Very Wideband Automated On-Wafer Noise Figure And Gain Measurements At 50-110

T. Vähä-Heikkilä, M. Lahdes, M. Kantanen,T. Karttaavi, and J. Tuovinen

MilliLab, VTT Technical Research Center of Finland, P.O. Box 1202, 02044 VTT, Finland,
Tel. 35894567219, Fax 35894567013, email: tauno.vaha-heikkila@vtt.fi

On-wafer noise figure and insertion gain measurement set-ups have been developed over 50-110 GHz frequency range. Wafer scale noise figure and insertion gain measurements can be done in an automatic manner using PC controlled automated probe station and in-house written software. In narrow band measurements, large systematic errors may remain undiscovered. These errors are usually caused by reflections in the set-up, which are difficult to calibrate out. Wideband measurements are often the only method, which can efficiently reveal these errors. This aspect is increasingly important as frequency increases.

INTRODUCTION

Several scientific and commercial millimetre wave applications demand very low noise receivers. Low noise amplifiers (LNA) are key components in the low noise receivers. Millimetre wave monolithic integrated circuit technology (MMIC) has created a breakthrough in cost efficient manufacturing of LNAs. To take a full advantage of MMIC processing and both component and system development, efficient on-wafer testing is essential. As examples of commercial applications, radio links at 38 and 59 GHz, wireless local area networks (WLAN) at 20-60 GHz, and intelligent cruise control radars for automobiles at 77 GHz can be mentioned. The highest frequency at millimetre waves, which is more widely used, is 94 GHz. At this frequency, applications are, for example, imaging systems. Scientific applications are mostly related to radio astronomy and cosmology.

Component characterization includes an on-wafer noise figure and gain measurements. The on-wafer noise figure and gain measurements are carried out using two set-ups over 50-110 GHz frequency range: one for V-band (50-75 GHz) and another for W-band (75-110 GHz). Previously, Rodriguez et al (1), Katoh et al (2), and Case et al (3) have presented millimeter wave noise figure measurement set-ups and results at W-band. Wideband measurements are important for obtaining reliable results. This is especially true for mm-wave noise figure measurements, where no good reference components exist. Large systematic errors may remain undiscovered in narrow band measurements. These errors are usually caused by reflections in the set-up, which are difficult to calibrate out fully. Wideband measurements are often the only method, which can efficiently reveal these errors. In addition to wide frequency band, bias conditions and temperature effects can be investigated. By measuring noise figure as a function of bias conditions, optimal operating point of the LNA can be found. Temperature can be adjusted continuously from 213 K to 573 K in these automated measurements.

MEASUREMENT SET-UP

The developed measurement set-ups for V- and W-bands are basically the same, but different components are used at different frequency bands. A noise source is connected to the input of the device under test (DUT). A noise receiver is in the output of the DUT. The principle measurement set-up is shown in Figure 1. Also, reference planes A, B, and C are presented. Wafer scale noise figure and gain measurements can be done in an automatic manner using computer controlled automated probe station and in-house written software. Noise diodes are used as noise sources in both set-ups. A 100 GHz LNA is used to increase the sensitivity of the noise receiver in the W-band set up. A LNA is not needed in V-band measurements, but if low gain devices are measured, it is possible to use a V-band LNA. The LNAs were obtained through the Planck Surveyor collaboration. Mixers are used to downconvert the noise power from V- and W-band to the frequency range of the HP8970A noise figure meter. Local oscillator chain consists of the HP83650A synthesized sweeper, HP 8349B microwave amplifier, and HP83557A mm-wave source module at V-band and HP83558A at W-band. Isolators are used to reduce impedance mismatches in the noise receiver and the noise source. All measurement instruments are controlled using a computer. Schematic description of the W-band set-up is shown in Figure 2.

NOISE FIGURE AND GAIN MEASUREMENT PROCEDURE

The measurements are carried out in three steps both in V - and W -bands separately: 1. Characterization of the passive network between reference planes A and B (shown in Figures 1 and 2). 2. Noise receiver calibration. 3. Noise measurements of the DUT. The passive network between reference planes A and B consists of the probe and the waveguide section. The passive network A-B cannot be measured directly with a vector network analyzer (VNA) because it is non-insertable. To characterize this network the VNA is first calibrated to the reference plane A by using one port waveguide calibration. Then the VNA is calibrated with an on-wafer 2-port LRRM calibration to the reference planes B and C. The scattering (S-) parameters of the passive network A-B are then calculated from two sets of error coefficients. Also one port SOL calibration could be done at reference plane B instead of the 2-port LRRM calibration. To characterize the noise receiver, an on-wafer thru line is connected between the probes. These reference planes are B and C in Figs. 1-2. The noise source is then connected to the noise receiver and the noise powers are measured in both the hot and cold states of the noise source. The noise figure of the noise receiver can be then determined. After the noise receiver calibration, the noise measurements of the DUT can be done. The thru line is replaced with the DUT. The first step is to find optimal operating point(s) for the DUT. Noise figure, F, and gain, G, are measured and noise measure, $M=(F-1)(1-1/G)^{-1}$, is calculated as a function of the voltage and current between the source and drain (V_{ds} and I_{ds}) of the device under test. Optimal operating point(s) can be found then and noise figure and gain measurements as a function of frequency can be carried out in the optimal operating point(s).

MEASUREMENT RESULTS

To find out the optimal bias points, noise figure, gain, and noise measure measurements were carried out as a function of the V_{ds} and I_{ds} of the LNA. As an example of these measurements, results for four stage LNA are shown in Figures 3 a) and b). These LNAs were processed using HRL Laboratories InP HEMT process. Measurement frequency was 70 GHz. As an example of automated wafer scale on-wafer measurements at W-band, the measured insertion gain and noise figure of four stages InP LNAs are presented in Figures 4 a) and b). Measurements covered 31 different LNAs from the same wafer. Operating point was V_{ds} = 1.2 V and I_{ds} = 25 mA in these measurement routines. To characterize devices, the S- parameters of the LNAs were also measured at W-band. These measurements can be used also in the verification of the gain measurements. Measured S_{21} results for 22 LNAs are presented in Figure 5. The operating point was V_{ds} = 1.2 V and I_{ds} = 25 mA respectively. A good agreement can be seen between the gain (Figure 4 a)) and the S_{21} measurement results. Noise figure and gain measurements were carried out both at V- and W-band. Figure 6 presents combined V- and W-band noise figure and gain measurement results for one four stage InP LNA. The operating point was V_{ds} = 1.2 V and I_{ds} = 25 mA. Measurement results show good overall continuity between different frequency bands. This figure shows also the importance of wideband measurements, as limitations and difficulties in the mm-wave measurement set-up and calibration cause unexpected local variation, e.g., around 72 GHz. The overall uncertainty of the noise figure measurements is about ± 0.5 dB. This is mostly due to the difficulties in the calibration of the measurement system, calibration of the noise source, and the sensitivity of the noise receiver.

CONCLUSIONS

The measurement set-ups for V- and W-band have been developed. The noise figure and gain of the four stage InP LNA have been measured at 50-110 GHz. The measurements can be done in an automatic manner and all devices on the wafer can be measured. Results show good repeatability. Also, continuity between V- and W-band noise and gain measurements is good. As known by the authors, these are the first presented wideband noise figure and gain results measured on-wafer over the V- and W-band.

ACKNOWLEDGEMENT

The help of Todd Gaier from Jet Propulsion Laboratory is greatly appreciated. This work has been supported by the European Space Agency (ESA/ESTEC) contract no. 1655/95/NL/MV and Graduate School GETA, Finland.

REFERENCES

(1) Rodriguez A., Dunleavy L. P., Kirby P.: "*Best Practice for On-Wafer Millimeter Wave Noise Figure Measurements*", 57th ARFTG conference digest, 2001

(2) Katoh T., Kashiwa T., Koski H., Inoue A.,. Ishikawa T.: "*Automated Millimeter-Wave On-Wafer Testing System*", IEICE Trans. Electron., vol. E82-C, pp. 1312-1317,1999

(3) Case M. G., Pobanz C., Weinreb S., Matloubian M., Hu M., Wetzel M., Janke P., Ngo C.*: "Low-Cost, High-Performance W-band LNA MMICs for Millimeter-Wave Imaging*", Proceedings of Spie, Passive Millimeter-Wave Imaging Technology IV, Volume 4032, pp. 89-96, 2000

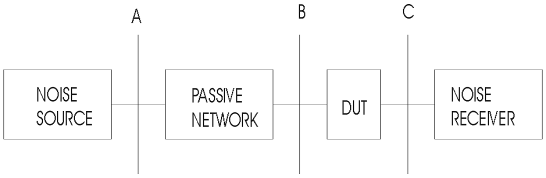


Figure. 1. Principle set-up for noise figure and gain measurements.

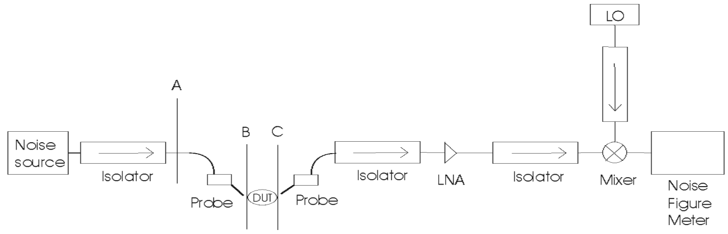
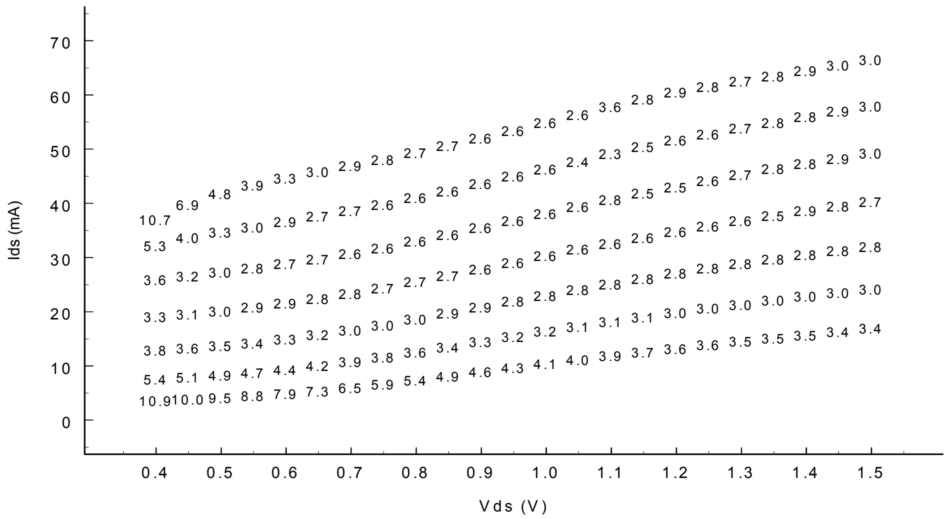
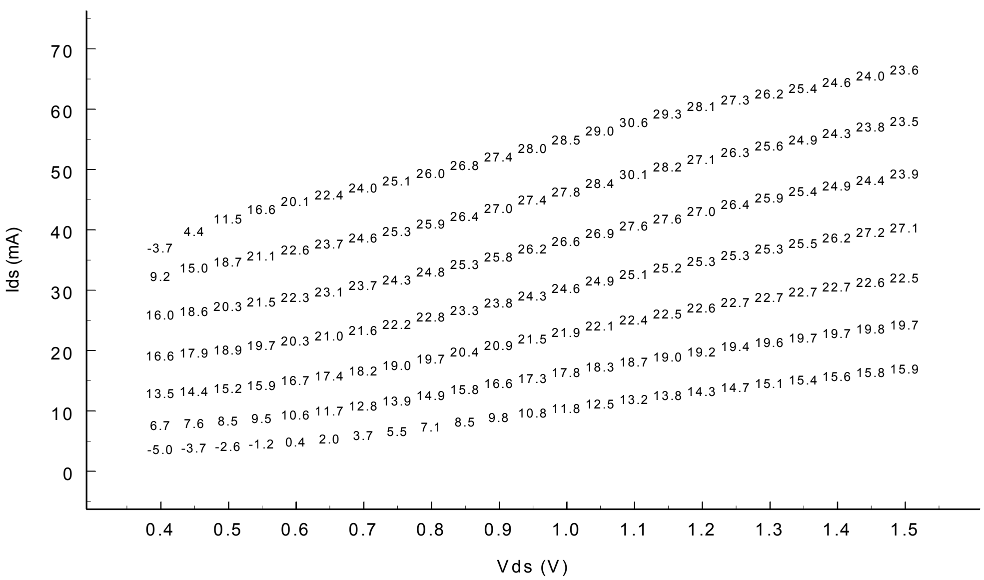


Figure 2. W-band noise figure and gain measurement set-up.

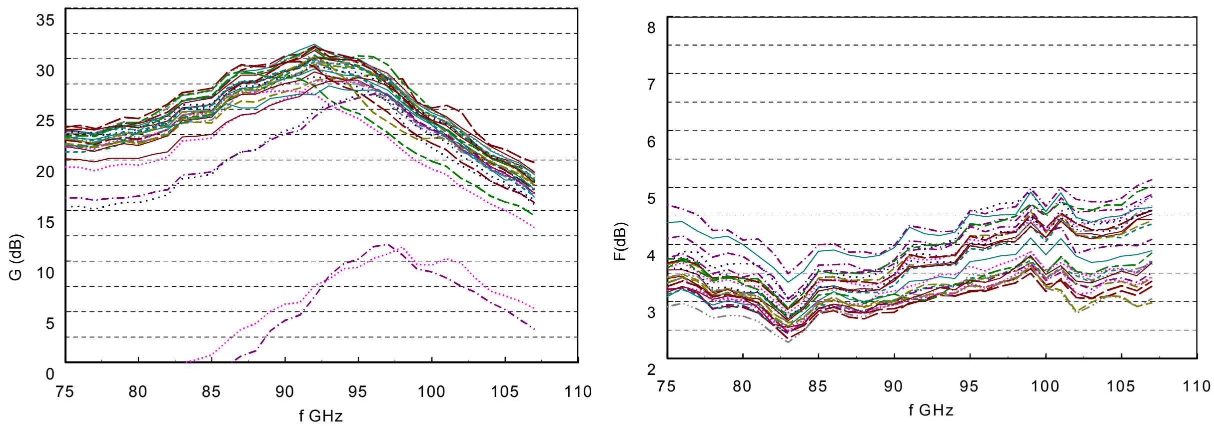


a)



b)

Figure. 3. a) Noise figure of the four stage LNA and b) gain of the LNA as a function of bias at 70.



a) b)

Figure 4. a) Measured insertion gain and b) noise figure for 31 four stages LNAs stages InP LNAs at W-band.

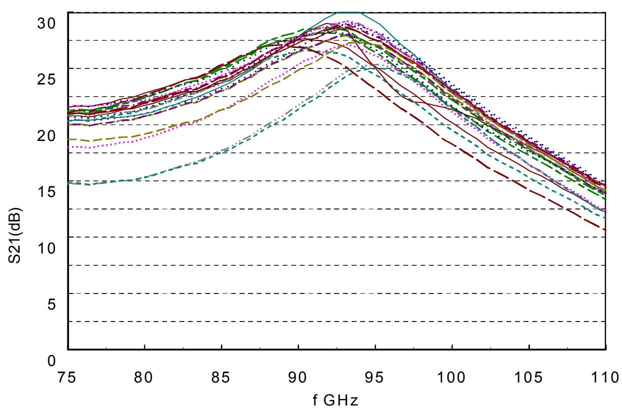


Figure 5. Meaured S_{21} for 22 four stages LNAs at W- band.

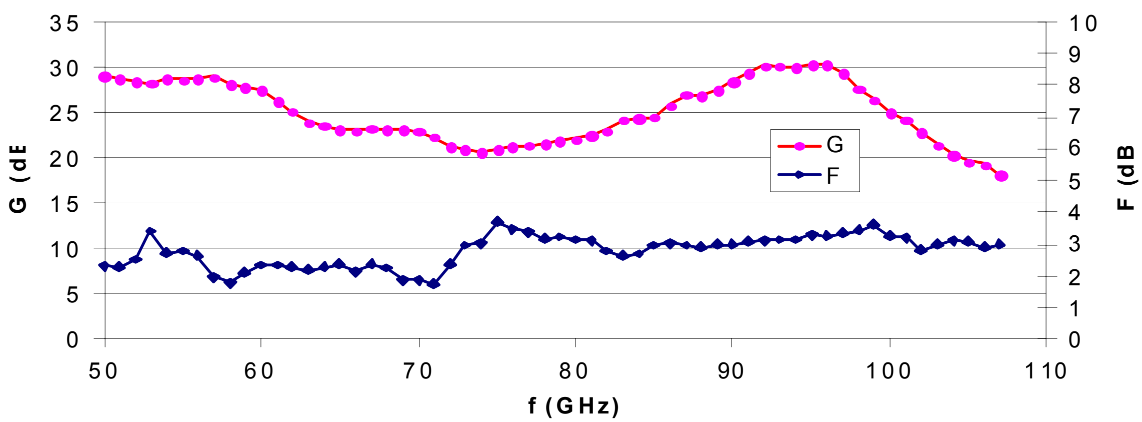


Figure 6. Noise figure and gain at V-and W-band.