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A Characterization of Integral, Real, and Gaussian Clifford+T Operators

In 2012, Giles and Selinger showed that Clifford+T operators correspond to matrices of the form $U = (1/\sqrt{2})^k M$ where k is a nonnegative integer and M is a matrix over the ring $\mathbb{Z}[\omega]$. Here, we consider the operators that arise when one restricts M to be a matrix over a subring of $\mathbb{Z}[\omega]$. We focus on the subrings $\mathbb{Z}$, $\mathbb{Z}[\sqrt{2}]$, and $\mathbb{Z}[i]$, which define the integral, real, and Gaussian Clifford+T operators, respectively. We prove that these restricted Clifford+T operators correspond to circuits over well-known universal sets of quantum gates. Explicitly, we show that the integral Clifford+T operators are generated by the gate set $\{X, CX, CCX, H\}$, from which the real and Gaussian operators are obtained by adding the CH and S gate, respectively.