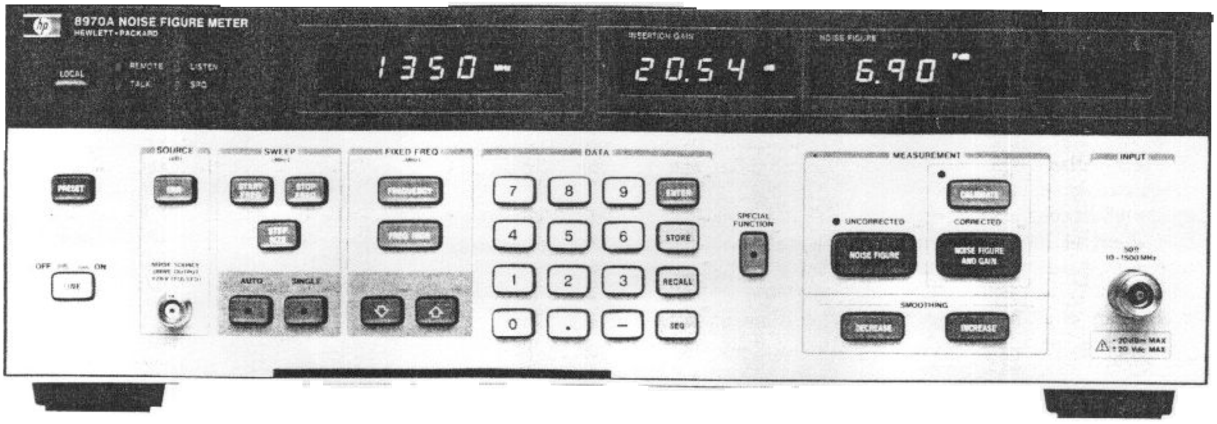
NOISE FIGURE METER

Automatic Noise Figure Meter, Noise Sources

Models 8970A, 346A/B/C

- Accurate and simple, swept or CW measurements.
- Automatic operation, 10 MHz—26.5 GHz.
- Second stage correction.
- Display of both noise figure and gain.
- Calibrated display on oscilloscope or recorder.
- Powerful special function enhancements.



HP 8970A

HP 8970A Noise Figure Meter

With the HP 8970A automatic noise figure meter, accurate and repeatable noise figure measurements are now easy. RF and microwave (with an external local oscillator) measurements from 10 MHz to at least 26.5 GHz are equally simple; any IF between 10 and 1500 MHz may be used. The ENR (Excess Noise Ratio) calibration table of the noise source may be stored in the HP 8970A, and a properly interpolated value is automatically used at each frequency. Automatic second stage correction makes accurate noise figure readings possible even for low gain devices. The HP 8970A's dynamic range allows it to measure either gain up to at least 40 dB (higher in some cases) or loss to −20 dB, with no external attenuation or amplification required.

Microprocessor and Controller Functions

The HP 8970A takes the mystery out of noise figure measurement. It uses a microprocessor to make the myriad calculations and corrections necessary for truly accurate, convenient and flexible noise figure measurement. The HP 8970A also acts as a controller to external HP-IB local oscillators (such as the HP 8673 synthesized signal generator or HP 8350 sweep oscillator) so that swept, broad-band microwave measurements of amplifiers, mixers, and transistors are essentially as simple as RF measurements.

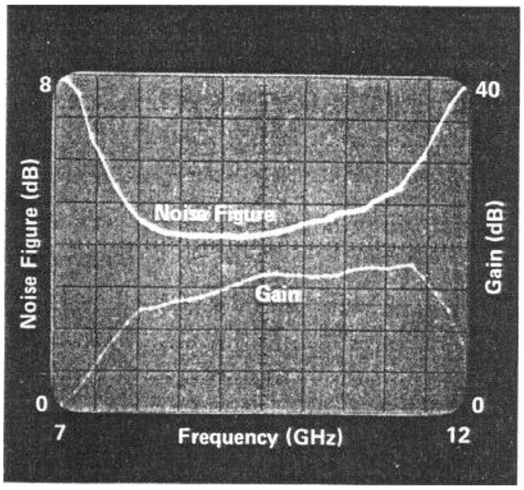
In addition to acting as controller for an HP-IB local oscillator at microwave frequencies, the HP 8970A is fully programmable. Virtually all front panel buttons and functions are accessible over HP-IB, which is Hewlett-Packard's enhanced implementation of IEEE-488.

Simple Calibration and Second Stage Correction

Accuracy is greatly enhanced because the HP 8970A measures its own noise figure (and that of the rest of the measurement system) at up to 81 points. It stores this information, interpolates if necessary, and corrects for it to remove second stage (measurement system) effects. The 8970A also measures the gain of the device under test (DUT).

Display

The HP 8970A has an LED digital front panel display. For swept display of noise figure and gain on an oscilloscope, or x-y recorder, rear panel BNC connectors are available. Either display mode is easily and accurately scaled from the HP 8970A from the front panel to any resolution desired. The swept oscilloscope display allows the design engineer to optimize his DUT in real time for both corrected noise figure and gain. The noise figure display is easily changed from noise figure to effective noise temperature (T_e) if desired, or Y factor.

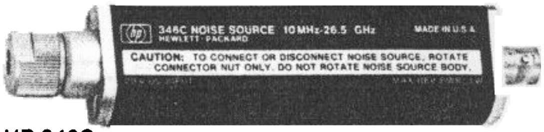


Typical oscilloscope display of amplifier.

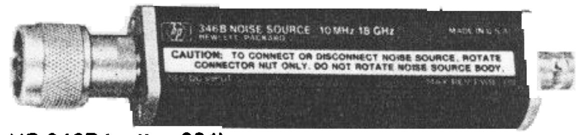
Front Panel and Special Functions

The HP 8970A front panel buttons control the number entry, calibration, and measurement functions. STORE, RECALL, and SEQ buttons allow up to 9 front panel settings to be stored and sequenced automatically or manually to save set-up time. Smoothing INCREASE and DECREASE buttons are used to average up to 512 readings before display, to eliminate flicker and increase accuracy.

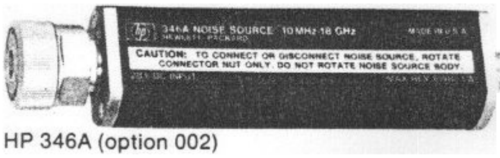
The simple front panel control of the HP 8970A satisfies many noise figure measurement needs. In addition, for those who may need even greater measurement power, there are more than 150 special functions that are easily selected via a numerical code and the SP button. Two examples are hot-cold measurements and automatic compensation for losses at the input of the DUT. One special function is a catalog that quickly indicates the current special function status. Three pull-out cards serve as a mini-reference manual to the instrument, including most of the special functions, the HP-IB formats and codes, and typical measurement setups. A complete set of service-oriented special functions can also be accessed.



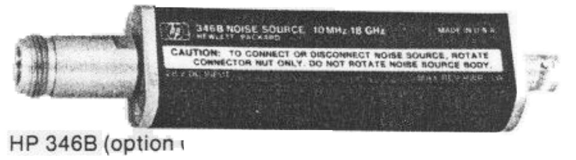
HP 346C



HP 346B (option 001)



HP 346A (option 002)



HP 346B (option

Noise Figure Measurement Repeatability and Accuracy

A very troublesome noise figure measurement problem is repeatability. For example, a vendor's system may not measure the same noise figure as his customer's. This is much less of a problem with the HP 8970A. Using randomly selected HP 8970As, HP 346Bs, mixers, and local oscillators, superimposed plots of a single DUT are routinely within 0.1 dB of each other.

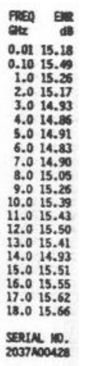
The HP 8970A internal circuitry is so accurate and linear that instrumentation uncertainty is less than ±0.1 dB. With the ±0.1 dB ENR uncertainty of the HP 346B at most frequencies, and the uncertainties due to mismatch, total root-sum-square measurement uncertainties of less than ±0.25 are easily attainable.

HP 346A/B/C Broadband Noise Sources

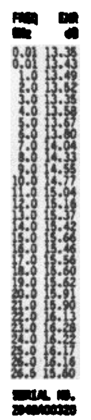
The ideal companion to the HP 8970A is the HP 346 family of noise sources. These noise sources, covering the microwave frequency range up to 26.5 GHz as well as the UHF and IF ranges, make it unnecessary to maintain a different noise source for each frequency band. Each source has individually calibrated values of ENR at cardinal frequencies printed on its label (see illustration) for easy loading into the HP 8970A. The low SWR of each noise source reduces a major source of measurement uncertainty—re-reflections of test signals. The variety of connectors available reduces the need for degrading accuracy with connector adapters.

The HP 346 family of noise sources are designed for a broad range of measurement applications. The HP 346C covers the broadest frequency range, 10 MHz to 26.5 GHz. The HP 346B has a high excess noise ratio, low SWR, and a variety of connectors to make it a general purpose noise source. The HP 346A is especially designed for accurately characterizing the noise figure of DUTs which do not include an isolator at the input, such as GaAsFETs and many UHF amplifiers. Without an isolator such devices can change gain during the noise figure measurement and thereby cause large errors in measuring noise figure. The HP 346A has a very small change in reflection coefficient (<0.01) from ON to OFF to minimize the gain changes. The ENR is large enough (~5.2 dB) to accurately measure noise figures of low noise GaAsFETs and UHF amplifiers.

HP 346A



HP 346B



HP 346C

Example lables of 346 Noise Sources

HP 346 Partial Specifications

(See technical data sheet for complete specifications.)

Frequency range: 10 MHz to 18 GHz for HP 346A/B; 10 MHz to 26.5 GHz for HP 346C.

Excess noise ratio (ENR) limits: HP 346A: 4.5 to 6.5 dB
HP 346B: 14 to 16 dB
HP 346C: 12 to 16 dB (10 MHz to 12 GHz) and 14 to 17 dB (12.0 to 26.5 GHz).

Maximum SWR (reflection coefficient) on and off:

HP 346A/B: 10 to 30 MHz — 1.3 (0.13)
30 to 5000 MHz — 1.15 (0.07)
5 to 18 GHz — 1.25 (0.11).

HP 346C: 10 MHz to 18 GHz — 1.25 (0.11)
18 to 26.5 GHz — 1.35 (0.15).

Power required: 28± 1 Vdc.

Dimensions: 140 H x 21 W x 30 mm D (5.5" x 0.8 x 1.2").

Weight: net, 0.108 kg (3.5 oz). Shipping, 0.5 kg (1 lb).

8970A Partial Specifications

(See technical data sheet for complete specifications.)

Noise figure measurement range: 0 to 30 dB.

Noise figure instrumentation uncertainty: ±0.1 dB for 0 to 55°C.

Noise figure resolution: 0.01 dB (0.001 dB over HP-IB).

Gain measurement range: −20 to at least 40 dB.

Gain instrumentation uncertainty: ±0.2 dB.

Gain resolution: 0.01 dB (0.001 dB over HP-IB).

Frequency range: tunable from 10 to 1500 MHz.

Tuning accuracy: (from 10 to 40°C) ± (1 MHz + 0.01 × freq.), 6 MHz maximum.

Frequency resolution: 1 MHz.

Noise figure: (for input power levels below −60 dBm) <7 dB + 0.003 dB/MHz.

Maximum operating input power: −10 dBm.

Maximum net external gain: 80 dB between noise source and HP 8970A RF input.

Noise source drive: 28.0 ±0.1 volt.

HP-IB capability: SH1, AH1, T5, L4, SR1, RL1, PP0, DC1, DT1, C1, C3, C28, E1.

Operating temperature: 0°C to 55°C.

Storage temperature: −55°C to 75°C.

Power: 100, 120, 220, or 240 V (+5, −10%); 48-66 Hz; 150 VA maximum.

Dimensions: 146 H x 425 W x 476 mm D (5.75" x 16.8" x 18.8").

Weight: net, 15.5 kg (34 lb). Shipping, 18.5 kg (40 lb).

Ordering Information

	Price
HP 8970A Noise Figure Meter	$10,300
Option 907: Front panel handle kit	add $43
Option 908: Rack mounting flange kit	add $25
Option 909: Both options 907 and 908	add $65
Option 910: Extra operating and service manual	add $25
HP 346A Noise Source	$1,500
HP 346B Noise Source	$1,400
HP 346C Noise Source	$1,900
Option 001 (HP 346A/B only): Type N (male) connector	N/C
Option 002 (HP 346A/B only): APC-7 connector	Add $25
Option 004 (HP 346A/B only): Type N (female) connector	N/C

Noise Figure

Modern receiving systems must often process very weak signals, and noise added by the receiving system components often determines whether or not an input signal can be processed properly. Noise figure is the figure of merit used to express how well a system and its components can process weak signals. It expresses the degradation in the S/N ratio as the signal passes through the system. Noise figure is unique and universal; it may be determined for transistors, amplifiers, mixers and entire systems. Considering the S/N ratio, it is often more economical to reduce the noise figure of the receiving system components than it is to increase the signal by increasing transmitted power or antenna gain.

Noise figure may also be expressed as the ratio of total output noise power (at a source temperature of 290K) compared to the output noise power if there were no noise added by the device under test (DUT), that is, a noise-free DUT. Consider the representation of the noise power at the output of a DUT vs. the temperature of the source impedance at the DUT input.

$$N_p = N_a + kGBT_s$$

Figure 1 is a graph of the equation. In the equation, N_a is the noise added by the DUT, k is Boltzmann's constant, G is the gain of the DUT, B is bandwidth in Hz, and T_s is the temperature of the source termination in Kelvins. Thermal agitation energy of the source impedance causes movement of the free-charge in that impedance. Energy of the moving charge that occurs within the bandwidth of the DUT masquerades as input signal, gets processed by the DUT, and contributes to power output. At absolute zero, there is no thermal energy transferred from the source impedance and the only power at the output is noise added by the DUT, N_a. As the source temperature increases, the power output increases in accordance with the gain-bandwidth product and with Boltzman's constant (which can be throught of as a conversion factor between two expressions for energy — kelvin temperature and joules). Noise figure is concerned with the behavior of the DUT compared to a noise-free DUT for a source temperature of 290K as shown in Figure 1. Noise figure is often expressed in dB by

$$F(dB) = 10 \log F$$

Effective Input Noise Temperature — (T_e)

Another figure of merit, the effective input noise temperature T_e, gives the noise performance without reference to a standard source temperature (290K). It is therefore commonly used for satellite system work where source temperatures are usually much lower than 290K. Once again the DUT output is compared to the output if no noise were added by the DUT (Figure 2). T_e is the source temperature necessary for the source of the noise-free DUT to produce the same output noise power as the added noise of the actual DUT. For convenience, the DUT may be modeled as a noise-free DUT with an extra source impedance at temperature T_e.

Noise Figure Measurement

Noise figure meters measure two points along the straight-line for the DUT (Figure 3), and then display the corresponding noise figure. The two source temperatures correspond to the noise source being turned on (for T_h) and off (for T_c). The cold temperature of

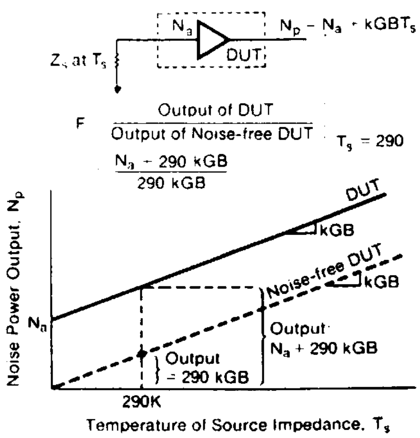


Figure 1. Available noise power and noise figure.

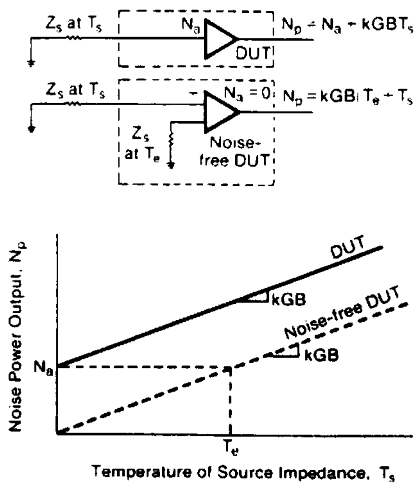


Figure 2. Available noise power & effective input noise temperature.

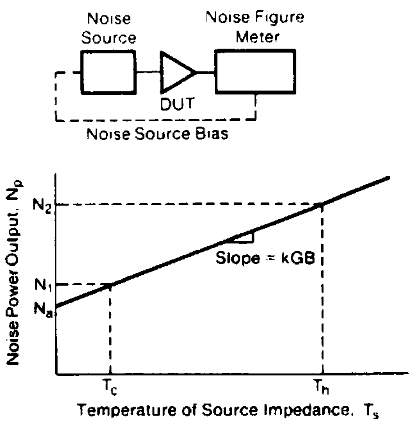


Figure 3. Available noise power and noise figure measurement.

a noise source usually corresponds to the ambient temperature. The hot temperature of a noise source is specified indirectly by its excess noise ratio (ENR), which is given by

$$ENR\ 10 \log \frac{T_h - 290}{290}$$

Before the microprocessor was employed in noise figure meters, several simplifying assumptions had to be made about the noise measurements for the analog circuits of the noise figure meter to display the noise figure. Increasing the measurement accuracy meant backing out the effect of those assumptions with a myriad of calculations and often further measurements. Assumptions commonly made included that T_c was equal to 290K, that T_h was constant at all frequencies, and that the added noise of the measurement system had a negligible effect on the measurement result.

A modern, microprocessor-controlled noise figure meter, the HP 8970A, eliminated those assumptions. It allows variable values of the T_c and it uses a stored table of ENR values at 20 or more frequencies for the particular noise source being used. The noise figure meter automatically interpolates among the stored ENR values for the proper value at each measurement frequency. Through system calibration, the HP 8970A measures the noise contribution of the measurement equipment and sets a gain reference. It can then correct for the noise figure of the measurement system and calculate and display the noise figure and gain of the DUT alone.

The microprocessor also adds a lot of needed conveniences. Examples include the display of effective input noise temperature, T_e, or of noise figure, simultaneous gain measurement, and correction of measurement results for adapter loss.

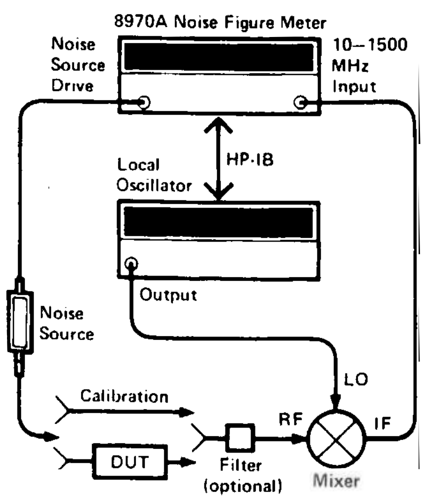


Figure 4. Swept microwave amplifier measurement.

10 MHz to 26.5 GHz Noise Figure Measurement

The HP 8970A can be tuned or swept anywhere between 10 and 1500 MHz. For testing devices and components with output frequencies above 1500 MHz, down conversion to the 10 to 1500 MHz range is necessary (see Figure 4). For measurements on amplifiers from 2 to 26.5 GHz, adding a suitable, commercially available, double-balanced mixer and a suitable LO (such as the HP 8672, 8673, 8340, or 8350) to the HP 8970A and its companion HP 346 series noise sources is all that is necessary. (For mixer and receiver measurement, see Product Note 8970A-1 mentioned below.) Since most low-noise LO's do not extend below 2 GHz, a different technique is often required from 1.5 to 2 GHz (single sideband, discussed in the next section). Through system calibration, the HP 8970A corrects for the noise contribution of the mixer, LO, and the HP 8970A. In Figure 4, the HP 8970A sends frequency commands over the interface bus (HP-IB) to tune the LO across the frequency band of interest. Thus, no external controller is necessary for error-corrected, swept, microwave measurements.

Single Sideband vs. Double Sideband

When an ordinary mixer is used in the setup of Figure 4, all measurements are double sideband. (LO/Noise-source mixing provides two bands, upper and lower sideband, that will convert to the IF). Since the self-calibration and measurement are both double sideband, the HP 8970A will display the correct noise figure and gain. For double sideband measurement, it is best to have a low IF, since the measurement is like an average of upper and lower sideband values.

If double sideband measurement is inappropriate, such as when the DUT response varies rapidly with frequency or in the 1.5 to 2 GHz range mentioned above, a single sideband measurement must be made. For these cases a high IF is best, so that the unwanted sideband may be easily filtered.

For 1.5 to 2 GHz amplifier measurements, for example, one method is to fix the LO to a proper frequency (such as 2.4 GHz), sweep the HP 8970A input (such as from 900 to 400 MHz), and the lower test sideband will sweep from 1.5 to 2 GHz. The upper sideband (sweeping from 2.8 to 3.3 GHz) may be filtered easily (an HP 360C works well). Another method uses a swept LO and an appropriate high fixed IF, with the HP 8970A controlling the external LO. In either case, the HP 8970A displays the measurement frequency during the sweep (1.5 to 2 GHz) and the microprocessor takes care of all of the control chores automatically.

Noise Figure Measurement Applications

Hewlett-Packard's noise figure measurement equipment is exceptional in a variety of applications. It exhibits the following benefits in these applications.

Amplifiers: 1) Simultaneous noise figure and gain measurement, 2) Results automatically corrected for ENR variations, ambient temperature, and mixer, LO, and IF noise contributions, 3) Real-time, swept, corrected output to oscilloscope for easy tuning (display is digitally stored), 4) Automatic control of an external LO for measurements above 1500 MHz without a separate computer.

Transistors: the above benefits, plus: 1) Easy real-time tuning for best noise figure and gain, 2) Real-time tuning to actual transistor F_{min} without second stage effects, 3) Easy single-sideband measurement (high HP 8970A IF makes filtering easy), 4) Low mismatch effects (the HP 346A features virtually identical impedance for T_h and T_c), 5) Easy to program for automatic systems.

Receivers and mixers: 1) Simultaneous measurement of gain (conversion loss) and noise figure, 2) Tunable and swept IF from 10 to 1500 MHz, 3) No external IF gain needed, 4) Automatic ENR correction, even for broadband sweeps, 5) Effects of LO power, IF power, and IF frequency changes on noise figure are easily observed, 6) Easy to program.

Literature

Product Note 8970A-1, Applications and Operation of the 8970A Noise Figure Meter, describes the HP 8970A and many of its applications in more detail. It is both an introduction to the HP 8970A and a summary reference manual.

Product Note 8350A-7, Microwave Noise Figure Measurements Using the 8350A Sweep Oscillator with the 8970A Noise Figure Meter, describes measurements with this popular combination of equipment.

Programming Note 8970A/HP 85-1, Introductory Operating Guide for the 8970A Noise Figure Meter with the HP-85 Personal Computer, shows the ease of programming the noise figure meter, local oscillator, and computer for automatic system using BASIC.

Application Note 57-1, Fundamentals of RF and Microwave Noise Figure Measurements, explains the theory behind noise figure and its measurement. This note includes an extensive glossary of noise related terms.