Linear to circular polarization conversion using microwave hybrids for BRAND (1.5-15.5 GHz)

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Abstract– Expected performance of 3dB-90º hybrid (YH90214-3022) changing linear to circular polarization is showed. Additional practical issues are addressed with the insertion of the component in the RF cold front-end relative to the cable length connections.

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1 Introduction

BRAND (Broad-bAND) is a joint research activity (JRA) carried out by the European consortium RadioNet, which is focused on the development of a broadband digital receiver for radio astronomy that will cover a frequency range from 1.5 to 15.5 GHz [1]. For the implementation of the wideband feed antenna, most of the candidate designs are based on linearly polarized antennas, including Eleven [2], quasi self-complementary (QSC) [3], and quad-ridged flared horn (QRFH) [4] feeds. Few exceptions, such as the Dyson conical quad-spiral array (DYQSA) [5], are based on circularly polarized antennas, although in this case additional circuitry (i.e., wideband baluns and combiners) is required to get two single-ended output ports.

Radio astronomy observations, VLBI in particular, require receivers with dual circular polarization reception. Consequently, the use of linearly polarized feeds for BRAND could imply a conversion from linear to circular polarization at some point of the system. In particular, the following options may be considered: hardware at the front-end or by digital reconstruction of the circular polarizations from linear ones [6]. This report deals with the first case, in which hybrids are proposed to directly convert the two linearly polarized signals from the feed into left- and right-handed circular polarizations (LHCP/RHCP). Figure 1.1 shows an outline of this configuration. The axial ratio, the cross-polar level and the increment in the receiver noise temperature are used as figures of merit to evaluate the feasibility of this option.

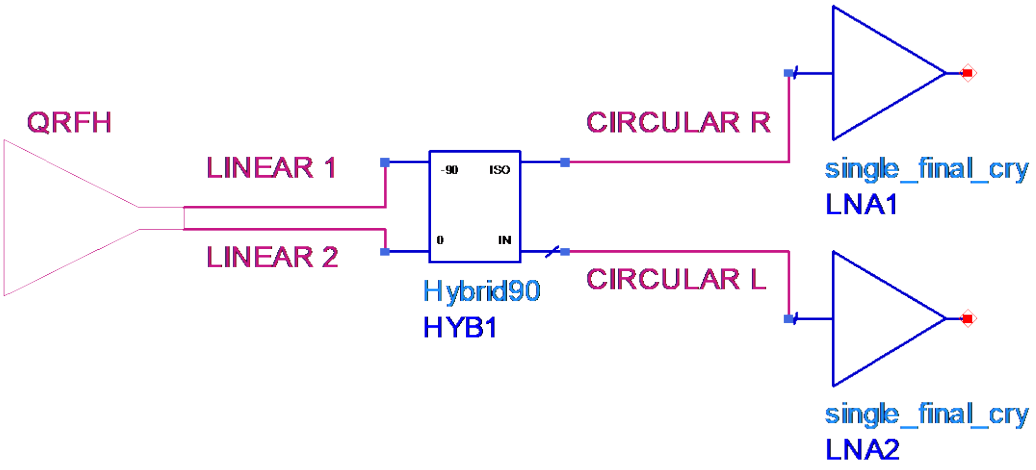

Fig. 1.1: Conversion from linear to circular polarization using a 3dB 90º hybrid.

2 Conversion from linear to circular polarization

In a general case, the electric field of a propagating electromagnetic wave traces out an ellipse in the plane normal to the direction of propagation. According to the notation used in Fig. 2.1, the polarization ellipse is characterized by its maximum and minimum field values (OA and OB), the sense of rotation, and the tilt angle (τ). The axial ratio (AR) is defined as

$$AR = \frac{\text{major axis}}{\text{minor axis}} = \frac{OA}{OB} = \frac{|E_{max}|}{|E_{min}|} \tag{2.1}$$

According to the previous definition, pure circular polarization corresponds to $|AR| = 1$, and in the case of linear polarization the axial ratio goes to infinite. These are the two extreme conditions, so any other case corresponds to elliptical polarization with certain axial ratio $1 \leq |AR| \leq \infty$.

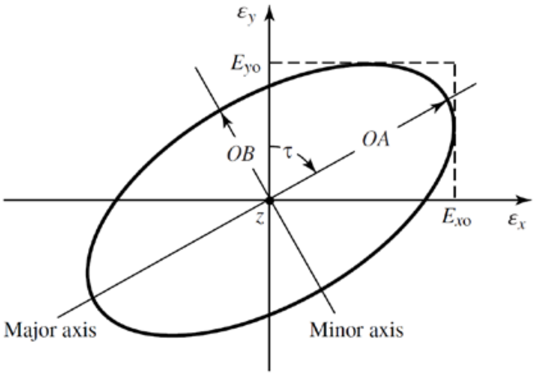

Fig. 2.1: Representation of the polarization ellipse.

A chart representing the axial ratio as a function of both amplitude and phase unbalances of the 90-deg hybrid is shown in Fig. 2.2 [7]. It should be noted that the phase unbalance is defined as the difference with respect to the nominal 90 degrees.

A simple but approximated formula for the axial ratio is given in [8]

$$AR_{dB} \approx \sqrt{(A_{dB})^2 + 0.15^2 \cdot \left(\Delta\phi_{deg}\right)^2}\ \text{(dB)} \tag{2.2}$$

where $A_{dB} = 10 \cdot \log_{10} A^2$ denotes the amplitude error in dB, and $\Delta\phi_{deg}$ denotes the phase error in degrees.

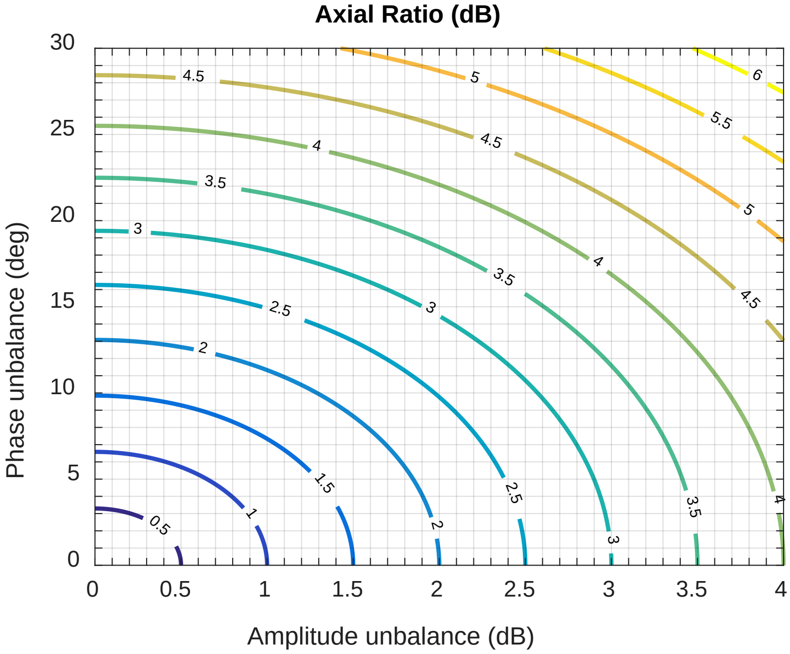

Fig. 2.2: Axial ratio as a function of amplitude and phase errors.

In addition, it is possible to define the polarization purity in terms of the cross-polar level as

$$XP_{dB} = 10 \cdot \log_{10}\left(\frac{|AR| - 1}{|AR| + 1}\right)^2\ \text{(dB)} \tag{2.3}$$

which denotes the discrimination between the circular co-polar and cross-polar components.

3 Wideband hybrid couplers for BRAND

Multioctave stripline hybrids are proposed as potential candidates to achieve circular polarization for the frequency range of BRAND (i.e., 1.5-15.5 GHz). This type of coupler has been specifically designed to operate at cryogenic temperatures [9]. We have two different designs of hybrids available for the BRAND band which will be referred as 5-stages (5-s) and 7-stages (7-s).

The measured performance of the 5-s hybrid is presented in Fig. 3.1. Return loss is better than -18dB. The difference between the amplitude of the direct versus coupled way (called "unbalance") is less than 1.2 dB over most of the band, and reaches a maximum value of 3 dB at the high end of the band. The phase unbalance is less than 2.5 deg in the whole band.

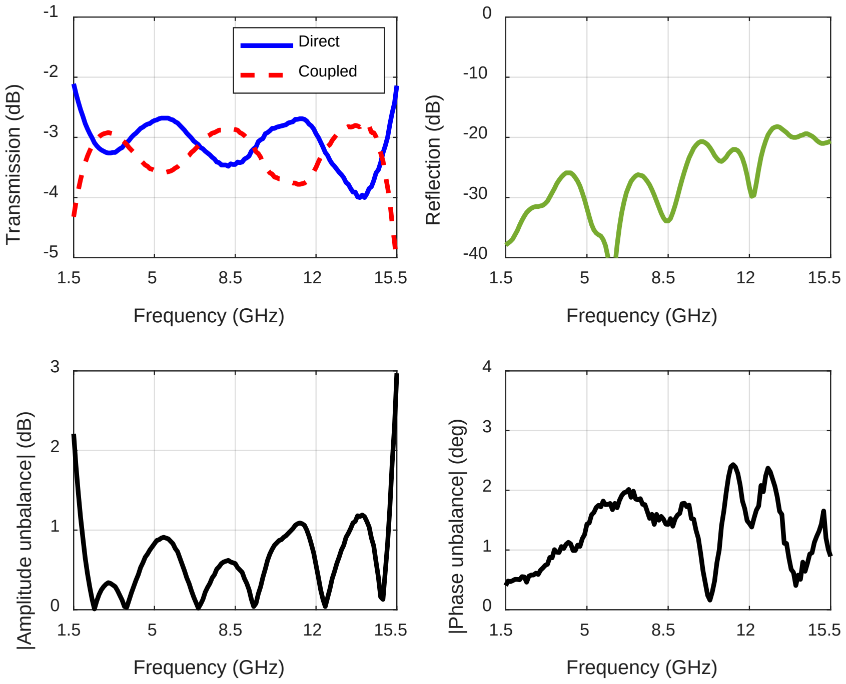

Fig. 3.1: Measured performance of the 5 stages 90-deg hybrid coupler for BRAND.

The7-s hybrid (not shown in the figure) has slightly higher loss but lower amplitude unbalance than the 5-s design. The amplitude unbalance in this case is less than 1.2 dB in the complete band, the phase unbalance is less than 4 deg and the return loss is lower than -15 dB up to 14 GHz, rising to -12 dB at the high end band.

4 Estimated performance

From the measured results of the hybrids, and based on the analysis presented in Section 2, it is possible to estimate the performance of the conversion to circular polarization that can be achieved with the couplers.

For this purpose, the axial ratio has been evaluated for the 5-s hybrid and has been plotted in Fig. 4.1. Furthermore, the corresponding cross-polar discrimination is plotted in Fig. 4.2. As the amplitude unbalance dominates over the phase unbalance in the hybrid, the axial ratio is well approximated by the amplitude unbalance. Consequently, the maximum **axial ratio is about 1.2 dB throughout almost the entire frequency range (3 dB worst case at the higher end of the band)**. In terms of **cross-polar discrimination, such value corresponds to -23 dB for the typical case and almost -15 dB for the worst case.**

Similar analysis for the **7-s hybrid results in a maximum axial ratio less than 1.2 dB corresponding to -23 dB of cross-polar discrimination in the whole band**.

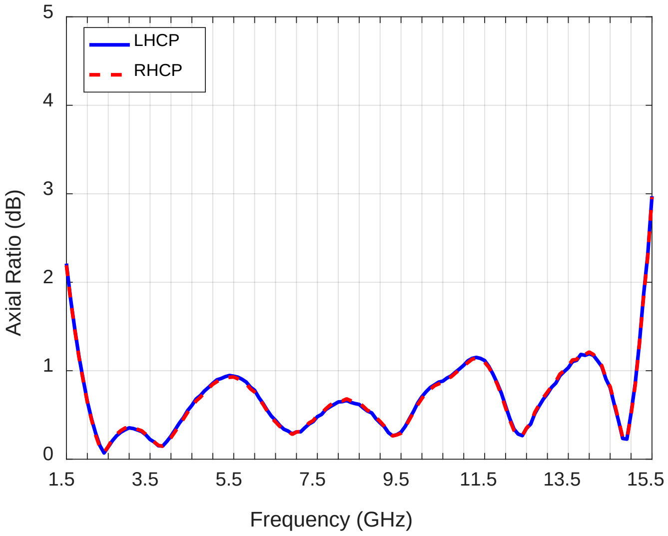

Fig. 4.1: Estimated axial ratio from the measured results of the 5-s hybrid.

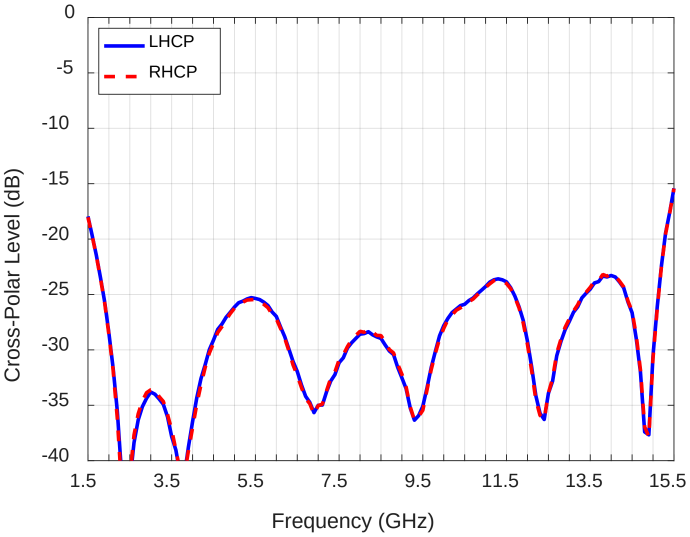

Fig. 4.2: Estimated cross-polar level from the measured results of the 5-s hybrid.

In terms of noise, all the dissipative losses added before the LNA will increase the noise temperature of the receiver. In this analysis the dissipative loss of the hybrid and the coaxial cable connecting the hybrid with the horn will be taken into account.

The most accurate estimation of the noise temperature contribution of the hybrid that we can provide comes from a comparison of the measured noise temperature of a single-ended amplifier versus a balanced amplifier using the same type of hybrid. As in the balanced amplifier, the excess noise temperature is also dominated by the dissipative loss of the input hybrid. Figure 4.3 shows that the average noise temperature contribution of the **5-s hybrid is about 1.5 K**. Similar measurements with the **7-s hybrid shows a contribution about 2.5 K**. It is believed that this is also a good estimate for the noise contribution when the hybrid is used to convert from linear to circular polarizations in the 1.5-15.5 GHz band.

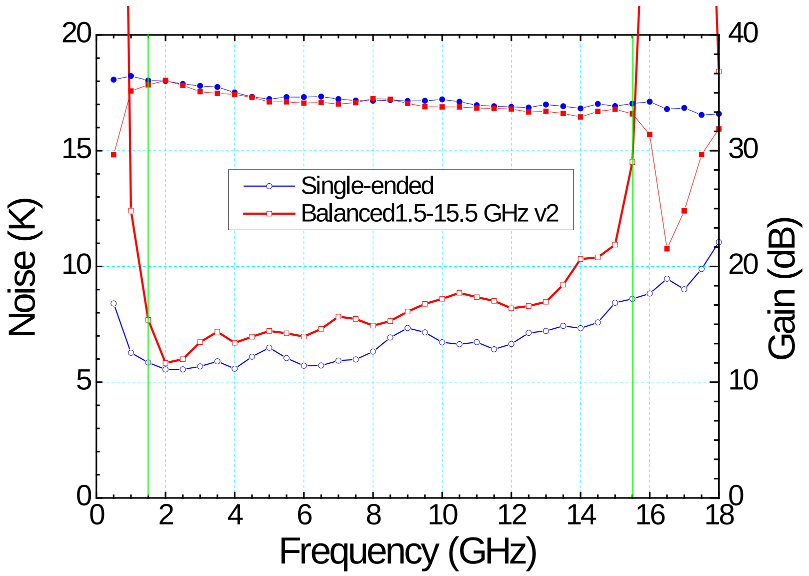

Fig. 4.3: *Cryogenic noise and gain of a balanced amplifier (in red) versus a single amplifier (blue), using a 5-s hybrid in the balance configuration (data obtained at 15 K).*

5 Feed, hybrid and LNA connections at the front-end

In terms of noise, regardless of a hybrid to transform the linear polarizations is used, a coaxial cable to connect the horn to the amplifier (or to the hybrid) is needed, which increases the noise temperature. A suitable coaxial cable could be a 0.141 copper cable with low density PTFE as a dielectric to reduce phase changes when cooling. A 10 cm long of this type of cable[1] has an approximate loss of 0.05 dB at 15.5 GHz and cryogenic temperature. Adding an estimation of the losses of the two connectors of the cable[2], the cable will increase the **noise temperature by about 0.5 K**.

In terms of phase, the feed contributes with phase unbalance between polarizations. However, the order of magnitude of unbalance is similar to the unbalance added with the two connecting cables between feed and hybrid. In consequence, phase unbalance of the feed can be corrected with tailored cables to balance the feed phase errors. These two connecting cables between the hybrid ports and the feed ports affects to the axial ratio because the accuracy in cable length construction will determine the phase unbalance. Typical phase constant of a PTFE coaxial cable is represented in Fig. 5.1. A difference in terms of length of 1 mm would correspond to phase difference of almost 27 deg at 15.5 GHz. The axial ratio assuming differences of length between the connecting cables of 0.2, 0.5 and 1 mm is represented in Fig. 5.2, and the corresponding cross-polar discrimination is represented in Fig. 5.3. It can be observed how the effect of the cables is particularly noticeable at the higher part of the band.

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[1] Data from Radiall for the UT-141-LL semi-rigid cable at a frequency of 15.5 GHz

[2] 2.9 mm connector losses could be around 0.04 dB at cryogenic temperature.

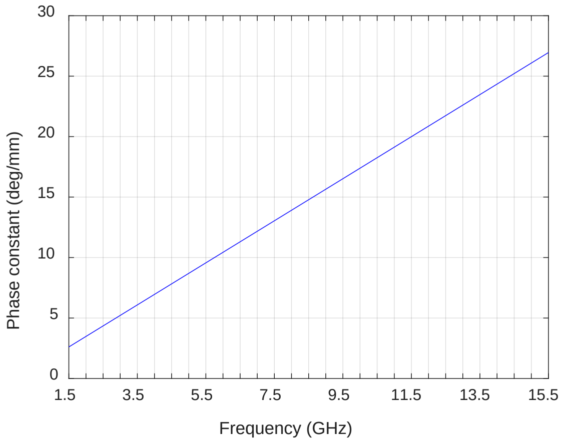

Fig. 5.1: Phase constant of a PTFE coaxial cable.

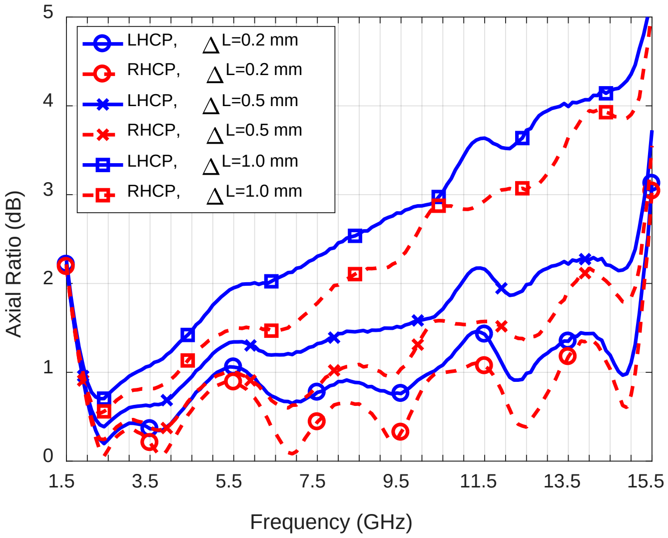

Fig. 5.2: Estimated axial ratio assuming differences in length ΔL between the connecting cables.

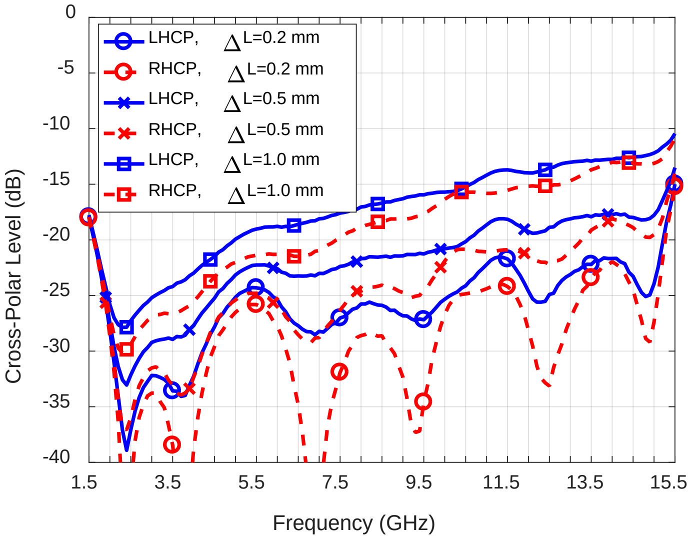

Fig. 5.3: Estimated cross-polar level assuming differences in length ΔL between the connecting cables.

6 Conclusion

The use of wideband hybrid couplers to obtain circular polarization in a radio astronomy receiver using dual linear polarization antennas has been analyzed and evaluated. In particular, the frequency range of the BRAND project, i.e. 1.5-15.5 GHz, has been considered. Two types of hybrids are currently available with a trade-off between axial ratio and noise increase: 5 stages hybrid would allow typical values of axial ratio better than 1.2 dB and up to 3 dB in the end edges of the band with a noise penalty of 1.5 K, while 7 stages hybrid allow axial ratio better than 1.2 dB in the complete band with a 2.5 K increase of the noise temperature of the receiver. Another important aspect to pay attention to is the connecting cables. On the one hand, 10 cm long cables connecting the feed to the hybrid (or to the amplifier) will increase about 0.5 K the noise temperature. On the other hand, length differences in such cables in the order of tenths of millimeter can introduce significant phase errors at high frequencies, which would degrade the overall axial ratio up to few dB.

7 References

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