

Implementation of a Noise Temperature Measurement Application



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A dissertation submitted to the Department of Electrical Engineering,
University of Cape Town, in fulfilment of the requirements
for the degree of Bachelor of Science in Engineering.

Cape Town, October 2008

Declaration

I declare that this undergraduate dissertation is my own work. It is being submitted for the degree of Bachelor of Science in Engineering at the University of Cape Town. It has not been submitted before for any degree or examination in any other university.

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Abstract

The objective of this report is to outline the development of a noise temperature measurement application using National Instruments LabVIEW. More specifically by achieving remote control of a spectrum analyser and using an RF amplifier and mixer as the DUT's.

The report begin by giving a brief introduction to concepts of noise temperature and noise figure, then goes into a discussion regarding the methods used to measure noise figure with aim of conducting these experiments. The purpose of the experiments is to identify possible implementable modules for the application. This is important as the application is required to be modular for ease of interpretation and possible modification. The control interface (Prologix GPIB controller) and software are also discussed briefly.

Development of the experimentation process revealed that the application could not be properly tested due to a lack of appropriate apparatus and time constraints. However, the application was developed, but its capabilities are not known as testing was not possible.

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List of Symbols

B	—	RF bandwidth
B_n	—	Noise bandwidth
c	—	Speed of light
f_{center}	—	Center frequency
f_{span}	—	Frequency span
f_{start}	—	Starting frequency
f_{stop}	—	Stopping frequency
F_{sys}	—	System Noise Figure
G	—	Gain
h	—	Planck's constant [6.23×10^{-34}]
P_{gen}	—	Thermal noise power generated
k	—	Boltzmann's constant [1.38×10^{-23}]
N_0	—	Input noise power density
N_x	—	Noise power density for stage x of a cascade
N_s^{on}	—	Noise source noise power density during on state
N_s^{off}	—	Noise source noise power density during off state
S_{21}	—	S parameter
SNR	—	Signal to Noise Ratio
T_a	—	Component's absolute temperature
T_e	—	Effective system temperature
T_o	—	Ambient temperature
T_s^{on}	—	Noise source noise temperature during on state
T_s^{off}	—	Noise source noise temperature during off state
RBW	—	Resolution bandwidth
VBW	—	Video bandwidth
V_n		Noise voltage
$VSWR$	—	Voltage Standing Wave Ratio
Y	—	Y-factor
Γ	—	Reflection coefficient
Ω	—	Ohm - Impedance symbol
Δ	—	Delta - Change in

Nomenclature

Band — Frequency

Block-diagram — Pictorial representation of a program or algorithm

CSV-file — Comma Separated Value file or format

Driver — Software that controls a specific hardware device

GPIB — General Purpose Interface Bus, the standard bus use for controlling electronic instruments with a computer

LabVIEW — Laboratory Virtual Instrument Engineering Workbench

Palette — Displays the tools used in building the block diagram or front panel

Span — a range of frequency

SubVI — Subordinate Virtual Instrument

Sweep-time — Time take to complete all samples within a range of interest

VCP — Virtual Communications Port

VI — Virtual Instrument

VISA — Virtual Instrument

Chapter 1

Introduction

1.1 Project Identification

Implementation of a Noise Temperature Measurement Application using National Instruments LabVIEW.

1.2 Purpose of Report

This report outlines a final year thesis project prepared at the University of Cape Town for the Department of Electrical. It describes the subject matter and gives a detailed description of the processes and developments that were undertaken towards the completion of the project.

1.3 Background to Report

In RF systems, the transmission and reception of any signal is influenced by the amount of noise that can be “picked up” by the system due to effects of the system components and the atmosphere around the system. We will however be focusing on the internal noise of components due to the electrical devices inside them. This noise can be characterized or quantified by the noise figure or noise temperature of the device. Noise figure gives a measure of the degradation of the SNR (Signal to Noise Ratio) at the input of a device to the SNR at the output. This premise can be extended to entire systems if the equivalent noise figure of the system is known. Noise temperature quantifies the thermal noise contribution of a component and can be represented by a fictitious noise source at the input to the device, giving similar SNR degradation as the component’s internal noise; this has the effect of modeling the device as noiseless. Noise figure and noise temperature quantify the

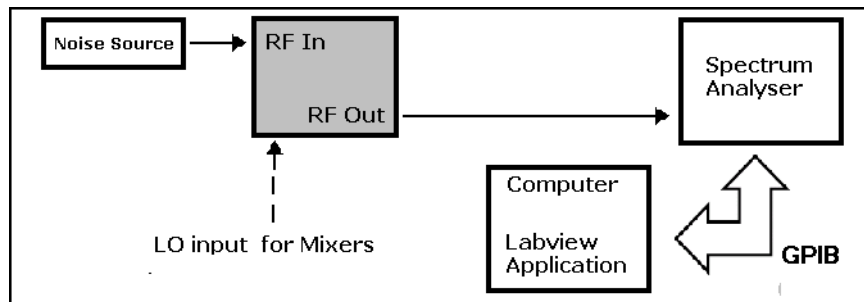


Figure 1.1: Experimental setup block diagram

noise of a component and hence are related. This project seeks to measure the noise temperature and hence noise figure of the following RF components:

1. RF amplifier
2. RF mixers.

The processes of this project will focus on noise figure measurement. There are numerous methods for measuring noise figure. Those that will be discussed are the Y-factor method and the Gain method. These will be investigated and studied for experimentation in order to obtain various parameters that may be needed to implement a measurement application. The aim of the project is to create a semi automated method of measuring noise temperature. To achieve this, a spectrum analyzer will be used in a noise figure measurement experiment, controlled with a computer application written in National Instruments LabVIEW. Thus, the use of a GPIB (General Purpose Interface Bus) will be necessary to create an interface that will be a communication platform between the LabVIEW application running from the computer and the test apparatus. The block diagram below illustrates the general test setup:

This diagram illustrates a typical setup for a noise figure measurement experiment. The noise source serves as input to the DUT (device under test) which is connected to a spectrum analyser that would be controlled remotely by a LabVIEW application through the GPIB interface. The application and methods applied should make provision to minimize the uncertainties that may arise due to the test equipment or the method used. Any occurrence that may give undesired results should be noted and investigated.

1.4 Project Objectives

1.4.1 Scope of Project

This project dealt with and was limited to the design and implementation of a noise temperature measurement application. This report aims to discuss the project material as outlined in the process and methodology, covering the following section:

- The relevant literature and references
- The design process and all data and work done in this regard
- The implementation and project consolidation.

1.4.2 Application Specifications

This project is aimed at developing a noise temperature measurement application to be implemented in National Instruments LabVIEW. There are certain requirements that the application is expected to comply with in this regard and these are outlined in this section.

- The application must be written and implemented using National Instruments LabVIEW
- The application should be run on a computer and must control a spectrum analyser remotely for data acquisition and analysis.
- It should be possible to configure the spectrum analyser from the application.
- Data must be obtained, displayed and stored for use by other applications.
- The application structure should be easy to implement and edit for future work.
- Two methods must be implemented in such that the experiment is semi automated. All experimental data and parameters must be sourced and set through the application.

1.4.3 Deliverables

- Report outlining project development and implementation
- Working semi-automated noise temperature measurement application
- LabVIEW application: coding for interface control and experiment algorithms
- Experimental setups, data and results
- Comparison of different methods

1.5 Methodology and Plan of Development

1.5.1 Chapter 2: Literature Review

The literature review discusses the subject of the project at length. It is important that a clear understanding of the subject matter is developed at an early stage in the project. The main topics that are covered in the literature review are as follows:

- the theory of noise temperature measurement, identifies some common methods and their merits. Furthermore, a comparison of these methods is to be made to ensure that the study can identify the most suitable method to implement.
- a study of the previously mentioned methods under the following performance parameters, identifying any trade-offs: system accuracy; range of measurement (i.e. frequency, bandwidth, temperature, etc.); error and uncertainties.
- labVIEW and the Prologix/GPIB interface: the functions related to this project.

1.5.2 Chapter 3: Application and System Development

This chapter aims to study the experimental application of the methods chosen for implementation in order to determine how the application should be structured and implemented. In essence, the aim is to test if the methods are feasible for implementation in LabVIEW. To do this the experimental procedure is described at length, discussing the apparatus needed, measurement parameters and the limitations to the experiment. Once this done the experiments are conducted to ensure that the application can be effectively tested. The information obtained from the experimentation will help identify the application structure. Furthermore, we will discuss the different structures of the application and how they are constructed. This will also identify some key elements in the LabVIEW language.

1.5.3 Chapter 4: Noise Figure Analyser Measurements

This chapter looks at the noise figure measurements done with a noise figure analyser in order to determine the range of accuracy that the application must achieve.

1.5.4 Chapter 5: Results and Project Reconciliation

This chapter gives a brief outline of the actual procedures undertaken in developing and testing the application. It also highlights the limitations that were encountered and gives explanations for the outcomes where necessary.

1.5.5 Chapter 6: Conclusion

In concluding, the main concepts addressed in the project will be briefly touched on in relation to the project outcomes. A summary of the results will be given, outlining the project requirements and what was achieved in the project, identifying any possible future work or areas of study.

Chapter 2

Literature Review

Noise figure measurements are an essential part of RF systems design. They help us minimize the problem of noise generated in receiver systems. The transmitted signal and noise cannot be differentiated by receiver components and are thus treated similarly. That is to say that they are amplified or attenuated by the same factors as they propagate through a network. Since there are limitations on the permissible transmit power, it is important that we conduct noise measurement applications to help ensure that the added noise is kept to a minimum in order to achieve the desired output.

2.1 Noise figure and Noise Temperature

Electrical noise is a common factor for all communication systems. In fact, it is always present, but often goes unnoticed due to signal levels that are significantly higher than the noise levels. Kraus et al. describes noise as “any extraneous electrical disturbance tending to interfere with the normal reception of the transmitted signal.” Krauss [14] In essence, this means that noise can render a radio system to “perform in a less than ideal error-free mode” Edward [12]. Noise consists of signals of both a deterministic and non-deterministic nature. The deterministic signals can generally be avoided through best practice designs and applications, whereas the non-deterministic signals can only be minimized through system optimization. There are numerous types of non-deterministic signals, the most common of these are generally characterized as and grouped under the collective term ‘thermal noise’, which is sometimes referred to as Johnson noise or Nyquist noise Krauss [14]. This means that we take on the assumption that the combined effect of these signals is caused by an equivalent thermal noise source [2].

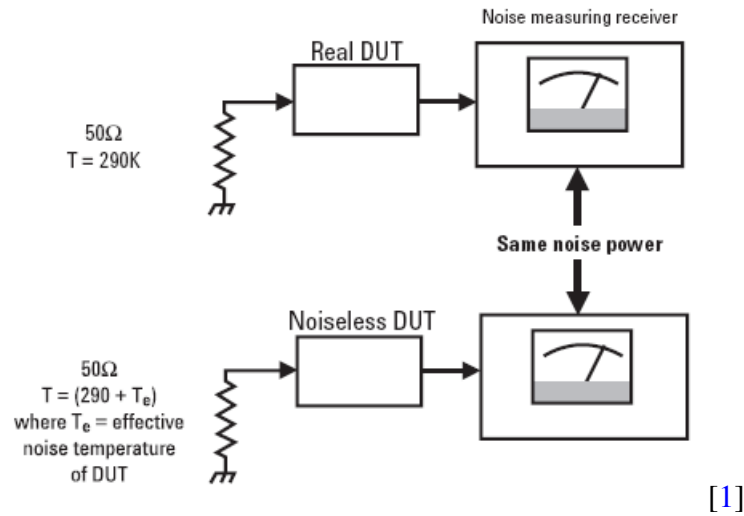


Figure 2.1: Resistor Modeling for Internal Noise

The performance of all RF and microwave communication systems is inevitably related to the desired output SNR. In this context, this refers to the ratio of the output signal to the thermal noise Siwiak [18]. Thus it is important that we are able to quantify this thermal noise in order to enable us to design systems in such a way that its effects are minimized as they ultimately determine the performance threshold of a system with regard to minimum signal detection Pozar [17]. Thermal noise is quantified by two parameters: noise temperature and noise figure. These two parameters are related as follows:

$$F = 1 + T_e/T_0 \quad (2.1)$$

where F is the noise figure and T_e and T_0 are the effective network temperature and ambient temperature respectively. This relationship and methods for measuring these parameters are discussed further in the sections to follow.

2.1.1 Thermal Noise and Noise Temperature

The noise temperature of a device is a result of the amount of thermal noise that the device generates. This thermal noise is a combination of different types of noise that arise due to the spontaneous fluctuations or vibrations in the conduction electrons, charge carriers, of electrical components within the device [2].

That is to say that in general any electrical component or conductor can be characterized by its characteristic impedance which can be simply represented by a resistor (R) of equivalent resistance. The conductor may have charge carriers that have random motion at temperatures above

absolute zero ($T_o > 0^\circ K$) which will induces a voltage drop across the resistor. From quantum mechanics, it can be shown that this voltage is given by

$$V_n = \sqrt{\frac{4hfBR}{e^{(hf/k_bT_a)} - 1}} \quad (2.2)$$

The level of excitation of the charge carriers is proportional to the conductor's resistance and its absolute temperature and will thus increase with increase in temperature, hence increasing the noise power density. Assuming that the resistance has a magnitude of 1Ω and the noise bandwidth is $1Hz$, the output power density in W/Hz is given by

$$N_o = hf \left[\frac{1}{e^{(hf/k_bT_a)} + 1} \right] \quad (2.3)$$

which reduces to $N_o = k_bT_a$ for frequencies smaller $10^{10}HZ$ [18]. For larger noise bandwidths, the noise power density, which is the mathematical definition of thermal noise, will be defined as

$$N_o = k_bT_aB_n \quad (2.4)$$

where T_a is the conductor's noise temperature[16 and]. The misconception here, is that the component is at a physical temperature of T_a , however, this is not the case, but rather, that its noise power density can be characterized by a thermal source of that temperature when placed in series with the resistor. It should be noted that although noise temperature and physical temperature are not directly related, there may be a dependence [2].

It can be seen from 2.4 that the noise power density is proportional to the noise bandwidth (B_n), which is determined by the circuit or component bandwidth. This is because thermal noise has a uniform spectral density, therefore the bandwidth and hence the noise transmitted through a device is determined by the device.

2.1.2 Noise Figure

Noise figure quantitatively characterizes the noise performance of a network. It is an important performance parameter in RF systems because together with the gain of a system, it gives an indication of how the input signal to a network, that being either a system or device, is affected. Noise figure is defined as the degradation of the signal to noise ratio from the input to the output of a device[1]:

$$F = \frac{S_{in}/N_{in}}{S_{out}/N_{out}} \quad (2.5)$$

Consider equation 2.5 for a noiseless network, both signal and noise applied to the input will be amplified or attenuated by the same factor and the SNR will be unchanged. However, if the network is noisy, i.e. the network components add extra noise to the signal, the noise will be increased to

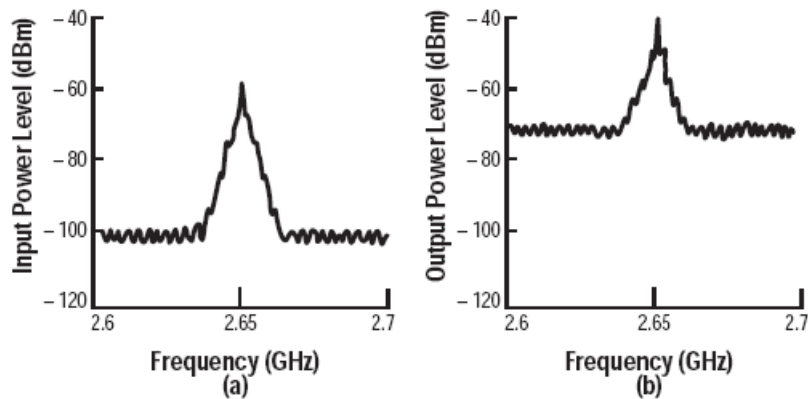


Figure 2.2: Amplified Signal with Added DUT Noise
[2]

a greater degree than the signal, hence reducing the SNR. Figure 2.2 illustrates this concept. The noise figure is a measure of this reduction Pozar [16] and thus a good way to quantify the noise characteristic of a network. Noise figure measurements are based on and generally defined for linear two port devices due their linear noise characteristic [2].

The relation between noise figure and noise temperature as shown in Pozar [16] is

$$F = 1 + \frac{T_e}{T_o} \quad (2.6)$$

This relation in 2.6 shows that noise temperature and noise figure are interchangeable in characterizing thermal noise properties as if a network has $T_e = 0$, and hence zero thermal noise, the total noise figure for the network will be unity or 0dB . Noise figure is independent of signal level while the network is operating in its linear range.

It should be noted that while there is often a distinction between the linear value referred to as “noise factor” and the value in dB is referred to as “noise figure”, this distinction will not be made here.

2.2 Methods for Noise Temperature Measurements

state the differences, strengths and weaknesses of the different methods. compare.

to date, there have been numerous methods practiced for noise figure and noise temperature measurement. this report will only focus on two of the most common, that being the Y-factor and Gain methods. these will be discussed in some detail in this section. there will also be a brief discussion on other methods explored and their merits and short comings.

2.2.1 Y-factor Method

The Y-Factor method is perhaps the most commonly used method today. It is implemented in numerous noise figure calculations and most of the popular noise figure analyzers also implement this method [2]. To calculate the noise figure we use two principles:

1. Excess Noise Ratio (ENR) - which is a ratio of the difference between the effective noise source temperatures in the on and off states to the ambient temperature:

$$ENR = \frac{T_s^{on} - T_s^{off}}{T_0} \quad (2.7)$$

In general, we find that $T_s^{off} = T_0$, however this does not always hold true. Should it be necessary to have $T_s^{off} = T_0$, one can apply temperature regulation methods to the noise source, thus forcing the two parameters to be equal and ensuring that the inequality holds.

2. Y-factor - this is the ratio of the measured output power densities with the noise source in both the on and off states:

$$Y = N_{on}/N_{off} \quad (2.8)$$

The Y-factor method is conducted as illustrated in figure 2.3. We use four noise power measurements to calculate the noise figure. These measurements are taken during both calibration (N_{2on} and N_{2off}) and measurement (N_{12on} and N_{12off}) phase. The subscripts represent the cascade stage at which the noise is measured.

- First the measurement system is calibrated by connecting a noise source of a specific ENR, which will depend on the DUT noise figure if it is known, to the measurement instrumentation and measuring the output noise power (N_{2on} and N_{2off}). This phase measures the measurement system noise figure. Any extra devices such as pads and isolators will also be factored into this measurement and if need be.
- The DUT is then connected between the noise source and the measurement system and once again the output power densities are measured (N_{12on} and N_{12off}). Since this method implements the use of ratios, the absolute accuracy of the power measurements is not important, however the relative accuracy is important to avoid large errors. The ratio of the two powers, the Y-factor, and the ENR are used to calculate the gain and effective noise temperature of the DUT by derivation [1] of the following equations:

$$G_{DUT} = (N_{12on} - N_{12off}) / (N_{2on} - N_{2off}) \quad (2.9)$$

$$T_{DUT} = T_{12} - T_2/G_{DUT} \quad (2.10)$$

By applying 2.10, the DUT noise figure can be calculated using 2.6. [1] and [2]

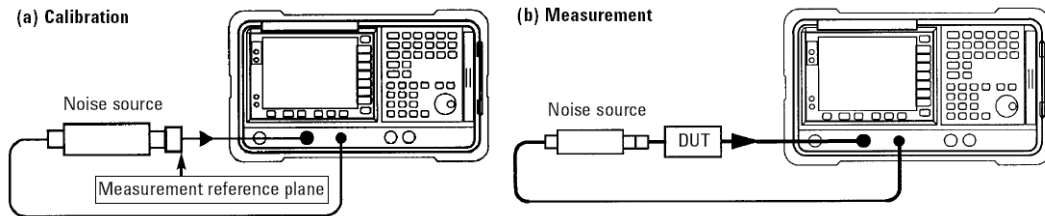


Figure 2.3: Y-Factor Method: Apparatus Setup

[1]

Advantages [5]

- noise figure can be measured over a wide range of frequencies

Disadvantages [5]

- if the DUT's noise figure is very high, the results may not be accurate depending on the limitations of the noise source. Generally the noise source is required to be within a few dB's of the DUT's noise figure.
- equipment must be stable to allow repeatable measurements otherwise jitter may be a factor in the level of uncertainty in the results.

2.2.2 Gain Method

Figure 2.4 illustrates a noise figure measurement using the gain method. This method is executed by using an matched load termination at the RF input of the DUT, taking noise power output readings and then, given the DUT gain and noise bandwidth, use specific formulae to calculate the noise figure of the DUT.[5]

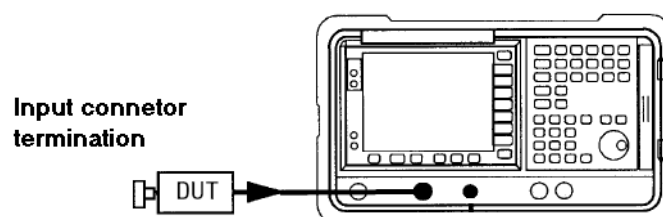


Figure 2.4: Gain method measurement setup

The first step is to calibrate the network with the DUT excluded. First we check the noise floor of the spectrum analyser create a reference margin. Then the matched impedance load, which in essence can be considered to characterise a noise source, is connected to the spectrum analyser for calibration. The termination will generate a finite noise which will be determined by T_0 as

$$N_{in} = kT_0B \quad (2.11)$$

where T_0 is the ambient temperature [6]. The second step is to connect the DUT and calculate its noise figure. Since the input noise, the measurement bandwidth and the gain are known, calculating the noise figure is not a problem and can be done using the following equation:

$$F_{DUT} = \frac{N_{out}}{GN_{in}} = \frac{GN_{in} + N_{DUT}}{GN_{in}} \quad (2.12)$$

This can be simplified using decibels to [5]:

$$F_{DUT(dB)} = 10\log(N_{DUT}) - 10\log(GN_{in}) \quad (2.13)$$

Advantages [5]

- good for high noise figure calculations 10dB upwards
- also good for low frequency measurements
- intuitive method
- the method uses a spectrum analyser, which can be used in numerous other applications as opposed to a noise figure analyser which can only be used for noise figure analysis.

Disadvantages [5]

- the spectrum analyser used must have a high resolution bandwidth and low noise floor of the order of about -130dB.
- the gain of the device must be known and thus the accuracy of the measurement will depend on the accuracy of the gain.

2.2.3 Two Temperature Method Using a Matched Impedance Termination

If a stable noise source is not available and the DUT gain is not known, an alternative method is to terminate the DUT input with a matched load as in the gain method. Then place the termination under temperature control to obtain two noise outputs at different temperatures. The on and off states of the termination will approximate a noise source ENR. This temperature regulation is required as a termination cannot be triggered on and off like a noise source. This method offers a simplistic approach to implementing the Y-factor method.

2.2.4 Signal Generator Twice Power Method

This method relies on power measurement under two conditions: one with the load at T_0 and one with the DUT receiving a signal that increases its output by 3dB. since the generator power level and the measurement bandwidth are known, the noise factor can be calculated [2].

$$F_{sys} = \frac{P_{gen}}{kT_0B} \quad (2.14)$$

2.2.5 Direct Noise Measurement Method

The DUT output is measured with the input termination at T_0 if the DUT gain and bandwidth are known, the noise factor can be calculated[2].

$$F_{sys} = \frac{P_{gen}}{kT_0BG}$$

these two methods are quite similar in nature

2.3 Factors Influencing Measurement Accuracy

Uncertainty is a factor in any kind of experiment where measurements are involved. In noise figure measurements, there are numerous factors or sources of error that influence the accuracy of the results. These can generally be classed into two categories: i) removable or reducible errors and ii) irremovable errors. In both case, it is important that the errors be minimized to ensure quality results. The following sections discuss these sources of errors and ways in which to minimize them.

2.3.1 Removable and Reducible Sources of Error

1. *The electromagnetic susceptibility* of RF systems means that the signal of interest is prone to interference from stray electromagnetic signals which can also be measured as noise power. Thus precaution should be taken to minimize the amount of electromagnetic activity in the test environment. Use of clean and correct equipment such as shielded cables and threaded connectors will help reduce errors. [3].
2. *Display jitter* can be avoided by the averaging of multiple measurements. By taking x readings, a jitter reduction of $1 - (1/\sqrt{x})$ can be achieved. Therefore, by taking 16 measurements, the overall jitter will be reduced by 75%. To reduce averaging during measurement, more averaging can be done during the calibration process[3].
3. *Non-linearities in devices* can induce an error in the measurement of certain values or parameters. Devices that are operated near saturation will tend to become non-linear as they approach compression. For those of high gain, it is recommended that in-line attenuators be used to increase linearity. However, it is always better to ensure that components are not operated near saturation to avoid having to compensate for the extra losses in the signal path and thus increasing measurement uncertainty. It is also crucial to look out for power supply drift and ensure that measurement equipment is first warmed up[3].
4. *Mixer characteristics* should be taken into account when working with mixers.
 - Select DSB or SSB measurement
 - For DSB, select LO close to RF signal
 - For SSB, select LO far from RF signal
 - Choose the LO to suit mixer
 - Filter the RF signal if necessary
 - Filter the IF signal if necessary
 - Document frequency plan to see what precautions are necessary
5. *Measurement correction* should be done during calibration and should take the following into account:
 - measurement system noise figure
 - path losses due to additional component such as connectors etc.
 - component positions within the network cascade.
 - use of pre-amplifier if needed, but care should always be taken not to exceed the measurement instrument's maximum input power.

6. *Finite Bandwidth* should be used for the measurement. It must be less than or equal to the DUT's 3dB bandwidth.
7. Component temperatures should be observed. It is generally good practice to allow the apparatus to run for a while before taking measurements to let it warm up. This reduces the uncertainty that arises from taking measurements from at two different temperatures.

2.3.2 Irremovable Errors

1. *Mismatch uncertainty* can generally be observed over the following three RF path sections:
 - (a) the noise source and DUT
 - (b) the DUT and measurement equipment
 - (c) the noise source and system input during calibration

The mismatch is due to *Impedance mismatch* along the RF path. This can be a serious source of error as a mismatch will cause voltage and current reflection along the path. When a mismatch occurs, the reflection coefficient (Γ) will be greater than zero, thus giving rise to a SWR of greater than unity. The reflections arising from the mismatch have the effect of changing the gain and noise figure of the DUT as shown in [2]:

$$G = |S_{21}|^2 \frac{1 - |\Gamma_s|^2}{|1 - \Gamma_s S_{11}|^2 (1 - |\Gamma_2|^2)} \quad (2.15)$$

Impedance mismatch can be caused by the change in the noise source's impedance between the on and off states. It could also be caused by dirty or faulty connectors. Mismatch uncertainty can be reduced by using isolators, attenuators or pre-amplifiers. The isolators and attenuators, between the DUT and noise source, and the pre-amplifier between the DUT and measurement instrument. This will eliminate reflections due to a mismatch and thus reduce error. [3, 4]

2. *ENR uncertainty of the noise source* is due to the difference in the calibrated and actual ENR value of the noise source. As the noise source is turned on and off, it does not always give the same output. The output has a variance that is generally negligible. [4]
3. *Measurement system uncertainty* refers to the uncertainty due to the instrumentation, which cannot be completely eliminated.

2.4 National Instrument LabVIEW and Data Acquisition

National Instruments LabVIEW (Laboratory Virtual Instrument Engineering Workbench) is a powerful tool that can be used for numerous applications such as simulations, signal processing and data

acquisition and storing. The programs written in LabVIEW are called virtual instruments (VI's) as they imitated real instruments with regard to their appearance and operation[7]. LabVIEW applications are quite extensive and can be categorized under these headings:

- Automated test and instrument control
- Data acquisition
- Industrial measurements and control
- Embedded design
- Academia

LabVIEW implements a data-flow programming language known as G. In data-flow programming, the execution can be fully controlled by the programmer and the sequence of execution is determined by the block diagram structure. Though LabVIEW makes use of graphical syntax, its execution sequence is defined as well as text-based languages [7].

2.4.1 Front Panel and Block Diagram

LabVIEW is operated from two linked panels, the front panel, which is the user interface, and the block diagram which is where the code for structures controlling the front panel is constructed.

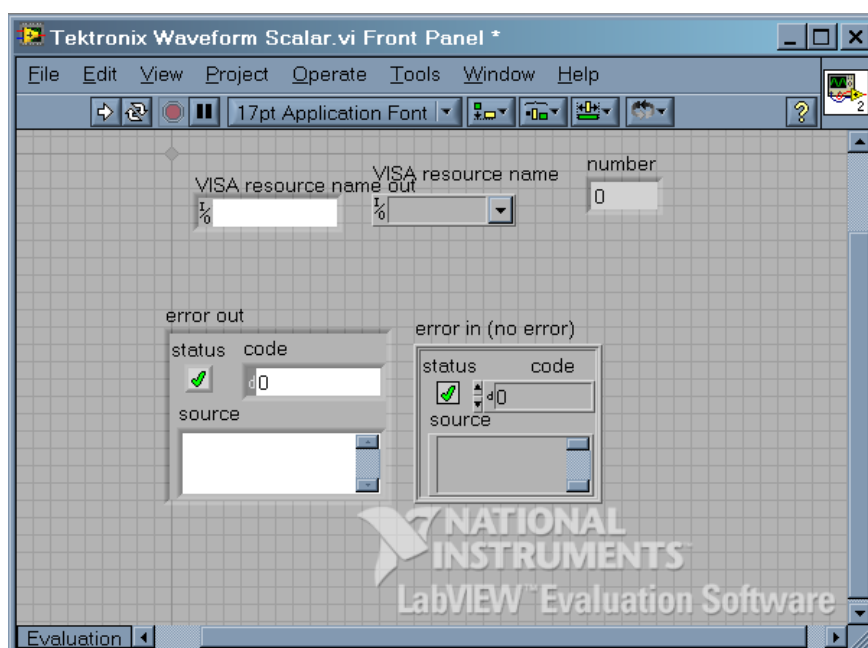


Figure 2.5: LabVIEW front panel schematic

Figure 2.5 show the front panel of a LabVIEW VI. In the front panel, anyone can operate a LabVIEW VI as it is a simple GUI that only requires that input from you. The front panel is not limited to just being a user interface, you can also add a limited amount of tool in the front panel. These are mainly (input) control or (output) indicators blocks like buttons, switches, dials and graphs, LED's and others [15].

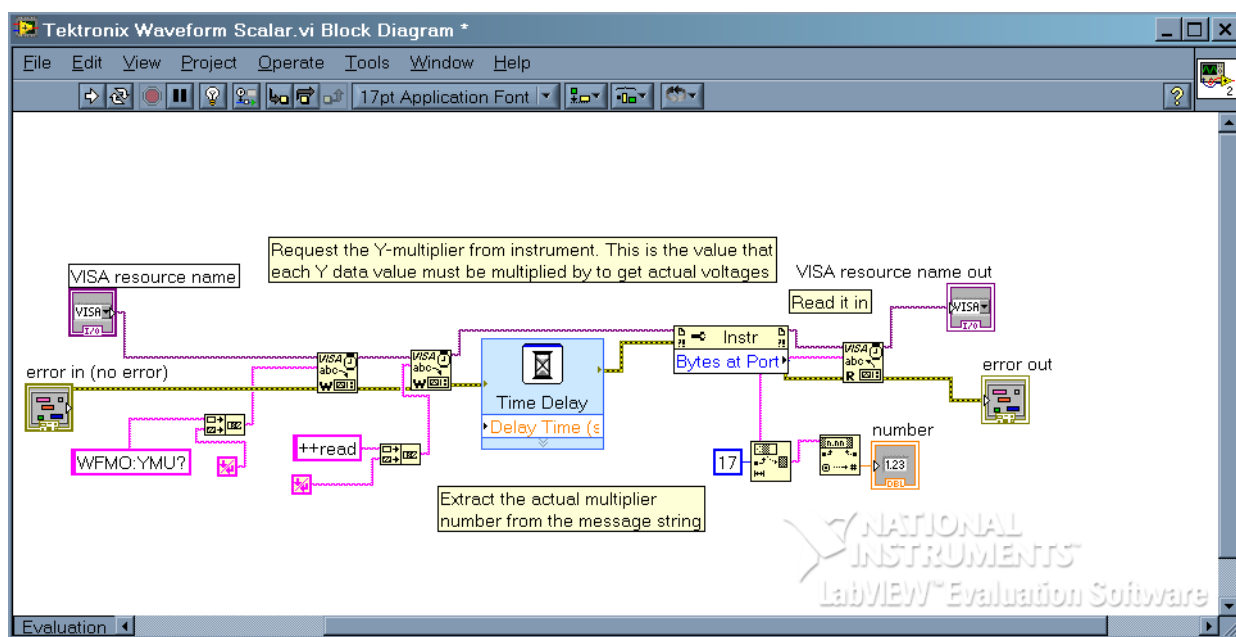


Figure 2.6: LabVIEW block diagram schematic

The block diagram however can be much more complex as it is where the main VI code is constructed. Figure 2.6 shows the block diagram of the front panel in figure 2.5. By studying these two figures, it can clearly be seen that the block diagram requires a more in depth understanding of the VI's as opposed to the front panel.

2.4.2 Instrument control

To be able to perform instrument control or remote data acquisition, there are a few things that are needed.

1. Check whether your instrument is supported by LabVIEW's data acquisition tool, this will determine the way in which you have to achieve control of your instrument.
2. Install the necessary instrument drivers
3. Install the necessary interface hardware and drivers or configuration tools [

The LabVIEW data acquisition tool has a host of instruments that it supports. For this list, the manual can be consulted

2.5 Prologix Adapter

The Prologix GPIB-USB controller is a type of GPIB that uses a USB to serial interface. The Prologix adapter is connected to the computer to create a virtual serial port which is the platform upon which LabVIEW communicates with the connected instrument. By convention, this communication is achieved with a GPIB PCI card that is installed on a computer, meaning that the communication is somewhat direct. Since the Prologix adapter creates a virtual port, it means that the communication schemes are quite different and the two are not interchangeable. However, the Prologix adapter is programmed in such a way that enables communication as though a PCI card is being used. The differences between the types of communication are outlined in [8].

The installation process for the Prologix GPIB USB controller is outlined in Appendix

Chapter 3

Experimentation and Application Development

Numerous methods for noise figure measurement were discussed in section 2.2 and two were presented as favourable for application in this project. Those were the Y-factor method and gain method. However, there were limitations on whether they could be implemented. These limitations are discussed within the experiment development in the sections that follow.

Development of the LabVIEW application requires that we determine the measurement procedure and parameters for the experiment to allow proper structuring of the application. Firstly we'll look at the DUT's and apparatus available for the experiment, then we'll look at parameters needed to setup the spectrum analyser for the measurements. Once this preparation is done, we can conduct the experiment which will give a clear indication how the application should be implemented.

3.1 Test Equipment and DUT's

3.1.1 Devices Under Test

The tables below contain the parameters of the DUT's as per their respective data sheets, which can be found in Appendix D. The availability of devices limited the variety that could be selected for the tests, but those selected will still however be able to demonstrate the strengths and weaknesses of the methods chosen.

RF-Amplifiers

Two amplifiers were chosen, both of them LNA's. This gives us the opportunity to test one of the amplifiers (DUT) with the other (LNA) used as a preamplifier between the noise source and the DUT. Both amplifiers have high gain, which is good for noise figure measurements, but both noise

figures are rather low, which means that there may be some error if the noise source used has too high an ENR.

Table 3.1: DUT Parameters- Amplifiers

DUT	Gain	Noise Figure	Input Impedance	1dB Compression	Frequency	Bandwidth
	$G[\text{dB}]$	$F[\text{dB}]$	$Z_{in}[\Omega]$	$[\text{dBm}]$	$f[\text{MHz}]$	$B[\text{MHz}]$
Amp 1	20 ± 1	1.6	50	8	1200-1700	500
Amp 2	19 ± 0.4	3.8	50	16	10-500	490

RF-Mixer

The mixer chosen is of a particularly high frequency and thus will help give an idea of what the method's capability is at high frequencies. The noise figure is reasonably high which will make the measurement more accurate.

Table 3.2: DUT Parameters- Mixer

DUT	CL	Noise Figure	Input Impedance	RF	LO	Bandwidth
	$CL[\text{dB}]$	$F[\text{dB}]$	$Z_{in}[\Omega]$	$f[\text{GHz}]$	$f[\text{GHz}]$	$B[\text{MHz}]$
Mixer 1	-6	6	50	9.3	8	500

3.1.2 List of Apparatus

- Spectrum Analyser [Agilent E4407B (9 kHz - 26.5 GHz)]
- Termination [50Ω Impedence]
- RF cable [50Ω]
- Power supply [-15V to +15V]
- RF connectors
- RF cables

3.1.3 Limitations Due to Lack of Equipment

From the list of available apparatus it can be deduced that the gain method can be performed where as the Y-factor method cannot. The Y-factor method requires that a noise source be used as input to the DUT, but one could not be sourced. To solve this problem and still be able to perform the Y-factor method, the two temperature method described in section 2.2.3 was considered. However, this too could not be performed as it requires a temperature regulation chamber that could not be sourced. This meant that the Y-factor method could not be performed in any way. Hence, the gain method was deemed the viable method to implement.

3.2 Measurement Setup

Figures 3.1 and 3.3 illustrate the how the experiment is setup for both the amplifiers and the mixer. These setup are similar in terms of the noise source and spectrum analyser configurations but different with regard to the DUT specific elements such as inputs, power supply, filters etc. Section 3.2.1 dicusses the general configuration of the noise source and the spectrum analyser. The individual DUT setups are discussed in sections 3.3.1 and 3.3.2. For both case, amplifiers and mixer, the GPIB connection to the computer and hence the LabVIEW application for automated calculations need only be made once the experiment can be done manually. That is to say that the measurements should be completed manually first in order to determine how to best implement the application.

3.2.1 General configuration

Impedence Termination Noise Source

The Gain method requires that an impedance termination be connected to the RF input of the DUT and hence act as a noise source. Table 3.3 gives the termination's parameters and the noise it generates at a hyperthetical ambient temperature of $290^{\circ}K$ over the various DUT bandwidths and the measurement bandwidth.

Parameter	Value [unit]
Impedence	50Ω
T_0	$290^{\circ}K$
N_0	$-174dB/Hz$
$N_0(B_n=10MHz)$	$-103.978 dBm$
$N_0(B_n=490MHz)$	$-87.988 dBm$
$N_0(B_n=500MHz)$	$-86.988 dBm$

Table 3.3: Impenece Permination (Noise Source) Parameters

Spectrum Analyser Settings

There are some considerations that need to be taken into account with regards to the spectrum analyser's signal processing. Sampling is a process that involves numerous factors and parameters that are either directly or inversly proportional. They need to be considered and addressed accordingly to ensure the best results. Below is a table listing all the parameters of interest in our measurement. It is followed by a short note on each parameter's significance and why the particular value was chosen.

Parameter	Value []
B	$B_n = B_{DUT}$
RBW	1Hz
VBW	1Hz
Samples	1000
Ave	100
Att	10dB

Table 3.4: Spectrum Analyser Parameters

- B** -the measurements bandwidth and hence the noise bandwidth is determined by the DUT bandwidth. for accuracy, it must be set to less than the DUT bandwidth (i.e. $B_n < B_{DUT}$). Once B_n is determined, f_{start} and f_{stop} or f_{center} and f_{span} can be set. However, it should be noted as expressed in equation 2.4 that noise is proportional to bandwidth. Therefore by increasing the bandwidth, both the input noise power and the instrument noise floor will increase. We have chosen a bandwidth of 10MHz. The factor influencing this choice were the RBW, N_o and noise floor magnitude. The RBW is discussed below.
- RBW** -the resolution bandwidth should be set as low as possible. This will reduce the instrument noise floor and increase the measurement accuracy, but the draw back is that the instrument will take much longer to do a single sweep. The choice of bandwidth will however limit the achievable RBW for most instruments. In the case of the E4407B, the lowest RBW is 1Hz at a span of 1-10MHz [9].
- VBW** -the video bandwidth by default is set to match the resolution bandwidth, thus achieving a RBW/VWB ratio of unity.
- Samples** -in any sampling application it is important that the number of samples be set as high as possible to ensure that when an average is taken it includes as many data points as possible. This will reduce the effects of jitter as discussed in section 2.3.1, but it will compromise the sweep time.
- Swp** -the sweep time is determined by the RBW and the number of sample points. Therefore, there needs to be a balance between the RBW and the number of samples used in the measurement to minimise the sweep time as this could make the measurement process rather time consuming if a lot of measurements are needed.
- Ave** - The number of averages is important as that is the number of times the instrument will use average the sample at each data point. Thus the more averages the better. Once again, this will influence the measurement time.

Att -the attenuation is in this case is a safety measure that helps protect the instrument against high signals. It specifies the degree of attenuation to be applied to an incoming signal. This only has a marginal negligible on the results as it is factored into the spectrum analyser’s calculations and output.

3.2.2 Limitations Due to Spectrum Analyser Characteristics

Parameter	$N_{floor}[dBm]$	$N_0[dBm]$
$B_n=10MHz$	-89.43	-103.978
$B_n=490MHz$	-85.63	-87.988
$B_n=500MHz$	-85.45	-86.988

Table 3.5: N_{floor} and N_0 over noise bandwidth for $T_0 = 290^\circ K$

The spectrum analyser noise floor plays a big part in these measurements. The table above shows the input noise power and the spectrum analyser noise floor at different noise bandwidths. Notably, the noise floor level is not changing with the increase in bandwidth, or conversely, it is not dropping as the bandwidth is decreased. This is a factor that delayed the performing of the experiments. The noise floor can mask the input signal if it not low enough.

3.3 DUT Specific Setup and Measurement

3.3.1 Amplifier Noise Figure Measurements

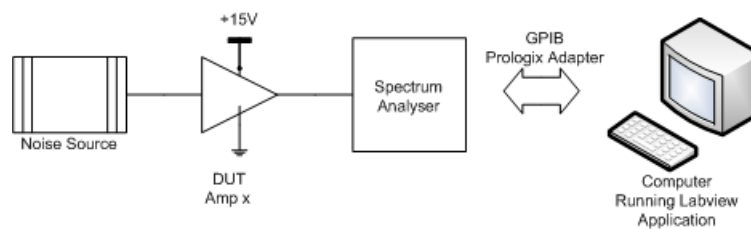


Figure 3.1: Experimental Setup for Amplifier Test

The amplifiers were tested with the setup shown in figure 3.1 with the noise source representing the termination . Application of the gain method is quite straight forward. Equations 2.12 and 2.13 use the added noise as one of the variable in the equation, though in practice, this won’t be known. From simple arithmetic, the following equation can be derived:

$$F[dB] = N_{out} - (N_o + G) \tag{3.1}$$

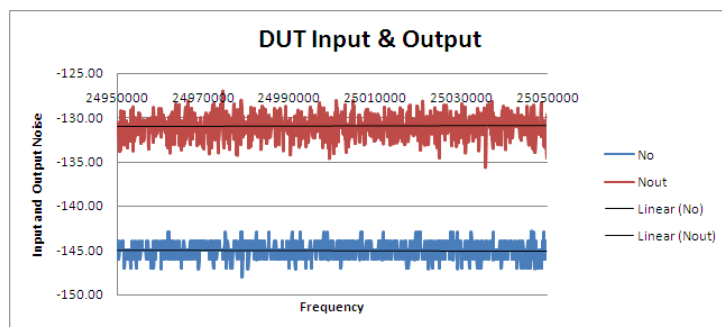


Figure 3.2: DUT input and output noise

Note that all variables must be expressed in dB's. This equation is rather intuitive and quite accurate. The figure below illustrates the input and output noise for Amp 1. The input is at a level of -145dB and the out at -132dB. Application of equation 3.1 gives a noise figure of 6dB. This quite close to the actual data sheet value for amp 1 which is 3.8dB.

3.3.2 Mixer Noise Figure Measurements

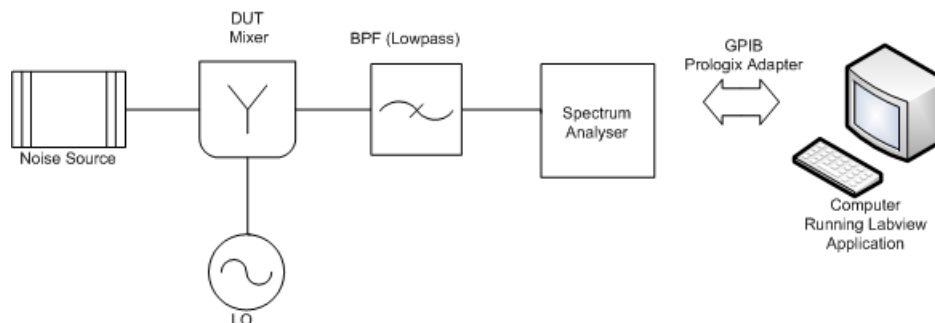


Figure 3.3: Experimental Setup for Mixer Test

The mixer measurement setup was as seen in figure 3.3. Unfortunately, it could not be tested as the noise floor of the spectrum analyser was too high for the IF to be detected.

3.4 LabVIEW Application Development

From the above sections, it is clear that the experiment is dependant on the actual experimental setup and the apparatus used. This is true for any measurement experiment. What this means is that any measurement experiment is unique as a result of circumstance and the limitation of the components and instruments used. Therefore, the application should not be developed for a specific experiment, but rather for a typical setup. This is the approach that we will take.

To begin with, we will identify the different functions that the application need to perform so that we can break up into modular entities that can be connected to give full working model. This greatly simplify the process. The modules will be constructed sequentially, as they will eventually be connected, thus ensuring that the application is indeed working properly at each stage. Once the application is functioning properly, we can conduct the experiment and compare the results to those in section 3.3.

3.4.1 Application Module Identification

The working modules of the application can easily be identified for their functions, which are similar to the different stages of the experimental. The modules needed and their specific functions are as follows:

1. *Instruments Control*

The first step is to obtain instrument control via a GPIB interface. This will allow for data to be written to and read from the instrument, thus enabling for the instrument to be configure for the experiment and for the necessary data to be sourced from it. Thus, the module needs to establish a connection between the computer and the instrument and create a platform (VCP) over which the two can communicate.

2. *Setting of Initial Measurement Parameters*

The instrument need to be configured so that it can perform the correct measurements with the correct settings. Therefore, this module must be able to control the necessary measurement parameters, that is set or read in all parameters of importance from the instrument.

3. *Obtaining Input Noise Power Density*

Once the instrument is configure and measurement can take place, we must be able to obtain data pertaining to the input signals to the instrument. This module must obtain input signal information in three forms:

- (a) the trace data from the instrument and write it to a CSV file
- (b) output a graph of the signal as seen on the instrument
- (c) the mean value of the noise power density over the module functions set out r the set band

These are to be done for all four measurements, meaning that there should be four of each.

4. *Calculate Noise figure and Noise Temperature*

This module will use all the data sourced from the instrument along with the set measurement parameters to calculate the noise figure and then the noise temperature of the DUT.

3.4.2 Module Development and Construction

The LabVIEW application did not have to be written from the beginning as a part of it had already been written for a previous project. Parts of the first three modules had already been written, so they had to be adjusted in a manner that suites the application and in some case, it was necessary to rewrite the whole module. The general structure of the already existing code was changed completely as it did not utilise LabVIEW’s modular structures that ensure coherent sequential execution. VI can consist of SubVI’s which are small VI’s written to make an application more manageable and easier to edit. Figure 3.4 shows how the section of the VI in the box can be saved as a SubVI, which ill reduce the block diagram to just three tiles.

Instrument Control

Figure 3.4 illustrates the SubVI that was used to obtain instrument control. There are numerous ways in which to do this, but generally it will depend on the type instrument you are attempting to control and the drivers that are needed for it. This SubVI uses a “VISA Configure Serial Port” tile, which marked (C) on the block diagram. By wiring the instrument address (A) and the VISA resource (the instrument) name(B) to the tile, the port where the instrument is connected will be initialised. Tiles (D) and (E) are enable the read and write sequences to the port and therefore the instrument. (F) contain a series of instruction that can be sent to the port, in this case, the instruction used requests the bytes at the port.

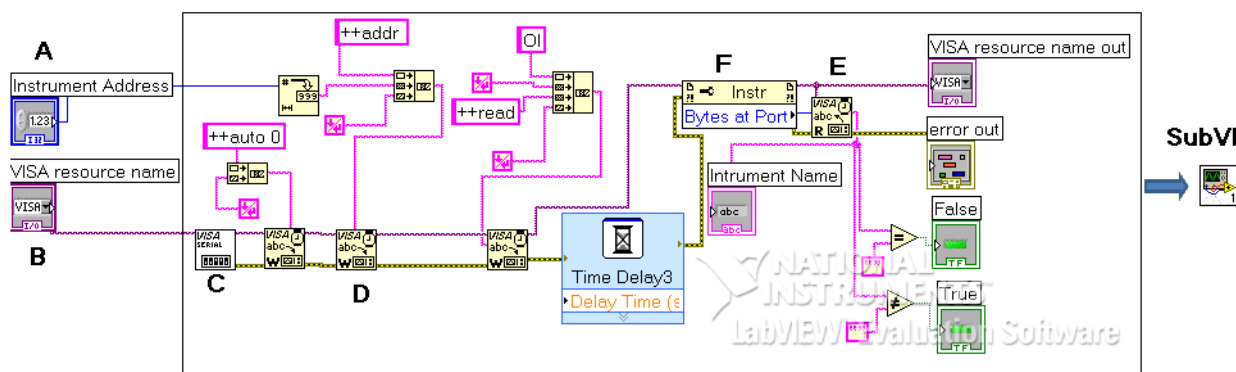


Figure 3.4: Find instrument SubVI

Setting of Initial Measurement Parameters

The setting of the spectrum analyser parameters is vital as these are the measurement settings. The need for these setting to be entered through LabVIEW is because once control is achieved by the 'find instrument' SubVI, the spectrum analyser keys are suspended and do not respond to any input for the duration of the connection.

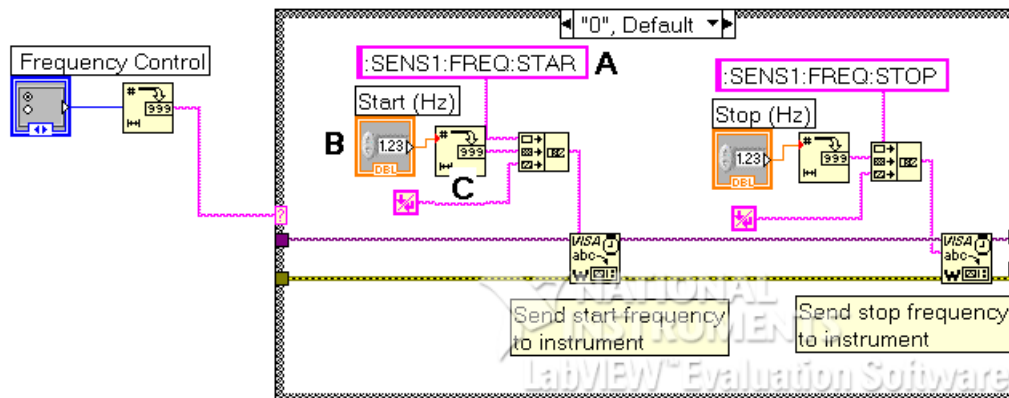


Figure 3.5: Setting spectrum analyser parameters SubVI

In setting the parameters, it is also essential that there is an option available for choosing how to configure the spectrum analyser. Therefore, to ensure this and to keep execution control in check we use execution structure such as while loops and sequence structures. In this case of figure 3.5, a 'case' block was used for the setting the measurement bandwidth. One option gives the option to specify the bandwidth using f_{start} and f_{stop} while the other uses f_{center} and f_{span} . The tile labelled frequency control is used to specify which case to execute. Tile (B) will translate into an input palette in the front panel where the desired parameter value can be entered. Tile (A) contains the programming code string for the spectrum analyser. The code tells the spectrum analyser what setting to adjust. Tile (C) converts the input from (B) to a decimal string. The two values are converted to an array and written to the port along with an end of line string that is platform dependant.

All other parameters are set in a similar way, though they are executed within a flat sequence structure that ensure that they are all set in turn one after the other, thus avoiding input output errors. Note the two wires on the 'VISA write' tiles, they are the 'VISA resource name' and 'error' bit line. They ensure that the write port is written to and that an error message is given when when the line is flagged.

Obtaining Input Noise Power Density

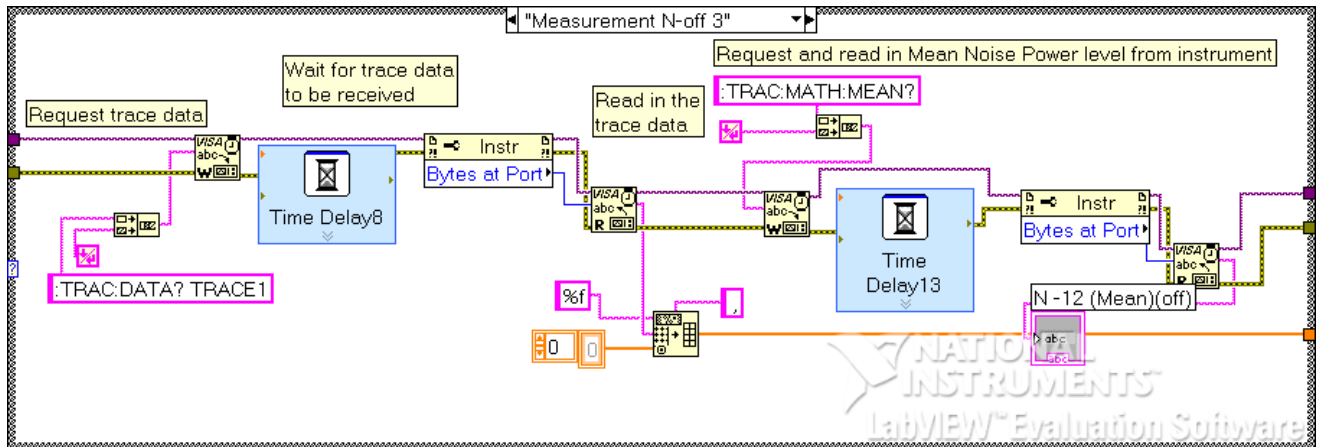


Figure 3.6: Obtaining trace data SubVI

To obtain data from the average noise power density read by the spectrum analyser, one of two methods can be used:

1. request the mean trace value, which will return average value of the trace data.
2. request the actual trace data. This will return a series of value that correspond to the instantaneous value of the noise power at various frequencies. These can be saved to a CSV file along with the corresponding frequencies and analysed using Matlab, Excel, or LabVIEW to get the mean value.

This module implements both methods. First it reads in the trace data and saves it to a CSV file should in case the raw data is needed, then it requests the mean value to avoid unnecessary computation. The first time delay in the figure should be set to $T_{delay} = T_{sweep}$ to ensure that the data read in is of the complete plot and not a partially completed one. To avoid error, do not calculate the sweep time and thus enter the time delay manually. The safe option is to request the sweep time once all the parameters have been set and wire it as input to the time delay token.

Calculating Noise Figure and Noise Temperature

The noise figure calculation is rather straight forward as all it involves is applying the formula. The figure shows an gain input control that can be set in the front panel, this along with the two noise power density value obtained from the spectrum analyser are inputs to the formula block that outputs the noise figure and displays it in the front panel.

The noise input have to placed into an array as they are obtained from using a case block as mentioned in section 3.4.2. Case statements have more than one output but only one can be accessed

at a time depending on the execution criteria. So each output needs to be appended to the array as the experiment is conducted and only once all measurements are done can the calculation be made. This is achieved by adding a toggle control switch that and an 'AND gate'. The 'AND gate' will activate the calculation only once the switch has been flicked on by the user, indicating that all measurements have been completed.

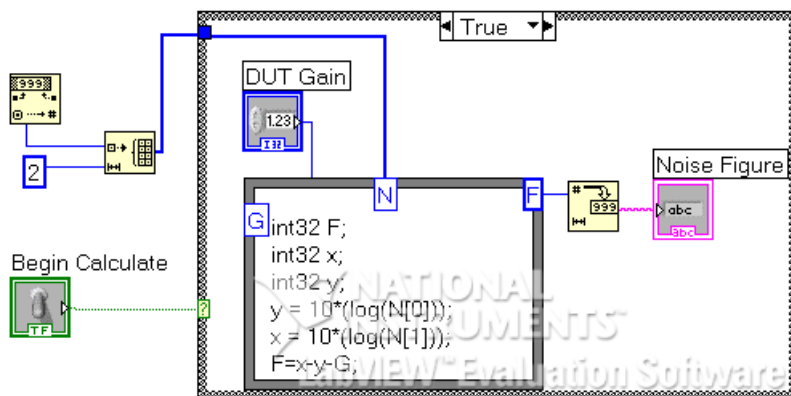


Figure 3.7: Gain method SubVI

Chapter 4

Noise Figure Analyser Measurements

In any experiment, there is a level of uncertainty that can be associated with the data and hence the results that are obtained by analysing the data. It is therefore necessary that we examine the uncertainty in the results to ensure that they are acceptable. This chapter looks at the results obtained from measurements taken using a noise figure analyser. This can serve as a guide as to how accurate measurement taken using the application should be, thus demonstrating the accuracy of the application and quality of the results obtained.

4.1 Results Comparison with Noise Figure Analyzer

- The DUT were tested under different conditions to those layed out in Chapter 3. Th measurements were conducted using the Agilent N8975 noise figure analyser and N4000A noise source. These devices are specially manufactured for the purpose of performing noise figure measurements and are thus ideal for checking the results obtained in chapter 3. However, these measurements were not conducted under strict control as access to the measurement instruments was limited and and there were time constraints. The results are therefore subject to a degree of error, this is discussed further below.

4.1.1 List of Apparatus

- Noise sorce [Agilent N4000A]
- Noise figure analyser [Agilent N8975]
- Network analyser
- RF cables
- RF connectors

4.1.2 Calibration and Measurement Parameters

To perform accurate measurements on the noise figure analyser, calibration needs to be performed over the frequency band of concern, which is determined by B_{DUT} , for each DUT. The process is done by executing the following steps:

1. There are generally two RF cables used in the measurement, between the noise source and the DUT and between the DUT and the instrument. These attenuate the noise signal to a certain degree. From figure 4.1, which gives the S_{21} characteristics of cable 1, it can be seen that the attenuation is constant over a small band and is also small for low frequencies and higher for high frequencies. This attenuation is taken into account by entering the S_{21} value and thier corresponding frequencies into an attenuation table on the noise figure analyser and is compensated for internally during the calculation. Only a few sets of values are needed as the instrument will interpolate these to create an approximation of the rest of the S_{21} characeristic.

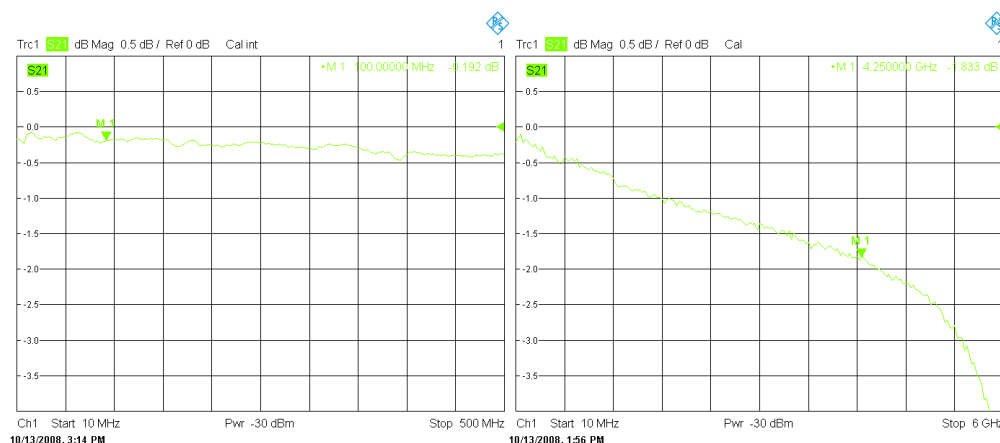


Figure 4.1: S_{21} Characteristic for RF cables 1 over bands 10-500MHz and 10MHz-6GHz

Frquency [GHz]	1.45	2.25	3.6	5
Cable 1- S_{21} [dB]	-0.87	1.15	1.51	2.35
Cable 2- S_{21} [dB]	-191	-2.71	3.46	5.14

Table 4.1: S_{21} Values for attenuation table and S_{21} characteric interpolation

- Enter all the necessary parameters as in table 4.2 on the noise figure analyser. It should be noted that the parameters chosen here are not similar to those in section 3.2.1. This is due the difference in the measurement instruments' tolerances. When using a dedicated noise figure analyser with the appropriate noise source, the noise floor issue is reduced and hence we able to measure using higher bandwidths. Issues regarding the sampling time however, are similar.
- When all the parameters have been entered, the noise source can be connected to the noise figure analyser for calibration. This is done by pressing the calibrate button on the front

Parameter	Value []
ENR	$6dB$
T_{cold}	$302.9^{\circ}K$
B	$B_n = B_{DUT}$
RBW	$4MHz$
VBW	$4MHz$
Samples pts	64
Averages	50
Attenuation	$0dB$

Table 4.2: Measurement condition and parameters for noise figure analyser tests

panel of the instrument. It should be noted that for accurate results, the calibration must be done with the exact parameters that will be used for the measurements.

4.1.3 Measurement Results

The results obtained from the tests are listed in table 4.3 along with the noise bandwidth of each DUT. For a clearer picture of the noise figure characteristic results for each of the DUT's, the graphs in figures A.1, A.2 and A.3 in Appendix A illustrate both the gain and noise figure of the DUT's across the span of their operating bandwidth.

DUT	B	$F_{datasheet}$	F_{NFA}	Variance
	[MHz]	[dB]	[dB]	[dB]
Amp 1	490	3.8	5.12	1.32
Amp 2	500	1.6	1.028	0.572
Mixer 2	50	6	4.86	1.14

Table 4.3: Noise figure analyser results

Amp1 The gain of Amp 1 is matched that in the component performance curves in Appendix ???. The noise figure is out by a approximately $1.32dB$. The figure characteristic also showed a peak of $6.69dB$ at $87.77MHz$. Therefore, the amplifier may have a deadband in that region and thus produces an excess amount of noise. The rest of the noise figure and gain characteristics are quite constant, and since the DUT gain is well approximated, the noise figure error could be attributed to experimental error.

Amp2 As with Amp 1, the gain here matched that in the component performance curves. The device gain is also quite constant over its band, as is the noise figure which is at a value of $1.028dB$.

Mixer The results obtained for the mixer were not quite as those for the two amplifiers. From figure A.3, it can be seen that both the mixer conversion loss and the noise figure

characteristic are not constant over the band (10MHz to 50MHz). However, as the characteristic tends to the IF frequency of 50MHz, the two parameters also tend to get closer to the expected noise figure and conversion loss values of 6dB, reaching 4.86dB and -3.15 respectively. From this it can be concluded that the characteristic would be similar if the IF was approached from the right.

4.1.4 Experimental Limitations

Due to a number of limitation on the experiment, the results obtained were not optimum. The limitations that affected these measurement an listed below.

1. *Time constraint*

The experiment was conducted at the SKA/KAT laboratory in Pinelands Cape Town. It is a private company and thus the access that can be granted to a student is limited. The measurements had to be conducted within a limited amount of time and with little control over how they should be conducted, thus limiting the achievable precision and the number of measurements that could be made. Only one measurements was acquired for each of the DUT's.

2. Calibration

Calibration was conducted for each over its respective band and bandwidth. The calibration for Amp2 was done with a lower RBW and using more averages than the other two DUT's. As a result, the noise figure measured for Amp 2 is more accurate than for the other DUT. From we can conclude that had all calibrations been and averages been conducted as for Amp 2, the results may have been more accurate over all.

Chapter 5

Results and Project consolidation

5.1 Noise Temperature and Noise Figure

The relation between noise temperature and noise figure was discussed in chapter 2. This project aims to measure noise temperature, however, noise figure was found to be the more feasible parameter to measure as it characterises noise temperature and it is the parameter that is conventionally used, for both measurements and performance specifications. For this reason, this project has addressed the concept of noise temperature by focussing on noise figure and relating it back to noise temperature as in equation 2.1.

5.2 Application Development and Testing

The application development was carried out in four phases:

1. Research on the project topic
2. Used experimentation to evaluate development approach.
3. Application programming and testing
4. Comparison with dedicated measurement instrument

5.3 Project Results

The requirements as stated in section 1.4.2 were addressed and the results obtained are discussed below.

5.3.1 Noise Figure Measurement methods

There were various existing methods for noise figure and hence noise temperature measurement. Of these, it was that the Y-factor method was the most commonly used and is in fact implemented in most of the industry standard instruments that are used for noise figure measurements. The gain method was also identified as reliable, though not as common as the Y-factor method. Other methods considered were found to be variations of the above mentioned methods and hence the two were chosen for experimentation, the results of which would be used to setup the constraints used to implement a noise figure measurement application in National Instruments LabVIEW.

5.3.2 Experimentation and Constraint Development

In chapter four, the feasibility of implementing the Y-factor method and the gain method were investigated by setting up laboratory experiments. However, it became clear that conducting the Y-factor method would not be possible due to limitations that arose due to the unavailability of the necessary apparatus. An alternative method was considered in its place, the two temperature method that approximates the Y-factor method. This too could not be realised for similar reasons.

The Gain method was deemed viable as all the necessary apparatus was available and thus measurements parameters were determined. Three devices were tested. Problems were encountered during experimentation when the spectrum analyser could not output any usable results. The use of pre amplifiers solved this problem and results were obtained. However, these results were not satisfactory as the noise figure values obtained did not correspond closely to those in the manufacturer's data sheets.

Though the experimentation did not succeed, the application could still be written as measurement parameters were obtained. Both methods were implemented in the application, thus ensuring the possibility for future testing and development.

5.3.3 Application Performance

The application developed utilizes LabVIEW's sequence structure block to achieve modularity. This will help ensure ease of use and modification. The structure that was focused on is the case structure. It ensures that the program only executes what needs to be executed as case structures are input dependant, hence the execution sequence is also input dependant.

5.4 Project Limitations

The project encountered a number of limitations that in essence greatly restricted the full development of the application. These limitations are as follows:

- not all apparatus needed was available, as a result, experiments could not be conducted.
- instrument thresholds limited the extent to which experiments could be conducted and hence both development testing of the application were also limited.

Chapter 6

Conclusion and Future Work

This project was aimed at developing a noise temperature measurement application using National Instruments LabVIEW. It involved investigating what methods could be implemented and using experimentation to develop and structure the application in a modular way.

LabVIEW is a very powerful tool and is quite versatile as it can be used in many different applications. Its use in this project demonstrates this. We were able to implement application structures for noise figure and hence noise temperature measurement as required. The application is able to configure the spectrum analyser for measurement and read data from it. The data is read in through structures that ensure sequential execution and calculation. The application does however have limited functionality as can be expected, but performs all necessary functions with regard to the requirements of this project. Should more functionality be needed, the code has been structured in such way as to allow ease of interpretation and modification.

There were numerous factors that limited the development of the project. Though these limitations were restrictive, the application was built, the drawback is that the application has not been properly tested.

There is a great potential for future endeavours regarding this project, they are as follows:

1. The application needs to be tested under ideal conditions to test the required functionality. That is to say, with the use of proper apparatus and instrument. This will allow for the optimisation of the application, also including and factoring any necessary correctional terms for compensation.
2. As mentioned, the actual functionality is limited to the requirements of this project. However, further development is possible where a number of other measurement or test applications can be included. With will come the need to enhance the control capabilities of the application, making them more in depth and easier to use.

Appendix A

Figures

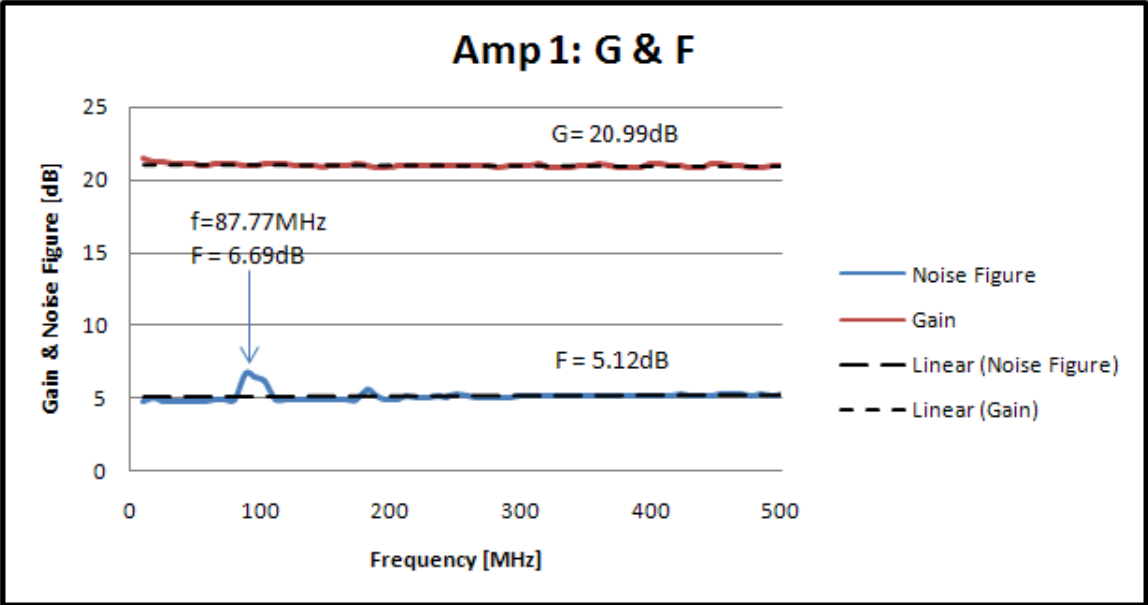


Figure A.1: Amp 1 gain and noise figure characteristic from noise figure analyser

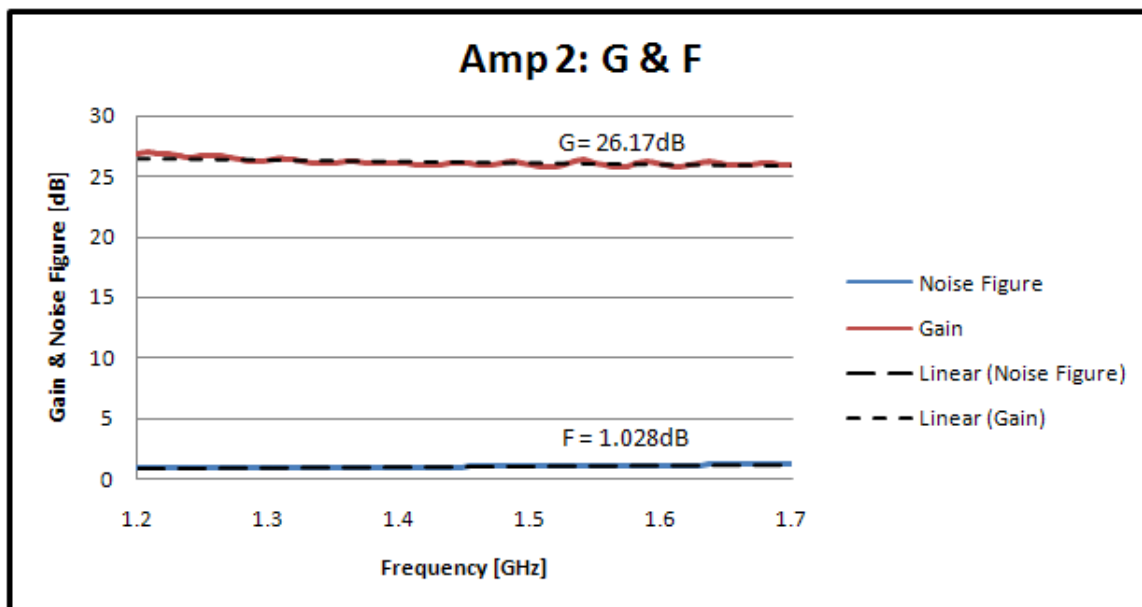


Figure A.2: Amp 2 gain and noise figure characteristic from noise figure analyser

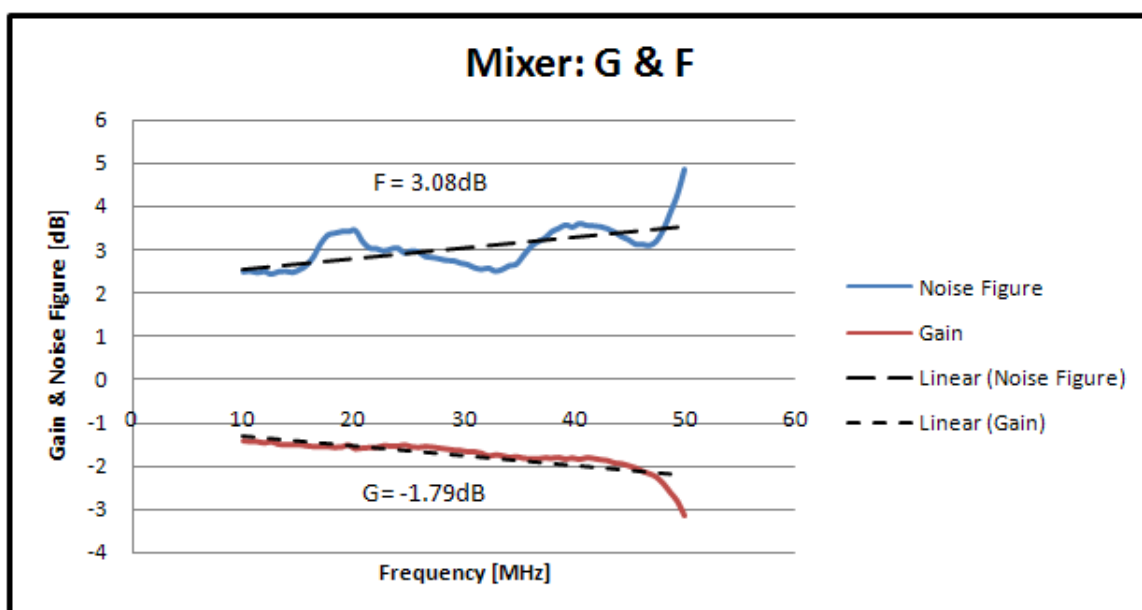


Figure A.3: Mixer gain and noise figure characteristic from noise figure analyser

Appendix B

Datasheets

B.1 Prologix GPIB-USB Controller Driver Installation

The Prologix GPIB-USB Controller requires that its drivers and configuration tool be installed before it can be used:

- The configuration tool is called the KE5FX GPIB Toolkit and it can be downloaded directly from the site below. It should contain all the necessary drivers. Upon installation, all the drivers will be automatically installed and the controller will be configured for default use, which usually does not need to be altered for basic use.

– <http://www.thegleam.com/ke5fx/gpib/readme.htm>

- Should the drivers need to be installed manually for whatever reason, they can be downloaded from <http://www.ftdichip.com/Drivers/D2XX.htm>. Ensure that the drivers you choose are the latest and are compatible with your operating system.

- The driver installation is a two step process as there are two set of drivers, one for the virtual serial port and the other for the USB serial converter. Both these have to be installed[8].

- The Prologix GPIB-USB Controller User Manual can be downloaded from <http://prologix.googlepages.com>

B.2 Amp 1 : Mini Circuits ZEL-1217LN

Low Noise Amplifier

ZEL-1217LN

Typical Performance Curves

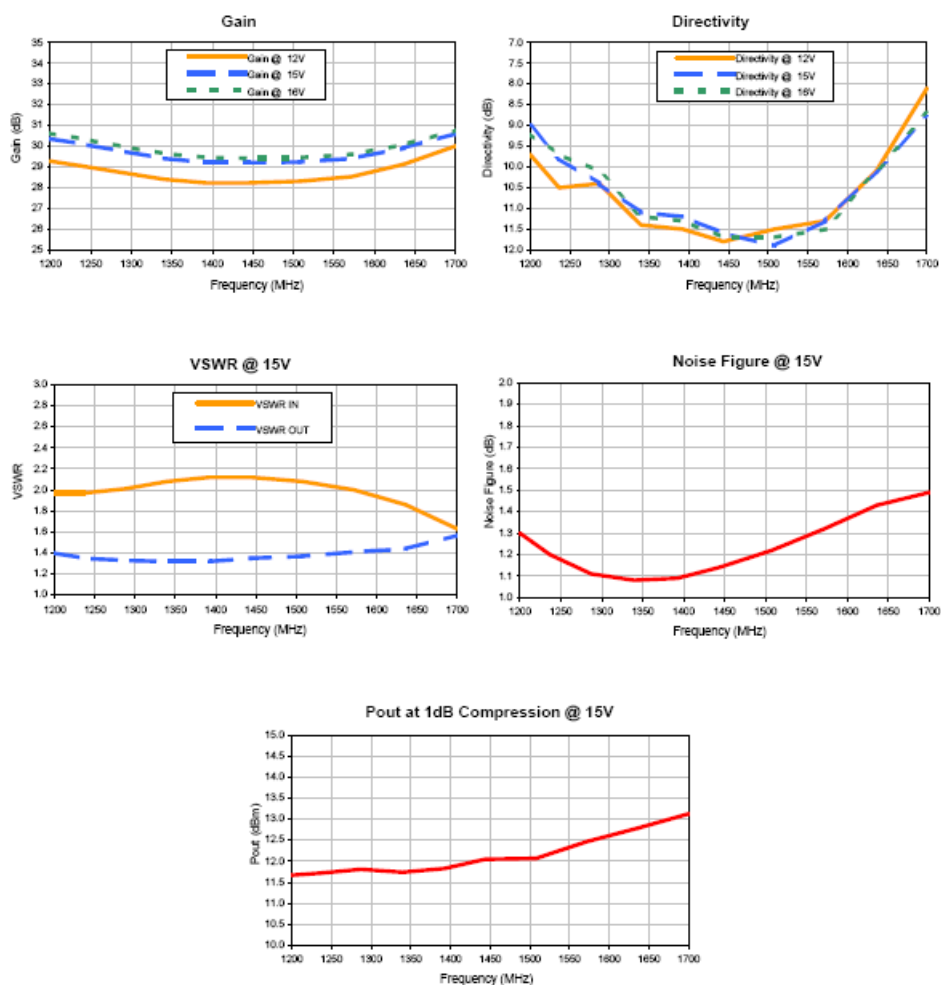


Figure B.1: ZEL-1217LN Typical performance curves

B.3 Amp 2 : Mini Circuits ZFL-500HLN+

Low Noise Amplifier ZFL-500HLN+ Typical Performance Curves

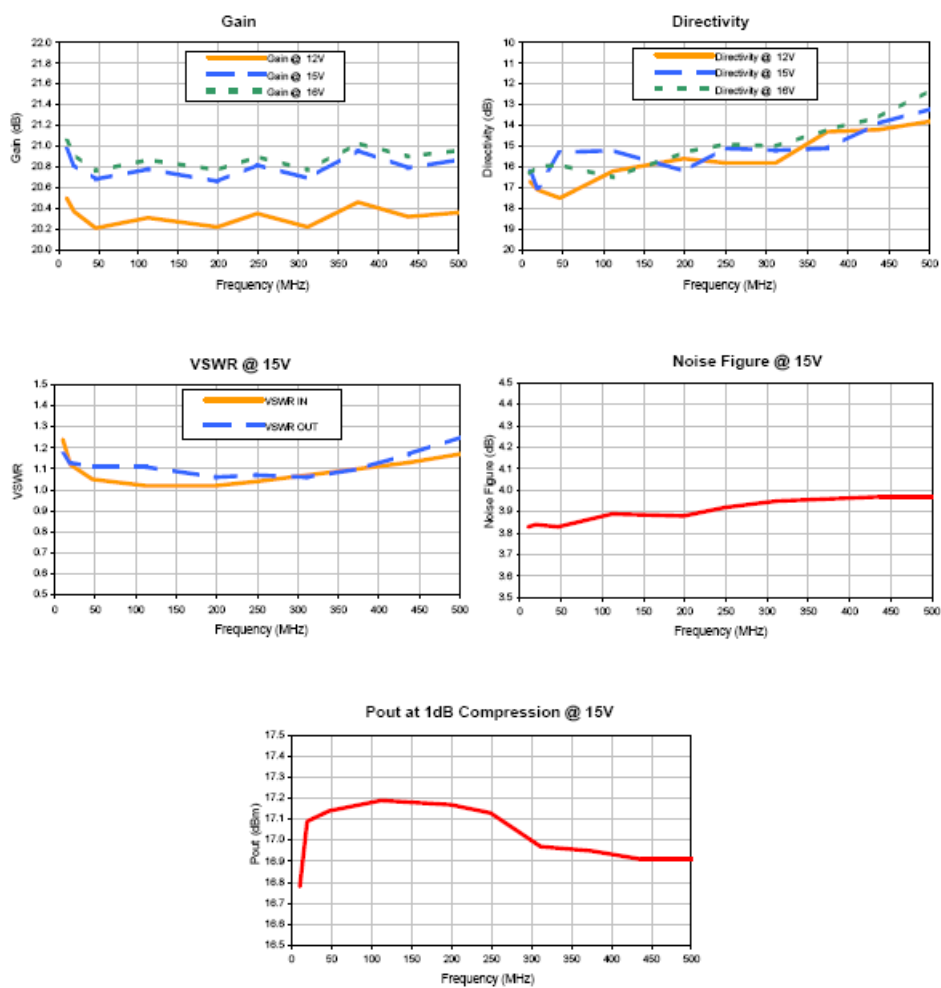


Figure B.2: ZFL-500HLN+ Typical performance curves

B.4 Mixer : Miteq

This component's data sheet was unavailable from the manufacturer's website.

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