

What's all this noise about?

Far from being a problem, electrical noise could just be the way forward for semiconductor design. By **David Boothroyd**.

Electrical noise is usually extremely bad news for the semiconductor industry; it can cause the 0s and 1s of digital data to flip, destroying information. For a long time, the worry has been that it will be impossible to produce really low power chips because noise will drown the information they are designed to process.

But noise may not be the culprit it was thought to be. Researchers are making good progress in not just avoiding noise, but also exploiting it. The future may well see nanoscale devices that use noise in circuits to store, carry and process information. Ironically, noise may be the phenomenon that makes possible extremely low power electronic devices.

"The whole idea of exploiting noise has slowly emerged over the last 30 years, based on a deeper and wider understanding of what noise is," says Luca Gammaitoni, a professor at the University of Perugia, who leads the university's Noise in Physical Systems (NiPS) laboratory. "Initially, noise was seen as a disturbance to be eliminated, or limited whenever possible. Eventually, people started to realise that noise has its roots in the fundamental physical properties of matter and, instead of merely being a limiting disturbance, is a manifestation of the way things work at the microscopic level."

Based on this understanding, scientists began to study noise in various microscopic phenomena, often in biological systems (see below). But it has also been of benefit in other areas, as Prof Gammaitoni says.

"The idea that noise could play an important role has contributed to the discovery of a number of new phenomena in dynamical systems, where the combination of noise and nonlinearities can be beneficial to the dynamics of the system itself. The most popular of these phenomena is undoubtedly stochastic resonance."

Stochastic resonance, or SR, shows how the addition of noise to a periodically driven, bistable or switch like system can improve its performance. If the noise level is just below the threshold required to switch the state of the system, even a tiny input voltage is enough to change the state – in effect, the SR effect of the noise is to increase the sensitivity of the switch. Prof Gammaitoni's laboratory recently developed a device that exploits this – a resonant tunnelling diode. This exploits quantum effects to enable electrons to tunnel through some resonant states at certain energy levels.

"SR has become very popular among scientists and has helped to spread the idea that noise could be beneficial and thus exploited," Prof Gammaitoni says. "Nowadays, there are a number of patents on the exploitation of SR like phenomena that embrace applications like signal detection, and magnetic and optical sensor functioning."

Like many others, Prof Gammaitoni is convinced that noise has the potential to have a major impact on information and communication technology (ICT). "A logic gate is based on the functioning of threshold devices and sometimes, due to the presence of noise, the switching of such devices fails. This induces errors in computation and slows the operation of the entire computer. In order to limit such errors, it is customary to operate with safely large voltages and limited clock frequencies. If, instead of avoiding switching errors, we could find a way to operate the logic gates as fault tolerant devices – that is in the presence of a significant amount of noise – we could almost certainly gain in speed and, more importantly, we could reduce energy consumption, solve the problem of critical heating and limit CO₂ emissions."

Keeping power levels down is one potential benefit of noise, but another relates to extracting power from noise – known as 'vibration energy harvesting' – which could have benefits for a range of applications, such as wireless sensor networks used for things like environmental monitoring, biomedical sensing and detecting harmful chemical agents.

"These all need distributed powering systems," Prof Gammaitoni points out, "and traditional batteries are not a viable solution, mainly because they have to be replaced once exhausted. Alternative solutions based on micro fuel cells and micro turbine generators are also not suitable; both involve the use of chemical energy and require refuelling when their supplies are exhausted."

Distributed power already operates devices like rf identity tags, smart cards and other passive electronic devices, which are powered by an external supply. But the operating distance for rf powering is short and the pickup coils can be bulky.

Kish: "This could provide performance comparable to quantum parallelism and beyond."



Gammaitoni: "The whole idea of exploiting noise has slowly emerged over the last 30 years."



“On the other hand, the power requirement of portable electronics has been decreasing constantly over the last 20 years,” Prof Gammaitoni says. “Current cmos based devices operate at minimum power levels, ranging from 1 to 10 W at around 100kHz. Radio transmitters usually need 1mW, but by using burst transmission with a low duty cycle, the average power level can be reduced substantially.”

“This has opened a window of opportunities for the introduction of a new class of powering devices – microgenerators that can generate electric power by transforming the energy present in the environment. A typical example of an energy harvesting based microgenerator would be a device that transforms the vibrations of solid bodies – mechanical noise – into electricity.”

Prof Gammaitoni’s NiPS Laboratory is coordinating Nanopower (www.nanopwr.eu), an EC project exploring this idea and which has just held its first meeting. NiPS has also created a spin off company named Wisepower.

Another EC project that aims to exploit noise and SR is SUBTLE (SUB kT Low Energy transistors and sensors). Here, nanoelectronic devices are being developed in which quantum confined electron channels are so closely spaced to each other that tailored feedback action occurs.

“The approach of SUBTLE is based on the application of two effects in miniaturised electronics – back action of the channel on the gate and noise induced switching – which one usually tries to avoid in device design,” says project coordinator Professor Lukas Worschech of the University of Wurzburg.

The aim is to exploit tailored feedback to enhance the signal. A channel gate is used to route a signal and back action is like feedback in an audio system. The subsequent noise can be used to switch the circuit from one channel to another.

“By using nonlinear transport in nanosystems, the SUBTLE project has the potential to open a new window for electronic applications covering SR

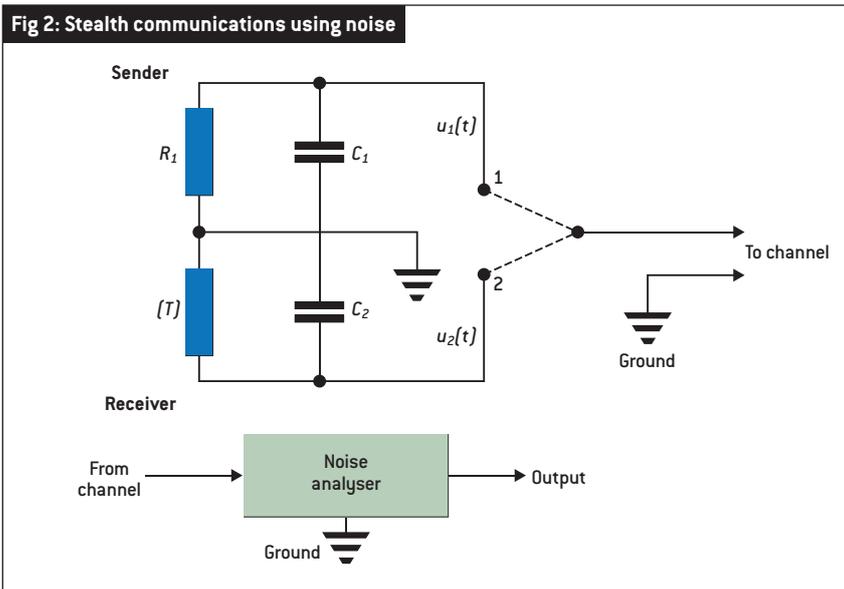
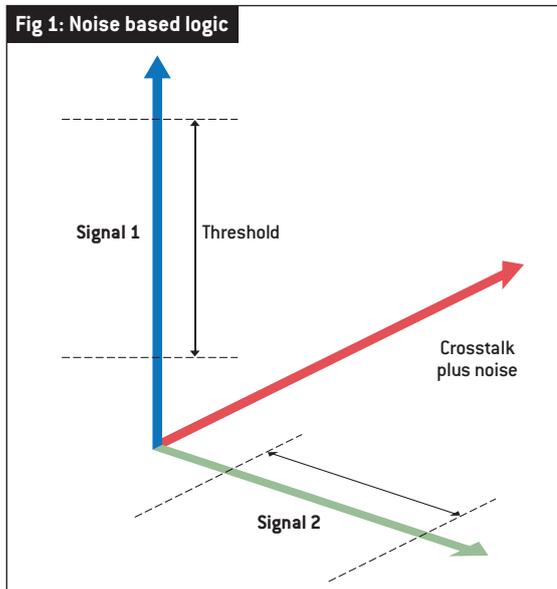


Fig 1: In this scheme, electronic noise is used as the carrier of a logic value. The figure shows noise based logic base vectors, which are orthogonal to each other and to the background noise. Fig 2: This zero signal power communication scheme uses the thermal noise (or Johnson noise) of resistors to data exchange in stealth mode. Information is transmitted using the statistical properties of the modulated noise.

phenomena, sub thermal switching and on chip noise control applications,” Prof Worschech says.

One area of SUBTLE’s work has resulted in submicron arrays of resonant tunnelling diodes that can act as artificial brain cells, or neurons. The hope is that such devices could mimic neuronal behaviour and serve as sensors for signals hidden under noise.

Another potential benefit is retention of the input. Conventional computers discard an input once it has been acted on, but the quantum transistors developed by SUBTLE can effectively reverse, allowing inputs to be retained.

“This could be a reversible computer, where you could return to the inputs from the output. It will probably be essential for quantum computing because there will be instances where you need the input,” explains Prof Worschech.

Perhaps one of the most ambitious attempts to use noise is being pioneered by Professor Laszlo Kish, Texas A&M University’s department of electrical and computer engineering, who is working on using noise as the information carrier in three different areas: fluctuation enhanced sensing (FES); secure communication; and noise based logic (NBL).

Prof Kish says the first two represent major advances and are near commercialisation. In FES, the small stochastic noise component of chemical sensors is separated, amplified and analysed. “It carries rich information about the chemical agents and, by using it, sensitivity of sensing is increased by 100 times or more and a single sensor can act as a complex multisensor electronic nose,” he says.

In his secure communication system, based on a technique called the Kish cypher, noise is the information carrier. Prof Kish claims the concept provides a higher level of data security than even quantum encryption, as well as being far cheaper – it would be possible to use power lines as communication cables.

The aim of NBL is to use the presence or absence of noise to represent the 0s and 1s of binary data, as opposed to voltage levels as in ordinary computers. It exploits the fact that noise has a pattern characteristic of its source, which means you can differentiate noise signals and therefore

compute with them. Any background noise will be different from the noise signals, making it possible to subtract its effect.

To represent one bit of data needs two sources of noise: one for 0, the other for 1. A string of n bits requires 2^n sources and this is easy to achieve with conventional chips, since transistors can be a good source of noise when operated at low voltage and chips already contain billions of them. Using a conventional cmos chip, the NBL architecture would be inherently about three times more complex than classical logic, Prof Kish says.

“But in the nanometre range, where it would be used, classical logic would (in practice) have to be 100 to 1000 times larger in terms of hardware complexity, due to error correction requirements. So NBL would actually be much simpler. It would have much lower energy dissipation and be extremely robust against dynamical errors.”

It has another intriguing potential feature – the ability to support a form of superposition of logic states, as quantum computers can do. Last year, Prof Kish and collaborators claimed noise signals could be superimposed and sent through a single wire without losing their identity. This means a series of calculations can be done simultaneously, as with quantum computing.

“For example, five 5 noise bits and their superposition represents about one billion logic values in a single wire,” Prof Kish says. “This could provide performance comparable to quantum parallelism and beyond.”

It is already known that stochastic resonance is used in biology to enhance sensitivity in neurons’ performance and the feeling among biologists is that it may be a widely used mechanism, at least in mammals. But could nature have gone further and exploited noise to do computing?

Prof Kish and a partner in biology, Sergey Bezrukov of the US National Institutes of Health, believe that is the case. They claim NBL could explain some features of neural activity, such as delays that occur in certain neural signals. They have also outlined how the brain could achieve its own version of noise based superposition.

It could turn out that we have a lot to thank noise for.