Aim of the Experiment: Concept of Generalized N-port scattering parameters, and formulation of these parameters into 2-port reflection and transmission coefficients.

Requirement:

You have to install a LabVIEW Run time Engine on your computer to run the exe file in order to perform the experiment. The Run Time Engine can be downloaded free of cost from the following link: http://joule.ni.com/nidu/cds/view/p/id/1101/lang/en

Knowledge Required for the Experiment:

- Z-matrix and Y-matrix for two port network
- Scattering matrix

Objective of Experiment:

This experiment is designed to explain the concept of scattering parameter of one-port, two-port, three-port and N-port network.

Theory:

**Scattering Matrix:**

Like the impedance or admittance matrix for an N-port network, the scattering matrix provides a complete description of the network as seen at its N ports. While the impedance and admittance matrices relate the total voltages and currents at the ports, the scattering matrix relates the voltage waves incident on the ports to those reflected from the ports. For some components and circuits, the scattering parameters can be calculated using network analysis techniques. Otherwise, the scattering parameters can be measured directly with a vector network analyzer.
Consider the N-port network shown in figure where $V_n^+$ is the amplitude of the voltage wave incident on port n and $V_n^-$ is the amplitude of the voltage wave reflected from port n. The scattering matrix or $[S]$ matrix, is defined in relation to these incident and reflected voltage waves as

$$
\begin{bmatrix}
    V_1^- \\
    \vdots \\
    V_N^-
\end{bmatrix} =
\begin{bmatrix}
    S_{11} & \cdots & S_{1N} \\
    \vdots & \ddots & \vdots \\
    S_{N1} & \cdots & S_{NN}
\end{bmatrix}
\begin{bmatrix}
    V_1^+ \\
    \vdots \\
    V_N^+
\end{bmatrix}
$$

Or

$$[V^-] = [S][V^+]$$

A specific element of the $S$ matrix can be determined as

$$S_{ij} = \frac{V_i^-}{V_j^+} \bigg|_{V_k^+ = 0 \ for \ k \neq j}$$

In words the equation says that $S_{ij}$ is found by driving port $j$ with an incident wave of voltage $V_j^+$, and measuring the reflected wave amplitude, $V_i$ coming out of port $i$. The incident waves on all ports except the $j^{th}$ port are set to zero, which means that all ports should be terminated in matched loads to avoid reflections. Thus, $S_{ii}$ is the reflection coefficient seen looking into port $i$ when all other ports are terminated in matched loads, and $S_{ij}$ is the transmission coefficient from port $j$ to port $i$ when all other ports are terminated in matched loads.

**Matched Networks:**

A matched network is one in which all of the ports are matched to the same impedance ($Z_0$). Looking at the scattering matrix, this means that the diagonal elements from top left to bottom right are all zero. If a network is matched to fifty ohms, its reflection coefficients have magnitude zero. This means we are at the center of the Smith chart, right at $Z_0$. If we look at the expression for reflection coefficient:

$$\Gamma = \frac{Z - Z_0}{Z + Z_0}$$

for $Z = Z_0$ reflection coefficient becomes zero.

**Reciprocal Networks:**

For a two-port network it is said to be reciprocal if the voltage appearing at port 2 due to a current applied at port 1 is the same as the voltage appearing at port 1 when the same current is applied to port 2. Exchanging voltage and current results
in an equivalent definition of reciprocity. In general, a network will be reciprocal if it consists entirely of linear passive components i.e. resistors, capacitors and inductors. In general, it will not be reciprocal if it contains active components such as generators.

**Symmetrical Networks:**

A network is symmetrical if its input impedance is equal to its output impedance. Most often, but not necessarily, symmetrical networks are also physically symmetrical. Sometimes also antimetrical networks are of interest. These are networks where the input and output impedances are the duals of each other.

**Lossless Networks:**

A lossless network is one which does not dissipate any power. The sum of the incident powers at all ports is equal to the sum of the reflected powers at all ports. This implies that the S-parameter matrix is unitary, i.e. \([S]^H[S] = [I]\), where \([S]^H\) is the conjugate transpose of \([S]\) and \([I]\) is the identity matrix.

Within the S-parameter matrix of a lossless network, the sum of the squares of the magnitudes of any row must total unity. If any of the rows' sum-of-the-squares is less than one, there is a lossy element within the network, or something is radiating.

**Note:** Sum of the squares of the magnitudes of any row will never be greater than unity.

**Lossy Networks:**

A lossy passive network is one in which the sum of the incident powers at all ports is greater than the sum of the reflected powers at all ports. It therefore dissipates power.

As we know that the impedance and admittance matrices are symmetric for reciprocal networks, and purely imaginary for lossless networks. Similarly, the scattering matrix for a reciprocal network is symmetric, and that the S matrix for a lossless network is unitary.

**One-port Network:**
One-port network can be considered as a transmission line with one end either open-circuited, short-circuited, terminated with matched load or terminated with an arbitrary load.

**Procedure:**

**Step 1:** Enter the characteristic impedance of the transmission line and the operating frequency in Giga Hertz.

**Step 2:** Select the load impedance. For the arbitrary impedance when selected there appears an input terminal, enter the impedance.

**Step 3:** See the output.

**Step 4:** To go back to the previous menu click STOP. Clicking the STOP button will close the terminal.

**Two-port Network:**

A two-port network is an electrical circuit or device with two pairs of terminals connected together internally by an electrical network. Two terminals constitute a port if they satisfy the essential requirement known as the port condition (the same current must enter and leave a port).

A two-port network makes possible the isolation of either a complete circuit or part of it and replacing it by its characteristic parameters. Once this is done, the isolated part of the circuit becomes a “black box” with a set of distinctive properties, enabling us to abstract away its specific physical buildup, thus simplifying analysis. Any linear circuit with four terminals can be transformed into a two-port network provided that it does not contain an independent source and satisfies the port conditions.

---

**Procedure:**

**Step 1:** For the evaluation of scattering parameter of two-port network select the “two-port network” option from the main menu of the exe file. Clicking the two-port network will open a new window.

**Step 2:** Select any of the given S-parameter option. This will show you the port matched and the selected parameter in terms of incident and reflected voltage.
**Step 3:** For the two-port network some examples are given, click on any example to evaluate S-parameter for the network. Or click stop to return to the previous menu.

*(If an example is selected)*

The selected network is enclosed in the “black box” as described above. The incident and reflected waves are shown accordingly.

**Step 4:** Enter the value of Z₁, Z₂, Z₃ and characteristic impedance Z₀.

**Step 5:** Selecting the desired S-parameter will show the corresponding port matched and will give the formula to evaluate the parameter and finally the result is displayed in terms of magnitude and phase of S-parameter.

Since we know that S-parameters are the ratio of reflected and incident voltage waves therefore, they are unit-less quantity.

**Three-port Network:**

Power dividers and directional couplers are some 3-port passive microwave components used for power division or power combining. A 3-port network will have 9 elements in its scattering matrix written as,

\[
\begin{bmatrix}
S_{11} & S_{12} & S_{13} \\
S_{21} & S_{22} & S_{23} \\
S_{31} & S_{32} & S_{33}
\end{bmatrix}
\]

Three port network is shown in the figure, with incident and reflected voltage wave
An interesting property of 3-port networks, however, is that they cannot be simultaneously reciprocal, loss-less, and perfectly matched.

**n-port Network:**

References: