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Additional Conveniences for Noise Figure Measurements

ABOUT a year ago an article* here described a new instrument for measuring the noise figure of microwave receiving systems and of components such as i-f strips and mixers. The described Noise Figure Meter was characterized by its ability to make measurements rapidly and automatically, by an improved measuring approach, and by high stability provided by a multi-stage AGC system. The Meter also provided such conveniences as an output for monitoring gain variations in the device under test as well as an output for recording measurements on a wideband basis. The basic measuring instrument was complemented by noise sources of refined design which provided standard-level white-noise outputs at microwave and i-f frequencies.

ADDITIONAL I-F FREQUENCIES

Since its announcement, this equipment has become widely used in the field. This use, in turn, has brought into view a need for noise-figure instrumentation for systems using i-f frequencies other than the 30 and 60 megacycles that the Meter accommodated. A variation of the parent instrument has therefore been designed—one that accommodates any four desired i-f frequencies in the range from 38 to 200 megacycles in addition to 30 megacycles. The parent instrument is also presently available for use with any two desired i-f frequencies in the range between 10 and 60 megacycles.

ADDITIONAL NOISE SOURCES

To complement the widened range of usable i-f frequencies, the i-f noise source is now available with outputs centered at any two desired frequencies between 10 and 60 megacycles. This source has selectable output impedances to match common i-f impedances from 50 to 400 ohms. A second VHF source has also been

*Howard C. Poulter, *An Automatic Noise Figure Meter for Improving Microwave Device Performance;* B. M. Oliver, *Noise Figure and Its Measurement,* Hewlett-Packard Journal, Vol. 9, No. 5, Jan., 1958. These articles contain discussions of the basic measuring equipment and measurement considerations which are supplemented by the information in the present issue.

Fig. 2 (above). *New Model 343A diode type VHF Noise Source provides flat noise output up to 600 megacycles without tuning for convenient testing of 50-ohm input receivers. Internal matching network compensates for transit-time effects in diode.*

Fig. 1 (left). *Supplemental model of -hp- Noise Figure Meter can be used with any four specified i-f's from 38 to 200 megacycles in addition to a fifth i-f of 30 megacycles. Text describes how NFM's can be used for measuring very low NF's where cooled loads are used.*

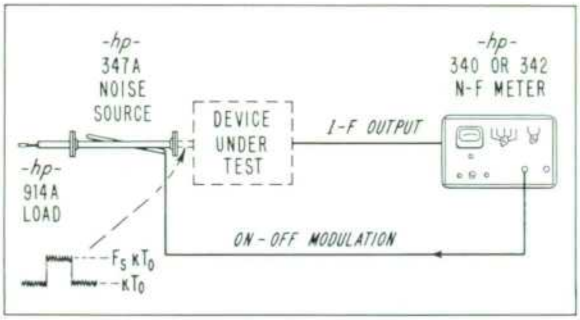

Fig. 3. *Typical equipment arrangement for measuring NF of conventional microwave receivers.*

designed with an output flat up to 600 megacycles. This source has a 50-ohm output to permit it to be used as an r-f source for receivers operating up to 600 megacycles.

BASIS OF MEASUREMENT

To make a measurement of noise figure on a device such as a receiver, the Noise Figure Meter interconnects with the receiver as indicated in Fig. 3. Here, the noise source, which generates white noise at a known power level, is connected to the receiver r-f or i-f input, as determined by the measurement to be made. The Noise Figure Meter square-waves the noise source on and off so that the input to the receiver consists of pulses of noise at a level many times that of normal thermal noise alternating with pulses of noise at thermal level from the termination behind the noise source.

An output is then taken from a high-level i-f stage in the receiver and applied to the Noise Figure Meter. The action of the NFM is to further amplify the "source on" pulses to a predetermined value through AGC action, and to apply the proportionately-amplified "source off" pulses to a metering circuit. At the receiver output the "source on" pulses thus consist of the amplified noise from the noise source added to the receiver-generated noise. Symbolically, the "source on" pulse N_2 has the value

$$N_2 = F_s\, kT \int G(f)\, df + (F-1)\, kT \int G(f)\, df$$

where F_s is the noise factor of the noise source (a standard value as discussed later), $(F-1)$ is the receiver's excess noise ratio, i.e., the factor by which receiver-generated noise exceeds amplified noise from a normal input termination, $kT = -114$ dbm/megacycle, and $G(f)$ is the gain-bandwidth product.

The "source off" pulses N_1 at the receiver ouput consist of amplified thermal noise from the passive termination at the receiver input added to receiver-generated noise or, symbolically

$$N_1 = kT \int G(f)\, df + (F-1)\, kT \int G(f)\, df$$

The ratio of these values is then

$$\frac{N_2}{N_1} = \frac{F_s\, kT \int G(f)\, df + (F-1)\, kT \int G(f)\, df}{kT \int G(f)\, df + (F-1)\, kT \int G(f)\, df} = 1 + \frac{F_s - 1}{F}$$

Noise factor F then equals

$$F = \frac{F_s - 1}{\dfrac{N_2}{N_1} - 1}$$

or, in db

$$NF\ (db) = 10 \log (F_s - 1) - 10 \log \left(\frac{N_2}{N_1} - 1\right)$$

Since F_s is known and N_2 is always amplified to a constant value, the only variable in the right-hand side of the expression is N_1. Because a square-law detector is used, the meter deflection is proportional to N_1 so that the instrument can be calibrated directly in Noise Figure.

The quantity $(F_s - 1)$ is the excess noise figure of the noise source. The *-hp-* noise sources are arranged to present one of two excess noise figures: 15.2 db for the microwave sources and 5.2 db for the lower-frequency sources. The meter in the NFM's contains two scales for these two values. On these scales Noise Figure is presented directly in db.

The measuring principle described above results in an instrument that makes measurements automatically and rapidly once the initial connections have been made, and is so simple in use that it can be operated by non-technical personnel. Provided the noise spectra of the receiver-generated noise are flat over the receiver i-f, as is normally the case, the measurements remain accurate, regardless of whether the receiver i-f bandwidth is wider or narrower* than the 1-megacycle bandwidth of the NFM. Anomalous conditions such as receiver preselector mistuning can, of course, affect the measurement and must be avoided.

Additional information on basic operation and measuring techniques is given in the original discussion (see footnote, first page), while additional information on very low NF measurements is given later herein.

VHF NOISE SOURCE DEVELOPMENTS

The new Model 343A VHF Noise Source provides an essentially constant output noise power over the range from 10 to 600 megacycles for use in testing 50-ohm systems. Like the Model 345 30/60 megacycle I-F Source, the VHF Source consists basically of a temperature-limited diode operating with a suitable matching network, which results in a source that requires no tuning. The output impedance of the new VHF source is fixed, however, where that of the Model 345 i-f source is selectable.

All of the noise sources, microwave or VHF (diode), are powered directly from the Noise Figure Meter, separate connectors being provided for the microwave and diode sources. The new Model 343A 10-to-600 megacycle source requires slightly different power from the Model 345 30/60 megacycle source, however, and in order to make it possible to operate either diode source from the same instrument a 5-pin rather than a 3-pin connector is used on the new 10-to-600 megacycle source. Both of the newer Noise Figure Meters (Model 340B two-frequency Meter and Model 342A five-frequency Meter) are also provided with a 5-pin panel connector for connecting to the diode sources. Originally, the Model 340A two-frequency meter and the Model 345A 30/60 megacycle diode source were provided with 3-pin connectors, but if desired these can readily

*In the few cases where the receiver i-f may be substantially narrower than 1 mc, *i.e.*, by a factor of 5 or more, the effective sensitivity of the NFM must be operationally treated as being reduced by this same factor for the measurements to remain accurate.

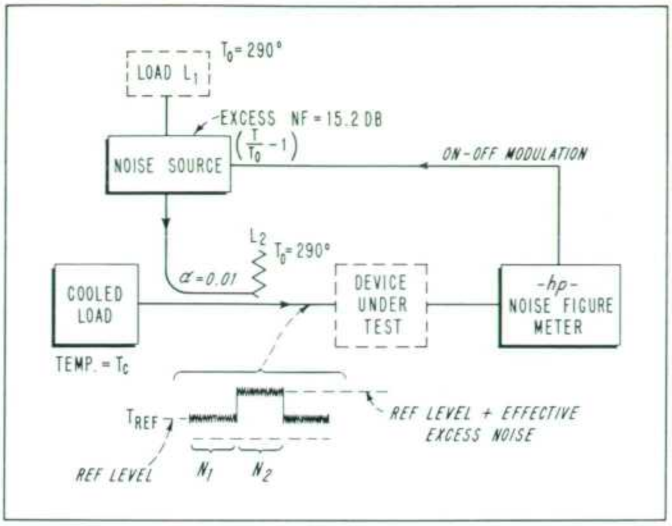

Fig. 4. *Typical equipment arrangement for measuring low NF's, as described in text. Cooled load and noise source outputs are coupled to receiver input by directional coupler. Load L_1 shown in dashed lines can be replaced with a short in this arrangement when an -hp- multihole directional coupler is used, since load L_2, which is a very high quality load contained internally in the coupler, will generate the thermal level required for the off condition of the noise source.*

be changed in the field to the 5-pin connector. Details of the 5-pin connector replacement are presented in a service letter available on request. The 30/60 megacycle source with the 5-pin connector bears the number Model 345B.

VERY LOW N-F MEASUREMENTS

The calibrations on the microwave scale of the NFM's extend down to 3 db, i.e., to the value where the noise generated by a device under test (as referred to its input) is equal to the thermal noise produced by the device's input load when at room temperature. This range permits straightforward measurements of typical microwave devices such as receivers, mixers, traveling-wave tubes, etc., which seldom have NF's lower than about 6 db. Noise figures lower than about 6 db are normally obtained only with such devices as masers and parametric amplifiers, where the techniques used to measure noise figure involve using thermally cooled loads in order to have a lower noise level for reference. Here, too, however, the -hp- NFM's are valuable in making the measurement, since the use of a cooled load has the effect of expanding the lower part of the NFM scale as well as extending the scale to lower values. The following describes the relation of the NFM readings obtained using a cooled load to a standard noise figure as referred to a room temperature load.

Fig. 4 indicates a setup wherein a cooled load is used with the NFM equipment. It is common to cool the load with liquid nitrogen, which has a boiling point of 78°K. The microwave noise source is connected to the receiver or other device under test through a 20 db directional coupler, which lowers the effective noise temperature of the source by the coupling factor of the coupler. For low noise-figure measurements, this means the effective level of the source and the level to be measured will be of the same order. Resulting readings will then be in the mid-portion of the NFM scale, where accuracy is highest. When the readings are obtained, of course, it will be necessary to apply a correction factor to take into account the altered noise level of the noise source. It will also be necessary to translate the value then obtained to noise figure at room temperature so as to conform to standard notation.

As discussed earlier, the NFM will indicate a value

$$\text{NF in db} = \text{Excess noise ratio in db} - 10\log\left(\frac{N_2}{N_1}-1\right) \quad (1)$$

For the setup of Fig. 4, however, the excess noise ratio in this expression will be referred to a noise temperature which is a combination of the temperature of the cooled load and the temperature of the room-temperature load L_1. The value of this reference temperature will be

$$\begin{aligned} T_{ref} &= T_c\ (1-\alpha)\ +\alpha T_o \\ &= T_c + \alpha(T_o - T_c) \end{aligned} \quad (2)$$

where T_c is the temperature of the cooled load, T_o is the temperature of the room-temperature load L_1, and α is the coupling factor of the directional coupler.

During the time the noise source is on, the receiver input will see a combination of the temperature of the cooled load and the "hot" temperature of the noise source. This combination will be

$$T_{on} = T_c\ (1-\alpha) + \alpha(T_o + T_{excess})$$

where T_{excess} is the rated excess noise temperature of the noise source referred to 290°.

The excess noise ratio, as it appears at the receiver input, can now be formed with respect to the reference temperature in (2) and will be

$$\begin{aligned} \text{Excess noise ratio} &= \frac{T_{on} - T_{ref}}{T_{ref}} \\ &= \frac{\alpha T_{excess}}{T_{ref}} \end{aligned} \quad (3)$$

where αT_{excess} is the effective excess noise ratio of the noise source, as seen at the receiver input. For the -hp- argon noise sources, T_{excess} has the value $33.1T_o$. Using a 20 db directional coupler ($\alpha = 0.01$) and the -hp- argon noise

Fig. 5. *-hp- Model 340B NFM and Model 345B I-F Noise Source (right) can be used with any two specified i-f's between 10 and 60 megacycles. Model 345 Source has selectable output impedances to match common i-f inputs between 50 and 400 ohms.*

sources, the excess noise ratio in (3) for the measurement becomes

$$\frac{33.1 \times 290^\circ \times 0.01}{T_{ref}} = \frac{96^\circ}{T_{ref}}$$

If T_c has a value of 78°K as the result of cooling with liquid nitrogen, T_{ref} in (2) above becomes

$$T_{ref} = 78^\circ + 0.01 \ (290^\circ - 78^\circ) = 80^+ \ ^\circ K.$$

Therefore, the excess noise ratio for the measurement is $96^\circ/80^\circ = 0.8$ db. The operating equation (1) for the NFM in this setup is then

$$F_{T_{ref}} = 0.8 \text{ db} - 10 \log \left(\frac{N_2}{N_1} - 1\right)$$

and this reading is referred to 80°K.

Since the 0.8 db effective excess noise ratio for the measurement is more nearly equal to the 5.2 db value for which the NFM's diode scale is calibrated than to the value for the microwave scale, it will be convenient to make readings on the NFM's diode scale by subtracting 4.4 db from the value read thereon. This corrected value can then be translated to standard noise figure at room temperature through the expression

$$F_o = 1 + (F_c - 1) \frac{290^\circ}{80^\circ}$$

or by using the chart published previously (see footnote first page).

COUPLER AND LOAD WAVEGUIDE LOSS

A consideration not included in the foregoing is the effect of dissipative losses in the waveguide system connecting the various loads to the input of the measured device. The effect of such losses will be to lower the effective noise temperature of the load and to add a noise temperature component associated with the loss. Usually, the waveguide loss will be small, but losses as low as 0.1 db will introduce a factor that should be corrected when best accuracy is desired. The corrected noise temperature of a noise source, as viewed from the output end of a waveguide at a temperature T_x, is

$$T_{eff} = (T \text{ source})\ (A) + T_x\ (1\text{-}A)$$

where A is the transmission of the waveguide (less than unity)*. Where it is desired to correct for transmission loss, the noise temperatures of the cooled load and of the room temperature load L_1 should be modified by this expression, as it will be seen that a loss of 0.1 db in the transmission system at room temperature will modify the apparent temperature of the sources by some 10%. The effective excess noise temperature $\alpha\, T_{excess}$ must also be modified since it will be referred to a somewhat different reference temperature, while loss in its waveguide path will alter its effective value.

*In practice, a temperature gradient may exist along the guide and this fact will cause both the waveguide unit-length noise contribution as well as the unit-length loss to increase as one travels from the cooled load to the receiver. A good first-order correction can be made, however, by postulating a linear temperature rise with distance along the guide up to the point where the guide becomes within a few degrees of room temperature and integrating the unit values obtained.

FUTURE DEVELOPMENTS

Two current programs may be of special interest to those concerned with systems planning and performance measurements. One program, which is approaching the completion of the laboratory stage, has resulted in a fully transistorized version of the Noise Figure Meter which is expected to meet military specifications for environmental conditions.

The second program is expected to achieve a noise source in the S-band region with coaxial output, where the present microwave sources all have waveguide outputs.

Details of these equipments will be published here as they become finalized.

ACKNOWLEDGMENT

Many of the developments described herein were carried out under Dr. Howard C. Poulter, project leader, presently on assignment as a Sloan Fellow in the Stanford Program in Executive Management.

—*Marco R. Negrete*

SPECIFICATIONS
-hp- MODEL 342A
NOISE FIGURE METER

Noise Figure Range: VHF or IF Noise Source: 0 to 15 db; indication to infinity. Waveguide Noise Source: 3 to 30 db; indication to infinity.

Accuracy: Noise Diode Scale: ±½ db, 0 to 15 db. Gas Tube Scale: ±½ db, 10 to 25 db; ±1 db, 3 to 10 db and 25 to 30 db.

Input Frequency: 30, 60, 70, 105 and 200 mc, selected by a switch. (30 mc and any four frequencies between 38 and 200 mc available on special order.)

Bandwidth: 1 mc minimum.

Input: −60 to −10 dbm (noise source on). Corresponds to gain between noise source and 342A of: VHF or IF Noise Source: Approximately 50 to 100 db. Waveguide Noise Source: Approximately 40 to 90 db.

Input Impedance: 50 ohms nominal.

AGC Output: Nominally 0 to −6 volts from rear binding posts.

Recorder Output: Maximum of 1 ma into a maximum of 2000 ohms to operate a recorder or remote meter.

Power Input: 115/230 volts ±10%, 50-60 cps, 185 to 435 watts depending on noise sources connected and line voltage.

Power Output: Will operate 343A VHF Noise Source, 345B IF Noise Source, or any 347A Waveguide Noise Source.

Dimensions: Cabinet Mount: 20½ in. wide, 12½ in high, 14½ in. deep. Rack Mount: 19 in. wide, 10½ in. high, 13½ in. deep behind panel.

Weight: Cabinet Mount: Net 40 lbs., shipping 63 lbs. Rack Mount: Net 34 lbs., shipping 74 lbs.

Accessories Furnished: 340A-16A, 6 ft. cable for connecting *-hp-* 342A to any *-hp-* 347A Waveguide Noise Source.

Price: Noise Figure Meter, Model 342A Cabinet Mount: $815.00; Model 342AR Rack Mount: $800.00. For operation at 30 mc and one to four special frequencies from 38 to 200 mc add $25.00; specify special frequencies and standard frequencies retained.

MODEL 340B NOISE FIGURE METER

Same as 342A except as listed below.

Input Frequency: 30 or 60 mc selected by switch. Frequencies between 10 and 60 mc on special order.

Price: Noise Figure Meter, Model 340B Cabinet Mount: $715.00; Model 340BR Rack Mount: $700.00. For operation at one or two frequencies between 10 and 60 mc add $25.00; specify frequencies.

MODEL 343A VHF NOISE SOURCE

Frequency Range: 10 to 600 mc.

Excess Noise: 5.2 db ±0.1 db, 10 to 200 mc
5.2 db ±0.25 db, 200 to 400 mc
5.2 db ±0.35 db, 400 to 600 mc

Source Impedance: 50 ohms, swr less than 1.1, 10 to 400 mc; less than 1.3, 400 to 600 mc.

Noise Generator: Temperature limited diode.

Input Power: Supplied by *-hp-* 340B or 342A Noise Figure Meter.

Dimensions: 2¾ in. wide, 2½ in. high, 5 in. deep.

Weight: Net ¾ lb., shipping 2 lbs.

Price: Model 343A VHF Noise Source $75.00.

MODEL 345B IF NOISE SOURCE

Spectrum Center: 30 or 60 mc, selected by switch.

Excess Noise: 5.2 db into conjugate load.

Source Impedance: 50, 100, 200, or 400 ohms ±4% as selected by switch. Less than 1μμf shunt capacitance.

Noise Generator: Temperature limited diode.

Input Power: Supplied by *-hp-* 340B or 342A Noise Figure Meter.

Dimensions: 2¾ in. wide, 2½ in. high, 5 in. deep.

Weight: Net ¾ lb., shipping 2 lbs.

Price: Model 345B IF Noise Source, 30/60 mc: $75.00. For operation at any two frequencies between 10 and 60 mc add $25.00.

MODEL 347A WAVEGUIDE NOISE SOURCE

	S347A	G347A	J347A	H347A	X347A	P347A
Frequency Range, kmc:	2.60-3.95	3.95-5.85	5.3-8.2	7.05-10.0	8.2-12.4	12.4-18.0
Excess Noise, db*:	15.2 ±.5	15.2 ±.5	15.2 ±.5	15.2 ±.5	15.2 ±.5	15.2 ±.5
Noise Generator:	Argon discharge tube	Argon discharge tube	Argon discharge tube	Argon discharge tube	Argon discharge tube	Argon discharge tube
SWR** ON:	1.2 maximum, less than 1.1 average.					
OFF:	1.2 maximum, less than 1.1 average.					
Input Power	Supplied by *-hp-* model 340A/B or *-hp-* Model 342A Noise Figure Meter.					
Approximate Length (in.):	22½	19	19	16	14¾	14¾
Weight Net:	7 lbs.	3.5 lbs.	3 lbs.	2 lbs.	2 lbs.	2 lbs.
Shipping:	17 lbs.	13 lbs.	12 lbs.	6 lbs.	4 lbs.	4 lbs.
Fits Waveguide Size (in.):	3x1.5	2x1	1½x¾	1¼x⅝	1x½	.702x.391
Price:	$190.00	$190.00	$180.00	$180.00	$180.00	$180.00

* Includes factor for insertion loss.
** Source terminated in a well-matched load such as that provided by the Hewlett-Packard 914 series.

All prices f.o.b. Palo Alto, California.
Data subject to change without notice.