

## RF engineering basic concepts: S-parameters

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### Abstract

The concept of describing RF circuits in terms of waves is discussed and the S-matrix and related matrices are defined. The signal flow graph (SFG) is introduced as a graphical means to visualize how waves propagate in an RF network. The properties of the most relevant passive RF devices (hybrids, couplers, non-reciprocal elements, etc.) are delineated and the corresponding S-parameters are given. For microwave integrated circuits (MICs) planar transmission lines such as the microstrip line have become very important.

## 1 S-parameters

The abbreviation S has been derived from the word *scattering*. For high frequencies, it is convenient to describe a given network in terms of waves rather than voltages or currents. This permits an easier definition of reference planes. For practical reasons, the description in terms of in- and outgoing waves has been introduced. Now, a 4-pole network becomes a 2-port and a  $2n$ -pole becomes an  $n$ -port. In the case of an odd pole number (e.g., 3-pole), a common reference point may be chosen, attributing one pole equally to two ports. Then a 3-pole is converted into a  $(3+1)$  pole corresponding to a 2-port. As a general conversion rule, for an odd pole number one more pole is added.

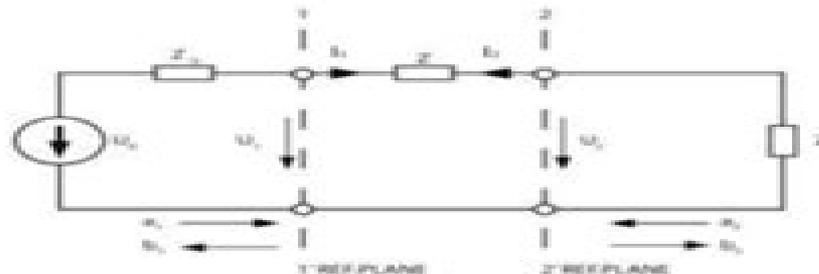


Fig. 1: Example for a 2-port network: a series impedance  $Z$

Let us start by considering a simple 2-port network consisting of a single impedance  $Z$  connected in series (Fig. 1). The generator and load impedances are  $Z_0$  and  $Z_L$ , respectively. If  $Z = 0$  and  $Z_L = Z_0$  (for real  $Z_0$ ) we have a matched load, i.e., maximum available power goes into the load and  $U_1 = U_2 = U_G/2$ . Note that all the voltages and currents are peak values. The lines connecting the different elements are supposed to have zero electrical length. Connections with a finite electrical length are drawn as double lines or as heavy lines. Now we would like to relate  $U_0$ ,  $U_1$  and  $U_2$  to  $a$  and  $b$ .

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