

## S-PARAMETER MEASUREMENT TECHNIQUE

The vector voltmeter measures the magnitude of a reference and test voltage and the difference in phase between the voltages. Because it can measure phase, it allows us to directly measure the S-parameters of a circuit. Unfortunately, the use of directional couplers and test cables connecting the measuring system to the vector voltmeter introduces unknown attenuation and phase shift into the measurements. These can be compensated for by making additional "calibration" measurements.

A) Reflection measurements: obtain  $S_{11}$  or  $S_{22}$

Set up the experimental arrangement shown in Figure 1. It is seen that the voltage at channel A of the vector voltmeter ( $A^D$ ) is proportional to the amplitude of the voltage wave entering the device under test (DUT) ( $a_1^D$ ). Similarly, the voltage at channel B ( $B^D$ ) is proportional to the amplitude of the voltage wave reflected from the DUT ( $b_1^D$ ). Thus, we can write

$$\begin{aligned} A^D &= K_A a_1^D \\ B^D &= K_B b_1^D \end{aligned} \quad (1)$$

where  $K_A$  and  $K_B$  are constants that depend on the connecting cables. Since  $a_2^D$  is zero because of the matched load at port 2,  $S_{11}$  is given by

$$S_{11} = \frac{b_1^D}{a_1^D} = \frac{B^D / K_B}{A^D / K_A} \quad (2)$$

To find  $K_A$  and  $K_B$  it is necessary to make a second measurement with a known DUT. This is called a "calibration" measurement. If the DUT in Figure 1 is removed and replaced by a short circuit, the voltages at channel A ( $A^S$ ) and channel B ( $B^S$ ) are given by

$$\begin{aligned} A^S &= K_A a_1^S \\ B^S &= K_B b_1^S \end{aligned} \quad (3)$$

where  $a_1^S$  is the amplitude of the voltage wave entering the short and  $b_1^S$  is the amplitude of the voltage wave reflected from the short. However, for a short circuit the ratio of these

amplitudes is -1 (reflection coefficient of a short). Thus

$$\frac{b_1^S}{a_1^S} = \frac{B^S / K_B}{A^S / K_A} = -1 \quad (4)$$

Thus

$$\frac{K_B}{K_A} = - \frac{B^S}{A^S} \quad (5)$$

Finally, substituting this into (2) gives the formula for  $S_{11}$

$$S_{11} = - \frac{\left( \frac{B^D}{A^D} \right)}{\left( \frac{B^S}{A^S} \right)} \quad (6)$$

Note that since the vector voltmeter displays quantities in terms of magnitude and phase, (6) can be written more conveniently as

$$S_{11} = \frac{\Gamma^D}{\Gamma^S} \angle (\phi^D - \phi^S - \pi) \quad (7)$$

where

$$\begin{aligned} \left( \frac{B^D}{A^D} \right) &= \Gamma^D \angle \phi^D \\ \left( \frac{B^S}{A^S} \right) &= \Gamma^S \angle \phi^S \end{aligned} \quad (8)$$

**NOTE:** The HP 8508A vector voltmeter can perform the calibration calculation (6) automatically (manual sheets available in the lab).

B) Transmission measurements: obtain  $S_{12}$  or  $S_{21}$ .

Set up the arrangement shown in Figure 2 with the DUT connected directly between two directional couplers. In this case the voltage at channel A of the vector voltmeter is proportional to the amplitude of the voltage wave incident on the DUT while the voltage at channel B of the vector voltmeter is proportional to the amplitude of the voltage wave transmitted through the DUT. Thus

$$\begin{aligned} A^D &= K_A a_1^D \\ B^D &= K_B b_2^D \end{aligned} \quad (9)$$

$S_{21}$  is then

$$S_{21} = \frac{b_2^D}{a_1^D} = \frac{B^D / K_B}{A^D / K_A} \quad (10)$$

To find the constants a calibration measurement must be made. Remove the DUT and connect the two directional couplers directly together. The known DUT in this case is just a zero-length guide with a transmission coefficient of unity. The measured voltages are thus

$$\begin{aligned} A^E &= K_A a_1^E \\ B^E &= K_B b_2^E \end{aligned} \quad (11)$$

where

$$\frac{b_2^E}{a_1^E} = \frac{B^E / K_B}{A^E / K_A} = 1 \quad (12)$$

Thus

$$\frac{K_B}{K_A} = \frac{B^E}{A^E} \quad (13)$$

Substituting this into (10) then gives the formula for  $S_{21}$

$$S_{21} = \frac{\left(\frac{B^D}{A^D}\right)}{\left(\frac{B^E}{A^E}\right)} \quad (14)$$

or

$$S_{21} = \frac{T^D}{T^E} \angle(\theta^D - \theta^E) \quad (15)$$

where

$$\begin{aligned} \left(\frac{B^D}{A^D}\right) &= T^D \angle \theta^D \\ \left(\frac{B^E}{A^E}\right) &= T^E \angle \theta^E \end{aligned} \quad (16)$$

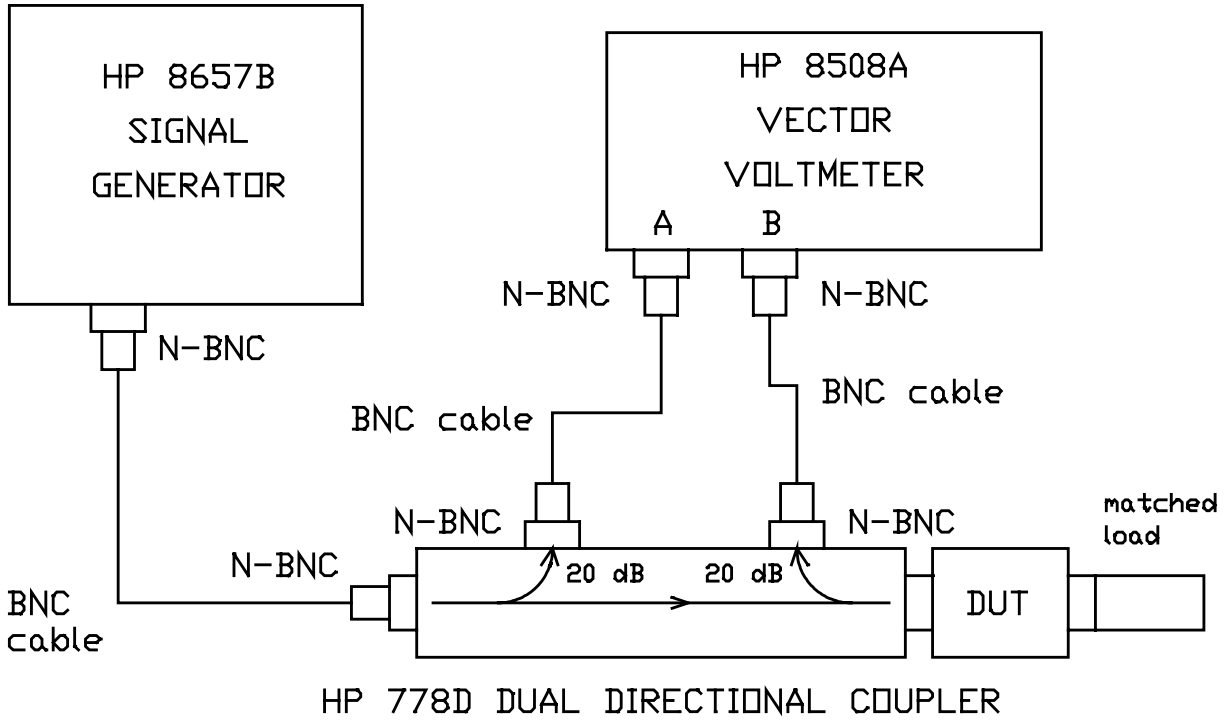


Figure 1. Experimental setup for measuring  $S_{11}$ .

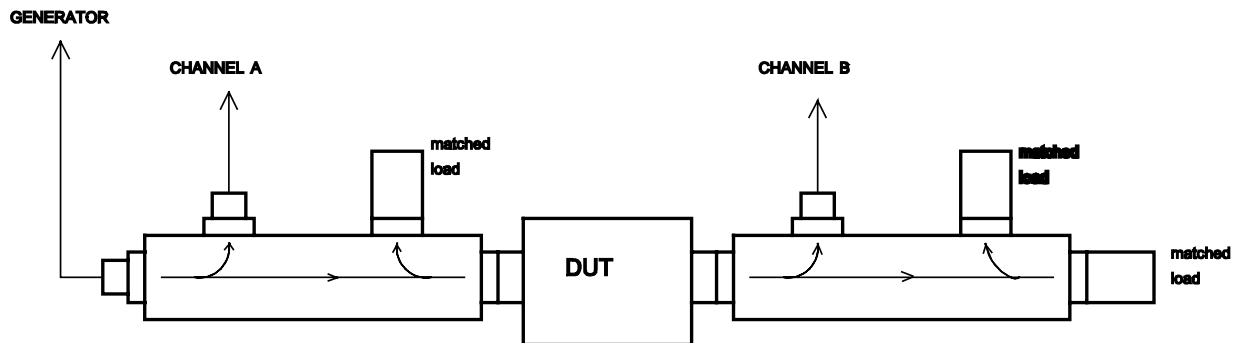


Figure 2. Setup for measuring  $S_{21}$ .