A method for simulating a random variable via numerical inversion of its cumulative distribution function was introduced in mathematical finance by P. Glasserman and Z. Liu. When the random variable is an increment of a Levy process, we present a fast and numerically stable method of computing the c.d.f. based on decomposing the jump part of the process into the sum of its positive and negative jump components, and applying the parabolic Fourier inversion method discovered by S. Boyarchenko and S. Levendorskii. In many important examples, the resulting simulation algorithm performs 10-100 times faster than its competitors.