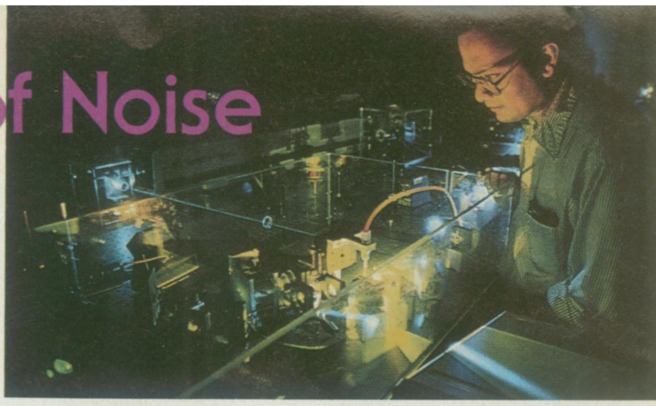
The Signal Value of Noise

Adding the right kind can amplify a weak signal

By IVARS PETERSON



Joe Schwartz/Georgia Tech

Rajarshi Roy operates a bistable ring laser to demonstrate that adding random noise to the system can enhance its response to a periodic external signal.

Radio listeners normally have nothing nice to say about static. This random crackling interferes with signals from favorite stations and often completely blankets the weak transmissions from distant broadcasters.

Yet under certain circumstances, noise can aid rather than hinder the detection of a weak, fluctuating signal. Researchers have discovered that an extra dose of noise actually permits certain types of detectors to pick up a signal initially too weak to trigger a response. Although the overall level of noise in the detector increases, the intensity of the detected signal goes up even more.

"That's very counterintuitive at first glance," says Rajarshi Roy, a physicist at the Georgia Institute of Technology in Atlanta. "Here you are with a [detector] that doesn't respond to a signal. Then you put in noise, and it begins to respond."

This amplifying effect, known as stochastic resonance, has recently surfaced in a number of electronic circuits and in specially contrived laser systems. Researchers are now pursuing the possibility of designing detectors and signal processors that specifically take advantage of noise to boost signals. Stochastic resonance may even play an important role in biological processes ranging from the way neurons function to the way the ear responds to sounds.

The concept of stochastic resonance emerged in 1981, when a group of Italian researchers proposed the idea to explain why ice ages seem to occur every 100,000 years or so. They initially argued that short-term, fluctuating forces, such as tides and sunspot activity, could enhance the periodic cooling and warming caused by a tiny wobble in the Earth's orbit at 100,000-year intervals. By itself, the wobble appears too small to induce such drastic changes in climate.

Researchers in Germany achieved the first laboratory demonstration of stochastic resonance in 1983, finding evidence for the effect in the behavior of an electronic system known as a Schmitt trigger.

In 1988, Roy and colleagues Bruce McNamara and Kurt Wiesenfeld revived interest in the topic by developing a theory to explain stochastic resonance and by reporting the first observation of the phenomenon in an optical device.

In their key experiment, the Georgia Tech group used a ring-shaped laser through which light could travel either clockwise or counterclockwise. When they injected some noise by introducing fluctuations into the electronic signals controlling the laser, they found that the laser light's direction would switch back and forth in time with an incoming, periodic signal normally too weak to influence the laser.

"We had no idea that we would actually see this happen in the laser system," Roy says.

The experiment stimulated a flurry of theoretical activity and a search for stochastic resonance in other physical systems, including a number of different electronic circuits. "The basic ingredients are generic enough that we expect it to occur in a wide variety of physical systems," Roy says.

To picture what happens in stochastic resonance, imagine a ball sitting in one of two overlapping wells separated by a small barrier. Such a bistable system can operate as a detector when a sufficiently strong external force — a signal — nudges the ball over the barrier into the second well (analogous to switching the direction in which light travels in a ring laser). If the force is too weak, the ball stays put and the system detects no signal.

In this scenario, noise — whether injected or natural — causes the wells to jiggle. Sometimes the jiggling is strong enough to nudge the ball from one well to the other, but this process occurs randomly.

A weak, incoming signal would gently rock the jiggling wells back and forth. Because the probability that the ball will switch from one well to the other is extremely sensitive to the apparent height of the barrier, and because that height varies slightly as the wells seesaw, the initially random switching rate becomes correlated with the weak, external signal.

In other words, the ball begins to flip back and forth between the wells in time with the external signal.

"You see a very, very large effect from a very weak, noisy signal," says Frank Moss of the University of Missouri at St. Louis, who has demonstrated the phenomenon in a number of electronic circuits.

"Of course, you can't arbitrarily introduce noise of any kind or any amount," Roy says. Add too little noise, and nothing happens. Add too much noise, and the noise drowns out the signal.

Researchers are now starting to explore potential applications of stochastic resonance in digital signal processing and for detecting weak signals. Adi Bulsara and his colleagues at the Naval Ocean Systems Center in San Diego, for example, are planning an experiment to demonstrate stochastic resonance in a single SQUID — a superconducting quantum interference device, generally used for detecting minute changes in magnetic fields. The possibility of increasing the sensitivity of such devices has major implications for geothermal prospecting, underwater surveillance and the detection of magnetic fields in biological systems, Bulsara says.

Stochastic resonance may also contribute to improvements in the performance of certain cameras and monitors. For example, a television screen contains an array of dots, or pixels, each of which acts as a detector by turning on or off in response to an external signal. If researchers could learn to control stochastic resonance, they might use the effect to improve the sensitivity and sharpness of such imaging arrays, Roy says.

Although scientists have yet to identify any natural phenomena that exhibit stochastic resonance, biological systems have many of the characteristics necessary for the effect to appear, Moss says.

Humans, for example, have an uncanny ability to pick out certain sounds against a noisy background. They can disentangle a conversation from the surrounding din or discern the pure, clear tone of a lone flute amid the collective voices of a symphony orchestra. Stochastic resonance may play a part in the signal processing needed to transmit the message from the eardrum to the brain.

Complex biological systems may have evolved to make use of noise for transmitting information, Moss suggests. "Nature," he says, "may have understood stochastic resonance long before we did." □