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This Week's Citation Classic

van der Ziel A. Thermal noise in field-effect transistors.
Proc. IRE 50:1808-12, 1962.
[Electrical Engineering Dept., Univ. Minnesota, Minneapolis, MN]

The fundamental noise in a junction field-effect transistor is identified as thermal noise of the voltage-controlled resistor describing the device. An expression for the noise intensity in the short-circuited output is evaluated. Other noise sources are indicated. [The *SCI*® indicates that this paper has been cited in over 105 publications since 1962.]

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"At the time this paper was written, I was a professor of electrical engineering at the University of Minnesota, engaged in noise studies in solid-state devices under sponsorship of the US Army Electronics Command, Fort Monmouth, New Jersey. At that time, good junction field-effect transistors had become available and it was decided to carry out an experimental investigation on the noise in these devices. I was thereby helped by my colleague, E.R. Chenette, now at the University of Florida, and by my graduate student, W.C. Bruncke. Parallel to this, I carried out a theoretical investigation on the predominant noise.

"Shockley[1] had given a theory of the junction field transistor, in which he treated the device as an active voltage-controlled resistor. I decided to apply his model to calculate the noise of the device in terms of this model; this implied that the limiting noise was interpreted as thermal noise of the conducting channel. This worked out quite well, and I was able to give a general, rather simple formula for the noise intensity in the short-circuited output.

"At that time, a rival theory had been proposed[2] in which the noise was compared to that of a vacuum triode, so that it consisted of partly suppressed shot noise. Due to a coincidence, the noise expressions for the two models are numerically virtually identical, so that the experiments could not decide which model was applicable. I felt, however, that the shot noise model put the wrong physics into the theory. To quote from my paper: 'There is no physical basis for such a suggestion. For evidently the field-effect transistor operates on the principle of true conductance modulation, as Shockley's theory indicates. Generally one associates *thermal* noise with a true conductance and *not* shot noise. It is hard to see how shot noise could ever be generated and, if generated, how it could be partly suppressed. As this paper indicates, the assumption of thermal noise allows a straightforward explanation of the observed noise.'

"The theory was verified by Bruncke.[3] To obtain agreement between theory and experiment he had to take into account not only the thermal noise of the channel itself, but also the thermal noise of the series resistances on the source and drain side of the channel, respectively. The expressions for the noise in that case are already found in my 1962 paper.

"The paper continues to indicate other noise sources in the device, such as generation-recombination noise, flicker noise, and shot noise in the gate currents. These sources were studied subsequently by various authors. Thermal noise in the conducting channel is the fundamental noise source, however.

"Possible reasons for the popularity of this paper is that it solved the fundamental noise problem in field-effect transistors at the time it was needed and that it was the first paper that correctly interpreted the noise in these devices."

1. **Shockley W.** A unipolar field-effect transistor. *Proc. IRE* 40:1365-76, 1952.
[The *SCI* indicates that this paper has been cited in over 290 publications since 1961.]
2. **Lauritzen P O.** Field effect transistors as low-noise amplifiers. *1962 International Solid-State Circuits Conference: digest of technical papers.* New York: Lewis Winner, 1962. p. 62-3.
3. **Bruncke W C.** Noise measurements in field-effect transistors. *Proc. IEEE* 51:378-9, 1963.