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Measurement Procedure for Noise Figure

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1. Introduction

1.1. Executive Summary

Test Procedure for Noise Figure of Active equipment used in Broadband networks

1.2. Scope

This procedure defines a method of measurement for Noise Figure of active Cable Telecommunications equipment. It is intended for measurement of 75-ohm devices having type "F" or 5/8-24 KS connectors, and for the measurement of true broadband noise as opposed to narrowband disturbances.

Test equipment characteristics limit this procedure to frequencies no lower than 10 MHz. See Appendix 3 - Low-Frequency Measurements for a further discussion of evaluation below 10 MHz.

1.3. Benefits

Uniform method of testing and measuring noise figure of active devices.

1.4. Intended Audience

Manufacturers and technical operations.

1.5. Areas for Further Investigation or to be Added in Future Versions

As networks evolve this procedure may be updated to encompass future needs.

2. Normative References

The following documents contain provisions, which, through reference in this text, constitute provisions of this document. At the time of Subcommittee approval, the editions indicated were valid. All documents are subject to revision; and while parties to any agreement based on this document are encouraged to investigate the possibility of applying the most recent editions of the documents listed below, they are reminded that newer editions of those documents might not be compatible with the referenced version.

2.1. SCTE References

- ANSI/SCTE 17 2007 Test Procedure for Carrier to Noise (C/N, CCN, CIN, CTN)
- ANSI/SCTE 82 2012 Test Method for Low Frequency and Spurious Disturbances
- ANSI/SCTE 96 2013 Cable Telecommunications Testing Guidelines

2.2. Standards from Other Organizations

- No normative references are applicable.

2.3. Published Materials

- No normative references are applicable.

3. Informative References

The following documents might provide valuable information to the reader but are not required when complying with this document.

3.1. SCTE References

- No informative references are applicable.

3.2. Standards from Other Organizations

- No informative references are applicable.

3.3. Published Materials

- No informative references are applicable.

4. Compliance Notation

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5. Definitions

NF (Noise Figure)	<p>The amount, in dB, by which the carrier-to-thermal noise (CTN) of a signal is degraded when passing through the device. For purposes of this measurement, some other non-external sources of noise (such as shot noise) of uniform spectral density will be treated as if they were part of the thermal noise. Stated as an equation (in dB):</p> $NF = (CTN)_{in} - (CTN)_{out} \quad (1)$
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	<p>The term Noise Factor (F) is often used to denote the same quantity expressed in terms of linear power ratio:</p> $F = \frac{(C/N)_{in}}{(C/N)_{out}} \quad (2)$ <p>The power ratio form will be used in some of the explanatory materials presented later.</p>
ENR (Excess Noise Ratio)	<p>A characteristic of noise generators, relating the effective noise temperature of the source to a reference temperature of 290° K (≈17° C). Specifically, if T_N is the actual noise temperature of the source (in ° K), and T₀ is the 290° K reference temperature, then (expressed in dB):</p> $ENR = 10 \log \left(\frac{T_N - T_0}{T_0} \right) \quad (3)$

6. Equipment

Only equipment specific to this procedure is described in detail here. The Test Procedures Introduction, ANSI/SCTE 96 2008, should be consulted for further information on all other equipment.

Required Test Equipment

- ANFM (Automatic Noise Figure Meter), Agilent 8970B or equivalent
- Broadband Noise Source, Agilent 346B or equivalent
- MLP (Minimum Loss Pads), 75 – 50 Ω, Agilent 11852B or equivalent

NOTE: Use of a lower ENR Noise Source, such as Agilent 346A, will usually require that the Minimum Loss Pad be omitted, or that a matching transformer be used instead. See Appendix 1 - Uncertainties and Corrections for a discussion of the pros and cons of the various approaches.

- Power Inserter (if required):
- 5 - 1000 MHz frequency range
- Current rating sufficient for the DUT (Device Under Test)
- Adapters, connectors, and cables as required

CAUTION: Be especially careful when using “N” connectors. The 50 Ω and 75 Ω types are not intermateable. Inserting the larger-diameter pin of a 50 Ω male connector into a 75 Ω female will result in severe damage to the female contact. Conversely, the smaller pin of a 75 Ω male connector will have intermittent or no contact if used with a 50 Ω female.

7. Setup

1. Connect the equipment as shown in Figure 1.

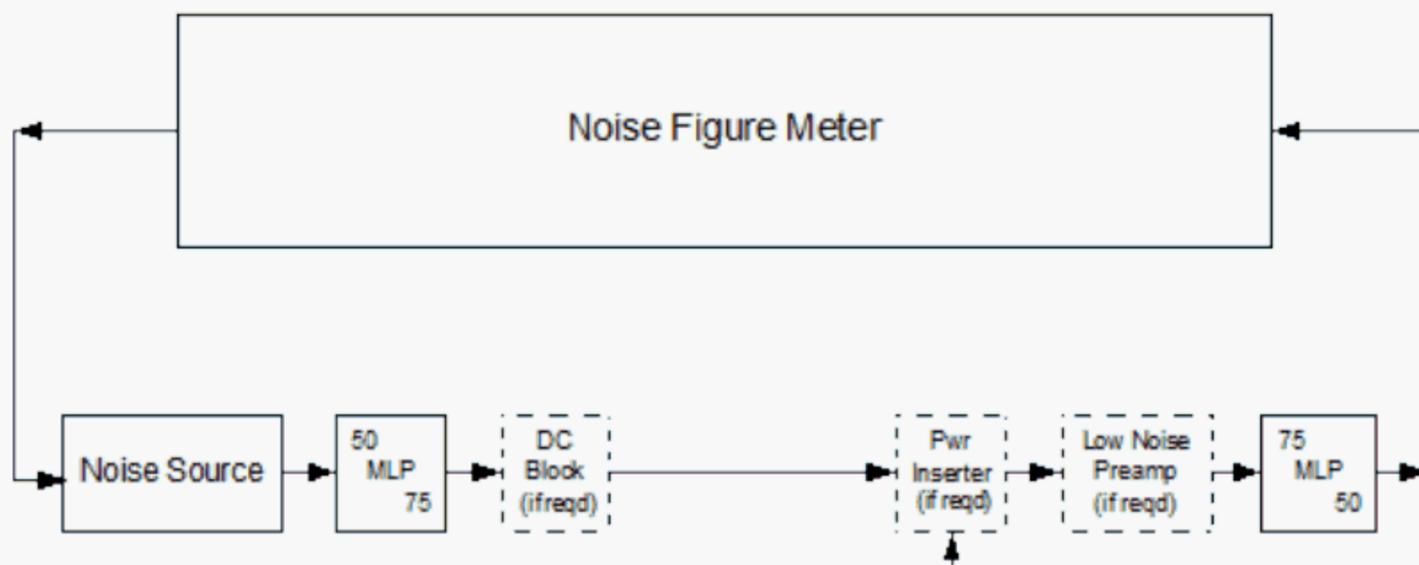


Figure 1 - Calibration Setup

2. Following the equipment manufacturer's recommendations, perform the appropriate calibration procedures. Allow adequate time for warm-up and stabilization beforehand. Make certain that the correct ENR values have been entered for the Noise Source in use. Using the Special Functions or equivalent mode, enter the 5.7 dB of the first MLP as a loss before the device under test (DUT). As a check, a corrected NF measurement taken on the calibration setup should show 0 ± 0.1 dB for both NF and gain.
 - a. If the ambient temperature differs significantly from the meter default value it will be necessary to adjust the entered value of T_0 in order to obtain a zero dB reading for NF. In the case of the Agilent 8970B, the default temperature is 296.5 K (23.3° C or 74° F).
 - b. If a DC block will be required ahead of the DUT (see Sec. 3.4), it should be included in the calibration setup and an additional 0.1 or 0.2 dB typically added to the loss entered for the MLP.
 - c. See Appendix 1 - Uncertainties and Corrections for a discussion of the conditions under which use of a Low Noise Preamp would be advisable. If needed, it must be included in the calibration as shown.

NOTE: The ANFM calibration routine assumes that any items in the setup above, the losses of which are not entered as discussed in 3.2, will be connected to the output of the DUT.

3. Connect the equipment as shown in Figure 2.

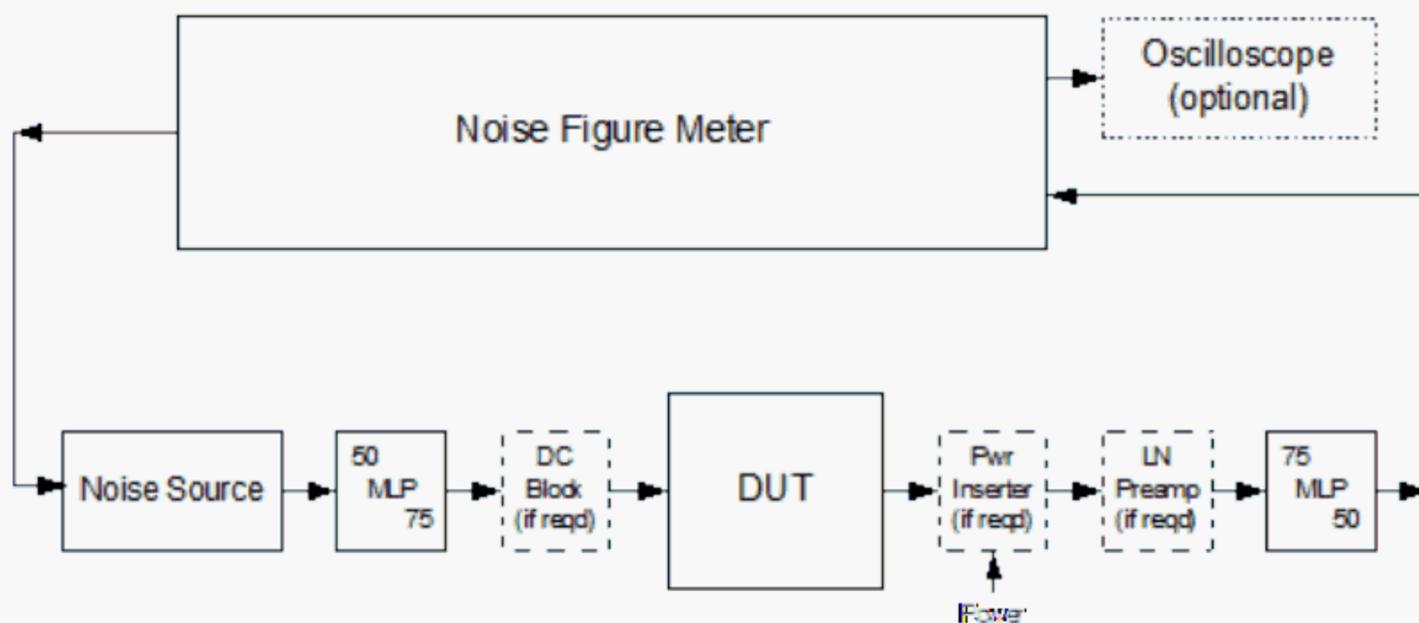


Figure 2 - Measurement Setup

4. Be especially cautious if the DUT is powered through its signal ports, as is typical for Cable Telecommunications line amplifiers. Use an appropriate Power Inserter at the DUT output as shown, being certain that the Inserter is configured to block power from the MLP or Preamp. Likewise, be certain that the DUT is configured to block power from its input port, or use a suitable power-blocking adapter.

8. Procedure

1. With the DUT connected into the setup and powered, allow time for the DUT to warm up and stabilize before making measurements.
2. Set the ANFM according to the manufacturer's instructions for measurements at the desired frequencies. Generally, the measurement mode selected will be corrected NF. In this mode, the system calculates the DUT NF from measurements of uncorrected NF and DUT gain. The concept is explained in Appendix 1 - Uncertainties and Corrections.
3. If desired, an oscilloscope (connected to the ANFM outputs provided for that purpose) can be used to graphically display the variation of NF and gain versus frequency. Also, a measurement of uncorrected NF can be made to show the magnitude of the correction being made for second-stage noise.
4. Record the test results. A suggested format is given in Appendix 5 - Test Report.

Appendix 1 - Uncertainties and Corrections

The modern ANFM makes measurement very quick and convenient. However, in order to properly evaluate the results, some knowledge of the sources of error and means to minimize them is necessary. To begin with, we should differentiate between avoidable and unavoidable errors.

One class of avoidable errors results from poor setup conditions. A noisy environment and inadequate shielding can allow extraneous signals to pollute the measurement. An oscilloscope connected to the ANFM scope / recorder output will usually show this. Before resorting to the ultimate solution of a shielded room, the integrity of all connections and quality of cables should be checked in order to eliminate or minimize the problem. Dirty or worn items can cause signal loss or intermittent readings, and must be cleaned or replaced.

Another avoidable error stems from the fact that the noise figures of many devices vary with source impedance. Since the noise source is switched between "on" and "off" states in making measurements, its output impedance could vary and affect the reading. Using a quality noise source such as that suggested can make this effect negligible.

Choice of noise source can, while not intrinsically causing errors, make certain errors more significant. As a rule-of-thumb, the noise source should have as low an ENR as practicable, but not less than about 10 dB below the expected NF being measured. (Note that this means available ENR, which is the noise source output minus the loss of an MLP.) A low-ENR (≈ 6 dB) avoids the possibility of overloading the DUT. Also, since some ANFMs adjust for higher input levels by adding input attenuation (thereby increasing its own NF), less second-stage correction of the measurement (see below) would have to be applied. Finally, since most low-ENR noise sources have a significant built-in attenuator, they generally have better output RL as well as more constant RL between the "on" and "off" states. On the other hand, if the available ENR is more than 10 dB below the NF of the DUT, there will be so little difference in DUT noise output between the source "on" and "off" states that measurement accuracy of the ANFM itself will be compromised.

The implication of the above discussion is that, for the NF range typically encountered in Cable Telecommunications devices, a low-ENR noise source would not be optimum when used with an MLP, and that a high-ENR (≈ 15 dB) source would be the better choice. If a low-ENR source must be used, then a matching transformer or a straight (unmatched) connector adapter could be employed. See Appendix 4 - Error Analysis for more information as to the effects of the resulting poorer match on overall accuracy.

Unavoidable errors are associated with the instrumentation and with the characteristics of the DUT itself. Of course, the Noise Source and ANFM must be calibrated at proper intervals, but the ANFM will still have some residual linearity errors, in both the NF and gain measurement modes. Also, there will be some error in tracing the noise source calibration (ENR value) to a recognized standard such as the National Bureau of Standards value.

A noise figure reading must be corrected for the noise contribution of the measuring instrument itself. Friis' formula for total NF of a system (in terms of power ratio):

$$F_T = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \dots \quad (4)$$

shows the sensitivity of a measurement to the gain of the DUT and the NF of the following stages. Thus, the accuracy of the correction made by the ANFM will depend on how accurately the gain of the DUT is being measured, as well as the accuracy with which its own NF can be determined. The greater the correction that has to be made, the greater the error introduced by any given inaccuracy in these measurements. Therefore, it is advisable to use a low-noise preamplifier between a low-gain DUT and the ANFM input to minimize the amount of this second-stage correction being made by the system. As shown in Figure 1, any preamp used must be included in the calibration.

The remaining significant unavoidable error results from mismatch between the Noise Source and the DUT. Assuming that the Noise Source and matching pad are as specified and properly calibrated, the main contributor will be the return loss of the DUT itself. A further discussion of this error is contained in Appendix 4 - Error Analysis.

Appendix 2 - Measurement Principles

The ANFM measures the noise power output of the DUT in the presence of two known amounts of external noise – that generated by the input termination resistance at ambient temperature, and the excess noise of the activated noise source (the ENR). From these results, it extrapolates back along the slope of the DUT transfer curve to determine the output in the absence of any external noise – the excess noise of the DUT itself. The meter thus depends for its operation on the DUT being in a linear portion of its transfer curve, so that its output power is directly proportional to its input.

This may seem at variance with the definition of Noise Figure given earlier in terms of carrier-to-noise, for there is obviously no carrier involved in the process. However, the fact that NF can be determined in the absence of a carrier can be seen by re-writing Equation (2). Consider that:

$$\text{Carrier - to - noise} = \frac{C}{N} \quad (5)$$

when expressed as a power ratio. Therefore:

$$F = \frac{C_{in}/N_{in}}{C_{out}/N_{out}} \quad (6)$$

But since:

$$C_{out} = GC_{in} \quad (7)$$

and:

$$N_{out} = G(N_{in} + N_{ex}) \quad (8)$$

where G is the gain of the DUT and N_{ex} is its own excess input noise, we have:

$$F = \frac{C_{in}/N_{in}}{GC_{in}/(GN_{in} + GN_{ex})} = \frac{GN_{in} + GN_{ex}}{GN_{in}} = 1 + \frac{N_{ex}}{N_{in}} \quad (9)$$

thus showing that the carrier term cancels and is not needed for measurement.

Appendix 3 - Low-Frequency Measurements

Although the Cable Telecommunications return (upstream) band has historically been considered as extending down to 5 MHz, commonly available automatic NF test equipment does not operate below 10 MHz, at least not in a calibrated mode.

One solution would be to employ a measurement technique known as the Y-factor method. The NF is derived from readings of the DUT output power in the presence of two external noise levels – from the input termination, and from the Noise Diode. (This is actually a manual version of essentially the same process that the ANFM accomplishes automatically.) A basic Y factor measurement setup is shown in Figure 3.

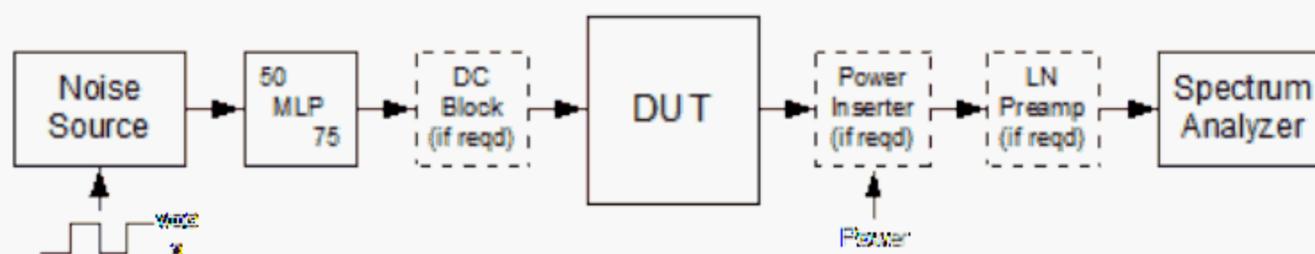


Figure 3 - Basic Y-Factor Setup

Recommended settings for the Spectrum Analyzer are:

Span = zero (tune to desired frequency of measurement)

RBW = 1 MHz

Video BW = 10 Hz

With the Noise Source driven by a square wave (sync'd to the AC line) of zero to its required supply voltage and the Analyzer set for line triggering, the display will be a square wave with the difference between the levels being the Y-factor. The Analyzer Marker and Marker Delta functions can be used to read out the value directly.

The NF is then calculated from:

$$\text{NF} = \text{ENR} - \left(10 \log \left[10^{\frac{\text{Y}}{10}} - 1 \right] \right) - 5.7 \quad (10)$$

where NF, ENR, and Y are in dB, and 5.7 dB is the assumed loss of the MLP.

The Y-factor method depends on the incremental accuracy of the Analyzer, as well as on other variables that affect the automatic method, such as match and ENR of the noise source. Any second-stage corrections needed have to be done manually, which makes the use of a low-noise preamp more imperative.

Alternatively, one can use ANSI/SCTE 17 2007 (Carrier to Noise) to quantify any degradation at frequencies below 10 MHz relative to 10 MHz and higher.

Cable Telecommunications amplifiers using modern, low-noise semiconductors will often be affected at the lowest upstream frequencies more by power supply switching frequency harmonics than by thermal noise. It is recommended that ANSI/SCTE 82 2007 (Low Frequency and Spurious Disturbances) be used to isolate these effects from those of true noise.

Appendix 4 - Error Analysis

Procedures for general error analysis as regards equipment calibration and reading uncertainties will be found in ANSI/SCTE 96 2008. However, in the measurement of Noise Figure, there are some additional issues that must be taken into account. One of these is mismatch error. It is complicated to analyze completely, and the one most often overlooked. For our purposes, a first-order analysis based only on mismatch losses will suffice.

Referring to Figure 2, consider that the Noise Source can have a reflection coefficient (ρ) of 0.07, while the 50 Ω side of the MLP will typically be 0.05 (26 dBRL). Substituting these numbers into the formulas for mismatch transmission uncertainty limits:

$$\text{dB} = 20 \log(1 \pm \rho_1 \rho_2) \quad (11)$$

results in a possible error of ± 0.030 dB for this interface. Similarly, the 0.03 ρ (30 dBRL) at the 75 Ω side of the MLP, driving an (assumed typical) 18 dBRL DUT ($\rho = 0.13$) can have an error of ± 0.033 dB. We have to also consider the error in insertion loss of the MLP. While not specified by Agilent, it is reasonable to assume the use of 1% resistors and a resulting tolerance of ± 0.044 dB.

Summing the three errors in this example on the RSS basis of TP 200 yields an uncertainty of approximately ± 0.06 dB. Note that the use of a DC block was not considered here. If used, it would add another interface mismatch as well as an insertion loss that would have to be determined. That is a good reason to use it only if it is not possible to block power from the DUT input port internally.

It is interesting to compare this to the error that might be expected if the MLP were omitted, trading off its insertion loss uncertainty and that of a second interface for a larger mismatch at the remaining connection. Assuming again a typical (75 Ω) 18 dBRL DUT, its ρ at 50 Ω could be as high as 0.32. With the Noise Source ρ of 0.07, the uncertainty would be on the order of ± 0.20 dB. Thus, assuming the loss in available ENR can be tolerated, it is better to accept the additional uncertainties of the MLP.

Although these errors were combined here for illustrative purposes, in practice they would be entered individually, along with all other equipment tolerances and reading uncertainties, in an overall RSS sum for the entire measurement.

Instrument calibration uncertainty is less straightforward, because the instrument errors are also involved in the second-stage corrections made by the ANFM. Rearranging the first two terms of Equation (4) in terms of the desired DUT NF, F_1 , we have:

$$F_1 = F_T - \frac{F_2 - 1}{G_1} \quad (12)$$

Applying Taylor's Theorem to find the total uncertainty of F_1 based on the three independent variables:

$$\delta F_1 = \frac{\partial F_1}{\partial F_T} \delta F_T + \frac{\partial F_1}{\partial F_2} \delta F_2 + \frac{\partial F_1}{\partial G_1} \delta G_1 \quad (13)$$

From (12) we can see that:

$$\frac{\partial F_1}{\partial F_T} = 1 \quad \frac{\partial F_1}{\partial F_2} = -\frac{1}{G_1} \quad \text{and} \quad \frac{\partial F_1}{\partial G_1} = \frac{F_2 - 1}{G_1^2}$$

Therefore:

$$\delta F_1 = \delta F_T - \frac{1}{G_1} \delta F_2 + \frac{F_2 - 1}{G_1^2} \delta G_1 \quad (14)$$

where all variables are expressed in power ratios, not dB. The δF and δG uncertainties are obtained from the ANFM data sheet. Actually, (14) would represent a worst-case error. As outlined in ANSI/SCTE 96 2008, the three terms on the right side of the equation (along with all the other uncertainties in the process) should be summed on an RSS basis to give a more realistic assessment of the total uncertainty to be expected.

Additionally, the fact that both the F_T and F_2 readings are affected by the ENR calibration requires that the two additional (power ratio) terms:

$$\delta \text{ENR} \quad \text{and} \quad -\frac{1}{G_1} \delta \text{ENR}$$

be included in the overall uncertainty summation. In theory, we should also consider the effects of match error on the second-stage readings, but for measurements within the scope of this procedure such second-order uncertainties can safely be ignored.

Appendix 5 - Test Report

Unit under test

Equipment Type:		Manufacturer:	
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Model Number:		Serial number:	
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Test equipment

Description	Manufacturer	Model Number	Serial Number	Calibration Date

Test Results

Frequency	Noise Figure

Frequency	Noise Figure

Tested by	Date