Dynamically modulated Autler-Townes effect in a transmon qubit

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Introduction

By applying a coupling microwave field gated by random-telegraph-noise (RTN), we report the experimental demonstration of dynamically modulated Autler-Townes effect (ATE) in an artificial atom – a superconducting transmon qubit – and obtain the distinguished characteristics when a system is affected by RTN. Numerical calculations agree well with the experimental data.

A superconducting qubit based on Josephson junctions can behave like an artificial atom and exhibit macroscopic quantum coherence. Such an artificial atom has been employed as a testing ground for atomic-physics and quantum optics experiments in a nearly macroscopic system. Numerous phenomena including those, which cannot even occur in natural atoms, have been explored in the superconducting qubit, one of which is the well-known Autler-Townes effect (ATE).

Generally speaking, in ATE a three-level (|a>,|b>,|c>) atom is irradiated by a sufficiently strong resonant (between |a>and |b>) external field; the uncoupled and degenerate states |a,N+1> and |b,N> (N represents the number of photons) will repel each other and are transformed into dressed states. This means the original energy levels split and manifest themselves as doublets around the transition frequency of the uncoupled system. Such doublets in the atom's absorption spectrum (between |b>and |c>) can be probed by another weak tone. The spacing of the doublet is equal to the coupler strength, i.e., Rabi frequency, of the resonant field.

In order to further explore the characteristics and possible application in quantum information processing and quantum simulation of other systems, here we focus on the dynamically modulated ATE in a superconducting transmon qubit. The coupling field is modulated by a random-telegraph noise (RTN) process. RTN is a stationary and dichotomous Markovian process characterized by an average jumping rate. The number of the jumps is a Poisson process.

Experimental set-up with **Triton 500 Cryofree** dilution refrigerator

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Experiment

Our device is a transmon qubit in an aluminum three dimensional cavity with its fundamental resonant frequency $\omega cav/2\pi$ = 10.678 GHz. The sample is made via electron beam lithography and double-angle evaporation on a high resistance Si substrate, in which a single Al/AlOx/Al Josephson junction is capacitively shunted by two Al pads as shown in Figure 1(a). The device is located in Oxford Triton 400 dilution refrigerator with careful electromagnetic shielding and filtering. The states of the transmon are measured using Jaynes-Cummings readout. From the spectrum we can get $\omega 01/2\pi$ = 8.865 GHz, $\omega 12/2\pi$ = 8.637 GHz. Due to the anharmonic characteristics of a transmon, only the ground (|0>), first (|1>), and second excited states (|2>) of the transmon qubit are considered in our experiment when the system is driven by fields resonant or nearly resonant with $\omega 01$ and $\omega 12$. Thus the qubit can be regarded as a ladder-type three-level artificial atom as shown in Fig. 1(b). The coupler (probe) fields are near resonant with the transition frequency between |1> and |2> (|0> and |1>).

We use a monochromatic field with RTN-process modulation to drive the transmon qubit. An arbitrary waveform generator is programed to generate a continuous pseudorandom rectangular waveform with two voltage levels 0 and 1.2 V to switch off/on the coupler field. The jumps of voltage levels during time t are consistent with the Poisson process with the probability of the number of jumping , $P_n(Xt) = (Xt)^n e^{-Xt}/n$, in which X is an average jumping rate. Then another weak probe field is applied to characterize the spectrum of the qubit.

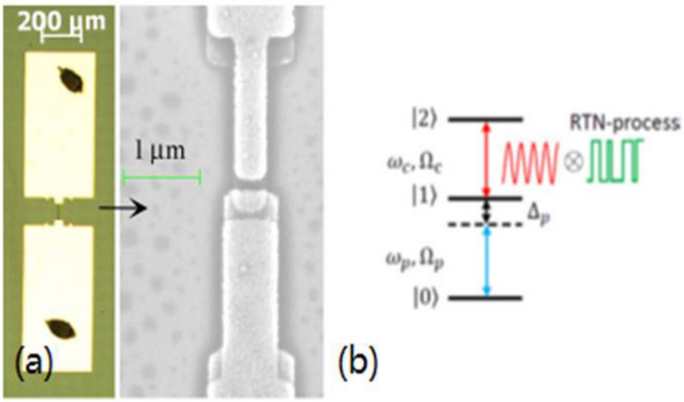

Figure 1. (a) Optical micrograph of transmon.
(b) Energy level diagram indicating the energy levels, probe, and couplers. The coupler is modulated by RTN process.

Experimental results

Figure 2 shows the result of ATE with RTN-process modulation. Here the strength of the coupler wave is $\Omega c/2\pi$ = 16 MHz. The spectrum versus the average jumping rate X of RTN process is obtained by sweeping the probe wave. As one can see, the spectrum is quite different from that without RTN process. In the regular ATE, there are only two peaks resulting from the dressed states |±> with spacing which is equal to the coupler strength $\Omega c/2\pi$ = 16 MHz. Here when the jumping rate is low, the spectrum shows three peaks. The middle peak located at $\Delta p = 0$ is the resonant peak at $\omega 01$, which disappears in the regular ATE for a strong coupler strength. The other two peaks locate symmetrically at $\Delta p/2\pi$ = ±8 MHz. These are the dressed states |±> in the regular ATE. Such effect comes from the RTN process. The switching on/off of the coupler wave means the coupler wave is applied or not randomly, which results in the appearance or disappearance of the spectral lines corresponding to |±> and |1> in the spectrum. When the jumping rate is not so high, the states |±> and |1> can switch swiftly back and forth, thus three peaks emerge. As the jumping rate increases, there is no time for the states |±> and |1> to drift into the direction of the noise. Therefore when the jumping rate is larger than a threshold, which we define as ξ, the population measured in the steady state is an average of that in the states |±> and |1>. So the previous three peaks merge pairwise into two new peaks located at $\Delta p/2\pi$ = ±4 MHz. Because the numbers and position of the peaks in the measured spectrum depend on the RTN, one may use the modulated ATE to detect RTN process.

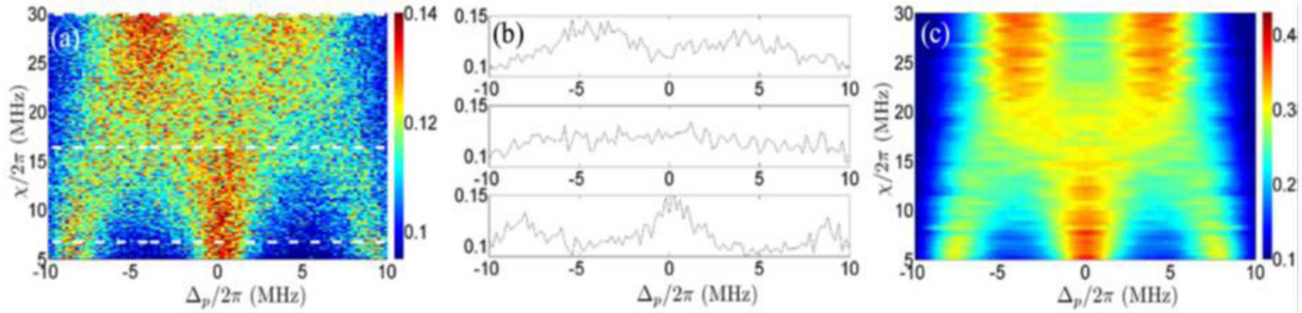

Figure 3. (a) Experimental and (c) numerical calculated spectra of the ATE with RTN-process modulation as a function of average jumping rate X with $\Omega c/2\pi$ = 16 MHz. (b) Horizontal cuts of the spectrum at $X/2\pi$ = 6.633 MHz, 16.432 MHz, 30 MHz in (a), respectively.

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Conclusion

In summary, we have observed RTN-modulated ATE in a superconducting transmon qubit. The measured spectra are drastically different from those in the regular ATE of a three-level atom. In the modulated ATE with RTN process, the dressed states in the regular ATE and the bare state will be averaged when the noise jumping rate in RTN process is larger than the coupler strength. The result may help us to detect RTN with modulated ATE and explore the robustness of quantum switches and quantum routers against RTN. Also it is promising in quantum simulation such as simulating the motional averaging in other systems.

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