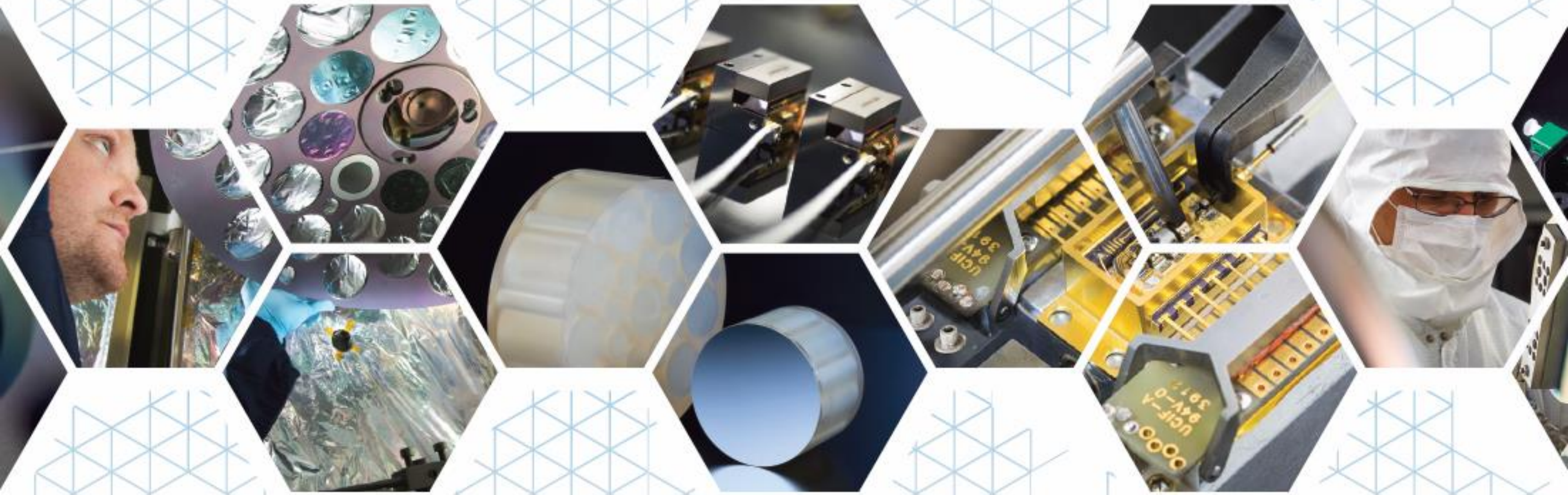

# SPACE PHOTONICS

## Gooch & Housego

Dr Leo Stampoulidis
Chief Scientist Space Photonics

Gooch & Housego
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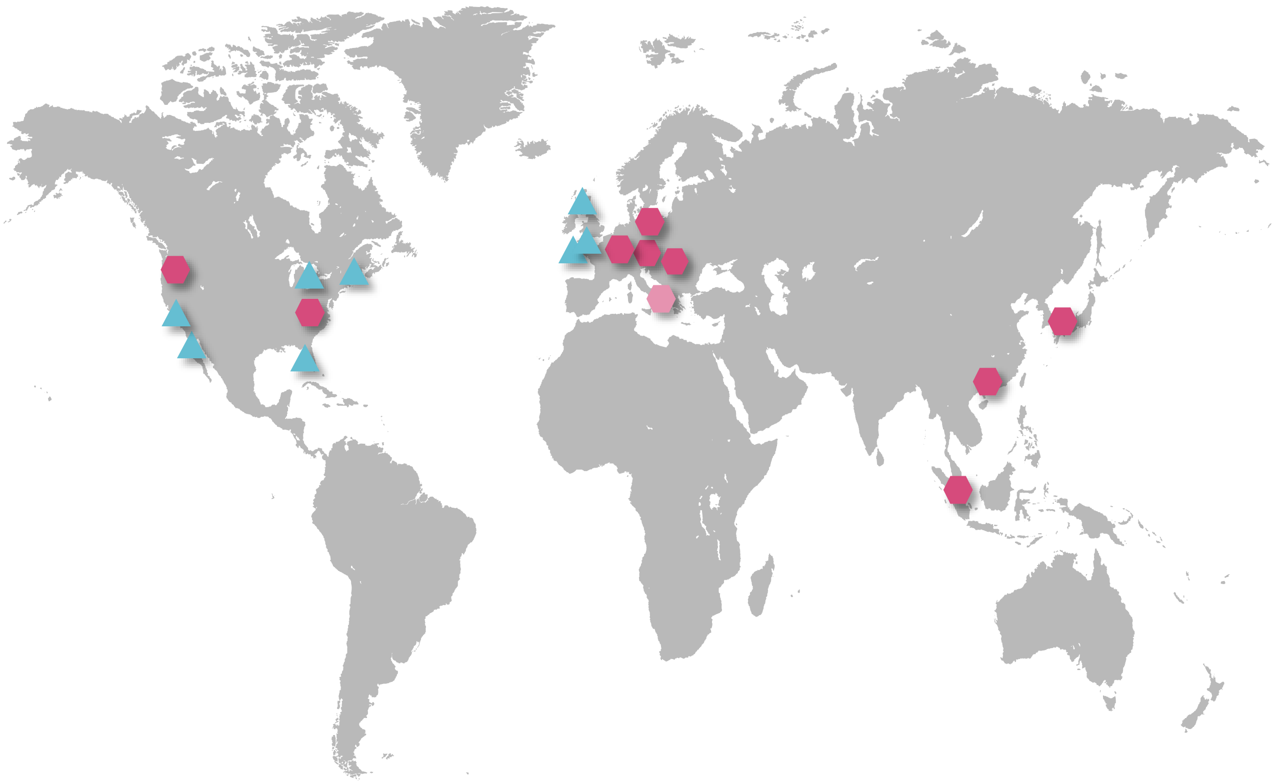
# AN INTERNATIONAL BUSINESS



TOTAL GROUP REVENUE

**£78.7m**

(2014 £70.1m)

| | | |
|---|---|---|
| USA | **£34.8m** | 44.2% |
| Continental Europe | **£16.9m** | 21.5% |
| United Kingdom | **£14.9m** | 18.9% |
| Asia Pacific & Other | **£12.2m** | 15.4% |

- Manufacturing
- Research and Development
- Sales Offices

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# MARKET SECTORS

## Industrial

Revenue:

**£46.1m**

(2014: £39.8m)

Percentage of Company Revenue:

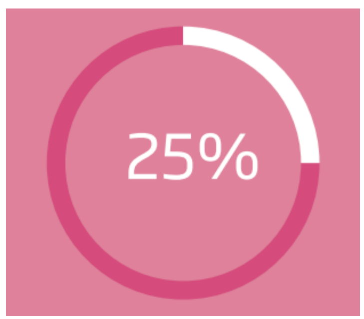

## Aerospace & Defence

Revenue:

**£19.8m**

(2014: £18.8m)

Percentage of Company Revenue:



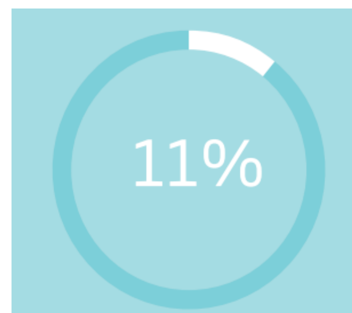

## Life Sciences

Revenue:

**£9.0m**

(2014: £7.3m)

Percentage of Company Revenue:



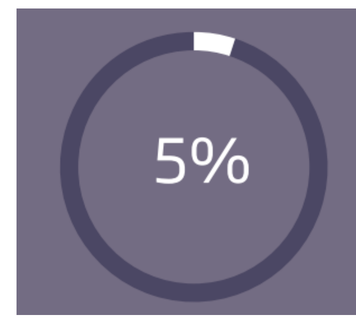

## Scientific Research

Revenue:

**£3.9m**

(2014: £4.1m)

Percentage of Company Revenue:

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# SPACE HERITAGE

| System | Agency | Hardware |
|---|---|---|
| Soil Moisture Ocean Salinity (SMOS) Earth Explorer | ESA | G&H passive fiber-optic modules |
| Materials International Space Station Experiment (MISSE) | NASA | G&H opto-electronic modules |
| Laser Communications Relay Demonstration (LCRD) | NASA | G&H opto-electronic and passive fiber-optic modules |
| Mars Curiosity | NASA | G&H precision optics |
| Lisa Pathfinder | ESA/NASA | G&H acousto-optic modules |
| Active Sensing of CO2 Emissions over Days, Nights and Seasons (ASCENDS) | NASA | G&H optoelectronic modules |
| Hayabusa 2 | JAXA | G&H acousto-optic modules |
| PROBA-III | ESA | G&H precision optics |
| Interface Region Imaging Spectrograph (IRIS) | NASA | G&H precision optics |
| ExoMars | ESA | G&H acousto-optic modules |


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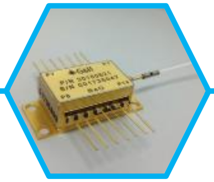
# SPACE OPTO-ELECTRONICS

# SPACE OPTO-ELECTRONICS

## Hermetic laser modules designed & built in house with high rel, space compatible packaging processes



### High-Power DFB Laser [14-pin, BFY]

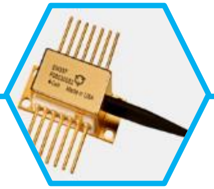
- Flown on the International Space Station (ISS)
- Intended for use on multiple space programs
- New product under ESCC evaluation within ECI program

### Single Mode Pump Laser [mini-DIL]

- Tested and deployed in demonstration missions
- Designed into and under qualification for lasercom missions
- Radiation and mechanical testing within ECI program

### High Power Multi-mode Pump Laser [14-pin]

- Designed into lasercom missions
- New 10W class product developed and tested
- Radiation and mechanical testing complete





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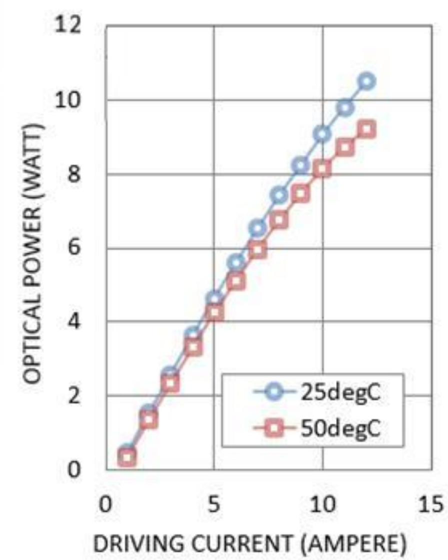
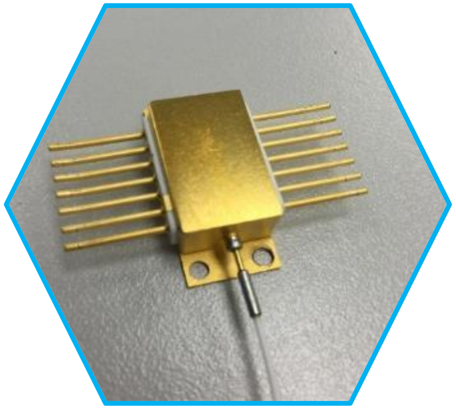
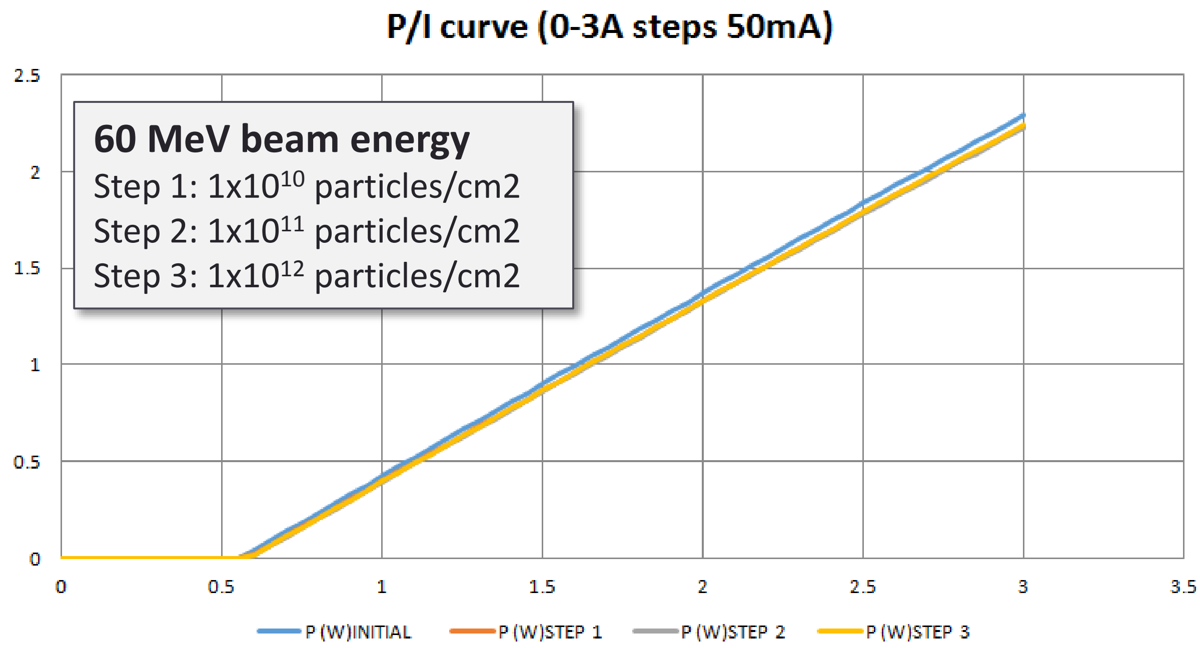
# 9xx nm HIGH-POWER PUMP LASERS

- Currently under development in the UK
- Part of EU R&D project HIPPO on "high-power photonics" with TAS-F
- Fully hermetic, un-cooled 915nm, up to 10 W ex-fiber
- Integrated power monitor and thermistor
- Used in high power fiber amplifiers in long distance lasercom links



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# SPACE FUSED FIBER OPTICS

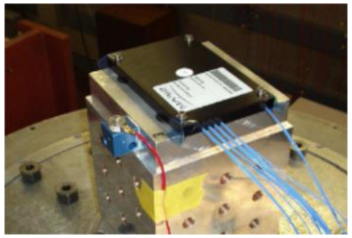
# SPACE FUSED FIBER OPTICS

## Heritage: Hi-rel / submarine

- Telecoms peak, shipping at rate of 1 million couplers per year
- Reputation sustained by having highest quality product and ZERO field failures
- #1 supplier of Hi Rel fused couplers (> 50% market share worldwide)
- Product range diversified to address wide range of markets & applications including Aerospace & Defence

## Application in Space

- World's first 1.55um fused couplers deployed in commercial Earth Observation Satellite (SMOS) in 2009
- Supply of fused opponents in various science & demonstration missions
- Supports internal demand for space-qualified components into G&H space systems



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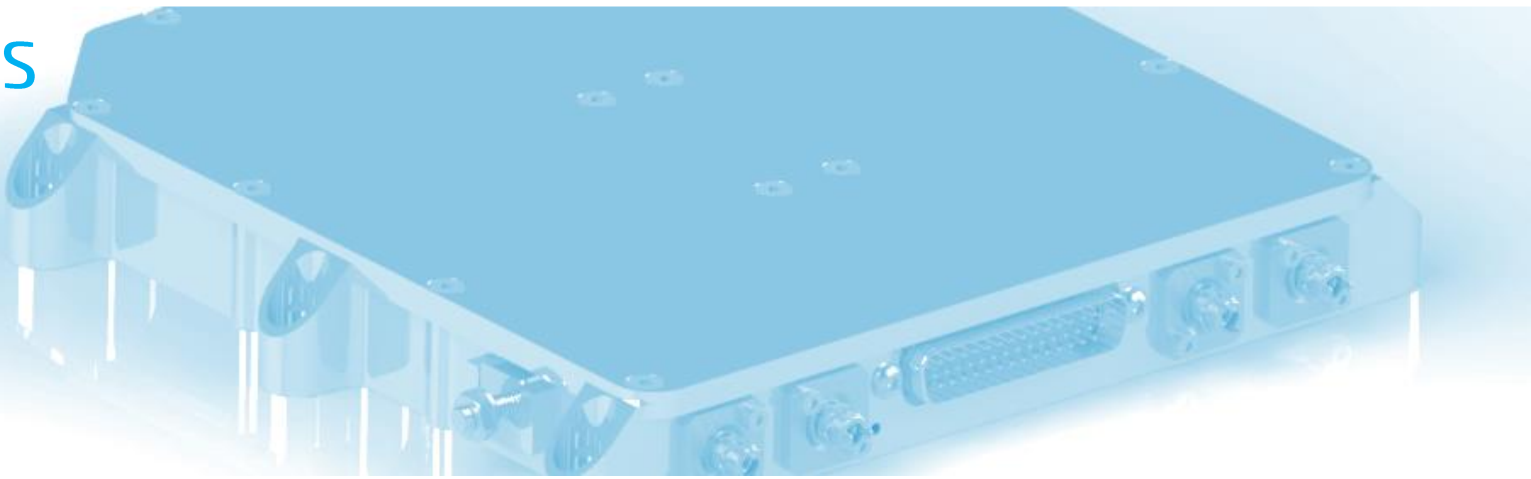
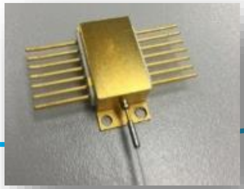
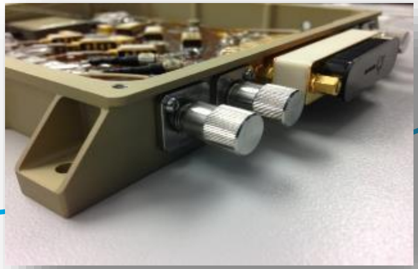
# SPACE UNITS

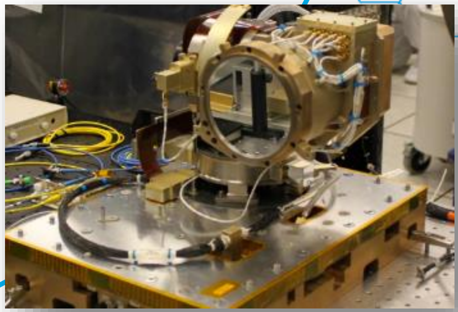


# MOTIVATION

- Vertical integration within G&H – supply chain control
- High-rel fused & O/E components fabricated in-house
- System integration of components into systems







| Fused components | Optoelectronics | Systems | Equipment |
|---|---|---|---|
| ☑ Couplers | ☑ Pump lasers | ☑ Fibre Amplifiers | |
| ☑ Pump combiners | ☑ DFB lasers | ☑ Transmitters | |
| ☑ Multiplexers | ☑ Photodiodes | | |
| | ☑ High Speed Detectors | | |

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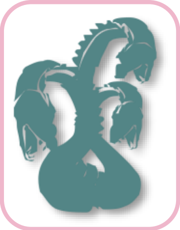
# OPTICAL FIBER AMPLIFIERS: PRODUCT LINE

## PEGASUS

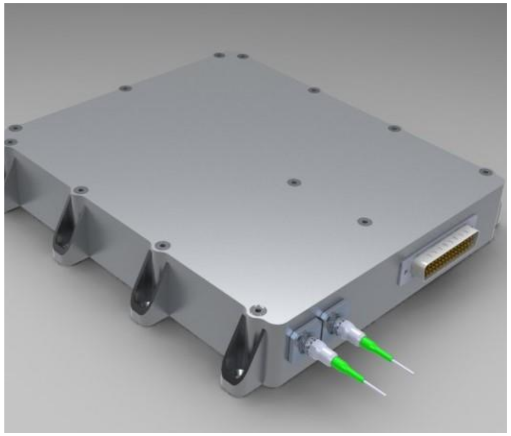
- **Pre-amplifiers**
- High gain
- Low-Noise

## HYDRA

- **Mid-power**
- ~+20dBm
- Amplifier arrays



## CENTAURUS



- **High-power**
- +30dBm to +40dBm
- High gain

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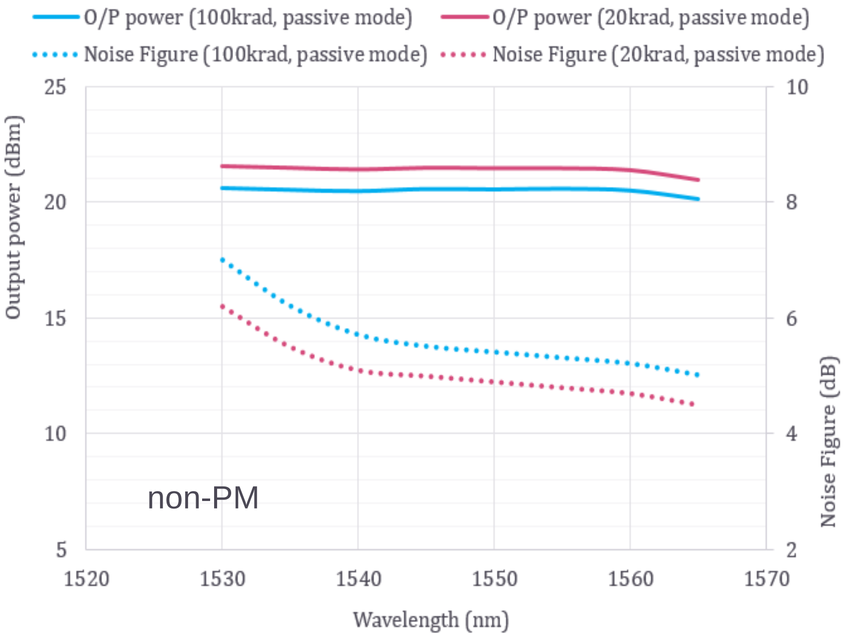
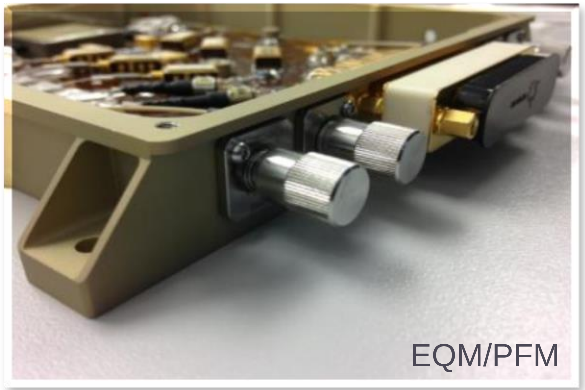
# HYDRA: Mid-power booster OFA



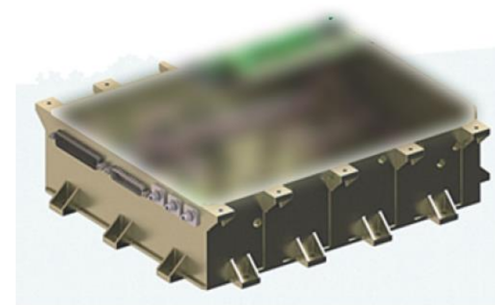

- Digital interface (LVDS, DAC/ADC)
- On-board DCDC converter
- I/O optical monitors
- ENABLE DISABLE
- Loss-Off-Input


| Specifications (BOL) | | |
|---|---|---|
| Saturated output power (dBm) | +16 | +21 |
| Wavelength range (nm) | 1530 | 1565 |
| Small signal gain (dB) | >28 | |
| Static gain flatness (dB) | <0.5 | |
| Noise figure (typ. @1550nm) (dB) | <5 | |

| Specifications (BOL) | | | |
|---|---|---|---|
| Optical interface | Mini-AVIM | | |
| Electrical interface | 44-pin HD D-Sub | | |
| Power supply (VDC) | 5 ± 5% | | |
| Power consumption (Watt) | <3.0 | | |
| Size W x D x H (mm) (EM) | 146 | 159.5 | 27.5 |
| Size W x D x H (mm) (EQM/FM) | 146 | 159.5 | 24.5 |
| Mass (g) | <650 | | |

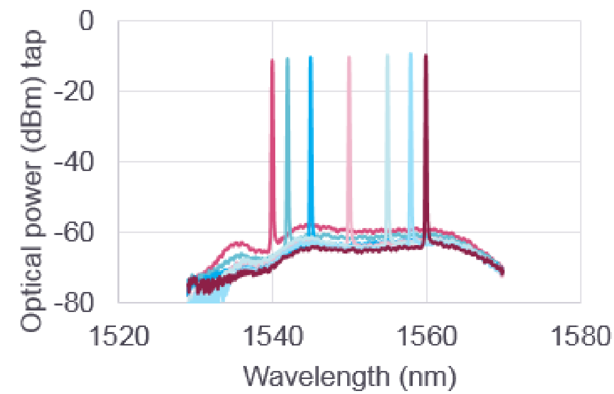
# CENTAURUS: HIGH POWER OFA



## CENTAURUS +35dBm

2015: BB version / 2016: EM version / 2017: PFM

| Specifications (BOL) | | |
|---|---|---|
| Saturated output power (dBm) | < +35 | |
| Wavelength range (nm) | 1540 | 1563 |
| Small signal gain (dB) | > 40 | |
| Static gain flatness (dB) | < 2 | |
| Noise figure (typ. @1550nm) | < 6 | |

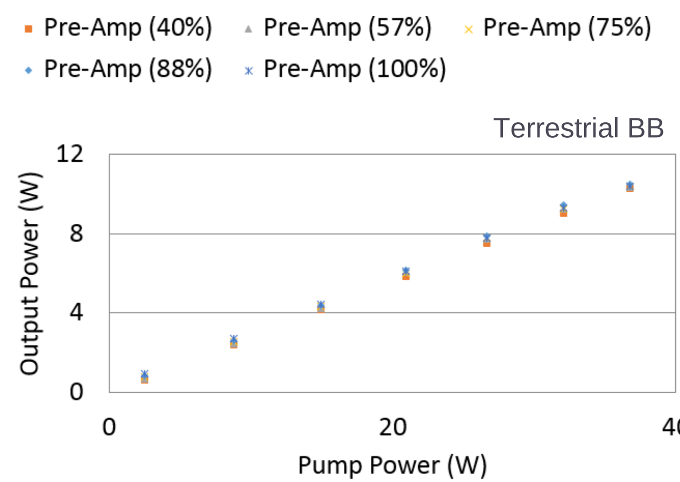



## CENTAURUS +40dBm esa

2016: BB version / 2017: EM version

Work-plan

- Gamma radiation & qualification of doped fibres
- Neutron radiation on gain blocks
- Thermal vacuum, mechanical testing on gain blocks




G&H ENABLING PHOTONIC TECHNOLOGIES

# G&H ECI PROGRAMS

- **Space validation of High-power DFB LASER at 1.55 um**

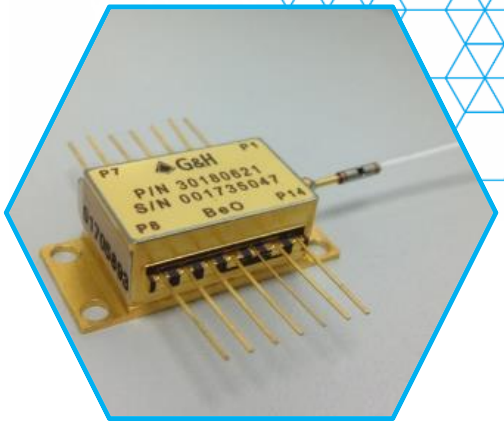
**ESA contract number 4000110310**

- **Space validation of rad-hard erbium optical fiber amplifier at 1.55 um**

**ESA contract number 4000110438**

- **Space validation of Rad-Hard Optical Fibre Amplifier at 1.55µm for high power application**

## SPACE VALIDATION OF HIGH-POWER DFB LASER AT 1.55 um



### Objectives

**Design and develop a High-power DFB Laser**

- Validate build process
- List component on EPPL

**Manufacturing in 2 Lots**

- Pre-Qual prototypes for functional performance validation
- Qualification build for Evaluation Test Plan

**Validate module performance in relevant environment**

- **ESCC 23201** EVALUATION TEST PROGRAMME GUIDELINES FOR LASER DIODE MODULES

ADV EO TEC

ThalesAlenia Space
A Thales / Finmeccanica Company

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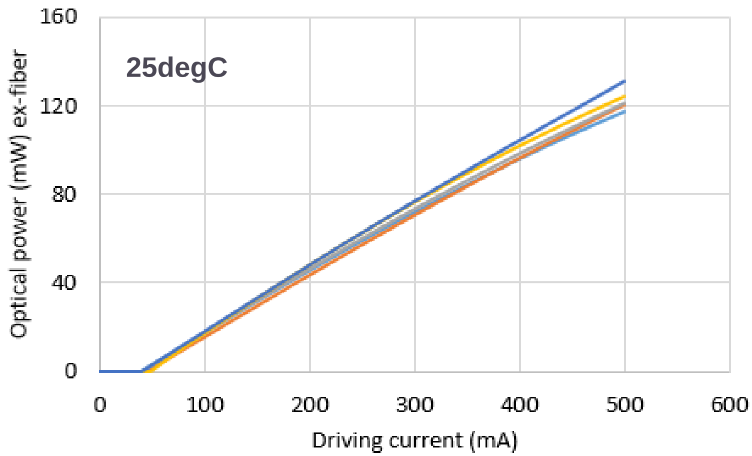
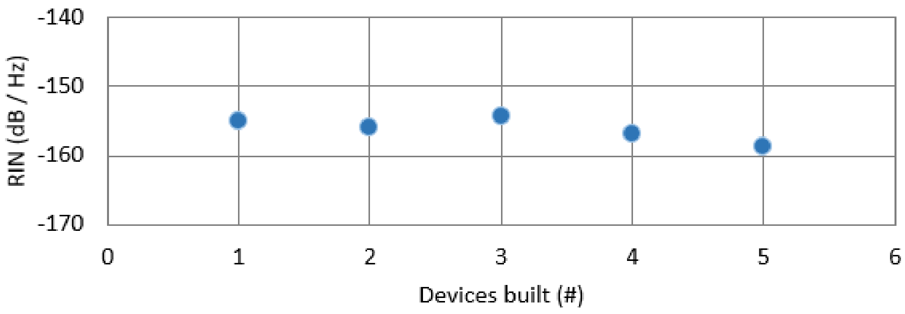
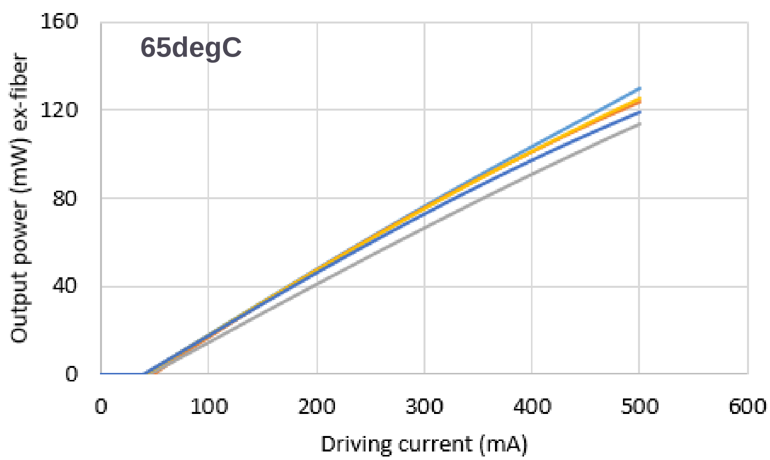
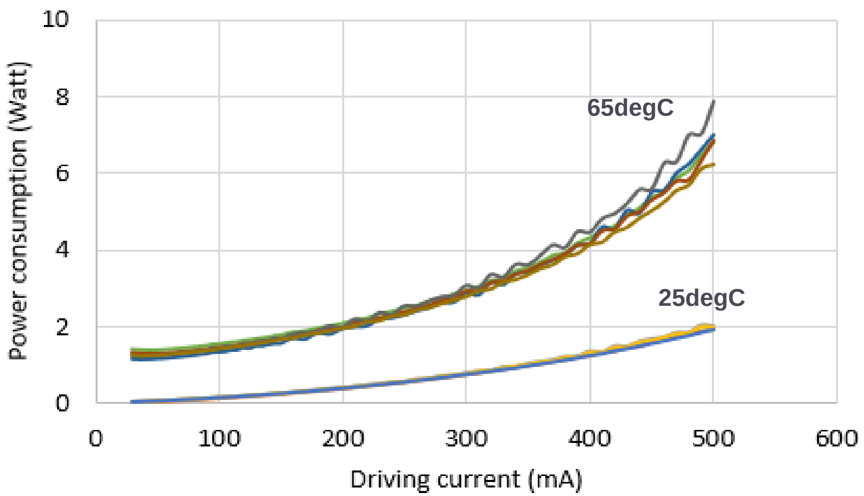
# DFB LASER PRE-LAT RESULTS

- Functional testing (L-I, RIN, PC)
- 40% power consumption reduction wrt to existing product



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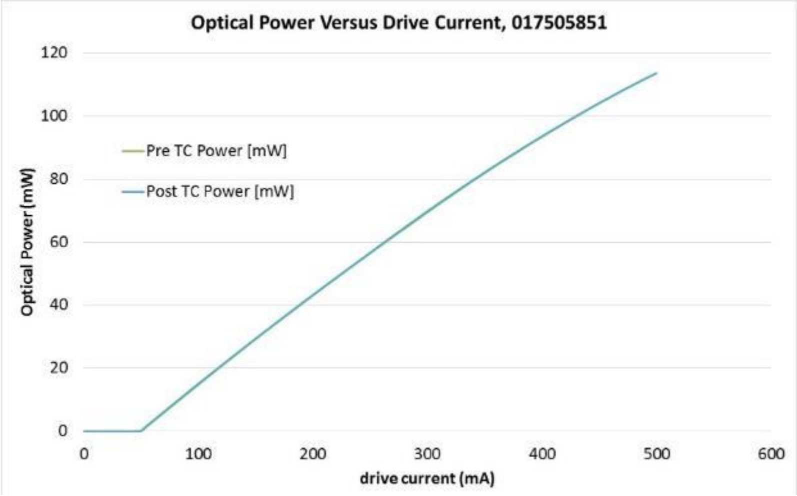
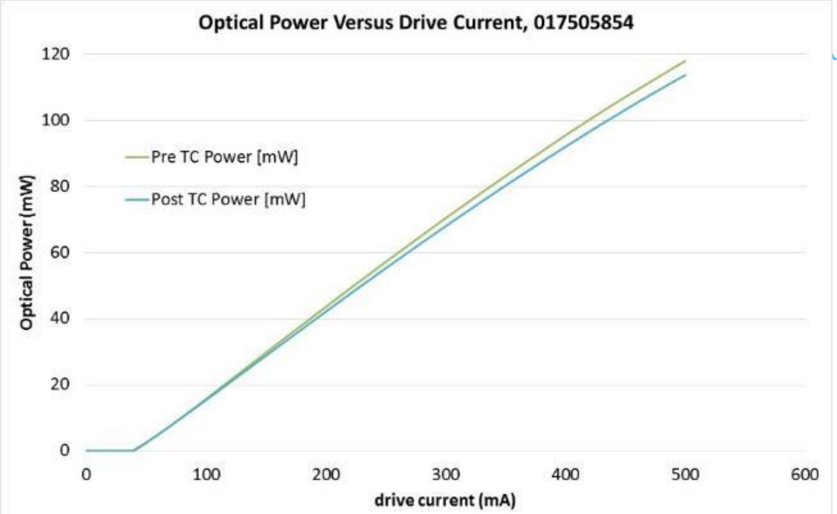
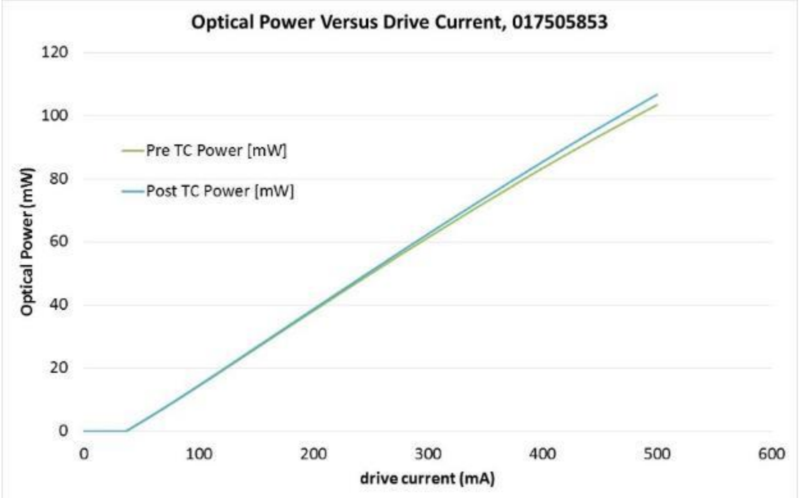
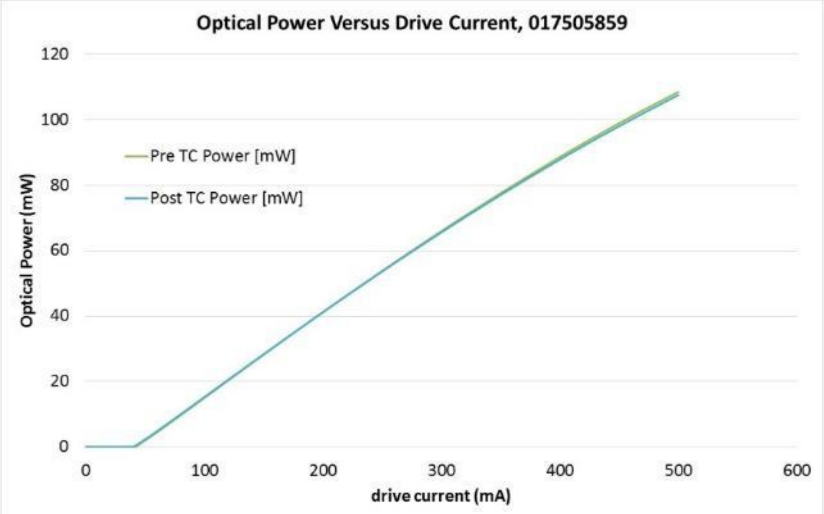
# DFB LASER PRE-LAT RESULTS

- Temperature cycling (20 cycles, -40 to +85 degC)



# DFB LASER PRE-LAT RESULTS

- Mechanical shock 500G and 1000G

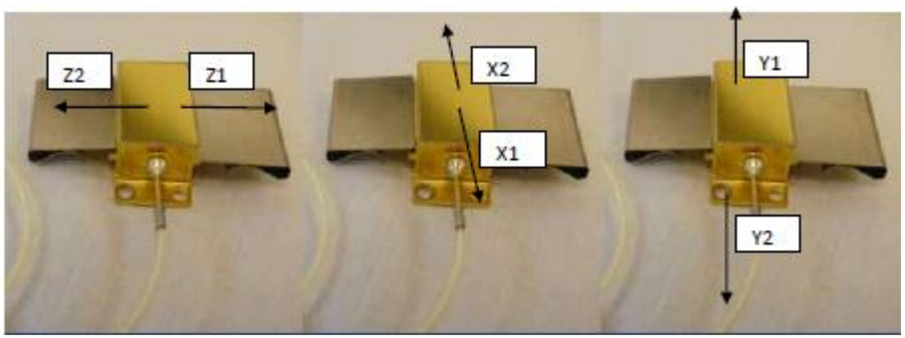
MIL-STD-883 Test Method 2002 on all axes

Tested @ all 3-axes / 5 shocks at each direction / total of 30 shocks

Applied to 8 samples

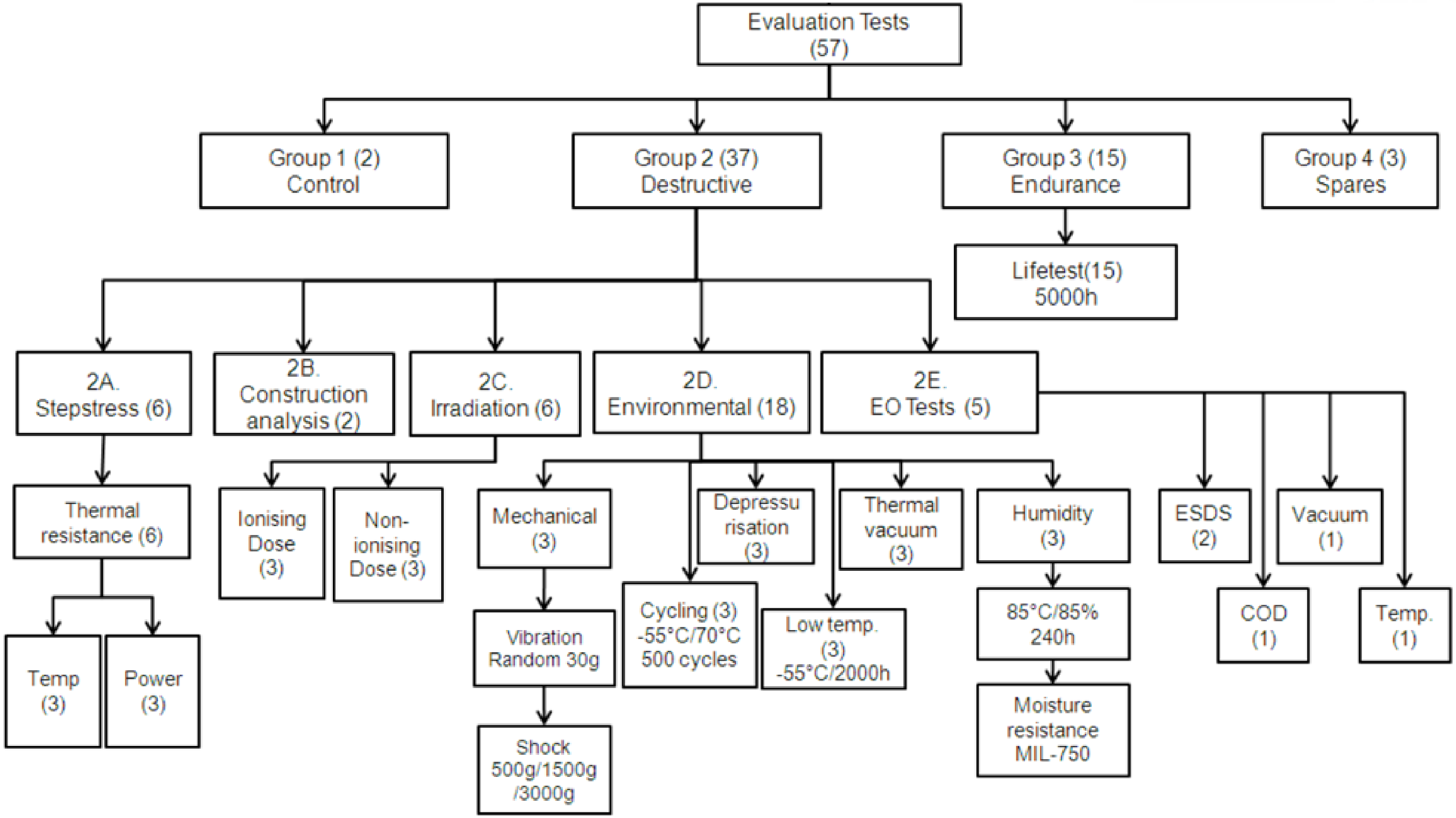
Measured: Laser, BFM, thermistor and TEC characteristics

**All samples passed at 500g and 1000g**



# DFB LASER ETP

- Next step: submit 60 devices to ETP






G&H ENABLING PHOTONIC TECHNOLOGIES

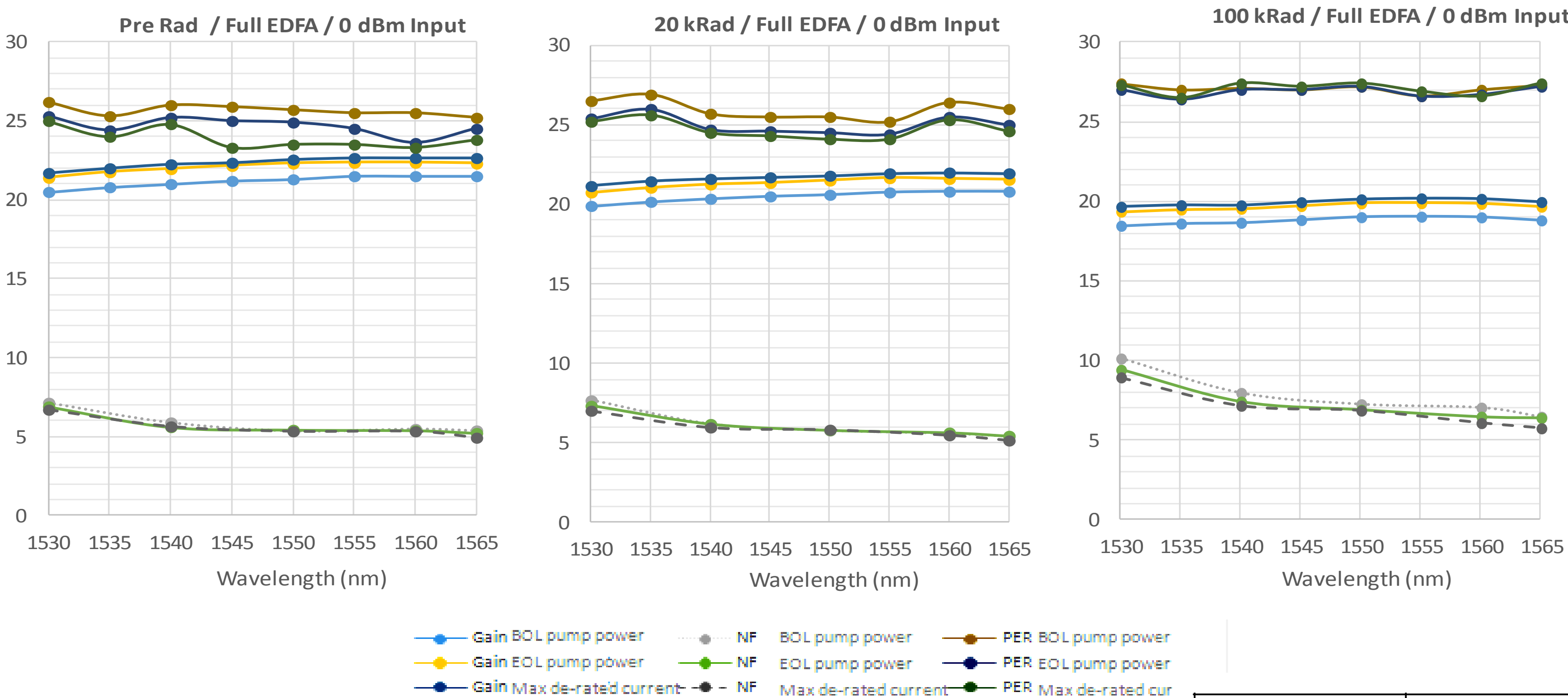
# SPACE VALIDATION OF RAD-HARD ERBIUM OFA AT 1.55 um

## Objectives

- **Ionizing radiation evaluation of Erbium-doped OFA**
  - Gamma radiation testing of various Er fibers
- **Non-ionizing radiation evaluation of pump laser module (PLM)**
  - Proton testing of PLM at various steps/fluence
- **Design two types of rad-hard optical fiber amplifier units**
  - Optical pre-amplifier
  - Polarization Maintaining Booster amplifier
- **Assemble, integrate and test**
  - EM models: Verify Assembly, Integration & Test process
  - Gain module: Verify mechanical design and thermal vacuum operation

# PM BOOSTER OFA FIBER RADIATION TEST

- Radiation tests of >15 doped fiber amplifier sub-assemblies
- Up to 100 krad @ 210 rad/h without any shielding
- ALTER, CNA 60Co source in Seville

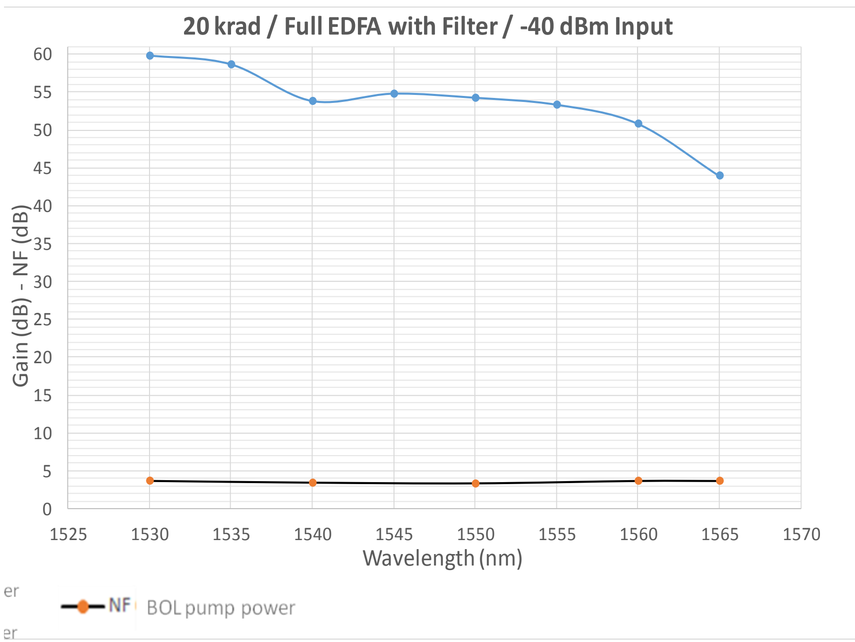


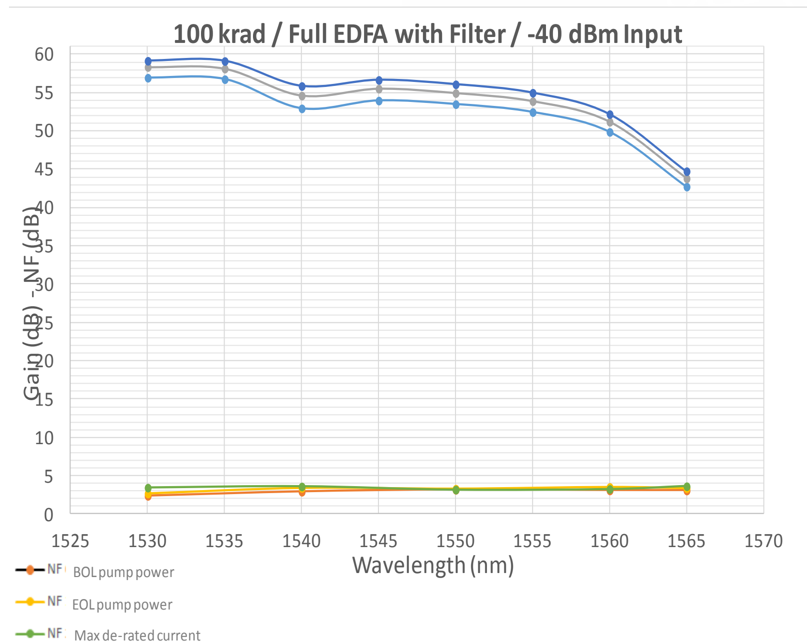

+20 dBm PM fiber amplifier optical design validated

| | Gain (@ 1550nm) (dB) | | |
|---|---|---|---|
| **Pump Powers** | $G_0$ | $G_{20}$ | $G_{100}$ |
| **BOL** | 21.3 | 20.6 | 19 |
| **EOL** | 22.3 | 21.5 | 19.87 |
| **@ Max. De-rated current** | 22.55 | 21.8 | 20.12 |

# OPTICAL PRE-AMPLIFIER FIBER RADIATION TEST

- Radiation tests of >24 doped fiber sub-assemblies
- Up to 100 krad @ 210 rad/h without any shielding




55 dB high gain pre-amplifier optical design validated

| | Gain (@ 1550nm) (dB) | |
|---|---|---|
| **Pump Powers** | **$G_0$** | **$G_{20}$** |
| **BOL** | 45.1 | 44.4 |
| **EOL** | 45.95 | 44.99 |
| **@ max de-rated current** | - | - |

| | Gain (@1550nm) (dB) | |
|---|---|---|
| **Pump Powers** | **$G_0$** | **$G_{100}$** |
| **BOL** | 45.2 | 43.82 |
| **EOL** | 45.95 | 44.56 |
| **@ max de-rated current** | - | 45.06 |

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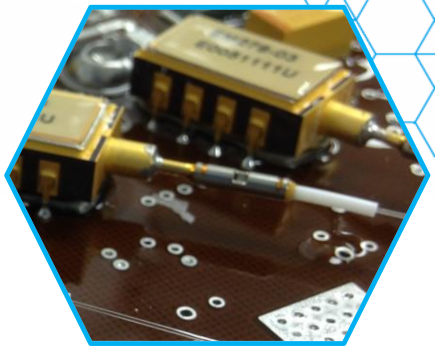
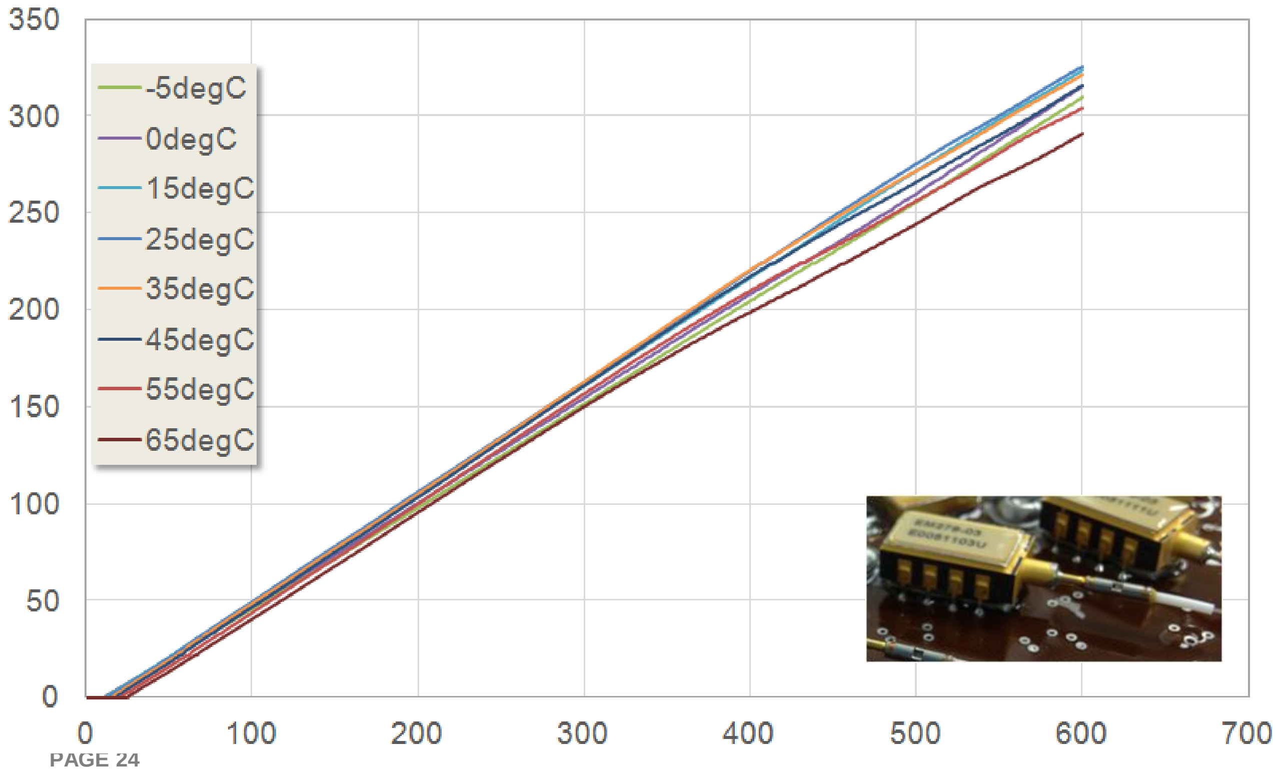
# 8-PIN MINI-DIL PUMP LASER PROTON RADIATION TEST

- 976 nm uncooled pump laser – critical component for EDFA
- LD, BFM, thermistor sub-assembly
- Extended temperature range due to fiber attachment method
- Proton radiation tested within ECI program





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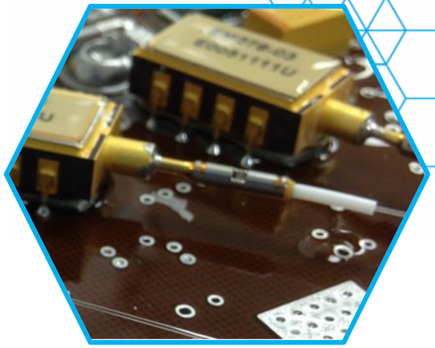
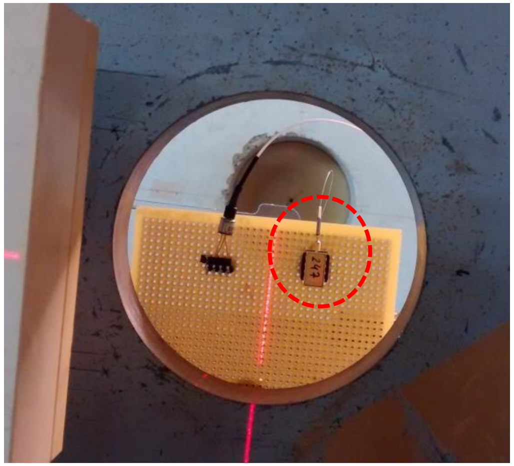
# 8-PIN MINI-DIL PUMP LASER

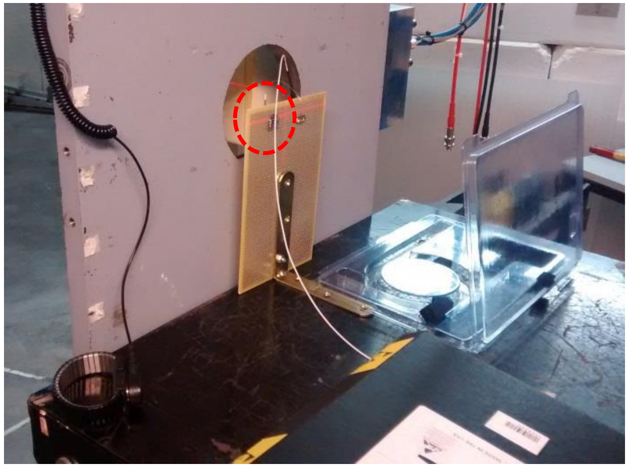
- ALTER test house using UCL facility



| STEP | 60Mev Beam flux (cm-2s-1) | Beam time (s) | Accumulated beam time (s) | Cumulative fluence |
|---|---|---|---|---|
| 1 | $1 \cdot 10^8$ | 100s | 100s | $1 \cdot 10^{10}$ |
| 2 | $1 \cdot 10^8$ | 900s | 1000s | $1 \cdot 10^{11}$ |
| 3 | $1.5 \cdot 10^8$ | 6670s | 7670s | $1 \cdot 10^{12}$ |

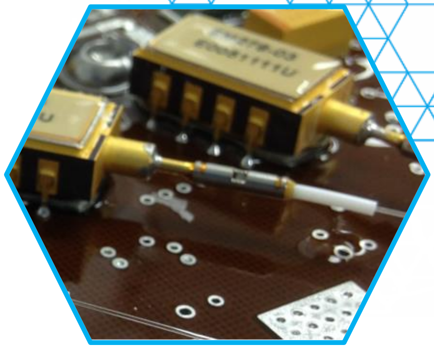
| **Parameter** | **Test condition** |
|---|---|
| Center Wavelength | Measured @ laser driving current of 400 mA |
| L-I curve (Fiber coupled power Vs driving current) | Measurement of Output power for:<br>Driving current step of 0.05 mA up to 55 mA<br>Driving current step of 5 mA up to 600 mA |

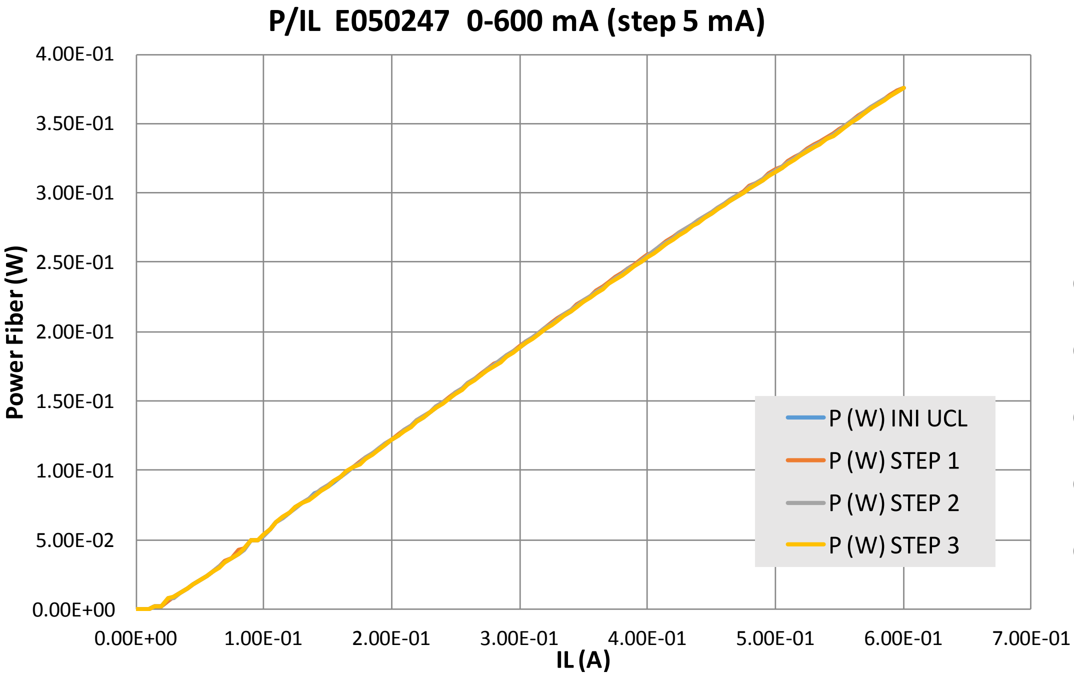


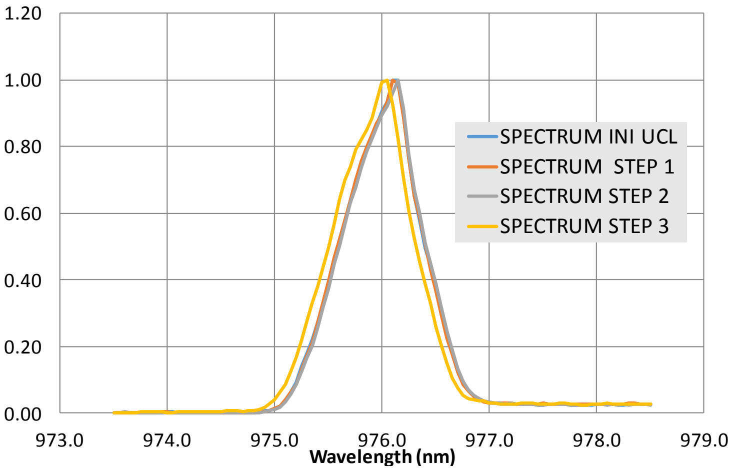


# 8-PIN MINI-DIL PUMP LASER

- Proton radiation test results



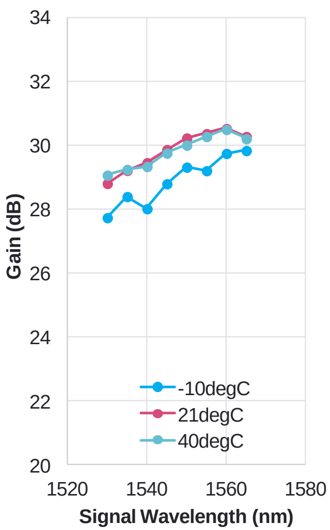


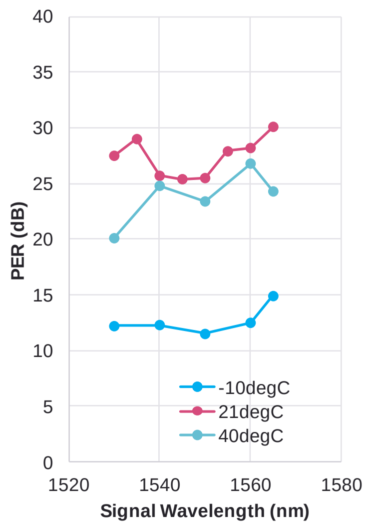



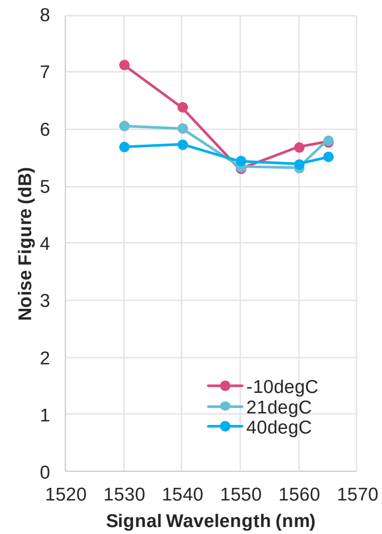

MiniDIL PLM robust against DD

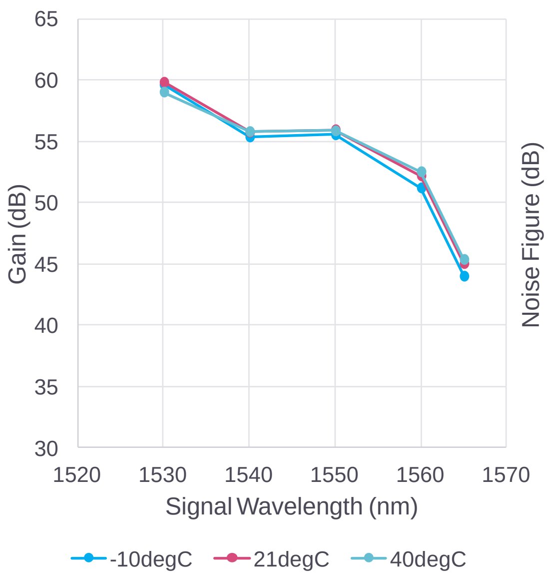
# UNIT ASSEMBLY INTEGRATION AND TEST

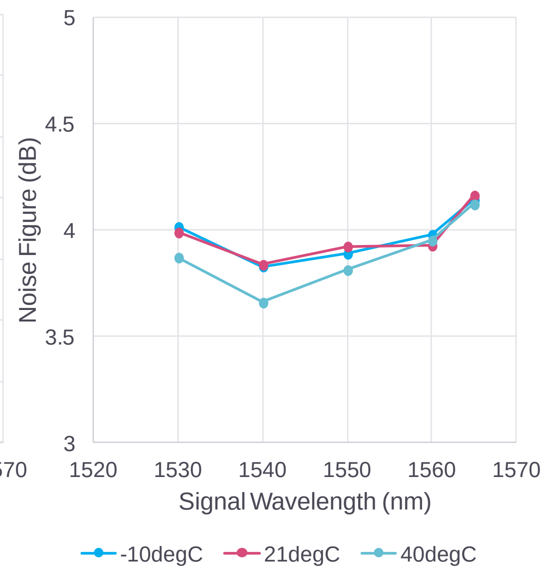
- Two EM models assembled and tested



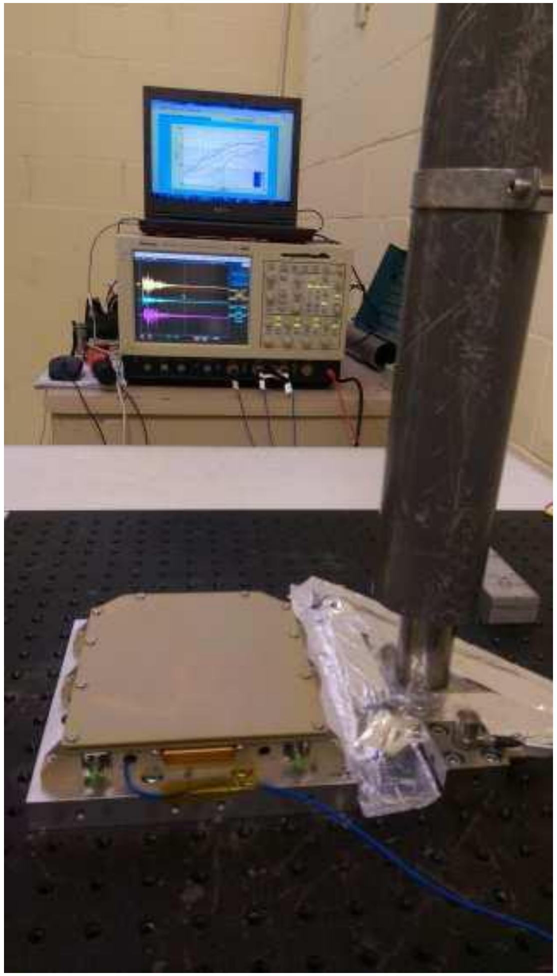



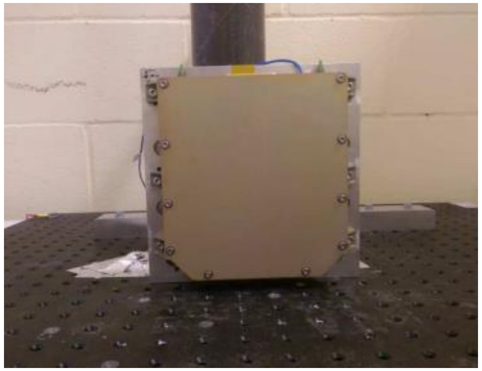



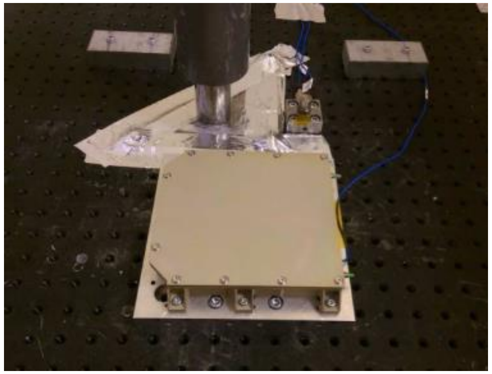



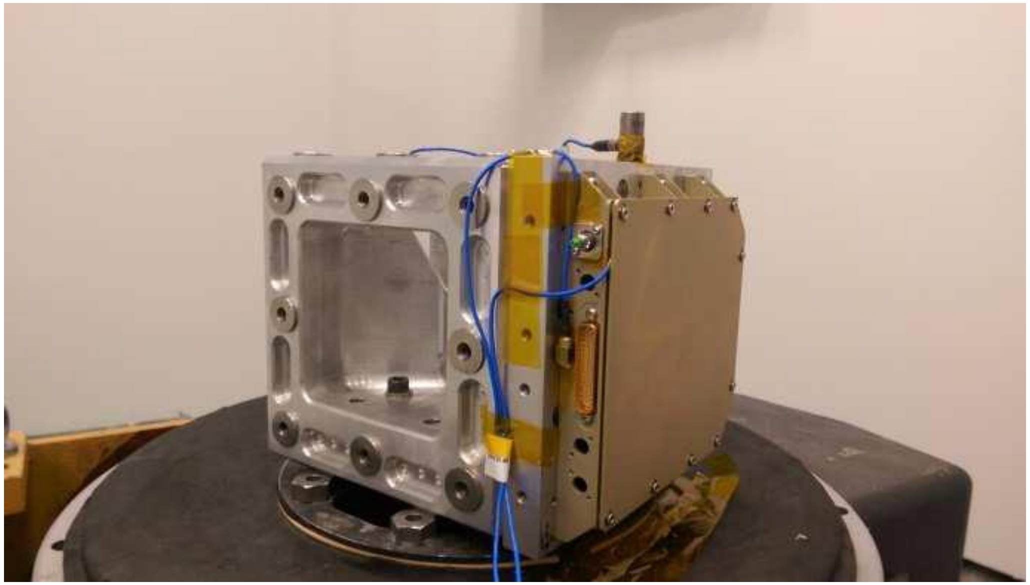

# UNIT ASSEMBLY INTEGRATION AND TEST

- Next step: Vibration, shock and TVAC test of Gain module





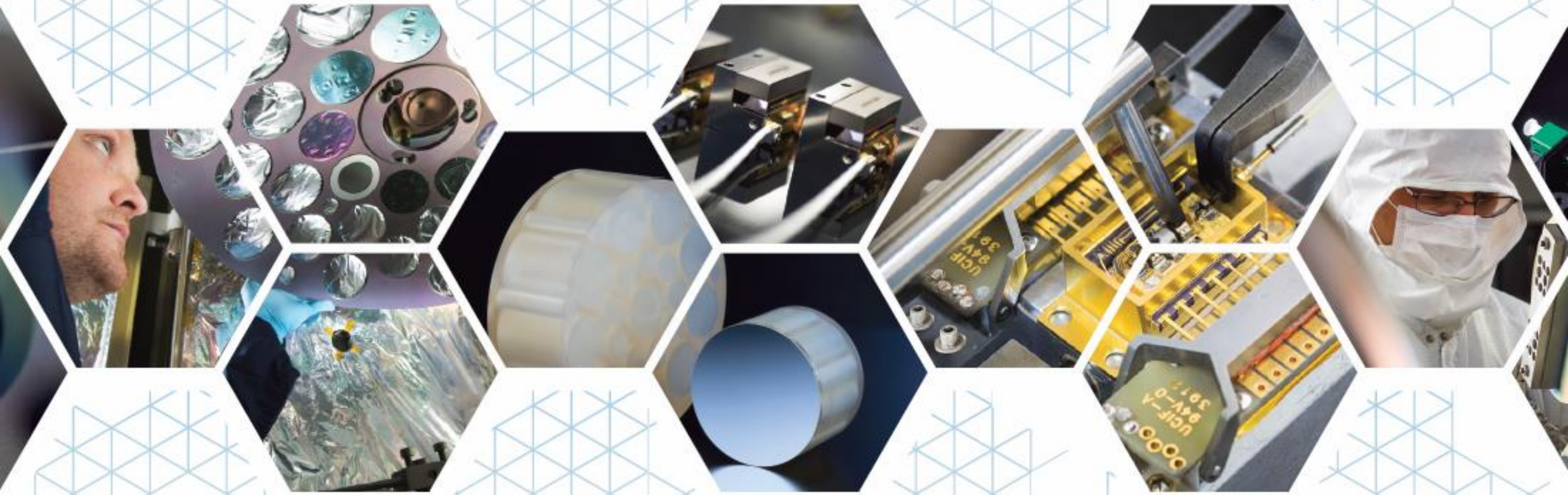




# ACKNOWLEDGEMENTS


## ESA/ESTEC project officers

- Ms Charlotte Bringer
- Mr Mustapha Zahir



# ECI 8119: Validation of Rad-Hard Optical Fibre Amplifier at 1.55μm for High Power Applications

Matthew Welch, Leo Stampoulidis

Gooch & Housego
ENABLING PHOTONIC TECHNOLOGIES

1. Optical Architecture

2. Radiation Results:

   1. Passive Fibre Optic Components
   2. Active Fibre

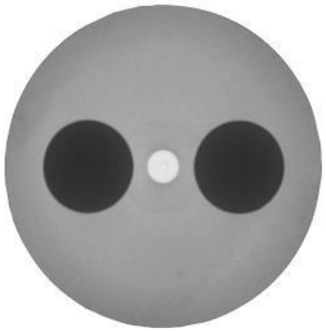
3. Conclusion

# Optical Architecture

# Power Amplifier Fibres

## 4 x Er/Yb Fibres Evaluated

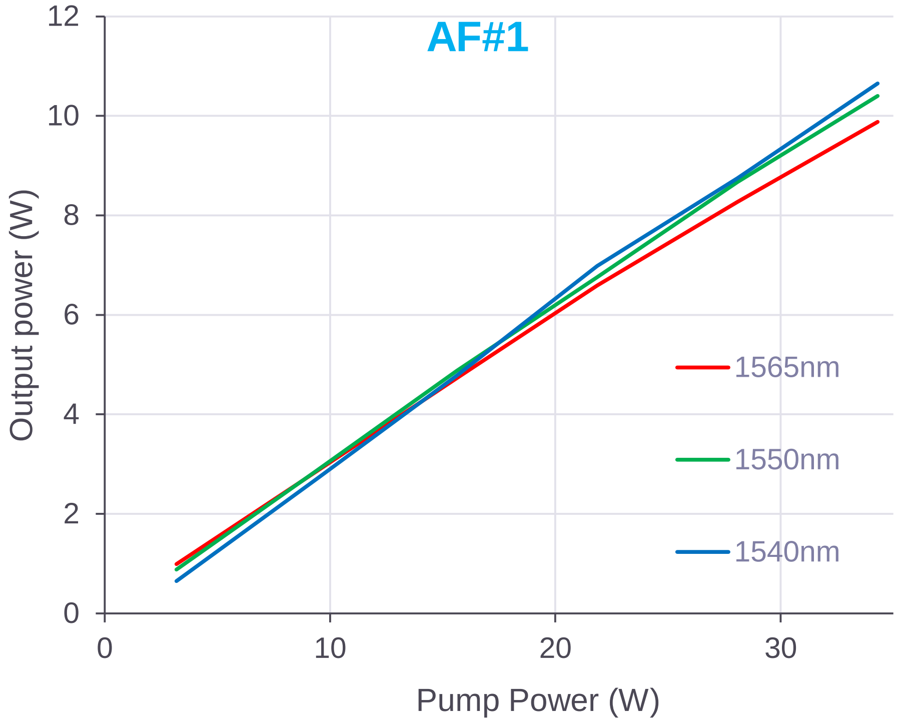
- **3 x PM**



- **1 x Random Polarisation**

| Fibre | Type |
|---|---|
| AF #1 | PM |
| AF #2 | PM |
| AF #3 | Random Pol’ |
| AF #4 | PM |

# Pre Irradiation Performance




| Fibre | Typical Optical to Optical Efficiency at 5W |
|---|---|
| AF#1 | 33% |
| AF#2 | 32% |
| AF#3 | 31% |
| AF#4 | 28% |

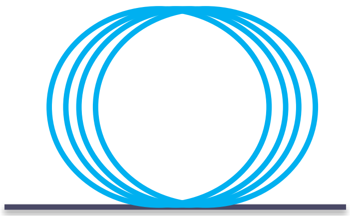
- **AF# 1, 2, 3 had similar Optical Efficiencies.**
- **AF# 4 had the lowest efficiency.**

# Gamma Irradiation

**Co-60 Source:**

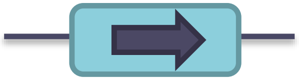
**Optical fibre tested at 3x dose levels**

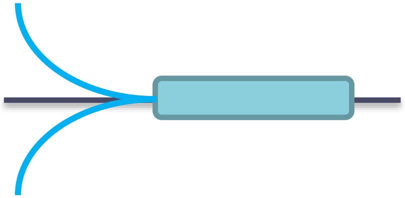
- 10krad
- 60krad
- 100krad



**Passive Components tested at 1x dose level**

- 100krad







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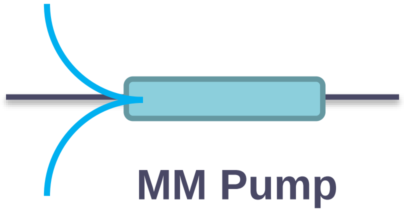
# Gamma Irradiation Results (Passive Components)

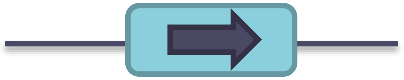
# Passive Component Performance

**Selected passive optical components showed no measurable degradation in performance with gamma irradiation.**



MM Pump Combiner

| | 0krad | 100krad |
|---|---|---|
| Core insertion loss | 0.55dB | 0.57dB |
| Average MM port insertion loss | 0.30dB | 0.36dB |



Isolator

| | 0krad | 100krad |
|---|---|---|
| Isolation | >50dB | >50dB |
| Insertion loss | 0.34dB | 0.29dB |
| Polarisation Extinction Ratio | 21.1dB | 22dB |

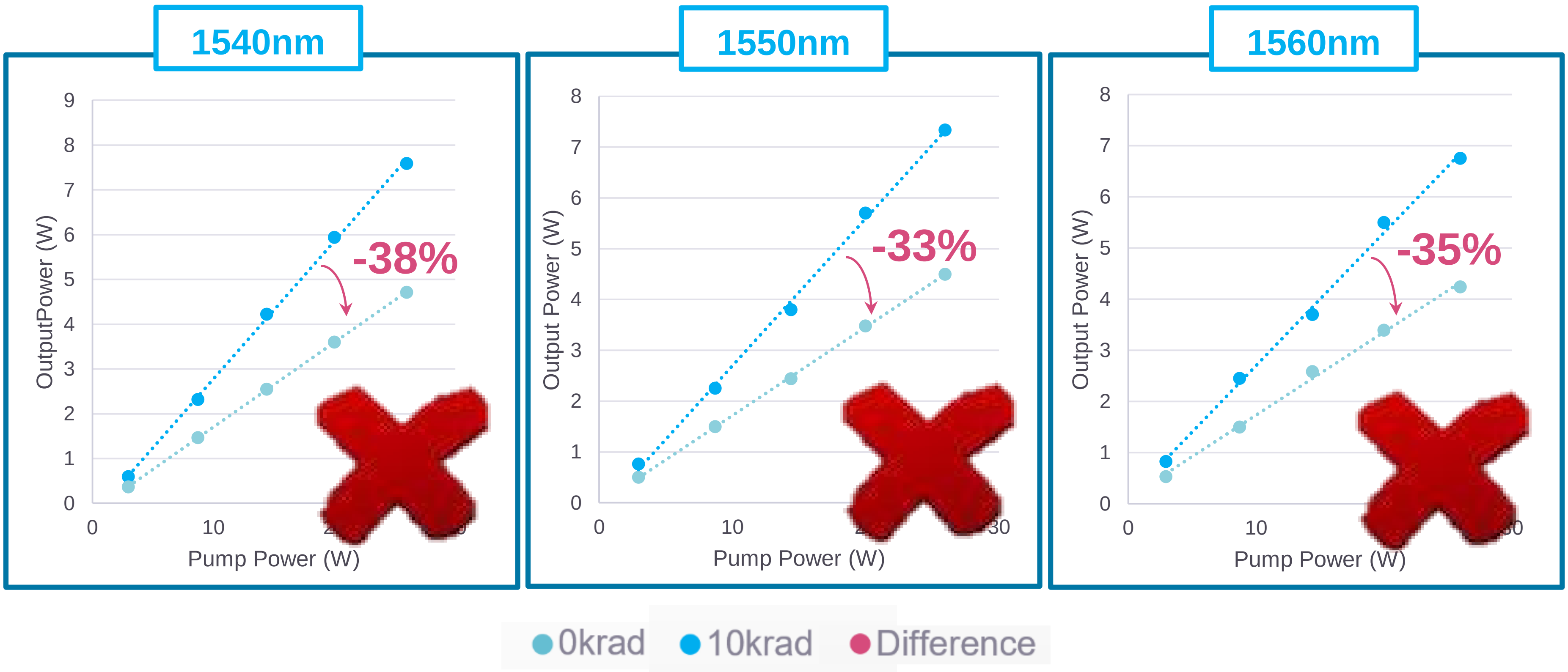
# Gamma Irradiation Results
# (Er/Yb Fibres)

# Gamma Irradiation Performance

## AF#1 & AF#3 Showed Large Degradation in Output Power at 10krad

- **Both fibres unsuitable for Space Applications!**

### Example Amplifier Results – AF#1



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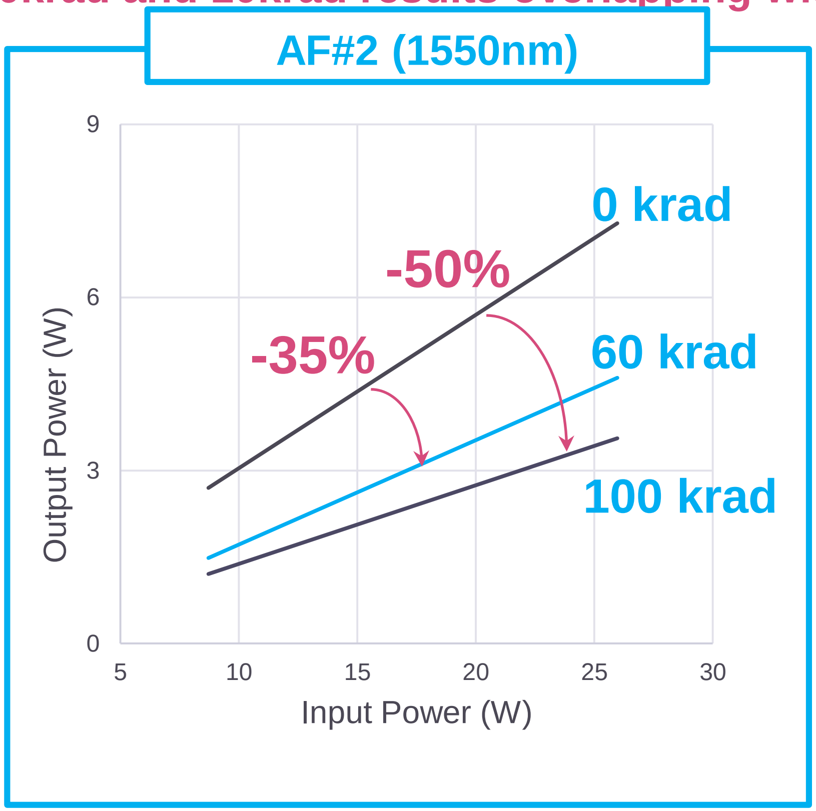
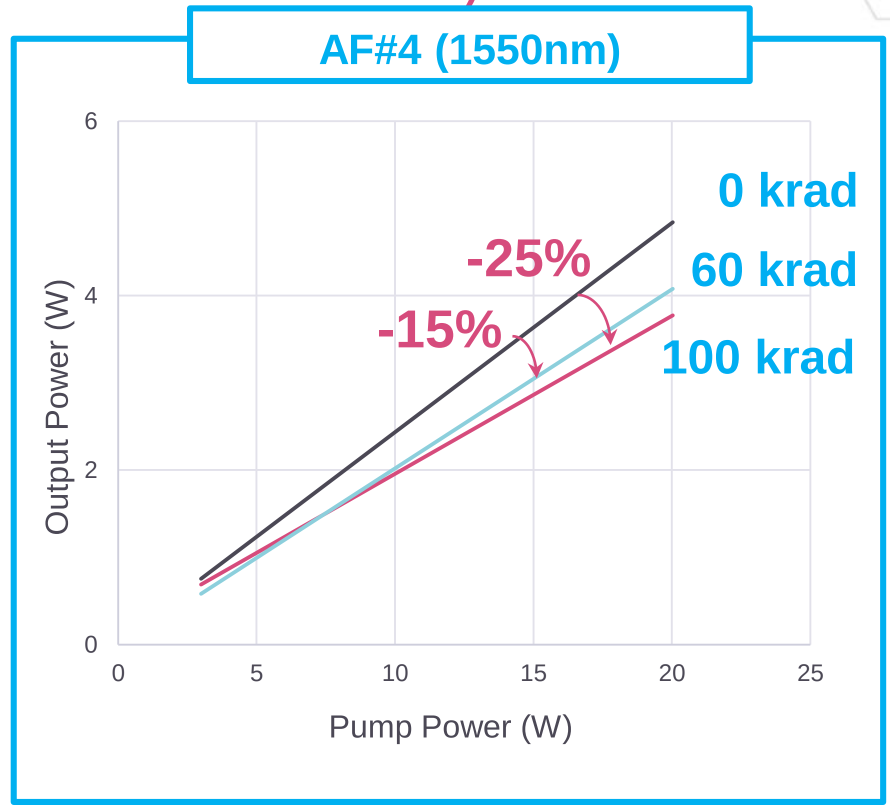
# Gamma Irradiation Performance

## Fibres AF#2 and AF#4 showed much better performance

**(0krad and 10krad results overlapping within measurement error)**



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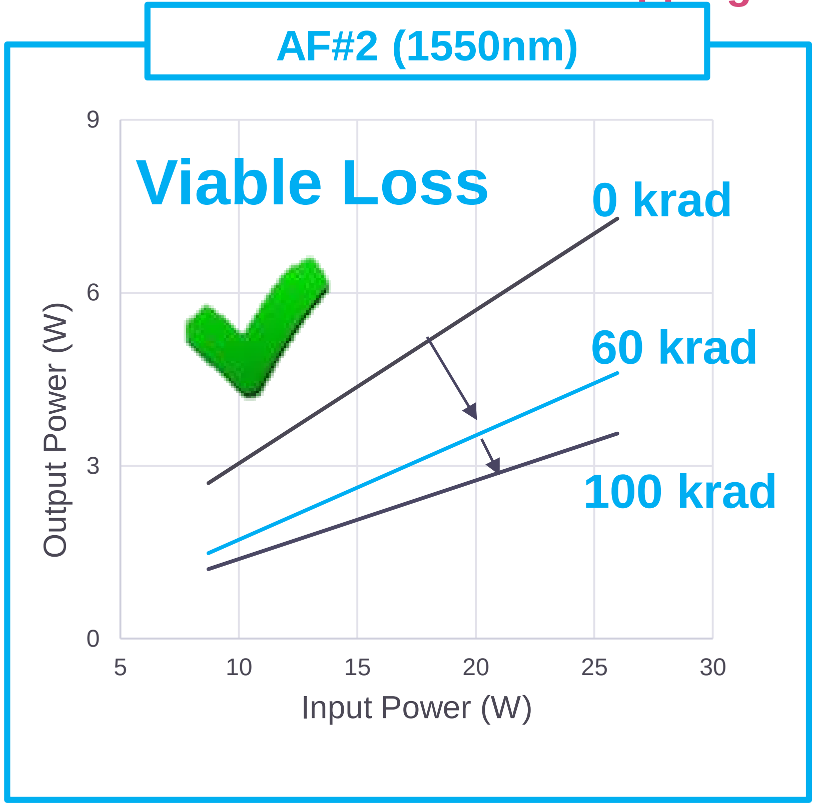


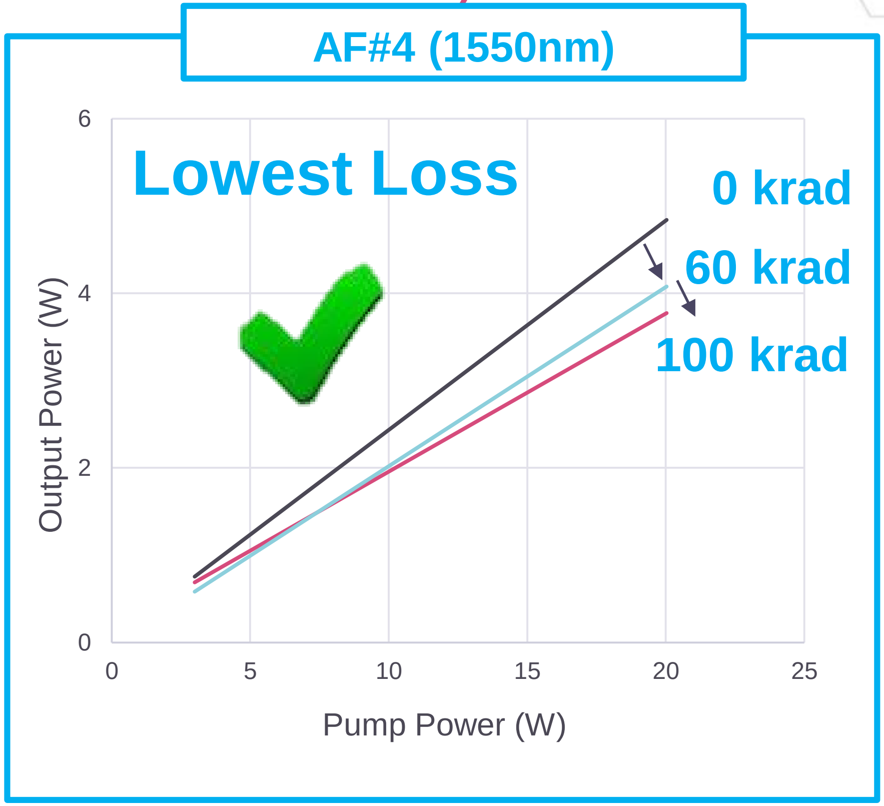




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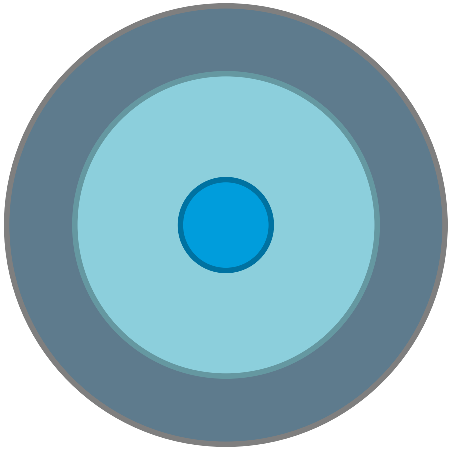
# Source of Power Loss

**Addition Fibre Propagation Losses**

**Two Wavelengths Matter:**

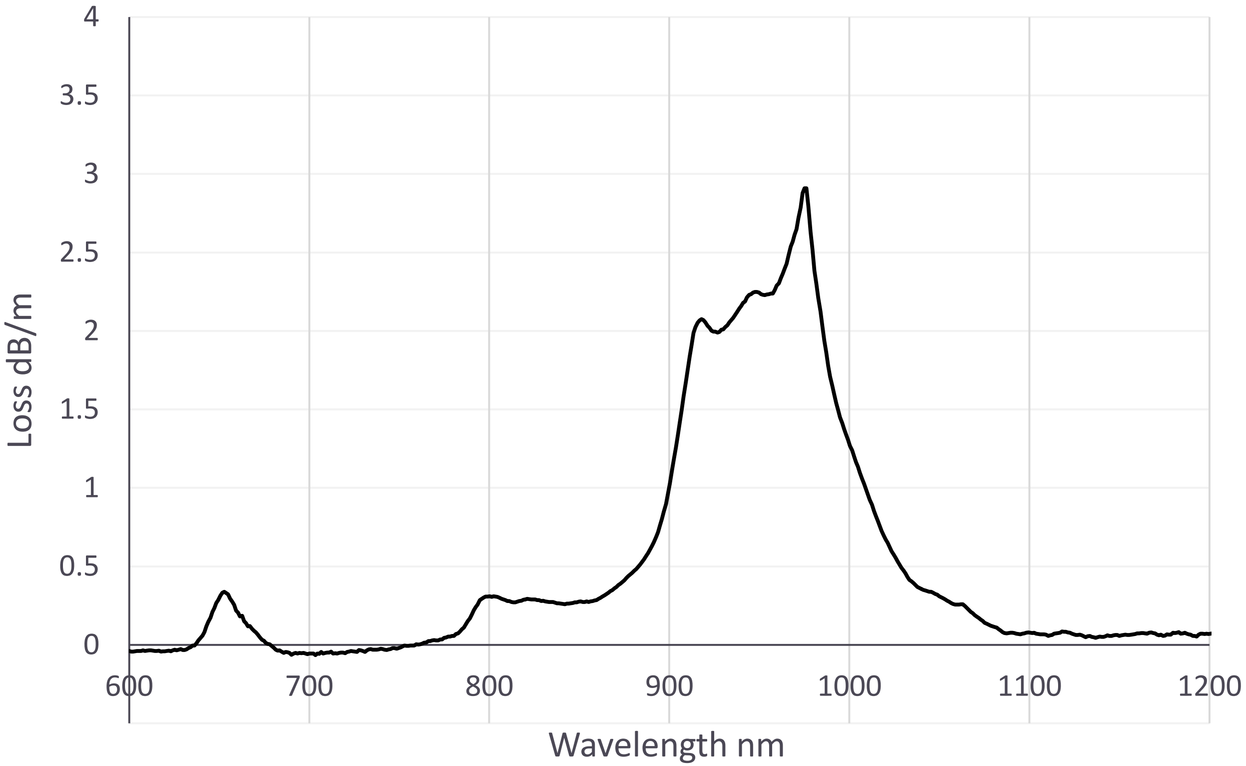
- **<u>Signal Loss at 1550nm</u> – (Core loss)**
- **<u>Pump loss at 915nm</u> – (Cladding Light)**



# 915nm – Pump (Cladding Loss)

# Pump Wavelength 915nm

## Example Loss Measurement : Pristine AF#3



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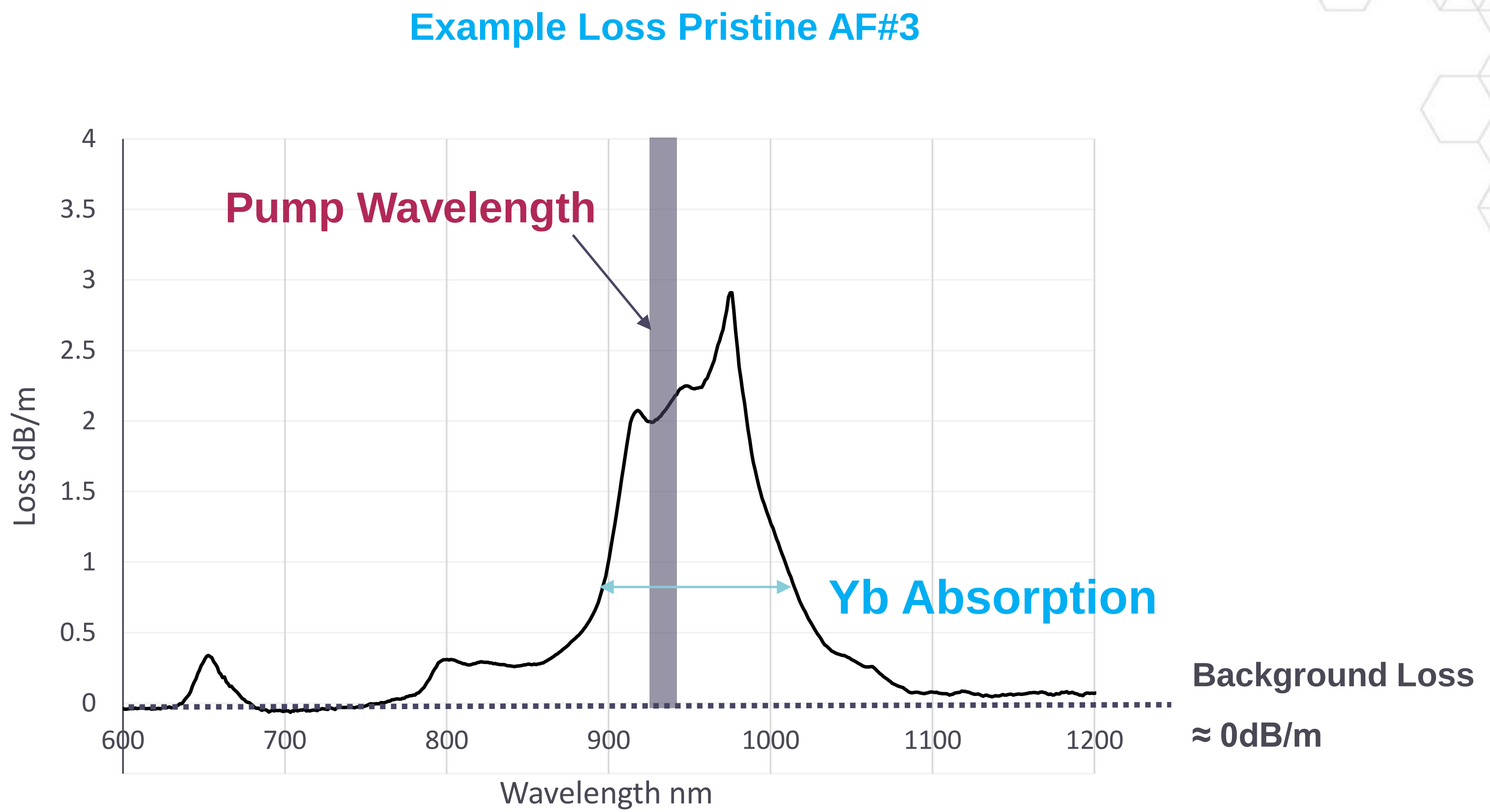
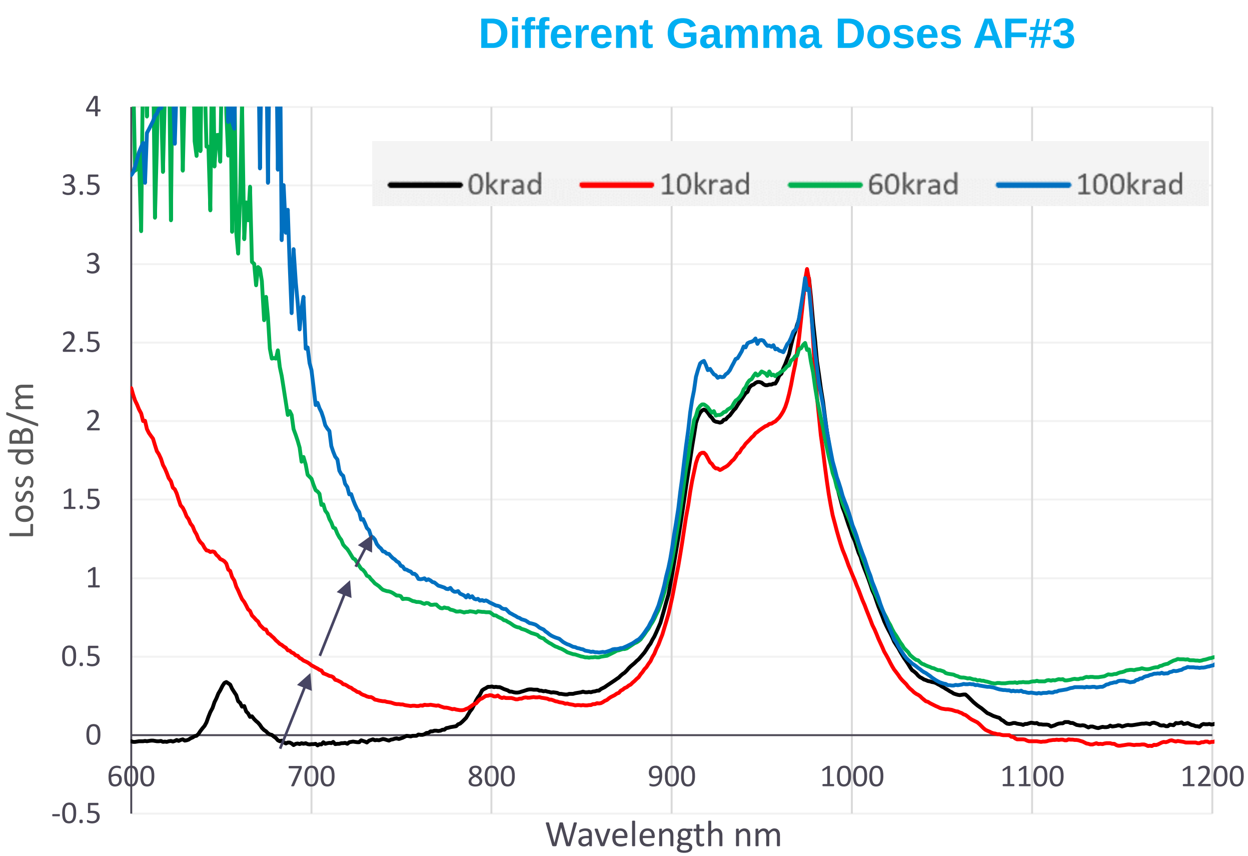
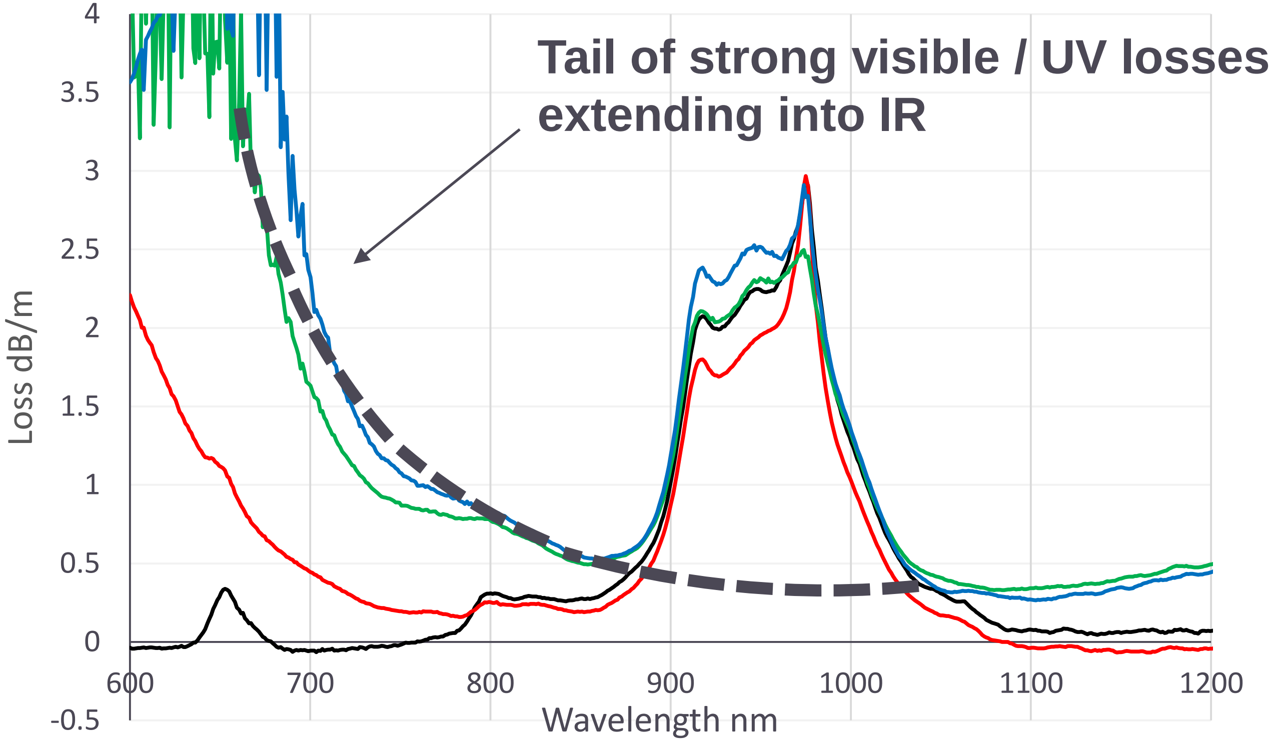
# Pump Wavelength 915nm



# Pump Wavelength 915nm



# Pump Wavelength 915nm



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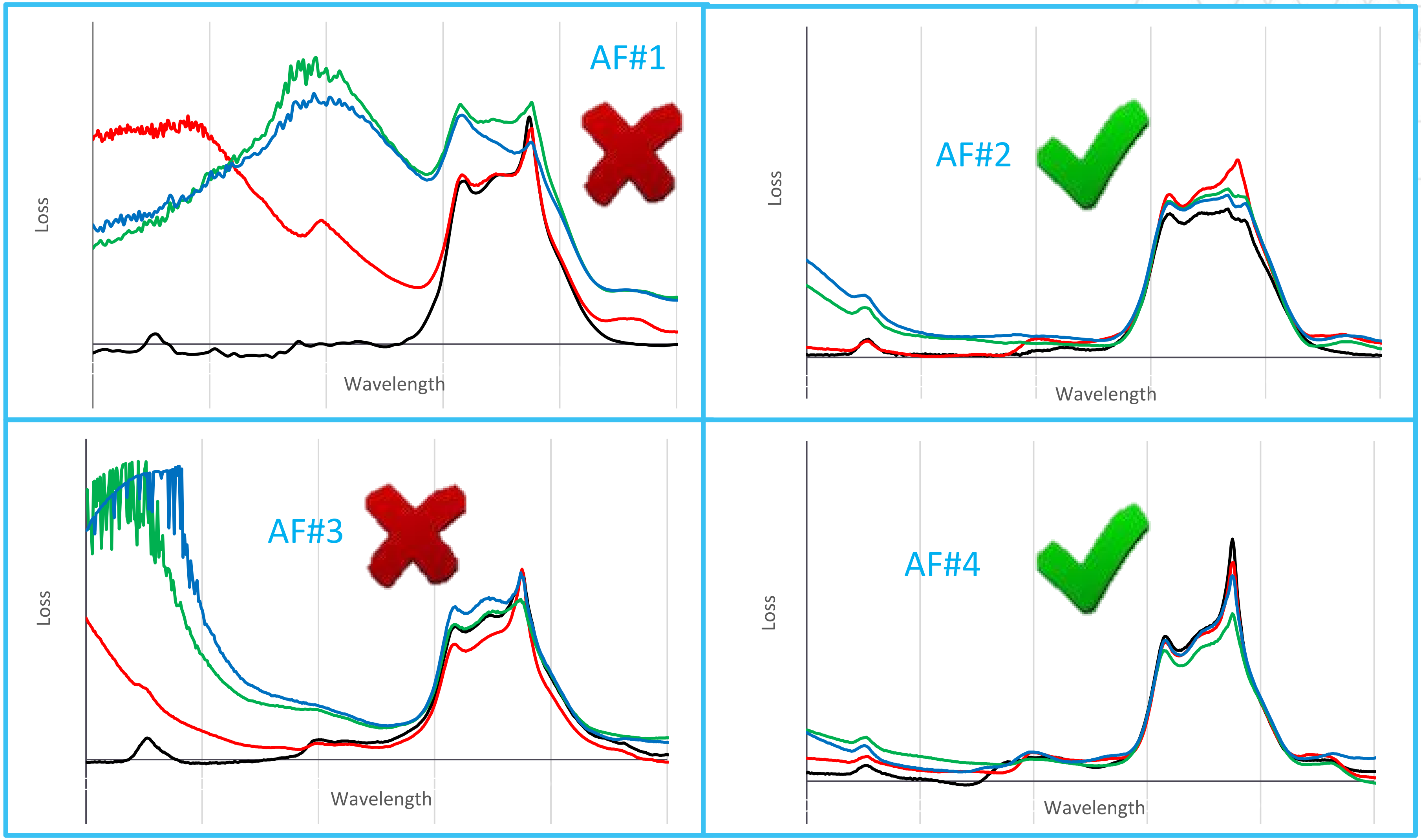
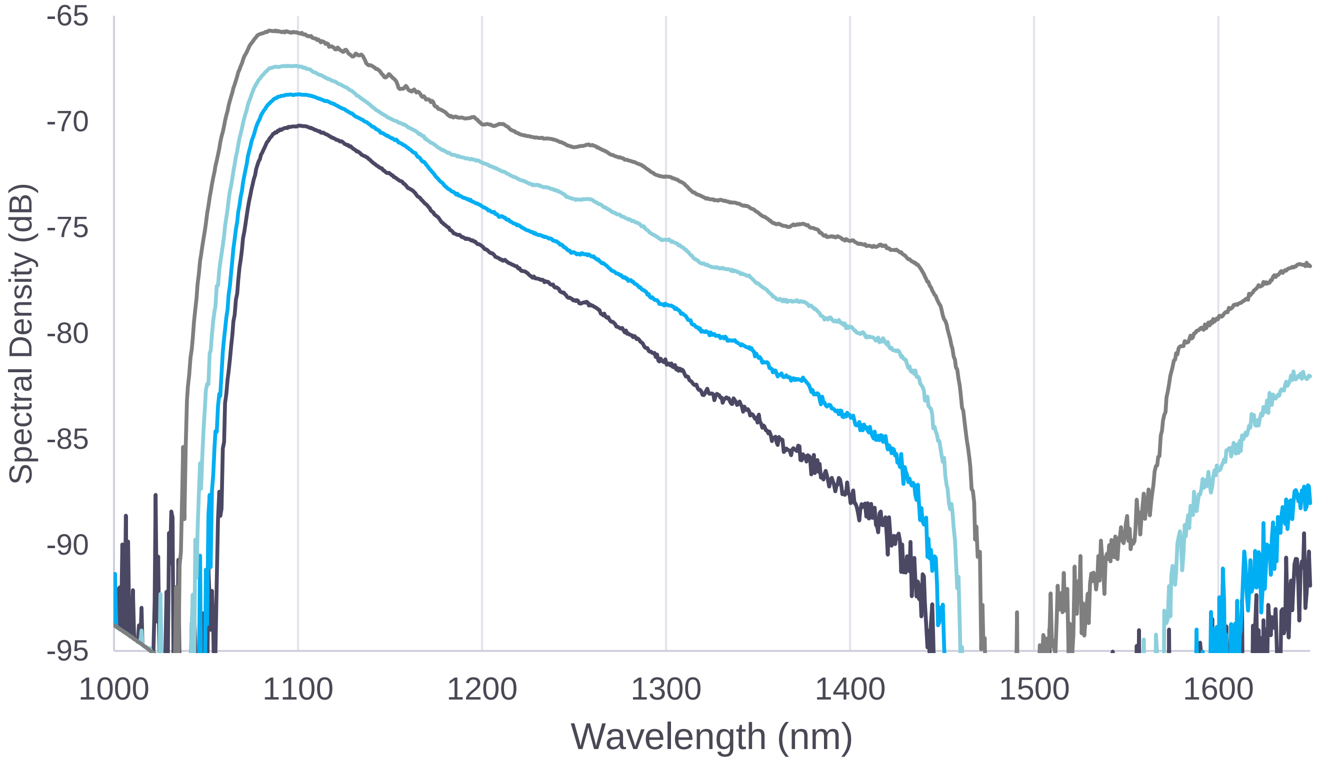
# Fibres AF#1, AF#2, AF#3, AF#4



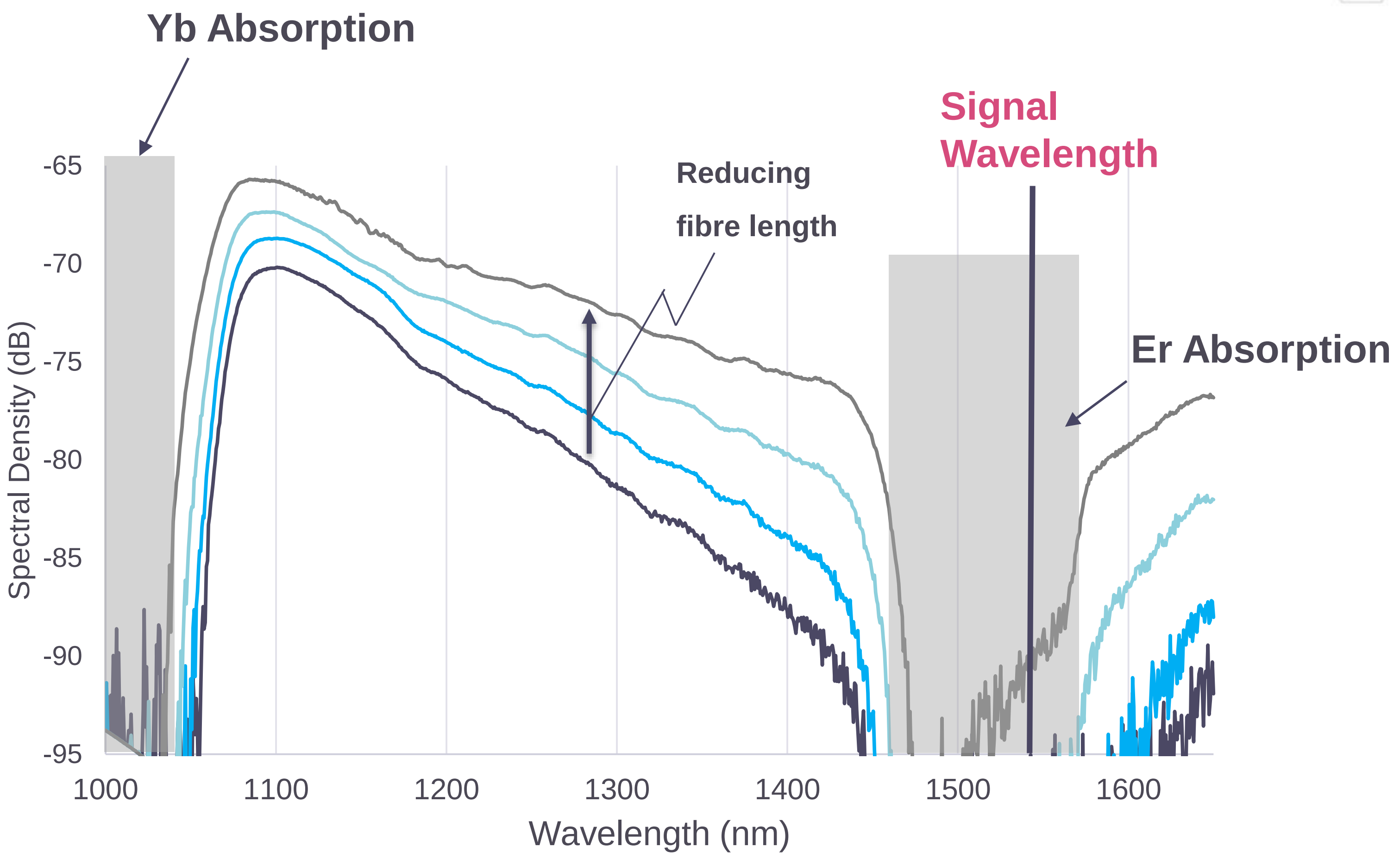
# 1550nm – Signal (Core Loss)

# Core loss

## Example Transmission Spectra AF#1 100krad

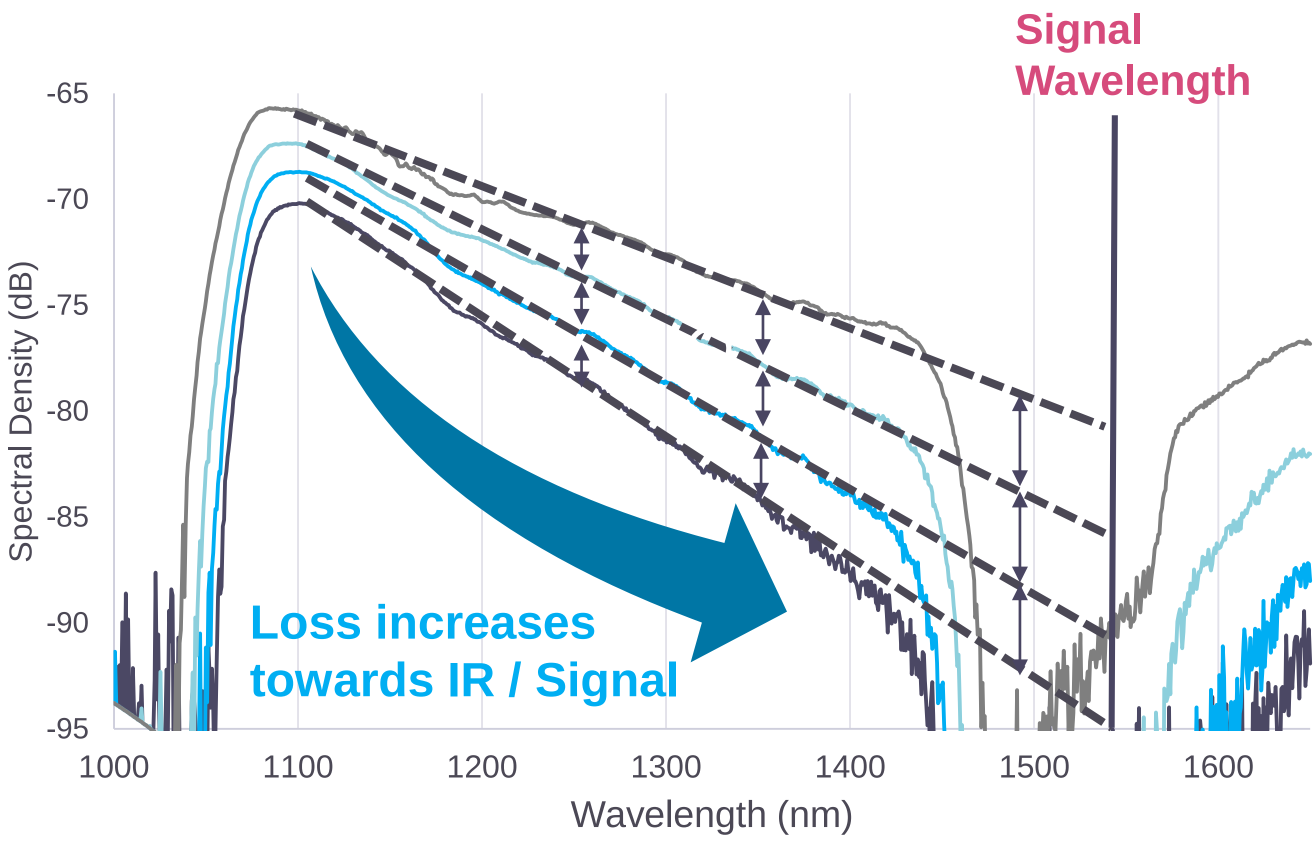


# Core loss

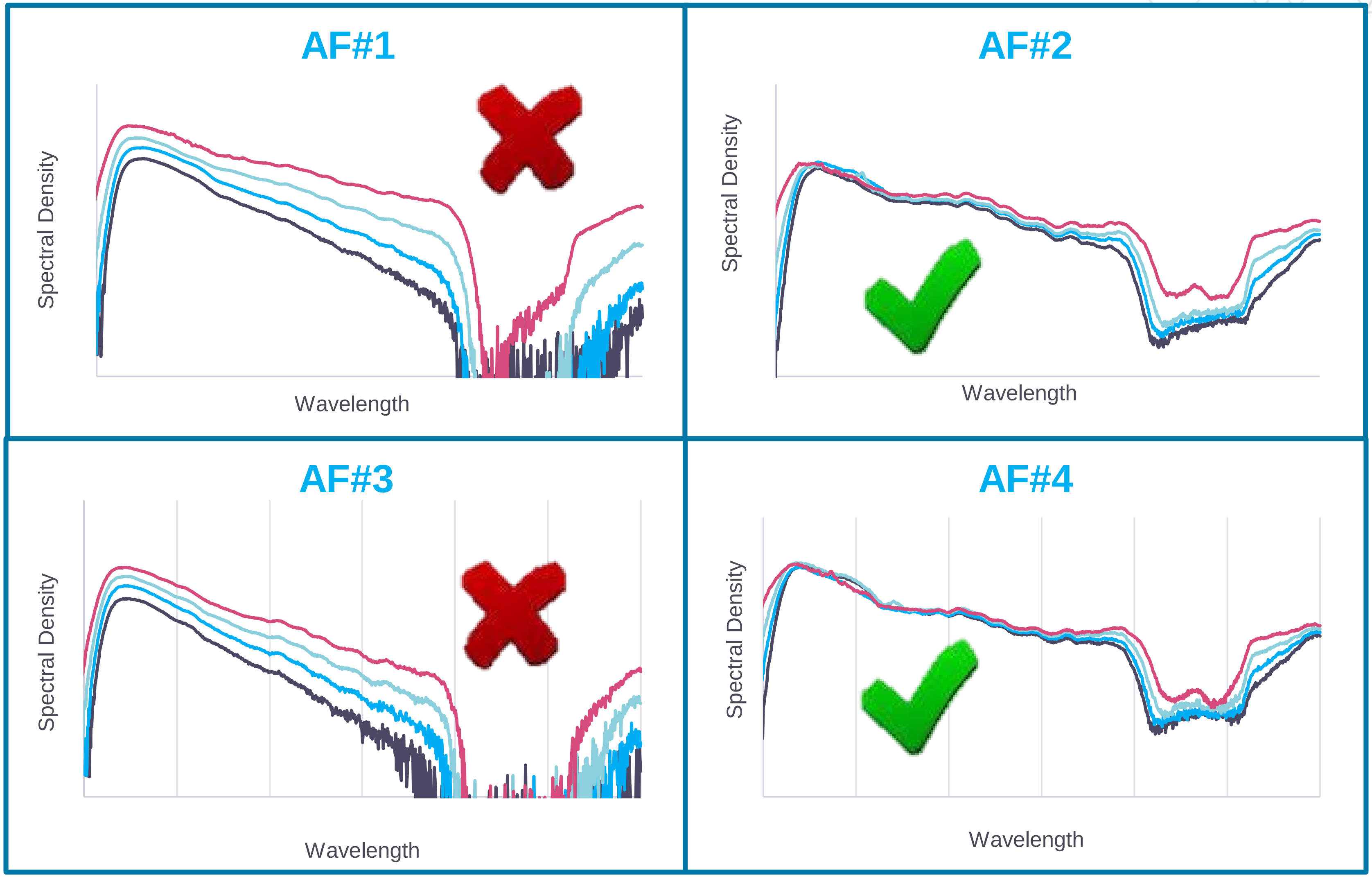


Yb Absorption
Signal
Wavelength
Reducing
fibre length
Er Absorption
-65
-70
-75
-80
-85
-90
-95
Spectral Density (dB)
1000
1100
1200
1300
1400
1500
1600
Wavelength (nm)

# Core loss


Signal
Wavelength
-65
-70
-75
-80
-85
-90
-95
Spectral Density (dB)
1000
1100
1200
1300
1400
1500
1600
Wavelength (nm)
Loss increases
towards IR / Signal

# Core Loss: AF#1, AF#2, AF#3, AF4



# Signal and Pump Loss Summary

# Correlation to Amplifier Results

**Combining core & cladding losses into simple model for total loss shows good agreement with measured amplifier power losses.**

| AF#1 | Predicted | Measured |
|---|---|---|
| 10krad | 39% | 35% |
| 60krad | 95% | 95% |
| 100krad | 100% | # |

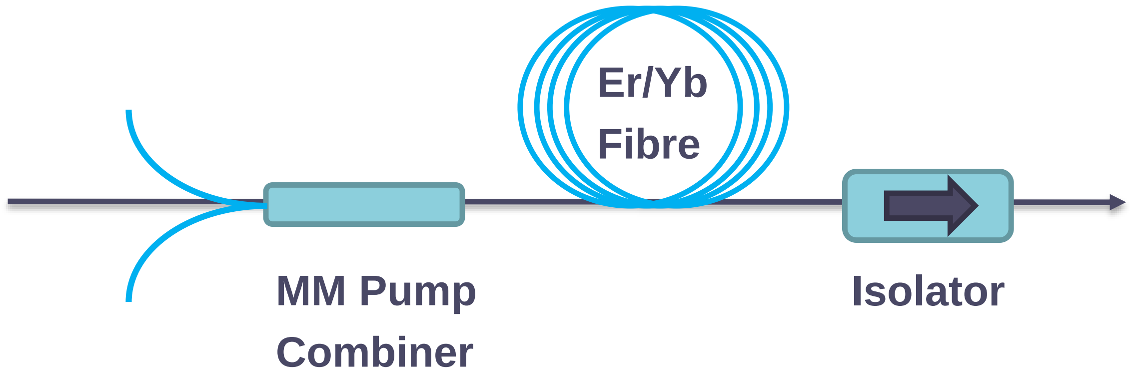
| AF#2 | Predicted | Measured |
|---|---|---|
| 10krad | 7% | 3% |
| 60krad | 37% | 34% |
| 100krad | 54% | 52% |

| AF#3 | Predicted | Measured |
|---|---|---|
| 10krad | 32% | 33% |
| 60krad | 90% | # |
| 100krad | 98% | # |

| AF#4 | Predicted | Measured |
|---|---|---|
| 10krad | 2% | # |
| 60krad | 8% | 15% |
| 100krad | 12% | 18% |

# Conclusion

- **2 Candidate Er/Yb active fibres identified**
  - Performance understood both in terms offline testing and testing in amplifier arrangement
- **Passive Optical Components Validated**




## Next Steps

**Construction of Prototype Module**

- **Utilising selected Components/Fibre**

**THANK YOU FOR YOUR ATTENTION**