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Definition and Misuse of Return Loss

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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 reason for this is uncertain. To remind everyone of the correct terminology, I review the definition of return loss, briefly outline the history of the term and give some examples of current misuse.

Return loss is a measure of the effectiveness of power delivery from a transmission line to a load such as an antenna. If the power incident on the antenna-under-test (AUT) is $\mathrm{P_{in}}$ and the power reflected back to the source is $\mathrm{P_{ref}}$, the degree of mismatch between the incident and reflected power in the travelling waves is given by the ratio $\mathrm{P_{in}/P_{ref}}$. The higher this power ratio is, the better the load and line are matched. Expressed in dB, return loss is defined

$$\mathrm{RL} = 10\log_{10}\left(\frac{\mathrm{P_{in}}}{\mathrm{P_{ref}}}\right)\ \mathrm{dB} \qquad (1)$$

which is a *positive* quantity if $\mathrm{P_{ref}} < \mathrm{P_{in}}$. Stated another way, RL is the difference in dB between the power sent towards the AUT and the power reflected. It is a positive non-dissipative term representing the reduction in amplitude of the reflected wave in comparison with the incident one. This is the situation for a passive AUT. A negative return loss is possible with active devices [3, p. 633f].

Expressing the power in terms of voltage (or equivalently as field strength) in a transmission line or waveguide (assuming a passive AUT), then (1) becomes

$$\mathrm{RL} = 10\log_{10}\left|\frac{1}{\rho^2}\right| \ \mathrm{dB} \tag{2}$$

$$= -20\log_{10}|\rho| \ \mathrm{dB} \tag{3}$$

where ρ is the complex reflection coefficient at the input of the AUT. That is, return loss is the negative of the reflection coefficient expressed in decibels. In terms of the voltage-standing-wave –ratio (VSWR) this is

$$\mathrm{RL} = 20\log_{10}\left|\frac{\mathrm{VSWR}+1}{\mathrm{VSWR}-1}\right| \ \mathrm{dB}. \tag{4}$$

$$= (40\log_{10} \mathrm{e}) \ \mathrm{artanh}\left|\frac{1}{\mathrm{VSWR}}\right| \ \mathrm{dB} \tag{5}$$

To reinforce the above description, I quote verbatim from the definition of return loss in [1]. There are two parts; both are applicable to antennas, cables or waveguides. Return loss:

“(1) (data transmission) (A) At a discontinuity in a transmission system the difference between the power incident upon the discontinuity. (B) The ratio in decibels of the power incident upon the discontinuity to the power reflected from the discontinuity. Note: This ratio is also the square of the reciprocal to the magnitude of the reflection coefficient. (C) More broadly, the return loss is a measure of the dissimilarity between two impedances, being equal to the number of decibels that corresponds to the scalar value of the reciprocal of the reflection coefficient, and hence being expressed by the following formula:

$$20\log_{10}\left|\frac{Z_1+Z_2}{Z_1-Z_2}\right| \ \textit{decibel}$$

where Z_1 *and* Z_2 *= the two impedances.*

(2) (or gain) (waveguide). The ratio of incident to reflected power at a reference plane of a network”. [1]

This definition accords with current usage of return loss in modern day text books (eg. [2], [3, p. 78]). Return loss is a convenient way of characterizing mismatch especially when the reflection is small.

The origin of the definition of return loss is somewhat hazy although its use in microwaves and antennas appears related to the adoption of the Smith chart. The original paper on the circular transmission line chart, now universally known as the Smith chart, was first published by P.H. Smith of Bell Telephone Laboratories in 1939 [4]. This chart was continually improved through to the late 1960s as described in [4]. It was not until 1949 that the chart first had nomographs of return loss and reflection coefficient at the foot of the chart that are shown today. In the 1940s a similar quantity, a power ratio in decibels[1] was used, which was related to the logarithm of the VSWR [6]. A few papers on microwaves in the 1950s by Bell Labs. staff used return loss (eg. [7]). However, most relevant textbooks prior to 1960 did not mention it.

Considerably earlier, workers in transmission systems (principally telephone) in the 1930s used return loss as given in the definition (1)(C) above. Research at Bell Labs provided guidelines for the control of ‘echo’ and ‘singing’ on all types of circuits. The reflected signal set-up oscillations on the telephone line and this led to an audible whistle if the return loss was too low. Within the band, singing return loss is the lowest return loss at any frequency that this occurs. The objective was to achieve an average return loss of about 11 dB as a compromise between sending and receiving in the telephone network [8].

My own experience in the late 1960s and early 1970s was that we preferred VSWR to describe reflections in transmission lines, waveguide and antennas. Return loss was only quoted when the VSWR was close to 1 (often VSWR<1.1 ie. RL ~26dB). This occurred with components for satellite communications or radioastronomy. Nowadays the requirements on reflection coefficient for wireless often specify a 10dB return loss bandwidth and VSWR provides insufficient discrimination to verify accuracy of simulations, measurements or establish lower reflection levels within the band.

[1] The present definition of decibel was not adopted until 1929 (see [5]).

Turning to present-day usage, return loss is now the most common term used to describe reflection and mismatch. Frequently, however, this term is confused with reflection coefficient that has been expressed in dB. The logarithm is taken of the magnitude of the reflection coefficient but this is incorrectly referred to as return loss; the result is still reflection coefficient albeit in decibels. The difference between the two is a minus sign as shown in (3).

Many recent microwave and antenna papers and several well known books carelessly use return loss. I won't name any for fear of embarrassing the authors. Suffice to say it is common-place to see plots captioned and labelled return loss when in fact they are really describing reflection coefficient. I have even had some reviewers asking authors to change the correct form to the incorrect one ie. change a positive sign to a negative one even though the authors labelled the plot correctly as return loss! Some authors are inconsistent in the use of terminology (including myself). On one hand they correctly show reflection coefficient but in the text or captions refer to return loss.

In considering the problem of misuse of return loss, I wondered initially if a standard textbook or a software package employed the incorrect definition; I found little evidence for this conjecture. Having become aware of a burgeoning problem, I introduced a reminder in the decision letter to authors of Transactions papers to check their usage of return loss before submission of the final manuscript. However, this reminder has had only a minor effect as the practice has continued and even increased. Now, where possible, authors are reminded prior to acceptance. More broadly and beyond return loss, correct use of technical terms is vital for promoting consistency and avoiding misunderstanding. Through our publications, and the Transactions in particular, the AP Society strives for the best possible publications and, therefore, it is vital that authors aim for accuracy and consistency. Next time you submit a paper, please carefully check your usage of return loss and reflection coefficient; misuse of these terms may delay publication of your paper.

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