DEVICE PHYSICS

No-nuisance noise

Adi R. Bulsara

'Silence is golden' is a maxim of limited applicability where stochastic resonance holds sway. The effect uses noise to boost signal output in certain systems — and has just been seen in oscillators on a very small scale.

Stochastic resonance[1,2] encapsulates the sexy notion that moderate (and, ideally, carefully controlled) levels of noise in a nonlinear dynamical system can actually enhance the information throughput — and so improve the sensing and processing of otherwise undetectable signals. Originally postulated as a mechanism to explain how ice ages occur, the effect has since been demonstrated in a plethora of laboratory experiments, and has also been proposed to be responsible for the way in which biological sensing mechanisms function to take advantage of inherent background noise. Writing on page 995 of this issue[3], Robert Badzey and Pritiraj Mohanty demonstrate the effect in a doubly clamped mechanical beam of nanometre size. But this is more than just another stochastic resonance demo: the authors' device (besides belonging to the buzzword class 'nano') also bestrides the murky gap between classical and quantum physics.

Badzey and Mohanty's nanomechanical beam, 8 μm × 200 nm × 300 nm in size, is made of crystalline silicon of high purity, clamped at either end. When small-amplitude radiofrequency excitations are applied to it, the beam behaves like a damped, driven harmonic oscillator, showing a standard, 'lorentzian' shape (that is, peaked at a resonant frequency) to its response–power spectrum. But when the forcing amplitude exceeds a critical value, determined by (among other things) the amount of power dissipated as heat and the natural frequency at which the beam resonates, its response becomes nonlinear — the beam buckles.

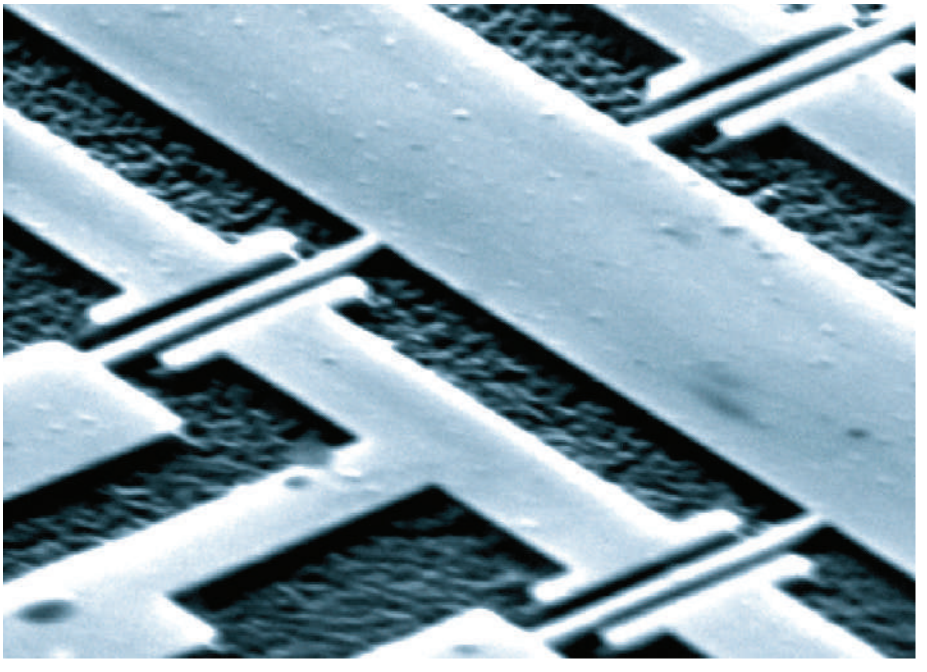
This is not a new phenomenon: the concept of buckling dates back to the eighteenth century, when Leonhard Euler developed the partial differential equations that describe elastic instability. This 'Euler instability' dictates that a slender elastic object, clamped at either end and initially in stable equilibrium, will move transversely if subjected to a longitudinal compressive force. If this force is increased beyond a critical value, the object will undergo a transition to an unstable equilibrium point. (Ref. 4 provides a simple derivation of this critical force.)

In Badzey and Mohanty's system[3], the compressive force comes from the application of a transverse driving force that changes the beam's length, making it longer than the distance between its two supports. When the beam vibrates from side to side, it is subjected to an additional compressive force from the clamping pads as it passes through equilibrium. If the driving force is large enough, the beam responds nonlinearly and acquires two different vibrational modes at a single frequency near resonance. Crucially, these buckled modes are not static, but dynamic, and are underpinned by a 'bistable' potential-energy function; that is, one consisting of two stable states, or 'wells', separated by an energy threshold. The bistable configuration — together with an applied periodic signal whose amplitude is smaller than the threshold — is a basic condition for stochastic resonance.

Badzey and Mohanty apply noise to their system and compute a signal-to-noise ratio at the applied signal frequency for a series of response–power spectra, each taken at a different noise power. The resulting curve reveals a maximum signal-to-noise ratio at a critical noise power. This is because, when there is too little noise, it fails to lift the system over the threshold between the two states: the system cannot switch between them, and so there is no flow of information (assumed to occur in the switching events between wells). Conversely, too much noise leads to a surfeit of (mostly incoherent) switching events and a corresponding loss of information. But between these two information minima, the switchings acquire maximum coherence with respect to the applied signal, and an information maximum occurs. Thus we have an intuitive result from otherwise counterintuitive behaviour — that applying noise can be helpful.

The result[3] conclusively demonstrates stochastic resonance in a nanomechanical oscillator at megahertz frequencies. But its significance does not end there. A basic criterion for the creation of a quantum harmonic oscillator is that the energy hf of the oscillator (where h is Planck's constant and f the oscillation frequency) must be larger than the broadening of the oscillator's energy spectrum that results from thermal effects. This energy spread is given by $k_B T$, where k_B is Boltzmann's constant and T is the temperature. At a temperature of 48 mK, for example, an oscillation frequency of 1 GHz ensures that this condition is met. Thus, the demonstration of stochastic resonance in the megahertz range paves the way for exploring the phenomenon in related structures — recently constructed by the same group[5,6] — that have higher, quantum-regime frequencies.

Specifically, stochastic resonance might be used to enhance and control a quantum-mechanical signal in a nanomechanical oscillator — to achieve coherent control of oscillations between two quantum energy levels, for example. The ramifications of a 'quantum' stochastic resonance effect, and its possible relevance to low-temperature macroscopic quantum tunnelling, are fascinating.



R. L. BADZEY & P. MOHANTY

Figure 1 | Hang in there. A scanning electron micrograph of a set of suspended silicon nanomechanical beams with electrostatic control gates. Each beam can be made to move between two buckled states (0 or 1) by applying a field to its control gates. Stochastic resonance could allow enhanced control in switching between the two discrete states, and use of these nonlinear states as nanomechanical memory cells.

They could pave the way to experiments in the as yet somewhat esoteric field of quantum measurement and control. For unsatisfied sceptics, Badzey and Mohanty have also developed a system of suspended nanomechanical beams made of silicon, each of which can be forced electrostatically to switch between its two stable states (Fig. 1). With stochastic resonance allowing enhanced control over such switching, these nonlinear states may eventually be useful as nanomechanical memory cells.

Stochastic resonance, although difficult to implement in practice, has always been an intriguing option for harnessing the background noise in certain systems. But the hubris of the 1990s was followed by a dearth of results to confirm that the mechanism underlies natural neurophysiological functions, and a general paucity of devices that were readily 'tunable' to take advantage of noise. These factors, together with the witches' brew of funding vicissitudes and some questionable publications, led to a waning of interest. Yet work such as that of Badzey and Mohanty[3] shows that the effect can be invoked in a noisy, nonlinear dynamic system under appropriate operating conditions, and that it can also be exploited in carefully crafted applications. The effect has also recently been used in biomedicine[7] and in the amplification of electric field signals in carbon nanotube transistors[8]. These achievements, and the demonstration that background electrical noise is involved in the 'hunting frenzy' of the paddlefish *Polyodon spathula* as it preys on swarms of the water-flea *Daphnia*[9,10], indicate that this effect is more than just a laboratory curiosity. ■

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1. Wiesenfeld, K. & Moss, F. *Nature* **373,** 33–36 (1995).
2. Bulsara, A. & Gammaitoni, L. *Phys. Today* **49**(3), 39–45 (1996).
3. Badzey, R. L. & Mohanty, P. *Nature* **437,** 995–998 (2005).
4. Feynman, R. P., Leighton, R. B. & Sands, M. *The Feynman Lectures on Physics* Vol. 1, Ch. 38 (Addison-Wesley, Redwood, CA, 1989).
5. Gaidarzhy, A. *et al. Phys. Rev. Lett.* **94,** 030402 (2005).
6. Gaidarzhy, A. *et al. Appl. Phys. Lett.* **86,** 254103 (2005).
7. Priplata, A., Niemi, J., Henry, J., Lipsitz, L. & Collins, J. *Lancet* **362,** 1123–1124 (2003).
8. Lee, I., Liu, X., Kosko, B. & Zhou, C. *Nano Lett.* **3,** 1683–1686 (2003).
9. Russell, D., Wilkens, L. & Moss, F. *Nature* **402,** 291–294 (1999).
10. Collins, J. *Nature* **402,** 241–242 (1999).

DEVELOPMENTAL BIOLOGY

Cell cycle unleashed

Takeo Kishimoto

How does fertilization cause animal eggs to begin embryonic development? Following entry of the sperm, the ingeniously regulated degradation of a protein seems to kick-start the stalled cell cycle.

In animal eggs, the cell-division cycle is held in check part-way through, awaiting sperm entry. A major event after fertilization is therefore the alleviation of this blockage so that cell division can begin in earnest to form the embryo. Thomas Mayer and colleagues (page 1048 of this issue)[1] and Liu and Maller, writing in *Current Biology*[2], now provide a molecular answer to the long-standing question of how the cell-cycle arrest is released by fertilization.

In sexual reproduction, development of the embryo cannot begin until completion of the specialized cell cycle that forms eggs (meiosis). This temporal coupling is coordinated such that the meiotic cell cycle in eggs is arrested at a particular stage and the arrest is released by fertilization. In vertebrates, including frogs, mice and humans, the stage of the cycle at which the cell typically arrests is called metaphase of meiosis II (or meta-II)[3]. Relieving the cell-cycle blockage requires the activity of a protein complex called APC/C^{Cdc20}. This complex is a highly regulated enzyme that targets several cell-cycle regulatory proteins for destruction by attaching a ubiquitin group to them. Removal of these regulatory proteins then allows the cell to exit from metaphase and move on to the next stage of the cell cycle[4].

Early studies in the 1930s by Lewis Victor Heilbrunn and Daniel Mazia showed that one of the earliest molecular events following fertilization is a rapid escalation in intracellular calcium ion concentration, and they suggested that this increase might be the signal that triggers embryo development. In frog and mouse eggs, this rise in calcium activates a protein called calmodulin-dependent protein kinase II (CaMKII)[5]. But how the activity of APC/C^{Cdc20} is inhibited during meta-II arrest, and how CaMKII abolishes that inhibition, have been largely unknown. Using extracts from frog eggs, Mayer and colleagues[1] and Liu and Maller[2] demonstrate that CaMKII acts on the protein Erp1 (for 'Emi1-related protein 1'), an inhibitor of APC/C^{Cdc20}. This causes Erp1 to be degraded and thereby allows APC/C^{Cdc20} to release the brakes on the cell cycle (Fig. 1).

50 & 100 YEARS AGO

50 YEARS AGO

In the leading article in *Nature* of August 20 on "Educational Problems of the Colonial Territories", it is stated that "only some 450 scientists are at present engaged in Colonial research"... Most British scientific workers are superannuated at the age of approximately sixty-five. Many of them are capable of another ten years of research, and a moderate amount of teaching. Some, at least, would be happy to work in a Colonial university or research institute. The necessary qualifications are the capacities to work in a tropical or subtropical climate, and to form friendships with non-Europeans... I think that the presence in a Colonial university of even two or three Fellows of the Royal Society carrying out fundamental research with African or Asian colleagues would help the local population to generate its own scientific culture. **J. B. S. Haldane**

From *Nature* 15 October 1955.

100 YEARS AGO

The Citizen, a Study of the Individual and the Government — Prof. Shaler, who is professor of geology at Harvard, has set before himself the practical and unambitious task of instructing the youth of the United States in the first principles of citizenship. In this he has succeeded; his work is interesting, suggestive and extremely sensible... A favourable specimen of his mode of argument may be found in the discussion of woman's suffrage. There is no reference to the various views held by thinkers from Plato downwards; but probably Prof. Shaler's one-page argument is quite sufficient, that women, owing to their usually secluded lives, are not fitted in the same way as men to form judgments on political questions, but that, after all, if a majority of women should desire to vote, it would probably be best to give them the franchise, for the reason that it is most undesirable to have any considerable body of the people in a discontented state.

From *Nature* 12 October 1905.