Errata

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HP References in this Application Note

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APPLICATION NOTE 43

CONTINUOUS MONITORING OF RADAR NOISE FIGURES

I. INTRODUCTION

A. PURPOSE

The purpose of this Application Note is to:

1. Review briefly automatic noise measuring theory.
2. Examine the radar system requirements for integral noise figure meters.
3. Describe the hp 344A Noise Figure Meter.
4. List some of the nominal specifications and ranges of operation which are possible with the hp Model 344A.

B. IMPORTANCE OF NOISE FIGURE

Operating radars require a number of important characteristics for proper operation. Examples are low noise figure and high gain in the receiver. However, high gain does not necessarily imply low noise figure, since noise generation in the first stages effectively reduces the usefulness of subsequent gain. So, low noise figure of a radar is even more important than optimized gain. It represents a knowledge of how well the initial amplification is taking place, where any noise generation is extremely critical. The ability to monitor this figure of merit not only offers a performance check but also assists in maintenance and alignment procedures. With the advent of longer range and more sophisticated radar receivers, noise figure is even more important.

C. BACKGROUND

Hewlett-Packard noise measuring equipment has been in the field for more than two years. Its principle of operation has received wide acceptance because of long term stability and ease of calibration and operation. In general the Model 340B and Model 342A Noise Figure Meters are used in research, development and production applications because of their continuous presentation of noise figure. In such applications, of course, the instrument requires that the system be completely devoted to making the automatic noise figure measurement. There is an increasing demand, however, for automatic noise figure measurements on operating radar systems where perhaps only one tenth of the scan time is allowed for noise sampling. The transistorized hp 344A Noise Figure Meter was developed specifically for these system applications.

D. THEORY

Automatic noise figure measurements depend upon the periodic insertion of an excess noise power into the input of the device under test. Subsequent detection of the noise power in later IF stages of the device results in a pulse train of two power levels. The power ratio of these two levels contains the desired noise figure information. For instance, in the simplified example of Figure 1, the various contributions of noise power to the pulse ratio are shown.

Total noise power output of the device with noise source "ON".

$$N_2 = GKTB + RCVR + EXCESS\ (G)$$

Total noise power output of the device with noise source "OFF".

$$N_1 = GKTB + RCVR$$

Since, $F = \dfrac{RCVR + GKTB}{GKTB}$,

By definition of noise figure

Then, $RCVR = (F - 1)\ GKTB$

Which is noise power output contributed by the RCVR.

Also

$$EXCESS = \left(\frac{T_2 - T}{T}\right) KTB$$

Excess noise power at input where T_2 is fired temperature of excess noise source.

Then the ratio

$$\frac{N_2}{N_1} = \frac{GKTB + RCVR + EXCESS\ (G)}{GKTB + RCVR}$$

or

$$\frac{N_2}{N_1} = \frac{GKTB + (F-1)\ GKTB + \left(\frac{T_2 - T}{T}\right) GKTB}{GKTB + (F-1)\ GKTB}$$

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and

$$F = \frac{\left(\frac{T_2 - T}{T}\right)}{\left(\frac{N_2 - N_1}{N_1}\right)}$$

Note that the gain-bandwidth factor has disappeared.

Finally

$$F_{db} = 10 \log \left(\frac{T_2}{T} - 1\right) - 10 \log \left(\frac{N_2}{N_1} - 1\right)$$

The first term is a known quantity and expressed in db of excess noise ratio. Then, the ratio of N_2/N_1 contains the noise figure information.

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

The specific method of measuring the power ratio between the two pulses (N_2 and N_1) is determined by such considerations as sensitivity required and system complexity. However, the only requirements for basic automatic noise figure measurements are a broadband noise source of known excess noise, a certain amount of gain in the receiving system, and an automatic noise figure meter on the output to synchronously detect and meter the power ratio produced.

The following sections discuss the application of this automatic noise measuring technique to an operating radar system. Specific system requirements and 344A design features are considered with application information for possible uses. In addition, since many variable quantities are involved when a noise figure meter is adapted to a radar system, a list of considerations is included to assure you that the important specifications are being evaluated.

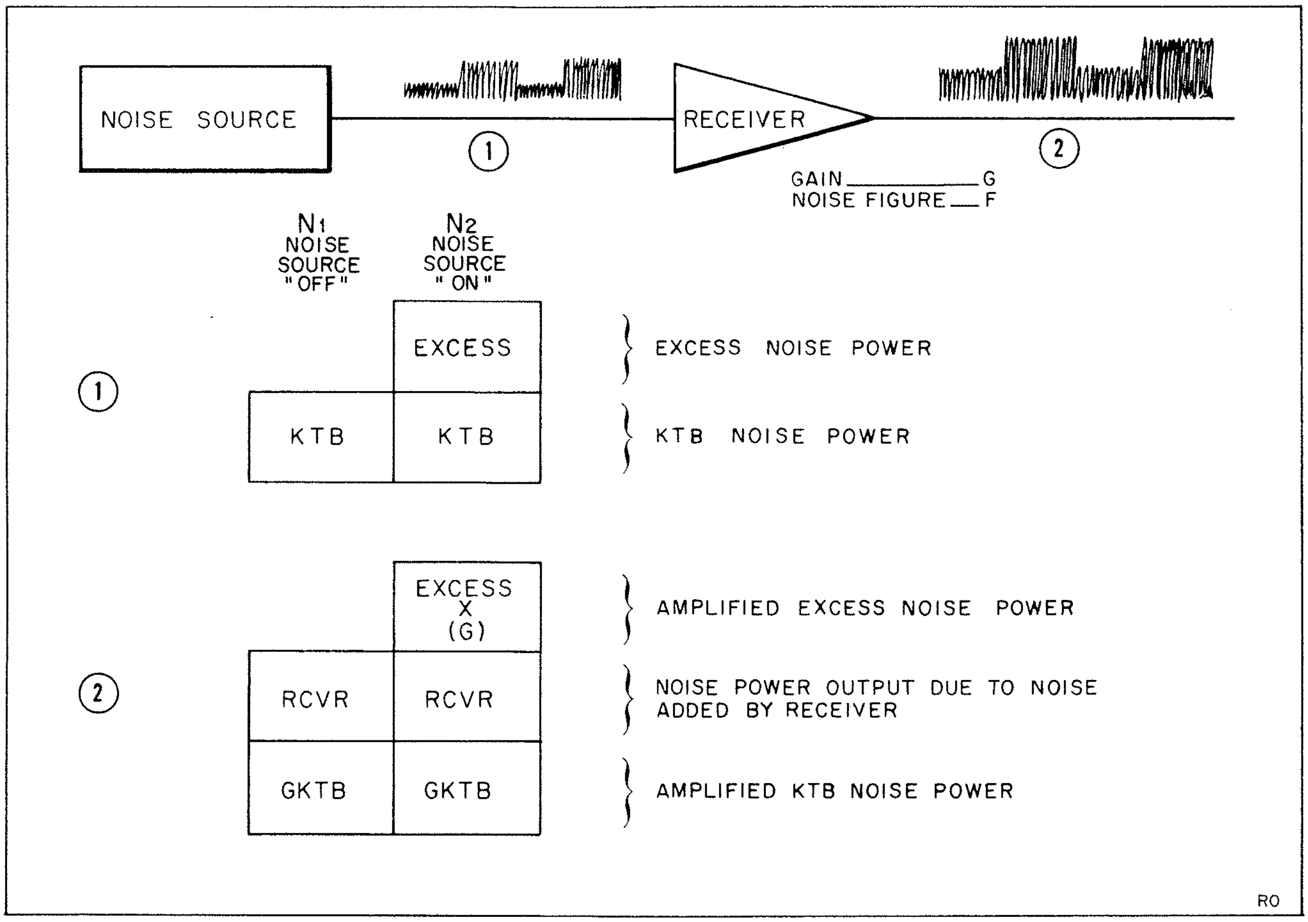

Figure 1. Automatic Noise Figure Measurement of Microwave Device (Composition of Noise Power)

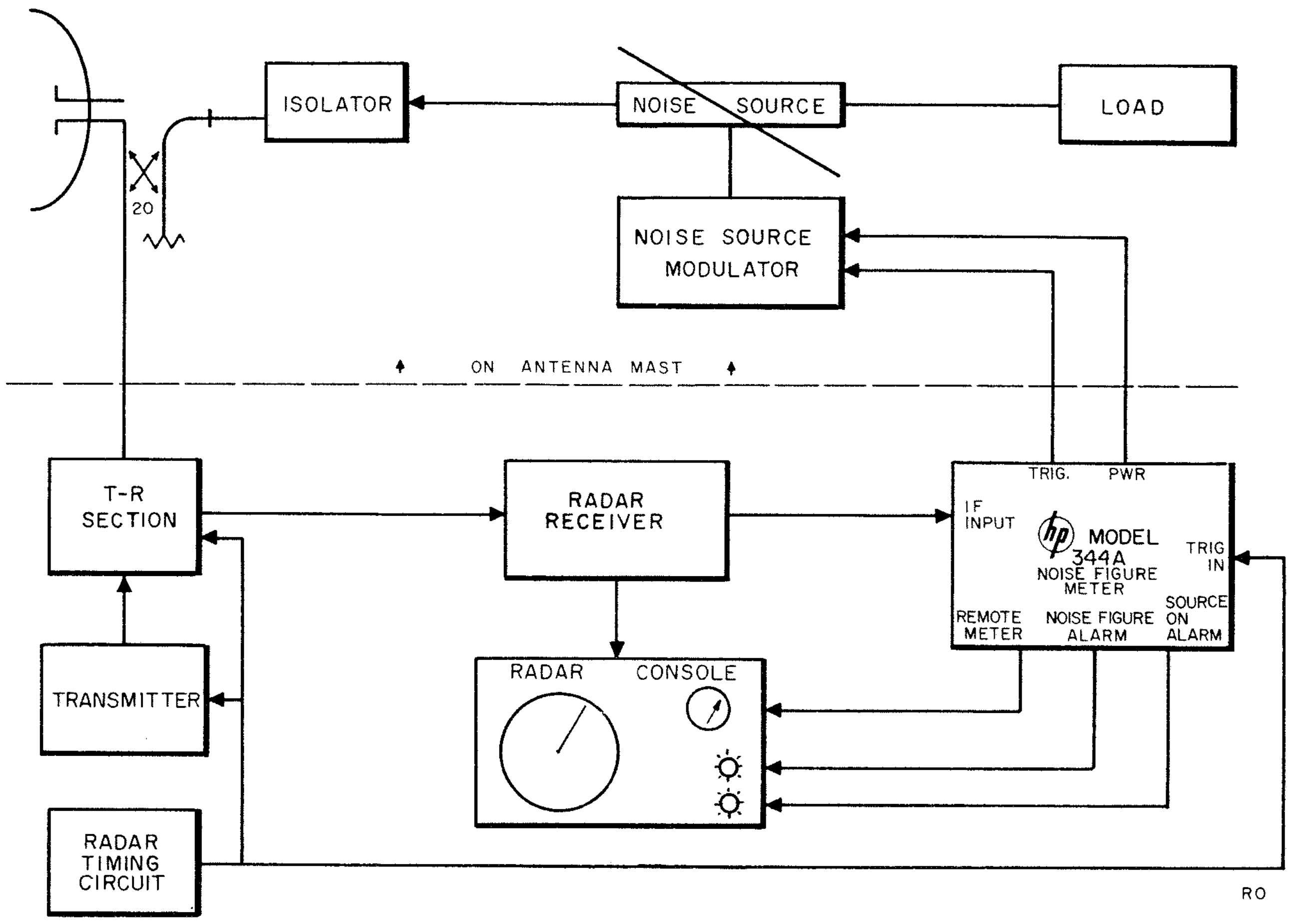

Figure 2. Typical Radar System with an Integral Noise Figure Meter

II. NOISE FIGURE METERS IN RADAR SYSTEMS

A. SYSTEM REQUIREMENTS

A typical radar system block diagram with an integral noise figure meter is shown in Figure 2. The normal timing relations are shown in Fig. 3.

The general requirement is the insertion of the excess noise as near to the antenna as practicable to include all possible sources of noise generation. The technique requires very loose coupling to avoid degrading the transmitting and receiving line powers, and to protect the noise source from excessive transmitter powers.

For instance, with a 20 db coupler as shown in Figure 2, 1/100th of the transmitter power passes out through the coupler arm. In addition, 1/100th of the received power passes to the terminating arm of the coupler. A 10 db coupler, on the other hand, takes 1/10 of the transmitter power out of the main line. Thus, as large a coupling factor as possible is desirable.

Timing information is supplied from the radar timing circuitry at the end of the radar scan to initiate the noise figure measuring action. Since the ⓗⓟ 344A Noise Figure Meter is relatively insensitive to repetition rate over a wide range of frequencies, it may be used in systems where jitter repetition rates are present.

Since ignition voltages up to 5000 volts are required by noise sources, it is important to keep them off the antenna slip rings. So, as shown in Figure 2, a remote (from the Noise Figure Meter) triggerable

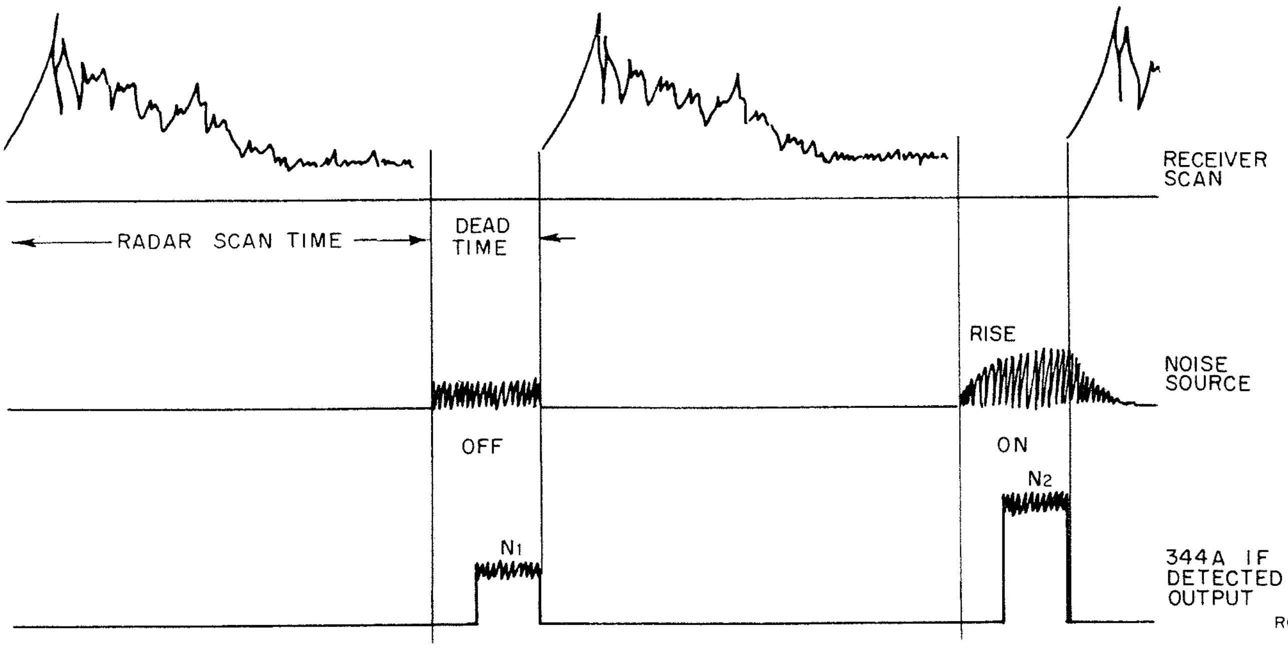

Figure 3. Timing Relations for the System shown in Figure 2

power supply (modulator) which can fire the noise source at the appropriate time is desired.

Other features such as internal calibration, direct reading meters and alarm capabilities are also very useful.

B. 344A NOISE FIGURE METER

1) Block Diagram

The 344A block diagram is shown in Figure 4. The radar timing circuitry furnishes a trigger at the end of the radar scan time. The 344A gate circuitry sends a trigger to the remote modulator on the antenna mast which fires the noise source on alternate radar scans. A known amount of excess noise from this source, injected through a 20 db directional coupler, appears as a change of noise power in the IF strip of the system under test. This change of noise power contains the desired noise figure information.

The 344A IF amplifier amplifies the noise power pulse train and drives an accurate square law detector followed by a video amplifier. Selective synchronous gating in three different integrating sections obtains dc voltage levels which are linearly related to the N_2 and N_1 pulse powers. AGC voltage is derived from the N_2 pulse and is used to control the gain of the 344A IF Amplifier. This technique results in a pulse train of constant amplitude N_2 pulses at the detector. The time constant of the AGC system was selected so that the same IF gain is presented to both the N_2 and N_1 pulses.

Since the amplitude of N_2 is constant, information about noise figure can be obtained from the measurement of the amplitude difference between the N_2 and the N_1 pulses. The 344A automatically makes this measurement and presents the noise figure on a meter. Two alarm circuits are provided, which are described later.

2) 344A Requirements and Limitations

a. IF input. The present instrument has IF frequency of 30 megacycles. However, operation up to 100 megacycles is possible, using a local oscillator-mixer combination as in the ℏ Model 342A Noise Figure Meter. Bandwidth is approximately 1 megacycle.

The 344A IF input should be obtained from a radar system IF interstage tap, because the 344A design requires both gating and AGC action before detection. In addition, the 344A has accurate square law detection circuits, another condition for accurate automatic noise figure measurements.

Input impedance of the 344A can be designed for either 50 or 75 ohms. A low return loss from the 344A input during the radar scan time is important to eliminate reflection of signals from a mismatch at the noise figure meter input. Any reflected signals would appear as another target. To make reflections insignificant hp specifies 20 db return loss over the 30 megacycles ±10 megacycles region, during scan time. Mismatch during dead time does not affect the noise figure measurement since it is present for both N_2 and N_1 pulses, and the ratio (and thereby noise figure) would remain the same.

In retrofit situations, where low impedance interstage IF taps are not available, high impedance pickoffs may be used, provided the mismatch loss involved with delivering the noise power to the 344A does not reduce the input below the minimum level.

With the 344A IF input sensitivity, at least 40 db of gain is required between the RF system input and the IF output tap. Since all noise measurements require a constant gain in the radar receiver during the test, the radar AGC or STC must be disabled during the dead time measurements. Since many radar systems already have computing circuitry for making gain tests, etc., during dead times, it should be possible to meet requirements for stabilized gains during the measurement periods. This requirement for stabilized gain is common to all automatic noise figure measurements, and is necessary with the 344A for only the pulse-to-pulse consideration. During longer terms, the 344A AGC circuit adjusts the IF gain to maintain calibration. The AGC time constant is about 10-20 seconds.

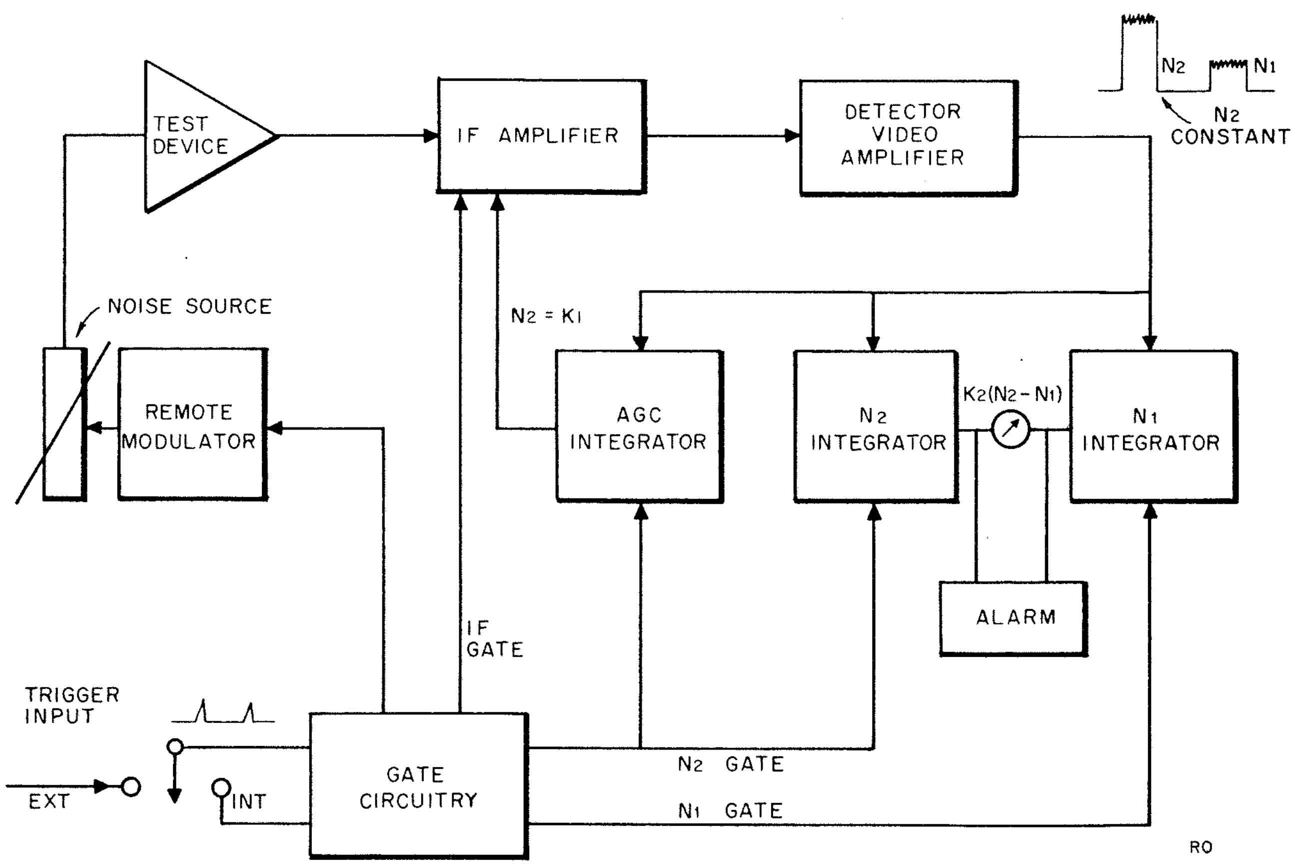

Figure 4. hp 344A Noise Figure Meter Block Diagram

b. Input Trigger. The 344A input circuits require a three-microsecond duration and a 2 to 40 volt positive pulse to the input trigger. A free run mode is available whereby the input stage is converted to a multi-vibrator which supplies an internal time base. This mode is useful for periodic measurements rather than continuous performance monitoring. In the free run mode it is not necessary to turn on the radar timing circuitry or transmitter if only receiver tests or maintenance are performed.

c. Duty Cycle. The minimum measuring duty cycle is .075. The 344A operates on the same 3 level principle as the vacuum tube Model 340B (0, N_1 and N_2). However, the 340B uses a 2 to 1 duty cycle but the 344A must use a significantly shorter duty cycle to minimize the dead time required.

Transistors are used in the 344A integrating amplifiers, and since I_{co} flows continuously, the integrated current of N_1 or N_2 must be large compared to I_{co} to minimize error. Thus as the measuring duty cycle gets shorter, higher peak currents must flow during measuring time to result in a given integrated value. As shown in Figure 5, these peak currents set a limit to minimum duty cycle (.075). For example, in a 100 PPS radar the 344A would require 750 microseconds of measuring dead time.

In addition, 100 microseconds prefire time should be allowed before the minimum measuring time starts to allow noise power build-up to stabilize. The 100 microsecond requirement is caused partially by the modulator voltage build-up and also, once fired, by the noise build-up itself. We start to measure only after the noise has stabilized. The portion of the radar scan cycle just before the injection of noise represents maximum distance targets and thus the noise should not be fired until the end of maximum ranging time. To be safe, a trigger supplied at the end of maximum ranging time will always give noise during dead time. In cases where dead time is particularly short it might be possible to supply a trigger slightly before maximum ranging time. 50 microseconds is required to build up the igniting pulse before the gas tube fires.

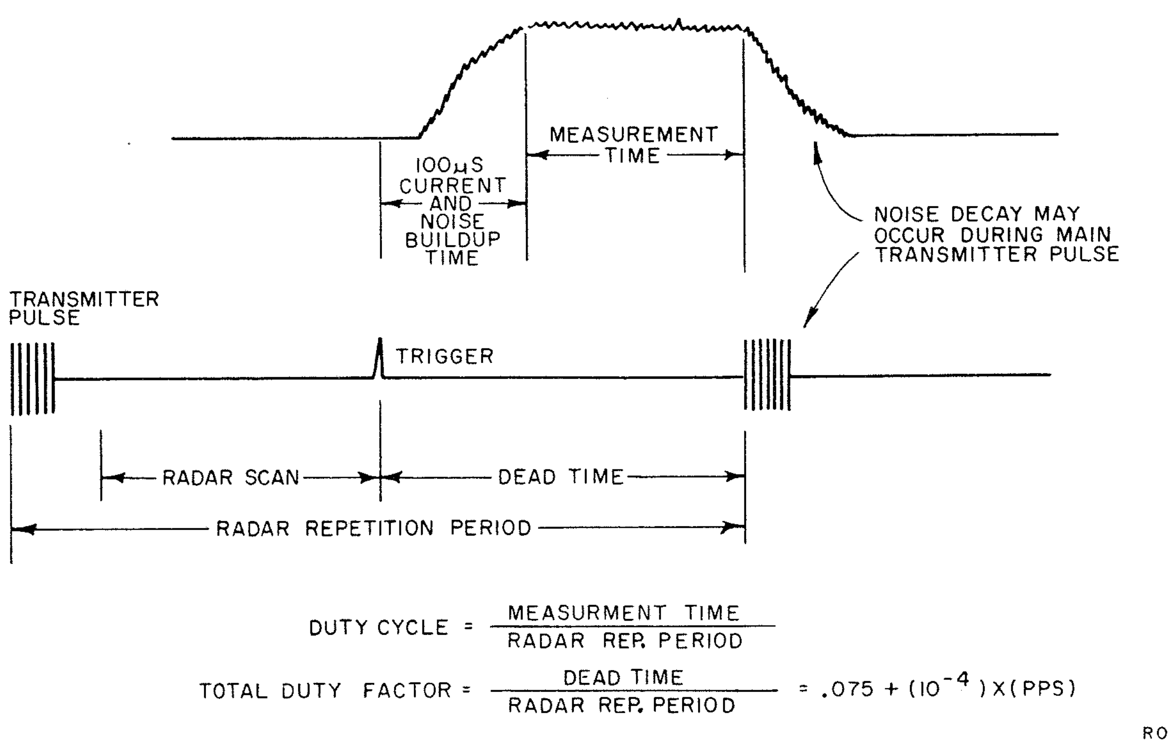

Figure 5. 344A Measurement Duty Cycle Requirements

Noise decay time (about 50 to 100 microseconds) is not a problem since it can occur during the main transmitter pulse or even during the minimum ranging time, because return signal powers are high and, in general, the excess noise injected into the main receiver line is only about 0.6 KTB. (Compare this with a receiver of 10 db noise figure which adds an equivalent 10 KTB to the input noise.)

d. Repetition Rates. The design limit for repetition rates is 90 to 500 pps. The lower rate is determined by meter response and filtering required by the AGC loop. The higher rate is limited by the fact that the effective duty factor, which includes build-up and decay times, of the noise source becomes too high, leaving no time for radar scan.

The 344A is designed for a fixed repetition rate between 90 and 500 pps with operating range to 25% above the design frequency. This operating range would be wide enough to allow work in systems which use jitter repetition rates. On free run mode, where the internal time base is used, repetition rates would be within the same limits.

e. Scale Calibration. Most present applications are expected to fall around noise figures of 3 to 10 db. For that reason three or four meter scale calibrations should suffice. Presently four are available: 200 to 5000°K, 0 to 15 db, 3 to 18 db, 6 to 20 db.

The excess noise ratio at the system RF input is determined by several factors and, in general, is the responsibility of the system engineer. The directional coupler which inserts the noise into the main receiver line is the first major factor. Normally as large a coupling as possible is used so as not to lose transmitter or receiver power into the secondary line. A value between 15 and 20 db is practical. For instance, with a 20 db coupler and a 17.9 db neon noise source, an excess noise ratio at the system input would be -2.1 db, which is one of the available designs. Also, the main transmitter pulse attenuated by the directional coupler coupling factor hits the noise tube. So if the power is too high into the noise tube an isolator may be required in the secondary line.

A second factor which might determine the excess noise ratio at the system RF input is the effect of preselectors, or image rejection elements in the front RF section. Since these elements control the effective excess noise ratio at the input, they should be considered. Gas discharge noise sources have a wide noise spectrum so the 344A reads noise figure based on the total bandwidth seen by the system IF which includes pass-bands on each side of the local oscillator. However, the typical radar receiver uses only one sideband for intelligence input. Thus its noise figure should be based on the specific application of one useful sideband and the additional noise coming in the image frequency should be charged to the receiver.

For example, without a preselector on the input of a receiver, the excess noise ratio is effectively 3 db higher, because the noise appears in both channels while the signal uses only one. The difference in noise figure with or without preselection is then 3 db. This effect must be included in the meter calibration.

The spread of calibration points on the meter scale is determined by the excess noise ratio at the system RF input. The calibration points are derived in Figures 6 and 7. The excess noise ratio is -2.1 db for this case (numerically, the excess noise power is 0.6 KTB). Three cases of noise figure are considered, 6, 10 and 20 db. The pulse amplitudes show relative noise powers for the various noise figures.

If we deliver the (N_2 - N_1) pulse to the meter, (Figure 8) set gain so 6 db represents full scale and ∞ db to represent zero current, you can calculate just where any given intermediate noise figure, such as 10 db, will read on the meter by considering the ratio of N_1 and N_2 for various noise figures.

This discussion shows that -2.1 db excess noise ratio is the lower limit on input ratio, because the randomness of the fluctuations on the top of the N_2 and N_1 pulses becomes important in the measurement of the difference, when N_2 and N_1 are very nearly equal.

f. Remote Modulator. To keep high voltage triggering pulses off the antenna slip rings, a remote noise source power supply is provided to mount up near the noise source. This supply accepts low dc voltages with low voltage trigger pulses from the noise figure meter whenever the noise tube is to be turned on. In operation it applies a very high voltage spike to the gas tube to initiate the discharge, and then after the tube is fired, it goes into a current regulating mode and holds the current to exactly 150 ma.

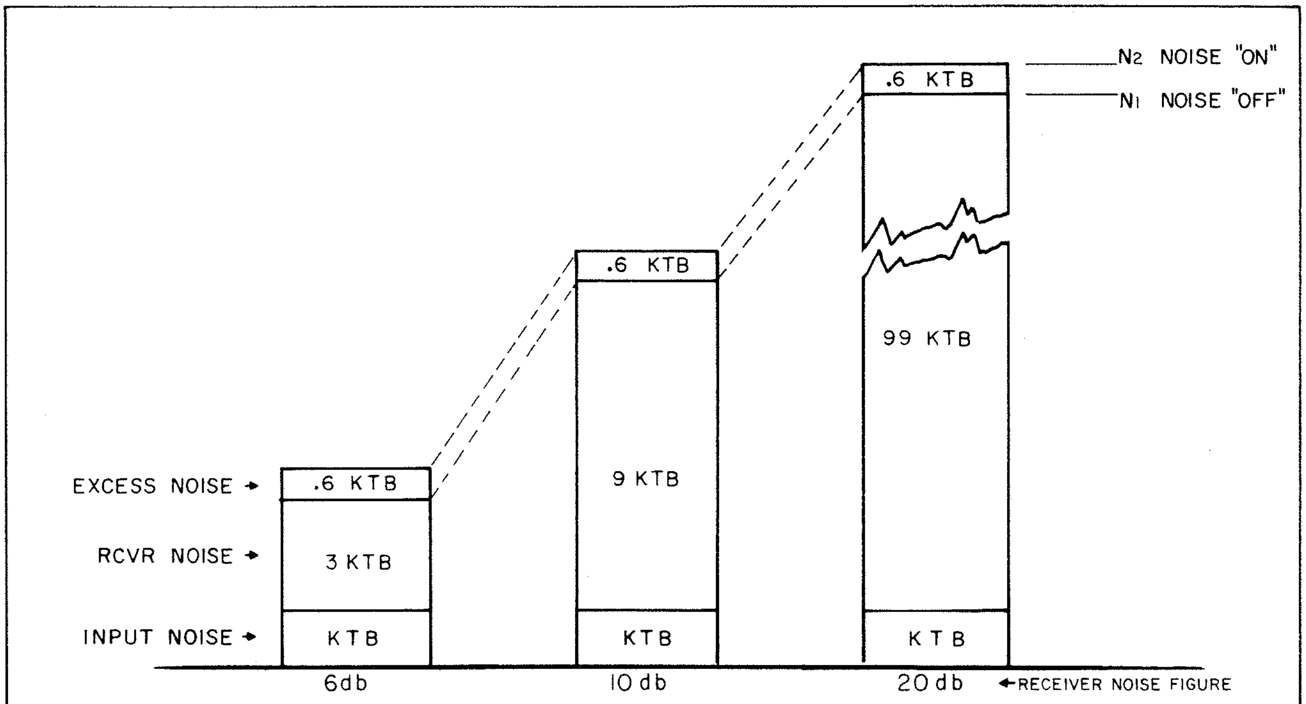

Figure 6. Derivation of Meter Scale Calibration

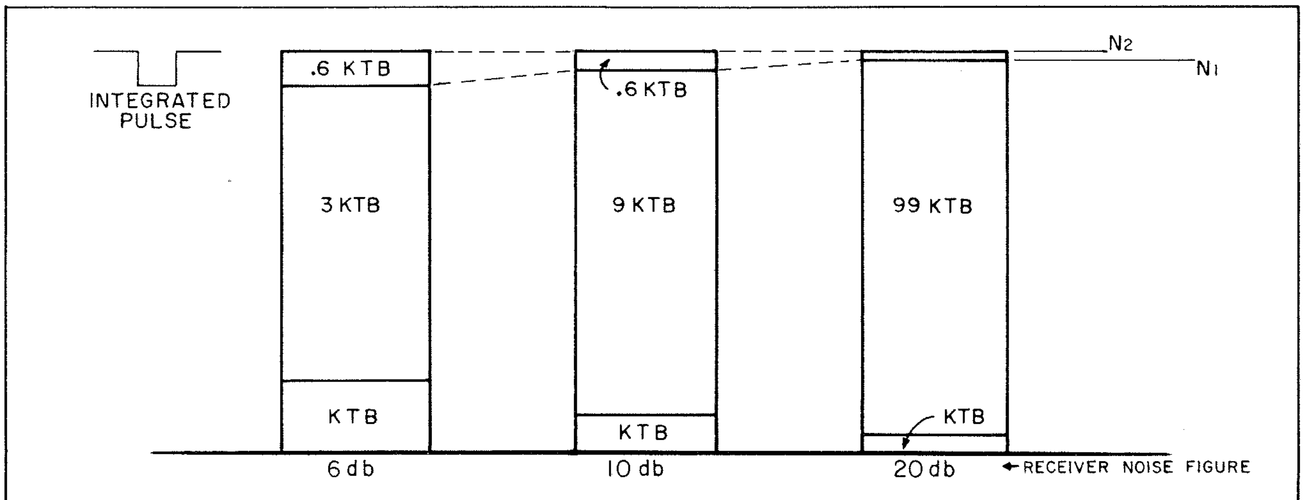

Figure 7. Normalized Pulse Ratio to Constant N_2

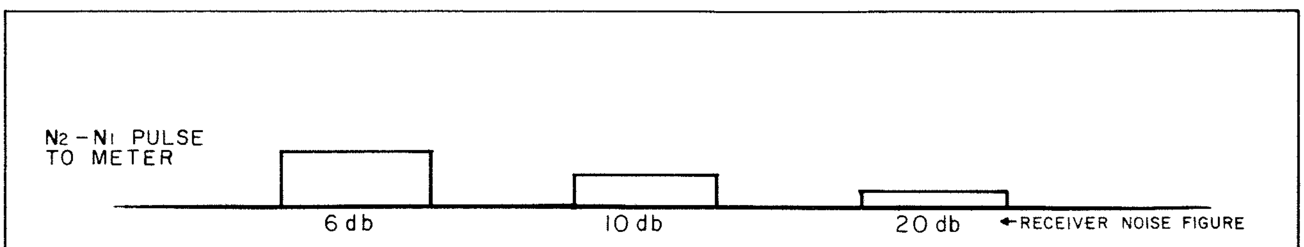

Figure 8. Relative Meter Current VS Noise Figure

The modulator should be within approximately six feet of the noise sources. Under these conditions it can fire most of the hp noise sources with either neon or argon tubes.

The allowable distance between the modulator supply and the main noise figure meter is determined by the connecting cable. The modulator requires less than about 1/2 ohm of cable resistance and, thus, longer distances require larger wire for the dc supply. A common distance would be about 200 feet with wire of reasonable size.

g. Alarms. Two alarms are offered with the 344A to make it more useful in the performance monitor application. The noise figure alarm is coincidence circuitry associated with the meter reading which allows an alarm noise figure position to be set on the meter face, and when the actual measured system noise figure exceeds this set limit, an alarm light fires on the front panel with a closure of some relay contacts for remote indication. This noise figure alarm may be set within 25% of the mid-scale meter reading with a front panel control. The accuracy of the alarm is within approximately ± 1/4 db of the meter reading.

A second alarm function is the noise source alarm. This alarm is functionally driven from the current regulating loop of the noise source modulator. The alarm is energized at any time when the noise tube current is appreciably different than 150 ma. It fires, for instance, when the noise tube is broken or when aging of the tube doesn't allow the full 150 ma to flow. The noise source alarm is required to eliminate the following ambiguity condition: If the noise source does not fire for some reason, both noise pulses in the pulse train arriving at the meter are equal, which is a condition of infinite noise figure. In this situation the noise figure alarm would also fire, showing a degraded noise figure of infinity. Without an indication that the noise source itself was inoperative you could not determine if the system was truly in error and if it should be deactivated to find out the cause of the indication. Thus, the source-on alarm bulb is necessary whenever an infinity noise figure reading is diagnosed. External contacts for both these alarm functions are provided so that external logic can be performed between the two to result in a true, unambiguous system noise figure alarm function.

h. Sources. In general, a broadband noise source should have an equal standing wave ratio in both the fired and unfired condition. hp broadband noise sources are loaded with polyiron slugs to provide a standing wave ratio of less than 1.2 under both fired and unfired conditions.

The match at the noise source is less important for a system monitor where very loose coupling is supplied between the noise source and the main receiver line because the receiver looking down the line sees the noise source through perhaps a 20 db coupler. Thus the requirement that the receiver see an equal impedance under both conditions can be met with a short circuit at the back of the noise source instead of a matched load. A short circuit is easier to obtain and in general results in a physically shorter noise source. The shorted sources can be used whenever the coupling factor is above 15 or 20 db.

The noise sources themselves can contain either an argon or neon gas tube; the argon tube provides noise temperatures that result in an excess noise ratio of 15.7 db while the neon bulbs provide 17.9 db excess noise ratio. The neon tube is desirable since it provides an extra 2.2 db of excess noise and thus allows that much additional decoupling from the main line.

A simple connector modification will adapt hp noise sources to the high voltage BNC type connector on the power supply.

3) Construction

The 344A Noise Figure Meter has been designed to operate under severe environmental conditions. It has an operating temperature range of 0° Centigrade to 52° Centigrade and will operate satisfactorily under humidity conditions up to 95%. It is a transistorized, ruggedized instrument in a small, light package, available in either a 5-1/4 inch high relay rack mount or a computer type module which has a panel dimension of about 6-13/16 by 8-1/2 inches.

4) Calibration

The Model 344A is designed with an internal calibrate function similar to the one in the Model 340B. Only meter end-point adjustment is required so the whole instrument can be calibrated easily within a minute. An interesting design feature is the speed of calibration, in spite of the long 344A AGC time constants. Long AGC time constants are required because of the severe fluctuations caused by the random nature of the signals being measured and the extremely high 344A sensitivity (detection of signals below the noise level in the receiver).

Since the meter time constants are typically about 20 or 30 seconds, they would cause exceedingly tedious calibration. Therefore the 344A calibration adjustments operate independently of the long AGC time constants so that the meter responds in the calibration function with time constants much less than one second. Long AGC time constants are switched in for the actual noise figure reading function.

5) Accuracy

The accuracy of the instrument is $\pm 1/2$ db over the useful operating range and ± 2 db over the upper part of meter. These specifications are conservative and include variations in repetition rate, temperature, and aging. If the meter is used over extremely wide temperature limits, a small adjustment of calibration may be necessary. However, since this adjustment is a fast, front panel adjustment, it can normally be performed in less than a minute. Periodic daily calibrations are probably desirable, although it may become obvious within a short time that they are not necessary.

III. OTHER APPLICATIONS

A. SYSTEMS

The general area of system compatibility was described. The pulse type radar with noise measurement during dead time is the common type of system installation. However, not all the various system considerations have been discussed. Each installation is a special case and will require on-the-spot discussions and tailoring of certain instrument characteristics.

B. HIGH REPETITION RATE RADARS:

In systems exhibiting very high repetition rates, such as high resolution radars or taxi radars, the noise build-up time of the noise sources becomes too large a part of the repetition period. Above repetition rates of 500 pps, several techniques are available to adapt the 344A to systems.

First is the straightforward method of counting down the radar repetition period until it is within the 90-500 pps rate and then inhibiting the entire transmitter pulse and radar scan for one period to allow for the noise measurement. That technique requires a small amount of computer circuitry in the radar timing circuits but still allows a continuous noise figure measurement. For instance, in a radar with a 2400 pps repetition rate, the omission of every tenth transmitter pulse would not appreciably affect the operation of the set, and yet would allow noise measurements with a basic 240 pps repetition rate, which is well within ⓗⓟ specifications. The whole radar repetition interval could be used for the noise figure measurement.

Second, a technique exists for operating the noise source at a slower rate, perhaps 400 pps, and allowing the source and meter integrating circuits to be on during a number of repetition periods. If the source is decoupled 20 db from the main line, excess noise added to the system is only 0.6 KTB. This excess noise will have very little effect on the system noise, especially with high repetition rate -- short range radars where signal levels are high. Samples of noise power are then taken during the very short "dead" times of the high repetition periods, by gating a 30 mc switch at the input to the 344A. This technique results in integration very similar to normal operation and can probably extend operation up to 5000 pps.

Finally, a very satisfactory solution to the high repetition rates is offered by periodic measurements. The radar transmitter can shut down for about 5 minutes each morning and the 344A operated in free run mode, to make an automatic measurement daily to note any trends. The configuration and design philosophy of the 344A make it highly desirable in operating systems, since it takes small amounts of panel space, very small amounts of power, and, in addition, offers the remote modulator for noise tube firing. Transistorized circuitry results in higher reliability. The main reason it should be used, rather than the Model 340B, is that the additional sensitivity allows the noise source to be decoupled from the line by 20 db. Under these conditions, no trigger is required from the timing circuitry.

C. AIRBORNE USE

In the general airborne radar, installation of a continuous noise figure monitor is questionable since, once airborne, the discovery that a radar system has a degraded noise figure would be of little use because no repairs are possible. However, the 344A may have some real advantage for pre-flight checkout applications. Thus the aircraft radar system would include a narrow band directional coupler near the antenna with a small noise source feeding into the coupler. The 2 pound noise source modulator would be attached near the noise source, so that high voltage cables would be minimized. The pre-flight check could be made by rolling the test stand which would contain the Model 344A next to the airplane. The low dc voltage and trigger connections could then be made to the noise source modulator and an IF tap from the radar IF connected back to the 344A. The noise figure of the radar could then be logged and any maintenance or adjustment could easily be performed to provide an optimizing capability.

D. CENTRAL RADAR MONITOR

Another possible application is the use of the 344A as a central performance monitor. The noise figure meter could be mounted in a control room which is the center of a number of radar sets. Each radar antenna would have the noise source installed on the mast and one remote modulator with cables from the various antennas leading back to the central control point. In addition, IF taps and timing circuitry from the various radars could be led to a central switching assembly. The 344A input timing would be switched among the various radar sets to sequentially energize the appropriate noise modulator and noise source. The remote modulator feature makes this a promising application.

E. HIGH NOISE FIGURES

The high sensitivity of the 344A allows you to make laboratory noise figure measurements up to 40 db on devices such as certain travelling wave tubes. These measurements may be made with instrument accuracies of only $\pm 1/2$ db and cover a region in which the 340B and 342A are less accurate or unusable.

The ⓗⓟ Model 344A was specifically designed for the broadest possible use in operating radar sets. Components which determine various system parameters are accessible to allow specific tailoring to present systems. Further information and engineering assistance is available from your ⓗⓟ Engineering Representative or by writing Hewlett-Packard Company.

John Minck
Marco Negrete

5/12/60
4/23/63
12/23/64