

## Recent Progress in Adiabatic Quantum-Flux-Parametron Logic

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**Abstract**— Adiabatic quantum-flux-parametron (AQFP) logic [1] is an ultra-low-power superconductor logic family based on the quantum flux parametron [2]. AQFP logic gates can operate with switching energy much less than the Josephson energy due to adiabatic switching [3,4], in which the potential energy shape changes from a single well to a double well gradually so that the logic state can switch adiabatically. We have investigated the energy efficiency of AQFP logic and demonstrated an AQFP circuit operating with an energy dissipation of 1.4 zJ per junction [5], which is only 24 times thermal energy at 4.2 K. Furthermore, we have established design methodology for AQFP logic, such as cell libraries and clocking schemes, and developed various AQFP digital circuits towards energy-efficient computing systems. In the present study, we report recent progress in AQFP logic. First, we briefly explain the operating principle of the AQFP. Then, we report on an AQFP microprocessor called Monolithic Adiabatic iNtegration Architecture (MANA) [6]. We have recently fabricated a 4-bit MANA chip, which includes as many as 21,460 Josephson junctions, and succeeded in demonstrating test programs with the chip. Moreover, we show several other systems that exploit the physical features of the AQFP, such as reversible computers [7], single-photon image sensors [8], and quantum applications. These systems indicate the feasibility of the wide application of AQFP logic in information and communications technology. Finally, we present future outlook on AQFP logic. The present study was supported by JSPS KAKENHI (Grants No. JP18H01493, No. JP18H05245, No. JP19H05614, and No. JP19H05615) and was partly based on results obtained from a project, JPNP16007, commissioned by the New Energy and Industrial Technology Development Organization (NEDO), Japan. The circuits were fabricated in the Clean Room for Analog-digital superconductivity (CRAVITY) at the National Institute of Advanced Industrial Science and Technology (AIST).

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