less variation in transmitter power one sees when phasing causes the two mismatches to be on opposite sides of the reference impedance.

Further, simple antennas are matched to a rather narrow range of frequencies, and it is a significant aspect of antenna design to extend the impedance match across a broad range of frequencies. One common form is a bi-conical antenna, often found for use in testing the radiated emissions from electrical components. On the other end of the spectrum is the desire for a narrow band antenna to have a very low return loss over a small frequency range to minimize reflected power back to the high power transmitter.

Antenna gain, or antenna gain pattern, describes the efficiency of an antenna in radiating into the desired direction (or beam) relative to a theoretical omnidirectional antenna, often referred to as an isotropic radiator. This figure of merit is known as dBi or decibels relative to an isotropic antenna.

Antenna pattern measurements are the measurement of the antenna radiation pattern, typically plotted as a contour of constant dBi on a polar plot, where the polar angle is relative to the main beam or “bore-sight” of the antenna. Antenna pattern measurements can range from very simple gain measurements on an antenna on a turntable to near-field probing of complex multi-element phased array structure. While these complex measurements are beyond the scope of this book, many aspects of antenna return loss measurement, including techniques to improve these measurements, will be covered.

1.13 PCB Components

While a very wide ranging topic, the measurement of passive PCB components is focused on the measurement of surface mount technology (SMT) resistors, SMT capacitors and SMT inductors. These components comprise the majority of passive elements used in radio circuits, and also create some of the most undesirable side effects in circuits due to the nature of their parasitic elements. Below is a review of the models of these elements; during measurement the difficulty is in understanding the relative importance of aspects of these models and extracting the values of the model elements.

1.13.1 SMT Resistors

Resistors are perhaps the simplest of electronic elements to consider, and Ohm’s law is often the first lesson of an electronic text

$$R = \frac{V}{I} \tag{1.91}$$

However, the model of an RF resistor becomes much more complex as frequencies rise and distributed effects and parasitic elements become dominant. In this discussion the focus will be on surface mount PCB components, because they are used almost exclusively today in modern circuits. Thin film or thick film hybrid resistors have similar effects, and although the parasitic and distributed effects tend to hold off until higher frequencies, much of this discussion applies to them as well.

A good model for a resistor consists of a resistive value in series with an inductance, both shunted by a capacitance. This is a reasonable model for an SMT resistor in isolation, but the

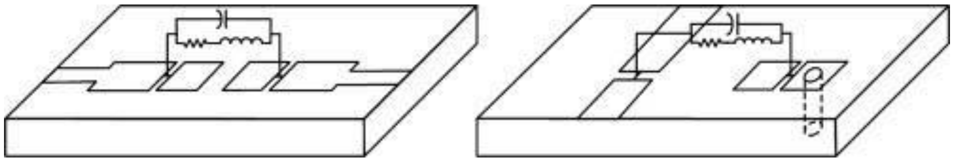

Figure 1.34 Models for a series resistor and a shunt resistor.

values and effects of the model are modified greatly by the mounting scheme of the component. For example, if it is mounted in series with a microstrip transmission line, and the impedance is such that the resistor is much narrower than the transmission line, then this model works well for predicting circuit behavior. On the other hand, if it is mounted on a very narrow line, then the contact pads will provide additional shunt resistance to ground, and the model must include some element to account for this effect. At lower frequencies, some shunt capacitance will do well, but at higher frequencies a length of low impedance transmission line might be a better choice.

A resistor used in shunt mode to ground can have an entirely different model, when it comes to parasitic effects, from that of a series resistance. While the RF value of the resistive element may stay almost the same as the series value (close to the DC value) the effective inductance can be substantially higher as the inductance of the ground via adds to that of the resistor in a microstrip configuration. A larger pad on the ground via, surprisingly, can add even more effective inductance as it resonates with the inductance of the via to increase the apparent inductance of the pair. Meanwhile the shunt capacitance of the resistor may be absorbed in the transmission line width. Figure 1.34 shows a model for a resistor mounted in the series and shunt configuration. Measurement examples to illustrate extracting these values will be shown in Chapter 9.

In many instances, one of the two parasitic elements will dominate the model for first-order high frequency effects. In fact, one can use some simple calculations to estimate a rough order of magnitude for these parasitic elements. Take for example an 0603 resistor, which has dimensions of approximately 0.8 mm width, 0.4 mm height (considering some excess plating, and some edge effect), and 1.6 mm length. If one considers the contact of the resistor wrapped around the body, one might reasonably divide the effective length by 3, to about 0.25 mm. Remembering that SMT resistors are often constructed on ceramic substrates, with a relative dielectric constant of about 10, then the capacitance can be computed as

$$C = \varepsilon_r \varepsilon_0 \frac{W \cdot H}{L} = 10 \cdot 8.85x10^{-15}(F/mm) \cdot \frac{.8 \cdot 0.4}{.25} = 0.11 \text{ pF} \quad (1.92)$$

The actual value may be substantially greater or less depending upon the exact attributes of the electrodes, but this gives a starting estimate. For inductance one can look to the formula of a transmission line, and assuming that the resistor is mounted on a narrow line, such that its impedance is high, the inductance is from half the length, computed as

$$l = \mu_0 \cdot L = 4\pi 10^{-10}(H/mm) \cdot 0.8 \text{ mm} = 0.8 \text{ nH} \quad (1.93)$$

Thus from the model one can compute the values of resistance for which the inductance or capacitive term dominates, at some frequency. For example, at 3 GHz, the inductance has a value of about 15 ohms reactance in series with the resistive element; the capacitance has a

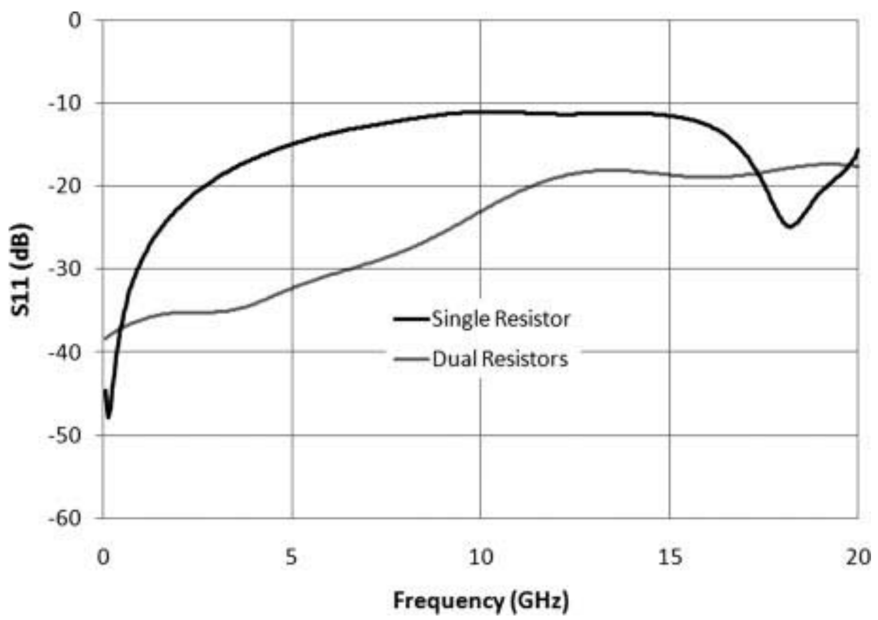

Figure 1.35 Input match of a single SMT resistor, and two in parallel.

value of about 1500 ohms reactive in shunt. At 50 ohms, the inductance value dominates, at 300 ohms; the capacitive value is the dominant parasitic effect. For low values of resistance and high frequency, the inductance becomes dominant and the series impedance is larger than expected, causing the loss through the resistance to be larger than expected due to this effect. At high values of resistance, the parasitic capacitance reduces the series impedance and the expected loss through the resistor is less than expected. The values change with the physical size of the component, thus crossover points differ in resistance and frequency, but with similar effects. This can be used to advantage as there exists a crossover point where the inductive and capacitive effects cancel somewhat, and the resistor behaves ideally to a higher frequency than for values below or above. Using this value of resistance in series or parallel arrangements can provide a range of resistances that avoid parasitic effects until higher frequencies. For the values above, a 50 ohm resistor terminated to ground will have about −18 dB return loss at 3 GHz; however, two 100 ohm resistors, terminated to ground will have about −36 dB return loss, thus providing a better RF resistance of 50 ohms than a single resistor. Thus, characterization of the parasitic effects, and proper compensation, can allow the use of SMT parts up to much higher than expected frequencies [16]. Figure 1.35 shows the effective impedance of a single 50 ohm SMT resistor and two 100 ohm SMT resistors in parallel, when used as a 50 ohm load. This effect also occurs for SMT inductors and capacitors.

1.13.2 SMT Capacitors

SMT capacitors have a different model from resistors. To a first order, their parasitic effects tend to be all in series, as shown in the model of Figure 1.36. The series inductance is primarily due to the package size, and is similar to that of a resistor. The series resistance is due to manufacturing characteristics of the capacitor, and thus cannot be easily estimated. However, its effect is typically very small in most wideband applications, where the capacitor is used as a series DC blocking capacitor or a shunt RF bypass capacitor. This is because the series