Comment on ''Protective measurement of the wave function of a single squeezed harmonic-oscillator state''

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Alter and Yamamoto [Phys. Rev. A **53**, R2911 (1996)] claimed to consider ''protective measurements'' that we have recently introduced. We show that the measurements discussed by Alter and Yamamoto *are not* the protective measurements we proposed. Therefore, their results are irrelevant to the nature of protective measurements. [S1050-2947(97)09206-8]

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In a recent Rapid Communication Alter and Yamamoto [1] considered sequences of certain measurements of a squeezed harmonic-oscillator state. They claimed that these are the *protective measurements* [2,3] that we have recently proposed for observing the wave function a single quantum system. While we do not want to make any statement about the significance of the measurements discussed by Alter and Yamamoto, we claim that these measurements *are not* the protective measurements we proposed. Therefore, we feel that all conclusions of the authors about protective measurements are unfounded and, in particular, their central result that ''[the] protective measurement requires a full *a priori* knowledge of the measured wave function'' is incorrect.

There are two basic ingredients in the protective measurements we have proposed. The first is that the quantum state of the system is protected, i.e., it is a nondegenerate energy eigenstate with a finite gap to a neighbor level. The second is that the interaction is not infinitely fast and strong as in ideal measurements, but slow and weak enough that the adiabatic approximation is applicable (the probability that the system leaves the energy eigenstate is negligible) and the state does not change significantly during the measurement, and therefore the measurement shows the property of the observed quantum wave function.

Our protective measurements have also a property that there is almost no entanglement between the system and the measuring device at the end of the measurement interaction. It seems that Alter and Yamamoto took the latter together with the weakness of the measurement coupling as the definition of a protective measurement, completely ignoring the first basic ingredient of the protective measurements, the protection. The squeezed harmonic-oscillator state on which measurements are described in Ref. [1] *is not protected*. It is not an energy eigenstate and it is not protected by frequent observations, an alternative protection procedure based on the quantum Zeno effect. (The process of ''driving the signal back to its initial excitation'' described in Ref. [1] does not entail the Zeno effect.)

The property that ''the signal and the probe are left disentangled after their interaction'' is also the property of ''ideal von Neumann measurements'' [4], which are frequently called ''nondemolition measurements'' [5]. If the initial state of the quantum system is an eigenstate of some observable, then an ideal (nondemolition) measurement of this observable does not change the quantum state. Weakening the von Neumann coupling does not change this property. Alter and Yamamoto considered such measurements with weak and strong coupling, naming the former ''protective measurements.'' Indeed, their procedure, together with ''driving the signal back'' falls into this category. The coupling leads to a known (for a given initial state) change, which is then corrected. Note also the difference between ''protective measurements'' and ''ideal measurements'' regarding the disentanglement property. If the initial quantum state is a protected state, then no adiabatic weak measurement of *any* variable leads to entanglement between the system and the measuring device. In contrast, ideal measurements of only the observables for which the initial state of the system is an eigenstate do not lead to entanglement.

The quantum state of a harmonic oscillator that can be observed using protective measurement is one of the energy eigenstates. We do not need to know the full information about the state: the only information needed is that it is an energy eigenstate and that the gap to any other eigenstate is larger than some value. This information is necessary for fixing the parameters needed for adiabaticity of the protective measurement.

If the potential, i.e., the strength and the location of the harmonic oscillator, is known, then the ideal measurement can tell us what the energy of the system is and we can calculate the expectation value of any observable, the outcome of corresponding protective measurement. (Moreover, we do not need any information about the energy gap for the ideal measurement of energy.) But, if we do not know the potential, the protective measurement can give us more information than any ideal measurement can. The bound on the energy gap is the only *a priori* information that is needed to find the complete wave function of a nondegenerate energy eigenstate of an unknown potential.

We note that our work on protective measurement has been misinterpreted (although in another way) before [6–8]. We hope that this Comment and our Reply [9] clarify the concept of protective measurements. We want also to point out a recent generalization of this concept to protective measurements of preselected and postselected systems [10] and to protective measurements of metastable systems [11].

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