Optimal Phase Sensitivity in an Unbalanced Mach-Zehnder Interferometer

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Reaching the optimal phase sensitivity for a balanced Mach-Zehnder interferometer (MZI) often boils down to properly matching the input state, the working point and the detection scheme [1, 2].

When it comes to an unbalanced MZI, two new parameters come into play; namely, the transmission coefficients of the first and, respectively, the second beam splitter (BS) [3]. We will denote them by T and, respectively, T'.

As we will discuss, the transmission coefficient of the first BS (T) can be unequivocally determined by employing the quantum Fisher information (QFI) [4]. We will discuss separately the single- and two-parameter QFI since they refer to detection schemes having or not access to an external phase reference [5]. Each QFI determines the respective quantum Cramer-Rao bound (QCRB) [6] which represents the ultimate achievable bound for the phase sensitivity. We can easily show that the availability of an external phase reference is never detrimental from a quantum metrological point of view [4].

The optimization of the second beam splitter's transmission coefficient (T') is detection scheme dependent; thus, one must specifically take into account the actually implemented scheme. As we will discuss, this optimization problem is actually a two-parameter one, and we have to extremize T' simultaneously, and the working point (φ_{opt}) [7].

While the (coupled) equations yielding the extrema seem to be analytically unsolvable, we show that for a number of popular detection schemes, they simplify yielding closed-form solutions. Moreover, we are able to point out, for each detection scheme, when a balanced MZI is optimal. We also discuss the scenarios when an unbalanced MZi is able to outperform in terms of phase sensitivity and its balanced counterpart.

References

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