METHOD 308
29 November 1961

CURRENT-NOISE TEST FOR FIXED RESISTORS

1. PURPOSE. This resistor noise test method is performed for the purpose of establishing the "noisiness" or "noise quality" of a resistor in order to determine its suitability for use in electronic circuits having critical noise requirements. This method is intended as a standard reference for the determination of current noise present in a resistor, for use in an application with specific current-noise requirements. It is not intended as a general specification requirement. Interference caused by the generation of spurious noise signals in parts tends to mask the desired output signal, thus resulting in loss of information. For low-level audiofrequency and other low-frequency circuits, where low-noise parts are used, resistors may become an important source of interfering noise. One source of noise in a resistor is molecular thermal motion which generates a fluctuation voltage termed "thermal noise." It is not necessary to determine the magnitude of thermal noise by measurement since the mean-square value of the fluctuation voltage is predictable from Nyquist's equation, which shows the mean-square value to be proportional to the product of resistance, temperature, and the pass band of the measuring system. Generally, an increase in fluctuation voltage appears when direct current (dc) is passed through resistive circuit elements. The *increase* in fluctuation voltage is termed "excess noise" or "current noise." The magnitude of current noise is dependent upon many inherent properties of the resistor such as resistive material and other factors such as processing, fabrication, size and shape of resistive element, etc. Since there is no apparent functional relationship between current noise and many of these factors, current noise generally cannot be predicted from physical constants. Therefore, it is necessary to measure current noise to determine its magnitude. The method employed in this test has been designed to evaluate accurately the "noisiness" or "noise quality" of individual resistors in terms of a noise-quality index. The noise-quality index, expressed in decibels (db), is a measure of the ratio of the root-mean-square (rms) value of current-noise voltage, in microvolts (uv), to the applied dc voltage, in volts. The pass band associated with the noise-quality index is one frequency decade, geometrically centered at 1,000 cycles per second (cps). This index is termed the "microvolts-per-volt-in-a-decade" index. In the design of circuits, an added advantage accrues from the definitiveness of the index which allows the estimation of interference attributable to current noise. Conversely, for a given limit of current-noise inteference in a particular circuit design, a maximum acceptable value of the index may be established. Ordinarily, it is not necessary to duplicate the operating conditions of the particular circuit design when measuring the current noise. The noise quality of populations of resistors may be reasonably estimated by measurement of the index of representative groups of resistors using suitable sampling procedures. Measurements on sample groups tend to have a normal distribution and once representative parameter values for the distribution have been established (the mean and standard deviation), such parameter values would serve as norms in judging "noisiness" and product uniformity insofar as noise is concerned.

1.1 Precautions. Adherence to the ambient temperature specified in 3.1 is emphasized as an important consideration of this method. It is also necessary, in making noise measurements, using the apparatus of this method, to delay reading the noise meter for a period of time no less than four times the effective time constant of the detector to allow the meter sufficient time to reach at least 98 percent of a representative average value. The effective time constant of the apparatus is normally adjusted to a value close to 1 second and therefore, a minimum time delay of 4 seconds is normally required for the noise meter to indicate a valid average. Immediately after this 4-second delay, the meter should be read even though it continues to fluctuate as the noise signal varies. Normally, the operator in making a visual reading of the fluctuating meter pointer, should estimate an average for a short duration, in the order of ½ to 1 second.

2. **APPARATUS.** Noise measurements shall be made on Quan-Tech Laboratories, Inc. Model 315 Resistor-Noise Test Set, or equal, built in conformance with specifications recommended by the National Bureau of Standards (NBS) and detailed in a report entitled "A Recommended Standard Resistor-Noise Test System," by G. T. Conrad, Jr., N. Newman, and A. P. Stansbury published in the IRE Transactions of the Professional Group on Component Parts, Volume CP–7, Number 3, September 1960. The NBS-test system provides a means for establishing direct current through the resistor under test and measuring the resutling dc voltage and noise voltage appearing at the terminals of the resistor. These two voltages are indicated simultaneously on scales calibrated in db. Instrumentation is so arranged that the associated value
in-a-decade" index may be readily determined in accordance with 3.3.

2.1 **Test system.** The test system shall be as shown in the simplified block diagram in figure 308–1. The dc portion of the system consists of a variable dc power supply and a dc vacuum-tube voltmeter (VTVM). The alternating-current (ac) portion of the system consists of a calibration signal source and an indicating amplifier. The interconnecting leads, as well as the resistor under test, should be adequately shielded.

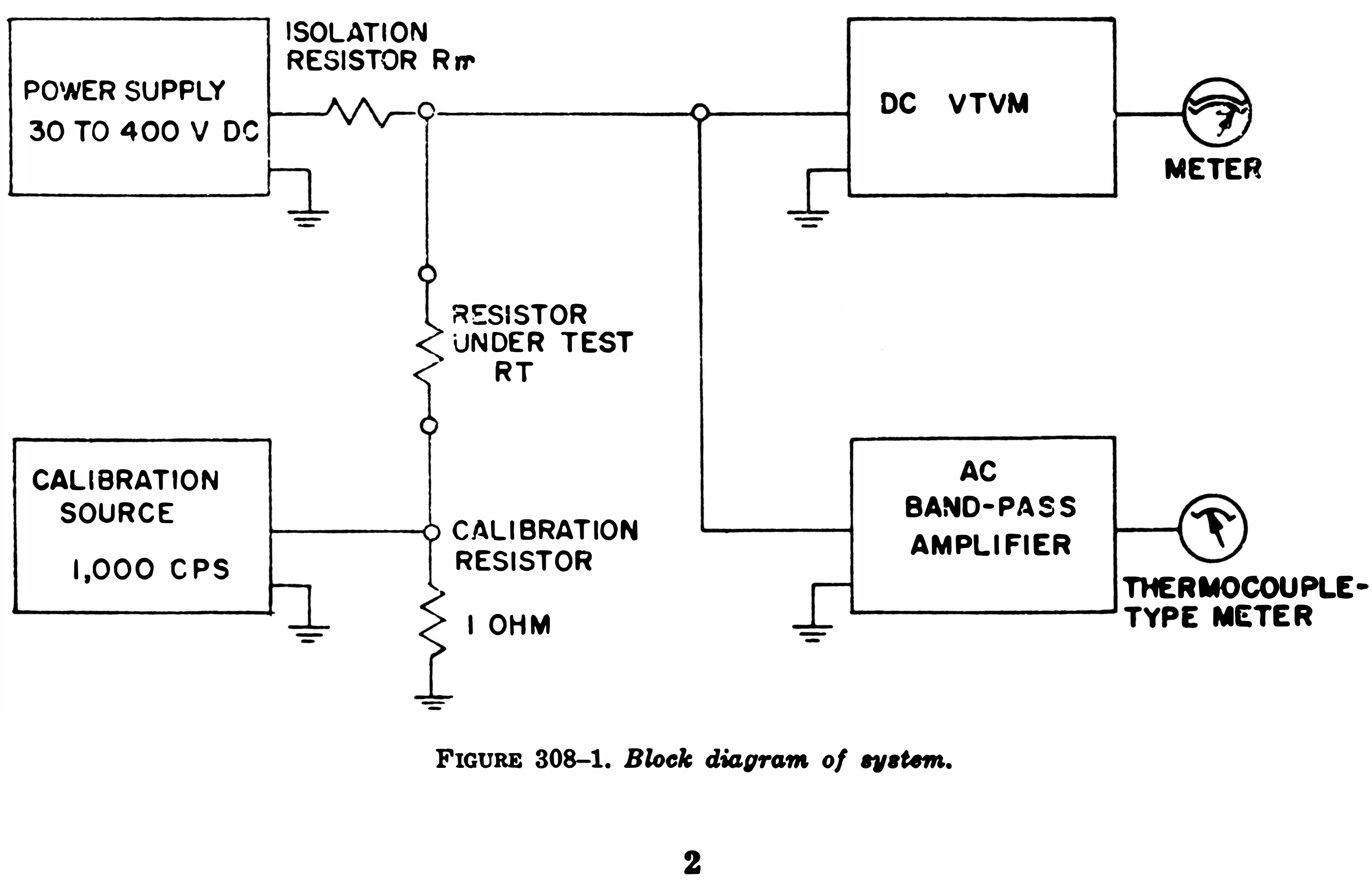

FIGURE 308–1. *Block diagram of system.*

2.1.1 *Dc-measurement considerations.* The variable dc power supply furnishes dc loading power through an isolation resistor to the resistor under test. The isolation resistor prevents noise, appearing at the terminals of the resistor under test, from being severely attenuated by the very low, parallel impedance presented by the output terminals of the dc power supply. The isolation resistor must be free of current noise. Quiet wirewound-type resistors are suitable. One of four values for the isolation resistor, Rm, (1,000 ohms, 10,000 ohms, 100,000 ohms, or 1 megohm (mego)) is selected, depending on the resistance of the resistor under test, RT. The dc voltage appearing across the resistor under test is indicated by the dc VTVM. The meter has two scales—one showing the dc voltage across the resistor under test, V, and the other indicating the quantity $D=20 \log V$, in db. The db scale simplifies computation of the current-noise index. The choice of value of the dc voltage is not critical, however, to avoid subjecting the resistor under test, and the isolation resistor as well, to excessive dc power dissipation or voltage, or both, standard nominal values of dc voltage and values for the isolation resistor are given in table 308–1.

2.1.2 *Ac - measurement considerations.* Noise voltage appearing at the terminals of the resistor under test is amplified and its rms magnitude is shown by the ac indicating amplifier. The indicating amplifier consists of a high-gain, low-noise amplifier, a filter, an rms detector, and an output meter. The filter restricts the frequency response of the amplifier to a flat-top, 1,000-cps pass band, geometrically centered at 1,000 cps. The output-meter scale, like that of the dc VTVM, is calibrated in db to simplify calculations.

2.1.3 *Calibration technique.* The calibration technique consists of first applying a predetermined value of 1,000-cps, sine-wave signal across a 1-ohm resistor located in series with the resistor under test, and then adjusting the gain of the amplifi
of a variable attenuator, until the output meter deflects to the "calibrate" line. This procedure standardizes the gain of the system and calibrates the indicating amplifier. It should be noted that since the calibration setting depends upon the impedance at 1,000 cps of the resistor under test, resistors having the same dc resistance may not calibrate alike. The resistance of the calibration resistor (1 ohm) is considered negligible compared to that of any resistor under test (100 ohms to 22 mego); therefore, the effect of the calibration voltage is equivalent to that of the calibration voltage appearing at the terminals of a zero-impedance generator located in series with the resistor under test. The magnitude of the calibration voltage is so chosen that the indicated output is equal to that which would be obtained if the calibration voltage were a noise voltage having an rms value of 1,000 uv in a decade. Such a signal should produce a reading of 60 db when the system is properly calibrated; thus, 0 db means 1 uv in a decade.

2.2 **Synopsis.** To summarize, this apparatus provides a measure of the rms value of the current-noise voltage generated in the resistor under test and transmitted in a frequency decade. The calibration technique refers the measured noise voltage to the terminals of an essentially zero-impedance noise-voltage generator located in series with the resistor under test. The noise voltage so measured, when corrected for the presence of system noise, is the "open-circuit" current-noise voltage of the resistor under test. Since both the current-noise voltage and dc voltage are expressed in db, the value of the "microvolts-per-volt-in-a-decade" index is obtained by subtracting the dc reading from the corrected noise reading. The corrected noise reading is discussed in 3.3.

3. PROCEDURE

3.1 Operating conditions. The test shall be performed at an ambient temperature of 25°±2° C., unless otherwise specified. The specimen under test shall be stabilized at room ambient temperature prior to test. No special preparations of the specimen are required other than that its leads be clean. Standard operating conditions, based on the resistance value of the specimen to be tested, are given in table 308–1. The values of the isolation resistor, RM, and the dc voltage, V, should be observed, although they are not critical, because the index is reasonably independent of the values of the isolation resistor and the dc voltage over a broad range. Therefore, it is not necessary to obtain the exact value of dc voltage given in table 308–1, rather to set it near the value, and to read carefully and record its value at the time of the measurement. In no case shall the ratings of the resistor under test be exceeded.

3.2 Measurements. After the operating conditions have been established, the measurement operation shall be performed in three steps, as follows:

(1) Calibration (see 3.2.1).

(2) Measurement of system noise (see 3.2.2).

(3) Simultaneous measurement of the dc voltage and the resulting total noise (see 3.2.3).

Generally, the measurements should be made in the order listed. The precautions in 1.1 should be observed.

3.2.1 *Calibration.* The calibration technique (see 2.1.3) standardizes the gain of the ac system for the particular resistor under test. For the noise measurements in steps 2 and 3 which follow, the sum of the ac attenuator setting and the ac meter reading, in db, is a direct indication of the noise present in terms of an "open-circuit' 'rms noise vol age appearing across the terminals of the resistor under test.

TABLE 308–1. *Standard operating conditions*

Resistance		Resistors ½ watt and higher			Resistors ¼, ⅛, and 1/10 watt		
Resistor under test (Rt)	Isolation resistor (Rm)	20 log V (D)	Dc voltage [1] (V)	Dc power dissipation (Pdc)	20 log V (D)	Dc voltage [1] (V)	Dc power dissipation (Pdc)
Ohms	*Ohms*	*db*	*Volts*	*Milliwatts*	*db*	*Volts*	*Milliwatts*
100	1,000	10.1	3.2	100	10.1	3.2	100
120	1,000	11.6	3.8	120	10.9	3.5	100
150	1,000	13.5	4.7	150	11.8	3.9	100
180	1,000	15.1	5.7	180	12.5	4.2	100
220	1,000	16.9	7.0	220	13.4	4.7	100
270	1,000	18.3	8.2	250	14.3	5.2	100
330	1,000	19.2	9.1	250	15.1	5.7	100
390	1,000	19.9	9.9	250	15.8	6.2	100
470	1,000	20.7	10.8	250	16.7	6.9	100
560	1,000	21.4	11.8	250	17.5	7.5	100
680	1,000	22.3	13.0	250	18.3	8.2	100
820	1,000	23.1	14.3	250	19.2	9.1	100
1,000	1,000	24.0	15.8	250	20.0	10.0	100
1,200	1,000	24.8	17.3	250	20.8	11.0	100
1,500	1,000	25.8	19.4	250	21.7	12.2	100
1,800	1,000	26.6	21.2	250	22.5	13.4	100
2,200	1,000	27.4	23.4	250	23.4	14.8	100
2,700	10,000	28.3	26.0	250	24.3	16.4	100
3,300	10,000	29.2	28.7	250	25.2	18.2	100

TABLE 308-1. *Standard operating conditions*—Continued

Resistance		Resistors ½ watt and higher			Resistors ¼, ⅛, and 1/10 watt		
Resistor under (Rt)	Isolation resistor (Rm)	20 log V (D)	Dc voltage [1] (V)	Dc power dissipation (Pdc)	20 log V (D)	Dc voltage [1] (V)	Dc power dissipation (Pdc)
3,900	10,000	29.9	31.2	250	25.9	19.7	100
4,700	10,000	30.8	34.3	250	26.7	21.7	100
5,600	10,000	31.5	37.4	250	27.5	23.7	100
6,800	10,000	32.3	41.2	250	28.3	26.1	100
8,200	10,000	33.2	45.3	250	29.1	28.6	100
10,000	10,000	34.0	50.0	250	30.1	32.0	100
12,000	10,000	34.8	54.8	250	30.9	35.0	100
15,000	10,000	35.8	61.2	250	31.8	39.0	100
18,000	10,000	36.6	67.1	250	32.5	42.0	100
22,000	10,000	37.4	74.2	250	33.4	47.0	100
27,000	0.10 mego	38.3	82.2	250	34.3	52.0	100
33,000	0.10 mego	39.2	90.8	250	35.1	57.0	100
39,000	0.10 mego	40.0	98.7	250	35.8	62.0	100
47,000	0.10 mego	40.7	108	250	36.7	69.0	100
56,000	0.10 mego	41.5	118	250	37.5	75.0	100
68,000	0.10 mego	42.3	130	250	38.3	82.0	100
82,000	0.10 mego	43.1	143	250	39.2	91.0	100
0.10 mego	0.10 mego	44.0	158	250	40.0	100	100
0.12 mego	0.10 mego	44.8	173	250	40.8	110	100
0.15 mego	0.10 mego	45.8	194	250	41.7	122	100
0.18 mego	0.10 mego	46.5	212	250	42.5	134	100
0.22 mego	0.10 mego	47.5	234	250	43.4	148	100
0.27 mego	1.0 mego	38.6	85.0	26.8	38.6	85.0	26.8
0.33 mego	1.0 mego	40.0	99.0	29.7	40.0	99.0	29.7
0.39 mego	1.0 mego	41.0	112	32.2	41.0	112	32.2
0.47 mego	1.0 mego	42.1	127	34.3	42.1	127	34.3
0.56 mego	1.0 mego	43.1	143	36.5	43.1	143	36.5
0.68 mego	1.0 mego	44.2	161	38.1	44.2	161	38.1
0.82 mego	1.0 mego	45.1	180	39.5	45.1	180	39.5
1.0 mego	1.0 mego	46.0	200	40.0	46.0	200	40.0
1.2 mego	1.0 mego	46.8	218	39.6	46.8	218	39.6
1.5 mego	1.0 mego	47.6	240	38.4	47.6	240	38.4
1.8 mego	1.0 mego	48.0	250	34.7	48.0	250	34.7
2.2 mego	1.0 mego	48.0	250	28.4	48.0	250	28.4
2.7 mego	1.0 mego	48.0	250	23.2	48.0	250	23.2
3.3 mego	1.0 mego	48.0	250	18.9	48.0	250	18.9
3.9 mego	1.0 mego	48.0	250	16.0	48.0	250	16.0
4.7 mego	1.0 mego	48.0	250	13.3	48.0	250	13.3
5.6 mego	1.0 mego	48.0	250	11.2	48.0	250	11.2
6.8 mego	1.0 mego	48.0	250	9.2	48.0	250	9.2
8.2 mego	1.0 mego	48.0	250	7.6	48.0	250	7.6
10 mego	1.0 mego	48.0	250	6.2	48.0	250	6.2
12 mego	1.0 mego	48.0	250	5.2	48.0	250	5.2
15 mego	1.0 mego	48.0	250	4.2	48.0	250	4.2
18 mego	1.0 mego	48.0	250	3.5	48.0	250	3.5
22 mego	1.0 mego	48.0	250	2.8	48.0	250	2.8

[1] Dc voltage across the resistor under test for the measurement of total noise.

3.2.2 *System noise (S).* System noise is the background noise present when direct current is not present in the resistor under test. System noise is indicated after turning off the calibration voltage. The algebraic sum of the ac attenuator setting and the ac meter reading gives the magnitude of system noise, S, in db.

3.2.3 *Total noise (T).* Both the dc voltage and the total noise are measured simultaneously. The value of dc voltage is given in table 308–1. The application of excessive dc voltage should be avoided by setting the dc voltage control to its minimum before applying the voltage, and when the voltage is applied, it should be increased to the desired value. The magnitude of the dc voltage is given by the sum, D, of the dc attenuator setting and the dc meter reading, in db. D equals 20 log V, where V is the dc voltage, in volts, applied to the terminals of the resistor under test. The associated noise measurement indicates the total noise present, ie, the quadratic sum of the system noise and the current noise. This total noise is indicated by T, in db.

3.3 Determination of the "microvolts-per-volt-in-a-decade" index. The current-noise index to be compared with the required index (see 5) shall be computed from the three measured quantities S, T, and D, in accordance with the following formula.

$$\text{(Index), in db} = T - f(T - S) - D.$$

Where:

$$f(T - S)\text{, in db} = -10 \log \left[1 - 10^{-(T-S)/10}\right].$$

The quantity f(T–S) is a correction for the presence of system noise while T is being measured. Values of f(T–S) are given in table 308–2 as a function of T–S. The quantity T–S represents the indicated increase in noise resulting from the presence of direct current. When this increase, T–S, is greater than 15.0 db, then f(T–S) is essentially zero, and T alone is the measure of current noise.

4. ERRORS. Accuracy and repeatability of determinations of the current-noise index are influenced by the combined effects of many factors including the following — characteristics of the test set, ambient temperature, inherent fluctuations in current noise, relative magnitude of current noise as compared to system noise, and delay between the application of dc voltage and observation of meter deflection. Therefore, in the interest of a better understanding of the significance of the measurement, a discussion of errors is included. The erro associated with the determination of the index is a function of two independent errors, one a bias-type or constant error, and the other a random-type or variable error. The bias eror is constant for any particular measuring condition. The maximum bias error introduced by the test set should not exceed 0.4 db. A conservative estimate of the bias error introduced by the permissible departure of ambient temperature from 25° C., as stated in 3.1, is at most 0.2 db. The "worst case" bias error for these two factors is the sum of their absolute values, 0.6 db. Although the bias error for any particular measurement is not known, for purposes of this discussion the "worst case" condition is assumed, and 0.6 db will be considered the magnitude of bias error associated with the index. The random error associated with the index is that of the current noise, [T — f(T–S)]. The index will be considered for two cases; the more simple case where the current noise is relatively large, ie, $T - S > 15.0$ db for which $f(T - S) \cong 0$, and therefore current noise is represented by T alone; and the second case where the current noise is not relatively large and is represented by [T—f(T—S)], with f(T—S) being significant. In either case, the probable error of the index is approximately equal to the error component which predominates,

TABLE 308-2. *Correction factor for presence of "system noise"*

T-S db	f(T-S) Correction factor	T-S db	f(T-S) Correction factor
1.0	6.9	5.4	1.4
1.1	6.5	5.5	1.4
1.2	6.2	5.6	1.4
1.3	5.9	5.7	1.3
1.4	5.6	5.8	1.3
1.5	5.3	5.9	1.3
1.6	5.1	6.0	1.2
1.7	4.9	6.1	1.2
1.8	4.7	6.2	1.2
1.9	4.5	6.3	1.1
2.0	4.3	6.4	1.1
2.1	4.1	6.5	
2.2	3.9	to	1.0
2.3	3.8	6.9	
2.4	3.6	7.0	
2.5	3.5	to	0.9
2.6	3.4	7.3	
2.7	3.3	7.4	
2.8	3.2	to	0.8
2.9	3.1	7.9	
3.0	3.0	8.0	
3.1	2.9	to	0.7
3.2	2.8	8.5	
3.3	2.7	8.6	
3.4	2.6	to	0.6
3.5	2.5	9.3	
3.6	2.4	9.4	
3.7	2.4	to	0.5
3.8	2.3	9.9	
3.9	2.2	10.0	
4.0	2.2	to	0.4
4.1	2.1	11.5	
4.2	2.0	11.6	
4.3	2.0	to	0.3
4.4	1.9	12.7	
4.5	1.9	12.8	
4.6	1.8	to	0.2
4.7	1.8	14.5	
4.8	1.7	14.6	
4.9	1.7	to	0.1
5.0	1.6	15.0	
5.1	1.6		
5.2	1.5	>15.0	≅0
5.3	1.5		

whether it be bias error or random error. For the first case, the only significant quantity which varies is T, and therefore the random-error component of the index error is equal to the random error associated with the measurement of the total noise, T. The random error of T is evidenced by fluctuations of the meter pointer and tends to have a normal distribution. The magnitude of the probable random error of T cannot be given explicitly because its value is necessarily a function of the resistor under test and must be determined from measurements. The probable random error of T for different resistors may range from values as low as approximately 0.2 db to values as high as several db in resistors having large noise variations. For resistors having a probable random error of T less than 0.6 db, the probable error of the index is approximately equal to the bias error, assuming the bias error is the "worst case," ie, 0.6 db. This means that on the average, one-half of the measurements would have an error no greater than 0.6 db. On the other hand, when the probable random error of T is greater than the bias error, the probable error of the index is equal to that of T. For the second case, the probable random-error component of the index is greater than that of T alone. This follows because the magnitude of current noise is determined from the difference between two measurements, T and S, each of which fluctuates, rather than from T alone. Measurements indicate that the probable random error of S should be in the order of 0.2 db. Assuming that this is the case, the probable random-error component of the index is approximately double that of T for the measurement condition T — S = 3 db, and approximately four times that of T for the condition T — S = 1.5 db. The limit of sensitivity for measuring the current-noise index is approached as the current noise approaches values to small to cause an increase as much as 1.0 db, ie, T–S equal to 1.0 db. However, the test method may serve as a qualitative means for comparing resistors having relatively low values of current noise where T — S is less than 1.0 db. Another possible source of measurement uncertainty is the transitory variations in current noise which may immediately follow application of dc voltage. Certain types of resistors tend to display very little, if any, transitory variations, whereas other types tend to display such variations to a measureable degree. For those resistors which exhibit such variations, the current noise usually settles to a more stable value after a short time, from 1 to several seconds. In some cases, the current-noise variations may continue to be relatively large and unstable for extended periods of time. Such resistors are usually very noisy. By adhering to the precautions regarding the procedures stated in 1.1, the effects of such variations on repeated measurements are reduced.

5. SUMMARY. The following requirement and details must be provided when this method is specified.

(a) Required values of the "microvolts-per-volt-in-a-decade" index (see 3.3).
(b) Ambient temperature, if other than that specified (see 3.1).
(c) Value of dc voltage, if other than those stated in table 308–1 (see 2.1.1 and 3.1).

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