

# Automation of Van der Pauw and Hall Effect Measurements

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This summer I worked in Dr. Vanessa Sih's lab on characterizing semiconductors. Dr. Sih's lab studies electron spin dynamics in semiconductors. My job was to automate the measurement of the charge carrier density in the samples. Charge carrier density is a parameter that determines many electrical properties of semiconductors. I corrected errors in, improved run time of, and added new functionality to previously written LabVIEW code.

## Background

Due to the quantization of energy levels, the conduction and valence bands in materials can either be overlapped or separated. Materials with overlapping bands are referred to as metals, as they allow electrons to freely flow in the conduction band. Insulators have greatly separated bands, prohibiting electrons from leaving the valence bands. Semiconductors are a class of materials between metals and insulators where the gap is small enough that a significant number of electrons can gain the energy required to leave the valence band. This either results in a surplus of electrons in the conduction band or a surplus of holes (the absence of an electron) in the valence band. The number of excess charge carriers per unit volume is referred to as the charge carrier density.

The charge carrier density of a semiconductor is easily able to be controlled during fabrication. It is possible to introduce impurities into the semiconductor that either add electrons to the conduction band (donors) or remove electrons from the valence band (acceptors). The concentration of these impurities is typically equal to the charge carrier concentration. Materials doped with donors have electrons as the primary charge carrier and are called n-type due to the negative charge of the electron. Acceptor doped materials have holes as the primary charge carrier and are called p-type as the absence of an electron results in a localized positive charge.

## The Hall Effect

The Hall Effect was discovered in 1879 by Edwin H. Hall and proved that electrons are the primary charge carrier in a current, despite conventional current describing the movement of positive charge.<sup>1</sup> Charge carriers moving through a magnetic field are subject to the Lorentz force. By applying a magnetic field orthogonal to a current passing through a material, the charge carriers are deflected to the sides of the material, creating a potential difference that is mutually orthogonal with the magnetic field and current. The potential directly across the material is the Hall voltage from which the charge carrier concentration can be calculated using known values. The Hall voltage is also polarity dependent, allowing for one to determine whether the primary charge carriers are holes or electrons for a sample whose type is unknown.

## The Van der Pauw Method

Another useful parameter, although it is not the primary focus of my work, is the mobility of the charge carriers. The mobility is a measurement of how fast charges in a material will move in the presence of an electric field. The mobility can be calculated if the carrier concentration and resistivity of the material are known. The Van der Pauw method is a four-probe resistivity measurement that allows materials of arbitrary shapes. This is useful in that our samples are in a shape similar to a plus sign. There are three major provisions required for this method to work (1) the sample is homogenous and uniform in thickness, (2) the contacts are small and on the edge of the sample, and (3) there no holes in the geometry of the sample (not to be confused with the charge carrier).<sup>2</sup>

## My Project

I worked on interfacing with the voltmeters, ammeters, voltages sources, and switchboard required to make the Van der Pauw and Hall Effect measurements automatic. I spent the first two weeks cleaning up and commenting old LabVIEW code in order to make it understandable. During this process I found a number of minor errors, such as the incorrect value for the charge of an electron, that likely accounted for the program's previous tendency to report inaccurate values. I also removed many unnecessary steps and timing delays in order to improve the run time of the program. The program now takes a little over half of a minute to perform a measurement that takes a couple minutes by hand. The program also revealed that one of the sourcemeters was malfunctioning and I was responsible for working the Tektronix to complete the repair process.

The next portion of my project was to introduce additional functions to the program. The first feature I added was the ability to repeatedly perform the measurements in a single run of the program, with the option of changing the magnitude of the voltage used to drive the current. From this it became clear that there was no strong dependence of the carrier density on the magnitude of the applied current, as was expected. The second feature I implemented was the introduction of lock-in techniques but due to time constraints I was unable to complete the debugging process and get the program to work.

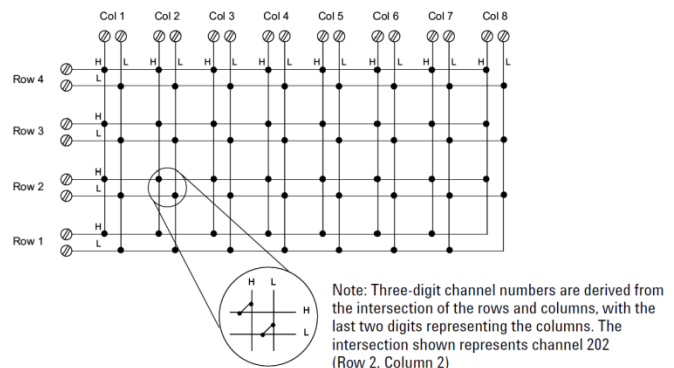


Fig. 1: The switchboard matrix. The circuit diagram (above)<sup>3</sup> and the breakout board (below).



*First number is High of Col (C#H) *Second is Low connection (C#L)		Rows: Connections to Instruments Columns: Connections to 10-pin from Sample	Resistivity (Ohm-cm) 0	Mobility(cm <sup>2</sup> /Vs) 0	
Col 1: 24	Col 4: 12	**Keithley 6482 must be connected to Row 1 - R1H and R1L	Carrier Concentration(cm <sup>-3</sup> ) 0	Input Voltage(V) 0	
Col 2: 13	Col 5: 23	**Keithley 2400 must be connected to Row 2 - R2H and R2L	Mean of Rho (Ohm-cm) 0.000000E+0	Std. Dev. of Rho (Ohm-cm) 0.000000E+0	
Col 3: 34	Col 6: 14		Mean of mu (cm <sup>2</sup> /Vs) 0.000000E+0	Std. Dev. of mu (cm <sup>2</sup> /Vs) 0.000000E+0	
K6482 Channel		Number of Steps	Thickness(cm)	Magnetic Field (T)	V_initial (V)
Ch 1		0	5E-5	0.3	0
Keithley 6482		Keithley 2400	V_final (V)		0
Keysight U2751A		Setpoint (K)	300K: V~0.4V 10K: V~12mV		
save file parameters		Extra Notes			
data directory	sub directory				
X:\data	test				
File Subtitle					
error in		error out			
status	code	status	code		
✓	0	✓	0		
source		source			

Fig 2. The completed interface of the main program.

## References

- [1] R. W. Thurber, Hall Effect Measurements Introduction, WWW Document, ([http://www.nist.gov/pml/div683/hall\\_intro.cfm](http://www.nist.gov/pml/div683/hall_intro.cfm)).
- [2] Van der Pauw, L.J. (1958). "A method of measuring the resistivity and Hall coefficient on lamellae of arbitrary shape". Philips Research Reports 13: 1–9.
- [3] Keysight U2751A USB Modular Switch Matrix- User's and Service Guide (2014)