In 1988, Aharonov et al. discovered “weak measurements” in quantum mechanics. Curiously, these measurements can be constructed such that their measurement results, or “weak values,” lie far outside the eigenspectrum of the observable being measured; in fact, they can take on any complex value. More explicitly, let $|\varphi\rangle$ denote the state of the quantum system prior to weak measurement (the “pre-selected state”), let $M$ denote the Hermitian observable being weakly measured, and let $|\psi\rangle$ denote the state of the quantum system after a strong measurement (the “post-selected state”). The corresponding weak value is then given by the following function on the vector space of Hermitian operators:

$$A_{|\varphi\rangle,|\psi\rangle}(M) = \frac{\langle \psi | M | \varphi \rangle}{\langle \psi | \varphi \rangle}.$$

We are driven by the following question. For a given complex number $\alpha$ and some arbitrary weak value function $A = A_{|\varphi\rangle,|\psi\rangle}$, what is the pre-image of $\alpha$ under $A$? It turns out that the solution is fundamentally geometric, and in turn reveals hitherto unseen underlying geometric structure in weak values. In the case of qubits, we provide a complete geometric characterization. (Received September 17, 2015)