# *Full Duplex Retrodirective Array using Mutually Exclusive Uplink and Downlink Modulation Schemes*

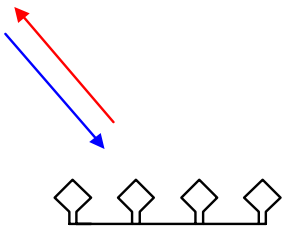
**Kevin Leong and Tatsuo Itoh**

Department of Electrical Engineering
University of California, Los Angeles
Los Angeles, CA 90095

**kleong@ee.ucla.edu**

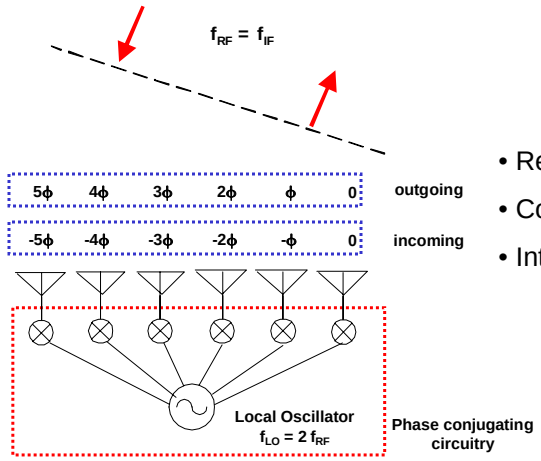


## Retrodirective Arrays



- Able to automatically transmit a signal response to the interrogation direction without any previous knowledge of the source direction
- Automatic target tracking
- Accomplished using purely analog processing

## Retrodirective Array Using Phase Conjugation Technique

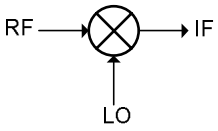



$$f_{LO} = 2 f_{RF}$$

- Recovered Wavefront
- Conformal Array Possible
- Integration of Other Functions



## Phase Conjugating Operation




$$V_{IF} = V_{RF}\cos(\omega_{RF}t + \theta_{RF}) \times V_{LO}\cos(\omega_{LO}t)$$
$$= \frac{1}{2}V_{RF}V_{LO}\left[\cos((\omega_{LO} - \omega_{RF})t - \theta_{RF}) + \cos((\omega_{LO} + \omega_{RF})t + \theta_{RF})\right]$$

**LSB**

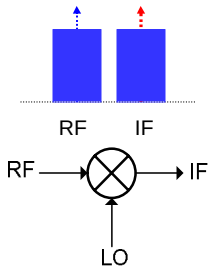
$$\omega_{LO} = 2\omega_{RF}$$

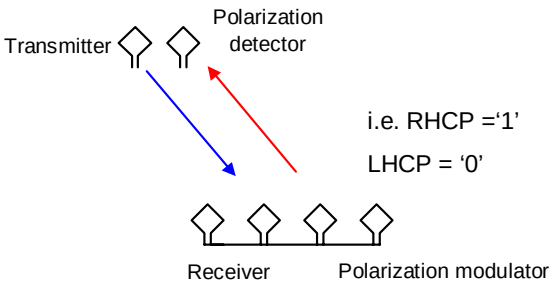
$$\cos(\omega_{RF}t - \theta_{RF})$$

**Phase conjugation**

## Full Duplex Communication using Time and Polarization Modulation

- Received information contained in time domain (AM, BPSK, etc.)
- Retrodirected information contained in polarization
- Limited for line of sight use due to scattering effect on polarization



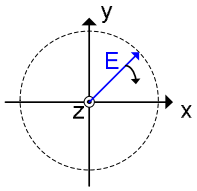






## Circular Polarization

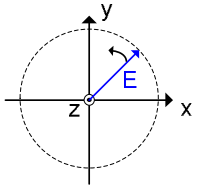
Right-hand CP: $\tilde{E}(z) = \frac{E_o}{\sqrt{2}}(\hat{x} + \hat{y}e^{j90^\circ})e^{+jkz}$

(-z traveling wave)

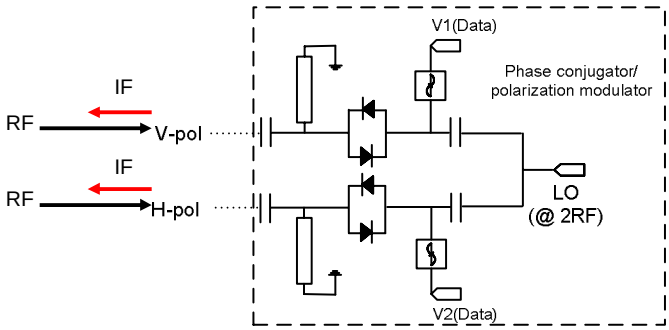



Left-hand CP: $\tilde{E}(z) = \frac{E_o}{\sqrt{2}}(\hat{x} + \hat{y}e^{-j90^\circ})e^{+jkz}$

(-z traveling wave)



## Phase conjugation and polarization modulation mixer



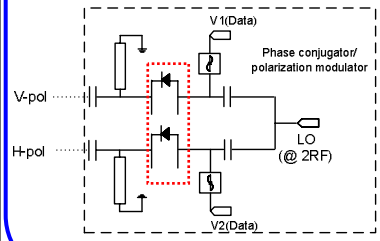

- **Shared RF/IF port**
- **LO=2RF, phase conjugation**
- **Mixer is connected to two ports of dual feed patch antenna**
- **Phase shift between V-pol and H-pol output controlled by V1 V2 pair**



## Modulation States

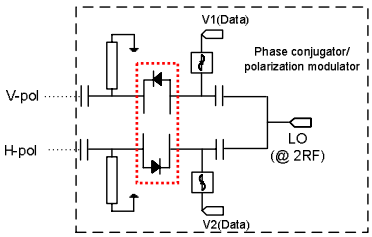
**Case 1: V1=V2**

**(Co-directional Diode Current)**




**Case 2: V1=-V2**

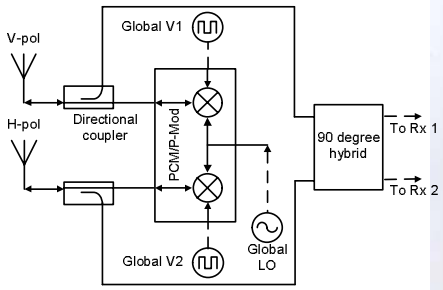
**(Anti-directional Diode Current)**



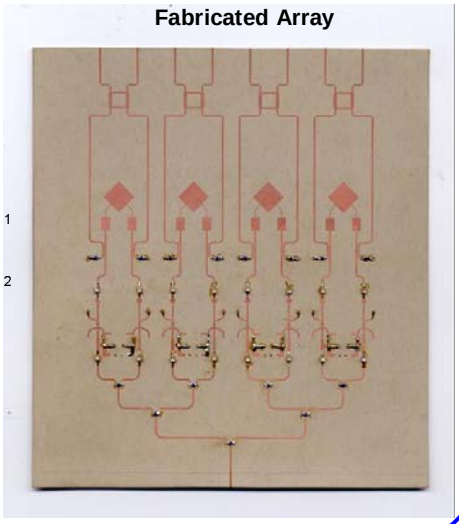

| $H_{in}$ | $V_{in}$ | Pol-Sense$_{in}$ | V(data) | $H_{out}$ | $V_{out}$ | Pol-Sense$_{out}$ |
|---|---|---|---|---|---|---|
| 0° | -90° | LHCP (-z prop) | V1=V2 | 0° | -(90)=+90° | LHCP (+z prop) |
| 0° | -90° | LHCP (-z prop) | V1=-V2 | 0° | -(-90)-180=-90° | RHCP (+z prop) |

## Retrodirective Transceiver Array

**Schematic of single element of array**

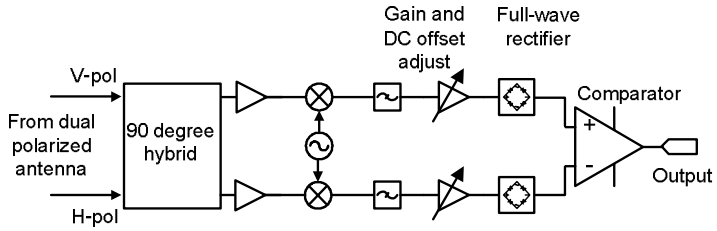



**Fabricated Array**



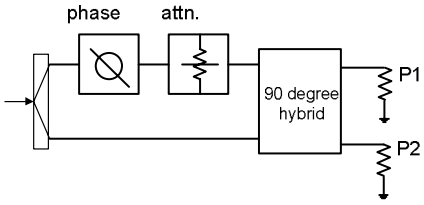


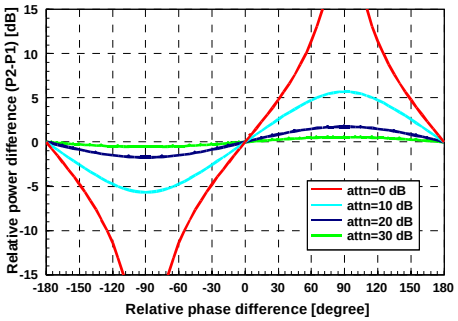
## Polarization Detector




- **Polarization sense by comparing the power of the two branches of hybrid coupler**
- **E.g. $P_{branch1} > P_{branch2}$ ⇒ LHCP '0'  $P_{branch1} < P_{branch2}$ ⇒ RHCP '1'**
- **Sensitive to circuit imbalance and DC offsets**

## Polarization Detector Tolerance



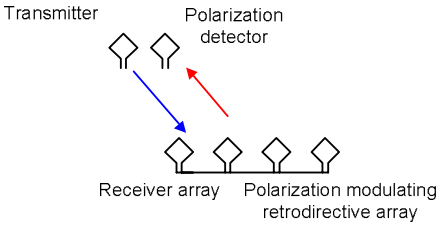




- **Relative amplitude and phase used to determine tilt, sense, axial ratio**
- **Detector functions even with elliptical polarization**
- **Polarization sense detector!**

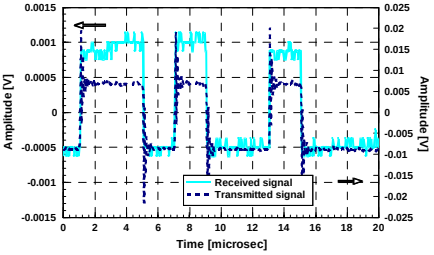
**CP: Phase =+/- 90 °, atten.= 0 dB**



## Measurement of Full Duplex Link

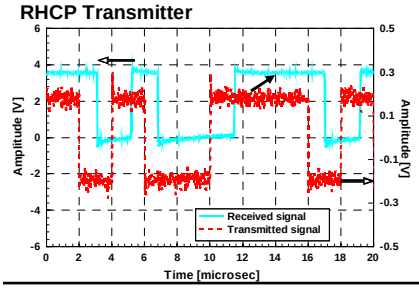



**Received signal at receiver array (transmitted by transmitter-time domain)**

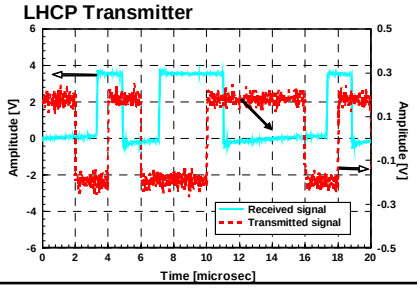



**Recovered polarization modulation data**

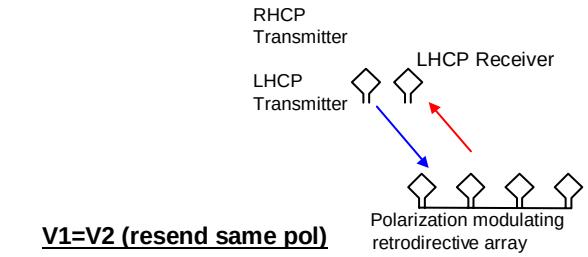
**RHCP Transmitter**



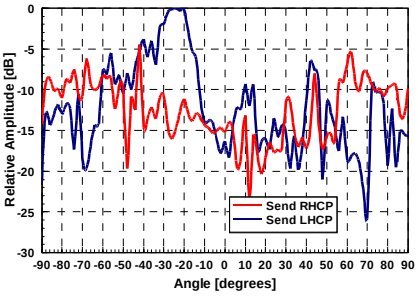

**LHCP Transmitter**



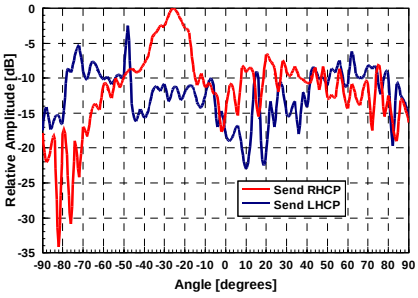
## Bi-Static RCS Measurement




**V1=V2 (resend same pol)**




**V1=-V2 (resend opp. pol)**






## Conclusions

- Downlink data time domain encoded
- Uplink data encoded in polarization of retrodirected return signal
- Phase conjugator/Polarization modulator presented
- Full duplex operation demonstrated