Mid-Infrared Photonics Group
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The University of Nottingham
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Progress of Round Robin on MIR active fibre modelling

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DIPARTIMENTO DI INGEGNERIA ELETTRICA E DELL'INFORMAZIONE

Outline

TEST PROBLEM

COUPLED SOLUTION METHOD (UFE PRAGUE)

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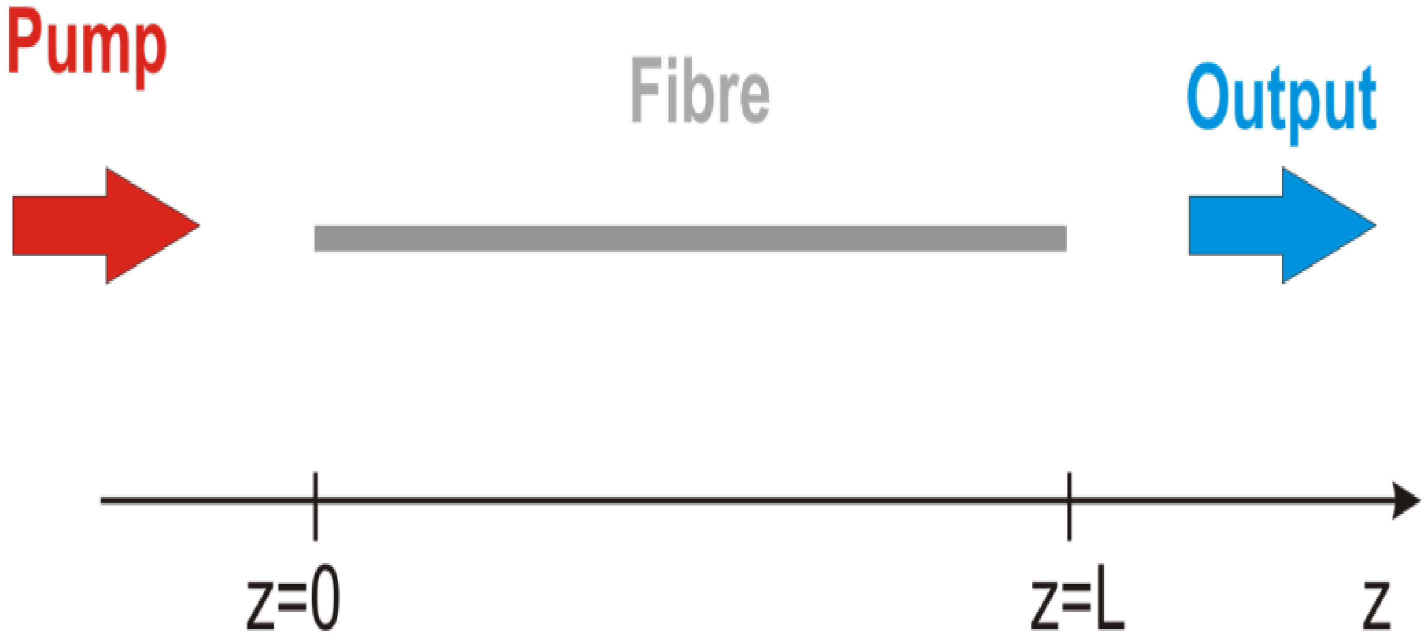
NEW TEST PROBLEM

SUMMARY

Test problem

Test problem

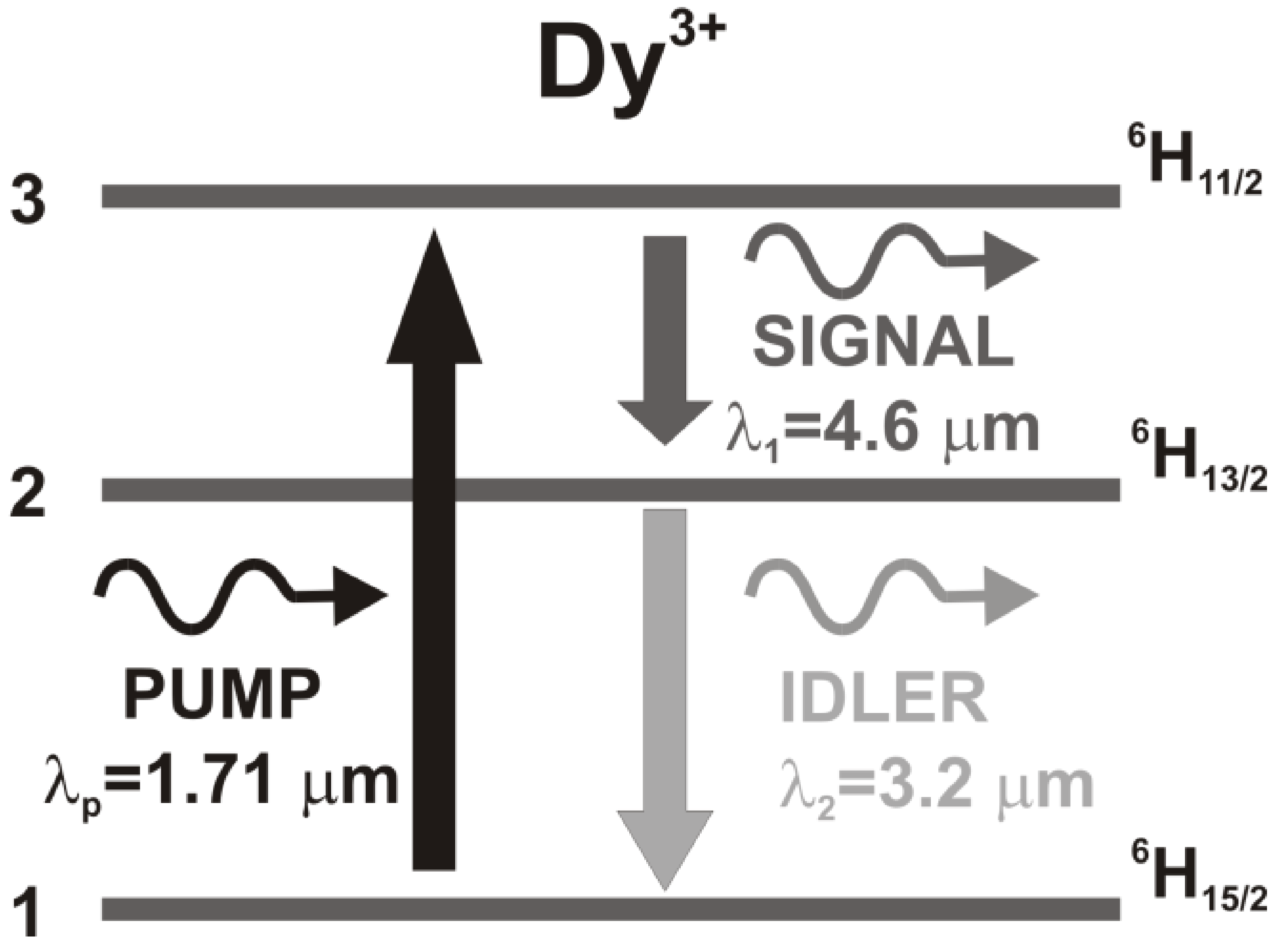
Dy^{3+} doped chalcogenide glass fibre pumped at one end (z=0). We wish to calculate the output power collected at z = L.



S. Sujecki: **An efficient algorithm for steady state analysis of fibre lasers operating under cascade pumping scheme, Int. J. Elec. Telecom., 2014**

Test problem

Dysprosium ion energy levels diagram



Test problem

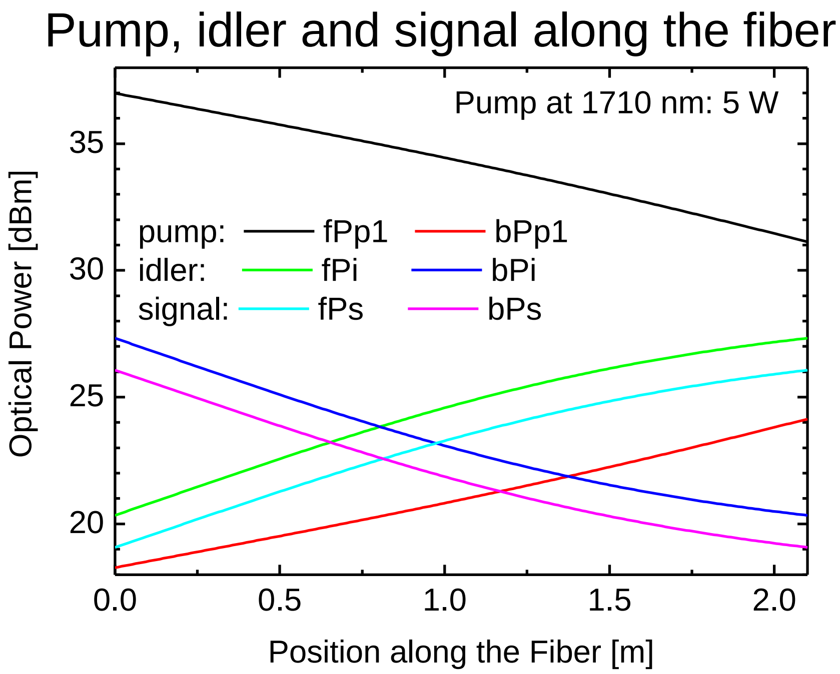
Dy^{3+}-ion concentration	$7x10^{19}$	cm^{-3}
Core radius	5.5	µm
Numerical aperture	0.2	
Cladding radius	30	µm
Fibre length L	2.1	m
Fibre loss at all wavelengths	1	dB/m
Lifetime of level 3	2	ms
Lifetime of level 2	5.2	ms
Branching ratio for 3-2 transitions	0.15	
reflectivity for idler, signal and pump at z = 0	0.2	
reflectivity for idler, signal and pump at z = L	0.2	

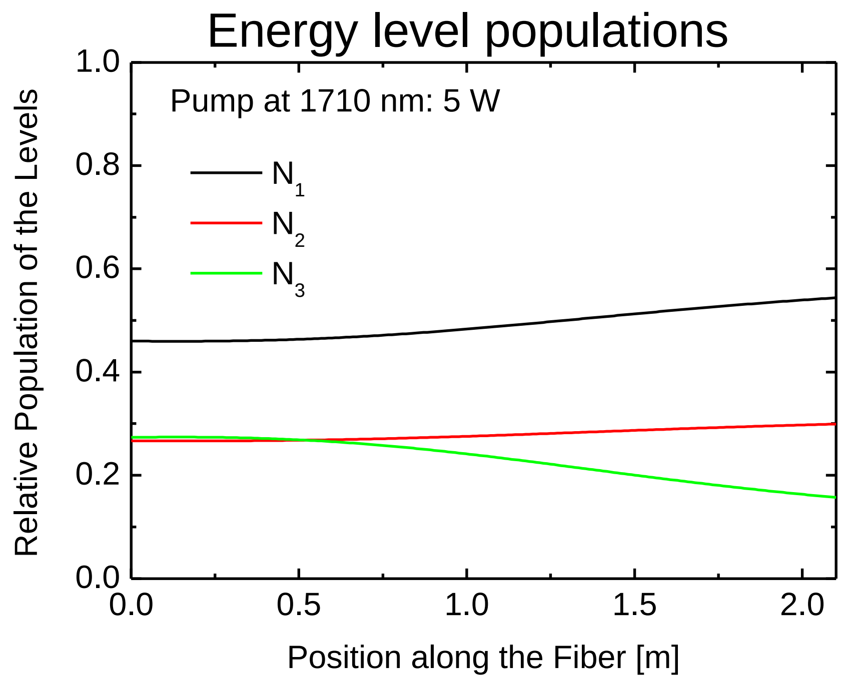
Test problem

Confinement factor for signal (λ_1)	0.8	
Confinement factor for idler (λ_2)	0.9	
Confinement factor for pump	0.034	
Pump wavelength	1.71	μm
Signal wavelength (λ_1)	4.6	μm
Idler wavelength (λ_2)	3.35	μm
Pump emission cross section	$0.318\text{x}10^{-20}$	cm^2
Pump absorption cross section	$0.501\text{x}10^{-20}$	cm^2
Idler emission cross section	$0.912\text{x}10^{-20}$	cm^2
Idler absorption cross section	$0.485\text{x}10^{-20}$	cm^2
Signal emission cross section	$0.097\text{x}10^{-20}$	cm^2
Signal absorption cross section	$0.016\text{x}10^{-20}$	cm^2

Coupled Solution Method (UFE Prague)

Optical power and energy level populations along the Dy^{3+} fiber





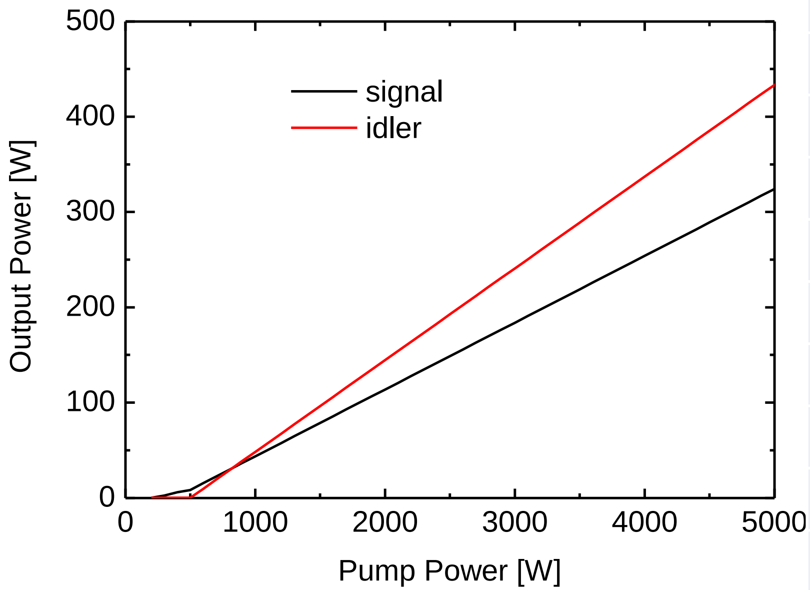
Numerical model: Iterative solution of laser rate equations and propagation equations (so-called coupled solution method)

P. Peterka et al.: **Thulium-doped fibre broadband source for spectral region near 2 µm, Opto-Electronics Review 24, 223-231 (2016)**

P. Peterka et al.: **Theoretical modeling of fiber laser at 810 nm based on thulium-doped silica fibers with enhanced 3H4 level lifetime, Opt. Express 19:2773 (2011).**

Comparison of the results

Laser output vs. pump power



pump	signal	signal PP	difference
0.2 W	4.73E-03	1.49E-08	-100.00%
0.4 W	8.74E-03	2.46E-03	-71.87%
1 W	4.89E-02	4.35E-02	-11.02%
5 W	3.18E-01	3.24E-01	1.79%
pump	idler	idler PP	diference
0.2 W	0	1.68E-04	-
0.4 W	0	2.14E-09	-
1 W	5.51E-02	4.81E-02	-12.55%
5 W	4.25E-01	4.33E-01	1.96%

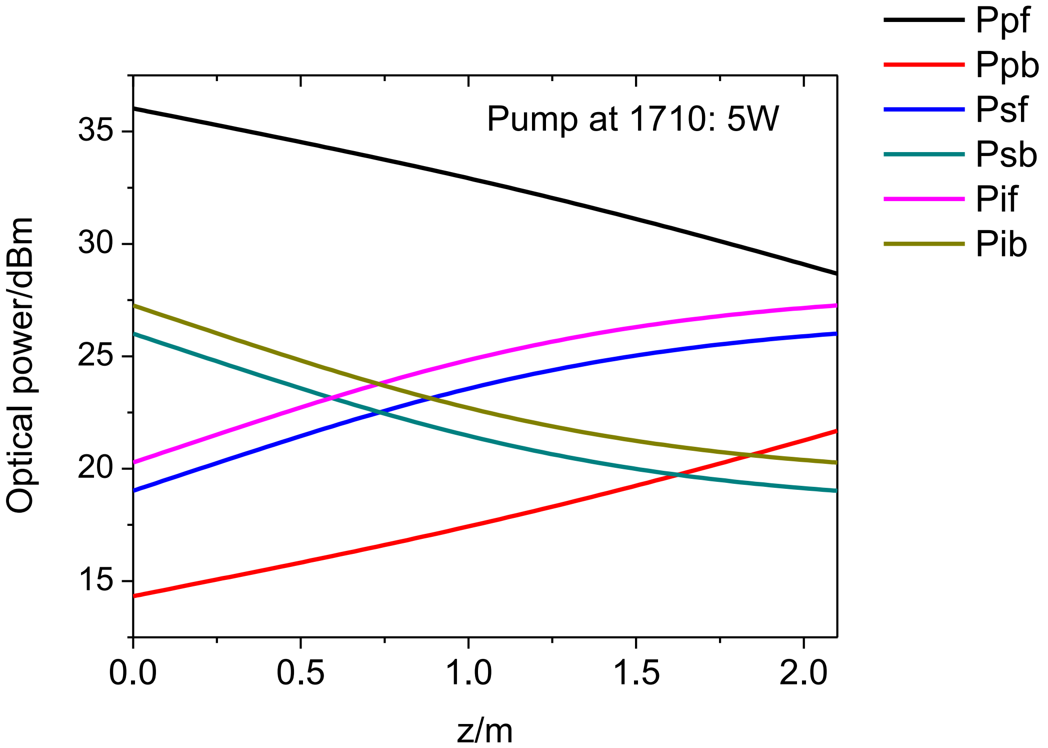
The laser threshold of the idler and signal is slightly higher.

At the pump power of 5 W, the difference is below 2%

Relaxation Method (NU, WrUT)

Cascade lasing in Dy^{3+}-doped chalcogenide fiber: Round-robin MIR active fiber modelling (WrUT)

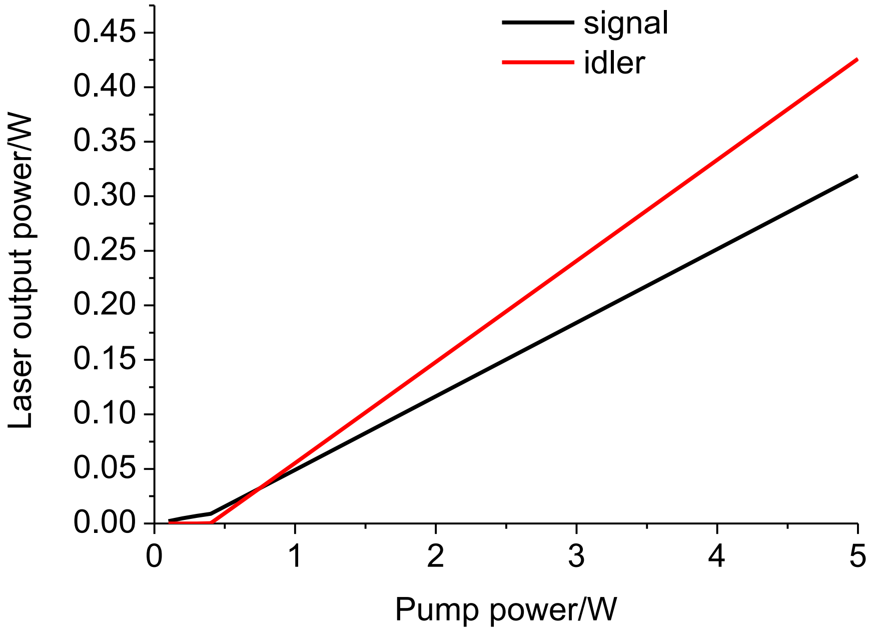
Optical power distribution for pump , signal and idler within laser cavity



Numerical model: Iterative solution of laser rate equations and propagation equations (relaxation method)

Comparison of the results

Laser output vs. pump power

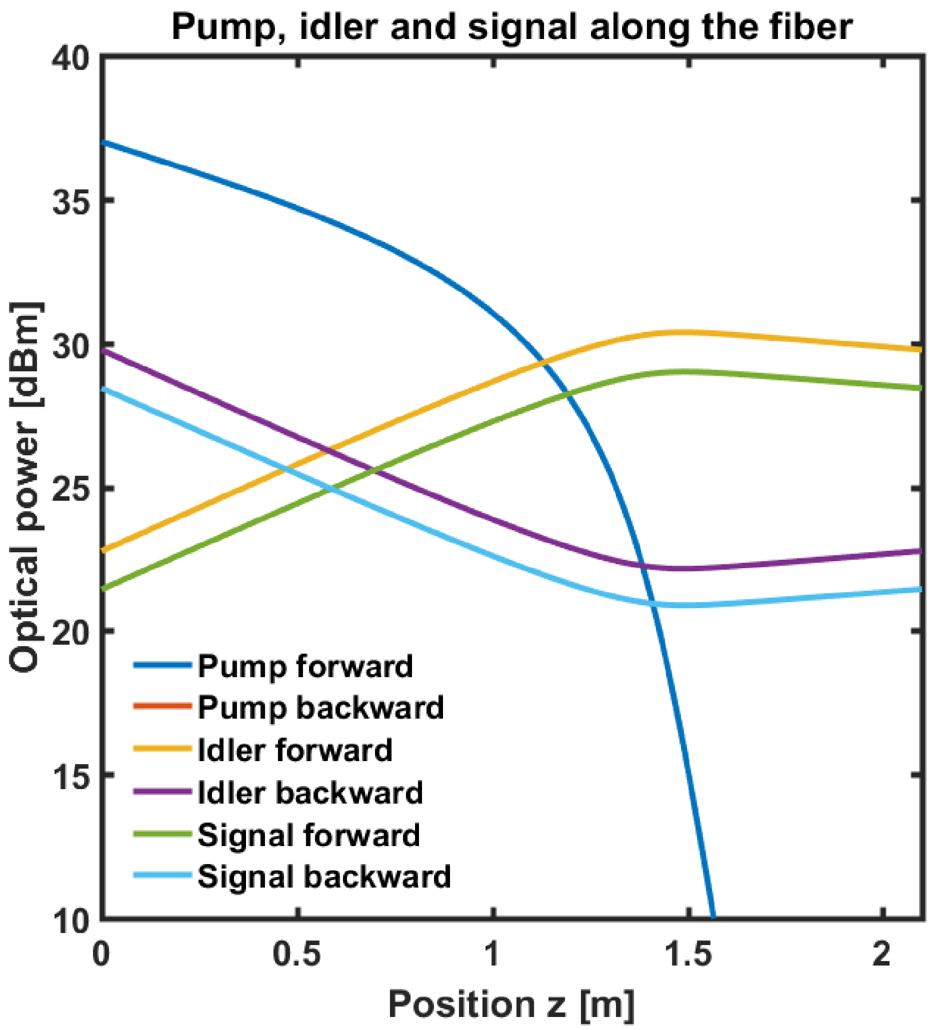


pump	signal	signal LS	difference
0.2 W	4.73E-03	4.733E-3	0.63%
0.4 W	8.74E-03	8.870E-3	1.4%
1 W	4.89E-02	4.912E-2	0.4%
5 W	3.18E-01	3.190E-1	0.22%
pump	idler	idler LS	diference
0.2 W	0	1.189E-32	-
0.4 W	0	2.219E-4	-
1 W	5.51E-02	5.536E-2	0.47%
5 W	4.25E-01	4.260E-1	0.23%

The overall differences in all considered cases are below 1.4%

Relaxation Method (PB)

Optical power and energy level populations along the Dy^{3+} fiber



The reflected backward pump power is negligible

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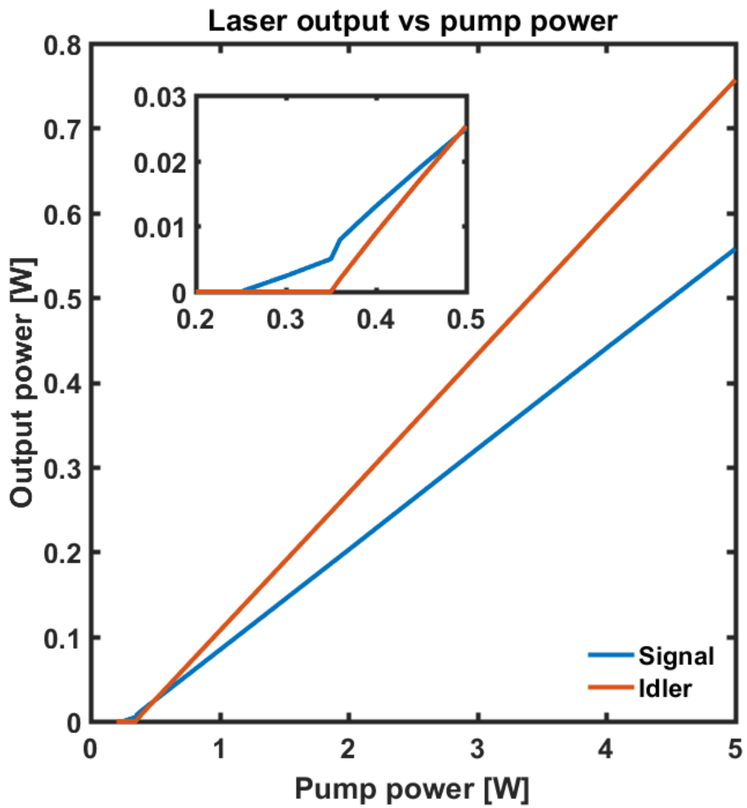
Laser input-output characteristics

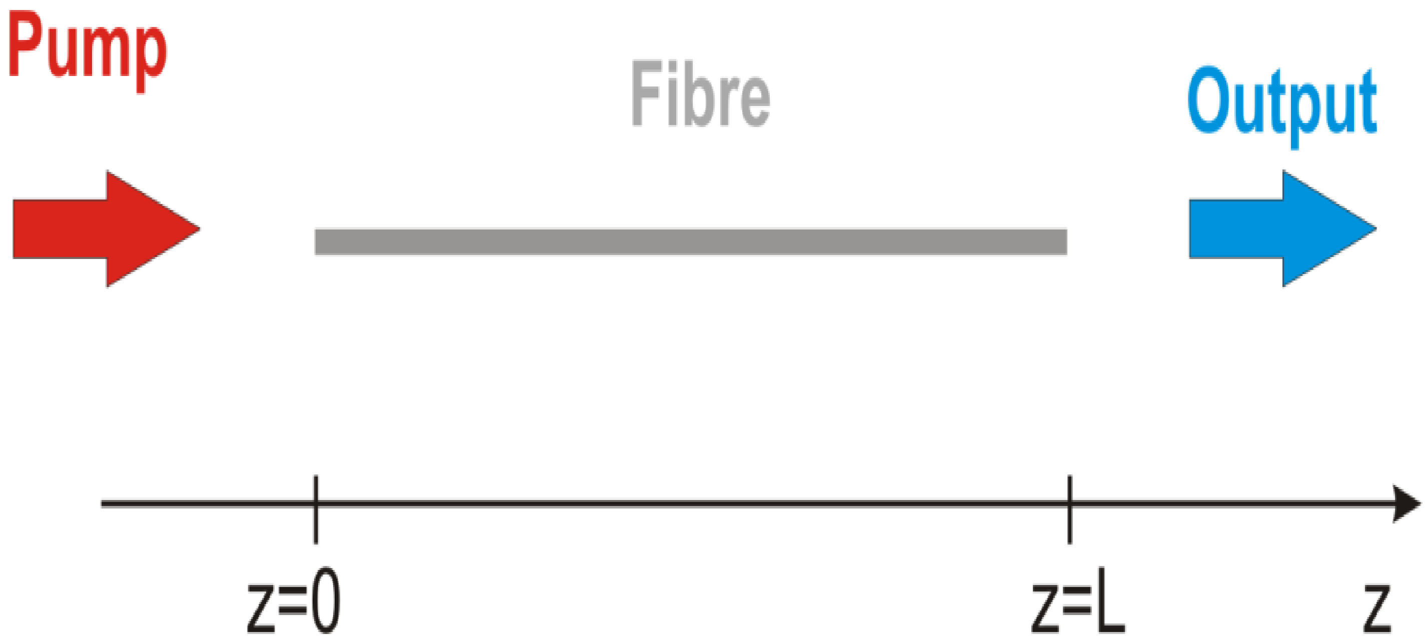


pump	signal	**Signal PB**
0.2 W	4.73E-03	**0**
0.4 W	8.74E-03	**1.31E-02**
1 W	4.89E-02	**8.40E-02**
5 W	3.18E-01	**5.58E-01**
pump	idler	**idler PB**
0.2 W	0	**0**
0.4 W	0	**9.00E-03**
1 W	5.51E-02	**1.06E-01**
5 W	4.25E-01	**7.57E-01**

New test problem

New test problem

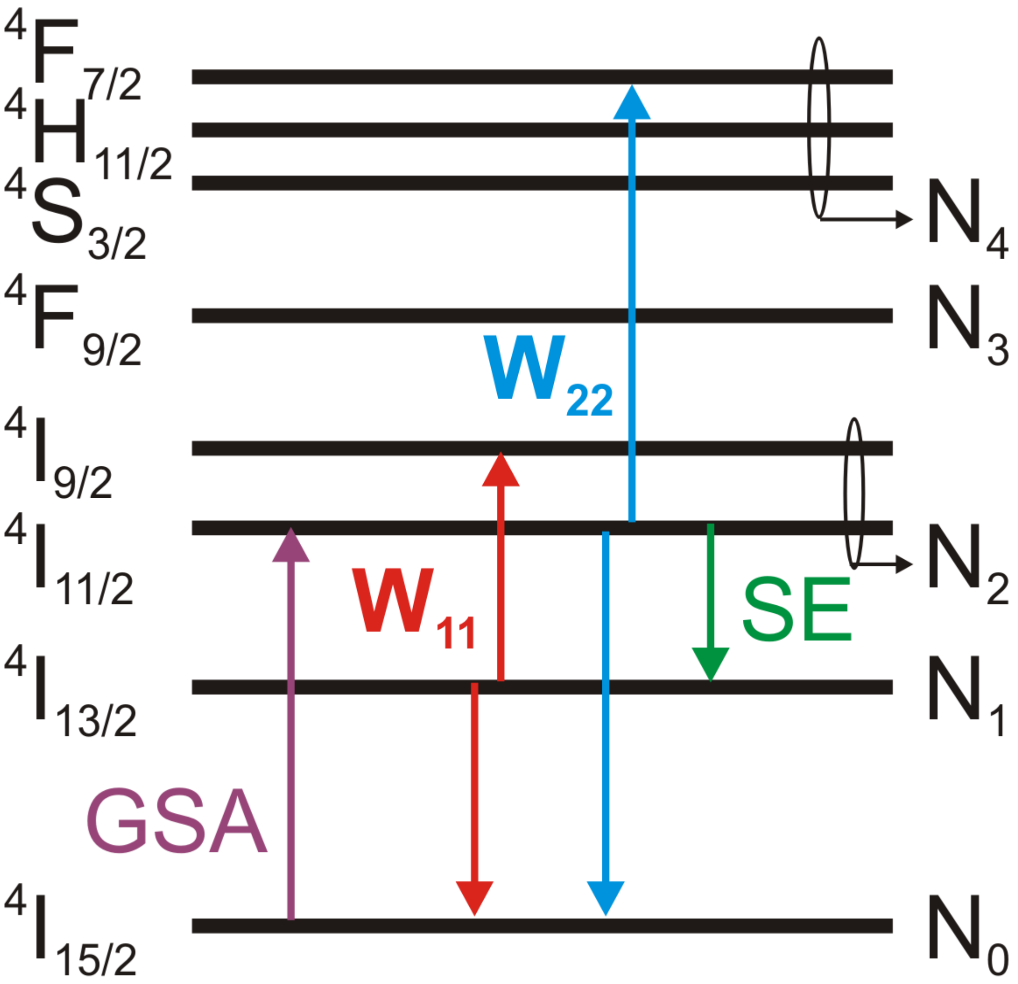
Er^{3+} doped ZBLAN glass fibre pumped at one end (z=0). We wish to calculate the output power collected at z = L.



S. Sujecki: **Simple and efficient method of lines based algorithm for modeling of erbium doped Q-switched fluoride fiber lasers, JOSA B, 2016**

New test problem

Erbium ion energy levels diagram



New test problem

parameter	Unit	value
b_1/b_2		0.1/0.16
W_{11}	m^3/s	$1x10^{-24}$
W_{22}	m^3/s	$0.3x10^{-24}$
λ_p	m	$976x10^{-9}$
λ_s	m	$2.8x10^{-6}$
σ_{GSA}	m^2	$2.1x10^{-25}$
σ_{SE}	m^2	$4.5x10^{-25}$
N_{Er}	$1/ m^3$	$9.6x10^{26}$
L	m	2.5
Γ_p		0.009
Γ_s		1.0
α_p	1/m	$23x10^{-3}$
α_s	1/m	$3.0x10^{-3}$
$R_p(z=0)$		0
$R_p(z=L)$		0.96
$R_s(z=0)$		0.04
$R_s(z=L)$		0.96

New test problem

parameter	Unit	value
τ_1	ms	9.0
τ_2	ms	6.9
τ_3	ms	10
τ_4	ms	120
β_{21}, β_{20}		0.37, 0.63
β_{32}, β_{31}, β_{30}		0.99, 0.0, 0.01
β_{43}, β_{42}, β_{41}, β_{40}		0.85, 0.006, 0.004, 0.14

Pump power/W	Output power/W	CPU time/s
5	1.39527600015	78.76
10	3.11902141885	85.94
15	4.85305182935	86.19
20	6.55663433930	84.27

Summary

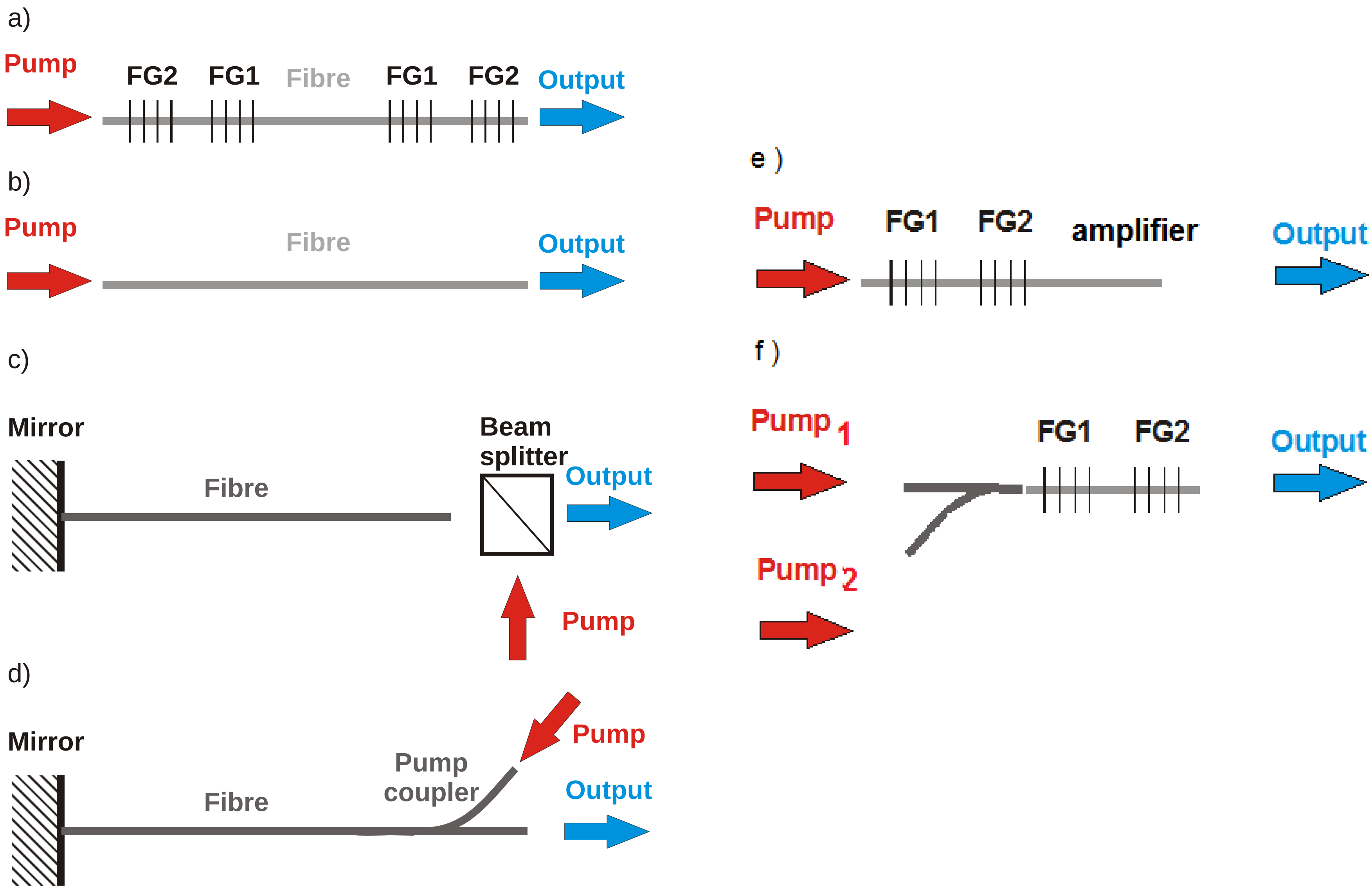
Summary

TEST PROBLEM: COMPARISON OF RESULTS BY UFE PRAGUE, NU, WRUT

DISCREPANCIES IN RESULTS SHOULD BE DISCUSSED

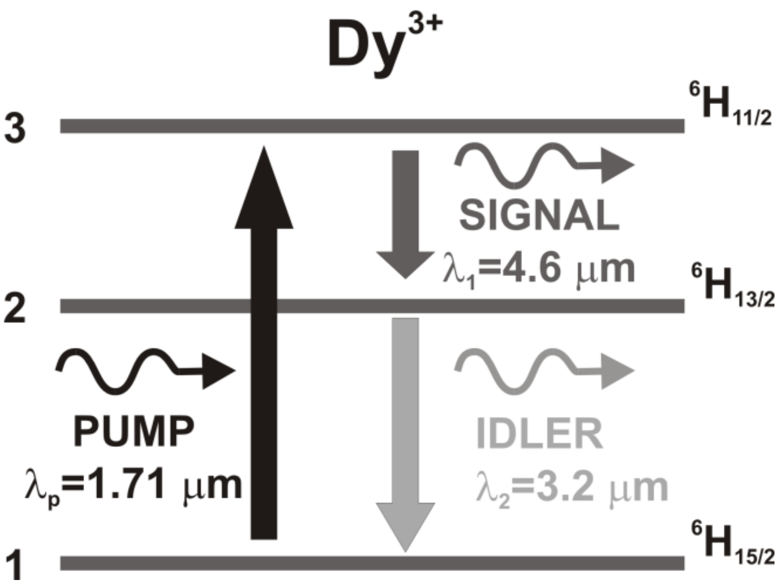
NEW TEST PROBLEM: ERBIUM ION DOPED ZBLAN FIBRE

Test problem



Cascade lasing in Dy^{3+}-doped chalcogenide fiber: Round-robin MIR active fiber modelling (UFE Prague)

Test problem



Test parameters taken from:

S. Sujecki: **An efficient algorithm for steady state analysis of fibre lasers operating under cascade pumping scheme, Int. J. Elec. Telecom., 2014**