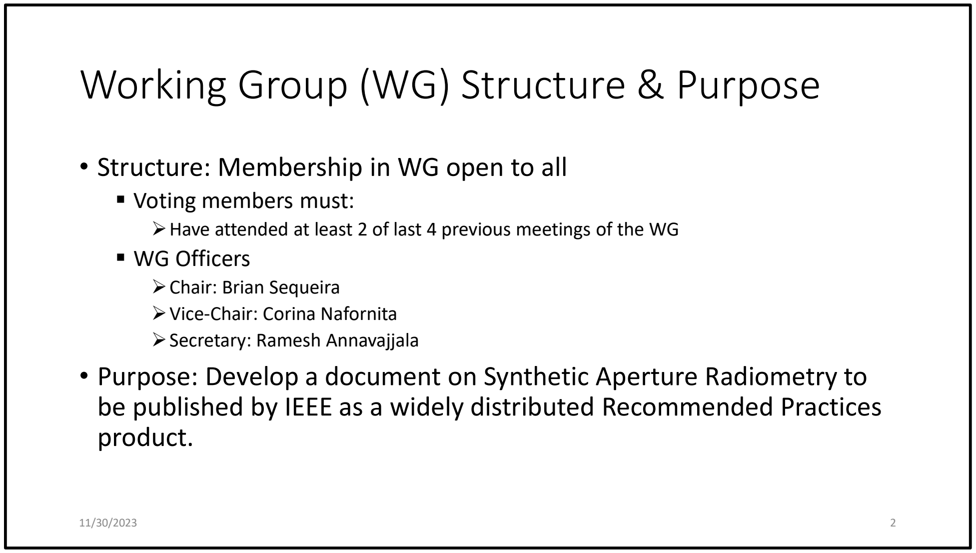
Review of Content Covered to Date

IEEE Synthetic Aperture Radiometry Working Group 10th Meeting
November 30, 2023

This presentation is for the benefit of newly joined members to the WG as well as a review for “veteran” members



Working Group (WG) Structure & Purpose

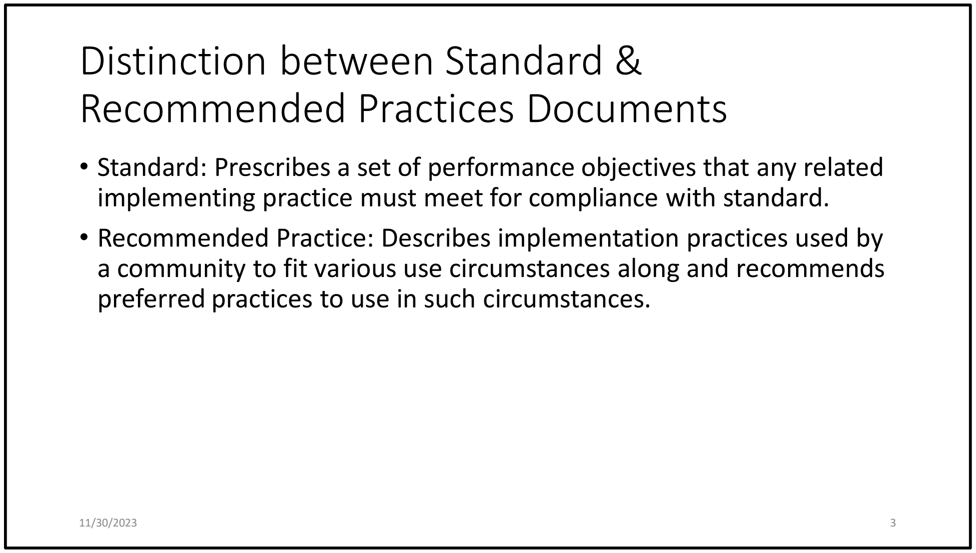
- Structure: Membership in WG open to all
  - Voting members must:
    - Have attended at least 2 of last 4 previous meetings of the WG
  - WG Officers
    - Chair: Brian Sequeira
    - Vice-Chair: Corina Nafornita
    - Secretary: Ramesh Annavajjala
- Purpose: Develop a document on Synthetic Aperture Radiometry to be published by IEEE as a widely distributed Recommended Practices product.

In this slide, we address the structure and purpose of the working group (WG).

Membership in the working group is open to all attendees regardless of professional society affiliation. This is in keeping with IEEE-SAS that documents are products of consensus of as large and diverse a community as possible. However, a voting member must have attended at least two of the last four meetings prior to the one where voting is exercised.

As required by IEEE-SA, each WG must have a chair, vice-chair, and secretary. Brian Sequeira is chair, Corina Nafornita is vice-chair, and Ramesh is the group's secretary.

The purpose of the WG is to craft for the Synthetic Aperture community at large and the Synthetic Aperture Radiometry community in particular, a Recommended Practices document that is widely embraced by both communities. All other considerations are subservient to this stated purpose.



Distinction between Standard & Recommended Practices Documents

- Standard: Prescribes a set of performance objectives that any related implementing practice must meet for compliance with standard.
- Recommended Practice: Describes implementation practices used by a community to fit various use circumstances along and recommends preferred practices to use in such circumstances.

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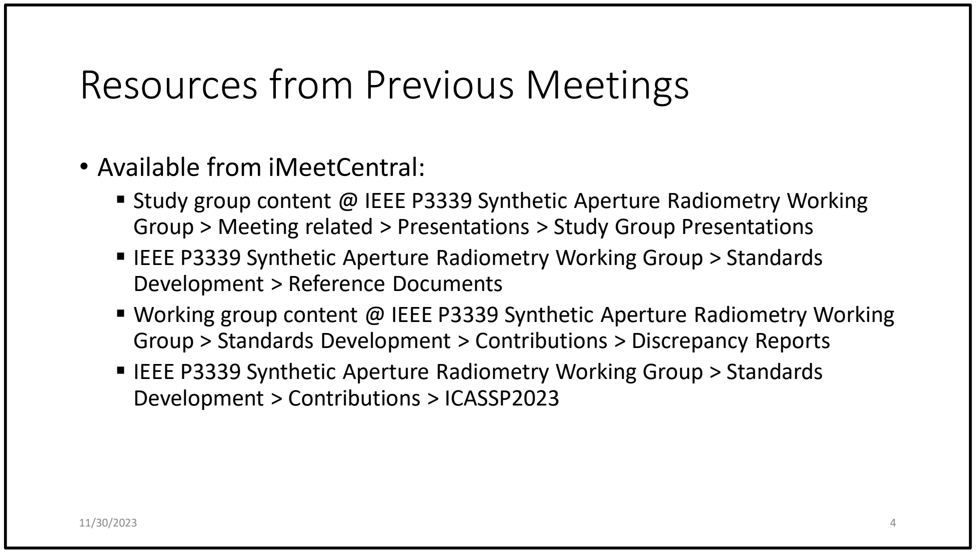
It is helpful to gain some insight into the difference between a standards and a recommended practices document. A standards document demands compliance by a implementer in an enterprise that is addressed by that standard. In that sense a standard is prescriptive.

A recommended practices document is descriptive of the practices used in a given enterprise. Such implementation practices produce articles that are designed to operate in a specific set of circumstances. A recommended practices document identifies a preferred set of practices, if appropriate that fits that set of circumstances. For example, if one implementation of a radiometer is suitable for ground operation exclusively, and another implementation is suitable for airborne operation exclusively, a recommended practices document may identify a preferred implementation that is appropriate for ground and airborne operation, and justify that recommendation by presenting a rationale for that choice.



Resources from Previous Meetings

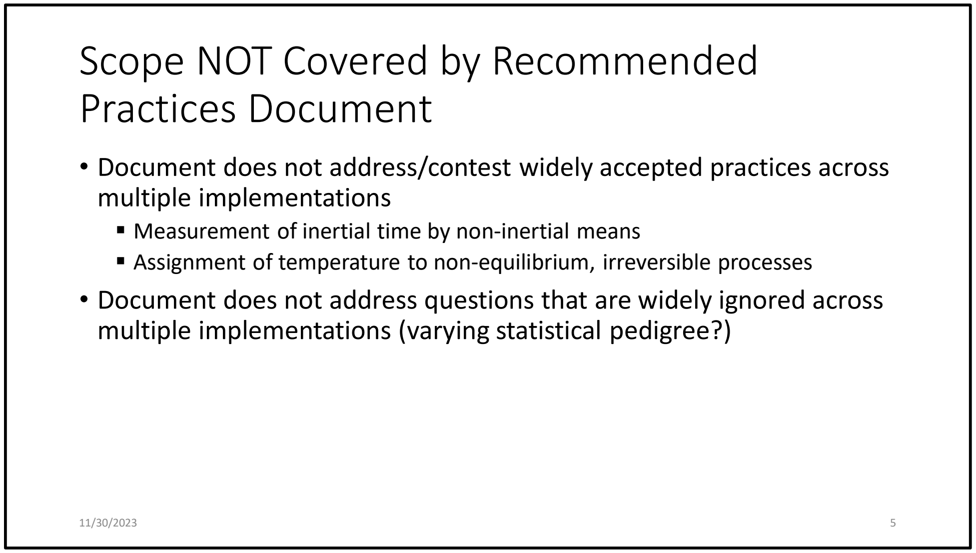
- Available from iMeetCentral:
  - Study group content @ IEEE P3339 Synthetic Aperture Radiometry Working Group > Meeting related > Presentations > Study Group Presentations
  - IEEE P3339 Synthetic Aperture Radiometry Working Group > Standards Development > Reference Documents
  - Working group content @ IEEE P3339 Synthetic Aperture Radiometry Working Group > Standards Development > Contributions > Discrepancy Reports
  - IEEE P3339 Synthetic Aperture Radiometry Working Group > Standards Development > Contributions > ICASSP2023

Past technical content covered in previous meetings of the working group and its predecessor study group can be found on iMeetCentral at the locations listed in this slide.

Members may find it useful to consult the contributions sub-folder first. The ICASSP2023 sub-folder has a paper and a presentation that spells out the scope of the working group’s recommended practices document, and presents rationale for topics to be incorporated into the document.

The sub-folder named “Discrepancy Reports” presents an example of bench-top calibration of a receiver. The report may be used as a template for describing other calibration methods such as describing the method, the uncertainties that affect post-calibration outcome, and the best practice recommended.

Members requiring background and tutorial assistance may consult presentations in the Study Group Presentations sub-folder, and the associated Reference Documents folder for further background.



Scope NOT Covered by Recommended Practices Document

- Document does not address/contest widely accepted practices across multiple implementations
    - Measurement of inertial time by non-inertial means
    - Assignment of temperature to non-equilibrium, irreversible processes
- Document does not address questions that are widely ignored across multiple implementations (varying statistical pedigree?)

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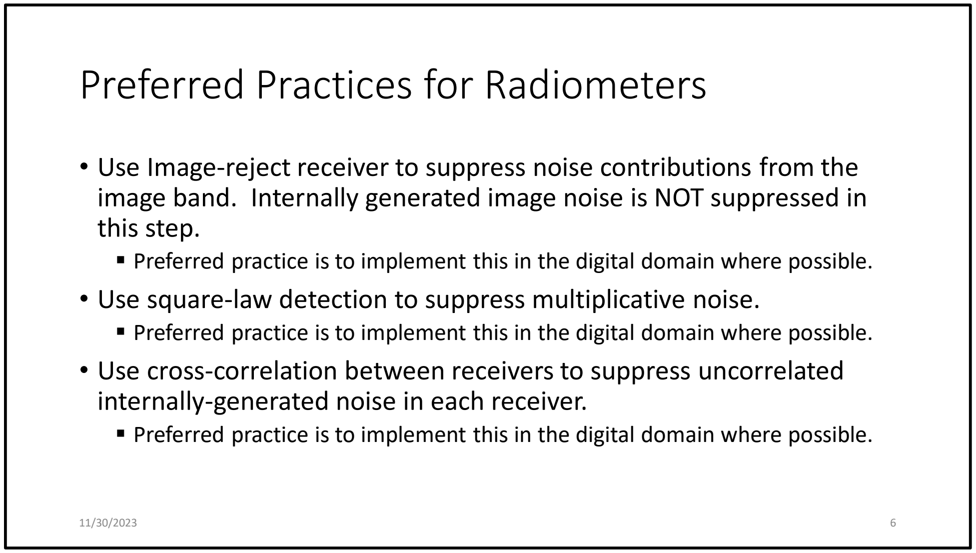
In the spirit of describing current practices we accept what is widely accepted across multiple practices and ignore what is widely ignored among them. Thus, although time is a critical element in the operation of a radiometer by itself and more critical when operated in an array, we will not explore the question of why we can use non-inertial means to measure what is an inertial quantity.

We shall also not contest the assignment of temperature to non-equilibrium irreversible thermodynamic processes even though temperature, strictly speaking, is a property of a system in thermodynamic equilibrium. We will, however, discuss the limitations of radiometer measurements because of such assignment.



Preferred Practices for Radiometers

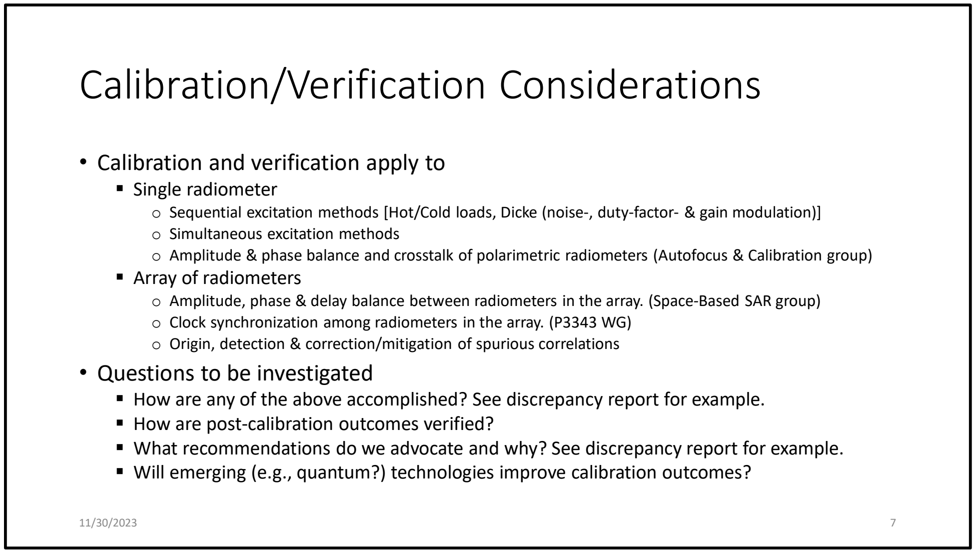
- Use Image-reject receiver to suppress noise contributions from the image band. Internally generated image noise is NOT suppressed in this step.
  - Preferred practice is to implement this in the digital domain where possible.
- Use square-law detection to suppress multiplicative noise.
  - Preferred practice is to implement this in the digital domain where possible.
- Use cross-correlation between receivers to suppress uncorrelated internally-generated noise in each receiver.
  - Preferred practice is to implement this in the digital domain where possible.

Within the confines of the foregoing limitations, certain preferred practices emerge from consideration of radiometer operation. Image-reject receivers are preferred to single ended ones because they reduce the contribution of noise from the background relative to the noise of interest. However, this step does not reduce the noise generated in the image band by the mixers and subsequent receiver stages themselves. Higher image rejection results from digital implementation of image suppression.

Square-law detection suppresses multiplicative noise caused by local oscillator phase noise and sampling clock jitter. Again, digital implementation is superior because it implements purer multiplication of the sampled sequence by itself. Moreover, the multiplication is free of variations of temperature and other environmental effects.

Internally-generated noise by each receiver is suppressed by cross-correlation between the outputs of a pair of receivers because that noise is uncorrelated. Again, digital implementation is preferred.

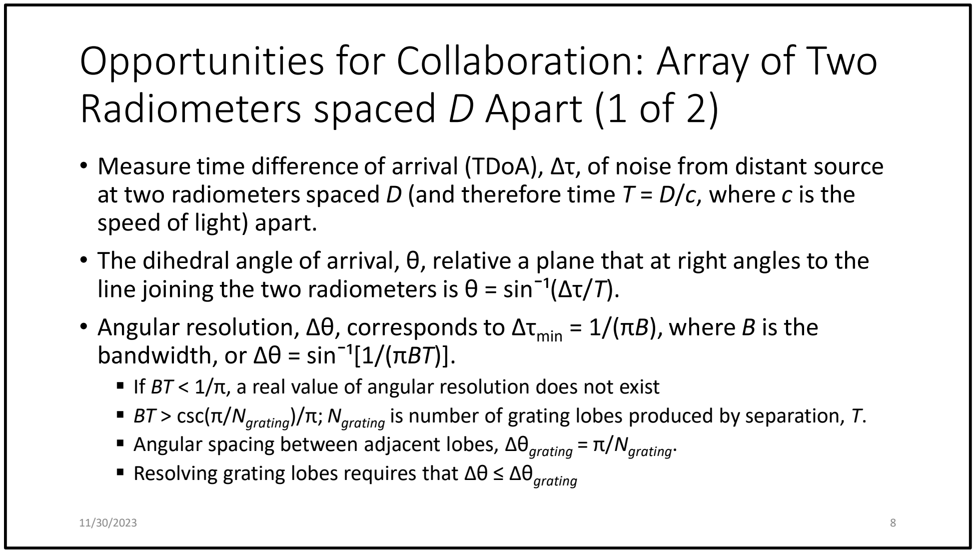
In cases where receiver bandwidths require Nyquist sampling rates that are beyond the reach of current state-of-the-art, digital implementation is not possible and fallback approaches such as analog mixing are among the available options.



Calibration/Verification Considerations

- Calibration and verification apply to
  - Single radiometer
    - Sequential excitation methods [Hot/Cold loads, Dicke (noise-, duty-factor- & gain modulation)]
    - Simultaneous excitation methods
    - Amplitude & phase balance and crosstalk of polarimetric radiometers (Autofocus & Calibration group)
  - Array of radiometers
    - Amplitude, phase & delay balance between radiometers in the array. (Space-Based SAR group)
    - Clock synchronization among radiometers in the array. (P3343 WG)
    - Origin, detection & correction/mitigation of spurious correlations
- Questions to be investigated
  - How are any of the above accomplished? See discrepancy report for example.
  - How are post-calibration outcomes verified?
  - What recommendations do we advocate and why? See discrepancy report for example.
  - Will emerging (e.g., quantum?) technologies improve calibration outcomes?

Here are some topics that the recommended practices document should cover under the general heading of calibration and verification.

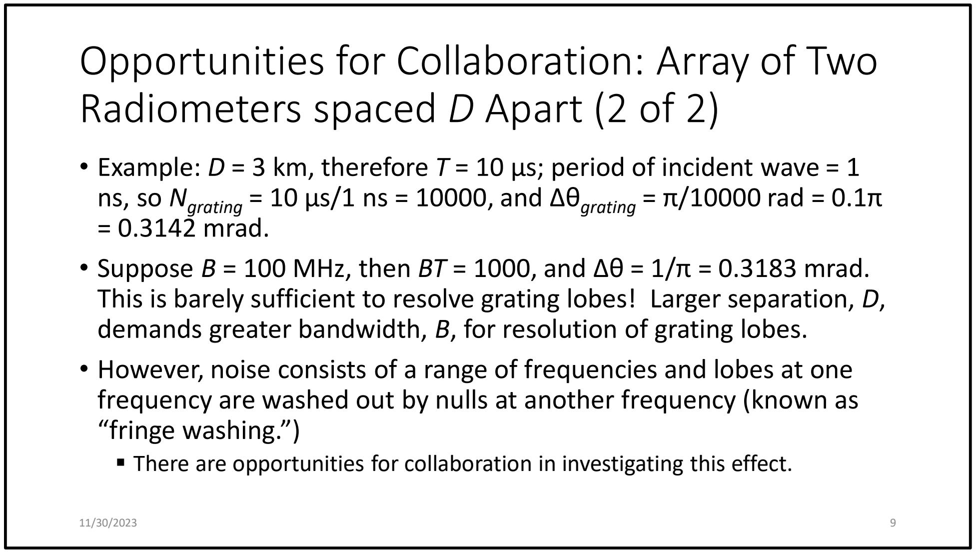


Opportunities for Collaboration: Array of Two Radiometers spaced *D* Apart (1 of 2)

- Measure time difference of arrival (TDoA), $\Delta\tau$, of noise from distant source at two radiometers spaced D (and therefore time $T = D/c$, where c is the speed of light) apart.
- The dihedral angle of arrival, θ, relative a plane that at right angles to the line joining the two radiometers is $\theta = \sin^{-1}(\Delta\tau/T)$.
- Angular resolution, $\Delta\theta$, corresponds to $\Delta\tau_{\mathrm{min}} = 1/(\pi B)$, where B is the bandwidth, or $\Delta\theta = \sin^{-1}[1/(\pi BT)]$.
  - If $BT < 1/\pi$, a real value of angular resolution does not exist
  - $BT > \csc(\pi/N_{grating})/\pi$; $N_{grating}$ is number of grating lobes produced by separation, T.
  - Angular spacing between adjacent lobes, $\Delta\theta_{grating} = \pi/N_{grating}$.
  - Resolving grating lobes requires that $\Delta\theta \le \Delta\theta_{grating}$

Here is one example of an opportunity for collaboration as it applies to two sensors separated by some distance. In this scenario, the two sensors estimate the time difference of arrival of a signal or noise from a distant source. The ratio of the time difference to the time interval that an electromagnetic beam takes to travel from one sensor to the other estimates the angle of arrival. The angular resolution of this method relates to the time resolution available to measure the time difference of arrival as given in the slide.

However, large separation between sensors cause grating lobes that give rise to ambiguity in direction of arrival estimates. This is especially problematic if the available bandwidth yields an angular resolution that envelops several grating lobes.



Opportunities for Collaboration: Array of Two Radiometers spaced *D* Apart (2 of 2)

- Example: D = 3 km, therefore T = 10 µs; period of incident wave = 1 ns, so $N_{grating}$ = 10 µs/1 ns = 10000, and $\Delta\theta_{grating}$ = π/10000 rad = 0.1π = 0.3142 mrad.
- Suppose B = 100 MHz, then BT = 1000, and $\Delta\theta = 1/\pi$ = 0.3183 mrad. This is barely sufficient to resolve grating lobes! Larger separation, D, demands greater bandwidth, B, for resolution of grating lobes.
- However, noise consists of a range of frequencies and lobes at one frequency are washed out by nulls at another frequency (known as "fringe washing.")
  - There are opportunities for collaboration in investigating this effect.

An example in this slide illustrates the nature of the problem by showing that a sensor separation of 3 km for a signal frequency of 1 GHz, requires greater than 100 MHz of bandwidth to resolve grating lobes. Fortunately, noise of wide enough spectral extent tends to wash out grating lobes. Simulations that quantify the relief of this problem when noise is measured presents an opportunity for collaboration.

Other Opportunities for Collaboration

- WG P3343™ Spatiotemporal Synchronization for a Synthetic Aperture of Distributed Sensors (Chair: Benjamin Deutschmann)
  - Addresses time distribution and synchronization for array of sensors.
    - Needs adaptation to distributed array of radiometers
- IEEE Calibration & Autofocusing Group (Chair: Ozan Dogan)
  - Addresses polarimetric calibration
    - Needs adaptation to polarimetric radiometers
- IEEE Space-Based SAR Group (Chair: Daniel Kamoun)
  - Addresses calibration among spatially-separated SAR sensors

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There are multiple opportunities for leveraging the work already being performed by other Synthetic Aperture groups, and adapting their analyses to radiometry.