Calibration of End-to-End Phase Imbalance of Polarimetric Radiometers

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Abstract—In this paper, the authors introduce a method for calibrating the end-to-end phase imbalance of polarimetric radiometers using a digital correlation technique. The method is based on the measurement of linearly polarized field at \(-45^\circ\) and \(+45^\circ\) angles with respect to the polarization plane of the transmitted field. This way, the effects of the polarization purity of the transmitted field and the polarization separation and cross-coupling of the antenna of the radiometer can be cancelled out. The remaining uncertainty consists of the pointing accuracy of the radiometer with respect to the transmitted field. It has been shown here that this effect can be reduced to the level that will make the method feasible.

Index Terms—Digital correlation, phase imbalance, polarimetric radiometer, Stokes parameters.

I. INTRODUCTION

The calibration of fully polarimetric radiometers is one of the main issues when performance is considered. The first and second Stokes parameter can be calibrated with conventional means using cold and hot loads, but the third and fourth parameters impose a problem. One option is to create enough linearly independent combinations of Stokes parameters. The approach presented in [1] and [2] assumes this technique. The drawback is the complexity of the load, which even increases as the wavelength increases.

Digital correlation techniques have been presented which solve the correlation coefficient excluding the amplitude of the measured field [3]. This means that by only knowing the phase difference, or phase imbalance, between the two receivers measuring the orthogonal polarizations, the third and fourth Stokes parameter can be solved [3]. This is called as the phase calibration. In general, if the antenna is excluded, the calibration of the phase difference of the receiver paths can be performed relatively easily [4]. With the presented method, however, the antenna can be included in the calibration procedure. The method is based on measuring the digital correlation coefficient from a polarized target. Note that the calibration of the offset of the digitizer and the quadrature error is required as well, but the calibration of these parameters is out of the scope of this paper (see, e.g., [4] and [5]).

A linearly polarized antenna load is introduced for retrieving the end-to-end phase imbalance. The load consists of an electrically shielded box with the inside covered with absorption material and of an active noise source that transmits linearly polarized noise, the brightness temperature of which is approximately 375 K. The antenna of the radiometer is polarized in two orthogonal polarizations, namely: 1) vertical (V) and 2) horizontal (H). The procedure of calibrating the phase imbalance is to measure the linearly polarized field in two different angles by rotating the antenna plane of the radiometer and performing complex correlation measurements.

The presented calibration procedure is a part of the test campaign and the calibration procedure of the engineering model of an L-band (center frequency 1.413 GHz) polarimetric Noise Injection Radiometer (NIR) [6], [7]. The NIR is part of the Microwave Imaging Radiometer using Aperture Synthesis (MIRAS) instrument, which is the main instrument on the European Space Agency’s (ESA) Soil Moisture and Ocean Salinity (SMOS) mission, scheduled for launch in 2007 [8], [9]. SMOS is a cooperation of ESA, the French Space Agency Centre National d’Études Spatiales (CNES), and Centro para el Desarrollo Tecnológico Industrial (CTDI) Spain. The main contractor of MIRAS is EADS CASA Espacio, Spain. The NIR engineering model (EM) has been developed by Elektrotub Microwave Ltd., Finland; the main subcontractor was the Helsinki University of Technology, Finland.

II. THEORETICAL BACKGROUND

A. Stokes Parameters

The electromagnetic radiation is commonly described with propagating plane waves. For a uniform plane wave propagating in the direction of the positive \(z\) axis in a Cartesian coordinate system, the electric field must lie in the \(xy\) plane [10]. The electric field vector \(\vec{E}\) is a function of time in any fixed point in space. The tip of the \(\vec{E}\) vector draws a curve in the \(xy\) plane as time changes. The form of the resulting curve dictates the polarization state of the field. The electromagnetic waves emitted by natural objects consist of a superposition of many statistically independent waves of different polarizations. This kind of a wave is said to be incoherent or unpolarized [10], which means that it does not correlate.

A plane wave can be written as a sum of the \(x\) component and \(y\) component of the wave. This is, however, the same as the sum of two linearly polarized waves, which are equal to the aforementioned components [10], i.e.,

\[
\vec{E}(z,t) = E_x(z,t)\hat{x} + E_y(z,t)\hat{y} = E_{x0} \cos(\omega t - \beta z)\hat{x} + E_{y0} \cos(\omega t - \beta z + \theta)\hat{y}. \tag{1}
\]
The resulting polarization of the whole wave can be mathematically identified by the phase difference $\theta$ and the magnitudes $E_{x0}$ and $E_{y0}$ of the components. In the case of the linear polarization, the phase difference $\theta$ equals zero, which is an important property for this work.

The Stokes parameters provide a very useful way of describing the polarization state of an electromagnetic wave. The modified Stokes parameters, which are commonly used in radiometry, can be defined as [11]

$$T_i = \frac{T_v}{T_h} = \lambda^2 \frac{2\text{Re} \langle E_v E_h^* \rangle}{2\text{Re} \langle E_v E_h^* \rangle + 2\text{Re} \langle E_v^* E_h \rangle},$$

where $T_v$, $T_h$, $T_3$, and $T_4$ are the brightness temperatures of the vertically and horizontally polarized radiation and third and fourth Stokes parameters, respectively; $\lambda$ is the wavelength; $k_B$ is Boltzmann’s constant; $\eta$ is the impedance of the medium; $B$ is the bandwidth; $E_v$ and $E_h$ are the vertically and horizontally polarized electric fields, respectively; and $V$ is the complex correlation between the vertical and horizontal fields. The brackets stand for infinite time average. Note that the phase of the complex correlation $V$ is the phase difference of the V-component and H-component of the field.

B. Digital Correlation

If the normalized complex correlation of two receivers is measured using one-bit/two-level digital correlators, as is done in this paper, the correlation value is given according to the following equation [12]:

$$Z = \frac{1}{N} \sum_{i=1}^{N} \text{sign} (x(t_i)) \text{sign} (y(t_i))$$

where $x(t)$ and $y(t)$ are the input signals being digitized and correlated and $N$ is the number of samples being correlated. This digital correlation value is related to the analog correlation value, when it is applied to the signal that has a limited spectrum, as [13]

$$\mu = \sin \left( \frac{\pi}{2} Z \right)$$

where $\mu$ is called here as the normalized correlation coefficient.

After the normalized correlation coefficient $\mu$ is corrected for the digitizer offset and quadrature error, the correlation coefficient is called as the quadrature-corrected normalized correlation and denoted with $M$.

The goal of the polarimetric measurements is to solve the third and fourth Stokes parameters. For ideal noise-free horizontally and vertically polarized radiometer measurements, the parameters may be written as

$$T_3 = 2\sqrt{T_v T_h} V_{i,i}$$

$$T_4 = 2\sqrt{T_v T_h} V_{q,i}$$

where $V_{i,i}$ is the denormalized (i.e., obtained with a noise-free receiver) correlation coefficient of the in-phase outputs (I) of the V-channel and H-channel, corresponding to the real part of the complex correlation, and $V_{q,i}$ is the denormalized correlation coefficient of the quadrature output (Q) of the V-channel and in-phase output of the H-channel, corresponding to the imaginary part of the complex correlation.

The complex correlation obtained with II and QI correlations is said to be nominal. It can also be obtained from QQ and IQ correlations and is then named as redundant. The measured redundant complex correlation is the complex conjugate of the nominal correlation.

For a real radiometric measurement, the denormalized correlation coefficient $V$ of (5) is defined from the following relation:

$$M = \tilde{g} V$$

where

$$\tilde{g} = g_{FW} \sqrt{\frac{T_v}{T_v + T_{rec,v}} + \frac{T_h}{T_h + T_{rec,h}}}$$

in which $T_{rec,v}$ and $T_{rec,h}$ are the equivalent noise temperatures of V-receiver and H-receiver and $g_{FW}$ is the so-called fringe-washing factor.

III. PRINCIPLE OF METHOD

A. Solving Phase Imbalance

The phase imbalance of the receivers of a polarimetric radiometer can be solved in an ideal case by measuring a pure linearly polarized electromagnetic field at a 45° angle with respect to the polarization plane of the antenna of the radiometer. This would yield a complex correlation coefficient, which has the phase equal to the phase imbalance of receivers because there is no phase difference in the transmitted field. In reality, however, there are two sources of nonidealities, which are as follows:

1) polarization purity of the transmitted field;
2) finite polarization separation and cross-coupling of the antenna of the radiometer.

Both of these sources create a residual offset to the measured correlation. The first is due to the fact that the nonprincipal polarization transmits undesired radiation added to the multipath propagation inside the load, and the second is due to the fact that the transmitted field leaks between receivers including the effect caused by the absorbers located in the near field of the antenna.

The solution is to rotate the transmitted linearly polarized field with respect to the polarization plane of the antenna of the radiometer by 90°, as is shown in Fig. 1. By rotating the polarization plane by 90°, the phase of the output signal is rotated by 180° as the field vector of one polarization (at the antenna plane) changes its sign, as happens for V-polarization in Fig. 1. The rotation of the phase is demonstrated in Fig. 2,
that, in the ideal case, the amplitudes of the measurements
H-channel can be divided into two parts as follows:
measured correlation coefficient between the V-channel and
B. Formulation
In the measurement of the end-to-end phase difference, the
measured correlation coefficient between the V-channel and
H-channel can be divided into two parts as follows:
where \( T^v_c \) and \( T^h_c \) are the brightness temperatures of the corre-
lated noise of V-polarization and H-polarization, respectively,
and the offset has an amplitude of
\[
M_{off} = \sqrt{\frac{T^c_v}{T^c_v + T_{rec, v}}} \sqrt{\frac{T^c_h}{T^c_h + T_{rec, h}}} \frac{|\chi_{vh}|^2}{T^c_h + T_{rec, h}}
\]
in which \( \chi_{vh} \) and \( \chi_{hv} \) are the cross-coupling factors (complex)
between the channels due to the polarization nonpurity and
the offset correlation is also constant during the measurement.
This makes it possible to cancel out the offset when the measurement
is done at the angles of \(-45^\circ\) and \(+45^\circ\) (see Fig. 2).
Hence, the phase imbalance can be solved from the measured
correlation coefficients in a straightforward manner as follows:
\[
\Theta = \arctan \left( \frac{M_{-45 | q, i} - M_{+45 | q, i}}{M_{-45 | i, i} - M_{+45 | i, i}} \right).
\]
Furthermore, the solution for the offset in the measurement
can be considered as the mean value of the two measurements
yielding
\[
M_{off} = \frac{M_{-45 | i, i} + M_{+45 | i, i}}{2} + j \frac{M_{-45 | q, i} - M_{+45 | q, i}}{2}.
\]
For understanding the measurement situation, the brightness
temperature incident to the antenna of the radiometer can be
written as
\[
T_v = T^v_c + T_{p, load} + T_{C}t_v(\alpha) \quad (13)
\]
\[
T_h = T^h_c + T_{p, load} + T_{C}t_h(\alpha) \quad (14)
\]
where \( T^v_u \) and \( T^h_u \) are the brightness temperatures of the un-
correlated noise of V-polarization and H-polarization, \( T_{p, load} \)
is the physical temperature of the load equaling the brightness
temperature of the load, \( T_{C} \) is the correlated noise transmitted
by the antenna in the load, and \( t_v \) and \( t_h \) are functions of
the rotation angle \( \alpha \) so that depending on the polarization,
a certain amount of transmission to the channel of the radiometer
is allowed. The relation of the functions for H-polarization
and V-polarization can be stated as follows:
\[
t_v(\alpha) + t_h(\alpha) \approx 1 \quad (15)
\]
but otherwise, the functions are unknown because they depend
on the polarization purity of the transmitted field and on the
polarization separation and cross-coupling of the antenna of the radiometer.

which shows the measured correlations \( M_{+45} \) and \( M_{-45} \), the
offset \( M_{off} \), and the phase imbalance of the receivers \( \delta \). Note
that, in the ideal case, the amplitudes of the measurements
at \(-45^\circ\) and \(+45^\circ\) angles are equal. With this procedure, the
nonidealities can be cancelled out as the offset is the same in
both measurements, and the imbalance can be determined from
the slope between the two measurement points.

\[
M = M' + M_{off}
\]

where the correlation without the offset has an amplitude of
\[
M' = \sqrt{\frac{T^c_v}{T^c_v + T_{rec, v}}} \frac{T^c_h}{T^c_h + T_{rec, h}}
\]
The baseline assumption is that the physical temperature of the radiometer is the same as the physical temperature of the load, i.e., $T_{p,\text{rec}} = T_{p,\text{load}}$. Deviation from this equality results as a small correlation offset. However, this offset is the same in both $-45^\circ$ and $+45^\circ$ measurements and is thus cancelled out as well.

C. Error Bounds

The presented method cancels out all the systematic error sources when they remain constant during the two measurements performed at $-45^\circ$ and $+45^\circ$ rotation angles. Random uncertainty consists of noise of the measurement, the effect of which can be removed by averaging.

The main sources for systematic errors are the following.

1) Change of the multipath radiation and the absorber effects in the near field of the antenna of the radiometer.
2) Change of the properties of the transmitted field and the properties of the antenna of the radiometer.
3) Change of the brightness temperature emitted by the load.
4) Change of the equivalent noise temperatures of the receivers.
5) Change of the physical temperature of the load with respect to the physical temperature of the radiometer.
6) Change of the orientation of the radiometer from one measurement to another in dimensions other than that of the rotation.

The first point affects the offset of the correlation, but it is not expected to change significantly between the two measurements because the symmetry of the load does not change. Also, the second point can be considered negligible due to the stability of these properties.

The third point affects the amplitude of the measurement and does not affect the determination of the phase imbalance. However, it has an effect on the offset, which can be minimized by making sure that the physical temperature of the load and the output of the noise source remain constant. The fourth point affects also the amplitude, and the same conclusion as in the case of the third point can be made, with the exception that it is the physical temperature of the radiometer that needs to remain constant. By limiting the variation of the physical temperature to a couple of degrees, its contribution to the offset is negligible, ruling out the fifth point.

The sixth point creates uncertainty to the measurements if the pointing of the radiometer is not very accurate. The magnitude of this uncertainty can be solved during the measurement by repeating the measurement several times at different angles. The uncertainty can be defined as the root mean square (rms) deviation of the individual measurements from the characteristic line between $-45^\circ$ and $+45^\circ$ angle measurements. This is

$$
\Delta M = \sqrt{\frac{1}{N} \sum (x - M_{i,i})^2 + (y - M_{q,i})^2}
$$

where $x$ and $y$ are the points on the line, $M$ is the measured correlation, and $N$ is the number of samples.

IV. EXPERIMENT

A. Measurement Setup

The measurement setup consists of a radiometer, which is the engineering model of SMOS NIR, and a linearly polarized antenna target. The linearly polarized antenna target is composed of an absorber load, linearly polarized transmitter antenna at the bottom of the load connected to a noise source through a step attenuator, and a polarizer grid made of wires. Fig. 3 shows a schematic diagram of the setup. With this setup, the phase imbalance of the radiometer can be measured at boresight, which is considered adequate. It is expected that the offset $M_{\text{off}}$ describing, among others, the cross-polarization ratio of the antenna depends on the view angle, but because this is a mere by-product, the measurement was not extended over a range of view angles in this experiment.

The distance of the grid from both radiometer and transmitter antenna satisfies the far-field condition, which yields in this case

$$
d = \frac{2D^2}{\lambda} \approx \frac{1}{2} \lambda
$$

where $d$ is the distance, $D$ is the diameter of the antenna, and $\lambda$ is the free-space wavelength. The distance of the antenna of the radiometer to the grid is one-and-a-half wavelengths and that of the transmitter antenna to the grid is one wavelength. The distance of the walls is about one wavelength from the edge of the antenna of the radiometer. See Fig. 3 for details.

The purpose of the polarizer grid is to improve the polarization purity of the transmitter antenna, although the presented
method cancels out the impurity of the transmitted load. This was confirmed in the experiment as measurements without the grid were carried out as well.

The absorber load is made out of a metal box with electrically shielded cover and absorber material covering the inside walls. The cover has a hole for the antenna of the radiometer. Fig. 3 shows a schematic diagram of the load. The return loss of the absorber is specified to be more than 20 dB all around the walls of the box (normal incidence), where the absorber is flat, and more than 35 dB in the bottom of the load, where the absorber is pyramid shaped (pyramids being about one wavelength in length).

The transmitter antenna is a linearly polarized microstrip patch antenna with a cross-polarization ratio of about 25 dB. It is connected to a noise source through a step attenuator, which can be adjusted in the range of 0–30 dB with 1-dB steps. The noise temperature of the transmitted field is adjusted, so that when the transmitted field is in the direction of either polarization, this polarization sees about 375 K in total (so that when the radiometer sees about 375 K). This value was chosen because it is used also for the internal phase calibration of the NIR.

The polarizer grid is a grid made out of metal wire with diameter of 3.0 mm and spacing of 9.4 mm. The total size of the grid is 540 × 630 mm. The attenuation of the grid at 1.4 GHz is 0.2 dB when the electric field is perpendicular to the grid and 32.5 dB when the electric field is parallel to the grid. The grid was designed based on the theory presented in [14] and [15].

NIR is a fully polarimetric radiometer using the noise injection method, but for this experiment, it is operated in a total-power measurement mode. Its vertical and horizontal receivers send one-bit/two-level digitized signals from in-phase and quadrature channels to a digital correlator, which solves the complex correlation coefficients.

B. Experimental Results

1) Phase Imbalance: Fig. 4 shows the obtained nominal correlations at angles equal to $-45° ± 5°$, $0° ± 5°$, $+45° ± 5°$, and $+90° ± 5°$ for nominal and redundant correlations.

![Correlation results at several angles](Image)

Fig. 4. Correlation results at rotation angles $-45° ± 5°$, $0° ± 5°$, $+45° ± 5°$, and $+90° ± 5°$ for nominal and redundant correlations.

Mean correlations at $-45°$ and $+45°$ rotation angles with offset and correction

![Mean correlations at -45° and +45° degree angles with offset and correction](Image)

Fig. 5. Mean correlations at $-45°$ and $+45°$ rotation angles with offset and corrected values (for nominal correlations). The complex conjugate of the redundant correlation is taken before plotting.

![Table I: Phase Imbalance of the NIR and the Offset of the Measurement, When Measured Both With and Without the Polarizer Grid](Image)

<table>
<thead>
<tr>
<th>Grid</th>
<th>Phase imbalance $\Theta$ [deg]</th>
<th>Offset [cu]</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>Nominal</td>
<td>35.30</td>
</tr>
<tr>
<td></td>
<td>Redundant</td>
<td>35.26</td>
</tr>
<tr>
<td>Grid</td>
<td>Nominal</td>
<td>35.40</td>
</tr>
<tr>
<td></td>
<td>Redundant</td>
<td>35.37</td>
</tr>
</tbody>
</table>

TABLE I

PHASE IMBALANCE OF THE NIR AND THE OFFSET OF THE MEASUREMENT, WHEN MEASURED BOTH WITH AND WITHOUT THE POLARIZER GRID

At $0°$ and $+90°$ angles, the effect of a $5°$ step is large, but at $-45°$ and $+45°$ angles, it is very small as expected. There are also deviations from the line, especially at $0°$ and $-5°$, which is most probably due to the pointing inaccuracy of the radiometer. Also, there is a difference between the result at $0°$ and $90°$, which is due to the rotation angle inaccuracy.

Fig. 5 shows the correlations at $-45°$ and $+45°$ angles, the offset calculated based on these using (12) and the corrected line without the offset. The angle, i.e., the phase imbalance, is calculated using (11). Table I lists the resulted phase imbalances and offset for nominal and redundant correlations, and Table II lists the obtained correlation values at $-45°$ and $+45°$ angles with the standard deviation of the measurement showing good resolution.

The uncertainty of the offset is calculated using (16) yielding 11.3 cu ($1 \text{ cu} = 10^{-4}$), which gives for the uncertainty of the phase imbalance measurement a value of $1°$, according to (17), as the amplitude of the $45°$ measurement is about 660 cu. The effect of this to the measured Stokes parameters can be evaluated by assuming that the maximum amplitude of either the third or fourth Stokes parameter is in a conservative case $10 K$; thus, $1°$ uncertainty would cause an uncertainty of

$$\Delta T_{3/4} = 10 \sin(1°) = 0.17 K$$

which is acceptable.

2) Result Without Polarizer Grid: The measurements were also made without the polarizer grid at rotation angles $-45°$, $0°$, and $+90° ± 5°$. The results are clearly located on a straight line.

Also, there is a difference between the result at $0°$ and $90°$, which is due to the rotation angle inaccuracy.
TABLE II
MEASURED QUADRATURE-CORRECTED NORMALIZED CORRELATIONS WITH ±45° ANGLES, WHEN MEASURED BOTH WITH AND WITHOUT THE POLARIZER GRID. THE REDUNDANT CORRELATION IS PRESENTED AS THE COMPLEX CONJUGATE OF THE MEASUREMENT RESULT

<table>
<thead>
<tr>
<th>Angle [deg]</th>
<th>Nominal / Redundant</th>
<th>Mean [cu]</th>
<th>STD [cu]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-45</td>
<td>Nom</td>
<td>560.0+j347.8</td>
<td>3.5</td>
</tr>
<tr>
<td>+45</td>
<td>Nom</td>
<td>-512.7+j412.2</td>
<td>3.1</td>
</tr>
<tr>
<td>-45</td>
<td>Red</td>
<td>563.7+j344.9</td>
<td>3.3</td>
</tr>
<tr>
<td>+45</td>
<td>Red</td>
<td>-513.6+j416.8</td>
<td>2.8</td>
</tr>
<tr>
<td>No Grid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-45</td>
<td>Nom</td>
<td>540.9+j363.4</td>
<td>3.0</td>
</tr>
<tr>
<td>+45</td>
<td>Nom</td>
<td>-521.4+j391.5</td>
<td>3.2</td>
</tr>
<tr>
<td>-45</td>
<td>Red</td>
<td>543.9+j361.1</td>
<td>3.3</td>
</tr>
<tr>
<td>+45</td>
<td>Red</td>
<td>-522.6+j396.2</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Mean correlations at -45° and +45° degree angles with offset and correction (no grid)

Fig. 6. Mean correlations at -45° and +45° rotation angles with the offset and the corrected values (for nominal correlations) when no grid was applied in the setup. The complex conjugate of the redundant correlation is taken before plotting.

correlation was introduced and demonstrated with experiments. The method is based on measuring a linearly polarized field at -45° and +45° angles with respect to the polarization plane of the antenna of the radiometer. The method has a significant impact on the calibration of polarimetric radiometers because there has been a lack of well-defined and usable procedure, especially for low-frequency polarimetric radiometers.

The experiments showed that the pointing of the radiometer is important for the accuracy of the retrieval of the phase imbalance. Another observation was that a moderate (25 dB) polarization purity of the transmitted field is sufficient for the successful determination of the phase imbalance.

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REFERENCES


Andreas Colliander (S’04) was born in Imatra, Finland, in 1976. He received the M.Sc. and Lic.Sc. degrees from the Helsinki University of Technology (TKK), Espoo, Finland, in 2002 and 2005, respectively. He is currently working toward the D.Sc. degree at the Laboratory of Space Technology, TKK.

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Jani Kettunen was born in Finland, in 1977. He is currently working toward the Master’s degree at the Helsinki University of Technology, Espoo, Finland. His Master’s thesis is focused on HUT-2D interferometric L-band radiometer antenna parameter characterization.

Since 2002, he has been with the Laboratory of Space Technology, Helsinki University of Technology. In addition to his Master’s thesis, he is working on the testing and characterization of the reference radiometers (L-band fully polarimetric noise injection radiometers) of the MIRAS instrument. The MIRAS instrument is the main instrument of the European Space Agency’s Soil Moisture and Ocean Salinity mission.

Martti T. Hallikainen (M’83–SM’85–F’93) received the Engineering Diploma (M.Sc.) and the Dr.Sc.Tech. degree from the Helsinki University of Technology (TKK), Espoo, Finland, in 1971 and 1980, respectively.

Since 1987, he has been a Professor of space technology with the Helsinki University of Technology. In 1988, he established the TKK Laboratory of Space Technology, and currently serves as its Director. In 1993–1994, he was a Visiting Scientist with the Institute for Remote Sensing Applications, European Union’s Joint Research Centre, Ispra, Italy. From 1981 to 1983, he was a Post-doctoral Fellow with the Remote Sensing Laboratory, University of Kansas. He was awarded an Asla-Fulbright scholarship for graduate studies at the University of Texas at Austin in 1974–1975. His research interests include the development of microwave sensors for airborne and spaceborne remote sensing, development of methods to retrieve the characteristics of geophysical targets from satellite and airborne measurements, and cryospheric applications of remote sensing. His team is currently involved in the development of the L-band synthetic aperture radiometer MIRAS for the ESA SMOS satellite and a similar airborne instrument (HUT-2D) for the Laboratory’s research aircraft.

Dr. Hallikainen has been a member of the IEEE Geoscience and Remote Sensing (GRSS) Administrative Committee since 1988 and served as President of IEEE GRSS in 1996–1997. He was the General Chair of the IGARSS’91 Symposium and the Guest Editor of the Special IGARSS’91 Issue of the IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING (TGARS). He was an Associate Editor of TGARS in 1992–2002. He has been the Vice President of the International Union of Radio Science (URSI) since 2005 and served as the Chair of URSI Commission F in 2002–2005. He has been a National Official Member of URSI Commission F since 1988 and was the Chair of URSI Finnish National Committee in 1997–2005. He has been the Vice Chair of the Finnish National Committee of COSPAR since 2000. He was a member of the European Space Agency’s (ESA) Earth Science Advisory Committee in 1998–2001. He is a national delegate to the ESA Earth Observation Data Operations Scientific and Technical Advisory Group (DOSTAG) since 1995. He has been a member of the European Association of Remote Sensing Laboratories (EARSeL) Council since 1985. He was the Secretary General of EARSeL in 1989–1993 and the Chairman of the Organizing Committee for the EARSeL 1989 General Assembly and Symposium. He has been a member of the Advisory Committee for the European Microwave Signature Laboratory of the European Union’s Joint Research Centre since 1992. He was the recipient of three IEEE GRSS awards: 1994 Outstanding Service Award, IGARSS’96 Interactive Paper Award, and 1999 Distinguished Achievement Award. He was awarded the Microwave Prize for the best paper in the 1992 European Microwave Conference and the IEEE Third Millennium Medal in 2000.