S-Parameters of Microwave Monolithic Integrated Circuit (MMIC) Amplifier

I. OBJECTIVE

Investigate by measuring the *S*-parameters of Microwave Monolithic Integrated Circuit (MMIC) amplifiers. Measure all four *S*-parameters

II. INTRODUCTION (From

The objective of microwave circuit analysis is to move from the requirement to solve for all the fields and waves of a structure to an equivalent circuit that is amenable to all the tools of the circuit analysis toolbox. However, the tools that are appropriate for lumped circuits must be extended to apply to distributed networks.

A matrix that is of great use in microwave network problems is the "scattering" matrix, so-called by analogy to the scattering or reflection of waves by a free-space reflector. As introduced in the prior notes, S-parameters have become the preferred description of microwave n-ports for the following reasons:

> Voltage and current are difficult to define and measure in distributed circuits
> The measurement of power in incident and reflected waves is a natural technique for microwave transmission lines. Voltage and current may not be well defined, or even defined at all, in some structures. The specification of voltage and current in a distributed circuit requires a specification of the exact location, and these parameters vary with location in the circuit. The determination of the individual parameters of voltage and current equation sets requires short or open circuit loads, which are sensitive to the precise location; in particular, it is not practical to mount a connector close enough to a microwave lumped device to be measuring its actual port voltages and currents. Also, many active devices cannot be operated with fully reflective terminations (short or open) of arbitrary phase, as they will oscillate, which is a large signal nonlinear condition and may even result in device failure.
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> Incident and reflected waves are the natural description for microwave structures
> The matched condition ($\Gamma = 0$) is a unique, repeatable termination. It is insensitive to the length of transmission line to the matched load, so that measurements can be made without requiring the reference planes (the port connectors) to be located directly at the device under measurement (or being described). A matched load is a natural structure that can maintain its character over a very broad frequency range.
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> S-parameters (in fact, all the parameter sets) benefit from the matrix toolbox.
> The toolbox of established matrix mathematics is directly applicable to the matrices that are the equivalent of the port equations of the parameter sets. For example, the S matrix can be inspected for lossless, reciprocal or unilateral character. If either or both of these conditions are present, many of the individual matrix elements can be determined by inspection.

Equivalence of Matrix and Equation Form

For a single port network, we have the following simple relationships from our study of Γ and Smith chart.

$b_1 = \Gamma a_1 = S_{11}a_1$ $b_1 = \Gamma a_1 = S_{11}a_1$

For a multi-port network the reflection coefficient is Γ defined as

$b_n = \Gamma_n a_n$, so $\Gamma_n = \frac{b_n}{a_n}$ where n is the port number.

Note that $\Gamma_n = S_{nn}$ only if all other ports are terminated, that is, only if all $a_m = 0$ for $m \neq n$. Otherwise it must be algebraically calculated from all the parameters.

The example of 2-port equations and their equivalent matrix is shown here to emphasize that both forms contain the same information, but the matrix form suggests the use of formal matrix algebra tools as an aid to analysis:

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \qquad \begin{aligned} b_1 &= S_{11}a_1 + S_{12}a_2 \\ b_2 &= S_{21}a_1 + S_{22}a_2 \end{aligned}$$

The following is true for any traveling wave that originates at the source:

1. A portion of the wave from a source and incident wave upon the two-port device (a_1) will be reflected (b_1) and another portion will be transmitted through the two-port device.
2. A fraction of the transmitted signal is then reflected from the load and becomes incident upon the output of the two-port device (a_2).
3. A portion of a signal (a_2) is then reflected from the output port back toward the load (b_2), while a fraction is transmitted through the two-port device back to the source.

Concluding the above, any traveling wave is made up of two components. For example, the output of the two-port device to the load consists of the portion that is reflected from the output of the two-port device (a_2) and the portion that is transmitted through the two-port device (a_1). Similarly, the total wave flowing from the input of the two-port device toward the source consists of the portion that is reflected from the input port (a_1) and the fraction of (a_2) that is transmitted through the two-port device.

These observations can be illustrated in the equation form as:

$b_1 = S_{11}a1 + S_{12}a_2$ and $b_2 = S_{21}a_1 + S_{22}a_2$

where,

S_{11} - the input reflection coefficient

S_{12} - the reverse transmission coefficient (reverse gain or loss)

S_{21} - the forward transmission coefficient (forward gain)

S_{22} - the output reflection coefficient

$S_{11} = b_1/a_1$ for $a_2 = 0$ or $Z_l = Z_o$.

This is an input reflection coefficient. S_{11} is equal to the ratio of a reflected wave and an incident wave with

Z_l=Z_o. Thus, S_{11} can be plotted on a Smith chart and the input impedance of the two-port device can be found immediately.

Similarly,

S_{22} = b_2/a_2 for $a_1 = 0$ or $Z_s = Z_o$.

This is an output reflection coefficient that can be plotted on a Smith chart and the output impedance of the two-port device can be found immediately.

The other two S parameters are found as follows:

S_{21} = b_2/a_1 for $a_2 = 0$ or Z_l=Z_o

S_{12} = b_1/a_2 for $a_1 = 0$ or $Z_s = Z_o$

Notice that in order to measure the individual S parameters, a_1 and a_2 must be set to zero. This is easily done by terminating a network (source and load) or forcing Zs and Z_l to be equal to the characteristic impedance of the measuring system, thus eliminating all reflections from the termination.

S-parameters are expressed **in Re/Im, Mag/Phase or dBMag/Phase**. Note that dB is calculated as $20\log\sqrt{(R_2 + X_2)}$ for all S-parameters.

III. PROCEDURE

A. Measure S-Parameters of MMIC Amp

Measure the S-Parameters for the MMIC Amplifiers provided at 100 MHz, 500 MHz, and 1000MHz. You may choose to plot the results using the Smith Chart output of the Network Analyzer

B. Comment On Your Results