JEDEC STANDARD

The Measurement of Transistor Equivalent Noise Voltage and Equivalent Noise Current at Frequencies of up to 20 kHz

JESD354

(Previously known as RS-354 and/or EIA-354)

APRIL 1968 (Reaffirmed: April 1981, April 1999, March 2009)

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EIA STANDARD

for

The Measurement of Transistor Equivalent Noise Voltage and Equivalent Noise Current at Frequencies up to 20 kHz

ELECTRONIC INDUSTRIES ASSOCIATION
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THE MEASUREMENT OF TRANSISTOR EQUIVALENT NOISE VOLTAGE AND EQUIVALENT NOISE CURRENT AT FREQUENCIES UP TO 20 kHz

(From Standards Proposal No. 963, formulated under the cognizance of JEDEC Committee JS-9 on Industrial Signal Transistors.)

1. INTRODUCTION

The following noise measurement method applies to transistors whose noise has a Gaussian power distribution, to transistors whose noise has a flat (white) power distribution, and to transistors whose noise has a 1/f (power inversely proportional to frequency) power distribution.

Figure 1 shows a suitable method for measuring the transistor equivalent noise voltage and equivalent noise current at frequencies equal to or less than 20 kHz. The values for the driving source impedance (as seen by the transistor), Z_s, the d-c operating conditions, and free-air, lead or case temperature will depend upon the application and upon the optimum conditions for any particular device. These quantities, as well as the test frequency, should be specified. Common-emitter (common-source) configuration is assumed unless otherwise indicated.

1.1 Definitions

"e_n" is the equivalent noise voltage for unity bandwidth. "$(\overline{e_n^2})^{1/2}$" represents the spectral density of the equivalent short-circuit noise voltage generator at the input of the transistor, as shown in Figure 2, at a specified frequency and bandwidth, expressed in units of volts/$\sqrt{\text{hertz}}$.

"i_n" is the equivalent noise current for unity bandwidth. "$(\overline{i_n^2})^{1/2}$" represents the spectral density of the equivalent open-circuit noise current generator at the input of the transistor, as shown in Figure 2, at a specified frequency and bandwidth, expressed in units of amperes/$\sqrt{\text{hertz}}$.

2. GENERAL

The test set-up must be very well shielded, grounded, and securely interconnected to prevent pick-up of unwanted signals and generation of additional noise.

2.1 Signal Generator

The signal generator is a sine-wave oscillator capable of operation up to 20 kHz.

2.2 Bias Supplies

Batteries or low-ripple d-c supplies should be used. All biases applied should be bypassed for both radio and audio frequencies.

2.3 Amplifier

The amplifier noise should be such that with the signal generator turned off, any transistor under test gives at least an increase of 15 dB above the reading due to the post amplifier itself with no transistor in the test circuit.

Heterodyne-type post amplifiers may be used but careful attention must be paid to the image and other spurious responses which can be encountered with such amplifiers. These spurious responses must be made negligible or must be accounted for in the measurement.

To provide for the crest factor of the noise, the amplifier must be essentially linear from the indicated RMS level to a minimum of 10 dB above the indicated RMS level.

2.4 System Pass-Band

The system pass-band which includes the transistor under test shall be adjusted by means of filters so that the response to white and/or 1/f noise would be the same to within the accuracy desired. Analysis of such filter systems are quite complicated; however, the following two systems have been analyzed:

1. With 1/f noise voltage applied to a single-section resonant filter having a Q of 6, the indicated noise voltage density will be 2.2% lower than the true spot noise voltage density at the resonant frequency of the filter. The equivalent white-noise bandwidth of the filter is 1.57 times the 3-dB bandwidth.[1]

2. With 1/f noise voltage applied to a maximally flat four-section filter having a white noise bandwidth numerically equal to the geometric center frequency of the filter, the indicated noise voltage density will be 1.9% lower than the true spot noise voltage density at the geometric center frequency. The equivalent white-noise bandwidth of the filter is 1.025 times the 3-dB bandwidth.[2]

2.5 Noise Detectors[3,4]

The noise detector must respond to the true RMS value or average value of the applied signal. If an average type detector is used, the RMS value indicated for noise will be 1.05 dB low. The integration

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[1]Valley and Wallman, *Vacuum Tube Amplifiers*, Radiation Lab. Series, Vol. 18, p. 169, 1948.

[2]A. Conrad, et al, *A Recommended Standard Resistor Noise Test System*, IRE Trans. of P.G. on Component Parts, Vol. CP-7, No. 3, September, 1960.

[3]W. R. Bennett, *Electrical Noise*, McGraw Hill, p. 45, 1960.

[4]A. van der Ziel, *Noise*, Prentice Hall, Chapter 13, 1956.

time should be as long as practical in accordance with the accuracy required as determined by the following equations:

True RMS Detector

For total integration time, t

$$\sigma = \frac{1}{\sqrt{Bt}}$$

For time τ = time constant

$$\sigma = \frac{1}{\sqrt{2B\tau}}$$

Averaging Detector (Linear Full-Wave Detector)

$$\sigma = \frac{1}{\sqrt{4Bt}}$$

$$\sigma = \frac{1}{\sqrt{8B\tau}}$$

where σ = the one-sigma deviation of the RMS value from the long-time average

B = the equivalent system noise bandwidth in hertz

t = total integration time in seconds

τ = simple RC time constant

3. TRANSISTOR UNDER TEST

The transistor under test shall be inserted in an amplifier circuit having the general configuration shown in Figure 1. A similar configuration in which the transistor is operated in the common-base (common-gate) or common-collector (common-drain) connection may be used.

4. METHOD OF TEST

4.1 Measurement of e_n

The driving source admittance is selected such that $\left(\frac{4kT}{|Y_s|}\right)^{1/2} \ll e_n$.

The attenuator is adjusted to give a convenient reading on the noise detector. The signal voltage, V_g, is adjusted such that the output voltage, V_{02}, is at least ten times as large as the output voltage, V_{01}, corresponding to zero-signal voltage. Thus, the equivalent noise voltage is:

$$\left(\overline{e_n^2}\right)^{1/2} = \frac{V_{01}}{V_{02}} \left(\frac{V_g}{\sqrt{B}}\right)$$

where B = the equivalent system noise bandwidth in hertz

k = Boltzman's constant 1.38054 X 10^{-23} J/deg

T = Absolute temperature of R_s in ^oK

V_g = Signal generator voltage

V_{02} = Output voltage

V_{01} = Output voltage at zero signal voltage

Y_s = Driving source admittance ($G_s \pm jB_s$) correspondingly

Z_s = Driving source impedance ($R_s \pm jX_x$) = $1/Y_s$

4.2 Measurement of i_n

The attenuator is adjusted to give a convenient reading on the noise detector. The signal voltage, V_g, is adjusted such that the output voltage, V_{02}, is at least ten times as large as the output voltage, V_{01}, corresponding to zero-signal voltage. Thus, the equivalent noise current is:

$$\left(\overline{i_n^2}\right)^{1/2} = \left[\left(\frac{V_{01}}{V_{02}} \frac{V_g}{|Z_s|} \frac{1}{\sqrt{B}}\right)^2 - \frac{4kTR_s}{|Z_s|^2} - \frac{\overline{e_n^2}}{|Z_s|^2}\right]^{1/2}$$

As Z_s is increased, the values of the second and third terms decrease. But, V_{01} generally increases with Z_s, due to i_n. Hence, for large values of Z_s:

$$\left(\overline{i_n^2}\right)^{1/2} \cong \frac{V_{01}}{V_{02}} \frac{V_g}{|Z_s|} \frac{1}{\sqrt{B}}$$

where B = the equivalent system-noise bandwidth in hertz

k = Boltzman's constant = 1.38054 X 10^{-23} J/deg

T = Absolute temperature of R_s in ^oK

V_g = Signal generator voltage

V_{02} = Output voltage

V_{01} = Output voltage at zero-signal voltage

Y_s = Driving source admittance ($G_s \pm jB_s$) correspondingly

Z_s = Driving source impedance ($R_s \pm jX_s$) = $1/Y_s$

5. SYSTEM ACCURACY

System errors consist of the following:

1. Calibration errors
2. Pass-Band determination (see Section 2.4)
3. Meter deviation (see Section 2.5)
4. Amplifier noise will increase the noise measured by less than 0.1 dB if it is more than 15 dB below that of the transistor under test.

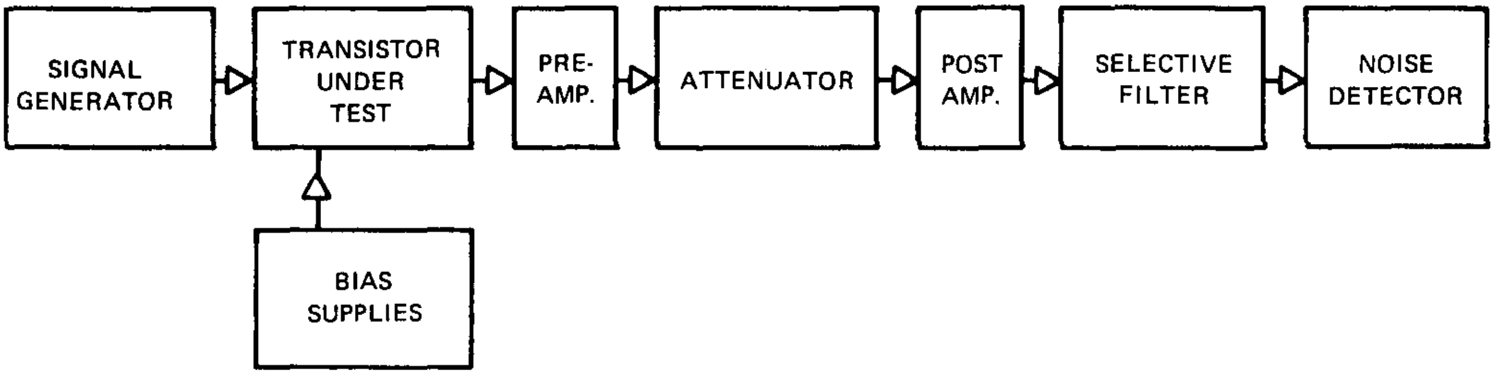

FIGURE 1

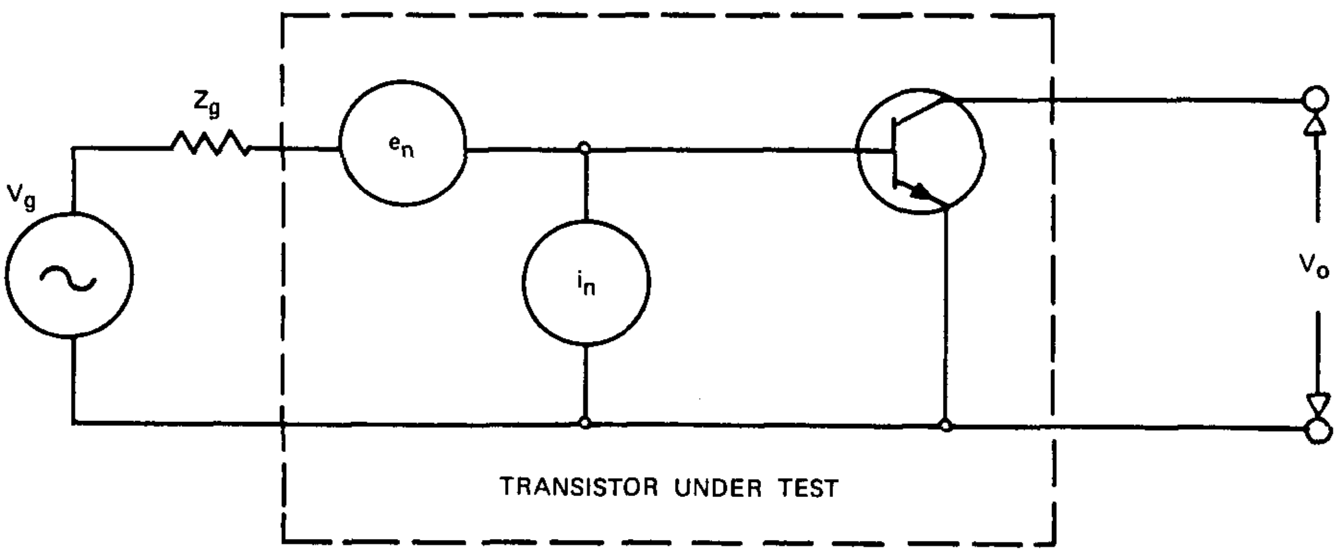

FIGURE 2

RELATED STANDARDS

In addition to this Standard the following EIA Standards pertinent to transistor noise figure measurements are available:

RS-283	Test Method for Transistor Noise Figure Measurements at Medium Frequencies (NEMA Publication No. SK 503-1963)	$ .60
RS-306	Measurement of Small Signal HF, VHF and UHF Power Gain of Transistors (NEMA Publication No. SK 506-1965)	.60
RS-311	Measurement of Transistor Noise Figure at HF and VHF (NEMA Publication No. SK 509-1965)	1.00
RS-353	The Measurement of Transistor Noise Figure at Frequences up to 20 kHz by Sinusoidal Signal Generator Method	.80

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