A Noise Re-radiation Calibration Technique in Interferometric Synthetic Aperture Radiometer for Sub-Y-type Array at Ka-Band

Seungwon Seo, Sunghyun Kim, Junho Choi, Hyuk Park, Hojin Lee and Yonghoon Kim

Sensor System Laboratory, Department of Mechatronics,
Gwangju Institute of Science and Technology (GIST),
1 Oryong-dong Buk-gu, Gwangju 500-712, Republic of Korea,
TEL:+82-62-970-2412, FAX:+82-62-970-2384, E-mail : coolseo@gist.ac.kr

Gumsil Kang
Satellite Application Department
Korea Aerospace Research Institute
45 Eoeun-dong, Yuseong-gu, Daejeon, 305-333, Republic of Korea
E-mail : wimikgs@kari.re.kr

Abstract: To overcome with large size noise source distribution network design difficulty in interferometric radiometer system, especially for sub-Y-type array, a new on-board calibration technique using noise re-radiation is proposed in this paper. The suggested calibration technique is using noise re-radiation effect of center antenna after noise source injection from matched load. This approach is especially proper to sub-Y-type array interferometric synthetic aperture radiometer in mm-wave frequency band. Compared with noise injection network of a conventional synthetic aperture radiometer, the system mass, volume, and hardware complexity is reduced and cost-effective. Only one internal noise source, matched load, is used for injection using noise re-radiation technique a small set of sub-Y receiver channels is calibrated. Detailed calibration scenario is discussed and simulation results about noise re-radiation effect are presented.

Keywords: Sub-Y-type array interferometric synthetic aperture radiometer, calibration, noise re-radiation

1. Introduction

In passive millimeter-wave imaging technology, remote sensing using interferometric aperture synthesis is becoming preferred concept for meteorology, earth observation like atmosphere or ocean monitoring applications. This interferometric synthetic aperture radiometer (hereafter ISARad) has been suggested as a valuable, practical alternative through aperture synthesis to realize required large aperture size of the antenna [1],[2],[3]. In addition, no mechanical scanning is required to form high resolution image map.

However, calibration method, which is one of important design considerations of an interferometric radiometer, is very complicated and difficult to be implemented in an interferometric structure. To get receiver error parameters through receiver calibration, originally a large number of noise source injections has been necessary. It increases system mass, volume, and hardware complexity.

To overcome with these design difficulty, a new on-board calibration technique using noise re-radiation is proposed in this paper. The suggested hardware calibration technique is proper to calibration methodology in ISARad system in millimeter-wave frequency band. With this proposed hardware calibration technique, we have developed 4 channel sub-Y-type array ISARad which is available at 35 GHz. This ISARad having sub-Y- type array antenna configuration has been proved that it has a highly improved angular resolution with a less number of antennas compared with the resolution of Y-type [4]. Design key features in calibration technique are as follows: the proposed calibration technique has required only one internal correlated noise source. The noise source signal injected to center antenna is re-radiated, and then it is received into all channels to be calibrated. With keeping proposed noise re-radiation injection technique, it is expected that developed 4 channel interferometric radiometer is able to be expanded to a large number of channels radiometer such as 40 channel RF receivers in future.

Using proposed technique very simple hardware calibration process has achieved. Large number of internal noise source input is reduced due to one correlated noise source which is re-radiated around.

In this paper, we will describe detailed hardware calibration structure scheme, proposed calibration scenario, and simulation results in 4 channel ISARad.

2. Proposed noise re-radiation calibration technique in sub-Y-array ISARad

A calibration method becomes very complicated problem in interferometric radiometer compared with a simple total power radiometer. A typical ISARad such as MIRAS has big noise source distribution network for calibrating receiver [3]. They have used a correlated noise source to each small set of adjacent antennas. Many sets of antennas are overlapped in order to

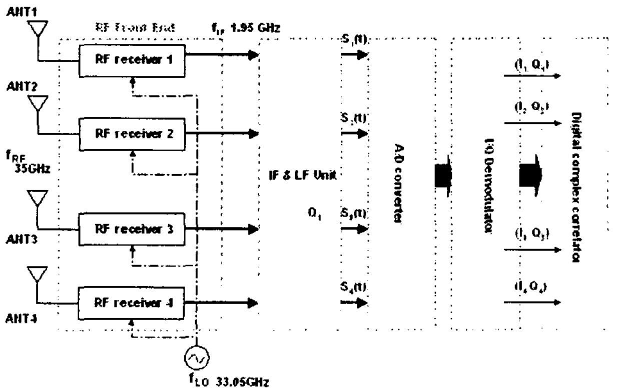

Fig. 1. Simplified Block diagram of 4-channel ISARad system – 4 receivers and digital correlator

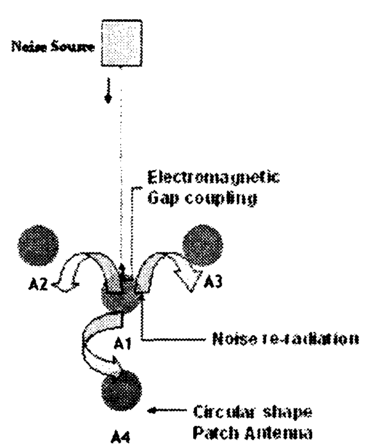

Fig. 2. Sub-Y-array configuration using circular patch antenna and noise re-radiation picture

maintain phase and modulus track along the array by switching adjacent correlated noise source ON and OFF. But MIRAS developed from ESA is limited to low frequency band such as L-Band. Because of large size of noise source distribution network, that noise source switching calibration technique is not proper to interferometric radiometer system in millimeter-wave band.

Here, simple calibration hardware configuration using re-radiation effect of noise signal, which is induced at Ka-band, has introduced. We have only one correlated noise source and injected it into 4 channel ISARad receivers for calibration.

1) Basic receiver scheme of 4-channel sub-Y- type array ISARad system

Fig.1 shows simple 4-channel Ka-band interferometric radiometer system block diagram. Developed 4 channel ISARad is consisted of 4 RF front-end receivers, IF section, A/D converter, I/Q demodulator and digital complex correlator. RF bandwidth is set from 34.95 GHz to 35.05 GHz. Each channel RF front-end module includes two LNA, bandpass filter (optional), and mixer. Local power is pumped about 2 dBm by external signal source at 33.05 GHz. IF frequency is 1.95 GHz and LF center frequency is 80 MHz. After IF and LF part, A/D converter, and I/Q demodulator, each in-phase and quadrature outputs, I(t) and Q(t), are sent into digital complex correlator. Through complex correlation process that outputs of two receivers are correlated, all visibility function are obtained and those are going to be image-reconstructed later by inverse algorithm.

All Antennas of basic cell are placed on duroid 5880 substrate and these are all circular patch type following sub-Y-type array configuration.

2) Noise re-radiation calibration technique in noise injection network

To get calibration of receiver a technique using noise re-radiation effect from patch antenna is proposed. As it is shown in Fig.2, noise source (matched load) is connected into sub-Y- type antenna array module by noise distribution network. To remove impedance mismatch effect between noise source feeding network and antenna followed by receiver module, microstrip line based impedance matching network is designed.

Simply noise source is injected into a patch antenna of center by electromagnetic gap-coupling. Which makes possible feeding to patch antenna at the center of sub-Y configuration. Now, the noise source power fed into antenna is re-radiated. We have focused on the noise power re-radiated from patch antenna at center. Radiated noise power is finally absorbed into all antennas around, which are A1, A2, A3, and A4 in Fig.2.

Here, re-radiated noise source power is mainly considered as one correlated noise source for radiometer calibration. Proposed idea is to change the injection method of correlated noise source. It does not require another external calibration source existing outside of system. That is, suggested calibration hardware scheme actively generates correlated noise source itself as if an external calibration source is settled into the circuit. This gives more compact hardware scheme reducing mass, volume of hardware for calibration network.

Also, while other interferometric radiometers have focused on only receiver calibration fed by noise source, this noise re-radiation technique has brought calibration result including both of antenna calibration and receiver calibration together. Therefore, more accurate calibration result than the case of only receiver calibration is also expected. Simulation results about noise re-radiation effect are shown Fig.3 and 4.

3) Calibration procedure

Calibration procedure is summarized as following : (1) Without RF switching mechanism connecting receiver and noise source, noise source is directly injected into a

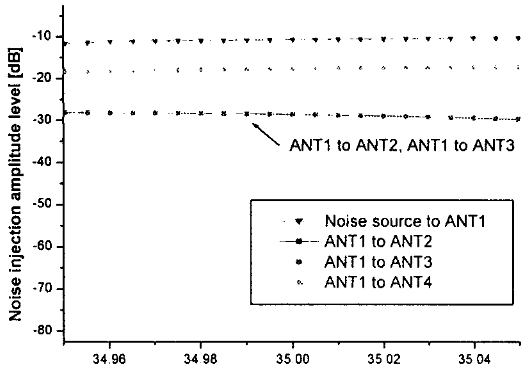

Fig. 3. Simulation result about noise injection amplitude level to Sub-Y-type antenna array by noise re-radiation calibration technique

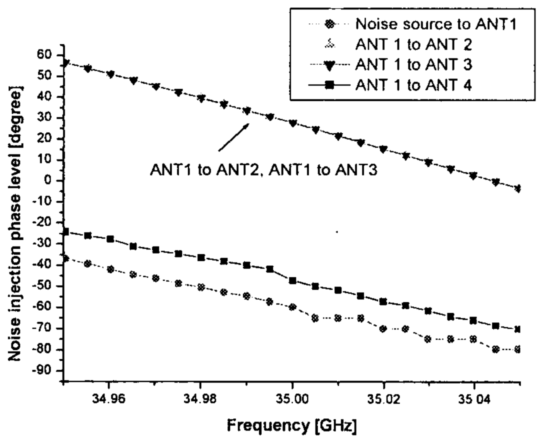

Fig. 4. Simulation result about noise injection phase level to Sub-Y-type antenna array by noise re-radiation calibration technique

patch antenna located at the center of sub-Y- array.
(2) Noise source is injected and fed into the center by electromagnetic gap-coupling.
(3) Noise power is re-radiated from the center antenna, this power is absorbed into around antennas.
(4) The re-radiated noise power is considered as a calibration source and absorbed noise power is used for solving receiver parameters in the on-board calibration process.
(5) In phase and amplitude calibration between baseline, a pair of receivers which are complex correlated, antenna A1 becomes a reference for baseline calibration.
(6) By re-radiated noise injection, a set of the correlation distribution to measure nominal correlation coefficient μ_{ii}, μ_{qi} (or redundant correlation coefficient μ_{iq}, μ_{qq}) is obtained [5],[6].

$$\mu^{err} = P_k \mu \qquad (1)$$

In Eq. (1), the matrix P_k, which is a set of the correlation distribution, gives us error included (measured) visibility function value from originally ideal visibility function.

To correct offsets between baseline, manual hardware calibration technique such as using phase shifter and attenuator is also proceeded.

3. Receiver calibration using noise re- radiation effect

Proposed calibration technique using noise re-radiation is basically following on-board calibration procedure. While on-ground calibration technique has suggested external calibration source for measuring the brightness temperature about observed target source, on-board calibration technique allows us to solve receiver parameters which is originally included in developed receiver. On-board calibration procedure is consisting of correlation offset correction, phase error correction and obtaining gain factors. In this case of proposed calibration idea with noise re-radiation effects, the antenna error stemming from antenna geometry, pattern, and mutual coupling effect is calibrated together with receiver chain.

1) On-board calibration analysis

On-board calibration using suggested noise re-radiation includes mainly phase error correction, offset terms and gain factors. Especially, in-phase error which is existing as a phase deviation from zero for each baseline and quadrature errors how much angle is deviated from the expected 90 degree for each receiver's I and Q outputs is very important to get receiver parameter [5],[6].

$$\begin{bmatrix} \mu_{ii} \\ \mu_{qq} \\ \mu_{iq} \\ \mu_{qi} \end{bmatrix} = g_{mj} g_{mk} \cdot \begin{bmatrix} \cos(\theta_{ik} - \theta_{ij} + \frac{\theta_{qk}}{2} - \frac{\theta_{qj}}{2}) & \sin(\theta_{ik} - \theta_{ij} + \frac{\theta_{qk}}{2} - \frac{\theta_{qj}}{2}) \\ -\sin(\theta_{ik} - \theta_{ij} + \frac{\theta_{qk}}{2} + \frac{\theta_{qj}}{2}) & \cos(\theta_{ik} - \theta_{ij} + \frac{\theta_{qk}}{2} + \frac{\theta_{qj}}{2}) \\ \cos(\theta_{ik} - \theta_{ij} - \frac{\theta_{qk}}{2} + \frac{\theta_{qj}}{2}) & \sin(\theta_{ik} - \theta_{ij} - \frac{\theta_{qk}}{2} + \frac{\theta_{qj}}{2}) \\ \sin(\theta_{ik} - \theta_{ij} - \frac{\theta_{qk}}{2} - \frac{\theta_{qj}}{2}) & \cos(\theta_{ik} - \theta_{ij} - \frac{\theta_{qk}}{2} - \frac{\theta_{qj}}{2}) \end{bmatrix} \cdot \begin{pmatrix} \mu_r \\ \mu_i \end{pmatrix} \qquad (2)$$

Eq. (2) shows about phase error correction. g_{mj} and g_{mk} are modulus terms and the matrix contains all phase errors. μ_r, μ_i is each showing part of complex correlation. Based on this equation, if correlated noise source power is fed, ideally μ_i becomes zero. Only the real part of the complex correlation is remained as the unity.

Therefore, we have finally derived two sets of equation below,

$$-\mu_{ii} \cdot \sin(\theta_{ik} - \theta_{ij} + \frac{\theta_{qk}}{2} + \frac{\theta_{qj}}{2}) = \mu_{qq} \cdot \cos(\theta_{ik} - \theta_{ij} + \frac{\theta_{qk}}{2} - \frac{\theta_{qj}}{2})$$
$$\mu_{iq} \cdot \sin(\theta_{ik} - \theta_{ij} - \frac{\theta_{qk}}{2} - \frac{\theta_{qj}}{2}) = \mu_{qi} \cdot \cos(\theta_{ik} - \theta_{ij} - \frac{\theta_{qk}}{2} + \frac{\theta_{qj}}{2}). \qquad (3)$$

The unknowns are the in-phase errors and the quadrature errors for receivers j and k. For the case of having 4 receivers, to solve the unknowns a required amount of baselines must be measured. There are all 8 unknowns, while 6 baselines giving overall 12 equations can be formed.

Correlation offset can be figured out as injecting uncorrelated noise source into each receiver channel. Modulus term products presented in the calibration procedure are defined as the ratio between the correlated noise T_{corr} and total noise T_{total} as shown in Eq. (4).

$$g_i = \sqrt{\frac{T_{corr}}{T_{total}}} = (1 + \frac{T_{Rm}}{T_{no}})^{-1/2} \qquad (4)$$

The noise source temperature T_{no} is measured and with iterative method to determine the receiver noise temperature is determined [6]. Gain factors are computed from antenna measurement.

Finally, the result we have interested in is summarized as Eq. (5) below.

$$\mu = P_k^{-1} \mu^{raw}. \qquad (5)$$

With calibration matrix embodying all error, offset terms and measured visibility function values, we are able to derive ideal visibility function values by inverse matrix method.

2) Simulation result for noise re-radiation injection

For the simulation about noise injection using noise re-radiation effect on the antenna plate, we have used momentum method. We assumed that a noise source, 50 ohm matched load, is stable. And re-radiated noise power from center diverges in omni-direction and it is absorbed around all antennas including radiator antenna 1.

Fig. 3 shows us the noise injection amplitude level to each receiver channel including its antenna. There some noise power difference between antennas absorbing re-radiated noise source power. The difference represents that sub-Y-type antenna array geometry has affected to the degree of absorbing calibration source power even though we assumed that re-radiated power from center patch antenna always gives out in omni-direction. As it is also shown in Fig. 4, its effect is confirmed in injected noise phase level either. With noise re-radiation technique using existing radiator structure itself, correlated noise source power from center antenna has experienced antenna and receiver error factors together. Therefore, it can be explained that this noise re-radiation calibration technique embodying all antennas and receiver structure gives us on-board calibration data for calibrating both sub-Y-type antenna array and receiver error parameters simultaneously.

Additionally, with this calibration technique using noise re-radiation effect, a number of modifications for the antenna feeding structure are able to be suggested for more stable noise distribution.

3. Conclusions

In this paper, a new suggestion for noise injection method of ISARad receiver calibration is presented. This calibration technique has applied to sub-Y-type array interferometric radiometer receiver. The idea of proposed method is based on using noise re-radiation effect from center antenna of sub-Y antenna array configuration. It is expected that suggested calibration technique brings simple noise distribution scheme for ISARad receiver calibration, especially working at millimeter-wave frequency band. It is going to effectively reduce the number of a set of correlated noise source input. So, the burden for injecting calibration source to ISARad having a large number of receivers is able to be relaxed.

Hardware calibration scenario and fundamental on-board calibration equations have been described. Simulation results are showing the noise power distribution to each antenna. And, with now simulation result we are waiting for actual implementation for receiver and field measurement for calibration.

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