

McCumber D E & Chynoweth A G. Theory of negative-conductance amplification and of Gunn instabilities in "two-valley" semiconductors.
IEEE Trans. Electron Devices **13**:4-21, 1966.
[Bell Telephone Laboratories, Murray Hill, NJ]

A theory of negative-conductance amplification and of Gunn-effect oscillation in 'two-valley' semiconductors such as GaAs and InP that agrees well with experimental observations is presented. [The SCI® indicates that this paper has been cited over 225 times since 1966.]

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"When Ian Gunn reported he had discovered a current instability in the semiconductor crystal gallium arsenide, it drew widespread attention because it was potentially useful as a solid state microwave generator, and because there was uncertainty as to the cause of the effect.¹ Now, a widely accepted tradition of applied research is that better understanding of an effect facilitates more effective exploitation. The challenge was to figure out what caused the 'Gunn-effect.'

"One of us recalled two theoretical predictions of instabilities made three years earlier in England by Ridley and Watkins² and by Hilsum.³ Gunn originally concluded that these predicted effects required much higher electric field strengths than he used; however, the suggestive parallels begged for a definitive experimental test. Such a test might be to follow changes in the onset conditions for the instability as the crystal was subjected to steadily increasing hydrostatic pressure. Such an experiment was performed by Hutson, one of our colleagues.⁴ But Murphy's Law must have been operating—the experiments were surprisingly negative, so much so that there followed a period of more than a year in which innumerable possible causes for the instability were considered, some new instabilities were even invented, and an increasing number of

experimental studies were made. All to no avail. By the exhaustive process of elimination we were led back to suspect the pressure experiment. We repeated it with samples more carefully chosen to correspond in their conductivity to samples normally used for the Gunn-effect. This time it worked! As the pressure increased, the onset conditions changed as predicted by the theory.

"With the fundamental cause of the instability identified, it was of concern to show how completely its characteristics—its frequency, growth rate, amplitude, etc.—could be accounted for. A comprehensive mathematical analysis of the instability followed. The results were conclusive, but how could they be best conveyed to readers? The computer outputs were piles of numbers showing the time-development of field profiles, but somehow, a few extracted graphs could hardly capture the enormous output of the computer.

"Around that time (about 1965), computer-generated movies were just beginning to emerge. This was just the technique for showing the time-development of the field profiles. The editor of the special issue of the journal in which the paper was planned to appear was receptive to printing short sequences of the movies in the outer margins of the journal pages so that when they were finger-flipped, as in old-time flip movies, the reader could see the movie sequence for himself. We often wonder what influence this publishing innovation had in attracting attention to our paper, though we do like to think that the paper represented a turning point in the evolution of Gunn-effect devices.

"Since our publication, many others have gone on to improve upon the analysis and to invent new forms of the device. We believe our work represented a relatively early application of massive computer techniques to solid state device development, where exploratory evaluations of changing various material and device parameters could be made rapidly and informatively without having to rely entirely on the more traditional, time and manpower consuming experimental approach involving the preparation of large numbers of samples and their characterization."

1. **Gunn J B.** Microwave oscillations of current in III-V semiconductors. *Solid State Commun.* 1:88-91, 1963.
2. **Ridley B K & Watkins T B.** The possibility of negative resistance effects in semiconductors. *Proc. Phys. Soc. London* **78**:293-304, 1961.
3. **Hilsum C.** Transferred electron amplifiers and oscillators. *Proc. IRE* **50**:185-9, 1962.
4. **Hutson A R, Jayaraman A, Chynoweth A G, Coriell A S & Feldman W L.** Mechanism of the Gunn effect from a pressure experiment. *Phys. Rev. Lett.* **14**:639-41, 1965.