A short preliminary report on

ENR Measurement of Noise Source and Noise Generator

BY

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I am thankful to **Prof. Yashwant Gupta, Prof. S. K. Ghosh** and **Prof. Jayaram Chengalur** for their guidance and encouragement.

Ideas in this report for measuring ENR are brainchild of **Mr. Ajith Kumar, Mr. SureshKumar** and **Mr. A. PraveenKumar.**

Preface:

This document is not complete in its own. It is intended for ease of understanding. I might have missed few things in it. I would like to have more cerebration on various methods explained here.

Abstract:

Homebrewed Noise Generator (Noise cal Injection Unit) is used in each Front-End box for calibrating RF chain. For accurate calibration, it is very important to know exactly how much noise is injected in RF path and what are the effects of ambient temperature and supply voltage variation on injected Noise. Thus output ENR of Noise source has to be measured accurately.

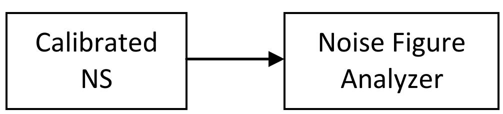
Note:
1. In this context, the term **Noise Source** is used for readily available noise sources that work on 28V pulsating DC signal from Noise Figure Analyzer while the term **Noise Generator** is used for homemade 'Noise cal Injection Unit' (that works on +15 DC supply) used in Front-End Boxes.
2. The term 'Temperature' refers to Noise Temperature unless and otherwise specified.

In this document I will discuss 3 basic things:

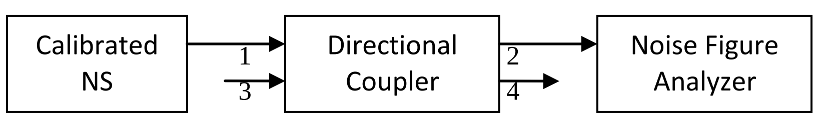
1. One method that can directly measure **Tcal** injected in RF channels
2. Various methods that can be used to measure **ENR** of Noise Generator/Source
3. Practical measurements using some of above methods

Method that can directly measure Tcal injected in RF channels:

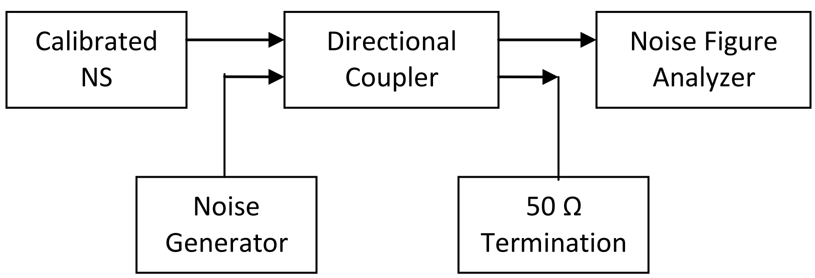
Calibrate Noise Figure Analyzer using calibrated Noise Source whose ENR values are known.



Now connect directional coupler between Calibrated Noise Source and Noise Figure Analyzer. Make sure that Calibrated Noise Source is connected to **incident port** i.e. port1 of directional coupler and NF analyzer is connected to **transmitted port** i.e. port2 of directional coupler as shown below.



Now connect Noise generator output to **coupled port** i.e. port3 of directional coupler and terminate **isolated port** i.e. port 4 as below.



Measure the noise temperature **T(ng_off)** of Directional coupler on NF Analyzer keeping Noise Generator off.

Now switch on Noise Generator and measure Noise Temperature **T(ng_on)** on NF Analyzer.

Then Noise Temperature injected **T(inje)** in path from Port1 to Port2 is given by

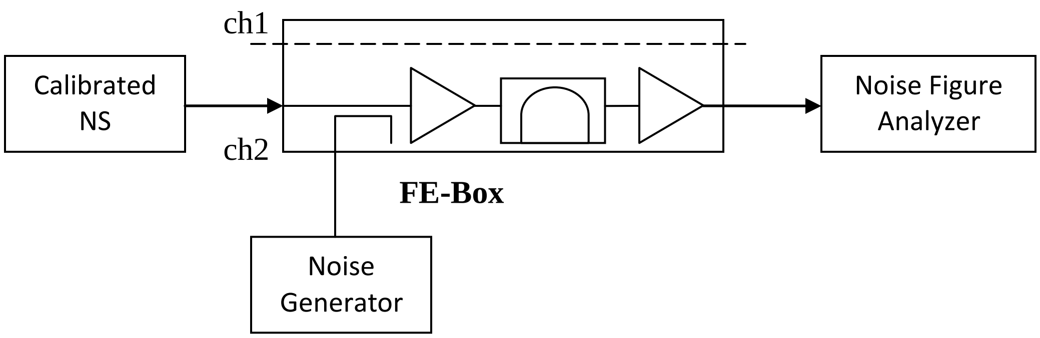
$$\boldsymbol{T}(\boldsymbol{Inje}) = \boldsymbol{T}(\boldsymbol{ng\_on}) - \boldsymbol{T}(\boldsymbol{ng\_off})$$

Calculate Noise Temperature output **T(op)** of Noise generator using

$$T(inje) = \frac{\boldsymbol{T}(\boldsymbol{op})}{CF} + \frac{CF - 1}{CF} T(dc)$$

where CF is coupling factor (in linear scale) of directional coupler and T(dc) is noise temperature of directional coupler.

For our application above experimental setup is simplified as



Front-End box is having directional coupler which is used for injecting calibrated signal in RF channels. Noise temperature of whole FE-Box is calculated with **Noise Generator OFF** and then **Noise generator ON**. Difference in both measurements is nothing but **Tcal** injected in RF channel.

Actual Measurements:

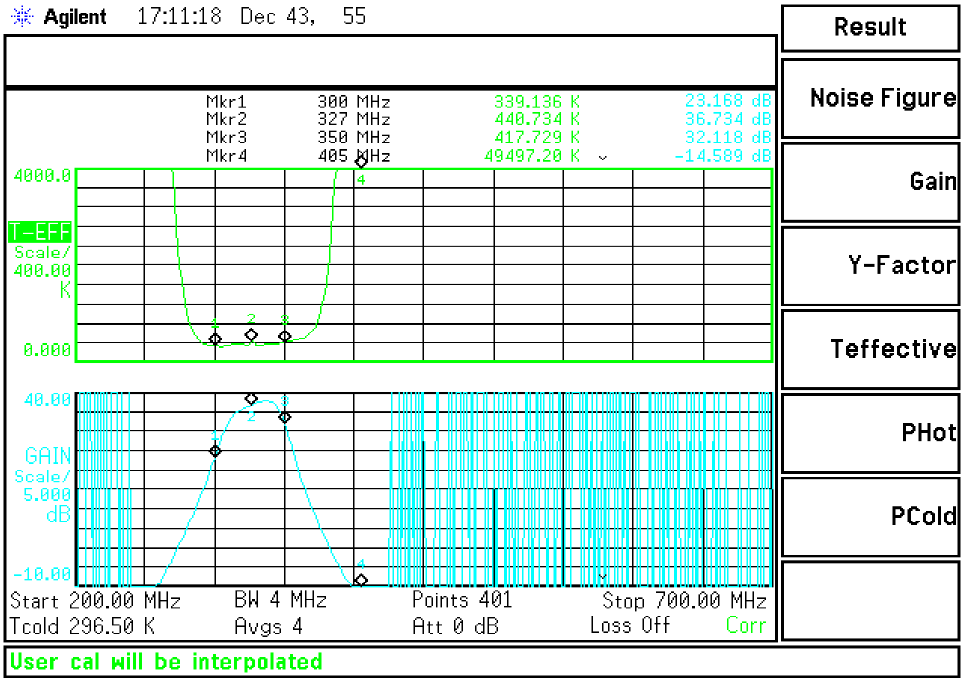


Fig: Temperature and Gain of Horizontal channel of 327MHz FE-Box with Noise Generator **OFF**

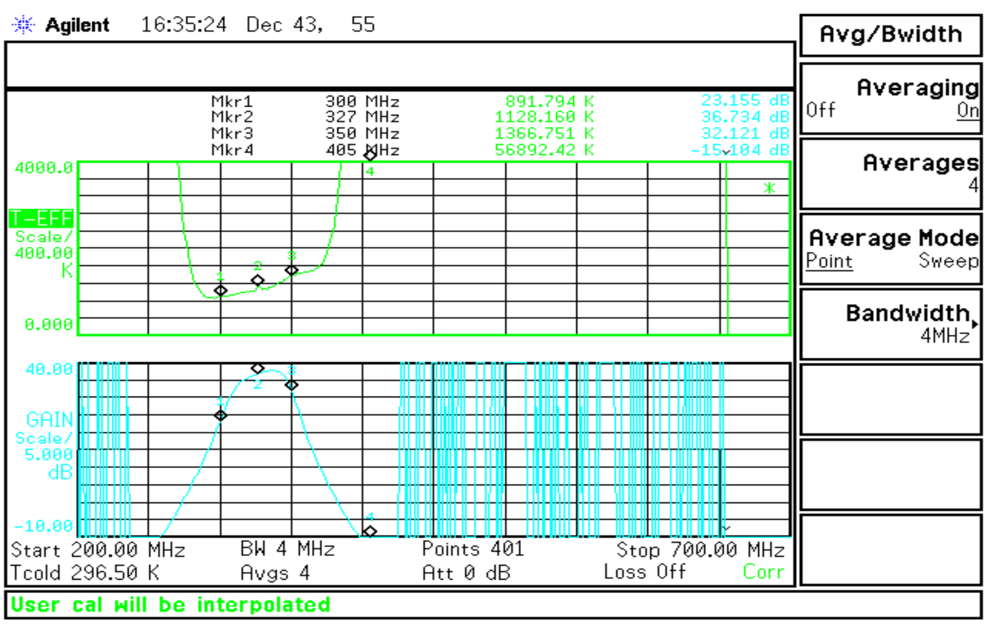


Fig: Temperature and Gain of Horizontal channel of 327MHz FE-Box with Noise Generator **ON** (Extra High cal)

Measurement Results for Tcal injected in Horizantal and vertical channels:

Cal Levels	233MHz FE Box			327 MHz FE Box			610 MHz FE Box		
	H	V	E	H	V	E	H	V	E
E.H. cal	2372.41	2388.62	800	723.43	676.33	400	794.85	816.03	400
High cal	552.92	560.48	200	153.28	159.52	100	181.72	178.83	100
Med cal	219.92	242.17	80	53.49	62.83	40	72.69	64.25	40
Low cal	50.73	48.33	20	8.83	21.71	10	24.84	4.95	10

Table: Noise temperature injected in RF channels for various cal levels

All noise temperatures are in Kelvin. Terms H, V and E represent Noise Temperature injected Horizantal channel, Vertical channel of FE box and expected temperature respectively

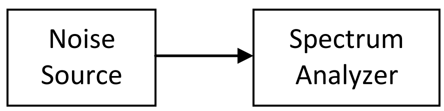
Inference drawn from above method:

Noise temperature injected in horizontal and vertical channel of Front-End Box is almost same for all levels of cal. But measured Tcal values are not matching with expected Tcal values. **More citation is required** for finding out reason of mismatch between measured and expected Tcal values. Suggestions are greatly welcome.

Various methods that can be used to measure ENR of Noise Generator/source:

1. Using Spectrum Analyzer
2. Using Noise-Figure Analyzer
   a. Using known Noise Source and calculating NF of DUT.
   b. Using known Noise source whose Temperature/ENR is known
   c. Using known Noise Source and calculating Temperature of DUT
   d. Measuring Phot and Pcold on NFA using manual measurement method.
   e. Y-Factor measurement
3. Using power meter.
4. Using ENR meter.

1) Using spectrum Analyzer



Measure Power (in dBm) of Noise Source using Spectrum Analyzer.

Calculate Temperature (Tn) from measured power using

$$P = 10Log\frac{K(Tn)\Delta F}{0.001}$$

Where, P = Power measured using Spectrum Analyzer

K = Boltzman Constant = 1.3806 x 10^{-23} J/K

Tn = Temperature of Noise source corresponding to given ENR

T0 = Ambient Temperature

ΔF = Video Bandwidth kept on spectrum Analyzer

Calculate ENR in dB using following Equation

$$ENR = 10Log\frac{Tn - T0}{T0}$$

Limitations:

1. Power measured is not repeatable over a period of measurement.
2. Power cannot be measured accurately because of fluctuation in measurement.
3. To get accurate ENR, precise ambient temperature (T0) has to be known.

Excerpt from Application Note from NoiseWave:

Why can't I see my noise source on a spectrum analyzer?

If you are attempting to measure a lower power noise source, < 30 dB ENR, in all probability the spectrum analyzer Noise Figure, which usually is at a minimum of 25 dB and many times is 35 dB, is above the noise level of noise source. At these levels we can approximate Noise Figure and ENR and compare directly to see if the noise source will be detectable. This source could be measured with an LNA in front of the Spectrum Analyzer although to get an exact ENR we would need to know the NF of the LNA and its gain but we can see if the approximate deflection occurs. For example a 15 dB ENR noise source should change the noise level about 10 dB if the noise figure of the LNA is about 5 dB, as long as the LNA gain is sufficient to overcome the Noise figure of the analyzer. Higher power noise sources can be measured on a spectrum analyzer for flatness and on a power meter for output power.

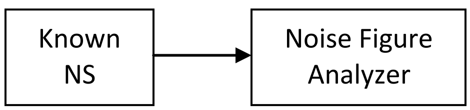
What are some pitfalls to watch out for with noise measurements on a spectrum analyzer?
Care must be used when making noise figure measurements on a spectrum analyzer. There are multiple possible sources of potential error. Since noise sources are very broadband their powers can increase quickly as gain is added. Couple this with the fact that the noise has large peaks that can start to compress the amplifier and the high noise figure of spectrum analyzers results in less range available then one might think.
The spectrum analyzer noise floor can be reduced by pulling out attenuation however if 0 dB is used then care must be exercised because the VSWR will be degraded, if the broad band response is very ripple then additional errors can be introduced
For more details see full article at http://www.noisewave.com/faq.pdf

2) **ENR measurement Using Noise Figure Analyzer:**

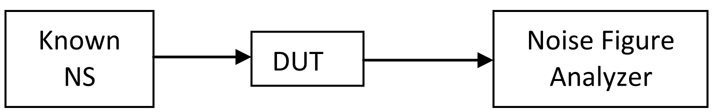
Note: First three methods using NF Analyzer can only be used to measure ENR of readymade Noise Source (which works on pulsed +28V noise source drive output from NF analyzer.) In case of our Noise Generator (which works on +15V dc), NF analyzer shows random values and lines.

a) Calculating NF of DUT

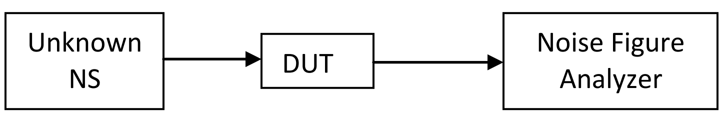
Calibrate Noise Figure Analyzer using calibrated Noise Source whose ENR values are known.



Measure NF of DUT (Device Under Test) e.g. LNA, Broadband Amplifier, Fixed attenuator) using calibrated Noise Source. Measure NF in linear not in dB form.



Measure NF of DUT using unknown Noise Source whose ENR values are to be measured. Measure NF in linear not in dB form.



Derive ENR of known calibrated noise source in Linear from given dB values.

Find out ENR of unknown source using Following equation:

$$\boldsymbol{ENR(unknown) = ENR(known) + NF(by\ known) - NF(by\ unknown)}$$

Note: All values are in linear scale

Advantages:

1. ENR values of unknown Noise Source can be calculated without measuring ambient Temperature.

Limitations:

1. ENR values of known Noise Source and unknown Source must be closer to each other. i.e. **ENR(known)** ≈ **ENR(Unknown).** If difference in ENR values is more then, Noise Figure of Source whose ENR values are larger cannot be shown on NF Analyzer.

Above method is verified by taking two calibrated noise sources and finding ENR values of second source using first source.
DUT = Broadband Amplifier in Common-Box

Let us assume that
Known source = Agilent 346A (serial number: 4015A05994)
Unknown source = NoiseCom NC346A (serial number: Z263)

Frequency	Known Source		Unknown Source		
	ENR (dB)	NF (dB)	NF (dB)	ENR(calculated) (dB)	ENR(given) (dB)
100MHz	4.8	6.911	5.608	6.103	6
1GHz	4.54	6.985	5.707	5.818	5.72
2GHz	4.82	7.811	6.956	5.675	5.48
3GHz	4.83	9.399	8.801	5.428	5.53

Now, Let us assume that
Known source = NoiseCom NC346A (serial number: Z263)
Unknown source = Agilent 346A (serial number: 4015A05994)

Frequency	Known Source		Unknown Source		
	ENR (dB)	NF (dB)	NF (dB)	ENR(calculated) (dB)	ENR(given) (dB)
100MHz	6	6.79	8.082	4.708	4.8
1GHz	5.72	6.928	8.191	4.457	4.54
2GHz	5.48	7.586	8.493	4.573	4.82
3GHz	5.53	9.434	10.163	4.801	4.83

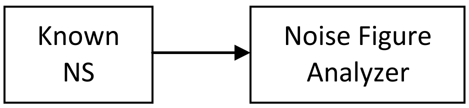
Conclusion drawn from above method:
Calculated ENR of assumed unknown noise source is almost equal to ENR values given in its ENR table.

b) Using Noise source whose temperature is known:

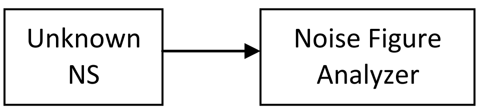
Calculate temperature **T(known)** of known noise source from given ENR values as

$$ENR(known) = 10Log\frac{\boldsymbol{T(known)} - T0}{T0}$$

Calibrate Noise Figure Analyzer using calibrated Noise Source whose ENR values are known.



Measure Temperature (say **Tmeas**) of unknown Noise Source on Noise Figure Analyzer. This temperature will be with reference to known noise source.



Find out temperature of unknown source using Following equation:

$$\boldsymbol{T(unknown) = T(known) + Tmeas}$$

Calculate ENR of unknown source using Following equation:

$$\boldsymbol{ENR(unknown)} = 10Log\frac{T(unknown) - T0}{T0}$$

Limitations:

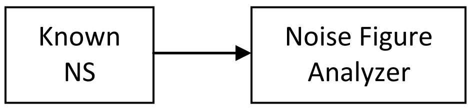
1. ENR values of known Noise Source and unknown Source must be closer to each other. i.e. **ENR(known)** ≈ **ENR(Unknown).** If difference in ENR values is more then, Temperature cannot be shown on NF Analyzer.
2. To get accurate ENR, precise ambient temperature (T0) has to be known.

c) Calculating Temperature of DUT (slight variation of above)

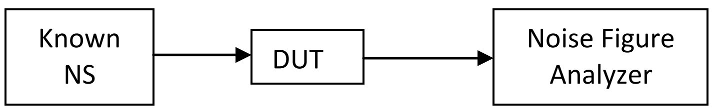
Calculate temperature **T(known)** of known noise source from given ENR values as

$$ENR(known) = 10Log\frac{\boldsymbol{T(known)} - T0}{T0}$$

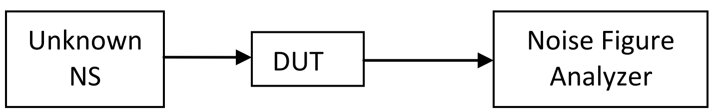
Calibrate Noise Figure Analyzer using calibrated Noise Source whose ENR values are known.



Measure Temperature **Tdut(known)** of DUT (Device Under Test) e.g. LNA, Broadband Amplifier, Fixed attenuator) using calibrated Noise Source.



Measure Temperature **Tdut(unknown)** using unknown Noise Source whose ENR is to be measured.



Find out Temperature of unknown source using Following equation:

$$\boldsymbol{T(unknown) = T(known) + Tdut(unknown) - Tdut(known)}$$

Calculate ENR of unknown source using Following equation:

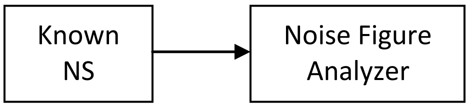
$$\boldsymbol{ENR(unknown)} = 10Log\frac{T(unknown) - T0}{T0}$$

Limitations: (Same as in above case)

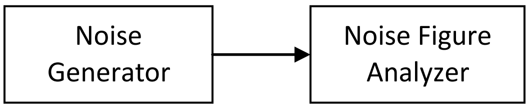
1. ENR values of known Noise Source and unknown Source must be closer to each other. i.e. **ENR(known)** ≈ **ENR(Unknown).** If difference in ENR values is more then, Temperature cannot be shown on NF Analyzer.
2. To get accurate ENR, precise ambient temperature (T0) has to be known.

d) Measuring Phot and Pcold using Manual measurement technique of NF analyzer:

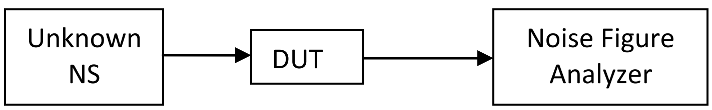
Calibrate Noise Figure Analyzer using calibrated Noise Source whose ENR values are known.



Connect the Noise Generator whose ENR is to be measured to Noise Figure Analyzer.



Switch off power supply to generator and measure **Pcold**. Then Switch on pwer supply and measure **Phot**. This measurement techniques are discussed in detail in manual of 'Noise Figure analyzer N8379A' on page 108-110.



Calculate ENR of unknown Noise Generator using Following equation:

$$\boldsymbol{ENR(unknown)} = 10Log\frac{Phot - Pcold}{Pcold}$$

Proof of above equation:

RHS $= 10Log\frac{Phot-Pcold}{Pcold}$

$= 10Log\frac{K(Th)\Delta F - K(T0)\Delta F}{K(T0)\Delta F}$

$= 10Log\frac{Th-T0}{T0}$

$= ENR(unknown)$

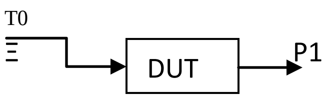
= LHS

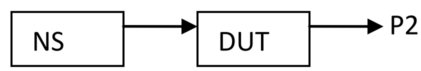
Note: Above method of manual measurement is explained for homemade *Noise generator*. For ENR measurement of *Noise source* which works on 28V pulsating DC from NF analyzer, value of Phot and Pcold are internally calculated in NF analyzer and directly displayed.

e) Using Y-Factor Method:

What is Y-factor?

Y-Factor is ratio of output power when noise source is on to output power when source is off.





Thus

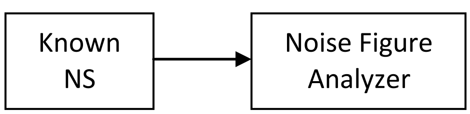
$$Y = \left(\frac{P2}{P1}\right)$$

What is relation between Y-factor and ENR?

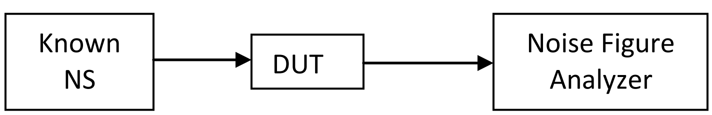
Relation is given by, $F = \frac{ENR}{Y-1}$

where F = Noise Factor of DUT, and ENR and Y-factor are in linear scale.

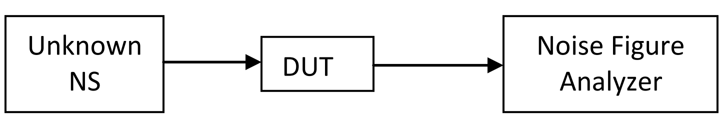
Calibrate Noise Figure Analyzer using calibrated Noise Source whose ENR values are known.



Measure NF of DUT (Device Under Test) e.g. LNA, Broadband Amplifier, Fixed attenuator) using unknown Noise Source whose ENR values are to be measured.



Measure Y-factor of DUT using unknown Noise Source whose ENR values are to be measured.



Find out ENR of unknown source using Following equation:

$$\boldsymbol{ENR(unknown) = NF * (Y - 1)}$$

3) Using Power-Meter:

Measure total power on power meter and calculate ENR from it. This method is useful for measuring average ENR for all frequencies.

4) Using Noise Figure Meter or ENR-meter:

This is simplest way of measuring ENR of Noise Generator. Noise Figure Meter directly displays ENR of Noise Generator connected to it.

Along with above discussion, I would like to get suggestions on following things

1. What is expected accuracy for Tcal injected in Front-End box?
2. I would like to get any previously measured values of Tcal injected in RF path available or its theoretical calculation.
   i.e. How it is calculated that 800K is injected in 233MHz FE-Box for Extra High cal?
3. How to theoretically calculate power deflection between Noise ON and Noise OFF?
4. Any suggestions on above methods or refining them for more accuracy or some other new method.

Conclusion:

There are various methods of finding out ENR of Noise Generator and Noise Source using different instruments. Using these methods, ENR of noise source can be approximately measured.