

# 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.

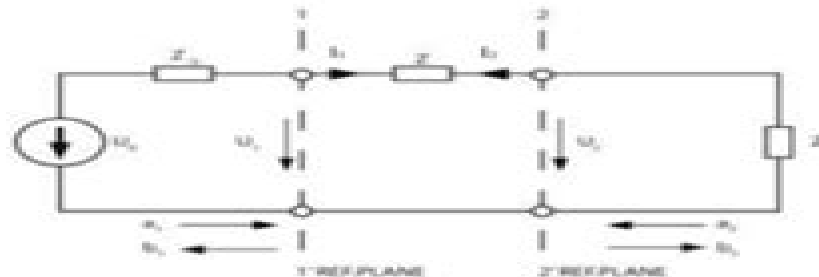


Fig. 1: Example for a 2-port network: a series impedance  $Z$

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  $U_a$ ,  $U_1$  and  $U_2$  to  $a$  and  $b$ .

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**Ankan Bhattacharya, Bappaditya  
Roy, Arnab De, Ujjal Chakraborty, Anup  
Kumar Bhattacharjee**

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*Advances in Microwave Engineering* Ankan Bhattacharya, Bappaditya Roy, Arnab De, Ujjal Chakraborty, Anup Kumar Bhattacharjee, 2023-11-21 This text showcases recent advancements in the field of microwave engineering starting from the use of innovative materials to the latest microwave applications. It also highlights safety guidelines for exposure to microwave and radio frequency energy. The book provides information on measuring circuit parameters and dielectric parameters. Explains microwave antennas, microwave communication, microwave propagation, microwave devices and circuits in detail. Covers microwave measurement techniques, radiation hazards, space communication and safety measures. Focuses on advanced computing technologies, wireless communication and fiber optics. Presents scattering matrix and microwave passive components and devices such as phase shifters and power dividers. Showcases the importance of space communication, radio astronomy, microwave material processing and advanced computing technologies. The text provides a comprehensive study of the foundations of microwave heating and its interactions with materials for various applications. It also addresses applications of microwave devices and technologies in diverse areas including computational electromagnetics, remote sensing, transmission lines, radiation hazards and safety measures. It emphasizes the impact of resonances on microwave power absorption and the effect of nonuniformity on heating rates. The text is primarily written for senior undergraduate students, graduate students and academic researchers in the fields of electrical engineering, electronics and communication engineering, computer engineering and materials science.

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