Hybrid- Versus Matched-Transmit-Receive Antenna
Dual- and Fully Polarimetric SAR: Polarization Efficiency and Applications

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Background

Compact & Hybrid:
- Transmitted polarization: H+V ($\pi/4$) or CP (hybrid)
- Received polarization: H and V

Firstly introduced in 1965 (Long 1967, Green 1968)

Resuscitated in 2005 (Souyris 2005, Raney 2007):

Mis-leading message:
- “Cheap way to do polarimetry at double swath” !!!!!
- “The dual-polarization hybrid Compact data always approach - and occasionally are comparable to analyzes of quad-pol data”

Big Confusion => Full Polarimetry (FP) questioned with reference to the Hybrid (Double swath, Half data volume)
OUTLINE

SAR Architecture: Hybrid versus Matched Antennas

- Compact (Hybrid-) versus (Orthogonal-) Dual CP in terms of antenna polarization efficiency
- Optimum architecture for Fully Polarimetric (FP) SAR
  - the Livingstone architecture => Convair 580

Applications: Dual-pol Hybrid (Compact) versus FP

- Quantification of the Compact loss of information using the degree of polarization (DoP) excursion and signature
- Reconstruction of FP from the Compact (Souyris method) and demonstration of the loss of key polarimetric information for peatland subsurface water monitoring
Hybrid Dual- and Quad-Pol

Transmit CP using H-V antenna
- Receive linear (H & V)
  - RCP=> RH-RV (Compact)
  - LCP=> LH-LV (Compact)

Convenient way for the implementation of Dual-CP using H-V antenna

Alert:
- RH and RV not Matched antenna
  - 50% efficiency => 3 dB Loss
- Transmitted RCP Not perfectly circular
  - RCM, ALOS2, and RISAT

Generation of CP from an H-V Antenna (Stutzman1984)
Polarization Efficiency: ratio of the power received by an antenna of a given polarization to the power that would be received from a plane wave of the same flux density and direction of propagation whose polarization state has been adjusted for maximum received power (IRE 1960)

E=1 when the antenna polarization is matched with the incident wave polarization, and all the energy contained in the completely polarized wave is absorbed by the antenna

Ko 1962, Stutzman 1983

δ: Angular distance between the antenna and the incident wave polarization states
Polarization efficiency variations as function of the antenna wave polarization mis-match angle and the DoP of the scattered wave (Ko 1962, Stutzman 83)

- $\delta = 0^\circ$ & $E = 1$: Matched Antenna
  - Unpolarized wave: $E = 0.5$
- **Hybrid**: $\delta = 90^\circ$  $\Rightarrow$  $E = 0.5$
  - Available power from the antenna minimum and independent of the DoP
- **Hybrid (RH-RV)**: 3 dB loss with reference to matched CP: RR-RL
  - Less accurate RL for signal of low S/N (with ref. to RR-RL)

H.C. KO, IRE, 1962
Forest: HV backscattering 6 dB lower than HH and VV

- HH: -4.86 dB
- HV: -11.26 dB

(Amazonia, Radarsat2)

Variable Gain Amplifier (VGA) or Switched Attenuator applied right after LNA to adjust the position of the receiver dynamic range to the expected range of backscattered power before ADC.
Fully Polarimetric System Design

The Livingstone FP Architecture (1988)

- HV&VH and HH&VV **routed** to two separate receivers
  - LNA well beyond the receiver
  - (HV-VH) - S/N increased of **6 dB**

- Adapted by JAXA to Active Array PALSAR (Shimada 2009)
  - HV **improved** of 9 dB in S/N
Hybrid versus Matched Transmit-Receive Antennas

**Dual-Pol:**

- RH and RV $\Rightarrow$ Receiving Wave-Antenna **Not Matched**
  - 50% **efficiency** $\Rightarrow$ 3 dB Loss
  - RL of low S/N affected

**Quad-Pol:**

- 50% **efficiency** $\Rightarrow$ 3 dB Loss
- X-Pol (RL and HV and ..) of low S/N affected

- Ko 1962, Stutzman 1983, and ... (1960)

**SAR requirements:** S/N **Not** NESZ ????!!!!!
Transmitted RCP assumed **perfectly circular**

**Not realistic**: Actual technology does **not permit** the generation of **perfect** CP (RCM, ALOS2, RISAT)

- RCM: 5° to 10° error in the ellipticity as a function of the Beam Scan Angle
- 2-3 dB error in RH and RV (300km)

**Calibration Requirements**:  
- RH and RV: within 0.5 dB in radiometry and 10° in phase
- **Synthesis** of RR, RL, Rπ/4, … etc

Generation of CP from H-V Antenna
Polarimetric Applications: Hybrid Versus FP

- Hybrid and FP ⇒ Similar target scattering classification (J.C. Souyris, K. Raney, P. Dubois, F. Charbonneau, … etc)

- Mis-leading message: “Cheap way to do polarimetry at double swath and half data volume” !!!!

- Comparison based on simple Coarse Scattering Classification: Surface scattering (Single Bounce)-double-bounce and Volume (Random) Scattering

- Polarimetry EQ Cloude-Pottier or Freeman Decomposition??!!

- Hybrid:
  - Raney Hybrid DoP-δ decomposition
  - Souyris Quad-pol reconstruction (from Hybrid)

- Polarization Synthesis ⇒ abandoned since Cloude-Pottier Decomposition 1996 and Freeman 1998
Hybrid Versus FP
Using DoP and Ro Excursion

- DoP extrema and Excursion ($\Delta p$) shown very promising for target scattering classification
- Scattered intensity $R_0$ extrema shown important
- Assessment of the Loss of information related to the use of only one transmitted polarization (CP or $\pi/4$) among the 180 x 90 ($\psi,\chi$) polarization possibilities using:
  - DoP excursion: $\Delta p$
  - DoP signature as a function of transmitted antenna polarization
  - $R_0$ excursion and signature
San-Francisco Segmentation using the maximum DoP and the DoP excursion $\Delta p$

Touzi R et al., “Polarimetric discriminators for SAR images”, 
Van Zyl Decomposition (1988)
Single-, Double-, and Volume scattering

Touzi DoP Classification 1988
VanZyl Classification 1988
Study Site: Mer Bleue Wetland
Convair-580 SAR HH (red), HV (green), VV (bleue)
Maximum DoP and DoP for H, V, and CP Polarization
DoP Excursion ➔ Hybrid Information Loss

Hybrid DoP

Δp
DoP and $R_0$ Signature as a function of transmitting antenna polarization

Target: Marsh field

**Diagram:**
- **DoP Contour**
  - $P_{max} = 0.05; P_{min} = 0.13; dP = 0.83$
  - $P_{max}: (\psi = 5^\circ, \chi = 6^\circ)$
  - $P_{min}: (\psi = 85^\circ, \chi = 16^\circ)$

- **Ro Contour**
  - $R_{max} = 0.345; R_{min} = 0.045; dR = 0.870$
  - $R_{max}(db) = 4.65 (\psi = 2^\circ, \chi = 6^\circ)$
  - $R_{min}(db) = -13.50 (\psi = 92^\circ, \chi = 0^\circ)$

**Area:** Marsh

**Incident angle:** 70.0°

**Area coord:** L (2351 - 2375); P (7951 - 8000)

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**R. Touzi**, Pol-InSAR13, Frascatti, 26 Jan. 2013
DoP and $R_0$ Signature
Urban Area

Incident angle: 0.06°
Area coord: L (15010 - 16360); P (697 - 736)

$P_{max} = 0.85$; $P_{min} = 0.01$; $dP = 0.85$

$P_{max}$: ($\psi = 177^\circ$; $\chi = 1^\circ$)
$P_{min}$: ($\psi = 91^\circ$; $\chi = 35^\circ$)

$R_{max}(dB) = -2.30$ ($\psi = 171^\circ$; $\chi = -1^\circ$)
$R_{min}(dB) = -4.74$ ($\psi = 61^\circ$; $\chi = 1^\circ$)
$(R_{max}-R_{min})(R_{max}+R_{min}) = 0.27$
DoP and R0 Signature of a Forest
C-band CV580 and L-band ALOS

R. Touzi, Pol-InSAR13, Frascatti, 26 Jan. 2013
Compact Versus FP
HV reconstruction from Compact (Souyris 2005)

• Reflection symmetry: \(<hh.hv^*> = 0 = <vv.vh^*>\)

• \(X = <|hv|{}^2>, H = <|hh|{}^2>, V = <|vv|{}^2>, P = <hh.vv^*>\)

• Iterative method to estimate \(<|hv|{}^2>\) under the condition:
  \[
  \frac{X}{H+V} \approx (1 - \rho_{hhvv^*}) / 4
  \]

➢ Estimate of FP covariance ➞

\[
\begin{bmatrix}
J_{\pi/4}
\end{bmatrix}
\approx
\begin{bmatrix}
H + X & P + X \\
P^* + X & V + X
\end{bmatrix}
\]

\[
\begin{bmatrix}
\hat{C}_{FP}
\end{bmatrix}
\approx
\begin{bmatrix}
\hat{j}_{11} - X & 0 & \hat{j}_{12} - X \\
0 & 2X & 0 \\
\hat{j}_{12}^* - X & 0 & \hat{j}_{22} - X
\end{bmatrix}
\]
Radiometric calibration error (3-6 dB)

- $<|hv|^2>$ reconstructed not reliable (CEOS Requirement 0.5 dB)
  - Sedge Fen: 3 dB error
  - Treed Bog: 2 dB
  - Marsh: more than 6 dB
Peatland subsurface water monitoring using L-Band PALSAR (Lac St Pierre)

PALSAR, Nov. 10, 2007

PALSAR, May 13, 2007

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Peatland: Poor fen + Bog

Cannot be discriminated with Optic Sensors

• **Bog:**
  - **Ombrotrophic:** precipitations, fog and snow are the primary water sources

• **Poor Fen:**
  - **Minerotrophic:** fens are connected to small streams and may also receive water from surrounding uplands.
  - As such, poor fens of high water retention are continuously irrigated with subsurface water even under no rainy conditions.
HH-HV-VV not sensitive to water flow variations beneath the peat surface.
Freeman **Coarse** Scattering Classification **not sensitive** to water flow variations **beneath** the peat surface.
Touzi phase $\phi_{as}$ generated from FP detects water flow variations beneath the peat surface.

- **Pink** $\Rightarrow$ subsurface water (less than 20 cm)
- **Fen**: subsurface run off water
- **Bleue** $\Rightarrow$ deep underground water
- **Bog**: water level at the catotelm (40-50 cm)

Essential information for monitoring Bog-Fen Transformations in the North due to climate change stress.
Reconstructed Compact: $\phi_{as}$ not sensitive to water flow variations beneath the peat surface.
Conclusions

- Hybrid convenient for generation of CP with H-V antennas
- Not efficient ➲ Not accurate RL (and HV) at low S/N
- Transmitted CP not perfectly circular
  ➲ Calibration requirements: 0.5 dB and 10° will be a Challenge
  ➲ Very hard to reach at high Faraday conditions and (-25dB) isolation
- CP antenna for Future P-band missions ➲ Operational use of single and dual-mode radiometry not affected by Faraday rotation

- Δp and DoP signature ➲ Quantification of Hybrid polarization information loss
  ➲ The one-transmitted polarization (CP or π/4) Cannot provide the full polarimetric information provided by FP that exploits 180x90 (ψ,χ) transmitted polarization possibilities

Polarimetry NEQ Freeman & Cloude-Pottier Decomposition

- The abandoned polarization optimization theory provides valuable information (polarization synthesis, DoP excursion and signature, target contrast optimization, unpolarized component signature ...)????!!!!!