Heterodyne Staring Array Active Imager (Active Range-Gated SWIR or MWIR)

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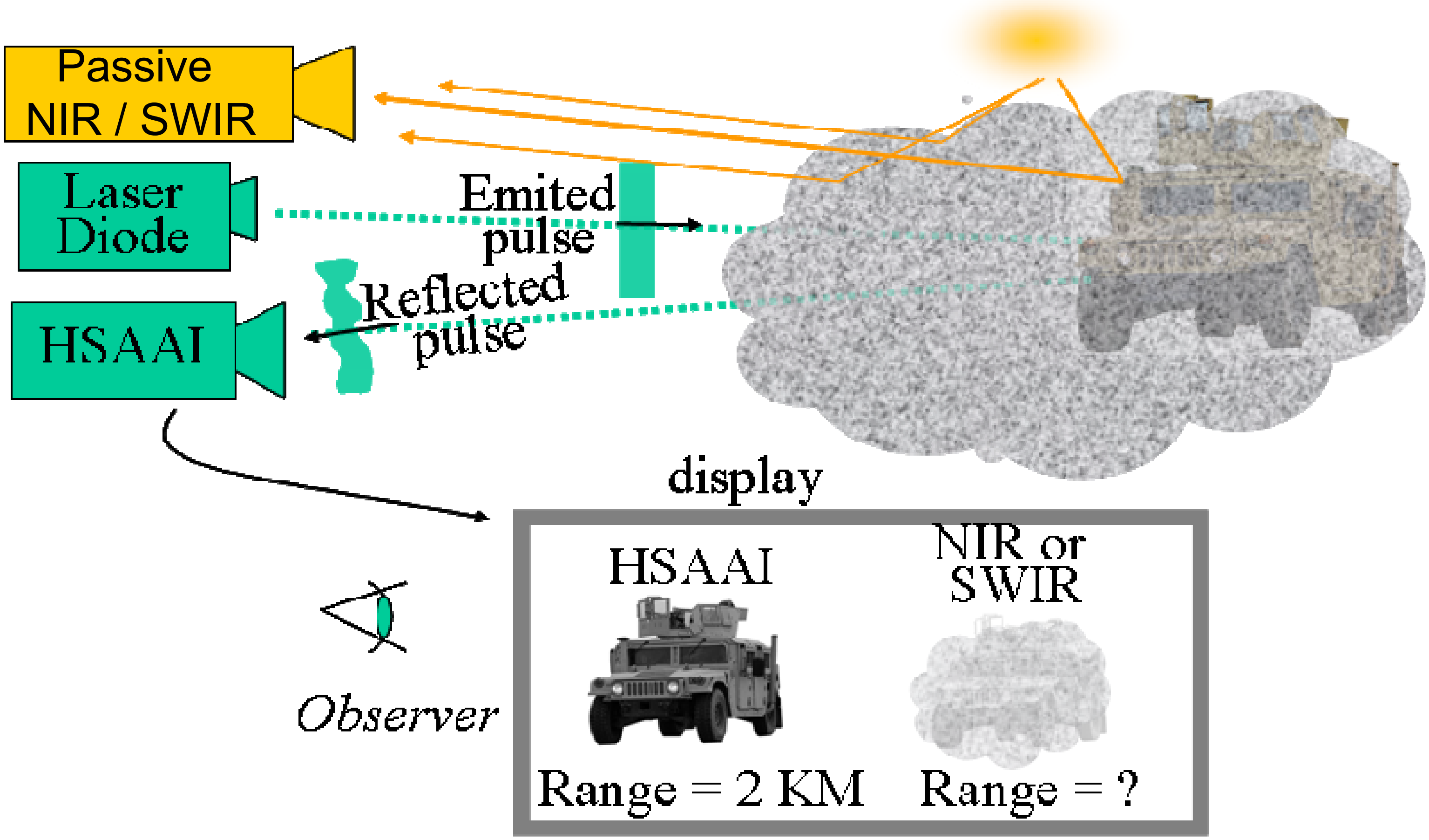
Heterodyne Staring Array Active Imager (HSAAI)



- HSAAI provides gated imaging and ranging day or night and is not affected by sunlight.
- HSAAI is a CMOS receiver and uses Light Emitting Diodes or Laser Diodes as gated illuminators

Heterodyne Staring Array Active Imager
Briefing Outline

- Start by describing some of the desirable characteristics and applications of HSAAI
- Examples of HSAAI performance
- Brief description of silicon waveguide technology
- Brief description of HSAAI type of heterodyning
- Describe HSAAI implementation
- Discuss needed CMOS process development
- Describe illuminator implementation
- Summary and Discussion

HSAAI Characteristics

- HSAAI provides range gated imagery and range to pixel
- HSAAI uses laser diodes (LD) or LED suitable for continuous wave (CW) operation
- The combination of CWLD illuminator and CMOS receiver provides an inexpensive, small, low power, completely solid state active imager.
- But CWLD provide little energy (Joules) per pulse, and many pulses are needed to get usable signal to noise.
  - When using direct detection, the long dwell times make dark current and sunlit backgrounds a problem
  - Dwells too long for spectral filtering to solve the problem
- HSAAI uses a heterodyned staring detector array to solve the noise problems and provide long range performance

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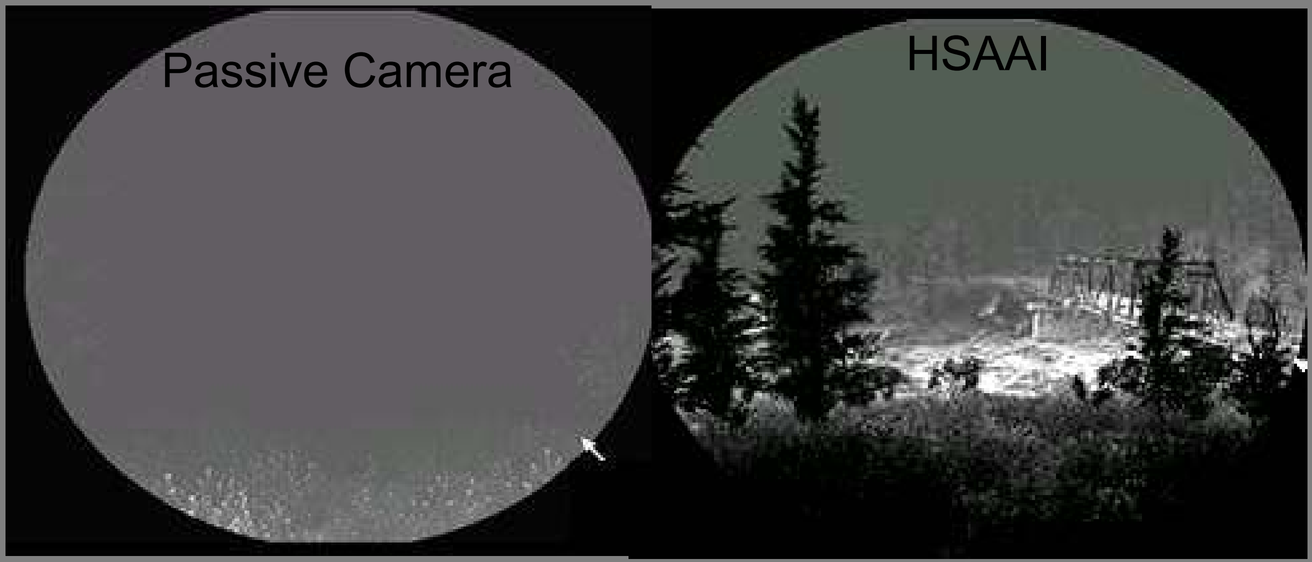
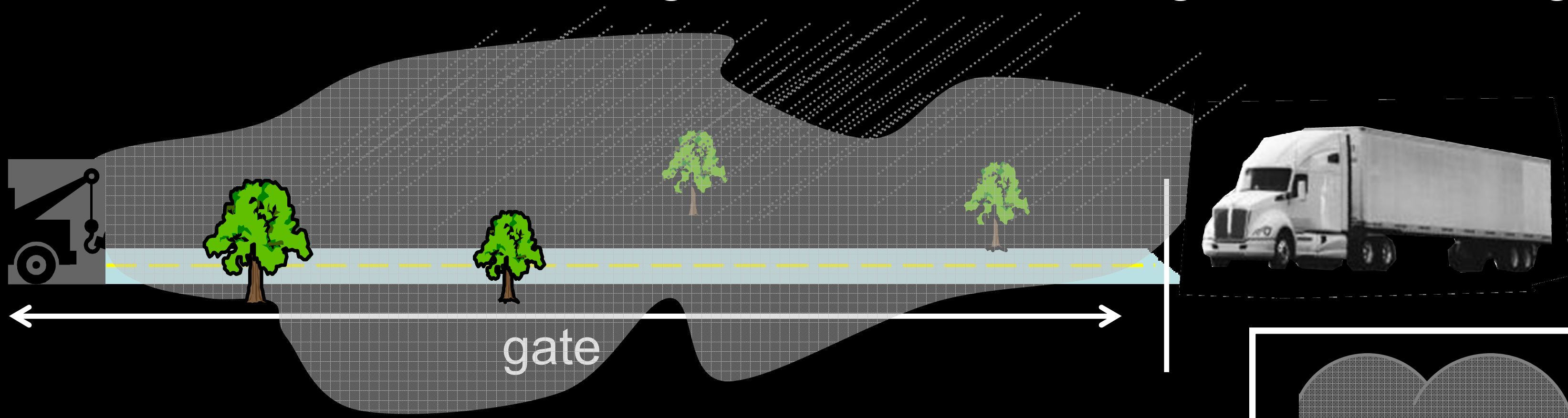
HSAAI aids vision in any weather at night and in fog and rain during the day

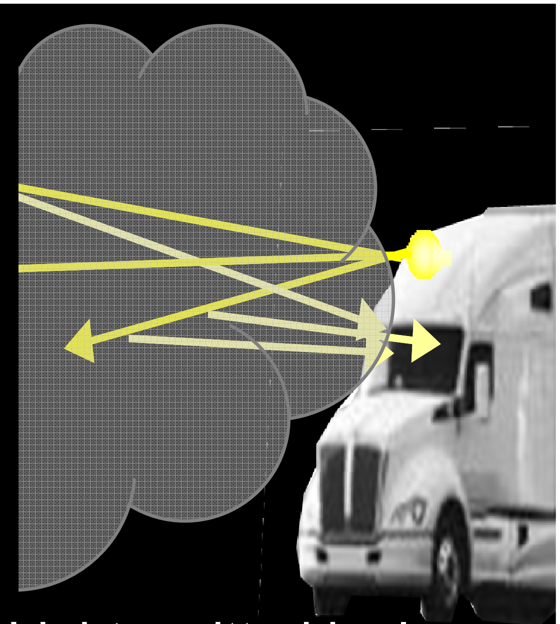
Gating helps even more in fog.



Gated Imager Used for Driving & Other things



- Gating is needed to eliminate backscatter in order to see through rain and fog.
- But beyond a short dark zone, the driver (or soldier, or pilot, or video tracker) needs to see the long road (or battlefield) ahead.
- With many pulses per frame (per image), HSAAI provides the ability to tailor apparent illumination versus range.



Light emitted by laser on truck scatters off fog & rain back into driver's eye and imager

HSAAI provides long range gates even in poor visibility

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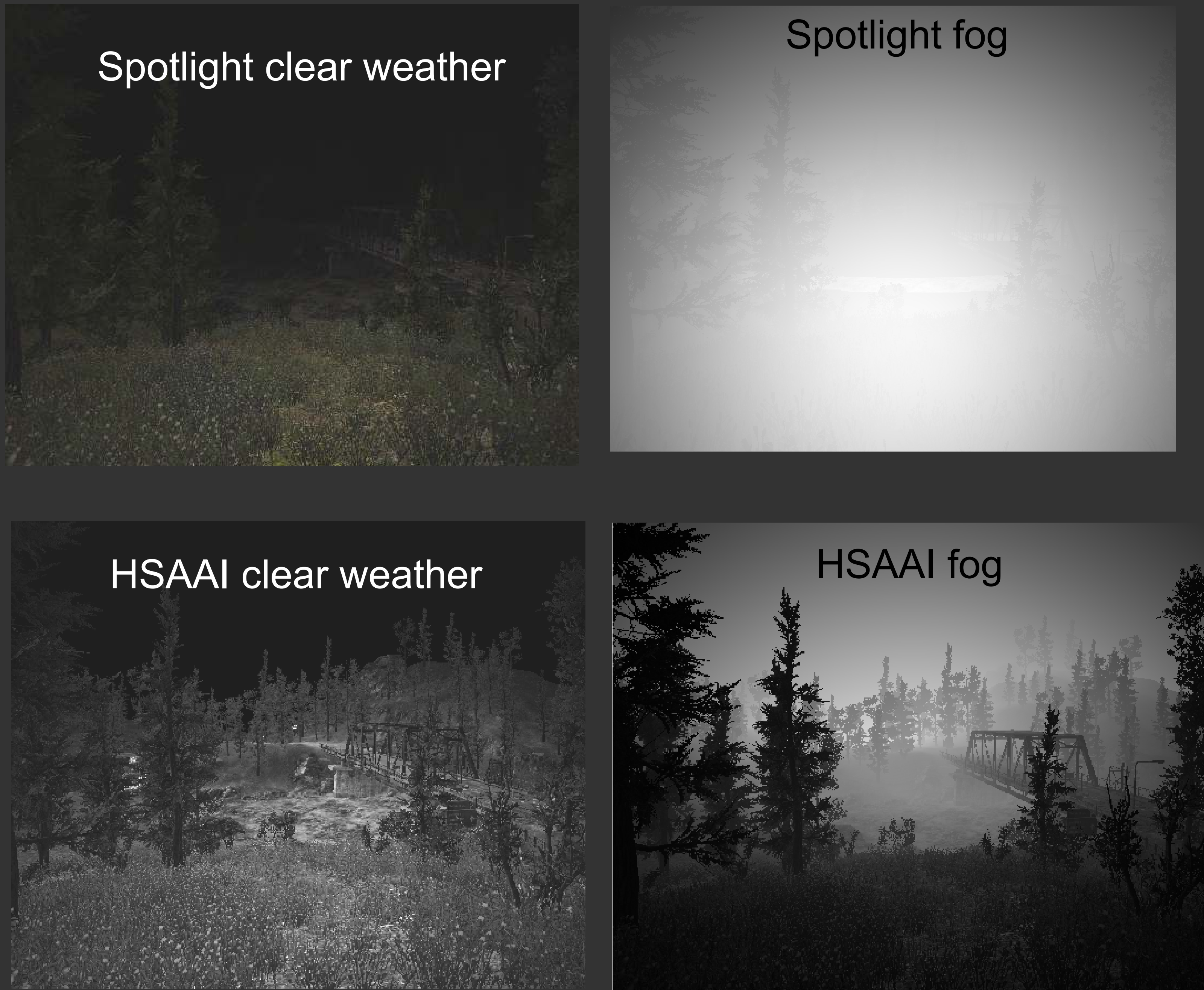

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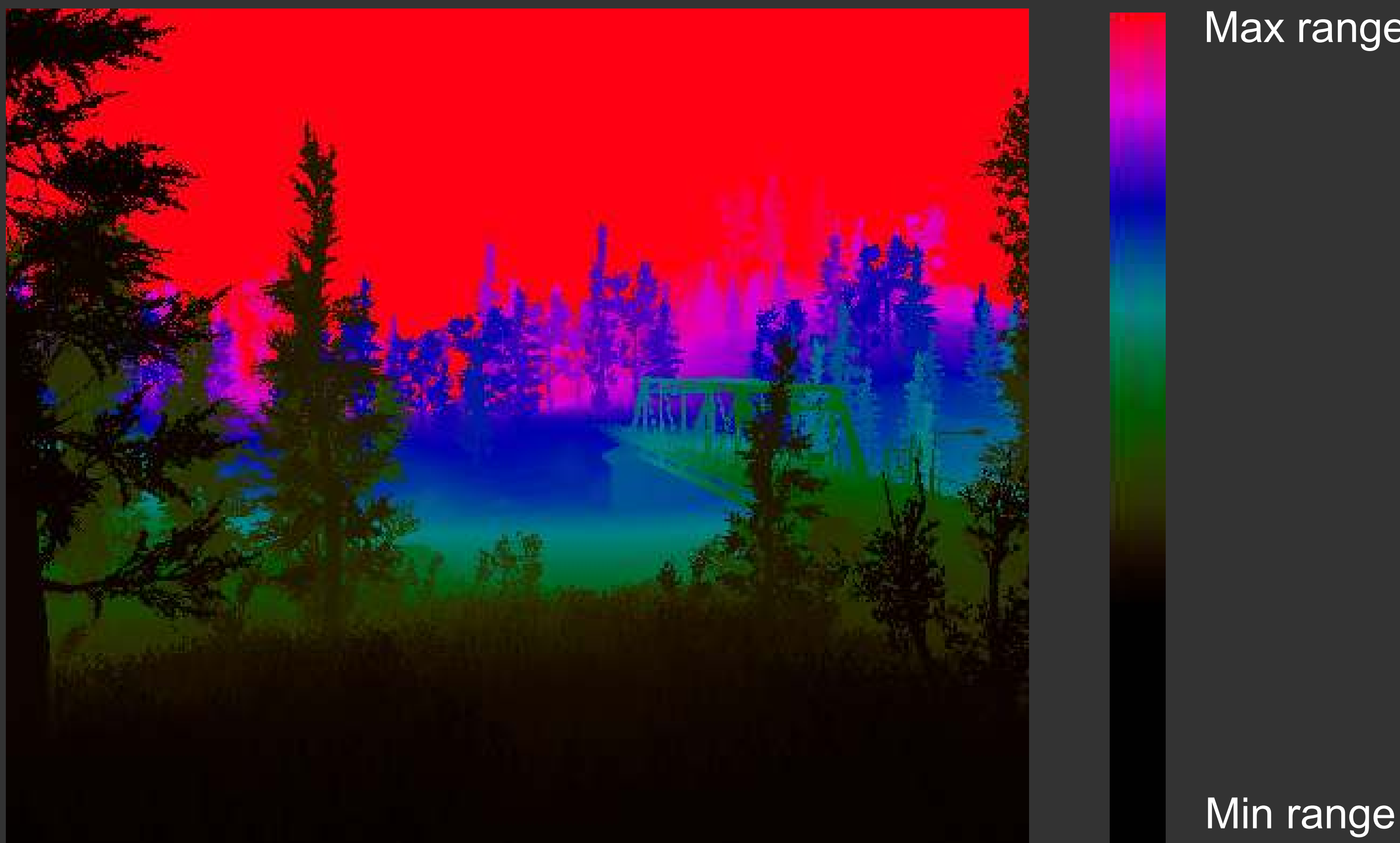
HSAAI also provides range to pixel

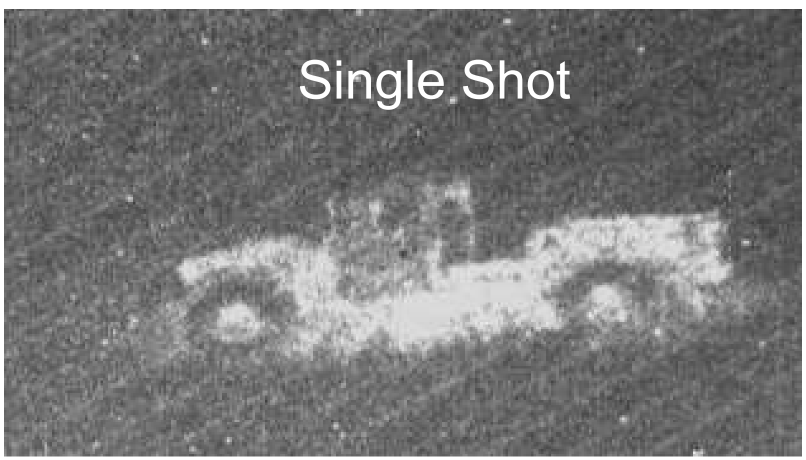


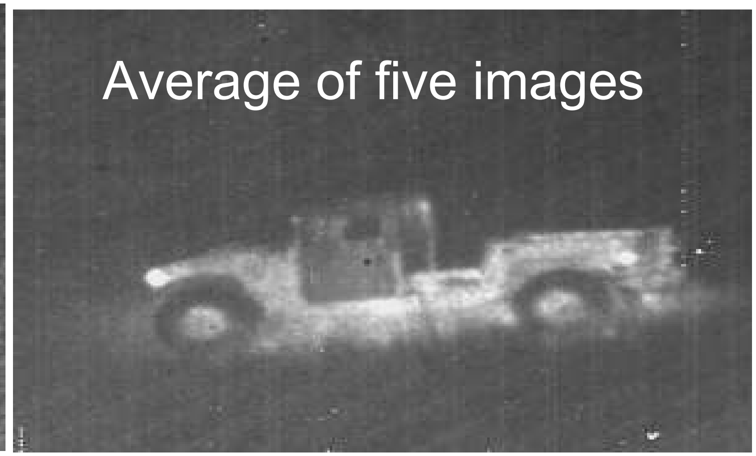
Can HSAAI Provide Short Range Gates?

- Yes
- Must have approximate target range from intel or from initial ranging frame or frames by HSAAI
  - No different than other active imagers
- In clear weather, short range gates do not extend dwell time because backscatter is not a problem.
- In fog or rain, short range gates require long dwell times
  - Because of heterodyne, extremely long dwells are not a problem for HSAAI
  - But, for example, a 250 meter range gate at 5 km in heavy fog would require up to 20X the time to integrate the same signal as normal HSAAI imaging (so as slow as three frames per second instead of 60)

Discuss Speckle

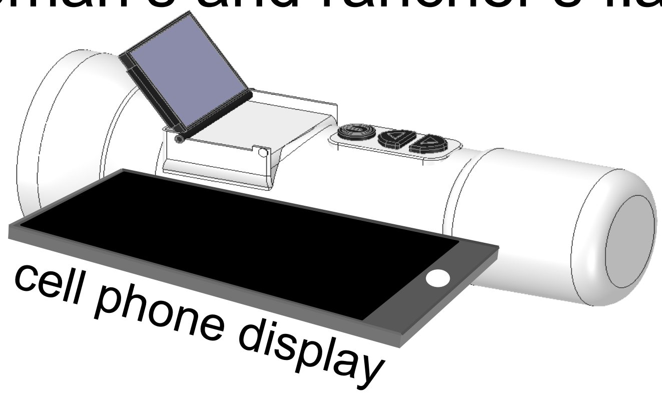
- HSAAI uses many pulses to form an image
- Eight pulses eliminates speckle
- For 60 Hz video, eight pulses per frame occurs with the maximum range set to 600,000 meters.
  - Closer than 600,000 meters, more than eight pulses are used to form an image.
- There is no speckle in a HSAAI image



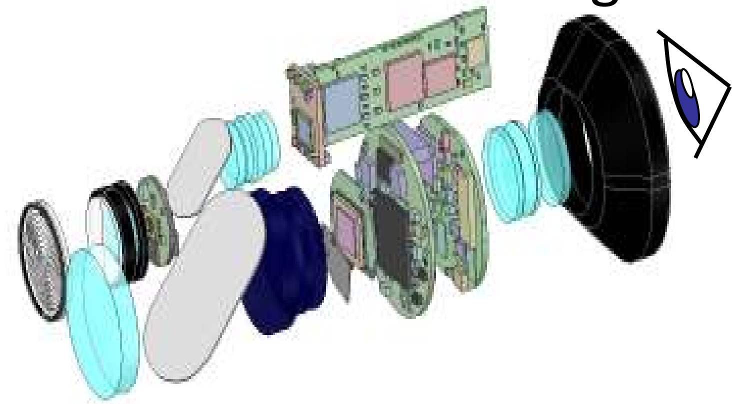


Applications for a compact SWIR active imager

Fireman's and rancher's flashlight



Active/passive SWIR & Thermal rifle Sight

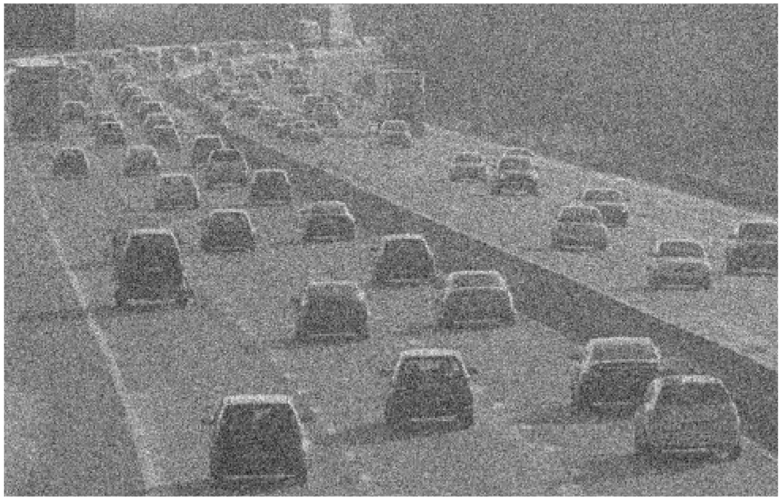


- HSAAI is solid state, compact, and can be inexpensive enough for security, firemen, ranchers, and other commercial applications.
- HSAAI is small enough for end game guidance and fusing
- HSAAI has sufficient range for terrain following or target acquisition applications
- HSAAI could provide end game tracking for threat warning (wake up on passive threshold) or several HSAAI could serve as the primary threat warning sensor if continuous active is acceptable

Range Performance Examples

- HSAAI operates at 1.3 microns wavelength
  - Can also operate in the mid wave infrared
- HSAAI uses germanium photo detectors at 1.3 μ; these detectors are commonly available at silicon foundries
- HSAAI provides 60 Hz. video but the performance is based on a single frame
- Predicted performance is for worst case long range gates.
- 1024 by 768 Light Collection Sites (pixels) each 15 microns on edge.
- 15.4 by 11.5 mm CMOS array

Pixel signal / noise = 1 is a usable picture



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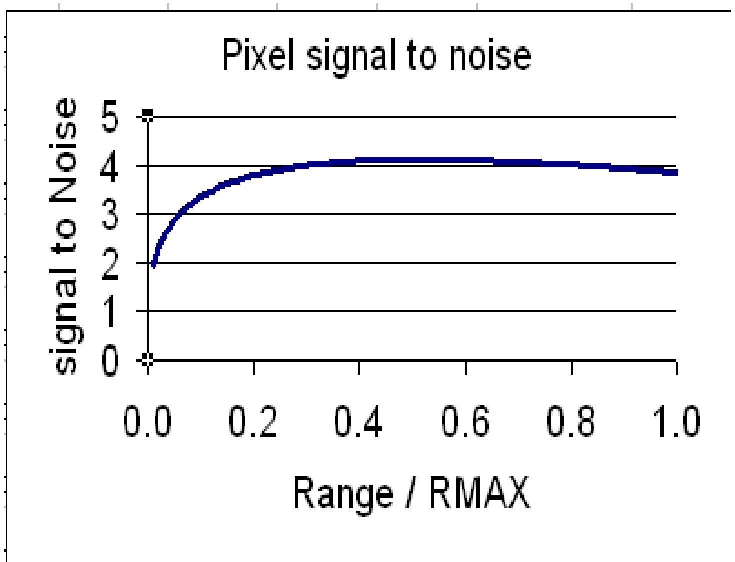
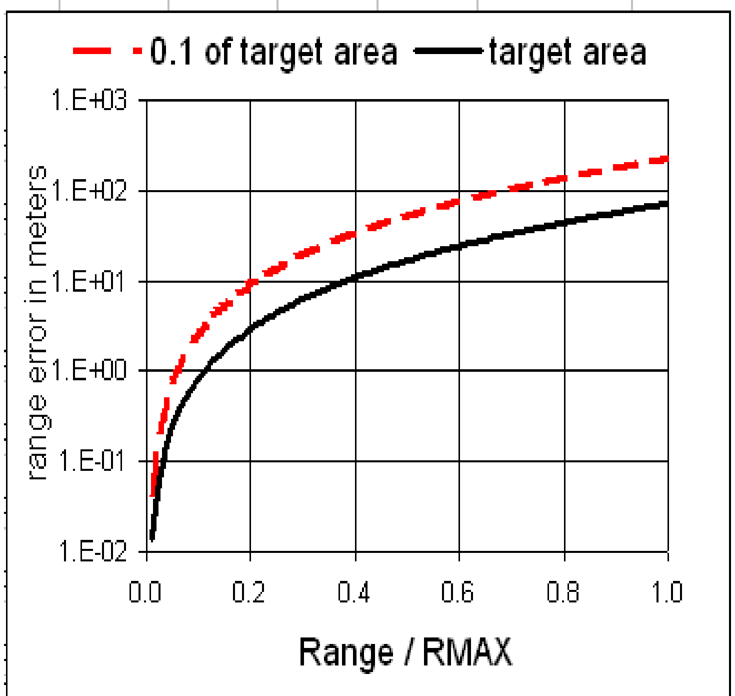
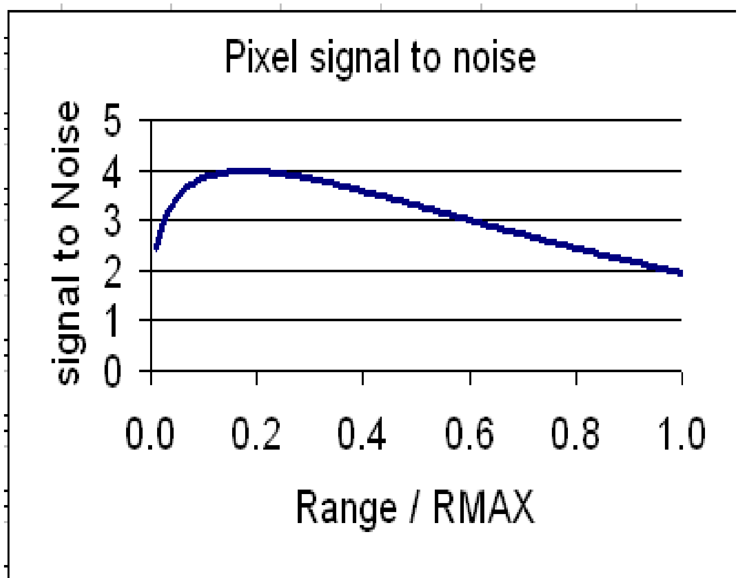
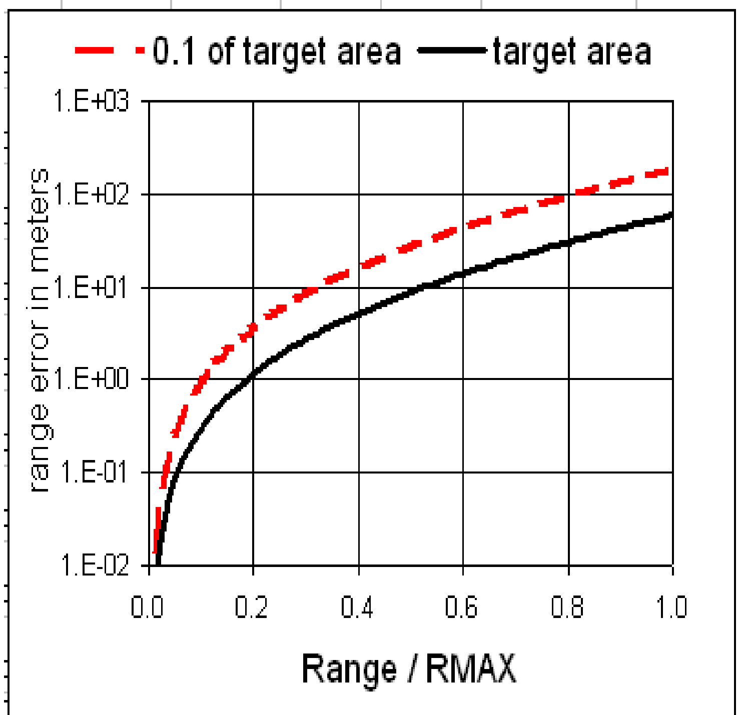
Range performance 30º FOV and 2 square meter target





- The top plot shows signal to noise for a 0.2 reflective target.
  - A white surface would have 5 times the signal but the same noise.
  - Signal to noise of 4 is a clear picture.
- Signal to noise initially increases with range because of gating.
- The bottom graph shows range error plotted against range for the specified target area in meters and 0.1 of target area.
- These plots are for F/1 optics. 300 meters maximum range, and an illuminator diode emitting 1 watt peak and 0.2 watt average power.
- Total scene to detector coupling efficiently from all factors is 0.15.
- Pixel pitch is 15 microns with 1024 by 768 pixels
- Atmospheric transmission is 0.2 per kilometer (poor weather).
- This kind of sensor might provide video as a driver's aid.

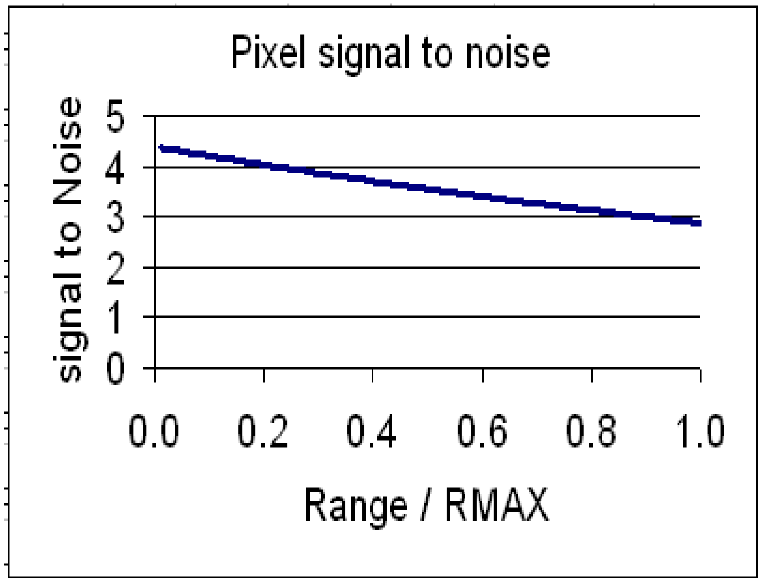


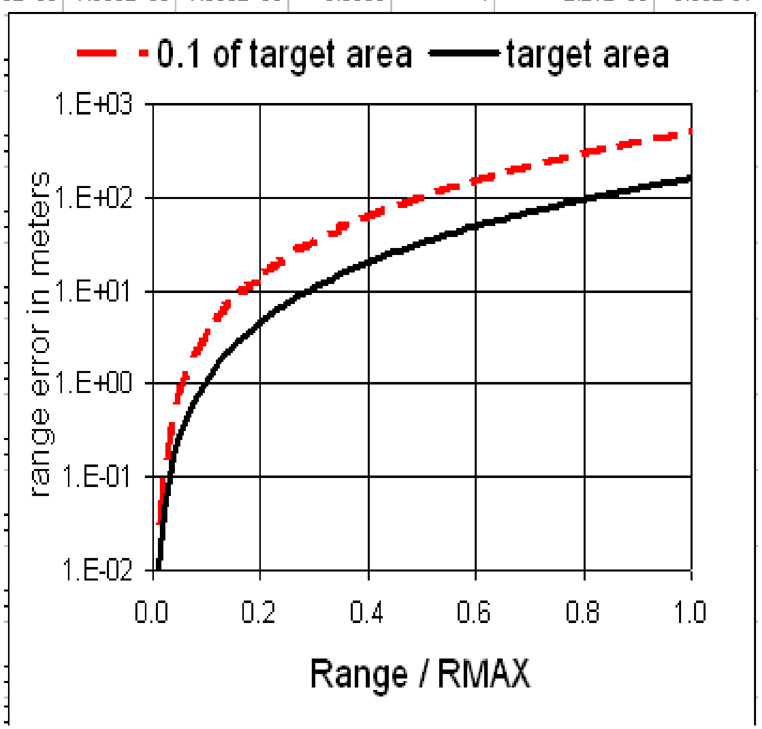


Range performance for a 2° rifle sight

- Range is to the 0.2 reflective ground near the target.
- The top plot shows signal to noise with a 5 kilometer maximum range and 0.5 per kilometer atmospheric transmission.
- These plots are for F/4 optics. 5,000 meters maximum range, and an illuminator diode emitting 5 watts peak and 1.0 watt average power.
- Total scene to detector coupling efficiently from all factors is 0.15.
- Pixel pitch is 15 microns with 1024 by 768 pixels
- Atmospheric transmission is 0.2 per kilometer (poor weather).
- This kind of sensor might be used as a rifle sight.

Different maximum range for the 2° rifle sight





- Everything is the same as for the last slide except the maximum range has been reduced to 4 kilometers.
- Near range signal to noise has improved because the gating sequence has been set for a closer range.
- It appears that the range error did not change, but remember that the range scale is fraction of maximum range. Also, in this case, range is to the ground, so "target size" got bigger in the plot on the last slide.

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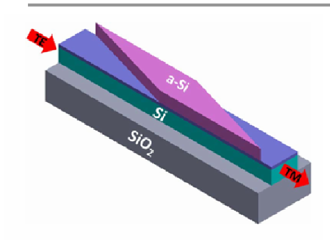
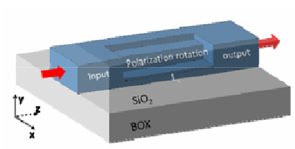
Waveguide Functional Components using CMOS Processes.

Mode converters





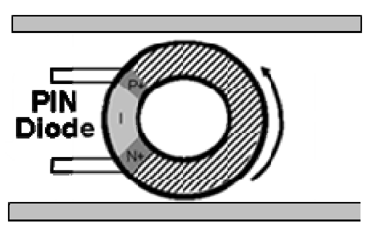
- Mode converters are “polarization diversifiers” and let us collect all the incoherent light.
- Waveguides conduct light efficiently

Ring Resonator

Drop: narrow band light out

Current through the PIN diode changes bandpass spectrum

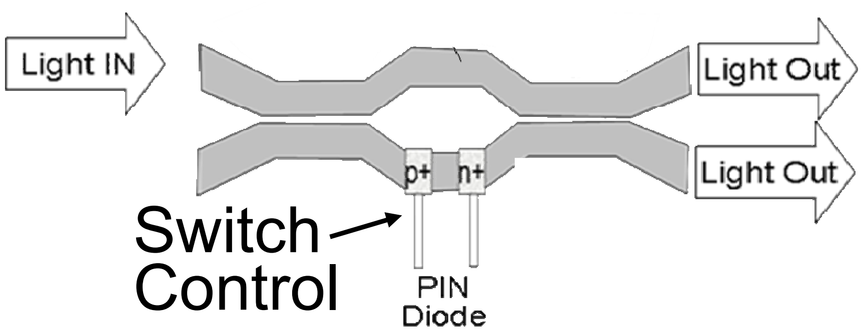
Add: Broad spectrum light in



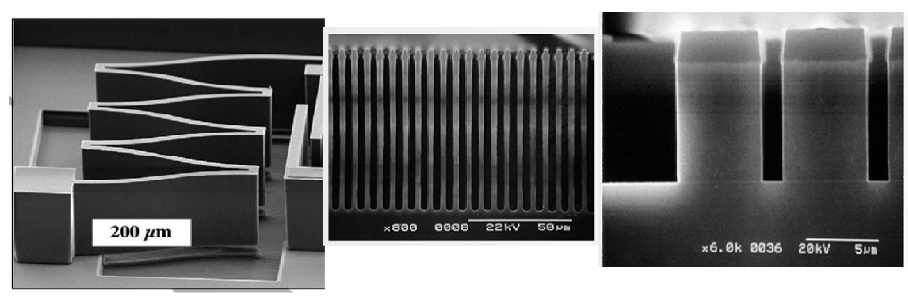
Demonstrated layout aids

- Turn right angle corners w/mirror
- Lay waveguides over other waveguides at right angles to avoid coupling
- Light from expanded waveguide will jump substantial gaps without loss

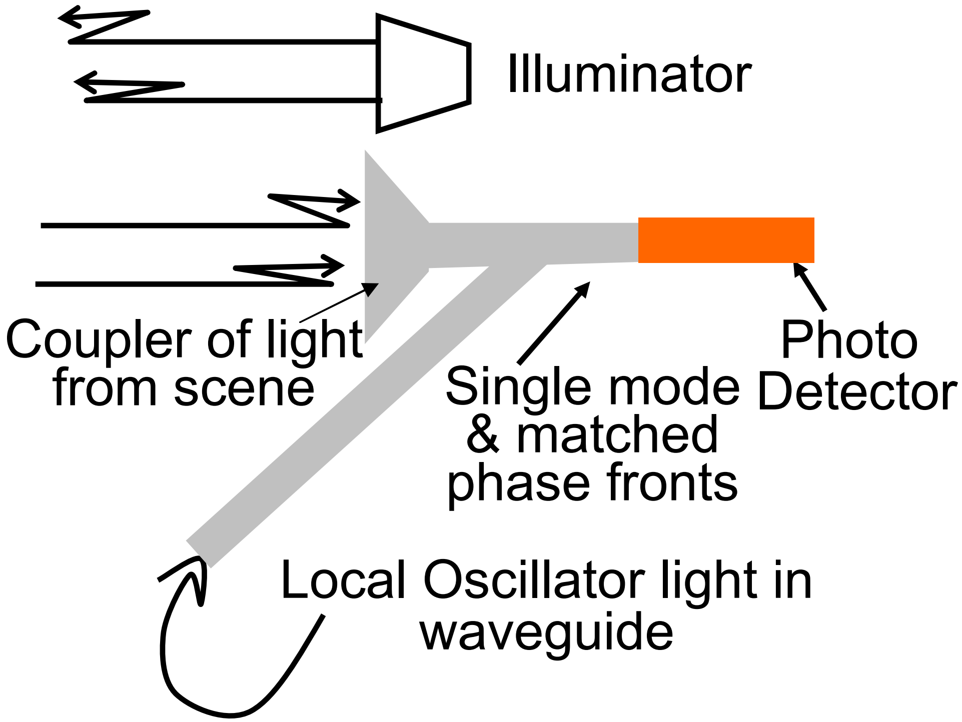
Mach Zehnder Interferometer used as optical switch

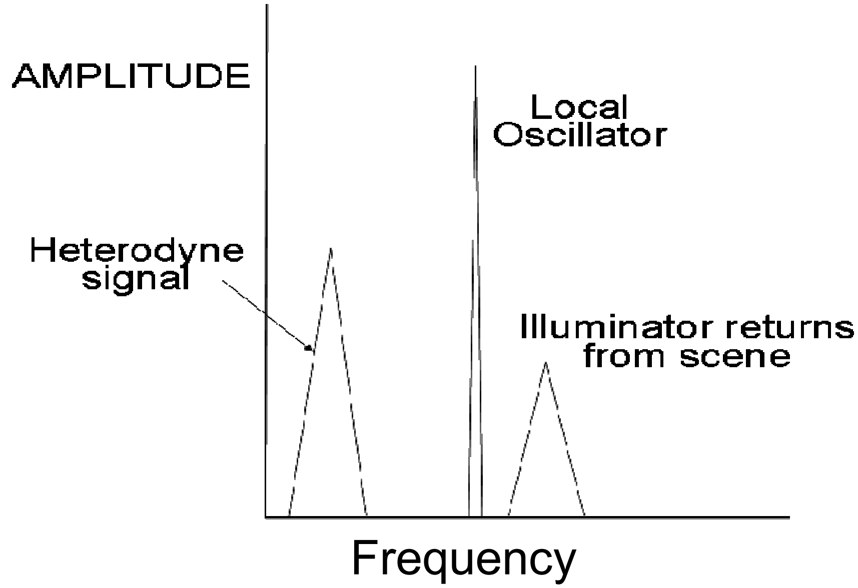


Etch structures out of silicon



Explain HSAAI Heterodyning





- Mixing scene and LO light in waveguide before photo detector aligns mode and phase fronts
- Heterodyne is used to bring the illuminator signal down to the detector temporal bandwidth
  - Multiplication in time is a convolution in the frequency domain

Explain HSAAI Heterodyning

- Coherence length of light, even a 0.3 nm spectrum at 1.3 micron, is extremely short (3.7 mm or 1.2E-11 seconds for this example).
- The difference frequency for 0.3 nm bandwidth is 53 GHz
- Not even one cycle at the highest frequency (53 GHz) can occur during a coherence time. The situation is worse for lower frequencies.
- The difference spectrum does not exist in the expected form.
- We can, however, treat the integration of the difference spectrum as the sum of many, many stationary spectrums each with phase jumps.
  - Meaning the spectrums add like noise, and a 100X power increase only results in a 10X signal increase over fixed noise.
- Given the square root (√), why would heterodyne be useful?

• The signal looking directly at the sun is substantially less than LO shot noise.
• Scene return signal is proportional to LO shot noise
• Therefore, HSAAI heterodyning makes the day or night use of CW illuminators possible

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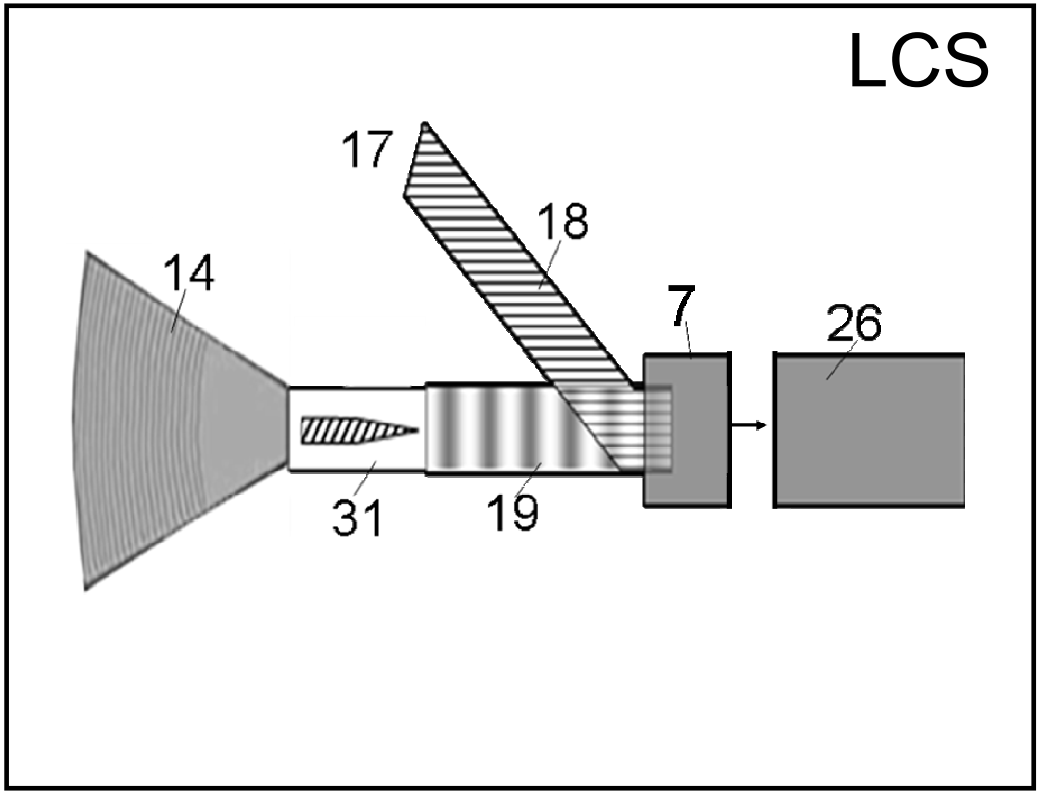
HSAAI consists of a two dimensional array of <u>Light Collection Site (LCS)</u>



14	Bragg Grating or horn-coupler
31	Polarization diversifier (with coupler)
17	Local Oscillator
18	Local Oscillator Waveguide
7	Photo diode
26	Detector electronics AC coupled

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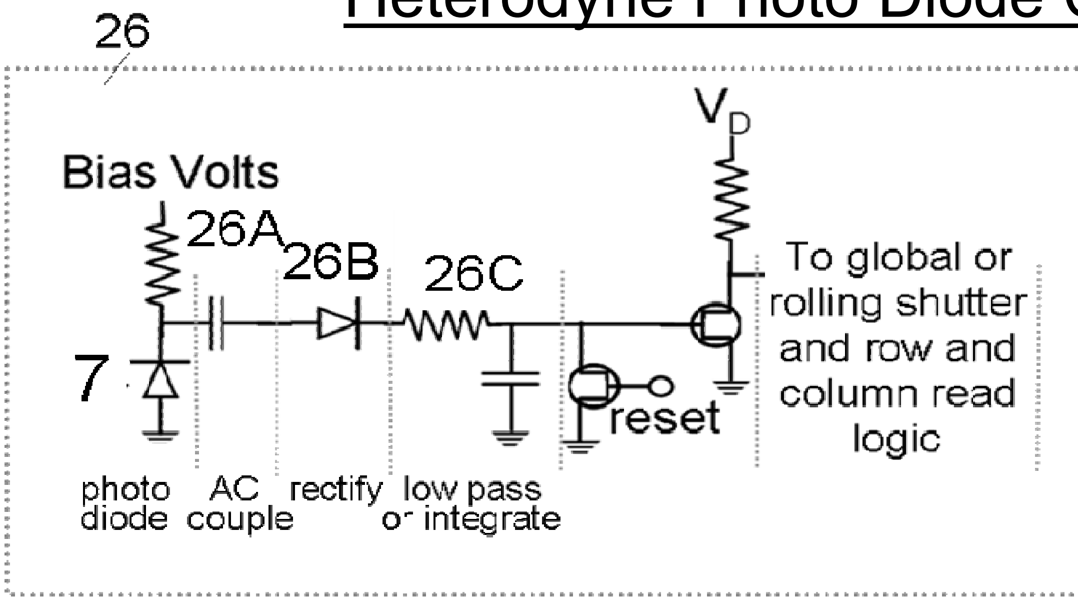
Heterodyne Photo Diode Circuit



Interpret as a logic diagram, not a circuit

- MOMS diode is plenty fast for this purpose
- Gating by moving local oscillator wavelength to put beat frequency out of photo diode temporal response
  - Sum photo charges from multiple pulses in place
  - No large transient pulse from gating local oscillator
- Add Mach Zehnder as optical switch on the input waveguide (19) for extra isolation if needed

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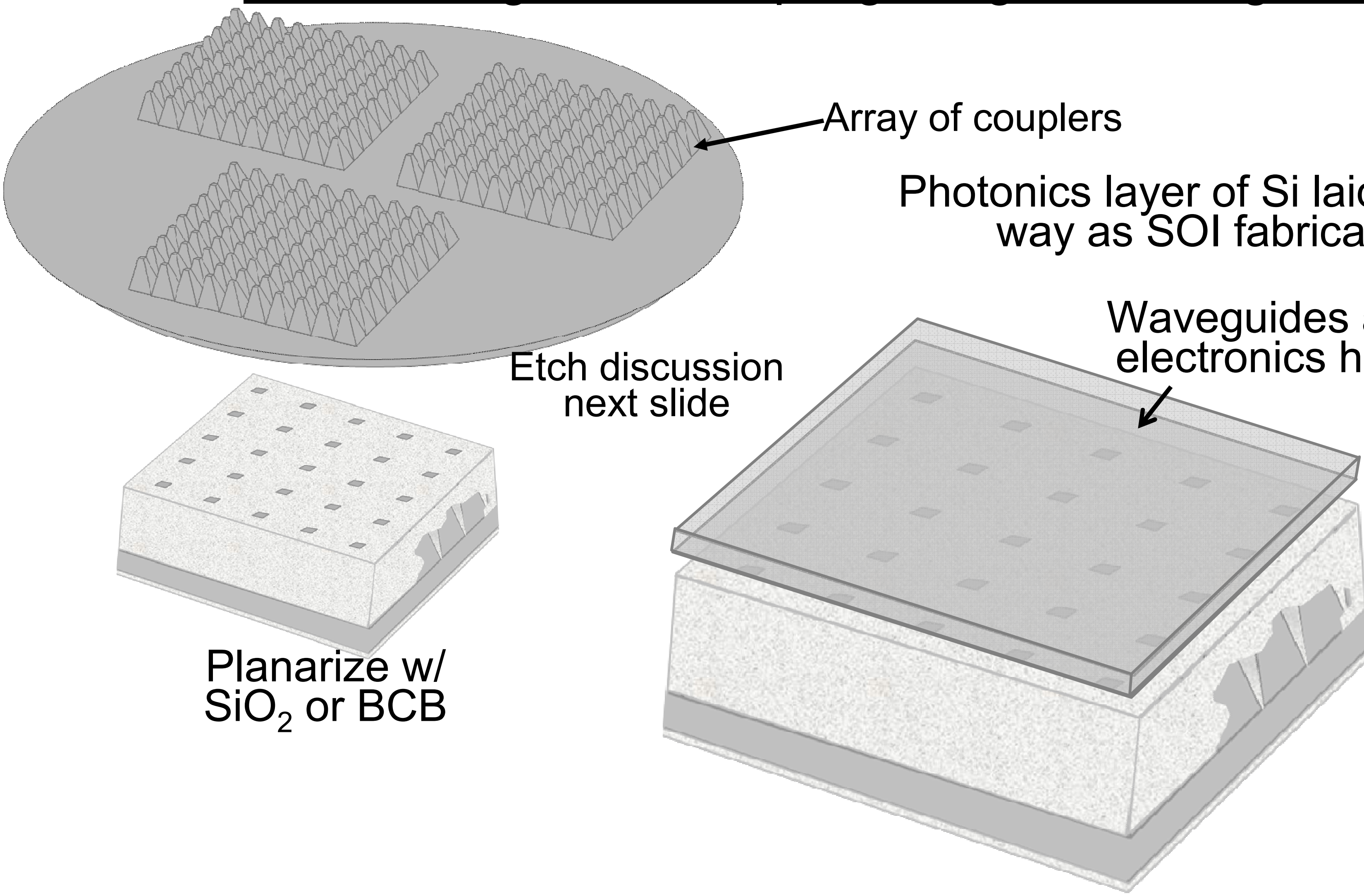
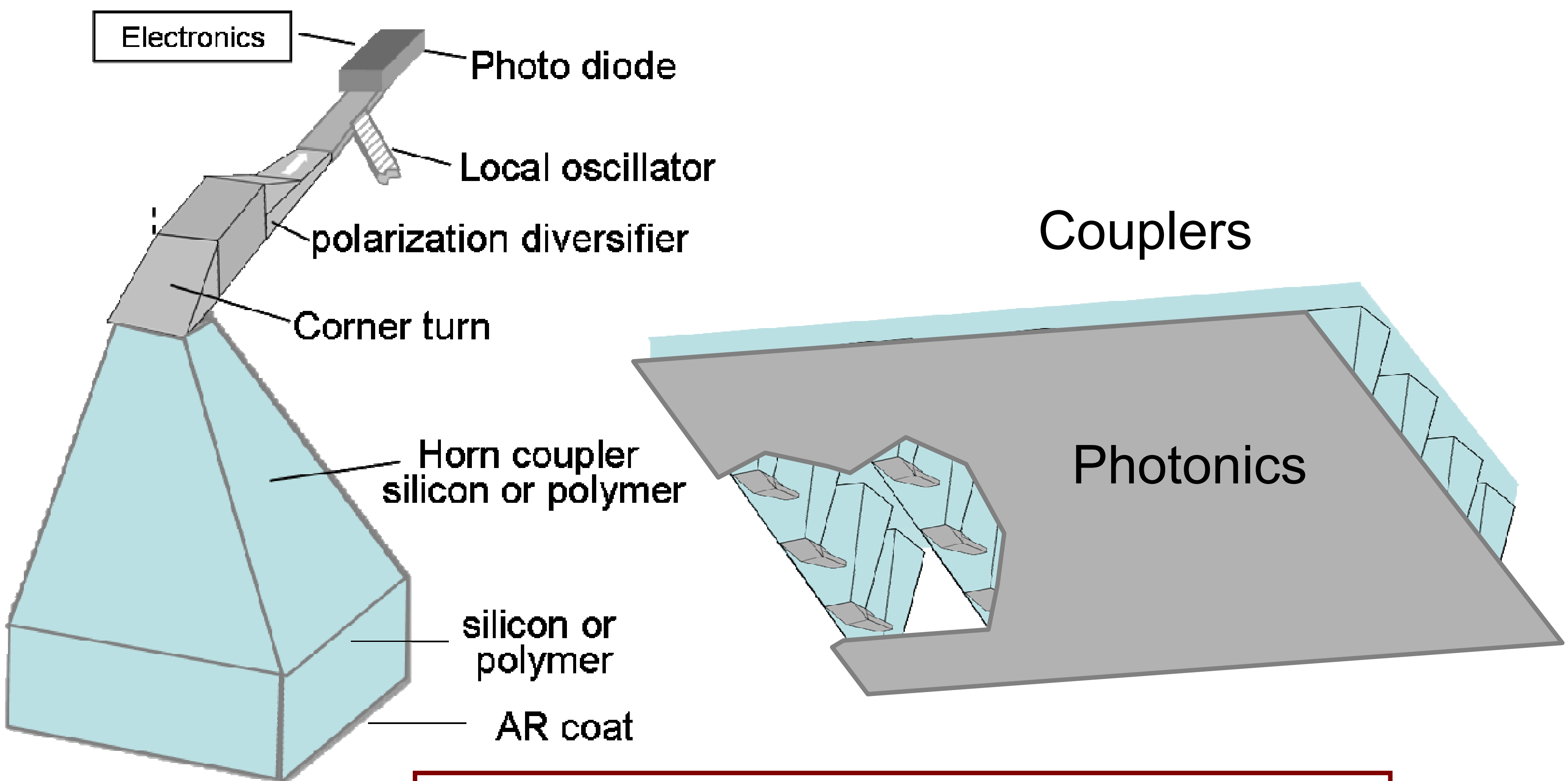
Some thoughts on coupling image to waveguides

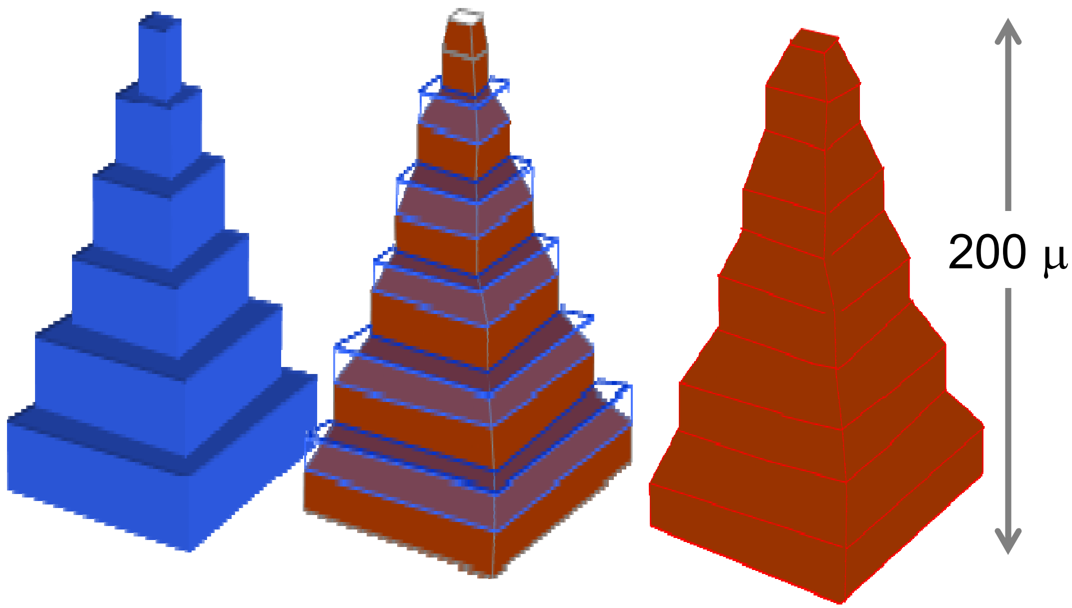


Coupler likely the aspect of HSAAI that needs the most process development



Illustrations at right and left are inverted

Some thoughts on coupling image to waveguides



- Dry etch (blue) can be used to define sharp vertical drops
  - Undercut of about 1 degree is typical.
- By selecting a wafer with the correct crystal orientation, a wet etch slants the sharp corners at 35.5 degrees to vertical removing blue material
- If the total length is 200 microns, then efficiency should be about 0.75.

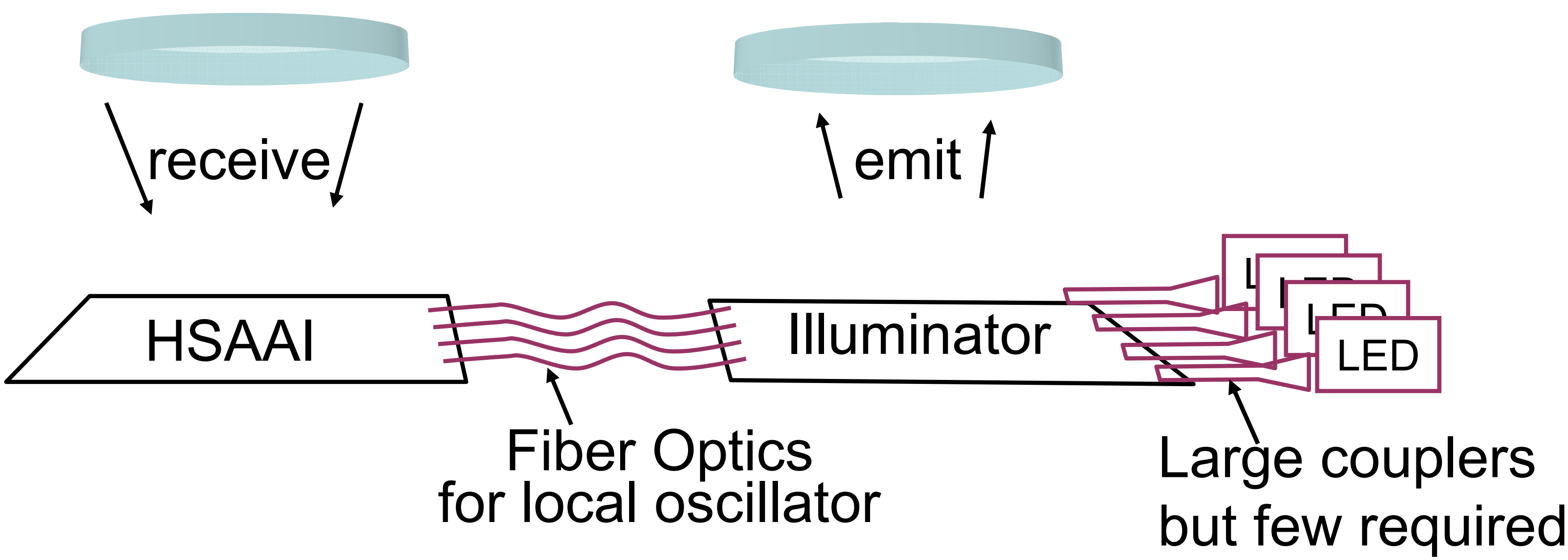
Bragg Gratings with Bragg reflectors are easier to fabricate but limit wavelength response and angle efficiency. Horn couplers are harder to fabricate but better performers in the long run.

Summary Comments on HSAAI Receiver

- HSAAI provides range-gated imagery and range to pixel and is essentially immune to the effect of sunlight.
- HSAAI is fabricated using CMOS technology and uses CW LED or laser diodes as illuminators
- The HSAAI feature requiring most process development is scene to LCS light coupler
- Bragg Gratings are easier to fabricate but limit spectral band and angle efficiency
- Bragg Gratings would also limit passive performance and frequency hopping and single chip waveband
- Illuminator options will be discussed next slide

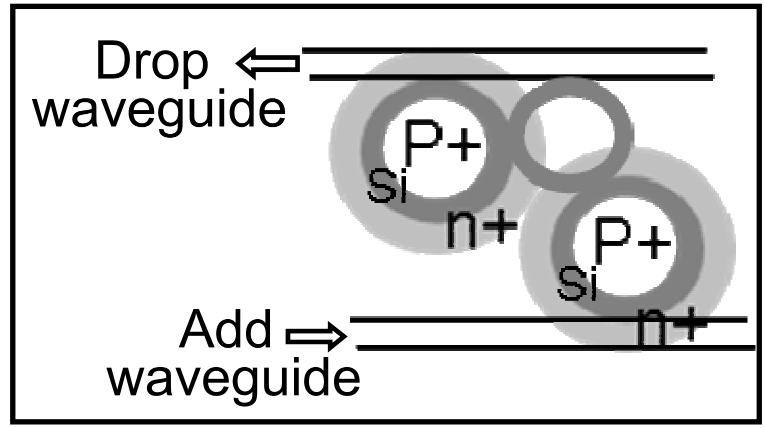
LED or Laser Diode Illuminator

- Derive both illuminator light and local oscillator (LO) light from LED or laser diode
- Large couplers make LED to illuminator transfer efficient.
  - There are only a few LED to chip couplers needed
- Fiber optic connects local oscillator signal to HSAAI



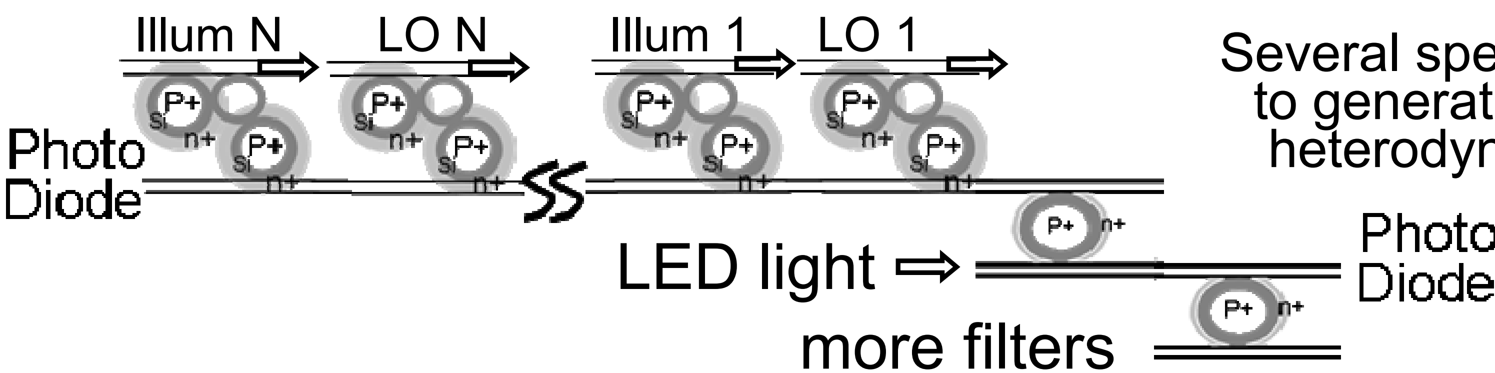
Generating illuminator and local oscillator light

- Spectral filters using rings or racetracks
- Spectrum controlled by PIN diode currents
- Divide LED or LD spectrum suitable for heterodyne
- The photo diodes sense light dumped by each filter and monitor spectral filters during operation



One spectral filter

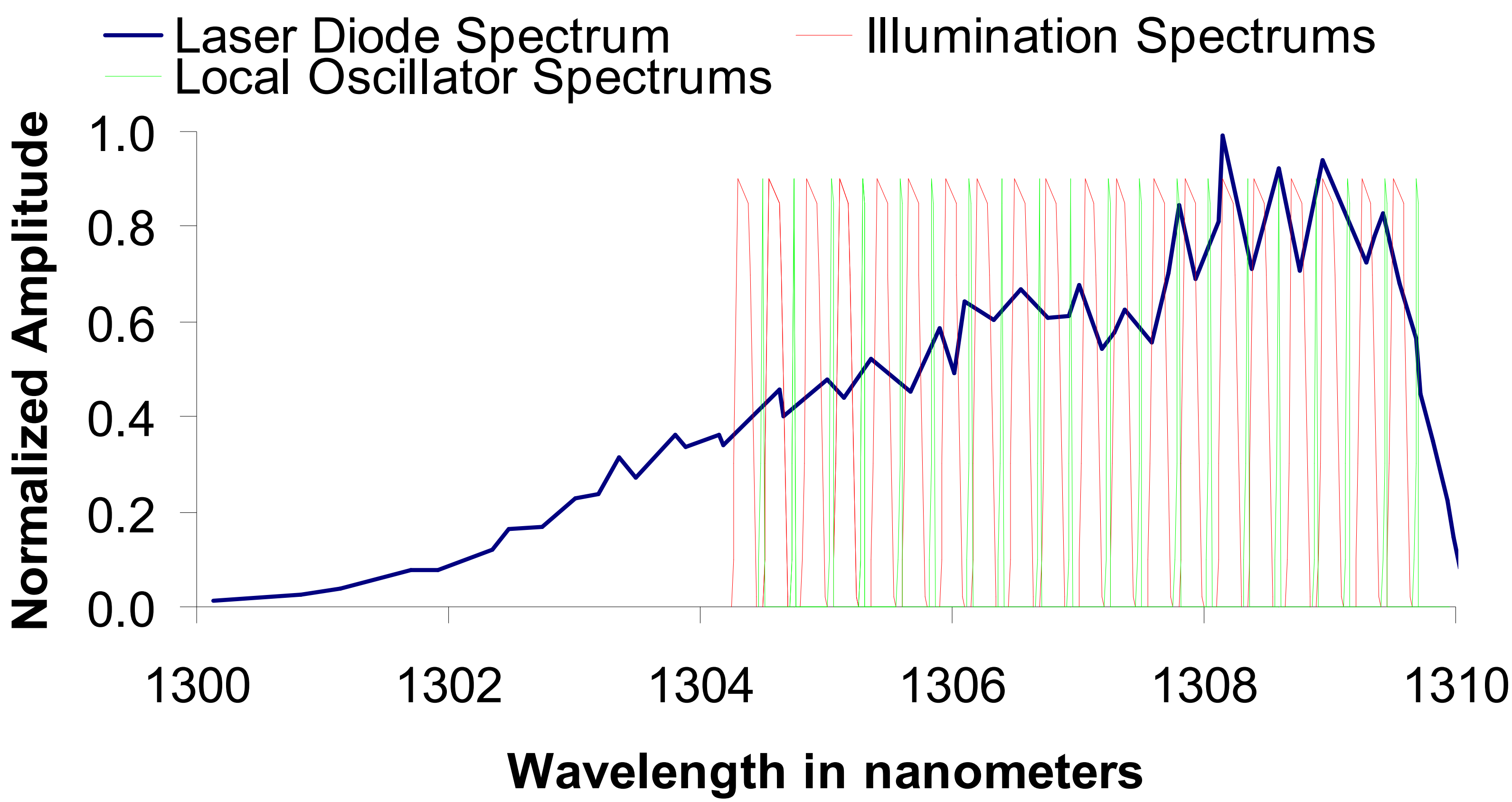
Illumination and LO spectral bands set up using photo diode signals



Several spectral filters to generate several heterodyne bands

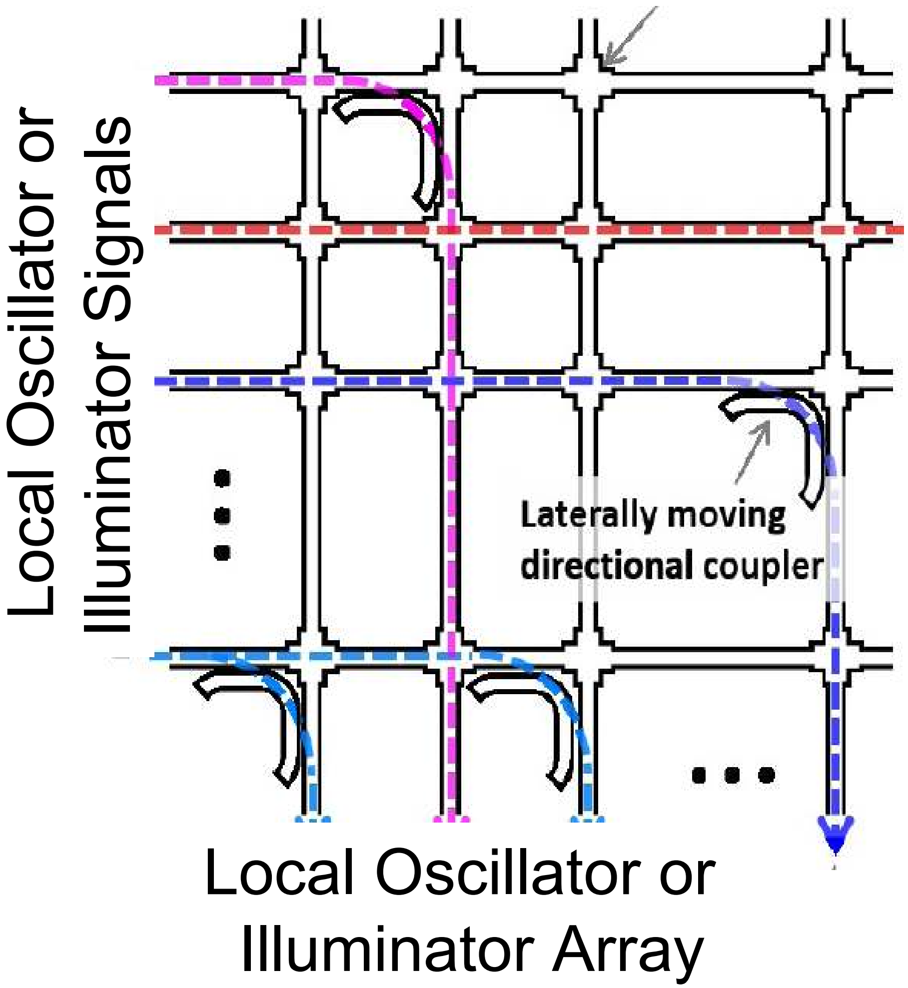
Generating illuminator and local oscillator light

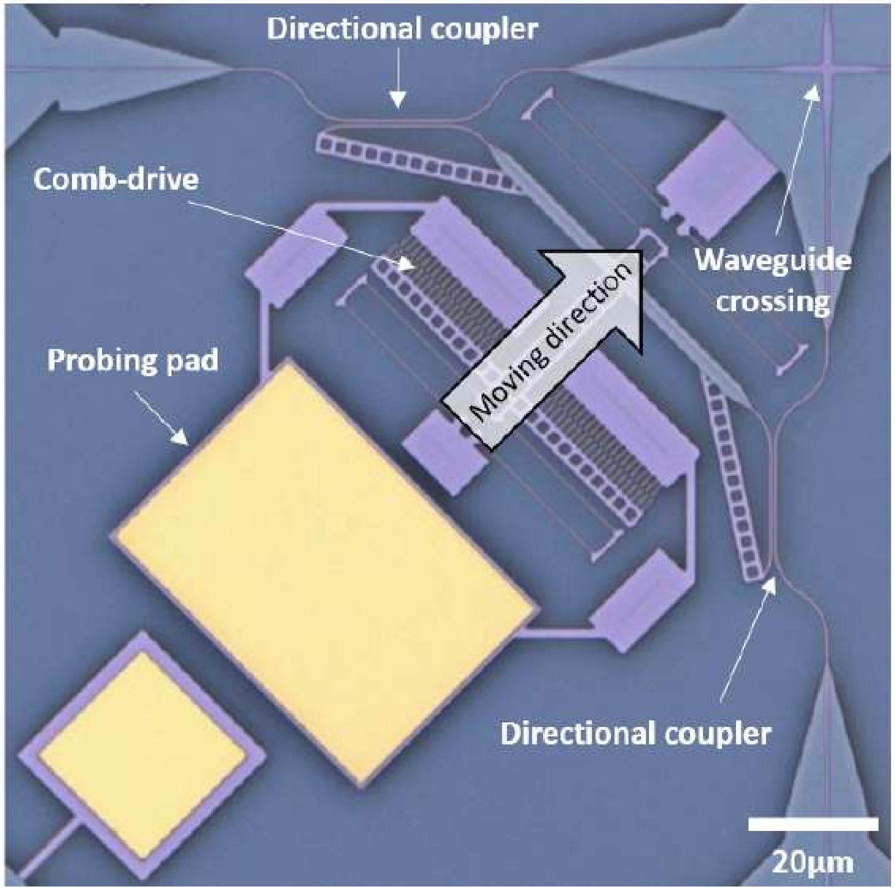
- Simple control logic using photo diodes separates out multiple illuminator and local oscillator spectral bands.
- This example would continuously operate illuminator diodes, but control logic to separate illuminator and LO is also simple.



LED Illuminator matrix

- Illuminator and HSAAI arrays divided into "N" areas
- Low loss multi-point switch. (Sangyoon Han, Tech Report UCB/EECS-2016-190)
- Other switch means available; this is an example.





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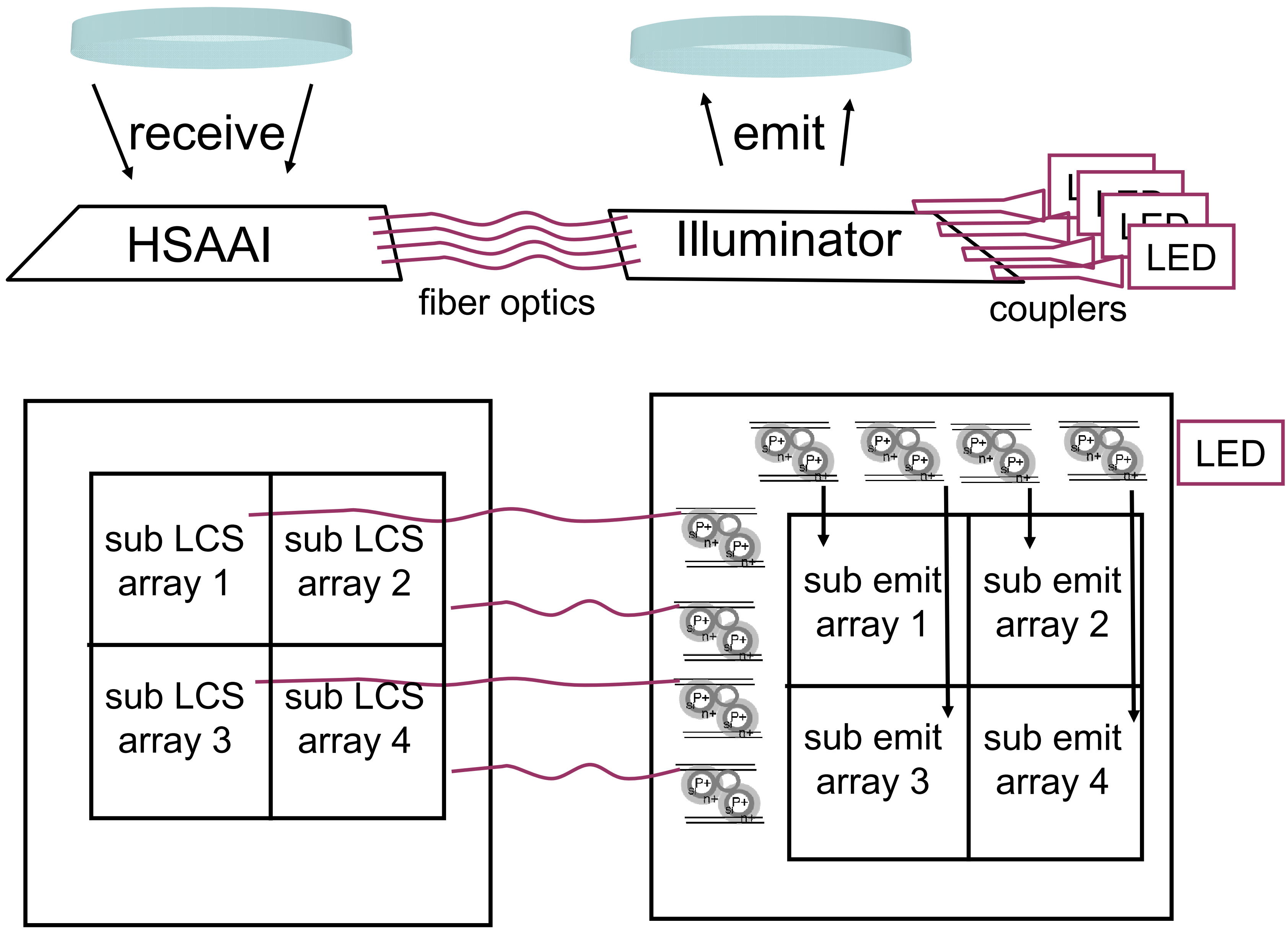
HSAAI & Diode Illuminator



Summary and Discussion

- HSAAI uses CMOS waveguide processes developed for communications to implement active heterodyne imaging
- HSAAI is used with CW illuminator diodes to achieve a compact, low power, comparatively inexpensive imager
- HSAAI provides gated imaging and range to pixel and is essentially immune to sunlit backgrounds
- CMOS waveguide technology can also be used to fabricate illuminators for use with HSAAI
- Wideband coupler fabrication requires CMOS process development that can be avoided by using Bragg Gratings
  - But both power efficiency and flexibility would suffer