Application Note

Noise Figure Measurement Methods

MS269xA-017/MS2830A-017/MS2840A-017

Noise Figure Measurement Function

Contents

1. Introduction

Against the background of the switchover to digital TV broadcasting, the increasing number of TV channels and the expanding market for duplex video communications (Video on Demand) are driving an increase in the number of broadcast satellites. Therefore, it is increasing the demand for Low Noise Block Down Converters (LNB) for receiving video transmissions from these satellites.
The signal-to-noise ratio (SNR) at the input of a radio receiver is a key parameter of communication systems. Because the transmission power that reaches the receiver is low, to reduce the Noise Figure (NF) in the satellite communication systems is especially important.
The LNB contains a Low Noise Amplifier (LNA) that corrects for the conversion losses of down converter and the transmission power that reaches the receiver, so measurement of the NF is a key item at every stage from design through mass production.
The measurement item of LNB is the 3rd order Intercept Point (IP3) as well as NF and conversion gain. There is a scene that uses the spectrum analyzer. It is advantage that spurious and IP3 and NF measurement can be covered using one spectrum analyzer.

This application note explains the basics of NF measurement as well as NF measurement methods using a spectrum analyzer.
The explanation is the divided into amplifier mode and converter mode. The amplifier mode is for measurement amplifier such as LNA. The converter mode is for measurement mixer and LNB.

In addition, it also explains precautions for evaluating an actual device under test (DUT).

2. Basics of Noise Figure (NF)

2.1. *What is Noise Figure?*

This section explains the noise figure (*NF*) by quantifying the noise in an amplifier.
In a linear amplifier, the ratio of the signal to the noise (*SNR*) is expressed by an index called the Noise Figure (*NF*). It is defined as the ratio of *SNR_out* (output signal noise ratio) to *SNR_in* (input SNR), and although it may be expressed differently according to the literature, in most cases, this ratio is called *F* (Noise Factor).

$$SNR = \frac{Signal\_Level[mW]}{Noise\_Level[mW]} \quad (SNR\_dB = Signal\_Level[dBm] - Noise\_Level[dBm]) \qquad ...(1)$$

$$F = \frac{SNR\_in}{SNR\_out} = \frac{S\_in / N\_in}{S\_out / N\_out} \qquad ...(2)$$

The value of *F* expressed in dB is called the Noise Factor and is defined by the following equation.

$$NF = 10 \times Log(F) \qquad ...(3)$$

For a better understanding of this equation, we need to consider a theoretical amplifier without noise.
In this circumstance, since the *SNR* does not change at the amplifier input and output, it is clear that *F* = 1, and *NF* = 0 [dB]. When using a semiconductor device linear amplifier and considering the *SNR* of the input signal (*SNR_in*), clearly the output of the amplifier after multiplication by the gain (*G*) is *S_out* = *G* x *S_in*, and the output multiplied by the gain (*G*) is *N_out* = *G* x *N_in* relative to Nin, but, actually it is output with some fixed noise power added (*N_add*).
This relationship is expressed by the following equation.

$$Sout = G \times S\_in$$

$$Nout = Nadd + G \times N\_in \qquad ...(4)$$

Substituting Eq. (4) into Eq. (2), gives the equation for the Noise Factor (*F*):

$$\mathrm{F} = \frac{Nadd + G \times Nin}{G \times Nin} \qquad ...(5)$$

Figure 2-1 illustrates Eq. (5) as a graph. The important point to draw from this is that Nadd and Gain can be found from the measurement results for any two points.

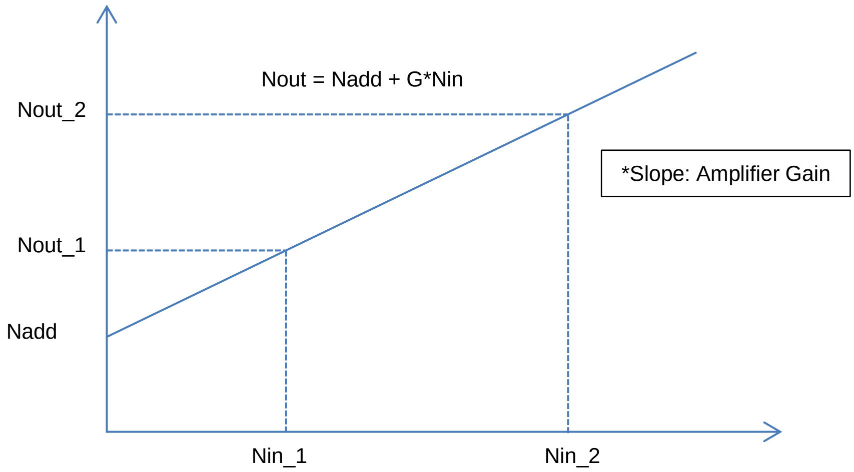

Fig. 2-1. Response at Input of Noise to Linear Amplifier

2.2. *Noise Figure at Multistage Connection*

This section explains the Noise Figure when active devices such as amplifiers that add noise are connected in a cascade.
First, consider the amplifiers connected in several stages as shown below:

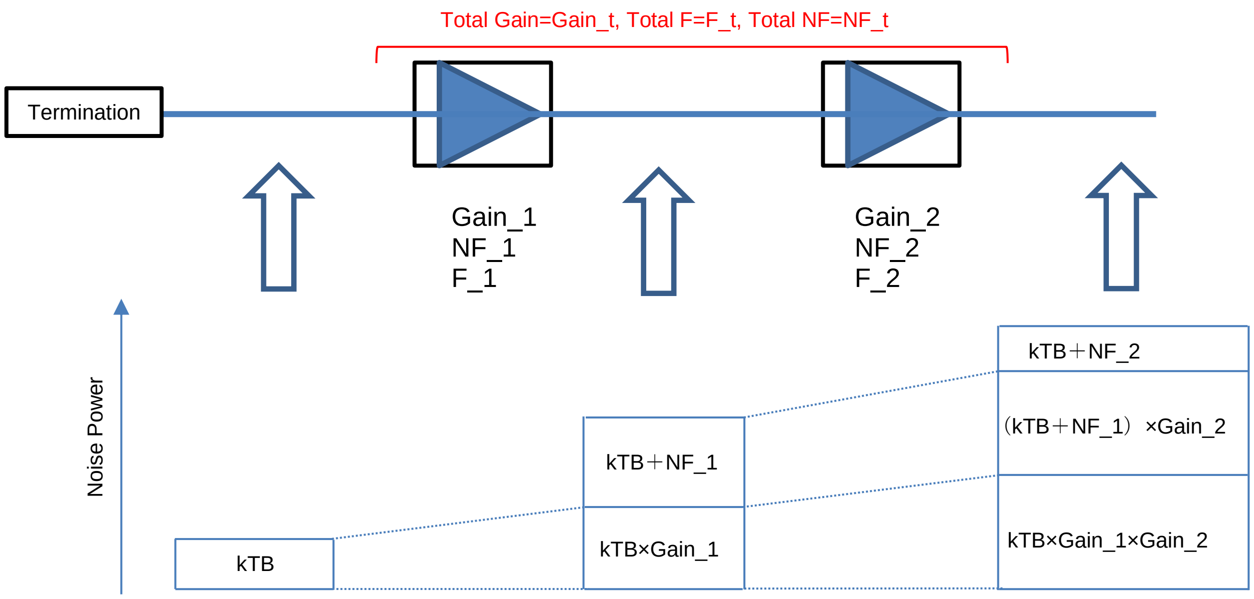

Fig. 2-2. NF Outline at Multistage Connection

From this equation, the value of *F* for the entire system can be defined by the following equation.

$$F\_t = F1 + \frac{F2-1}{Gain\_1} \quad ...(6)$$

$$F\_t = F1 + \frac{F2-1}{Gain\_1} + \frac{F3-1}{Gain\_1 \times Gain\_2} + \dots + \frac{Fn-1}{Gain\_1 \times Gain\_2 \times \dots \times \mathrm{Gain\_n}} \quad ...(7)$$

From Eq. (7), the value of *F* (*NF*) for the entire system has a smaller impact in the latter stages when using an amp with a large gain and smaller *F* (*NF*) is the first stage. This is the basic principle of a preamplifier used in a spectrum analyzer.

*Role of Preamplifier in Spectrum Amplifier
In a spectrum analyzer, a low-noise amplifier (LNA) is used at the stage before the 1st Mixer as a method to improve the Displayed Average Noise Level (DANL) of the spectrum analyzer. This LNA is called the preamp.
According to Eq. (7), the preamp is most effective when it is positioned at front-most block and the most effective way of improving the spectrum analyzer DANL is simply to attach the preamp to the spectrum analyzer input terminal. When measuring low power levels like at NF measurement, it is best to use an internal preamp to achieve low spectrum analyzer DANL.
Additionally, attaching another external preamp to the RF input of the spectrum analyzer can improve the DANL even further.

2.3. *Noise Figure Measurement Methods*

2.3.1. *Direct Method*

In the direct method, a spectrum analyzer is used to measure the absolute power of the noise and the *NF* is calculated from this value. The advantage of this method is the simple system configuration, but the disadvantage is the need for a high-performance measuring instrument.

The following shows and explains some concrete measurement examples.

(1) Measuring amp with 10 dB gain and 3 dB *NF* using spectrum analyzer with –141 dBm/Hz DANL

$$-141\ dBm/Hz + 10 \times (-174\ dBm/Hz + 3\ dB) = -140.96\ dBm/Hz \quad \text{...(8)}$$

→A level change of about 0.04 dB compared to the DANL when the spectrum analyzer is terminated can be monitored.

(2) Measuring amp with 10 dB gain and 3 dB NF using spectrum analyzer with –161 dBm/Hz DANL

$$-161 dBm/Hz + 10 \times (-174 dBm/Hz + 3 dB) = -158 dBm/Hz \quad \text{...(9)}$$

→A level change of about 3.0 dB compared to the DANL when the spectrum analyzer is terminated can be monitored.

First, in example (1), a level difference of 0.04 dB is captured and the DUT *NF* is found to be about 3 dB. When the power measurement accuracy of the measuring instruments is ±0.01 dB at this time, the uncertainty of the calculated *NF* value is +0.9 dB / –1.4 dB.
On the other hand, in example (2), a level difference of 3.0 dB is captured, and although the DUT *NF* is found to be about 3 dB, in example (1), when the power measurement accuracy is ±0.01 dB, the uncertainty of the calculated NF value is +0.04 dB / –0.04 dB.

In this measurement method, the uncertainty of the calculated *NF* value can be very different depending on the measured noise level, so a high-performance measuring instrument is required for measuring small *NF* values.

*–174 dBm is the thermal noise level at room temperature. It is called kTB noise and is calculated from the following equations at 27°C (300K).

$$k \times T \times B = 1.38 \times 10^{-23} \times 300 \times 1 = 4.14 \times 10^{-21} [W/Hz]$$

$$10 \times Log\{4.14 \times 10^{-21} \times 10^{3} [mW/Hz]\} = -173.82 [dBm/Hz] \quad \text{...(10)}$$

*To simplify Eq. 8 and Eq. 9, a value of –174 dBm/Hz is used.

k: Boltzmann Constant [1.38×10^{-23}]
T: Absolute Temperature [K]
B: Bandwidth [Hz]

2.3.2. *Y Factor Method*

In this method, two signals with different levels are input to the DUT and the *NF* of the DUT is calculated by comparing the *SNR* of the inputs and outputs for the two signals.
The Y factor method is a parameter expressing the ratio of the two level conditions defined as follows:

$$Y = \frac{Nout\_2}{Nout\_1} = \frac{Nadd + G \times Nin\_2}{Nadd + G \times Nin\_1} \quad ...(11)$$

$$F = \frac{Nin\_2 / Nin\_1}{Y - 1} \quad ...(12)$$

$$F = \frac{ENR}{Y - 1} \quad ...(13)$$

In general, a noise source that accurately defines the ratio between the noise levels is used to generate *N_in*_1 and *N_in*_2.
The ratio between these noise levels is called the Excess Noise Ratio (*ENR*) and is provided as calibration figures.

$$ENR\_dB = (NoiseSource\_on[dBm]) - (NoiseSource\_off[dBm])$$

$$ENR\_Linear = \frac{NoiseSource\_on[mW]}{NoiseSource\_off[mW]} \quad ...(14)$$

3. Measuring NF using Spectrum Analyzer (Amplifier Mode)

3.1. *NF Measurement and Principles using Y Factor Method*

This chapter explains NF measurement using the Y factor method.
There are 3 steps as the NF measurement.

- Setting: Frequency setting, ENR table setting, analysis time setting, etc.
- Calibration: Measurement NF of the measurement system (NF_2) using Y factor method, and then it normalizes NF and conversion gain.
- Measurement: measurement total NF (DUT + measurement system) using Y factor method, and then it calculates the NF of the DUT (NF_1) using Eq. (7).

It explains the detailed instructions below.

1) Calibrate the measurement system.
This calibration connects the noise source directly to the spectrum analyzer input and performs measurement using the Y factor method to calculate the NF of the measurement system (spectrum analyzer).

Figure 3-1 shows the measurement setup for calibration. At calibration, the noise source connector on the back panel of the spectrum analyzer and the noise source power terminal are connected, and the noise source output is connected directly to the spectrum analyzer.
Additionally, DC voltage is sometimes output, depending on the noise source. When using this type of noise source, as shown in Figure 3-2, attach a DC block to the spectrum analyzer input and connect the noise source to the block. (Refer to section 5 for noise sources with DC output.)

Calibration

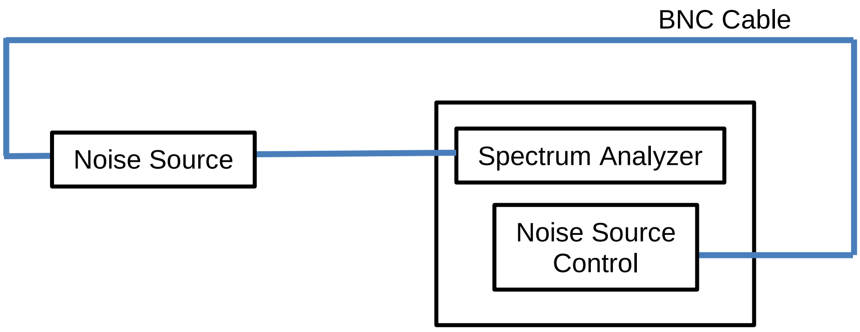

Fig. 3-1. Measurement Setup at Calibration (when DC Block Not Required)

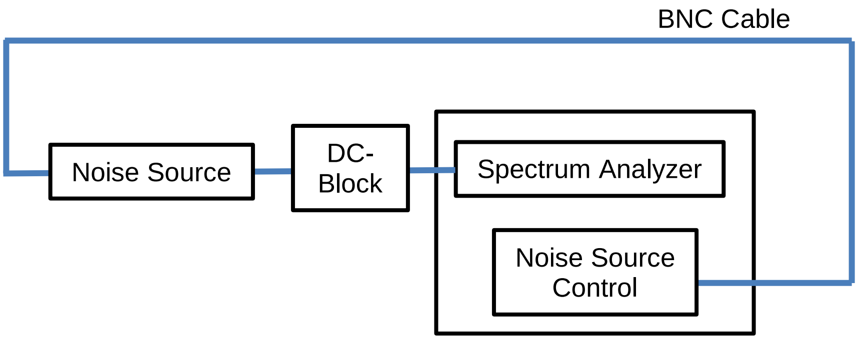

Fig. 3-2. Measurement Setup at Calibration (when DC Block Required)

2) Set the measurement conditions.
First, set the parameters for the noise source.
Refer to ENR values calibrated by noise source and set the ENR as shown in Figs. 3-3 to 3-5.
Also, create an ENR table like that shown in Fig. 3-6 for each noise source.

[Procedure]
Set the ENR value by recalling file

1. Press [Common Setting].

2. Press [ENR].

3. Press [Meas Table].

4. Press [Recall Meas Table].

5. Select the file from the list.

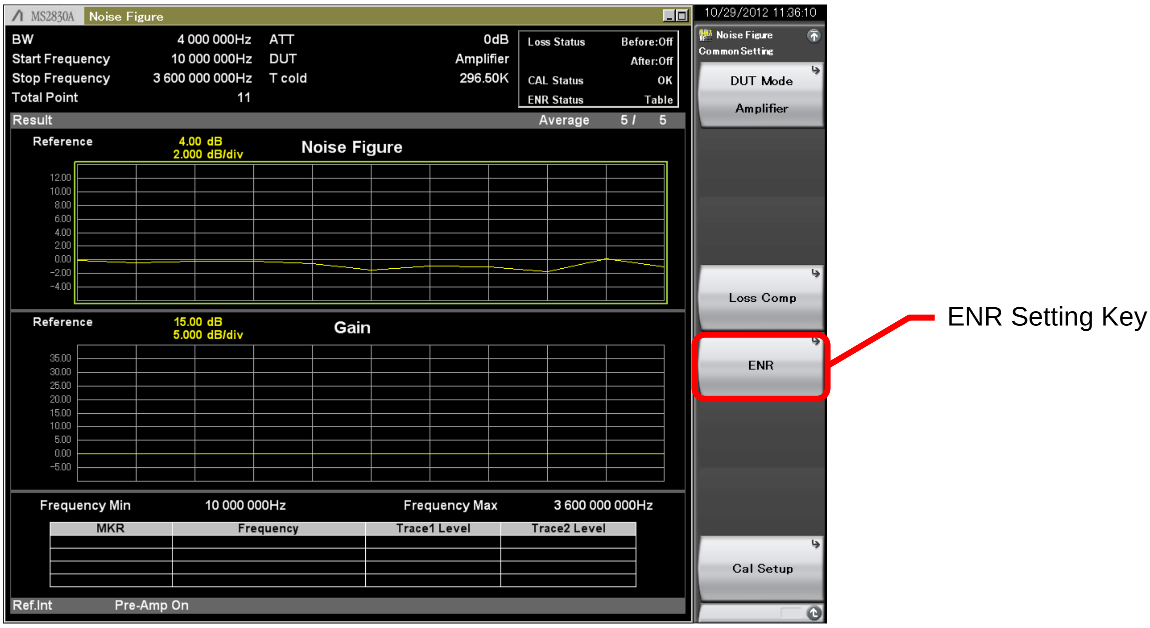

Fig. 3-3. ENR setting display at calibration

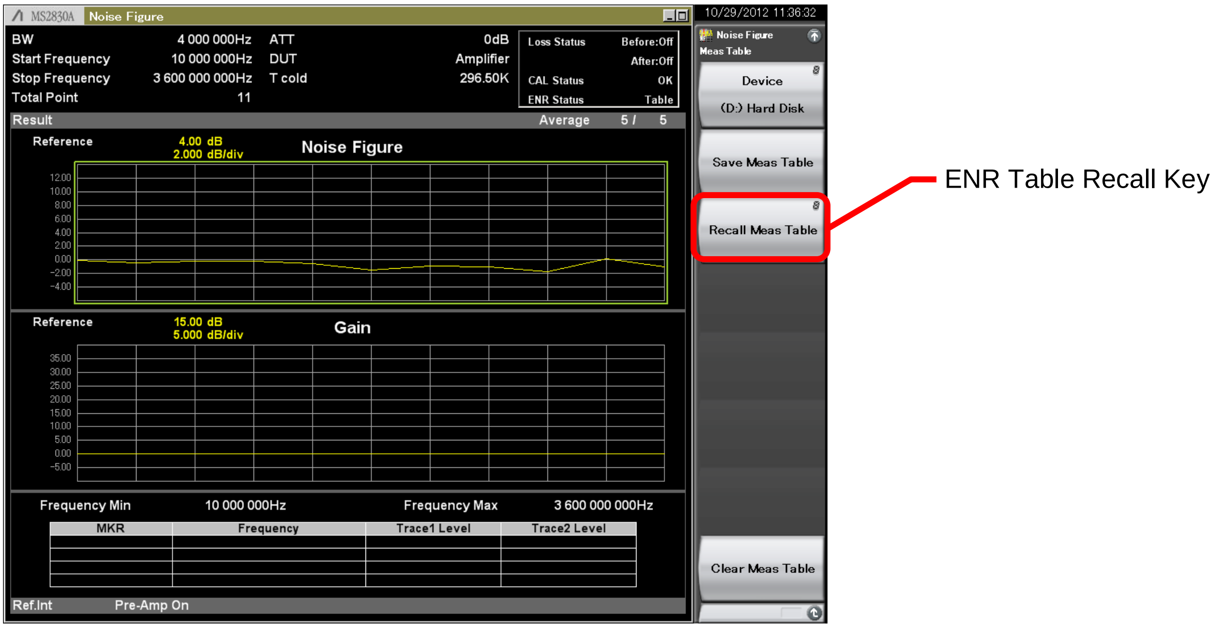

Fig. 3-4. Recall display for ENR file

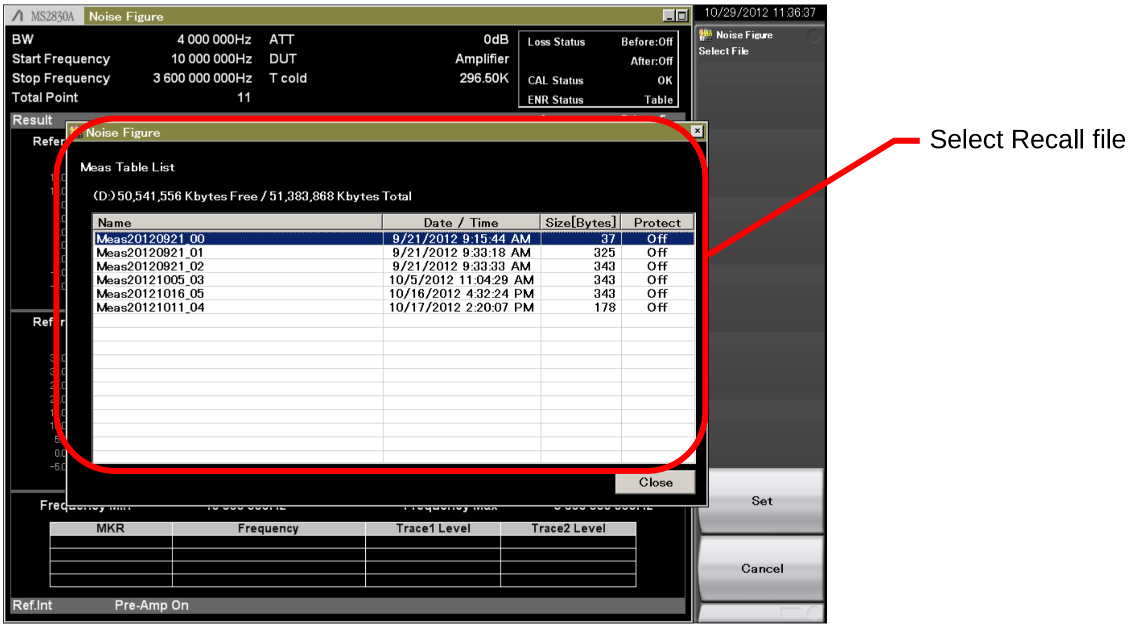

Fig. 3-5. ENR file selection display

How to edit the ENR file creates a new file by making a save once, and then edit the file.

Save directory
\ANRITSU CORPORATION\SIGNAL ANALYZER\USER DATA\NF Data\ENR

Name of default file
MeasYYYYMMDD_NN: YYYYMMDD is a date and NN is a suffix number.

[Procedure]
Set the ENR value by recalling file

1. Press [Common Setting].

2. Press [ENR].

3. Press [Meas Table].

4. Press [Save Meas Table].

5. Open the file in the save directory.

6. Input the frequency and ENR value. The format is [Frequency,ENR value]. The unit of frequency is Hz.

7. Save the file.

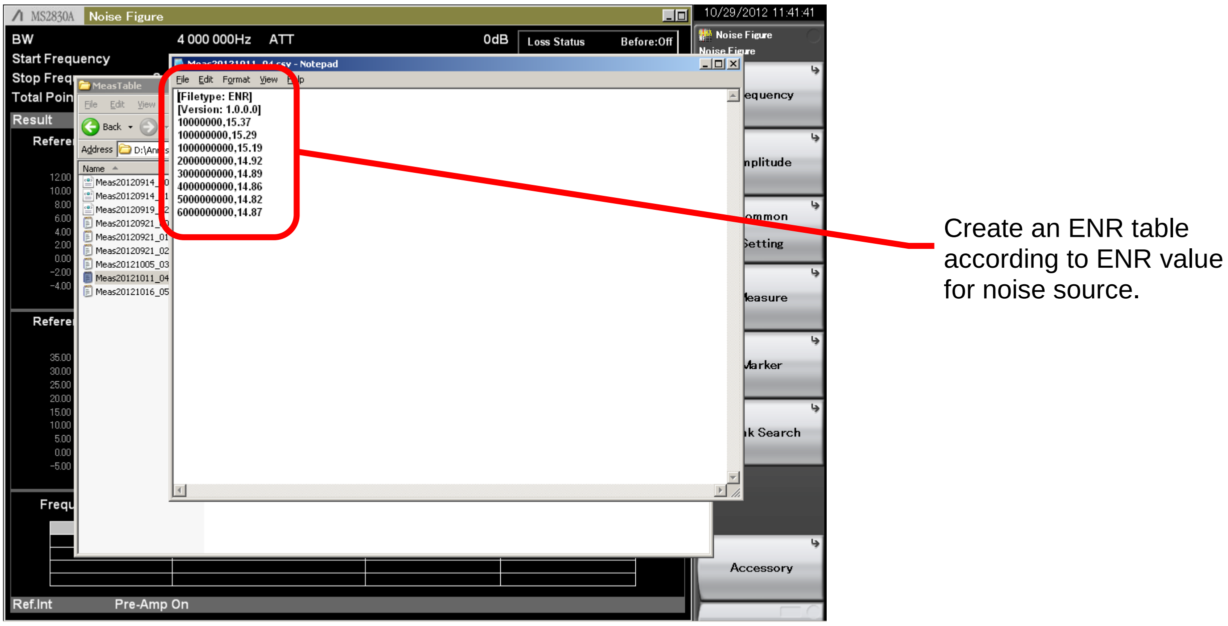

Fig. 3-6. ENR file edit display

Next, set the measurement frequency range, number of measurement points, measurement bandwidth, analysis time and Storage On/Off (Fig. 3-7 and 3-8).
Lengthening the analysis time and setting the averaging processing with the Storage On/Off setting improves the measurement accuracy but there is a tradeoff in increased measurement time.

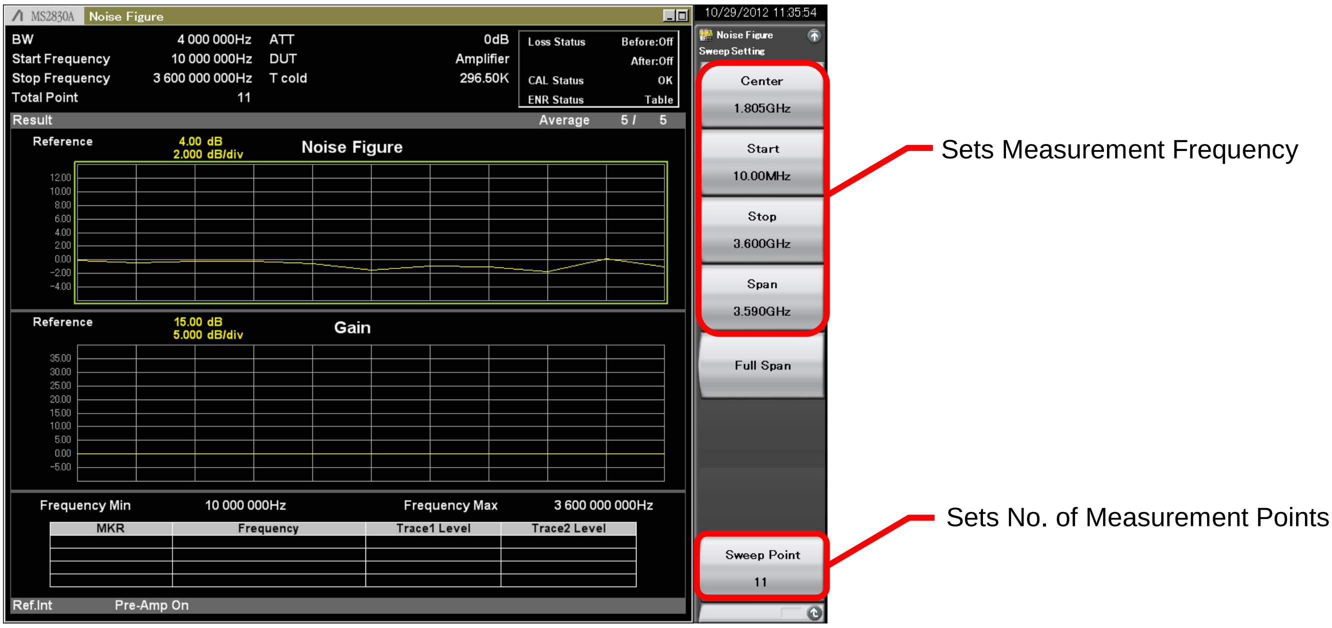

Fig. 3-7. Measurement frequency setting display

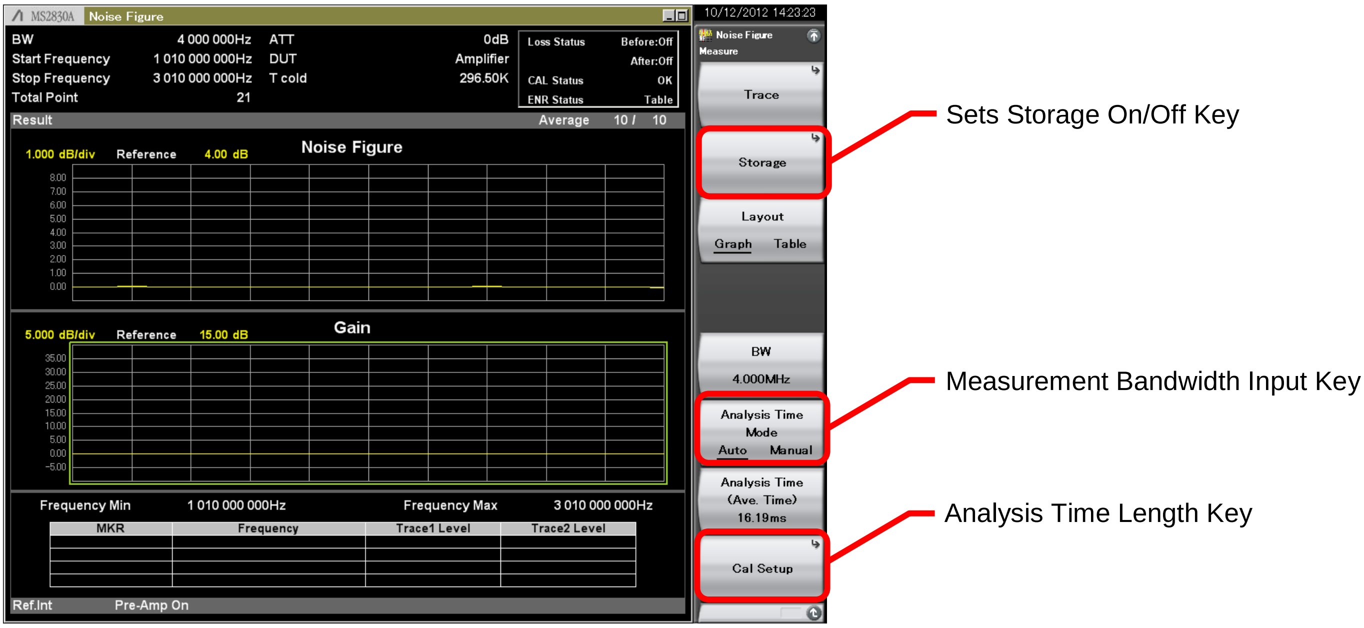

Fig. 3-8. Measurement condition setting display

This explains an example that the measurement accuracy is improved by increasing the analysis time.
The following table shows the dispersion of measurement taken 10 times in the case that the analysis time are 300ms and 100ms. This is one of measurement example, this value is not guaranteed.

Analysis Time	dispersion of measurement taken 10 times
100ms	0.054dB
300ms	0.026dB

3) Execute calibration (obtaining NF of measurement system)
Calibrate by touching the [Calibration Now] key shown in Fig. 3-9.
Clicking the [Cancel] key shown in Fig. 3-10 stops calibration. (Calibration is completed when progress bar reaches 100%.)

[Procedure]
Executes calibration.

1. Press [Common Setting].

2. Press [Cal Setup].

3. Press [Calibration Now]

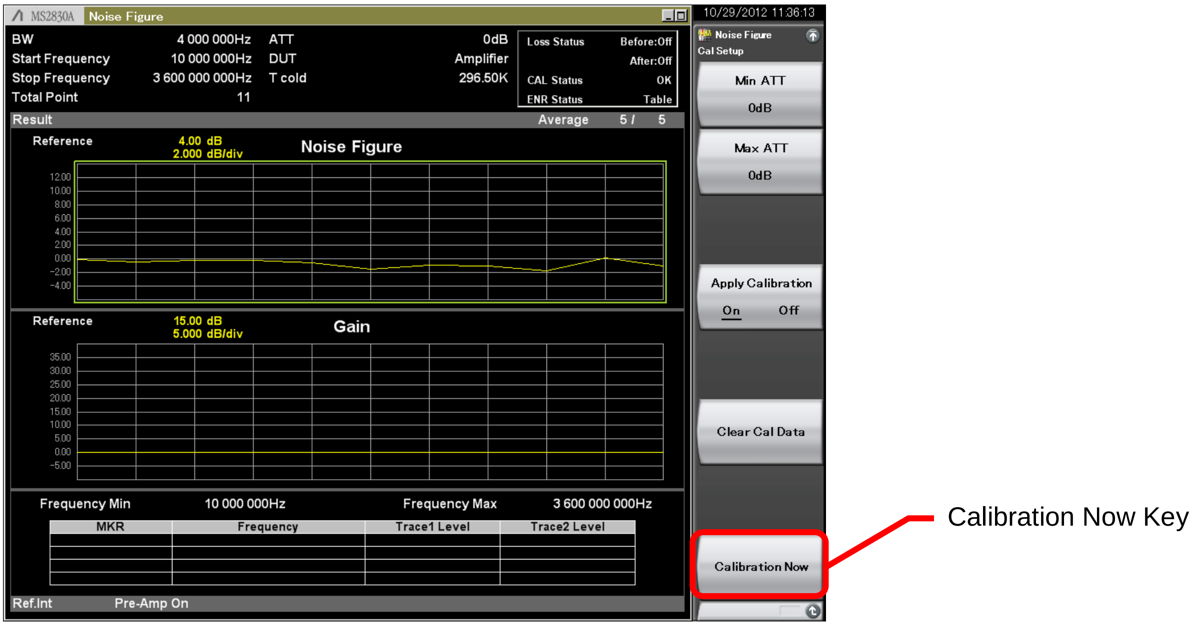

Fig. 3-9. Calibration execution display

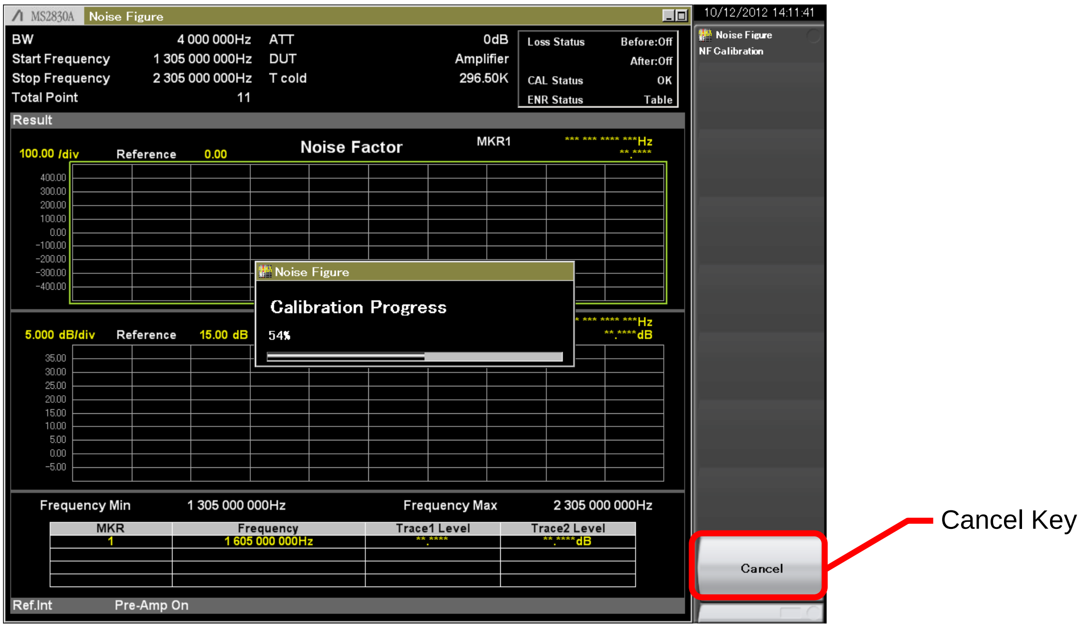

Fig. 3-10. Display during calibration

4) Perform measurement with the DUT connected.

The DUT is connected between the noise source and measurement system (spectrum analyzer) after calibration has been executed. The NF calculated at this step using the Y factor method is the total NF (DUT + measurement system).

Using the NF Measurement Function calculates the *NF* of the DUT (*NF*_1) from the *NF* measured with the DUT connected (*NF*_t) and the *NF* of the measurement system measured at calibration (*NF*_2) using Eq. (7), and shows calculating result in a table or graph.

DUT Setup

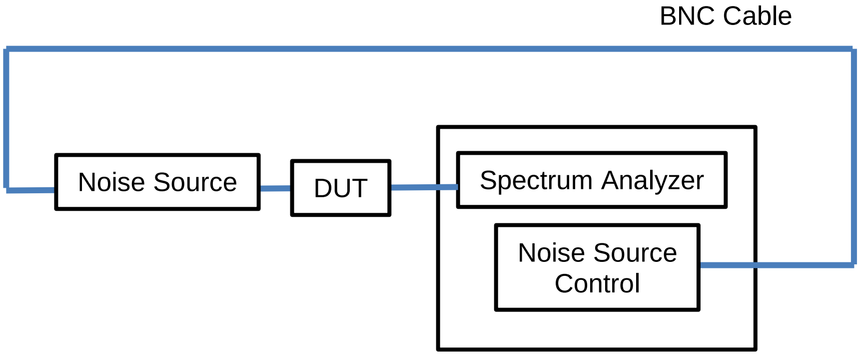

Fig. 3-11. Measurement system with the DUT connected (when DC block not required)

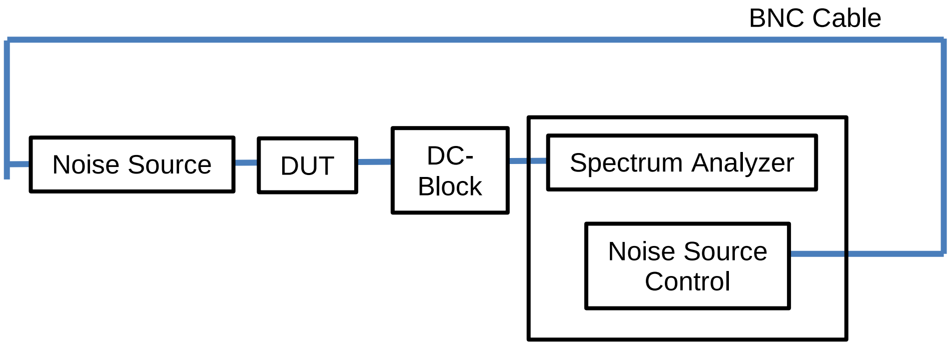

Fig. 3-12. Measurement system with the DUT connected (when DC block required)

Operate the Measure key to switch the display layout.

[Procedure]
Switch the display layout to the table from the graph.

1. Press [Measure].

2. Press [Layout].

Fig. 3-13. Measurement result display (Graph)

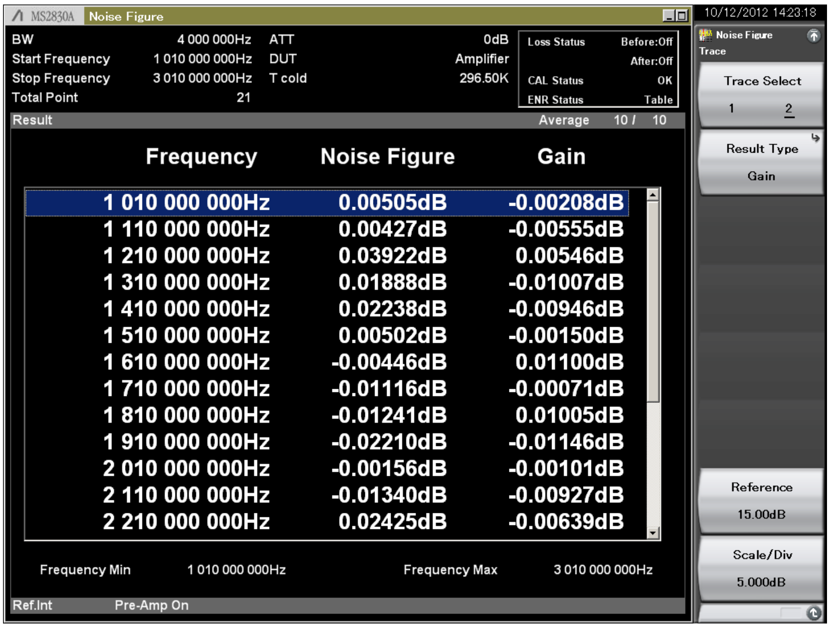

Fig. 3-14. Measurement result display (Table)

4. Measuring NF using Spectrum Analyzer (Converter Mode)

4.1. *NF Measurement with Frequency Converter*

Several connection examples are shown when measuring a frequency converter such as a mixer or a module incorporating a mixer.

When using Opt-020 or Opt-021 as Local Oscillator

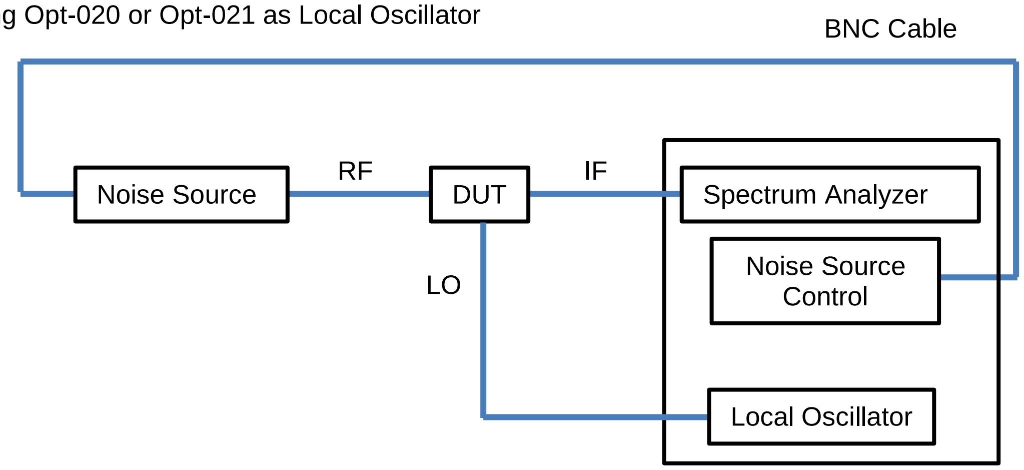

Fig. 4-1. Example of Connections for Opt-020 or Opt-021

When Using External SG as Local Oscillator

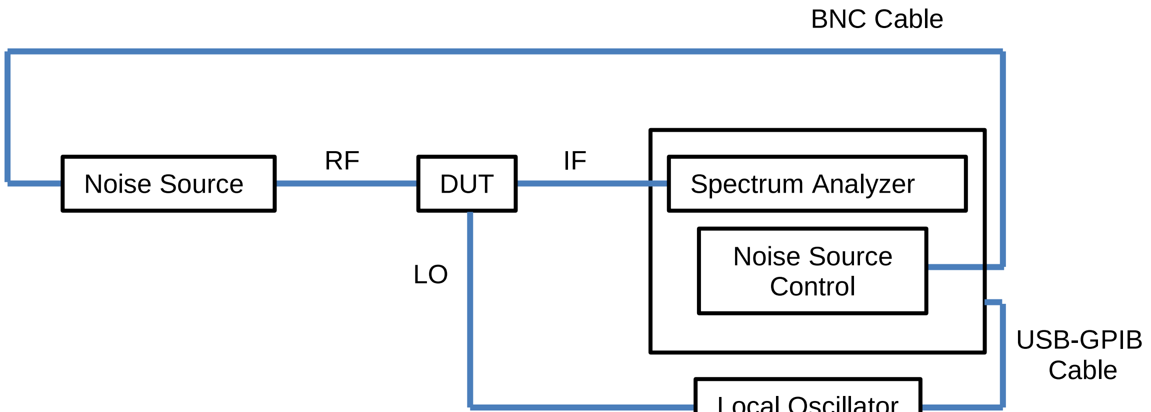

Fig. 4-2. Example of Connections when Measuring DUT using External Signal Generator as Local Oscillator

When Using DUT with Built-in Local Oscillator, such as LNB (Low Noise Block Converter)

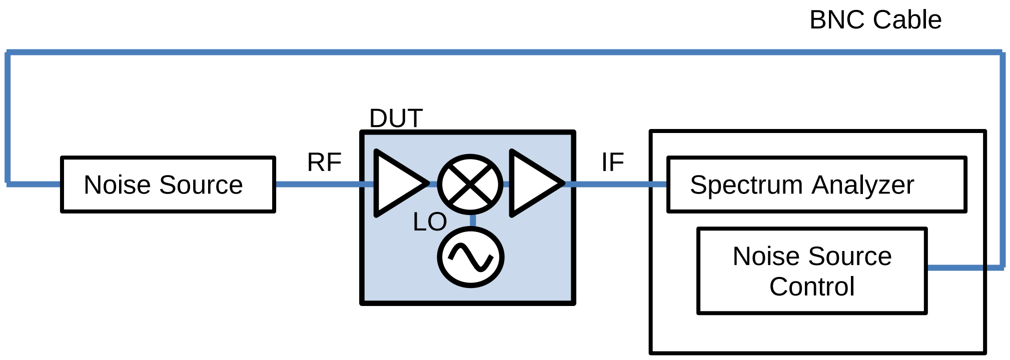

Fig. 4-3. Example of Connections when Measuring DUT with Built-in Local Oscillator

When the DUT is a frequency converter, there are some characteristics affecting NF measurement.

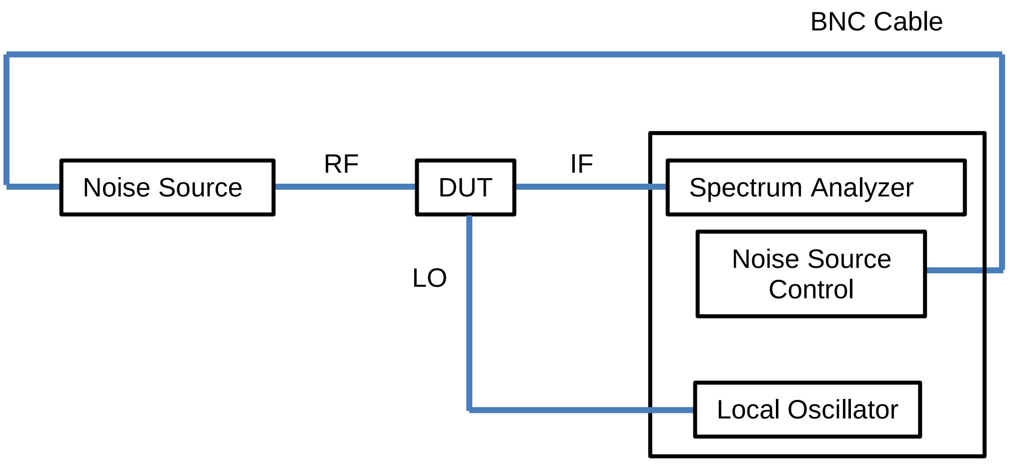

Fig. 4-4. Example of Connections for Opt-020 or Opt-021

RF...Between Noise Source and DUT; indicates input port to DUT
LO...Between DUT and Spectrum Analyzer; indicates output port from DUT
IF...Between Local Oscillator and DUT; indicates DUT LO signal input port from Local Oscillator

- Effect of Spurious such as Image Response
  With frequency converters, such as mixers, unexpected signals are generated by image responses, multiple responses, and IF feedthrough to become noise sources.
- Effect of Local Oscillator
  When noise in the local oscillator is converted by the mixer to IF bands it is added to the system NF. It changes according to the amount of noise in the local oscillator but is also affected by frequency-related noise such as image responses, multiple responses, etc.
- Effect of Local Oscillator Leaks
  If the mixer LO–IF isolation is low and there are LO components at the IF port, sometimes other spurious signals may be created.

The appropriate filters must be added to each port at measurement to eliminate concerns over these effects.

4.2. *Measurement Investigation*

The following four items have been selected to examine and measure the NF of a frequency converter using a MIXER as the DUT:

RF Frequency: 11 to 12 GHz
LO Frequency: 10 GHz
IF Frequency: 1 to 2 GHz

1. Select the DUT Mode.
This depends on whether the DUT is a frequency down or frequency up converter.
In the example, the down converter is selected because the frequency relationship is the IF < RF.

2. Select the LO Mode.
By selecting a fixed LO it is possible to investigate the IF frequency response of a DUT with changing IF. The RF frequency is calculated from the set LO and IF frequencies.
By selecting a variable LO it is possible to investigate the RF frequency response of a DUT with fixed IF. The LO frequency is calculated from the set RF frequency and IF frequency.
In the example, fixed LO is selected because the LO frequency is at one point.

3. Select the Side Band Mode.
A mixer with two responses (fLO+fIF, fLO-fIF) is called a Dual Side Band (DSB) mixer. Correspondingly, a mixer with a single side band is called a Single Side Band (SSB) mixer, while a mixer with only the upper side band (fLO+fIF) is called an Upper Side Band (USB) mixer and one with only the lower side band (fLO-fIF) is called a Low Side Band (LSB) mixer.
In the example, USB is selected because RF frequency is calculated as LO frequency + IF frequency.

4. With/Without Filter
A filter is inserted to suppress the effects of image responses, multiple responses, and IF feedthrough.
In the example, either an 11-GHz HPF or a 11- to 12-GHz BPF is inserted to prevent generation of image responses, along with either a 2-GHz LPF or a 1- to 2-GHz BPF inserted at the IF port.

There are 10 permutations based on selections 1 to 3 and the following two pages introduce the setup diagrams.

Figure 4-5 shows the frequency relationship as an example.

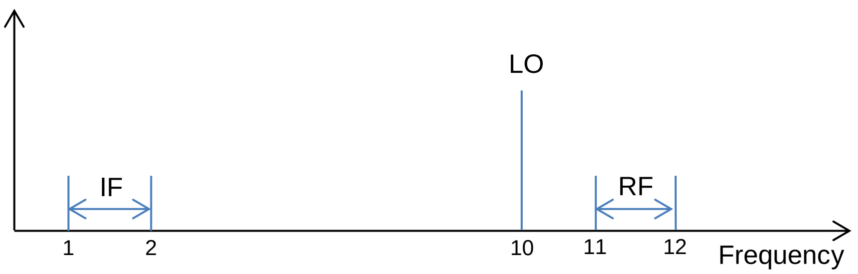

Fig. 4-5. Frequency Relationship in Example

There are 10 possible permutations depending on the settings of the DUT Mode, LO Mode, and Side Band Mode. The following figures show the frequency relationship for each and the automatic computation equation.

RF RF Frequency
LO LO Frequency
IF IF Frequency

 Frequency setting at LO Mode

 Frequency setting at the display

Blank Automatically calculated frequency

DUT Mode: With Down Converter

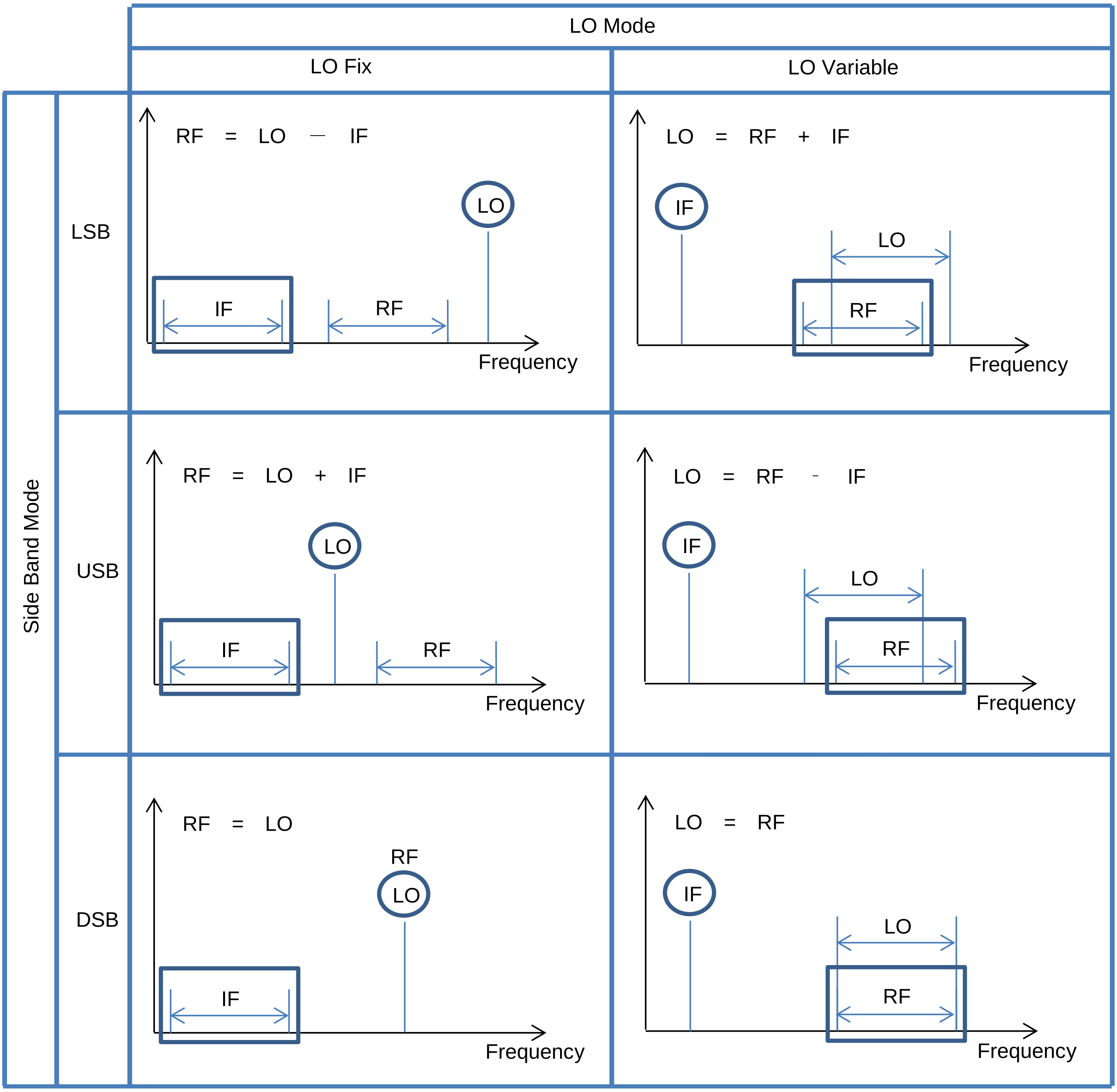

Fig. 4-6. Combination in Down Converter Mode

DUT Mode: With Up Converter

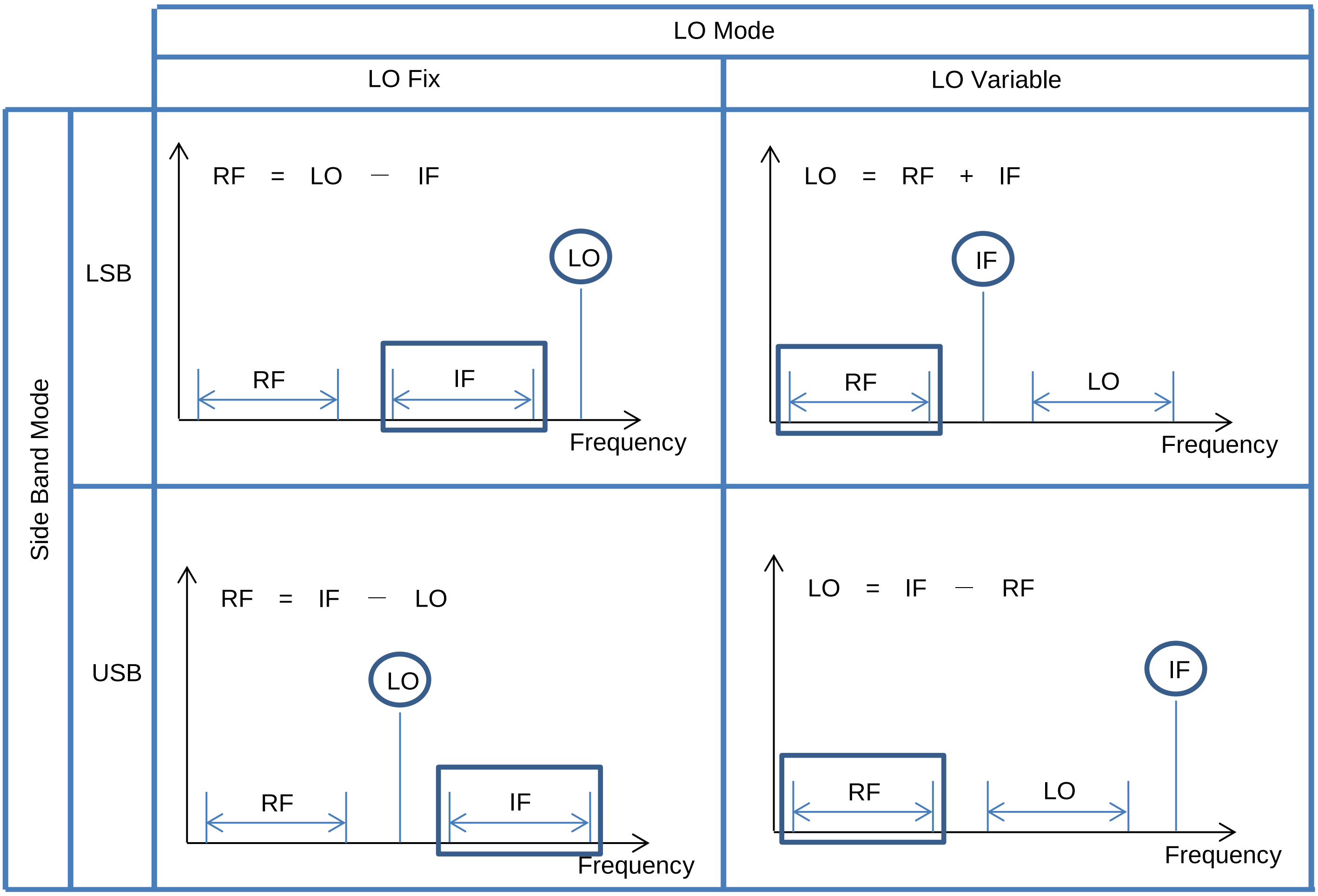

Fig. 4-7. Combination in Up Converter Mode

4.3. *NF Measurement Procedure in Converter Mode*

There is difference part to select the DUT mode, but the measurement procedure of converter mode is the same as the amplifier mode.

1) Prepare for measurement.
Set the DUT mode as shown in Fig. 4-8 and 4-9 and then set the LO Mode and Side Band Mode.
Set either the Local Freq or IF Freq depending on the LO Mode setting.
When using a signal generator as the LO input to the DUT, set [LO Control] to On and then press the [LO Select] key to select the signal generator (Fig. 4-10).
When there is only one signal generator, the relevant name is displayed.

[Procedure]
Set the DUT mode, the LO Mode, and the Side Band Mode

1. Press [Common Setting].
2. Press [DUT Mode].
3. Select [Down Converter]
4. Press [Convert Setup]
5. Press [LO Mode]
6. Select [Fixed]
7. Press[LO Freq] and set the LO frequency to 8GHz.
8. Press [Side Band Mode]
9. Select [LSB]

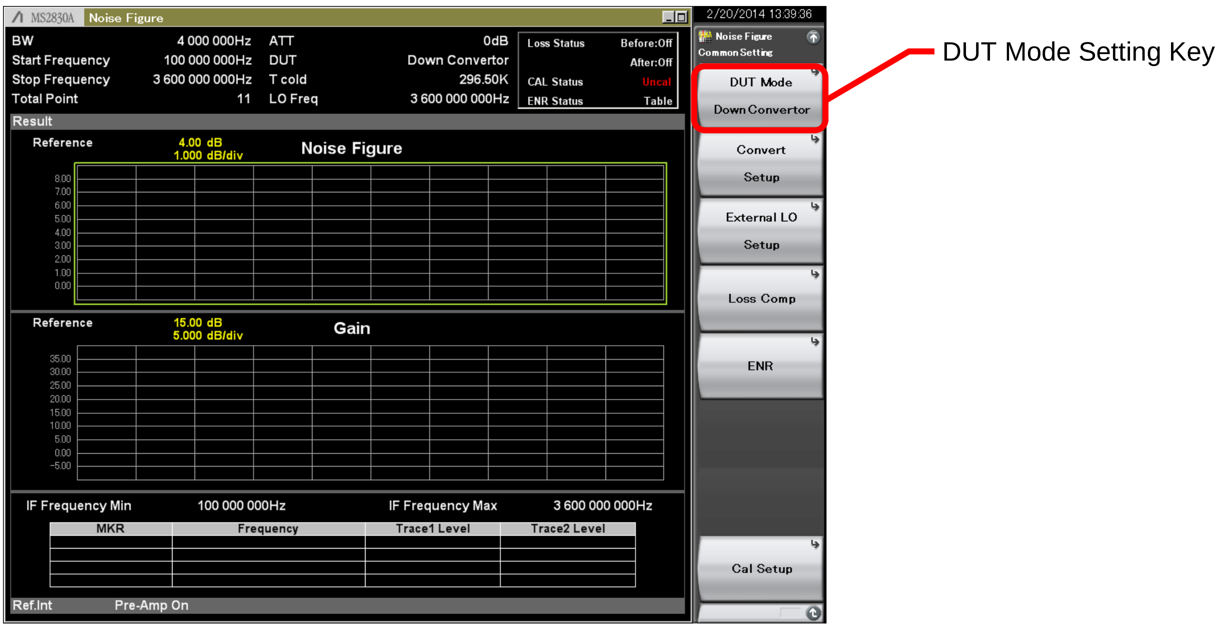

Fig. 4-8. DUT Mode Setting Display

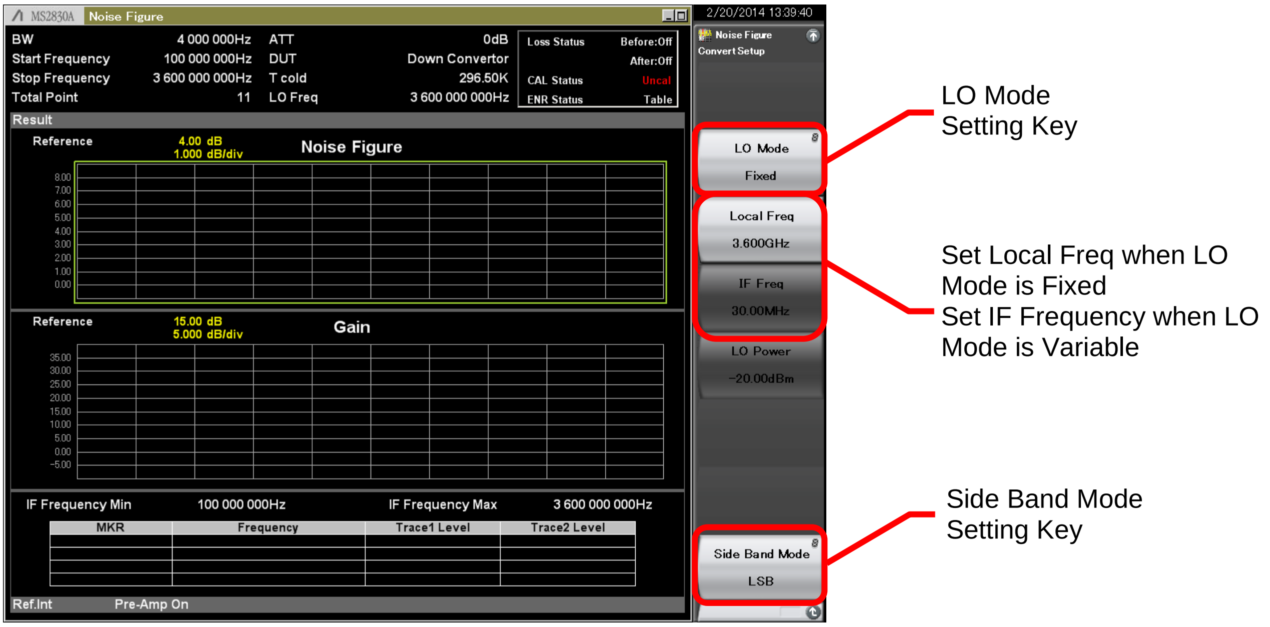

Fig. 4-9. LO Mode, Side Band Mode Setting Display

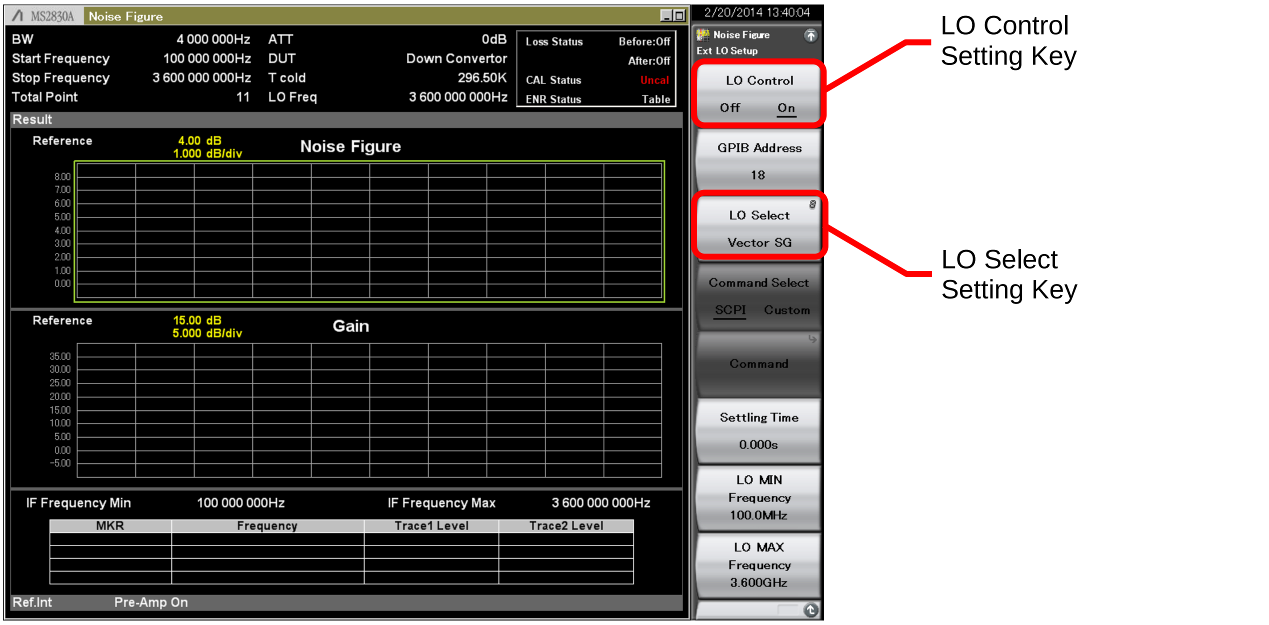

Fig. 4-10. LO Control Setting Display

2) Input the ENR value
The files can be read as shown in Figs. 3-3 to 3-6, but it is also possible to perform direct the ENR value as shown in Figs. 4-11 to 4-14.
Press the [Edit] key to change the ENR value at each frequency and the frequency.
When using a different noise source at measurement from the noise source used at calibration, select CAL Table after pressing the [Use Table for CAL] key as shown in Fig. 4-12, and input the ENR value of the noise source used at calibration to the CAL Table.

[Procedure]
Set the ENR value and save the ENR table.

1. Press [Common Setting].
2. Press [ENR].
3. Press [Meas Table].
4. Press [Edit].
5. Press [Freqency] and set the frequency to10MHz.
6. Set the ENR value to 15.2dB.
7. Set each the frequency and the ENR value that it is wrote on the noise source.
8. Press [Save Meas Table] to save the ENR value.

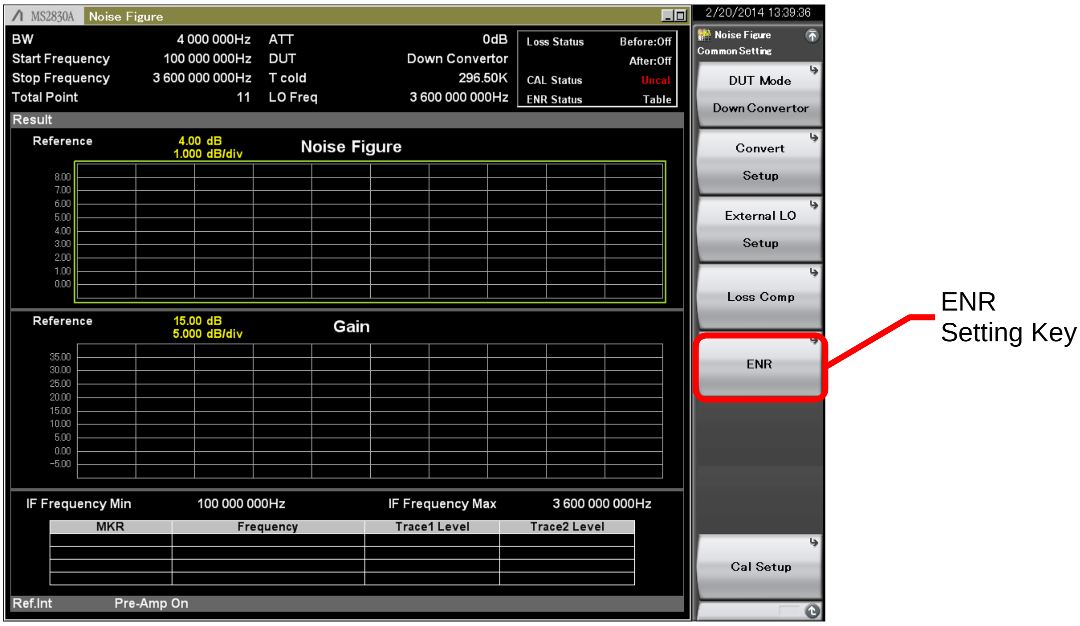

Fig. 4-11. ENR Setting Display

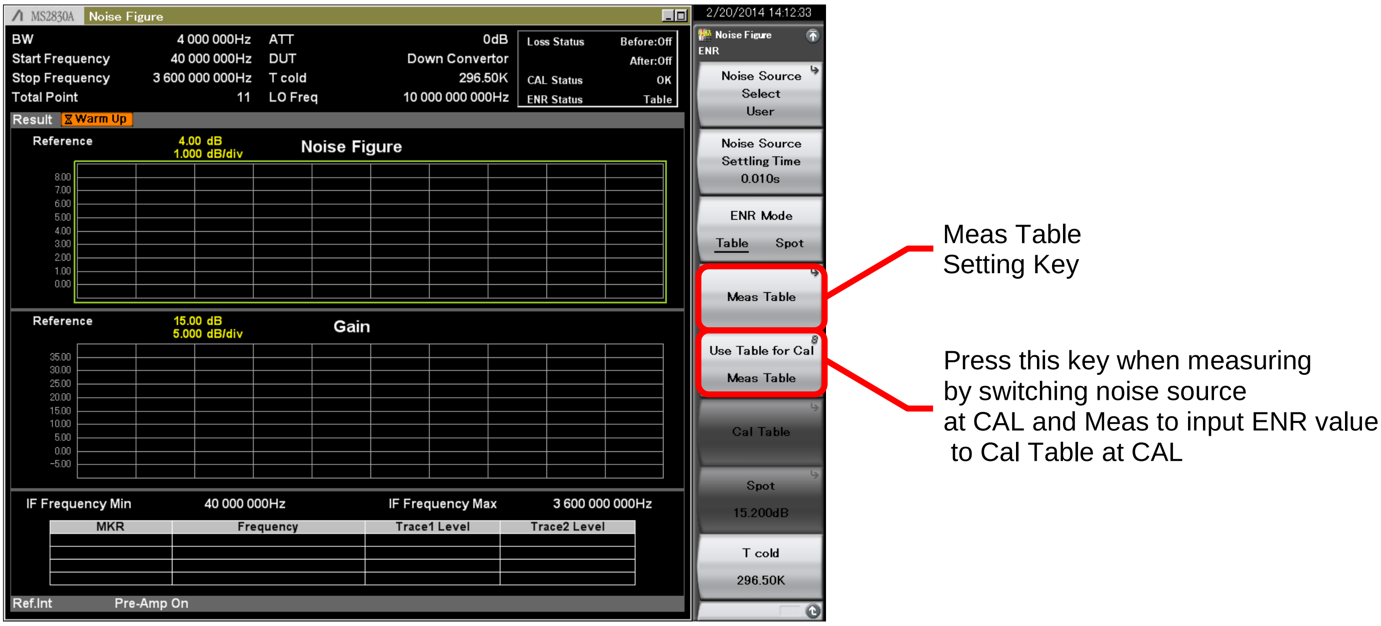

Fig. 4-12. Meas Table and CAL Table Setting Display

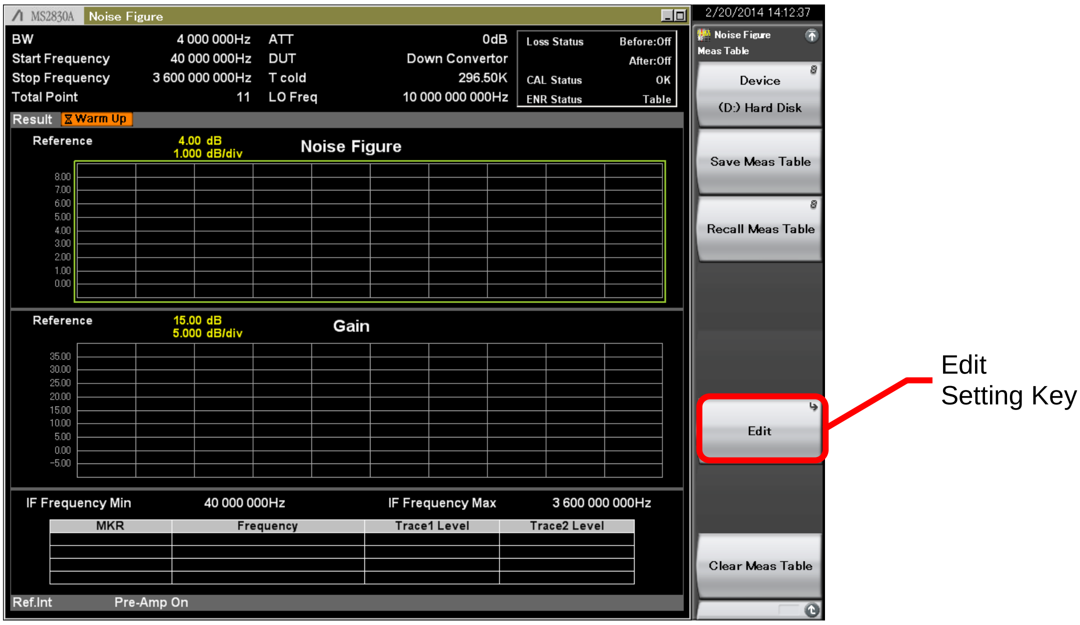

Fig. 4-13. ENR Value Edit Function Setting Display

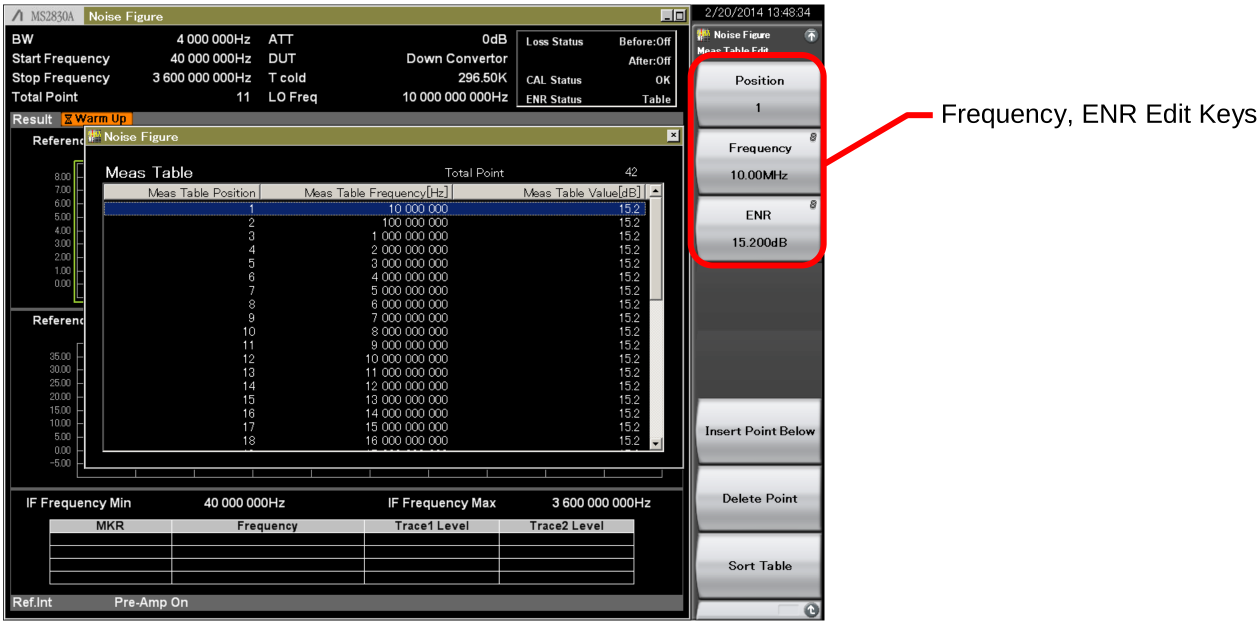

Fig. 4-14. ENR Value Editing Display

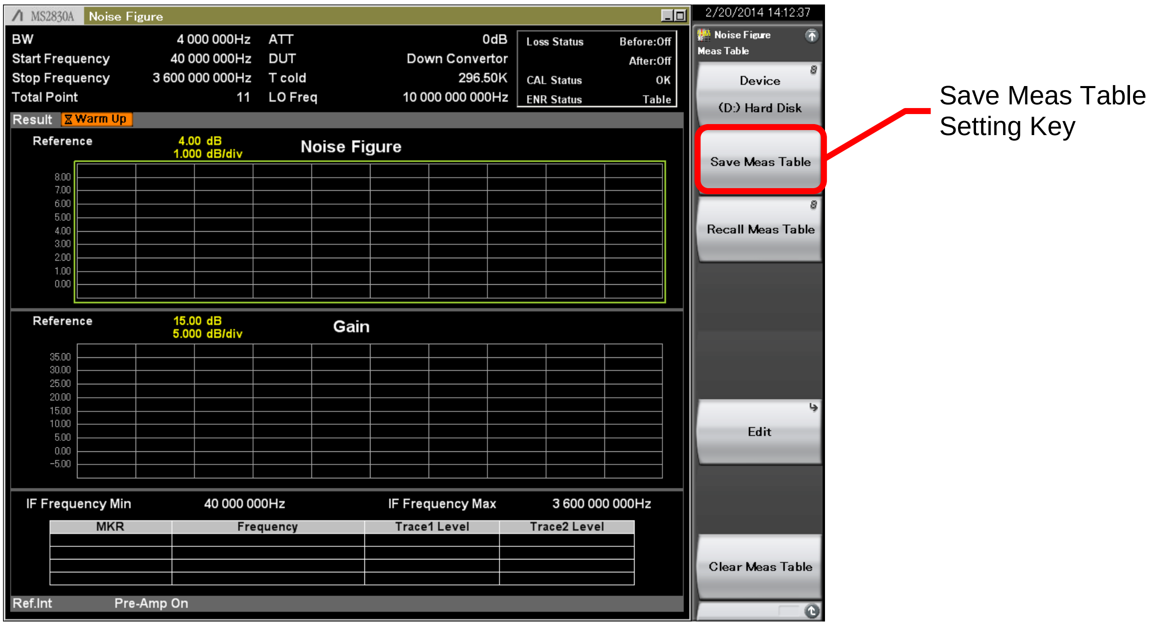

Fig. 4-15. Save the ENR Value Setting Display

Next, set the measurement frequency, number of measurement points, measurement bandwidth, analysis time length, and Storage On/Off setting. These operations are the same as shown in Figs. 3-7 and 3-8.
The measurement accuracy is improved by lengthening the analysis time and performing averaging by setting Storage On/Off but there is a trade-off in longer measurement time.

Fig. 4-16. Measurement Frequency Setting Display

Fig. 4-17. Measurement Conditions Setting Display

3) Executes calibration. (Obtain the NF of the measurement system.)
Executes calibration by pressing the [Calibration Now] key shown in Fig. 4-18.
Additionally, calibration can be stopped by pressing the [Cancel] key shown in Fig. 4-19. (Calibration is finished when the Calibration Progress bar reaches 100%.)

[Procedure]
Executes calibration.

1. Press [Common Setting].

2. Press [Cal Setup].

3. Press [Calibration Now]

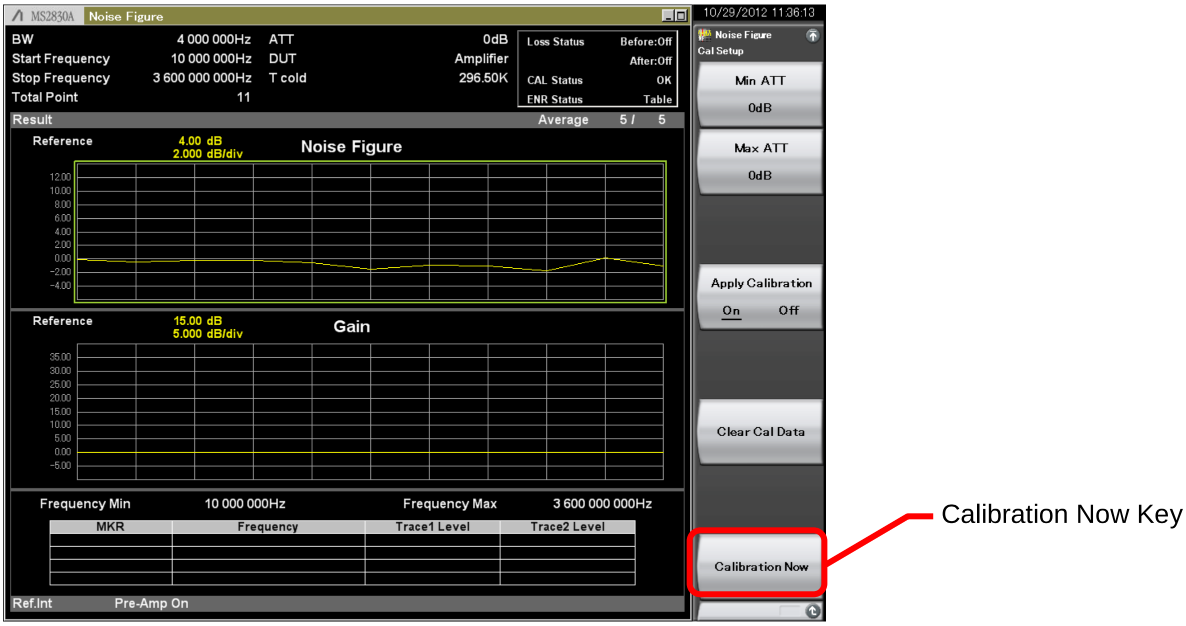

Fig. 4-18. Calibration Display

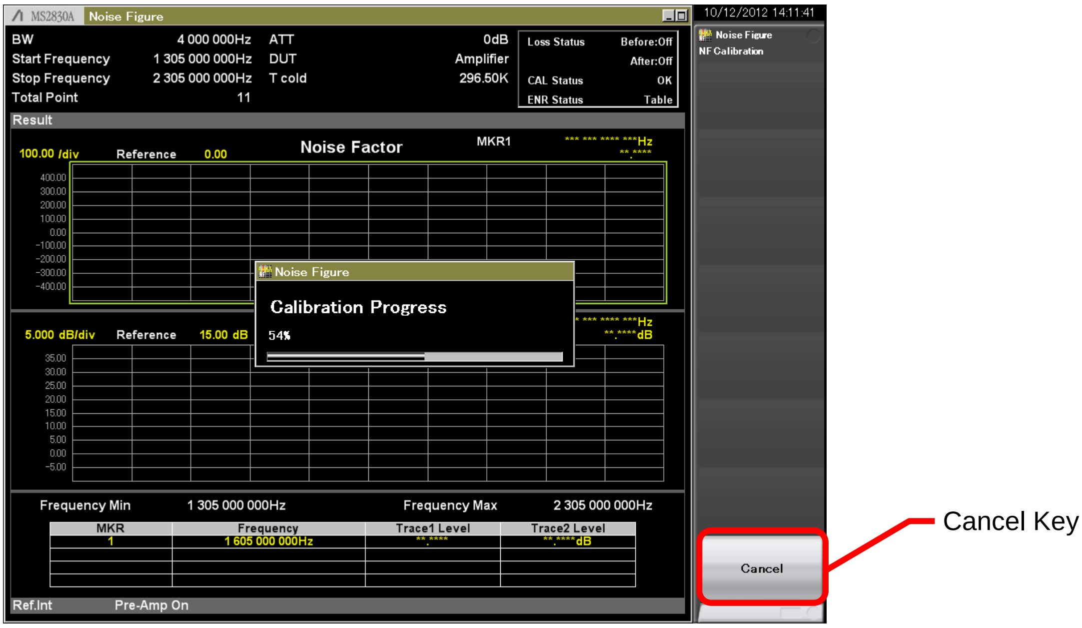

Fig. 4-19. Calibration Progress Display

4) Perform measurement with the DUT connected.
Using the calibrated system, connect the DUT between the noise source and measurement system (spectrum analyzer). The NF calculated at this time using the Y factor method is the total NF (of the DUT and measurement system).

The NF measurement function calculates the NF of the DUT (NF_1) using Eq. 7 from the NF measured when the DUT is connected (NF_t) and the NF of the measurement system measured at calibration (NF_2), and shows calculating result in a table or graph.

<u>DUT Setup</u>

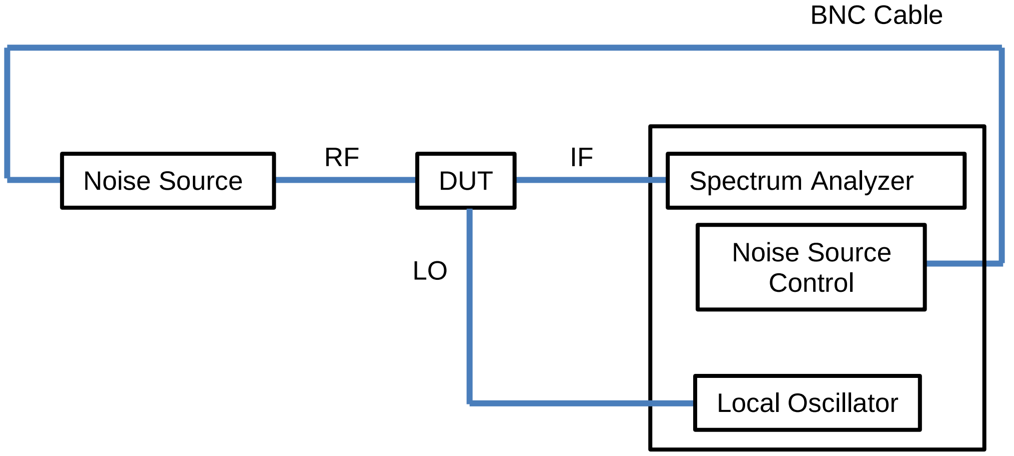

Fig. 4-20. Measurement Setup at DUT Connection

Operate the Measure key to switch the display layout.

[Procedure]
Switch the display layout to the table from the graph.

1. Press [Measure].

2. Press [Layout].

Fig. 4-21. Measurement Results Display (Graph)

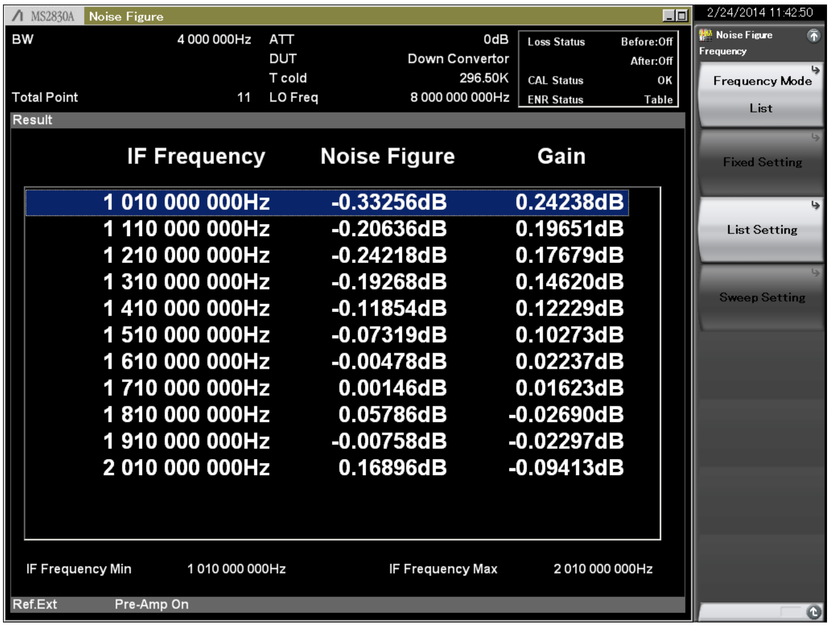

Fig. 4-22. Measurement Results Display (Table)

Sometimes, it may be necessary to insert filters before and after the DUT when unwanted responses such as image responses and LO leak occur at mixer measurement. Additionally, it may be necessary to insert an attenuator to match impedance or an amplifier to increase measurement accuracy.
In these cases when the measurement results include a filter or attenuator, the Loss Comp function can be used to measure the losses of parts other than the DUT to extract the value for the DUT from the measurement results for the overall system.

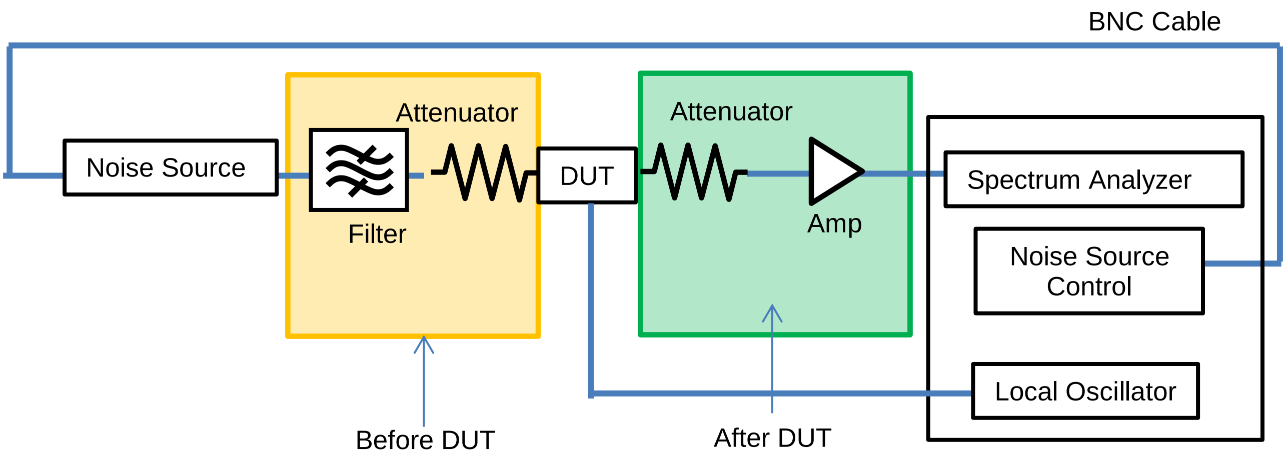

Fig. 4-23. Measurement Setup when Attenuator and Amp, etc., Connected Before and After DUT

[Procedure]
Set the Loss Comp. For example, Before DUT Loss is 3.1dB and After DUT Loss is 7.8dB.

1. Press [Common Setting].
2. Press [Loss Comp].
3. Press [Before DUT].
4. Select [Fixed].
5. Press [Before DUT Fixed] and set 3.1dB with the Before DUT Loss.
6. Press [After DUT].
7. Select [Fixed].
8. Press [After DUT Fixed] and set 7.8dB with the After DUT Loss.

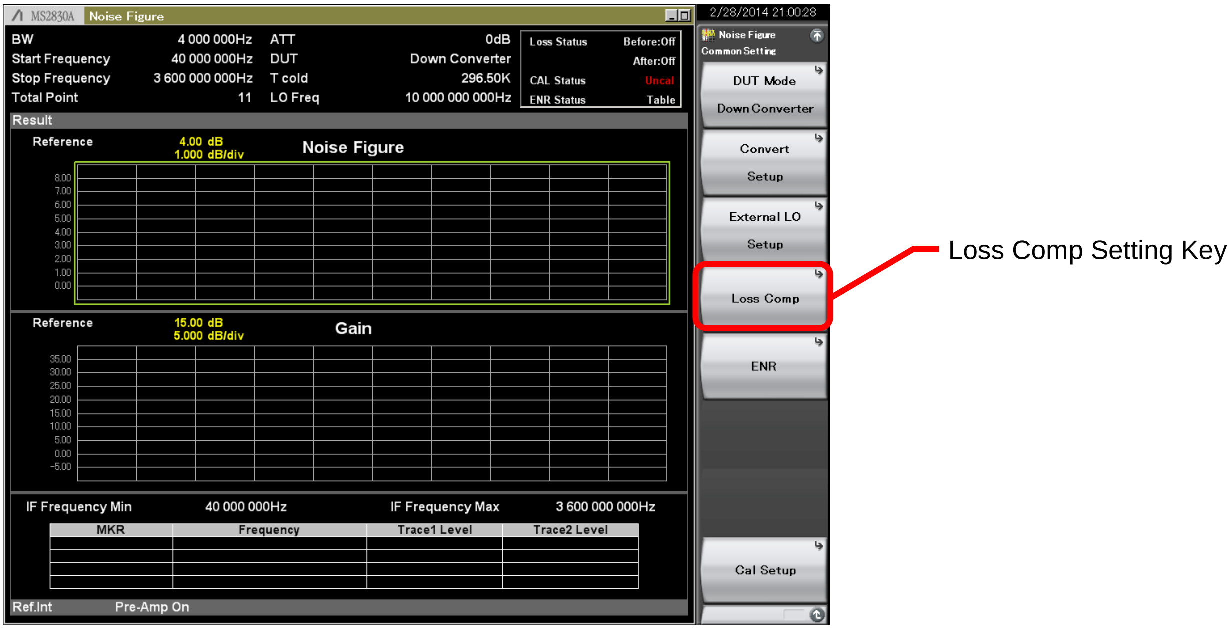

Fig. 4-24. Loss Comp Setting Display

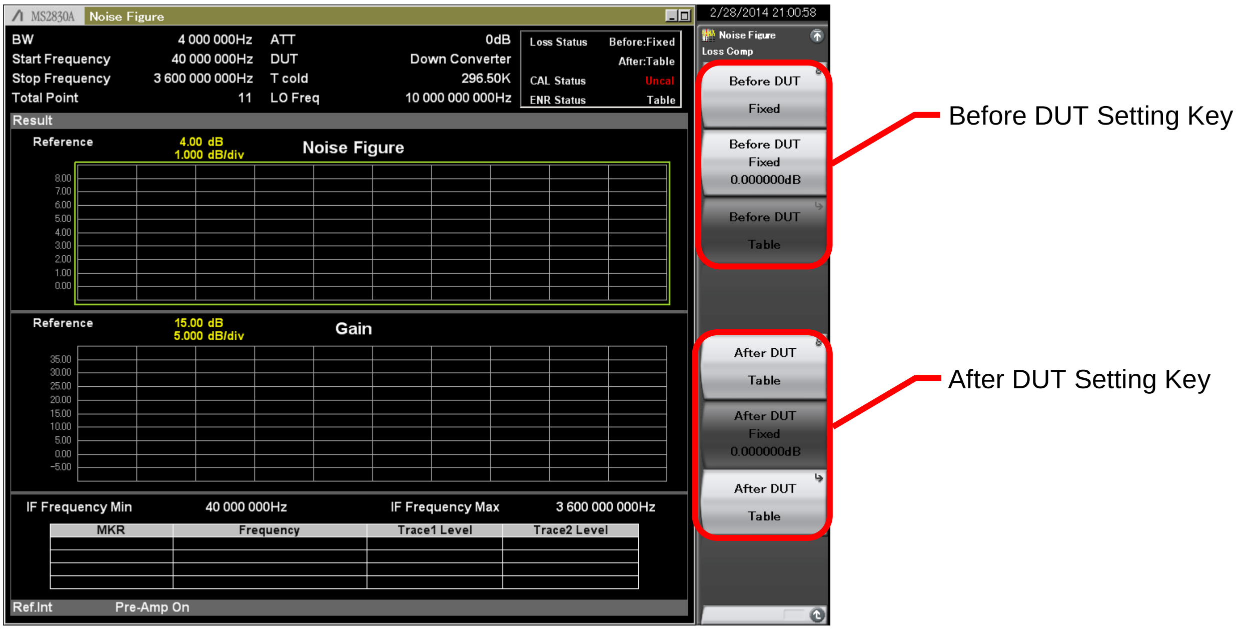

Fig. 4-25. Before DUT, After DUT Setting Display

5. Other Measurement Precautions

External Factors

Since NF measurements involve measurement of extremely small noise powers, it is necessary to consider the status of the DUT.
For example, when measuring an environment with wireless communications such as mobile telephones, the impact of these wireless signals cannot be ignored and sometimes it may be difficult to obtain accurate measurement results.
If the DUT is affected by external factors and the measurement results are believed to be inaccurate, measurement errors may be prevented by protecting the DUT from external factors by using the shield case.

Gain Measurement Range

At NF measurement, it may sometimes be necessary to pay heed to the measurement range at gain measurement. Gain measurement means determining the slope of the line shown in Figure 2-1 due to parameters having an effect at calibration and when the DUT is connected.
As an example, consider the case when using a noise source with an *ENR* of 24 dB. When this noise source is off, wideband noise of about –174 dBm/Hz is output; when it is on, wideband noise of about –150 dBm/Hz is output. These noise components are band controlled by the stage before the mixer input due to the spectrum analyzer internal blocks and are input to the 1st Mixer of the spectrum analyzer. As a result, when the noise source is connected directly to the spectrum analyzer and the noise source is on, the mixer input level is
–150 dBm/Hz + 10*Log (6 GHz) ≒ –52 dBm/6 GHz.
On the other hand, the spectrum analyzer linearity error performance must be considered. Since linearity error indicates the error in the spectrum analyzer at relative value measurement, it must be assured at some input level. As a result, if a higher input level is input to the spectrum analyzer, the gain cannot be measured accurately because linearity cannot be assured due to distortion at the internal semiconductor parts.
At NF measurement, always choose a noise source with an ENR matching the gain and bandwidth of the DUT to be measured and set the attenuator at measurement.

Noise source selection

Note the following points when selecting the noise source.
Many noise sources impress bias on an avalanche diode to generate wideband noise when the avalanche collapses. However, due to this operation principle, sometimes there may be DC voltage at the output of the noise source. (Depending on the noise source, there may be an internal filter to block this DC voltage so there is no DC voltage at the output terminal.)
When using this type of noise source, perform measurements with the DC filter block inserted at the input of the spectrum analyzer.

Supports noise sources from Noisecom NC346 series. NC346 series models and summary specifications are listed below. See the NC346 series catalog and datasheet for detailed specifications.

Table5-1. NC346 series summary specifications

Model	RF Connector	Frequency [GHz]	Output ENR [dB]	DC Offset	DC Block
NC346A	SMA (M)	0.01 to 18.0	5 to 7	No	Not required
NC346A Precision	APC3.5 (M)	0.01 to 18.0	5 to 7	No	Not required
NC346A Option 1	N (M)	0.01 to 18.0	5 to 7	No	Not required
NC346A Option 2	APC7	0.01 to 18.0	5 to 7	No	Not required
NC346A Option 4	N (F)	0.01 to 18.0	5 to 7	No	Not required
NC346B	SMA (M)	0.01 to 18.0	14 to 16	No	Not required
NC346B Precision	APC3.5 (M)	0.01 to 18.0	14 to 16	No	Not required
NC346B Option 1	N (M)	0.01 to 18.0	14 to 16	No	Not required
NC346B Option 2	APC7	0.01 to 18.0	14 to 16	No	Not required
NC346B Option 4	N (F)	0.01 to 18.0	14 to 16	No	Not required
NC346D	SMA (M)	0.01 to 18.0	19 to 25*1	No	Not required
NC346D Precision	APC3.5 (M)	0.01 to 18.0	19 to 25*1	No	Not required
NC346D Option 1	N (M)	0.01 to 18.0	19 to 25*1	No	Not required
NC346D Option 2	APC7	0.01 to 18.0	19 to 25*1	No	Not required
NC346D Option 3	N (F)	0.01 to 18.0	19 to 25*1	No	Not required
NC346C	APC3.5 (M)	0.01 to 26.5	13 to 17	Yes*3	**Required*3**
NC346E	APC3.5 (M)	0.01 to 26.5	19 to 25*1	Yes*3	**Required*3**
NC346Ka	K (M)*2	0.10 to 40.0	10 to 17	Yes*3	**Required*3**

*1: Flatness better than ±2 dB
*2: Compatible with SMA and APC3.5
***3: When using noise sources output by DC, always use in combination with a DC block.**

Table5-2. Specifications outlines of recommended DC Blocks and Adapters

	Ordaring		RF Connector	Frequency Range
	Model	Name		
DC Block	J0805	DC Block, N type (MODEL 7003)	N (M)-N (F)	10 kHz to 18 GHz
	J1555A	DC Block, SMA type (MODEL 7006-1)	SMA (M)-SMA (F)	9 kHz to 20 GHz
	J1554A	DC Block, SMA type (MODEL 7006)	SMA (M)-SMA (F)	9 kHz to 26.5 GHz
	K261	DC Block	K (M)-K (F)	10 kHz to 40 GHz
Adapter	J0004	Coaxial Adapter	N (M)-SMA (F)	DC to 12.4 GHz
	J1398A	N-SMA Adapter	N (M)-SMA (F)	DC to 26.5 GHz

Table5-3. Recommended DC blocks / Adaptor combinations for MS269xA/MS2840A/MS2830A series signal analyzer.

	Model	Frequency Range	RF connector	Recommended DC Block Order Name	Recommended Adapter Order Name
MS269xA Series	MS2690A	50 Hz to 6 GHz	N (F)	J1555A	J0004
	MS2691A	50 Hz to 13.5 GHz	N (F)	J1555A	J1398A
	MS2692A	50 Hz to 26.5 GHz	N (F)	J1554A	J1398A
MS2840A	MS2840A-046	9 kHz to 44.5 GHz	K (F)	K261	Not Required
MS2830A Series	MS2830A-040	9 kHz to 3.6 GHz	N (F)	Not Required	Not Required
	MS2830A-041	9 kHz to 6 GHz	N (F)	Not Required	Not Required
	MS2830A-043	9 kHz to 13.5 GHz	N (F)	Not Required	Not Required
	MS2830A-044	9 kHz to 26.5 GHz	N (F)	J1554A	J1398A
	MS2830A-045	9 kHz to 43 GHz	K (F)	K261	Not Required

6. Uncertainty of NF Measurement Methods

As explained in the previous section, the Y factor method supports DUT *NF* measurements. This section explains the uncertainty of NF measurements.
The following figures show the uncertainty at calibration and when the DUT is connected.

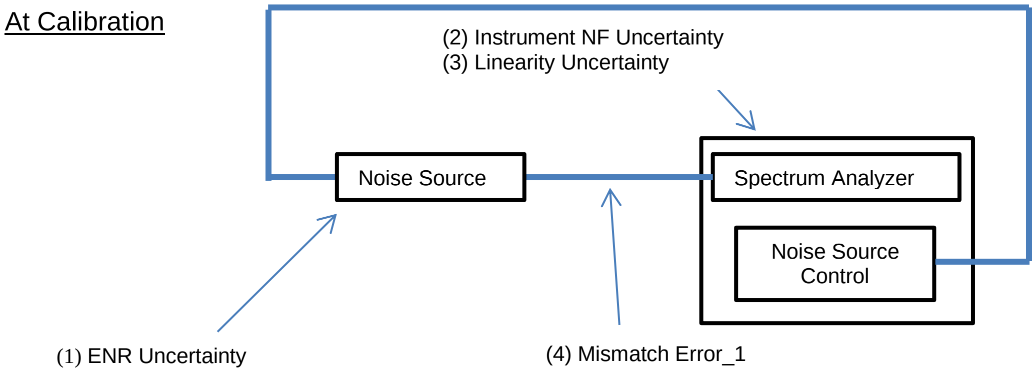

Fig. 6-1. Uncertainty at calibration

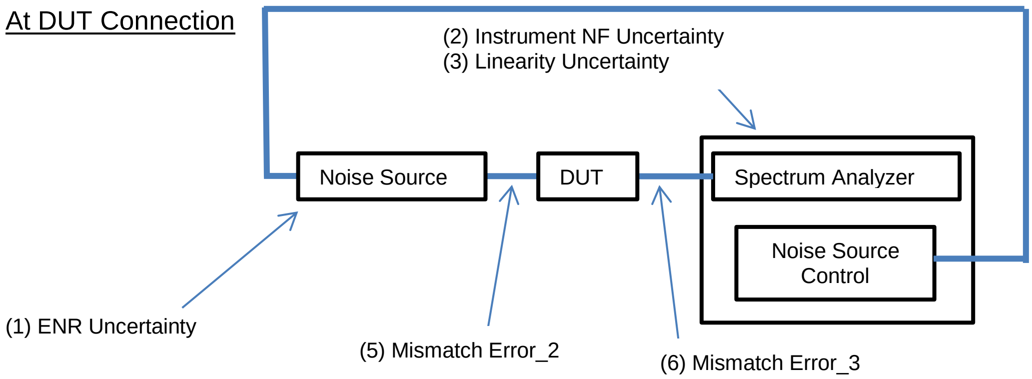

Fig. 6-2. Uncertainty when DUT connected

(1) ENR uncertainty causes an error when calculating the Noise Factor, *F*.
*Refer to Ref. (13).

(2) This uncertainty is caused by the spectrum analyzer level resolution. It is uncertainty due to the internal calculation of the NF of the spectrum analyzer obtained from calibration.

(3) This uncertainty is caused by the spectrum analyzer linearity error.
*When determining the *NF* of the DUT using the Y factor method, the DUT gain must be measured. It can be found from the gradient of data as shown in Figure 2-1 calculated from the measurement results when the DUT is connected at calibration. When measuring the relative values of the two levels at the spectrum analyzer (at calibration and with DUT connected), the uncertainty is standardized as the linearity error.

(4) This is mismatch error between the noise source and spectrum analyzer at calibration.

(5) This is mismatch error between the noise source and DUT when the DUT is connected.

(6) This is mismatch error between the DUT and spectrum analyzer when the DUT is connected.

The values of these uncertainties vary, depending on the DUT and the ENR of the noise source.
As a result, an Uncertainty Calculator tool is provided to calculate the uncertainty by inputting parameters (1) to (6).

The uncertainty of the NF found by the NF Measurement Function can be calculated by inputting the parameters for (1) to (6) and the measurement results into the following Uncertainty Calculator.

Uncertainty Calculator

01,November,2012
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This spreadsheet calculates the total uncertainty of noise figure measurement.
Please input parameters of your devices and environment into the orange cells.
For more information, please see the "Tutorial" spreadsheet.

(orange) Input Parameter
(green) Calculation Result

Measure Parameter								
		Unit	Linear					
Temperature	296.5	K						
kTB	-173.88096	dBm						
DUT NF : F1=	3	dB	1.995262315		F12/F1=	1.09149013		
Y factor	4	-	2.511886432					
ENR	15	dB	31.6227766					
DANL	-161.0356							
Instrument NF : F2=	12.8453632	dB	19.25468049		F2/F1G1=	0.096502		
DUT GAIN : G1=	20	dB	100		(F2-1)/F1G1=	0.09149013		
Combined NF : F12=	3.38019812		2.17780912		(F12/F1)-(F2/F1G1)=	0.99498813		
Mismatch Error								
Match	VSWR	Unit	Reflection coefficient			Negative	Positive	Max
Noise Source=	1.1	-	0.047619048		Uncertain NS-DUT IN=	0.0831192	0.08233132	0.0831192
DUT Input=	1.5	-	0.2		Uncertain NS-NFA=	0.11898665	0.11737867	0.11898665
DUT Output=	1.5	-	0.2		Uncertain DUT OUT-NFA=	0.51108209	0.48257359	0.51108209
Instrument=	1.8	-	0.285714286					
System Uncertainty								
Uncertainties		Unit						
Instrument NF=	0.02	dB	*1		Uncertain NF12=	0.19842503		
Gain Uncertainty=	0.07	dB	*3		Uncertain NF2=	0.21532109		
Noise Source ENR=	0.18	dB	(Amplifiers Only)*2		Uncertain G1=	0.55798117		
Noise Source ENR=	0.18	dB	(Receivers Only)*2		Uncertain ENR=	0.18		
					Total Uncertainty =	0.28348851	dB	

*1 : Instrument NF Uncertainty
Analysis Time : Auto. <+/-0.034dB
*2 : Noise Source/ENR Uncertainty
Uncertainty is +/- .18 dB (NC346 series)
*3 : Gain Uncertainty
Gain is defined by the following. So, Gain Uncertainty is effected by "Linearity Error" of Spectrum Analyzer.
Gain=(N'2-N'1)/'(N2-N1)
*Support scope
This sheet is applicable to MS269xA-017/117. and MS2830A-017/117.

Figure6-3. Example of input to Uncertainty Calculator

Microsoft Excel Worksheet

The Uncertainty Calculator has been put in this application note as embedded files.

7. Summary

This Application Note explains the basic principles of NF measurement and some notes on measurement. To measure NF accurately, it is important to understand the measurement principles and to use the most appropriate measurement method.

Anritsu's MS269xA-017/MS2840A-017/MS2830A-017 Noise Figure Measurement Function is the ideal platform supporting designers requiring NF measurements.

Anritsu

Specifications are subject to change without notice.

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