# The current filament model of the microwave induced zero-resistance state

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**Abstract.** The most frequently used picture of the zero-resistance state it the so called current domain picture. It implies an almost complete change of the physics of current flow in the QHE regime. In contrast, we suggest an alternative model, which is based on well known facts of the QHE-regime, but requires a slight lateral re-arrangement of the carriers in the top LL. We demonstrate, that the creation of randomly distributed narrow stripes of integer filling, which are physically equivalent to incompressible stripes (referred as current filaments), leads to a suppression of the longitudinal resistance, while leaving the Hall effect of the system unaffected.

**Keywords:** quantum Hall effect, network model, zero resistance state, current domain
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## INTRODUCTION

The experimental observation of the zero resistance state in a very high-mobility 2D electron gas [1, 2], which is driven by microwave irradiation, attracted a great deal of attention and theoretical work [3, 4, 5, 6, 7]. An often used model is the so-called current domain (CD) picture [5]: The sample is separated in longitudinal direction into two CDs, in which dissipation less currents flow in opposite direction. Thus, the position of the domain wall inside the sample determines the net current in the sample. The sample in the CD picture is considered to be infinitely long, meaning that the boundary problem at the contacts is avoided by the CD model so far.

It is not the purpose of this paper to address the mechanism of the microwave action on the 2DEG, but we want to propose an alternative scenario for the QHE regime, which behaves similar to the CD picture, which means the suppression of the longitudinal voltage while keeping the Hall effect unaffected. For this purpose we use a network approach for magneto transport [8], which has been already used successfully for modeling the integer quantum Hall effect (QHE) for realistic sample geometry including the boundary problem at the contacts [9, 10]. As proposed by e.g. Ahlswede et al [11] and also evident from our simulations, the dissipation-less current does not flow within the edge stripes, but within the incompressible regions between edge stripes of different potential. This has been demonstrated already in [12]: The whole QH-conductor (sample) is considered to be close to half filling and is divided in longitudinal direction into two parts by a single narrow stripe of integer filling. This is achieved by keeping the filling factor in the designated incompressible stripe at that integer value, which is closest to the actual filling factor of the bulk. Further details of our filament model will be published elsewhere and just the main results are presented below.

## RESULTS

The calculations for the results shown in Fig. 1 have been done for a single LL close to half filling. Half filling in the bulk leads to the normal dissipative regime of a standard QHE sample (Fig.1a). With an incompressible narrow stripe as indicated in Fig.1b, the situation changes drastically. As can be seen in Fig. 1b the whole potential drop appears only in a narrow region close to the current contacts. For voltage probes far from the current contacts this results in a vanishing longitudinal voltage drop, just like in the CD picture. In this way it is demonstrated, that for a single LL our simulations create a lateral potential profile, which is similar to that one expected from the CD picture (see Fig.1b) and the narrow incompressible stripe shows up like the associated domain wall. Since our model also addresses the boundary near the current contacts, the obtained lateral potential profile clearly indicates a transition from dissipative bulk current flow near the current contacts to dissipation-less current flow in the incompressible stripe far from the contacts. At some distance from the contacts there occurs some sort of "focusing" of the sample current into the incompressible stripe (indicated by the arrows in Fig.1b). This means, that the current gets injected as a normal dissipative current at the contacts, but gets redistributed into the incompressible stripe where it continues to flow dissipation-less. Therefore it appears to us more appropriate to use the term "current filament" for those incompressible stripes. But there is no need to assume a single longitudinal incompressible stripe which runs all along the sample. In fact,

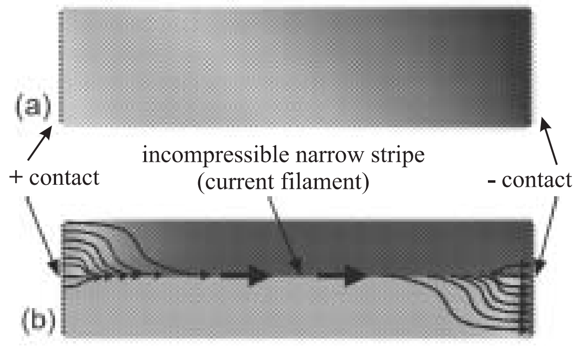


**FIGURE 1.** 2D gray scale picture of the lateral potential distribution for a single LL close to half filling (a) without and (b) with a narrow incompressible stripe. The gray scale from light to dark indicates a potential changing from high to low values. As seen in (a), without the filament we get a smooth longitudinal voltage drop, which indicates the presence of a homogeneous dissipative bulk current. With the incompressible stripe in (b) we get a longitudinal voltage drop only close to the contacts, which turns into a purely transverse voltage drop at some distance from the contacts. The associated lateral current distribution is indicated by the arrows and shows some sort "focusing" of the current from the bulk near the contacts into the incompressible stripe, where it does not produce any further longitudinal voltage drop.

almost the same is achieved by a system of shorter incompressible stripes which are randomly distributed over the bulk of the sample, but all aligned in parallel along the sample (see insert of Fig.2). There is also no need to restrict our model to the presence of just a single LL. Since our model also handles the parallel contribution of several LLs, we can address also the low field regime at high filling factors[8], but creating the filaments only in the top LL like already explained. Fig.2 shows the simulation result for a magnetic field sweep starting at low field and using several filaments distributed over the bulk of the sample like indicated in the insert of Fig.2. The current is injected across the whole width of the sample and point contacts at the edge are used for probing the Hall and longitudinal voltage. The results are shown for both cases, with and without the presence of current filaments. Without current filaments $R_{xx}$ behaves as usual [8], while the presence of current filaments leads to a suppression of the longitudinal voltage to zero. In contrast, the Hall resistance remains unchanged. We attribute the remaining small spikes in $R_{xx}$ to numerical errors due to the iterative procedures used in our model and to an insufficient number of current filaments distributed over the sample. More detailed investigations are in progress.

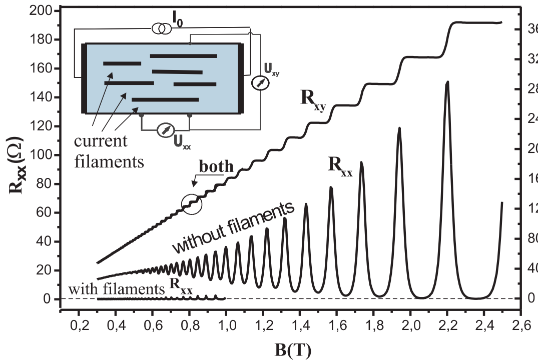


**FIGURE 2.** Simulation results for the longitudinal and Hall resistance with and without current filaments. The filament distribution as used for the simulations is indicated in the insert. Without filaments $R_{xx}$ is finite and shows a normal set-in of the Shubnikov-deHaas oscillations as shown in [8]. In the presence of filaments the longitudinal resistance drops to zero, while the Hall resistance remains the same.

## SUMMARY AND CONCLUSION

We have shown that it is possible to create a scenario in the QHE regime, which leads to a vanishing $R_{xx}$ also at non integer overall filling, while the Hall resistance still continues to increase with magnetic field. We generate this behavior by introducing incompressible narrow stripes, which have to be created by a slight lateral rearrangement of the carriers just in the top LL. On this background we propose the scenario of having several incompressible narrow stripes distributed along the current path, which act as dissipation-less current filaments. These suppress the longitudinal resistance while leaving the Hall resistance unaffected. In this context we have found another possible mechanism for realizing a zero-resistance state in the QHE regime, which could also serve as a candidate for driving the experimentally observed unique microwave induced zero-resistance state.

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