Miniature Packaging Concept for LNAs in the 200-300 GHz Range

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Abstract — In this work, we describe new miniaturized low noise amplifier modules which we developed for incorporation in small-scale satellites or Cubesats, and which exhibit similar or better performance compared to previously reported LNAs in the literature. We have targeted the WR4 (170-260 GHz) and WR3 (220-325 GHz) waveguide bands for the module development. The modules include two different methods of E-plane probes which have been developed for low loss, and stability at high frequencies. MMIC LNAs were also developed for these frequency ranges and fabricated in Northrop Grumman Corporation's 35 nm InP HEMT technology, and we have experimentally verified that noise performance is lower than reported in prior work. The best results include a miniature LNA module with 550K noise at 224 GHz, and a wideband LNA module with 15 dB gain from 230-280 GHz.

Index Terms — MMIC, Low noise amplifiers, InP, WR3, WR4.

I. Introduction

In this paper, we describe developments on miniaturized low noise amplifier modules covering the 200-300 GHz range. Several prior papers on LNAs in this frequency range have been reported [1-6], with results as low as 600K-800K noise in this frequency range. These results have utilized a variety of packaging techniques and waveguide probe transitions. Integrated probes [1- 3] made right on the MMIC, as well as hybrid probes made of quartz have been described [4]. Integrated probes offer many advantages in performance, however the processing involved as well as laser dicing of non-rectangular chips can be expensive. Our miniaturized approach to packaging the MMIC LNAs is a low-cost alternative which requires no special processing techniques beyond the rectangular MMIC chip fabrication.

The miniature modules that we report on make use of hybrid E-plane transitions made either of quartz or GaAs. In our work, the total size of the module is reduced by reducing the total waveguide inside the module, as well as reducing the size of the internal printed circuit bias board, and shortening the E-plane transitions. A photograph of the miniature amplifier module is shown in Fig. 1, alongside with a US nickel, and measures 4 mm in length. The purpose of the size reduction in the module is twofold – 1. Reducing the input waveguide loss will improve the LNA noise; and 2. A miniature package will be very useful for applications that require small size and mass, such as in commercial test equipment, small-scale satellites or Cubesats, where miniature receivers could be used for atmospheric remote sensing on a very small platform, and any application which requires a portable receiver. While these prototype modules contain only amplifiers, future modifications could include integrated miniature mixers or detector diodes, providing a full receiver instrument in an ultrasmall package.

II. Miniature Amplifier Module Description

The mini-module contains a custom printed circuit board for DC biasing of the MMIC amplifiers inside (Fig. 2), which contains screwholes for alignment of the block halves. A Nanonics 4-signal DC connector was used to bring power into the MMIC. The modules contain low noise amplifier chips which were fabricated in Northrop Grumman Corporation's 35 nm gate length InP HEMT technology. The chips have a gain range of 150-320 GHz, and are processed on 50 μm thick InP substrates. The HEMT devices are 2-finger devices from 18 μm to 30μm in width. The circuits made use of three or four stages of gain, designed in grounded co-planar waveguide, with both common-source and cascode gain stages. Common-source was used as the input stage for all results reported here.

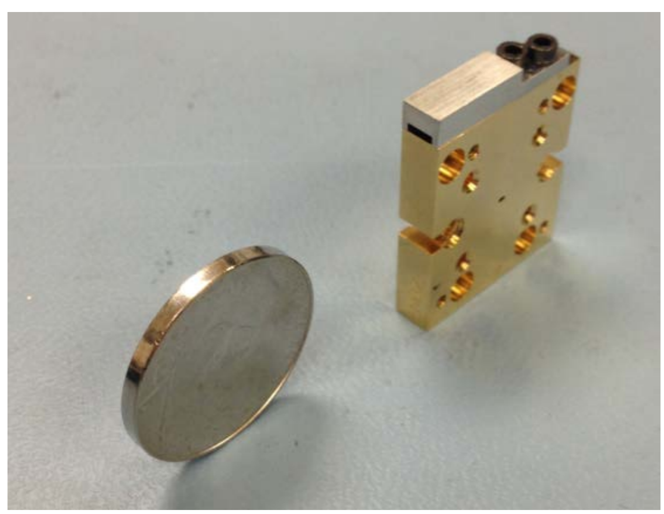

Fig. 1. Side view of miniature amplifier with US nickel for scale.

The connections to waveguide were accomplished in two ways: 1) using a 3 mil quartz hybrid E-plane transition with a wirebond, and 2) a 1 mil thick GaAs E-plane transition, which contained a beamlead connection on the probe, and which was tack-bonded to the input line of the MMIC chip. Micrographs showing the packaging with the GaAs beamlead probes are shown in Fig. 3, and the quartz probes in Fig. 4. The modules also have a unique stacking feature [7]. Since the modules are so thin, connecting them to standard waveguide requires longer screws as they are effectively as long as a typical waveguide shim. Cascading two or more modules, as is frequently done in low noise receivers, are done with other screws and threaded holes placed on the broad face of the module. Modules are then cascaded by rotating neighboring modules by 180 degrees to prevent screw interference, as shown in Fig. 5.

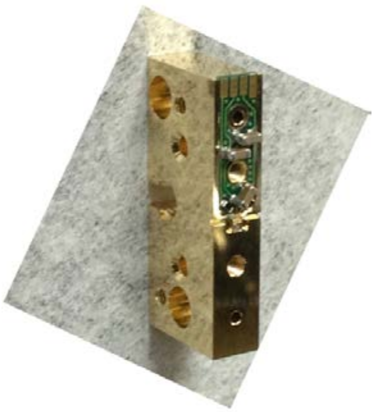

Fig. 2. Bottom half of split miniature amplifier module.

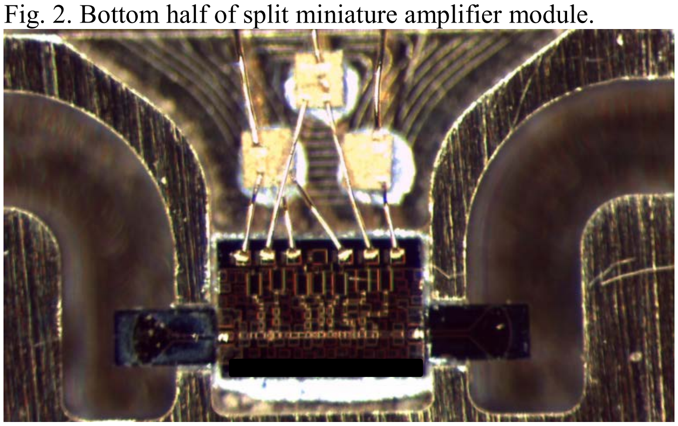

Fig. 3. MMIC LNA with GaAs beam lead E-plane probes.

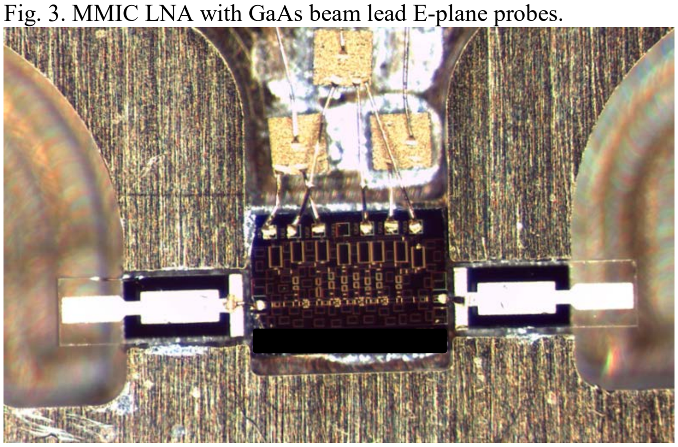

Fig. 4. MMIC LNA with quartz E-plane probes.

III. Miniature Amplifier Measurements

The mini-modules were measured for S-parameters and noise. The S-parameters of one of the LNA chips are shown in Fig 6. We first measured the chips on-wafer using WR5 and WR3 waveguide frequency extenders and GGB industries waveguide probes. The measured results were compared to the design simulations created in ADS, and agree favorably over a wide bandwidth. Slight variations in the gain and return loss are observed, though given the wide bandwidth of the amplifier, these seem in reasonable agreement.

The LNA was packaged in the WR3 miniature module using the GaAs beam lead probes, and measured for S-parameters again (Fig. 7). The packaging losses are fairly small up to 280 GHz, but diverge from the on-wafer S-parameters above 280 GHz. This could be the result of unexpected ohmic losses in the GaAs beam lead probe. To further explore this, we measured thru lines using the GaAs beam lead probes, and were able to verify some of the losses due to the probe loss, possibly due to the background carrier concentration in the GaAs material used. The mini-module was measured for noise performance by placing it in front of a VDI WR3 subharmonic mixer, and performing a Y-factor measurement with the IF signal using liquid nitrogen as the cold load. We observed a noise temperature of 1090K at 260 GHz, and very flat gain and noise from 230-280 GHz (Fig. 8). The noise is consistent with simulated noise of 800K and the possible ohmic loss in the GaAs beam lead probe which could add as much as 1 dB.

A second set of mini LNA modules was measured which used the commercially fabricated quartz E-plane transition of Fig. 4. S-parameters revealed between 15-20 dB of gain. We also measured noise of the WR4 quartz mini LNAs using a WR4 VDI subharmonic mixer, in the same way as the WR3 modules. The noise performance of the three modules is shown

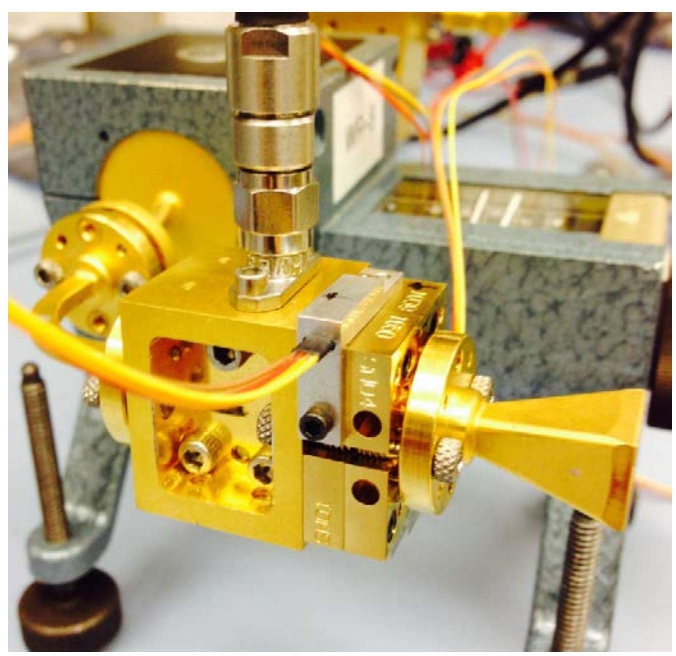

Fig. 5. Two cascaded amplifier modules, one flipped 180 degrees to keep the overall receiver size small, shown with a commercial horn and mixer.

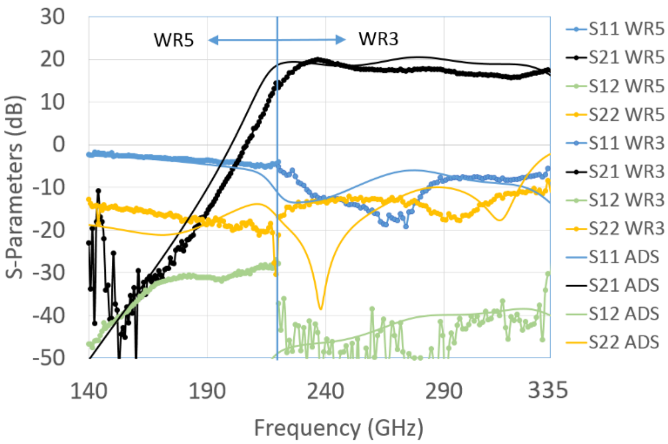

Fig. 6. Measured on-wafer S-parameters of one of the LNA chips, in WR5 and WR3 waveguide bands, and compared to the design simulations (thin solid lines).

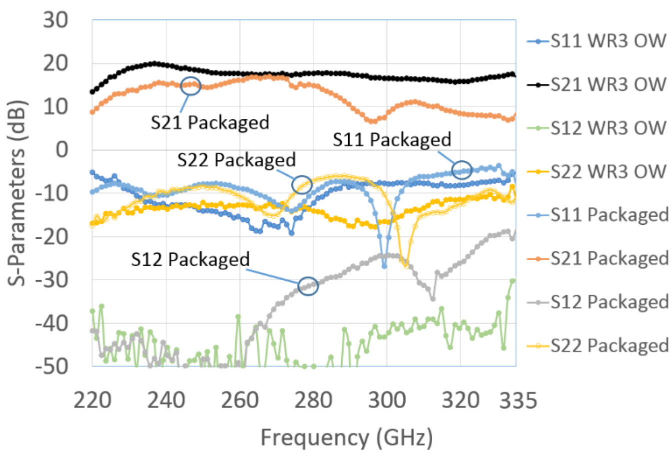

Fig. 7. S-parameters of the mini-module utilizing the LNA of Fig. 6. OW indicates on-wafer measurements.

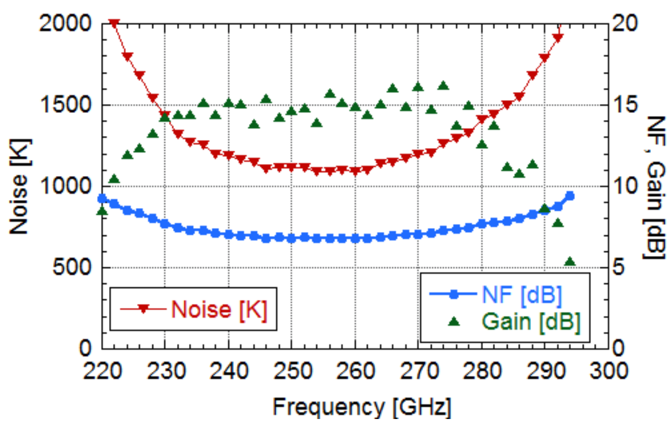

Fig. 8. Gain, NF and noise temperature of the WR3 mini LNA.

in Fig. 9, along with the total gate periphery indicated. Modules 1 and 2 use the quartz probes, while Module 3 of Fig. 8 uses the GaAs probe. The best results from Module 1 include noise as

Table 1. Packaging method and LNA performance.

Freq	Method	Probe	Noise [K]	Noise [dB]	Ref.
220	Hybrid	Quartz 3 mil	600	4.9 dB	[4]
224	Hybrid	Quartz 3 mil	550	4.6 dB	This Work
230	Integrated	InP 1 mil	~700	5.3 –6 dB	[3]
232	Integrated	GaAs 2 mil	630	5.0 dB	[1]
243	Integrated	GaAs 2 mil	760	5.6 dB	[1]
243	Integrated	GaAs 2 mil	870	6 dB	[2]
250	Hybrid	Quartz 3 mil	690	5.3 dB	This Work
260	Hybrid	GaAs 1 mil	1090	6.8 dB	This Work
270	Integrated	GaAs 2 mil	670	5.2 dB	[1]

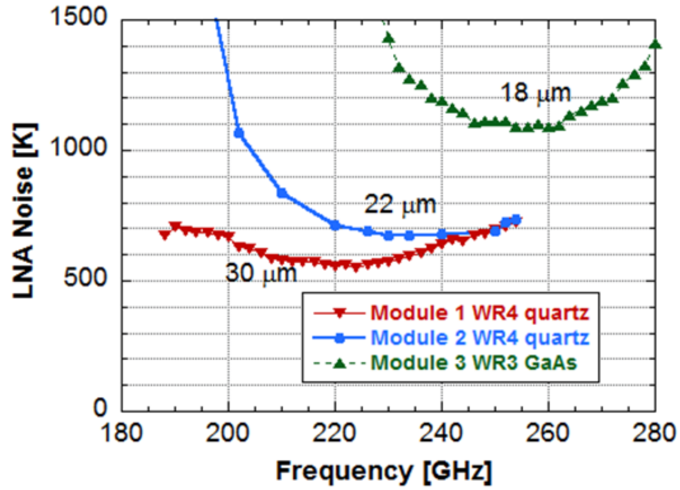

Fig. 9. LNA noise vs. frequency for three chip and module designs, with transistor size indicated.

low as 550K (4.6 dB) at 224 GHz, and below 600K (4.9 dB) from 210-238 GHz in a chip with 30 μm periphery HEMTs. Module 2 with a different chip design (and smaller gate periphery of 22 μm) had a minimum noise of 670 K (5.2 dB) at 234 GHz, and noise below 700K (5.3 dB) from 220-250 GHz. Module 3 used 18 um periphery. The minimum noise tuning as a function of gate periphery is evident, as MMICs with smaller periphery devices tune to higher frequency. Table 1 summarizes our results along with best reported results in the literature. Our hybrid approach, with miniature packaging scheme, compares favorably with more expensive integrated probe techniques or laser dicing singulation, and even surpasses some prior work in terms of low noise.

IV. Conclusion

We developed highly miniaturized low noise amplifier modules for the WR4 and WR3 waveguide bands using quartz E-plane transitions and GaAs E-plane transitions. The mini LNAs had record noise performance in the 210-230 GHz range, mainly due to the reduced waveguide length enabled by miniaturization of the bias board, and the InP MMIC chip performance. While somewhat lossier than the quartz probes, the GaAs probes led to exceptionally wideband stable operation. The best overall noise performance was 550K (4.6 dB) at 224 GHz, and 690K (5.3 dB) at 250 GHz.

Acknowledgments

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