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THE COSMIC MICROWAVE BACKGROUND AND THE PLANCK MISSION

Santander (Cantabria), Spain
22–25 June 1998

Guest Editors

E. Martínez-González, J. L. Sanz, L. Cayón, J. Portilla,
E. Artal, N. Mandolesi and M. Bersanelli

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A Wideband Detector for the 30 GHz Channel of the Planck Mission Low Frequency Instrument

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Abstract - Design considerations of a 30 GHz detector prototype for the Planck Low Frequency Instrument (LFI) are presented. A simple detector configuration based on a commercial Schottky diode is used, featuring a good linearity and sensitivity in a broad frequency band to meet the accuracy requirements of the LFI.

1. Introduction.

The Planck Low Frequency Instrument (LFI) is composed by a number of radiometers covering the millimeter-wave region from 30 GHz to 100 GHz [1]. The Planck Phase-A study [1] and the proposal that was recently submitted and approved by ESA [2], foresee that the radiometers have a differential configuration and no frequency conversion. Power is directly detected at RF by means of two detectors (one per channel) included in the radiometer back-end. Detectors based on a Schottky diode as the detector device, are widely used in radiometric applications in the millimeter-wave band [3,4]. To meet the radiometric sensitivity requirements, the diode noise contribution (i.e., the detector tangential sensitivity (TSS)) must be kept to a minimum. Moreover, a good detector linearity must be achieved to avoid accuracy degradations in the determination of the scene temperature [5].

Although wideband, high sensitivity detectors are commercially available [6], it is desirable to develop specific designs for the Planck-LFI radiometers, in order to meet the LFI specific requirements, and to easily integrate the detector in the radiometer back-end. In this paper, the design of a 30 GHz detector, based on a commercial Schottky diode mounted on a conventional microwave substrate, is presented. The main purpose for this work is to evaluate the detector practical performances, in particular sensitivity, linearity and transfer characteristic. A careful selection of the diode bias point is performed, to enhance the detector TSS. To achieve a good detector voltage sensitivity, a broadband input matching network is provided. Experimental verification of the detector transfer characteristic and TSS in the operating band is given.

2. Design method.

The detector (see Fig. 1) is composed by coupled-line DC-block, a broadband input matching network, a Schottky diode with a bias circuit, and a low-pass (video) filter. A commercial MA/COM beam-lead diode was selected (model MA40416). The detector TSS depends on the detector intrinsic voltage-sensitivity (β_v) and noise, according to the following expression [7]:

$$TSS = \frac{2.8}{\beta_v}\sqrt{4KTB\left(R_j \frac{n}{2}\frac{I_o + 2I_s}{I_o + I_s} + R_s + R_a\right)} \qquad (1)$$

where B is the Video Bandwidth, T is the temperature, K is the Boltzmann constant, R_j is the junction RF resistance, n is the diode ideality factor, R_s is the diode series resistance, R_a is the

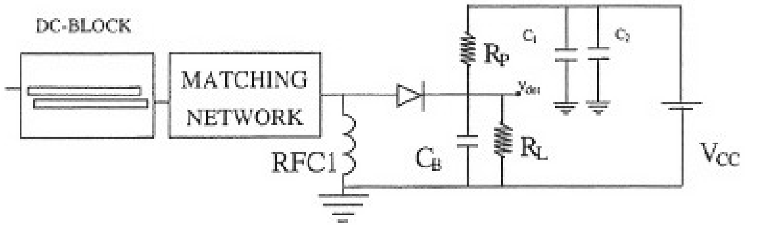


Figure 1. Detector Schematic.

equivalent noise-resistance of the video amplifier, I_o is the diode bias-current, and I_s is the diode inverse saturation current. In eqn. (1) it is assumed that the Flicker noise contribution is below thermal and shot noise. Since R_j and β_v are functions of the diode bias-current, the TSS is bias-dependent. To determine the optimum bias point, eqn. (1) is plot as a function of bias-current, using the diode equivalent circuit supplied by the manufacturer. An optimum TSS of -55.8 dBm was found for a bias current of 20 μA (assuming B = 1 MHz). Since β_v decreases with bias current, there is a trade-off between the TSS and β_v. However, provided that the DC bias-current is kept low, the detector effective voltage-sensitivity, β_v' ($\beta_v' = \beta_v \cdot (1-|\Gamma_{IN}|^2)$; Γ_{IN} is the detector input reflection coefficient), is preserved or even increased, because a lower $|\Gamma_{IN}|$ can be achieved due to a smaller R_j.

A Chebyshev-type impedance-matching network [8] is used. It features a filter-like response in the passband (27 - 33 GHz), while it allows to match a complex load (diode impedance) to 50 Ω. To compute the matching-network elements, the diode equivalent circuit (supplied by the manufacturer) must be accurately modelled by a suitable resonant circuit in the passband. In practice, matching properties strongly depend on the accuracy of both, manufacturer's data and resonant circuit model. Practical implementation is performed with transmission lines printed on a standard dielectric substrate (CuClad-217-5000, 0.127 mm thick). To isolate the RF input port from DC, a DC-block is required. A coupled-line configuration for this element [9] is adequate to cover the passband with minimum losses and good return loss. Line dimensions for an optimum design are: length = 2 mm, width = 0.05 mm, gap = 0.05 mm. The DC bias-circuit and the low-pass filter are composed by lumped (chip) resistors and capacitors (R_p, C_1, C_2 and C_B, R_L in Fig. 1, respectively). Since the diode is biased, a DC-return is provided by means of a shortcircuited stub already included in the matching network (RFC_1 in Fig. 1). The detector is mounted on a brass enclosure that includes a 2.4 mm connector (RF input port), and two SMA connectors (detector output and DC-bias input, respectively). A view of the detector prototype is shown in Fig. 2. Box dimensions are 40 x 15 x 20 mm. Beam-lead diode dimensions are 0.2 x 0.3 mm (chip) plus two leads of 0.1 x 0.2 mm. Simulated detector performances, (including, DC-block, matching network, diode, DC bias-circuit and low-pass filter) are $\beta_v' = 2600$ μV/μW and $|\Gamma_{IN}| \geq 0.12$ (9dB return loss) for a bias current of 20 μA.

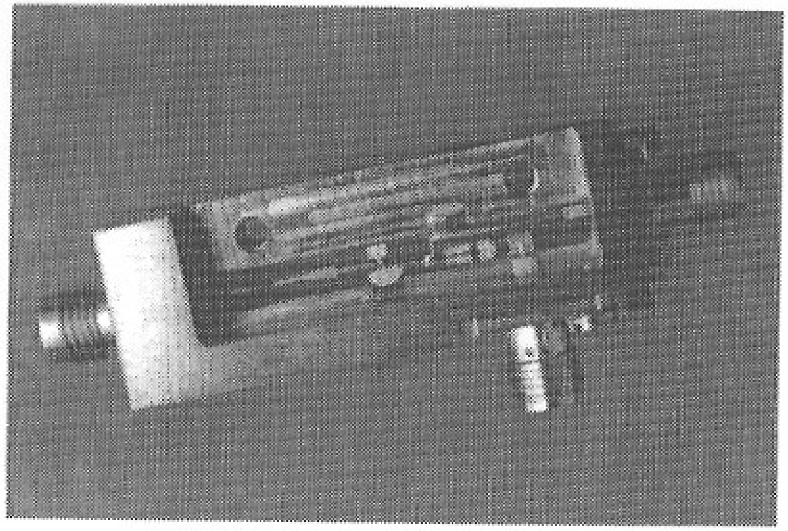
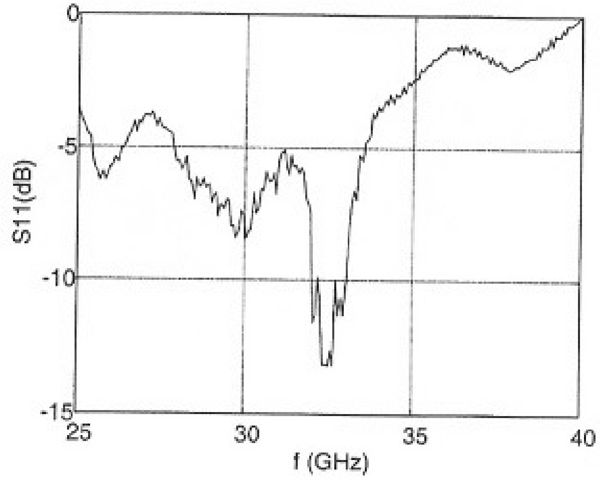


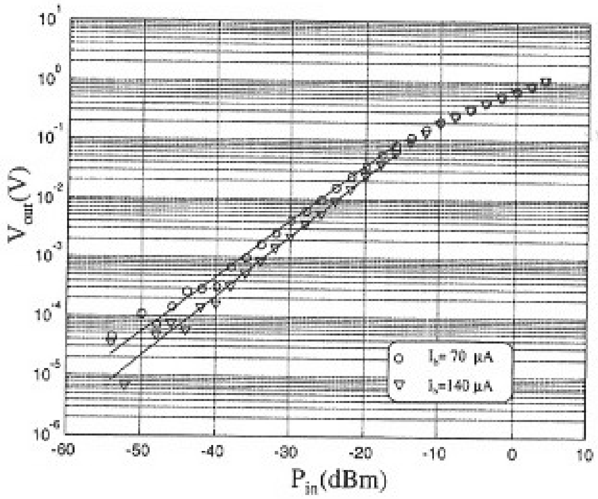
Figure 2. View of the 30 GHz detector prototype. RF input (left) is a 2.4 mm connector. Detected output (right) and DC-bias input (bottom) are SMA connectors. (See Color Plate VIII).

3. Experimental results.

The measurement of the detector input return-loss was performed with an HP 8510B network analyser. Experimental results (see Fig. 3a) for a 20 μA bias current show that the return loss is better than 4-5 dB in the passband. This figure is poorer than results from simulations (9 dB minimum). Two factors determine the matching level that can be achieved in practice. First factor is technological. The relatively thick metal layer (17.5 μm) produce inaccurate DC-block linewidth and gap dimensions in the etching procedure. Second factor is the inaccuracy of the manufacturer's data, specifically the elements of the diode equivalent-circuit model. To increase the detector return loss, the DC bias-current is increased. For a 140 μA current, return loss is better than 8 dB..



(a)



(b)

Figure 3. Experimental results. (a) Detector input return-loss for a 20 μA DC bias-current. (b) Detector transfer characteristic for 70 and 140 μA DC bias-currents.

A semiautomatic set-up based on a Ka-band sweep oscillator (HP 8350B) and a low-frequency spectrum analyser (HP 3651) has been used to measure the detector transfer characteristic (detected voltage versus RF input power) of the detector. To level out the sweeper output power, external elements are required. The leveling loop is composed by a directional coupler, a power sensor (R486) and a power meter (HP 432A). The power delivered to the detector is controlled by means of a variable atenuator connected at the leveling loop output. A programmable power-supply (HP 6629A) is used to bias the detector. A program on a PC was written to automate the mesurement procedure. It generates suitable commands to control the sweeper (frequency and power sweeps), the power supply (DC-bias sweeps) and the spectrum analyser (power data readings). Care must be taken to compensate for the detector DC offset, because it masks the measurement of the detected signal for low input powers (less than -35 dBm). Fig. 3b shows the measured detector transfer characteristic for two bias-currents. The detector is linear for an input power range from - 16 dBm to less than -50 dBm. Voltage sensitivity is 3900 μV/μW for 70 μA, and 2000 μV/μW for 140 μA, respectively. These results are better than those expected from simulations. From Fig. 3b, an aproximate value of -53 dBm can be assumed for the TSS. However, this last result must be checked with an accurate, specific detector noise measurement that compensates for the spectrum analyser noise contribution.

4. Conclusions.

A 30 GHz detector prototype for the Planck LFI has been presented. An important design consideration is the trade-off between voltage sensitivity and noise (TSS). The detector is implemented using conventional elements and standard technological processes. The measured characteristics show excellent results. A voltage sensitivity of 3900 μV/μW and a TSS of -53 dBm have been obtained. The detector linear margin ranges from an input power of - 16 dBm to less than -50 dBm. Future work will be dedicated to investigate and measure the detector noise contribution, in particular the Flicker (1/f) noise.

5. Acknowledgements

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