Consider a light wave propagating in the z direction. For simplicity let the light be linearly polarized with electric field vector $\vec{E}$ pointing in the x direction.

$$\vec{E}(t,x,y,z) = \begin{pmatrix} E_x \cos(kz - \omega t) \\ 0 \\ 0 \end{pmatrix}$$

Symbol ω is angular frequency and k is the wave number $k = \omega/c$.

The corresponding wave function is

$$\psi = A \left| n - \tfrac{1}{2} \right\rangle + B \left| n + \tfrac{1}{2} \right\rangle$$

where n is the number of photons per unit volume and

$$A = \exp\left(-i \left(n - \tfrac{1}{2}\right) \omega t\right)$$
$$B = \exp\left(-i \left(n + \tfrac{1}{2}\right) \omega t\right)$$

The electric field operator is

$$\hat{\mathscr{E}} = C\hat{a} + \bar{C}\hat{a}^\dagger$$

where $\hat{a}$ and $\hat{a}^\dagger$ are the lowering and raising operators such that

$$a \left| n + \tfrac{1}{2} \right\rangle = \sqrt{n} \left| n - \tfrac{1}{2} \right\rangle$$
$$a^\dagger \left| n - \tfrac{1}{2} \right\rangle = \sqrt{n} \left| n + \tfrac{1}{2} \right\rangle$$

The quantity C is

$$C = \sqrt{\frac{\hbar\omega}{2V\varepsilon_0}} \, \exp(ikz),$$

where V is a unit volume.

Apply electric field operator $\hat{\mathscr{E}}$ to wave function ψ.

$$\hat{\mathscr{E}}\psi = C\hat{a}\psi + \bar{C}\hat{a}^\dagger\psi$$
$$= CA\sqrt{n-1} \left| n - \tfrac{3}{2} \right\rangle + CB\sqrt{n} \left| n - \tfrac{1}{2} \right\rangle + \bar{C}A\sqrt{n} \left| n + \tfrac{1}{2} \right\rangle + \bar{C}B\sqrt{n+1} \left| n + \tfrac{3}{2} \right\rangle$$

The observed electric field is the eigenvalue $\mathscr{E}$ such that $\hat{\mathscr{E}}\psi = \mathscr{E}\psi$.

$$\mathscr{E} = \psi^\dagger \hat{\mathscr{E}} \psi$$
$$= \left\langle n - \tfrac{1}{2} \right| \bar{A}CB\sqrt{n} \left| n - \tfrac{1}{2} \right\rangle + \left\langle n + \tfrac{1}{2} \right| \bar{B}\bar{C}A\sqrt{n} \left| n + \tfrac{1}{2} \right\rangle$$
$$= \sqrt{n}\,C \exp(-i\omega t) + \sqrt{n}\,\bar{C} \exp(i\omega t)$$
$$= \sqrt{\frac{2n\hbar\omega}{V\varepsilon_0}} \cos(kz - \omega t)$$

Identifying $\mathscr{E}$ as the first component of $\vec{E}$ we have

$$E_x \cos(kz - \omega t) = \sqrt{\frac{2n\hbar\omega}{V\varepsilon_0}} \cos(kz - \omega t)$$

Hence the electric field amplitude E_x is proportional to the square root of photon density.

$$E_x = \sqrt{\frac{2n\hbar\omega}{V\varepsilon_0}}$$