# Correspondence

## On the Thermal Noise Introduced by a Resistor in a Circuit

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### I. Introduction

In a previous paper [1] we showed that the thermal noise introduced by some resistors in some circuits diminishes when their values are increased. Others have obtained similar results for a different circuit [2]. We show here the following general result: the noise introduced by an arbitrary resistor in an arbitrary linear circuit diminishes as the resistor value increases, provided this value is high enough.

Let $R$ be an arbitrary resistor, connected in an arbitrary linear circuit (Fig. 1). The resistor sees an impedance $Z(s)$. Let $H'(s)$ be the transfer function from the terminals of the resistor to the output of the circuit. The output noise voltage spectral density due to the resistor is

$$V_{on}(f) = V_n \cdot |H(j2\pi f)| = V_n \cdot \left| \frac{Z(j2\pi f)}{Z(j2\pi f) + R} \cdot H'(j2\pi f) \right|. \quad (1)$$

Here $V_n$ is the thermal noise voltage spectral density, and $H(s)$ is the transfer function for $V_n$. Because of the finite $Z(s)$, we have $H(s) \neq H'(s)$. If $R \gg |Z(j2\pi f)|$ we have

$$\begin{aligned} V_{on}(f) &\approx \frac{V_n}{R} \cdot |Z(j2\pi f) \cdot H'(j2\pi f)| \\ &= \frac{\sqrt{4kTR}}{R} \cdot |Z(j2\pi f) \cdot H'(j2\pi f)| \\ &= \sqrt{\frac{4kT}{R}} \cdot |Z(j2\pi f) \cdot H'(j2\pi f)|. \end{aligned} \quad (2)$$

It can be observed that, because $H'(s)$ and $Z(s)$ are independent of $R$, the noise diminishes as $R$ increases.

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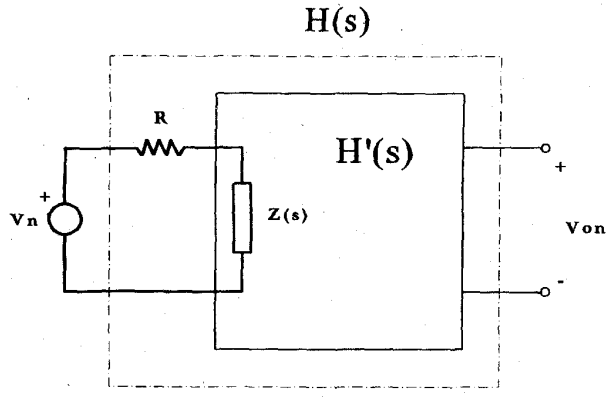


Fig. 1. Diagram showing the resistor $R$, the impedance $Z(s)$ and the thermal noise voltage spectral density $V_n$.

This result is intuitively reasonable. If the resistor is withdrawn, which implies a very high resistance value, it no longer contributes to the total noise of the circuit. This by not means implies that a large resistor can be beneficial at any port of a circuit. In particular, a large resistor in series with a voltage signal would degrade the signal-to-noise ratio. Equation (2) shows that large resistors are not necessarily a problem because of their thermal noise. Their contribution to the output noise voltage depends on the input impedance and transfer function seen from its terminals.

### References

[1] M. Vargas and R. Pallás-Areny, "The seemingly paradoxical noise behavior of some active circuits," *IEEE Trans. Instrum. Meas.*, vol. 43, pp. 764–767, Oct. 1994.

[2] *Linear Design Seminar*, Reference Book, Texas Instruments, pp. 2.78–2.86, 1993.