



## An Automatic Noise Figure Meter For Improving Microwave Device Performance

**B**ECAUSE it compares actual output noise power with the output noise power of a theoretically ideal device, the quantity noise figure is generally used to specify in a fundamental manner the quality of amplification

SEE ALSO:  
"Noise figure and  
its measurement,"  
p. 3

provided in microwave devices such as receivers, forward-wave and backward-wave tubes, etc. In addition to being a fundamental property, however, noise figure can also be much faster and easier to measure than equivalent measurements with signal generators. From a performance standpoint, improving receiver noise figure in a system such as a radar is just as valuable and tremendously more economical than increasing transmitter power an equivalent amount. A 5 db improvement in receiver noise figure, for example, is equivalent to increasing transmitter power by 3:1.

To enable noise figure to be measured simply and accurately and with economy of equip-

ment, a noise figure meter has been developed which both measures noise figure automatically and has a number of important conveniences not previously available. The meter can be used with either 30- or 60-megacycle i-f receivers and has a primary measuring range from 3 to 30 db.

The instrument is designed to operate with gas discharge noise sources for measurements on microwave devices and with temperature-limited diodes for measurements on i-f amplifiers. A diode source and a series of high-performance waveguide noise sources have been developed for these purposes. Supply voltages for the sources are provided by the instrument.

The instrument provides two additional outputs for simplifying various measurements. One of these is a voltage that increases with the gain of the device being measured and is thus valuable in such work as adjusting twt's to the optimum gain region during the NF measurement.

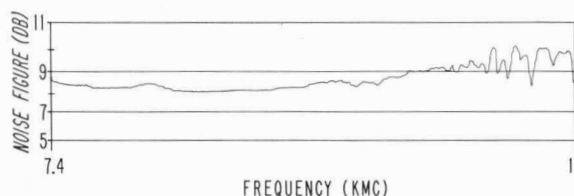
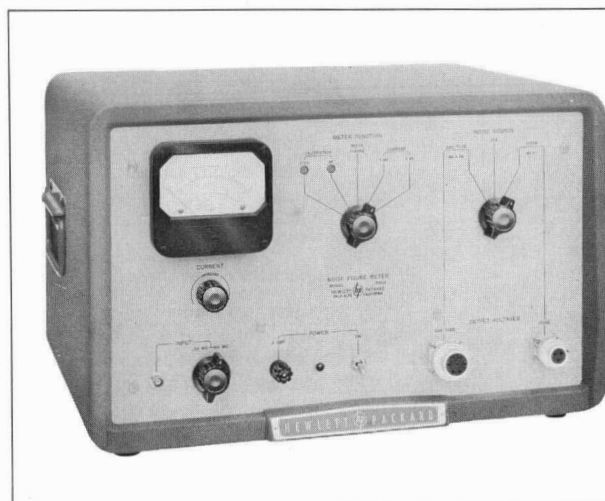


Fig. 2. Recorded swept NF measurement made of X-band low-noise twt at General Electric Microwave Laboratory, Palo Alto, using swept measurement techniques described in text.

Fig. 1. (at left) -hp- Model 340A Noise Figure Meter automatically measures noise figure of microwave receivers and amplifiers over 3 - 30 db range and of 30- or 60-megacycle i-f systems over 0 - 15 db range. Waveguide and i-f noise sources have also been designed for these uses. NF meter outputs are provided for recording swept measurements and for indicating variations in gain of devices such as twt's.

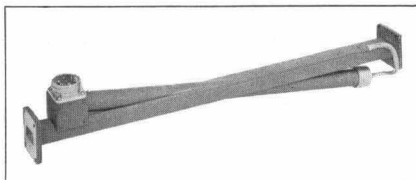


Fig. 3. Waveguide noise sources provide excess NF of 15.2 db and are designed to achieve a good match in both fired and off conditions.

The second output makes available the current in the indicating meter so that permanent records can be made of swept measurements.

Provision is also made for measuring

noise figure manually by means of an external attenuator.

#### WAVEGUIDE NOISE SOURCES

Particular care has been taken in the design of the waveguide noise sources to achieve a high order of performance in the several respects that are important to the accuracy of noise figure measurements. One of these considerations is the impedance that the source offers not only in the fired condition but in the cold condition as well, since cold mismatch is as important as fired mismatch to the accuracy of measurement. The 8.2 - 12.4 kmc source is rated as having a maximum reflection

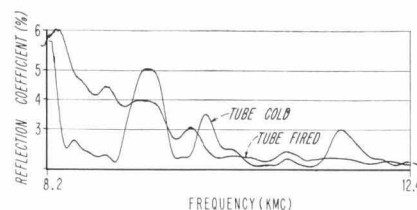


Fig. 4. Typical off and fired reflection coefficient of 8.2 - 12.4 kmc noise source. Mismatch rating of sources is based on continuous-frequency measurement so that no peaks that can introduce additional error in NF measurement are overlooked.

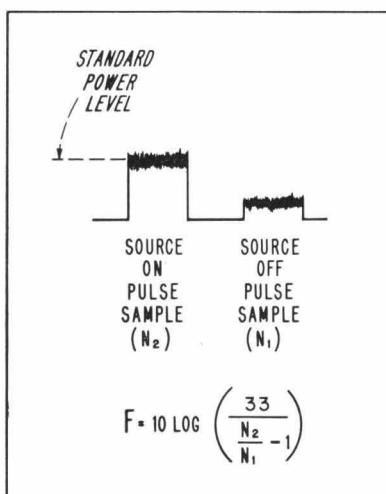
The basic operating principle of the new Noise Figure Meter is indicated in the accompanying illustrations in terms of a typical measurement on a receiver. The receiver input is connected to the waveguide noise source, which is automatically on-off modulated by the NF meter, while an i-f output is taken from a convenient point in the receiver ahead of the second detector and applied to the noise figure meter. During "on" times, the receiver output thus consists of the amplified power from the noise source plus the amplified receiver noise (second illustration). During "off" times, the receiver output consists only of the amplified receiver and input termination noise. The NF meter is arranged with a gating provision such that it alternately samples the "on" and "off" noise levels as obtained from the receiver i-f amplifier. The ratio of these two noise powers gives the noise figure from the expression

$$F(\text{db}) = 10 \log \left[ \frac{F_s - 1}{\frac{N_2}{N_1} - 1} \right] \quad (1)$$

(see Oliver, p 4, herein).

Internally, the instrument takes the ratio of the two powers by fixing the

#### PRINCIPLE OF OPERATION



Sketch illustrating measuring principle of Model 340A. Receiver output when noise source is on is amplified to standard value. Resulting amplified receiver output power when source is off is then a measure of noise figure.

level of the "on" power level  $N_2$  through AGC action and measuring the "off" level  $N_1$  in the meter. Since  $(F_s - 1)$  is the excess noise figure of the source when fired (15.2 db for the gas tubes used), while  $N_2$  is the

receiver output power level with the source on and is always amplified to a standard value by the AVC action of the NF meter, expression (1) can be re-written

$$F(\text{db}) = 15.2 \text{ db} - 10 \log \left( \frac{K}{N_1} - 1 \right) \quad (2)$$

The only variable now is  $N_1$ , the metered value. The meter can thus be calibrated to display noise figure directly.\*

I-f noise figure measurements are made in a similar manner, except that the diode noise source is used and is applied directly to the input of the receiver i-f amplifier. The i-f noise source is arranged with a 10 db lower excess noise figure (i.e., 5.2 db) in keeping with typical i-f requirements. A 10 db lower calibration is therefore provided on the meter face for use with this source.

\*The same result is obtained if the oft-cited noise figure definition

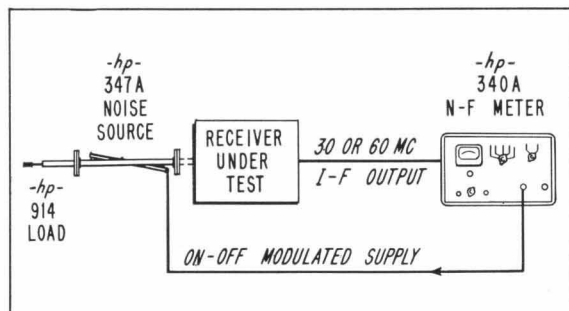
$$\frac{\text{Signal power input}}{\text{Thermal noise power input}} \div \frac{\text{Signal power output}}{\text{Noise power output}}$$

is used.  $\frac{\text{Signal power input}}{\text{Thermal noise input}}$  is always

15.2 db. Signal power output  $S_o$  is equal to (total power output  $N_2$ ) - (noise power output  $N_1$ ) or  $S_o = N_2 - N_1$ .  $N_2$  is then amplified to a standard value in the NF Meter and is thus constant, so the expression becomes

$$F(\text{db}) = 15.2 \text{ db} - 10 \log \frac{K - N_1}{N_1} \\ = 15.2 \text{ db} - 10 \log \frac{K}{N_1} - 1$$

which is identical with (2) above.



Typical equipment arrangement for using Model 340A to measure receiver NF.

coefficient magnitude of 9%, a rating that covers both cold and fired mismatch (Fig. 4) and is based on continuous-frequency measurements so that no peaks are overlooked. This is a consideration of some importance because such peaks are often overlooked and where they exist cause measurement error limits to be increased by  $\frac{1}{2}$  to 1 db.

#### PULSE CHARACTERISTICS

Since gas discharge tubes of the type used have a power output build-up and decay that is a large fraction of a millisecond, a special arrangement is used

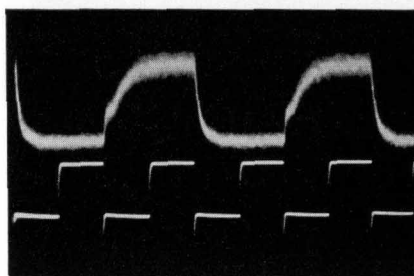


Fig. 5. Oscilloscope showing relation of gas tube noise build-up to gating of amplifier in NF Meter. Gating occurs during last half of source on and off times to insure essentially complete build-up and de-ionization before noise power samples are taken by NF meter.

in pulsing the sources to keep these effects from influencing the measurement. The elements of this arrangement are indicated in Fig. 5. The gas tube is square-wave modulated at a 500 cps rate to give a nominal pulse width of 1 millisecond. The NF meter amplifier, however, is gated on for  $\frac{1}{2}$  millisecond intervals which are arranged to occur during the last half of the "on" and "off" intervals. This enables the gas tube noise to build up to its steady-state value before its level is sampled by the NF Meter and also allows essen-

(Continued on p. 5)

## NOISE FIGURE AND ITS MEASUREMENT

**A**N ideal receiver or amplifier would add no noise over and above that delivered, along with the signal, by the source to which its input is connected. With the possible exception, however, of parametric amplifiers and of recent devices capable of operation at very low temperature, additional noise in considerable amounts is contributed by the first stages of the receiver. To compare actual to ideal devices, the terms noise factor and noise figure are usually used<sup>1</sup>. The noise factor of an amplifier is the ratio of the actual output noise power available to that which would be available if the amplifier merely amplified the thermal noise of the source.

The noise figure is this power ratio expressed in db.

Let

$S_i(f)$  = signal power at frequency  $f$ , available from source into conjugate match

$S_o(f)$  = signal power at frequency  $f$ , available at output into conjugate match

$G(f)$  = available power gain =  $S_o(f)/S_i(f)$

$N$  = actual output noise power, available into conjugate match

Since the noise power per cycle available from a source at absolute temperature  $T$  is  $kT$ , where  $k$  is Boltzmann's constant, the noise power  $N_o$  available at the output of an ideal receiver would

be

$$N_o = kT \int_0^\infty G(f) df$$

Thus the noise factor is

$$F = \frac{N}{N_o} = \frac{N}{kT \int_0^\infty G(f) df} \quad (1)$$

and the noise figure is  $10 \log_{10} F^*$ .

#### SOURCE TEMPERATURE CONSIDERATIONS

The noise figure as defined by (1) involves the temperature of the source. Because a majority of sources are at or near room temperature, it has become customary to take  $T = 290^\circ \text{K}$ , which makes  $kT = 4 \times 10^{-21}$  watts per cycle. If a receiver is operated with a source at this temperature, and if thermal noise alone corrupts the signal available from this source, then the noise figure gives directly the degradation in signal-to-noise ratio produced by excess noise in the receiver. In many important cases receivers are operated under these conditions, so that an improvement of 3 db in noise figure produces as much improvement in system performance as doubling the transmitter power.

In other important applications the receiver may be operated from a source whose effective temperature is much less than  $290^\circ \text{K}$ . In many radar, scatter propagation, and radio astronomy applications, for example, the atmos-

phere may be highly transparent at the frequencies used. The antenna then faces the average temperature of interstellar space which is only a few degrees Kelvin. If the ohmic loss of the antenna and transmission lines is negligible, this low temperature value will be the effective source temperature. A decrease of 3 db in the noise figure referred to the actual source temperature will still improve the signal-to-noise ratio 3 db, but this may represent only a small decrease in noise figure referred to  $290^\circ \text{K}$ . It is obviously of importance to be able to relate noise figures referred to different source temperatures.

Equation (1) may be rewritten

$$N = kT \int_0^\infty G(f) df + (F-1)kT \int_0^\infty G(f) df$$

Amplified thermal noise from source      Excess noise due to sources in receiver

Thus, if  $F_o$  is the noise factor for a source at  $T_o$ , the available output power at temperature  $T$  will be

$$N = kT \int_0^\infty G(f) df + (F_o-1)kT_o \int_0^\infty G(f) df$$

and the noise factor for the new temperature is

$$F = 1 + (F_o-1) \frac{T_o}{T} \quad (2)$$

Equation (2) shows that if the noise factor is 1 (0 db) at any reference temperature, it will be the same for all source temperatures: an ideal receiver is ideal regardless of the source. Fig. 1 is a conversion chart for noise figures based on Equation (2).

\*Eq. (1) is Friis' equations (3) and (5) combined. It is felt to be more fundamental than his Eq. (4) which is usually cited as the definition of noise factor, inasmuch as it does not involve a somewhat arbitrary signal, nor the definition of an input noise fictitiously band-limited.

<sup>1</sup>H. T. Friis: "Noise Figure of Radio Receivers," Proc. IRE, Vol. 32, No. 7, July, 1944; pp 419-422.

# NOISE FIGURE AND ITS MEASUREMENT

(Continued from p. 3)

## MEASUREMENT OF NOISE FIGURE

The noise figure of a receiver may be measured using a signal generator and an output power (square law) detector. For the measurement to be meaningful, the signal generator must present the source impedance for which the receiver is designed. With the signal generator output at zero the power out of the receiver will be from (1)

$$N = FkT \int_0^\infty G(f) df$$

If the generator is now tuned to  $f_0$ , where the receiver power gain is  $G(f_0)$ , the total output power will be

$$P = FkT \int_0^\infty G(f) df + SG(f_0)$$

where  $S$  is the available signal power. If  $S$  is now adjusted so that  $P = 2N$ , i.e., so that the reading of the square law detector doubles, then

$$FkT \int_0^\infty G(f) df = SG(f_0)$$

$$F = \frac{S}{kT \frac{1}{G(f_0)} \int_0^\infty G(f) df} = \frac{S}{kTB} \quad (3)$$

where

$$B = \frac{1}{G(f_0)} \int_0^\infty G(f) df = \text{effective noise bandwidth}$$

In order to find  $B$  it is usually necessary to measure the power gain as a function of frequency and integrate the curve graphically. This method has major disadvantages, however, since it is time-consuming and since  $G(f)$  may vary with different conditions of adjustment. A further disadvantage is the difficulty of determining  $S$  with the required accuracy at the low levels involved.

Another method of measuring noise figure which overcomes these drawbacks and which lends itself to dynamic, continuous display of the noise figure uses a standard white noise source in place of the signal generator. At i-f frequencies the temperature-limited diode is a suitable source, while at microwave frequencies the argon discharge tube in a waveguide is accurate and reliable<sup>2</sup>. Both of these sources give a

noise spectrum which is flat with frequency and which has known power. The method here is to compare the noise power out of the receiver with the noise source off ( $N_1$ ) and on ( $N_2$ ). With the source off we have from (1)

$$N_1 = \underbrace{kT \int_0^\infty G(f) df}_{\text{Amplified source noise (thermal only)}} + \underbrace{(F-1)kT \int_0^\infty G(f) df}_{\text{Amplified excess receiver noise}}$$

If now  $F_s$  = ratio of available power per cycle from noise source to  $kT$ ,

then with the noise source on

$$N_2 = F_s kT \int_0^\infty G(f) df + (F-1)kT \int_0^\infty G(f) df$$

Taking the ratio:

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

from which  $F = \frac{F_s - 1}{\frac{N_2}{N_1} - 1}$  (4)

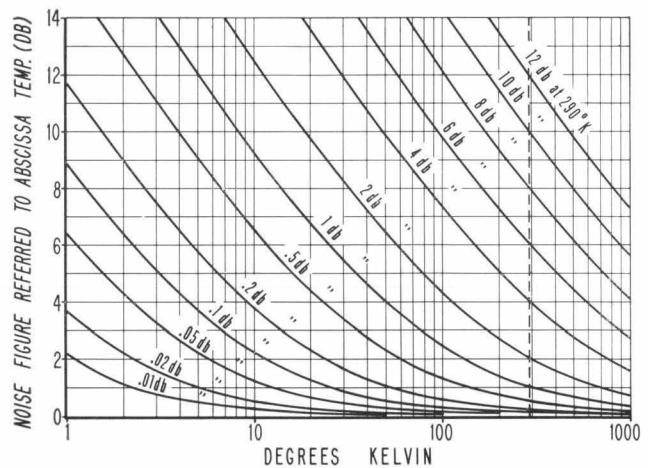
This is a much simpler equation than (3) since the receiver power gain is

calculated and is  $1 + \frac{1}{2} \frac{q}{kT} IR$  where

$q$  is the charge of the electron,  $I$  is the d-c current and  $R$  is the load resistor.

In the noise-source method of noise figure measurement it is extremely important that the noise source present the same impedance to the receiver when turned on as when turned off. Otherwise variations of receiver output noise with source impedance will affect  $N_2/N_1$  and cause errors in noise figure as computed from (4) even though the actual noise figure may not be a rapid function of source impedance. Of course it is also desirable that this impedance be either the normal impedance seen by the receiver (if the noise figure under operating conditions is desired) or some standard reference value (if the measurement is for comparison purposes). One way to allow the receiver to see very nearly its normal operating source impedance at all times is to couple the noise source to the input through a directional coupler of sufficient loss.

Fig. 1. Chart for converting noise figures when device is operated from source at room temperature to noise figure when another source temperature is used. A noise figure of 2 db with room temperature source, for example, becomes a noise figure of 4.3 db when device is operated from a 100°K source.



not involved: all we need to know is the factor  $F_s$  for the source and the observed output power ratio  $N_2/N_1$ .

For the argon tube sources,  $F_s$  has been accurately measured by comparison against hot loads. There is some dispersion between the reported figures but a value of  $F_s - 1 = 33$  (i.e., 10 log  $(F_s - 1) = 15.2$  db) is typical. For temperature limited diodes,  $F_s$  can be

## EFFECT OF SPURIOUS RESPONSES

It frequently happens in superheterodyne receivers, particularly in the microwave region, that appreciable transmission exists at the image frequency. In fact, unless special steps are taken to prevent it,  $G(f)$  may be as large at the image response as it is in the desired band. In this event, an apparent discrepancy may result between the noise

<sup>2</sup>W. W. Mumford: "A Broad-Band Microwave Noise Source," B.S.T.J., Vol. 28, No. 4, Oct., 1949; pp 608-618.



figure as measured with a signal generator and with a wide band noise source. This arises because in the signal generator method one is likely to integrate  $G(f)$  over the desired band only, while noise is actually contributed by the image band also. With a wide band noise source, the added noise will also appear in both bands. The result is that the "noise figure" as measured with the noise source method may be as much as 3 db lower than the "noise figure" as measured using the signal generator method if one image is excluded in computing

$$\frac{1}{G(f_0)} \int G(f) df.$$

The question is: which figure is "right"? Of course, if the limits of the integral are indeed taken as zero and infinity as we have written up to this point, the two methods will always agree. The performance of the system, however, will correspond to the higher noise figure. For this reason, North<sup>3</sup> has advocated that spurious responses be deliberately omitted in computing

$$\int G(f) df$$

and a considerable precedent has been established for this procedure. Under this viewpoint the "true" noise figure can be obtained by the signal generator method while the noise source method gives a reading which must be corrected.

An equally valid viewpoint is to regard the spurious response, or responses, as simply part of the total passband of the receiver. There is then no discrepancy, both methods yielding the lower noise figure. The loss in system performance due to the spurious responses is now attributed to failure to match the system bandwidth to the signal spectrum. That is, the receiver has transmission where no signal power is present. It is just as if there were no "spurious" responses and the bandwidth were made twice as wide as necessary.

This latter viewpoint has the advantage that it more clearly associates noise figure with excess noise power spectral density at r-f frequencies and assigns the blame for degraded performance where blame is due. After all, if the mixer and i-f amplifier were abso-

lutely noise free, we would like to think of the noise figure as being 0 db, whereas the first viewpoint would result in a 3 db figure for the assumed case of one equal-strength image response. In a typical microwave receiver employing a crystal mixer without pre-amplification, failure to eliminate the noise in the image band will usually degrade the performance by only about 1 db or less. This is because the mixer noise is low and the conversion loss causes the i-f noise to dominate. On the other hand, the properly matched signal for such a receiver is one in which *coherent* signal power is supplied in both r-f response bands. As compared with the usual mode of operation (signal in only one response band), 3 db less signal power is required for the same output, and the performance corresponds to the noise figure as measured with a wide band noise source.

#### OVERALL PERFORMANCE AND NOISE FIGURE

Noise figure is only one of the factors which determine the threshold of operation of a system. As indicated in the previous section, another equally important factor is the matching of the receiver filter characteristic to the signal spectrum. What is an optimum match here depends on the later detection processes which are used. If the system is pulse operated, for example, and if what is desired out of the detector is the greatest ratio of peak signal to RMS noise, then as is well known, the filter characteristic of the receiver should be the conjugate of the signal (pulse) spectrum. On the other hand, if the receiver is supposed to give the best least square approximation to the signal the filter should have the transmission

$$A(\omega) = \frac{S(\omega)}{S(\omega) + N(\omega)}$$

where  $S$  and  $N$  are the signal and total noise power spectra at the input.

It would be nice to be able to assert unequivocally that it is possible to optimize band shape and noise figure independently. As the last example shows, however, this is not always true since the magnitude if not the shape of  $N(\omega)$  depends on the noise figure. Conversely, the realizable noise figure may in certain cases depend on the bandwidth desired since this affects the input impedance levels which may be realized.

As a practical matter, the interaction

is usually not strong and considerable improvement in noise figure may be brought about through proper adjustment of mixer currents, source and load impedances, selection of crystals and/or tubes, etc., without either producing or requiring much bandwidth modification. As a result one may say that a good means of measuring noise figure is a necessary tool in achieving top system performance, but that it does not replace signal generators and other tools needed to check pulse response.

—B. M. Oliver

## NF METER

(Continued from p. 3)

tially complete de-ionization before the "off" level is sampled.

#### OTHER NOISE SOURCE DATA

The waveguide noise sources use a cold-cathode argon-type tube which is rated to have an excess noise figure of 15.2 db. The tolerance on this rating is  $\pm 1/2$  db for most of the tubes used for the various bands, although in the case of the 2.6 - 3.95 kmc tube it is  $15.25 \pm 0.20$  db. As implied by the low value of the mismatch rating cited earlier, care has been taken in the design of

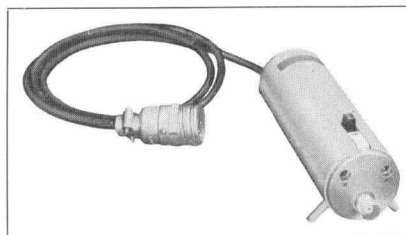


Fig. 6. Noise diode probe has excess NF of 5.2 db and is arranged for use with 30- and 60-mc i-f systems.

the tube mount so that spurious modes arising from the necessity of cutting into the guide are suppressed.

The source is designed to be used with an external termination on the open end. The -hp- Model 914 loads are recommended for this use, since those loads have a VSWR of not more than 1.01. The rating given earlier for the 8.2 - 12.4 kmc mount is predicated on the use of this load.

The use of an external load has the further advantage that it is relatively isolated thermally from the gas tube so that the load's temperature is not

<sup>3</sup>D. O. North: Discussion on "Noise Figure of Radio Receivers", Proc. IRE, Vol. 33, No. 2, Feb., 1945; pp 125-126.

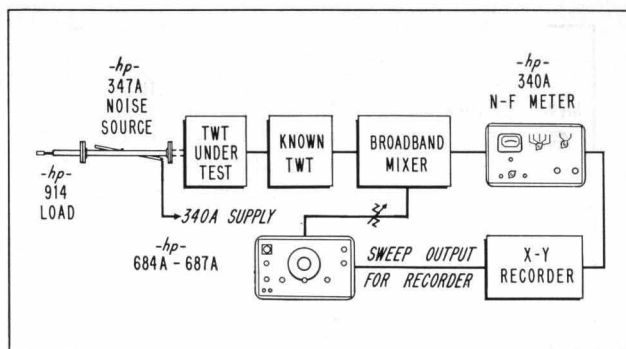


Fig. 8. Setup for making electronically-swept measurements of twt noise figures in permanent-record form using hp- 684A-687A sweep oscillators.

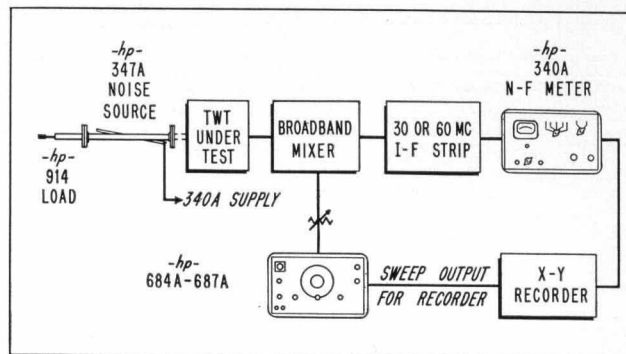


Fig. 9. Alternate method for making electronically-swept permanent-record measurements of twt NF's.

significantly affected by the heat from the tube. This heat is also small, though, since the tube is a cold cathode type with only a 12 watt dissipation.

In addition to the 8.2 - 12.4 kmc source described, waveguide sources for the 2.6 - 3.95, 3.95 - 5.85, 5.3 - 8.2, 7.05 - 10, and 12.4 - 18 kmc ranges will be available in the near future.

#### I-F NOISE SOURCE

The i-f source consists of a type 5722 diode mounted in a convenient probe which is designed to permit short-lead connection to an i-f system. A special feature of the source is that it is arranged to match a variety of i-f impedances from 50 to 400 ohms. This is accomplished by providing the source with special clip-in high-frequency type resistors which are accurate within 1%. A switch on the probe body which selects either 30- or 60-megacycle tuning assures proper noise output over these bands.

The i-f source is designed to provide (and the diode meter scale is calibrated for) an excess noise figure of 5.2 db, 10 db below that of the waveguide source in keeping with the fact that the NF of a typical i-f system is considerably lower than that of an r-f system. Since the diode is also arranged to be flexible as regards source impedance, the diode plate current required will depend on the source impedance used in accordance with the relation  $5.2 \text{ db} = 10 \log 20 I_{\text{diode}} R_{\text{load}} \text{ or } I_{\text{diode}} = 0.166/R_{\text{load}}$ . Diode current can be easily adjusted, because the NF meter is arranged with a special switch position that causes the indicating meter to read diode plate current on a calibrated scale. A panel control is also

provided for adjusting the diode filament power which in turn controls the plate current. The accompanying table shows the proper plate currents for the four load resistors provided with the source.

SOURCE RESISTANCE	DIODE PLATE CURRENT
50 ohms	3.3 ma
100 ohms	1.66 ma
200 ohms	0.83 ma
400 ohms	0.414 ma

The reproduction of the meter face given in Fig. 7 shows the high readability of the current scales provided on the meter.

Current for the diode filament is provided from a regulated source to reduce the effects of line voltage changes on diode plate current.

The diode output is provided at a type BNC plug on the probe nose. Legs are provided on the probe to properly orient the diode according to manufacturer's recommendations, although the tube is operated as such a low filament power level that another orien-

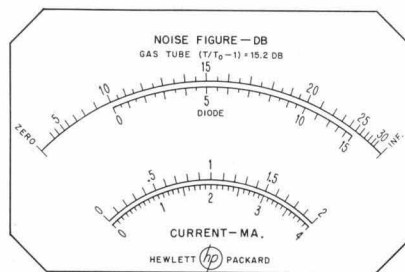


Fig. 7. Approximately half-scale reproduction of Model 340A meter face. Top scale is for waveguide sources, second scale for diode source. Current scales at bottom are for measuring and setting current in sources.

tation is probably not deleterious. The diode is also oriented so that the probe can be held vertically in cases where this is desirable.

The low filament power also implies long diode life. Extrapolation of manufacturer's data shows that tube life should exceed 10,000 hours.

Pulsing of the diode is related to the gating of the 30/60 mc amplifier in the NF Meter in the same way as that of the waveguide sources.

#### SWEPT NF MEASUREMENTS

When a wide-band device such as a tunable microwave receiver or a traveling-wave tube is to be investigated, it is always desirable and usually simple to make NF measurements on a swept basis. Since the Model 340A has a recorder output, permanent records can be made simultaneously with the swept measurement, a valuable feature in both laboratory and production work.

Figs. 8 to 10 indicate equipment arrangements that can be used for such measurements. Fig. 8 is one of several possible arrangements for making swept single-frequency measurements of traveling-wave tubes and one that has the special advantage of electronic sweeping. In Fig. 8 the twt under investigation is followed by a second twt of known noise figure to provide additional amplification ahead of the mixer. This arrangement is useful where the twt's have sufficient gain to mask the effect of the crystal mixer noise figure.

Another usable arrangement is shown in Fig. 9. In this setup the additional twt ahead of the mixer is replaced by additional gain in the form of an i-f strip following the mixer. Such a strip must have a center frequency of 30

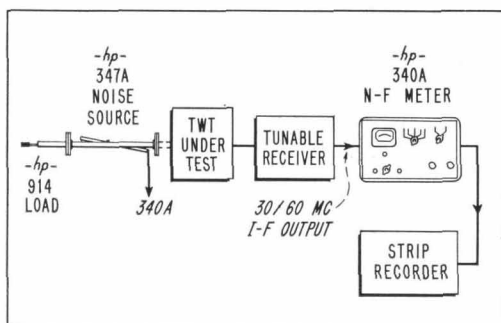


Fig. 10. Setup for measuring twt NF's in permanent-record form using tunable receiver. Same setup except without twt can be used for NF measurements of tunable receivers.

or 60 megacycles to match the internal amplifier of the Model 340A.

It is desirable in these measurements that the noise figure of whatever devices follow the twt being measured be reasonably low, because the noise figure of additional devices adds to that of the device under test according to the

$$\text{relation } N.F. = 10 \log \left[ F + \frac{F_2 - 1}{G_t} \right]$$

where  $F$  and  $F_2$  are the noise figures of the device under test and the following device (amplifier, receiver, etc.) and  $G_t$  is the power gain of the device under test. Thus, if the tested device has high gain and if the noise figures of the following devices are not high, they do not seriously affect the measurement.

If the device under test is immediately followed by a mixer and then by more amplification, it is desirable to expand the above expression to take into account the effect of the mixer and additional amplification. In the expanded expression NF in db equals

$$10 \log \left[ F + \frac{F_{\text{mixer}} - 1}{G_t} + \frac{F_{\text{amp}} - 1}{G_t G_{\text{mixer}}} \right]$$

In this expression  $F_{\text{mixer}}$  is the mixer NF,  $F_{\text{amp}}$  is the NF of the additional amplification, and  $G_{\text{mixer}}$  is the gain (normally less than unity) of the mixer.

The NF of twt's is also commonly measured using a tunable receiver as indicated in Fig. 10. While this arrangement does not have the convenience of the former two methods because the receiver must be tuned by hand over the band of interest, it is nevertheless a practical method and one in which a strip-chart recorder can be used to record the measurement. The noise figure of the receiver should be considered in accordance with the first expression given above, although with a receiver having in the order of a 10 db noise figure and a twt with a gain of 30 db, the correction will be insignificant.

## RECEIVER MEASUREMENTS

In the field of receiver testing instances are known where truly dramatic improvements in receiver performance have been obtained through noise figure measurements. Radar installations, for example, have achieved significant increases in range through noise figure improvement. This is not surprising when it is considered that mixer crystals can readily be damaged by accidental overloads, that duplexer tubes may contribute substantial noise and/or loss ahead of the receiver input, that noisy and lossy joints may be present in the receiver input run, or that LO's become noisy, all of which will deteriorate receiver operating noise figure.

Permanent-record testing of wide-band tunable receivers can be accomplished with the same type of setup indicated previously for twt's. In a tunable receiver, however, and usually in single-channel receivers as well, the matter of image response must be considered.

A receiver that has one or more spurious responses in the band of the noise source will result in a noise figure meter reading that is the same as it would be if the receiver had no such response. This occurs because the receiver will accept both noise source and thermal noise power at the image frequency and will thus not alter the pulse-on to pulse-off ratio at the receiver output over the case

Fig. 12. Setup using 340A to make manual measurements or to measure extra-low NF microwave devices. Setting precision attenuator to 10 db permits readings to be made directly on 0 - 15 db diode scale on 340A meter.

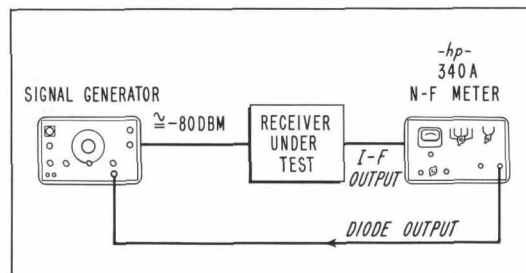


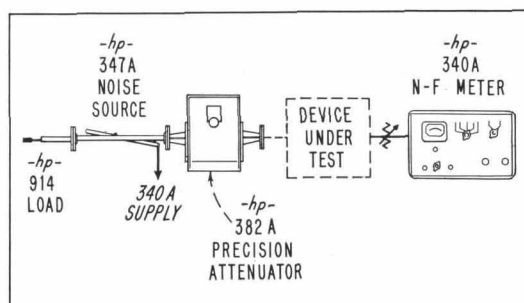
Fig. 11. Setup for optimizing performance of receivers with spurious responses. Readings will be relative but will indicate whether adjustments are improving receiver performance. Most -hp- generators can be suitably modulated directly from diode output on 340A.

where the receiver has only a single band response. Oliver (accompanying article) discusses the various interpretations of this situation and emphasizes that the performance of a receiver with one equal strength image response will correspond to a noise figure typically from approximately 1 to 3 db above that indicated by the meter. It has also been shown by Strum\* that the presence of several spurious responses rarely degrades receiver performance by more than 5 db.

## PERFORMANCE OPTIMIZATION IN SPURIOUS-RESPONSE RECEIVERS

One of the special features of the Model 340A is that it may be used to optimize the performance of receivers with multiple responses. For such work the waveguide noise source is replaced by a signal generator which is square-wave modulated by the noise diode supply of the 340A. The setup is indicated in Fig. 11. The signal generator is typically set for an output in the vicinity of -80 dbm and is tuned to the signal channel of the receiver. A NF meter indication will then be obtained, although it will not be absolute. The necessary adjustments for spurious response reduction can then be made within the receiver to obtain a mini-

\*Peter D. Strum, "A Note on Noise Temperature," IRE Transactions on Microwave Theory and Techniques, July, 1956.



imum reading on the NF Meter. The readings will be relative and are not the receiver noise figure, but they will decrease monotonically with increasing noise performance. A NF measurement with the noise source can then always be made.

#### VERY LOW NF MEASUREMENTS

In the event that a very low noise figure r-f device is to be measured, it is desirable to expand the lower part of the noise figure scale. This can readily be accomplished by inserting a 10 db attenuator between the waveguide noise source and the device being tested. Noise figure can then be read directly from the 0 - 15 db diode scale.

#### MANUAL MEASUREMENT

Provision is also made for "manual" measurement of noise figure by use of an external precision attenuator where desired.

For making manual measurements, a switch is provided at the rear of the Model 340A. Basically, this switch converts the instrument to an indicator. The measurement is then made as indicated in Fig. 12. Initially, the gain of the device is adjusted for a convenient reading (preferably "1" on the upper current scale of the Model 340A) with the noise source off and with the -hp-382A attenuator set at zero. The noise source is then turned on by setting the Model 340A panel switch to the "gas tube" position. This will cause the meter reading to increase. The attenuator is then adjusted so that the meter reading is doubled as read on the linear current scale. Using this procedure noise figures up to 15.2 db can be read and are given by 15.2 db (the excess NF of the source) minus the attenuator reading in db. The range of manual measurement can be extended beyond 15.2 db by reading on-off ratios from the meter current scales without using the attenuator and substituting into the expression

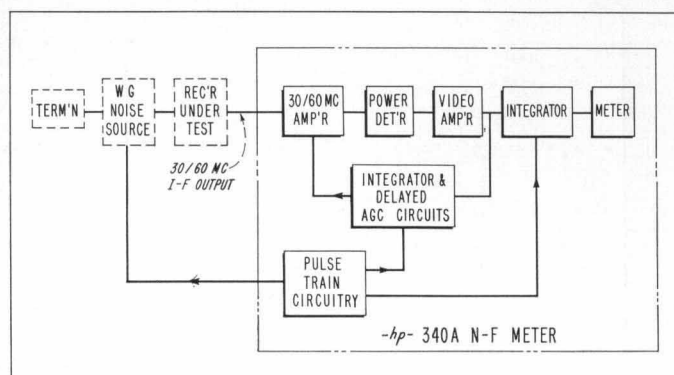
$$N.F. = 15.2 \text{ db} - 10 \text{ LOG} \left( \frac{\text{gas tube on}}{\text{gas tube off}} - 1 \right)$$

where  $\frac{\text{gas tube on}}{\text{gas tube off}}$  is the ratio of the current scale readings. For best readability the "gas tube on" readings should be set with the attenuator at the 340A input to full scale on the current scale.

#### ACKNOWLEDGMENTS

The noise figure meter is produced under a license agreement with the firm of Magnetic AB of Stockholm, Sweden, who conceived the basic plan

Fig. 13. Basic circuit arrangement of Model 340A NF meter. Repetition frequency of pulse trains can be adjusted over approximately  $\pm 10\%$  range to accommodate external systems where desired. AGC and meter current outputs are provided in addition to source supplies.



of the instrument. Special acknowledgment is due Mr. Arne Bernow of that firm who assisted in the development of the final production version of the instrument at the -hp- plant. Apprecia-

tion is also expressed to the General Electric Microwave Laboratory, Palo Alto, for permission to use the curve shown in Fig. 2.

—Howard C. Poulter

#### SPECIFICATIONS -hp- MODEL 340A NOISE FIGURE METER

Frequency Range: Depends on noise source used.

Noise Figure Range:

IF Noise Source: 0 to 15 db, indication to infinity.

Waveguide Noise Source: 3 to 30 db, indication to infinity.

Accuracy (340A only):

Noise Diode Scale:  $\pm \frac{1}{2}$  db, 0 to 15 db.

Gas Tube Scale:  $\pm \frac{1}{2}$  db, 10 to 25 db;  $\pm 1$  db, 3 to 30 db.

Required Receiver or R-F Amplifier Gain:

Approximately 40 db. (Corresponds to a minimum noise input with source on of 220 microvolts into 50 ohms.)

Dynamic Range: 60 db.

Input Frequency: 30 or 60 mc, selected by switch.

Bandwidth: 1 mc minimum.

Input Impedance: 50 ohms nominal.

Recorder Output: Jack at rear provides 1 ma. max. meter current for operating external recorders; 5 kilohm max. external resistance.

AGC Output: Binding posts at rear provide nominal 0 to -10 v AGC voltage for external monitoring.

Power Input: 115/230 volts  $\pm 10\%$ , 50-60 cps, 320 watts.

Power Output: Sufficient to operate -hp-345A IF Noise Source or -hp-347A Waveguide Noise Sources.

Dimensions: Cabinet Mount: 20½" wide, 12½" high, 14½" deep.

Rack Mount: 19" wide, 10½" high, 13½" 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' cable for connecting -hp-340A to any -hp-347A Waveguide Noise Source.

Price: -hp- Model 340A Noise Figure Meter, Cabinet Mount, \$715.00 f.o.b. Palo Alto, California.

-hp- Model 340AR Noise Figure Meter, Rack Mount, \$700.00 f.o.b. Palo Alto, California.

#### -hp- MODEL 345A IF NOISE SOURCE

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

Source Impedance: Depends on internal resistor installed. 50, 100, 200 and 400 ohm interchangeable resistors supplied with instrument.

Current Range: 0.33 to 3.33 milliamps.

Input Power: Supplied by -hp-340A.

Dimensions: 5½" long x 2" diameter.

Weight: 2 lbs.

Price: \$75.00, f.o.b. Palo Alto, California.

#### -hp- MODEL 347A WAVEGUIDE NOISE SOURCES

	S347A	G347A	J347A	H347A	X347A	P347A
Frequency Range	2.60-	3.95-	5.3-	7.05-	8.2-	12.4-
km:	3.95	5.85	8.2	10.0	12.4	18.00
Excess Noise, db:	15.25	15.2	15.2	15.2	15.2	15.2
	$\pm 2$	$\pm 5$	$\pm 5$	$\pm 5$	$\pm 5$	$\pm 5$
Gas Tube Employed:	Bendix TD-38	Bendix TD-39	Bendix TD-39	Bendix TD-40	Bendix TD-41	Bendix TD-42
SWR*: ON:	1.2 maximum, less than 1.1 average					
OFF:	1.2 maximum, less than 1.1 average					
Input Power:	Supplied by -hp-340A					
Approximate Length:	24"	20"	20"	16¾"	14¾"	14¾"
Waveguide Dimension	3" x	2" x	1½" x	1¼" x	1" x	.702" x
Outside:	1.5"	1"	¾"	¾"	½"	.391"
Waveguide Flange:	Cover	Cover	Cover	Cover	Cover	Cover
Price:	\$190.00	\$190.00	\$180.00	\$180.00	\$180.00	\$180.00

\*Source terminated in a well-matched load such as that provided by the -hp-914 series.

All Prices f.o.b. Palo Alto, California

Data subject to change without notice