Simulation of Actively Polarimetric Calibration Source Based on Correlated Noise Signals by Simulink

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Abstract— Fully polarimetric microwave radiometer can receive both the two orthogonal polarization components and their complex correlation components, which are defined as the third and fourth Stokes parameters, of the signals radiated from the detected target. In order to achieve the precisely quantitative remote sensing of fully polarimetric radiometer, an accurate calibration is necessary. For this purpose, a uniformly stable and accurate calibration source which is performed as the calibration standard is of vital importance. The traditional and commonly used blackbody calibration target can't radiate signals with polarized components. So it is significant to design an active calibration source to generate noise signals with full polarized components for fully polarimetric microwave radiometer calibration. With the full investigation into the pre-existing polarimetric calibration sources and their characteristics, this paper design a miniature and portable actively polarmetric calibration source. First of all, the design principles of the calibration source of fully polarized microwave radiometer based on correlated noise signals are elaborated. Secondly, MATLAB/Simulink is used to establish the simulation model of the calibration source. The reference signals generation module generates the original reference signals with full polarized components which can be controlled by program language. The original reference signals are converted to the signals with the designed frequency by the frequency modulation module. The noise voltage control module outputs the noise signals with different voltages which covered all the counts needed for polarimetric radiometer calibration within the voltage counts of cold and hot target. Finally, the power spectrum of each module of the simulation model is given. The results show a great consistency between the theoretical and simulated results. Thus, the feasibility of the designed calibration source for fully polarimetric microwave radiometer based on the program language controlled correlated noise signals is verified. Therefore, the functional block diagram of the real circuits of this calibration source based on the simulation is designed for the practical application.

1. INTRODUCTION

The radiation of the object are always partially polarized. The traditional microwave radiometer can only detect the vertical and horizontal polarization components, which are defined as the first and second Stokes parameters. However, the polarization parameters of the electromagnetic radiation radiated from the object also include the complex correlation components of these two orthogonal polarization components, which are defined as the third and fourth Stokes parameters. With the four detected Stokes parameters, the polarimetric microwave radiometer can obtain the informations of ocean surface wind vector fields, which is one of the major applications for polarimetric microwave radiometer [1, 2]. Furthermore, the distribution of hydrometeors and the vertical distribution of mesosphere can also be detected by polarimetric microwave radiometer [3, 4]. These significant applications inspired the development of polarimetric microwave radiometer. Calibration of polarimetric microwave radiometer is of great importance for the purpose of accurately quantitative remote sensing. The traditional dual polarized microwave radiometer can be calibrated with two unpolarized blackbody calibration targets. While the calibration of polarimetric radiometer needs a source which can radiate polarized signals covered the four Stokes parameters.

The pre-existing calibration sources for polarimetric microwave radiometer fall into two categories, they are passive sources, and active source. Two calibration standards use passively polarized calibration source are proposed and applied: FPCS — HUT fully polarimetric calibration standard [5] and NOAA/ETL fully polarimetric calibration standard [6]. These two passive calibration sources have some common disadvantages that are they need very precise mechanical structure and temperature control system, and both of the two calibration sources are too large. NSSC had designed a similar calibration target used for calibrating full-polarimetric microwave radiometer [7]. As for active source, Colliander proposed a calibration standard use a fully polarized microwave transmitter to radiate the polarized reference signals [8]. This method is too complex to apply, and the errors come from the transmitter make the reference signals not that precise. Ruf proposed the correlated noise calibration standard (CNCS) which is composed of a commercial dual-channel arbitrary waveform generator (AWG) and the frequency modulation circuit to calibrate interferometric, polarimetric, and autocorreclation microwave radiometer [9]. Peng applied the CNCS for L-band fully polarimetric radiometer [10]. The whole device of CNCS is big because of the usage of AWG though the design ideas are good for radiating controllable signals with fully polarized.

Inspired by the CNCS, we proposed an actively polarimetric calibration source based on correlated noise signals, which is small and precise. In addition, we simulated this source by Simulink to verify its feasibility. The simulation results are given and the functional block diagram of the real circuits of this calibration source based on the simulation is designed for the practical application.

2. DESIGN PRINCIPLE AND SIMULINK SIMULATION

2.1. Basic Composition of the Actively Polarimetric Calibration Source

The functional block diagram of the actively polarimetric calibration source is shown in Figure 1. The source is composed of four modules: signal generation module, frequency modulation module, local oscillator and voltage control module. The signal generation module generate two orthogonally original reference signals whose magnitude and phase of their complex correlation components can be controlled by program language. These two original reference signals are converted to the signals with the designed frequency by the frequency modulation module and the local oscillator. The noise voltage control module outputs the noise signals with different voltages which covered all the counts needed for polarimetric radiometer calibration within the voltage counts of cold and hot targets.

2.2. Generation of the Original Reference Signals

The two orthogonally original reference signals X_V and X_H are complex signals in reality.

$$\begin{aligned} X_V &= x_1 + jx_2 \\ X_H &= x_3 + jx_4 \end{aligned} \tag{1}$$

where x_1, x_2, x_3, x_4 are four mutually independent random numbers of a Gaussian vector, which all obey the standard normal distribution. The complex correlation of X_V and X_H is

$$r_{VH} = r_R + jr_I = \rho e^{j\theta} \equiv \frac{\langle X_V X_H^* \rangle}{\sigma_V \sigma_H} \tag{2}$$

where ρ and θ are the amplitude and phase of the complex correlation r_{VH}. So the real and imaginary parts of r_{VH} are

$$\begin{aligned} r_R &= \frac{\langle x_1 x_3 \rangle}{\sigma_V \sigma_H} = \frac{\langle x_2 x_4 \rangle}{\sigma_V \sigma_H} = \frac{\rho \cos\theta}{2} \\ r_I &= -\frac{\langle x_1 x_4 \rangle}{\sigma_V \sigma_H} = \frac{\langle x_2 x_3 \rangle}{\sigma_V \sigma_H} = \frac{\rho \sin\theta}{2} \end{aligned} \tag{3}$$

Thus, we can give the partial correlation matrix among x_1, x_2, x_3, x_4.

$$R = \begin{bmatrix} 1 & 0 & \frac{\rho\cos\theta}{2} & -\frac{\rho\sin\theta}{2} \\ 0 & 1 & \frac{\rho\sin\theta}{2} & \frac{\rho\cos\theta}{2} \\ \frac{\rho\cos\theta}{2} & \frac{\rho\sin\theta}{2} & 1 & 0 \\ -\frac{\rho\sin\theta}{2} & \frac{\rho\cos\theta}{2} & 0 & 1 \end{bmatrix} \tag{4}$$

With the partial correlation matrix R and the x_1, x_2, x_3, x_4, the two orthogonally original reference signals X_V and X_H. ρ and θ of matrix R can be set to arbitrary value, so the complex correlation of X_V and X_H can be set to any value designed. X_V and X_H are than input to the band-pass filter respectively to obtain the baseband signals with the same center frequency f_0 and the same bandwidth B_0. So far, X_V and X_H are obtained with designed center frequency, bandwidth, and their complex correlation is programed controlled.

2.3. Design of the Frequency Modulation Module

The frequency modulation module is designed to modulate the frequencies of the two original reference signals the frequency of the radiometer which will be calibrated by the actively polarimetric

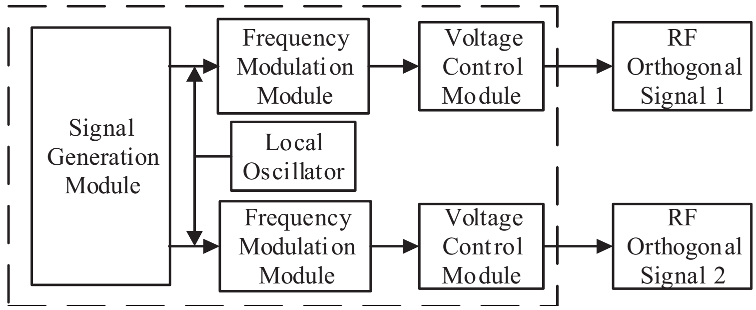


Figure 1: Functional block diagram of the actively polarimetric calibration source.

calibration source. Each of the original reference signal is input into the mixer along with the signal of the local oscillator to achieve the up-conversion frequency modulation. The center frequency of the output signal of the mixer is the sum and difference of the frequency of local oscillator f_{LO} and f_0. After that, the band-pass filter is used to filter out the signal whose frequency is covered the difference of the frequency of f_{LO} and f_0. The signal with center frequency $f_{LO} + f_0$ is reserved, and $f_{LO} + f_0$ is the center frequency of the radiometer which will be calibrated by the source. The simulation design of the frequency modulation module by Simulink is shown in Figure 2. The two orthogonal reference signals generated from the signal generation module are separately mixed with two sine signals generated from the sine wave modules in the mixer module to obtain the two signals with designed frequencies.

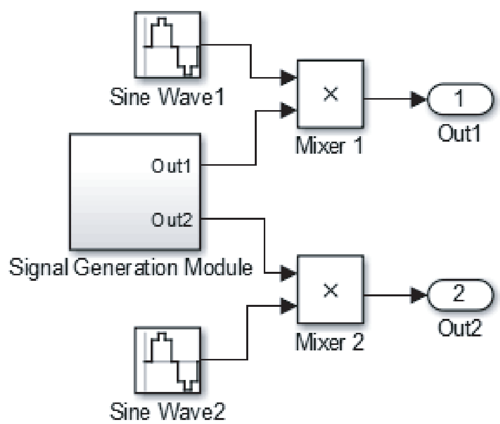


Figure 2: Simulation design of the frequency modulation module.

2.4. Design of the Voltage Control Module

The two orthogonal signals which are after the frequency modulation are input to the voltage control module. The different voltages which covered all the counts needed for polarimetric radiometer calibration within the voltage counts of cold and hot targets are obtained by the linear combination of the simulative counts of cold and hot targets, and are added to the two orthogonal signals, respectively. The sum of the linear combination result and each of the orthogonal signals can be controlled to any counts among the limits, and this is beneficial to calibrate the radiometer more accurately because all the radiation counts within the counts of hot and cold targets can be covered with this actively calibration source. The simulation design of one path in voltage control module by Simulink is shown in Figure 3. The In1 module inputs one path of signal output from the frequency modulation module. The voltage counts of cold and hot targets are multiplied by their scale factors respectively and then the sum of these two multiple results and the input is the final signal output. With the help of the two scale factors, all the counts between the counts of the cold target and the hot target can be set.

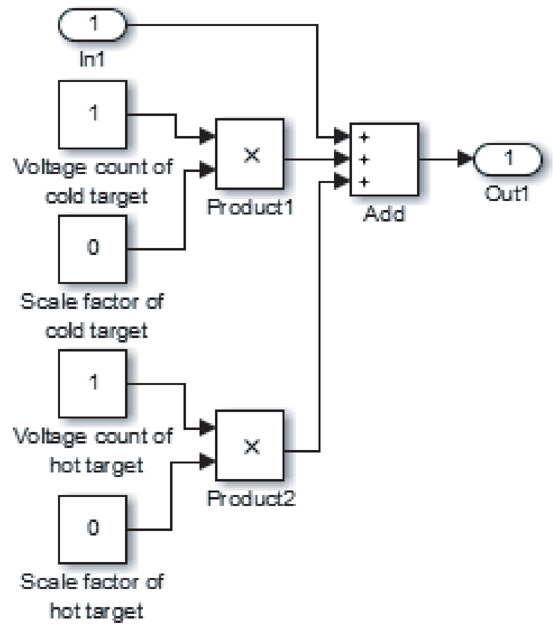
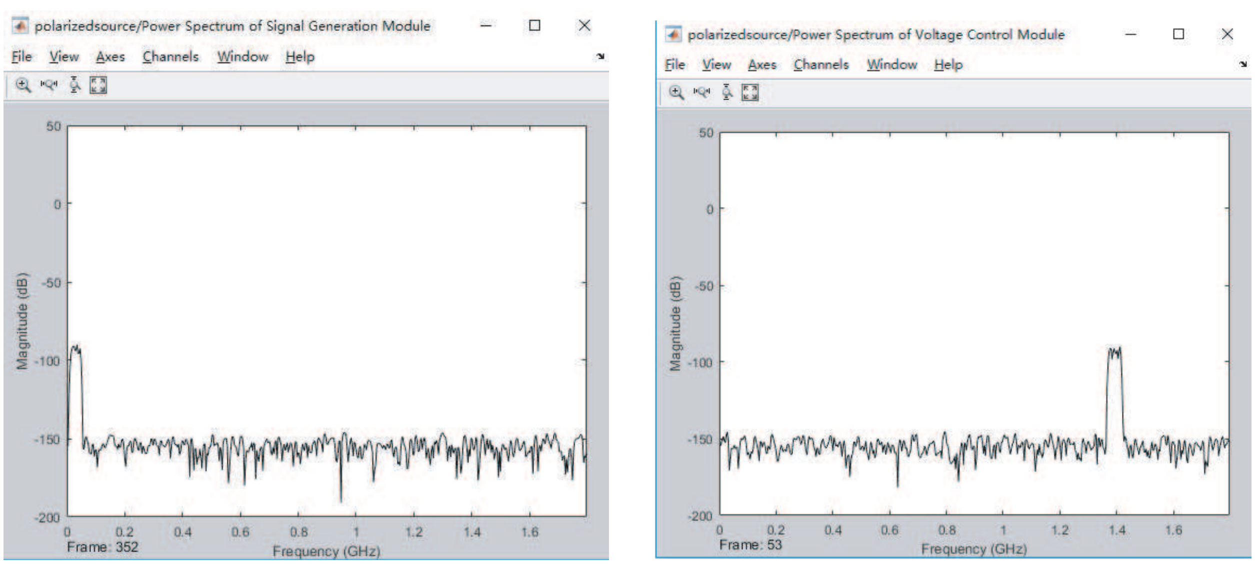


Figure 3: Simulation design of one path in the voltage control module.

3. SIMULATION RESULTS AND THE SUGGESTION FOR CIRCUIT IMPLEMENTATION

Here we simulate an L-band actively polarimetric calibration source. The design indicators of the power spectrum of each module are: the center frequencies of the outputs of the two original reference signals are 30 MHz, the center frequencies of the outputs of the frequency modulation module and the voltage control module are 1.4 GHz, the bandwidths of the outputs of these three modules are all 30 MHz. The power spectrums of signal generation module and the voltage control module are shown in Figure 4. From Figure 4, the power spectrums of the simulation are all consistent with theoretical design. Thus, the simulation verified the feasibility of the actively polarized calibration source in frequency domain.



(a) (b)

Figure 4: (a) The power spectrum of signal generation module. (b) The power spectrum of voltage control module.

On the basis of the Simulink simulation results, the functional block diagram of the real circuits of this calibration source is given in Figure 5.

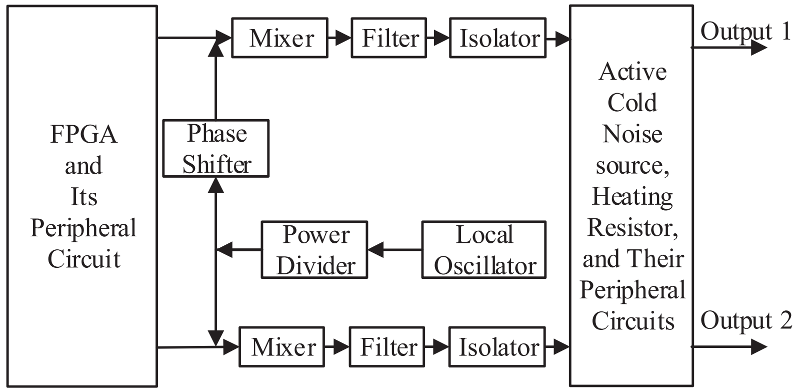


Figure 5: The suggested functional block diagram of the real circuits of actively polarized calibration source.

The FPGA and its peripheral circuit are used to generate two orthogonally original reference signals whose complex correlation can be controlled by program language. In order to make the two output signals of the actively polarized calibration source have coherence, the local oscillator is divided into to same parts by the power divider, and one of the parts is input to the phase shifter before input to the mixer while the other part is input to the mixer directly. The filters after the mixer are used to filter out the unrequired frequency components. The isolators are used to increase the isolation. As for the voltage control part, the Active Cold Noise Source (ACNS) developed by the Key Laboratory of Microwave Remote Sensing, National Space Science Center, Chinese Academy of Sciences is used as a stably cold reference, which can output the brightness temperature to the minimum of 85.3 K up to now [11]. The heating resistors are used as the hot reference. The peripheral circuits of these two references are used to ensure the stable temperature outputs of them and generate the linear combination of the counts of cold and hot references. With this design, the whole device of the actively polarized calibration source can be small, and the outputs of this source are stably output and accurately controlled by program language.

4. CONCLUSION

This paper simulate an L-band actively polarized calibration source by Simulink. This source can radiate all the stokes parameters needed for polarimetric radiometer calibration. The feasibility of the actively polarized calibration source in frequency domain is verified. And the suggested functional block diagram of the real circuits of actively polarized calibration source is given. However, the time-domain simulation of this source need to be simulated with the given functional block diagram before the application of the source. Above all, this actively polarized calibration source can be small and convenient for polarimetric radiometer calibration, and the program controlled stokes parameters and the stable output voltage counts controlled by the linear combination of the counts of ACNS and the heating resistors are conducive to the entirely meticulous calibration for radiometer.

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