



WDM for Military Platforms

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Micro-WDM for Reconfigurable Military Information Systems

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Micro-WDM for Reconfigurable Military Information Systems

- **Platforms and WDM**
- **Micro-WDM Comparison**
- **Switch Comparison**
- **Roadmap**

Micro-WDM for Reconfigurable Military Information Systems

- **A Potentially Ubiquitous Technology**
 - **Space: Space-Based Radar**
 - **Air: UCAV**
 - **Ground: Telco**
 - **Sea: Advanced Networks**

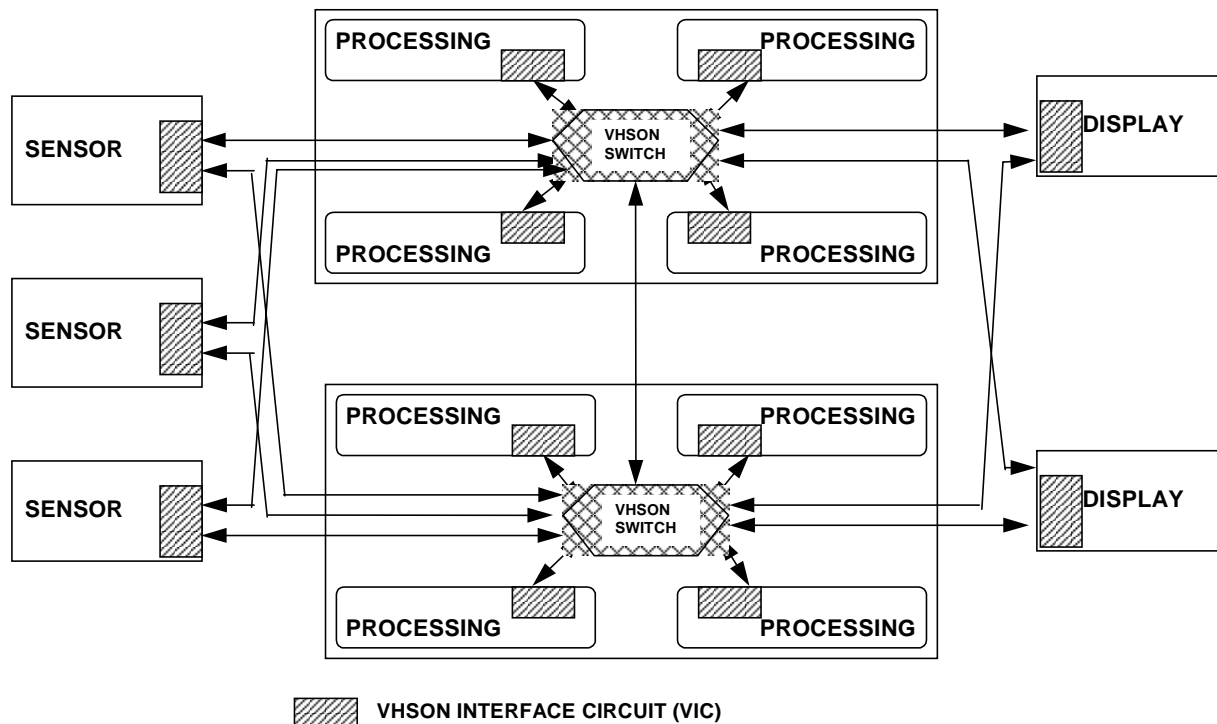
- **System Benefits Include:**
 - **Reduced Size, Weight, Power, Parts Count, System Complexity**
 - **Growth/ Upgrade Facilitation**
 - **Increased Bandwidth, Fault Tolerance, System Flexibility**

Configurable High Speed Optical Networks (Near Term)

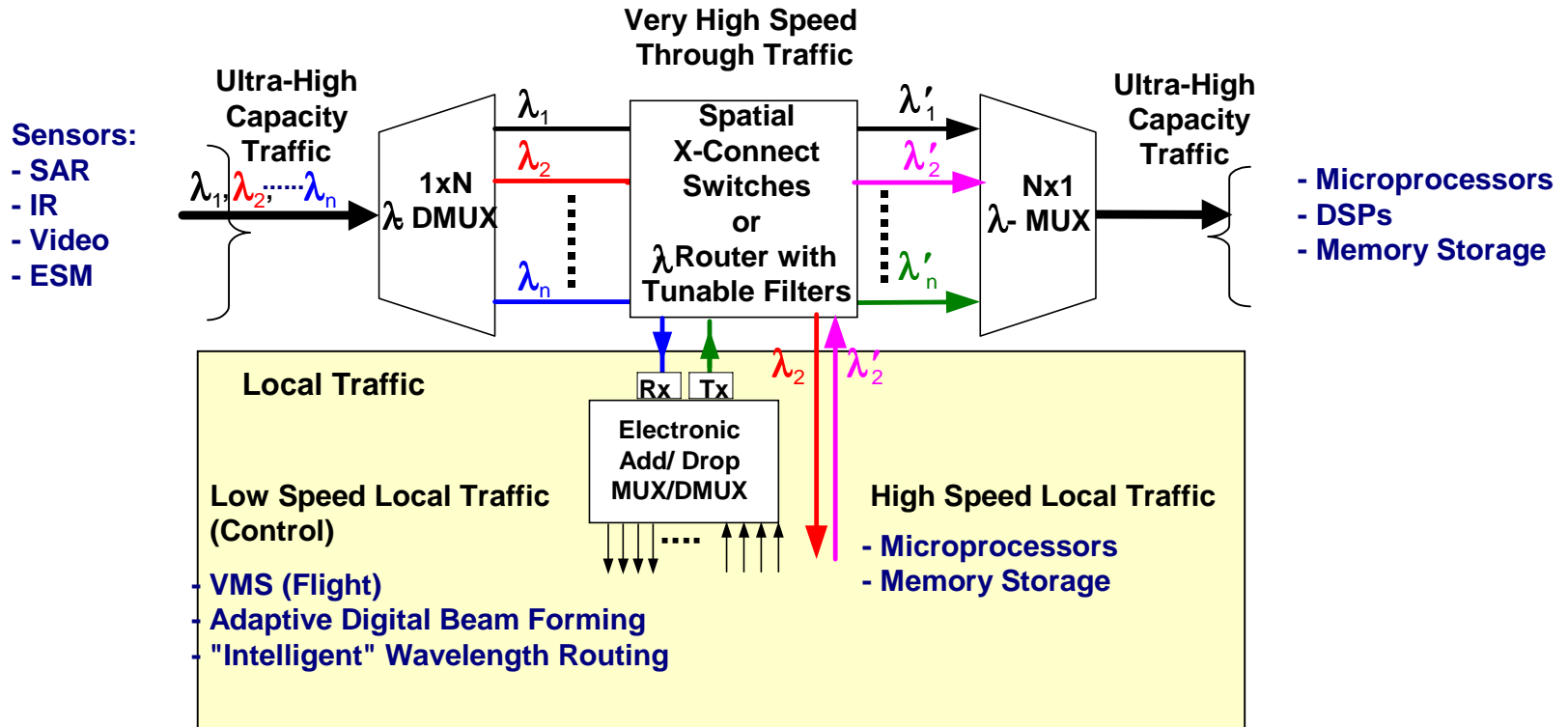
- Tactical Aircraft

- High Bandwidth Fiber Optic I/O for Remote Sensor Fusion, Processing, Storage, and Control
 - IR (eg. hyperspectral), Video, SAR, ESM
 - Microprocessor and Memory
 - Flight Control (Migration from Electrical to Optical)
- Optical Routed Paths (Mesh) (eg. Monterey/ Cisco)
 - Electrical SEM-E Circuit Switch Upgrade

- Scalable, Optical Routable Paths for “Very High Speed Optical Networks” (VHSON)



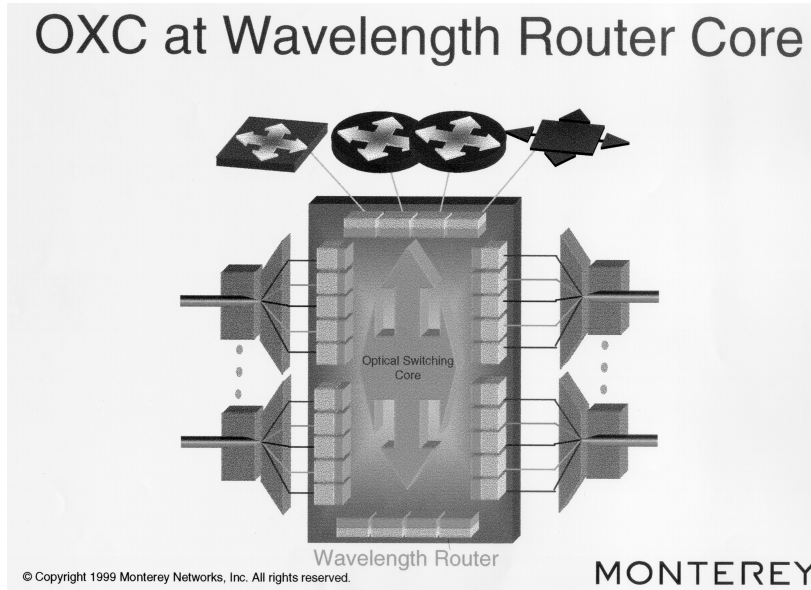
Configurable Optical Wavelength and IP Network (Notional)



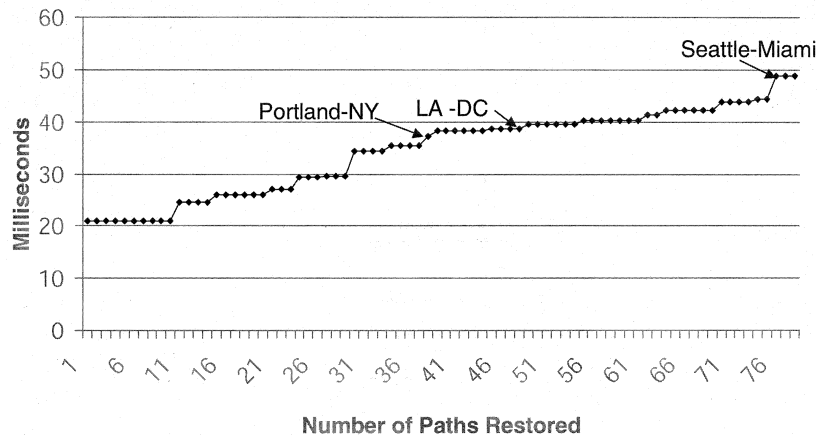
Configurable optical wavelength and IP networks will:

- switch low speed packets of IP data
- establish wavelength circuits or paths for high speed IP data
- establish paths in real-time


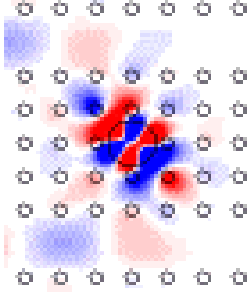
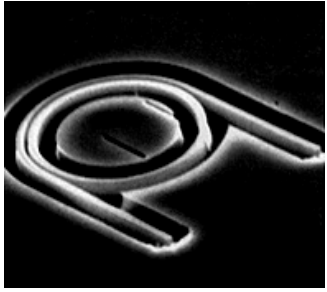
Power Dissipation of This Wavelength Router Will Be Greatly Reduced with an Optical Switch Core !



Dynamic Wavelength Routing Protocol (WARP) Distributed Mesh WaRP Restoration Times



Micro-WDM Technology for Reconfigurable Network Systems

Technology	COTS Array WG Device	Photonic Bandgap (PBG)	Microresonators (MR)
State-of-Art R&D	 <p>Photonic Integration Research Inc.</p>	 <p>Joannopoulos et. al. (MIT) theory & exp.</p>	 <p>Nanovation Tech. Inc. S. T. Ho et. al.</p>
Maturity	64 Channel Devices Available	Patents, 10 yrs. R&D 1 channel filter 5 yr. est. avail.	Patents, 10 yrs. R&D few channel filter avail. today
Insertion Loss	8 dB	3-4 dB (from fiber)	3-4 dB (from fiber)
Crosstalk	22 dB	TBD	TBD
Potential Channel Separation (1500 nm)	50 GHz	< 50 GHz	< 50 GHz
Size	10 cm x 5 cm x 2 cm	1 μm^3 (fiber driven)	1 μm^3 (fiber driven)

Approaches to Micro-WDM

Photonic Crystals with Photonic Bandgaps (PBG)

Approach	Technology	Advantages
PBG microcavity filters in series (see Fan et al, <i>Opt. Express</i> , 3, p.4, 1998 for example)	Photonic crystal of dielectric rods or PBG air bridge in Si	<ul style="list-style-type: none">• Very large Q cavities little crosstalk between channels• Tolerance to fabrication imperfections• Very small $\sim(\lambda/2n)^3$

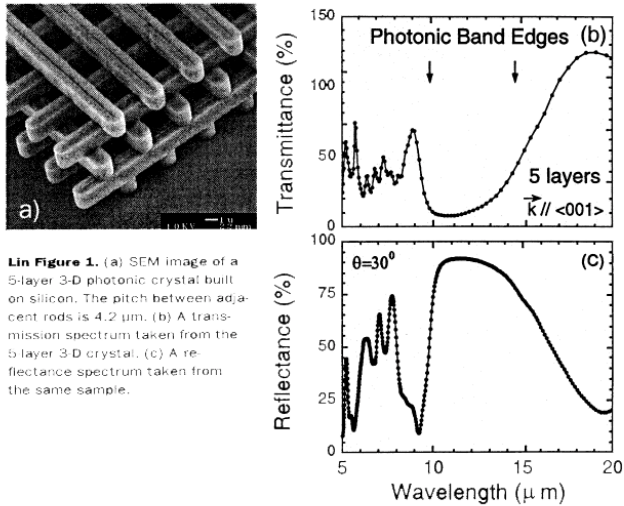
Microresonators (MR)

Approach	Technology	Advantages
<ul style="list-style-type: none">• Extension of high density integrated optics with large Δn	Microresonators <ul style="list-style-type: none">• Nanovation• NWU, MIT	<ul style="list-style-type: none">• Commercially available in few element arrays

Photonic Crystal Super- Prisms

Examples of Photonic Band Gaps

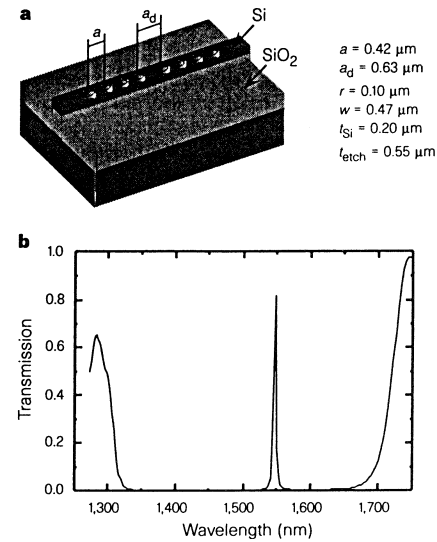
Creation of a 3-D Silicon Photonic Crystal



Lin Figure 1. (a) SEM image of a 5-layer 3-D photonic crystal built on silicon. The pitch between adjacent rods is 4.2 μm . (b) A transmission spectrum taken from the 5 layer 3-D crystal. (c) A reflectance spectrum taken from the same sample.

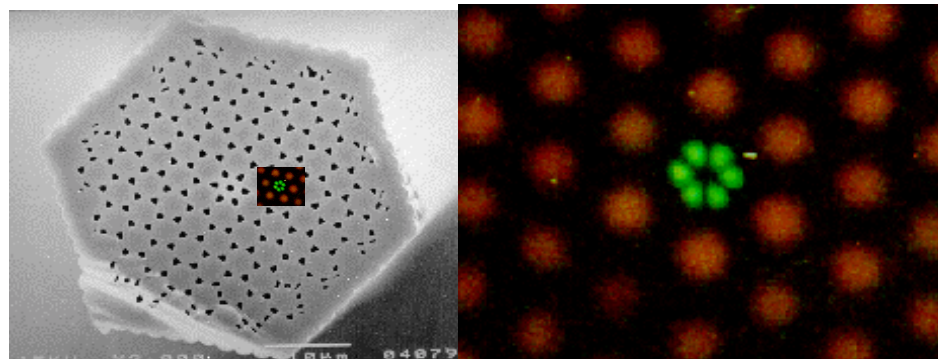
Shawn-Yu Lin and J.G. Fleming, Sandia National Laboratories, Optics and Photonic News / p. 35, December 1998

Photonic Bandgap Filter in Optical Waveguide



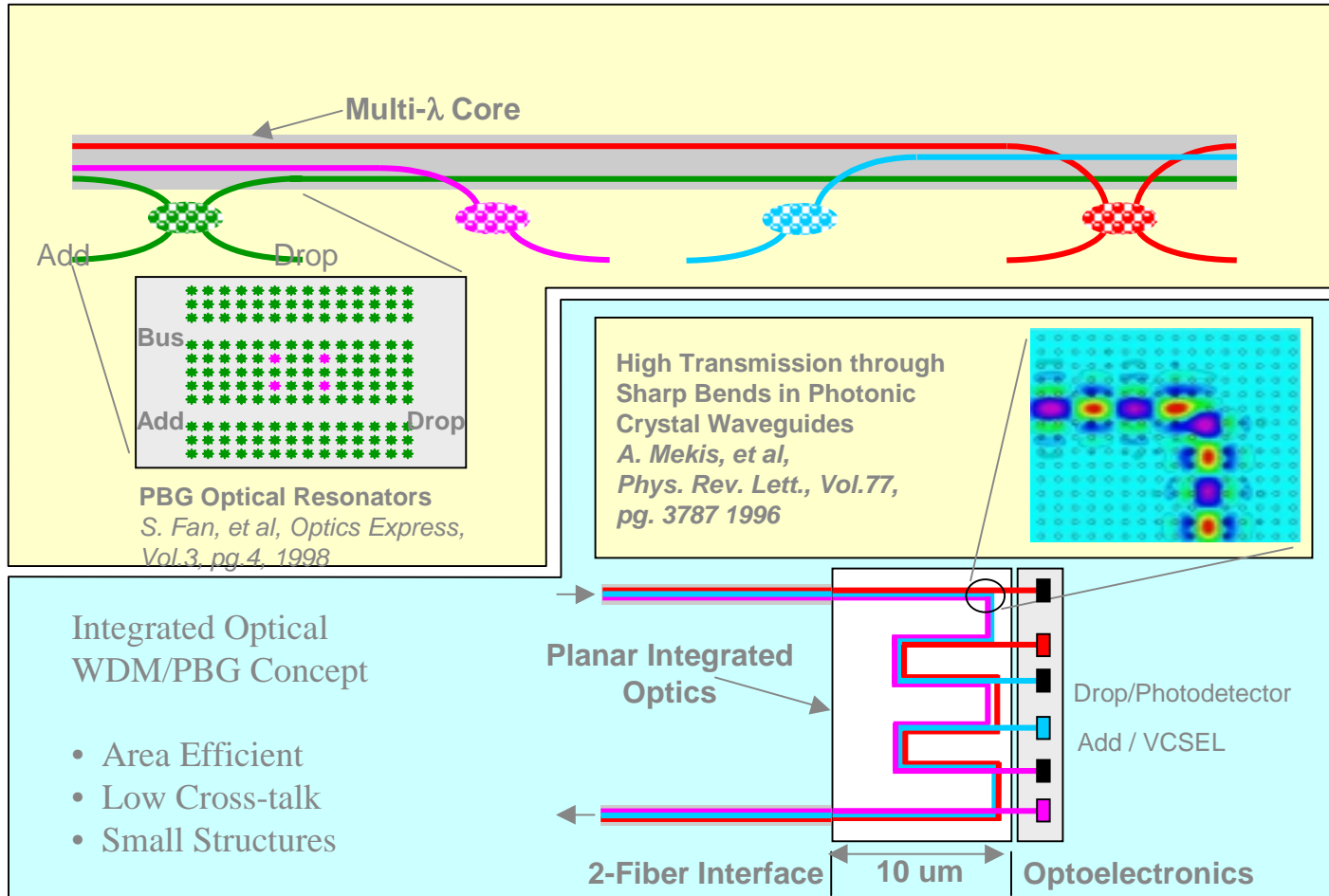
J.S. Foresi, P.R. Villeneuve, et al., MIT, Nature, vol. 390, pp. 143-5, 1997

Narrow 2-D PBG fiber waveguide: extra “defect” air core filters white light source



<http://www.bath.ac.uk/Departments/Physics/opto/research.htm#pbg>

Optical Fiber WDM/PBG Channel Add/ Drop Filter



Photonic Crystal Super- Prisms

Key Characteristics

- **Highly anisotropic dispersion engineered “super-prism” material has exceptional angular wavelength dispersion characteristics (NTT, NEC)**
- **Angular dispersion that is 2 orders of magnitude larger than**
 - **gratings**
 - **prisms**
 - **PBG prism**

leads to 2 orders of magnitude shorter WDM elements

- **photonic crystal: 0.99 um and 1.00 um separated by 50°**
- **conventional crystal: 0.99 um and 1.00 um separated < 1°**

Fast Reconfigurable Switches for Micro-WDM

Parameter	Electrical	Optical
Ports	16	32
Data Rate	1 Gbps	> 2 Gbps
Media	fiber	fiber
Switch Fabric	ASIC or network processor	optical ADM or cross-connects
Matrix Latency	0.5 usec	N/A
Connect Time	3 usec	0.1 usec to 10's usecs
Power Consumption	45 W per switch card plus transceivers	control only (<10 W)
Protocol	Fibre Channel	IP
Size	SEM-E card	.001" x .001" to 1' x 1'
Markets	military platforms and telco	military platforms and telco

- If 3 order of magnitude improvement in optical switching speed, then...

Possible Electrical to Optical Switch Evolution

- Fast Electrical Packet Switching for Low Port Counts (10's)
- Medium Speed Optical "Circuit" Switching for High Port Counts (1000)
- Fast "MPLS" Optical Switching for "Visionary" Future Systems (TBD)

Optical Switches* (in Decreasing Order of Switch Time)

Technology	Status	Max Array Size (N x N)	Switch Array Time	Insertion Loss	Latching
Bulk optomechanical (tilting mirrors)	Product	1 x 16	15 msec	2 dB	Yes
Liquid crystal	Development	1 x 8	10 msec	3 dB	No
Bulk optomechanical (free space)	Development	576 x 576	5 msec	6 dB	No
Thermo-Optic	Product ?	8 x 8	1 msec ?	5 dB	No
Bubble/ TIR¹	Product	32 x 32	1 msec ?		No
Microelectromechanical Systems (MEMS)² (+/- 45⁰)	Development (for Optical Switches)	32 x 32	10's usec	3 dB	Yes
128 Level MEMS³ 2N rather than N² Limits	Development (for Optical Switches)	1000 x 1000	1 msec		
Microelectromechanical Systems (MEMS)^{2,3} (+/- 45⁰)	Development (for Optical Switches)	32 x 32	10's usec	3 dB	Yes
Microelectromechanical Systems (MEMS)¹ (+/- 10⁰)	Product (for Digital Light Projectors)	500 K	10's usec	N/A	Yes
Lithium Niobate⁴	Development	8 x 8	0.1 usec	9 dB	No
Lithium Niobate	Product	4 x 4	0.1 usec	8 dB	No

1) Agilent

2) Lucent, OMM, ...

3) OMM,

4) EO Space, Lucent, ...

Micro-WDM Development Needs

- **Define roadmap to large-scale Micro-WDM**
- **Trade and down-select micro-WDM technologies**
- **Perform basic device research**
- **Improve processing technology**
- **Develop optimum device designs**
- **Demonstrate passive WDM arrays**
- **Perform large-scale device integration**
- **Integrate high port density switches (near term) (and control)**
- **Demonstrate initial micro-WDM fast switch concepts**
- **Establish WDM and switch characterization, test, and measurement**

Aerospace Role

- **Assess system opportunities and benefits**
- **Assess & guide micro-WDM technology**
 - Device modeling
 - Experimental characterization
 - Recommend optimum technology
- **Initiate development team and identify “dual-use” apps**
 - **Universities, Component Manufacturers**
 - passive high density arrays
 - fast switch elements
 - **Network Companies**
 - software control, management, reliability, optical path routing
- **Execute WDM-based network demonstrations**
 - integrate tunable Tx/Rx with passive arrays and switches
- **Engineer WDM-based networks for deployed systems**

Micro-WDM for Reconfigurable Military Information Systems

Goal: Mobile, wideband, scalable, protocol transparent, open systems

Technology Roadmap

Tx/Rx-AWG-MEMS-AWG-Rx/Tx

↓ 2 - 5 years

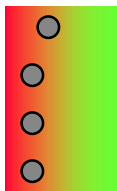
Tx/Rx-UR/PBG-MEMS-UR/PBG-Rx/Tx

↓ 5 -10 years

Tx/Rx-UR/PBG-SOA-AWG-Rx/Tx

Relative Risks

- Microresonator CDFs today
- PBG and super-prism CDF arrays
- Design and nano-fabrication
- Fast reconfiguration switches



Channel Drop Filter (CDF)

Related Challenges

- Tunable Sources and Detectors
- Array Cross Talk and Insertion Losses
- Packet or Channel Addressing
- Virtual Light Path Contention:
 - Wavelength Conversion
 - Optical Buffer Memories
 - Synchronization

Summary: 10 um Scale WDM Technology in F/O networks will bring trunking and routing of terabit/sec capacity optical fiber buses to mobile platforms. Fixed and tunable integrated add/ drop filters (and N x N optical cross-connects) reduce size and power, provide fault tolerance, reconfiguration, and mixed nets.

Approach

- Smooth, scalable growth will result in migration from IP/ATM/SONET(ADM and DCS)/DWDM networks to MPLS/ optical mesh networks
- Tunable Tx and Rx will enable single part for WDM transport
- Wavelength routing switches will provision λ paths to resources
- May support mixed RF and digital networks in fault tolerant dual rings (and meshes)

Schedule:

