

Additional Noise Information

7-1. THERMAL NOISE

7-1a. The limitation in sensitivity of electronic systems due to noise has been known for many years. So called ideal amplifiers always have their sensitivity limit established by the thermal noise of the source resistance. Nyquist's formula based on the statistical theory of thermo-dynamics gives the noise voltage at the terminals of an impedance.

$$\overline{E_{th}^2}^{1/2} = (4k TBR)^{1/2} \quad (\text{Equation 7-1})$$

where

$$\overline{E_{th}^2}^{1/2} = \text{RMS value of the thermal noise voltage in volts.}$$

$$k = \text{Boltzman's constant: } 1.38 \times 10^{-23} \text{ (Joules/degree)}$$

$$T = \text{Temperature in degrees Kelvin}$$

$$B = \text{Bandwidth of the measuring system in Hz.}$$

$$R = \text{Real part of the impedance in ohms.}$$

7-2. CURRENT NOISE

7-2a. In addition to thermal noise, semiconductor bulk material exhibits noise whose magnitude is proportional to the average current in the sample. This statement may be rewritten to read noise whose magnitude is proportional to current density which leads to some interesting conclusions regarding current noise magnitude vs. component reliability.

7-2b. Unlike thermal noise, which is "white" or independent of frequency, resistor current noise has a decreasing power vs. frequency spectrum. The relationship of frequency, dc current, and current noise in a resistor (or other semiconductor bulk material) is given by the equation:

$$\overline{e(f)^2} = CI^\alpha f^{-\gamma} \quad (\text{Equation 7-2})$$

where:

$$\overline{e(f)^2} = \text{Mean square noise voltage in a one Hz bandwidth at center frequency, } f.$$

$$C = \text{Constant, determined by the physical and chemical properties of the resistor.}$$

$$I = \text{Average current in amperes}$$

$$f = \text{Frequency in Hz.}$$

$$\alpha = 1.4 \text{ to } 2.2 \text{ dependent upon the resistance material (Mean value 1.9)}$$

$$\gamma \cong 1.0$$

Thus for most purposes, equation 7-2 may be written:

$$\overline{e(f)^2} = \frac{CI^2}{f} \quad (\text{Equation 7-3})$$

showing the 1/f characteristics of current noise power spectral density.

Resistor current noise for a given bandwidth may be obtained by the integration of equation 7-3.

$$\overline{E_c^2} = \int_{f_1}^{f_2} \frac{1}{e(f)^2} df \quad (\text{Equation 7-4a.})$$

Since

$$e(f)^2 = CI^2 f^{-1}, \text{ then}$$

$$\overline{E_c^2} = \int_{f_1}^{f_2} CI^2 f^{-1} df \quad (\text{Equation 7-4b.})$$

$$\overline{E_c^2} = CI^2 \ln f \Big|_{f_1}^{f_2} \quad (\text{Equation 7-4c.})$$

$$\overline{E_c^2}^{1/2} = \left[CI^2 (\ln f_2 - \ln f_1) \right]^{1/2} \quad (\text{Equation 7-4d.})$$

or

$$\overline{E_c^2}^{1/2} = \left[CI^2 \ln \left(\frac{f_2}{f_1} \right) \right]^{1/2} \quad (\text{Equation 7-4e.})$$

It can be seen from equation 7-4e that bandwidths having equal ratios of upper to lower cutoff frequencies will contain equal noise powers.

7-3. INDEX: Standard Unit for Current Noise

7-3a. The National Bureau of Standards has recommended the unit, microvolts of noise per volt of dc applied in a decade of frequency (expressed in dB) as a standard for current noise in a resistor.

The above unit or INDEX is defined by:

$$\text{INDEX} = 20 \log \frac{\overline{E_c^2}^{1/2}}{V} \text{ dB (in a decade of frequency)} \quad (\text{Equation 7-5})$$

Therefore, equation 7-4e may be changed to:

$$\overline{E_c^2}^{1/2} = V 10^{\text{INDEX}/20} \left(\log \frac{f_2}{f_1} \right)^{1/2} \quad (\text{Equation 7-6})$$

where $\frac{\overline{E_c^2}^{1/2}}{V}$ = total RMS current noise voltage

V = dc voltage applied.

f_1 and f_2 = lower and upper effective bandpass limits.

Since current noise has a $1/f$ power characteristic, its effect will be masked by thermal noise at high frequencies and will become more predominate at low frequencies. The 1KHz center frequency selected for INDEX measurement provides a compromise between high sensitivity to $1/f$ noise at a very low frequency and a practical time requirement for measurement.

7-4. CURRENT NOISE VS: PHYSICAL STRUCTURE INTEGRITY

7-4a. The dependency of current noise upon average current density in a semiconductor bulk material leads to the logical conclusion that noise testing will be effective in screening many kinds of physical structures and contacts other than resistor elements as such. A few of the areas in which noise testing has been shown to be economical and effective are;

1. Current path uniformity in all semiconductor devices (ie. diodes, LEDs, transistors, ICs.)
2. Metallic lead connection to resistive elements extending to include connections made to the bulk material of all of the semiconductor devices.
3. Fixed metallic to metallic contacts such as made by welding or soldering.
4. Intermittent or moveable contacts such as with connectors and relays.
5. Detection of unwanted conduction paths such as dielectric breakdown and contamination of semiconductor junctions.

7-5. DIODE AND OTHER COMPONENT NOISE TESTS ON THE MODEL 315B

7-5a. The Model 315B will be found to be a very versatile piece of noise measuring equipment if a little time is spent in gaining understanding of the electronic circuits. The sensitivity or system noise is sufficiently low that practically any two terminal devices can be effectively tested providing the proper set-ups are used.

7-5b. In general the dc capabilities of the device to be tested and the dynamic impedance at the test conditions will determine the front panel control settings of the Model 315B. An external ammeter can be used to measure current at a given set of conditions (and then removed for the noise test or approximate current levels may be obtained through the knowledge of open circuit voltage and isolation resistor values for each of the RESISTOR RANGE positions.

7-6. ADDITIONAL TECHNICAL DATA

7-6a. Following this section is a set of technical articles containing information and discussion pertinent to resistor noise measurements.