

# Hybrid-Polarity SAR Architecture

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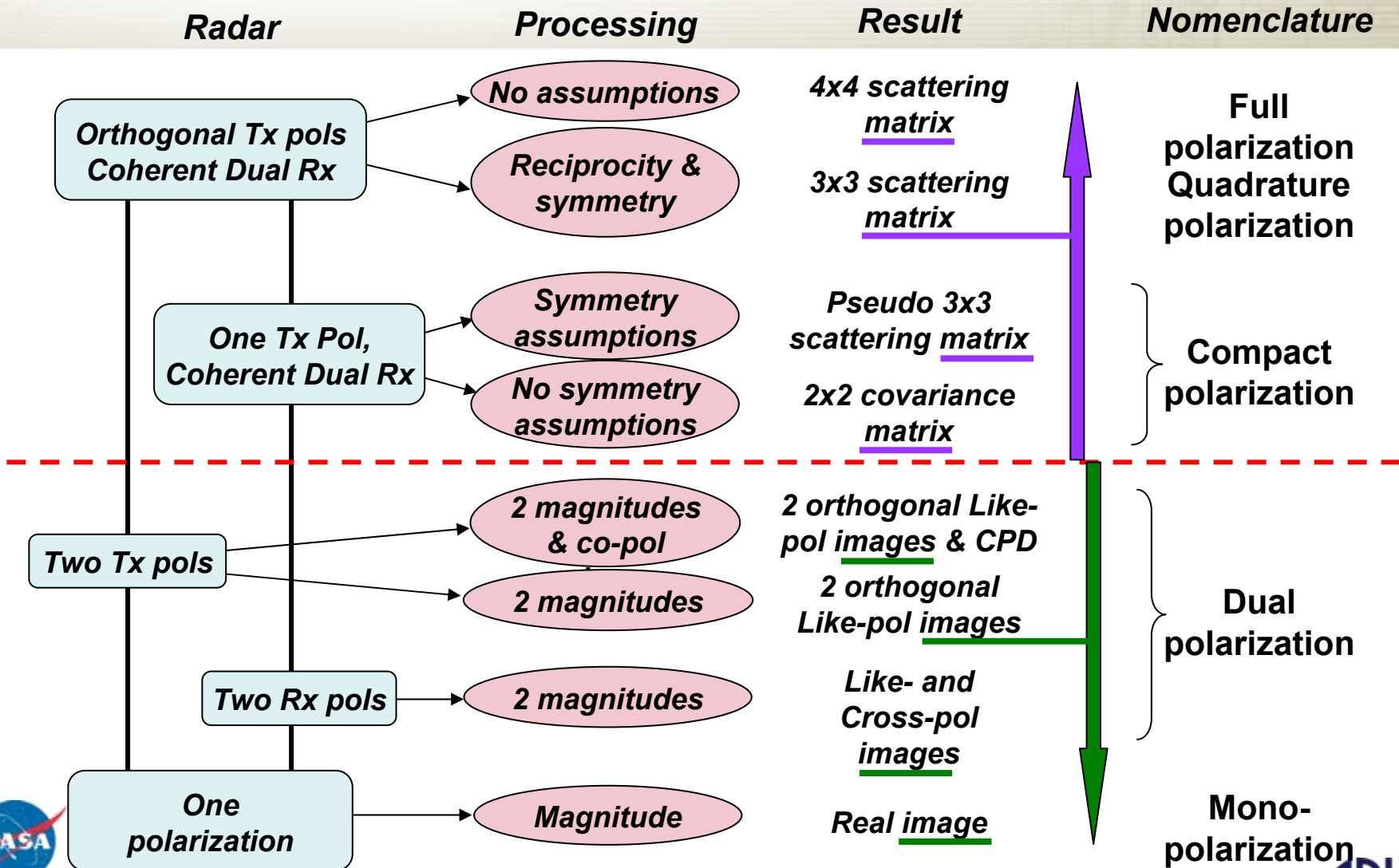
# Overview of Hybrid-Polarity Architecture

## Executive Summary

- 1) Hybrid-Polarity: Transmit circular; Receive H and V (and their relative phase)
- 2) In the dual-polarized context, it is one form of “compact polarimetry”
- 3) Generalizes to Quad-pol systems (with advantages... :~)



# Polarimetric Imaging Radar Hierarchy

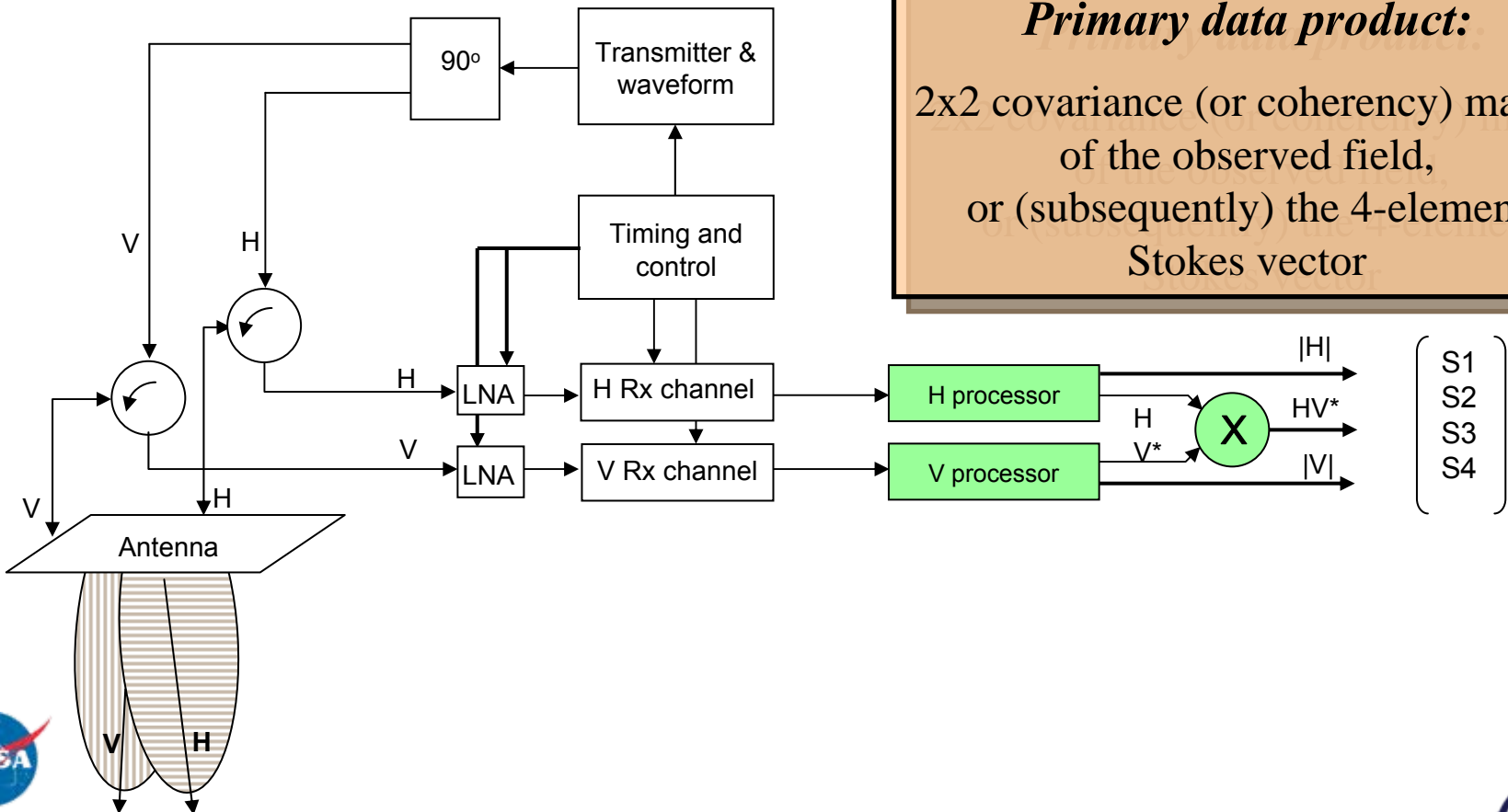


# Dual Hybrid-Polarity Architecture (CL)

Transmit CP (note the  $90^\circ$  hybrid)  
 Receive (coherently) linear (H & V)

**Primary data product:**

2x2 covariance (or coherency) matrix  
 of the observed field,  
 or (subsequently) the 4-element  
 Stokes vector



# The Stokes Parameters

*Highlights re: the coherent dual-pol received data*

- **The four Stokes parameters are sufficient to fully characterize the observed (*partially polarized quasi-monochromatic backscattered*) EM field**
- **Data products are rotationally-invariant with respect to illuminated features *iff* the transmit polarization is circular**



# The Hybrid Dual-Polarized Architecture

Transmit circular polarization. Then

- ✓ The Stokes parameter values are independent of the polarization basis of the dual receivers
- ✓ Therefore, a linear basis on receive enjoys equivalent information content as classical circular receive polarity
- ✓ Receiver noise ( $N_0$  per channel) appears *only* in  $S_1$

**CL Hybrid Polarity**

**Circular/circular\***

$$S_1 = \langle |E_{RH}|^2 + |E_{RV}|^2 \rangle + 2 N_0 = \langle |E_{RR}|^2 + |E_{RL}|^2 \rangle + 2 N_0$$

$$S_2 = \langle |E_{RH}|^2 - |E_{RV}|^2 \rangle = 2 \operatorname{Re} \langle E_{RR} E_{RL}^* \rangle$$

$$S_3 = 2 \operatorname{Re} \langle E_{RH} E_{RV}^* \rangle = 2 \operatorname{Im} \langle E_{RR} E_{RL}^* \rangle$$

$$S_4 = -2 \operatorname{Im} \langle E_{RH} E_{RV}^* \rangle = -\langle |E_{RR}|^2 - |E_{RL}|^2 \rangle$$

*\*Note the order of the subscripts*



# The -3 dB SNR Issue: Hybrid-Dual Pol

*Circular => Simultaneous  $\otimes$  Linear Polarizations*

**Transmit:**

*e.g. Right-Circular Polarization =>  $E_H - jE_V$*

*Consequence:*

*> Splits power: Only 1/2 on either “H” or “V”*

*“Urban Legend”:*

~~*> Hybrid-polarity => -3 dB SNR loss*~~

**Fact: Circular pol data products preserve SNR**



# Theorem 1: Conservation of Dual-pol SNR

“SC”: RCP data product:  $\frac{1}{2} [S_1 - S_4] = \langle |E_{RR}|^2 \rangle + N_o$

“OC”: LCP data product:  $\frac{1}{2} [S_1 + S_4] = \langle |E_{RL}|^2 \rangle + N_o$

***QED***

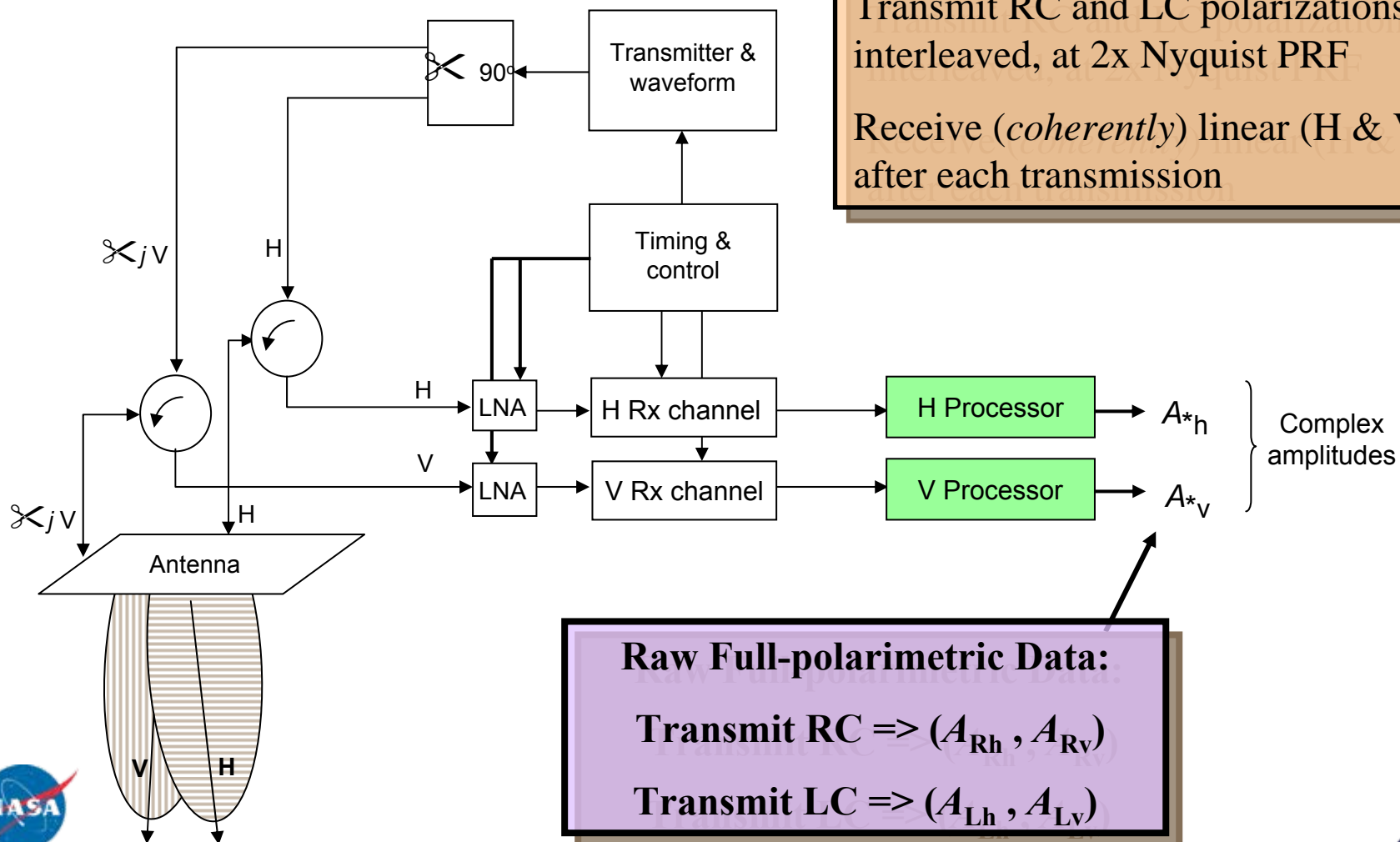
CL Hybrid Polarity	Circular/circular	
$S_1 = \langle  E_{RH} ^2 +  E_{RV} ^2 \rangle + 2N_o$	$= \langle  E_{RR} ^2 +  E_{RL} ^2 \rangle + 2N_o$	←
$S_2 = \langle  E_{RH} ^2 -  E_{RV} ^2 \rangle$	$= 2 \operatorname{Re} \langle E_{RR} E_{RL}^* \rangle$	
$S_3 = 2 \operatorname{Re} \langle E_{RH} E_{RV}^* \rangle$	$= 2 \operatorname{Im} \langle E_{RR} E_{RL}^* \rangle$	
$S_4 = -2 \operatorname{Im} \langle E_{RH} E_{RV}^* \rangle$	$= -\langle  E_{RR} ^2 -  E_{RL} ^2 \rangle$	←

# Observations 1: Hybrid Dual-Pol

- **Nominal SNR is preserved (*no 3-dB loss*) in CP data products with hybrid-polarity dual-pol architecture**
- **(*Generalization: SNR preservation is true iff the output basis is selected to match the transmitted basis*)**
- **Covariance element values of the EM field do not depend on polarization basis of the receivers**
- **Stokes parameter values (*and information content*) do depend on the polarization basis of the transmitted field**
- **Hybrid- (Compact-) dual polarity extends to ScanSAR, enabling wide-swath (pseudo-) polarimetry**



# Hybrid-Quad-Pol Architecture



# On Choice of Polarization Basis

**The information content  
of the (scattering matrix) data product  
from a fully-polarized (or a quad-pol) radar  
is invariant  
with respect to the polarization basis  
of either the transmitted or the received EM fields**



## Theorem 2: Conservation of Quad-pol SNR (1/3)

**Transmit:** L and R circular polarizations, Nyquist multiplexed

$$E_L = E_h + jE_v$$

$$E_R = E_h - jE_v$$

**Receive:** H and V polarizations (coherently) after each transmission

$$A_{Lh} = a_{hh} + ja_{vh} + n_1$$

$$A_{Rh} = a_{hh} - ja_{vh} + n_3$$

$$A_{Lv} = a_{hv} + ja_{vv} + n_2$$

$$A_{Rv} = a_{hv} - ja_{vv} + n_4$$

**NOTE:** include additive receiver noises



# Theorem 2: Conservation of Quad-Pol SNR (2/3)

## *Assumptions*

### ➤ Additive noises:

- ✓ Zero-mean complex Gaussian
- ✓ Statistically independent of the signals
- ✓ Statistically independent of each other
- ✓ Equal variances ( $\langle |n_k|^2 \rangle = N_o$  for all k)

### ➤ Cross-polarized signal terms

- ✓ eg:  $a_{hv} = a_{vh}$  (reciprocity)
- ✓ eg:  $\langle a_{hh} a_{hv}^* \rangle = 0$  (statistical independence)



## Theorem 2: Conservation of Quad-Pol SNR (3/3)

*Then:*

*“HH” component:*  $\langle |a_{hh}|^2 \rangle + \frac{1}{2} N_0$

*“VV” component:*  $\langle |a_{vv}|^2 \rangle + \frac{1}{2} N_0$

*“HV” cross-product component:*

$$\langle |a_{hv}|^2 \rangle + \frac{1}{4} N_0$$



*QED*

**APL**

# Comments on Hybrid Quad-Pol SNR

- The factor of “ $\frac{1}{2}$ ” on the HH and VV noise terms balances the fact that only half of the power transmitted in circular pol is allocated to H or V, hence SNR is conserved
- The additional factor of “ $\frac{1}{2}$ ” on the cross-pol noise term is a consequence of  $a_{hv} \sim a_{vh}$  reciprocity, in exactly the same manner as conventional HV quad-pol systems



## Observations 2: Hybrid Quad-Pol SAR

- Nominal SNR is preserved (*no 3-dB loss*) in HH and VV data products with hybrid-polarity Quad-pol architecture
- (*This result generalizes to arbitrary polarization bases*)
- Stokes parameter values—hence the information content—for quad-pol data products do not/not depend on polarization basis of either the transmitter or the receiver
- Choice of polarization bases (Tx and Rx) for a quad-pol radar can be driven by hardware optimization concerns (*cross-talk, calibration, ambiguity levels, etc*) since the architecture has no first-order impact on science



# Hybrid Quad-Polarity: Selected Advantages

- **Balanced (mean) signal levels in both channels**
- **Simpler hardware (*e.g., no need for adaptive signal level compensation*)**
- **Range ambiguity levels significantly reduced**
- **Direct observation of receive channel-to-channel phase/amplitude/spectral imbalances**
- **Calibrate without a corner reflector: looking at nadir => “H” statistically identical to “V”**
- **Standard “quad-pol” algorithms apply**



# Outlook

- 1) Two Hybrid-pol lunar “Mini-RF” radars (on Chandrayaan-1 and LRO)
- 2) C-band active phased-array Earth-viewing SAR RISAT, to be launched by India (ISRO) in 2009, includes a hybrid-dual-polarity mode
- 3) India (ISRO) has concluded Phase A studies for an earth-viewing L-band SAR based on hybrid polarity
- 4) Canada is studying Hybrid-Polarity dual-pol as a mode on Radarsat-3 (“Constellation”)
- 5) NASA JPL’s current SAR promotion is DESDynI (*Deformation, Ecosystem Structure, and Dynamics of Ice*), hosting a lidar/SAR dual payload; the SAR quad-pol mode will be hybrid-polarity
- 6) ALOS-2 initial plans include hybrid-polarity modes



# Conclusions

- ✓ **A Compact Polarimetry mode — especially Hybrid-polarity (*transmit circular/receive coherent linears*) — deserves consideration for any new orbital SAR**
- ✓ **For any quad- (or fully-) polarized SAR mode, Hybrid-polarity deserves consideration as the preferred architecture**

