Local and nonlocal entanglement for quasiparticle pairs induced by Andreev reflection

Zhao Yang Zeng$^{1,2,3}$, Liling Zhou$^{1,4}$, Jongbæ Hong$^{5}$, and Baowen Li$^{3,5,6}$

$^1$Department of Physics, Jangzi Normal University, Nanchang 330027, China
$^2$School of Physics & Center for Theoretical Physics, Seoul National University, Seoul 151-747, Korea
$^3$Department of Physics and Centre for Computational Science and Engineering, National University of Singapore, 117542, Singapore
$^4$Department of Physics, Hunan Normal University, Changsha, 410081, China
$^5$Laboratory of Modern Acoustics and Institute of Acoustics, Nanjing University, Nanjing 210093, China
$^6$NUS Graduate School for Integrative Sciences and Engineering, Singapore 117597, Singapore

(Dated: March 23, 2022)

We investigate local and nonlocal entanglement of particle pairs induced by direct and crossed Andreev reflections at the interfaces between a superconductor and two normal conductors. It is shown theoretically that both local and nonlocal entanglement can be quantified by concurrence and detected from the violation of a Bell inequality of spin current correlators, which are determined only by normal reflection and Andreev reflection eigenvalues. There exists a one-to-one correspondence between the concurrence and the maximal Bell-CHSH parameter in the tunneling limit.

PACS numbers: 73.50.Td,74.45.+c, 03.67.Mn, 03.65.Ud

Quantum entanglement is a peculiar nonlocal correlation between distant quantum mechanical systems. It plays a key role in the emerging tasks of quantum information science, such as quantum cryptography, quantum dense coding, quantum teleportation, quantum error correction, and quantum computation. Entanglement is also critical for enabling a quantum computer to perform some computational tasks exponentially faster than any classical one. This kind of nonclassical puzzling correlation has been demonstrated experimentally for photons and atoms. However, it remains a challenging task for experimentalists to demonstrate electronic entanglement in solids.

There is growing interest in controllable entanglement between electrons in solids, especially in mesoscopic systems. A variety of schemes have been proposed, focusing on the creation, manipulation, and/or detection of spin entanglement of electron pairs by using either quantum dots or superconductors. A mesoscopic normal-conductor-superconductor (NS) device has been designed for the creation and detection of orbital entanglement between electron pairs. All of the proposals with hybrid NS structures only allow for ideal spin-independent tunneling at the interface between the normal conductor and the superconductor. The degree of entanglement is still not, to the best of our knowledge, quantified for electron pairs emitted from a superconductor. A novel idea for electron-hole entanglement produced in tunneling events in normal conductors has been recently put forward by Beenakker et al. Concurrence and the Bell-CHSH parameter for entangled electron-hole pairs have also been analyzed based on the scattering matrix theory.

In this work, we study local and nonlocal entanglement between pairs of quasiparticles (electrons and holes), which are created in Andreev reflection processes in hybrid normal-conductor-superconductor systems. As an example, we consider a structure with two normal conductors connected to a common superconductor via tunnel barriers, as depicted in Fig. 1. The separation $d$ between these two normal conductors should be comparable to the superconducting coherence length $\xi$, in order to guarantee the occurrence of the crossed Andreev reflection process. One can expect entangled pairs of either electrons or holes depending on the sign of voltage applied to one of the two normal conductors. If a negative voltage $\pm eV$ is applied to the left conductor, an incident spin-up (down) hole (electron) in the left conductor can be Andreev reflected as a spin-down (up) electron (hole) either $(i)$ at the left conductor, or, $(ii)$ at the right conductor. The former process is termed as direct Andreev reflection, and the latter is crossed Andreev reflection. Since the absence of a hole (electron) in the filled Fermi sea is equivalent to the creation of an electron (hole), the above process can be viewed as emission into the conductors $L$ and $R$ of two electrons (holes) with opposite spins from the superconductor.

We first consider a simple case in which the transparencies $T_{L/R}$ of the tunnel barriers for spin-up and spin-down particles are the same. In the tunneling limit ($T_{L/R} \ll 1$), the outgoing state will be a superposition of the vacuum state $|0\rangle$, the local entangled state $|\uparrow (E)L \downarrow (E)L - \downarrow (E)L \uparrow (E)L\rangle/L/\sqrt{2}$, and the nonlocal entangled state $|\uparrow (E)\rangle_{L} |\uparrow (E)\rangle_{R} - |\downarrow (E)\rangle_{L} |\downarrow (E)\rangle_{R}/\sqrt{2}$ with weight $\sqrt{1 - T_{L}^{2} - T_{L}T_{R}\lambda(d)}$, $T_{L}, \sqrt{T_{L}T_{R}\lambda(d)}$, where $\lambda(d) \propto e^{-2d/\xi}$. $\lambda(d)$ describes distance suppression of breaking-up of a pair in s-wave superconductors.

Now we consider a general case allowing for an arbitrary value of barrier transparency and spin-flipping at the NS interface. Two normal conductors are labeled by $L$ and $R$ for brevity. A negative voltage $-eV$ is applied to the normal conductor $L$ to create entangled pairs of electrons. Then the input state describing a stream of holes at energies $0 < E < eV$ injecting to the superconductor...
FIG. 1: A schematic picture of direct and crossing Andreev reflection in the standard semiconductor model: two normal conductors (L and R) are connected to a superconductor (middle) via tunnel barriers, with a negative voltage $-eV$ being applied at the conductor L. The shaded region is the filled electron state. A hole (open circle) with spin down (up) below the superconducting chemical potential incident on the superconductor from L will be either converted as an electron (filled circle) with spin up (down) above the chemical potential at L or at R. The process can be viewed as emission of an electron pair from the superconductor. The inset is the schematics of a hybrid structure with a superconductor and two normal conductors with separation $d$.

can be written as

$$|\Psi_{in}\rangle = \prod_{0<E<eV} a_{L}^{\dagger}(E)a_{L}^{\dagger}(E)|G\rangle,$$  

where the ground state $|G\rangle$ is the filled Fermi sea up to the superconducting chemical potential in the normal conductors. $a_{X}^{\dagger}(E)$ is the creation operator exciting an incident spin-$\sigma$($\uparrow$, $\downarrow$) hole($\alpha = h$) or electron($\alpha = e$) state with energy $E$(which is counted from the superconducting chemical potential) in normal conductor $X = L, R,$ and similarly for operators $b$ of an outgoing state.

Since in this work we want to discuss the entanglement arising only from Andreev reflection, a more general discussion in the presence of cotunneling events will be given elsewhere. The experimental setup should satisfy the condition $eV \ll \Delta$ (the superconductor energy gap) where the cotunneling rate between the two normal conductors is negligibly small. Taking into consideration the crossed Andreev reflection, a scattering matrix relating the output state to the input state will be

$$
\begin{bmatrix}
  b_{L}^{y}
  \\
  b_{R}^{y}
\end{bmatrix}
= 

\begin{bmatrix}
  S_{LL}^{ee} & S_{LL}^{eh} & S_{LL}^{eh} & 0 \\
  S_{LL}^{he} & S_{RR}^{ee} & S_{RR}^{eh} & 0 \\
  S_{LL}^{he} & S_{RR}^{he} & S_{LL}^{ee} & 0 \\
  0 & 0 & 0 & S_{RR}^{ee}
\end{bmatrix}
\begin{bmatrix}
  a_{L}^{x}
  \\
  a_{R}^{x}
\end{bmatrix},
$$

where $b_{X}^{\alpha} = (b_{X}^{\alpha_{1}}, b_{X}^{\alpha_{2}})^{T}$, $a_{X}^{\gamma} = (a_{X}^{\gamma_{1}}, a_{X}^{\gamma_{2}})^{T}$, with $T$ denoting the matrix transpose. The $2 \times 2$ submatrices $S_{XY}^{\alpha}$ in Eq. (2) is spanned in the spin space, and the elements of the submatrices are $S_{XY}^{\alpha \beta}$. They describe normal reflection, direct Andreev reflection and crossed Andreev reflection processes. The scattering matrix can be obtained from the scattering matrix approach by matching the wavefunctions at the NS interface. In general, the scattering matrix has a product of the local scattering matrices of the barriers in the presence of crossed Andreev reflection. Fortunately, it takes a simple form in the tunneling limit, as we show later.

Following Beenakker et al., we rewrite the input state in the following form

$$|\Psi_{in}\rangle = \frac{i}{2} \prod_{0<E<eV} a_{L}^{\dagger} \sigma_{y} a_{L}^{\dagger} |G\rangle.$$  

In Eq. (3), $\sigma_{y}$ is the Pauli matrix $\begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$. One finds from Eq. (2)

$$a_{L}^{\dagger} = b_{L}^{\dagger} S_{LL}^{eh} + b_{L}^{\dagger} S_{LL}^{he} + b_{R}^{\dagger} S_{RL}^{eh},$$

The input state evolves unitarily into the output state $|\Psi_{out}\rangle = U|\Psi_{in}\rangle = \prod_{i} U a_{i}^{\dagger} U^{\dagger} |G\rangle$ in the Schrödinger picture. However, in the Heisenberg picture, vector states remain unchanged, and operators transform as $a_{i} \rightarrow b_{i} = U_{i} a_{i} U = \sum_{j} S_{ij} a_{j}$. The operation $U a_{i} U^{\dagger}$ appearing in the evolution from the input state to the output state can be considered as a time-reversal evolution as compared to the original transformation between $a_{i}$'s and $b_{i}$'s. Such an evolution is equivalent to exchanging the role of inputs and outputs, i.e., $U \rightarrow U^{\dagger}$, $S \rightarrow S^{\dagger}$ and $a_{i} \rightarrow b_{i}$. Then we have $U a_{i} U^{\dagger} \rightarrow U^{\dagger} b_{i} U = \sum_{j} S_{ji} b_{j}$, which means that a direct substitution of $b_{i}$'s for $a_{i}$'s in the input state via the related scattering matrix relation gives the correct output state. Therefore, we obtain the output state by inserting $U a_{i}^{\dagger}$ into $|\Psi_{out}\rangle$.

$$|\Psi_{out}\rangle = |\Psi_{in}\rangle \prod_{0<E<eV} \left( (S_{LL}^{eh} \sigma_{y} S_{LL}^{eh})_{12} b_{L}^{\dagger} b_{L}^{\dagger} + b_{L}^{\dagger} S_{LL}^{eh} \sigma_{y} S_{LL}^{eh} b_{L}^{\dagger} b_{L}^{\dagger} + S_{RL}^{eh} b_{R}^{\dagger} T_{X}^{\dagger} + \sum_{X=L,R} [(S_{LL}^{eh} \sigma_{y} S_{LL}^{eh})_{12} b_{X}^{\dagger} (T_{X}^{\dagger})_{12} b_{X}^{\dagger} + b_{X}^{\dagger} S_{RL}^{eh} \sigma_{y} S_{LL}^{eh} b_{L}^{\dagger} b_{L}^{\dagger} \right] |G\rangle.$$  

This expression reveals distinct physical processes. The first term represents normal reflection with the incoming holes reflecting backward at the NS interface, the second and third terms describe high-order Andreev reflection processes with the incoming holes transforming into electrons at the left and/or right conductors, and the last term gives direct and crossed Andreev reflection, which constitutes the desired local and nonlocal entangled pairs of particles.

Defining some auxiliary states as

$$|\psi_{X}\rangle = \frac{1}{\sqrt{X}} \prod_{0<E<eV} b_{X}^{\dagger} S_{XX}^{eh} \sigma_{y} S_{XX}^{eh} b_{L}^{\dagger} b_{L}^{\dagger} |G\rangle,$$

$$|\psi_{LR}\rangle = \frac{1}{\sqrt{\lambda}} \prod_{0<E<eV} b_{L}^{\dagger} S_{RL}^{eh} \sigma_{y} S_{RL}^{eh} b_{R}^{\dagger} b_{R}^{\dagger} |G\rangle.$$
we rewrite the output state in the following form
\[ |\Psi_{\text{out}}\rangle = i \left\{ A|\psi_L\rangle + A_X|\psi_X\rangle + \prod_{0 < E < eV} \left( S_{LL}^{eh} \sigma_y S_{XL}^{ehT} \right)_{12} \right\} b_{L \uparrow}^\dagger b_{L \downarrow}^\dagger \phi_{L\downarrow}^\uparrow + \sum_{X = L, R} \left( S_{XX}^{eh} \sigma_y S_{XL}^{ehT} \right)_{12} b_X^\dagger |\xi_X\rangle \].

With the help of unitary conditions of the scattering matrix [2], the state normalization condition yields: \[ A_X = \left( Tr \hat{Y}_{XL} \hat{Y}_L^\dagger \right)^{1/2}, A = \left( Tr \hat{Y} \hat{Y}^\dagger \right)^{1/2}, \] with \( \hat{Y}_{XL} = S_{XL}^{eh} \sigma_y S_{LL}^{ehT} \sigma_y \) and \( \hat{Y} = S_{LL}^{eh} \sigma_y S_{RL}^{ehT} \sigma_y \).

To manifest the entanglement more clearly, we transform from the electron-hole picture to an all-electron picture with the particle-hole transformation, \( c_{L\sigma}^\dagger (-E) = b_{L\sigma}^\dagger (E) \), \( c_{L\sigma}^\dagger (E) = b_{L\sigma}^\dagger (E) \). The new vacuum state is defined by \( |0\rangle = \prod_{0 < E < eV} a_{L\sigma}^\dagger (E) |G\rangle \), and the renormalized output state becomes to leading order in the Andreev reflection matrix \( S_{eh} \)

\[ |\Psi_{\text{out}}\rangle \simeq \sqrt{1 - \zeta_L - \zeta_R(0)} + \sqrt{\zeta_L} |\psi_L\rangle + \sqrt{\zeta_R} |\psi_R\rangle, \]
\[ |\psi_L\rangle = \prod_{0 < E < eV} \zeta_L^{-1/2} c_L^\dagger (E) \hat{Y}_{LL} c_L^\dagger (-E) |0\rangle, \]
\[ |\psi_R\rangle = \prod_{0 < E < eV} \zeta_R^{-1/2} c_R^\dagger (E) \hat{Y}_{RL} c_R^\dagger (-E) |0\rangle, \]

where \( \zeta_X = A_X^2 \). The output state is a superposition of the new defined vacuum state \( |0\rangle \), and local and nonlocal entangled states \( |\psi_L\rangle, |\psi_R\rangle \). The local entangled state consists of electron-electron pairs at the same conductors and nonlocal entangled states of electron-electron pairs at two different conductors. Notice that the entanglement states here are a product of two-particle entangled states at different energies.

In the tunneling limit \( T_{L,R}/t \ll 1 \), all the elements of the Andreev reflection matrices \( (S_{XX}^{eh})_{ij} \ll 1 \). Expanding the product in the output state \( \Phi \) to first order in \( (S_{XX}^{eh})_{ij} \) and using the fermion commutation relations repeatedly[13], the output state after rearranging operators becomes

\[ |\Psi_{\text{out}}\rangle \simeq \sqrt{1 - \zeta_L - \zeta_R(0)} + \sqrt{\zeta_L} |\psi_L\rangle + \sqrt{\zeta_R} |\psi_R\rangle, \]
\[ |\psi_L\rangle = \int_{0 < E < eV} dE \zeta_L^{-1/2} c_L^\dagger (E) \hat{Y}_{LL} c_L^\dagger (-E) |0\rangle, \]
\[ |\psi_R\rangle = \int_{-eV}^{eV} dE \zeta_R^{-1/2} c_R^\dagger (E) \hat{Y}_{RL} c_R^\dagger (-E) |0\rangle. \]

Such a state is a sum of superposition states of the newly defined vacuum state, and local and nonlocal entangled states at different energies, which describes a wave-packet-like entanglement state.

For a two-qubit pure state \( |\psi\rangle \), one can quantify the degree of entanglement by concurrence[20] \( C = ||\psi|\sigma_y \otimes \sigma_y|\psi^*\rangle \), where the superscript * denotes complex conjugate. For the local and nonlocal entangled states \( |\psi_L\rangle \)’s and \( |\psi_R\rangle \)’s, one finds

\[ C(\psi_{L,R}) = 2 \sqrt{R_{L,R} A_{LL}/R_{L,R} A_{LL}/R_{L,R}}. \]
Performing a similar calculation as in Refs.\cite{22} and\cite{24} results in the maximal Bell-CHSH parameter $B$ for the local and nonlocal entangled spin states $|\psi_L\rangle$ and $|\psi_R\rangle$

$$B(\psi_{L/R}) = 2\left[1 + \frac{AR_{L/L}A_{LL/R^+}A_{LL/R^-}}{(R_{L/L}A_{LL/R^+} + R_{L/L}A_{LL/R^-})^2}\right]^{1/2}. \quad (13)$$

In the tunneling limit, the maximal Bell-CHSH parameter becomes

$$B(\psi_{L/R}) = 2\left[1 + \frac{4A_{LL/R^+}A_{LL/R^-}}{(A_{LL/R^+} + A_{LL/R^-})^2}\right]^{1/2}. \quad (14)$$

From Eq. (13) one can readily obtain the following expected relation $B = 2(1 + C)^{1/2}$ as compared with Eq. (14). The maximal Bell-CHSH parameter always violates the Bell inequality as long as $R_{L/L}, R_{L/L}, A_{LL/R^+}, A_{LL/R^-} \neq 0$. In the spin-independent tunneling case, $B = 2\sqrt{2}$, the Bell inequality is maximally violated. As expected, there exists a one-to-one correspondence between the concurrence $C$ and the maximal Bell-CHSH parameter $B$ in the tunneling limit. We notice that, the expressions of the concurrence and the maximal Bell-CHSH parameter bear formal similarities compared to that in tunneling between normal conductors.\cite{22}

The dephasing effect on the entanglement in our system can be discussed in a way similar to Refs.\cite{22} and\cite{24}. Here we discuss possible experimental realizations. For pure superconductors, the coherence length is of order $\xi \sim \hbar/\delta p \sim h\nu_F/\Delta \sim \frac{1}{k_F}\frac{\nu_F}{\Delta}$. $\nu_F$ is typically $10^3 \sim 10^4$ times $\Delta$, $k_F$ is of order of $10^8$ cm$^{-1}$, and $\xi$ is typically $10^3 \sim 10^4$ nm.\cite{22} Therefore, the exponential suppression with increasing distance between two tunneling barriers poses no severe restriction to experimental setup. A pair of tunneling barriers has been already prepared with distance of the order $10$ nm.\cite{22} Since $k_F\xi \gg 1$, the distance suppression is dominated by a polynomial term $(k_Fd)^{-2}$ if the superconductor considered is three-dimensional. One way to reduce or exclude such a power-law decay is to replace the three-dimensional superconductor by a lower-dimensional one.\cite{22} Since the Andreev reflection process involves two quasiparticles with one particle energy above and the other below the superconducting chemical potential, energy-resolving or spin-filtering current noise detectors can be used to measure the low-frequency current correlators.\cite{22} Alternatively, one can also use a pair of spin-resolved edge channels in the quantum Hall effect proposed by Beenakker et al.\cite{22} for our purpose.

In summary, we consider a unique accessible structure in which both local and nonlocal entangled spin states for both electrons and holes can be produced at the same time. The concurrence and the maximal Bell-CHSH parameter have a simple dependence on the eigenvalues of the normal and Andreev reflection matrices, and possess a one-to-one correspondence in the tunneling limit. Possible experimental realization is also discussed.

Z. Y. Zeng was supported by the NSFC under Grant No. 10404010, the Project-sponsored by SRF for ROCS, SEM and the Excellent talent fund of Jiangxi Normal University. This work was also supported in part by Korea Research Foundation Grant No. KRF-2003070C00020, a FRG grant of NUS and the DSTA under Project Agreement POD0140553. Z. Y. Zeng also acknowledge the hospitality of ICTP at Trieste, Italy where part of this work was done.

\begin{thebibliography}{99}
\bibitem{1} B. M. Terhal, M. M. Wolf, and A. C. Doherty, Phys. Today 56, 46 (2003).
\bibitem{2} A. K. Ekert, Phys. Rev. Lett. 67 661 (1991).
\bibitem{3} C. H. Bennett and S. J. Wiesner, Phys. Rev. Lett. 69 2881 (1992).
\bibitem{4} C. H. Bennett, G. Brassard, C. Crépeau, R. Josza, A. Peres and W. K. Wooters, Phys. Rev. Lett. 70, 1895 (1993).
\bibitem{5} P. Shor, Phys. Rev. A 52, R2493 (1995).
\bibitem{6} *The Physics of Quantum Information*, edited by D. Bouwmeester, A. Ekert, and A. Zeilinger (Springer, New York, 2000), *Quantum Computation and Quantum Information*, M. A. Nielsen and I. L. Chuang (Cambridge University Press, 2000).
\bibitem{7} R. Jozsa, *The Geometric Universe: Science, Geometry, and the Work of Roger Penrose* F369-375, edited by K. P. Tod, S. T. Tsou, N. M. J. Woodhouse, S. A. Huggett (Oxford University Press, 1998).
\bibitem{8} A. Aspect, J. Dalibard, and G. Roger, Phys. Rev. Lett. 49, 1804 (1982); W. Tittel, J. Brendel, H. Zbinden, and N. Gisin, *ibid.* 81, 3563 (1998); G. Weihs, T. Jennewein, C. Simon, H. Weinfurter, and A. Zeilinger, *ibid.* 81, 5039 (1998).
\bibitem{9} E. Hagley, X. Maitre, G. Nogues, C. Wunderlich, M. Brune, J. M. Raimond, and S. Haroche, Phys. Rev. Lett. 79, 1 (1997); C. A. Sackett, D. Kielpinski, B. E. King, C. Langer, V. Meyer, C. J. Myatt, M. Rowe, Q. A. Turchette, W. M. Itano, D. J. Wineland, and C. Monroe, Nature (London) 404, 256 (2000).
\bibitem{10} G. Burkard, D. Loss, and E. V. Sukhorukov, Phys. Rev. B 61, R16303 (2000); A. T. Costa, and S. Bose, Phys. Rev. Lett. 87, 277901 (2001); W. D. Oliver, F. Yamaguchi, and Y. Yamamoto, Phys. Rev. Lett. 88, 037901 (2002); X. Hu and S. Das Sarma Phys. Rev. B 69, 115312 (2004); M. Blaauuboer and D. P. DiVincenzo Phys. Rev. Lett. 95, 160402 (2005).
\bibitem{11} G. B. Lesovik, T. Martin, and G. Blatter, Eur. Phys. J. B 24, 287 (2001); N. M. Chichkalev, G. Blatter, G. B. Lesovik, and T. Martin, Phys. Rev. B 66, 161320(R) (2002); C. Beno, S. Vishveshwara, L. Balents, and M. P. A. Fisher, Phys. Rev. Lett. 89, 037901 (2002).
\bibitem{12} P. Recher, E. V. Sukhorukov, and D. Loss, Phys. Rev. B 63, 165314 (2001).
\bibitem{13} T. Samuelsson, E. V. Sukhorukov, and M. Böttiker, Phys.

\end{thebibliography}
Rev. Lett. 91, 157002 (2002); New. J. Phys. 7, 176 (2005).
C. W. J. Beenakker, C. Emary, M. Kindermann, and J. L. van Velsen. Phys. Rev. Lett. 91, 147901 (2003).
W. K. Wootters, Phys. Rev. Lett. 80, 2245 (1998).
J. S. Bell, Physics 1, 195 (1964); J. F. Clauser, M. A. Horne, A. Shimony, and R. A. Holt, Phys. Rev. Lett. 23, 880 (1969).
Existence of crossed Andreev reflectoin has been very recently certified in tunneling experiment in such a structure, see, e.g., D. Beckmann, H. B. Weber, and H. V. Löhneysen, Phys. Rev. Lett. 93, 197003 (2004); S. Russo, M. Krong, T. M. Klapwijk, and A. F. Morpurgo, Phys. Rev. Lett. 95, 027002 (2005).
G. Deutscher and D. Feinberg, Appl. Phys. Lett. 76, 487 (2000).
S. Datta, P. F. Bagwell, and M. P. Anantram, Phys. Low-Dim. Struct. 3, 1 (1996); C. W. J. Beenakker, Rev. Mod. Phys. 69, 731 (1997). We thank Datta for sending us a copy of the paper.
W. K. Wootters, Phys. Rev. Lett. 80, 2245 (1998).
M. Büttiker, Phys. Rev. B 46, 12 485 (1992); Ya.M. Blanter and M. Büttiker, Phys. Rep. 336, 1 (2000).
P. A. Mello, N. Kumar, Quantum Transport in Mesoscopic Systems: Complexity and Statistical Fluctuations (Oxford University Press, 2004).
S. Popescu and D. Rohrlich, Phys. Lett. A 166, 203 (1992).
N. W. Ashcroft and N. D. Mermin, Solid State Physics (Brooks Cole, 1976).
T. Martin, A. Crepieux, N. Chtchelkatchev, Quantum Noise in Mesoscopic Physics, edited by Yuli V. Nazarov (Springer, 2003). cond-mat/0209517