Hybrid-Polarity SAR Architecture

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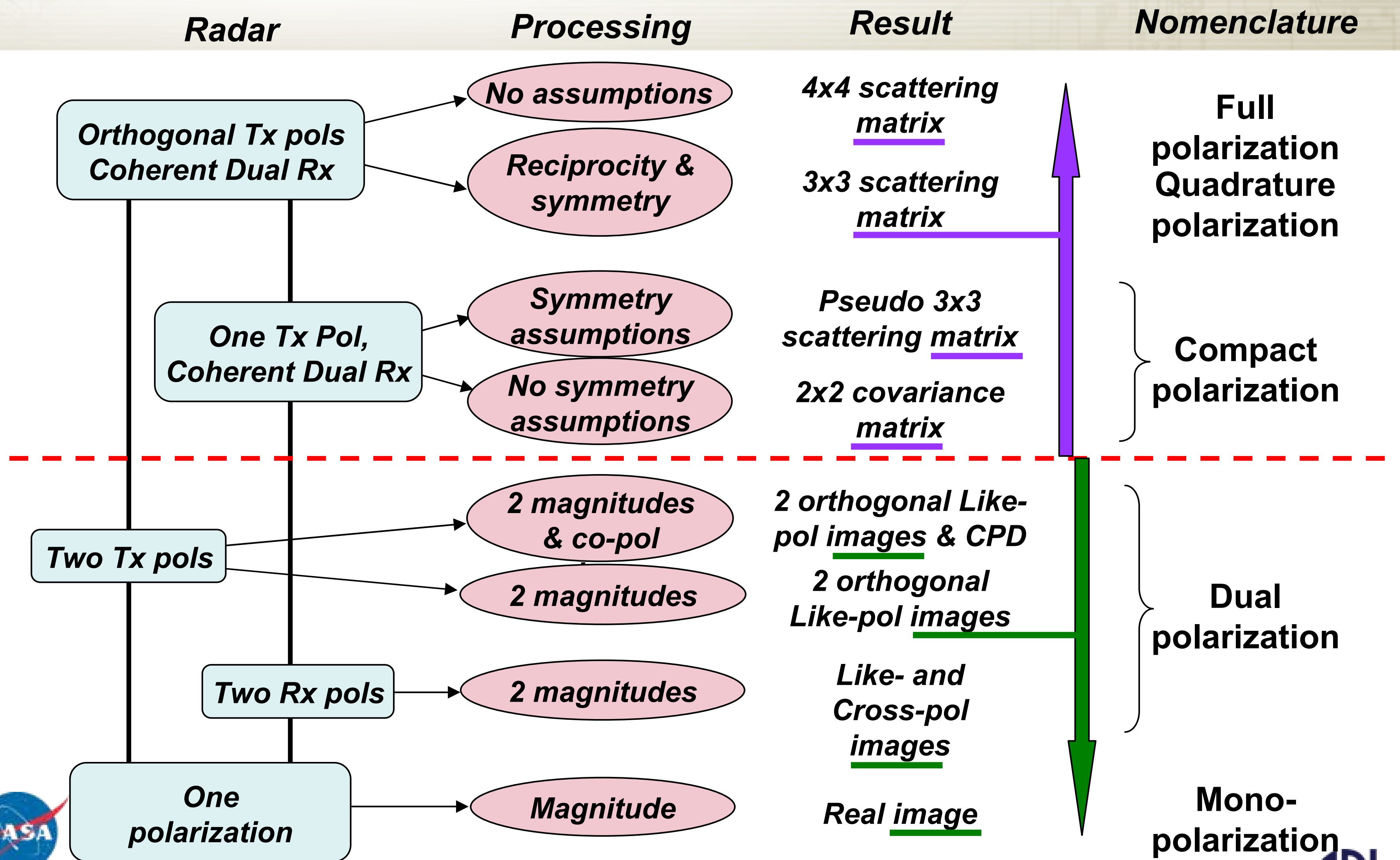
Overview of Hybrid-Polarity Architecture

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



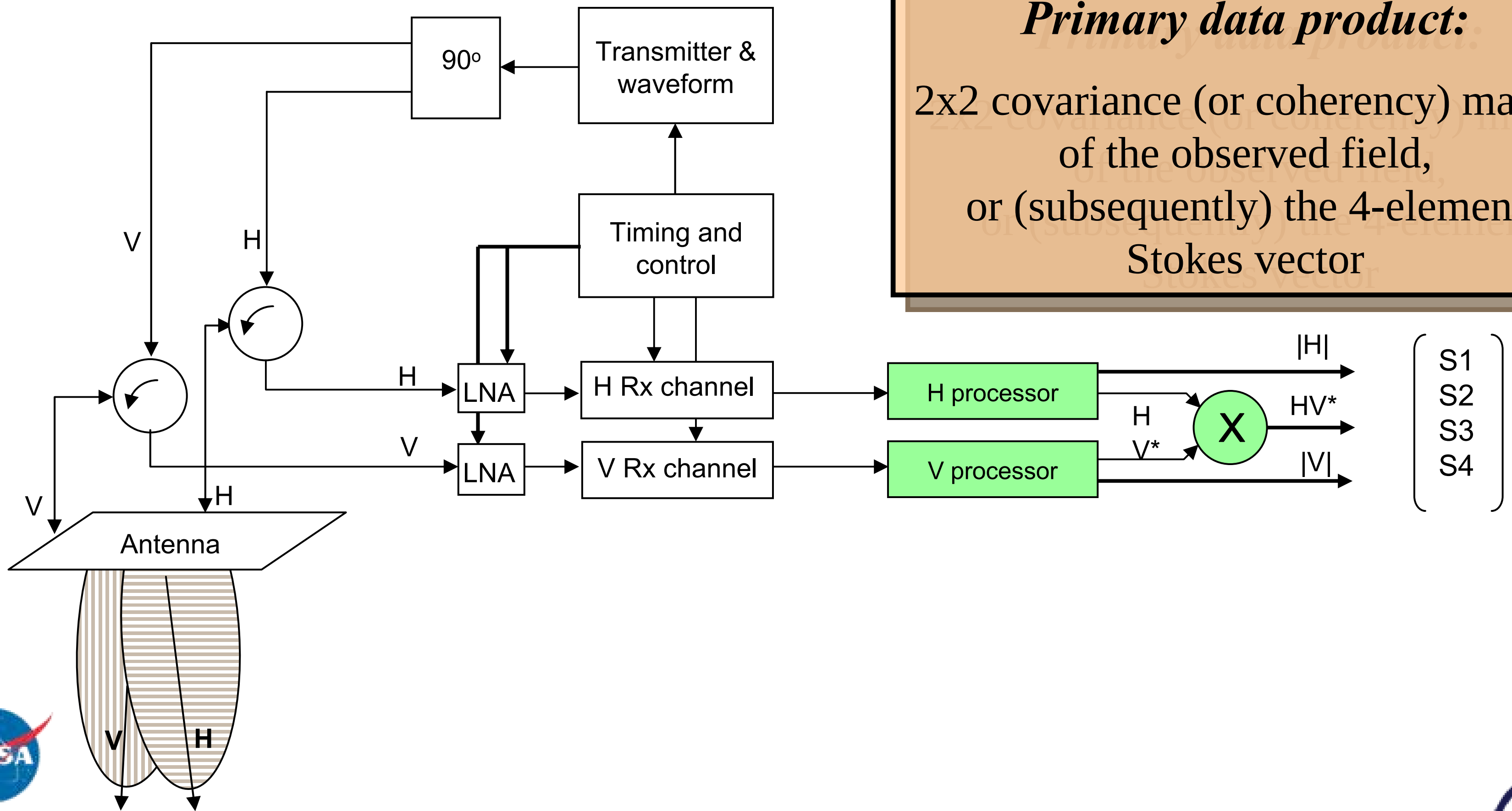
Dual Hybrid-Polarity Architecture (CL)

Transmit CP (*note the 90º 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_o per channel) appears *only* in S_1**

	CL Hybrid Polarity		Circular/circular*
S_1	$= <\|E_{RH}\|^2 + \|E_{RV}\|^2> + 2\,N_o$	$=$	$<\|E_{RR}\|^2 + \|E_{RL}\|^2> + 2\,N_o$
S_2	$= <\|E_{RH}\|^2 - \|E_{RV}\|^2>$	$=$	$2\,\mathrm{Re} < E_{RR}E^*_{RL} >$
S_3	$= 2\,\mathrm{Re} < E_{RH}E^*_{RV}>$	$=$	$2\,\mathrm{Im} < E_{RR}E^*_{RL} >$
S_4	$= -2\,\mathrm{Im} < E_{RH}E^*_{RV}>$	$=$	$- <\|E_{RR}\|^2 - \|E_{RL}\|^2>$

***Note the order of the subscripts**

The −3 dB SNR Issue: Hybrid-Dual Pol

Circular => Simultaneous ⌘ 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: $\frac{1}{2}[S_1 + S_4] = \langle|E_{RL}|^2\rangle + N_o$

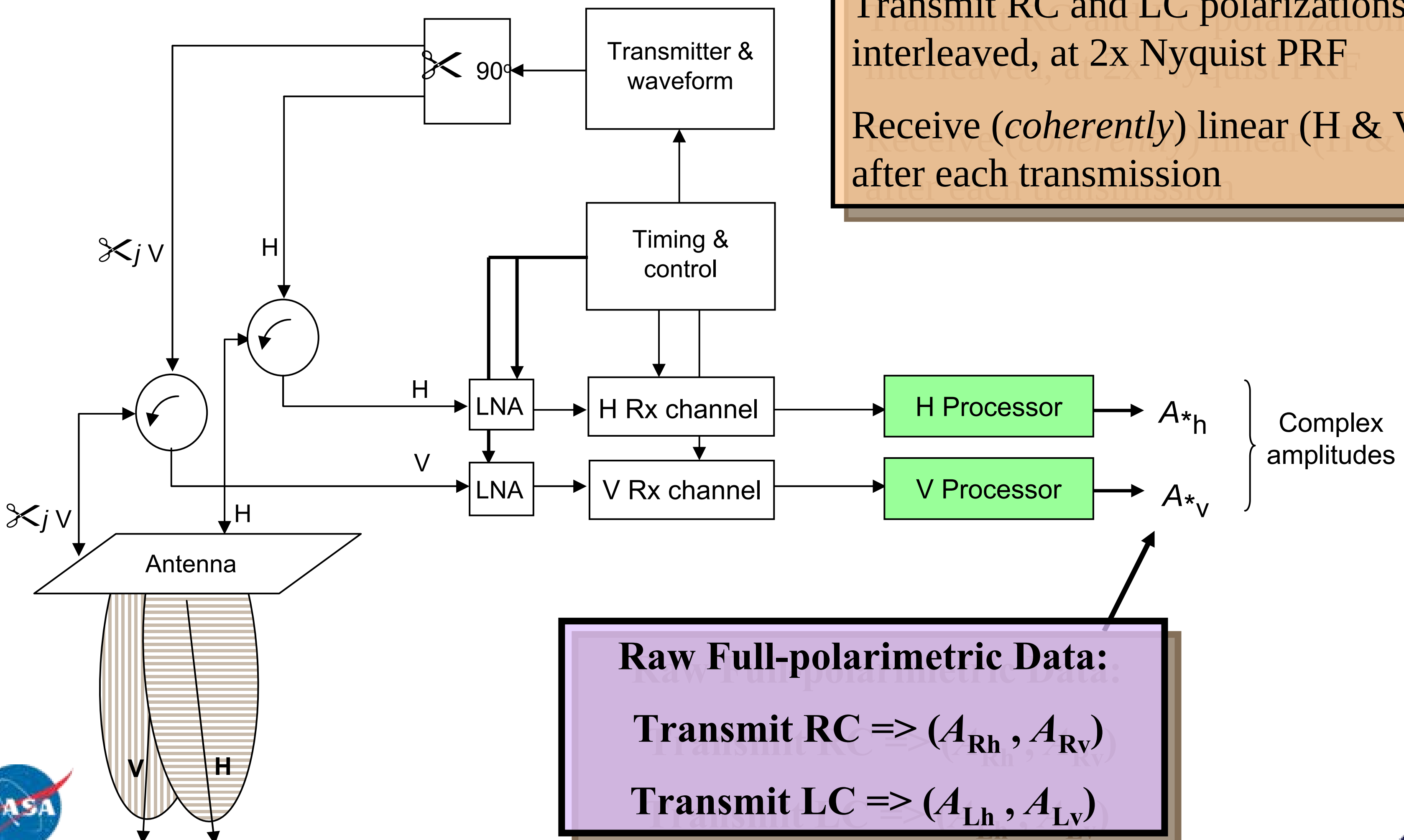
QED

	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	$= \langle |E_{RH}|^2 - |E_{RV}|^2 \rangle$	$=$	$2\,\mathrm{Re}\langle E_{RR}E_{RL}^* \rangle$
S_3	$= 2\,\mathrm{Re}\langle E_{RH}E_{RV}^* \rangle$	$=$	$2\,\mathrm{Im}\langle E_{RR}E_{RL}^* \rangle$
S_4	$= -2\,\mathrm{Im}\langle E_{RH}E_{RV}^* \rangle$	$=$	$-\langle |E_{RR}|^2 - |E_{RL}|^2 \rangle$

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



Transmit RC and LC polarizations, interleaved, at 2x Nyquist PRF

Receive (*coherently*) linear (H & V) after each transmission

Raw Full-polarimetric Data:

Transmit RC => (A_{Rh} , A_{Rv})

Transmit LC => (A_{Lh} , A_{Lv})

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**

$$E_{\mathrm{L}} = E_{\mathrm{h}} + jE_{\mathrm{v}}$$

$$E_{\mathrm{R}} = E_{\mathrm{h}} - jE_{\mathrm{v}}$$

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

$$A_{\mathrm{Lh}} = a_{\mathrm{hh}} + ja_{\mathrm{vh}} + n_1 \qquad A_{\mathrm{Rh}} = a_{\mathrm{hh}} - ja_{\mathrm{vh}} + n_3$$

$$A_{\mathrm{Lv}} = a_{\mathrm{hv}} + ja_{\mathrm{vv}} + n_2 \qquad A_{\mathrm{Rv}} = a_{\mathrm{hv}} - ja_{\mathrm{vv}} + n_4$$

***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 ($<|n_k|^2> = N_o$ for all k)
- **Cross-polarized signal terms**
  - ✓ *eg*: $a_{hv} = a_{vh}$ (reciprocity)
  - ✓ *eg*: $<a_{hh}\, a^*_{hv}> = 0$ (statistical independence)

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

Then:

"HH" component: $<|a_{hh}|^2> + \frac{1}{2} N_o$

"VV" component: $<|a_{vv}|^2> + \frac{1}{2} N_o$

"HV" cross-product component:

$$<|a_{hv}|^2> + \frac{1}{4} N_o$$

QED

Comments on Hybrid Quad-Pol SNR

- The factor of " ½ " 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 " ½ " on the cross-pol noise term is a consequence of $a_{hv} \sim\sim a_{vh}$ 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