18 Circuit Theory for the Electrically Declined

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18.1 The Soldering Iron and the Spin Electronician

Such is the sophistication of many contemporary University Physics Courses that their followers are at ease with the finer details of the Dirac equation and have no difficulty in thinking in a many-dimensioned Hilbert-space: however they are often less confident when faced with knowing which end of a soldering iron gets hot. Spin Electronics is above all a practical science which ultimately promises to implement a new and revolutionary technology in a form which will ultimately impact everyday existence. Card-carrying theoretical physicists doubtless have their part to play in this new and exciting field, but for the rapid and successful development of this science, the importance of practical knowledge and experimental dexterity is paramount. Those who would claim proficiency as Spin Electronicians must, above all, be capable of the simple, basic skills with which every TV repair engineer is acquainted. To those devotees of Spin Electronics whose degree courses have left you electrically deprived, this chapter is dedicated to you. Evidently, in the few pages available, only the surface of this topic may be scratched, but at least the basics can be laid, topics of major confusion like transistors and transformers can be treated and signposts pointed to further study.

18.2 Ohm’s Law and Simple DC Circuits

Ohm’s Law underpins all of electrical and electronic theory. On reflection it seems bizarre that, in a physical world where non-linearity seems to be the rule, not the exception, it is experimentally so easy to find systems which exhibit such a perfect linear relationship between current and voltage. The reason is simple. Components such as resistors are homogeneous: voltages applied to them are dropped uniformly over the entire structure and the local electric fields are small. Even if phenomena exist which invoke higher powers of electric field than the linear response, the smallness of the field implies that these non-linear effects are unobserved since higher power terms are vanishingly small. When inhomogeneous electrical devices are made, such as junction diodes where most of the voltage is dropped on a small region of the device, the non-linearities return with a vengeance – which is why we can use diodes for rectification purposes.

Ohm’s Law, for all its simplicity, is a very capable tool. We will show later in this chapter that even quite complicated electronic circuits may be analyzed accurately using little more than Ohm’s Law and a bit of common sense.
18.2.1 The Potential Divider

Ohm’s Law affords us the tools to analyze a simple but useful circuit – the potential divider. Two resistors of values $R$ and $R^*$ are connected as in Fig. 18.1. The question is what voltage appears at the output? The resistors pass current $I = V_{in}/(R + R^*)$. This current generates a voltage across $R^*$ given by $V_{out} = R^*I = V_{in}R^*/(R + R^*)$, so the input voltage has been divided in the ratio $V_{out}/V_{in} = R^*/(R + R^*)$.

This circuit element is widely used in electronics wherever it is necessary to define a potential, for example for biasing devices. As discussed below, it has the disadvantage that its source impedance is high, i.e. the voltage drops if significant current is drawn from it.

![Fig. 18.1. Schematic diagram of a potential divider.](image)

18.2.2 Voltage Sources

An ideal voltage source is one which maintains a given voltage between its two output terminal irrespective of the current which is drawn from it. For real voltage sources such as batteries, the voltage drops when a load current is drawn and this is modelled by treating such a source as an ideal voltage source in series with a source resistance, $R_s$, as shown in Fig. 18.2.

Figures 18.3 & 18.4 show examples of real voltage sources:

Fig. 18.3 is a 12 volt car battery with a 0.01 \(\Omega\) source impedance. When a starter current of 60 Amps is drawn, the battery output voltage thus drops to 11.4 Volts.

Figure 18.4 is a potential divider consisting of a 9 Volt battery and divider resistors of value 6 k\(\Omega\) and 3 k\(\Omega\) respectively. The open-circuit (i.e. no-load) output voltage is 6 Volts. Having read the section below on Norton–Thevenin transforms, the reader will be able to deduce that the source impedance is 3 k\(\Omega\).