1st RadioNet-FP7

Engineering Forum Workshop

Low Noise Figure Measurements at Cryogenic and Room Temperatures

Gothenburg, Sweden

23-24 June 2009

Chalmers University of Technology

Organized by Onsala Space Observatory

Participant List

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6.	Bij de Vaate Jan Geralt	ASTRON, NL
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12.	Esterhuyse Willem	MeerKAT, ZA
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30.	Mariotti Sergio	INAF-IRA, IT
31.	Massler Hermann	Fraunhofer IAF, Freiburg, DE
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34.	Missous Mohamed	University of Manchester, UK
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38.	Panella Dario	INAF - Osservatorio Astrofisico di Arcetri, IT
39.	Pantaleev Miroslav	OSO, SE
40.	Pettersson Lars	OSO, SE
41.	Pospieszalski Marian	NRAO, USA
42.	Rodilla Helena	University of Salamanca, SP
43.	Roddis Neil	SPDO
44.	Rottmannn Izabela	MPIfR-Bonn, DE
45.	Schäfer Frank	MPIfR-Bonn, DE
46.	Seelmann-Eggebert Matthias	FhG-IAF, DE
47.	Sobis Peter	Chalmers University of Technology, SE
48.	Stokroos Martin	SRON, NL
49.	Strandberg Magnus	GARD/OSO, Chalmers, SE
50.	Sundin Erik	GARD/OSO, Chalmers SE
51.	Tegnander Christina	Omnisys Instruments AB, SE
52.	Türk Senner	MPIfR-Bonn, DE
53.	Vassilev Vessen	Chalmers University of Technology, SE
54.	Wadefalk Niklas	Chalmers University of Technology, SE
55.	van der Wal Erik	ASTRON, NL
56.	Weinreb Sander	CalTech, USA
57.	Wilkinson Peter	University of Manchester, UK

Agenda

23 June 2009

08.00 - 08.20	Registration
08.20 – 08.30	**Welcome and Introduction** *Reinhard Keller*
08.30 - 09.30	**Fundamentals of Noisy Networks** *Sander Weinreb*
09.50 - 10.10	**Cryogenic low-noise amplifiers: From InGaAs channel to hybrid module** *Per-Åke Nilsson*
10.15 - 10.35	**Characterization of FhG-IAF low-noise mHEMTs at cryogenic temperatures : DC, S-Parameters and Noise** *Frank Schäfer*
10.40 - 10.55	*Coffee Break*
10.55 - 11.25	**Noise Parameters of FET's: Measurement, Modeling and Use in Amplifier Design** *Marian Pospieszalski*
11.35 - 11.55	**Estimation of Uncertainty in Noise Measurements Using Monte Carlo Analysis** *Juan Daniel Gallego*
12.00 - 12.20	**Practical aspects on noise figure measurements** *Sergio Mariotti*
12.25 - 12.45	***Cryogenic LNA Characterization: GARD Experience*** *Erik Sundin*
12:50 – 13:10	**LNA Performance Optimisation Using Post-production Noise Characterisation** *Andrea Cremonini*
13:15 - 14.00	*Lunch*
14:00 – 15:00	*Labs Visit*
15.00 – 18.00	*Trip To Onsala Space Observatory*
19.30 -	*Social Dinner*

Agenda

24 June 2009

08.00 – 08.10 *Administrative Issues*

08.10 – 08.40 **The IAF mHEMT Low-Noise Technology and its Extension to Cryogenic Applications**
Matthias Seelmann-Eggebert

08:50 – 09.10 **Millimeter HEMT amplifier measurements at cryogenic temperatures**
Francois Mattiocco

09.15 - 09.35 **Measurement Setup for ALMA Band 5 Prototype Cartridge**
Magnus Strandberg

09.40 - 09.55 **A Measurement Test Set for ALMA Band 9 Amplifiers**
Isaac Lopez-Fernandez

10.00 - 10.15 *Coffee Break*

10.15 - 10.45 **Cryogenic Measurements of CMB Polarimeters**
Pekka Kangaslathi

10.55 - 11.15 **Progress on FPA LNA developments and LNA characterization**
Laurens Bakker

11.20 - 11.40 **Noise measurements for the SKA**
Neil Roddis

11.45 - 12.05 **Active antenna design and characterization for the mid-SKA**
Jan Geralt Bij de Vaate

12.10 – 13.00 *FORUM*: **FETs for Low Noise Amplification: Reasons of success, limits and potential for improvements in cryo-LNAs"**
Moderator: Matthias Seelmann-Eggebert

13.00 - 13.15 *Concluding remarks*

13.15 – 14.00 *Lunch*

ABSTRACTS

Fundamentals of Noisy Networks

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Abstract

The fundamentals of noisy networks, developed 40 years ago, will be reviewed and applied to current problems of low noise amplifier design and measurement. The choice of noise parameters for a given problem will first be discussed. Given the noise parameters of a transistor, fundamental theorems, which limit and quantify the optimum noise performance with arbitrary input, output, and feedback networks will be described. Techniques for measurements of differential and non-50 ohm amplifiers and the simplification of noise parameter measurements by use of S parameter data will be presented.

Outline

- Choose Your Weapons (basis and choice of noise parameters)
- It Takes Two to Tango (correlation depends on choice of variables)
- Noise match vs input impedance match
- Obey the laws (invariants and feedback)
    - Embedding
    - The essence of N (not Rn)
    - The essence of Mmin (or Tcasmin)
- Non 50 ohms is easy (use a series or shunt resistor)
- Differential is easy (dip a resistor in LN2)
- Noise parameters are easy (use S parameters + device physics)

Cryogenic low-noise amplifiers: From InGaAs channel to hybrid module

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Abstract

The InGaAs-based HEMTs (or InP HEMTs) is still the best alternative for the first transistor stage in cryogenic LNAs for microwave/mm-wave applications. However, the InP HEMT is not an off-the-shelf component and the relation between device quality and noise performance in the LNA is complex.

In a new project, we have established a full-wafer 110 nm InP HEMT processing with enhanced reproducibility and stability. This is made within the framework of an ESA-ESOC project for base stations. Furthermore, a pure InAs channel HEMT device has been tested as an alternative for the InP HEMT. InP HEMTs are implemented in hybrid IF modules for 4-8 GHz and 32 GHz.

Characterization of FhG-IAF low-noise mHEMTs at cryogenic temperatures : DC, S-Parameters and Noise

Frank Schäfer[1], Sonja Lenz, Sener Türk, Wolfgang Meiers
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Abstract

In an ongoing collaboration between various institutes the optimization potential of mHEMT devices for operation at cryogenic temperatures in low-noise receivers for radio astronomy shall be examined. The devices used in this work were produced at Fraunhofer IAF and are routinely used for mm-wave MMICs operating at room temperature. For the design of cryogenic, low-noise hybrid- and MMIC-LNAs for application in radio astronomy a lumped element model of the active device usually is employed for modelling of the LNA in a circuit simulator. The existing IAF-model gives accurate S-parameter and noise data at room temperature and had to be extended with a temperature dependence down to cryogenic temperatures around 15K in order to mimic the behaviour of the HEMT device operating at cryogenic temperature under different bias conditions. For this purpose we measured DC-IV curves and S-Parameters at room and cryogenic temperatures as well as temperature dependant access resistances of devices with gatelengths of 50nm and 100nm up to 50GHz. Instabilities that were found in the DC-IVs for some 100nm devices will be reported.

The measurement of noise data at cryogenic temperatures for the devices will be carried out using the well known F50 method which has distinct advantages on methods using mechanical or electronic tuners outside the cryostat at room temperature. Our implementation of F50 and their calibration will be described. We will give an overview of the existing cryogenic probing facilities at MPIfR and plans for their future extensions. An outlook on future developments planned on noise probing schemes that could benefit from using highly integrated tuner and post amplifier heads at cryogenic temperatures will be given. The latter developments will be enabled using IAF's 50nm process to integrate tuners, switches and broadband LNAs.

Noise Parameters of FET's: Measurement, Modeling and Use in Amplifier Design

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Abstract

This talk will attempt to summarize the lessons learned at the NRAO Central Development Laboratory over the past quarter century in the development of extremely low noise cryogenic amplifiers for radio astronomy receivers with special emphasis on the methods of characterization of both devices and amplifiers at cryogenic temperatures.

Firstly the current state of the art in cryogenic low noise InP HFET amplifiers will presented and the methods of measurements of these amplifiers employed at CDL will be reviewed. The accuracy of different methods of noise measurements and the sources of errors will be briefly reviewed.

Secondly signal and noise models of a FET required for a successful design of amplifiers will be explored. In that context a method of measurement of noise parameters at cryogenic temperatures employed at NRAO will be briefly described and the resulting development of cryogenic noise model will be reviewed. Some general properties of noise model which provide for fast and easy check of consistency of measured data will be emphasized. The optimal noise bias condition will be discussed and interpreted in terms of noise model parameters.

Finally sources of unrepeatability of noise performance of FET devices and amplifiers at cryogenic temperatures will be discussed. The so called "poor pinch off" effect, arguably the most important reason behind the unrepeatability of cryogenic performance, will be illustrated. Other, not yet understood effects which were observed in devices evaluated at CDL and were found to influence cryogenic noise performance will be briefly summarized.

Estimation of Uncertainty in Noise Measurements Using Monte Carlo Analysis

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Abstract

Modern automatic Noise Figure Meters (NFMs) have made very easy to perform noise measurements at microwave frequencies. However, the error in the measured noise is seldom quoted and very often is quite significant, especially for very low noise devices. There are many factors affecting the accuracy of noise measurements and the complexity of the problem discourages its estimation in everyday practice. The problem becomes critical for cryogenic amplifiers, where, even with the maximum care, the error is usually an important fraction of the total measured value. This work presents an easy, practical and accurate approach for the calculation of the uncertainty in noise measurements based on the Monte Carlo method.

The presentation will be illustrated with calculations of uncertainty in the noise temperature measurement of several representative examples. Two different noise diodes (high and low ENR) and one set of hot-cold (LN2) calibration loads will be evaluated for the measurement of the same amplifier at ambient temperature. For cryogenic temperature, the analysis of the well known cold attenuator method will be presented, and the dependence of the accuracy with several factors will be analyzed.

The software used for this work was developed for MathCAD and Matlab with the goal of being easily used and/or modified to fit different necessities. This software will be made freely available to all the RadioNET community.

Practical aspects on noise figure measurements

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Abstract

1) A transfer LNA is presented. The transfer LNA may travel around European laboratories in order to be measured by different people on different laboratories using different instruments. The results will be collected and compared, then, as a consequence, each workgroup will decide if apply some adjustment to their own ENR.

2) The cryogenic measurement of lots of LNAs takes long time, many weeks. A method to speed up the cooling down the CTI cryocooler is presented. The cool down time of the laboratory Dewar drops down from 4h to 2h or even down to 30 min.

Cryogenic LNA Characterization: GARD Experience

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Abstract

Group for Advanced Receiver Development, GARD, Radio and Space Science Department with Onsala Space Observatory, Chalmers University of Technology, Sweden

Cryogenic low-noise microwave amplifiers based on III-V HEMT devices reach the noise temperatures as low as 0.25 K /GHz. This now approaches level of 5 times the quantum noise 0.048K/GHz. Measuring such low-noise devices with acceptable accuracies requires accurate characterization of the measurement setup and use of precision noise sources.

A superconducting tunnel junction, SIS, biased in its linear region is commonly used as a noise source to confirm operation of the IF chain in a SIS mixer receiver. The shot-noise generated from such junction is defined by fundamental physical constants and the DC current through the junction and could thus be used as a noise source directly connected at the input of the amplifier, minimizing the number of error factors. The normal state resistance of the junctions used in SIS mixers is however often not 50 Ohm but of the order of 5-10 Ohm. For this purpose, a dedicated chip and test structure was designed and fabricated to evaluate the possibility for use in Y-factor noise measurements.

The small power budget available for each cartridge in the ALMA receiver required a major cut in power dissipation for the cryogenic LNAs, compared to earlier projects. To resolve this issue, a design implementing InP in first stage was developed. The method for cryogenic (12K) characterization of amplifiers used in GARD laboratory and the measurement results will be presented.

NA Performance Optimisation Using Post-production Noise Characterisation

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Abstract

An alternative LNA design flow that addresses some of the typical issues connected with MMIC realisation is given in this contribution. Using an external Input Matching network can give more flexibility in design and better performances if we can get MMIC Noise parameters. Following the proposed design flow, a MMIC LNA test vehicle has been realised and a measurement setup has been arranged in order to get Noise Parameters.

The IAF mHEMT Low-Noise Technology and its Extension to Cryogenic Applications

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Abstract

Metamorphic high electron mobility transistors (mHEMT) combine the advantages of low mass/high speed InGaAs channel based hetero-structures with the properties of GaAs as a mechanically stable and inexpensive substrate material. In the past years improving technology at the IAF has facilitated a steady increase of the transit frequency from 220 GHz, 375 GHz to 500 GHz by a reduction of the gate length from 100 nm, 50 nm to 35 nm, respectively. These improvements in cutoff frequency mainly have been exploited to build increasingly faster MMICs and lead to excellent noise performance in LNAs. Though the noise level of a LNA is known to strictly correlate with the high cutoff frequencies of the mHEMTs, to date less attention has been drawn to the expected enhanced noise performance at low microwave frequencies. Upon reduction of gate length, the channel temperature becomes increasingly important as another noise determining factor beside cutoff frequency. With the provided high electric fields and the weak interaction with the solid the accelerated electrons heat up to very high temperatures. The temperature rise related noise tends to counteract the improvements in cutoff frequency. For the sake of grace the effective noise temperature is controlled by the geometric average of electron and ambient temperature.

A bias dependent scalable mHEMT model has been extracted from S-parameter measurements up to 120 GHz and a respective noise model was established from room temperature NF50 noise measurements at W-band frequencies. This model was extended to cryogenic temperatures by addition of the variation of the access resistances, mobility and dielectric constants as measured for test-structures. The predictions of this model are discussed and compared with measurements. It is pointed out that noise performance of InGaAs-HEMTs is highly sensitive to gate leakage in particular at C- and X-Band frequencies.

Millimeter HEMT amplifier measurements at cryogenic temperatures

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Abstract

IRAM is designing an 84-116 GHz dual polarisation HEMT receiver in order to get experience in using such receivers at the Pico Veleta Observatory, which can then be applied to a future project of building a 3 mm HEMT focal plane array. Preliminary measurements of HEMT MMIC amplifiers in terms of gain, noise temperature, saturation, and stability at 300 K and at 4 K will be described. Two solutions are presented for the down converting of the HEMT amplifier output: the first uses a very large (4-36 GHz) IF band and a fixed tuned LO at 80 GHz while the second is designed with a smaller IF band (4-12 GHz) and a 67-91 GHz tunable LO. In the 84-116 GHz range, receiver noise temperatures between 32 and 51 K were obtained. The measured stability (1s > t > 100s) is below 4x10-4 at 101 GHz.

Outline

• MOTIVATION:
Cryogenic millimeter HEMT amplifier measurements to build the 84-116 GHz PV front-end

• UMASS HEMT amplifiers tested in an 84-116 GHz receiver built with 32 GHz IF band [4-36 GHz]
- HEMT |Sij|2, receiver gain and noise temperature at 300K and at 4K
- Receiver stability & saturation

• UMASS HEMT amplifiers tested in an 84-116 GHz receiver built with 8 GHz IF band [4-12 GHz]
- Measurement setup (HPF, coupler and mixer responses at 300K)
- Receiver noise temperature at 4 K -Noise across the 4-12 GHz IF band
- Receiver stability

• CONCLUSION

Measurement Setup for ALMA Band 5 Prototype Cartridge

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Abstract

The ALMA frontend is designed for ten separate receiver bands, together covering the frequency range 30-960 GHz. The receiver accommodates these receiver bands as pluggable, fully electrically autonomous cartridges. ALMA Band 5 cartridge is a dual-polarization heterodyne receiver employing 2SB SIS mixers with IF band 4-8 GHz and covers the frequency band 163-211 GHz. The prototype for the ALMA Band 5 cartridge development is carried out by Group for Advanced Receiver Development (GARD) in Gothenburg, Sweden, with the aim to provide six Band 5 cartridges for the ALMA Project.

An important issue for the ALMA Band 5 is the location of the water vapor emission line present at 183 GHz, in the middle of ALMA Band 5, resulting in an significant increase of the system noise temperature due to less atmospheric transparency. This also introduces difficulties in lab measurements during the cartridge characterization due to the major existence of water vapor in Gothenburg, which is situated at sea level, and appropriate measures has to be considered.

At the workshop, we plan to present the design details of measurement setup for ALMA Band 5 cartridge, such as hot/cold measuring system, beam measuring system and cryogenic measurement.

A Measurement Test Set for ALMA Band 9 Amplifiers

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Abstract

The Centro Astronómico de Yebes (Observatorio Astronómico Nacional, Spain) is in charge of the production of the low noise cryogenic amplifiers for bands 7 and 9 of ALMA. Manufacturing of Band 7 units (4-8 GHz) has been transferred to a Spanish company, but Band 9 production (more than a hundred 4-12 GHz amplifiers) is being entirely made in our labs. Cryogenic noise, gain and reflection characterization with the accuracy needed for ALMA is a time consuming task requiring a considerable effort. To speed up the tuning and test processes, a completely new and dedicated measurement system has been developed. The dewar is capable of measuring up to three amplifiers in the same cooling cycle. The use of carefully calibrated mechanical switches avoids the problems related with the frequent mating and de-mating of connectors, eliminating some typical error sources. One of the measurement lines implements a calibrated attenuator in the cryostat to measure noise by means of the cold attenuator method. Normally it would have been difficult using that line for measuring the input reflection of the amplifier simultaneously (in the same cool down), but the calibration applied allows obtaining the S11 data with relatively good accuracy. This is of enormous help especially for tuning and bias optimization.
Some results and statistics of the measurements of more than 70 amplifiers will be presented, together with the lessons learned in the course of this systematic and repetitive measurement plan. Also, details of the calibration and equipment employed will be given.

Cryogenic Measurements of CMB Polarimeters

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Abstract

QUIET intends to make very sensitive measurements of the polarization of the cosmic microwave background radiation, using the technology of coherent correlation polarimeters. It takes advantage of a breakthrough developed at JPL for the packaging of the polarimeters ("radiometer on a chip"), which allows their mass production so that thousands of detectors can be used. QUIET is a multi-year program to measure the CMB with large arrays of coherent detectors from the ground. The arrays will consist of receivers at two frequencies (40 and 90 GHz) and use multiple telescopes (3x2m + 1x7m) at 5,080m in Chile in the Atacama desert. The measurements will cover angular scales from a few arcminutes to a few degrees. QUIET is currently in its first NSF approved phase and is currently fielding two receivers: a 91 element W-band array and a 19 element Q-band array.

This talk will discuss the testing of the W-band polarimeters and Q-band polarimeters.

Progress on FPA LNA developments and LNA characterization

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Abstract

This talk will address the developments on single ended LNAs for a Focal Plane Array prototype at ASTRON. This talk will address LNA developments at room temperature based on commercial of the shelf transistors and the measurement of the noise parameters of the realized designs using a tuner setup.

Noise measurements for the SKA

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Abstract

Like all radio telescope projects the SKA requires very low noise receivers, and hence some means of verifying that the low noise amplifiers currently being developed for the SKA meet the noise temperature requirements. However, the SKA is presenting several new challenges to low noise receiver engineers, including requiring them to measure differential as well as single-ended LNAs, both at cryogenic and room temperatures. Furthermore, the feeds and antenna elements currently under consideration have a range of different impedances up to 300 ohms. The SKA also needs large numbers of LNAs, possibly millions, so we will require highly automated test systems to test mass-produced low noise amplifiers with sufficient accuracy to ensure that we finish up with a radio telescope that meets specification.

Active antenna design and characterization for the mid-SKA

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Abstract

For the realization of low cost low noise front-ends for SKA Aperture Arrays we focus on the active antenna integration. Three aspects will be discussed:
-The design and test of differential LNAs with off-the-shelf components
-The design and test of differential LNAs with state-of-the-art GaAs mHEMT processes
-The noise temperature measurements of integrated active antennas

Poster:
Active Low Noise Terminations: Simulation Approach and Verification

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The equivalent noise temperature T_e has a different implication for a 2- or a 1-port network. In the former it is related to the network's noise factor. In the latter case, the equivalent noise temperature is proportional to the termination's available noise power. Typically CAD applications are able to compute the first type of equivalent noise temperature but not the latter. Two approaches are presented and experimentally verified.

First CAD Approach

It consists in evaluating the noise power available from the active termination using an AC-type simulation. Referring to Fig. 1 (left), e_n is defined as the RMS noise voltage associated to the active termination. Through this value the noise power delivered to the input termination (P_{Z0}) is derived:

$$P_{Z_0} = \frac{|e_n|^2}{Z_0} \tag{1}$$

The noise power available from the termination is estimated considering it's input reflection coefficient Γ_{in}:

$$P_{av} = \frac{P_{Z_0}}{1-|\Gamma_{in}|^2} \tag{2}$$

Finally the equivalent noise temperature is obtained:

$$T_e = \frac{P_{av}}{k_B B} = \frac{|e_n|^2}{k_B B Z_0} \frac{1}{1-|\Gamma_{in}|^2} \tag{3}$$

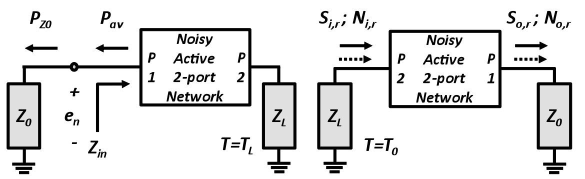

Fig. 1 Electrical schematic used to determine the active termination's RMS noise voltage (left) and the active termination's available noise power (right).

Second CAD Approach

An alternative approach consists in evaluating the reverse signal to noise ratio combining S-parameter simulations with the device's reverse noise factor computation. In this approach Z_L at $T=T_0$ acts as a "noise source" whose contribution is processed by the 2-port network's reverse gain/noise operation. In this approach the reverse parameters of the 2-port network are used (we consider the reverse gain and reverse noise figure, i.e. from the 2-port network's port 2 to port 1) as depicted in Fig. 1 (right).

A 2-port network's noise factor is defined as the ratio between the input port and output port signal-to-noise ratios when the input noise source is kept at T_0=290K.

$$F_r = \frac{S_{i,r}/N_{i,r}}{S_{o,r}/N_{o,r}} \Rightarrow N_{o,r} = F_r N_{i,r} G_{av,r} \tag{4}$$

Where F_r is the reverse noise factor, $S_{i/o,r}$ and $N_{i/o,r}$ are respectively the signal and noise power at the network's input and output ports and $G_{av,r}$ the reverse available gain. In this case the 2-port network's port 2 is connected to the physical load Z_L at $T=T_0$ while the 2-port network's port-1 is connected to Z_0. If Z_L's temperature is different than T_0 then an appropriate temperature correction must be added in (4). The S-parameters simulation approach allows to determine F_r and to compute $G_{av,r}$. The termination's equivalent noise temperature can be expressed as:

$$T_e = \frac{N_{o,r}}{k_B B} = \frac{k_B T_0 B F_r G_{av,r}}{k_B B} = T_0 F_r G_{av,r} \tag{5}$$