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Coming In Loud and Clear-Via Chaos

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factor for *myc* in the cell as well as in the test tube. "What regulates *myc* in vivo is kind of controversial," notes Marcu. That's at least partly due to the fact that the gene is turned on in many different kinds of cells in response to several different growth factors and other stimuli. As a result, Marcu explains, "the gene ends up being somewhat mosaic in the control sequences. This allows it to re-

spond to different players depending on which player is in town." It also makes life difficult for molecular biologists who are studying *myc* gene control, although cloning the PuF gene makes possible a variety of experiments to see if the protein does regulate *myc*.

But even if it doesn't, it might not be the end of the world for PuF/NM23 as a transcription factor. The sequence that binds the pro-

tein "is actually pretty common. It occurs in front of a variety of genes," says Levens. "Even if [PuF/NM23] is not used in *myc* control it might still be important" for regulating one or more of the others. While the goal judge hasn't yet signaled a hat trick, Postel's serendipitous finding could at least turn out to be a key assist toward understanding gene regulation.

—Jean Marx

## PHYSICS

### Coming In Loud and Clear—Via Chaos

When chaos theory was just coming into vogue, in the early 1980s, researchers delighted in its ability to describe with unprecedented mathematical rigor unkempt and seemingly random phenomena such as frost formation and variations in the intervals between heartbeats. But now the field is moving from theory toward application: Physicists and electrical engineers are devising new communication schemes that could harness simple chaotic systems to send private messages or more efficiently transmit information in the clear.

At first blush this may seem surprising, since chaos looks like the antithesis of intelligible communication. But that's precisely the rationale of one scheme, already developed into a working system at the Massachusetts Institute of Technology (MIT), which uses a chaotic signal to mask information in a private transmission. Another group of researchers, though, envisions a way to encode information in the chaotic signal itself by exploiting the hair-trigger sensitivity of chaotic systems to initial conditions. By nudging a chaotic circuit back and forth between two states, such a chaotic transmitter could generate binary code for digital communication.

Even exploiting chaos as a smoke screen isn't straightforward, as electrical engineers Kevin Cuomo and Alan Oppenheim of MIT report in the 5 July *Physical Review Letters*. To turn chaotic circuits into an experimental communication system, they needed a way to faithfully transmit a chaotic signal, which entails synchronizing the complex voltage and current fluctuations of the receiver circuit with those of the transmitter. That's a difficult task: Because of the sensitivity of chaotic systems to small differences in prior conditions, two apparently synchronized systems quickly drift out of step. But in 1989 physicists Louis Pecora and Thomas Carroll of the Naval Research Laboratory showed that certain pairs of distinct chaotic circuits indeed could be synchronized when linked by a common signal.

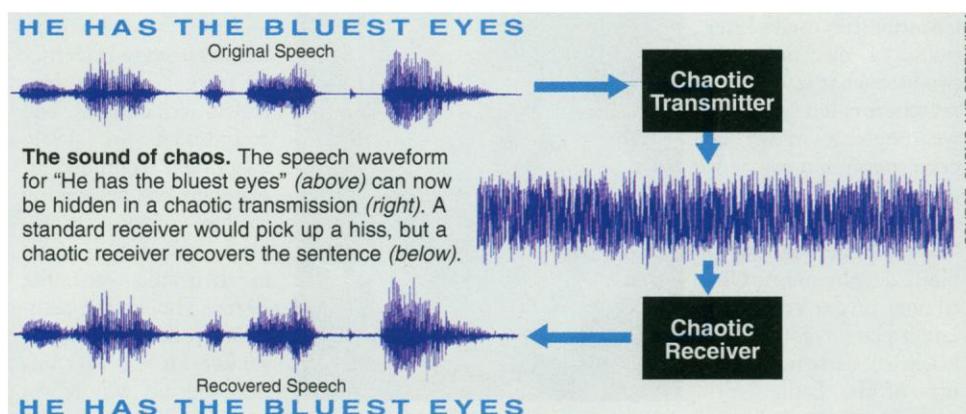
Simply passing a chaotic signal from one circuit to another, though, is akin to sending and receiving static—not exactly an information-rich exchange, notes Cuomo. To send meaningful messages, the MIT re-

searchers first combine a small information-bearing signal such as a speech waveform with the stronger chaotic signal from the transmitter circuit. Provided the added signal is weak compared to the chaotic signal, the receiver can still regenerate a clean copy of the chaotic portion and subtract it from the raw hybrid signal, unmasking a reasonably faithful copy of the information-bearing component. "The recovered speech is highly intelligible," Cuomo says.

But intelligible only to the receiver, notes physicist Edward Ott of the University of Maryland. Unmasking the information, he says, requires knowing everything about the

on complex control electronics that limit the power at which the transmitter can be operated. But Ott and his colleagues Celso Grebogi of the University of Maryland and Scott Hayes of the U.S. Army Research Laboratory in Adelphi, Maryland, think there's a way to take advantage of such chaos. In the 17 May *Physical Review Letters*, the researchers suggested that engineers could use microelectronic controls to coax an intelligible message from a chaotic transmitter. Possible payoffs, Ott suggests, would be more efficient transmitters or ones that could broadcast at higher power.

Ott and his colleagues say they are on their way to demonstrating their scheme in a real circuit, but as a proof-of-principle, they



communications system including details of the circuitry and the specific voltages and currents running through it. "Knowing the system that produces the signal is akin to having the key" to a code, says Ott. A determined eavesdropper equipped with a powerful computer might be able to generate a simulated receiver that could unmask the signal buried in an otherwise chaotic transmission. However, "it probably would take days or weeks or months" to do so, suspects Pecora. "In combat, you may only need a few minutes of privacy or maybe a few days if you're making a business deal over a cellular phone," he says.

If privacy isn't a consideration, a chaotic communicator might turn to the other scheme for harnessing the phenomenon. The high-power oscillators used to generate radio transmissions are prey to instabilities; to keep this chaos at bay, engineers now rely

tested the effects of very small adjustments to, say, a resistor or amplifier in a so-called double scroll circuit, which they simulated in a computer. Normally, this chaotic circuit fluctuates unpredictably between two states (defined by voltage and current values) that look roughly like a scroll when depicted in a graphical form. But small electrical nudges to the running circuit, the simulations suggested, can steer its output into a pre-chosen pattern of those states, which can correspond to the binary code of a message.

Regardless of the practical payoffs of this early crop of communications schemes, they mark a turning point for the field, Pecora adds. Researchers like Cuomo and Oppenheim "are shifting to synthesizing things," he says. Rather than using chaos theory as a tool for analyzing existing phenomena, they are using it to create new ones.

—Ivan Amato