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58.2 Bipolar Noise

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Bipolar transistors and other electronic devices generate internal electrical noise. This limits the device operation at a small-signal range. There are a few different sources of noise, such as thermal noise, shot noise, flicker noise or $1/f$ noise, burst noise or "popcorn noise," and avalanche noise [1], [6].

Thermal Noise

Thermal noise is created by random motion of charge carriers due to the thermal excitation [1]. This noise is sometimes known as the Johnson noise. The thermal motion of carriers creates a fluctuating voltage on the terminals of each resistive element. The average value of this voltage is zero, but the power on its terminals is not zero. The internal noise voltage source or current source is described by Nyquist equation

$$\overline{v_n^2} = 4kTR\,\Delta f \qquad \overline{i_n^2} = \frac{4kT\,\Delta f}{R} \tag{58.75}$$

where k is the Boltzmann constant, T is absolute temperature, and $4kT$ is equal to $1.66 \times 10^{-20}\,\mathrm{V \cdot C}$ at room temperature. The thermal noise is proportional to the frequency bandwidth Δf. It can be represented by the voltage source in series with resistor R, or by the current source in parallel to the resistor R. The maximum noise power can be delivered to the load when $R_L = R$. In this case maximum noise power in the load is $kT\,\Delta f$. The noise power density $dP_n/df = kT$, and it is independent of frequency. Thus, the thermal noise is the white noise. The rms noise voltage and the rms noise current are proportional to the square root of the frequency bandwidth Δf. The thermal noise is associated with every physical resistor in the circuit. In a bipolar transistor, the thermal noise is generated mainly by series base, emitter, and collector resistances.

Shot Noise

Shot noise is associated with the carrier injection through the pn junction. In each forward biased junction, there is a potential barrier that can be overcome by the carriers with higher thermal energy. This is a random process and the noise current is given by

$$\overline{i_n^2} = 2qI\,\Delta f \tag{58.76}$$

where q is the electron charge and I is the forward junction current. The shot noise depends on the thermal energy of carriers near the potential barrier. Similar to the thermal noise, the shot noise has constant and frequency-independent noise power density. It is also the white type of noise. Shot noise is usually considered as a current source connected in parallel to the small-signal junction resistance.

Flicker—1/*f* Noise

Flicker noise in bipolar transistors is associated mainly with generation-recombination centers [2]–[4]. Free carriers are randomly trapped and released by these centers. This is a relatively slow process and it cannot be seen at high frequencies. The flicker noise is always associated with a current and is approximated by

$$\overline{i_n^2} = K_F I^{A_F} \frac{\Delta f}{f} \tag{58.77}$$

where K_F is the flicker-noise coefficient and A_F is the flicker-noise exponent. Both K_F and A_F are device dependent. With modern technology the number of trapping centers can be significantly lowered, thus the effect of flicker noise is meaningfully reduced. The $1/f$ nature of the flicker noise is such that sometimes this noise component is considered to be responsible for the long term device parameter fluctuation.

Other Types of Noise

The burst or "popcorn" noise is another type of noise at low frequencies [3], [4]. This noise is not fully understood, but it seems that it is related to the heavy-metal ion contamination. The burst noise looks, on an oscilloscope, like a square wave with the constant magnitude, but with random pulse widths. It has significant effect at low frequencies. In audio amplifiers the burst noise sounds as random shoots, which are similar to the sound associated with making popcorn. Obviously, bipolar transistors with large burst noise must not be used in audio amplifiers and in other analog circuitry. The burst noise is often approximated by

$$\overline{i_n^2} = K_B \frac{i_D^{A_B}}{1 + \left(\dfrac{f}{f_B}\right)^2} \Delta f \tag{58.78}$$

where K_B, A_B, and f_B are experimentally chosen parameters, which usually vary from one device to another. Furthermore, a few different sources of the burst noise can exist in a single transistor. In such a case, each noise source should be modeled by a separate Eq. (58.78) with different parameters (usually different corner frequency f_B).

Where R_n and R_s are shown in Fig. 58.66(b). It is customary to use 290 K as the reference room temperature for the noise temperature calculations.

Noise Figure

The noise figure is the ratio of the output noise of the actual two-port to the output noise of the ideal noiseless two-port when the resistance of the signal source R_s is the only noise source.

$$F = 10 \log\left(\frac{\text{total output noise}}{\text{output noise due to the source resistance}}\right) \tag{58.83}$$

The noise figure F is related to the noise resistance and the noise temperature in the following way:

$$F = 10\log\left(1 + \frac{R_n}{R_s}\right) = 10\log\left(1 + \frac{T_n}{290\ \text{K}}\right) \tag{58.84}$$

The noise figure F is the most common method of noise characterization.

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