8th International Conference on Unsolved Problems on Noise

Gdańsk University of Technology, Gdańsk, 9-13 July 2018

Random fluctuations, and their effect on systems, have always been an interdisciplinary subject that has attracted some of the best scientists. The aim of the UPoN conference is to provide a forum for researchers working on different fields of noise, fluctuations and variability, where they can present their scientific problems which do resist solutions and discuss together in a fruitful atmosphere.

22 years since the inaugural at Szeged in 1996 !

Thanks to ONR-USA and ONR-Global for support, now and then!

Many thanks to Janusz

who must beat the heat now!

Janusz Smulko (Chair)

UPoN GDAŃSK 2018

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He had a good training for beating the heat in 2003...

~ 40^{o}C, Palo Duron Canyon, Texas, on the way to Santa Fe,
SPIE’s “Fluctuation an Noise Symposium”, 2003 May.

Quantum-thermal noise in thermal equilibrium at zero temperature?

L.B. Kish

Department of Electrical and Computer Engineering, Texas A&M University, College Station, TX , USA

Abstract. The question of the existence of non-zero thermal noise at zero temperature is an unsolved problem of noise that is recognized to be unsolved by only a few papers among the many that ignores that fact. Experimental proof is controversial because it is limited to a narrow set of situations while in other situations the effect does not exist, facts that are often ignored. It is somehow "*politically incorrect*" to question the zero-point term in the Fluctuation-Dissipation Theorem even though many scientists in solid state physics and atomic physics say it cannot exist. In fact, the theory contradicts to Fermi-Dirac statistics in a solid resistor and the measurement proofs seem to originate from the energy-time uncertainly principle indicating that setups of different nature would not show the effect. **We believe the theory is incomplete; it must be made "more quantum" by including the measurement setup, in order to solve the controversy.**

Is there thermal noise at zero temperature?

Note: this issue, which can lead to heated debates ☺

At UPoN-2015 in Barcelona...

My role here??? Not being a quantum theorist or quantum experimentalist, my role is the role of a ***car driver*.** I am a *user*: ***using these results*** in my ***research*** about computing and secure communication concepts, and also ***teaching*** them.

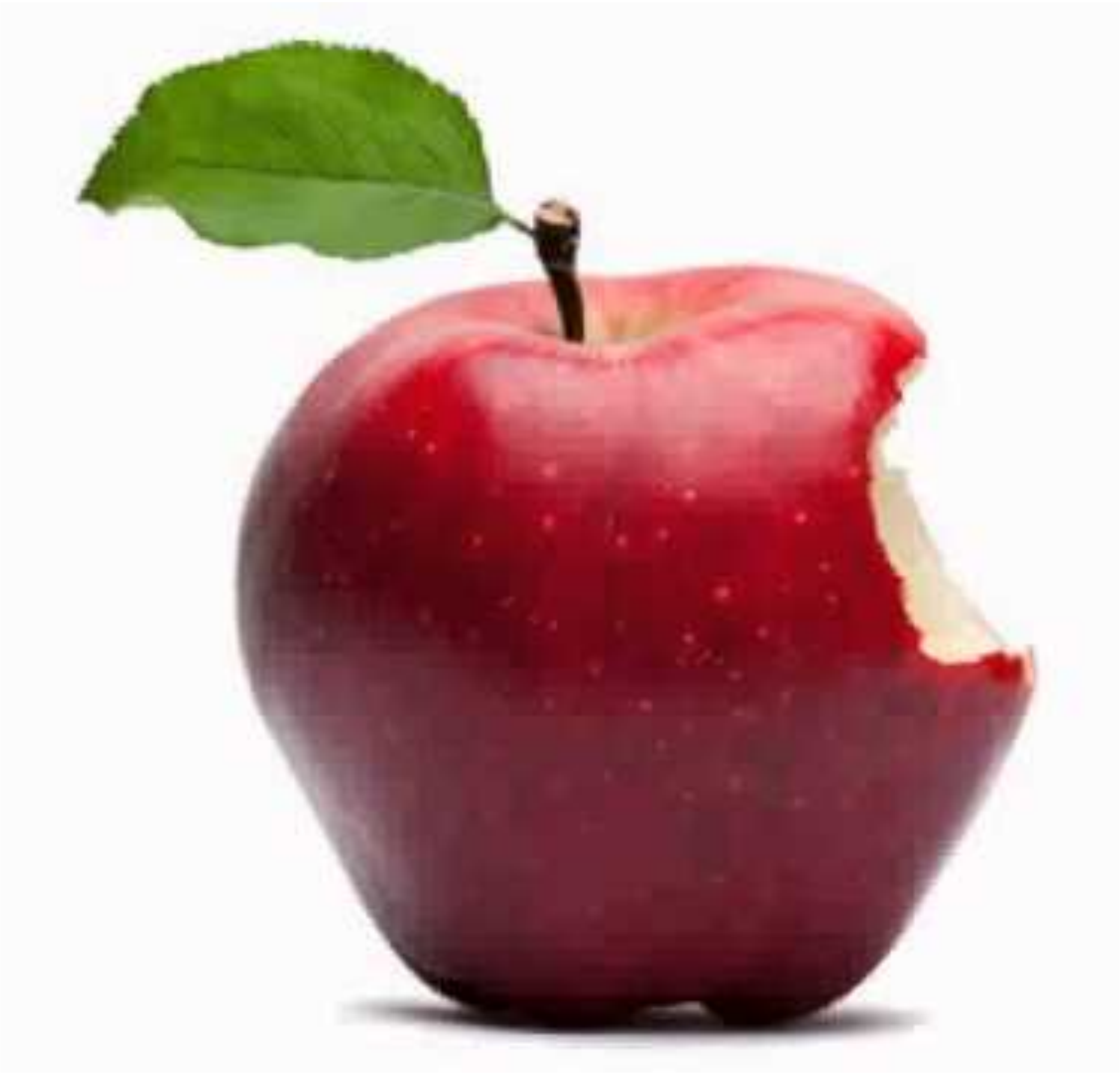
Many ***car repairmen*** are telling me that my car has ***passed all the tests*** thus it is in a perfect condition!!! Few other ***car repairmen*** say just the opposite.

And my own driving experience is that **something is very fishy with this car !**

Apple of knowledge

What if there is a wormhole in it?

Should we bite into that apple?

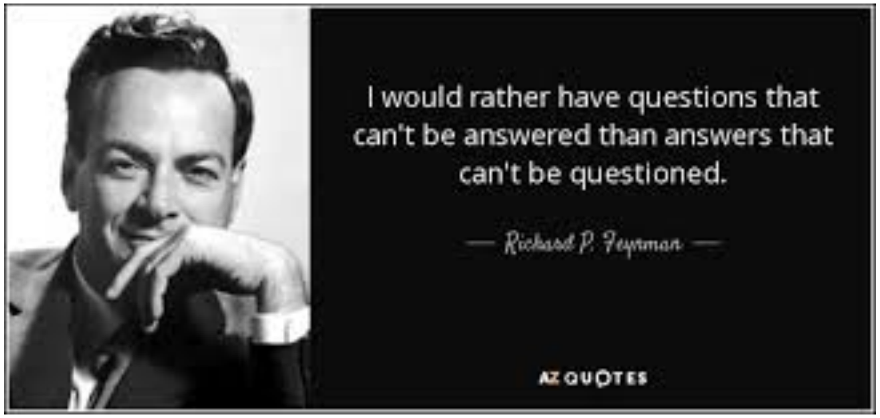


Some bad surprises may follow

The role of unbiased scientists is to detect and investigate wormholes, that is, clarify inconsistencies in theories and experiments...

About challenging widely accepted dogmas, Feynman wrote:

I would have rather ***questions that cannot be answered*** *than* ***answers that cannot be questioned****.*



I would rather have questions that can't be answered than answers that can't be questioned.

— Richard P. Feynman —

van Kampen's note at ICNF-1987, when he criticized several different theories by showing this:


[redacted]

Theory is good for you

van Kampen's note at ICNF-1987, when he criticized several different theories by showing this:

Theory is good for you

Provided the theory is correct

van Kampen's note at ICNF-1987, when he criticized several different theories by showing this:

Theory is good for you

Provided the theory is correct

we add here: **and complete**

We add here:

A careful experiment is good for you

We add here:

A careful experiment is good for you

Provided its interpretation is correct

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2. Experimental results supporting it

3. Experimental results denying it

4. Conceptual problems with the zero-point noise claim

5. Conclusion, unsolved problems and proposed steps

6. A conjecture about the zero-point noise with wide-band amplifiers

Valuable discussions are appreciated (listing not guarantees agreement):

Gunnar Niklasson (co-author of related papers; J.Stat. Phys. 2016, FNL 2016)

Claes-Goran Granqvist (co-author of related papers; J.Stat. Phys. 2016, FNL 2016)

Igor Goychuk

Peter Rentzepis

Massimo Macucci

Boris Grafov

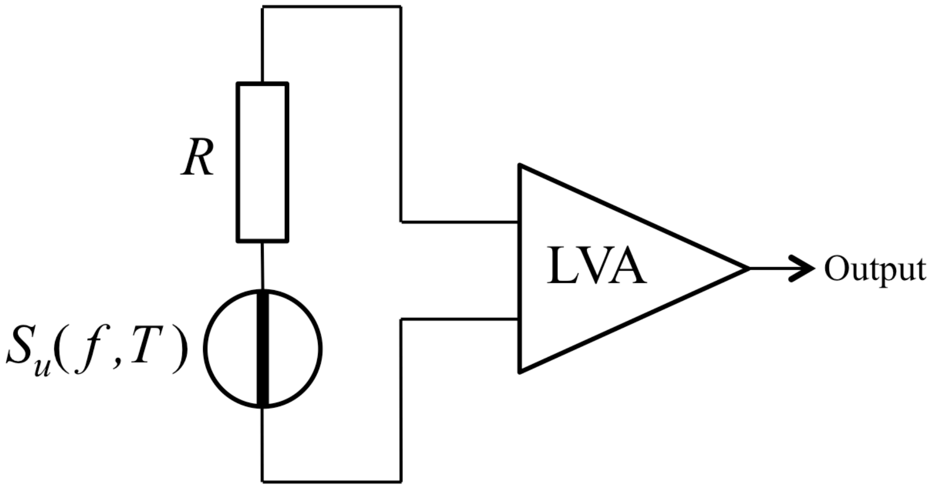
Kyle Sundqvist

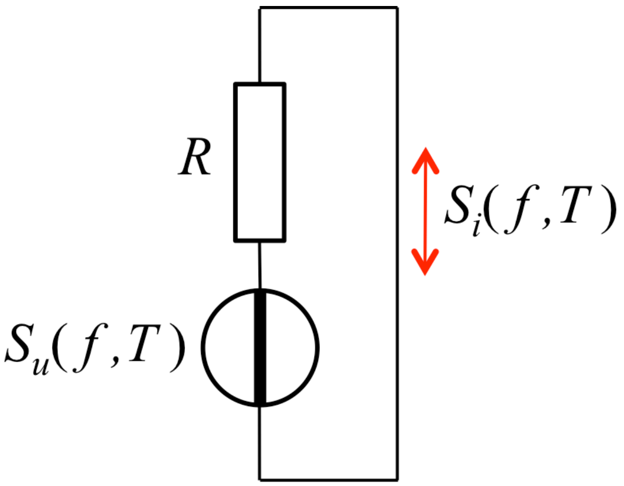
Mark Dykman

- L.B. Kish, G.A. Niklasson, C.G Granqvist, "Zero-point term and quantum effects in the Johnson noise of resistors: A critical appraisal", J. Stat. Mech. 2016 (2016) 054006. Online: http://arxiv.org/abs/1504.08229 .
- L.B. Kish, G.A. Niklasson, C.G. Granqvist, "Zero thermal noise in resistors at zero temperature", Fluct. Noise. Lett. 15 (2016) 1640001.
  Online: http://www.researchgate.net/publication/303959024_Zero_Thermal_Noise_in_Resistors_at_Zero_Temperature

- J. Basset, H. Bouchiat, and R. Deblock, “High-frequency quantum admittance and noise measurement with an on-chip resonant circuit”, PRB 85, 085435 (2012)
- A. Crépieux, P. Eyméoud, F. Michelini, “Getting information from the mixed electrical-heat noise”, arXiv: 1703.08124v3
- J.B. Johnson, "Thermal agitation of electricity in conductors", Nature 119, 50 (1927).
- H. Nyquist, "Thermal agitation of electric charge in conductors", Phys. Rev. 32, 110-113 (1928).
- H.B. Callen and T. A. Welton, "Irreversibility and Generalized Noise", Phys. Rev. 83, 34 (1951).
- R. Kubo, M. Toda and N. Hashitsume, Statistical Physics II (Springer, Berlin, 1985).
- V. L. Ginzburg and L. P. Pitaevskii, "Quantum Nyquist formula and the applicability ranges of the Callen–Welton formula", Sov. Phys. Usp. 30, 168 (1987).
- M.H. Devoret, "Quantum fluctuations in electrical circuits", in S. Reynaud, E. Giacobino and J. Zinn-Justin, eds., Fluctuations Quantique: Les Houches, Session LXIII, 1995 (Elsevier, Amsterdam, 1997) .
- D.K.C. MacDonald, "On Brownian movement and irreversibility", Physica 28, 409 (1962).
- I.A. Harris, "Zero-point fluctuations and thermal-noise standards", Electron. Lett. 7, 148 (1971).
- G. Grau and W. Kleen, "Comments on zero-point energy, quantum noise and spontaneous-emission noise", Solid-State Electron. 25, 749 (1982).
- L.B. Kiss, "To the problem of zero-point energy and thermal noise", Solid State Comm. 67, 749 (1988).
- H. Koch, D. J. van Harlingen and J. Clarke, "Observation of zero-point fluctuations in a resistively shunted Josephson tunnel junction", Phys. Rev. Lett. 47, 1216 (1981).
- H.A. Haus and J.A. Mullen, "Quantum noise in linear amplifiers", Phys. Rev. 128, 2407 (1962).
- H. Heffner, "The fundamental noise limit of linear amplifiers", Proc. IRE 50,1604 (1962).
- L. Reggiani, P. Shiktorov, E. Starikov and V. Gružinskis, "Quantum fluctuation dissipation theorem revisited: remarks and contradictions", Fluct. Noise Lett. 11, 1242002 (2012).

Johnson 1927: Thermal noise of resistors at low frequencies ($hf \ll kT$)





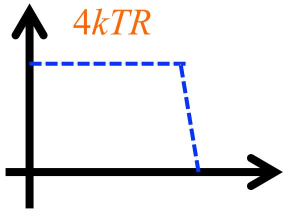
$$S_u(f,T) = 4kTR \qquad S_i(f,T) = 4kTG$$

$$S_u(f,T) = Q(T)R \qquad S_i(f,T) = Q(T)G$$

$Q(T) = 4kT$ in the low-frequency limit

Nyquist 1928: arbitrary frequency range

$$S_u(f,T) = \underbrace{4hfN(f,T)}_{Q(f,T)=4hfN(f,T)}R$$



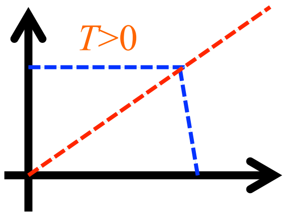
Planck's quantum number $N(f,T) = \left[\exp(hf/kT) - 1\right]^{-1}$

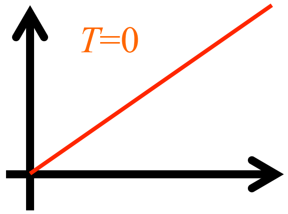
For $f << kT/h$, or $hf/k << T$, *classical* Johnson noise formula: $S_u \cong 4kTR$

For $\boldsymbol{kT/h << f}$, or $\boldsymbol{T << hf/k}$, exponential cut-off in accordance with the cut-off of Planck's black-body radiation formula

Callen-Welton (quantum FDT), 1951:

$$S_{u,q}(f,T)=\underbrace{4hf\left[N(f,T)+0.5\right]}_{Q(f,T)=4hf\left[\underset{\substack{\uparrow\\ \textbf{Nyquist 1928}}}{N(f,T)}+0.5\right]}R$$



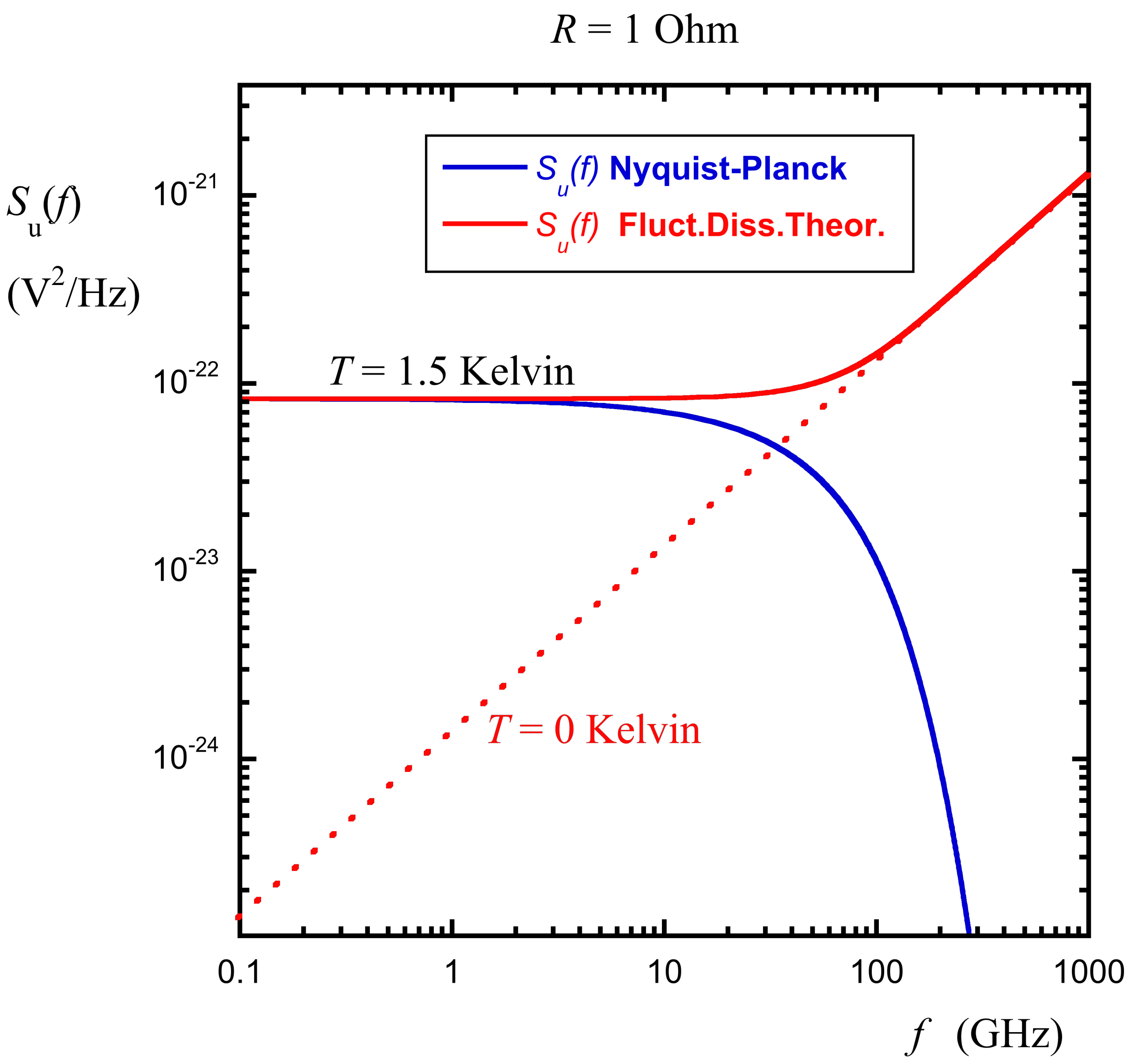


Planck quantum number $N(f,T)=\left[\exp(hf/kT)-1\right]^{-1}$

For $f<<kT/h$, or $hf/k<<T$, *classical* Johnson noise formula: $S_u\cong 4kTR$

For $kT/h<<f$, or $T<<hf/k$, **zero-point noise** formula: $S_{u,ZP}=2hfR$

similar for current noise: $S_{i,ZP}=2hfG$


R = 1 Ohm
S_u(f) Nyquist-Planck
S_u(f) Fluct.Diss.Theor.
S_u(f)
(V²/Hz)
10⁻²¹
10⁻²²
10⁻²³
10⁻²⁴
T = 1.5 Kelvin
T = 0 Kelvin
0.1
1
10
100
1000
f (GHz)

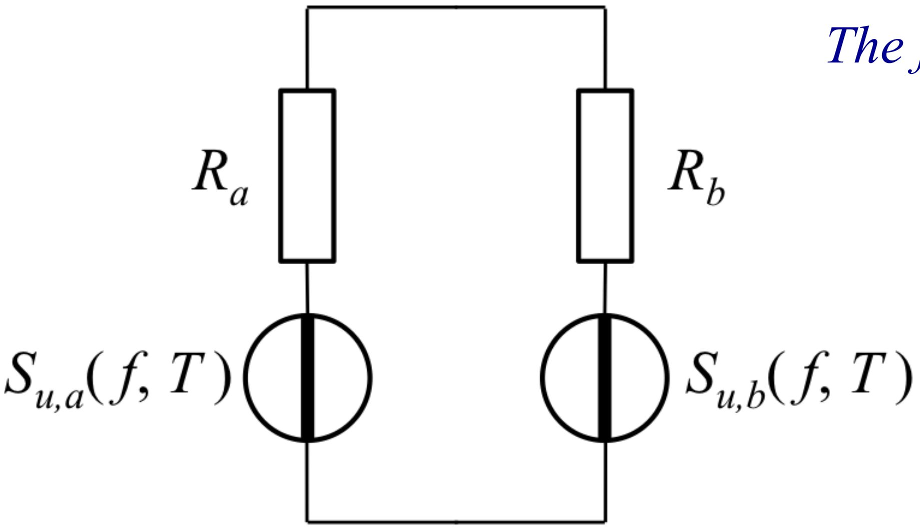
Modern theories: two-sided spectra (QED):

- only negative frequencies (absorption) carry the zero-point term

- positive frequencies (emission) carry the Nyquist-Planck term

In standard classical noise measurements, the one-sided spectrum is the sum of the two terms at the absolute value of the frequency.

Physical impact that the zero-point term is only in the absorption?



Second Law of Thermodynamics

The formula must be universal

When $T_A = T_B$, $P_{A\to B}(f, \Delta f) = 0$

$$S_u(f,T) = R(f)Q(f,T) \qquad S_i(f,T) = G(f)Q(f,T)$$

$$P_{A\to B}(f,\Delta f) = (T_A - T_B)Q(f,T)\frac{R_A R_B}{(R_A + R_B)^2}\Delta f$$

The formula must be universal; any deviation is a violation.

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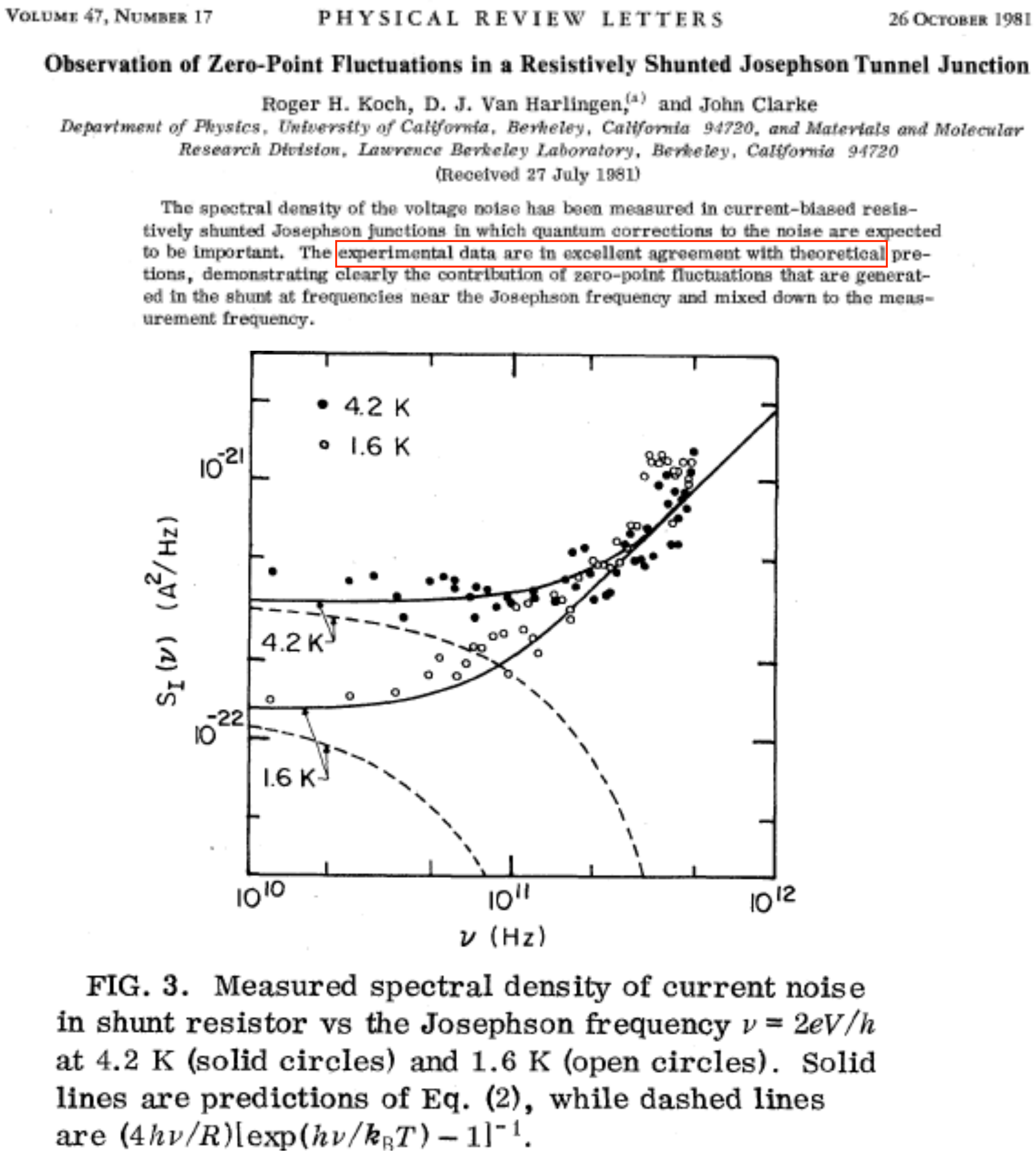
The first experiment: Josephson-junction heterodyne detection (spectral analysis by frequency mixing to near DC).

$$S_{u,q}(f,T) = 4Rhf\left[N(f,T) + \mathbf{0.5}\right]$$



VOLUME 47, NUMBER 17 PHYSICAL REVIEW LETTERS 26 OCTOBER 1981

Observation of Zero-Point Fluctuations in a Resistively Shunted Josephson Tunnel Junction

Roger H. Koch, D. J. Van Harlingen,[a] and John Clarke

Department of Physics, University of California, Berkeley, California 94720, and Materials and Molecular Research Division, Lawrence Berkeley Laboratory, Berkeley, California 94720

(Received 27 July 1981)

The spectral density of the voltage noise has been measured in current-biased resistively shunted Josephson junctions in which quantum corrections to the noise are expected to be important. The experimental data are in excellent agreement with theoretical predictions, demonstrating clearly the contribution of zero-point fluctuations that are generated in the shunt at frequencies near the Josephson frequency and mixed down to the measurement frequency.

FIG. 3. Measured spectral density of current noise in shunt resistor vs the Josephson frequency $\nu = 2eV/h$ at 4.2 K (solid circles) and 1.6 K (open circles). Solid lines are predictions of Eq. (2), while dashed lines are $(4h\nu/R)[\exp(h\nu/k_BT) - 1]^{-1}$.

John Clarke, Brian Jones

ICNF, Montreal, May 27, 1987

Similar Josephson–junction based experimental confirmations and improvements have been around since, including the *Hakonen Group*'s experiments with observing high-frequency sidebands (Hakonen, ICNF 2017); see the 3rd talk at this morning.

Note: the existence of the zero-point term when measured by a Josephson-junction is also *everyday experience* in radio astronomy (I saw that with my own eyes at a Japanese Radio Astronomy Observatory where Josephson junctions were fabricated and tested for the purpose).

Question: ***are there wide-band amplifier based measurements of thermal noise in the quantum range?***

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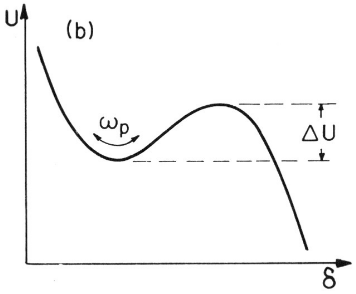
Negative experiments

1981, Voss and Webb: potential threshold crossing rate strictly follows thermal activations and stays **4-9 orders of magnitudes** below zero-point noise limit!

Richard Voss



Their conclusion was the potential well models of Josephson junctions with Langevin type formulation were inappropriate. *The possibility that the zero-point noise was not present was not mentioned.*

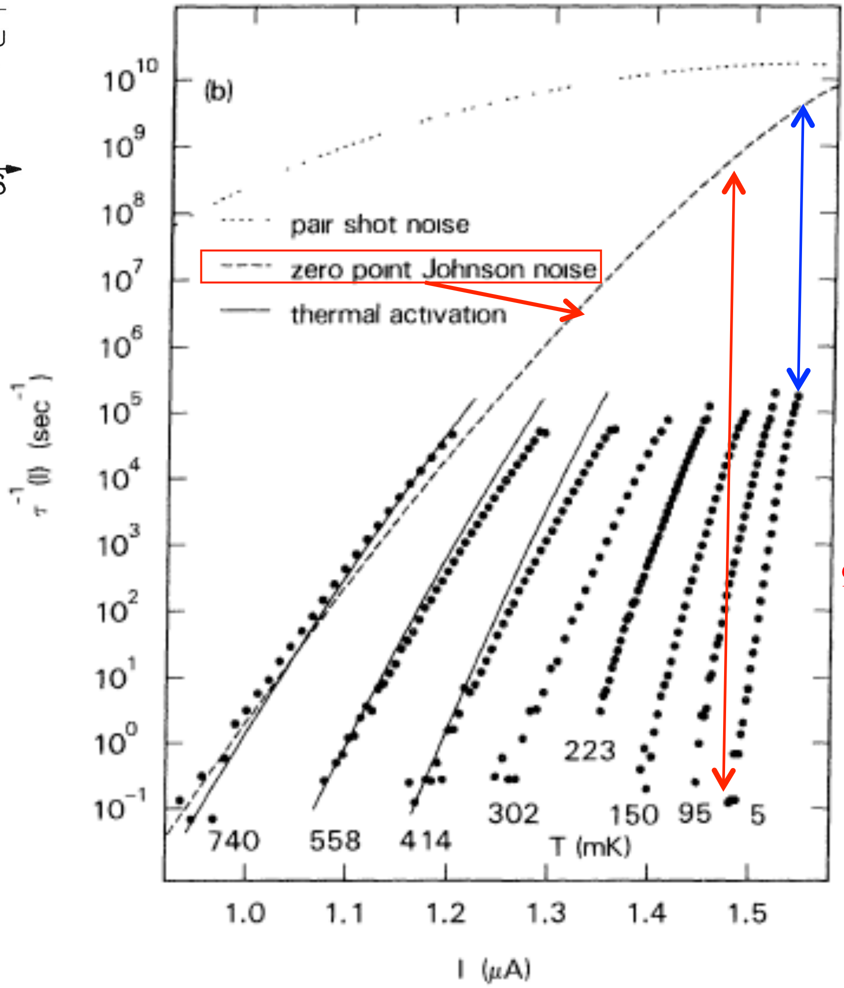
PHYSICAL REVIEW B VOLUME 24, NUMBER 12 15 DECEMBER 1981

Pair shot noise and zero-point Johnson noise in Josephson junctions

Richard F. Voss and Richard A. Webb
IBM Thomas J. Watson Research Center, Yorktown Heights, New York 10598

$$S_{u,q}(f,T)=R\,4hf\left[N(f,T)+\cancel{0.5}\right]$$

Transition rates $\tau^{-1}(I)$ with theoretical predictions.



4 orders of magnitude

9 orders of magnitude

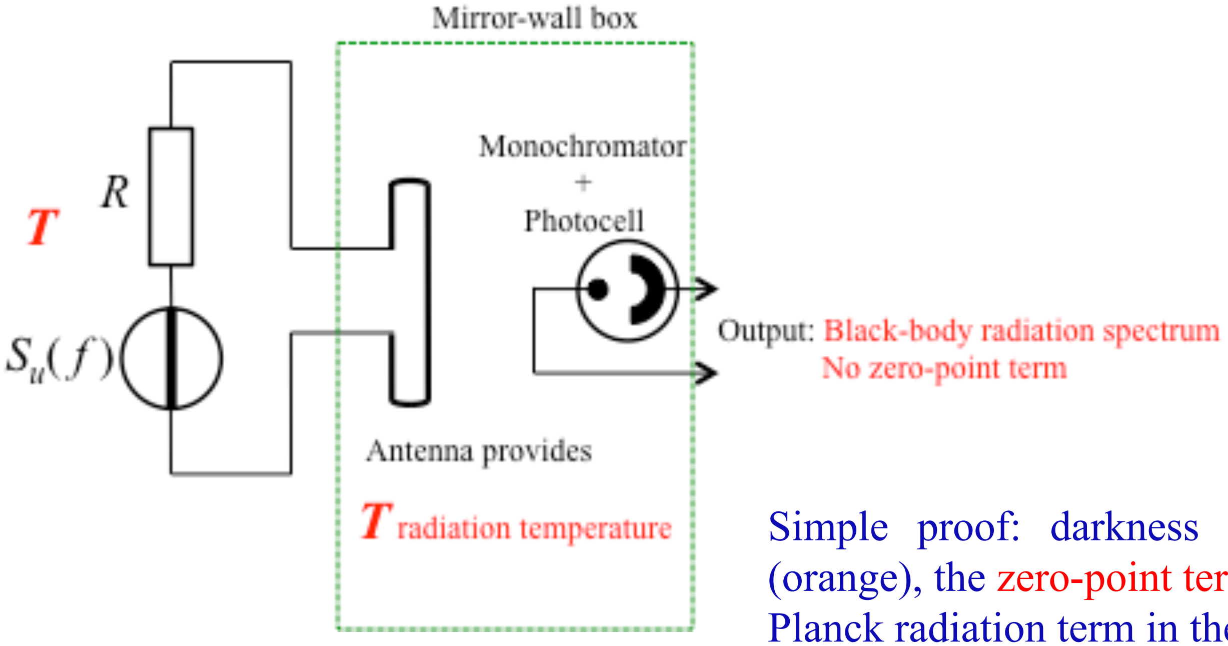
Negative experiments Wilhelm Wien 1896:

Black-body radiation (see Planck formula) in the high-frequency limit

Photocell vs antenna, G. Grau and W. Kleen, Solid-State Electron. 25, 749 (**1982**)

$$S_{u,q}(f,T) = R\,4hf\left[N(f,T) + \xcancel{0.5}\right]$$

Werner Kleen 1967



Simple proof: darkness in a dark room. At 600 nm (orange), the zero-point term is 30 times greater (!) than the Planck radiation term in the sunshine.

Correct claim and it has not been answered by quantum the FDT theory from the very beginning!

mean-square field of radiation:

Callen_Welton_PhysRev.83.34, (1951)

$$\langle \mathcal{E}_x{}^2\rangle = (4/3)\pi^{-1}c^{-3} \times \int_0^\infty \{\tfrac{1}{2}\hbar\omega + \hbar\omega[\exp(\hbar\omega/kT)-1]^{-1}\}\omega^2 d\omega. \quad (6.7)$$

zero-point thermal radiation (**not visible in light!**)

CW avoids analyzing the discrepancy that the zero-point term in resistor noise is not visible in the light.

energy density of radiation:

Energy density

zero-point energy (in quantum linear oscillator)

$$= \pi^{-2}c^{-3}\int_0^\infty \{\tfrac{1}{2}\hbar\omega + \hbar\omega[\exp(\hbar\omega/kT)-1]^{-1}\}\omega^2 d\omega. \quad (6.9)$$

A. van der Ziel's negative experimental outcome for non-heterodyne microwave measurements.

$$S_{u,q}(f,T) = R\,4hf\left[N(f,T)+\xcancel{0.5}\right]$$

They did not see the zero-point term via direct (non-heterodyne) measurements of *Hanbury Brown-Twiss (HBT)* type microwave circuitry at 1 Kelvin temperature and up to 95 GHz frequency, even though this frequency limit at this temperature is about 5 times beyond the *kT/h* classical/quantum boundary and their accuracy to measure noise-temperature was 0.1 Kelvin.

C.M. Van Vliet, Equilibrium and non-equilibrium statistical mechanics, (World Scientific 2008).

A. van der Ziel, Proc. ICNF, Washington DC, 1981.

(The *HBT* principle of the instrument is based upon the correlation between the rectified outputs of two independent receivers.)

I guess they saw only the black body radiation and gave it up due to the KVC experiments in *PRL* ...

Aldert van der Ziel

Montreal, ICNF, May 27, 1987

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Conceptual objections

a) Quantum systems in ***ground state*** do not emit power; see atoms, etc.

b) To detect *zero-point energy*, a system parameter must either be varied and then only a *finite energy* can be extracted, such as Casimir force, or

For a steady emission power, an external excitation is needed, such as to detect molecular zero-point vibration side bands in emission spectra. *Not available at passive thermal noise measurement at zero temperature.*

c) Lack of the zero-point term in the thermal radiation

d) Perpetual motion machines

e) Experimental artifact due to the uncertainty principle: It takes care of c) and d) above:

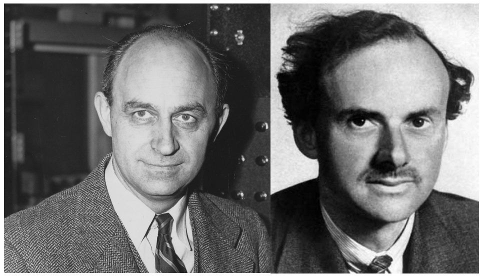
The Josephson-junction measurements are experimental artifacts due to the time-energy uncertainty principle. Thus measuring the noise in a different way, the zero-point term will be different or it will not be there. The FDT does not specify the way of measurement thus it is an incomplete theory which contradicts experiments at many situation, see c) and d) above and in forthcoming slides.

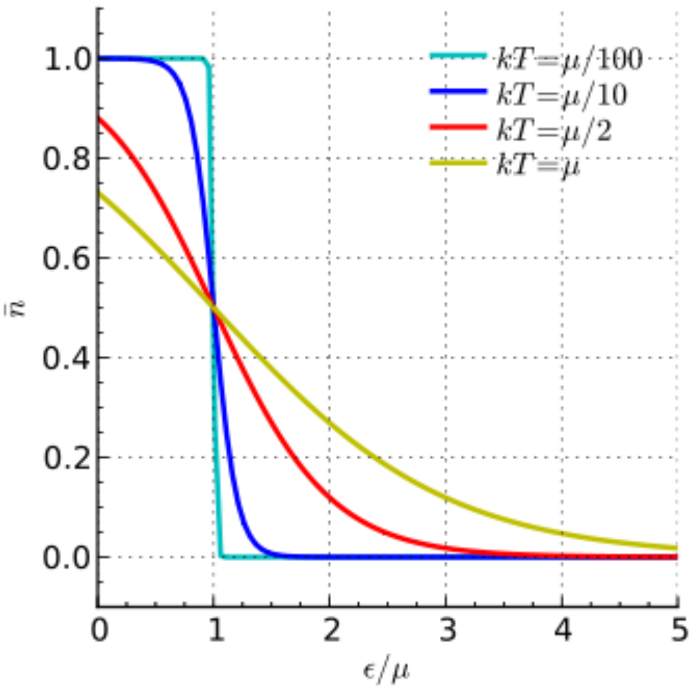
Violation of the Fermi-Dirac statistics

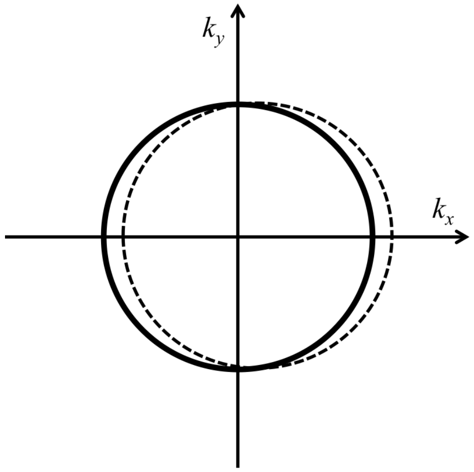
Kish, Niklasson, Granqvist, *Fluct. Noise. Lett.* **15**(2016)

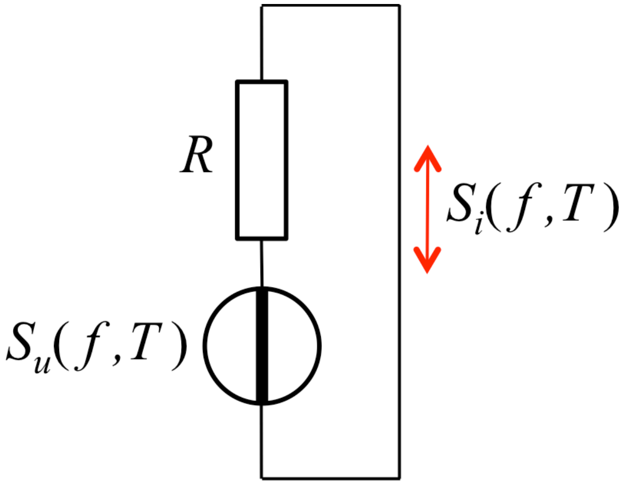
The claim of zero-point current noise contradicts to the Fermi-Dirac statistics in metallic conductors when the temperature is approaching zero. Then all states are occupied up to the Fermi surface and no states can be occupied above. That prohibits any current, including noise current, in this situation.

$$P(E,T) = \frac{1}{1+\exp\left(\frac{E-E_F}{kT}\right)}, \qquad P(E,T=0) = \begin{cases} 1 & \text{for } E \le E_{\mathrm{F}}, \\ 0 & \text{for } E > E_{\mathrm{F}}, \end{cases}$$









$$S_{u,q}(f,T) = R\,4hf\,[N(f,T)+\xcancel{0.5}]$$

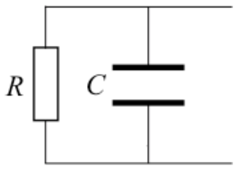
Perpetual motion machines ?

- In fact, already the **antenna-blackbody-radiation system** (Kleen 1982, see above) offers a perpetual motion machine if the FDT is correct.

$$S_{u,q}(f,T) = R\,4hf\left[N(f,T) + \cancel{0.5}\right]$$

- Resistance-dependent energy in a capacitor if the FDT is correct:

L.B. Kish, Solid State Comm. 67, 749 (**1988**): *If the zero-point noise exists, perpetual motion machines could be constructed by moving capacitor plates. Realization of such was not shown that time.*

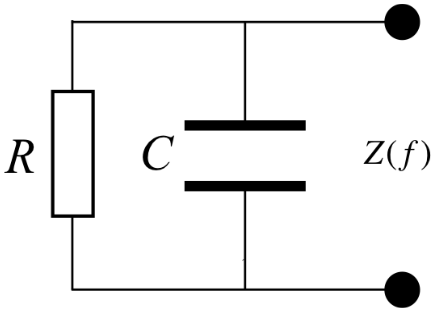


$$S_{u,q}(f,T) = R\,4hf\left[N(f,T) + \cancel{0.5}\right]$$

L.B. Kish, G.A. Niklasson, C.G Granqvist, J. Stat. Mech. **2016** (2016) 054006

UPoN-2015: We showed two perpetual motion machines. If the zero-point noise is objectively present, we can create at least 2 different types of perpetual motion machines, that is *the Second Law is violated*. One is with a *fixed* capacitor, and another one with a *moving capacitor plate*.

Consider the mean energy due to the zero-point noise term in a capacitor shunting a resistor:

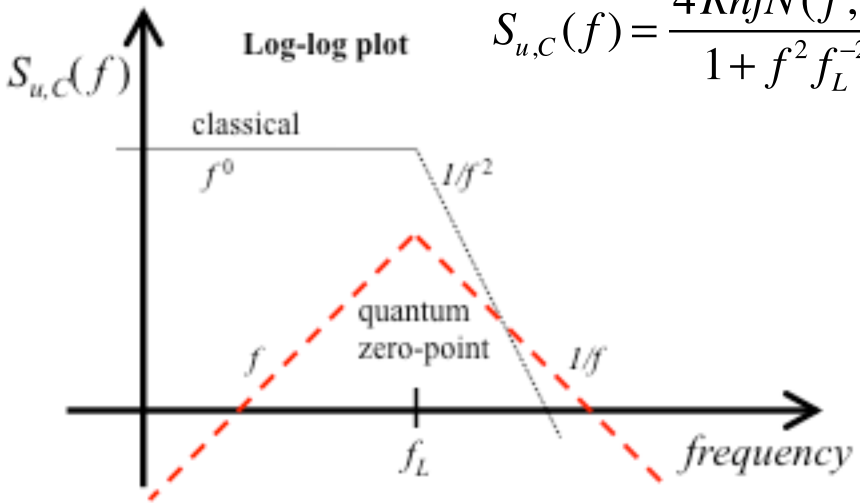


$$Z(f)=\frac{R}{1+\mathbf{j}\frac{f}{f_L}}$$

$$\mathrm{Re}\left[Z(f)\right]=R\left(1+f^2 f_L^{-2}\right)^{-1} \qquad f_L=\left(2\pi RC\right)^{-1}$$

$$S_{u,q}(f,T)=4\,\mathrm{Re}\left[Z(f)\right]hf\left[N(f,T)+\mathbf{0.5}\right]$$

$$N(f,T)=\left[\exp(hf/kT)-1\right]^{-1}$$



$$S_{u,C}(f)=\frac{4RhfN(f,T)}{1+f^2 f_L^{-2}}+\frac{2Rhf}{1+f^2 f_L^{-2}}$$

$$\left\langle E_C\right\rangle=0.5C\left\langle U_C^2(t)\right\rangle=0.5C\int_0^{f_c}S_{u,C}(f)df$$

Heat generator from zero-point noise (if the zero-point noise in the FDT is correct)

It is an ensemble of M Units, each one containing two different resistors and one capacitor controlled by the same flywheel in asynchronous way. The capacitors in the Units are periodically alternated between the two resistors by centrally controlled switches, in a synchronized fashion, that makes the relative control energy negligible.
See, LBK, "Johnson noise engines", Chaos, Solitons & Fractals 44, 114 (**2011**)

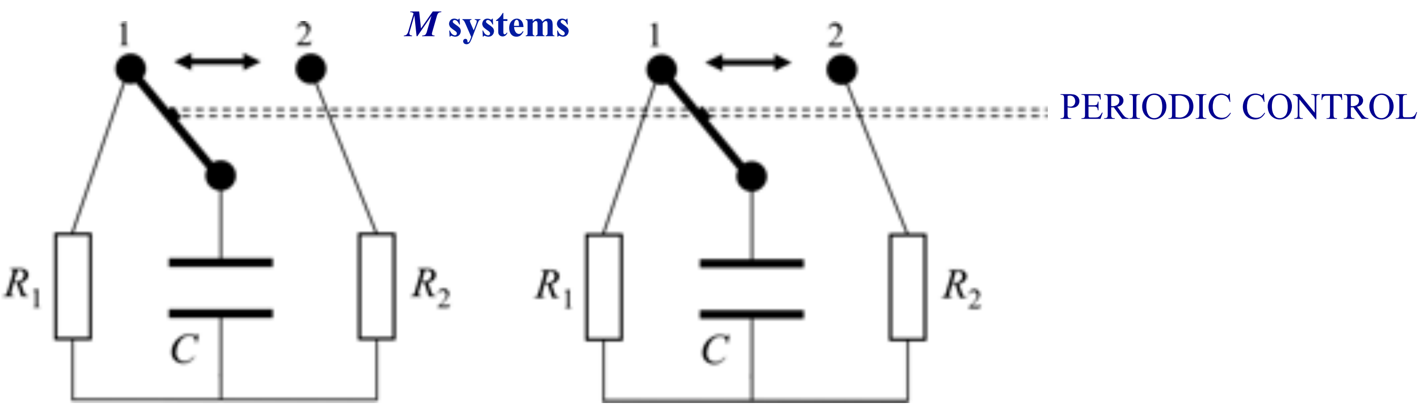
The duration of the period is much longer than any of the RC time constants thus the capacitors are "thermalized" by the zero-point noise in each state. Suppose, $R_1 < R_2$.

Then at each 1 ➔ 2 transition

$$\boxed{0 < E_h = M \frac{h}{8\pi^2 C}\left[\frac{\ln\left(1+4\pi^2 R_1^2 C^2 f_c^2\right)}{R_1} - \frac{\ln\left(1+4\pi^2 R_2^2 C^2 f_c^2\right)}{R_2}\right]}$$

energy is dissipated in R_2 .

This energy is coming from the zero-point noise of R_1. It can be used to drive the flywheel that controls the system.



***M* systems**

PERIODIC CONTROL

Thus, the zero-point term cannot exist: $\boxed{S_{u,q}(f,T) = R\,4hf\left[N(f,T)+\cancel{0.5}\right]}$

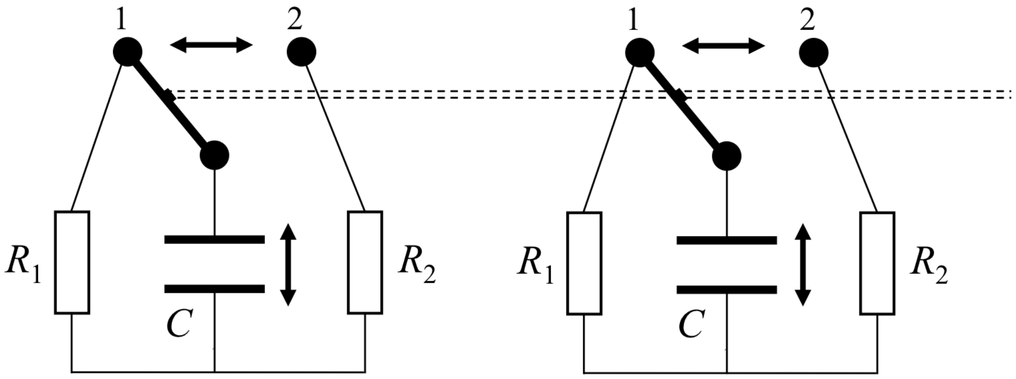
Two-stroke engine (and heat generator) from zero-point noise (if the FDT is correct)

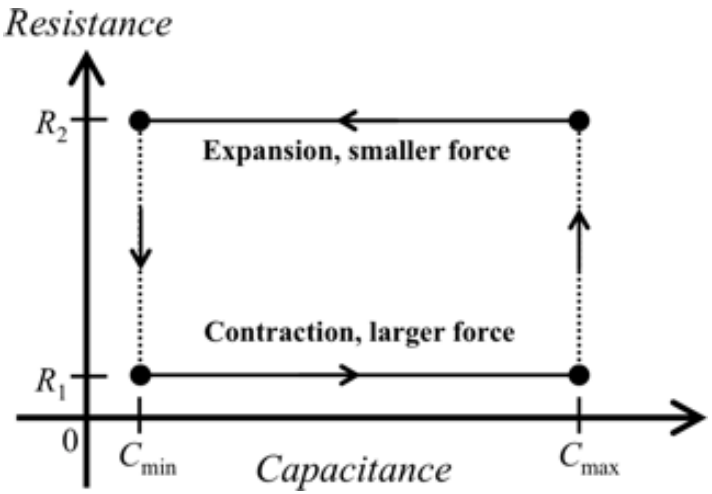
The engine has M parallel cylinders with identical elements and parameters as in the heat generator. The plate-capacitors have a moving plate, which acts as a piston. The moving plates are coupled to a flywheel, which moves them in a periodic, synchronized fashion. When the plate distance reaches its nearest and farthest distance limits respectively, the switch alternates the driving resistor. *During contraction and expansion, we have R_1 and R_2, respectively.*

The mean force in the plate-capacitors is:

$$\langle F(x)\rangle = \frac{\langle E_C\rangle}{x} = \frac{1}{x}\frac{h}{8\pi^2 RC(x)}\ln\left[1+4\pi^2R^2C^2(x)f_c^2\right]$$

With $R_1 < R_2$, at any given plate distance x (and corresponding capacitance value), the force is stronger during contraction than during expansion.





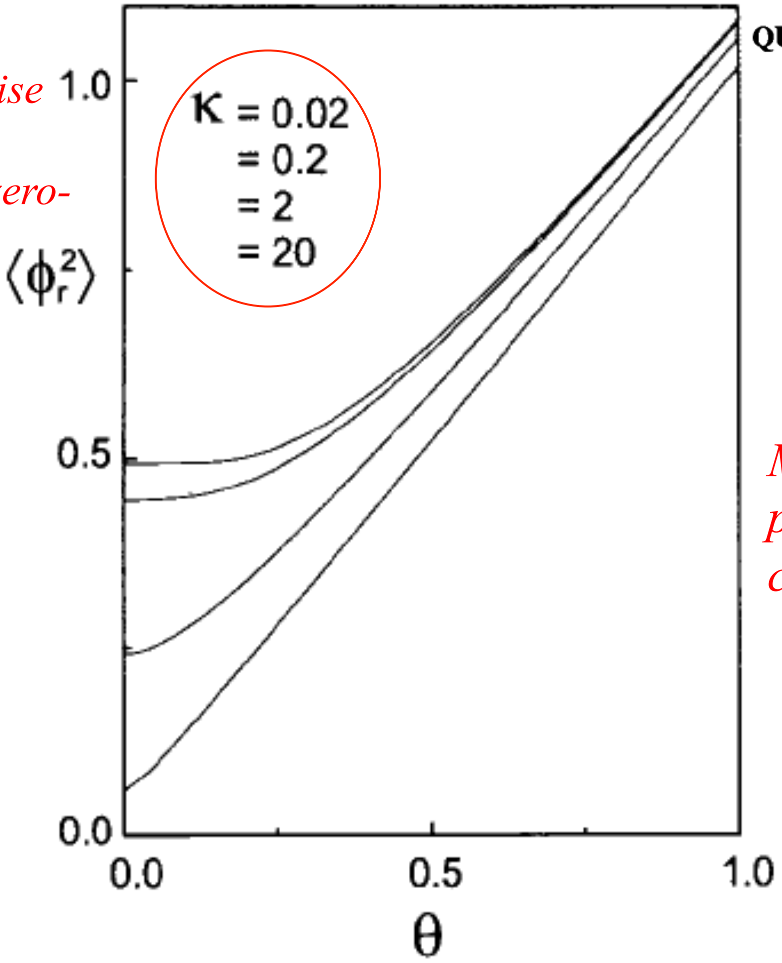
The heat-generation effect also kicks in, that is, heat is generated in R_2, similarly to the first perpetual motion machine.

Thus, the zero-point term cannot exist: $\boxed{S_{u,q}(f,T) = R\,4hf\left[N(f,T)+\cancel{0.5}\right]}$

Already former theories contain hidden perpetual motion machines!

$S_{u,q}(f,T)=4Rhf\left[N(f,T)+\mathbf{0.5}\right]$

Different magnetic noise energy at different resistances! All from zero-point noise!



QUANTUM FLUCTUATIONS IN ELECTRICAL CIRCUITS

Michel H. Devoret

Service de Physique de l'Etat Condensé
CEA-Saclay, F91191 Gif-sur-Yvette, France

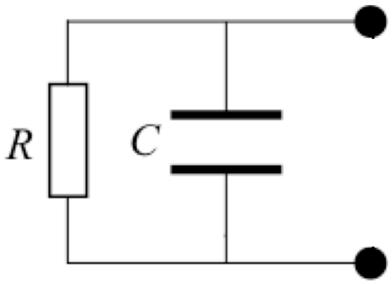
(1997)

Magnetic versions of the above perpetual motion machines can be constructed if the FDT is correct!!!

Fig. 10. Variations of the dimensionless variance $\langle\phi_r^2\rangle = \langle\Phi^2\rangle/(\hbar Z_0)$ of flux fluctuations of the LCR circuit as a function of the dimensionless temperature $\theta = k_B T/\hbar\omega_0$ for different values of the dimensionless damping coefficient $\kappa = (2RC\omega_0)^{-1}$.

Heisenberg's uncertainty principle is relevant. Voltage amplifier is a quantum measurement of the ***instantaneous voltage*** thus the quantum measurement of the energy in the geometric capacity of the resistor. The same situation is for the energy in the inductance of the shorted resistor versus the noise current (-amplifiers).

Time-uncertainty: bandwidth related.



$$E(t)=\frac{1}{2}CU^2(t)$$

$$\boxed{\Delta E\,\Delta t \sim h}$$

Thus, the zero-point noise represent the energy-uncertainty in the system exhibited by the voltage or current noise seen in voltage and current amplifiers.

- This type of problem is absent in the capacitor based engines, where the operation is adiabatic;

$$\boxed{\Delta t \to \infty \quad \Rightarrow \quad \Delta \mathrm{E} \to 0}$$

- Similarly, the problem is absent in the black-body radiation because the ***monochomator*** tests the ***location-momentum uncertainty principle***, where the uncertainty effect will show up in the line-width of the measured photons, not in the intensity of radiation at the given frequency. (Grating related)

About amplifiers: much former history.

Time-energy uncertainty principle: measurement artifact

$$S_{u,q}(f,T) = 4Rhf\left[N(f,T) + \mathbf{0.5}\right]$$

W. Kleen, Solid-State Electron. 30, 1303 (**1987**). :

The observed zero-point noise in the KVC experiments is not coming from the resistor but it is the amplifier noise due the phase-particle number (energy-time) uncertainty noise of quantum amplifiers (masers, Heffner, 1963)

The effect is indeed there and it disqualifies the Josephson junction experiments as proofs of zero-point noise. However, it cannot prove that the zero-point noise itself does not exist in the resistor.

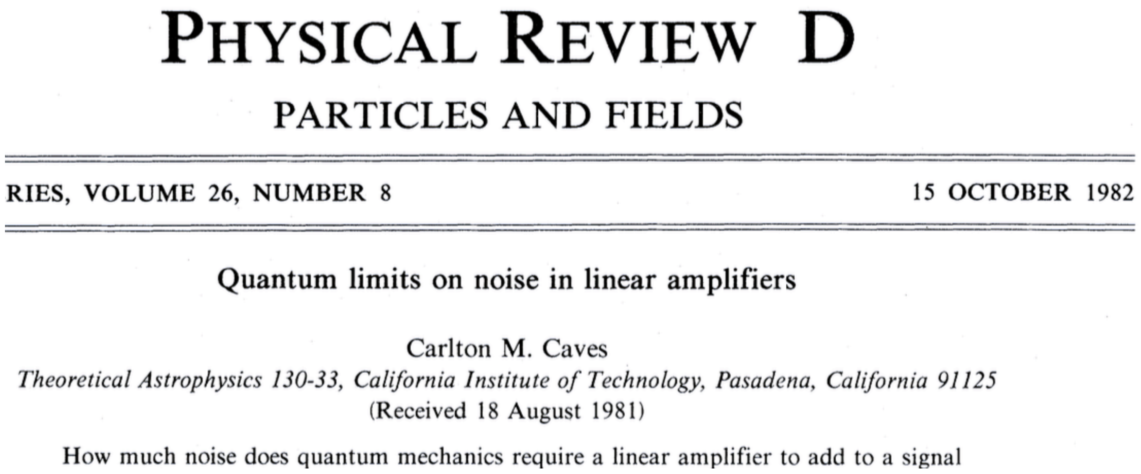
(based on J. Weber, "Quantum theory of a damped electrical oscillator and noise", Phys. Rev. 90, 977 (**1953**) and H. Heffner, "The Fundamental Noise Limit of Linear Amplifiers", Proc. IRE 50, 1604 (**1962**))

There are many related old papers about the quantum noise of amplifiers, e.g.:

I.A. Harris, Electron. Lett. 7, 148 (**1971**) (at National Buro of Standards)

The available (observable) noise power should include only the Nyquist term and any other quantum term associated with the detector or receiver.

(based on J. Weber, "Quantum theory of a damped electrical oscillator and noise", Phys. Rev. 90, 977 (**1953**) and H. Heffner, "The Fundamental Noise Limit of Linear Amplifiers", Proc. IRE 50, 1604 (**1962**))



PHYSICAL REVIEW D

PARTICLES AND FIELDS

RIES, VOLUME 26, NUMBER 8 15 OCTOBER 1982

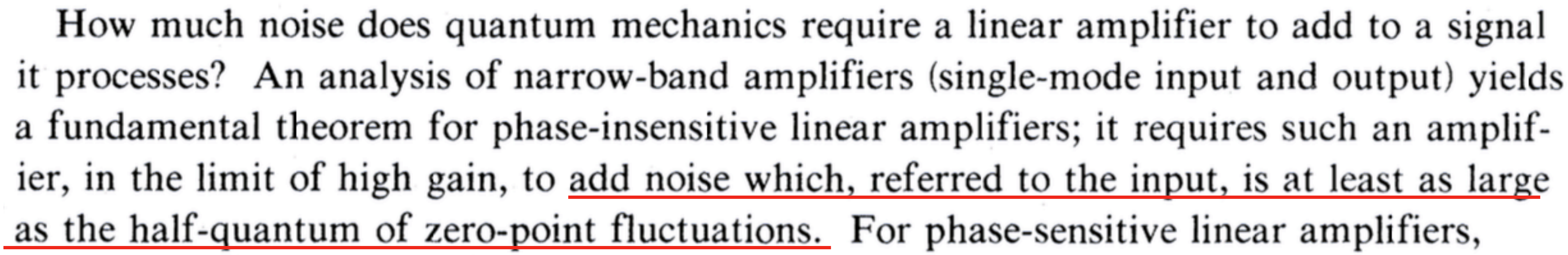
Quantum limits on noise in linear amplifiers

Carlton M. Caves

Theoretical Astrophysics 130-33, California Institute of Technology, Pasadena, California 91125

(Received 18 August 1981)

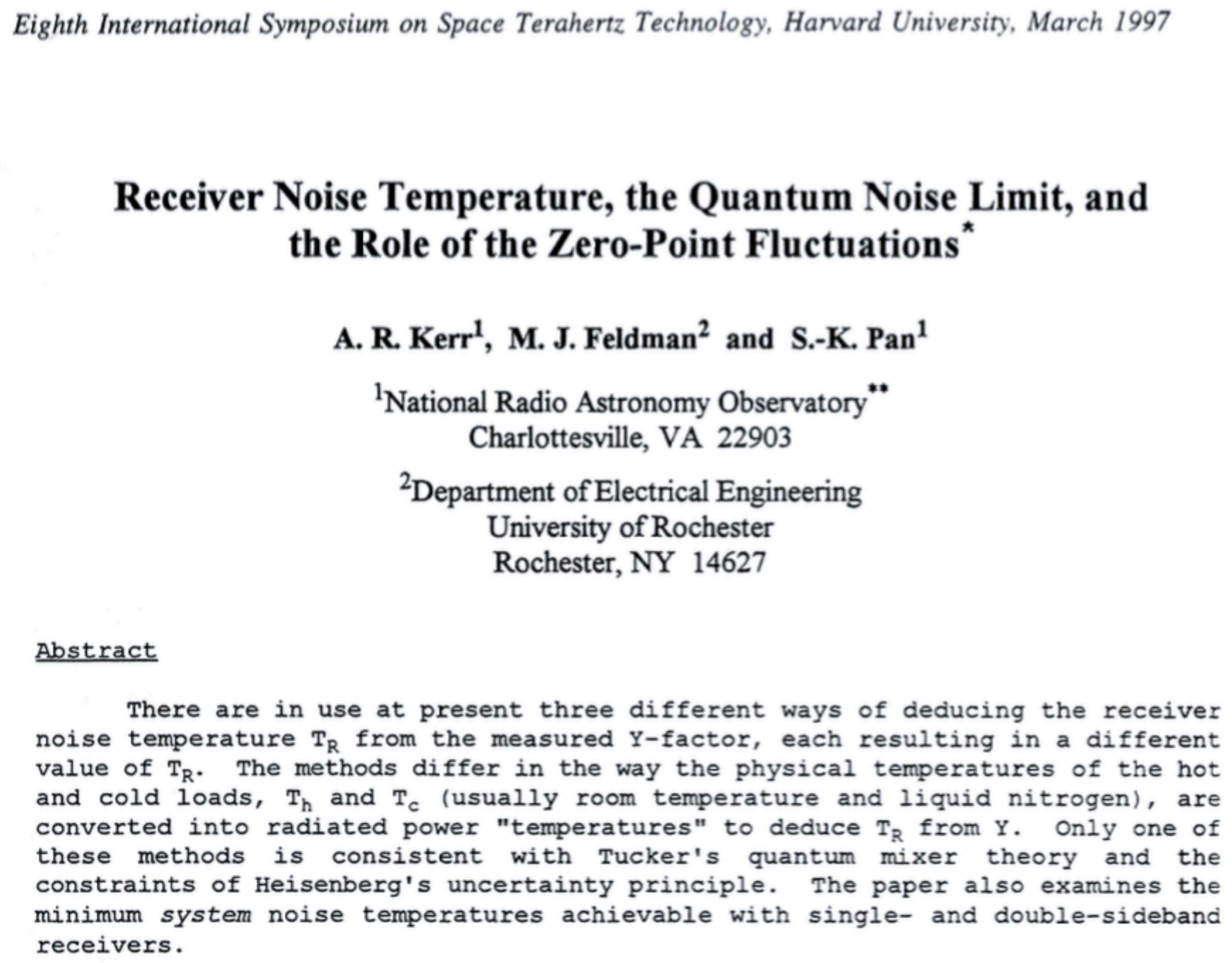
How much noise does quantum mechanics require a linear amplifier to add to a signal



How much noise does quantum mechanics require a linear amplifier to add to a signal it processes? An analysis of narrow-band amplifiers (single-mode input and output) yields a fundamental theorem for phase-insensitive linear amplifiers; it requires such an amplifier, in the limit of high gain, to add noise which, referred to the input, is at least as large as the half-quantum of zero-point fluctuations. For phase-sensitive linear amplifiers,

For a special wide-band amplifier he gets down to **1/4 quantum** !

The issue of quantum mixer measurements and their interpretation is controversial. These authors present three views and conclude that the *measured* zero-point noise ***should be double*** of the *Callen-Welton* and *Koch, et al* result, due to the amplifier.



Eighth International Symposium on Space Terahertz Technology, Harvard University, March 1997

Receiver Noise Temperature, the Quantum Noise Limit, and the Role of the Zero-Point Fluctuations*

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[2]Department of Electrical Engineering
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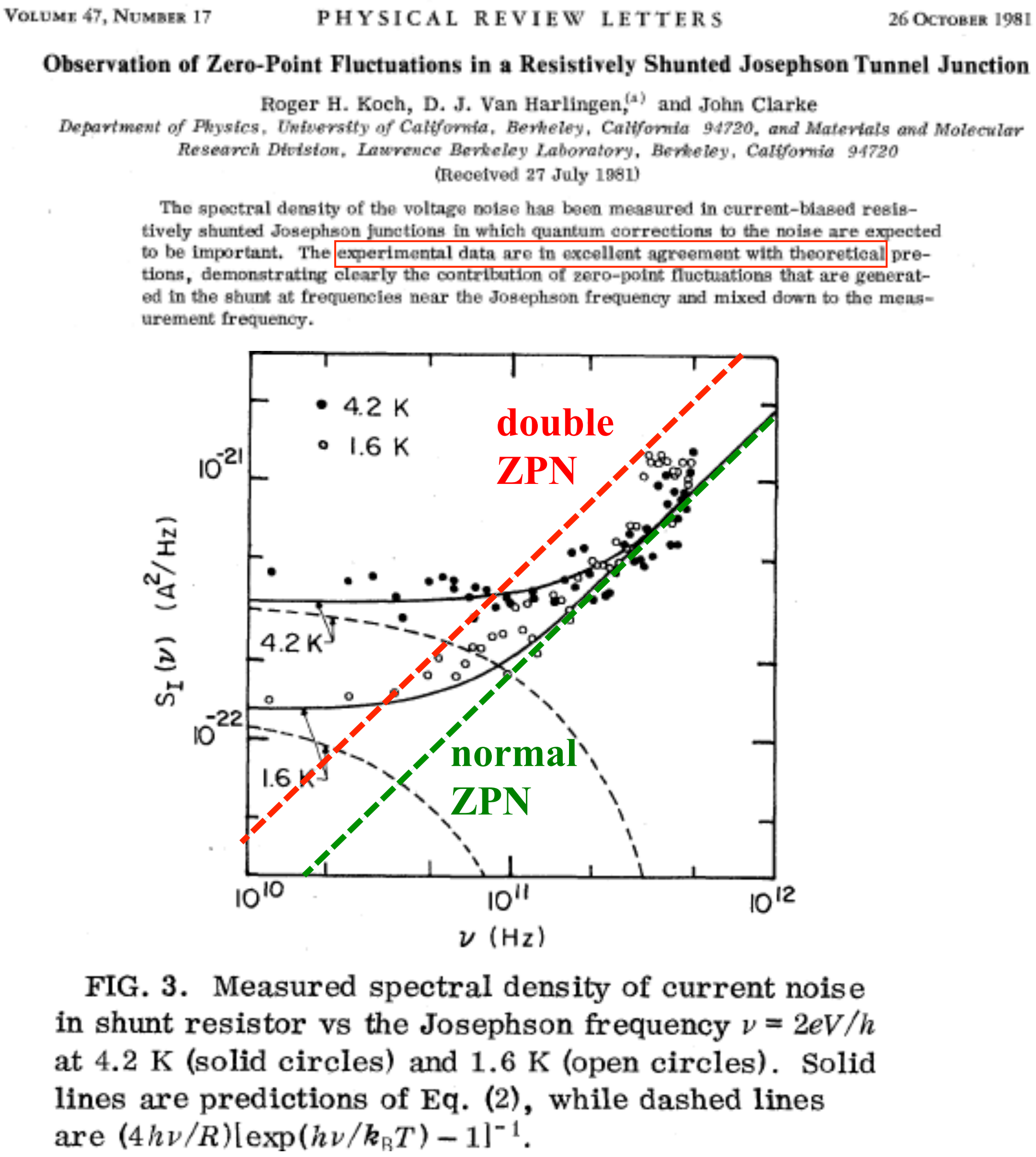
Abstract

There are in use at present three different ways of deducing the receiver noise temperature T_R from the measured Y-factor, each resulting in a different value of T_R. The methods differ in the way the physical temperatures of the hot and cold loads, T_h and T_c (usually room temperature and liquid nitrogen), are converted into radiated power "temperatures" to deduce T_R from Y. Only one of these methods is consistent with Tucker's quantum mixer theory and the constraints of Heisenberg's uncertainty principle. The paper also examines the minimum *system* noise temperatures achievable with single- and double-sideband receivers.

The first experiment: Josephson-junction heterodyne detection (spectral analysis by frequency mixing to near DC).

$$S_{u,q}(f,T) = 4Rhf\left[N(f,T) + \mathbf{0.5}\right]$$



VOLUME 47, NUMBER 17 PHYSICAL REVIEW LETTERS 26 OCTOBER 1981

Observation of Zero-Point Fluctuations in a Resistively Shunted Josephson Tunnel Junction

Roger H. Koch, D. J. Van Harlingen,[a] and John Clarke

Department of Physics, University of California, Berkeley, California 94720, and Materials and Molecular Research Division, Lawrence Berkeley Laboratory, Berkeley, California 94720

(Received 27 July 1981)

The spectral density of the voltage noise has been measured in current-biased resistively shunted Josephson junctions in which quantum corrections to the noise are expected to be important. The experimental data are in excellent agreement with theoretical predictions, demonstrating clearly the contribution of zero-point fluctuations that are generated in the shunt at frequencies near the Josephson frequency and mixed down to the measurement frequency.

FIG. 3. Measured spectral density of current noise in shunt resistor vs the Josephson frequency $\nu = 2eV/h$ at 4.2 K (solid circles) and 1.6 K (open circles). Solid lines are predictions of Eq. (2), while dashed lines are $(4h\nu/R)[\exp(h\nu/k_BT) - 1]^{-1}$.

John Clarke, Brian Jones

ICNF, Montreal, May 27, 1987

FDT derivations are incorrect?

Recently, L. Reggiani, et al. criticized the FDT derivations.
L. Reggiani, P. Shiktorov, E. Starikov and V. Gružinskis, "Quantum fluctuation dissipation theorem revisited: remarks and contradictions", *Fluct. Noise Lett.* **11** (2012) 1242002 .

Lino Reggiani

Pavel Shiktorov

Evgeni Starikov

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Moreover: Lino Reggiani and Eleonora Alfinito recently published a manuscript claiming that the *zero-point term is invisible because of Casimir force in the material*.

At this stage I cannot comment on that work because of issues that are unclear for me and some other points where we disagree.

Content

1. The zero-point noise theory and its claims

2. Experimental results supporting it

3. Experimental results denying it

4. Conceptual problems with the zero-point noise claim

5. Conclusion, unsolved problems and proposed steps

6. A conjecture about the zero-point noise with wide-band amplifiers

Conclusion, unsolved problems and proposed steps

1) The existence of zero-point thermal noise voltage or current in a metal would ***violate the Fermi-Dirac statistic*** in the zero temperature limit.

2) Neither the resistor-antenna-spectroscope arrangement nor the work executed by a moving-plate-capacitor–resistor system can exhibit the zero-point noise effect otherwise ***the Second Law is violated***.

3) The zero-point thermal noise voltage or current in resistors is seen only in a ***fraction of experiments.***

4) ***But the uncertainty principle can explain all these***, at the "***big picture***" level.

5) The Fluctuation-Dissipation Theorem does not claim ***material-*** or ***measurement-type-limitations*** for the predicted zero-point noise thus the FDT is, ***at least incomplete*** in its current form. *Theoretical works are needed to address these unsolved problems.*

6) It would be interesting to see ***other-then-***Josephson-junction ***experiments***, such as measurement with a ***wide-band linear amplifier*** **(no quantum mixer)**. For example, to check Caves's 1/4 quanta which would be half of the FDT's prediction. See the conjecture about wide-band amplifiers in the last slide too.

Content

1. The zero-point noise theory and its claims
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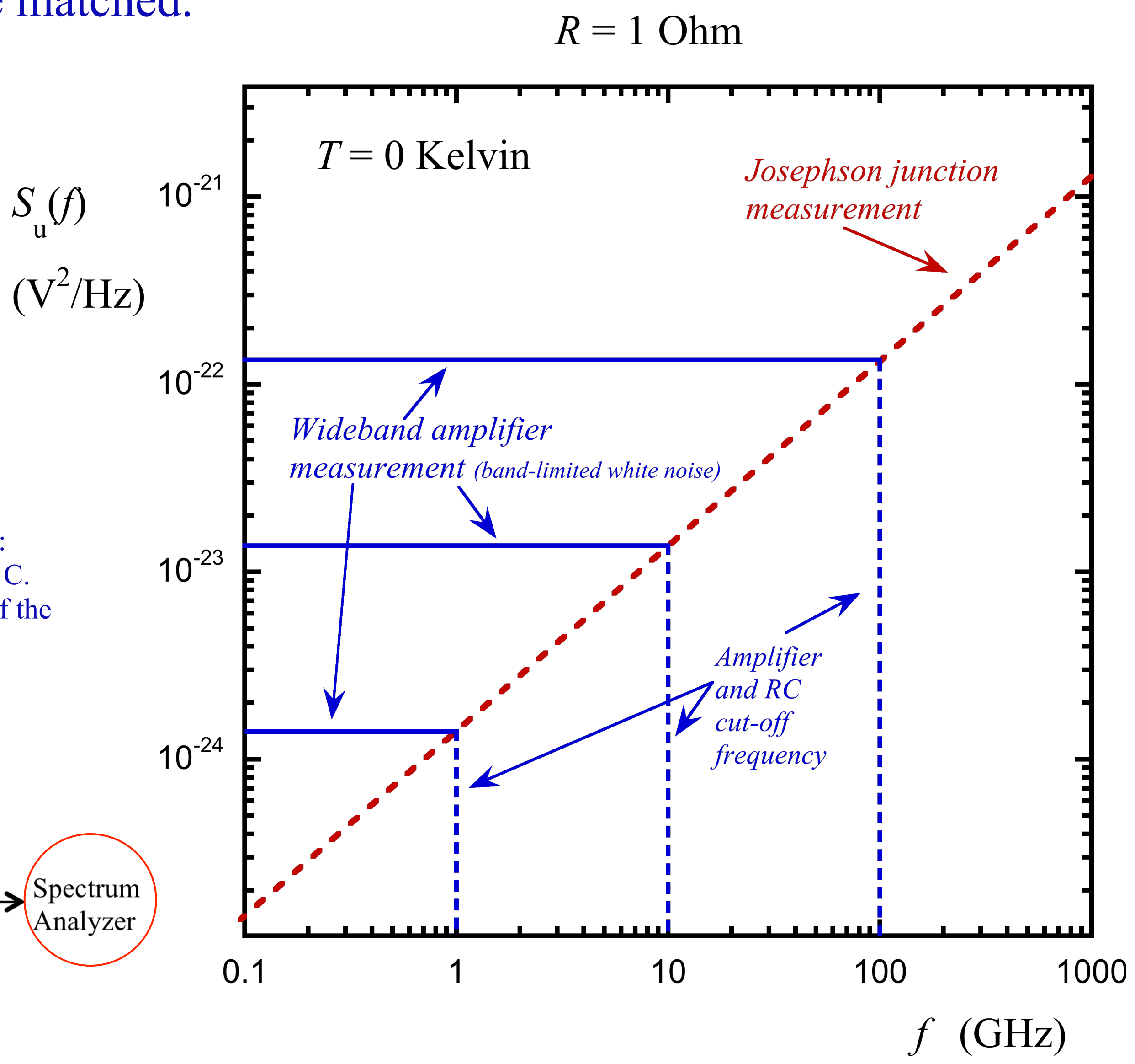
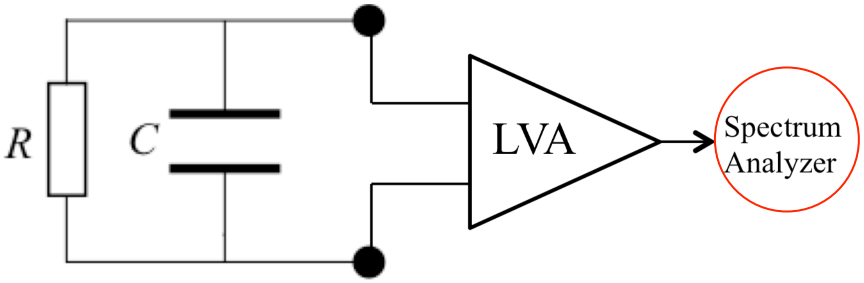
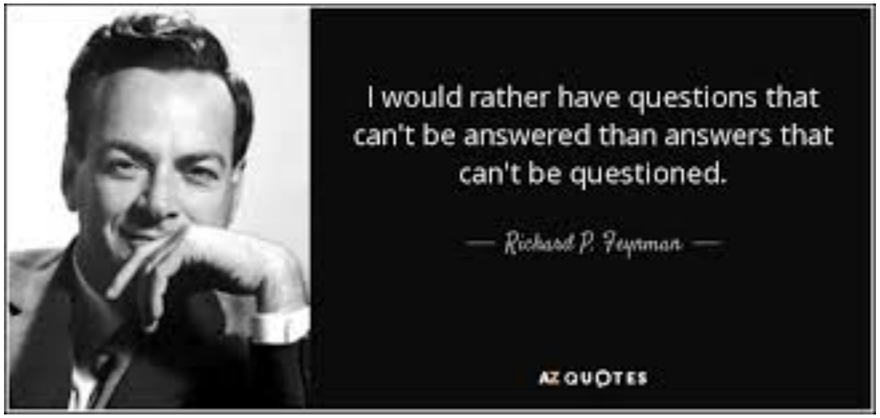
Conjecture for thermal noise seen by a wideband amplifier (spectral analysis at its output where the signal is classical, not at the input, where it is quantum)

Cut-off of *RC* and amplifier are matched.



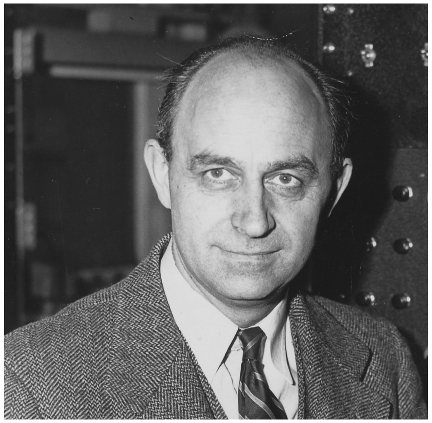
For example, these people have the setup to test this:
E. Zakka-Bajjani, J. Ségala, F. Portier, P. Roche, D. C. Glattli, A. Cavanna and Y. Jin, “Experimental Test of the High-Frequency Quantum Shot Noise Theory in a Quantum Point Contact”, *PRL* **99**, 236803 (2007).



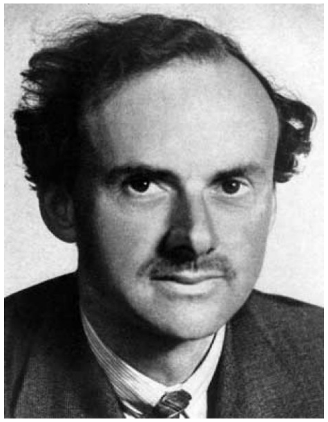


I would rather have questions that can't be answered than answers that can't be questioned.

— Richard P. Feynman —



Enrico Fermi



Paul Dirac

End of talk

Werner Heisenberg

NOTE: Casimir effect in the capacitor is irrelevant!

In the perpetual motion machines introduced above the Casimir effect can always be made negligible by the proper choice of the range of distance x between the capacitor plates during operation.

The Casimir-pressure in a plain capacitor decays with x^{-4}, which implies that

the Casimir force at fixed capacitance value decays with x^{-3}

see G. Bressi, et al, Phys. Rev. Lett. 88, 041804 (2002).

At the same time, the force due to the zero-point noise decays as $\boldsymbol{x}^{\mathbf{-1}}$.

Returning to our perpetual motion machine issue, is this the correct answer? :

In the case of measuring the mean-square thermal noise *by the average force in a capacitor in an RC configuration*:

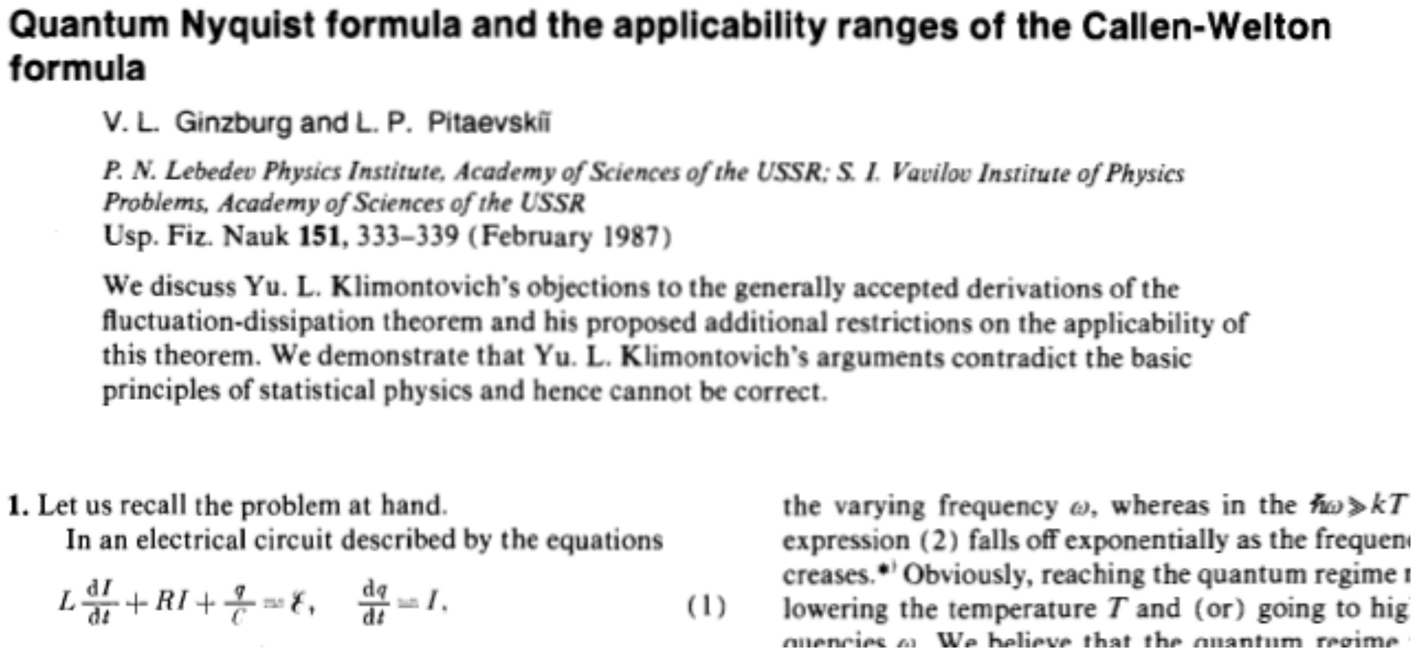
- The zero-point term of the FDT is nonexistent; $S_{u,q}(f,T) = R\,4hf\left[N(f,T) + \xcancel{0.5}\right]$ YES!

- ~~and Nyquist's formula is the correct theory.~~ $\xcancel{S_{u,q}(f,T) = 4Rhf\,N(f,T)}$ NO!

A simple scaling analysis shows that Nyquist's formula has similar problem in thequantum range with a weaker effect and opposite sign. Thus that also allows a perpetual motion machine. At a single frequency the zero-point and Nyquist effects cancel.

Massimo Macucci, as the Reviewer of our paper has even calculated the exact result of the integral for the Nyquist case.

Massimo Macucci



Quantum Nyquist formula and the applicability ranges of the Callen-Welton formula

V. L. Ginzburg and L. P. Pitaevskiĭ

P. N. Lebedev Physics Institute, Academy of Sciences of the USSR; S. I. Vavilov Institute of Physics Problems, Academy of Sciences of the USSR

Usp. Fiz. Nauk **151**, 333–339 (February 1987)

We discuss Yu. L. Klimontovich's objections to the generally accepted derivations of the fluctuation-dissipation theorem and his proposed additional restrictions on the applicability of this theorem. We demonstrate that Yu. L. Klimontovich's arguments contradict the basic principles of statistical physics and hence cannot be correct.

1. Let us recall the problem at hand.

In an electrical circuit described by the equations

$$L\frac{dI}{dt}+RI+\frac{q}{C}=\mathcal{E}, \qquad \frac{dq}{dt}=I, \qquad (1)$$

the varying frequency ω, whereas in the $\hbar\omega \gg kT$
expression (2) falls off exponentially as the frequen
creases.*) Obviously, reaching the quantum regime r
lowering the temperature T and (or) going to hig
quencies ω. We believe that the quantum regime

They use the same kind of calculations for a serial RLC circuit as we do for the perpetual motion machine calculations. They show that, with the Callen-Welton zero-point noise spectrum result, the energy in the weakly-damped LC resonator is equal to the energy of the of the quantum linear harmonic oscillator. At zero temperature, and small resistance, this energy converges to the zero-point energy of the oscillator, $hf_0/2$.

However, there is a problem. If their derived result is correct, then in the large resistance and small inductance limit, *they will get our results and a perpetual motion machine with it!* Thus the assumption that the zero-point noise is in the resistor in this passive situation must be dropped.

Conclusion: it is not possible to derive the zero-point energy of the oscillator with this unphysical assumption that the zero-point voltage noise in the resistor is objectively present there. The agreement in the small resistance limit is only a coincidence.