Pulses and $1/f$ Noise

Kirk T. McDonald
Joseph Henry Laboratories, Princeton University, Princeton, NJ 08544
(January 24, 2015)

1 Problem

Discuss the relation between pulsed phenomena and $1/f$ noise.

2 Solution

Low-frequency fluctuations with a $1/f$ frequency spectrum were first noticed by Johnson [1] in thermionic-emission currents in vacuum tubes, and exist in a very wide range on phenomena.[1] A feature common to most of these phenomena is that they involve a quasirandom sequence of pulses on the microscopic scale.

The spectrum of energies associated with a short pulse of characteristic width Δt is roughly flat up to $E_{\rm max} = \hbar/\Delta t$. In general, the pulse process can be associated with quanta (such as phonons or photons) of energy $\hbar\omega$, so the number spectrum of these quanta varies as $1/\omega$ up to $\omega_{\rm max} = 1/\Delta t$.

When a phenomenon consists of a sequence of closely spaced pulses, such that the macroscopic behavior is quasistatic, the microscopic behavior involve fluctuations with the frequency spectrum of the assciated quanta, namely $1/\omega$, *i.e.*, $1/f$.

While the author considers the above to be fairly "obvious", the literature on $1/f$ noise mainly involves much more arcane, and less satisfactory, explanations. The above view was advocated by Handel in 1975 [11, 12] (in the context of Bremsstrahlung emitted by conduction electrons in collisions with lattice ions), although it seems to be regarded with surprising (to this author) skepticism.[2]

References

[1] J.B. Johnson, *The Schottky Effect in Low-Frequency Circuits*, Phys. Rev. **26**, 71 (1925), physics.princeton.edu/~mcdonald/examples/statistics/johnson_pr_26_71_25.pdf

[2] F.N. Hooge, *Discussion of Recent Experiments on $1/f$ Noise*, Physica **60**, 130 (1972), physics.princeton.edu/~mcdonald/examples/statistics/hooge_physica_60_130_72.pdf

[3] W.H. Press, *Flicker Noises in Astronomy and Elsewhere*, Comm. Astro. **7**, 103 (1978), physics.princeton.edu/~mcdonald/examples/statistics/press_ca_7_103_78.pdf

[1]See, for example, [2, 3, 4, 5, 6, 7, 8, 9, 10].
[2]See, for example, sec. IIIC of [6]. Exceptions are [13, 14]. For a "fractal" view of $1/f$ noise, see [7].

[4] M. Gardner, *White and brown music, fractal curves and one-over-f fluctuations*, Sci. Am. **238**, April, 16 (1978),
physics.princeton.edu/~mcdonald/examples/statistics/gardner_sa_238_4_16_78.pdf

[5] D.A. Bell, *A survey of l/f noise in electrical conductors*, J. Phys. C **13**, 4425 (1980),
physics.princeton.edu/~mcdonald/examples/statistics/bell_jpc_13_4425_80.pdf

[6] P. Dutta and P.M. Horn, *Low-frequency fluctuations in solids: $1/f$ noise*, Rev. Mod. Phys. **53**, 497 (1981), physics.princeton.edu/~mcdonald/examples/statistics/dutta_rmp_53_497_81.pdf

[7] P. Bak, C. Tang and K. Wiesenfeld, *Self-Organized Criticality: An Explanation of $1/f$ Noise*, Phys. Rev. Lett. **59**, 381 (1987),
physics.princeton.edu/~mcdonald/examples/statmech/bak_prl_59_381_87.pdf

[8] M.B. Weissman, *$1/f$ noise and other slow, nonexponential kinetics in condensed matter*, Rev. Mod. Phys. **60**, 537 (1988),
physics.princeton.edu/~mcdonald/examples/statistics/weissman_rmp_60_537_88.pdf

[9] E. Milotti, *$1/f$ noise: a pedagogical review*, (Apr. 2002),
http://arxiv.org/abs/physics/0204033

[10] L.M. Ward and P.E. Greenwood, *$1/f$ noise*, Scholarpedia **2**, 1537 (2007),
http://www.scholarpedia.org/article/1/f_noise

[11] P.H. Handel, *Quantum Theory of $1/f$ Noise*, Phys. Lett. **53A**, 438 (1975),
physics.princeton.edu/~mcdonald/examples/statistics/handel_pl_53a_438_75.pdf

[12] P.H. Handel, *Quantum approach to $1/f$ noise*, Phys. Rev. A **22**, 745 (1980),
physics.princeton.edu/~mcdonald/examples/statistics/handel_pra_22_745_80.pdf

[13] A. Van der Ziel, *Unified Presentation of l/f Noise in Electronic Devices: Fundamental l/f Noise Sources*, Proc. IEEE **76**(3), 233 (1988),
physics.princeton.edu/~mcdonald/examples/statistics/vanderziel_pieee_76_3_233_88.pdf

[14] C.M. Van Vliet, *A Survey of Results and Future Prospects on Quantum $1/f$ and $1/f$ Noise in General*, Solid State Elec. **34**, 1 (1991),
physics.princeton.edu/~mcdonald/examples/statistics/vanvliet_sse_34_1_91.pdf