagating beams from the Sagnac loop, a Mach-Zehnder interferometer my be formed.
- The output from MZI gives output proportional to Φ and differentiation yields to required dΦ/dt. Simpel division of the Sagnac phase oddset by dΦ/dt finally gives the desired distace Z, of point of disturbace P.

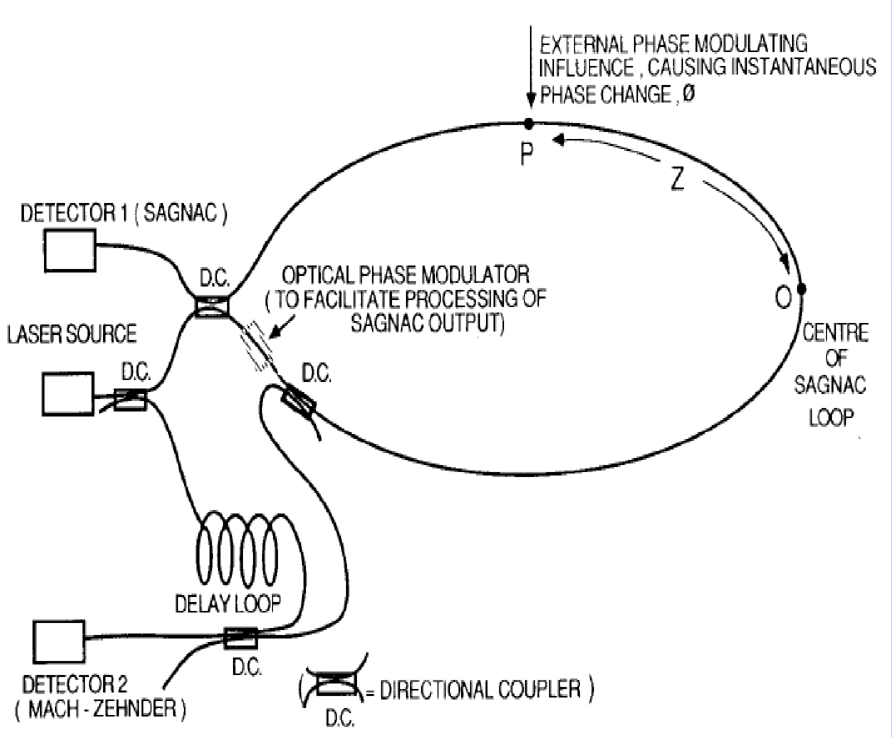
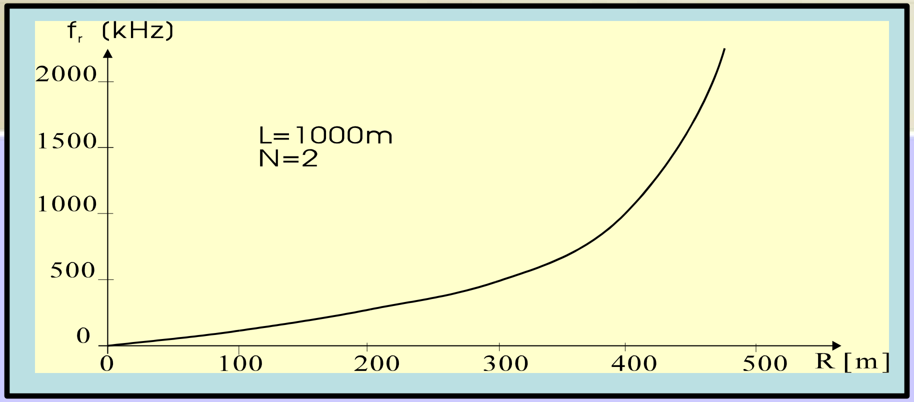
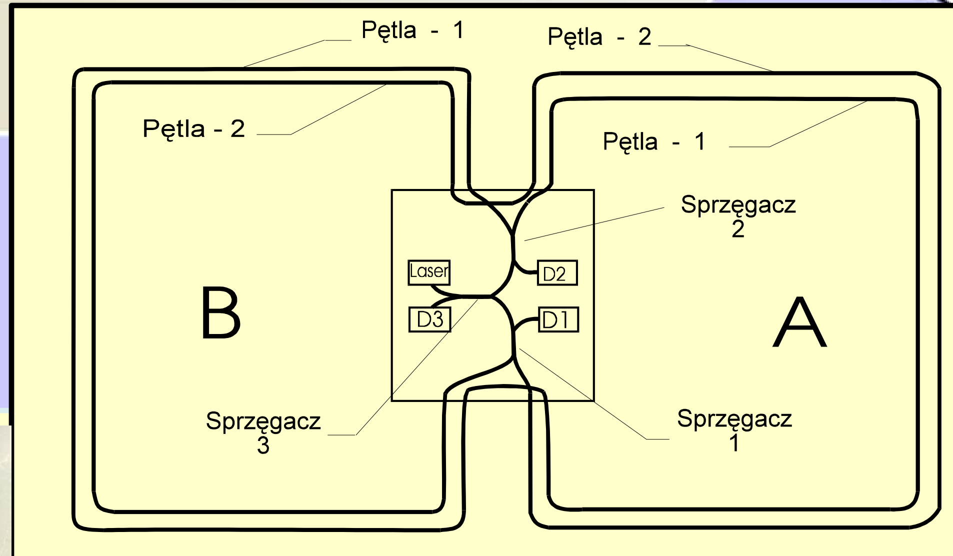
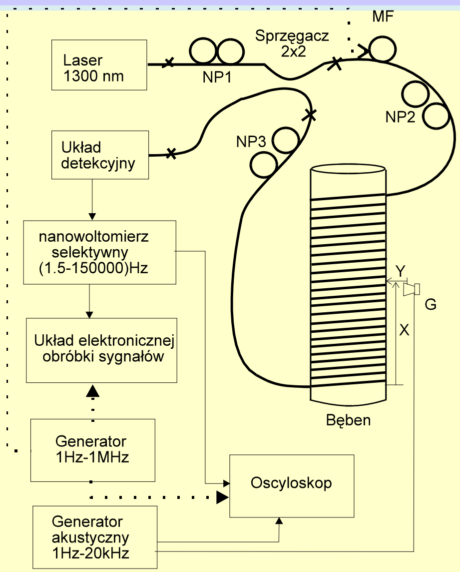


Fig. Modified Sagnac interferometer with Mach-Zehnder reference interferometer for disturbance location

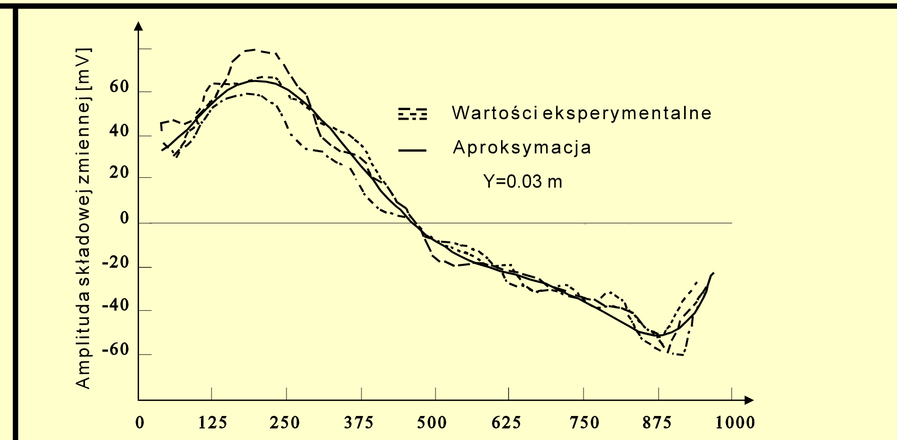
- Major source of phase error in FOG may occur if rapid changes in optical path length, due to thermal or mechanical effects ont the fibers.
- The reason for error is that the two counterpropagating beams encouter the temporally varring path length changes at different moments in time and therefore will suffer ***different phase changes***!!!


f_r (kHz)
2000
1500
1000
500
0
L=1000m
N=2
0
100
200
300
400
500
R [m]

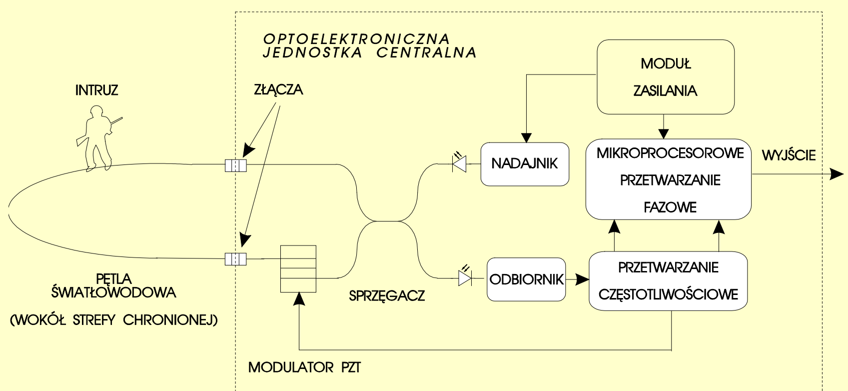

Pętla - 1
Pętla - 2
Pętla - 2
Pętla - 1
Sprzęgacz 2
Laser
D2
D3
D1
B
A
Sprzęgacz 3
Sprzęgacz 1


MF
Sprzęgacz 2x2
Laser 1300 nm
NP1
NP2
NP3
Układ detekcyjny
nanowoltomierz selektywny (1.5-150000)Hz
Układ elektronicznej obróbki sygnałów
Generator 1Hz-1MHz
Generator akustyczny 1Hz-20kHz
Oscyloskop
Bęben
Y
G
X

a)


Amplituda składowej zmiennej [mV]
60
40
20
0
-20
-40
-60
Wartości eksperymentalne
Aproksymacja
Y=0.03 m
0
125
250
375
500
625
750
875
1000
Lokalizacja źródła fali [m]

b


OPTOELEKTRONICZNA JEDNOSTKA CENTRALNA
INTRUZ
ZŁĄCZA
MODUŁ ZASILANIA
NADAJNIK
MIKROPROCESOROWE PRZETWARZANIE FAZOWE
WYJŚCIE
ODBIORNIK
PRZETWARZANIE CZĘSTOTLIWOŚCIOWE
PĘTLA ŚWIATŁOWODOWA
(WOKÓŁ STREFY CHRONIONEJ)
SPRZĘGACZ
MODULATOR PZT


ŚWIATŁOWODOWY SYSTEM OCHRONY
OPTIMUS SA