# This Week's Citation Classic

**Clorfeine A S, Ikola R J & Napoli L S.** A theory for the high-efficiency mode of oscillation in avalanche diodes. *RCA Rev.* **30**:397-421, 1969.
[RCA Laboratories, Princeton, NJ]

**High-efficiency oscillations, previously observed in avalanche diodes and simulated with a computer, are explained by means of an analytic theory in which all the relevant physical processes are clearly displayed and tied together. It is shown how efficiencies of 50-60 percent can be achieved. [The *SCI*® indicates that this paper has been cited over 85 times since 1969.]**

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"In 1967, research on microwave oscillations in semiconductor diodes reverse-biased into their avalanche regions was being pursued in many laboratories. Simplified theory had predicted maximum efficiencies of 30 percent; however, detailed computer simulations at Bell Laboratories had shown that when all loss mechanisms were accounted for, no more than 12 percent could be expected. Actual laboratory results showed efficiencies lower yet with maximum achieved powers of a small fraction of a watt.

"In view of this background, results at RCA's David Sarnoff Research Center one afternoon seemed incredible. Sherman Weisbrod, a gifted technician working under the supervision of H.J. Prager and K. Chang, found that his power sensing elements were repeatedly burning out. Using larger elements and changing to other more appropriate instrumentation permitted peak power readings (made with short pulses to prevent diode burnout) to be obtained.

"None of us, including Weisbrod, initially accepted the results, which extended the power frontier for these devices by several orders of magnitude. Surely an attenuator had been mislabeled or some other instrument was misbehaving. But when others at RCA using different power-measuring schemes came up with similar results, doubt vanished. Powers of over 400 watts with efficiencies of 60 percent were indeed being obtained. This mode of operation was referred to variously as 'Anomalous,' 'High-efficiency.' 'Chang,' and eventually 'TRAPATT.'

"How to account for these results —which far exceeded even theoretical limits —became the task of my colleagues, Ray Ikola and Lou Napoli, and myself.

"Our sense of urgency was heightened by the knowledge that a group of outstanding researchers at Bell Laboratories was also feverishly attacking the problem. Also, they had the aid of fully developed computer programs that modeled avalanche diodes and, in fact, were then simulating oscillations with efficiencies as high as 26 percent. Other research teams were also hard at work.

"The coupled set of nonlinear differential equations that described the problem seemed to be intractable, even with simplifying assumptions. Finally, a series of breakthroughs—including the adoption of moving coordinates and an assumption of piecewise waveforms that were both amenable to analysis and self-consistent —led us to a theory that was published in the *RCA Review* in September 1969, more than two years after the experimental observations.

"The personal satisfaction of our team was enormous —we had taken a very surprising and difficult-to-explain phenomenon, persisted despite many false starts, and, finally, had come up with a simple and elegant analytic theory that was consistent with the measurables and led directly to useful design formulae. Also, we had done so ahead of our friendly rivals at Bell Laboratories and elsewhere. A subsequent RCA Achievement Award based largely on this work was further reason for gratification. The article's popularity likely results from its being the first reasonably comprehensive explanation of a device that captivated many researchers over the better part of a decade."