Supplementary Material for

A programmable two-qubit solid-state quantum processor under ambient conditions

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I. EXPERIMENT SETUP

The diamond was mounted on a home-built confocal setup as shown in Fig. S1. Spin-state initialization and detection of the NV center was realized with a 532 nm green laser controlled by an acousto-optic modulator (ISOMET, power leakage ratio ~1/1000). To preserve the NV center's longitudinal relaxation time from laser leakage effects, the laser beam was passed twice through the acousto-optic modulator before going through an oil objective (Olympus, PLAPON 60*O, NA 1.42). The phonon sideband fluorescence (wavelength, 650-800nm) went through the same oil objective and was collected by an avalanche photodiode (APD) (Perkin Elmer, SPCM-AQRH-14) with a counter card. A solid immersion lens (SIL) is created around the NV center to increase the fluorescence collection efficiency. The spin states were manipulated with microwave and radio-frequency pulses. A broadband coplanar waveguide (CPW) with 15 GHz bandwidth was designed and fabricated to feed the microwave. The radio-frequency pulses were carried by a home-built coil.

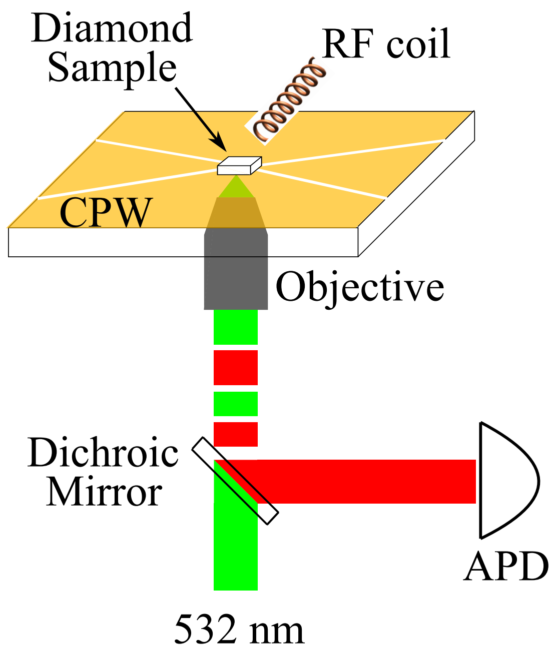

FIG. S1. (color online). Schematic of the experiment setup.

II. ERRORS CONSIDERED IN THE SIMULATION RESULTS

The imperfect polarization and the decoherence of the electron spin contribute to the difference between ideal and simulation results. At the magnetic field strength of 500 G, the spin state of the NV center is effectively polarized to $|m_S = 0, m_I = +1\rangle$ After the optical pumping, 95% of the population occupies the $|m_S = 0\rangle$ state of the electron spin and 98% of the population occupies the $|m_I = +1\rangle$ state of the nuclear spin. The imperfect polarization indicate an initialization error of about 7%. The processor suffered from the dephasing noise during the process of the two-qubit entangling gate U_{zz}. The practice Hamiltonian become $H_{prac} = 2\pi(\delta_0 Sz + A_{zz} S_z I_z)$. The dephasing noise, δ_0, mainly comes from the Overhauser field (due to the interaction with the nuclear spin bath), the magnetic field fluctuation and the instability of the microwave frequency. The δ_0 satisfies a Gaussian distribution $P_0(\delta_0) = \exp(-\delta_0^2/2\sigma^2)/\sigma\sqrt{2\pi}$ with $\sigma = 0.131(5)$ MHz[1]. The simulation results are obtained with the consideration of initial polarization and the dephasing noise distribution $P_0(\delta_0)$.

[1] Rong, X. et al. Experimental fault-tolerant universal quantum gates with solid-state spins under ambient conditions. *Nature Commun.* **6**, 8748 (2015)