Broadband Back-End Module for Radio-Astronomy Applications in the Ka-Band

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***Abstract*— This paper presents the design, simulation and measurement of a broadband Back-End Module (BEM) for radio-astronomy applications in the Ka-band. It is a direct conversion receiver based on low noise amplification, band pass filtering and Schottky diode detection. System simulations are based on individual linear-subsystems S-parameters measurements together with non-linear detector model. Measurements show more than 30 dB of RF gain over the 26 to 36 GHz band with a noise figure below 3.9 dB. Detected voltage is in the range 1-10 mV which meets the application specifications.**

I. Introduction

Cosmic Microwave Background (CMB), is of great interest in the scientific community since it is considered the key evidence of the Big-bang theory. Together with satellite missions, like the ESA Planck satellite [1] to be launched this year, there are ground-based projects designed to measure other CMB parameters and to complement data coming from the satellites.

QUIJOTE is a new project to be installed and operated at Teide observatory (Canary Islands, Spain) aimed for characterizing the polarization of the CMB and other galactic and extragalactic emission processes. These measurements will complement those obtained by Planck mission, correcting galactic contamination [2].

QUIJOTE radiometers, shown on Fig. 1, are based on Planck scheme [3]. Radiometers are comprised of a Front-End Module (FEM) operating at cryogenic temperatures, T_a = 20 K, and a Back-End Module (BEM) operating at room temperature, T_a = 296 K.

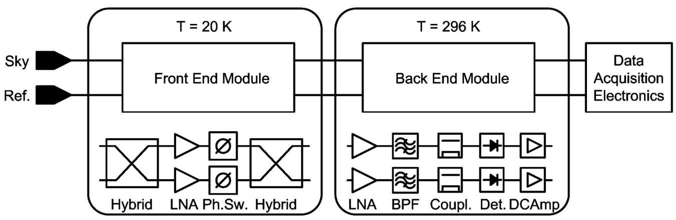


Fig. 1. QUIJOTE radiometer scheme.

This document presents the results obtained with the Ka-band BEM first prototype which meets QUIJOTE preliminary specifications appearing in Table 1. This proves the feasibility of the selected scheme to fulfil the project goals.

TABLE I
QUIJOTE PRELIMINARY BEM SPECIFICATIONS

Bandwidth	26 to 36 GHz
Input power	-53 dBm (expected from FEM)
Detected voltage	In the range 1 – 10 mV
Input Connection	WR-28 waveguide
Output Connections	RF output: 2.92 mm connector DC output: detected voltage
Noise Figure	< 4.35 dB (T_e < 500 K)

II. BEM Design

The designed BEM prototype in Fig. 2 is a simplified version of the one appeared in Fig. 1. Coupler and video amplifiers have been skipped while detector has been mounted in a separate module. This enables a parallel design and test of the DC and RF parts.

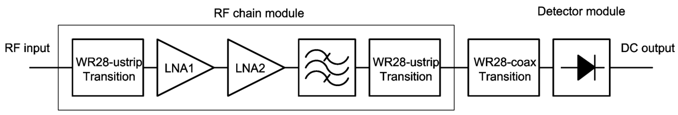


Fig. 2. Designed BEM prototype.

A. WR28 to microstrip transition

BEM input is specified to be a WR28 waveguide which covers the whole band of interest. A waveguide transition has been designed using HFSS software [4]. A cross-section of the transition is shown in Fig. 3. Ridge thickness is 1 mm.

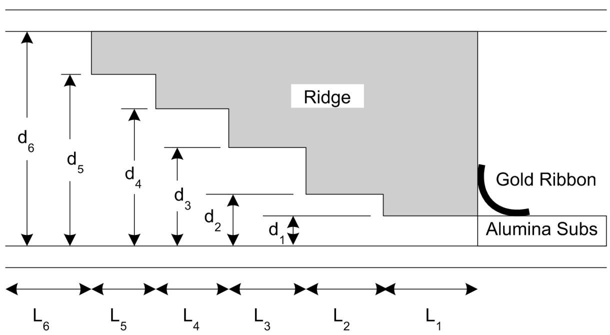


Fig. 3. Cross-section of the designed ridge waveguide transition

TABLE II
RIDGE TRANSITION DIMENSIONS AND CHARACTERISTIC IMPEDANCES

i	Z_c (Ω)	d_i (mm)	L_i (mm)
1	50.5	0.25	3
2	63.92	0.35	2.37
3	98.99	0.65	2.41
4	192.05	1.50	2.56
5	315.42	2.60	2.79
6	387.91	3.56	1.86

Impedance transformation from microstrip to waveguide is achieved through five sections, where the first section has the same height (d_1) as the substrate thickness. Transition dimensions are presented in Table II. Fig. 4 shows test results of the transition measured in a back-to-back configuration.

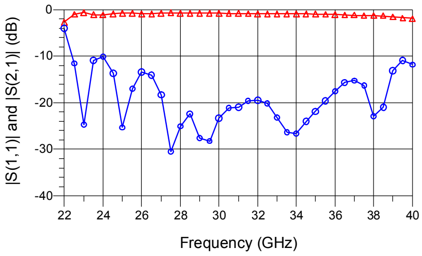
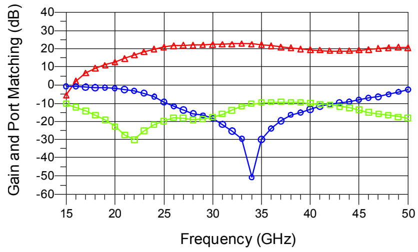


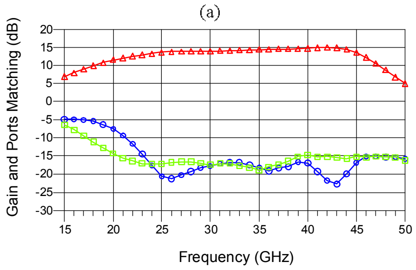
Fig. 4. Measured results of the ridge waveguide transition: S(2,1) (red triangles) and S(1,1) (blue circles).

B. Low Noise Amplifiers (LNAs)

To meet the BEM specifications around 30 dB of RF gain is needed. This gain is achieved through two commercially available MMIC LNAs. First LNA is model AMMC-6241 from Avago Technologies while second LNA is model ALH140 from NGST. These MMICs have been measured using a coplanar probe station together with PicoProbe coplanar-microstrip transitions to include the effect of the input and output bonding wires. Results are depicted in Fig. 5.



(a)



(b)

Fig. 5. Measured characteristics of (a) AMMC-6241 and (b) ALH140: S_{21} (red triangles), S_{11} (blue circles) and S_{22} (green squares). Bias set to typical values recommended by the manufacturers.

C. Band pass filter

Fig. 6 shows the designed band pass filter. Broadband requirements are difficult to achieve with coupled-line filters, therefore a stub filter was selected. It was designed on Alumina substrate (ε_r = 9.9 and h = 254 µm). Measurements have been carried out using PicoProbe coplanar-microstrip transitions and the results are presented in Fig. 7. Insertion loss is less than 0.8 dB in whole band while the return loss is better than 10 dB.

Fig. 6. Designed band pass filter together with coplanar-microstrip transitions.

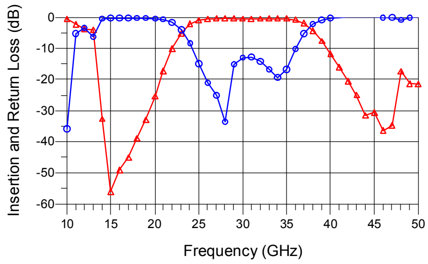


Fig. 7. Band pass filter measurements: S(2,1) (red triangles) and S(1,1) (blue circles).

D. Detector

The zero-bias beam lead Schottky diode MZBD-9161 from Aeroflex Metelics has been used to design a square-law detector. The detector has been designed in Alumina substrate with a TaN resistive layer of 20 Ohm/sq. The thin film distributed resistors are used to flatten the frequency response and to achieve a good input matching.

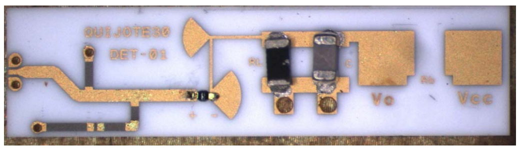


Fig. 8. Designed square-law detector.

The detector was designed with a coplanar-microstrip transition to be able to take measurements prior to be mounted in a module. Results of these measurements are presented in Figs. 9 and 10.

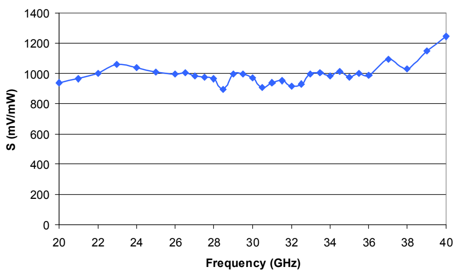


Fig. 9. Detector sensitivity over frequency with a P_{in} = -30 dBm.

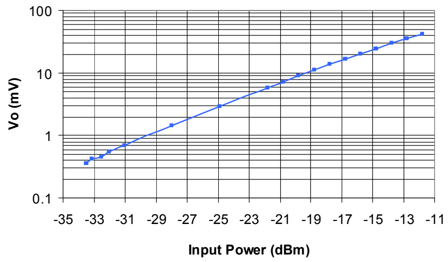


Fig. 10. Detector compression characteristic at f_{in} = 31 GHz. P_{1dB} is -13.8 dB.

In this first BEM prototype the detector has been mounted in a separate module, which permits more flexibility in tests since the RF and DC parts are separated. Input matching of the detector mounted in its module is showed in Fig. 11.

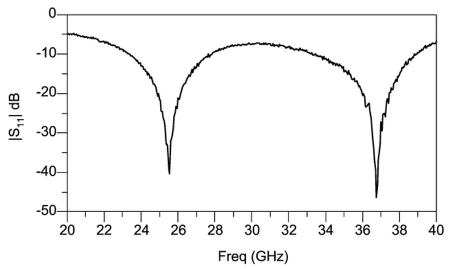


Fig. 11. Detector module input matching.

III. Simulation

For BEM simulation, S-parameters from the different measurements have been used for the linear subsystems, i.e. WR28-microstrip transition, LNAs and filter. The detector has been simulated using a non-linear model of the diode [5].

The simulation was carried out in ADS software from Agilent Technologies using Harmonic Balance (HB) and Large Signal Scattering Parameters (LSSP) [6]. Simulation results are presented in Figs. 12-13, 15-16 together with measurements.

IV. BEM Measurement Results

A. RF chain results

Gain, input matching and noise of the BEM have been measured on the RF chain module. S-parameters have been tested with the E8364A PNA using R11644A calibration kit. Noise has been measured with the N8975A noise figure meter and R347B noise source, all from Agilent Technologies.

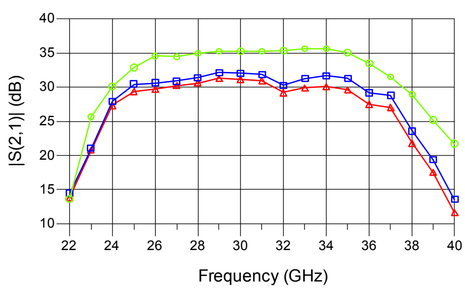


Fig. 12. Gain results. First LNA bias: V_{dd1} = 3 V (red triangles), V_{dd1} = 2 V (blue squares). Simulation (green circles).

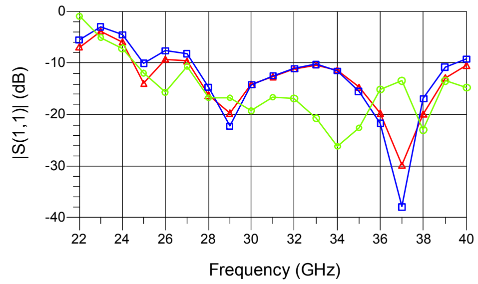


Fig. 13. BEM input matching results. Measurements with two different first LNA bias: V_{dd1} = 3 V (red triangles) and V_{dd1} = 2 V (blue squares). Simulation result is shown with green circles.

Figure 14 shows noise results with a noise figure less than 3.9 dB in the band, which is almost 0.5 dB below the specifications.

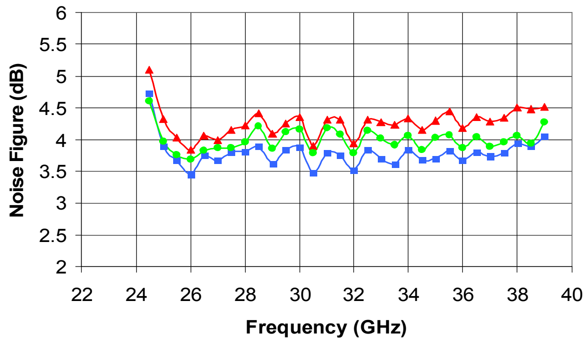


Fig. 14. BEM noise with different bias points of the first LNA: V_{dd1} = 3.5 V (red triangles), V_{dd1} = 2 V (blue squares) and V_{dd1} = 1.5 V (green circles).

B. RF to DC results

To measure RF to DC conversion the detector module was connected to the RF chain module through a waveguide to coaxial transition. The 83650B sweeper generator from Hewlett-Packard was used as signal generator for the tests.

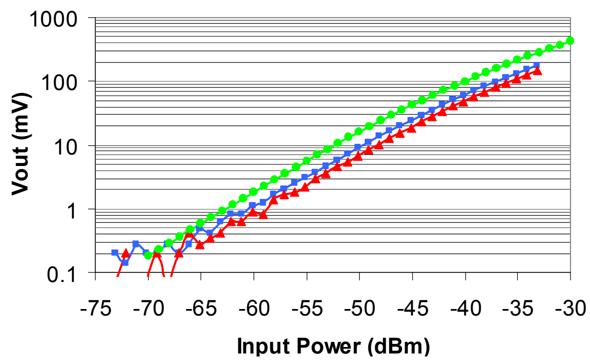


Fig. 15. Output DC voltage versus BEM input power at f_{in} = 31 GHz for different bias points of the first LNA: V_{dd1} = 3 V (red triangles) and V_{dd1} = 2 V (blue squares). Simulation result is shown with green circles.

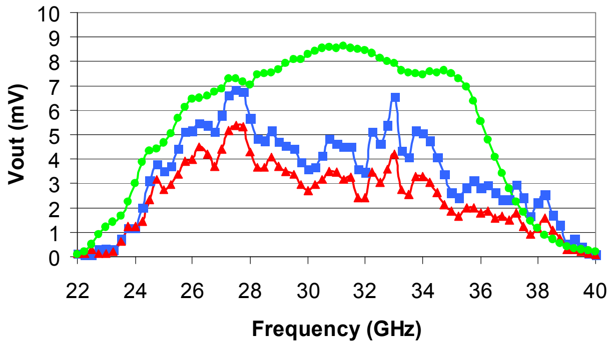


Fig. 16. Output DC voltage over frequency at BEM P_{in} = -53 dBm for different bias points of the first LNA: V_{dd1} = 3 V (red triangles) and V_{dd1} = 2 V (blue squares). Simulation result is shown with green circles.

Output DC voltage is in the range 1 to 10 mV for a BEM input power of -53 dBm, which meets the preliminary specifications.

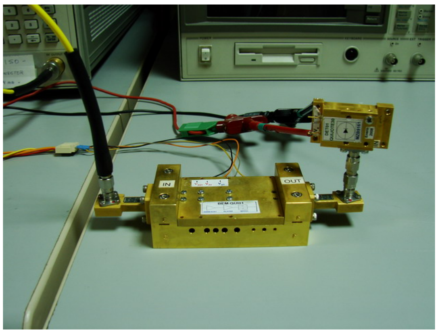


Fig. 17. BEM and detector modules while taking RF to DC measurements.

V. Conclusions

This paper has presented the design, simulation and measurement results of a broadband back-end module in the Ka-band for QUIJOTE project, which is a new ground-based experiment for measuring CMB polarization and complement data from Planck mission.

Both simulation and BEM prototype results prove feasibility of the proposed scheme and fulfill the preliminary specifications.

Acknowledgment

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