Multiflux modeling of transport in a general transistor structure

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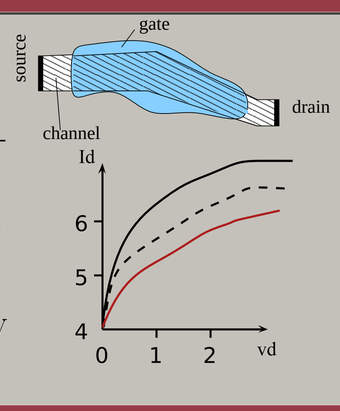
Abstract

We present here a multiflux based modeling of carrier transport in general transistor structure. It is also presented how an equivalent circuit can be calculated using connected scattering-centers based on phase-space partiotioning

Motivation

- a general transistor structure (source - drain - gate structure) is modeled
- channel is controlled by gate (length dimensions can vary)
- How can be used scattering centers as partiotioning aim?
- Could we deduce a characteristics starting from geometry and scattering event types selected?



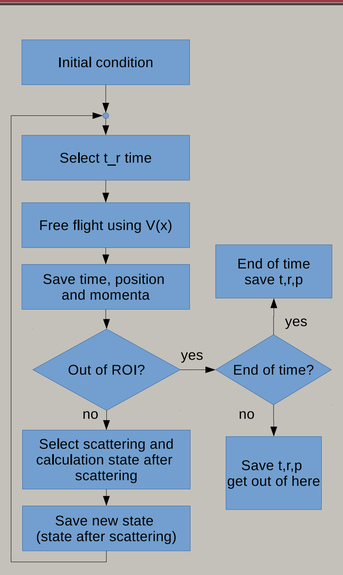
Three steps of calculation

Monte-Carlo (scattering based) simulation of the device → Extraction of scattering parameters from phase-space → Scattering matrix based equivalent circuit using scattering parameters from Step 2.

Step 1. Step 2. Step 3.

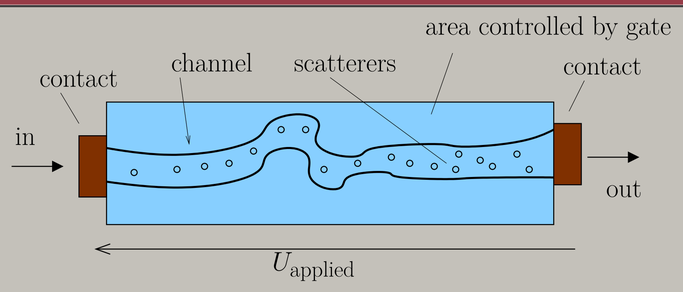
- steps are independent from each others
- scattering parameters of n-port describe device (at a statistical (averaging) depth)
- stationary operation (steady-state conditions) is modeled

Some words about Monte-Carlo simulations



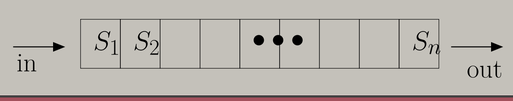
- particle based simulations, using random numbers (MC)
- different scattering rates used for different interactions
- electromagnetic effects are included in free flight
- few assumptions are made ⇒ general description
- effects of different scattering event types can be identified
- **large** number of simulations needed (a lot of runnings)
- output of simulations : space and velocity of charge carriers (supercharges) as a function of time
- ROI = Region Of Interest (geometry and time)

Modelling a one-dimensional channel

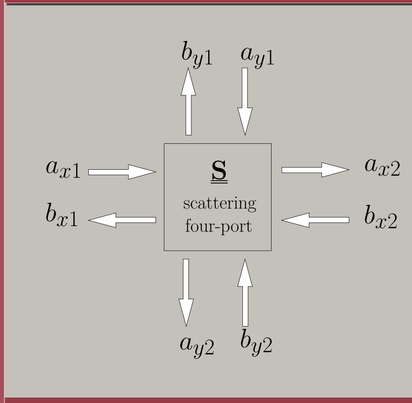


- charge transport takes place only in channel
  - channel's cross section is small

E_x - electric field along channel



Scattering parameters of an n-port



- $a_{x,p}$ – amplitude of the wave moving to direction of positive x (moving right or down)
- $b_{x,p}$ – amplitude of the wave moving to direction of negative x (moving left or up)

characteristics of a four-port using scattering parameters

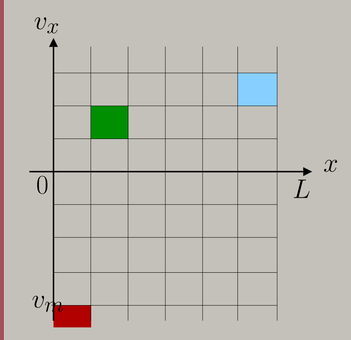
$$\begin{pmatrix} a_{x2} \\ b_{x1} \\ a_{y2} \\ b_{y1} \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{pmatrix} \cdot \begin{pmatrix} a_{x1} \\ b_{x2} \\ a_{y1} \\ b_{y2} \end{pmatrix} = \begin{pmatrix} t_{xx} & r'_{xx} & \cdot & \cdot \\ r_{xx} & t'_{xx} & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \end{pmatrix} \cdot \begin{pmatrix} a_{x1} \\ b_{x2} \\ a_{y1} \\ b_{y2} \end{pmatrix}$$

Post processing of MC simulations Phase-space parameter extraction

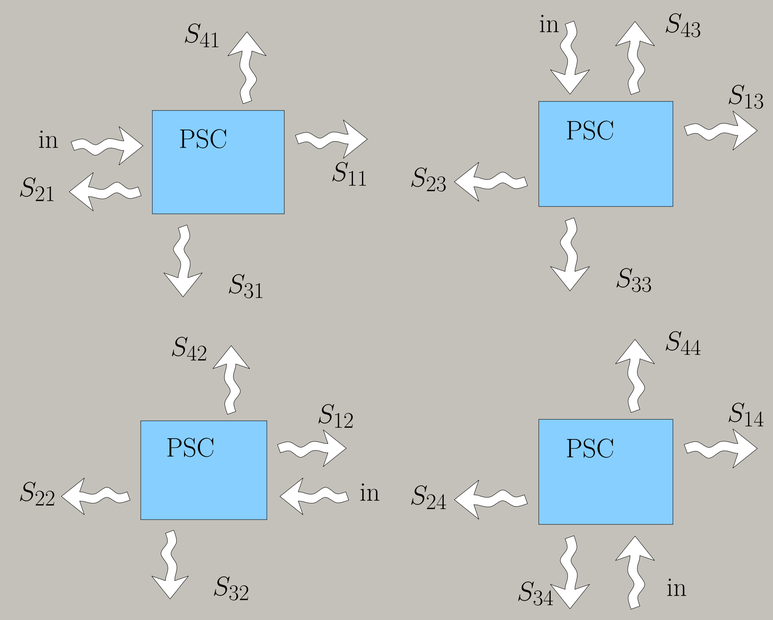
- electrons are divided into groups according to their velocity → fluxes are formed
-

current caused by electrons can be calculated : $I = \sum_p I_p = \sum_p n_p \cdot q$.

where I_p is p-th subflux, n_p is number of electron in the p-th subflux mode



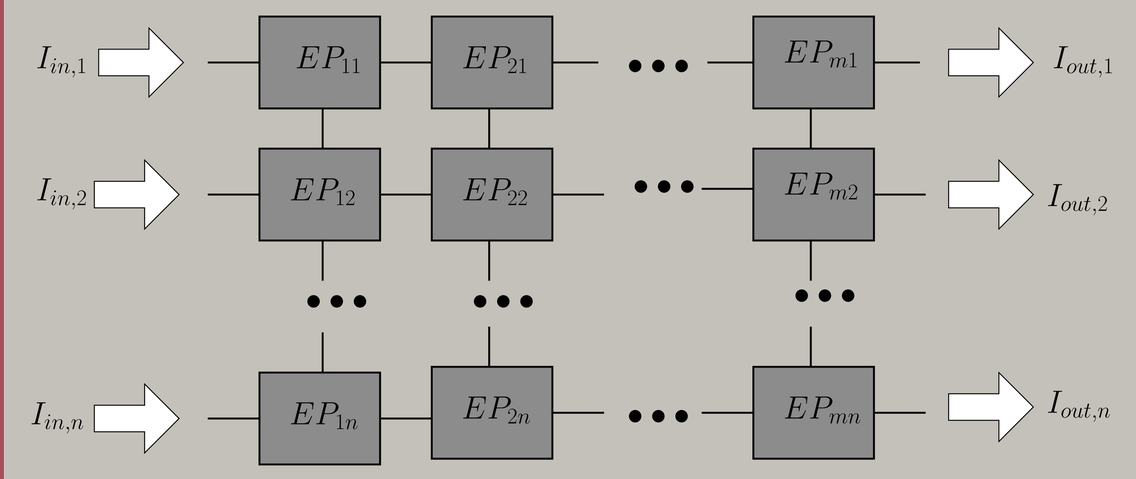
- phase-space is partitioned into subcells
- only neighbour cells are used (cold electron transport)
- green cell shows a general phase-space-cell (PSC)
- red cell is special SPC that represents velocities $v < v_m$ at the beginning (source side) of channel
- blue cell is at the end (drain side) of channel



- $S_{32} = \dfrac{\text{number of electrons left SPC to downward}}{\text{number of electrons came in from right}}$ | only from right comes electrons

Equivalent circuit using four-ports

- divide (electron) current into n partitions (according to step 2. partitions)
- create equivalent four-ports (EPs) and calculate their scattering parameters



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