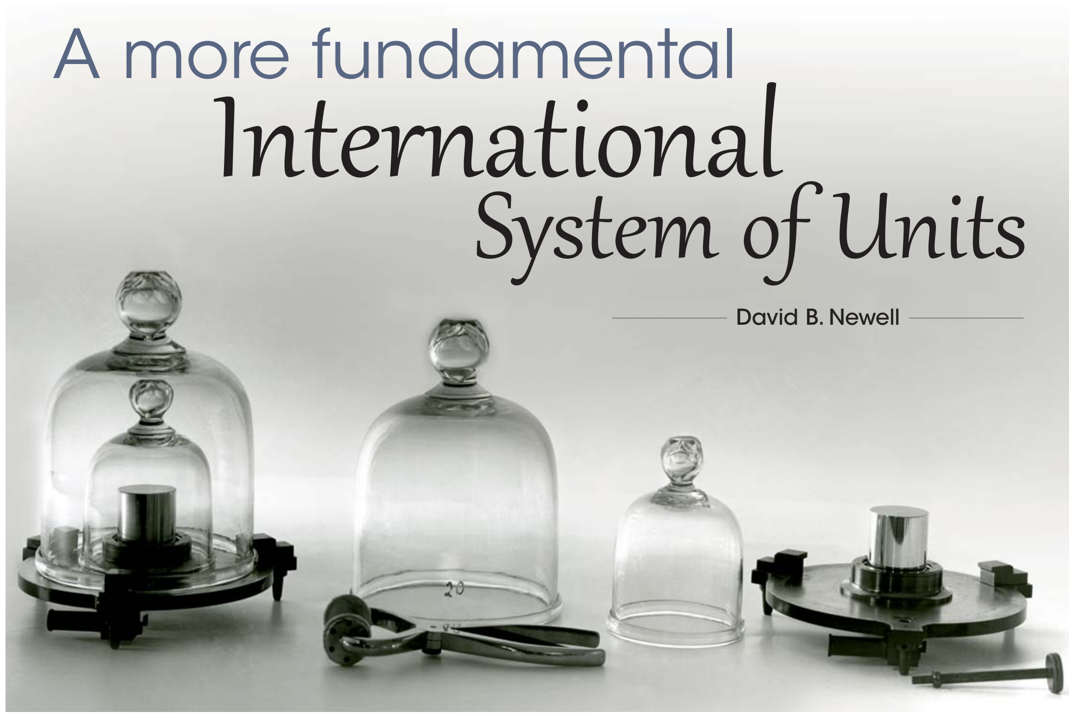


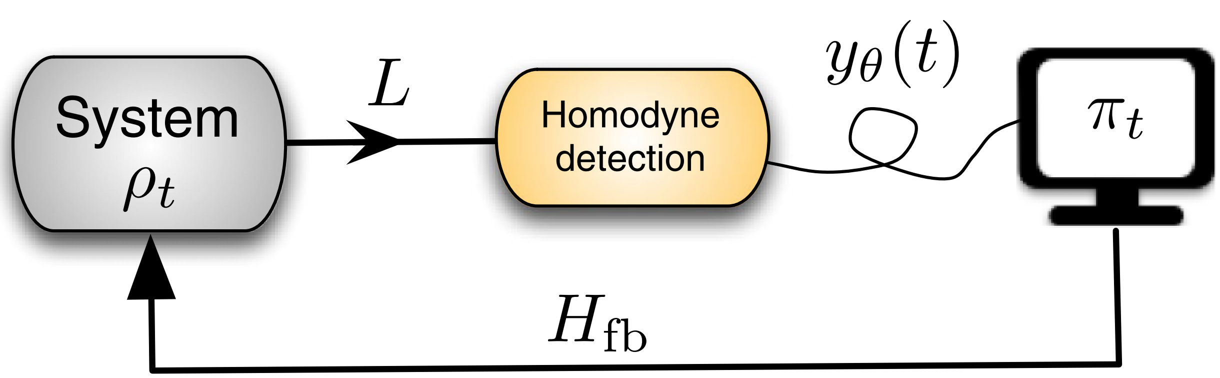
Physics Today **67**(7), 35 (2014)

$$E = h\nu = mc^2 = eV = kT,$$

PRL **113,** 020407 (2014) PHYSICAL REVIEW LETTERS week ending 11 JULY 2014

Ignorance Is Bliss: General and Robust Cancellation of Decoherence via No-Knowledge Quantum Feedback

Stuart S. Szigeti,[1,*] Andre R. R. Carvalho,[2,3] James G. Morley,[4] and Michael R. Hush[4]



$$\dot{y}_{\pi/2}(t) = \dot{\xi}(t)$$

$$H \to H + L\dot{y}_{\pi/2}(t)$$

$$\partial_t \rho_t = -i[H, \rho_t]$$

Figure 1. Evolution of the SI. A brief timeline of the history of the International System of Units since John Wilkins's 1668 essay is scaled to a meter bar. The photograph shows a marble meter standard in Paris, dating from the 18th century. (Photo courtesy of LPLT\Wikimedia Commons.)

1668
John Wilkins's essay is published.

1799
The metric system is born. The Archives de la République in Paris receives two platinum artifact standards representing the meter and kilogram.

1875
Seventeen member nations sign the Meter Convention. Work begins on constructing new international prototypes for the meter and kilogram.

1889
The first General Conference on Weights and Measures (CGPM) approves a system of measures with the base units meter, kilogram, and second.

1954
The ampere, kelvin, and candela are officially adopted as base units by the 10th CGPM.

1960
The 11th CGPM adopts the name International System of Units (SI) with the base units meter, kilogram, second, ampere, kelvin, and candela. The meter is redefined as the wavelength of radiation from a specific excitation in krypton-86.

1967
The second is redefined in terms of the hyperfine splitting frequency of the cesium-133 atom.

1971
The mole becomes a new base unit of the SI, and the list of base units grows to seven.

1983
A new definition of the meter links it to the speed of light in vacuum.

2018
The new SI will specify the exact values of seven fundamental constants, shown in table 2. All SI units will be based on those defining constants.

The meter is the one ten-millionth of the distance along the Earth's meridian through Paris from the North Pole to the equator.

Table 1. Present SI base quantities, base units, and definitions

Base quantity	Base unit	Definition
Time	second	The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.
Length	meter	The meter is the length of the path traveled by light in vacuum during a time interval of 1/299 792 458 of a second.
Mass	kilogram	The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.
Electric current	ampere	The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per meter of length.
Thermodynamic temperature	kelvin	The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.
Amount of substance	mole	The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon-12; the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.
Luminous intensity	candela	The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian.

Table 2. New SI base quantities, defining constants, and definitions

Base quantity	Defining constant	Definition
Frequency	$\Delta\nu(^{133}\text{Cs})_{\text{hfs}}$	The unperturbed ground-state hyperfine splitting frequency of the cesium-133 atom $\Delta\nu(^{133}\text{Cs})_{\text{hfs}}$ is exactly 9 192 631 770 hertz.
Velocity	c	The speed of light in vacuum c is exactly 299 792 458 meter per second.
Action	h	The Planck constant h is exactly $6.626\text{X} \times 10^{-34}$ joule second.
Electric charge	e	The elementary charge e is exactly $1.602\text{X} \times 10^{-19}$ coulomb.
Heat capacity	k	The Boltzmann constant k is exactly $1.380\text{X} \times 10^{-23}$ joule per kelvin.
Amount of substance	N_A	The Avogadro constant N_A is exactly $6.022\text{X} \times 10^{23}$ reciprocal mole.
Luminous intensity	K_{cd}	The luminous efficacy K_{cd} of monochromatic radiation of frequency 540×10^{12} hertz is exactly 683 lumen per watt.

The symbol X in the numerical values indicates additional digits to be set upon redefinition of the SI. The term "defining constant" is used in the broader sense to include invariants of nature such as the hyperfine splitting frequency of the cesium-133 atom and the luminous efficacy.

Consequences

- no international prototype of the kilogram
- new SI with increased scalability, accessibility
- exact conversion factors for energy

$$E = h\nu = mc^2 = eV = kT,$$

Table 3. Changing uncertainties for fundamental constants

Quantity	Symbol	Present SI $u_r \times 10^9$	New SI $u_r \times 10^9$
International prototype of the kilogram	$m(K)$	0	44
Permeability of free space	μ_0	0	0.32
Permittivity of free space	ε_0	0	0.32
Triple point of water	T_{TPW}	0	910
Molar mass of carbon-12	$M(^{12}C)$	0	0.70
Planck constant	h	44	0
Elementary charge	e	22	0
Boltzmann constant	k	910	0
Avogadro constant	N_A	44	0
Molar gas constant	R	910	0
Faraday constant	F	22	0
Stefan–Boltzmann constant	σ	3600	0
Electron mass	m_e	44	0.64
Atomic mass unit	m_u	44	0.70
Mass of carbon-12	$m(^{12}C)$	44	0.70
Josephson constant	K_J	22	0
von Klitzing constant	R_K	0.32	0
Fine-structure constant	α	0.32	0.32
$E = mc^2$ energy equivalent	J↔kg	0	0
$E = hc/\lambda$ energy equivalent	J↔m^{-1}	44	0
$E = h\nu$ energy equivalent	J↔Hz	44	0
$E = kT$ energy equivalent	J↔K	910	0
1 J = 1 (C/e) eV energy equivalent	J↔eV	22	0

Relative uncertainties, u_r, for some fundamental constants and energy equivalents are given in parts in 10^9. Present relative uncertainties are based on the 2010 CODATA adjustment of the fundamental constants.[10] Note that u_r of $m(K)$ in the present SI is 0 only by definition. The new SI relative uncertainties assume fixed values of the Planck constant h, elementary charge e, Boltzmann constant k, and Avogadro constant N_A.

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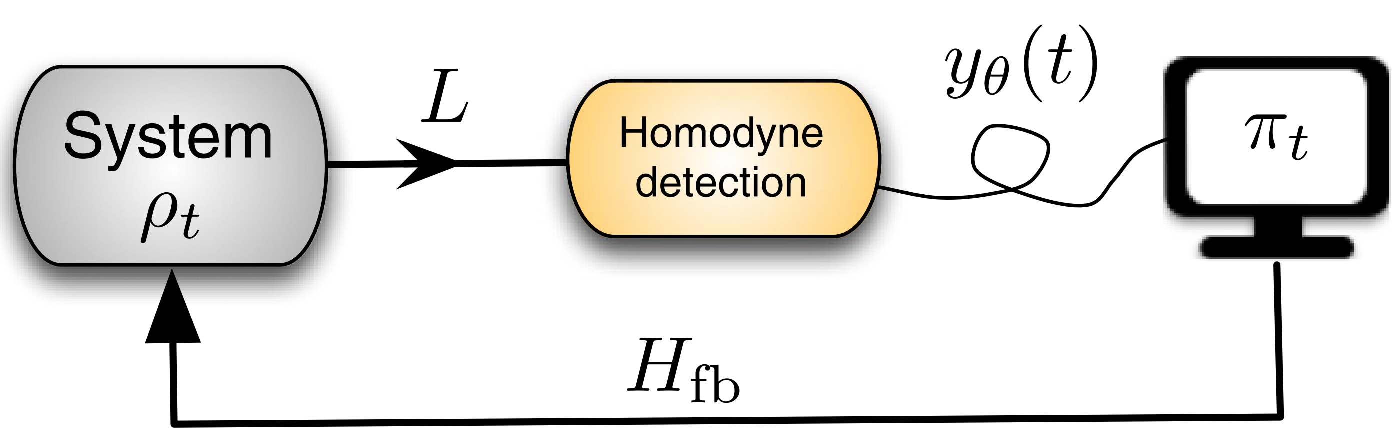
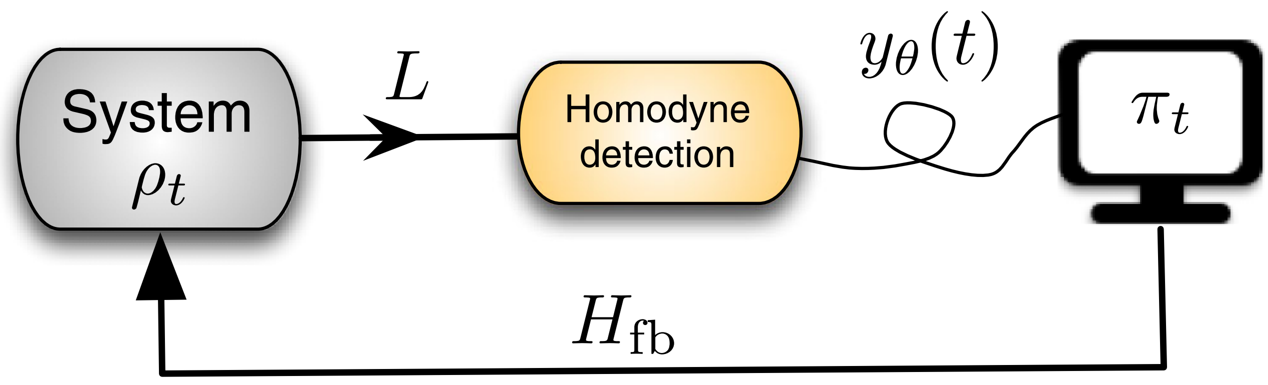
A "no-knowledge" measurement of an open quantum system yields no information about *any* system observable; it only returns noise input from the environment. Surprisingly, performing such a no-knowledge measurement can be advantageous. We prove that a system undergoing no-knowledge monitoring has reversible noise, which can be canceled by directly feeding back the measurement signal. We show how no-knowledge feedback control can be used to cancel decoherence in an *arbitrary* quantum system coupled to a Markovian reservoir that is being monitored. Since no-knowledge feedback does not depend on the system state or Hamiltonian, such decoherence cancellation is guaranteed to be general and robust, and can operate in conjunction with any other quantum control protocol. As an application, we show that no-knowledge feedback could be used to improve the performance of dissipative quantum computers subjected to local loss.

- error correction codes
- dynamical decoupling
- reservoir engineering
- feedback control
- decoherence-free subspace



"No-knowledge" measurements



master equation

$$\partial_t \varrho_t = -i[H, \varrho_t] + \mathcal{D}[L]\varrho_t \equiv \mathcal{L}\varrho_t,$$

$$\mathcal{D}[Z]\varrho_t = Z\varrho_t Z^\dagger - (Z^\dagger Z\varrho_t + \varrho_t Z^\dagger Z)/2.$$

conditional master equation

$$\partial_t \rho_t = \mathcal{L}\rho_t + \sqrt{\eta}\mathcal{A}[Le^{i\theta}]\rho_t y_\theta(t) - \frac{\eta}{2}\mathcal{A}^2[Le^{i\theta}]\rho_t$$

$$\mathcal{A}[Z]\rho_t = Z\rho_t + \rho_t Z^\dagger$$

$$\mathcal{A}^2[Z]\rho_t = Z(\mathcal{A}[Z]\rho_t) + (\mathcal{A}[Z]\rho_t)Z^\dagger$$

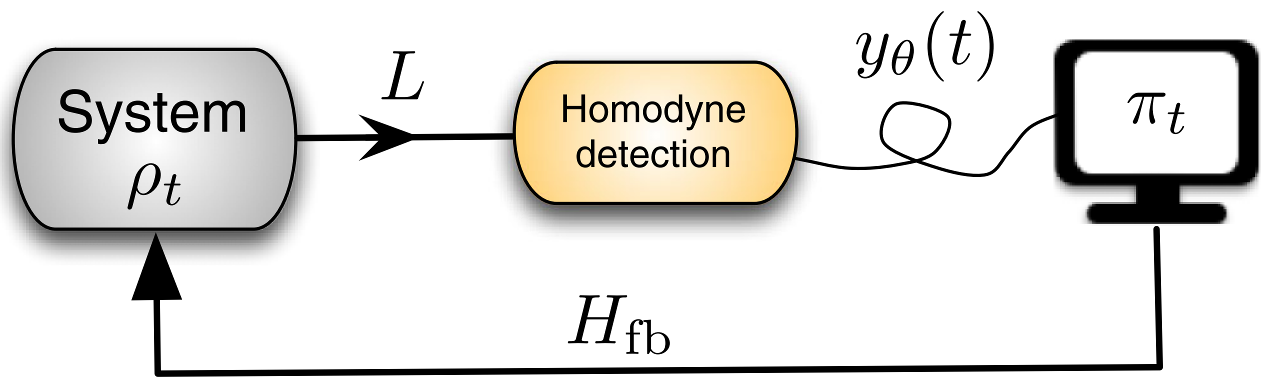
innovation

$$y_\theta(t) = \sqrt{\eta}\langle Le^{i\theta} + L^\dagger e^{-i\theta}\rangle_t + \xi(t)$$

signal

If $L = L^\dagger$ and $\theta = \pi/2$, then $y_{\pi/2}(t) = \xi(t)$ returns only noise.

Canceling noise without knowledge



$$y_{\pi/2}(t) = \xi(t)$$

$$\partial_t \rho_t = -i[H - L y_{\pi/2}(t), \rho_t]$$

$$H \rightarrow H + L y_{\pi/2}(t) \qquad \partial_t \rho_t = -i[H, \rho_t]$$

No-knowledge feedback only requires a correct identification of the no-knowledge quadrature, which depends only on the coupling operator L, and the ability to monitor this decoherence channel. *A precise description of the system state and its unitary evolution is not required.* This natural

Canceling noise without knowledge

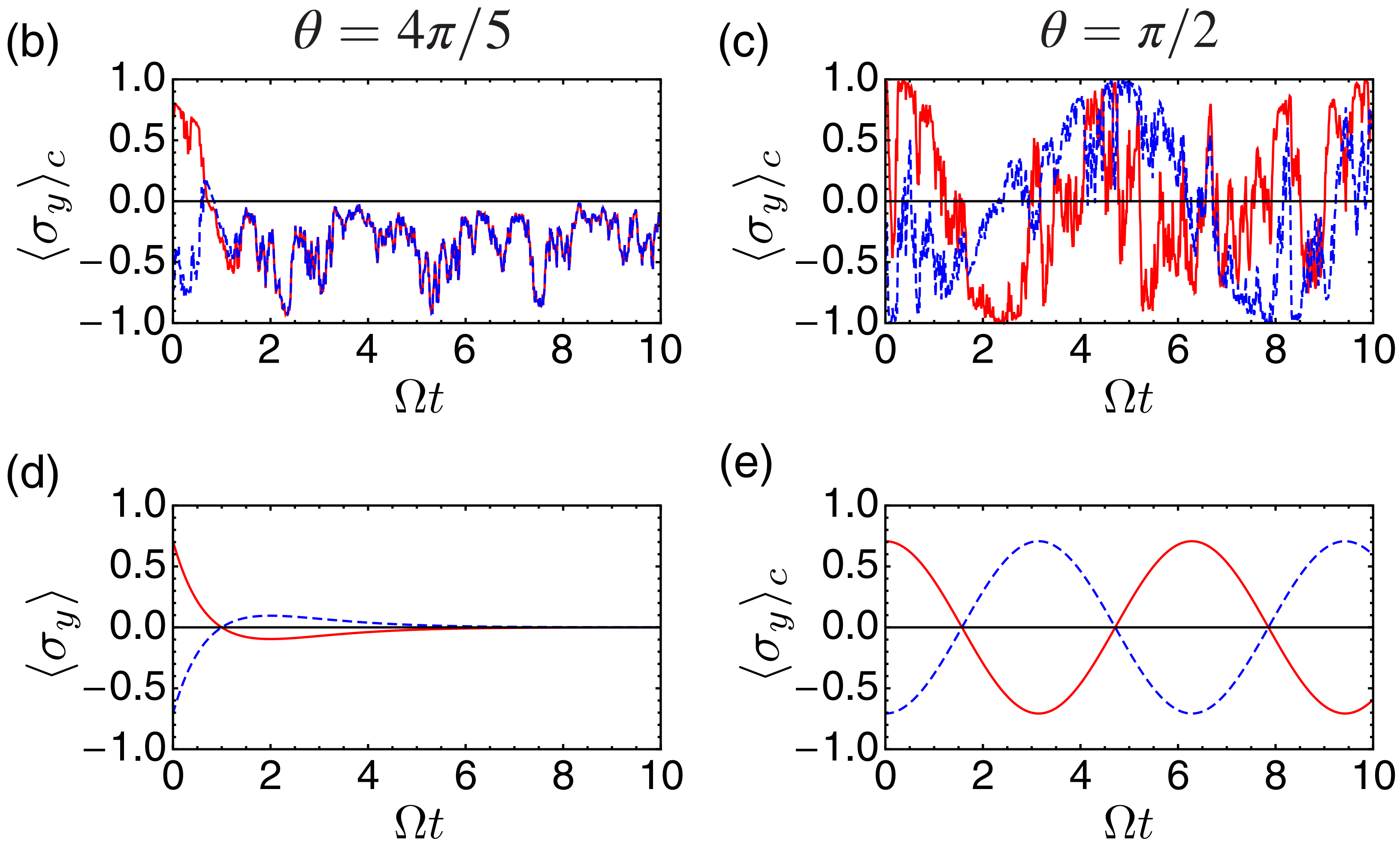
- dephasing in qubits ($L = \sigma_z$)
- position measurement ($L = x$)
- for non-hermitian operators

$$\partial_t \varrho_t = -i[H, \varrho_t] + \mathcal{D}[L]\varrho_t + \mathcal{D}[L^\dagger]\varrho_t.$$

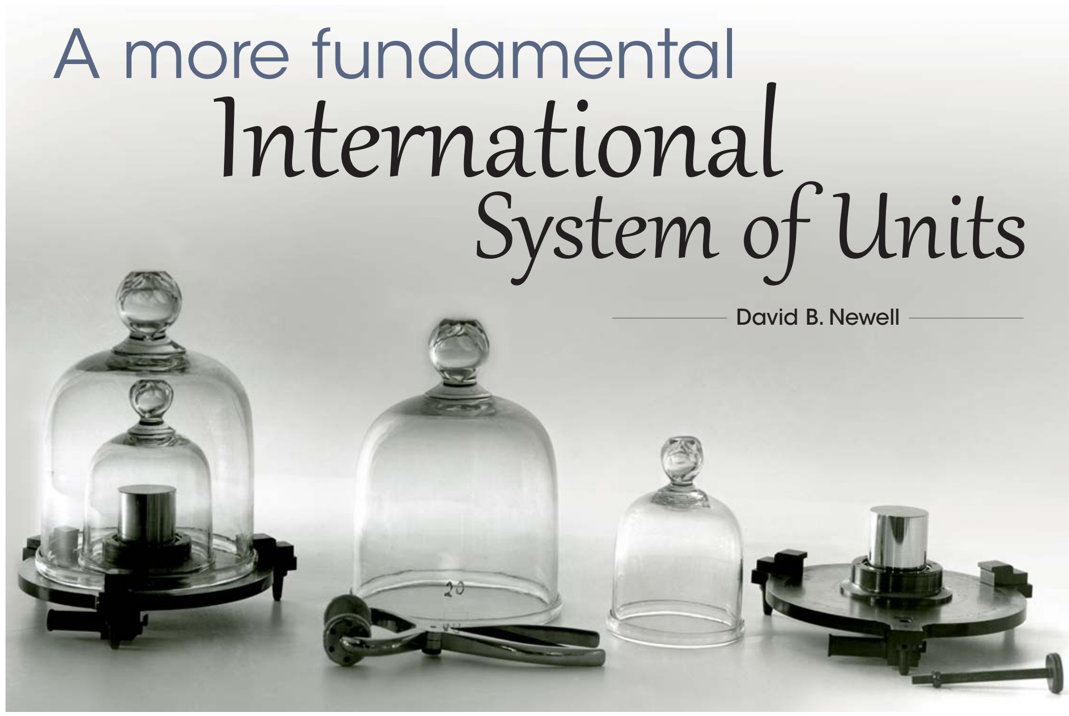
The "trick" is to recognize that $\mathcal{D}[L]\rho_t + \mathcal{D}[L^\dagger]\rho_t = \mathcal{D}[L_+]\rho_t + \mathcal{D}[L_-]\rho_t$, where $L_\pm = i^{(1\mp1)/2}(L \pm L^\dagger)/\sqrt{2}$ are Hermitian. Thus, $L_\pm$ are effective coupling operators that admit no-knowledge measurements.

Example: Driven qubit with dephasing

$$H = \Omega\sigma_x,\ L = \sqrt{\gamma}\sigma_z, \text{ and } \Omega/\gamma = 1.$$



system [cf. Eq. (1)]. (e) Dephasing is canceled by directly feeding back the no-knowledge measurement via the Hamiltonian $H = \Omega\sigma_x + \sqrt{\gamma}\sigma_z y_{\pi/2}(t)$. Despite the filter's inaccurate estimate of ρ_t, decoherence is completely removed, demonstrating that accurate knowledge of the system is not required for effective decoherence cancellation.



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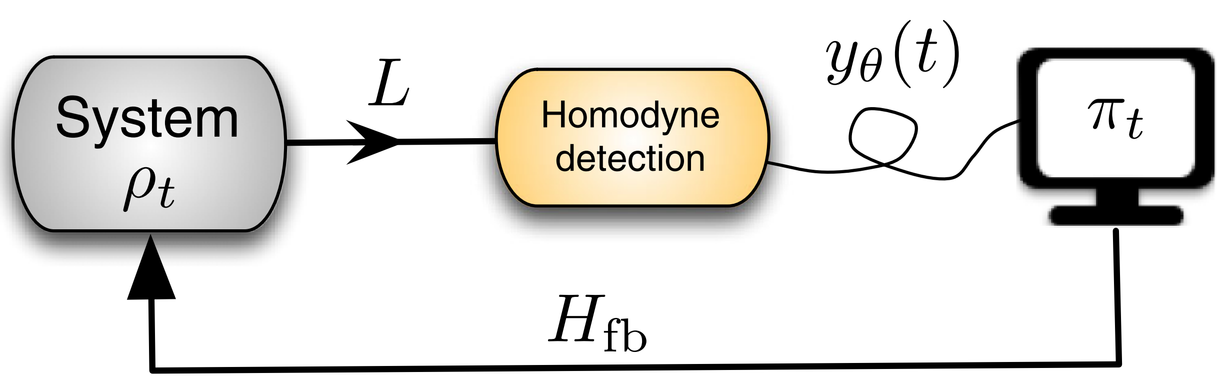

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