# A Constellation Concept for Microwave Interferometric Radiometry from Geostationary Orbit

Ahmed Kiyoshi Sugihara El Maghraby*, Adrian Tatnall and Angelo Grubišić

Faculty of Engineering and the Environment, University of Southampton

*asem1g14@southampton.ac.uk

***Abstract*—A novel concept for interferometric radiometry at arbitrary microwave frequencies using a constellation of formation-flying spacecraft is presented. The concept improves on the achievable spatial resolution by several factors compared to single-satellite (monolithic) interferometers. Two configurations are found suitable to establish synthetic apertures of 14.4 m and larger. These aperture sizes will enable microwave radiometry from the geostationary orbit at frequencies lower than 53 GHz.**

***Index Terms*—Interferometry, Radiometry, Geostationary, Constellation, Atmospheric sounding**

## I. Introduction

Microwave radiometry is a versatile tool for Earth-observation enabling variety of measurements including surface temperature, soil moisture and ocean salinity, precipitation, tropospheric temperature and humidity [1], [2], [3].

The introduction of interferometry by SMOS has allowed apertures larger than physical antennas which meant improved spatial resolution [2]. Apertures large enough to provide the required spatial resolution from geostationary orbit however have not yet been developed.

The challenge in developing such apertures is illustrated by Airy's diffraction limit which often caps the spatial resolution of a radiometer, given by

$$\delta x = 1.22R\frac{\lambda}{D} \tag{1}$$

where $R$ is the range to the ground, $\lambda$ is the wavelength, and $D$ is the aperture dimension. Given that the range from a geostationary orbit is approximately 50 times longer than that from a typical Low-Earth Orbit, apertures in tens of metres would be necessary to reach the same resolution at the same wavelength.

To keep the aperture dimension requirement to a few metres, geostationary-bound radiometers such as the Geostationary Atmospheric Sounder, the Geostationary Synthetic Thinned Aperture Radiometer and the Geostationary Interferometric Microwave Sounder have moved to higher frequencies (>53 GHz) [4], [5], [6].

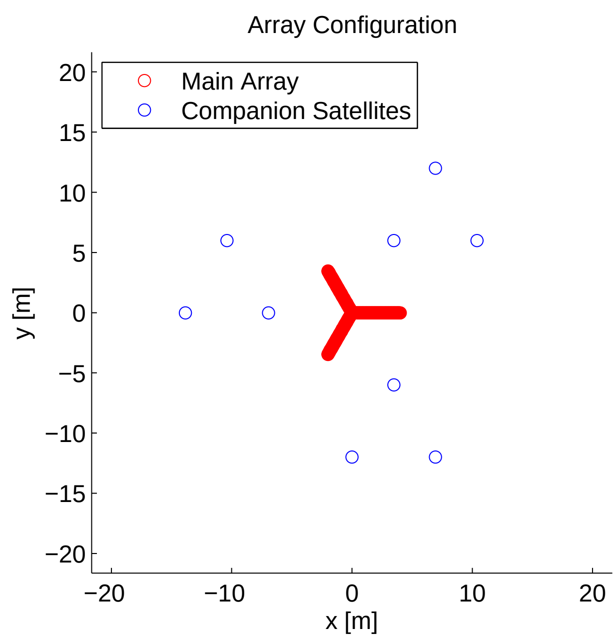


Fig. 1: Proposed array configuration (configuration 1) described in Section II establishing 14.4 m circular aperture.

For applications that require longer wavelengths however, larger apertures are necessary. To address this, a constellation concept is hereby proposed. The major advantage of using several free-flying spacecraft for aperture synthesis is that it doesn't require an unmanageable size spacecraft to provide the resolution required. Two "configurations" are proposed: one with a single SMOS-sized spacecraft in formation-flight with microsatellites, and another with six SMOS-sized spacecraft.

## II. Configuration 1

The first configuration, as shown in Figure 1, consists of one central rotating Y-shaped interferometer accompanied by nine free-flying non-rotating microsatellites. Each arm of the central interferometer is uniformly populated with antennas, spaced by the minimum requirement to view the Earth-disc from geostationary altitude (aliasing limit), which is approximately $3\lambda$.

The accompanying microsatellites each carry one antenna element. As the central array rotates, this constellation samples the visibility in manner shown in Figure 2 after a third of a rotation. Samples taken within the central array (green) and those taken between the central array and the companion satellites (blue) overlap, sampling as a result an equivalent visibility taken by a real circular aperture, where its diameter is 3.6 times the length of the boom (red).

This factor is scalable by increasing the number of microsatellites. This is listed in Table I, and an example of 18-microsatellite constellation is shown in Figure 3. The aperture sizes are based on 4 m booms, and the total mass are estimated using the launch mass of SMOS for the central array [2], and 70 kg microsatellites for the companions.

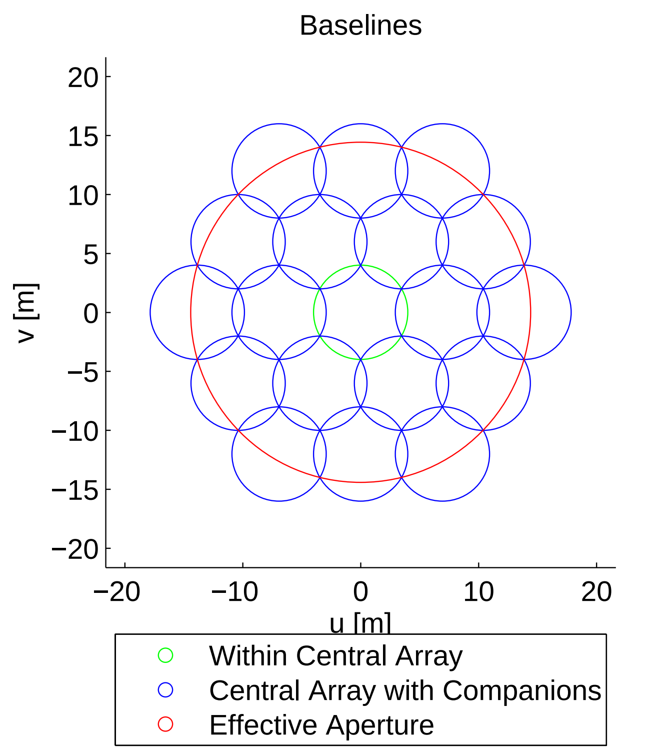


Fig. 2: Baseline samples achieved the array shown in Figure 1.

The relative positions and the phase errors between the antennas are continuously measured in flight to a precision smaller than the wavelength and the wave period of the observed band respectively. The companions perform the down-conversion and send their sampled IF signals to the central array where all signals are correlated. The formation of the constellation is maintained by active control.

| **Companions** | **$B_{Max}$ [m]** | **Mass [kg]** |
|---|---|---|
| 3 | 8.0 | 868 |
| 9 | 14.4 | 1288 |
| 18 | 20.0 | 1918 |
| 30 | 26.2 | 2758 |
| 45 | 32.0 | 3808 |
| 63 | 38.2 | 5068 |
| 84 | 44.0 | 6538 |

TABLE I: Scaling of maximum baseline established by the proposed array shown in Figure 1.

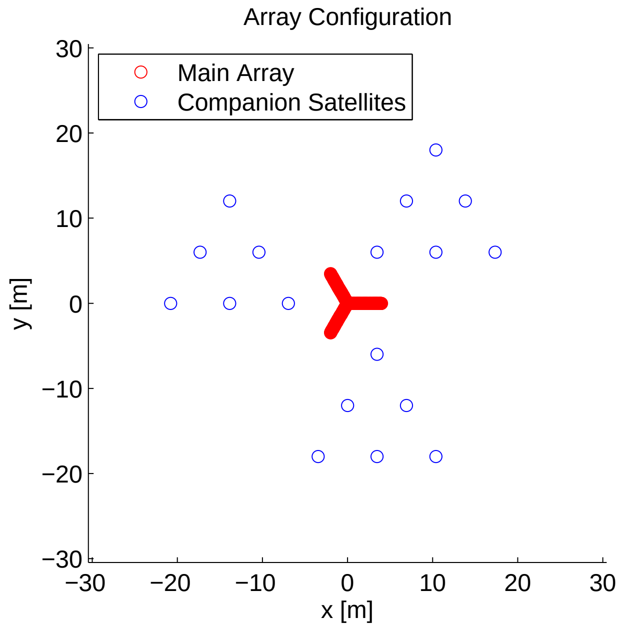


Fig. 3: Up-scaled first array configuration with 18 microsatellites, increasing the aperture size to 20.0 m.

## III. Configuration 2

The second concept employs a constellation of six rotating two-boom interferometers flying in a triangular formation. Shown in Figure 4 is an example with satellites with 4 m booms. This configuration is capable of establishing baselines twice as long as the first configuration, meaning that it produces an aperture equivalent to a real circular aperture where its diameter is 7.2 times the length of the boom. This configuration is also scalable by increasing the number of satellites, as shown in Table II. However it follows that several launches and rendezvous to the geostationary orbit are necessary to fully deploy the constellation.

Similarly to the first configuration, the relative position of the satellites must be known at all times within the observed wavelength. This configuration however also requires the measurement of the relative angular position of the booms, which makes this configuration more complex than the first.

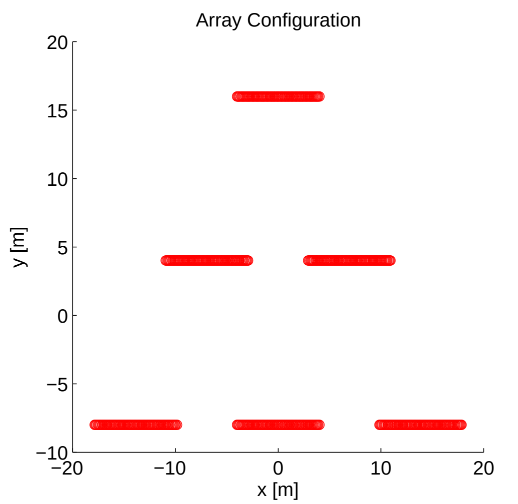


Fig. 4: Proposed six-satellite array configuration (configuration 2) establishing 28.8 m circular apertures.

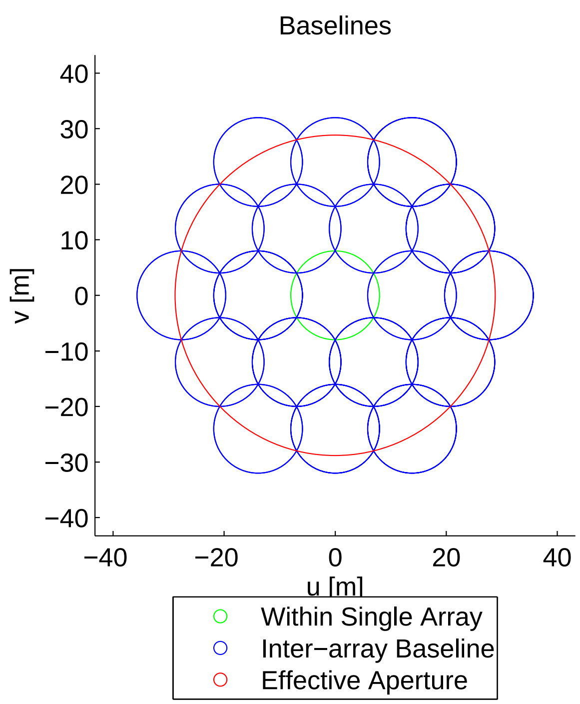


Fig. 5: Baseline samples achieved by rotating the central array shown in Figure 4.

| Satellites | $B_{Max}$ [m] | Mass [kg] |
|---|---|---|
| 3 | 16.0 | 1974 |
| 6 | 28.8 | 3948 |
| 9 | 40.0 | 5922 |
| 12 | 52.5 | 7896 |
| 15 | 64.0 | 9870 |
| 18 | 76.3 | 11844 |
| 21 | 88.0 | 13818 |

TABLE II: Scaling of maximum baseline by proposed array shown in Figure 4 by increasing the constellation size.

## IV. Performance

A simulator is being developed to study the performance of these arrays and its response to position and phase deviations and uncertainties. With the Blackman window described in [7], the expected beam performance — the point-source response — of the array at 53 GHz from the geostationary orbit is shown in Figure 6. To illustrate the potential of these arrays, the ideal properties of the beam excluding position and phase errors are shown in Table III.

| | Config 1 | Config 2 |
|---|---|---|
| -3dB Beam Efficiency | 46.1% | |
| Null Beam Efficiency | 98.6% | |
| -3dB Beam Width | 17.3 km | 8.6 km |
| Null Beam Width | 42.1 km | 21.0 km |
| Side-Lobe Level | -29 dB | |

TABLE III: Simulated beam performance of the two presented concepts.

## V. Conclusion

Two concepts for performing microwave interferometry using a constellation of free-flying satellites have been presented. The first constellation is a rotating Y-shaped interferometer accompanied by nine formation-flying microsatellites, while the second constellation is of six rotating two-boom interferometers flying in a triangular formation.

It has been found that the first concept has the advantage of being deployable in a single launch, while the second concept can achieve longer baselines. The length of the maximum baseline achievable per unit mass of the constellation however are roughly equivalent, with the first configuration being in a slight advantage.

Both of these concepts achieve baselines in excess of ten metres, which may enable microwave radiometry at lower frequencies from the geostationary orbit, where global, real-time, continuous and high temporal resolution measurements can be made.

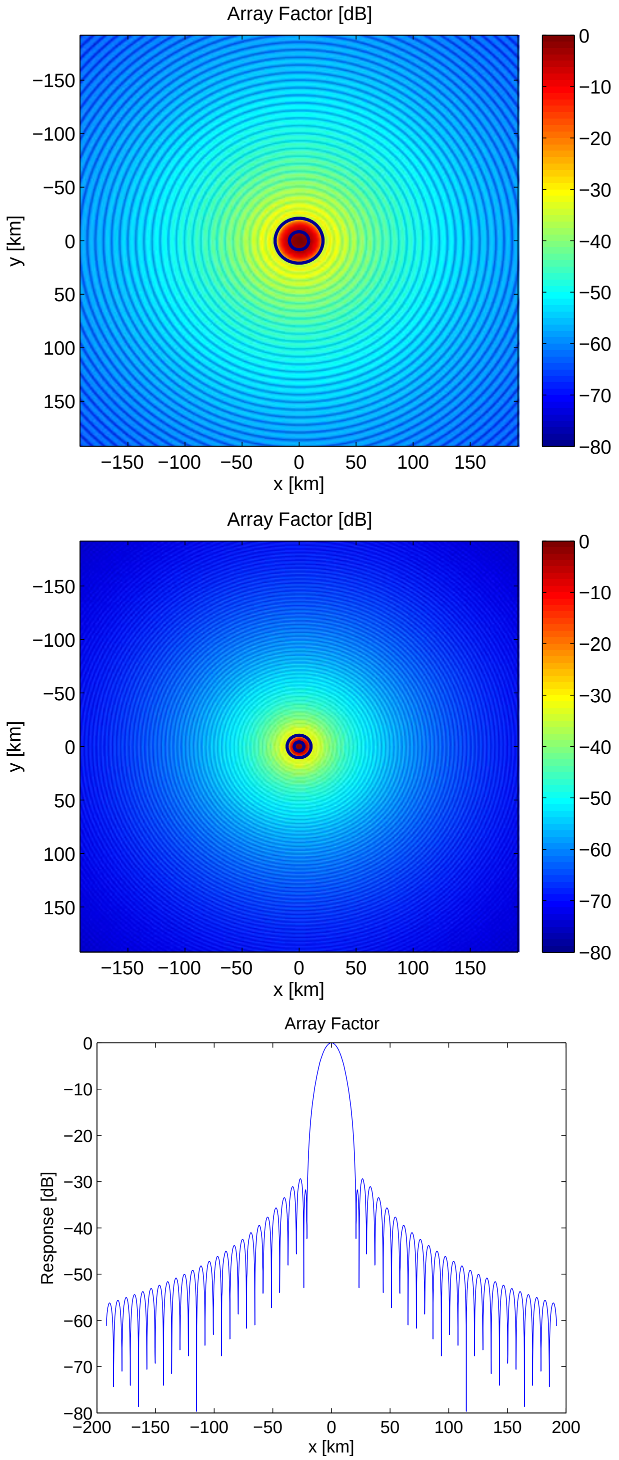


Fig. 6: Expected Array Factor (impulse response) of first concept (top) and the second concept (mid) at 53 GHz from geostationary orbit with Blackman windowing. Cross-section of the first beam is shown (bottom). Half-power beam is shown (inner circle) as well as beam null (outer circle). Beam properties are shown in Table III

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