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NEW EYES LOOKING AT SOLAR ACTIVITY

The Use of Planar Feeds for Solar Radio Observations

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Abstract We describe the results of test observations obtained with a 5-m single-dish radiotelescope (RT5) using novel planar feeds designed to detect circularly polarized emission in the 1.5 – 3.9 GHz band. The beam of such feeds is wide; nevertheless, solar scans have been successfully done using feeds at the focus of the primary mirror of the RT5. The sensitivity is about 1 sfu at each polarization and about 1.4 sfu at the I Stokes parameter. We estimate that it is possible to detect flares with fluxes above 5 sfu at the I Stokes parameter.

1. Introduction

The microwave range of the solar spectrum has been largely observed. However, homogeneous observations over wide ranges and with enough spectral resolution are necessary to trace spectral features, such as those due to gyroresonance during flares. At present, new instruments with such characteristics are under construction (Yan *et al.*, 2011); however, most of the wide-band feeds are complex and of large dimensions (Welch *et al.*, 2009; Du *et al.*, 2013).

Planar feeds of different shapes and technical characteristics have been developed in recent years (Ebnabbasi *et al.*, 2010; Holland and Vouvakis, 2011). They are based on microstrip technology which is cheap, light, and simple for manufacturing. An outstanding feature of planar feeds is the feasibility of working in wide frequency bands in the microwave

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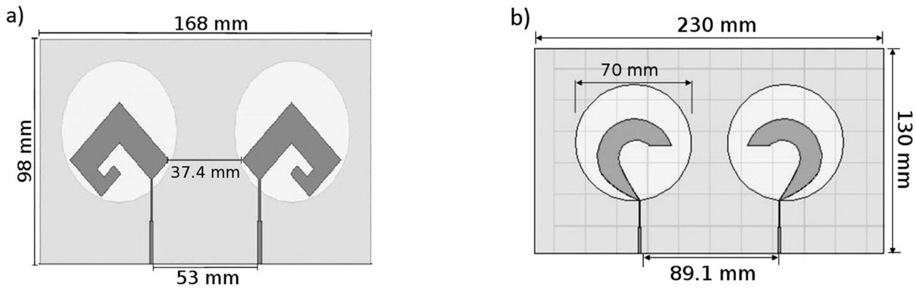


Figure 1 Circularly polarized planar feeds. (a) A pair of feeds formed by rectangles of different dimensions leading to a spiral-like shape with straight borders. Pointed to the primary mirror, the left feed detects RCP and the right feed detects LCP. (b) Curved feeds, known as trunked spirals, also designed to detect circular polarization.

range and at millimeter wavelengths (Lau and Luk, 2005; Joseph and Fukusako, 2012; Hung and Lin, 2006). At present, using computer simulations, it is possible to test different feed designs to have suitable technical characteristics for some applications, as for example, for solar observations.

2. Detection of Circular Polarization

Circular polarization can be mainly detected in two ways:

i) By receiving the linearly polarized signals at the feeds, both vertical and horizontal, and then recovering the circular components.
ii) By directly receiving both circular polarized signals at the feeds.

It is possible to recover the circular polarization from initial linear polarized signals by delaying their phases appropriately with the use of hybrid couplers (Palacios-Fonseca, 2013), but this requires a more complex electronics. Linearly polarized feeds are able to work in bands wider than 100 % of the central frequency; the information of the circular polarization can be obtained later from such wide bands. However, a disadvantage of this type of feed is that additional noise appears when using more than one. Nevertheless, with the use of filters the noise can be considerably reduced and linearly polarized feeds can be used even to design arrays with dozens of elements (Holland and Vouvakis, 2011; Colín-Beltrán, 2013; Colín-Beltrán *et al.*, 2013). This means that linearly polarized feeds still represent an option for studying circularly polarized signals, but the need to transform linear to circular polarization and to reduce the noise due to the use of two feeds implies complex electronics. In this article, we discuss the use of circularly polarized feeds, which do not present such problems. Solar scans obtained using such feeds are presented and analyzed.

In Figure 1, two different types of planar feeds that directly detect circular polarization are shown. They have been designed to operate in a $\sim$2 GHz band and have the best performance around 2.4 GHz. The sizes shown in Figure 1 indicate that they are small. They are built on a plate with two parallel conducting surfaces. The detecting element (the rectangles in one case and the trunked spiral in the other) is located on the side that faces the antenna surface or primary mirror (parabolic surface). The back surface is used for the electrical ground. The curved cavities at the back surface (an ellipse in Figure 1a and a circle in Figure 1b), are made to reduce the amplitude of the waves on the substrate.

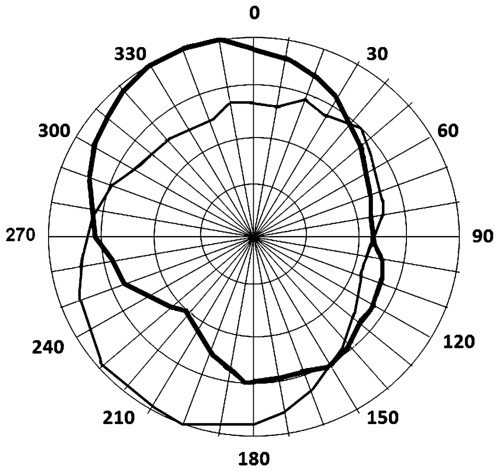


Figure 2 The radiation pattern for a feed like that of Figure 1a obtained at an anechoic chamber where the transmitter is located at the zero angle and the feed rotates taking a measurement of the signal from the transmitter each 10°. The radial scale is in dB with a difference of 10 dB between contiguous circles. The patterns are for a single feed; the thick continuous line is for the RCP whose maximum is obtained when the transmitter is nearly in front of the feed plate, and the thin line is for the LCP where the maximum is obtained almost at the backside of the plate.

The polarization vector of the incident electric field rotates going from the open extreme of the feed to the extreme connected to the wire of the feed. Then, if the array is facing to the antenna surface, the left feed of Figure 1a detects right circular polarization (RCP), which rotates clockwise, and the right feed detects left circular polarization (LCP). Also, seen from the antenna surface, the left feed of Figure 1b detects LCP and the right detects RCP.

In Figure 2 the radiation patterns for the left feed of Figure 1a are shown. It may be seen that they are wide (more than 100°) and that the radiation pattern for the RCP signal is not rotated in the same way as the LCP one, but there are some differences between them. For this feed, the RCP signal first encounters the detecting element (either the rectangles or the trunked spiral) while the LCP meets first the backside surface. For this reason it is better to use two feeds, each of them for a given polarization whose detecting element is facing the primary mirror. The maximum of each pattern does not point to the zero angle, *i.e.*, the maximum response of the feed does not take place in the direction perpendicular to the feed surface (the substrate plate) but at an angle which is slightly different for the RCP signal with respect to that for the LCP one (about 25° for both of them).

The pattern for the trunked spiral feed is very similar to that of the rectangle-like feed but its maximum occurs at an angle of about 15°. The operation band for the rectangle-like feed, as measured in the laboratory, is about 80 % of the central frequency (*i.e.* a 1.9 GHz band) and for the trunked spiral it is about 70 %. For the observations presented in this article, made with rectangle-like feeds, we used a 1.5 GHz band (from 1.5 to 3.0 GHz), which is smaller than the operation band.

The feeds were first tested with their plane oriented perpendicular to the primary mirror axis. It was found that the pointing was not good. Then the angle of the maximum of each beam was aligned with the primary mirror axis, as shown in Figure 3.

In Figure 4, we show the solar scans made in the afternoon of March 3, 2013 at the two circular polarizations. Based on *Nobeyama Radioheliograph* daily fluxes, the flux at 2.4 GHz was estimated to be about 130 sfu. No flares were reported at the time of the observations, and we can assume that the recorded emission of the Sun was unpolarized. If we consider that, for the quiet Sun, the fluxes at the LCP and RCP should be equal to each other (*i.e.* 65 sfu), then the sensitivity can be estimated using the standard deviation of each scan, which was about 1 sfu in both cases. Then for the I Stokes parameter, which is the addition

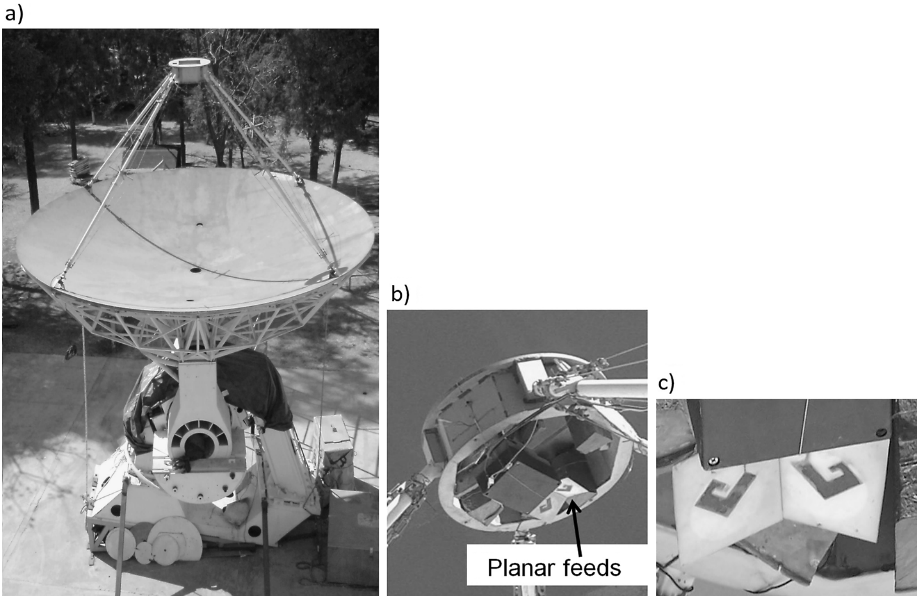
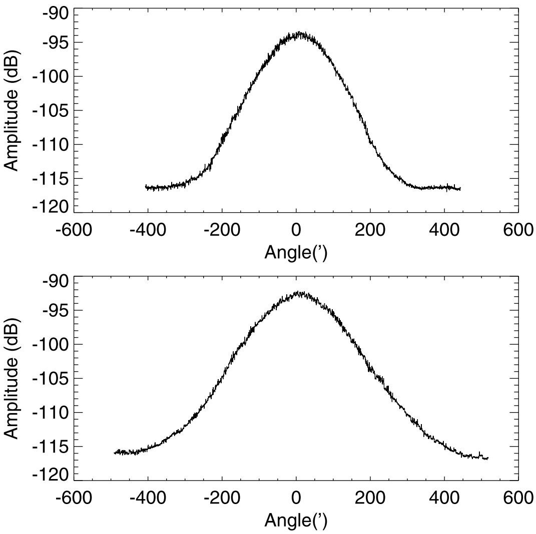


Figure 3 (a) The RT5 radio telescope with the mechanical support of a tetrapod at the focus of its primary mirror. The base of the support is perpendicular to the axis of the primary mirror. (b) The circularly polarized planar feeds installed at the support. (c) A closer view of the feeds which are located at the support. It can be seen from panels (b) and (c) that the planes of the feeds are not parallel to the base of the support.

Figure 4 Solar scans observed with the feeds of Figure 1a, upper panel for LCP and lower panel for RCP.



of the LCP and the RCP, the sensitivity is about $\Delta S_F = 1.4$ sfu. Taking 3 ΔS_F as a reliable value for the detection of a flare, then, for the full band, flares of about 5 SFU can be detected. If we divide the full band into n sub-bands, the sensitivity would be $\Delta S_s = \Delta S_F \sqrt{n}$, where ΔS_F is the full band sensitivity and ΔS_s corresponds to the sensitivity for a sub-band. For $n = 100$ the sensitivity at a sub-band would be about 15 sfu, which is good enough to detect moderate and strong flares and at the same time to trace the spectrum along the full band with good spectral resolution. This could allow identifying features like those due to gyroresonance. Linearly polarized planar feeds have also been used to make a circular polarization spectrometer (Palacios-Fonseca, 2013), and they could be used to trace such features but, as mentioned above, they require more complex electronics.

The estimated full width at half maximum (FWHM) of the LCP is 5.4° and 6.8° for the RCP. A misalignment of the feeds, mainly due to their angle with respect to the primary mirror axis, could explain of the difference. Also, the defocusing of the feeds could play a role.

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The need of each circularly polarized feed to be oriented at the angle of its lobe maximum is a disadvantage for this kind of feed but the orientation can be improved with a suitable mechanical support to accurately adjust them.

3. Conclusions

Broad band (of about 80 % of the central frequency) circularly polarized planar feeds made based on the microstrip technique were used to obtain solar scans in LCP and RCP. The sensitivity for a ~ 1.5 GHz band at each polarization is ~ 1 sfu and in the I Stokes parameter it is ~ 1.4 sfu. With these parameters, the feeds are suitable to observe moderate and strong flares at microwaves in a very wide band.

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