

## CURRENT-SHARING IN A QUANTUM HALL DEVICE USED FOR AC MEASUREMENTS

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### Abstract

We use a simple technique for sharing current between contacts of a quantum Hall device to reduce the current and frequency dependence of its quantized Hall resistance.

### Introduction

A method of sharing the current between several contacts to the two-dimensional electron gas of a quantum Hall device has been proposed by D. Dominguez *et al.* [1] as a way of improving the dc current-carrying capability of the device. It seemed possible that this technique might also be beneficial in ameliorating the slight frequency and current dependence which prevent a quantum Hall device from being a perfect standard of ac impedance. The current and frequency dependence seem to vary from device to device and even with magnetic field direction in a given device.

At the Bureau International des Poids et Mesures (BIPM) we have investigated this technique when applied to a device fabricated by the Physikalische-Technische Bundesanstalt (PTB). The device (type P143-9) is a GaAs-AlGaAs heterostructure grown by Molecular Beam Epitaxy (MBE) and fitted with 10 tin ball contacts. Devices of this type are perfectly satisfactory when used with dc [2]. However, we have found that ac current and frequency dependencies are easily observed for the device used here. The results presented here suggest that current sharing is indeed a useful technique which can improve the ac properties of a device significantly. In our measurements we used the  $i = 2$  plateau which was centred on about 9.9 T rather than the 8.8 T expected for a device of this type operated in the dark. Illumination through the clear perspex terminating plate of our insert is almost certainly the cause of this shift. Lowering the insert whilst this plate was partially obscured resulted in a plateau at an intermediate field.

The Hall device was measured at 1.2 K against a temperature-controlled 12.9 k $\Omega$  Vishay resistor which has negligible current dependence and a frequency dependence of only -2 parts in  $10^8$  per kHz. The frequency dependence of this Vishay resistor was deduced from measurements made against a 1.29 k $\Omega$  coaxial resistor of the Haddad type [3] built at the BIPM. The Vishay resistor was also compared with quadrifilar resistors built at the National Physical Laboratory (NPL). The frequency dependence of the quadrifilar resistors has been reliably computed from knowledge of the geometrical and other properties of their construction [4].

The quantum Hall resistance (QHR) of this device when measured using 6 contacts only in a bridge with triple-series connections [5] exhibited a current coefficient, proportional to frequency, of about 1 part in  $10^7$  per  $10 \mu\text{A}$  at 1 kHz. The QHR resistance current coefficient was about halved when the direction of the applied magnetic field was reversed. When the field was reversed, the Hall resistance on the  $i = 2$  plateau appeared to be unstable when observed with a current of 40  $\mu\text{A}$  or greater.

### Modification of the current connections to the device.

The current dependence of the Hall resistance ( $R_H$ ) makes accurate ac measurement more difficult, as all resistance values have to be extrapolated to the measurement condition of negligible current. A model of the cause of current dependence is that the power dissipated at the current-carrying contacts increases the effective temperature of the electron gas. If the current were to be shared between several contacts by connecting resistors of values 0,  $R_H$ ,  $2R_H$ ,  $3R_H$  and so on in series with them, the current through each contact would be the total current divided by the number of contacts [1]. The power dissipated in the device would be reduced in proportion to the number of these contacts for a given total measuring current and this ought to reduce the current dependence significantly. It should also enable a greater measuring current to be used if the maximum permissible current is limited by the contacts rather than by the density of the edge current.

A printed-circuit board which incorporated three current-sharing resistors (Vishay type) for each end of the device was made. The sample was mounted on it with four current-carrying connections, one made directly and

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the others via the resistors near each end, together with the usual two potential-measuring connections, one in the centre of either side, as illustrated in figure 1.

Figure 2 shows the QHR current dependence with a) single current injection and b) quadruple current injection, at frequencies ranging from 771 Hz to 3082 Hz. Figure 3 shows the QHR frequency dependence with a) single current injection and b) quadruple current injection at currents ranging from 5  $\mu\text{A}$  to 40  $\mu\text{A}$ . All data correspond to the same direction of the magnetic field. It will be seen that the use of the quadruple current injection reduces the QHR current dependence by a factor of about 0.3 at all frequencies. The frequency dependence is reduced only by a factor of about 0.7 at 30  $\mu\text{A}$  and is practically unchanged at 5  $\mu\text{A}$ . This suggests that with single current injection at 5  $\mu\text{A}$  the effective electron temperature is not significantly higher than the bath temperature (1.2 K). The maximum current that could be carried by the device was also increased by multiple injection, but only by a factor of about 1.5. This latter increase only happened when the device had been cooled for 24 hours. During this time the centre of the plateau also moved from about 9T to about 9.9T. It is possible that both phenomena were caused by the cumulative effect of exposing the device to the light penetrating down into the cryostat through the transparent terminating plate.

The capacitance across the device, and therefore its apparent phase-angle, increased because of the capacitance between the current-sharing resistors on either end of the device. This increase could be prevented by appropriate screening. As the electric field associated with this capacitance did not impinge significantly on the device, no other major change in characteristics than an increased phase angle was expected or found.

### Conclusions

Sharing current between contacts by using distributing resistors appears to be helpful in reducing significantly the QHR current dependence. The frequency dependence is also reduced but by a factor which approaches unity when the measuring current tends to zero.

### References

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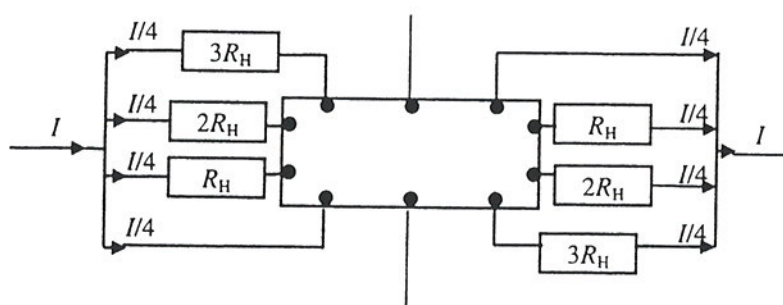


Figure 1 : Network for dividing current nearly equally between four contacts if the magnetic flux density is directed downwards from the plane of the paper.

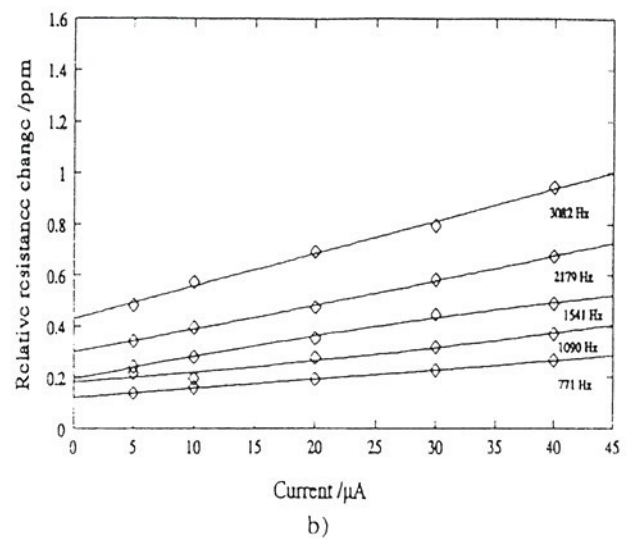
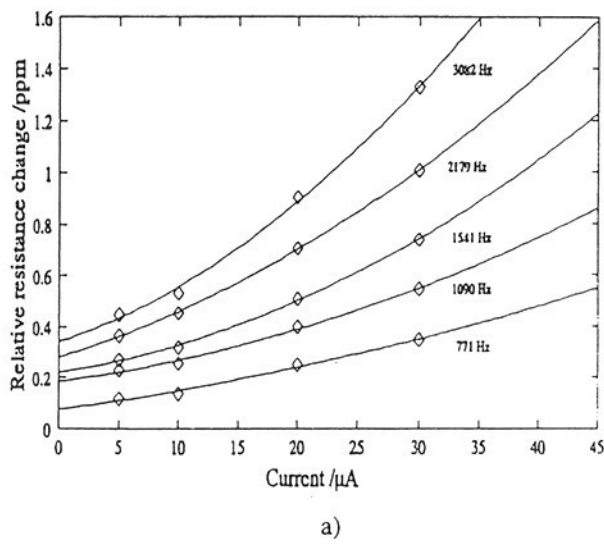


Figure 2. Current dependence of  $R_H$  ( $i=2$ ) with a) single current injection, and b) quadruple current injection.

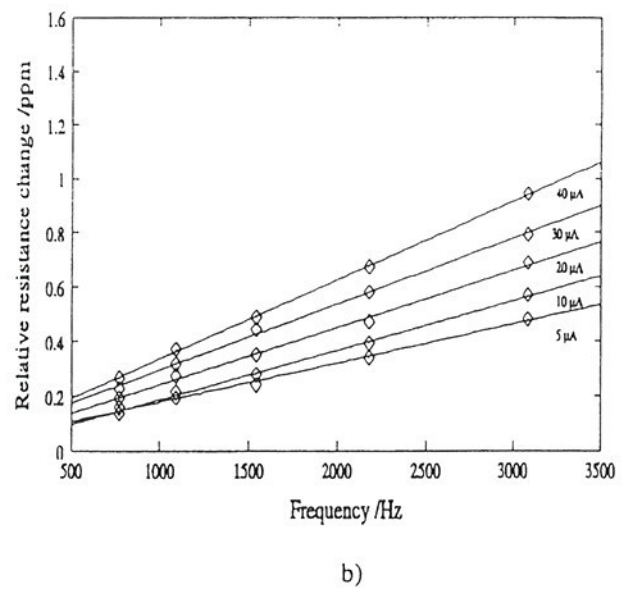
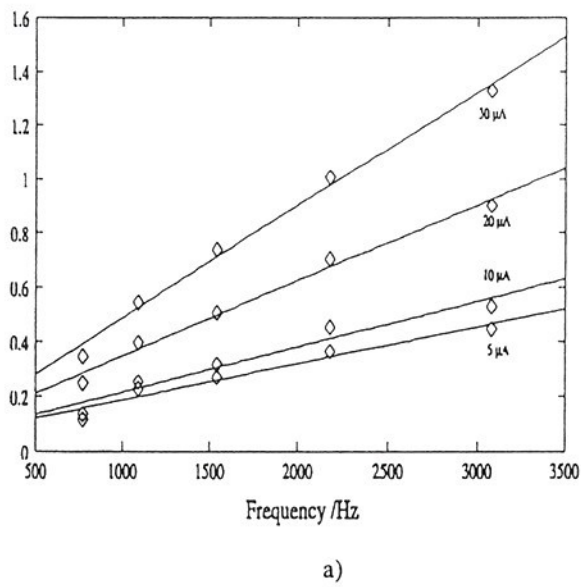


Figure 3. Frequency dependence of  $R_H$  ( $i=2$ ) with a) single current injection, and b) quadruple current injection.