S-26.3120: Lab 4: Amplifier design - Noise measurement

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There are different options of measuring noise figure. This hand note is based on so called hot/cold method or the Y-factor method. The Y-Factor method is the basis of most noise figure measurements whether they are manual or automatically performed internally in a noise figure analyser. Using a noise source, this method allows the determination of the internal noise in the DUT and therefore the noise figure or effective input noise temperature. With a noise source connected to the DUT, the output power can be measured corresponding to the noise source on and the noise source off (N2 and N1). The ratio of these two powers is called the Y-factor. The power detector used to make this measurement may be a power meter, spectrum analyser, or a special internal power detector in the case of noise figure meters and analysers.

Required equipment:

1. Wideband noise source with known ENR (Excess Noise Ratio)
2. Wideband, high gain (30dB) pre-amplifier
3. DC Power supply for noise source, pre-amp, and DUT (if required)
4. DUT

Measurement Procedure:

The available noise source in the lab (HP 346C) has not enough power that can be detect by the spectrum analyser or commonly used power meter. A wideband pre-amplifier with 30dB gain (Avantek AWI-6033) available in the lab is used to have higher output power from the noise source. Since we include the pre-amplifier in the measurement chain we must measure the noise figure of the pre-amplifier. The measurement is performed in two steps.

Step 1:

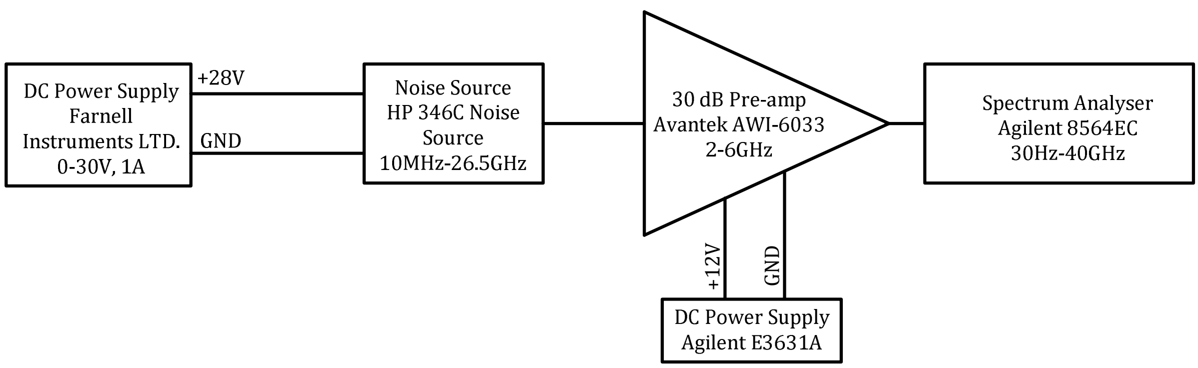

Fig. 1: Measurement setup for measuring the noise figure of the pre-amp

First, the noise source is connected directly to the pre-amplifier and performs the Y-factor method for determining the noise figure of the pre-amplifier. Figure 1 shows the measurement setup for measuring the noise figure of the pre-amplifier. The available noise source and the pre-amplifier used for noise measurement are shown in Fig. 2 and 3.

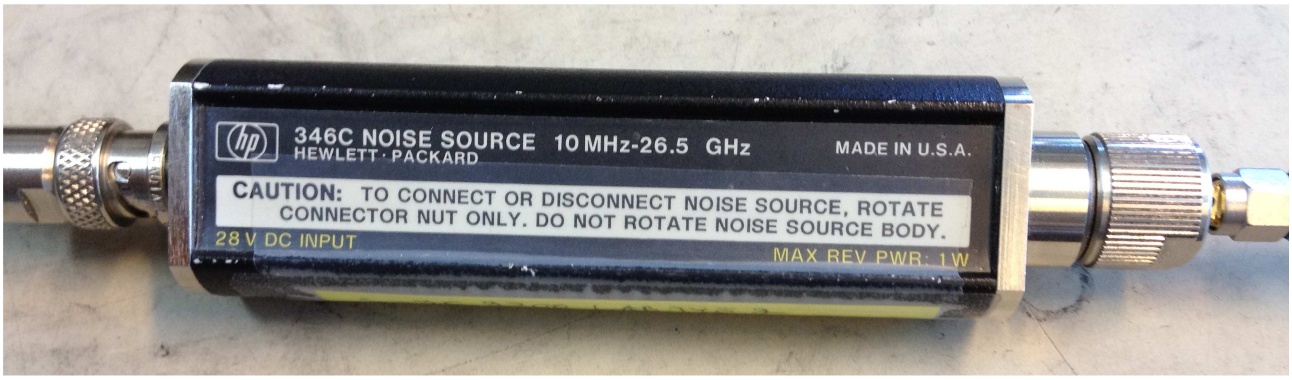

Fig. 2: Noise source used for noise measurement

Fig. 3: Pre-amplifier used for noise measurement

In order to do the low level power measurement with spectrum analyser, one should take into consider the settings of the spectrum analyser. In this particular example, the frequency of interest was 2.2GHz and the setting of the spectrum analyser was: centre frequency: *2.2GHz*, Span: *500MHz*, RBW: *1MHz*, VBW: *1KHz*, Attenuation: *0dB*, and Reference level: *-10dBm.*

When DC voltage is supplied to the pre-amplifier and the noise source is switched off, the 'cold' measurement is performed with the measurement setup shown in Fig. 1. Now, for the same setup but with noise source is switched on, the 'hot' measurement is performed. The marker read out from the spectrum analyser at the frequency of interest is recorded and shown in Table 1.

Measurement step	Measurement	Noise Source	Power (dBm)	Power (W)
1	P_C	OFF	-80	$10*10^{-9}$
	P_H	ON	-71	$79.43*10^{-9}$
2	P_C	OFF	-70	$100*10^{-9}$
	P_H	ON	-60.3	$933*10^{-9}$

Table 1: Measured data from spectrum analyser for both the measurement setups

Calculation:

The equations used to perform Y-factor method is well defined and can be found in any RF and Microwave Engineering books and also in the course lecture slides (S.26.3120: Noise measurement).

$$Y = \frac{P_H}{P_C} \tag{1}$$

$$T_H = \left(10^{\frac{ENR}{10}} + 1\right) T_0 \tag{2}$$

$$T_e = \frac{T_H - YT_C}{Y - 1} \tag{3}$$

The ENR of the noise source at 2.2 GHz is 13dB. Therefore, from Eq. 2, $T_H = 6076$. The Y-factor is calculated by Eq. 1 and finally the noise temperature of the 30dB pre-amplifier is calculated by using Eq. 3.

$$Y = \frac{79.43 \times 10^{-9}}{10 \times 10^{-9}} = 7.943$$

$$T_{30dB} = \frac{6076 - 7.943 \times 290}{7.943 - 1} = 543.42K$$

Step 2:

The DUT is now connected to the measurement chain and give proper DC biasing voltage and perform the same measurement as described for the measurement step 1. Measurement setup for the step 2 is shown in Fig. 4. The measured results from this step are also shown in Table 1.

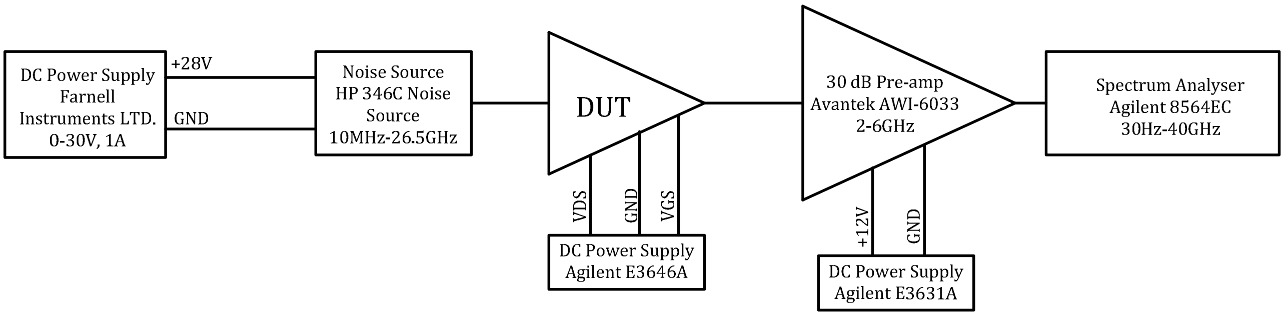

Fig. 4: Measurement setup for measuring the noise figure of the complete chain

Calculations:

Again the new Y-factor and the total noise temperature of both DUT and pre-amplifier are measured by using Eq. 1 and 3.

$$Y = \frac{933 \times 10^{-9}}{100 \times 10^{-9}} = 9.33$$

$$T_e = \frac{6076 - 9.33 \times 290}{9.3 - 1} = 406K$$

This equivalent noise temperature is the cascaded temperature of the DUT and the pre-amplifier. We may now find the noise temperature of the DUT alone by using the following equation of cascaded system.

$$T_e = T_1 + \frac{T_2}{G_1} + \cdots \cdots \qquad (4)$$

Now from Eq. 4:

$$T_e = T_1 + \frac{T_2}{G_1} + \cdots \cdots = T_{DUT} + \frac{T_{30dB}}{G_{DUT}} = 406K$$

The gain of the DUT used in this example was 7.5dB and a separate measurement was performed to measure that gain by using a VNA (vector network Analyser). Finally, the DUT noise temperature is calculated, $T_{DUT} = 309K$.

Now from the noise temperature, the noise figure of the DUT can be calculated as

$$F = 1 + \frac{T_{amp}}{T_0} = 1 + 1.066 = 2.066 = 3.15dB$$

NB: The outcome of this measurement may lead $\pm 1dB$ of error!!