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Planck Satellite 70 GHz EBB-Version Back End Module

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ABSTRACT

The first complete 70 GHz Back End Module (BEM) of the coming Planck satellite is described. It includes an H-plane waveguide band pass filter, an INP HEMT amplifier, a diode detector made on 0.1 mm alumina substrate and video amplifiers. RF parts are designed, manufactured, and measured individually and then the complete BEM is tested. Stringent requirements are set through the mechanical layout of the entire functional unit. Most specifications have already been met with the exception of conversion loss in band ripple which must be further reduced.

INTRODUCTION

Starting 2007, the coming Planck satellite will measure the most detailed map of the cosmic microwave background radiation between frequencies 30-850 GHz. The so-called low frequency continuous comparator total power receivers (33, 40, 70, and 100 GHz) are based on cryogenically cooled INV HEMTs while the higher frequency receivers are bolometers. The low frequency front end is cooled down to 20 K for normal operation but the back end operational temperature is 300 K [1,2]. The 70 GHz receiver front and back end units are developed in Finland in co-operation with Millilab, Ylinen Electronics, and Metsahovi Radio Observatory.

The 70 GHz frond ends have 35 dB gain and 25 K noise temperature over the entire operating bandwidth of 63-77 GHz. One complete receiver measures two orthogonal polarizations from the antenna ports and compares this signal with the 4 K physical temperature of the reference loads. The compared signal goes from FEM to BEM trough 1 m long waveguides. The back end module amplifies, filters, detects, and video amplifies each input signal [1].

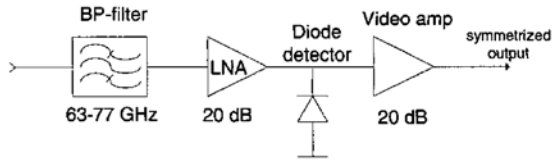

Fig. 1. A simplified functional block diagram of the 70 GHz Planck satellite back end module

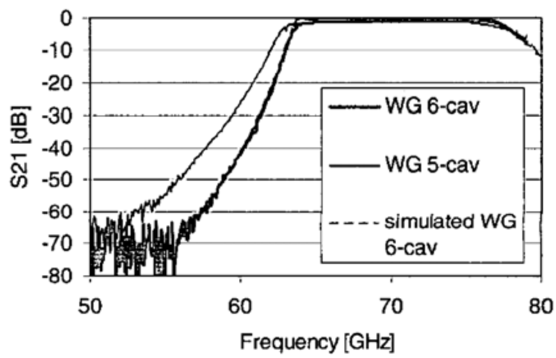

Fig. 2. Measured S_{21} of six and five cavity H-plane WR-12 waveguide filters and the respective simulated S_{21} of the six cavity device

INDIVIDUAL RF PARTS

The measured background microwave radiation will be about 3 K at 70 GHz. The receiver's antenna temperature is 28 K giving 190 kW of input power to BEM when using an effective bandwidth of 14 GHz. The operating frequency range

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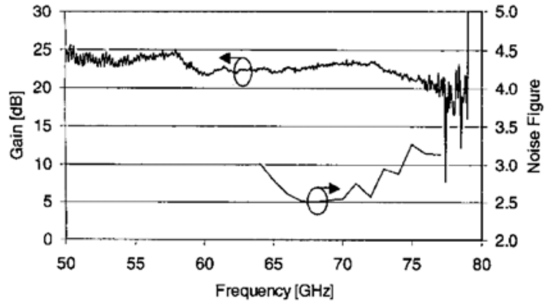

Fig. 3. The measured gain and noise figure of a split block packaged INP-LNA. Higher band ripple is due to the WR-15 waveguide measurement set-up

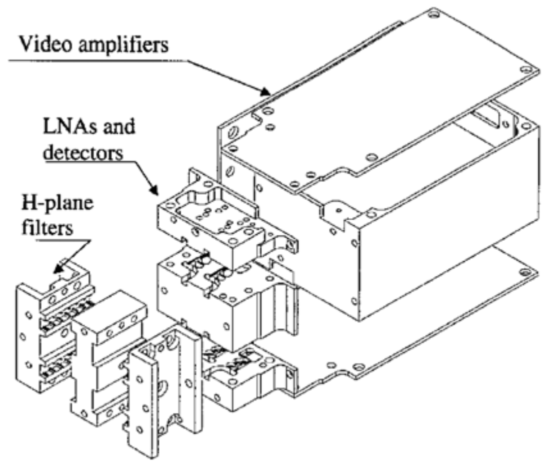

Fig. 6. The final EBB BEM mechanical construction

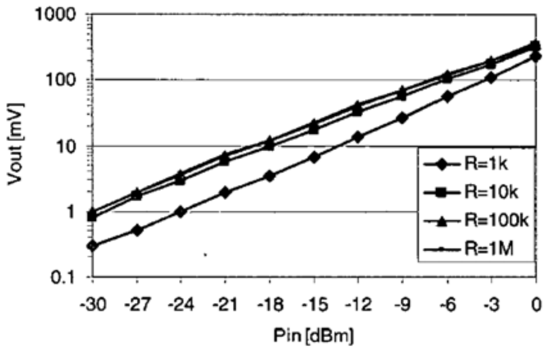

Fig. 4. Diode detector sensitivity at 70 GHz with different load resistor values

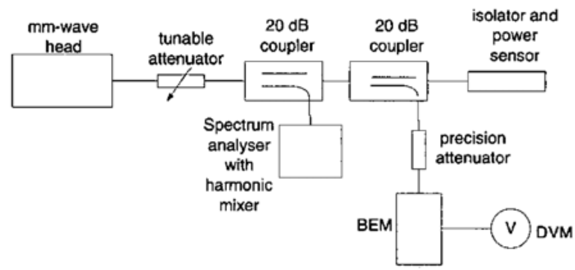

Fig. 7. BEM frequency response measurement set-up

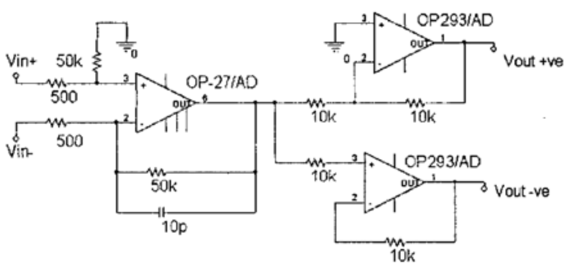

Fig. 5. EBB BEM video amplifier circuitry

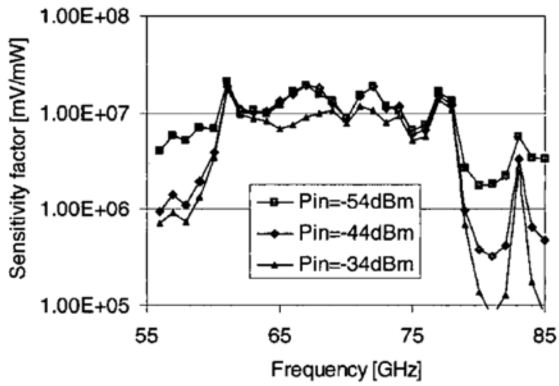

Fig. 8. BEM conversion factor frequency response with a stimulus level from –60 dBm to –40 dBm in 3 dB increments

is limited in the BEM with band pass filters and the RF signal is amplified to be in the square law region of the diode detector. A simplified BEM block diagram is shown in Figure 1.

The waveguide filter is the first functional element of the BEM used to minimize unwanted waveguide to microstrip transmissions. Basic approximate filter calculations were done according to principles outlined in [3, 4, 5] and the final structure was fixed with the HFFS electromagnetic field simulator. The simulated and measured waveguide filter responses are shown in Figure 2.

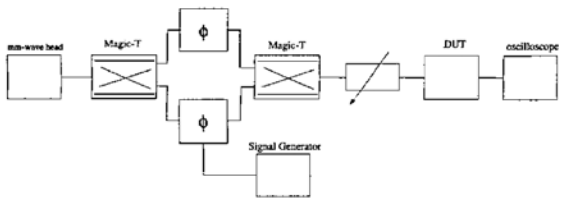

Fig. 9. BEM transient response measurement

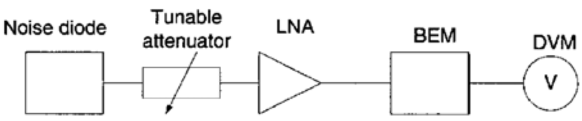

Fig. 10. Wide band noise sensitivity measurement

The LNAs were measured individually in split block packages and the bias point was optimized for gain. The chosen LNAs are described in more detail in [6], and recently in ***Systems***, [7], and further in [8]. Figure 3 illustrates the typical frequency response and noise figure performance of the LNA.

The detector design is based on Agilent HSCH-9161 diodes and ADS simulations. We chose the one diode solution although a two diode structure might have been more sensitive [9]. The chosen detector substrate was 0.1 mm alumina. The detectors were measured individually in the split block packages. Figure 4 shows diode sensitivity curves with different load resistor values. Op27 operational amplifiers were selected as video amplifiers. A schematic of the video amplifiers is shown in Figure 5.

MECHANICAL DESIGN

The mechanical layout design was done in the Mechanical Desktop 5 environment. There was a certain predefined physical "envelope" or volume for the BEM having dimensions of $15 \times 30 \times 90$ mm^3. All four channels with filter, LNA, detector, video amplifiers, bias supplies, and connectors have to fit inside the given envelope. The final EBB BEM mechanical construction is shown in Figure 6. In this physical layout, the waveguide filter, LNA-detector module and video amplifiers can be measured individually. The RF parts were made symmetric, so that a good match between filters and the LNA could be found if there were differences between chains.

COMPLETE BEM MEASUREMENTS

The following parameters were tested with the complete BEM:

- CW frequency response
- transient response with a CW stimulus
- sensitivity with CW and wide band noise stimulus.

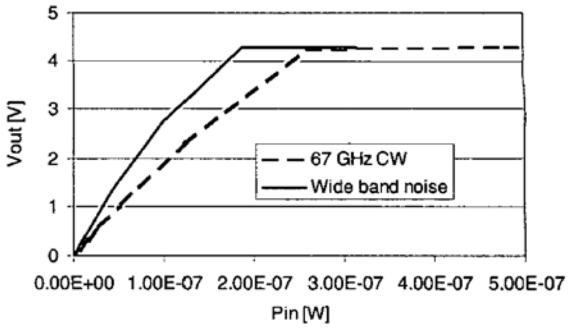

Fig. 11. BEM dynamic range measured with 67 GHz CW and with wideband noise

A VNA mm wave head was used as a CW source from 55 to 85 GHz at 1 GHz increments. The input power was measured with a power sensor from the directional coupler main arm, while the 20 dB coupling was used to reduce the BEM input level.

The block diagram of this setup is highlighted in Figure 7.

The conversion factor describing the output voltage as a function of input power was calculated from the frequency response measurement. Results are illustrated in Figure 8. The frequency response ripple is likely caused by the mismatch between the LNA and the diode detector. If matching turns out less favorable, this will be fixed with an attenuator between the LNA and the detector.

The transient response was measured with Tektronics TDS 754 B oscilloscope and CW stimulus. CW amplitude modulation was applied with two Millitech CMT-12R60S0 magic, T's and two Pacific mm-Product 6090m phase switches as illustrated in Figure 9. A modulation depth exceeding 30 dB could be achieved when using phase matched waveguides. The time constant of the phase switches was measured to be less than 50 µs with Elva ZBD-15 diode detectors. The BEM time constant was 0.5 ms and is limited by video amplifiers.

The BEM sensitivity was measured with a CW stimulus and wide band noise. For the CW measurement, the setup shown in Figure 7 was used. For wide band sensitivity measurements, the scheme in Figure 10 was applied. The CW and wide band noise sensitivities are shown in Figure 11. In the noise diode measurements, the BEM input power was calculated from the known attenuation, LNA gain, and BEM waveguide filter frequency response using averaged values. The difference between noise diode and CW sensitivity is known to be due to average input power calculation in the noise diode method. The 4.2 V upper limit is due to 5 V supply voltage of video amplifiers.

CONCLUSION

The construction of the entire 70 GHz Planck satellite EBB BEM package met all mechanical and most of the RF requirements. Very strict size limitations could be obeyed. A new V-band H-plane band pass filter was simulated, constructed, and measured. Both mm-wave and video amplifiers have been found to work satisfactorily. However, the diode detector layout has to be redesigned to solve the ripple in the conversion factor frequency response.

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