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Design and Component Selection of a 1310/1550 nm Wavelength Division Multiplexed Fiber Optic Detection System with Optical Feedback Monitoring

Abstract

This project presents the design and component selection of a wavelength division multiplexed (WDM) fiber optic detection system operating at the telecommunications wavelengths of 1310 nm and 1550 nm. The proposed system combines two independently modulated laser diode sources using a passive WDM multiplexer and routes the combined optical signal through an optical filtering stage before wavelength separation and photodetection. A passive optical feedback coupler is incorporated into the design to monitor the combined optical signal prior to filtering. The system utilizes standard telecommunications single-mode optical fiber, a laboratory-grade amplified InGaAs monitoring detector, and lower-cost telecom-compatible InGaAs photodiodes for wavelength detection. Multiple implementation approaches, including laboratory-grade, telecom-grade, and low-cost surplus architectures, were evaluated based on complexity, performance, affordability, and component availability. A hybrid telecommunications/laboratory architecture was ultimately selected due to its balance

between realistic implementation, modularity, scalability, experimental capability, and cost-effectiveness.

Introduction

Fiber optic communication systems are widely used in modern telecommunications because they provide extremely high bandwidth, low attenuation, and strong immunity to electromagnetic interference. One of the most important technologies used in fiber optic communications is Wavelength Division Multiplexing (WDM), which allows multiple optical wavelengths to simultaneously propagate through a single optical fiber.

The wavelengths of 1310 nm and 1550 nm are commonly used in telecommunications systems because they correspond to low-loss transmission regions in silica optical fiber. The 1310 nm wavelength region provides low chromatic dispersion in standard single-mode fiber, while the 1550 nm region offers extremely low attenuation and compatibility with optical amplification systems.

The purpose of this project was to design a wavelength-selective optical system capable of:

- generating modulated optical signals at 1310 nm and 1550 nm,
- combining both wavelengths onto a single optical fiber,
- monitoring the combined optical signal,
- filtering optical wavelengths,
- separating the wavelengths using passive WDM hardware,
- and detecting the separated wavelengths using InGaAs photodetectors.

The system was designed using commercially available optical components while emphasizing affordability, modularity, compatibility with standard telecommunications hardware, and realistic engineering implementation methods.

System Requirements and Design Goals

The primary objective of the project was to create a practical and affordable wavelength-selective optical system using commercially available telecommunications hardware.

Design Requirements

Table 1: System Requirements

Requirement	Design Goal
Operating Wavelengths	1310 nm and 1550 nm
Optical Fiber Type	Single-mode fiber
Multiplexing Method	Passive WDM
Detection Method	InGaAs photodetection
Optical Monitoring	Passive feedback coupler
Laser Operation	Modulated optical sources
Cost Objective	Minimize total cost
Expandability	Telecom-compatible modular design
Safety	Low-power fiber-coupled lasers

System Architecture

Proposed System Architecture

The final proposed optical system architecture is shown below.

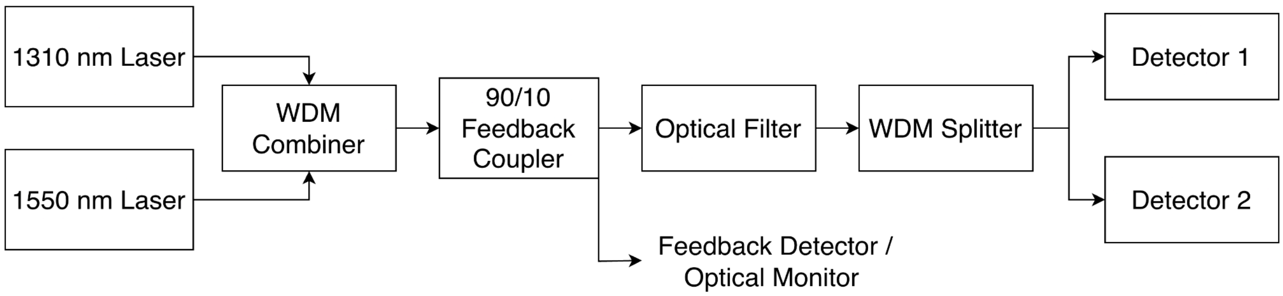

Figure 1. Proposed 1310/1550 nm WDM optical detection system architecture with hybrid optical monitoring and wavelength detection.

The system begins with two independently modulated laser diode sources operating at 1310 nm and 1550 nm. These optical signals are combined onto a single optical fiber using a passive WDM multiplexer.

A 90/10 optical feedback coupler is placed after the combiner stage to tap a small portion of the combined optical signal for monitoring purposes. The feedback branch is connected to a laboratory-grade amplified InGaAs detector to verify that both wavelengths are present prior to filtering.

The combined signal then passes through a passive optical filtering stage designed to remove one wavelength while allowing the other wavelength to continue propagating through the system.

After filtering, a second WDM component acts as a demultiplexer to separate the wavelengths into independent output paths. The WDM splitter routes different wavelengths into separate detector paths, allowing the active detector channel to indicate which wavelength remains present after filtering.

Theory of Operation

Modulated Laser Sources

The proposed system uses two independently modulated laser diode sources operating at 1310 nm and 1550 nm. Modulation capability allows the optical signals to carry information or test waveforms similar to those used in telecommunications systems.

Fiber-coupled laser sources with built-in modulation capability were investigated because they simplify implementation and eliminate the need for custom laser driver circuitry.

Single-mode fiber was selected because it is optimized for transmission at 1310 nm and 1550 nm while minimizing modal dispersion.

Wavelength Division Multiplexing

Wavelength Division Multiplexing allows multiple optical wavelengths to share a single optical fiber simultaneously. Passive WDM components contain wavelength-selective optical filters that route different wavelengths between different ports.

The first WDM combines the 1310 nm and 1550 nm optical signals onto one fiber path, while the second WDM separates the wavelengths into independent detector channels.

Advantages of passive WDM systems include: no electrical power requirements, low insertion loss, high wavelength isolation, and compatibility with standard telecommunications hardware.

Optical Feedback Monitoring

A 90/10 optical coupler is incorporated into the system to monitor the combined optical signal before filtering. Approximately 90% of the optical power continues through the primary signal path while 10% is routed to a monitoring branch.

The monitoring branch uses a Thorlabs PDA10CS2 amplified InGaAs detector. This detector includes integrated amplification and direct BNC oscilloscope interfacing, allowing the combined optical signal and modulation characteristics to be monitored without additional analog front-end circuitry.

This stage allows verification that both optical wavelengths are present, modulation is functioning properly, and the combined optical signal is propagating correctly before entering the filtering stage.

Optical Power Budget

An approximate optical power budget was evaluated to ensure sufficient optical power reaches the detector stage after insertion losses from passive optical components.

Assuming a typical SFP optical transmitter output power of approximately 1 mW (0 dBm), each passive WDM introduces approximately 0.5 dB insertion loss. The 90/10 feedback coupler diverts approximately 10% of the optical power to the monitoring branch while allowing roughly 90% of the optical signal to continue through the primary optical path.

After accounting for WDM insertion losses, connector losses, and feedback coupler attenuation, the expected optical power reaching the detector stage remains well within the sensitivity range of standard InGaAs photodetectors. This confirms that the proposed architecture is feasible using commercially available telecommunications components.

Optical Filtering

The optical filter stage selectively removes one wavelength from the combined optical signal. Several filtering approaches were investigated including dedicated optical bandpass filters, Fiber Bragg Gratings, and reused WDM components.

Using an additional telecommunications WDM component as a wavelength-selective filter was determined to be the most affordable and practical solution.

Photodetection

The proposed system utilizes a hybrid detector architecture to balance performance, simplicity, and overall system cost.

The optical monitoring branch utilizes a Thorlabs PDA10CS2 amplified InGaAs detector to simplify oscilloscope interfacing and modulation verification. This detector includes integrated amplification and direct BNC output connectivity, allowing the combined optical signal to be monitored without requiring external analog amplification circuitry.

The wavelength output branches utilize lower-cost telecom-compatible InGaAs photodiodes because these detectors only need to confirm wavelength presence and relative optical power levels after wavelength separation. A 1 mm active-area InGaAs photodiode in a TO-46 package was selected because the larger active area simplifies optical alignment compared to smaller precision photodiodes while maintaining compatibility with 1310 nm and 1550 nm telecommunications wavelengths.

Since the WDM splitter routes different wavelengths into separate output paths, the active detector channel identifies which wavelength is present after filtering.

Component Selection

Modulated Laser Source Selection

Table 2: Laser Source Selection

Part	Wavelength	Output Power	Cost (per unit)	Datasheet	Manufacturer
SFP1G-LX-31	1310nm	~1 mW	$10.00	FS.com datasheet	FS.com
SFP1G-ZX-55	1550nm	~1 mW	$34.00	FS.com datasheet	FS.com
Thorlabs S3FC1310	1310nm	1.5 mW	$3,484.01	Product datasheet	Thorlabs
Thorlabs S1FC1550	1550nm	1.5 mW	$1,794.76	Product datasheet	Thorlabs

Selected Solution

Telecommunications SFP optical transceiver modules were selected because they provide integrated laser driver circuitry, stable telecom wavelength generation, direct fiber coupling, and digital modulation capability while maintaining very low system cost.

The selected SFP modules also provide compact implementation, compatibility with standard single-mode telecommunications fiber, low optical power operation, and simplified system integration compared to discrete laser diode driver designs.

Laboratory-grade Thorlabs laser systems were investigated as higher-performance alternatives but were ultimately not selected due to significantly higher cost.

WDM Combiner and Splitter Selection

Table 3: Combiner/Splitter Selection

Part	Wavelength	Type	Cost (per unit)	Datasheet	Manufacturer
FS #65811 FWDM	1310 nm / 1550 nm	Passive	$43–$65	FS.com datasheet	FS.com
WDM13500129UC	1310 nm / 1550 nm	Passive	$16.95	Vendor datasheet	Fiber Instrument Sales
WD1315-L-91X	1310 nm / 1550 nm	Passive	$138	Vendor datasheet	Fiber-Mart
High Temperature 200°C 1310/1550 WDM	1310 nm / 1550 nm	Passive	$398	Vendor datasheet	LightOptics
F-CPL-B14350	1310 nm / 1550 nm	Broadband Optical Coupler	$215	Product datasheet	Newport

Selected Solution

Telecommunications-grade passive FWDM components were selected because they provide low insertion loss, compatibility with 1310 nm and 1550 nm telecommunications wavelengths, passive operation without electrical power, low implementation complexity, and realistic telecommunications system architecture.

The FS.com #65811 FWDM modules were selected because they provide the best balance between affordability, compatibility, availability, and realistic telecom implementation.

Optical Feedback Coupler Selection

Table 4: Feedback Coupler Selection

Part	Connector Type	Split Ratio	Cost (per unit)	Datasheet	Manufacturer
SDW13510129UC	FC/APC	90/10	$24.00	Vendor datasheet	FiberOptics4Sale
FIS-1X2-SM-1310/ 1550-10/90	FC/APC	90/10	$16.95	Vendor datasheet	Fiber Instrument Sales
TD1315R2A1	FC/APC	99/1	$307	Product datasheet	Thorlabs
F-CPL-B12351-FC APC	FC/APC	Broadband	$300+	Product datasheet	Newport

Selected Solution

A dual-window 1×2 single-mode fused fiber coupler with a 90/10 split ratio was selected for optical feedback monitoring because it supports both 1310 nm and 1550 nm telecommunications wavelengths while minimizing insertion loss and overall system cost.

The selected coupler allows approximately 10% of the combined optical power to be routed toward the monitoring detector while preserving approximately 90% of the optical signal within the primary transmission path.

Optical Filter Selection

Table 5: Filter Selection

Part	Connector Type	Type	Cost (per unit)	Datasheet	Manufacturer
Additional FS #65811 FWDM	LC/UPC	Passive	\$43–\$65	FS.com datasheet	FS.com
1550 nm Bandpass Filter	FC/APC	Passive	\$400	Product datasheet	Thorlabs
Fiber Bragg Grating	FC/APC	Passive	\$800	Product datasheet	Newport

Selected Solution

An additional telecommunications FWDM module was selected as the optical filtering stage because it provides:

- low insertion loss,
- simplified fiber integration,
- passive wavelength routing,
- low implementation complexity,

- and strong compatibility with the selected telecommunications hardware architecture.

Using an additional FWDM module as a wavelength-selective filter significantly reduced overall system cost compared to dedicated laboratory optical filtering hardware.

Detector Selection

Table 6: Detector Selection

Part	Complexity	Type	Cost (per unit)	Datasheet	Manufacturer
1 mm TO-46 InGaAs Photodiode	Low	Passive	$51.52	Vendor datasheet	Generic Telecom Supplier
PDA10CS2 Amplified Detector	Low	Powered	$509.71	Product datasheet	Thorlabs
Newport Amplified Detector	Medium	Powered	$1200	Product datasheet	Newport
Lilly Electronics 0.3 mm InGaAs PD	Medium	Passive	$158	Product datasheet	Lilly Electronics
Lilly Electronics 0.5 mm InGaAs PD	Medium	Passive	$228	Product datasheet	Lilly Electronics

Selected Solution

A hybrid detector architecture was selected to balance performance, instrumentation capability, and overall system cost.

The optical monitoring branch utilizes a Thorlabs PDA10CS2 amplified InGaAs detector to simplify oscilloscope interfacing and modulation verification.

The wavelength output branches utilize lower-cost telecom-compatible InGaAs photodiodes because these detectors only need to confirm wavelength presence and relative optical power levels after wavelength separation.

The selected 1 mm active-area TO-46 photodiodes provide easier optical alignment and significantly lower cost compared to smaller precision photodiodes while remaining fully compatible with 1310 nm and 1550 nm telecommunications wavelengths.

Fiber and Connector Selection

Table 7: Fiber/Connector Selection

Part	**Complexity**	**Type**	**Cost (per unit)**	**Datasheet**	**Manufacturer**
SMF-28 Fiber Cable	Low	Single-mode	$10	Corning datasheet	Corning
FC/PC Connectors	Low	Passive	$7	Manufacturer datasheet	FS
FC/APC Connectors	Low	Passive	$12	Manufacturer datasheet	Thorlabs

Selected Solution

SMF-28 single-mode fiber with FC/PC connectors was selected because it is: affordable, standardized, compatible with telecommunications wavelengths, and widely available.

Tier Comparison and Cost Analysis

Table 8: Comparison Table

Tier	Performance	Complexity	Estimated Cost	Advantages	Disadvantages
Full Laboratory	Excellent	Medium	\$4000–\$12000+	Highest precision and instrumentation capability	Extremely expensive
Hybrid Telecom/Lab (Selected)	Very Good	Medium	\$1000–\$1800	Excellent balance of cost, capability, and realism	Slightly more complex
Budget Telecom	Moderate	Low	\$350–\$700	Very affordable and simple	Reduced monitoring capability

The hybrid telecommunications/laboratory implementation was selected because it provided the best balance between affordability, instrumentation capability, scalability, and realistic engineering implementation.

Final Selected Design

Table 9: Final Recommended Components

Component	Selected Solution
Laser Sources	FS.com SFP1G-LX-31 and SFP1G-ZX-55
WDM Combiner	FS.com #65811 FWDM
Feedback Coupler	SDW13510129UC
Monitoring Detector	Thorlabs PDA10CS2
Optical Filter	Additional FS.com #65811 FWDM
WDM Splitter	FS.com #65811 FWDM
Output Detectors	1 mm TO-46 InGaAs Photodiodes
Fiber	Corning SMF-28 Single-Mode Fiber

Consolidated Bill of Materials (BOM)

Table 10: BOM Table

Item	Manufacturer	Part Number	Qty	Unit Cost	Extended Cost	Purchase Link
1310 nm Laser Source	FS.com	SFP1G-LX-31	1	$10.00	$10.00	https://www.fs.com/products/75327.html
1550 nm Laser Source	FS.com	SFP1G-ZX-55	1	$34.00	$34.00	https://www.fs.com/products/29856.html
WDM Combiner	FS.com	#65811 FWDM	1	$65.00	$65.00	https://www.fs.com/products/65811.html
Feedback Coupler	FiberOptics4Sale	SDW13510129UC	1	$24.00	$24.00	https://www.fiberoptics4sale.com/products/sdw13510129uc
Monitoring Detector	Thorlabs	PDA10CS2	1	$509.71	$509.71	https://www.thorlabs.com/item/PDA10CS2
Optical Filter	FS.com	#65811 FWDM	1	$65.00	$65.00	https://www.fs.com/products/65811.html
WDM Splitter	FS.com	#65811 FWDM	1	$65.00	$65.00	https://www.fs.com/products/65811.html
Output Detector	Generic Telecom Supplier	1 mm TO-46 InGaAs PD	2	$51.52	$103.04	https://www.ebay.com/itm/196670817057
Single-Mode Patch Cable	Fiber Instrument Sales	FCBUFCFC-2M	6	$7.95	$47.70	https://www.fiberinstrumentsales.com/fis-duplex-3mm-sm-fc-fc-apc-ultra-fiber-patch-cable-1-mtr.html

Table 11: Estimated Total System Cost

Category	Estimated Cost
Laser Sources	$44.00
WDM Components	$195.00
Feedback Coupler	$24.00
Monitoring Detector	$509.71
Output Detectors	$103.04
Fiber Patch Cables	$47.70
Estimated Total	**$923.45**

Challenges and Limitations

Several engineering challenges were identified during the design process including: connector compatibility, insertion losses through passive optical devices, detector spectral overlap, sourcing affordable telecommunications hardware, and maintaining low overall system complexity.

Additional considerations included optical reflections, coupling efficiency, and laser safety since 1310 nm and 1550 nm optical signals are invisible to the human eye.

Future Improvements

Potential future improvements include:

- CWDM or DWDM expansion
- tunable optical filters
- FPGA or microcontroller-based signal processing
- optical spectrum analyzer integration
- automatic wavelength identification
- and BER analysis

The addition of digital signal processing could significantly expand the system's measurement capabilities.

Conclusion

A wavelength division multiplexed fiber optic detection system operating at 1310 nm and 1550 nm was successfully designed using commercially available telecommunications hardware. The proposed system incorporates modulated laser sources, passive WDM multiplexing, optical feedback monitoring, wavelength-selective filtering, and hybrid photodetection architecture.

Multiple implementation tiers were evaluated and compared based on cost, complexity, performance, and component availability. A hybrid telecommunications/laboratory architecture was ultimately selected because it provided the best balance between affordability, instrumentation capability, realism, modularity, and engineering practicality.

The proposed system demonstrates many of the same wavelength routing, monitoring, and detection techniques used in modern telecommunications systems while remaining accessible for educational and laboratory applications.

Appendix A — Purchasing Links and Component Sources

Modulated Laser Sources

Component	SKU / Part Number	Supplier	Estimated Cost	Direct Link
Selected 1310 nm Modulated Source	SFP1G-LX-31 / FS SKU 75327	FS.com	$10.00	https://www.fs.com/products/75327.html
Selected 1550 nm Modulated Source	SFP1G-ZX-55 / FS SKU 29856	FS.com	$34.00	https://www.fs.com/products/29856.html
Laboratory 1310 nm Laser Source	S3FC1310	Thorlabs	$3,484.01	https://www.thorlabs.com/thorproduct.cfm?partnumber=S3FC1310
Laboratory 1550 nm Laser Source	S1FC1550	Thorlabs	$1,794.76	https://www.thorlabs.com/thorproduct.cfm?partnumber=S1FC1550

WDM Components

Component	SKU / Part Number	Supplier	Estimated Cost	Direct Link
Selected Telecom FWDM	FS #65811	FS.com	$43–$65	https://www.fs.com/products/65811.html
Budget Telecom WDM	WDM13500129UC	Fiber Instrument Sales	$16.95	https://www.fiberinstrumentsales.com/fis-1x2-sm-dual-window-1310-1550nm-wdm-50-50-ratio-900um.html
Mid-Range Precision WDM	WD1315-L-91X / Item #16724	Fiber-Mart	$138	https://www.fiber-mart.com/wdm-coupler-singlemode-13101550nm-wdm-p-16724.html
High-Temperature Industrial WDM	High Temperature 200°C 1310/1550nm WDM Coupler	LightOptics	$398	https://www.lightoptics.co.uk/products/high-temperature-wdm-1310-1550nm-single-mode-wdm-coupler
Laboratory Broadband Optical Coupler	F-CPL-B14350	Newport	$215	https://www.newport.com/p/F-CPL-B14350

Feedback Couplers

Component	SKU / Part Number	Supplier	Estimated Cost	Direct Link
Selected 90/10 Feedback Coupler	SDW13510129UC	FiberOptics4Sale	$24.00	https://www.fiberoptics4sale.com/products/sdw13510129uc
Alternative 90/10 Coupler	FIS-1X2-SM-1310/1550-10/90	Fiber Instrument Sales	$16.95	https://www.fiberinstrumentsales.com/fis-1x2-sm-coupler-dual-window-1310-1550-10-90-split.html
Laboratory Tap Coupler	TD1315R2A1	Thorlabs	$307	https://www.thorlabs.com/item/TD1315R2A1
High-End Broadband Coupler	F-CPL-B12351-FCAPC	Newport	$300+	https://www.newport.com/p/F-CPL-B12351-FCAPC

Detectors

Component	SKU / Part Number	Supplier	Estimated Cost	Direct Link
Monitoring Detector	PDA10CS2	Thorlabs	$509.71	https://www.thorlabs.com/item/PDA10CS2
Selected Output Detector	1 mm TO-46 InGaAs PD	Generic Telecom Supplier	$51.52	https://www.ebay.com/itm/196670817057
Alternative Output Detector	0.3 mm InGaAs PD	Lilly Electronics	$158	https://www.lillyelectronicsllc.com/400-1700nm-0-3mm-ingaas-pin-photodiode-with-3mm-flat-wwindow-package-to-46
Alternative Output Detector	0.5 mm InGaAs PD	Lilly Electronics	$228	https://www.lillyelectronicsllc.com/400-1700nm-0-5mm-ingaas-pin-photodiode-with-3mm-flat-wwindow-package-to-47

Fiber and Patch Cables

Component	SKU / Part Number	Supplier	Estimated Cost	Direct Link
FC/FC Single-Mode Patch Cable	FIS Duplex 3mm SM FC-FC APC Ultra Fiber Patch Cable, 1 m	Fiber Instrument Sales	$4.25	https://www.fiberinstrumentsales.com/fis-duplex-3mm-sm-fc-fc-apc-ultra-fiber-patch-cable-1-mtr.html
Ultra Low Loss FC/APC Cable	Ultra Low Loss 0.1 dB FC/APC to FC/APC Single-mode Simplex Cable	SpeedyFiberTX	$10.11	https://www.speedyfibertx.com/products/ultra-low-loss-fc-fc-apc-singlemode-simplex-ofnp

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