SAND2019-13616C

Photonic Integrated Circuits for Simultaneous Channelization and Downconversion

November 5, 2019

Benjamin B. Yang, Brandon Lovelace, Brian Wier, Jacob Campbell, Mark Bolding, Cheong-Wo Chan, J. Glen Vinson, Tarun Muthuchamy, Rajib Bhattacharjea, T. Robert Harris, Kyle Davis, Andrew Stark, Christopher Ward

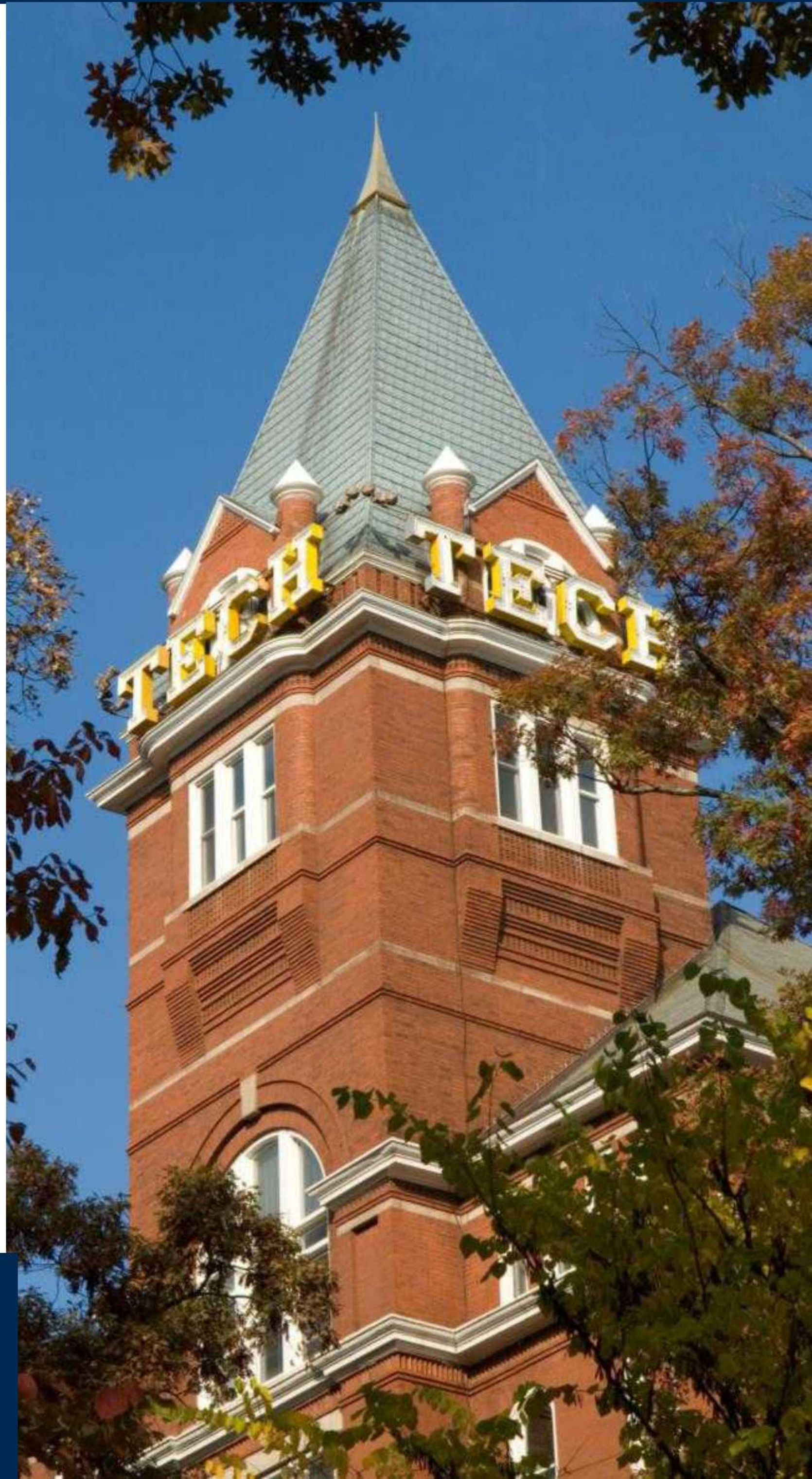
Georgia Tech Research Institute

Christian Bottenfield, Stephen E. Ralph

Georgia Institute of Technology

Michael Gehl, Ashok Kodigala, Andrew Starbuck, Christina Dallo, Andrew Pomerene, Doug Trotter, Anthony Lentine

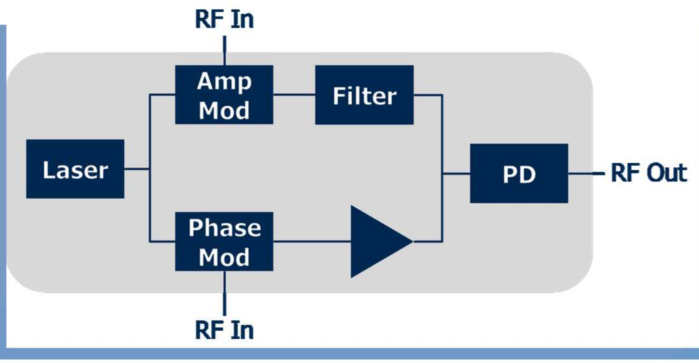
Sandia National Laboratories



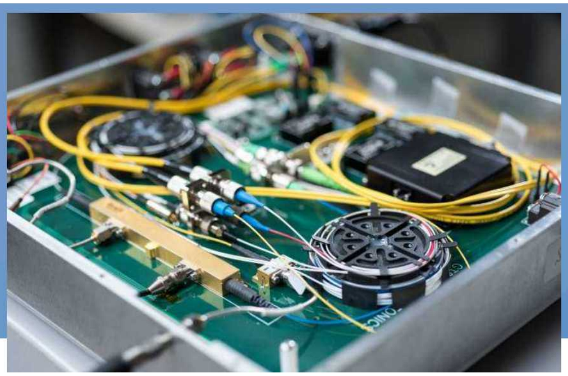
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Research Vision: End-to-End Technology Development Capability for Low Size-Weight-and-Power (SWaP) RF processing solutions for Avionic Applications

Concept Development

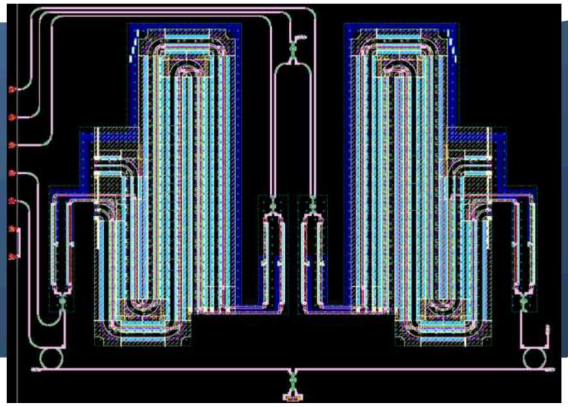


Discrete Component Demonstration

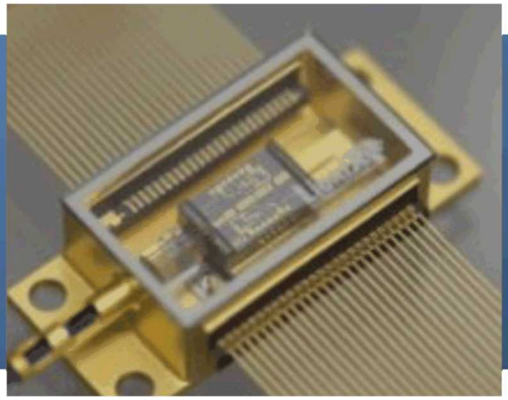


Spectrum Access

Integrated Circuit Fabrication

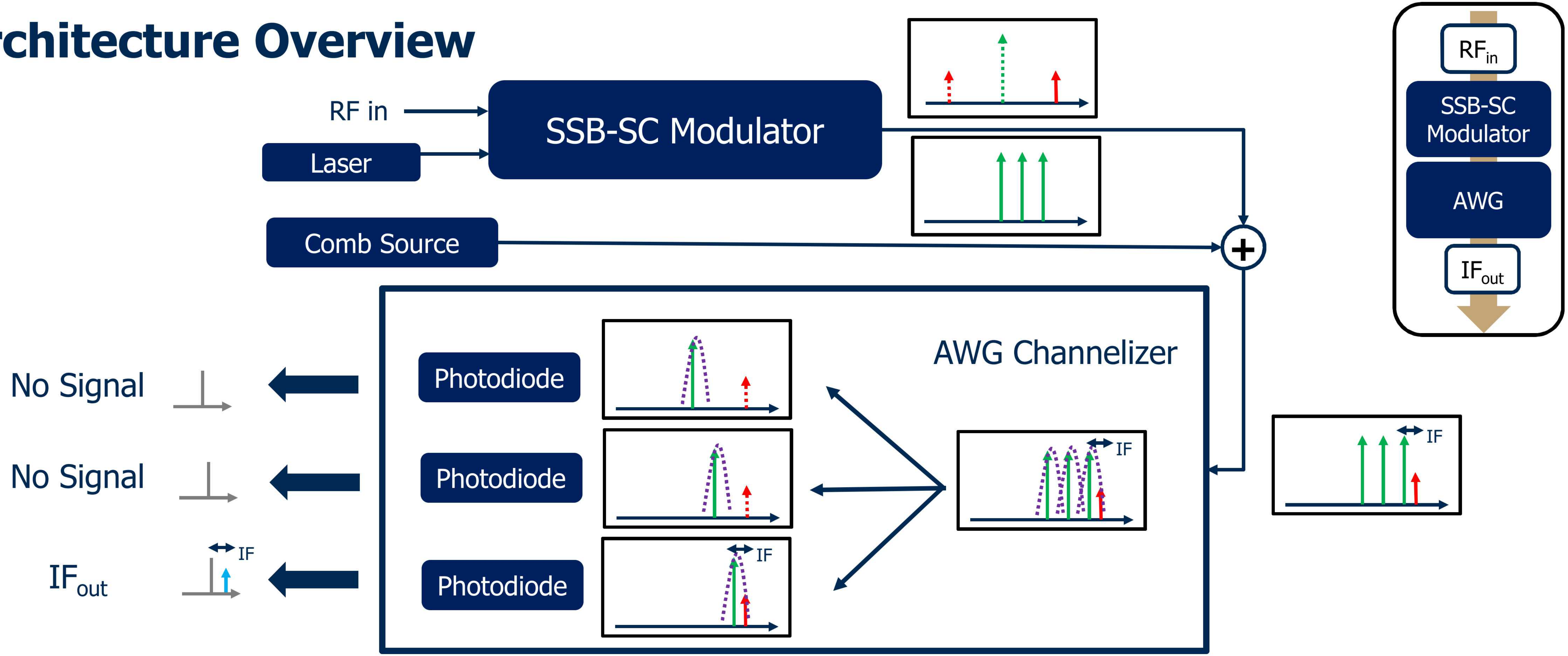


Advanced Packaging



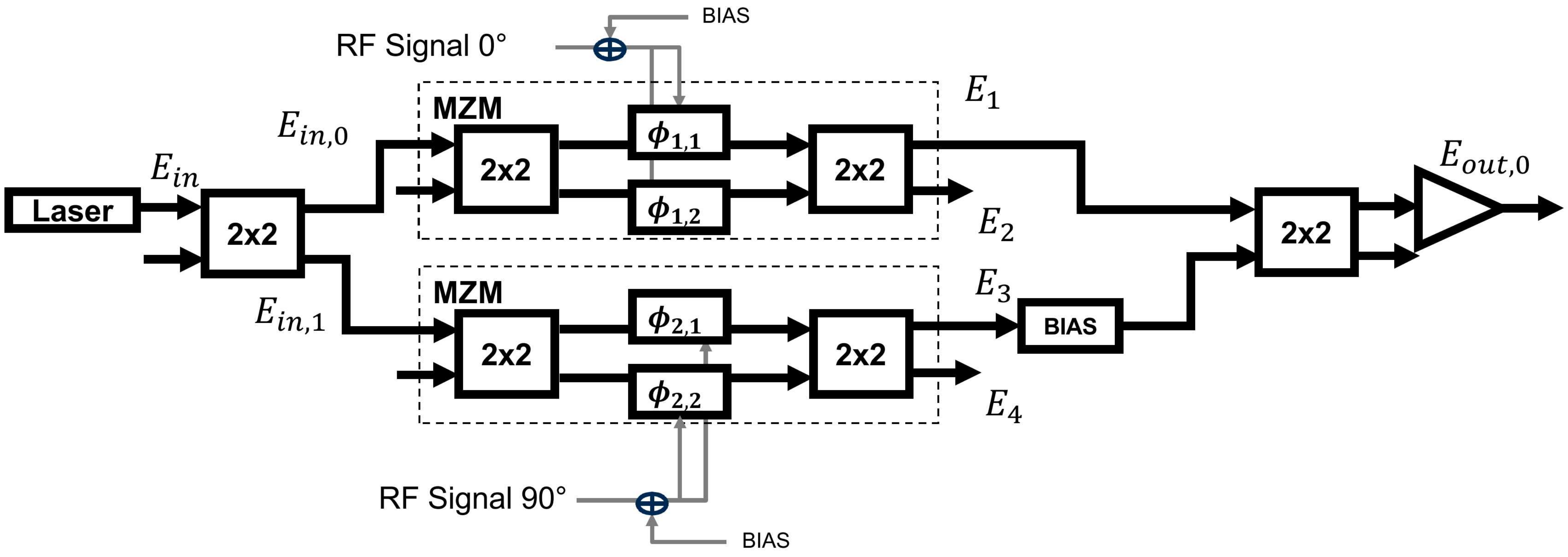
SWaP

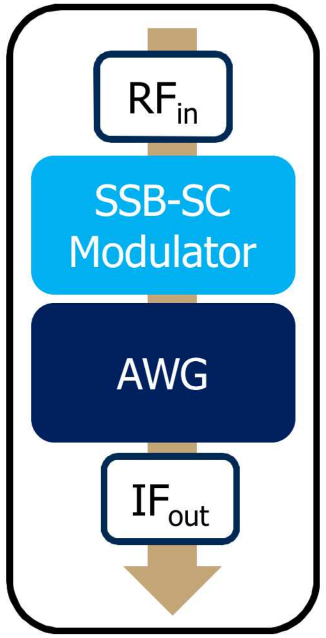
Architecture Overview



- **Proposed architecture performs simultaneous channelization and RF down conversion to intermediate frequency (IF).**
- This paper focuses on development efforts to mature integrated circuit implementations of the single sideband suppressed carrier (SSB-SC) modulator and arrayed waveguide grating (AWG) channelizer for avionic platforms.

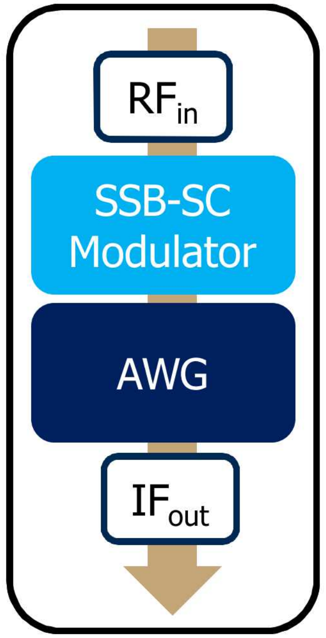
IQ Modulator-based SSB-SC



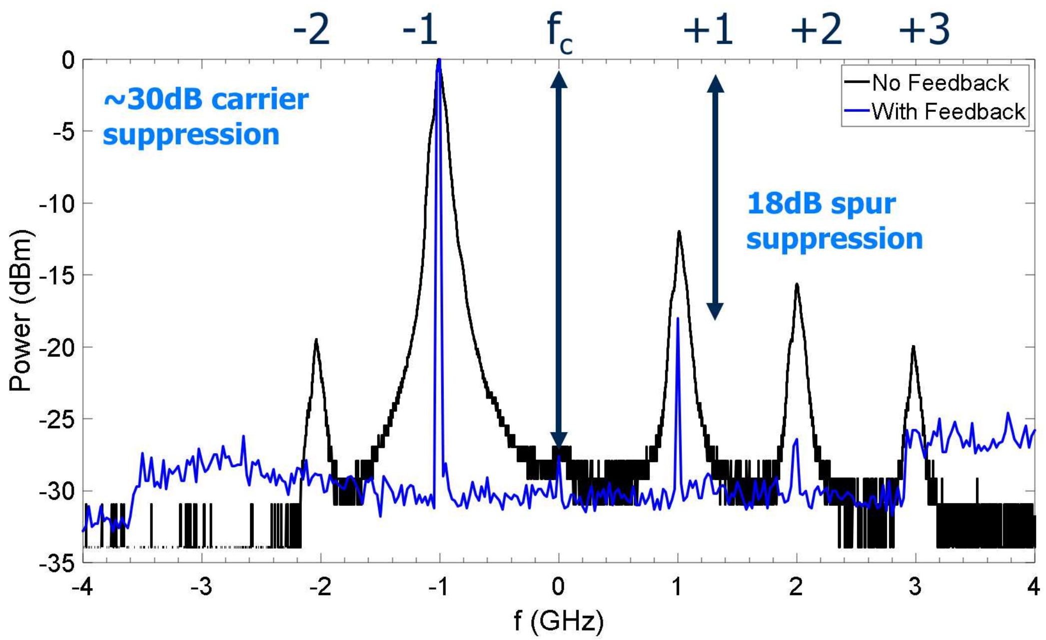


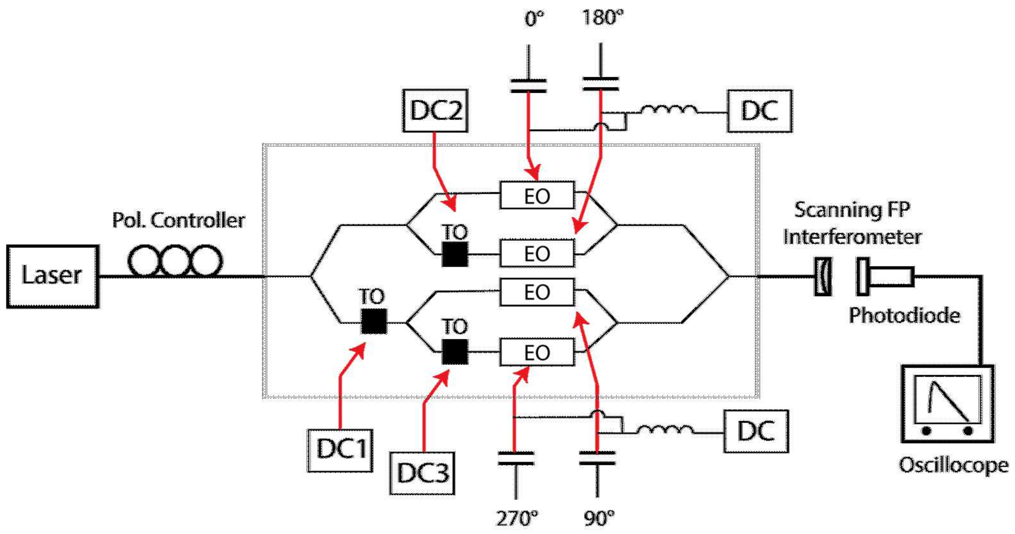
- **IQ modulator approach enables SSB-SC operation within an integrated circuit form factor for low SWaP applications.**
- Performance depends on phase modulator performance, RF 90º hybrid limits, and successful design of couplers.

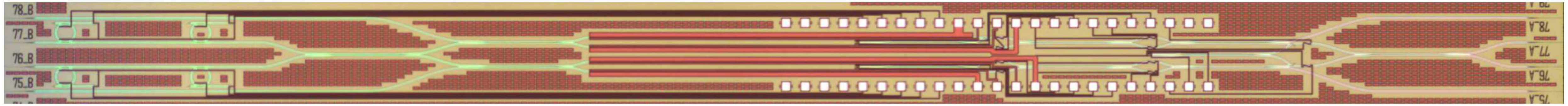
Silicon Photonics SSB-SC Implementation



- Designed and fabricated at Sandia National Laboratories.
- Achieved **30 dB carrier suppression** and 18 dB spur suppression.
- Significant improvement in active feedback of thermo-optic phase shifters.
- Modeling shows improvement with additional RF phase & amplitude balancing
- Currently testing bulk modulator designs
- Presented chip bandwidth limited to <4 GHz but established traveling wave designs should allow > 20GHz performance.
- Vπ ~ 0.55 V cm, which requires ~400 mW total RF power needed for peak conversion efficiency.

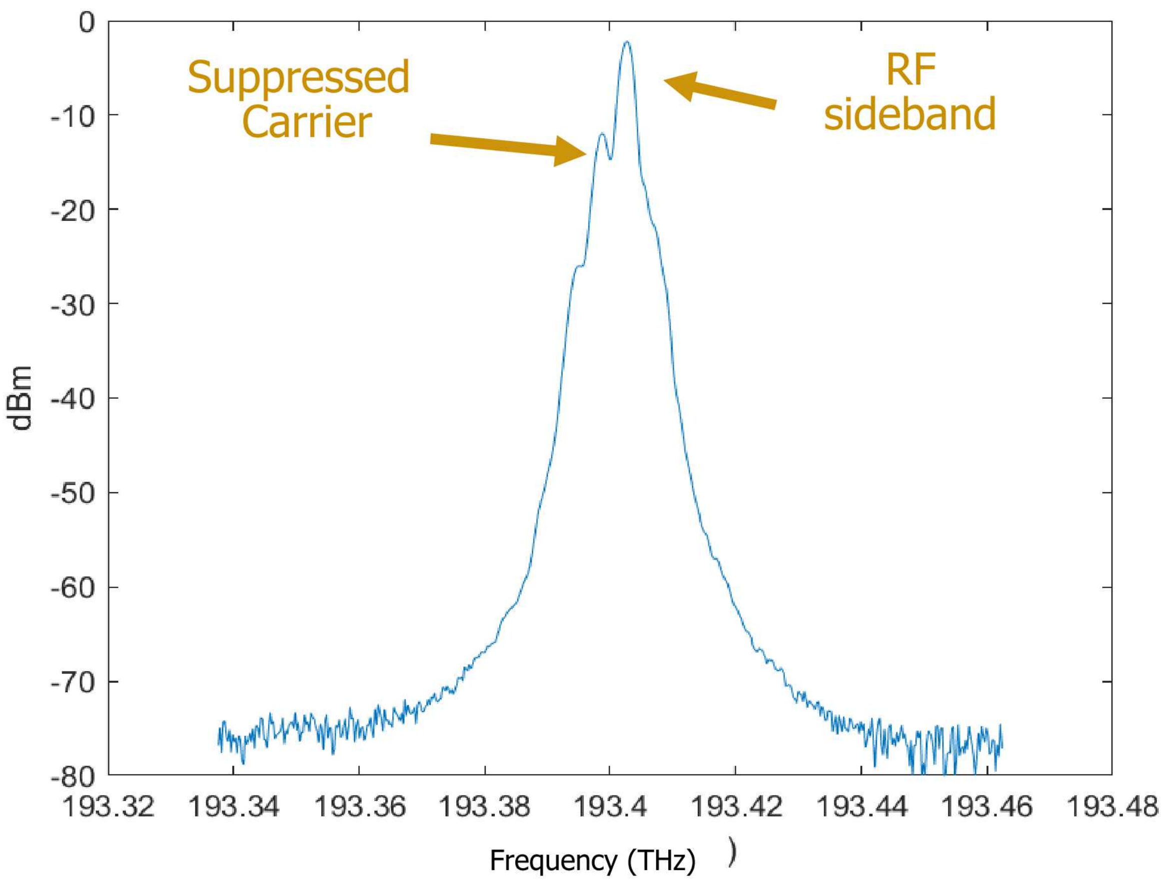


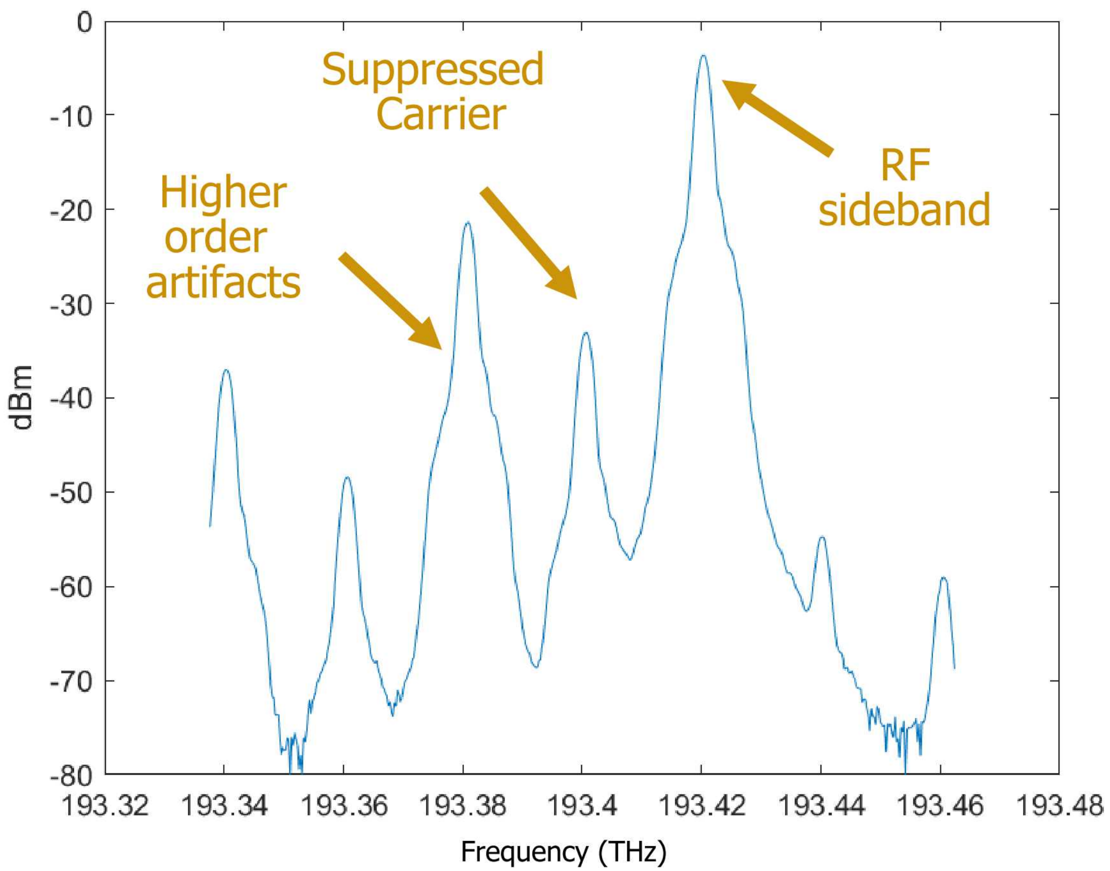


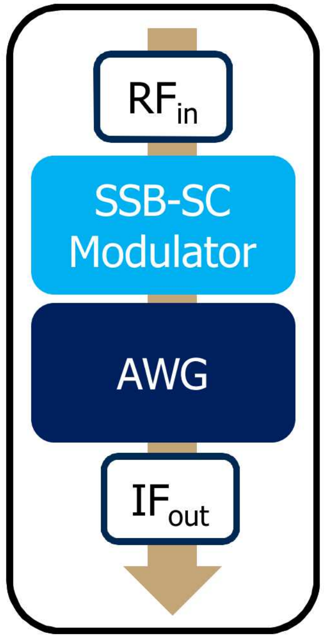


A. Kodigala, M. Gehl, et al. 'Silicon Photonic Single-Sideband Generation with Dual-Parallel Mach-Zehnder Modulators' ***CLEO*** (2019)

Indium Phosphide SSB-SC Implementation 1

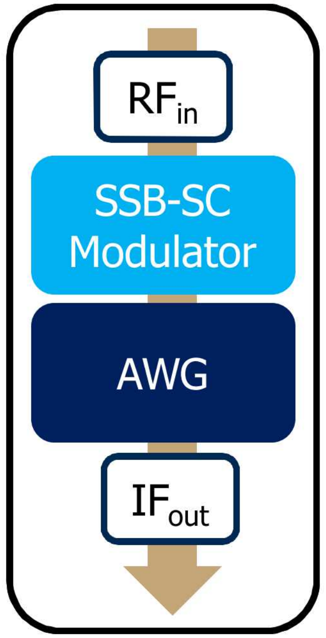




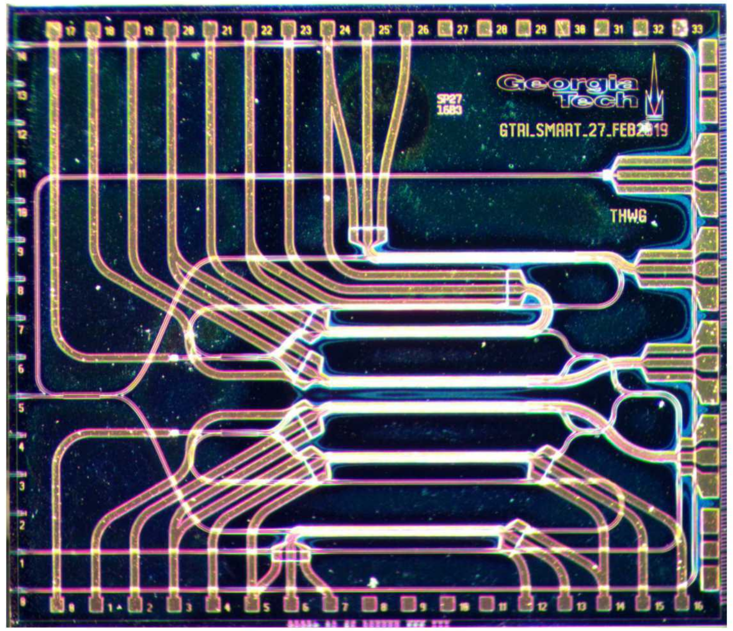


- Experimentally demonstrated carrier suppression with a 2-40 GHz RF signal using discrete components with ~20dB carrier suppression.
- Measurements made with carrier laser at 193.35 to 193.45 THz.

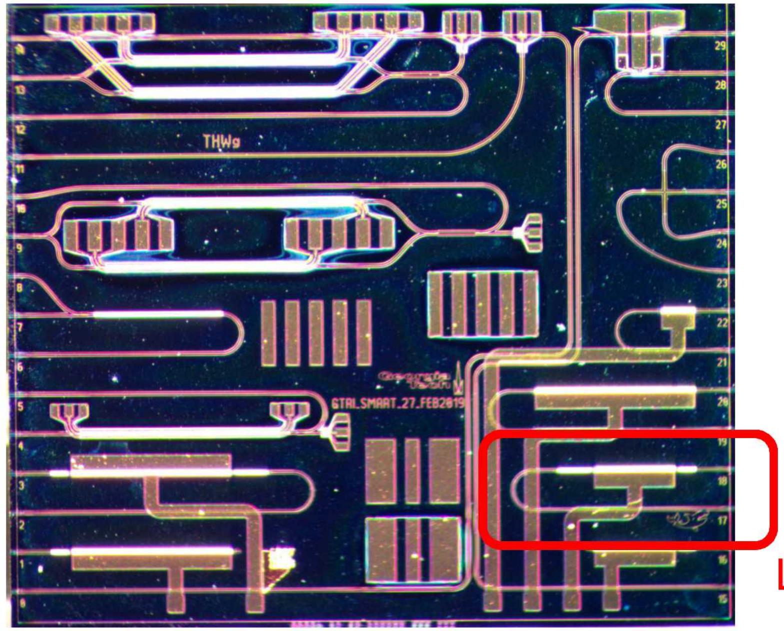
Indium Phosphide SSB-SC Modulator Implementation 2



- **Designed and fabricated a SSB-SC on the SMART Photonics Indium Phosphide (InP) platform with an eye towards avionics-ready RF_{in}-RF_{out} package.**
- Layout incorporates internally-developed packaging layout standards.
- Bandwidth limited to 8 GHz by RF phase modulators.
- Characterization of InP SSB-SC and on-chip laser design attempt is ongoing.
- Next steps:
  - Develop photonic packaging.
  - Integrating on-chip laser with improved SSB-SC design.
  - Explore other InP foundry services.



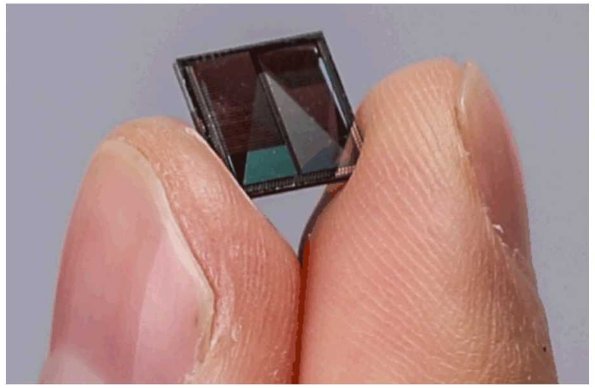
SSB-SC Chip

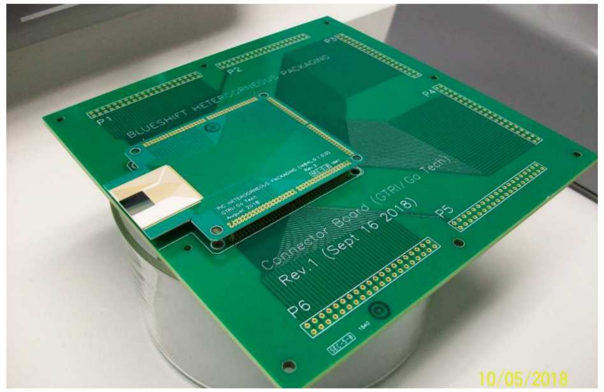


Performance Characterization Chip

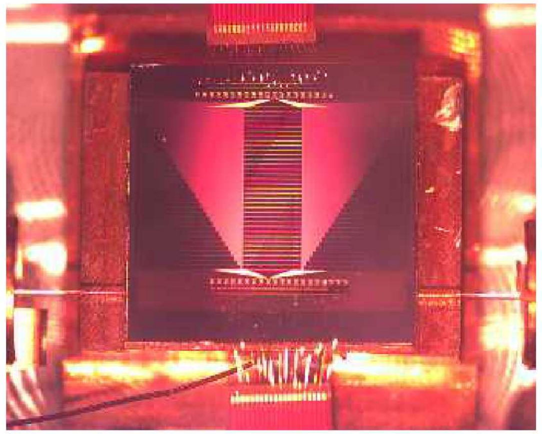
Package Design Mockup

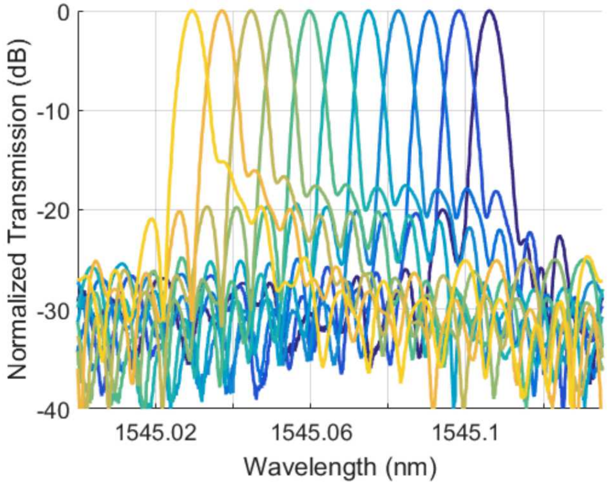
Arrayed Waveguide Grating Implementation



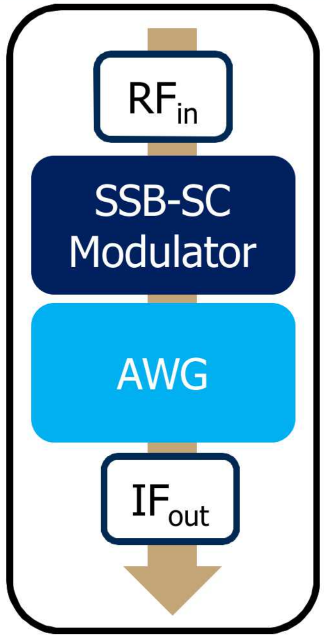


Tuning algorithm development for 27 x 2 GHz AWG for 54 GHz with integrated photodiodes.





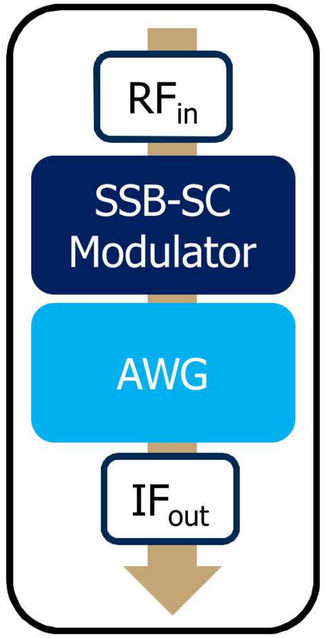
Circuit simulation using measured data on 11 x 1 GHz AWG.



- AWGs can channelize with better power-handling than ring resonator approaches.
  - Narrowband (<10 GHz) channelization requires active phase adjustment to overcome manufacturing errors.
  - The 27 x 2 GHz AWG is the first AWG with integrated photodiodes and has 55 phase shifters.
- **Algorithms to tune phase shifters** without interferometric measurements of individual waveguide paths enables **in-situ adjustment in a fielded system in response to environment changes**.
- **Circuit-level simulations** were performed using 11 x 1 GHz AWG data to test architecture.

M. Gehl, D. Trotter, A. Starbuck, A. Pomerene, A. L. Lentine, and C. DeRose, "Active phase correction of high resolution silicon photonic arrayed waveguide gratings," Opt. Express 25, 6320-6334 (2017)

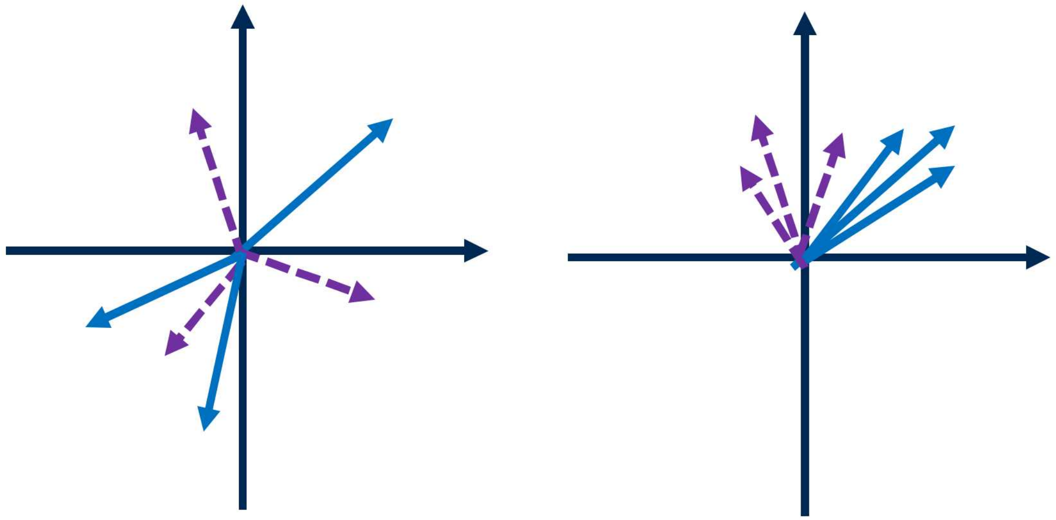
AWG Tuning Algorithm Development



Linear Approach

Better and more sensitive than brute force.

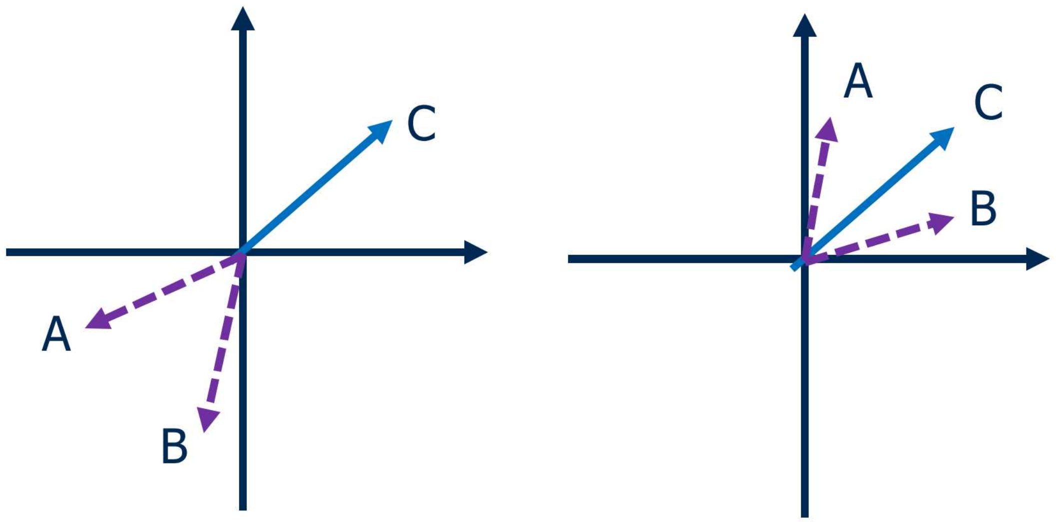
- Rotate each set of N vectors as a set to maximize alignment.
- Form N-groups of N-vectors and scan to find max alignment
- Repeat until alignment is maximized.



Exponential Approach

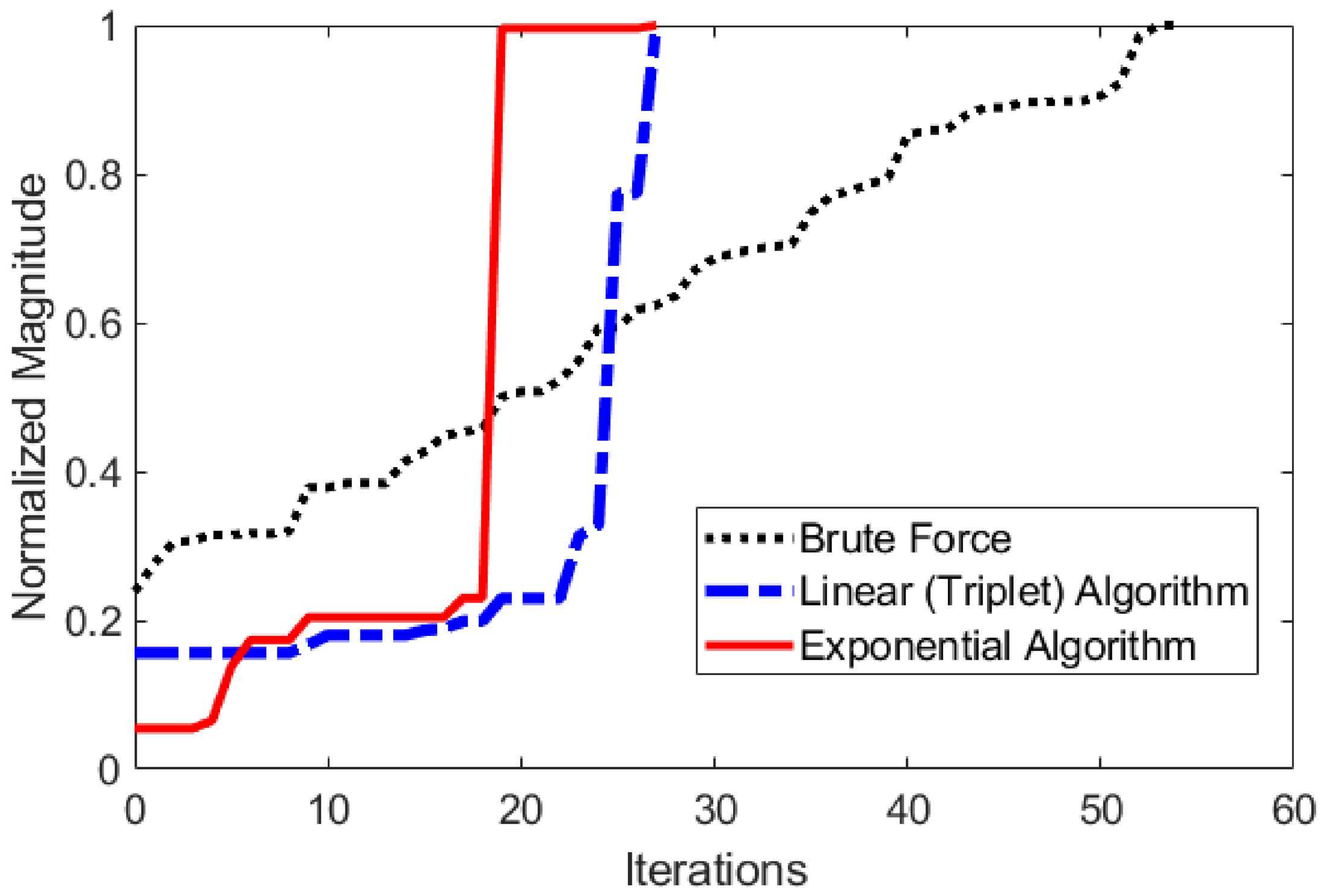
Computationally efficient but may not always work.

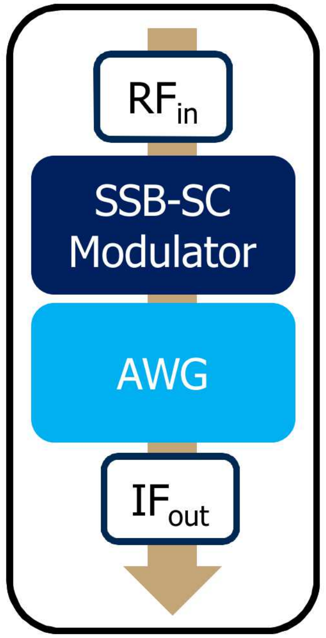
- Rotate phasor A and B in unison until maximum alignment with C
- Rotate A and C in unison until maximum alignment with vector B
- Repeat for all permutations for all sets of N vectors



Two methods are proposed to perform the tuning. Effectiveness depends on the relative magnitude of the vectors in question.

Algorithm Effectiveness

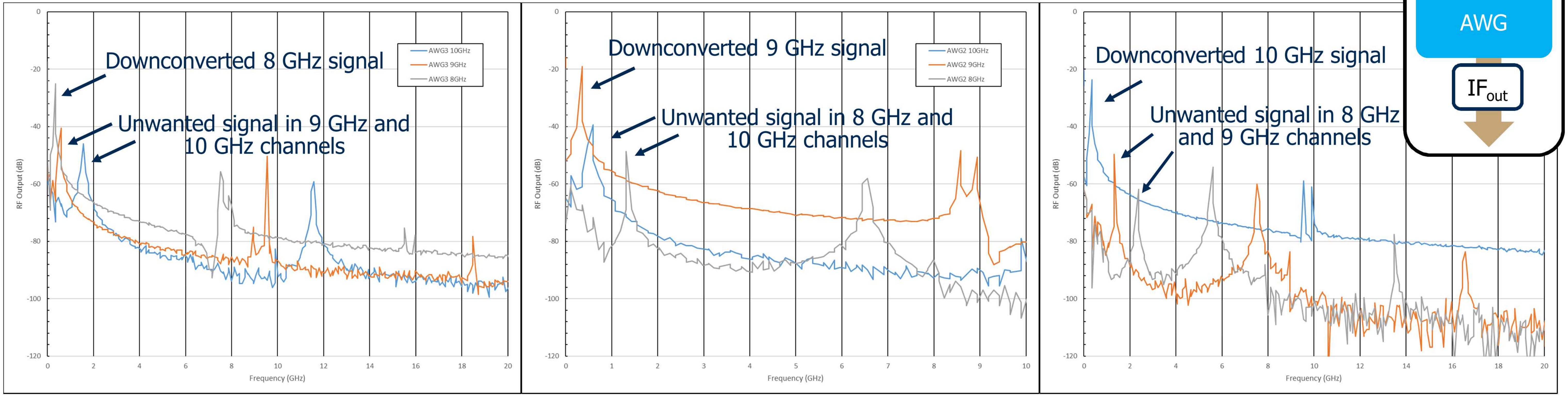




- Linear algorithm and exponential algorithm are both able to reach maximum figure of merit half the iterations as a brute force approach.
- Effectiveness of the three approach may depend on the relative magnitude of vectors (signal strength in each channel).

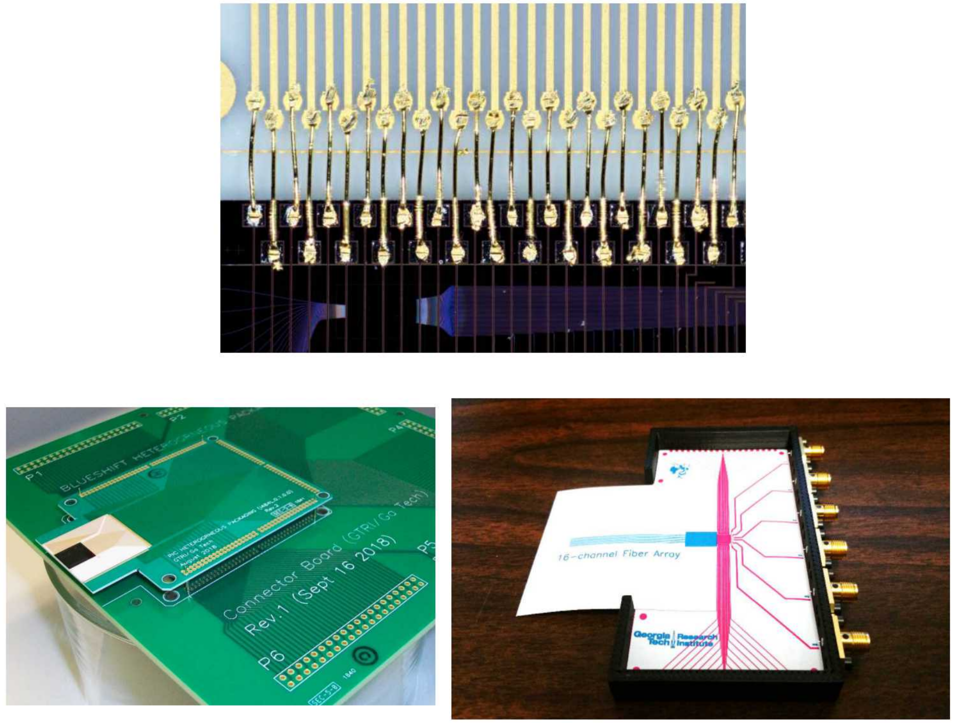
Circuit Level Modeling of AWG – Scan of input frequency

RF_{in} = 8GHz | RF_{in} = 9 GHz | RF_{in} = 10 GHz

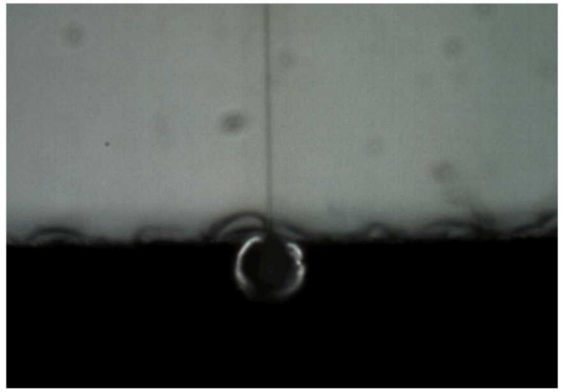


- Circuit level simulations were performed using OptSim Circuit to model photodiode response.
- The frequency response of the 1 x 11 GHz AWG was used as the channelization filter function.
- Simulations show successful **down conversion with channel isolation >16 dB**.

System Packaging and Integration



High electrical/RF I/O count photonic integrated circuit packaging.



Enhanced on-chip coupling using 3D lithography (WD3, 4:15 PM)

Nanosystec Nanoweld coming soon in 2020!

- Current efforts include parallel development towards a fully-packaged, ruggedized, multi-chip version of this architecture.

Conclusion

- An photonic architecture for **simultaneous channelization and downconversion** of an RF signal was explored for avionic applications.
- **Integrated circuit implementations of a SSB-SC modulator** in silicon and indium phosphide were demonstrated.
- Two **tuning algorithms for the AWG channelizer** were presented for improvements beyond brute force approaches **enabling in-situ retuning and robustness to environmental changes**.
- **Circuit level simulation of the architecture** validates the functionality of the architecture, predicting >16 dB isolation between unprocessed channels. Additional signal processing and filtering could improve these results.

Thank you for your attention!