High-resolution 3D imaging technique in forward scattering bistatic configurations

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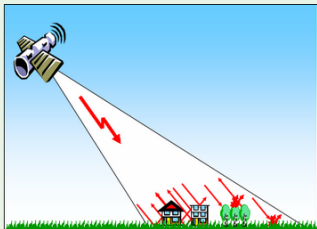[1] ISAE-Supaero, U. Toulouse, France
[2] CESBIO, U. Toulouse, France
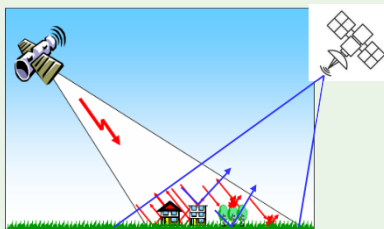[3] FI-NDT, Nantes, France

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Monostatic Back-Scattering vs. Bistatic Forward-Scattering

BSC imaging

- Adapted to 2-D ground mapping
- Monostatic Tx and Rx chains
  - ▶ may share devices
  - ▶ easy synchronization
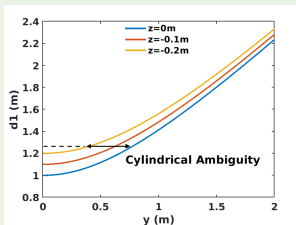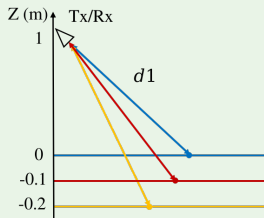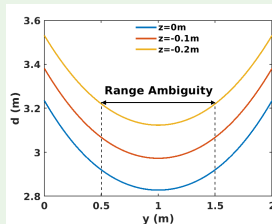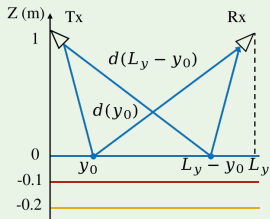- Variety of scattering mechanisms

FSC imaging

- Intrinsic z–mapping: $\delta d \to \delta z$
- Filters out DB scattering
- Emphasizes specular scattering
- Significantly enhanced SNR

Monostatic Back-Scattering vs. Bistatic forward-scattering
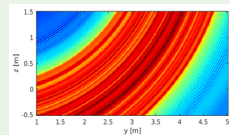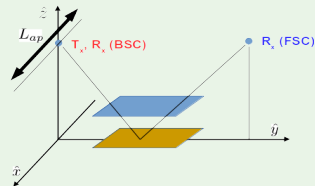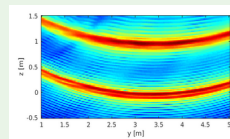
Mapping & ambiguities
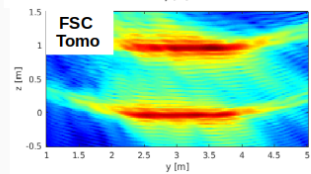

(a) BSC

(b) FSC

Simulations

(a) BSC

(b) FSC

Bistatic FSC tomography using an additional aperture

Snow pack

Artificial volume

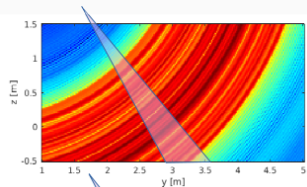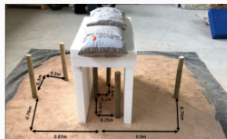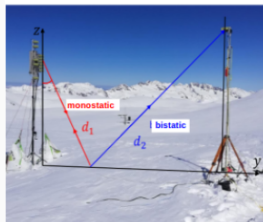**Snow covered sea-ice**
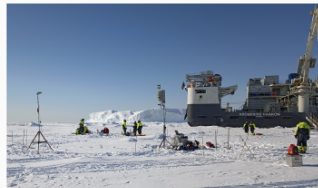
Roadway defects

MISO system

R_x (FSC)

T_x, R_x (BSC)

L_z

θ_1

θ_2

d_1

d_2

SISO system

(b) COSBis acquisition geometry
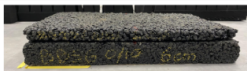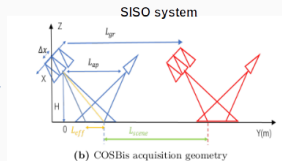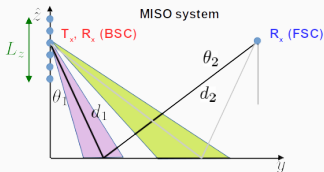
(e) Vertical Gap

(f) Horizontal Gap

(a) COSBis SAR System operated in SOSB mode

- Minimal complexity configuration: 1 Tx & 1 Rx
- Opposite side sliding system:
  - ▶ angular diversity through horizontal aperture
  - ▶ provides ground-range resolution (vertical ones depends on B_f)
  - ▶ relaxes sampling constraint

(a) Single-BSC

(b) Single-FSC

(c) Nadir-looking GPR
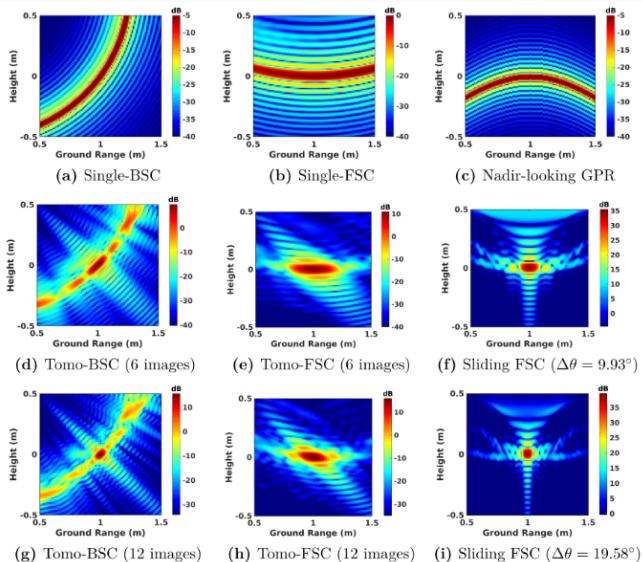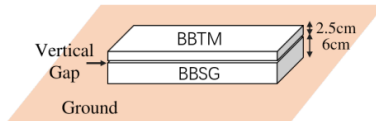
(d) Tomo-BSC (6 images)

(e) Tomo-FSC (6 images)

(f) Sliding FSC ($\Delta\theta = 9.93°$)

(g) Tomo-BSC (12 images)

(h) Tomo-FSC (12 images)
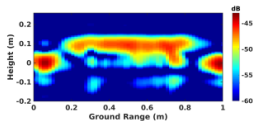
(i) Sliding FSC ($\Delta\theta = 19.58°$)

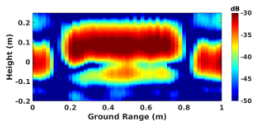■ Cosbiz images have a quasi rectangular spectrum (orthogonal sidelobes)
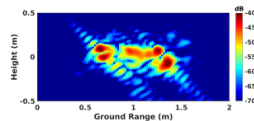
Detection of a vertical gap
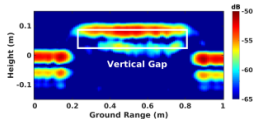

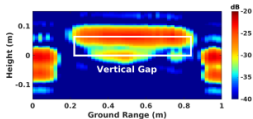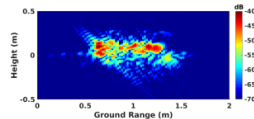(a) Geometrical Configuration - Vertical Gap

(b) AIR GAP_C_GPR

(c) AIR GAP_C_HH
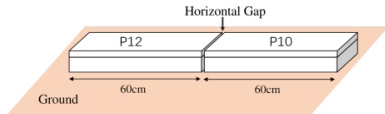
(d) AIR GAP_C_VV

(e) AIR GAP_X_GPR

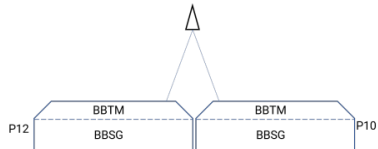(f) AIR GAP_X_HH

(g) AIR GAP_X_HH

- Nadir-looking and COSBiz configurations have similar performance
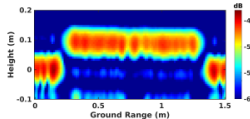- BSC imaging: speckle + dominating DB scattering patterns

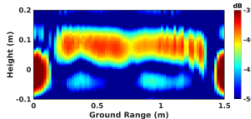# Detection of a horizontal gap

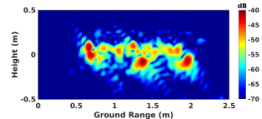**(a)** Geometrical Configuration - Horizontal Gap

(b) Geometrical Configuration - GPR Mode

(c) AIR GAP_C_GPR
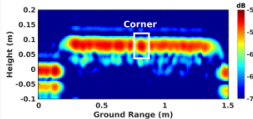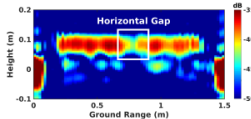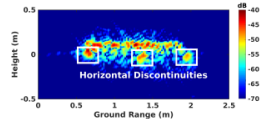
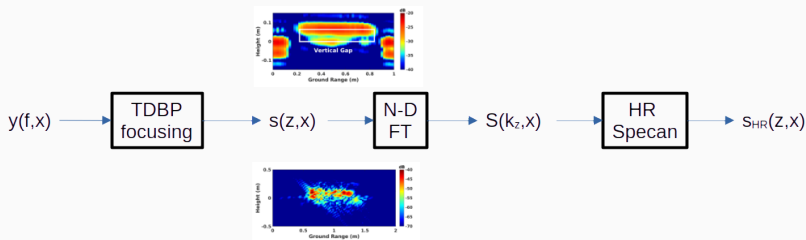**(d)** AIR GAP_C_VV

(e) AIR GAP_C_VV

(f) AIR GAP_X_GPR

(g) AIR GAP_X_VV

(h) AIR GAP_X_VV

- Nadir-looking configuration fails
- FSC: DB mechanism prevents forward scattering −> gap detection

$y(f,x) \longrightarrow$ TDBP focusing $\longrightarrow s(z,x) \longrightarrow$ N-D FT $\longrightarrow S(k_z,x) \longrightarrow$ HR Specan $\longrightarrow s_{HR}(z,x)$

- Classical spatial filtering in BSC mode:

$$s(z,x) \to S(k_z,x) \to \mathbf{R} = \frac{1}{L}\sum_l \mathbf{s}(x_l)\mathbf{s}^H(x_l) = \sum_t \mathbf{R}_t$$
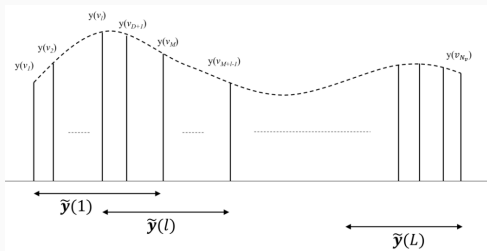
- CosBiz: coherent scattering (no speckle pattern)

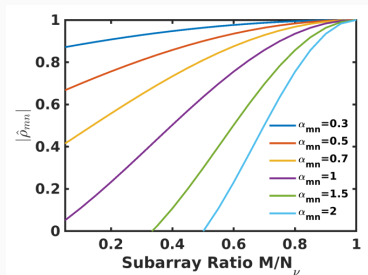$$\mathbf{s}(x_l) \propto \mathbf{s}(x_0) = \sum_t \mathbf{s}_t \to \mathrm{rank}(\mathbf{R}) = 1$$

Non-separable target sub-spaces!

- A solution: spectral smoothing (exploits phase diversity)

- Decorrelation - Fourier resolution loss compromise

- Original resolution

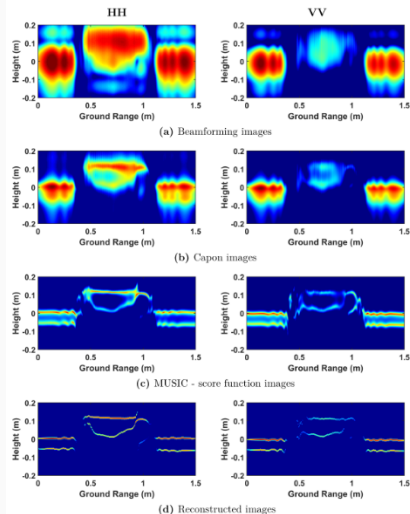(a) Geometry of the horizontal crack

(b) HH polarization

(c) VV polarization

- High resolution

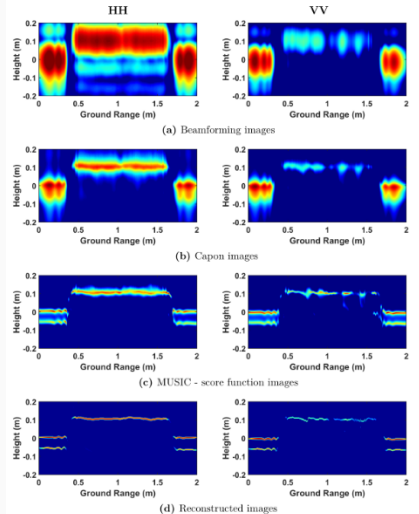(a) Beamforming images

(b) Capon images

(c) MUSIC - score function images

(d) Reconstructed images
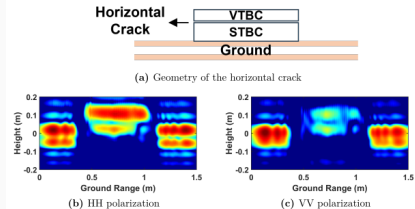
- Original resolution
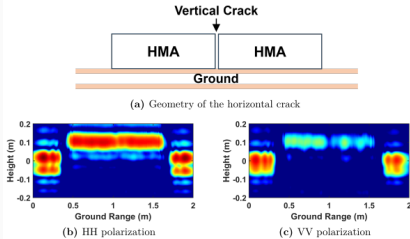
- High resolution

- Very low complexity elevation-range FSC imaging solution:

  CosBiz

- Monostatic vs. highly bistatic configuration:

  radically different scattering mechanisms

- High-Resolution processing adapted to particular statistical behavior