Automatic Noise Figure and Gain Measurements with a Spectrum Analyser.

Luis Cupido - CT1DMK

Abstract

A relatively simple automatic Noise Figure (NF) meter was developed which is using a spectrum analyser as the receiver and logarithmic power detector. The presented circuit makes use of the X and Y output signals available on most spectrum analysers. It processes these signals to control a noise head and obtain Y, Gain and NF values. These values are then displayed on digital or analogue meters.
This simple instrument will enable easy real time alignment and optimisation of preamplifiers and converters for best performance.

Introduction

To perform a NF measurement without an automatic PANFI /1/ the operator needs to make a few power measurements and calculate the corresponding NF. This, can be accomplished, with good accuracy, using a Spectrum Analyser (SA) equipped with an additional low noise preamplifier and calibrated noise head, However one cannot tune a device for best performance while looking at the SA display.

The circuit presented employs the SA as receiver for the automatic measurement and then displays NF, Y factor and gain simultaneously thus enabling a real time tuning of preamplifiers and converters for best performance. With this scheme any frequency covered by the spectrum analyser can be used for the measurement regardless if it is the operating frequency or the intermediate frequency coming out from a converter.

Principle of operation

All (to my knowledge) commercial SAs have accessible the X and Y output signals to be used by external displays, recorders and other devices.
The Xout signal is the horizontal scan of the display and indicates the received frequency. The Yout output contains a voltage signal proportional to the power of the incoming signal in dB, depending on the vertical scale selected at the instrument.

The Yout signal is affected by the SA settings and contains exactly what shows up on the SA display. We consider that one knows how to operate a SA and therefore do not go into any further details.

For a NF measurement two values of power are to be measured:

1- the noise power of the device with the noise source OFF (we will refer it as "cold").
2- the noise power of the device with the noise source ON (we will refer it as "hot").

From these two values the ratio Y is defined as:

Y = Hot / Cold (in power units)
Y = HOT - COLD (in dB)

Knowing the ENR of the noise head, the NF can be calculated as follows:

NF = ENR / (Y - 1) (in power units)

In our design, the noise head is toggled between on and off states in successive scans of the SA. Visually two traces appear on the SA display; the top trace corresponds to the hot state and the bottom trace to the cold state. The hot state is also used for the gain measurement.
The Yout value is sampled at the centre of the screen for each of the traces, resulting in two DC values, Hot and Cold. With only analog processing we can obtain an Y factor value and an approximation of NF and a Gain. The instrument has two voltmeters (analog or digital, as you like) so that any two of the resulting values can be displayed simultaneously.
Since all values are obtained from the Yout signal that is dB proportional, the display devices for this instrument are calibrated such as to present values directly in dB.

If we use for the NF display an analog μA meter with appropriate NF scale, we will be measuring a correct NF as far as drawn on the instrument scale.

If we use a digital voltmeter, NF will be obtained from the approximation

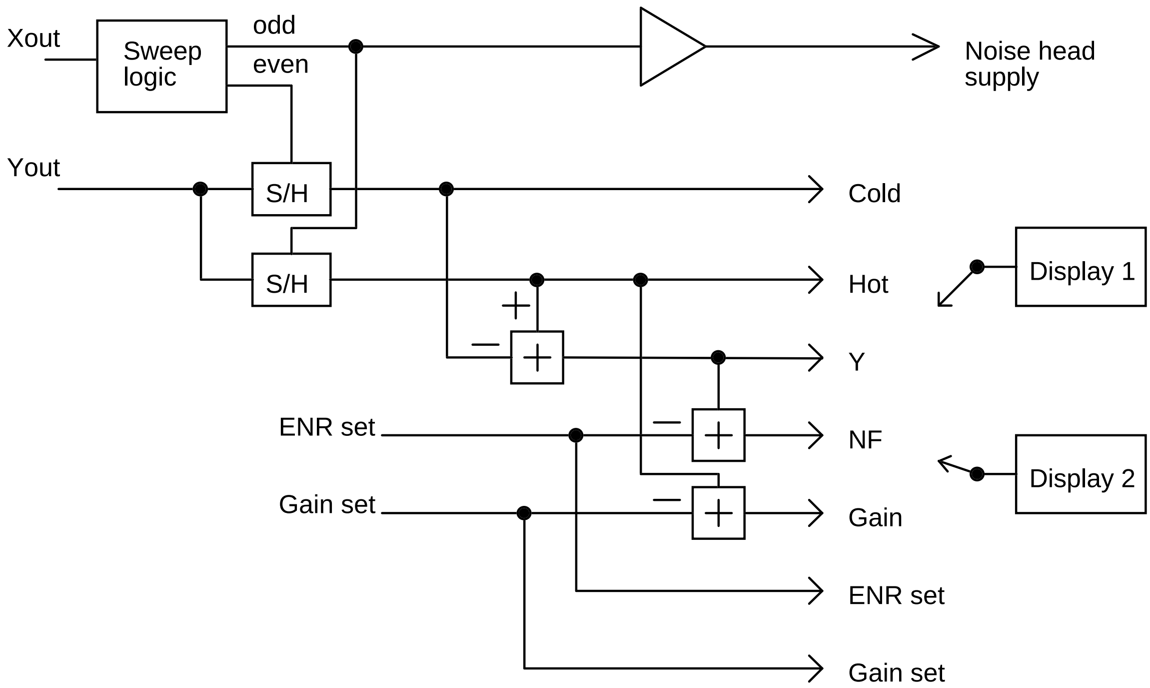
NF(dB) = ENR(dB) - Y(dB)

and the error associated in NF with this approximation is:

ER = ENR / (Y2 - Y) (linear units)

For the NF values for which this instrument is useful i.e. for NF below 3 dB the error is small, in the order of 0.1 dB.
Another solution, besides a direct display of NF on an analog instrument and its NF scale, is to have a microprocessed digital voltmeter with the corrective function built in. Such solution is not presented in this article, but can be developed with a minimum effort based on a microcontroler with an internal ADC.

The gain measure is obtained from the Hot value minus an offset to correct from the trace position on the SA.
Once the instrument displays are calibrated to present dB values, the ENR and Gain settings can be checked and also displayed in the same units (exception is made for the NF value on digital displays, for the above mentioned reasons).



Circuit description

The Xout signals from the SA are conditioned by R1 and R2 to be -1V to +1V maximum during the sweep. The values of R1 and R2 are dependent on the Xout signal from a particular SA. If the Xout is unipolar an additional resistor (to VCC or VEE) has to be added to bring the resulting signal to the -1 to +1V range. This signal is applied to U1A (voltage follower) and is processed by a window comparator that produces a pulse near the zero crossing. This pulse is the sampling signal "window" and its width is controlled by RV1.
A pulse is produced from the Xout signal during the SA trace return that toggles the flip-flop U5A. The signals at the flip-flop output correspond to the even and odd sweeps. Selecting the Q output to control the noise head supply switch we have a "hot" sweep at Q=1 and a "cold" sweep at Q=0. These signals gated with the sampling pulse U4C and U4D produce the sampling pulse for Hot and Cold sample&holds respectively. Q1 and Q2 will switch the +24V supply for the noise head during the "hot" period.

The Yout signal has to be conditioned to a 0 to 1V range corresponding to the bottom and top of the SA display. Again, the values of R13 and R14 depend on the signal range from the SA's Y output. Also if the Yout is, in this case bipolar, an additional resistor (to VCC or VEE) has to be added to bring the resulting signal to the 0 to +1V range.
The Yout signal is sampled during successive sweeps by Hot and Cold sampling gates and these DC signals are connected to U6A and U6B. The U7B/C/D perform an analog subtraction of Hot and Cold signals thus producing the Y factor value of the measurement. U8D subtracts the ENRset value from this Y value producing the NF value (an approximation, if measured by digital voltmeters, as explained above). U8C subtracts the Gain-set value from the Hot, producing the Gain of the Device Under Test (DUT).
Construction
The circuit employs only conventional technology and therefore can be implemented in single or double sided PCB with little concern, since only DC and low frequencies are involved. As a matter of precaution the prototype was built on a double sided PCB with ground plane on the component side. For voltmeters one can use LCD or LED types with 2 1/2 or 3 digits or analog μA meters with the appropriate resistors.
For a NF analog meter the appropriate scale must be drawn and fitted to the μA meter.

Calibration and operation

The circuit requires only few calibrations although the calibration to obtain direct dB readings on the displays is important and should be done with some care.
First of all the input circuits of the Xout and Yout are to be adjusted with the help of an oscilloscope (resistors R1, R2, R13, R14). This calibration is to provide -1 to 1V for sweep signal and 0 to 1V for the power signal, as explained above. This calibration does not require much precision, although it should be done with 1% fixed resistors
and not changed later.

After the input settings select the Hot output F5-5 to the instrument display. By making a change of +10dB on the trace position on the SA (can be done on the SA ref level) we have to calibrate the display to read an increase of 10.0 (previous reading + 10.0, decimal point is fixed before last digit).
This is done with the meter reference adjust or input divider or both, making coarse adjust with two resistors (as a voltage divider) and after fine adjusting the reference, most LCD voltmeters modules have a variable resistor (I used a pair of ICL7106 based LCD meters with success).
It is also necessary to change the decimal point to the correct position (ICL7106 based meters have a jumper selection of the d.p. position).

Once this calibration is done for the meter (or the two meters if two are used) all the other readings of values from any of the outputs are directly in dB since all the internal analog computations have a unity gain for all the operations. (It is thus better not to use R20 to have always x1 gain) (use this to get expanded Y or NF scale).

The ENR setting is done with POT1 located on the front panel while RV2 adjusts the maximum value that ENRset can go. I suggest a range 0 to 20, that is more than enough for the usual noise heads available.

The Gain-setting is done with POT2 on the front panel while RV3 adjusts the maximum value that can be offset in the gain measurement. Since most SA have dynamic ranges more than 80dB I suggest to set the maximum gain-set to 100dB (or 99.9dB if no extra digit available). If RV2 or RV3 do not provide enough range to set the desired limits their values can be increased.

RV1 adjusts the sampling window size. The pulse width of the sampling gate is adjusted to be smaller than the scan width occupied by the signal on the SA screen, that is to be smaller than the selected band-width/scan-width combination present on the SA. If the SA is operated at span=zero, this adjustment becomes irrelevant as long as it has some width to sample, one or two grid-spaces on the SA screen are enough.

Important note on the SA input sensitivity

Most SA inputs have a 10dB attenuator selected by default, and the input device is usually a mixer. Although these instruments are sensitive they have noise figures of about 10 to 20 dB (even with input attenuator set to 0 dB). For the measurement of low noise preamplifiers and converters it is necessary to have a broadband preamplifier in front of the SA thus bringing the input NF of the measuring set-up down to a few dB (2 to 4 dB is easily obtained by employing MAR or ERA amplifiers from MiniCircuits, and these will cover most of the desired frequency range). Whatever the case, the measuring set-up should be sensitive enough to see an increase of noise by several dB when in the Hot state.
This is without any device under test, and the noise head connected directly to the measurement set-up (comprising the SA and a preamplifier plus the necessary interconnections and cables).

How to proceed for a NF and gain measurements with this instrument:

After a calibration and assuming the instrument is performing as it should we can make a real measurement and tune-up of a Device Under Test (DUT) by performing the following steps :

1- Connect the noise head direct to the input of the SA preamplifier without DUT (note the noise increase).

2- Move the traces to the middle of the screen of the SA.

3- Select the desired centre frequency on the SA.

4- Select the maximum bandwidth of the SA (or the largest possible that does not contain any spurious signals, such as local oscillators etc.).

5- Select a frequency span narrow enough to have a flat signal at the centre of the screen (if a single frequency is of concern, select zero span).

6- With meter selected to ENRset adjust to the correct ENR value of the noise head.

7- With meter selected to Gain adjust Gain-set to 0.0dB reading (i.e. no device gain).

8- Select for example NF or Y for meter A and Gain for meter B.

9- Insert the DUT, read the values from the meters and tune the DUT for the best performance.

10- If a more accurate value of NF is required it is possible to calculate it from the ENR and Y values and expand the scale if this option was built.

Conclusion

A simple automatic NF meter was developed using a spectrum analyser as the receiver and logarithmic power detector. The circuit was constructed and tested and is now in use by the author around an Advantest R4131D spectrum analyser.
Ivo ZS6AXT had also constructed one unit to be used around a HP141 series spectrum analyser.
Results obtained so far are in good accordance with the values obtained on modern commercial test equipment.