A Simple Way To Measure Noise Figure Using An Amplifier With A Calibrated Noise Figure

Dallas Lankford, 1/11/2011, rev. 3/12/2014

Wide null aperture, low signal output, MW arrays like the DDFA and QDFA require a preamp with as low as possible noise figure as the preamp (or first preamp in the preamp cascade). Noise figures of about 1.0 dB or less are desirable for best weak signal performance with these kinds of antenna arrays. Such preamps are not "off the shelf" items, and have only recently been developed for the MW band.

In this articled we develop a method for measuring the noise figure of amplifiers using an amplifier with a calibrated noise figure.

The definition of noise factor F is

$F = (S_i / N_i) / (S_o / N_o)$,

where S denotes signal, N denotes noise power, i denotes input, o denotes output, and where

$N_i = kTB$

when the input impedance of the amplifier is equal to R_s, the resistance of the thermal input noise source, where k = 1.38 X 10^{-23} J/°K is Boltzmann's constant, T is temperature in degrees Kelvin (nominally room temperature 290°K), and B is the system noise power bandwidth in Hertz.

By algebraic rearrangement of the noise factor definition,

$F = N_o / [(S_o/S_i) N_i]$, so that
$F = N_o / (G N_i)$, where G is the gain of the amplifier, so that
$N_o = FGN_i = FGkTB$.

The noise output power is in watts, so we multiply by 1000 to convert to milliwatts.

$N_o = 1000 FGkTB$,

which we convert to dBm

$N(dBm) = 10 \log(F) + 10 \log(G) + 10 \log(B) + 10 \log(1000kT) = NF + 10 \log(G) + 10 \log(B) - 174$

where NF is the noise figure of the amplifier and N(dBm) is the noise output power of the amplifier in dBm.

If we make measurements of two amplifiers and subtract the tow equations corresponding the the two measurements, after rearrangement we get the following

$N_1(dBm) - NF_1 - 10 \log(G_1) = N_2(dBm) - NF_2 - 10 \log(G_2)$, or equivalently

$[N_1(dBm) - N_2(dBm)] - [10 \log(G_1) - 10 \log(G_2)] = NF_1 - NF_2$.

Thus only the noise output powers (in dBm) and gains need to be measured in order to measure the noise figure of an amplifier given a second amplifier with a calibrated noise figure.

The test frequency was 1.9 MHz. A Perseus receiver was used for all measurements.

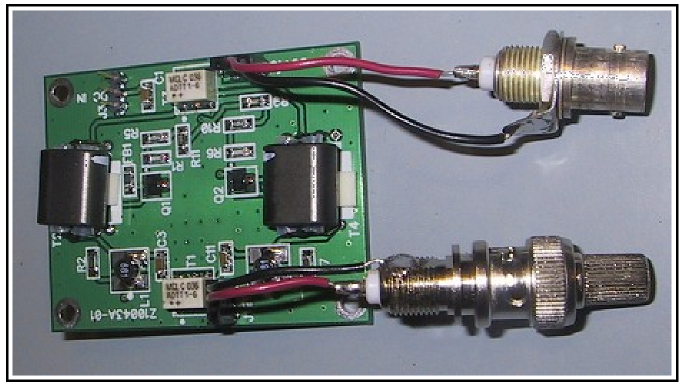
Example 1: A 10.4 dB gain standard push-pull Norton transformer feedback amplifier with MRF581A's was compared to a 11.0 dB gain push-pull Mini-Norton transformer feedback amplifier with calibrated NF from Jack Smith of Clifton Laboratories. The noise power output of the standard Norton was 0.3 ± 0.2 dB less than the Mini-Norton. Using the formula

$[N_1(dBm) - N_2(dBm)] - [10 \log(G_1) - 10 \log(G_2)] = NF_1 - NF_2$ it follows that

$NF_1 - NF_2 = -0.3 - (10.4 - 11.0)$.

To help avoid mistakes, let $NF_1 = NF_{N\text{-}MRF581A}$ and $NF_2 = NF_{MiniN}$. From the above we have

$NF_{N\text{-}MRF581A} - NF_{MiniN} = -0.3 - (10.4 - 11.0) = 0.3\ (\pm 0.2)$.



The Clifton Laboratories Mini-Norton has a calibrated noise figure of about 1.4 dB ± 0.2 dB at 10 MHz. Assuming the Mini-Norton NF at 1.9 KHz is also 1.4 dB ± 0.2 dB , it follows that

$NF_{N\text{-}MRF581A} = 1.4 + 0.3 = 1.7$ dB (± 0.4 dB).

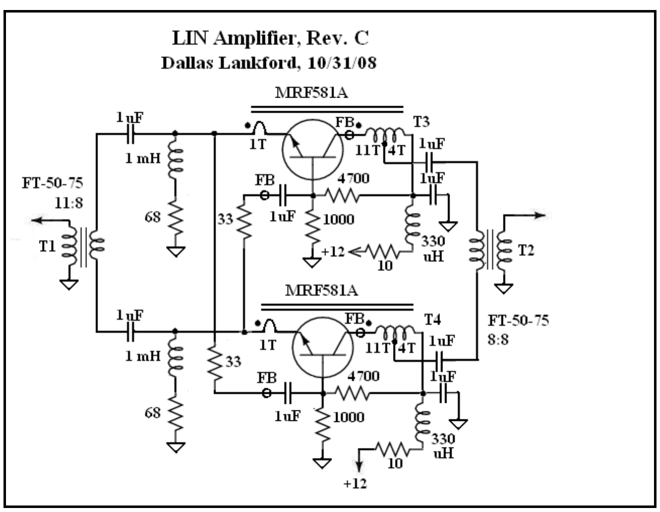
A photo of the Mini-Norton is given at right.

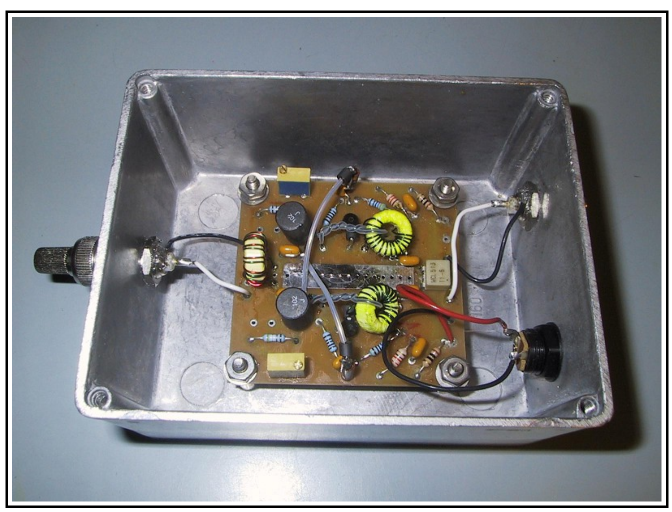
Example 2: A 13.4 dB gain LIN transformer feedback amplifier with MRF581A BJT's was compared to the 10.9 dB gain 1.4 dB NF Mini-Norton transformer feedback amplifier. The noise power output of the LIN was 2.0 dB greater than the Mini-Norton.

$NF_{LIN\text{-}MRF581A} - NF_{MiniN} = 2.0 - (13.4 - 10.9) = -0.5$ so that

$NF_{LIN\text{-}MRF581A} = 1.4 - 0.5 = 0.9$ dB (± 0.4 dB).

A schematic of the LIN amplifier is given below, followed by a photo of its PC board. The original LIN did not have the 33 ohm resistors and FBs for parasitic prevention, and no parasitics have ever been observed without them. None of my LIN amplifiers currently have 33 ohm resistors, but they do have ferrite beads.





Example 3: A 13.4 dB gain Clifton Laboratories LIN-Z10042A transformer feedback amplifier with NE85634A BJT's was compared to a 10.9 dB gain (sometimes my system measures it as 11.0, sometimes 10.9, here 11.0 will be used) push-pull Mini-Norton transformer feedback amplifier with calibrated NF which has been developed recently by Clifton Laboratories. The noise power output of the LIN-Z10042A was 4.0 dB greater than the Mini-Norton. Similar

to Example 3 it follows that

$NF_{LIN\text{-}Z10042A} - NF_{MiniN} = 4.0 - (13.4 - 11) = 1.6$ so that

$NF_{LIN\text{-}Z10042A} = 3.0$ dB (± 0.4 dB).

This measurement was done after Jack Smith of Clifton Laboratories reported substantially higher NF's for a LIN-Z10043A at 10 MHz and above. It appears that the Z10042A and Z10043A NF's increase substantially after doing the LIN mod. The NF of a LIN-MRF581A was subsequently measured at 10.75 MHz and found to be 0.9 dB (+/- 0.4 dB). There are circuit differences between the LIN-Z10042A / LIN-Z10043A and the LIN-MRF581A amplifiers as well as different BJT's which may explain why the LIN mod which was done on those two Clifton Laboratories amplifiers did not reduce their noise figures.

Acknowledgment

I would like to express my appreciation to Jack Smith, K8ZOA of Clifton Laboratories for sending me a Mini-Norton amplifier with a calibrated NF, for many helpful discussions about noise figure measurement and other matters, and for correcting a terrible mistake which I made in an earlier version of this article. Of course, I alone am responsible for any remaining mistakes in this article.