

DESIGN AND PERFORMANCE OF WIDEBAND, LOW-NOISE, MILLIMETER-WAVE AMPLIFIERS FOR MICROWAVE ANISOTROPY PROBE RADIOMETERS

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Abstract - Differential pseudo-correlation radiometers covering 20-25 GHz, 28-37 GHz, 35-46 GHz, 53-69 GHz and 82-106 GHz are used in the Microwave Anisotropy Probe (MAP) mission to be launched in late 2000. This paper describes the design, performance and manufacturing of 140 InP HFET amplifiers suitable for cryogenic cooling which exhibit low noise performance and complex gain match over the given radiometer bandwidths (typical noise temperature of 90 K, or 1.2 dB noise figure, for W-band amplifier at 80 K ambient).

INTRODUCTION

The Microwave Anisotropy Probe (MAP) to be launched in late 2000 is designed to make a full-sky map of the cosmic microwave background (CMB) with 20 μ K sensitivity per $.3^{\circ}.3^{\circ}$ pixel during the two-year lifetime of the mission. Differential pseudo-correlation radiometers covering 20-25 GHz, 28-37 GHz, 35-46 GHz, 53-69 GHz and 82-106 GHz are used in this mission. A schematic view of a MAP radiometer is shown in Fig.1 [1]. The input optics, horns, orthomode transducers (OMT), input hybrid T's and input amplifiers with about 30 dB of gain are passively cooled to about 80 K. The other amplifiers (needed to achieve about -23 dBm signal level at the square law detectors), phase switches, output hybrid T's and bandpass definition filters are kept at about 300 K. A major design challenge was to achieve a complex gain match between two separate signal paths while maintaining the lowest noise and flat gain over the required bandwidth. This led to the amplifier electrical specifications listed in Table I, further augmented by the limits on mass, power dissipation and requirements of space qualification procedures. The following sections give brief descriptions

of the amplifier design process, manufacturing procedures and measured performance of about 140 amplifiers. Previous published results [2]-[6],[10] establish the achievable performance of InP HFET amplifiers. This paper describes for the first time the performance of a relatively large number of amplifiers for a space-based system which required very repeatable noise and complex gain response among the set.

DESIGN

The MAP amplifier specifications required the use of .1 μ m gate length, InAlAs/InGaAs/InP HFET's. More mature GaAs-based technologies could not guarantee the noise performance required by the scientific goals of the mission or satisfy the requirement for the total power dissipation needed to achieve the required gain per channel and maintain the cold station temperature. At the beginning of the project in July 1996, a hybrid "chip-and-wire" MIC realization was chosen over that of using MMIC's. There were several reasons for that decision. In 1996 there was no working example of a MMIC-based cryogenic receiver, but there were already several radio astronomy receivers employing InP HFET MIC amplifiers at K_a- and Q-bands in use. A complex gain matched pair of 60-90 GHz cryogenically-coolable amplifiers had already been demonstrated [2]-[4]. Also, the project schedule requiring deliveries of first amplifiers within a year made the choice of MMIC technology untenable. Consequently, the MIC approach developed over the years at NRAO [2]-[4], [7] was adopted while the component selection, machining, plating, bonding and other assembly procedures were modified to meet the space-qualification requirements.

The InP HFET's having .1 μ m gate length were developed and delivered by HRL Laboratories [8]. Devices of two different gate widths were employed, 100 μ m wide for K-, K_a- and Q-band amplifiers and 50 μ m wide for V- and W-band amplifiers. All amplifiers were designed with CAD

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tools with special emphasis on addressing the microwave design and package design concurrently. For the purpose of noise modeling at room and cryogenic temperatures, the noise model of [9] was employed as described in [2]-[3]. All amplifiers have at their input and output full waveguide bandwidth, E-plane probe waveguide-to-microstrip transitions (IRL > 18 dB). The input, output and interstage microstrip networks use pure PTFE, .003" thick substrates with the coupling capacitors realized using .003" quartz substrates. These networks were designed to achieve low average noise temperature as well as flat gain across the band. The bias networks use a variety of capacitors and resistors connected by bondwires to assure stability and desired out-of-band response. When necessary, the distributed models of these networks were used in the design process.

The gain specifications required four stages of amplification for K-, K_a - and Q-band amplifiers, five for V-band amplifiers and six for W-band amplifiers. The design of both room temperature and cold amplifiers was exactly the same. This allowed for greater flexibility in obtaining the best noise performance and complex gain match in both channels of a radiometer by proper selection of amplifier pairs. Upon final selection, only the bias had to be set for operation at a particular temperature.

The radiometer's performance is strongly dependent on amplifier gain fluctuations due to intrinsic as well as extrinsic factors. The $1/f$ -like random gain fluctuations related to $1/f$ noise of the HFET's were addressed in the previous paper [4]. In order to minimize the susceptibility of amplifier gain to the temperature variations, a constant gate voltage bias scheme was employed. As shown in [3], this type of supply reduces the susceptibility of gain variations at room temperature and virtually eliminates it in the 80 to 95 K range, the desired operating temperature of the cold part of the radiometers.

MEASUREMENTS

The noise measurements were carried out in a receiver setting using "hot" (297 K) and "cold" (78 K) loads placed in front of a horn connected to an amplifier which, in turn, was connected to a room temperature mixer with swept LO frequency. For cold measurements, both the amplifier and the horn were cooled to 80 K, and, consequently the "hot" and "cold" loads were "viewed" through a vacuum window of a dewar. The receiver noise temperatures measured in this way are shown in Fig. 2. Room temperature data contain all deliverable amplifiers while the data at 80 K include only the data for the amplifiers designated for cold operation. Repeatability of both cryogenic and room temperature performance is excellent.

An example of gain at 300 K and 80 K of 15 K_a -band amplifiers is shown in Fig. 3. The corresponding phase tracking plots for 11 K_a -band amplifiers, both at room and cryogenic temperatures, are shown in Fig. 4. The plots show the phase difference between a phase response of a particular amplifier and the average phase response computed for the set of 11 amplifiers. Another example of gain measurements of 40 W-band amplifiers is shown in Fig. 5. The phase tracking plots of 30 W-band amplifiers at 297 K and 23 W-band amplifiers at 80 K, computed as in the K_a -band case, are shown in Fig. 6.

CONCLUSIONS

The design and performance of a series of cryogenically-coolable, InP HFET amplifiers for the MAP mission have been described. The amplifiers not only exhibit the state-of-the-art performance but also an excellent repeatability of noise temperature and complex gain sufficient for the construction of the phase switched pseudo-correlation radiometers with 20 percent relative bandwidth, even at the W-band frequencies. The choice of hybrid MIC technology, dictated by the state-of-the-art of the less mature (at the time of decision) InP MMIC technology and also by schedule concerns has been validated. The advancements in InP MMIC design and technology will likely make a different choice appropriate for some future projects. Yet, in low volume, low budget, and some high performance applications, this approach could prove to be cost effective and schedule efficient for years to come.

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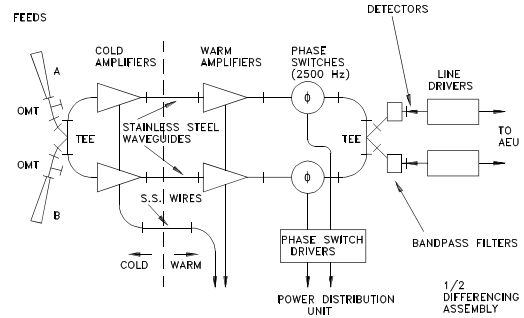


Fig. 1. Schematic of MAP pseudo-correlation radiometer.

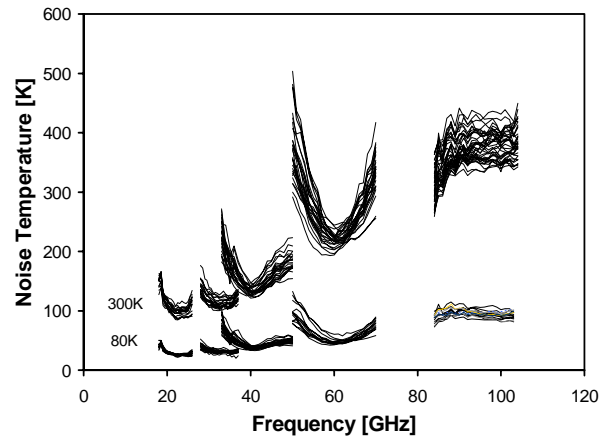


Fig. 2. Measured noise performance of all MAP amplifiers at room temperature and 80 K.

TABLE I. NRAO MAP Amplifier - Technical Specification

Freq. Band [GHz]	InP HEMT [μm^2]	Noise (80/300K) [K]	Gain (80/300K) [dB]	Gain Flatness [dB]	Phase Tracking [deg]	Power (80/300K) [mW]
20-25	0.1 x 100	<27/100	35/34	± 1.5	± 15	<(24+9)/45
28-37	0.1 x 100	<40/145	33/34	± 1.5	± 15	<(24+9)/45
35-46	0.1 x 100	<50/180	36/31	± 2.0	± 20	<(24+9)/45
53-69	0.1 x 50	<80/300	36/31	± 2.5	± 20	<(30+9)/45
82-106	0.1 x 50 (unpassivated)	<130/460	35/29	± 3.0	± 25	<(28+9)/54

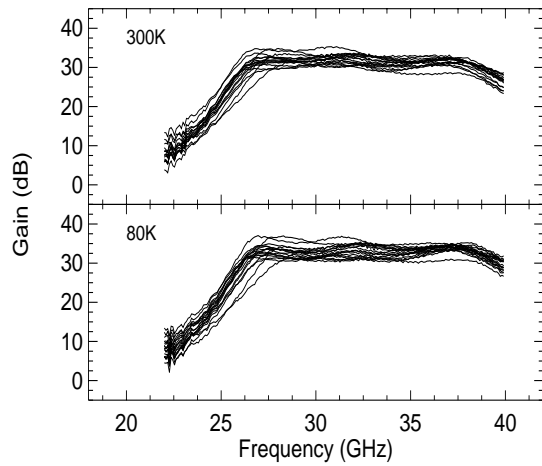


Fig. 3. Measured gain performance of K_a -band amplifiers.

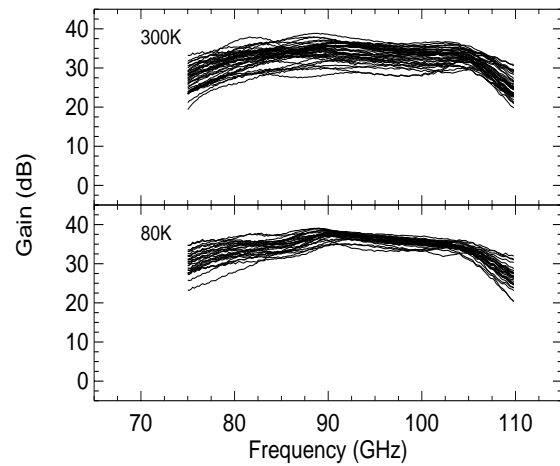


Fig. 5. Measured gain performance of W-band amplifiers.

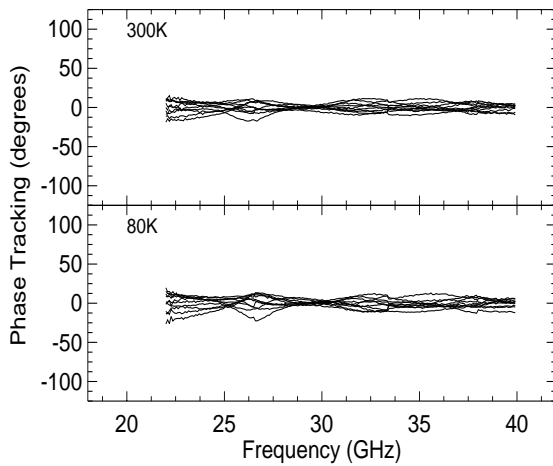


Fig. 4. Phase tracking of 11 K_a -band amplifiers at 300 K and 80 K.

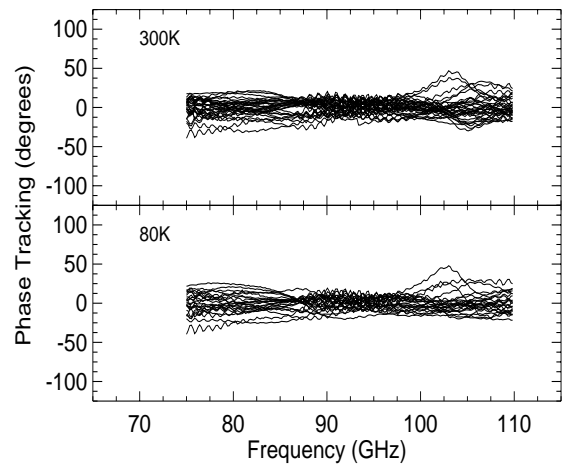


Fig. 6. Phase tracking of 30 W-band amplifiers at 300 K and 23 W-band amplifiers at 80 K.