Unambiguous Estimation of Deformation in GBSAR through Successive Referencing

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Outline

- ✓ GBSAR: Concept & Applications
- ✓ Proof of concept set-up using SDR in the lab environment.
- ✓ Data processing to extract deformation
  - ✓ Unambiguous Estimation
  - ✓ Successive referencing

Microwave ground based synthetic aperture radar (GBSAR):

- ✓ A unique remote sensing concept
- ✓ Suitable for all-weather, all-time monitoring
- ✓ Detects subtle structural deformations with high resolutions
- ✓ This forms an early-warning system with very high accuracy and reliability.
- ✓ Once deployed in the field, it has potential to persistently monitor wide area from the remote location

GBSAR: Applications

Constant Monitoring of:

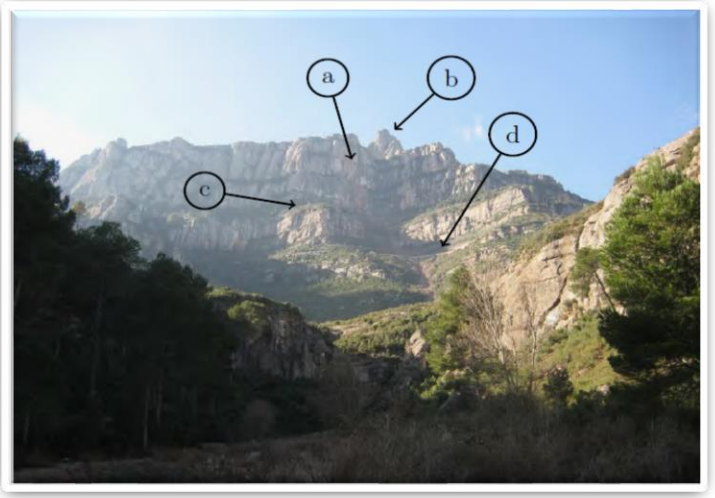
- Land Slides
- Volcanoes
- Glacier ices
- Man-made structures:
  - Dams
  - Bridges
  - Mining Areas
  - High rise buildings
  - Power lines
  - Transmissions towers

End Use

Hazard Preventive Assistance

Alarm

Structure Monitoring



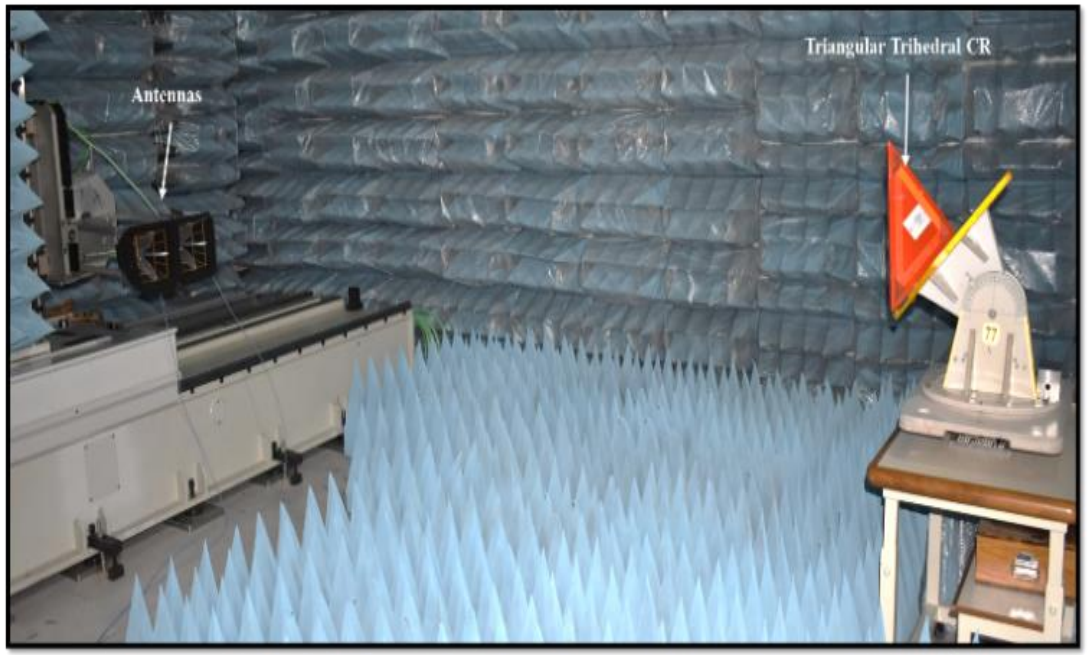
Landslide Monitoring

Bridge Monitoring

Dam Monitoring

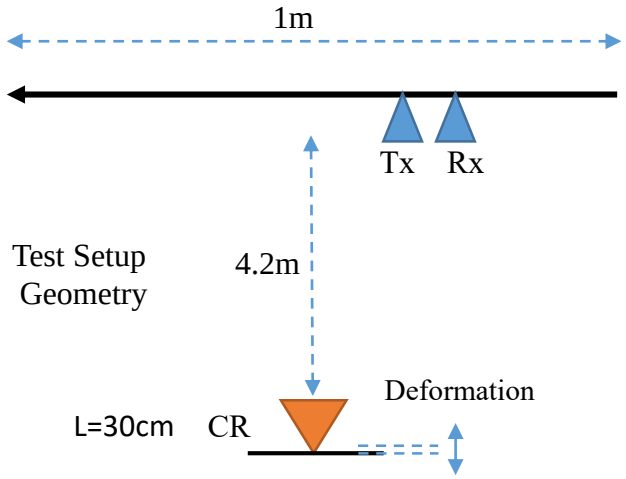
GBSAR: Proof of concept set-up using SDR in the lab environment

- ✓ Typically, POC Set-up consists of:
  - ✓ Universal Software Radio Peripheral (USRP) (SDR)
  - ✓ Horn Antennas (Transmit (Tx) and Receive (Rx))
  - ✓ Triangular trihedral corner reflector (CR) mounted on micro positioner (meant for inducing deformations)



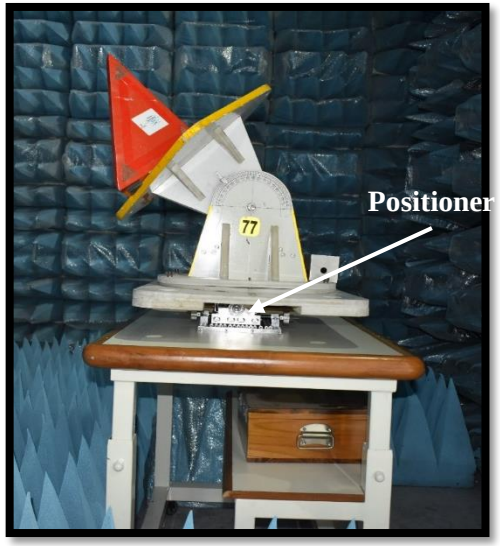
- ✓ Tx/Rx antennas are mounted on a scanning structure.
- ✓ Pulsed Chirp signal is transmitted and reflected signal from CR is received though Rx horn antenna.
- ✓ The data acquired over the aperture length is processed to form the phase-map of SAR image.

GBSAR: Proof of concept set-up using SDR in the lab environment



Parameters	Value
Velocity	450 mm/min
PRI	2.4 sec
Pulse Width	10 us
Centre frequency	5.4GHz
Bandwidth	160MHz
Synthetic Aperture Length	1 m
Slant Range Resolution	1 m
Cross Range Resolution	28mrad (28m @ 1km)

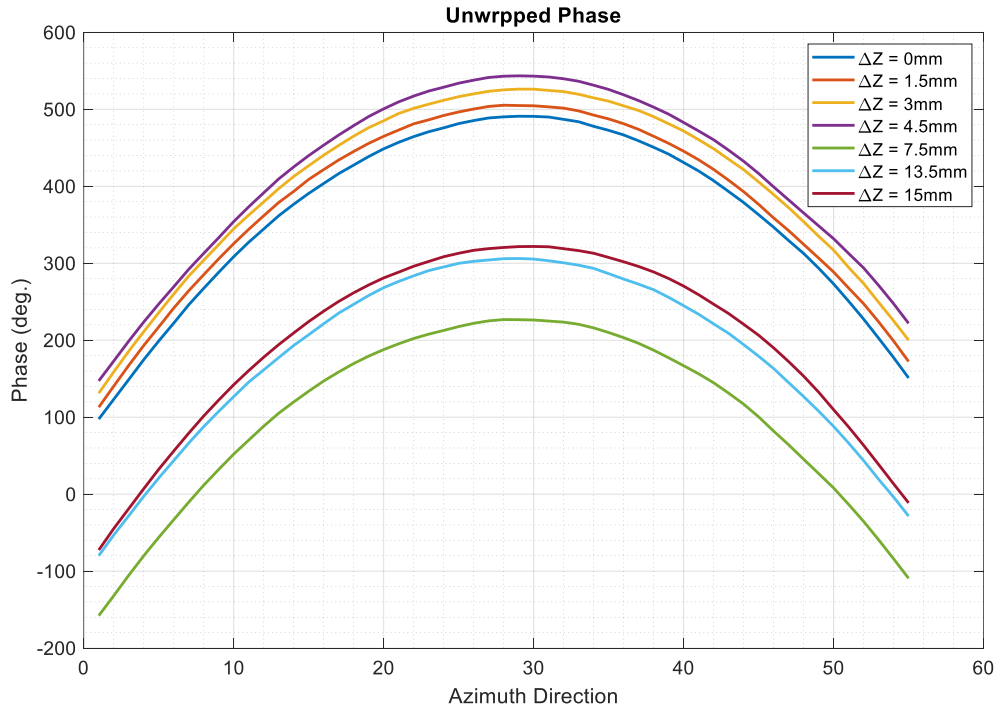

Pair of Transmit and Receive Horn Antennas



Line-of-sight deformation is simulated using a positioner (step size: 1.5mm).

Data Processing to Extract Deformation

- ✓ For each position, we get phase information corresponding to delay (i.e. path length).



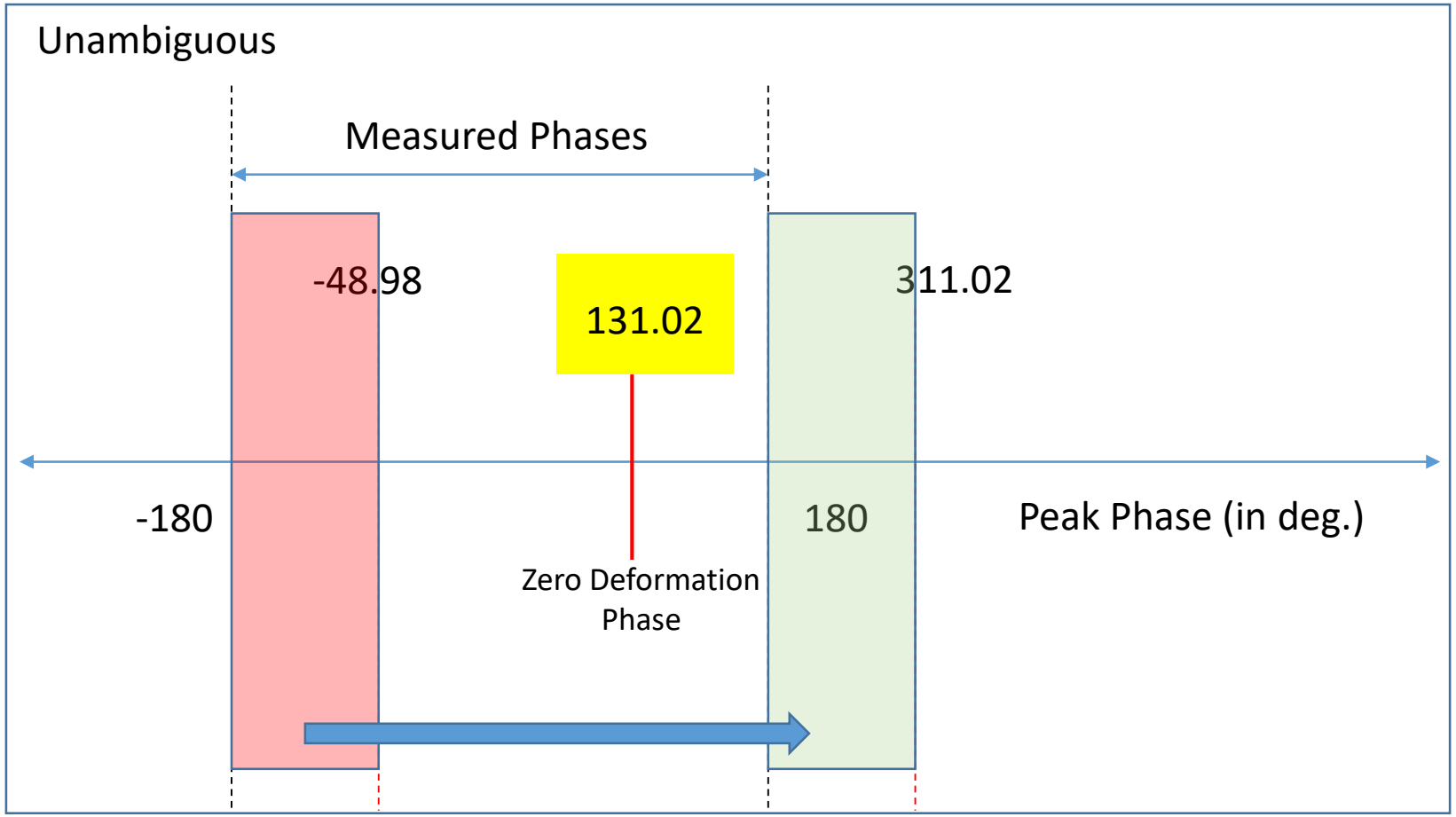
C-band : 5.4GHz

- ✓ In general multi-target case, it is compressed in azimuth direction to resolve targets and obtain their respective phases.

Deformation Estimation after Phase Correction w.r.t. Fixed Reference

Scan No	Delta Deformation (mm)	Cumulative Deformation (mm)	Peak Phase	After Correction (fixed reference)	Change in Phase w.r.t first	Estimated Cumulative Deformation
0		0	131.02	131.02		
1	1.50	1.50	145.35	145.35	14.33	1.11
2	1.50	3.00	166.28	166.28	35.25	2.72
3	1.50	4.50	-176.47	183.53	52.51	4.05
4	3.00	7.50	-133.14	226.86	95.84	7.39
5	6.00	13.50	-53.83	306.17	175.15	13.51
6	1.50	15.00	-38.19	-38.19	-169.21	-13.06
7	7.50	22.50	52.97	52.97	-78.05	-6.02
8	7.50	30.00	143.70	143.70	12.68	0.98

Deformation Estimation after Phase Correction w.r.t. Fixed Reference



Deformation Estimation after Phase Correction w.r.t. Fixed Reference

Scan No	Delta Deformation (mm)	Cumulative Deformation (mm)	Peak Phase (deg.)	After Correction (fixed reference) (deg.)	Change in Phase w.r.t first (deg.)	Estimated Cumulative Deformation (mm)
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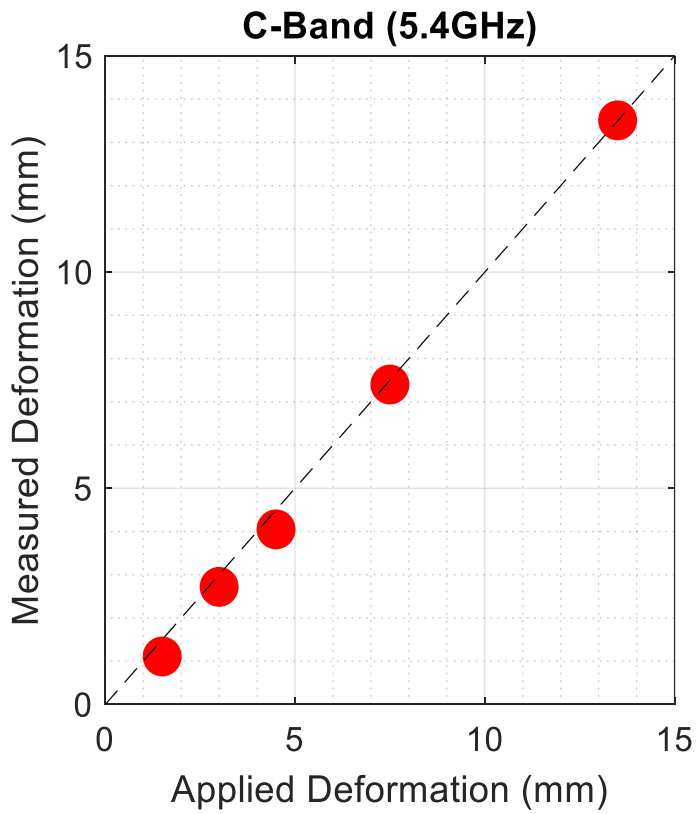
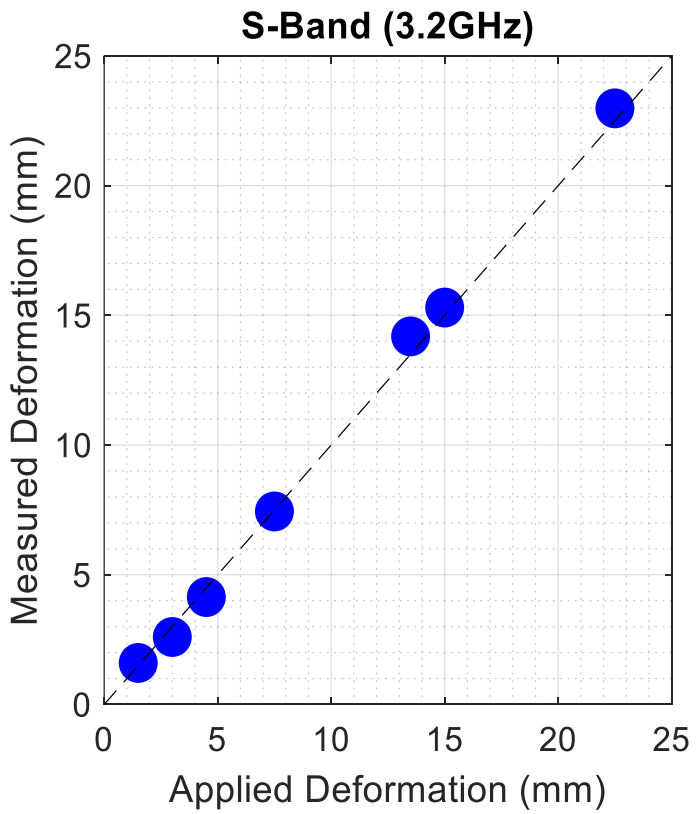
8	7.50	30.00	143.70	143.70	12.68	0.98

At 5.4GHz, $\lambda/4$ is 13.9mm

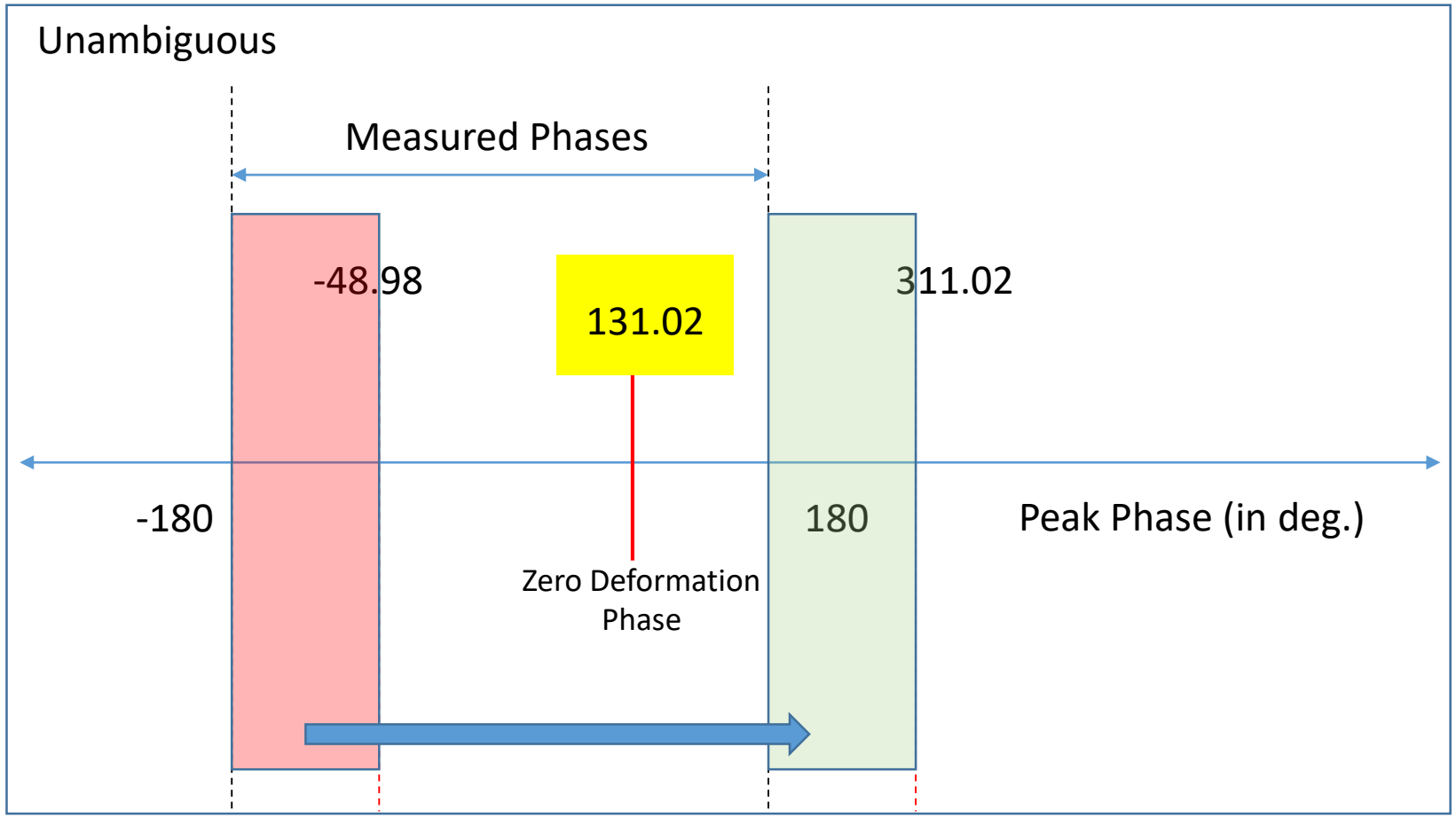
Deformation Estimation after Phase Correction w.r.t. Fixed Reference

- ✓ POC was carried out for C and S bands.





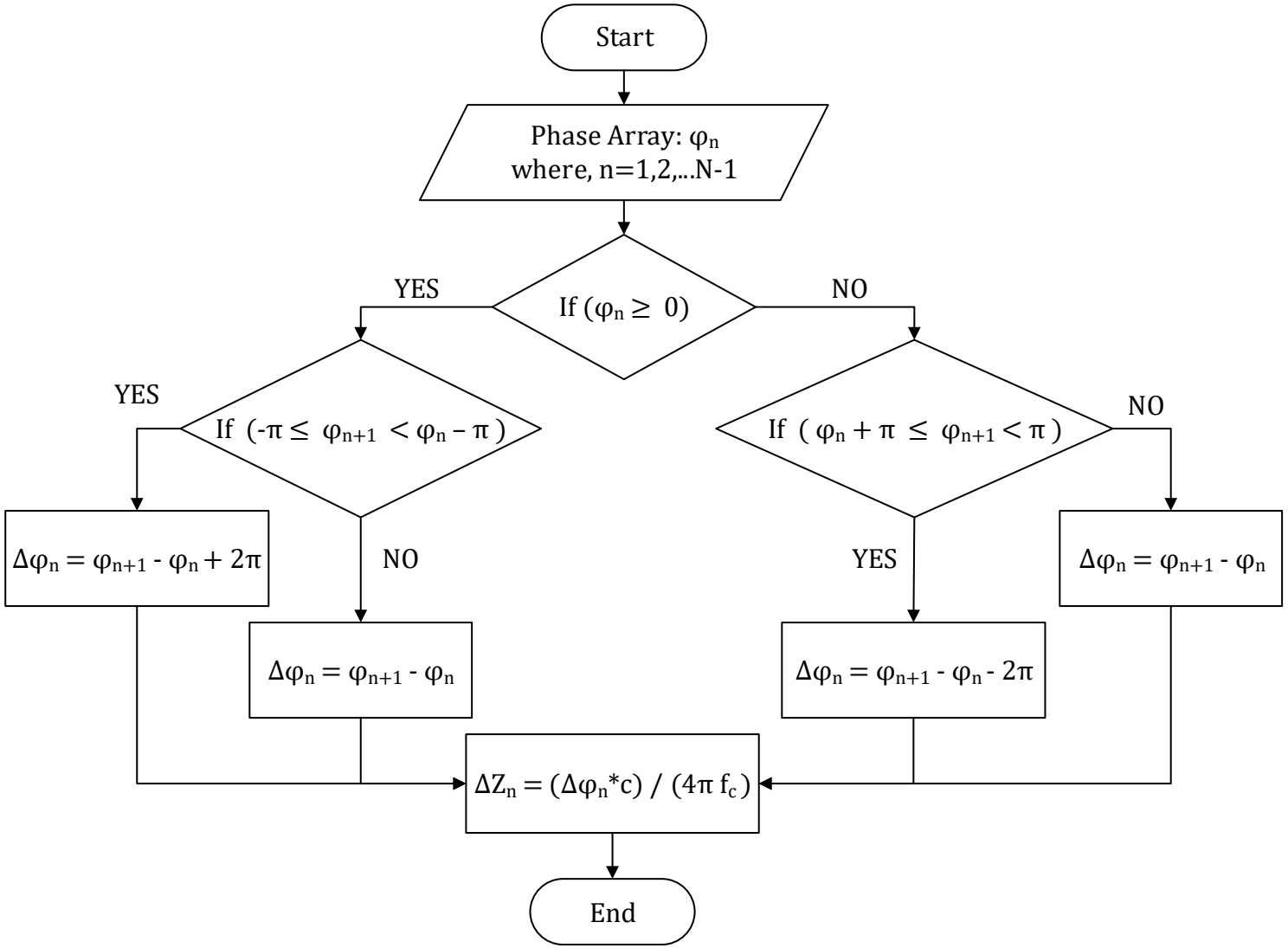
Deformation Estimation after Phase Correction w.r.t. Successive References



Successive

131.02 : Reference to be updated successively

Unambiguous Estimation of Deformation



Deformation Estimation after Phase Correction w.r.t. Successive Reference

Scan No	Delta Deformation (mm)	Cumulative Deformation (mm)	Peak Phase Azimuth (deg.)	After Correction (successive reference) (deg.)	Successive Change in Phase (deg.)	Cumulative Change in Phase (deg.)	Estimated Cumulative Deformation (mm)
0		0	131.02				
1	1.50	1.50	145.35	145.35	14.33	14.33	1.10
2	1.50	3.00	166.28	166.28	20.93	35.25	2.72
3	1.50	4.50	-176.47	183.53	17.26	52.51	4.04
4	3.00	7.50	-133.14	-133.14	43.32	95.84	7.39
5	6.00	13.50	-53.83	-53.83	79.31	175.15	13.51
6	1.50	15.00	-38.19	-38.19	15.64	190.79	14.71
7	7.50	22.50	52.97	52.97	91.15	281.95	21.74
8	7.50	30.00	143.70	143.70	90.73	372.68	28.74

Thus, successive deformations limited to $\lambda/4$ can be accurately estimated through successive referencing.

REFERENCES:

- Chan, Yee-Kit, et al. "A Ground-Based Interferometric Synthetic Aperture Radar Design and Experimental Study for Surface Deformation Monitoring." IEEE Aerospace and Electronic Systems Magazine 36.10 (2021): 4-15.
- Pieraccini, Massimiliano, and Lapo Miccinesi. "Ground-based radar interferometry: A bibliographic review." Remote Sensing 11.9 (2019): 1029.
- Monserrat, O., M. Crosetto, and G. Luzi. "A review of ground-based SAR interferometry for deformation measurement." ISPRS Journal of Photogrammetry and Remote Sensing 93 (2014): 40-48.
- Noferini, Linhsia, et al. "DEM by ground-based SAR interferometry." IEEE Geoscience and Remote Sensing Letters 4.4 (2007): 659-663.
- D. Tarchi, H. Rudolf, M. Pieraccini, and C. Atzeni, “Remote monitoring of buildings using a ground-based SAR: Application to cultural heritage survey,” Int. J. Remote Sens., vol. 21, no. 18, pp. 3545–3551, 2000.
- R. Balmer and P. Hartl, “Synthetic aperture radar interferometry,” Inverse Problems, vol. 14, pp. 1–54, 1998.

Thank You.