Introduction to the Random and Fluctuating World:
Celebrating Two Decades of *Fluctuation and Noise Letters*

by

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1 Fundamentals of noise

Seeking the physical origin of a noise phenomenon often brings scientists closer to the fundamentals of their research topic. For example, propounded centuries after Newton's discovery of his three laws of mechanics, and several decades after Maxwell-Boltzmann statistical physics, Einstein's correct explanation of Brownian motion (1905) simultaneously confirmed the atomicity of matter, Maxwell-Boltzmann statistics, and the applicability of Newton's laws on the microscopic scale. Perhaps this is why a significant fraction of Physics Nobel Prize lectures contains the words "fluctuations" and/or "noise".

On the other hand, the scientific depth required for a fundamental understanding of the noise in a system often triggers debates between different scientists and schools where some or all of the parties may have partial or incorrect understanding of the reality.

The first two papers by van Kampen,[1] and by Mannella and McClintock,[2] focus on examples of the latter. In his Foreword to *FNL* (the historic first paper to be published in the journal) van Kampen discusses, amongst other things, why the Langevin/Focker-Plank stochastic differential equation descriptions can be invalid in certain nonlinear systems, such as a diode. Mannella and McClintock survey the related Ito-Stratonovich debate about which stochastic calculus is "correct" – a debate that seems to re-emerge every generation. They emphasise that *both* are correct, the Stratonovich calculus being applicable to continuous systems, and the Ito calculus to discrete systems like the number of fishes in a lake. These two papers describe how science often evolves via debates that lead to a deepening of understanding. Van Kampen's final sentence is prophetic: "My final conclusion is that there is ample material for this journal!"

Starting from the generalized Wiener process, Dubkov and Spagnolo[3] derive a new correlation formula for stochastic functionals. This allows them to obtain the general Kolmogorov equation directly from the Langevin equation with a non-Gaussian white noise source. The well-known Kolmogorov-Feller equation for purely discontinuous Markovian processes, and the fractional Fokker-Planck equation describing fast diffusion in the form of Levy flights, are special cases of this fundamental result.

Dykman and Golding[4] point out that a high-intensity, high-frequency, field can significantly influence escape rates from a potential well, in an unexpected way. A reader familiar with tape-recorder technology may wonder if the high-frequency, high-amplitude, bias signal superimposed on the acoustic signal driving the magnetic recording head (to improve linearity) has a similar purpose?

During the analysis of measured fluctuations – ranging from biology to economics, – superimposed slow drifts (trends) often pose a problem by influencing the spectra, correlations and information seen at higher frequencies. Grafov *et al*[5] and Lin, *et al*[6] explore advanced techniques for reducing or removing trends: Grafov and his coworkers demonstrate that Chebishev spectra have strongly reduced trend sensitivity; Lin and coworkers introduce a new algorithm that diminishes several of the negative impacts of trends.

There have been many attempts and failed inventions attempting to circumvent the Second Law of Thermodynamics. Sooner or later, of course, physicists identify the error lying at the core of each scheme proposed. The paper of Nieuwenhuizen and Allahverdyan[7] provides a nice example of fundamental criticism of an experimental claim that had stirred up the pot by claiming a Second Law violation.

Everybody knows that no standing wave can exist in a cable below the frequency limit ("wave limit") where the half-wavelength matches the length of the cable. This is the basic design rule of musical instruments, too. And quantum physics and solid state physics also have these same limitations on their states, including the electron states in atomic shells. Yet, researchers working with microwaves often produce kinematic mathematical descriptions of slow processes with waves. But what does physics say, particularly statistical physics? The paper by Chen *et al.*[8] proves that the existence of physical waves below the wave limit would violate the Second Law.

2 Noise in quantum systems

The interpretation of quantum physical experiments and theory often triggers debates between experts from different schools, and these discussions have impacted the history of quantum science. Most of today's debates are about correlations, coincidence-phenomena, or other statistical properties of the quantum noise itself. Yet there have been disputes – sometimes historically long ones – even within the topic of transport processes manifesting quantum noise phenomena.

Van Kampen's article[9] discusses the proper approach to energy dissipation and damping in quantum systems. The basic formulations of quantum mechanics were Hamiltonian, that is, dissipation-free, which led to open questions and failed approaches later when physicists tried to introduce damping. A related issue is discussed by Alicki,[10] who points out that quantum error correction fails for Hamiltonian models.

Klyuev *et al.*[11] discuss the spatial fluctuations of "monopoles" in spin ice, a disordered material with frustrated ferromagnetic interactions that imitate the existence of magnetic monopoles.

Motivated by the need for theoretical tools to study the relationship between the AC spectrum and electron dynamics in nanoelectronic devices, Albareda *et al.*[12] develop formalism using both standard and Bohmian quantum mechanics, obtaining identical results. They point out that, for many-body systems, Bohmian trajectories make numerical calculation of the total current easier and illuminate the interplay between quantum electron-dynamics and displacement currents. Note, orthodox quantum theorist say that these trajectories do not exist and they can have at most a statistical meaning. Perhaps if they were called "Bohmian virtual trajectories", both parties (Bohmian and Orthodox) could agree?

The three debate articles by Cohen and Hrasko[13,14,15] show that the much-heralded quantum teleportation (of an unknown quantum state) is not quite so special as portrayed by the media. The well-known "weirdness" of conditional probabilities is responsible for producing many of its features and even classical physical systems, such as coins in boxes, can demonstrate such features. At the conclusion of the discussion, it is pointed out that several key features of the quantum teleportation process, aspects that are commonly considered to be non-classical, are still present in Cohen's purely classical version of teleportation. The implication of this is not that quantum teleportation requires only classical transfer of information, but rather that the role of the non-classical component of information transfer within the quantum teleportation process is subtler than is generally assumed.

Green and Das argue[16] that there are flaws in the Landauer-Buttiker formalism of mesoscopic transport. A growing number of people are coming to accept their arguments but the matter remains highly controversial.

And finally in this section, an historical enigma: can the thermal noise of resistors exist at zero temperature? The view of Kish *et al.*[17] is that, whether or not Johnson-Nyquist noise persists at temperatures approaching zero depends on the way in which quantum measurement is used for its detection. Whenever it is visible, it is an uncertainty relation artifact of the instrumentation. Even standard Fermi-Dirac quantum statistics prohibits its fundamental existence.

3 Noise in complex systems

Noise in complex systems is, in general, hard to deal with because of the double difficulty of the noise and the complexity, sometimes also including dynamical chaos.

Lindner *et al*[18] study the diffusive motion of an overdamped Brownian particle in a tilted periodic (wasboard-like) potential – which represents a paradigm for flow in ratchets of all kinds, including some with relevance to the internal machinery of biological cells. Mapping the continuous dynamics onto a discrete cumulative process they find exact expressions for the diffusion coefficient and the Péclet number (ratio of the advection and diffusive transport rates) characterizing the transport and show that there is a characteristic tilt at which optimized transport occurs for a given noise intensity.

Stochastic resonance (SR), in which the amplitude and/or signal/noise ratio (SNR) of a weak, low-frequency, periodic signal in a noisy nonlinear system can be enhanced by adding extra noise, was still under intense investigation during the early years of *FNL*. It came to be appreciated that the SNR of a given signal cannot be improved by passing it through a “stochastic resonator”, as some had hoped, but that SR can be useful where the signal is initially generated in a nonlinear system of an appropriate kind. Makra et al.[19] investigate SR in a Schmitt trigger circuit and in a double well potential, to see what SNR gains these systems can provide, and demonstrate SNR gains much greater than unity for both.

Dating back to 1994, Parrondo’s paradox involves a counter-intuitive “survival of the weakest” principle, and refers to circumstances where two losing situations can be combined in order to win. It is exemplified by simple coin tossing games. In his review, Abbott[20] first explains the paradox and then points out the deep connections that exist between the Parrondo effect and a whole host of diverse phenomena that arise in physics and beyond. These include the flashing Brownian ratchet, stochastic resonance, the ratchet and pawl machine, the thermodynamics of games of chance, the Brazil nut paradox, the interplay of redundancy and pleiotropy, longshore drift on beaches, costly signalling in biology, the two-girlfriend paradox, and stock market trading. His two take-home messages are (i) that the process of switching is a nonlinearity, so that switching can radically alter the overall system behavior, and (ii) that the interaction between noise and asymmetry can give rise to directed motion under non-equilibrium conditions, even against a gradient.

Buceta *et al*[21] build on these ideas by proposing a mechanism whereby a random alternation of two distinct dynamics, each of which by itself leads to a homogeneous state, can generate complex, ordered, patterns and structures. The authors point out the relevance of their study to other situations where pattern formation occurs, such as reaction-diffusion systems.

A novel approach to the treatment of separatrix chaos has enabled Soskin *et al*[22] to address and solve some long-standing problems in that area. By introducing a new criterion for chaos in the separatrix map, they find analytically the maximum width of the separatrix chaotic layer and describe an example of the dramatic facilitation of the onset of global chaos between separatrices.

Reports of rogue waves on the ocean – fluctuations *very* much larger than those around them – were traditionally treated sceptically as “mariners’ tales” – until relatively recently when the famous New Year Wave was recorded quantitatively with modern instrumentation on the Draupner oil platform (1995). Since then their reality has become well-established, and they have been identified in other systems too, including superfluid helium, optics, and Bose-Einstein condensates. Residori *et al.*[23] review experimental results on the statistical properties of giant optical waves in spatially extended systems. They consider different experimental set-ups and discuss the ingredients that are needed for the creation of optical rogue waves.

4 Noise in biological systems

Without the rare random events that give rise to occasional mutations in DNA there would be no evolution, no life, and certainly no us. Noise and fluctuations are of crucial importance in biology. This is true on all length scales, ranging from chemistry where reaction rates are controlled by thermal activation over energy barriers, through biological cells and their subcellular machinery, interactions between whole systems in an organism, right up to the level of population dynamics. Biological systems are typically characterised by strong internal interactions. So the physicist's usual approach of focusing on a particular subsystem and modelling it in isolation can often be a poor approximation. For the same reason, fluctuations and noise in biology tend to be complicated and the assumption of Gaussian white noise may also be a poor approximation. Conversely, the form of the fluctuations usually carries a lot of information about the underlying biology.

Bezrukov[24] discusses how analysis of the noise in single protein nanocontacts can provides important information about their structure and function, allowing us to study protein dynamics and interactions with different solutes at the single molecule level. In addition to yielding deeper scientific understanding, the noise analysis brings practical consequences by illuminating the molecular mechanisms of human illnesses and the underlying mechanisms of drugs.

Selective conduction by ion channels in cellular membranes, where the favoured ion may be selected over other ions by a ratio of 1000:1, is needed for all forms of life. Tindjong *et al.*[25] describe a nonequilibrium rate model for the stochastic permeation of an ion through an open ion channel, taking explicit account of the relevant electrostatic interactions and leading to transition rates in satisfactory agreement with biological experiments. This general approach subsequently led on to the discovery of ionic Coulomb blockade in biological ion channels and to a full-blooded statistical theory of the permeation process.

Ions are used in the **se**nsing of **p**hage-**t**riggered **i**on **c**ascades (SEPTIC) for fast bacterial identification, based on fluctuation-enhanced sensing in a fluid medium. The concept was introduced by Kish and Dobozi-King in 2004. Kish *et al.*[26] discuss the sensitivity and detection limits of SEPTIC and show that, under optimal conditions, 200 bacteria is a sufficient number to be detected/identified reliably.

Suki *et al.*[27] consider fluctuations in cardio-pulmonary physiology, relating the scaling behaviour to the structure-function relationship in normal and diseased states of the system. They discuss the application of wavelets and multifractal approaches, avalanche behavior of airway openings and the associated crackling sound, as well as the relationship between the observed scaling properties and the design features of the pulmonary vascular tree. They also show how the network failure of lung tissue leads to emphysema.

There has been significant effort to detect the occurrence of stochastic resonance (see section 3) in biological systems, and to see how nature may perhaps use SR to improve efficiency. Stocks *et al.*[28] show that the a variant of the phenomenon known as suprathreshold SR can improve speech comprehension by enhancing information transmission along the cochlear nerve. There is evidence from experiments on paddlefish[29] that animals can make use of the increased sensory information provided by SR in their sensory nervous systems, as demonstrated for a vital unlearned natural behavior, namely feeding. By investigating a stochastic generalization of the Hodgkin–Huxley model, Schmid *et al.*[30] found evidence for SR due to the intrinsic channel noise where there were sufficiently large clusters of ion channels whose internal noise strength was below its optimal value.

Many, perhaps most, biological processes are oscillatory in character. The resultant fluctuations are also oscillatory, but with the special feature that they are in general non-periodic. This is attributable to the strong interactions within biological systems – so that any given oscillatory process is subject both to the influences of its changing environment and to the effects of other local processes that may also be oscillatory, usually at different frequencies. Even where a biological oscillation is very strong, e.g. the heartbeat measured in arterial blood pressure, its frequency and amplitude are time-varying, and require special analysis methods. The interactions between different oscillations can result in their synchronisation, not necessarily on a 1:1 basis but sometimes e.g. 1:4 in cardio-pulminary synchronisation (4 heartbeats per breath). Synchronisation can be maintained even if the frequencies are varying. Rosenblum *et al.*[31] review the application of synchronization theory to the analysis of multivariate biological signals. They address the problem of phase estimation from measured data and the detection and quantification of weak inter-oscillator interaction, as well as quantification of the direction of coupling, and they discuss the advantages and limitations of the approach.

The phase coherence between two signals is a more subtle quantity than synchronisation. It takes a value between zero and unity and quantifies the tendency for the phase difference between the two signals at a particular frequency to remain constant. A phase coherence of unity would imply synchronisation; at the other extreme, where two signals are unrelated, their phase difference changes continuously in time and so their phase coherence is near zero. Bernjak *et al*[32] establish the *wavelet phase coherence* (allowing for time variability) between fluctuations in skin blood flow and in oxygen saturation. They find clear evidence for coherence over a range of frequencies, thus yielding the first detailed insight into the dynamics of blood oxygenation.

5 Noise in materials, circuitry, devices and sensing

Electronic noise appears in materials, circuitry and devices where its role is not always negative. Noise can even have practical applications, such as in sensing. A well-known example is thermal noise thermometry. Obviously, the topic of electronic noise is extremely wide, so that we can sample only a small fraction of the published papers, even within *FNL*. Our choice here is designed to give the flavor of research within a selected set of sub-topics.

In the first paper that we consider, Sundqvist *et al*[33] discuss the physical aspects of Chua's seminal memristor theory of 1971, which claims to introduce the "missing" passive circuit element (additional to resistors, inductors and capacitors). The paper[33] proves that Chua's mathematical model is unphysical because its thermodynamics is undefined due to its lack of thermal noise. In other words, Chua's equations cannot address the question of whether the device is passive. They are therefore unable to define the "missing" passive circuit element. The topic has triggered several debates during the last 50 years and, to date, this paper seems to have concluded the discussion.

Barkhausen noise during the magnetization/demagnetization of ferromagnetic materials is due to jumps in domain walls and avalanches of these phenomena measured by a pickup coil. Mills *et al*[34] use a modified version of the Haar transform to observe the markers of time asymmetry. The method works even with overlapping avalanches, without need of an ability to detect discrete pulses.

Electronic shot noise is a current noise that arises when charge carriers are crossing a potential barrier. It is the simplest quantum noise because its spectrum is proportional to the value of elementary charge q carrying the current. In classical, Maxwellian, continuum charge transport this noise would not exist. In a typical case the current noise spectrum is $S_i = 2FIq$, where I is the DC current value and the Fano factor $F = 1$ represents the situation where the electrons are crossing the potential barrier independently (Poisson statistics). The present frontier of research lies in situations where the Fano factor differs from 1. For example, when the charge carriers form groups when crossing (correlated crossing), such as in Josephson junctions, F is greater than 1. In the opposite situation – anticorrelated crossing – F can be less than 1. However, there are also other situations of anomalous Fano factor. Marconcini *et al.*[35] discuss aspects of diffusive transport (where there is no shot noise). They consider the thickness of the potential barrier in relation to the Debye length in the context of Fano factor reduction. Gokce *et al.*[36] describe an interesting experimental study with magnetic tunnel junctions and their arrays. One interesting finding is that serial junctions show a voltage-noise-based Fano factor that scales inversely with the number of junctions.

The history of $1/f$ (flicker) noise research is full of debates. This is also true of device noise research. Vandamme[37] discusses the origin of $1/f$ noise in MOSFETs. The famous (but incorrect) McWhorter model from 1957 was probably the first to assume that the number of free electrons was the core fluctuating quantity (due to interface trapping). The alternative explanation is based on mobility fluctuations, which is not at all an obvious matter. Vandamme's paper is an effort to clarify the situation.

Rumyantsev *et al.*[38] study and compare different types of heterostructure field effect transistors. The results indicate that, in these devices, the core fluctuating quantity is the number of free electrons (due to trapping).

Danneville *et al.*[39] offer an explanation of how the $1/f$ noise, which dominates at low frequencies, can become an issue in the microwave frequency range. The low-frequency components are transferred up to the high-frequency regime by nonlinear mixing. It is the nonlinear features of FETs that are the vehicles making this happen.

The electrical breakdown of PN junctions with breakdown voltage beyond 7 V are dominated by the avalanche effect, which is very noisy, and it surprisingly shows strong $1/f$ noise, too. Marinov and Deen[40] offer a complex theoretical model utilizing microplasma noise, diffusion and threshold phenomena to explain the low-frequency dynamics.

The next two papers in this section deal with electrical circuitry for low-noise applications: amplifiers and cold resistor circuitries. The design of low-noise amplifiers for the low-frequency range is challenging for a variety of reasons, such as $1/f$ noise, drift and ageing. Cold resistor circuitry imitates a resistor with strongly reduced noise temperature, but there have also been contradicting theories. The paper by Ciofi *et al.*[41] presents the state of the art of dedicated instrumentation for low-frequency noise measurement systems. Song and Kish[42] deduce a systematic theory of cold resistor circuitry with a useful equation for design purposes.

The following two papers utilize noise measurements for sensing. Fluctuation-Enhanced Sensing (FES) uses the noise spectral pattern of chemical sensors to extract chemical information. Smulko *et al.*[43] explore new, higher order, statistical tools, including bispectra, to enrich the extracted information. However, these tools work only if non-Gaussian components are present in the noise. In the other paper, Smulko[44] explores noise measurements for corrosion detection: a tool that can potentially be useful to avoid catastrophes due to corroded building elements.

Finally, the last paper in this section is about circuitry on a much larger scale: power line networks. Crucitti *et al.*[45] analyze practical the power line networks in France, Italy and Spain and identify the "hot-spots" where damage would make the largest impact on the network. They also propose improvements. (We note here: it is lucky that terrorists do not read academic noise papers).

6 Noise, computation and energy dissipation

Logic operations involve switching events and each such event dissipates energy. Every laptop-user who has experienced an overheated processor knows that energy dissipation in computing is a potentially serious limitation of computing performance. Google's mean computation power reached 12.7 terawatt-hours in 2019, up from 2.86 terawatt-hours in 2011.

The related scientific researches have two main frontiers: Finding the fundamental lower limit of energy dissipation in logic operations; and inventing special-purpose computing schemes (such as quantum computing) that requires progressively less dissipation to carry out the corresponding limited computation.

The history of the fundamental lowest limit of energy dissipation is rich of controversies and mistakes and famous physicists have also contributed such as Leo Szilard and Leon Brillouin. The former came up with the famous $kT\ln(2)$ lower limit, which is nowadays mistakenly called the "Landauer limit". Szilard presented his result as the minimum energy dissipation to generate 1 bit of information. In his related papers, Brillouin first confirmed the Szilard result but later refined it to the correct $kT\ln(1/\varepsilon)$ value, where ε is the bit error probability (BEP) due to thermal noise, and the result holds in the small error limit. According to information theory, $\varepsilon = 0.5$ represents the zero information case and, even though 0.5 is not a small error probability, this fact also indicates that the Szilard result is only a lower limit but not the ultimate one, the "highest lower limit". Recently it was shown by Kish that the Brillouin limit holds only within the autocorrelation time of the thermal excitation and that, for longer observations, the formula has a logarithmic correction by the observation time. Finally, it is worthwhile to note that the energy dissipation vs. information entropy reduction is a flawed approach because in accordance with Renyi's comments on information entropy, deterministic systems, such as a digital computer, do not change the information entropy. Thus there is no justification for using the above formulae for information entropy. Correctly, the proper wording should be "number of switching operations". Many leading schools and papers in top journals fell into this trap including, arguably, the Landauer principle which claims that information erasure involves energy dissipation.

The first paper[46] in this section illustrates the typical kind of debates that arises about the energy dissipation limits. It points out that a paper in a leading magazine neglected the energy dissipation in the control circuitry of a cantilever-based logic gate. This is the reason for the published dissipation value being unphysically low.

The papers that follow deal with various issues in noise-based logic, a classical physical logic scheme that provides exponential performance improvement for special-purpose computational tasks, similarly to quantum computers. An N-bit "quantum-computer-mimicking" noise-based logic (QCM-NBL) represents an exponentially large $2N$-dimensional Hilbert space where the vectors are all the N-bit long binary numbers.

Wen and Kish[47] show why noise as an information carrier has both physical and complexity advantages compared to deterministic signals in QCM-NBL. Peper and Kish[48] demonstrate that the binary version of noise-based logic is universal.

The paper by Stacho[49] introduces an algorithmic method for decoding the product signal strings that carry the N-bit binary numbers in QCM-NBL.

Kish and Daugherity[50] introduce new types of logic gate construction for QCM-NBL. As an example, they realize the CNOT gates and their non-commutative chain operations, which had been a tough call.

7 Noise in finance

One has only to open a newspaper to appreciate that almost all financial quantities, e.g. currency exchange rates or share prices, are noisy and subject to continuing fluctuations. Sometimes these fluctuations have an obvious cause, like wars or pandemics, but more often they seem at first sight to be spontaneous and intrinsic to the international financial system in its current form. To try to understand the fluctuations and model their effects, it is natural to apply the methods developed and used successfully for analysing fluctuations in scientific and engineering contexts.

By applying methods drawn from statistical physics to 16 stocks traded on the London Stock Exchange, Lillo and Farmer demonstrate[51] the crucially important role played by fluctuations in financial liquidity in determining large price changes. Their findings not only illuminate the mechanisms giving rise to "fat tails" (i.e. greater than Gaussian) in the probability distribution and long memory processes, but also offer some understanding of what determines financial risks and clues about how to reduce them.

Han *et al.*[52] investigate the correlation structure of the Chinese stock market around the time of the Great Crash in 2008. They apply random matrix theory to show that Chinese stocks had stronger average correlation and partial correlation in 2008 than in 2007, that the average partial correlation was significantly weaker than the average correlation in each period and, accordingly, that the largest eigenvalue of the correlation matrix is greater than that of the partial correlation matrix in each period. They point out that the calculated eigenvalues could in principle be used to construct a measure of systemic risk and that the eigenportfolio of the largest eigenvalue could provide the basis of a new stock market index.

8 Noise and security in communications

The heart of any symmetric key-based secure communication systems is the secret key that is used by Alice and Bob (at the communicating stations) to encrypt and decrypt the messages. The system cannot be more secure than its key. Alice and Bob must possess the same key (their shared secret), and this key must be refreshed frequently by secure key exchange/distribution to reduce the chance of statistical attacks.

Most commercial secure communication systems utilize the exchange of random numbers obtained by proper algorithms. Processing these numbers will eventually result in a common secret key on Alice's and Bob's sides. Eve (the eavesdropper) can record these communicated random numbers, so that she has all the information needed to calculate the key. However the protocol utilizes such problems as the solution for Eve being mathematically hard (requiring an exponentially long time and/or hardware complexity) while, for Alice and Bob (who know also the input of their algorithm and their hardware), it is much simpler (polynomial time/hardware complexity). Because Eve has all the information required for extracting the key, these schemes offer zero security at the information entropy level. Yet, with the *conditions* that Eve's computational power is limited, and that there is no efficient algorithm (requiring polynomial time/hardware complexity) immediately available to her, the system is *conditionally secure*. These schemes offer no future proof of their security, and even their security in the present is based on unproven assumptions. However, they are cheap and easy to use.

Real security: i.e. *unconditional* (information theoretic) security is at the frontier of security research. In this case, neither infinite calculating power, nor infinite time for processing the information, can compromise secrecy. But these schemes do have their own issues: bit errors, information leak towards Eve, a much higher price, and less versatility than conditionally secure schemes. Unconditionally secure key exchange requires specific hardware which itself offers attack opportunities for Eve because building elements are never ideal. Thus a thorough security proof is needed and, even then, future surprises can still happen with device issues that had not been foreseen and considered earlier.

The well-known quantum key distribution (QKD) scheme provides a good example of what should be, in principle, an unconditionally secure key exchange. Yet, one must bear in mind the successful cracking by hackers of the earliest commercial implementations of QKD.

In this short selection of papers on unconditional security, that by Kim[53] proposes a new key exchange method utilizing phase and intensity fluctuations of the communicated signals. Its ultimate security and possible ways of attack are unknown, yet it is an interesting and original scheme.

The rest of the papers deal with various aspects of the Kirchhoff-law-Johnson-noise (KLJN) key exchange protocol, which is based on hardware mimicking the thermal noise of resistors. Mingesz *et al.*[54] prove the earlier conjecture that only Gaussian noises guarantee perfect security. The next paper, by Kish,[55] reports the surprising finding that the KLJN scheme is naturally immune against the famous man-in-the-middle attack. The last paper by Cao *et al.*[56] explores how the KLJN system can offer unconditional security for autonomous vehicle systems.

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