



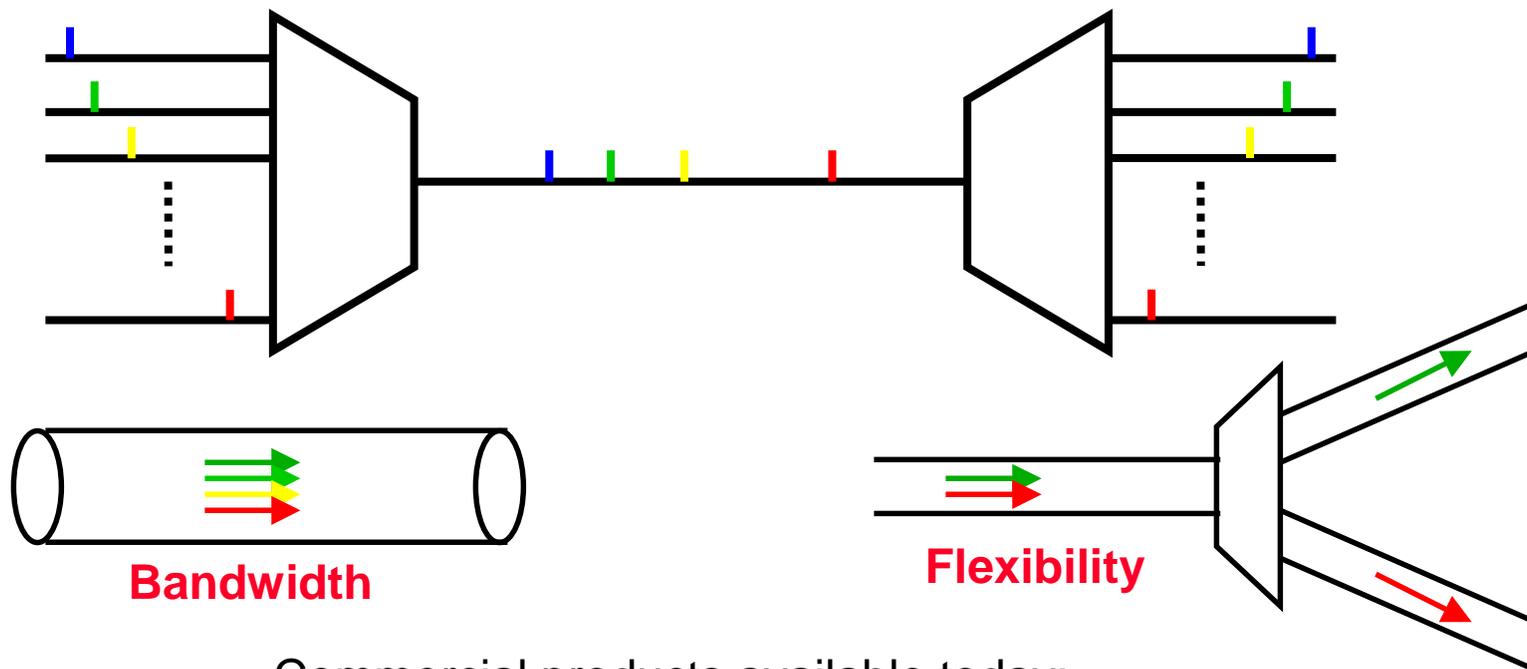
Selected WDM Military Interests

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DARPA WDM WORKSHOP
28 JUN 01

Wavelength Division Multiplexing (WDM) Commercial Technology

WDM uses multiple wavelengths of light to increase the *bandwidth* and architectural *flexibility* of a fiber optic networking system.



Commercial products available today:

2 to 100+ wavelengths (DWDM/CWDM)

> 400 Gb/s capacity

Evolution of IP Photonic Networks

Trend towards less network management

IP
ATM (QOS)
SONET
WDM

1998

IP w/ MPLS
SONET
WDM

2001

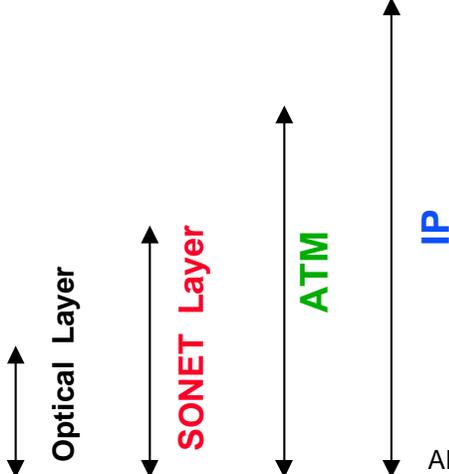
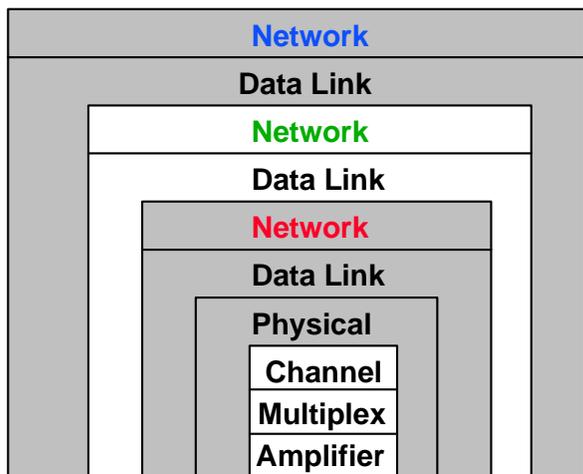
LAN / MAN
IP
10Gb Ethernet
WDM

2004

Along with Ethernet technology, WDM technology will become prominent in Metro Area Networking (MAN) and Local Area Networking (LAN) topologies.

Military platform networking most resembles the MAN environment with high priority on Quality of Service (QoS).

Level 3 and below



WDM Technology

Commercial implementations

- mature technology for long haul **high bandwidth** networks (DWDM)
- recent commercial implementation in MANs and SCM access
- many system implementation competitors (Lucent, Nortel, Ciena, AT&T,..)
- many component suppliers (JDSU, Corning, Lucent, Nortel, Alcatel, Agere, ...)

Research and Development

- Components
- Applications, e.g., CWDM
Ethernet; optical packet
switching

Narrow band laser transmitters / VCSELs	Photodiode receivers
Optical multiplexers / demultiplexer	Optical amplifiers
Fiber Bragg gratings	Add-drop filters
Narrow band optical filters	Wavelength converters
External modulators	Optical switches
MEMS devices	Integrated optical circuits

Military can leverage on commercial WDM investment

- future bandwidth requirements
- **additional** Navy/DOD requirements and applications

Military WDM Technology

A few areas of military WDM interest:

- **Network ruggedization**
 - **Mixed signal antenna networking**
 - **Optical signal processing**
 - **Optical domain microwave filtering**
- Need to differentiate required technology from ongoing **commercial activities**
- Need to differentiate required technology from **DARPA AOSP** Program requirements

Need for Advanced Mixed Signal Optical Networking

Current Optical Networking Technology

High-speed digital networks

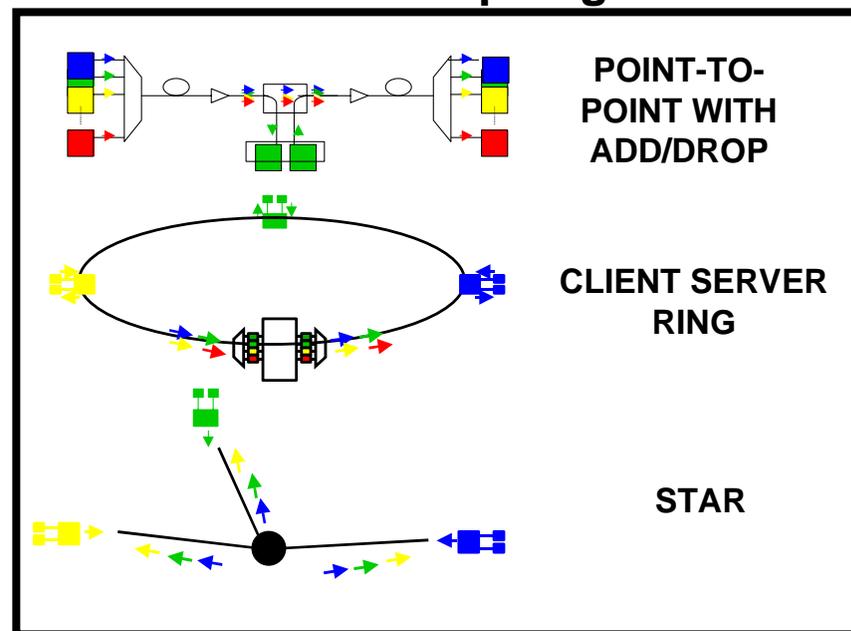
- 10 Gb ethernet
- WDM with >100 channel throughput

High-speed RF networks

- Low loss microwave fiber optic links
- High dynamic range links
- >40 GHz bandwidth available
- Sub-Carrier Multiplexing (SCM)

[CATV, MAN]

Network Topologies



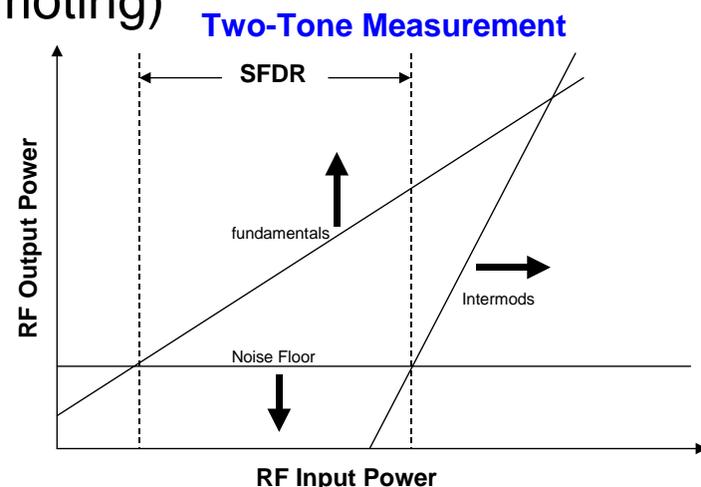
Future Military Optical Networking Vision

High-capacity mixed signal SCM/WDM fiber-optic networks satisfying Military Vision 2020 platform requirements.

High Bandwidth / High Fidelity / High Sensitivity Military RF Networking Issues

- SIGINT/RADAR/COMMS: >80 dB SFDR typical with close to thermal limited RF detection
- *Wideband* military requirements much more demanding than commercial applications that require either *Fidelity* at high input RF powers (CATV) OR *Sensitivity* with lower dynamic range (Wireless Remoting)

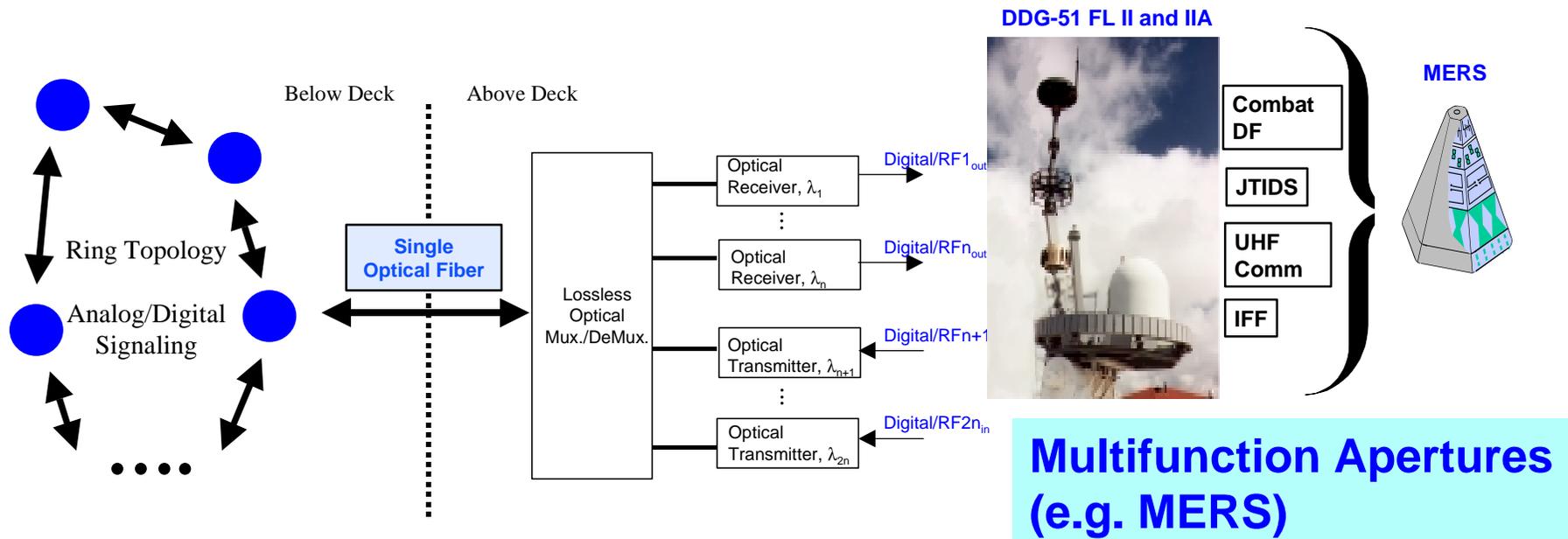
Can military RF signals share a common WDM backbone network with digital signals???



RF Network Components

- Modulators (efficiency, linearity, bandwidth)
- Lasers (DFB; FP; VCSEL) (power, efficiency; amplitude noise, linearity, bandwidth)
- Receivers (efficiency, power handling)
- Fibers (MMF; SMF) (modal, polarization, and chromatic dispersion)
- EDFAs (noise figure, optical bandwidth)
- MUX/DEMUX/ADD/DROP/COUPLERS (loss, isolation, polarization sensitivity)
- Switch Arrays (loss, isolation, polarization sensitivity)

WDM/SCM Sensor & Platform Information Networking



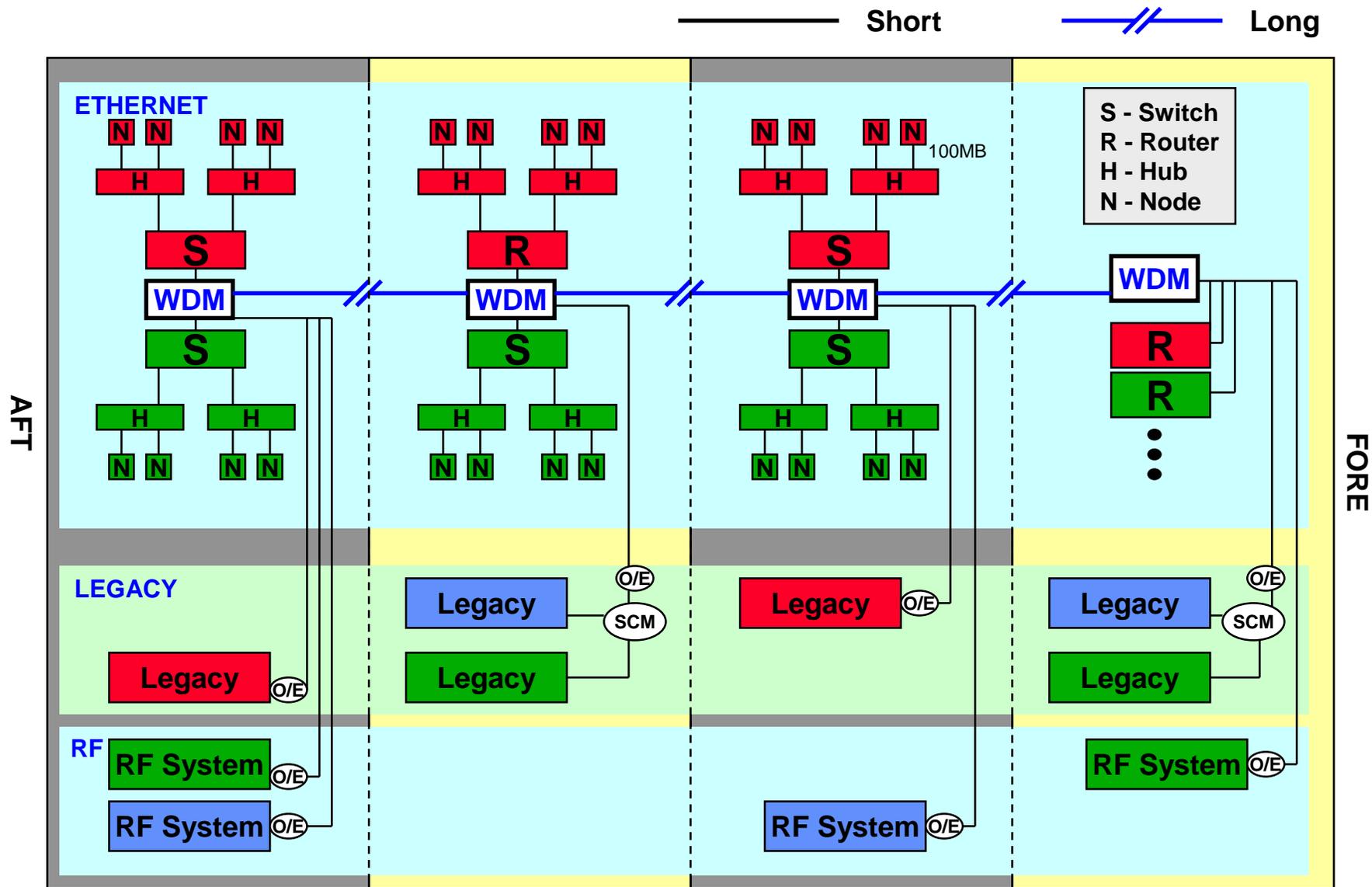
- Network accommodates **ANALOG** and **DIGITAL** signaling
- Useful for Vision 2020 military networks and multifunction antennas
- Sensor and network information available in real-time on demand
- WDM provides increased flexibility, reduced installation & servicing time

Remaining R&D Challenges:

1. Improved **Analog WDM** fiber optic link performance
2. **Integration & Packaging** of SCM/WDM link components

Future Shipboard Networking

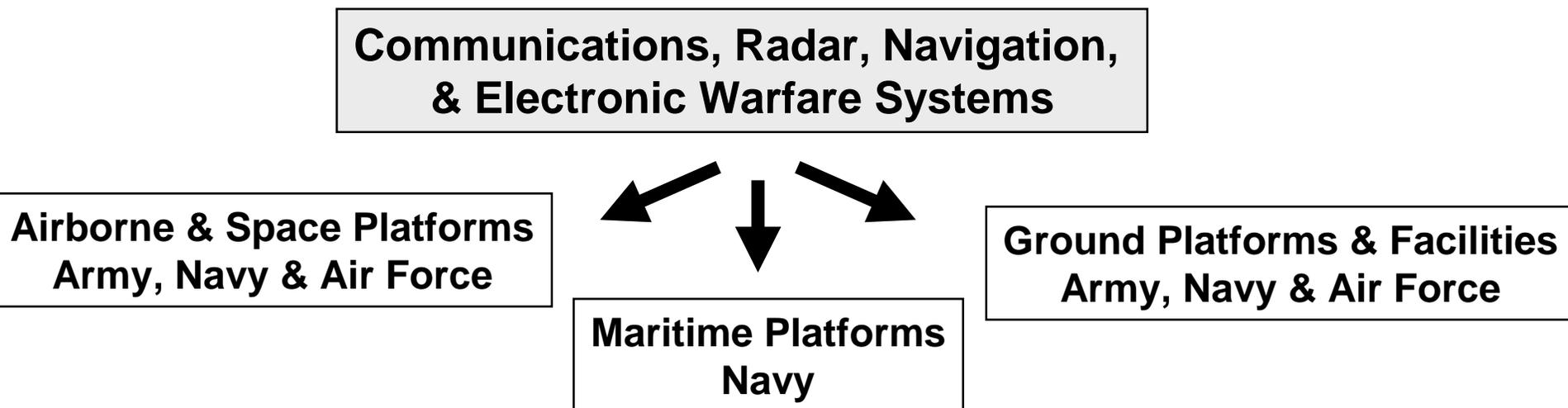
Connections via WDM backbone



Microwave Photonic Signal Processing System Capabilities

- Optical Domain RF Frequency Conversion & Filtering
- Optical True-Time-Delay (TTD) RF Beamforming
- Fiber Optic Delay Line RF Signal Processing

Military RF System Insertion Targets

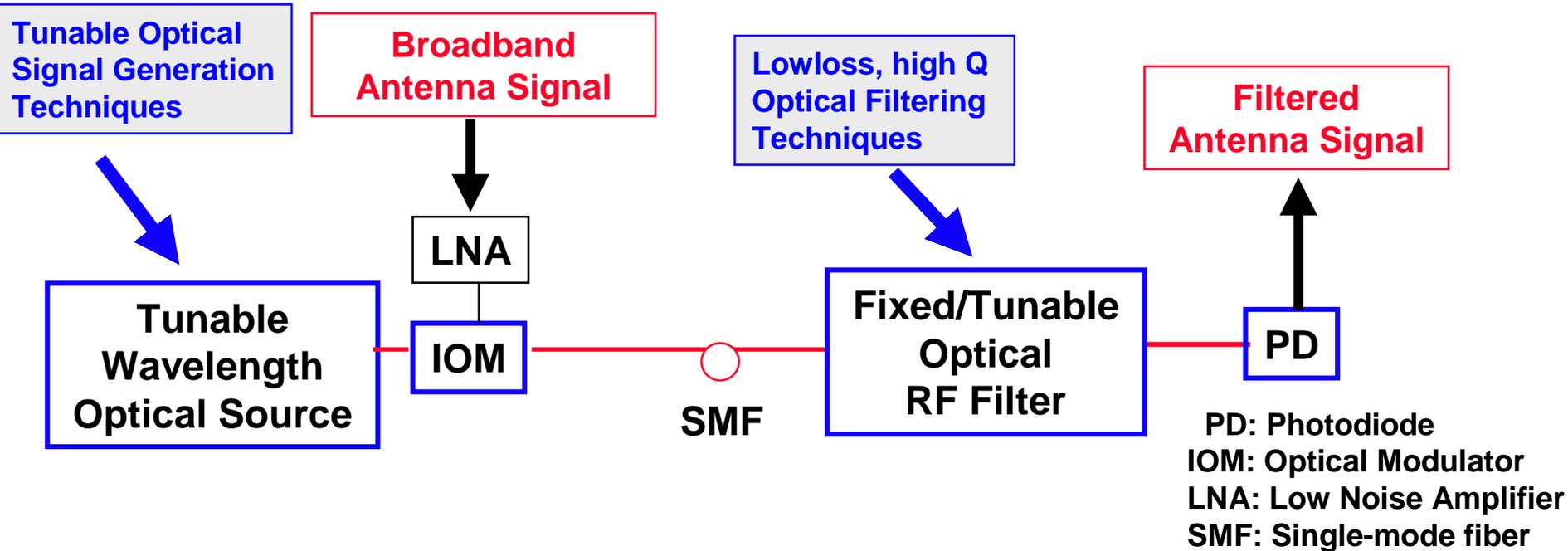


Microwave Photonic Signal Processing

Example

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Optical Domain Microwave Filtering (All Optical Superheterodyne Receiver)

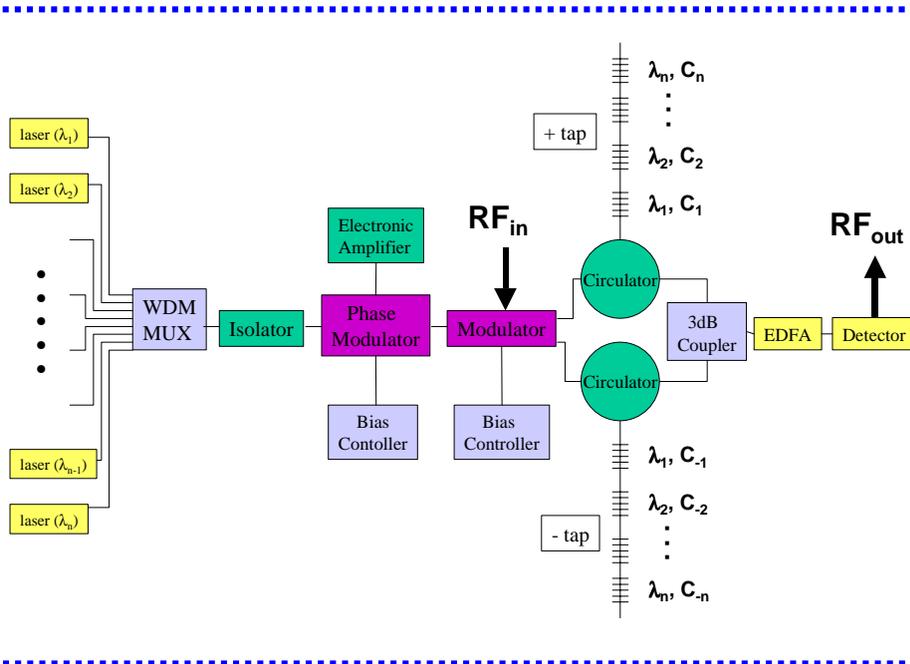


- Eliminates need for electronic mixer (reduced front-end complexity)
- Incorporates pre-selector filtering in optical domain
- Builds upon commercial DWDM telecommunications and millimeter-wave fiber-radio system technologies

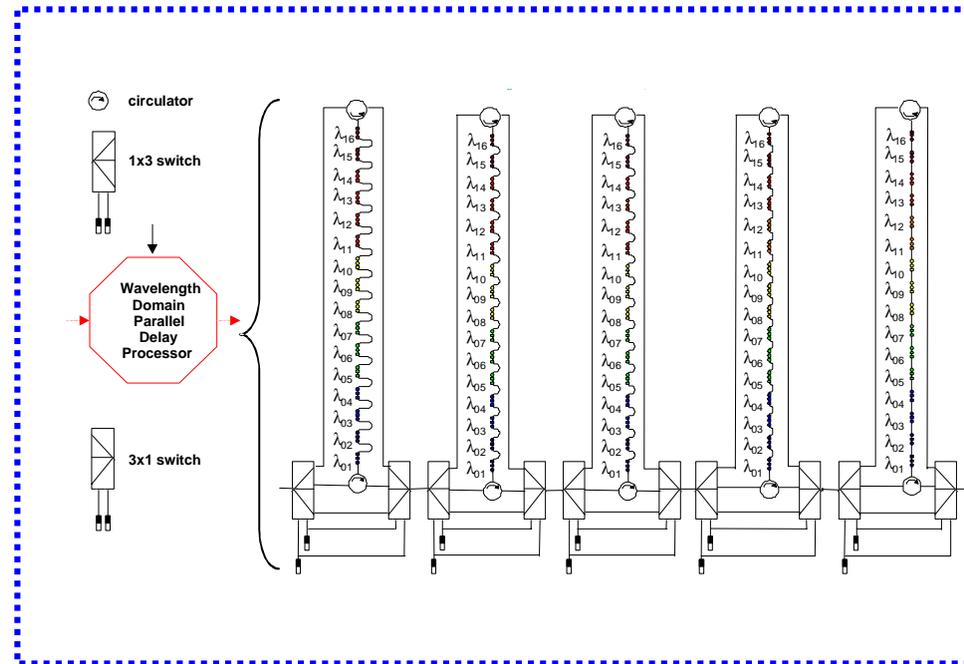
Microwave Photonic Signal Processing

Example

WDM Based Signal Processors



**RF PHOTONIC FRONT-END
TRANSVERSAL FILTER**



**WIDEBAND OPTICALLY MULTIPLEXED
TTD BEAMFORMING ARCHITECTURE**

- Wavelength dispersive signal processing architectures
 - Fast tunable lasers
 - Broadband optical sources

Enabling WDM Component Technologies

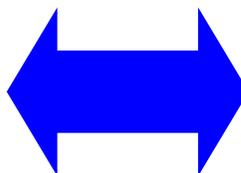
WDM-Based Building Block Examples:

- High channel isolation (>40 dBo), polarization independent passive components
- Fiber Bragg Grating (FBG) arrays
- High-speed (<1 μ sec) tunable optical filters
- Optical domain tunable microwave filters
- High-performance digital/analog WDM transmitter arrays
- High power, low noise, wavelength selectable laser diodes
- High-speed tunable lasers (continuous and discrete)
- High power, spectrally equalized supercontinuum optical sources
- Optically broadband E-O modulators/switches
- Low loss WDM optical switching arrays
- Ruggedized Erbium Doped Fiber Amplifiers (EDFAs)

Proposed Program Goal: Integrated WDM Modules & Functionality

Grand Challenges

Low cost
Size, weight and power
Environmental stability



**Advanced Fabrication,
Integration & Packaging**