Quantum Theory of 1/f Frequency Fluctuations Part 1
- DeCoherence as the Cause of Fundamental 1/f Noise -
Quartz, Electronics, MEMS, Clocks & Sensors

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Abstract: **The conventional Quantum 1/f Effect is present in any scattering cross section or process rate involving charged particles or current carriers. The present paper shows how bremsstrahlung and decoherence at all frequencies yield probability density fluctuations at all frequencies in the outgoing scattered beam, that are observed as fundamental base-band 1/f noise and as 1/f frequency fluctuations, or phase noise close to carrier, in materials, devices and systems. We emphasize the role of the phenomenon of quantum decoherence showing that the fundamental, universal 1/f noise is both a phenomenon of decoherence and of the infrared divergence of quantum electrodynamics. This eliminates the last persisting misunderstandings of the Quantum 1/f Theory and this new field of Infraquantum Physics. On this basis we give the first universal engineering formulas, applicable for the ultra-low noise optimization of all Hi-Tech applications, of the materials, devices and systems of modern industry, microelectronics, nanotechnology, highest stability resonators, oscillators and clocks, MEMS, and any resonant and non-resonant sensors. Quantum 1/f noise, i.e, the coherent and conventional Q1/f Effects is a new fundamental aspect of quantum physics, as basic as space and time.**

Quantum 1/f Noise is derived in 3 steps:

1. **Any Process Generating Radiation**
2. **Decoherence of Scattered Energy Loss Components**
3. **1/f Noise in the Scattered Beam**

Let us derive the quantum 1/f effect semiclassically.
We start with the classical (Larmor) formula $2q^2\mathbf{a}^2/3c^3$, for the power radiated by a particle of charge q and acceleration **a**. The acceleration can be approximated by a delta function $\mathbf{a}(t) = \Delta\mathbf{v}\delta(t)$ whose Fourier transform $\Delta\mathbf{v}$ is constant and is the change in the velocity vector of the particle during the almost instantaneous scattering process. The one-sided spectral density of the emitted bremsstrahlung power $4q^2(\Delta\mathbf{v})^2/3c^3$ is therefore also constant. The number $4q^2(\Delta\mathbf{v})^2/3hfc^3$ of emitted photons per unit frequency interval is obtained by dividing with the energy hf of one photon. The probability amplitude of photon emission $[4q(\Delta\mathbf{v})^2/3hfc^3]^{1/2}e^{i\gamma}$ Is given by the square root of this photon number spectrum, including also a phase factor $e^{i\gamma}$. Let ψ be a representative Schrödinger catalogue wave function of the scattered outgoing charged particles, which is a single particle function, normalized to the actual scattered particle concentration. The beat term in the probability density $\rho=|\psi|^2$ is linear both in this bremsstrahlung amplitude and in the non-bremsstrahlung amplitude. Its spectral density will therefore be given by the product of the squared probability amplitude of photon emission (proportional to 1/f) with the squared non-bremsstrahlung amplitude which is independent of f. The resulting spectral density of fractional probability density fluctuations is obtained by dividing with $|\psi|^4$ and is therefore

[1] P. H. Handel:"Decoherence and Conventional Quantum 1/f Noise," Proc. ICNF'13, Montpellier, France, June 2013, pp. 1-4, DOI: [10.1109/ICNF.-2013.6578914].

$$|\psi|^{-4}S_{|\psi|^2}(f) = 8q^2(\Delta\mathbf{v})^2/3hfNc^3 = 2\alpha A/fN = j^{-2}S_j(f),$$

where $\alpha = e^2/c = 1/137$ is the fine structure constant and $\alpha A = 4q^2(\Delta\mathbf{v})^2/3hc^3$ is known as the infrared exponent in quantum field theory, and is known as the quantum 1/f noise coefficient, in electrophysics. The experimentally measured quantity also depends on many superposition or averaging processes and is often called, for historical reasons, Hooge constant.

The Quantum Theory of 1/f Noise was misunderstood by some for many years, for many reasons, but finally for only one reason: In general, the bremsstrahlung energy loss components emerging from any scattering, or from other processes, are known not to interfere with the main wave function, (while I have claimed, interference usually happens. with random phases. As a special exception, I had also observed that decoherence happens only to 10% in beta radioactive decay!). The emergent bremsstrahlung energy loss components are indeed known to be orthogonal, with phases differing by 90 degrees in a certain quantum representation. Therefore, some said that my theory, based on such interference, was not valid. But the experiment always verified my formulas in all domains, universally. Their mistake was that they ignored the universal phenomenon of quantum decoherence,. Indeed, soon after the superposition state with 90 degrees phase differences is created, decoherence scrambles the hases, *randomizing them*, as I always assumed in my theory of both the conventional and coherent quantum 1/f effects, which I introduced.This is why the Schrödinger cat is never found half dead and half alive, and why we don't have quantum computers yet!
This was finally understood by the scientific community, after a 2013 paper of mine [1], and there are no other logical objection left to my theory, and to my simple, prac-practical, universal engineering formulas. They are applicable to all high-tech fields, for anything existing in any domain, in time and space. It's as basic as time and space, since it also happens with gravitons as infraquanta! I have all formulas for that quantum gravidynamic 1/f aspect also, including the "s' " parameters, mixing the gravidynamic coherent and conventional contributions. It limits all existence in time and space, it sets fundamental limits to highest frequency stability, and to our knowledge of time and frequency. My amply verified [2], universal, simple Q1/f engi-neering formulas allow us to reduce these fundamental li-mits, by optimizing the system.

This clarified understanding will be exemplified with a partridge allegory. The nude partridge **FIG. 1** acquires his beautiful plumage **FIG. 2**, after an interaction process, e.g., the loss of a phonon from the main resonator mode of the clock. This elementary dissipation process is followed by DECOHERENCE, whereby the plumage of the partridge becomes separated and independent **FIG. 3,** with random positions or "phases." These disconnected partial components of the wave function of the complete quartz crystal (the partridge) interfere now with the main, non-bremsstrahlung part (the naked partridge), with random phases, yielding the conventional Q1/f noise in the disipation rate, and resulting 1/f resonator frequency fluctuations, given by my well-known Q1/f frequency fluctuation formulas. It works similarly in atomic clocks, fountain, etc.

[2] F. Sthal, M. Devel, S. Ghosh, J. Imbaud, G. Cibiel# and R. Bourquin: "Volume dependence in Handel's model of quartz crystal resonator noise" IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control, September 2013, Vol. 90, No. 9, pp. 1971-1977 (2013)

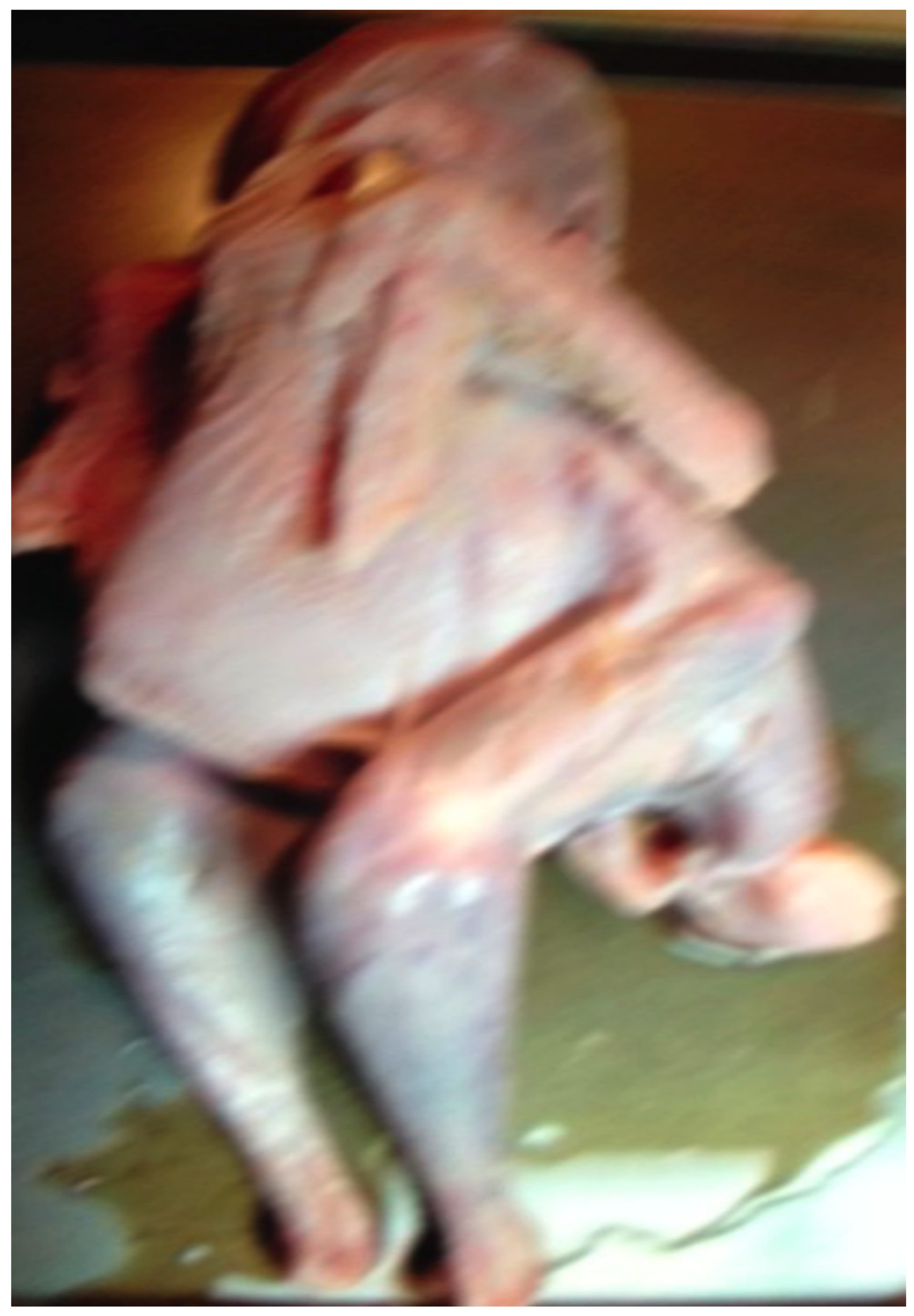

FIG. 1

FIG. 2

FIG. 3: 1/f Noise & Phase Noise