

# Noise Figures

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**Abstract**—In this paper, we present a short tutorial description of noise figures for two-port linear transducers and entire receiver systems. Due to the long history of the use of noise figures to specify noise performance, numerous definitions have evolved. The relationships between the various noise figure definitions found in the literature are specified in this paper and tables are provided as a cross reference to the notation and naming conventions used in the references.

## I. INTRODUCTION

THE concept of a noise figure is a common and useful means of describing the noise performance of receiving systems in communications, radar, and related subjects. The long history of the use of noise figures to describe performance has given rise to a variety of notation and definitions for the quantities involved. At times, the explicit definitions are omitted, and in other cases similar names are given to distinctly different noise figure definitions. This can be a source of confusion to the student and the practitioner. The purposes of this paper are to: 1) present a tutorial description of noise figures for two-port transducers and receiver systems, 2) specify the relationship between the different noise figure definitions, and 3) provide a cross reference of noise figure definitions and notation found in the literature. The goal is not to establish yet another set of names and notation, but to provide a point of reference for comparison of the notation and definitions which are in place.

The definitions presented here are not original to this paper. As indicated by the references, the seminal work was published more than forty years ago [1], [2]. An excellent overview of the historical development of noise modeling, description, and measurement is given by Okwit [3].

The terms noise figure and noise factor are often used interchangeably in the references, with the former used more commonly. A few references do make a distinction between the two, with noise figure defined as the noise factor expressed in decibel notation. We shall not make any distinction between the two terms and will use the term noise figure.

All noise figures discussed here are average noise figures [4], rather than single frequency or spot noise figures. They are figures of merit for the average noise performance of the device over some operating band of

frequencies. In addition, only single response frequency bands are considered. The additional noise which can occur from image frequencies in a heterodyned system is not considered.

The naming conventions used in this paper have been chosen to denote both the scope of the hardware being described and the reference temperature at which the noise figure is defined. The notation used in this paper has been selected to coincide with common notation found in the references. This effort cannot be completely successful, of course, so tables providing notation and naming cross references are included.

## II. NOISE FIGURE FOR A TWO-PORT TRANSDUCER

We begin by defining the noise figure for a linear two-port transducer, such as an amplifier, a cascade of amplifiers, a passive device, or an entire receiver (not including the antenna). The two-port noise figure is a measure of the noise performance of the transducer and there is little variation in the definitions given in the references. Let  $F_n$  be the *two-port noise figure* as defined in [5]:

$$F_n = \frac{\text{Noise output of a real device}}{\text{Noise out of an ideal device with input at temperature } T_o} \quad (1)$$

where  $T_o = 290$  K is the standard reference temperature.

### A. Active Two-Port Transducers

An ideal device is one which adds no additional noise to the signal passing through the device. The only noise at the output of the ideal device is the noise at the input which has been amplified by the gain of the device. Thus, the noise figure is the actual noise power output divided by the noise power output due only to the input noise generated by the input termination at  $T_o$ . Initially, we assume that the output resistance (real part of the output impedance) of the source and the two-port transducer are both positive. The negative resistance case is discussed in Section II-D.

Let the available power gain of the device be  $G = S_o/S_i$  where  $S_o$  and  $S_i$  are the available output and input signal power levels, respectively. The available power is the maximum power which can be drawn from a source by arbitrary variation of its terminal current or voltage [6]. The available input noise power to the device, due to the input terminated at temperature  $T_o$ , is  $N_i = kT_oB_n$  [7]

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where  $k = 1.38 \times 10^{-23}$  J/°K is Boltzman's constant, and  $B_n$  is the noise bandwidth. If we let  $N_o$  be the actual noise output power from the real device, then we can write the noise figure for the device as

$$F_n = \frac{N_o}{GN_i} = \frac{N_o}{GkT_oB_n}. \quad (2)$$

If we let  $\Delta N$  be the noise at the output of the transducer due to the device itself, we can express the noise figure as

$$F_n = \frac{N_iG + \Delta N}{GkT_oB_n} = 1 + \frac{\Delta N}{GkT_oB_n}. \quad (3)$$

Note that  $F_n \geq 1$ ; the best two-port noise figure a device can achieve is a value of one.

A block diagram model of a two-port transducer is shown in Fig. 1. If we represent the noise added by the device,  $\Delta N$ , as an additive noise source at an effective noise temperature of  $T_e$  referred to the input of an ideal (noiseless) device, then noise power of this source has a value of  $kT_eB_n$ . The equivalent circuit for this representation of the noise source and ideal device is shown in Fig. 2. From (3), we express

$$F_n = 1 + \frac{T_e}{T_o} \quad (4)$$

or

$$T_e = T_o(F_n - 1). \quad (5)$$

### B. Passive Two-Port Transducers

If the two-port device is purely passive, such as a transmission line or attenuator, the effective input noise temperature  $T_e$  is a function of the device's thermodynamic temperature  $T_i$ , and the available loss  $L$  [8]:

$$T_e = T_i(L - 1). \quad (6)$$

The available loss is defined as  $L = S_i/S_o$ , which is just the reciprocal of the available gain  $G$ .

Equation (6) gives the effective noise temperature of the transducer referred to the *input* of the passive device. Several references give the effective noise temperature of the passive device referred to the *output* of the device  $T_i$ :

$$T_i = T_e(1 - 1/L). \quad (7)$$

This effective noise source at the output of the device can be referred to the input by multiplying the effective output noise temperature  $T_i$  by the available loss of the device:

$$T_e = LT_i = T_i/G. \quad (8)$$

### C. Cascade of Two-Port Transducers

If transducers are cascaded, we can calculate the noise figure of the entire cascade from the noise figures and gains of the individual stages. Let  $F_1$ ,  $F_2$ , and  $F_3$  be the two-port noise figures for the first, second, and third stages

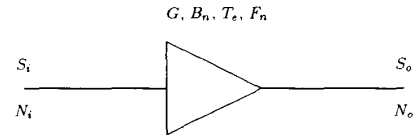


Fig. 1. Block diagram of two-port transducer.

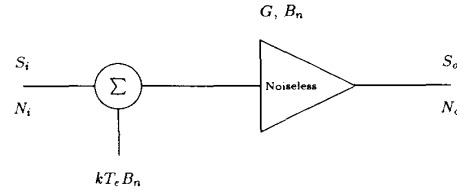


Fig. 2. Equivalent model of two-port transducer.

in a cascade of transducers. Let  $G_1$ ,  $G_2$ , and  $G_3$  be the power gains of the three stages, respectively, and let  $T_1$ ,  $T_2$ , and  $T_3$  be the effective input noise temperatures of the three stages, respectively. From (2), we can show that

$$F_{123} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} \quad (9)$$

where  $F_{123}$  is the two-port noise figure of the cascade of the three stages. A similar result can be obtained for the equivalent input noise temperature of the cascade  $T_{123}$ :

$$T_{123} = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2}. \quad (10)$$

These results can be extended to  $n$  stages [9].

### D. Modifications for Negative Output Resistance

In the above discussion, we have assumed that the output resistances have been positive. If there are negative output resistance values, the available power is infinite and we obtain indeterminate results for the noise figure of a cascade of two-port transducers.

Haus and Adler [6] have shown that the results of the previous sections can be extended to the negative resistance case if we modify the definitions for available power and gain. The following definitions and results are from [6].

Let the exchangeable power  $P_e$  be the stationary value (extremum) of the power output from the source, obtained by arbitrary variation of the terminal current (or voltage). If a source is represented by its Thévenin equivalent circuit with voltage  $E_s$  and impedance  $Z_s$  where  $R_s$  is the real part of  $Z_s$ , then

$$P_e = \frac{|E_s|^2}{4R_s} \text{ for } R_s \neq 0. \quad (11)$$

Note that  $P_e$  will be negative when  $R_s < 0$  and it reduces to the usual definition of available power when  $R_s > 0$ .

If  $P_{e|o}$  is the exchangeable power output from a two-port transducer, and  $P_{e|s}$  is the exchangeable power at the

input to the transducer, then we can define the exchangeable gain as

$$G_e = \frac{P_{e|o}}{P_{e|s}}. \quad (12)$$

Note that  $G_e$  can be negative.

As in (3), if we define  $\Delta N_e$  as the exchangeable noise power at the output terminals of the transducer with no noise power from the source, then we can define  $F_e$ , the two-port noise figure for the general case where negative output resistances may be included:

$$F_e = 1 + \frac{\Delta N_e}{G_e k T_o B_n}. \quad (13)$$

Note that  $F_e < 1$  only when the source resistance is negative.

The cascading results of (9) now apply if we use the definitions of this section for  $G_e$  and  $F_e$ . The results reduce to the previous definitions of gain and two-port noise figure when the output resistances are positive [6].

The definition and notation for the noise figure of a two-port transducer are common and fairly uniform in the references; see Figs. 5–7. Differences in notation, definition, and nomenclature usually arise when the overall noise performance of the entire receiver system *including the antenna* is considered.

### III. NOISE FIGURE FOR A RECEIVER SYSTEM

We now consider describing the noise performance of an entire receiver system, including the antenna, with a *system noise figure*. The block diagram of the system to be modeled is shown in Fig. 3.

The “electronics” portion of the receiver is modeled as a two-port device with noise figure  $F_n$ . An equivalent description of the noise performance of the receiver is provided by the effective noise temperature  $T_e$ . The block diagram of the equivalent model of the system is shown in Fig. 4. We have implicitly included any passive lossy components between the antenna and the receiver in the receiver model.

All noise, other than that generated internally by the receiver, is modeled by an additive noise source of value  $kT_a B_n$ . The temperature  $T_a$  is called the effective antenna temperature. Note that no additional noise enters the system through the antenna in this model. All external noise sources, such as galactic noise and warm body emission, are included in the appropriate selection of the value of  $T_a$ . If we let  $T_s = T_a + T_e$  be the *effective system noise temperature*, then the noise power output from the system is given by

$$N_o = kT_s B_n G. \quad (14)$$

We now consider two definitions for system noise figure. The first definition is for the standard system noise figure  $F_s$ . In this paper, the term “standard” is used, as in [10], because this noise figure is referenced to the standard temperature,  $T_o = 290$  K. The second definition is

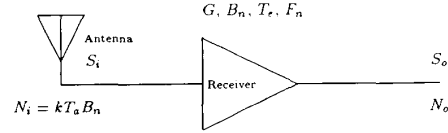


Fig. 3. Block diagram of receiver system.

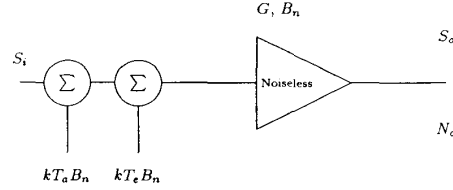


Fig. 4. Equivalent model of receiver system.

for the operating system noise figure  $F_o$ . The term “operating,” as used in this paper, indicates that this noise figure definition is referenced to the effective operating temperature at the input of the receiver system. Here is where confusion can set in when comparing definitions from various texts and papers. The standard noise figure defined in this paper is the same as the standard noise figure defined by Skolnik in [10]. North calls this the “operating” noise figure in [1], [11], and other references use further variations on the name. We shall use the names and definitions given in this section for their mnemonic value in specifying the reference temperature.

Each of these system noise figures is derived from the basic definition given in (2). Although these two noise figures are different in value, name, and definition, they provide complementary representations of a receiver's noise performance.

We begin by presenting the definition for each system noise figure and then discuss some points of comparison between the two forms.

#### A. Standard System Noise Figure

The *standard system noise figure*  $F_s$  is as presented (in some cases under a different name and notation) by North, Skolnik, and others listed in Figs. 8 through 10. The “standard” in the name refers to the fact that the noise performance of the system is referenced to the standard temperature  $T_o = 290$  K.

The system to be modeled is shown in Fig. 4. In terms of this model, the definition for noise figure given by (2) can be written as

$$F_s = \frac{kB_n G (T_a + T_e)}{kB_n G T_o} \quad (15)$$

from which we can obtain

$$F_s T_o = T_a + T_e = T_s \quad (16)$$

and

$$F_s = \frac{T_a}{T_o} + \frac{T_e}{T_o} \quad (17)$$

$$= \frac{T_a}{T_o} + F_n - 1. \quad (18)$$

Note that  $F_s \geq 0$ , whereas  $F_n$  is restricted to values greater than or equal to one.

Now, let us perform a similar development for the operating system noise figure.

### B. Operating System Noise Figure

The *operating system noise figure*  $F_o$  presented here is as given by Barton, Davenport and Root, and others listed in Fig. 11. The "operating" in the name refers to the fact that the noise performance of the system is referenced to the actual effective input temperature of the system  $T_a$ .

As in the previous section, the system to be modeled is as shown in Fig. 4. The definition for noise figure given by (2) can be written as

$$F_o = \frac{kB_n G(T_a + T_e)}{kB_n GT_a} \quad (19)$$

$$= 1 + \frac{T_e}{T_a} \quad (20)$$

$$= 1 + \frac{T_o}{T_a} (F_n - 1). \quad (21)$$

Note that the reference temperature at the input has been changed to  $T_a$  instead of  $T_o$  as presented in (2).

This is a fundamental change from the definition provided in [5]; however, we shall see that the resulting operating noise figure definition is consistent with the other noise figure definitions presented here.

From (21), it can be seen that  $F_o$  must be greater than or equal to one, just like  $F_n$ . The standard system noise figure  $F_s$  is the only one which can have a value less than one when the output resistances are positive.

### C. $F_o$ in Terms of $F_s$

We can now determine the relationship between the operating system noise figure and the standard system noise figure. From (18), we solve for the receiver noise figure:

$$F_n = F_s + 1 - \frac{T_a}{T_o}. \quad (22)$$

Similarly, from (21), we obtain

$$F_n = 1 + \frac{T_a}{T_o} (F_o - 1). \quad (23)$$

Set these two equations equal to obtain

$$F_o = \frac{T_o}{T_a} F_s. \quad (24)$$

Equation (24) provides the conversion between the operating system noise figure and the standard system noise figure.

THIS ARTICLE	$T_e$	$T_a$	$T_s$	$T_o$	$F_n$	$F_s = \frac{T_e}{T_o}$	$F_o = \frac{T_o}{T_a} F_s$	COMMENTS
Adler & Haus [13]	$\bar{T}_e$	$\bar{T}_i$	$\bar{T}_{op}$		$\bar{F}$			
Ambrozy [14]					$F$			
Barton [15]	$T_e$	$T_a$	$T_s$	$T_o$	$F_n$			
Berkowitz [16]	$T_N$			$T_o$	$F$			In Chapter 4 by Nergaard
Carlson [17]	$T_e$	$T_s$	$T_N$		$F$			The symbol used in this reference is actually closer to a "cursive T" rather than the calligraphic $T$ shown here.
Carlson [18]	$T_e$			$T_o$	$F$			
Clarke & Hess [19]					$F$			
Erst [20]	$T_{eff}$	$T_a$		$T_o$	$F$			$F$ is called the "noise factor," and $NF = 10 \log F$ is called the "noise figure."
Fink [21]	$T_e$			$T$	$F$			
Freeman [22]	$T_e$	$T_a$	$T_{sys}$	$T_o$	$NF$			
	$T$	$T_{ant}$						
	$T_e$							
Friis [7]				$T$	$F$			
Gagliardi [23]		$T_b^o$	$T_{eq}^o$		$F$			
Hartmann [24]	$T_e$			$T_o$	$F$			

Fig. 5. References that define only a two-port noise figure.

### D. Discussion

It is useful to consider the functional forms of  $F_s$  and  $F_o$ . Both noise figures depend on the same three variables ( $T_o$ ,  $T_a$ , and  $F_n$ ); however, the value of  $F_s$  increases with larger values of  $T_a$  whereas  $F_o$  decreases. The apparent noise performance of a system may be manipulated by the selection of the value of  $T_a$  at which the system's noise performance is measured. If  $F_s$  is used as the figure of merit for the system, an unrealistic value of  $T_a = 0$  would imply the best possible noise performance. In this case,  $F_s = F_n - 1$ , which will be greater than zero for an actual system. If  $F_o$  is chosen as the figure of merit, a very large value for  $T_a$  (also unrealistic) would force the value of the noise figure to the "perfect system" value,  $F_o = 1$  [12]. For a given value of  $F_n$ , the value of either system noise figure can be manipulated by selection of  $T_a$ ; however,  $F_s$  can only be forced to a lower bound value of  $F_n - 1$ , but a large value of  $T_a$  will force  $F_o$  to the "perfect" value.

We now have  $F_s$  and  $F_o$  defined in terms of the noise figure of the receiver electronics, the effective antenna temperature, and the standard temperature  $T_o$ . Appropriate questions to ask at this point are "Why do we define two different system noise figures?" and "Are they equivalent?"

The answer to the first question is historical. Both definitions are found in the literature on the subject. One purpose of this paper is to show the relationship between the two.

The answer to the second question is yes. The definitions are not identical; however, receiver noise perfor-

THIS ARTICLE	$T_e$	$T_a$	$T_s$	$T_o$	$F_n$	$F_s = \frac{T_e}{T_o}$	$F_o = \frac{T_a}{T_o} F_s$	COMMENTS
Haus & Adler [6]					$F$			Presents an extension of the definition to the case of negative resistance input termination.
Haus & Adler [25]				$T_o$	$F_e$			
Helstrom [26]	$T$			$T$	$F$			
Helstrom [27]				$T_s$	$F$			
IEEE Dictionary [28]				$T_o$	$\bar{F}$			
IEEE Dictionary [5]	$T_e$	$T_i$	$T_{op}$		$\bar{F}$			
IRE Standard [29]	$\bar{T}_e$	$\bar{T}_i$	$\bar{T}_{op}$		$\bar{F}$			
IRE Standard [4]	$T_e$				$\bar{F}$			
Jordan & Penney [30]	$T_e$	$T_s$	$T_{sp}$	$T_o$	$\bar{n}_F$			$N_F = 10 \log n_F$
		$T_{ant}$						
Locke [31]					$F$			
Maral & Bousquet [32]	$T_R$	$T_A$		$T_o$	$F$			
Middleton [33]				$T_o$	$F_i$			
Mumford & Scheibe [12]	$T_e$	$T_i$		$T_o$	$F$			This book also includes a cross reference of notation and definitions through 1968.

Fig. 6. References that define only a two-port noise figure, continued.

THIS ARTICLE	$T_e$	$T_a$	$T_s$	$T_o$	$F_n$	$F_s = \frac{T_e}{T_o}$	$F_o = \frac{T_a}{T_o} F_s$	COMMENTS
Nathanson [34]	$T_e$	$T_A$	$T_s$		$\bar{F}$			
Schwarz [35]	$T_e$	$T_s$	$T$		$F$			Schwarz defines the two-port noise figure as $F = 1 + \frac{T_e}{T_s}$ (his notation). Note that $F$ is referenced to the effective antenna temperature, not $T_o$ as in this paper and the other references.
Smith [36]	$T_e$			$T$	$\bar{F}$			$F$ is called the "noise factor" and $NF = 10 \log F$ is called the "noise figure."
Taub & Schilling [37]	$T_e$	$T_{ANT}$		$T_o$	$\bar{F}$			
Ulabay & Moore [38]	$T_E$	$T_A$	$T_{SYS}$	$T_o$	$F$			
		$T_{REC}$						
Van Trees [39]	$T_e$							
Van Voorhis [40]	$T_i$				$F$			
Ziener & Trantor [41]	$T_e$	$T_s$		$T_o$	$F$			

Fig. 7. References that define only a two-port noise figure, continued.

mance can be specified by either noise figure and the results are identical.

#### IV. NOTATION CROSS REFERENCE

Figs. 5-11 provide a cross reference between the notation and naming conventions used in the references. In each figure, the top entry contains the notation used in this paper and each reference is listed in separate row.

THIS ARTICLE	$T_e$	$T_a$	$T_s$	$T_o$	$F_n$	$F_s = \frac{T_e}{T_o}$	$F_o = \frac{T_a}{T_o} F_s$	COMMENTS
Barton [42]	$T_E$	$T_A$		$T_o$	$NF$			From the paper "General Radar Equation" by Hall, 1962.
Berkowitz [16]		$T_a$	$T_i$	$T_o$	$NF$	$NF_o$		$NF_o$ is called the "operating noise figure" in Chapter 1, by Barton.
	$T_e$	$T_A$		$T_o$	$\bar{F}$	$F^*$		$F^*$ is called the "average system noise factor" in Chapter 3, by Chorton.
Blake [8]	$T_e$	$T_i$	$T_s$	$T_o$	$NF$	$NF_s$		$NF_s$ is called the "system noise figure."
Carpentier [43]	$T_R$	$T_M$	$T_N$	$T_o$	$N_R$	$N_{RS}$		$T_M$ includes the microwave transmission line and any losses.
Currie & Brown [44]	$T_{sys}$	$T_A$		$T_o$	$F(n)$	$NF_o$		$NF_o$ is called the "system operating noise figure."
					$F$			
					$NF$	$NF$		$NF$ is called the "system noise figure" and $NF$ is called the "receiver noise figure."
					$F_s$			
Difranco & Rubin [45]	$T_e$	$T_o$	$T_i$	$T_o$	$F_n$	$F_n$		The symbol used in this reference is actually closer to a "cursive $T$ " rather than the calligraphic $T$ shown here.

Fig. 8. References that define a standard system noise figure.

THIS ARTICLE	$T_e$	$T_a$	$T_s$	$T_o$	$F_n$	$F_s = \frac{T_e}{T_o}$	$F_o = \frac{T_a}{T_o} F_s$	COMMENTS
Goldman [46]		$T_A$		$T$	$F$	$F + \frac{T_A}{T_o} - 1$		Goldman does not use separate notation to refer to the standard system noise figure, although the quantity is identified.
Hansher [47]		$T_a$	$T_s$	$T_o$	$F$	$F_s$		$F_s$ is called the "system noise figure."
Lawson & Uhlenbeck [9]		$T$		$T_o$	$F_i$	$F^*$		$F^*$ is called the "modified noise figure."
Miya [48]	$T_e$	$T_a$		$T_o$	$F$	$F_{op}$		$F_{op}$ is called the "operating noise figure."
North [2]		$T_o$		$T_o$	$F$	$F_{op}$		$F_{op}$ is called the "operating noise factor."
North [1]		$T_a$		$T_o$	$N$	$NF(\text{operating})$		
North [11]		$T_a$		$T_o$	$N$	$N(\text{operating})$		
Okwit [3]	$T_e$	$T_a$	$T_{sp}$	$T_o$	$F$	$N_{op}$		Okwit presents an excellent historical perspective on the development of noise performance modeling and description.
Panier [49]	$T_e$	$T_a$	$T_s$	$T_o$	$\bar{F}$	$F_{op}$		$F_{op}$ is called the "operating or effective noise figure of the receiving system."

Fig. 9. References that define a standard system noise figure, continued.

In some of the references, different subscripts are used with the temperature and noise figure variables to denote the specific hardware being modeled. Space limitations preclude putting all variations from each reference into

THIS ARTICLE	$T_e$	$T_a$	$T_s$	$T_o$	$F_n$	$F_s = \frac{T_e}{T_a} F_n$	$F_o = \frac{T_e}{T_a} F_s$	COMMENTS
Povejsil [50]				$T$		$F$		In Chapter 3, by Raven.
		$T_a$			$F$			In Chapter 7, by Healey.
Rohan [51]		$T_a$		$T_o$	$F$	$\frac{T_e}{T_a} + F - 1$		Rohan does not use separate notation to refer to the standard system noise figure, although the quantity is identified.
Sklar [52]	$T_R$	$T_A$	$T_s$	$T_o$	$F$	$F_{op}$		$F_{op}$ is called the "working or effective noise figure."
Skolnik [53], [10]	$T_e$	$T_a$	$T_s$	$T_o$	$F_n$	$F_s$		
Valley & Wallman [54]				$T$	$F$			In Chapter 12 by E. J. Schremp.
		$T$		$T$	$F_A$	$F$		In Chapter 13, by Y. Beers, where $F$ is called the "over-all noise figure . . . of the system."
Wehner [55]	$T_e$	$T_a$	$T_s$	$T_o$	$F_n$	$F$		
Westman [56]	$T_R$	$T_a$		$T_o$	$F$	$F'$		

Fig. 10. References that define a standard system noise figure, continued.

THIS ARTICLE	$T_e$	$T_a$	$T_s$	$T_o$	$F_n$	$F_s = \frac{T_e}{T_a} F_n$	$F_o = \frac{T_e}{T_a} F_s$	COMMENTS
Barton [57]		$T$					$(NF)$	From the paper "Range Performance of CW, Pulse, and Pulse Doppler Radar" by J. J. Bussgang et al., 1959.
				$T$		$(NF)$		This interpretation, or the one shown above, depends on how the statement "... $T$ is the absolute temperature . . ." is construed in the paper.
Davenport & Root [58]		$T_{eq}$		$T_o$	$\bar{F}$		$\bar{F}_o$	$\bar{F}$ is called the "average standard noise figure" and $\bar{F}_o$ is called the "average operating noise figure."
Peebles [59]	$\bar{T}_e$	$T_a$	$\bar{T}_{sys}$		$\bar{F}_o$		$\bar{F}_{op}$	$\bar{F}_o$ is called the "average standard noise figure."
	$\bar{T}_R$	$\bar{T}_s$						
Shea [60]	$\bar{T}_e$	$\bar{T}_i$	$\bar{T}_{op}$	$T_o$	$\bar{F}$		$F'$	$F'$ is called the "operating noise factor."

Fig. 11. References that define an operating system noise figure.

these tables. The notation shown in the tables has been selected to represent the fundamental form used in the reference and minor variations should be self evident when reading the specific reference.

## V. CONCLUDING REMARKS

In this paper, we have presented the definition for the noise figure of the two-port linear transducer and the definitions for two system related noise figures.

The definitions for the two-port transducer noise figure  $F_n$  and the standard system noise figure  $F_s$  follow naturally from the basic definition given in [5]. The definition of

the operating system noise figure  $F_o$  requires a change in the reference temperature from that given in reference [5].

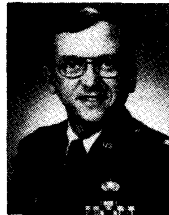
The noise performance of a receiver system can be described by either the standard system noise figure or the operating system noise figure. The results are equivalent, and the noise performance description can be transformed from one noise figure to the other.

Given the long historical record of literature, and the wealth of references, it probably is not feasible to standardize the notation and naming conventions for noise figures. However, the cross-reference tables should ease the comparison of receiver and transducer noise performance when variations in symbols and names are encountered.

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