IR Electro-Optical Correlator for a Large Format Interferometer

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EWASS 2015 Meeting

Session: “The quest for detecting the primordial gravitational wave background”.

La Laguna (Tenerife), June 2015

CONTENTS

Introduction

-Goal: *Develop an instrument sensitive enough to detect B-mode polarization at 30 GHz.*

-Detection Technology: *Bolometers are not optimal in this frequency range. Ultra Low Noise receiver-based polarimeters can be used.*

-Opto-Mechanics: *Size limiting factor for imaging instruments due to the restricted focal plane area of the required telescope.*

-Large Format Interferometer*: Not limited by the focal plane area. Potentially hundreds or even thousands of receivers to have optimal sensitivity*

Introduction

-***Main Challenge*****:** *Develop a correlator for hundreds of wideband microwave (MW) signals. The routing, combination and detection result complex and very expensive.*

-***Proposal*****:** *Use Electro-Optical (EO) modulators to up-convert MW signals to the Infra Red (IR) wavelength (1550 nm).*

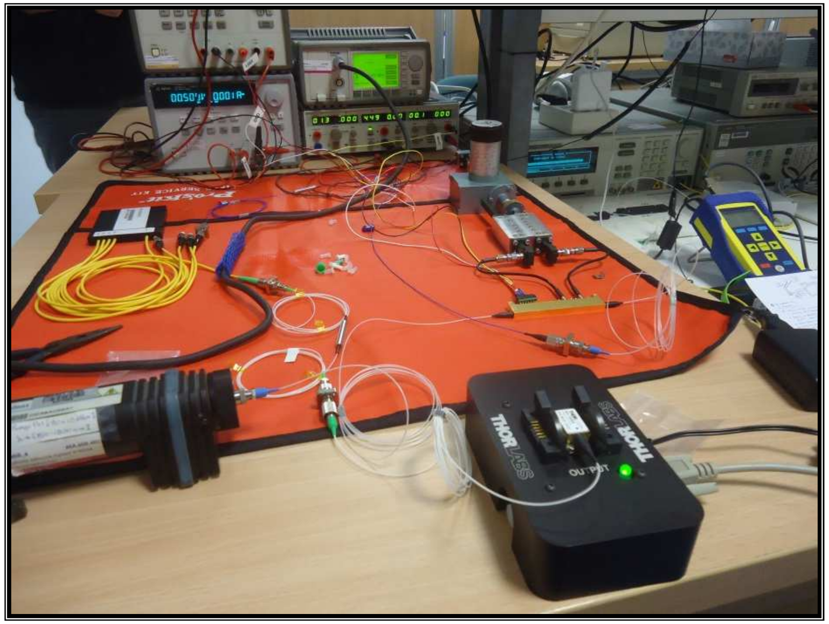
-The correlation and detection can be performed using optical fibers, lenses and IR cameras.

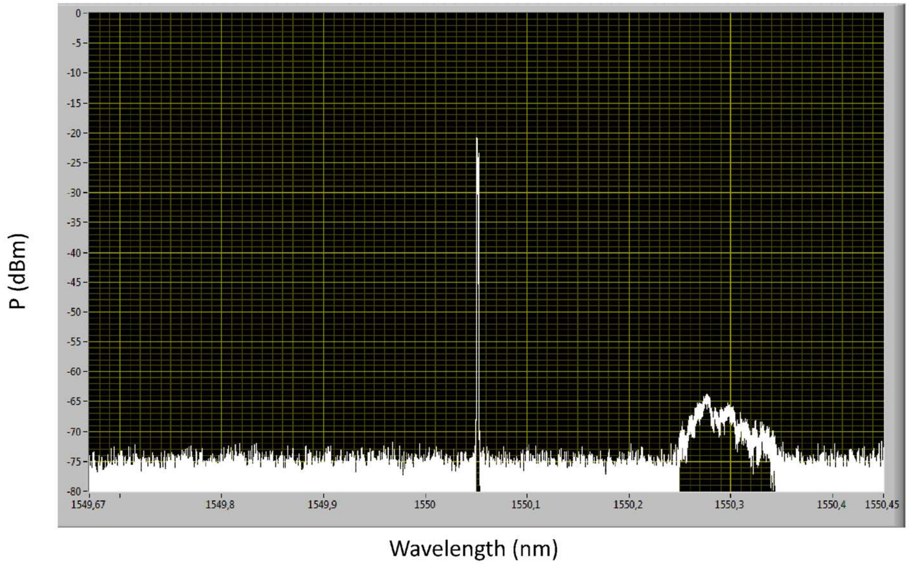
-High density detection and low cost.

-Very well understood technology to implement a synthesized imager.

MZM-Based Optical Correlator

Up-conversion of MW Signals to the IR





-Use of Mach-Zehnder Optical Modulator to perform the frequency range conversion.

-Optical carrier needs to be filtered.

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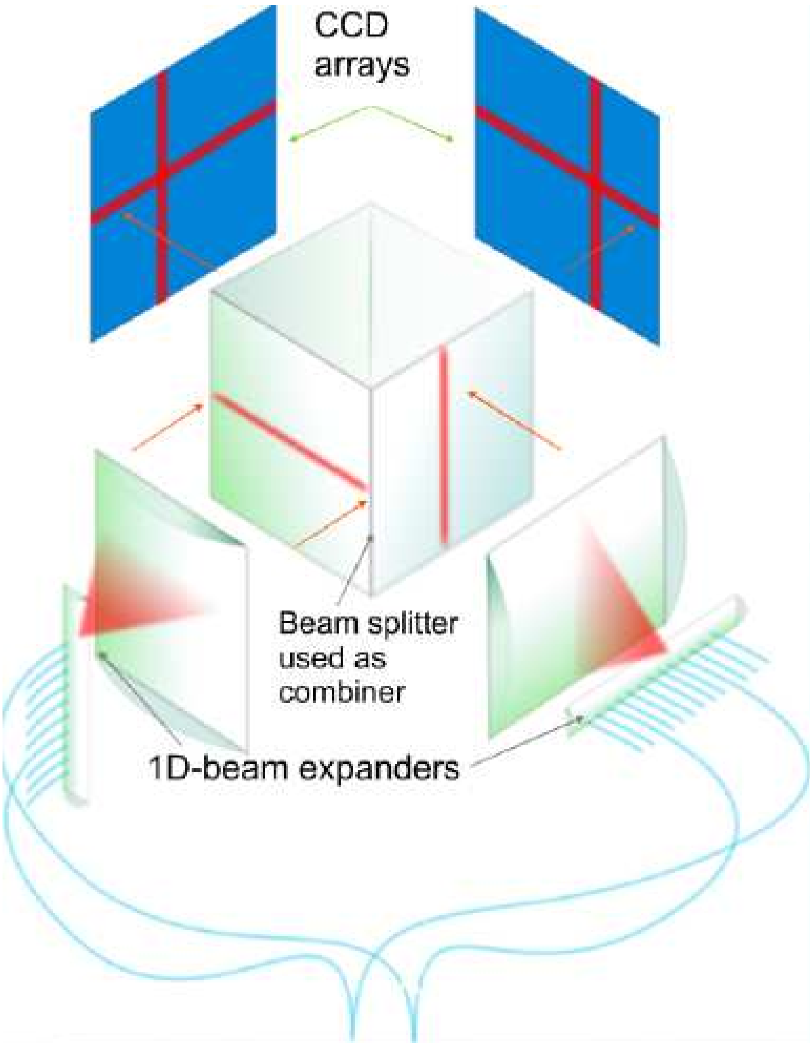
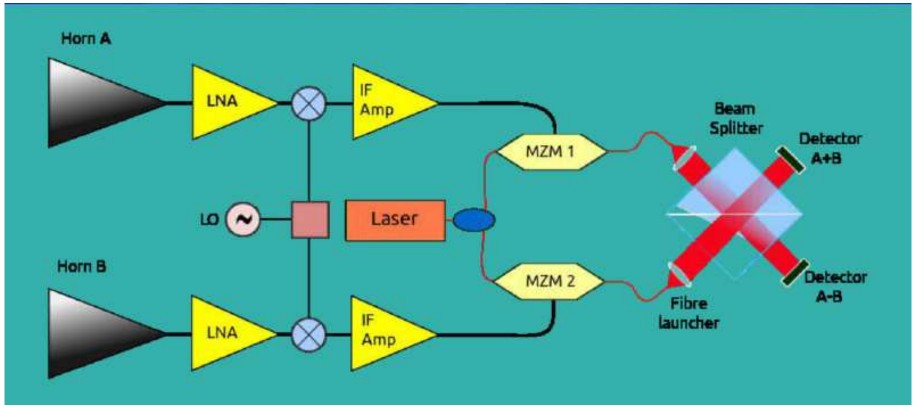
MZM-Based Optical Correlator

Michelson type correlator:





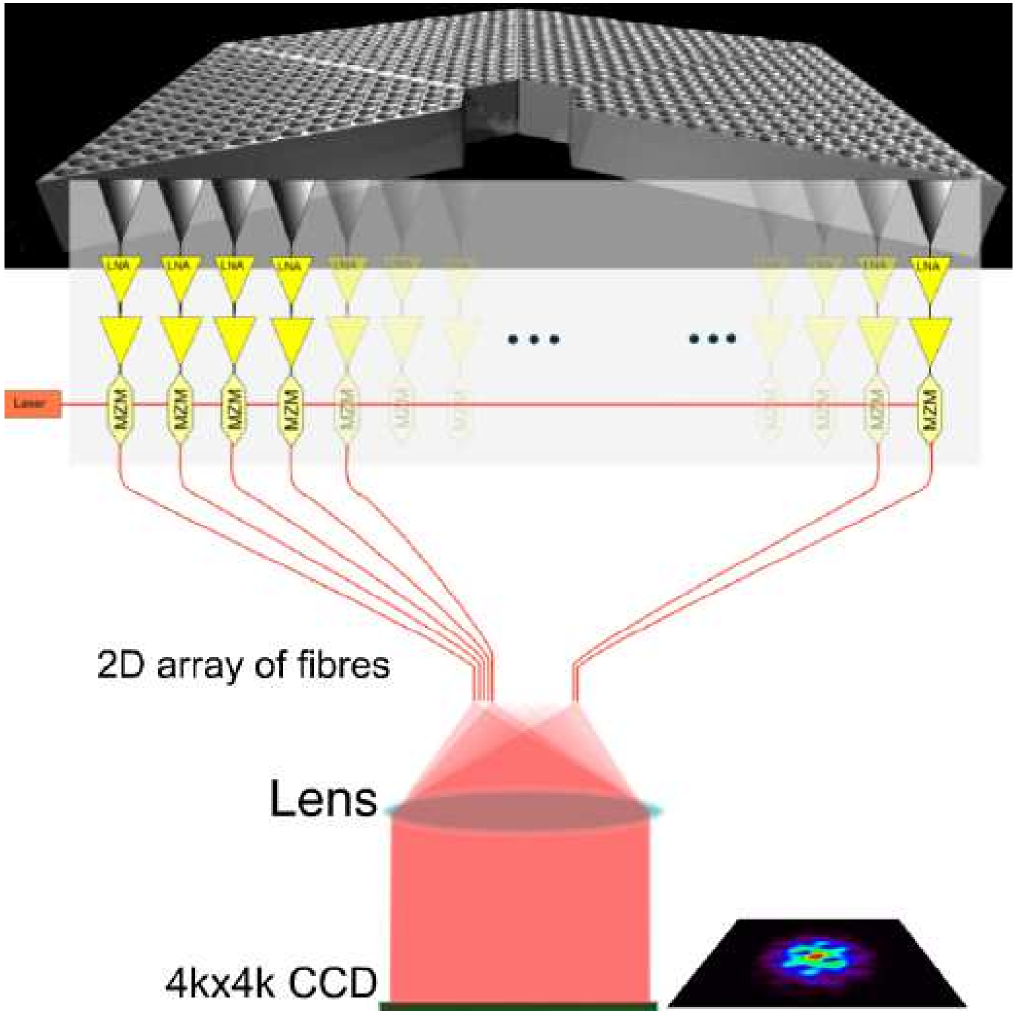
-Visibilities from combination of horizontal and vertical fringes.

- Projection on to a CCD.

- Number of baselines (n(n-1)/2) not a problem. 1K x 1K CCD arrays are easily available.

MZM-Based Optical Correlator

Fizeau type correlator:



- Phased array of Young's slits.

- Less flexible.

- Systematics probably not as good as Michelson.

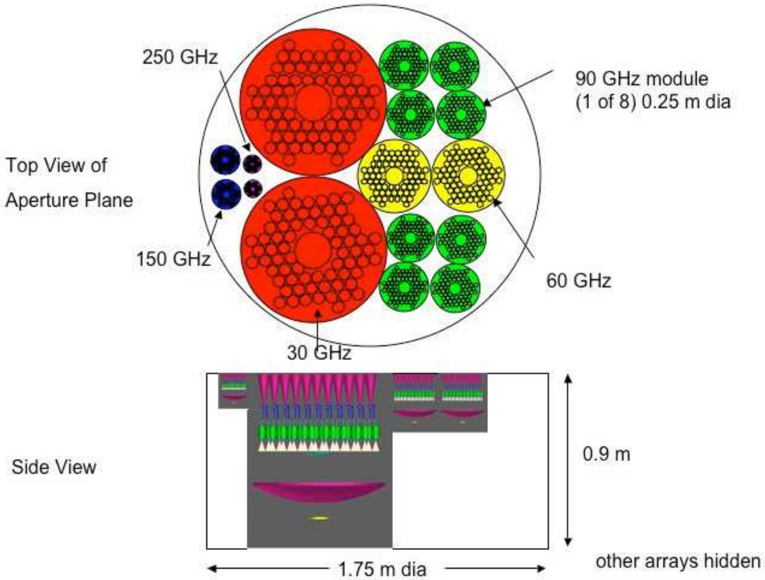
- Radically simpler design.

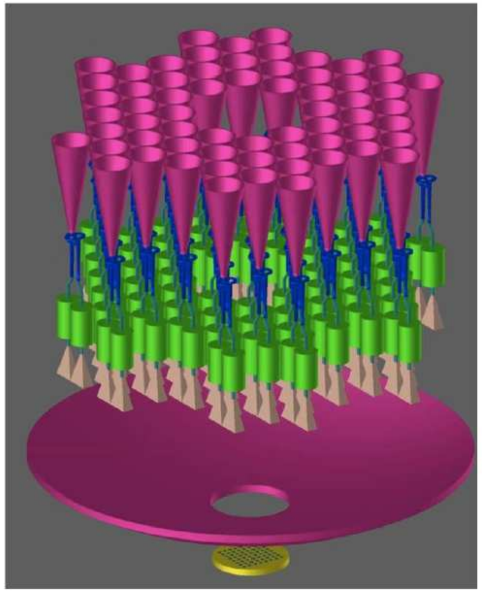
- Polarization modulation, by complex phase switching, can be implemented in both the MW or IR domain.

- A good option for big arrays of receivers.

Instrumental Precedents

EPIC: Space mission concept





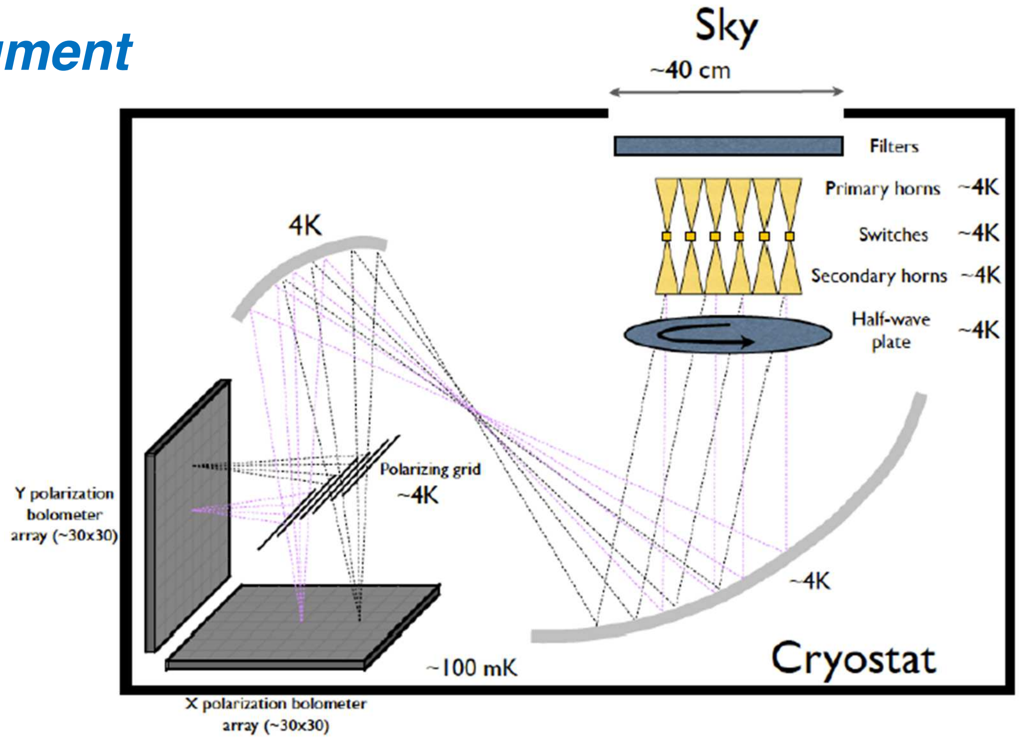
The Einstein Polarization Interferometer for Cosmology or EPIC is a proposed space probe to measure the B-modes of the CMB Polarization. It consists of a series of interferometric arrays tuned to various frequencies to precisely measure the CMB and to remove galactic foregrounds from infrared dust emission and syncrotron radiation. Each array as shown below has a set of 64 conical

- *From 30 to 300 GHz.*
- *Bolometric Interferometer*
- *Fizzeau Beam Combiner*

Instrumental Precedents

QUBIC: Ground-based Instrument

- *Synthetized Imager*
- *97, 150 and 220 GHz*
- *Antarctica Concordia Station*
- *Fizzeau Beam Combiner*



The signal on the bolometers as a function of time is[2]:

$$R(\vec{d}_p, t) = S_I(\vec{d}_p) \pm \cos(4\omega t) S_Q(\vec{d}_p) \pm \sin(4\omega t) S_U(\vec{d}_p)$$

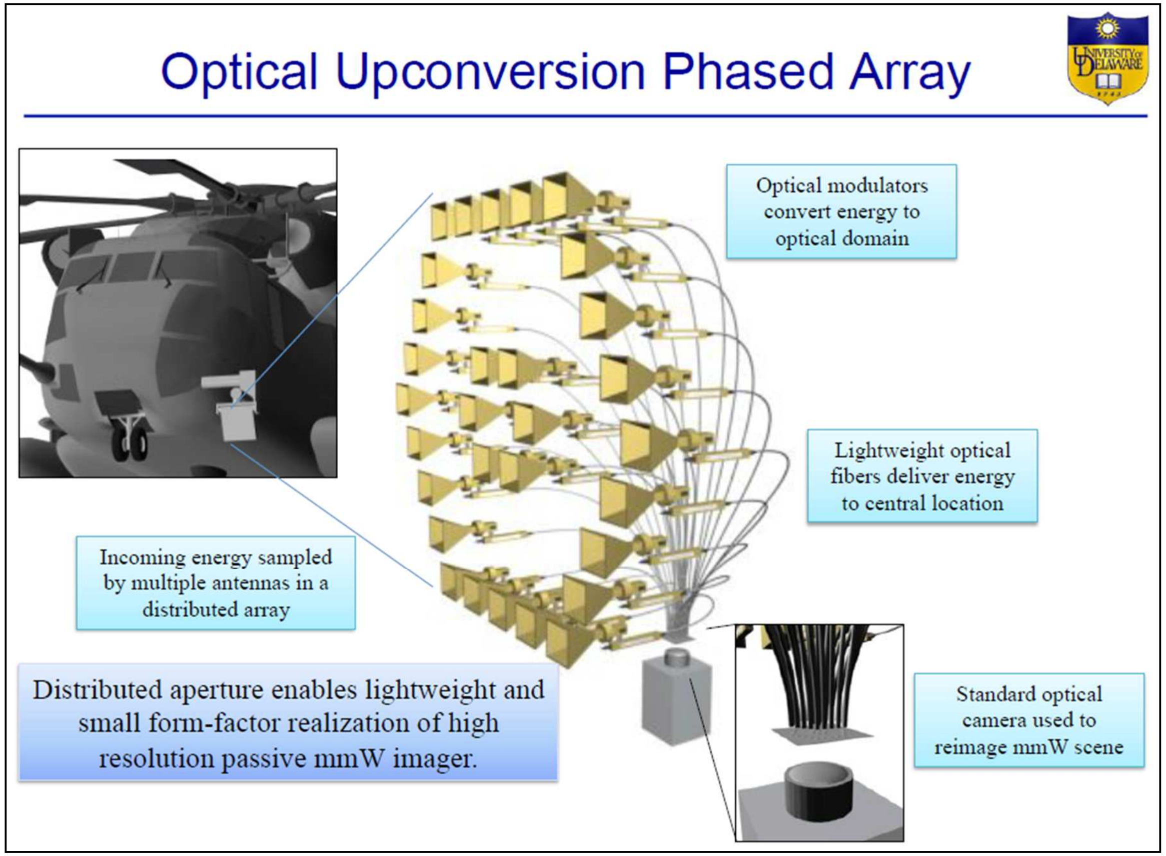
where the ± is + for one of the focal planes (polarized in one direction) and − for the other one polarized in the other direction.

This kind of interferometers act as imagers

(Battistelli et al., Astroparticle Physics 34, 2011, 705-716)

MW to IR Up-Conversion Application Example

Distributed Aperture Millimeter-Wave Imaging System using Optical Up-conversion



- Collaboration: University of Delaware and Phase Sensitive Innovations.

- 30 elements at 35 GHz.

- Optical processor stabilizes phase of each channel.

- Also enables electronic image enhancement techniques.

MW to IR Up-Conversion Application Example

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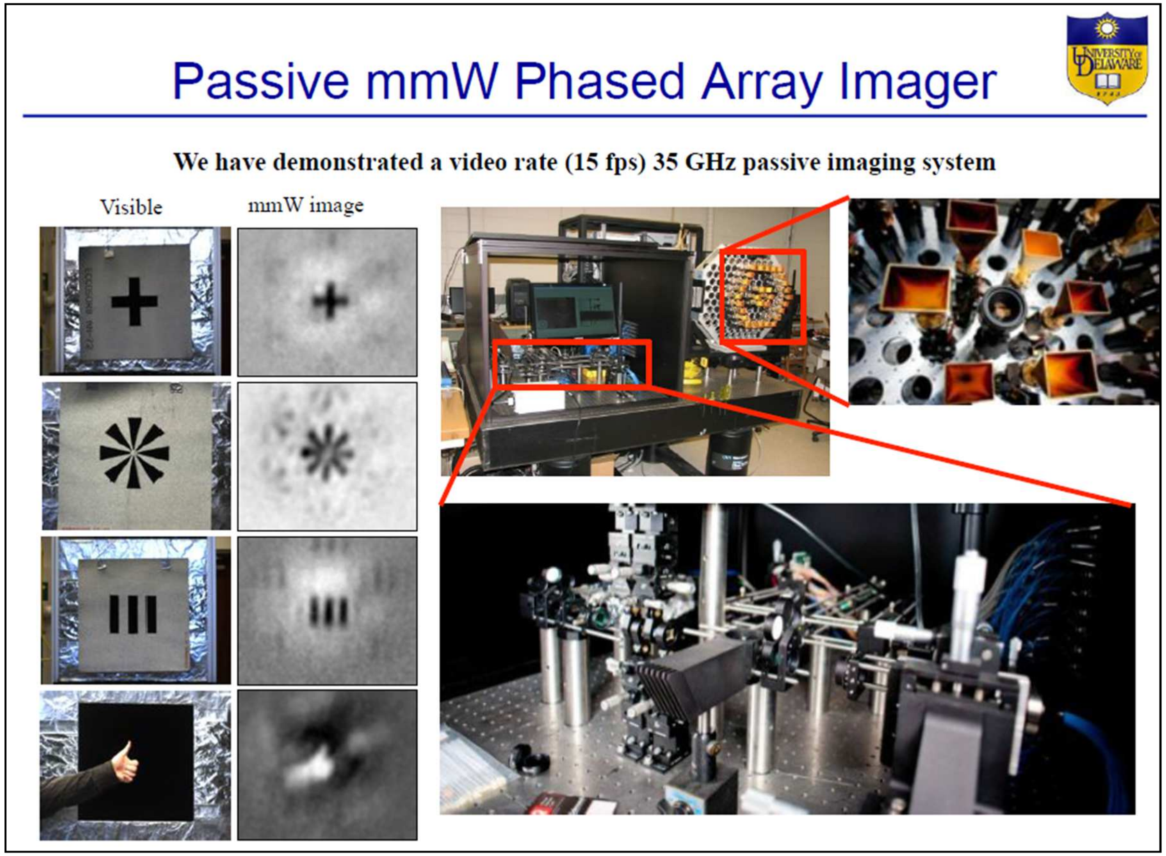

- *Collaboration: University of Delaware and Phase Sensitive Innovations.*
- *30 elements at 35 GHz.*
- *Optical processor stabilizes phase of each channel.*
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MW to IR Up-Conversion Application Example

220 Elements at 75 GHz:

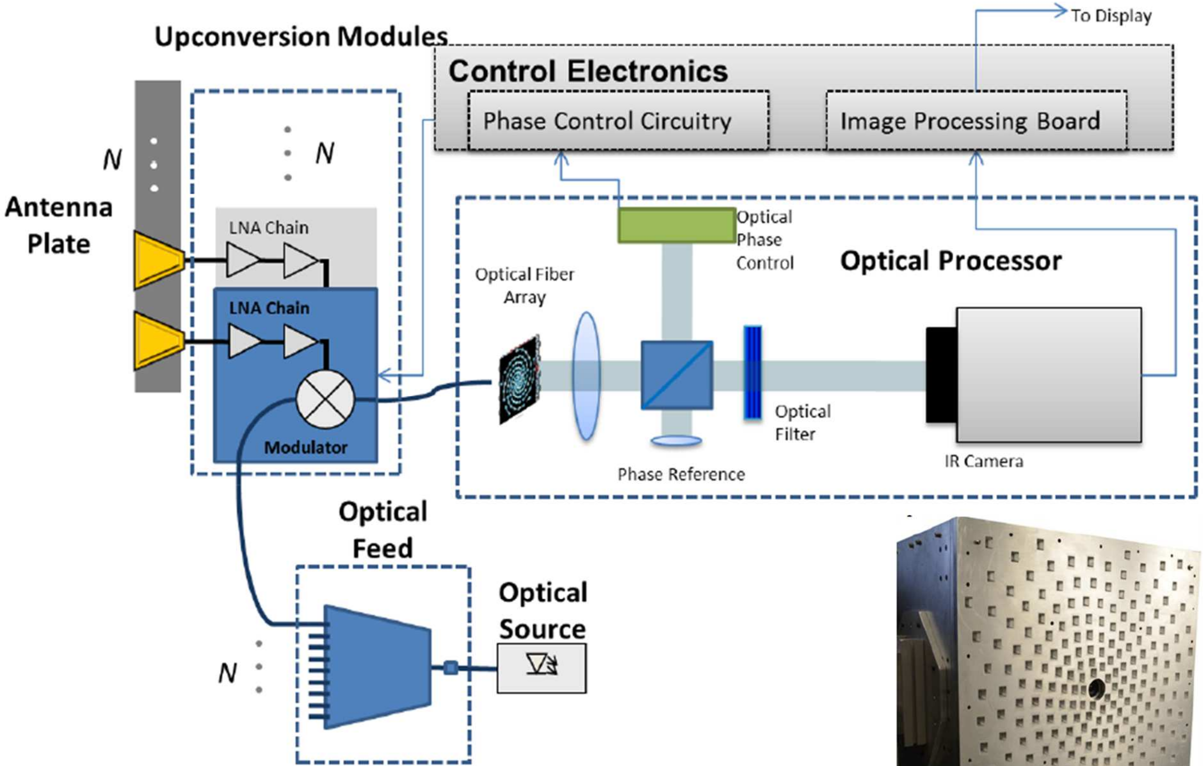
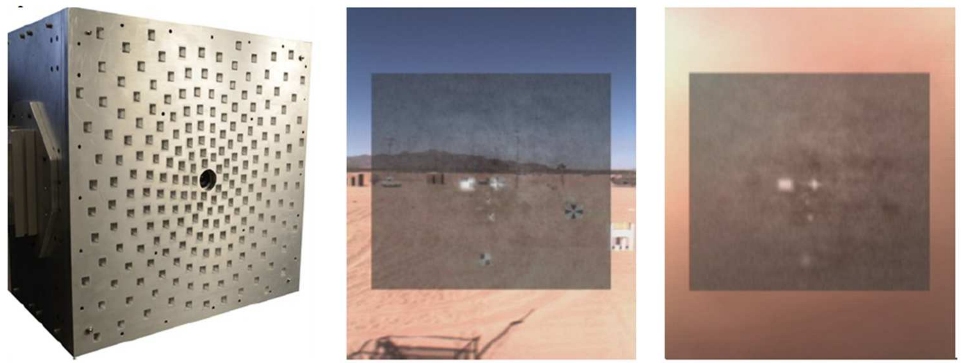


Figure 3. Block diagram of system components within the optical upconversion imager.

-A SWIR InGaAs CCD camera.

-Active phase control (to control vibrations from an helicopter!)



(a) (b) (c)

Figure 2. Showing (a) picture of the 220-channel, 75-GHz imager as well as snapshots from visible with passive millimeter-wave video overlaid taken during a recent field testing event for rotorcraft brownout mitigation in both (b)clear air and (c)in brownout. Distance to the central cross target is approximately 250'.

-1W and 1558nm fiber laser

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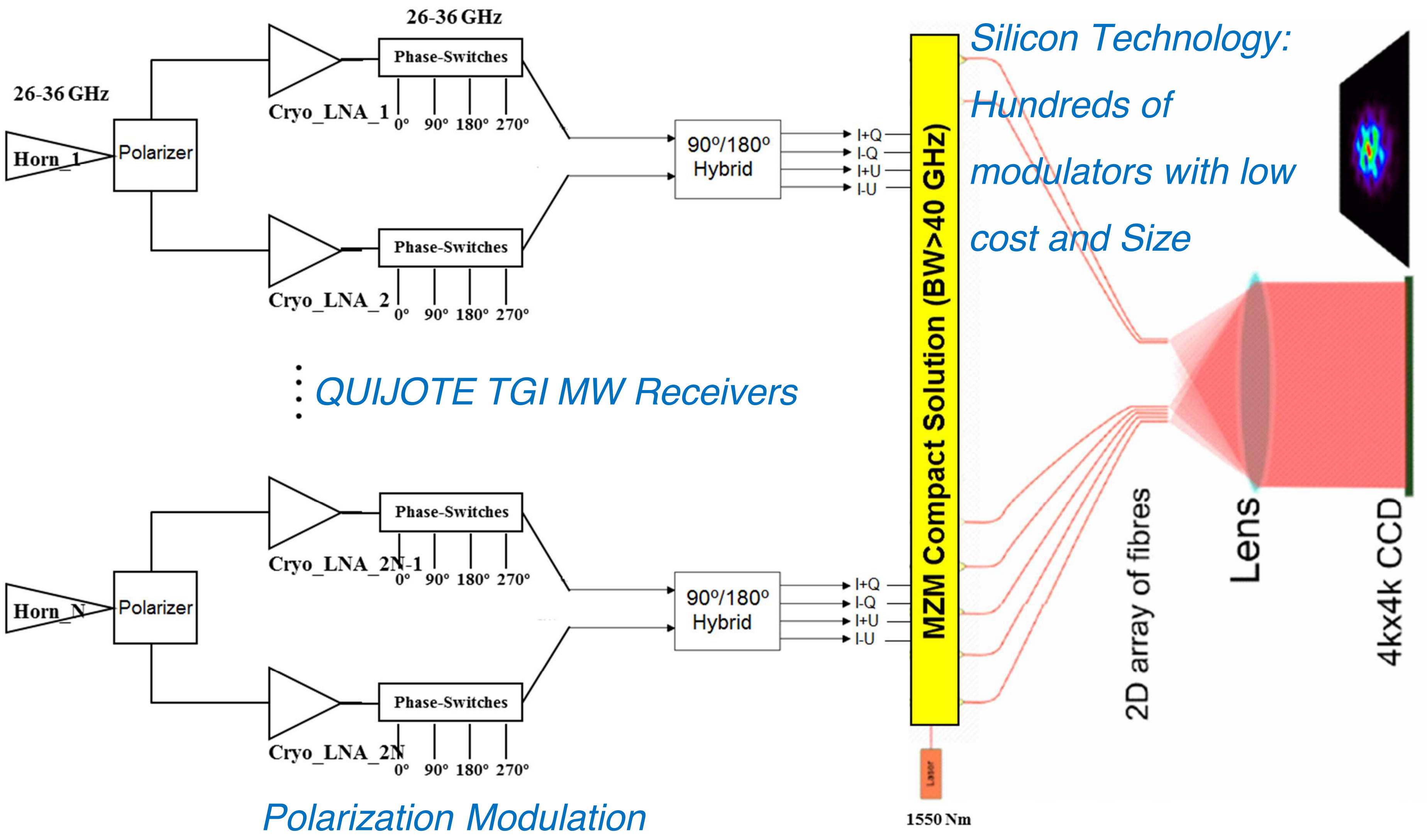
Interferometer Implementation Proposal



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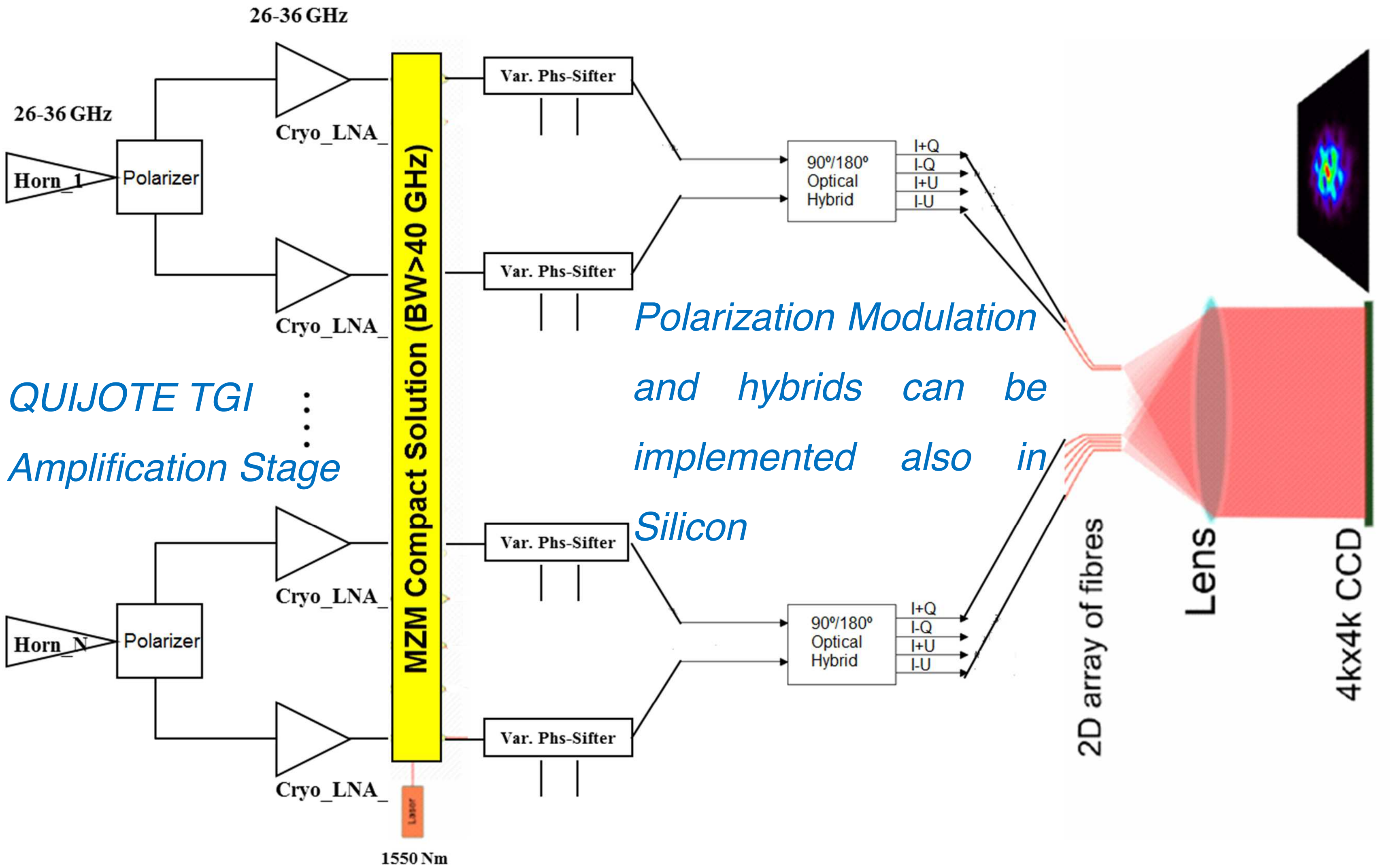

CONCLUSIONS

· An optical correlator based on MZM technology has been proposed to implement a large format interferometer at 30 GHz.

· With the reported technology Michelson but also Fizeau type interferometers can be implemented. This work focus in Fizeau.

· Precedent astronomical instruments (EPIC, QUBIC) are being developed using bolometers for higher frequencies.

· Two MW to IR up-conversion based imagers have been shown. The 1st with 30 pixels at 30 GHz and the 2^{nd} with 220 pixels at 75 GHz.

· The proposed interferometer uses the receiver scheme of the QUIJOTE TGI to achieve images of the polarization parameters I, Q and U.

· Polarization modulation and signal combination functions can be implemented in the MW or IR domain. The latter would be the optimal solution in terms of integration and cost by using Silicon technology, which is also advantageous for the MZM implementation.