Enhancing EW and Radar Systems with Microwave Photonics

Charles Middleton

11 December 2025

SOLUTIONS AT
THE SPEED OF LIGHT

Problem Statement: EW in 2035

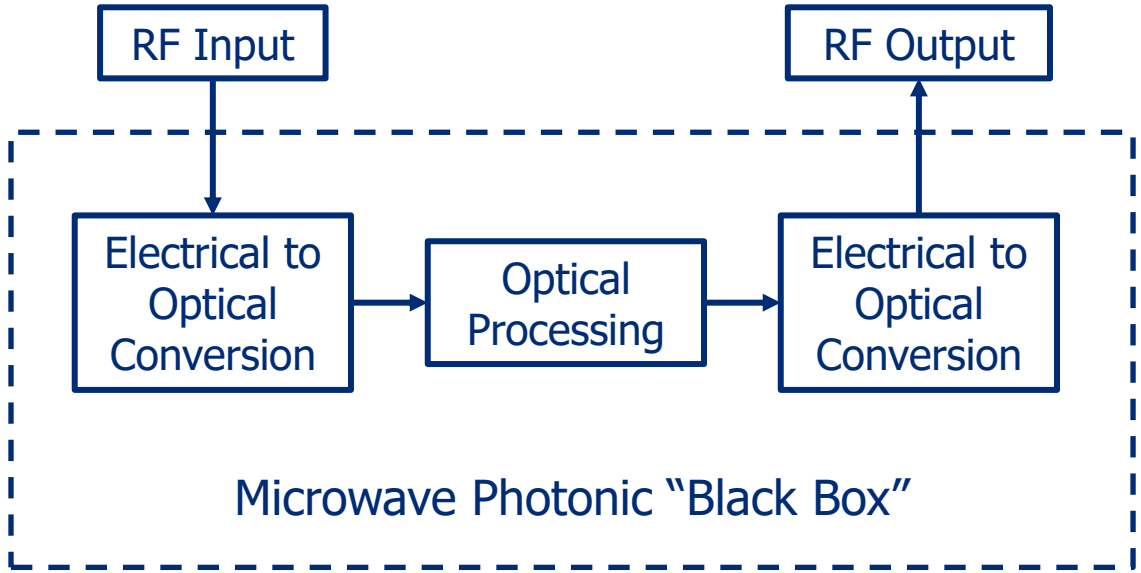
Modern EW and radar arrays face rapidly intensifying demands:

- Wider operational bandwidths
  - Threats span VHF to mmWave, often simultaneously
  - Instantaneous bandwidths exceed what conventional RF front-ends and filters can manage
- High dynamic range in dense, contested environments
  - Co-channel and in-band interferers overwhelm receivers
  - Protecting the receiver without sacrificing sensitivity is increasingly difficult
- Need for flexible signal distribution across multiple EW functions
  - Platforms host RWR, SIGINT, EA, comms, and radar simultaneously
  - Fixed RF plumbing limits resource sharing and rapid reconfiguration
- Severe SWaP constraints and physical limitations
  - Small platforms and distributed apertures cannot host full RF chains at each sensor point
  - Coax routing introduces loss, EMI, weight, and thermal penalties
- Growing requirement for multiple beams, fast adaptation, and wideband capture

EW systems must move wideband, high-dynamic-range RF signals with far less loss, far less hardware, and far greater flexibility

MWP Basics: Converting RF to Light and Back

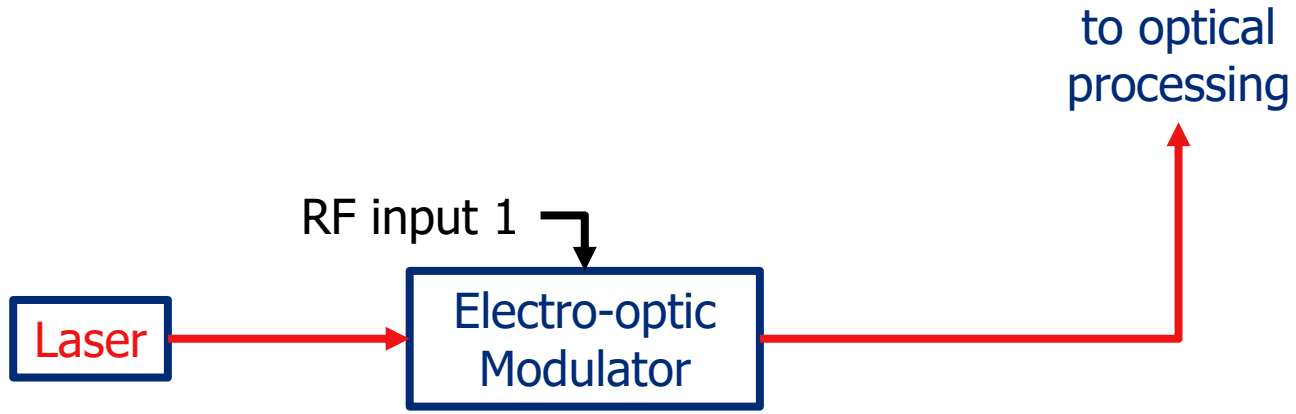
- Microwave photonics: performing microwave system functions with the help of photonics
- Advantages
  - Wide bandwidth (100+ GHz)
  - Low loss signal transport
  - EMI resistance
  - Flexible switching
  - Reconfigurable filtering
  - Advanced analog processing capabilities
- Challenges
  - Requires efficient conversion between electrical and optical signals
  - Component maturity is low
  - Requires specialized knowledge

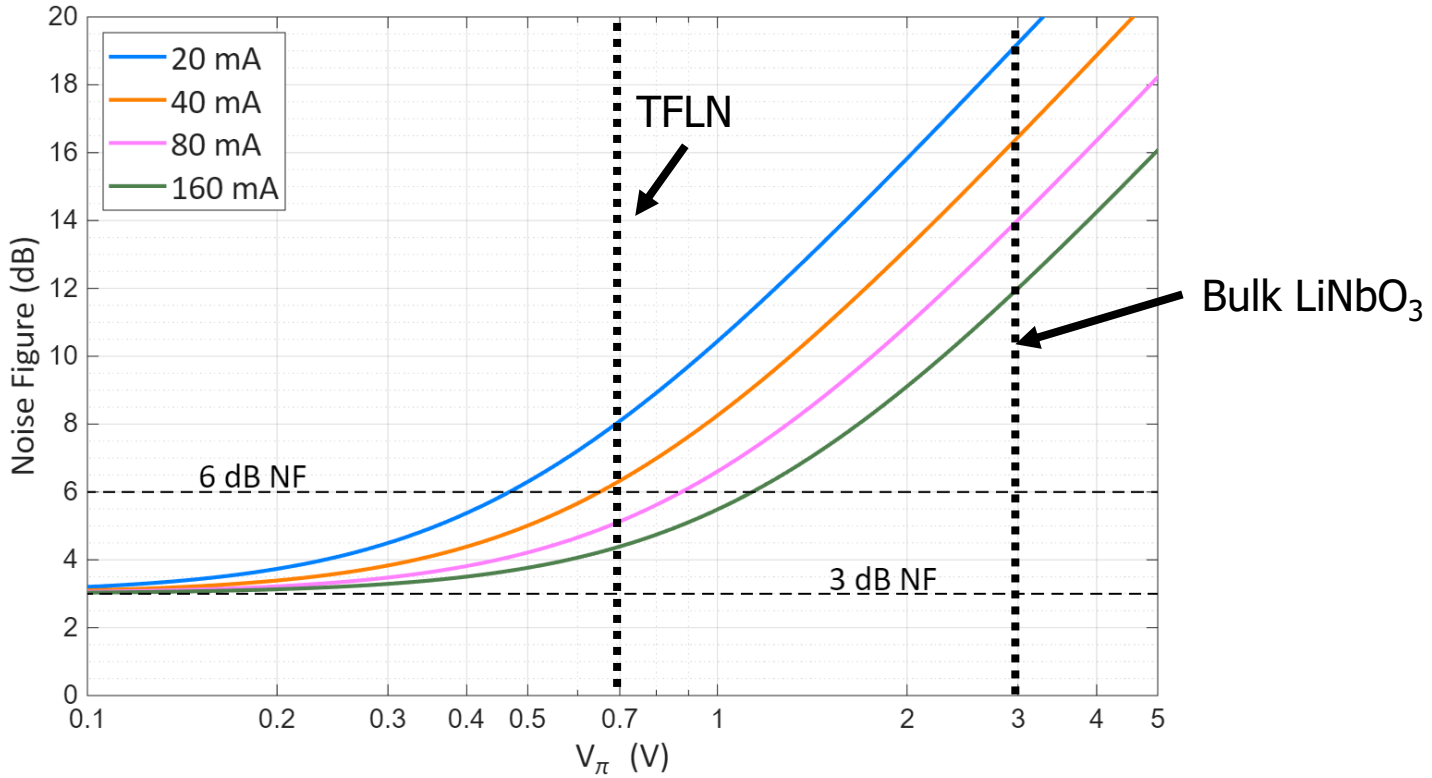


Capability 1: Ultra-Wideband Electro-Optic Front End

Electro-optic modulators have seen recent breakthroughs

- Wider frequency range
  - DC to 110 GHz
- Higher modulation efficiency
  - Noise figures approaching 3 dB without an LNA at the input

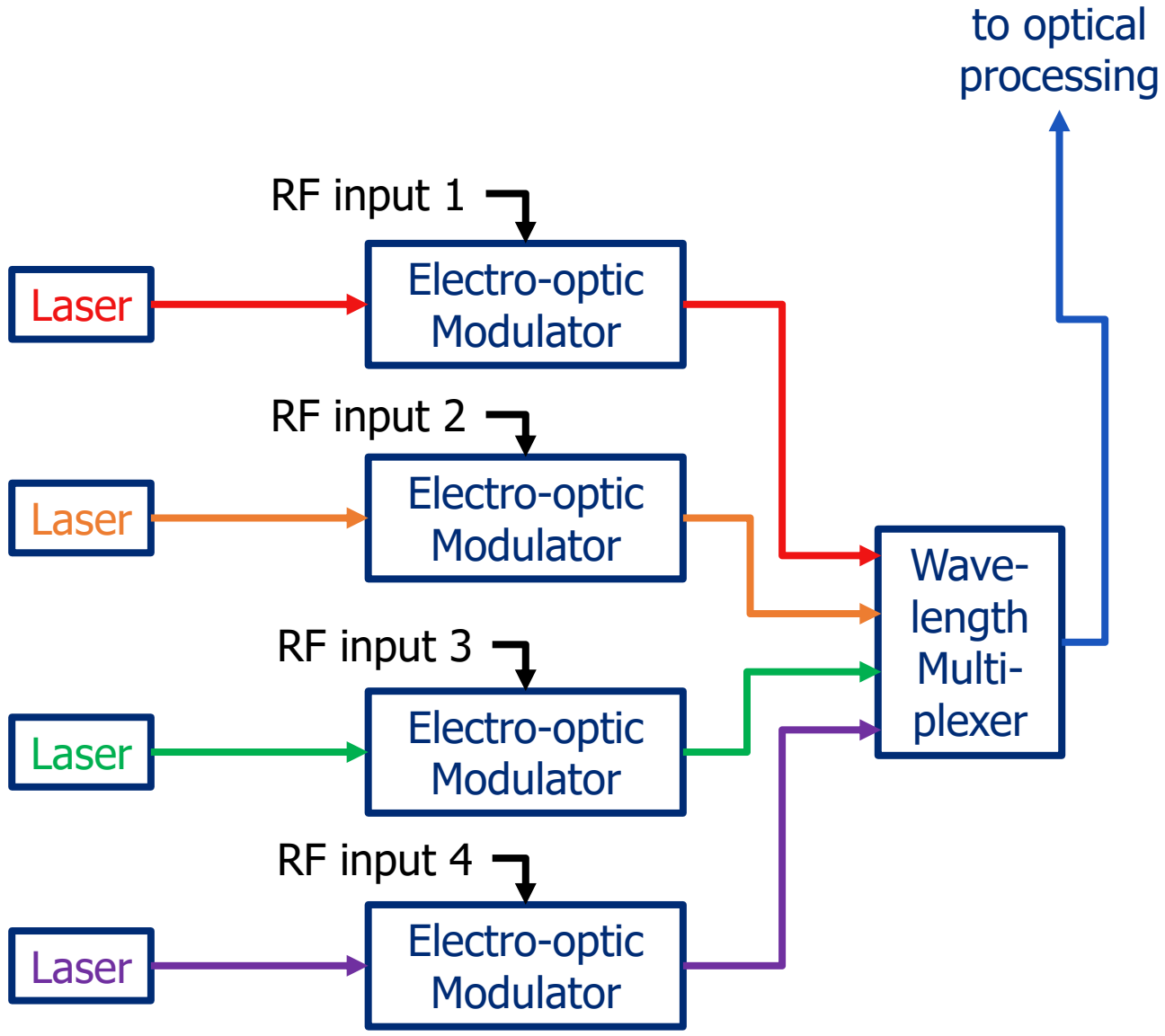




Capability 1: Ultra-Wideband Electro-Optic Front End

Electro-optic modulators have seen recent breakthroughs

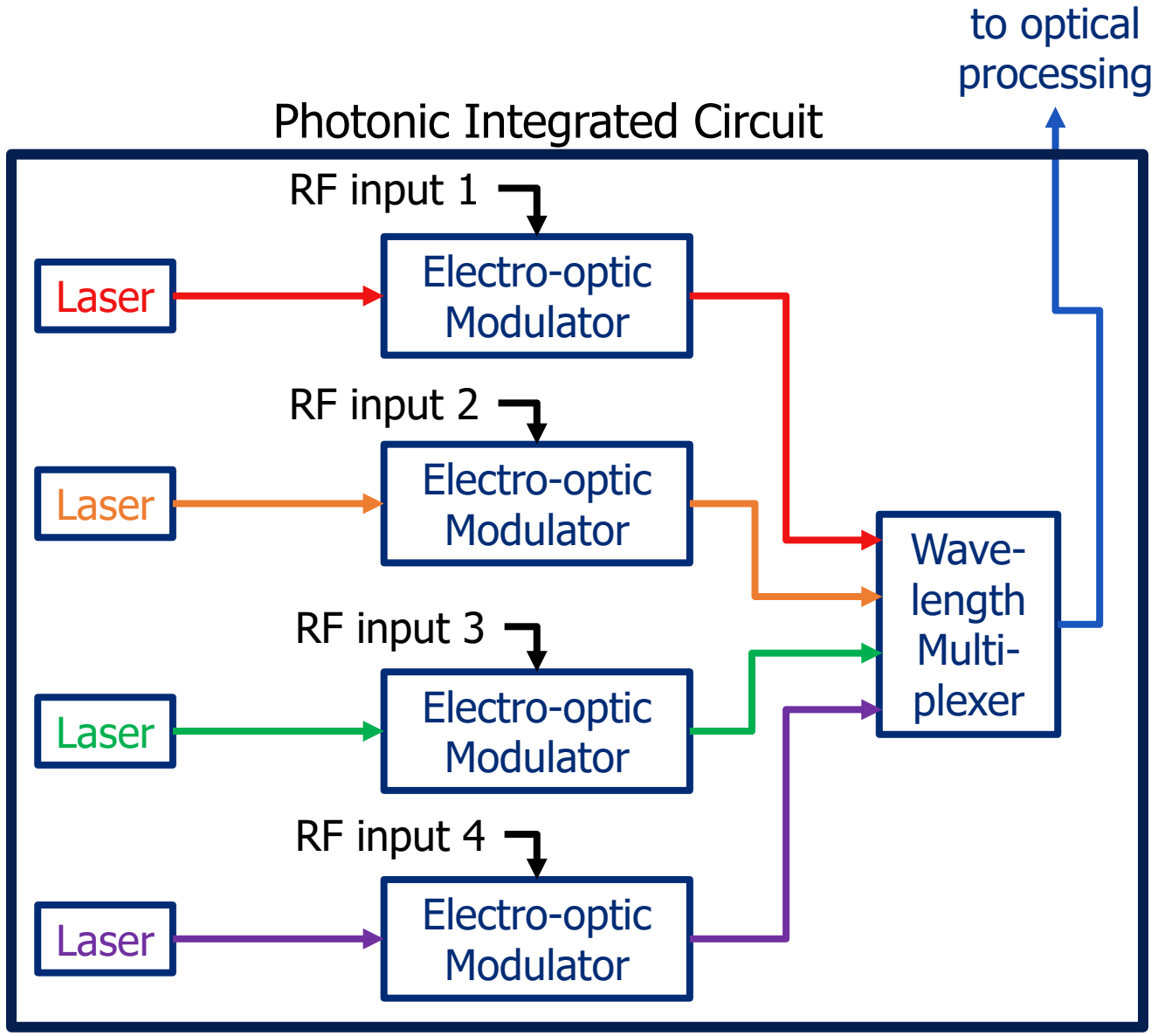
- Wider frequency range
  - DC to 110 GHz
- Higher modulation efficiency
  - Noise figures approaching 3 dB without an LNA at the input
- Separate optical wavelengths can be used to simplify cabling and reduce SWaP



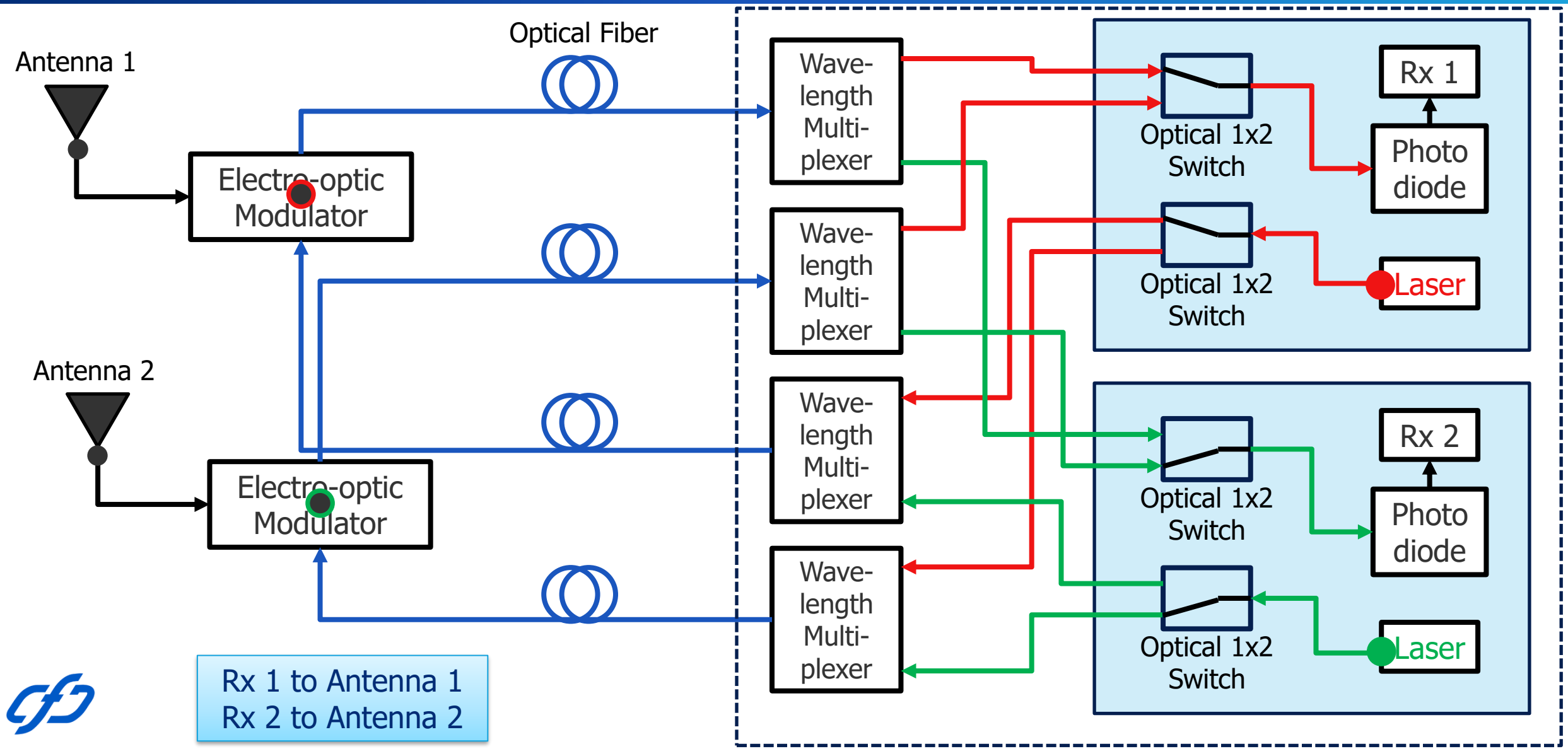
Capability 1: Ultra-Wideband Electro-Optic Front End

Electro-optic modulators have seen recent breakthroughs

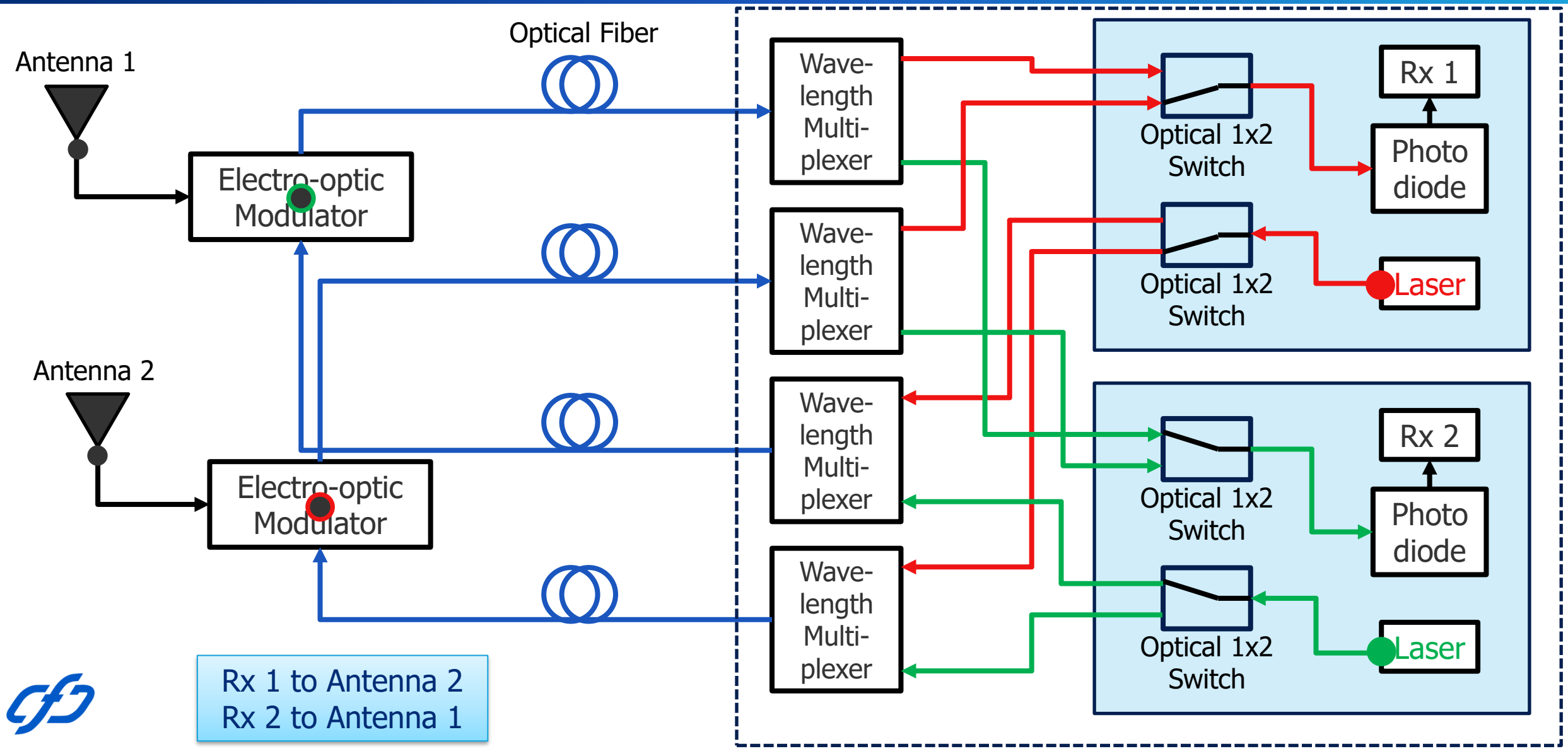
- Wider frequency range
  - DC to 110 GHz
- Higher modulation efficiency
  - Noise figures approaching 3 dB without an LNA at the input
- Separate optical wavelengths can be used to simplify cabling and reduce SWaP
- Photonic integration can dramatically reduce footprint
  - Four independent RF channels on a single 2 mm x 4 mm chip



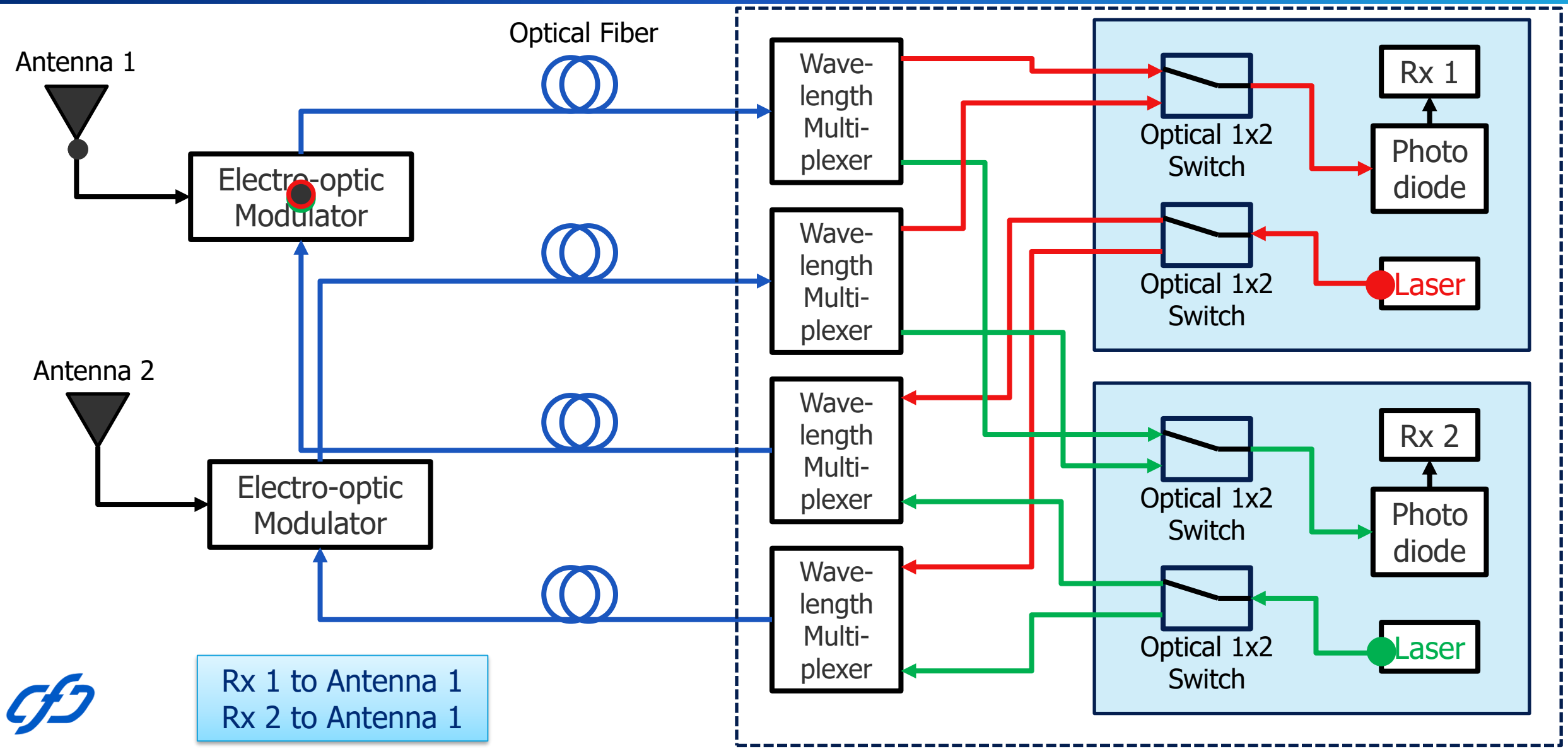
Capability 2: Non-blocking Photonic Switching



Capability 2: Non-blocking Photonic Switching

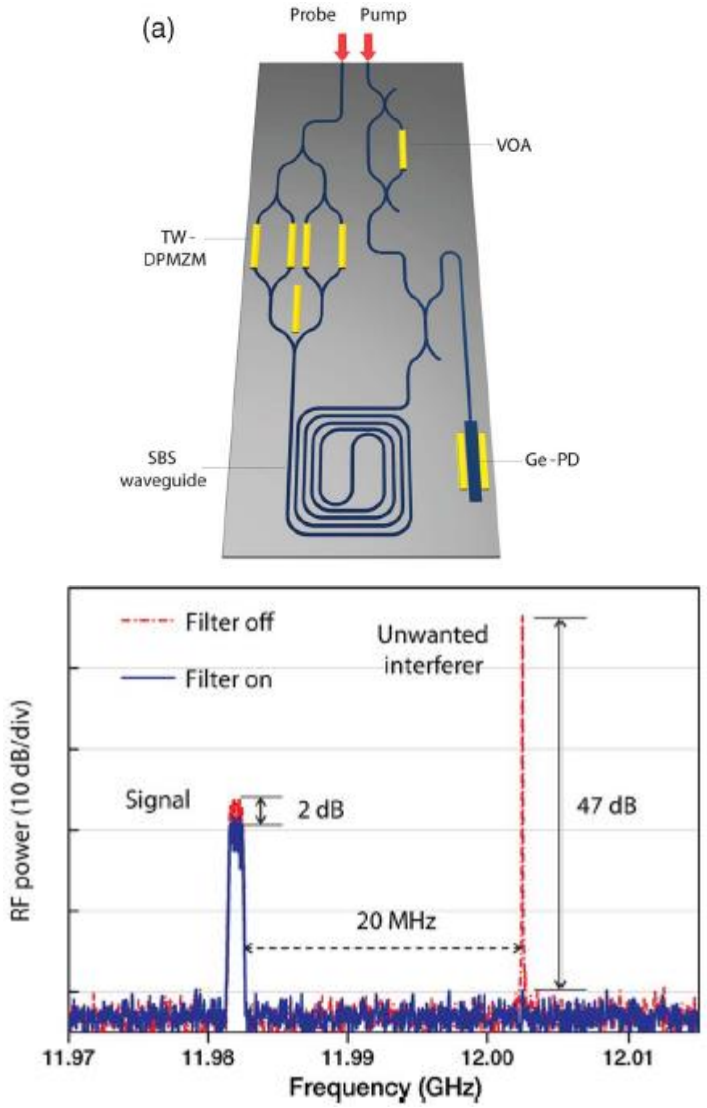


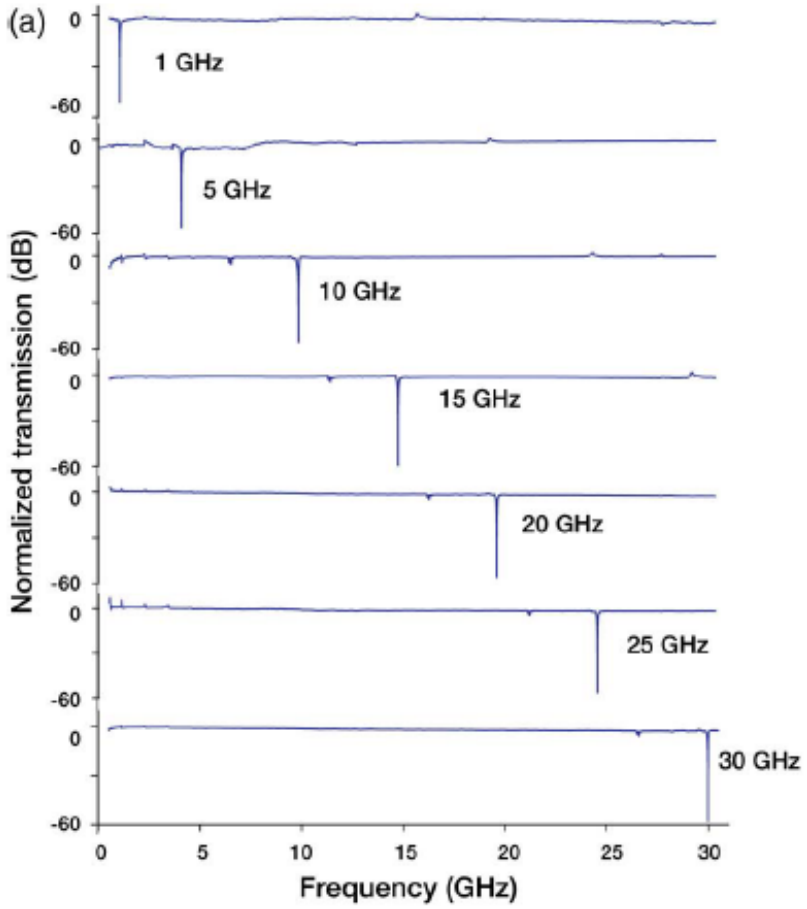
Capability 2: Non-blocking Photonic Switching



Capability 3: Software-Defined Notch Filters

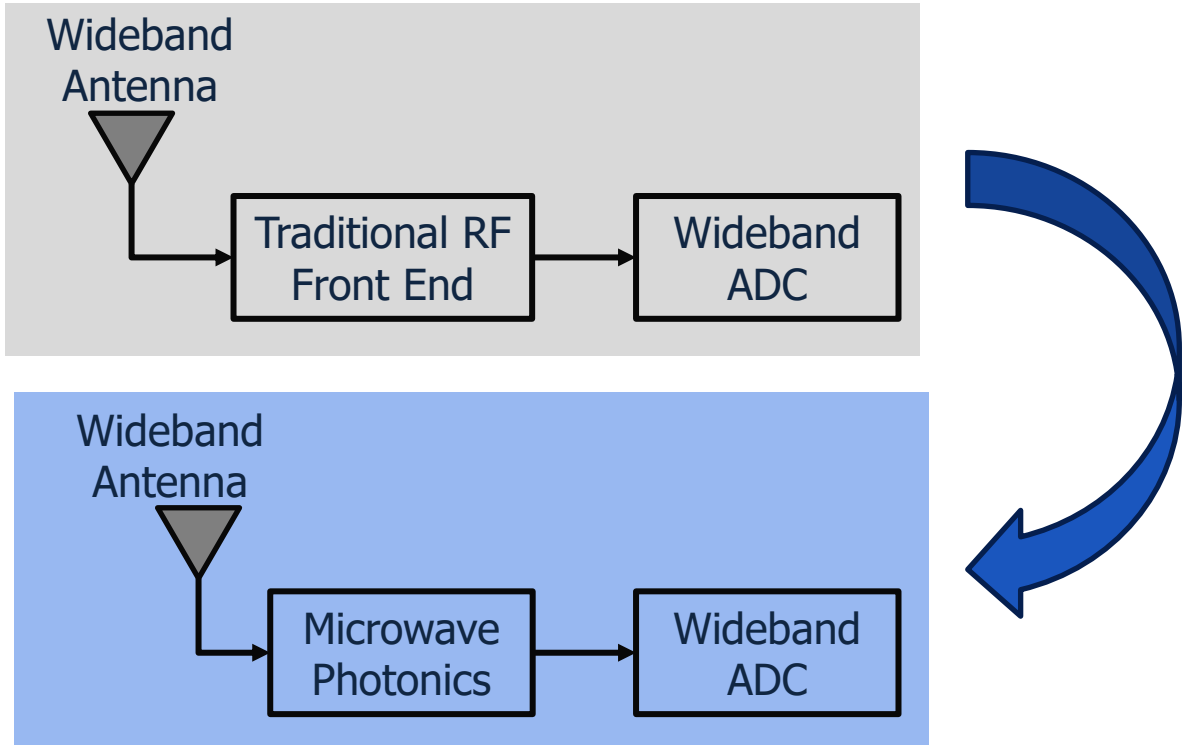
- Photonic techniques can generate narrow notch filters across the RF spectrum
- Filters are widely tunable
- ~30 MHz bandwidth at any RF frequency
- Notch depths > 50 dB
- Multiple notches can be produced simultaneously

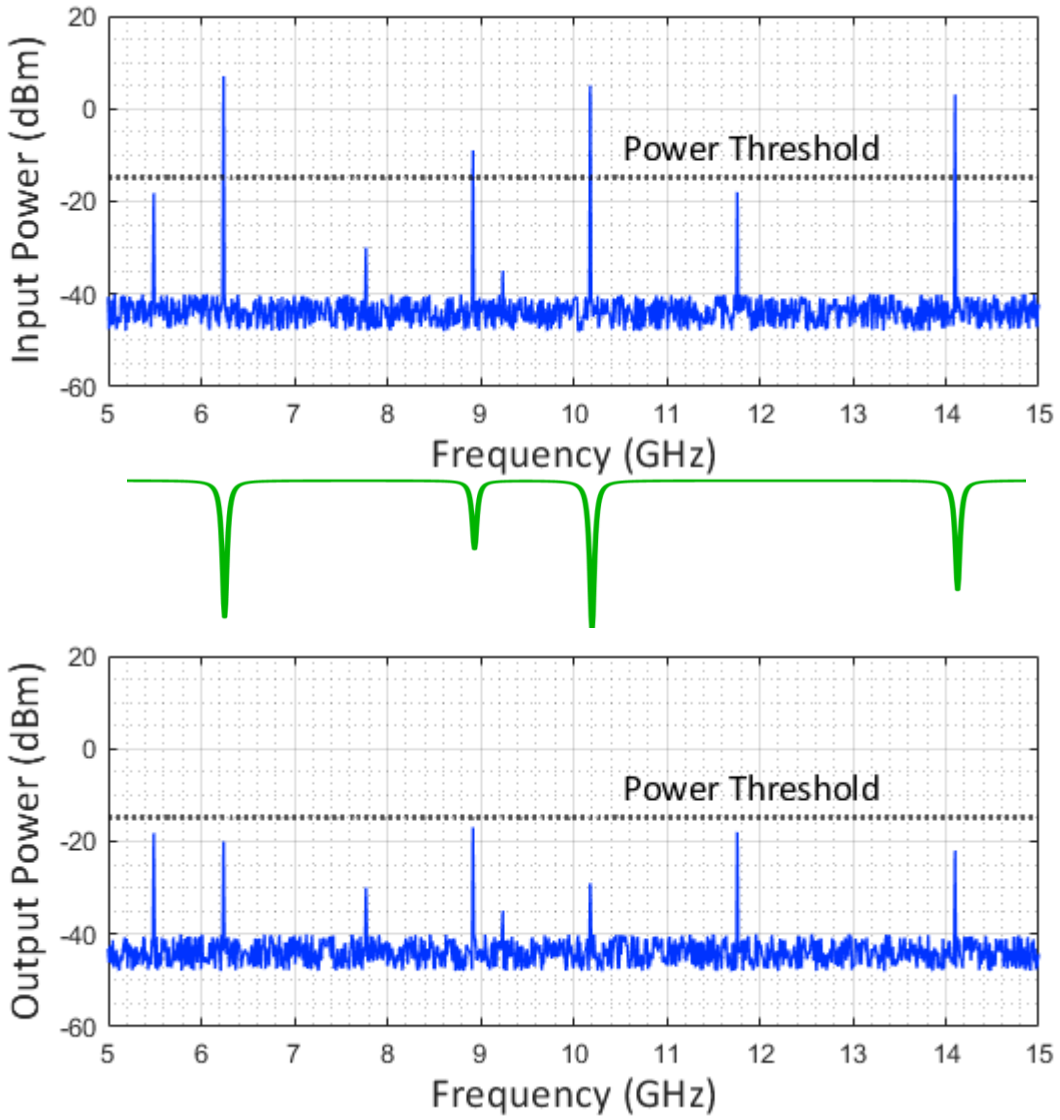




Marpaung, David, et al. "Low-power, chip-based stimulated Brillouin scattering microwave photonic filter with ultrahigh selectivity." *Optica* 2.2 (2015): 76-83.

Capability 4: Self-Tuning Limiting Filters





Capability 4: Self-Tuning Limiting Filters

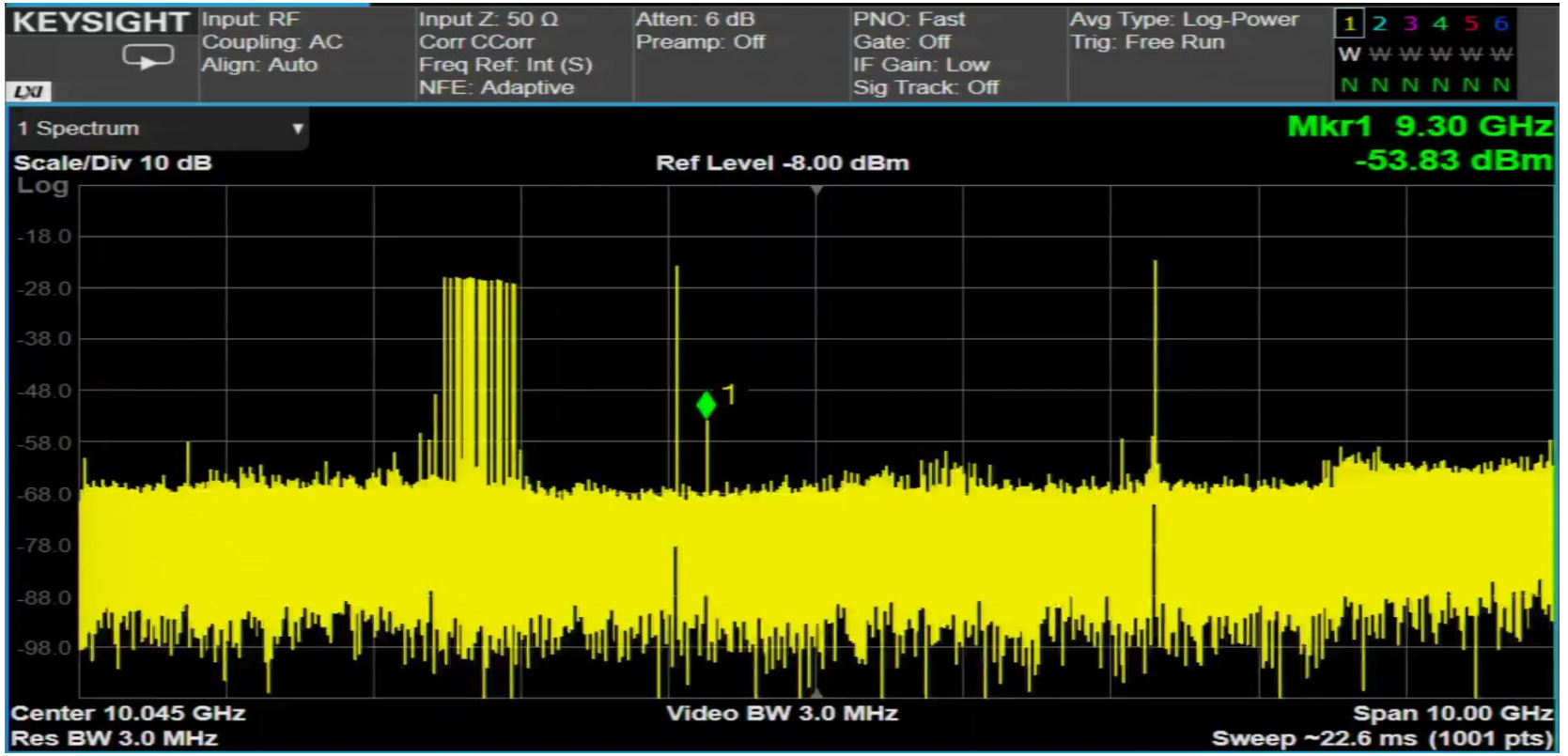
Frequency Range: 5 – 15 GHz

SOI
Frequency: 9.3 GHz
Amplitude: -53 dBm

Interferer 1
CW Triangle, 500 MHz/100 µs
Frequency: 7.5 GHz
Amplitude: -26 dBm
Suppression: ~ 25 dB

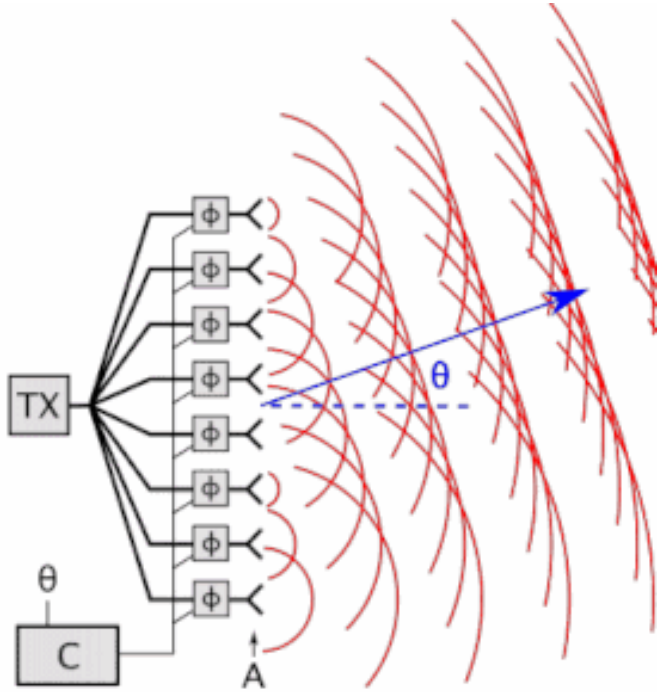
Interferer 2
Frequency: 9.1 GHz
Amplitude: -23 dBm
Suppression: ~ 40 dB

Interferer 3
Frequency: 10.5 – 12.5 GHz (swept)
Amplitude: -23 dBm
Suppression: ~ 40 dB



Capability 5: Photonics for Phased Arrays

- Electrically steered arrays (ESAs) combine multiple antenna elements with true time delays to create steerable antenna beam patterns
- Arrays are getting smaller, wider-band, and more distributed, making RF hardware at each element harder to fit
- Analog beam steering requires hardware for time delay at the aperture
  - Limited independent beams
  - True time delay is difficult in RF
- Digital beam steering provides the greatest flexibility
  - Fast steering
  - Multiple independent beams
- But digital beam steering requires an ADC behind each antenna element
  - Huge SWaP impact
  - ADC performance degrades at higher frequencies



RF Frequency	λ/2 Spacing
1 GHz	15 cm
10 GHz	1.5 cm
40 GHz	3.7 mm
100 GHz	1.5 mm

Capability 5: Photonics for Phased Arrays

Photonics-enabled Digital Beamforming

Key mechanism:

- Phase modulators at each element and remote wavelength-multiplexed lasers shared across the array
- Signals travel optically to a protected processing location
- Shared optical LO for down-conversion, coherent IF across channels

Advantages:

- Element-level IF digitizers are centralized
- Unlimited beams
- Excellent calibration stability with common LO
- Very low front-end SWaP at element

Limitations:

- All beams share the same IF (shared LO)
- Requires high digital compute

Photonics-enabled Analog Beamforming

Key mechanism:

- Per-element outputs pass through common true time delay (TTD) stages (one per row and column)
- A single photodetector performs coherent RF summation of antenna elements

Advantages:

- True wideband steering without RF phase shifters
- Very low latency
- Simpler control of beam steering components

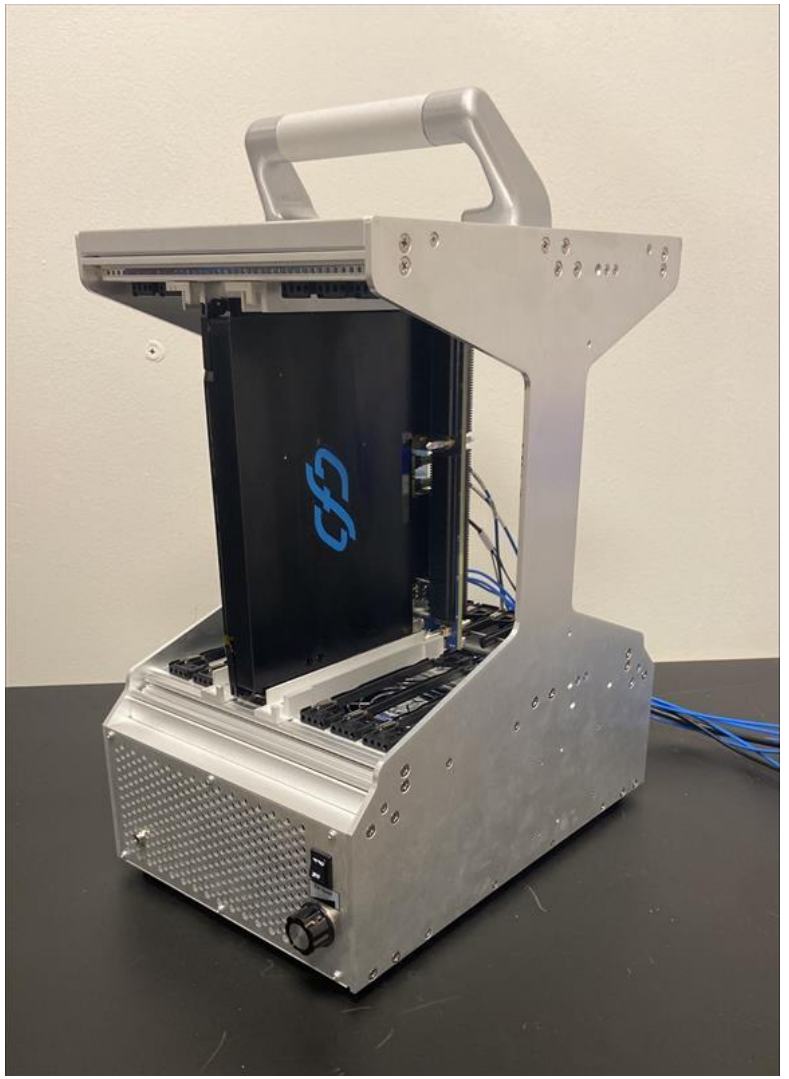
Limitations:

- Each independent beam needs its own TTD hardware path
- Difficult to scale to very large numbers of beams

A hybrid system with analog photonic steering for sub-arrays shows great promise to overcome limitations of each approach

Packaging and SOSA Alignment

- Rugged packaging of microwave photonic systems in 6U and 3U card formats can be achieved using today's traditional telecom components
- For many EW applications, no optical interfaces are needed on the card
  - RF in, RF out
  - All photonic connections are internal
- Can be compliant with SOSA™ (Sensor Open Systems Architecture), a standard for C5ISR systems



Roadmap: Building the Photonic Infrastructure to 2035

2025 – 2028: Photonic Building Blocks (TRL 4 – 6)

- Ultra-wideband EO modulators at the aperture
- Wavelength multiplexing signal transport
- Software-defined optical notch filters
- Self-tuning photonic limiters
- Non-blocking optical switching
- Optical beamforming sub-arrays
- SOSA-aligned packaging

2028 – 2032: Microwave Photonic Backplanes and Shared-Aperture Remoting (TRL 5 – 7)

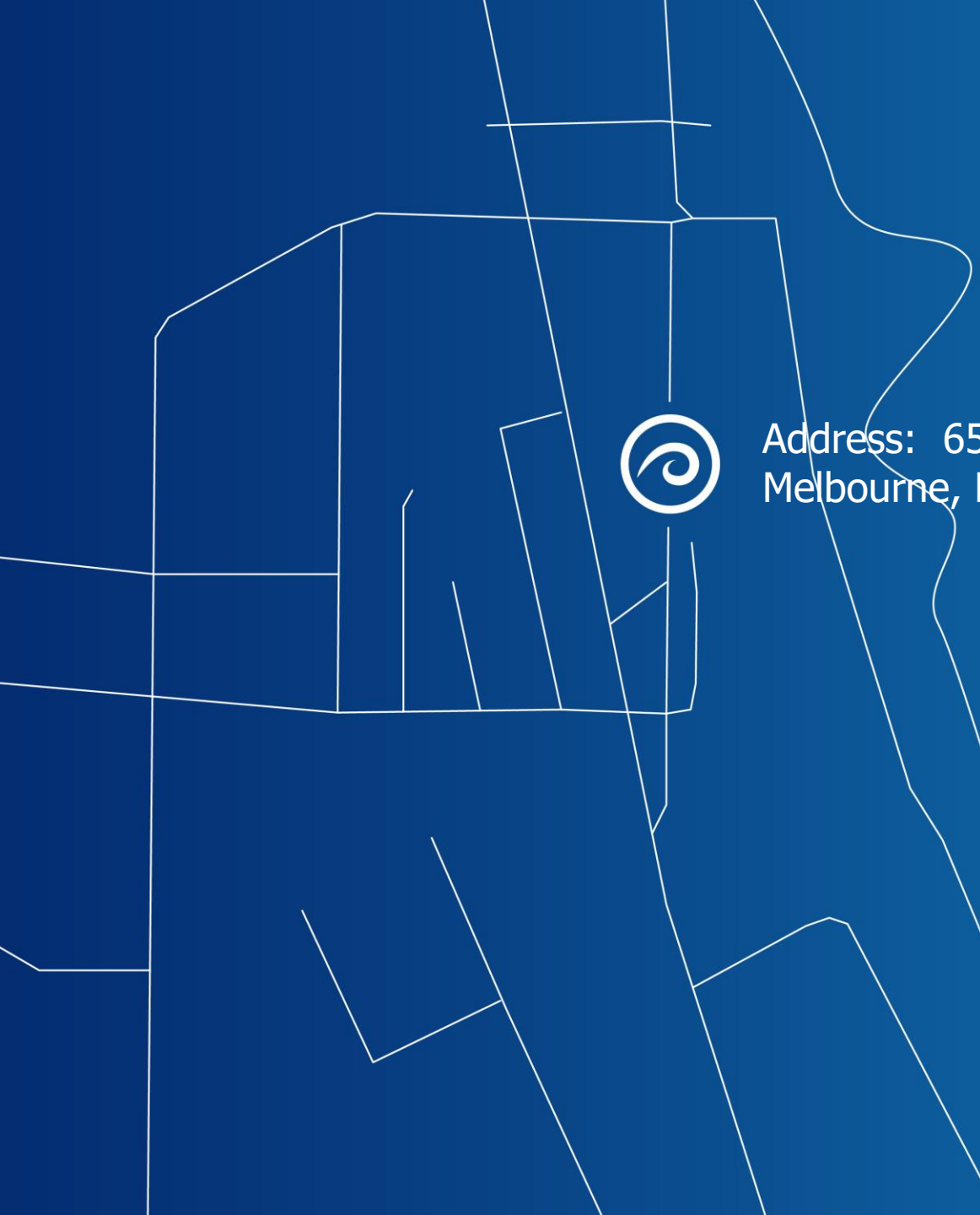
- Optical RF distribution across EW functions
- Any antenna routed to any receiver
- Reduced coax/EMI/cabling burdens
- Expanded optical beamforming

2032 – 2035: Adaptive Photonics-Enabled EW Architectures (TRL 6 – 8)

- Fast reconfigurable signal paths
- Adaptive bandwidth allocation
- Automated interference protection
- Wideband, agile beamforming
- Flexible sharing of sensing/jamming/processing resources

Questions

- Where do current EW systems hit limits in bandwidth, dynamic range, or interference protection?
- Which platforms need flexible antenna-receiver routing or shared apertures?
- What mission scenarios require more agile beam steering or wideband aperture scalability than currently available?



Address: 650 Atlantis Rd,
Melbourne, FL 32904

CONTACT INFORMATION

Phone: (321) 343-5611

Email: cmiddleton@criticalfrequency.com