Minimizing RF mismatch errors and uncertainties

Application Note

Mismatch errors are one of the most significant contributions to errors and uncertainties in RF and microwave calibration. Mismatch error depends on the source and load match:

$$\text{Power Error} = \left\{ 1 - \frac{1}{\left(1 \pm |\Gamma_S||\Gamma_L|\right)^2} \right\} \times 100\,\%$$

Source reflection coefficient (Γ_S); Load reflection coefficient (Γ_L)

Where Γ_S is the source reflection coefficient and Γ_L is the load reflection coefficient. The reflection coefficient Γ (gamma) is a vector quantity; however often only its magnitude |Γ| is known from a scalar measurement. Reflection coefficient, return loss and voltage standing wave ratio (VSWR) are all related measures of match, with VSWR probably being the most commonly used, where:

$$\text{Reflection Coefficient (gamma)} \quad |\Gamma| = \frac{VSWR - 1}{VSWR + 1}$$

$$\text{Return Loss} = 20\log|\Gamma|^{-1}$$

The quality of the source and load match both contribute to the mismatch error. If either one is very good (close to the ideal 50 Ω, with VSWR approaching 1.0:1), the impact of the other being relatively poor is reduced. This latter effect can be exploited in practical measurement situations to reduce mismatch errors by deliberately inserting a device with good match characteristics (low VSWR). The device, an attenuator, often referred to as a "masking pad" or "matching pad," is inserted at the point where doing so will bring the greatest benefit – at the point where the match is worst or most variable. In this instance the attenuator's purpose is only match improvement, not signal level reduction. (Note that the term "matching pad" is also used for impedance conversion pads, used to convert between 75 Ω and 50 Ω, and these are different devices).

An example of mismatch error reduction is shown in Figures 1 and 2. Figure 1 depicts the reflection of a proportion of the signal at the interconnection of a source and load device where a mismatch occurs. When the masking pad is inserted, as shown in Figure 2, the reflection travels through the masking pad twice. Therefore, the magnitude of the reflection is reduced by twice the pad attenuation value, thus reducing the effect of the otherwise poor match.

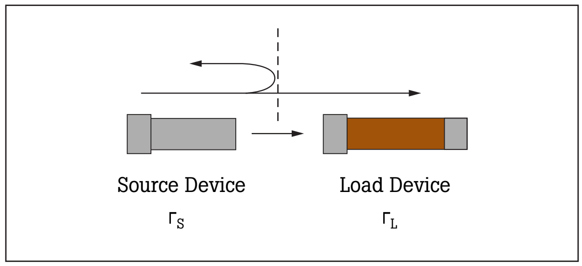

Figure 1. Reflection occurs at the mismatch between source and load.

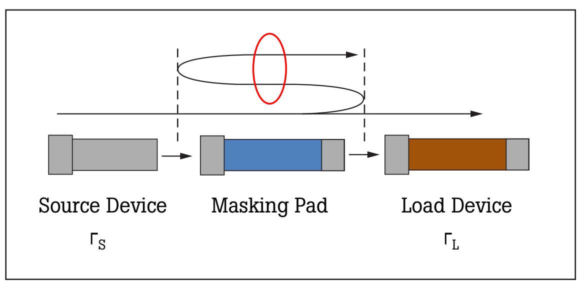

Figure 2. The reflection travels twice through the masking pad inserted between source and load.

Inserting attenuation, and therefore reducing signal level, can negatively impact measurements, either by moving signal levels closer to the noise floor or requiring higher input levels and placing greater demands on signal source output capability. However, relatively small value pads (3 dB or 6 dB) are generally sufficient to improve match conditions significantly and reduce mismatch errors, with only moderate and generally tolerable signal level reductions. It is relatively easy to obtain attenuator devices with good match performance. However, there can be a limit where the masking pad match may not be good enough to provide significant improvement over the match provided by the source and load connected directly if they are also well matched devices.

Most commonly the masking pad technique is used to improve match of active devices such as output match of a signal source or input match of a measuring device, where the output or input is directly from/to an active device with no passive circuits or attenuator to better define matching conditions. The masking pad should be placed at the end of any interconnecting cable furthest away from the signal source, such that it “masks” the match of both the generator and cable. Another common application is switched step attenuators, which may be permanently fitted with masking pads at their input and output to ensure the various attenuator stages work into a constant well defined match. Frequently the entire attenuator and masking pad combination is submitted for calibration as a single unit, for example as shown in Figure 3.

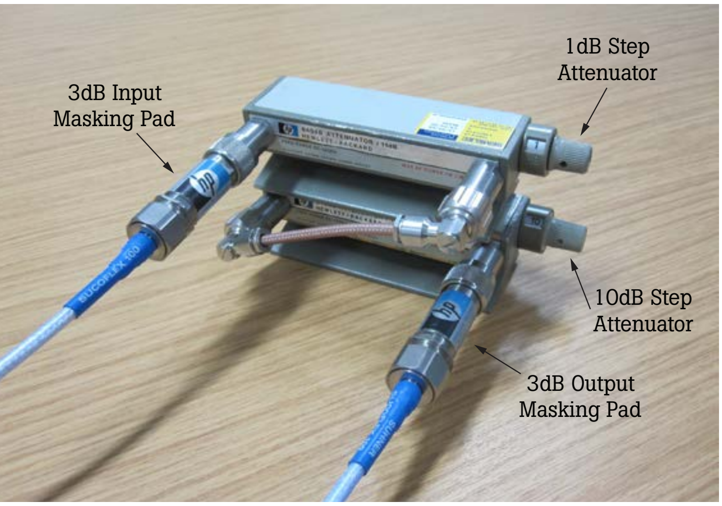

Figure 3. 1 dB and 10 dB step attenuator combination fitted with 3 dB masking pads at the input and output.

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Printed in U.S.A. 7/2015 6005964a-en
Pub-ID: 13460-eng