Use of Pseudo-Random Noise Sequences in Microwave Radiometer Calibration


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Abstract— The calibration of large aperture synthesis interferometric radiometers such as the Microwave Imaging Radiometer by Aperture Synthesis (MIRAS) aboard ESA’s SMOS mission is a crucial issue. Due to the large number of receiving channels, calibration techniques based on the centralized noise injection from a single noise source would require a large and stable distribution network, which is unfeasible from the point of view of mass, volume and phase equalization. Distributed noise injection techniques have been proposed, but are unable to correct for all types of errors. This work analyzes the possibility of using Pseudo-Random Noise (PRN) instead of a centralized noise source. PRN sequences are signals with very long repetition periods that are used in a variety of applications, such as CDMA communications or positioning systems. They have a relatively flat spectrum over a bandwidth determined by the length of the sequence and the symbol rate. Since their spectrum looks like that of noise, calibration of a microwave correlation radiometers can benefit from their use.

Index Terms— Aperture synthesis interferometric radiometers, Pseudo-Random Noise, PRN.

I. INTRODUCTION

At present, the calibration procedures of large aperture synthesis interferometric radiometers based on distributed noise injection from several noise sources to the receivers through smaller distribution networks have been proposed [1] as an alternative solution to alleviate mass, volume and phase equalization. However, the thermal noise introduced by the distribution network itself induces an error in the measured cross-correlations (instrument observables) that must be compensated by taking differential measurements using two noise levels [2].

Pseudo-Random Noise (PRN) sequences are signals with very long repetition periods that are used in a variety of applications, such as CDMA communications or positioning systems. They have a relatively flat spectrum over a bandwidth determined by the length of the sequence and the symbol rate. Their spectrum looks like that of noise, and the calibration of a microwave correlation radiometer (either interferometric or polarimetric) can benefit from these properties. Instead of injecting thermal noise generated by noise sources with a large excess noise ratio (ENR) and distributed along the receiving elements, the PRN sequences can be:

- generated in a central point and distributed modulated at RF, in which case a distribution network is required, or
- generated in a central point and distributed to all receivers at baseband, in which case an up-converter is needed at each receiver input, and all must be phase looked to a common reference, or
- generated at each receiver input.

This approach has several advantages:

- the signal amplitude is constant and therefore the power can be much higher than in the case of injecting noise (no need to have margin to avoid signal clipping) making the calibration less sensitive to the receivers’ thermal noise,
- 1 bit digital correlators can be used, as those currently planned in the MIRAS instrument aboard the SMOS mission, and
- the signal pattern is deterministic, which allows us to conceive other calibration approaches that are not possible when thermal noise is injected (cross-correlations between the receivers outputs).

This work describes the different strategies listed above, their advantages and disadvantages, and presents the simulation results obtained with the simulator of the PAU instrument: a novel hybrid L-band pseudo-correlation radiometer and GPS-reflectometer under development at UPC to test new techniques to make the sea state correction in the salinity retrieval from space [3, 4].

The results presented can be directly applied to the studies of the SMOS follow on missions known as SMOSops (SMOS operational system).

II. SCHEME UNDER TEST

The scheme simulation is divided in two parts. On the one hand the PRN generation with an appropriate Symbol Rate in order to obtain a relatively flat spectrum over a bandwidth. On the other hand the block diagram corresponding to the receiver...
design (Fig. 1) which is based in the PAU-SEOSAT receiver architecture [5].

The main PAU-SEOSAT receiver front-end parameters are: gain G = 100 dB, bandwidth B = 19 MHz, sampling frequency f_s = 110 MHz and Noise Figure NF = 2.15 dB.

Each receiver includes two chains. Each one has a RF front-end down converter plus an ADC. The correlation in each chain is performed in the frequency domain between the reference baseband PRN code \( X(f) \) and the output signal of the digital processing block, \( Y(f) = PRN(f) \cdot H(f) \):

\[
Corr_{PRN-Sout}^{1,2}(f) = PRN(f) \cdot (PRN(f) \cdot H(f))^* = [PRN(f)]^2 \cdot H_{1,2}^*(f)
\]  

Each receiver frequency response \( H_{1,2}(f) \) can them be obtained as (eqn 2):

\[
H_{1,2}(f) = \frac{Corr_{PRN-Sout}^{*}(f)}{|PRN(f)|^2}.
\]  

Once both frequency responses have been determined, \( H_1(f) \) and \( H_2(f) \), the so-called Fringe-Wash Function (FWF), is computed as a reference to assess the goodness of this technique:

\[
R_{12}(\tau) = \text{ifft} \left( H_1(f) \cdot H_2^*(f) \right),
\]

\[
FWF = \frac{R}{|R|_{MAX}}.
\]

Note that in the usual definition the FWF is normalized at \( \tau = 0 \), while in this case it has been normalized to its maximum value.

The receiver parameters to study are the number of averages and number of bits required the ADC.

III. PRN GENERATION

The PRN generation has been obtained by a Linear Feedback Shift Register (LFSR) as used for example in GPS applications. A Symbol Rate (SR) parameter is used to determine the speed of the PRN code in order to control the width of the spectrum. Its maximum value is:

\[
SR_{MAX} = \frac{f_s}{\text{gold_rate}} = \frac{110 \text{ MHz}}{1.023 \text{ MHz}} = 107.
\]

The minimum value of Symbol Rate (SR=1) involves 107 bits per chip of the PRN code; this is the slowest code and therefore narrower spectrum. The maximum Symbol Rate value (SR=107) implies 1 bit per chip: this is the fastest PRN code with the widest spectrum. As shown in Fig. 2, the higher the Symbol Rate the flatter the spectrum. This parameter can be implemented controlling the delay of the feedback in order to obtain either fast or slow PRN codes. The equivalent PRN noise temperature (A) is the second parameter for the PRN code. It has been chosen in the 1 K to 100 K range.

IV. SIMULATION RESULTS

This section has been divided in two parts: the first one is an overall analysis focusing on the FWF shape module and phase versus the Symbol Rate. The second part is a trade-off analysis between FWF errors versus the Symbol Rate, ADC bits, \( H(f) \) average and equivalent noise temperature of the PRN signal being injected.

A. FWF shape vs. Symbol Rate

The phase and amplitude of the FWF at the origin are the phase and amplitude by which the complex cross-correlations must be calibrated. If receivers’ frequency response are the same, the phase is equal to 0º and the amplitude is equal to 1. The shape of the FWF around \( \tau = 0 \) is used in the image reconstruction algorithms to compensate for the spatial decorrelation effects. This section evaluates the importance of choosing an appropriate Symbol Rate in order to have a good reference with a wide spectrum that looks like white noise.
Since the variable under test is the Symbol Rate, the rest of variables such as ADC bits, number of H(f) averages and equivalent noise temperature of the PRN signal have been assigned to no critical values.

The selection of an appropriate Symbol Rate plays a determinant role in order to obtain a relatively flat spectrum over the system bandwidth. Since the system bandwidth is 19 MHz, two different values of Symbol Rate have been chosen to appreciate the relevance of this variable. Figure 2 shows the PRN spectrum versus the Symbol Rate. With a value of SR=10 the PRN bandwidth at -3 dB is about 5 MHz less than the system requirements. As a consequence the FWF amplitude and phase estimates have an unacceptable error. The red line represents the ideal case and the dots the simulation results at different clock periods (Fig. 3).

A second value of Symbol Rate has been chosen to minimize this error: with SR=50 the bandwidth of the PRN code is larger than the system one (Fig. 2). Therefore the error in the FWF is negligible, as shown in Fig. 4.

**B. Trade-off between FWF errors and Symbol Rate, ADC bits, averaging, and T_{PRN}**

To determine the optimum parameters to obtain satisfactory results in the FWF (amplitude and phase), a wide range of simulations has been performed. The most significant results are presented here. The objective of this part is to find the best FWF behavior in relation to the considered parameter while the others remain constant. Figures 4-8 show the FWF amplitude and phase errors around \( \tau = 0\) (\( \tau = -T_s, 0, +T_s\)).

Figure 5 shows some relevant results, for two extreme situations: a) with an equivalent noise temperature of the PRN signal \( T_{PRN} = 10\) K and 30 averaging the phase error is 0.65° and the amplitude error is 0.1%, b) number of averages=2 and \( T_{PRN} = 100\) K the phase error is 0.5° and the amplitude error is 0.1%. In both cases errors converge is achieved at a Symbol Rate of SR=15. For larger values of SR there is no improvement.

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<th>Phase error vs Symbol Rate, ( T_{PRN} = 10) K, averages=30, ADC=8 bits</th>
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Figure 6 shows the performance of the FWF with the equivalent noise temperature of the PRN signal using 1 bit ADCs. At an equivalent noise temperature of 90 K the error decreases down to 2.6° in phase and 0.1% in amplitude.
Finally, Fig. 7 shows the dependence with the ADC number of bits. Fluctuations are due to the finite number of simulations and just 30 averages. The results using 1 bit are $1^\circ$ of phase error and 0.1 % of amplitude, and does not improve with the number of bits.

V. CONCLUSIONS

A Matlab simulator has been developed to analyze the use of PRN codes with very long repetition periods running at different speeds (Symbol Rate) as sources to calibrate interferometric and polarimetric radiometers, thanks to their relatively flat spectrum over a specific bandwidth. The FWF has been chosen as a parameter to assess the performance of the calibration. Since the PRN amplitude is constant, the input power can be much higher than in case of the noise injection, making it less sensitive to receiver’s thermal noise. PRN pattern sequences are easy to implement using LFSRs and the higher the Symbol Rate the flatter the spectrum, looks like more to a noise spectrum over the receivers’ bandwidth. Averaging can be replaced by using longer PRN codes. In the case of using low values for the equivalent PRN temperature is necessary to increase the number of averages. Trade-off between Symbol Rate, equivalent PRN temperature, number of averages and number of bits of ADC have been studied. Optimum parameters are Symbol Rate > 30 (Note that $B_{PRN} / B = 30.69 \text{MHz}/19 \text{MHz} = 1.6$), $T_{PRN} = 100 \text{ K}$, number of averages > 30, and at least 1 bit obtain a phase error of $1^\circ$ and amplitude error of 0.1%. These values can be improved increasing the number of averages and the $T_{PRN}$.

ACKNOWLEDGMENT

This work has been conducted as part of the award “Passive Advanced Unit (PAU): A Hybrid L-band Radiometer, GNSS-Reflectometer and IR-Radiometer for Passive Remote Sensing of the Ocean” made under the European Heads of Research Councils and European Science Foundation EURYI (European Young Investigator) Awards scheme in 2004, was supported by funds from the Participating Organizations of EURYI and the EC Sixth Framework Programme.

It has also been supported by the Plan Nacional del Espacio (PNE) ESP2006-28462-E

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