

DESIGN NOTES

Return Loss, Reflection Coefficient and $|S_{11}|$

A recent note in *QST* magazine [1] provided a reminder to use the correct presentation of the various data formats for input match measurements. These data are often presented incorrectly regarding positive or negative values, potentially causing confusion and erroneous performance calculations.

Along with the basic information on these measurements and their usage, author Ed Wetherhold, an engineer retired from Alliant Techsystems, identified an additional reference on this subject: In 2009, Dr. Trevor S. Bird of CSIRO, Editor-in-Chief of *IEEE Transactions on Antennas & Propagation*, wrote an article for *IEEE Antennas & Propagation Magazine* on this subject [2]. In the introduction, Dr. Bird noted,

“As Editor-in-Chief of the Transactions, I have noticed over the past year or so that the occasional incorrect use of the term return loss has now grown into a flood of misuse. Perhaps over 30% of all antenna papers submitted to the Transactions in the past twelve months have used return loss incorrectly.”

The rest of this Design Note is a summary of information presented by Mr. Wetherhold and Dr. Bird, along with some additional details.

Measurement types

Return Loss (RL) — This was first used in the telephone industry to measure the “echo” on the various bidirectional circuits and lines. It is simply the logarithmic ratio of relative magnitudes of input power and reflected power:

$$RL \text{ (dB)} = 10 \log_{10} \left(\frac{P_{in}}{P_{ref}} \right)$$

Reflected power cannot exceed input power, which explains the use of the word *loss* in the original naming of this parameter. Thus $P_{ref} < P_{in}$ and *RL* is a positive number.

Reflection Coefficient (ρ)—This term may have originated with the use of slotted line microwave measurements, since the results of such standing wave measurements are easily interpreted in terms of traveling waves, resulting directly in the value of ρ .

$$\rho = \frac{E_{ref}}{E_{fwd}}$$

In this case, the quantity of interest (magnitude of the reflected wave) is compared to the initial quantity (magnitude of the forward wave). Thus, $\rho < 1$ for all cases. Later in history, when scattering matrix analy-

sis became popular, ρ became one element of the matrix S_{11} .

Causes of confusion

When reflection coefficient is expressed in terms of a dB ratio instead of a numerical ratio, it is always a negative number since $\rho < 1$. Now, with both *RL* and ρ in dB, we can note they are the same numbers, but with opposite signs. As a result, it is quite easy to interchange references to either term. This leads to the common error of presenting *RL* using negative numbers, typically in a plot of *RL* versus frequency.

Complicating the issue is the continuation of these errors in RF/microwave instrumentation. A review of instruction manuals for current production instruments revealed several cases. For example, in a new portable instrument with scalar network analysis capabilities, an application note stated that the unit measures, “ S_{11} , which is return loss.” The data is displayed as negative numbers, appropriate for S_{11} but incorrect for *RL*.

Another manufacturer has two instruments with similar capabilities, one for lab use and the other for field service. The field service model displays reflected power data as return loss and VSWR, with correct labeling of the plots. The lab unit displays data as *S*-parameters, but the instruction manual includes references to return loss—even when the example display screen clearly shows S_{11} and is labeled in negative numbers.

As you might expect, product specifications and technical papers include this common error as well.

In practice, few people will misunderstand the meaning of an individual graph or table of data with the incorrect sign. After all, the magnitude is correct and we know that reflected power will always be less than forward power. However, the data is still wrong and greater precision is needed in the way it is presented. For example, if used in cascaded performance computations, the data would yield incorrect results.

Mr. Wetherhold’s and Dr. Bird’s concerns are valid, requiring reminders like their articles (and this column) to be presented from time-to-time. We believe there has been some progress raising awareness of these errors, but incorrect usage continues.

References

1. Ed Wetherhold, “Return Loss Definition,” in the Technical Correspondence column of *QST*, September 2010.
2. ieeeps.org/aps_trans/docs/ReturnLossAPMag_09.pdf