A Result of the Instrumental Polarization Measurement of the Chinese Spectral Radioheliograph

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Abstract

The polarization calibration is very important to the Chinese Spectral Radioheliograph (CSRH) for obtaining high-quality radio images. In this paper we discuss a convenient method on how to use interferometer to measure the polarization leakage to CSRH when the feeds have the similar characteristics. Without adjusting the feeds we can use the cross-correlation and self-correlation between two antennas to calculate the parameters of polarization.

1. Introduction

The Chinese Spectral Radioheliograph(CSRH) is an advanced new generation solar radio observing equipment, which uses the synthetic aperture technology with two-dimensional imaging capability. CSRH will observe dynamic property of solar activity and solar corona in decimeter and centimeter wavelength simultaneous with high frequencies, high time and high spatial resolution.

As shown in Fig.1, the antennas receive the solar radio signals, which will be divided into 0.4-2(CSRH I) GHz, and 2-15(CSRH II) GHz bands. The bands are then transmitted to the indoor unit by optical fibers. The signal of each band will be processed digitally. The scientific objectives of these observations include high energy transient phenomena, coronal magnetic field and structure of solar atmosphere, confirming the solar flares and source region of coronal mass ejection(CME)[1,2], so we can understand the solar dynamic transition zone and corona. A briefness system block diagram is shown in Fig.1.

The specifications of CSRH is shown in Table 1[3]. CSRH utilizes improved eleven feed which is composed of several log-periodic arranged folded dipoles. The improved eleven feed has low Voltage Standing Wave Ratio(VSRW≤2, mostly around 1.5) [3], while the original version has VSRW around 4[4]. In order to get dual circular (L, R) polarized signals in all its frequencies, usually we combine the orthogonal linear signal components provided by the electric bridge with 90-degree phase shift to generate circularly polarized signals shown as Fig.2.

Table 1. The specifications of CSRH.

	CSRH-I	CSRH-II
Frequency range	0.4-2 GHz	2-15 GHz
Number of antennas	40×4.5m	60×2m
Antenna type	parabolic	parabolic
Polarizations	Dual circular	Dual circular
The Max baseline	∼ 3000 m	∼ 3000 m
Field of view	∼ 1.9° - 9.5°	∼ 0.7° - 5.2°
Time resolution	∼ 25 ms	∼ 200 ms
Spatial resolution	∼ 10.3″ - 51.6″	∼ 10.3″ - 1.4″

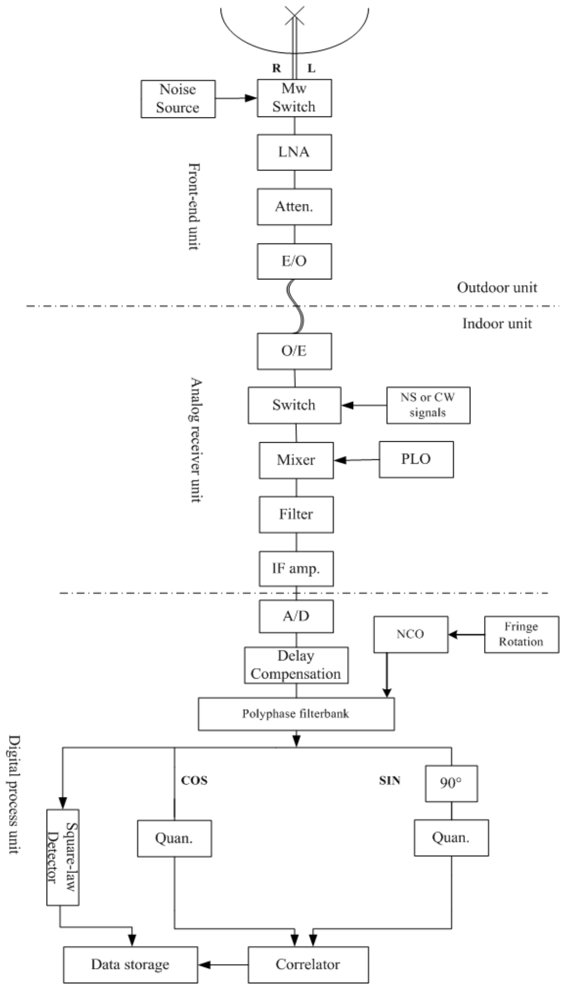

Fig.1. The system block diagram of CSRH.

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If we inject two signals with equal amplitude and orthogonal polarization, expressed as signal A($\overrightarrow{E_A} = E_0\overrightarrow{e_x}$)and signal B($\overrightarrow{E_B} = E_0\overrightarrow{e_y}$), into the phase shifter, we can obtain two circularly polarized signals as follows:

$$\overrightarrow{V_r} = \overrightarrow{E_A} + \overrightarrow{E_B}e^{-j90^o} = E_0(\overrightarrow{e_x} - j\overrightarrow{e_y})$$

$$\overrightarrow{V_l} = \overrightarrow{E_B} + \overrightarrow{E_A}e^{-j90^o} = E_0(\overrightarrow{e_y} - j\overrightarrow{e_x})$$

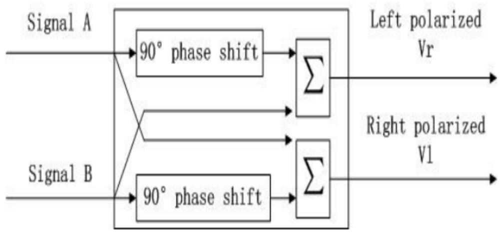

Fig.2. The circular polarization network..

The response to the combination discussed above is derived on the assumption that the two linearly polarized signals are exactly orthogonal, which is not the case in practice. So the polarization ellipse can never be maintained as a perfect circular and the primary problem of imperfect circular polarizers is a coupling of the left circularly signal into the right circularly signal or a coupling of the right circularly signal into the left circularly signal. The imperfect characteristics of the antennas will cause an unpolarized source to appear polarized and decrease the sensitivity and dynamic range of the image, which is called instrumental polarization, defined as D-terms[5].

2. Interferometer Response

In general, the complete state of the radiation field is most conveniently described by two orthogonal polarization. When we use two antennas (each with two differently polarized outputs) to observe a source producing four complex correlations. For example, if we use two dual-polarization feeds to measure the left circular polarization (L) and the right circular polarization (R), we can obtain four visibility functions (R*R,L*L,R*L,L*R)[6]. For circular polarization the leakage terms can be given by the following equations: $v_r^{'} = v_r + D_r v_l$ and $v_l^{'} = v_l + D_l v_r$; where subscripts r and l indicate two orthogonal polarization, $v^{'}$ indicates the signal received, v indicates the signal that would received with an ideal antenna, and D terms indicate the leakage of the orthogonal polarization into antenna. If the dual-polarization feeds provide opposite sense of rotation (denoted by r and l) and four correlators, for a weakly polarized source and nearly perfect feeds, any higher order terms involving source or instrument polarization can be ignored as well as the products of such terms[7]. The linearized approximation when we observe unpolarized radiation from an unresolved source located at the phase tracking center for equatorial mount antenna with circularly polarized feed:

$$V_{rmrn} = g_{rm}g_{rn}^{*}I \qquad (1)$$

$$V_{lmln} = g_{lm}g_{ln}^{*}I \qquad (2)$$

$$V_{rmln} = g_{rm}g_{ln}^{*}I(D_{rm} + D_{\ln}^{*}) \qquad (3)$$

$$V_{lmrn} = g_{lm}g_{rn}^{*}I(D_{lm} + D_{r\mathrm{n}}^{*}) \qquad (4)$$

The g terms represent the voltage gains of the corresponding signal channels. This provides us with a way to determine the D-terms.

3. Observation

Now suppose we can rotate one feed by 90 degree about an axis pointed towards the target source. This makes the feed polarization ellipse by the same angle. Now the cross-polarization response are[7]:

$$V_{rmln}^{*} = g_{rm}g_{ln}^{*}I(D_{rm} - D_{\ln}^{*}) \qquad (5)$$

$$V_{lmrn}^{*} = g_{lm}g_{rn}^{*}I(D_{lm} - D_{r\mathrm{n}}^{*}) \qquad (6)$$

where the superscript R denotes the visibility observed after the feed has been rotated. Now using equation (1) and (2) we can determine the G terms. Also the D terms are determined with equation (3) (4) (5) and (6).

The observations were performed with the antenna IB1 and IC1. First, we observed the sun with the usual state. The schedule of the observation are as follows:

	IB1	IC1	f(GHz)		IB1	IC1	f(GHz)
1	R	R	0.4~0.8	9	L	L	0.4~0.8
2	R	R	1.0~1.4	10	L	L	1.0~1.4
3	R	R	1.2~1.6	11	L	L	1.2~1.6
4	R	R	1.6~2.0	12	L	L	1.6~2.0
5	L	R	0.4~0.8	13	R	L	0.4~0.8
6	L	R	1.0~1.4	14	R	L	1.0~1.4
7	L	R	1.2~1.6	15	R	L	1.2~1.6
8	L	R	1.6~2.0	16	R	L	1.6~2.0

where R and L represent right circular polarization and left circular polarization. For example the first term represent that we observed the sun with IB1 and IC1 with right circular polarization in 0.4GHz-0.8GHz frequency band. Second, we observed the sun with the feed of IB1 rotated by 90 degrees and repeated the above table again.

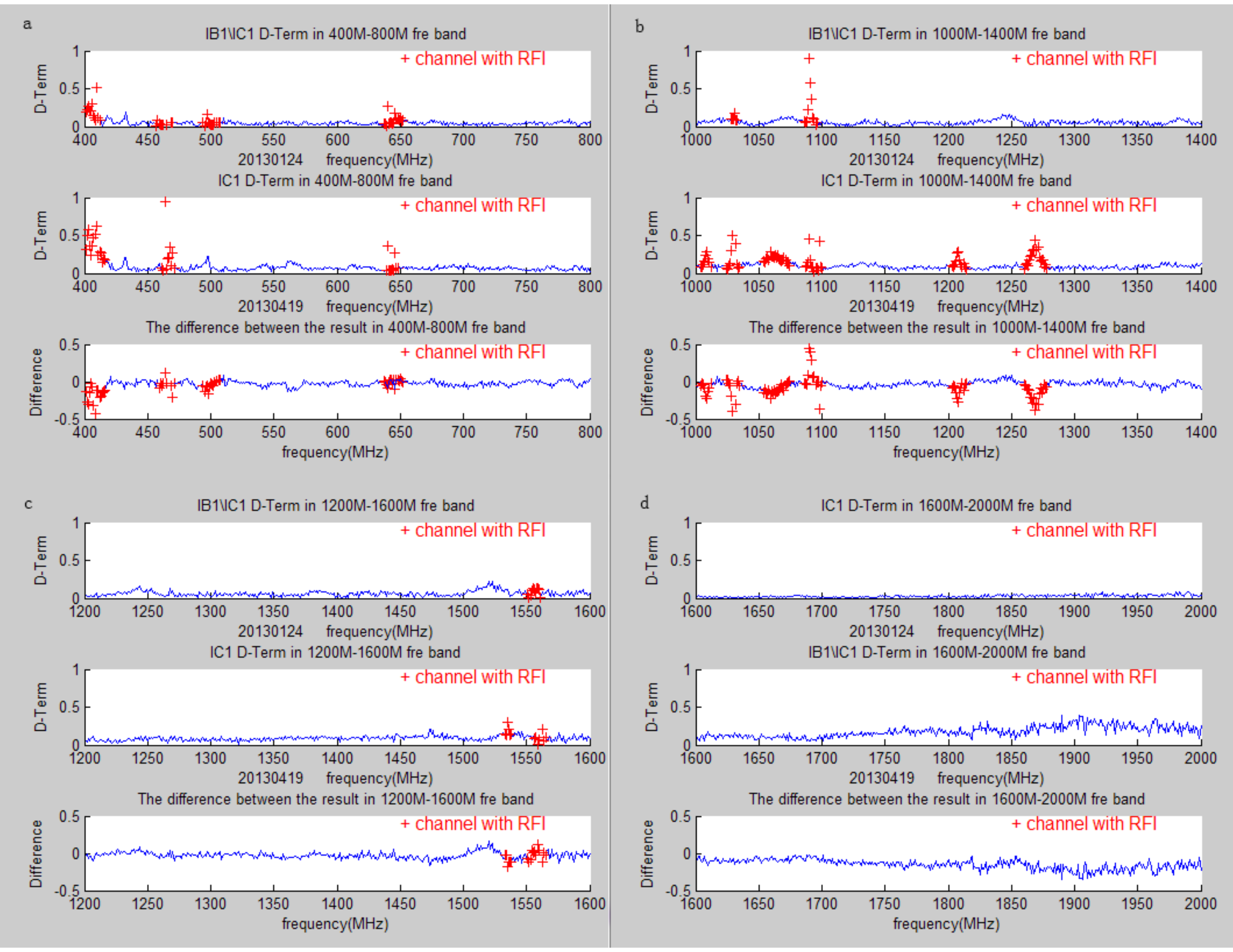

Fig. 3. The D-Term in all four frequency band with two different methods. The difference represents the difference of the value with the two methods. The red crosses represent the radio-frequency interference.

3.1 Result

Now using equation (1) (2) (3) (4) (5) and (6) we can determine the D terms as Fig.3 shown. If we assume that IB1 and IC1 have the similar characteristics, the D-terms without rotating the feed can be defined as:

$$D = V_{lmrn} / \sqrt{V_{rmrn} * V_{lmln}} \qquad (7)$$

Fig.3 illustrates the D terms in all four frequency band with two different methods. In Fig.3a, b, c, and d, the top row is the D term which we assumed the feeds of IB1 and IC1 have the similar characteristics of IB1 and IC1; the middle row is the D terms which we have rotated the feed of IB1 with 90 degree of IC1; and the bottom row is difference of the two methods(the top row - the middle row).Fig.3a shows the d term in 400MHz to 800MHz frequency band, 76.8% of the difference between two methods are less than 0.1. Fig.3b shows the d term in 1000MHz to 1400MHz frequency band, 95.2% of the difference between two methods are less than 0.1. Fig.3c shows the d term in 1200MHz to 1600MHz frequency band, 95.8% of the difference between two methods are less than 0.1. While the d term in 1600MHz to 2000MHz in Fig.3d have a deviation of two methods. This may caused by the affect of rotating the feed which will be checked in the following testing.

4. Discussion

Compared all the curves in Fig.3, although we assumed that the feeds have similar characteristics, we found the D-terms was similar with the method of rotating the feed. This method provides us a convenient way to measure the D-terms of the similar feeds without rotating one of the feed. Also this method proved that the feed of the CSRH have the similar character and meet specifications.

5. Acknowledgments

This paper is supported by NSFC grants (Nos.:11221063,11003028,Y011141001) and National Major Scientific Equipment Research and Design project (ZDYZ2009-3).

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