

Integration of MIRAS Breadboard and Future Activities

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ABSTRACT

The European Space Agency (ESA) is conducting a feasibility study on MIRAS, a Microwave Imaging Radiometer using two dimensional Aperture Synthesis, for the mapping of soil moisture and ocean salinity from space. An aircraft breadboard of this instrument is currently being integrated and will be flown in Spring 1996. This paper concentrates on the results achieved following the integration of the prototype. The breadboard consists of an 11 element Y-shaped bi-dimensional L-band interferometer which can be switched to measure the two polarizations.

In addition the future activities related to MIRAS are presented. A technology demonstrator of MIRAS is proposed as a first major step towards a future spaceborne sensor.

AIRBORNE DEMONSTRATOR

The second part of the MIRAS program is devoted to the demonstration of the concept capabilities through a breadboard to be flown on a C 130. Miras breadboard is identical to the central part of Miras spaceborne instrument, i.e. it works at L band and has a Y shape antenna with 0.65 m long arms and 11 Elementary Radiating Elements. The 11th one enables the phase restoration capability to suppress phase errors due to mechanical deformation of the antenna and residual receiver errors.

The main elements of MIRAS breadboard are: a Y-shaped 11 element array, the L-band receivers with switched polarization, an optical harness which distributes the clock reference to the receivers and a correlator unit which digitizes in 1 bit the receivers outputs and correlates them during an integration time of 0.285

seconds. Two kinds of calibration signals are provided to the receivers within the breadboard: a common noise reference supposed to produce a known output correlation and 11 independent 50 ohms loads supposed to produce a zero output.

MIRAS Antennas

The 11 cup dipole antennas of MIRAS demonstrator have been manufactured and tested with their environment. Their diagram patterns are very similar with directivities lying between 9 and 9.2 dB (18.5 cm aperture), including the effects of the thermal box side walls simulated during the measurements. The half power beamwidth is between 65° and 70° depending on the cut plane and the polarisation. The normalized phase discrepancy between antennas is less than 5° within the IFOV. The cross polarisation level is -20 dB but -30 dB inside the IFOV. The coupling between antennas is less than -25 dB.

L-band Receivers

The low noise amplification, radio interferences filtering, and I and Q demodulation are achieved by 11 receivers units installed around the structure, phase locked onto a common clock distributed by optical fibers. They exhibit 100 dB gain and 1.3 dB noise figure at 1.41 GHz.

Correlator Unit

MIRAS demonstrator requires 55 complex (or 110 real) correlators. They are implemented in a single 10 dm³ unit based on FPGA circuits for the digital sections. The

two critical performances of the correlators are the noise and the accuracy. MIRAS correlator perfectly fits to the 1 bit correlator theory, no additional noise being observed. As far as the correlation accuracy is concerned the almost only contributor is the offset of the A/D 1 bit converter. Using independent noise sources as input signals, the correlators give outputs as low as 10^{-4} , some of them reaching 3×10^{-3} which has a negligible impact on MIRAS breadboard performances.

SYSTEM PERFORMANCE AND ERROR ANALYSIS

The system basic performance of the spaceborne version of MIRAS has been further studied in terms of spatial resolution and radiometric sensitivity. Spatial resolution has been computed including all the available (u,v) samples given by the Y-array. The synthesized half-power beamwidth ranges from 0.77° to 1.10° at boresight, depending on the weighting function. It broadens up to 0.82° or 1.14° respectively due to fringe-washing effects at the swath edge. The radiometric sensitivity has been studied taken into account predetection filters shape, the use of DSB receivers and the effect of the digital correlator being used. Snap-shot radiometric sensitivity for 0.3 seconds integration time is between 13 and 5 K, depending on the weighting function. This sensitivity is improved by a factor of 6 when the complete dwell time corresponding to the pixel is used as integration time. The radiometric resolution reaches a saturation threshold for large signal to noise ratios due to discretization errors.

The sources of error have been classified according to their origin and the feasibility of their calibration into the following three main groups:

- 1) antenna errors: amplitude and phase ripple in the pattern, coupling, mispointing, in-plane and out-of-plane position errors, polarization cross-talk;
- 2) receiver errors: in-phase channel errors (phase and delay time offsets), I/Q quadrature errors and amplitude errors;
- 3) baseline errors: phase and amplitude errors (differences of frequency response between receivers chains), offset errors due to unwanted correlated signals (i.e. LO leakage), as well as 1 bit quantizer threshold offsets.

Receiver errors appear as separate amplitude factors or phase summand errors in the measured visibility samples and can be calibrated by a distributed network of noise sources. On the contrary, baseline amplitude and phase errors appear as mixed terms with parameters coming from the particular pair of receivers and must be calibrated by noise injection from a single noise source.

The analysis of system errors shows that the most important contributors to the radiometric resolution are the antenna pattern amplitude and phase ripple (must be known to 0.25% and 0.5°), antenna mutual coupling (mu-

tual impedances to within 5%) and the baseline phase and amplitude errors which requires very well matched filters. These errors must be known to the mentioned levels in order to be able to correct them during the inversion process.

ON-BOARD MIRAS CALIBRATION PROCEDURE

An original hardware calibration scheme is proposed for MIRAS spaceborne sensor whose potential can be tested with the aircraft breadboard [2, 4]. The method avoids the problems of a centralized noise distribution network, namely, the mass of the cables and their electrical matching. This is possible by using several noise sources distributed along the array which inject calibration noise into groups of 8 receivers with an overlapping of 4 receivers between groups. Only the half of the noise sources which is connected to non overlapping groups of receivers is switched at a time, so that the noise sources are switched sequentially.

This scheme provides a set of calibration measurements that allows to solve for the receiver phase and quadrature error terms. It also allows to compute the equivalent noise temperature of the receivers and the amplitude of the calibration noise signals themselves (except the reference one which is assumed to be known), which determine the gain factors of the normalized visibility samples. The main hardware calibration steps are:

- 1) correlators offset calibration by injection of uncorrelated noise (matched loads);
- 2) inversion of the 1-bit/2-level digital correlator response to find the normalized visibility samples ;
- 3) estimation of the in-phase and quadrature receiver errors by alternated correlated noise injection;
- 4) removal of the noise contribution of the noise distribution network and addition of the noise induced by the antenna network;
- 5) application of the normalization gain factors to the normalized visibility samples (antenna temperature measured by the total power radiometer and receiver noise temperatures);
- 6) calibration of in-phase and quadrature receiver errors using (3) through (5);
- 7) calibration of antenna coupling using ground antenna measurements.

INVERSION ALGORITHM

An inversion algorithm is proposed based on the hexagonal FFT presented in [5] which is able to operate directly with the measured (u,v) samples over the hexagonal grid given by the Y-shaped array, avoiding any interpolation process, signal to noise ratio degradation and induced artifacts. Hexagonal processing can be performed efficiently with standard rectangular FFT's provided that the

(η, ξ) direction cosines grid is chosen over the reciprocal grid of the (u, v) one: memory savings are 13.4% and the computational load is reduced by a 25%. The number of brightness temperature pixels in the basic hexagonal cell is the same as the total number of correlations, redundant or not. The number of visibility samples which must be set initially to zero is equal to the number of redundant correlations.

The image reconstruction procedure can be decomposed into three main steps. In order to get rid of phase errors due to antenna deformations and residual errors from the on-board hardware calibration, an operation of redundant spacing calibration is performed first. The cost for this spectral reduction of phase closure data is a translation indetermination in the real space [3]. The very process of image reconstruction comes next based on the linear relationship between the visibilities and the brightness temperature distribution. The final step consists in raising the translation indetermination for which several strategies can be adopted.

The initial guess of the reconstruction algorithm is obtained by direct Hexagonal Fourier inversion of the calibrated visibilities and compensation by the average antenna radiation pattern [2, 5]. The inversion process is accelerated by processing zero mean differential visibilities, which are obtained by subtracting the visibility contributions of the sky and that of an hypothetical constant brightness temperature Earth as measured by the total power radiometer. This technique has been tested in a preliminary MIRAS spaceborne software simulator [1] and has shown to converge in a few iterations.

LABORATORY TESTS ON MIRAS CONCEPT

A bi-dimensional synthetic aperture radiometer has been used to simulate the Y-shaped antenna structure used in MIRAS. This demonstration model consists of a calibrated 2-channel Ku-band (16 GHz) correlation radiometer with two horn antennas and an antenna mounting structure enabling the horns to be mounted in relevant positions within a certain aperture. A total aperture synthesis is obtained by sequentially placing the two antenna elements in all required pairs of positions and measure the corresponding samples of the visibility function. Pointing the instrument at a stationary target and accepting a longer total time for a measurement, the synthetic aperture principle can be demonstrated in this way.

The number of samples with different positions taken one by one add up to a thousand and the total measurement takes several hours. The spacing between the antennas in the Y-shaped structure is 0.8λ which is comparable to the 0.89λ in MIRAS. The demonstration model has been used to simulate a two dimensional aperture with 16 elements on each arm which is more representative of the spaceborne design. The tests are performed

on targets like the horizon with simple structures like a power plant and a 50 meter chimney [6]. The two channel demonstration has been used to evaluate calibration topics as well. However, the two channel set-up is less useful for the demonstration of overall instrument calibration because errors tend to add up in the image reconstruction as the same channels are used for all measurements.

FUTURE ACTIVITIES ON MIRAS

In the near future (Spring 1996) the aircraft MIRAS breadboard will be flown on board an Hercules C-130 of the Danish Air Force over a site in the north of Denmark. It is expected that these measurements together with the integration ground tests which are currently being performed will demonstrate the feasibility of the L-band two-dimensional aperture synthesis MIRAS radiometer.

Further hardware developments on a Light weight Cost Effective L-band antenna/receiver assembly (LICEF) and on an advanced Digital CORrelator for aperture Synthesis applications (DICOS) are being undertaken by ESA at present. These developments aim at building a spaceborne MIRAS demonstrator to test key functions of the system in orbital flight conditions.

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