Differential RF Scalar Correction for ATE

By Bill Jasper

Differential RF components usually require balun transformers to adapt to common ATE single-end instruments. Test parameters involving gain and particularly noise require that signal levels be precisely known at the DUT input and output. This paper outlines some techniques to correct for fixture losses and gains. A low noise amplifier (LNA) will be used for specific example but the techniques should apply to other differential components.

Fixture Design

Consider a differential amplifier where we wish to measure common parameters such as gain, noise figure, distortion and bandwidth. The parameters have conflicting goals so that the fixture needs to multiplex component input and output paths. For example, noise measurement is done at very low levels, often requires active gain applied in front of the DUT and attenuation is not allowed. On the other hand, distortion measurement often requires attenuation with no active amplification. The fixture networks must be characterized across the DUT bandwidth and corrected for. The first task is design a flexible fixture to cover the suite of test parameters.

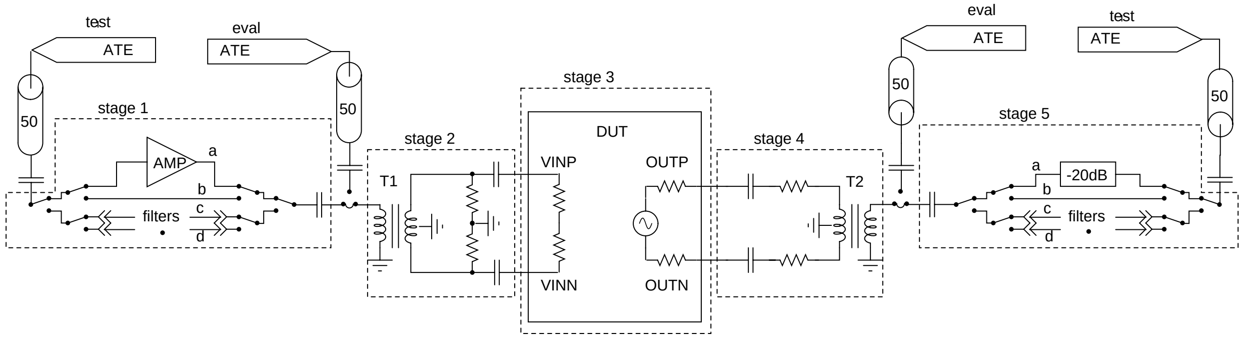

Figure 1. ATE Fixture Schematic

Figure 1 shows a fixture that uses relay trees to switch between the needed support components. On the input side an amplifier is available to bring the DUT noise above ATE noise floor. Filters are provided to remove harmonics from the ATE source. And the balun transformer with impedance matching network should be designed to establish a good match to the 50 Ω ATE environment. The output side transformer should mirror the input side. The output impedance matching network also should establish a good match to the ATE 50 Ω environment. The output relay tree provides an attenuator for measurement of fundamentals during distortion tests. ATE receivers can easily contribute to measurement distortion, so care should be taken to keep the fundamental tone levels presented to the ATE receiver low. Output filters are provided to remove the high level fundamentals when measuring the low level harmonics/intermods of DUT distortion. Filters should be coax connected for flexibility during DUT characterization. And coax interconnect of a common length should be used to connect to the ATE for calibration flexibility. The ATE should be calibration corrected to the end coax plane. This component set provides a good base to cover the range of expected tests.

Note the jumper intercepts at the input and output baluns. They provide access points to break the component blocks into manageable pieces. And, most important, to establish symmetry at the DUT socket so that input and output levels can be known.

Component Block Segregation

Let's assume our tests consist of gain, noise, 1-tone SDR and 2-tone SDR. And assume the 1-tone and 2-tone tests are at frequencies differing enough to require different filters. Each of the component paths need to be characterized in order to precisely know the DUT input and output levels. First, gain will use input path 1b and output path 5a consisting of input relay THRU and output relay attenuator. Next, noise will use input path 1a and output path 5b consisting of input relay amplifier and output relay THRU. For SDR, fundamentals are applied using input filter paths 1c|1d. SDR DUT fundamentals are measured through output attenuator path 5a. And SDR DUT harmonics are measured through output filter paths 5c|5d. These paths can be broken down into 4 unique input components, 4 unique output components and 2 DUT/balun components.

Component Characterization

The four ATE access points can be used to characterize each of the distinct components. The characterization will consist of a file of frequency and power (dB) tuples in reasonable frequency increments across the DUT bandwidth. These files will be loaded at run-test time to correct measured values to the exact DUT input/output levels. Figure 1 shows the 5 stages that the fixture will be broken into. This 5 stage segregation is important for noise correction.

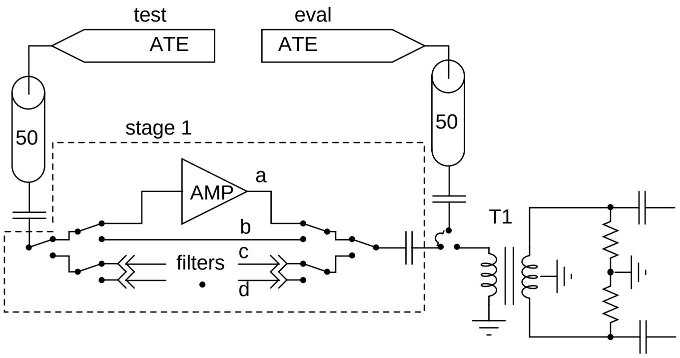

Figure 2. Input Stage 1 Characterization

Figure 2 shows the measurement path to characterize the 4 variations (a, b, c and d) of Stage 1. The output relay tree is characterized in the same fashion and generates 4 variations of Stage 5.

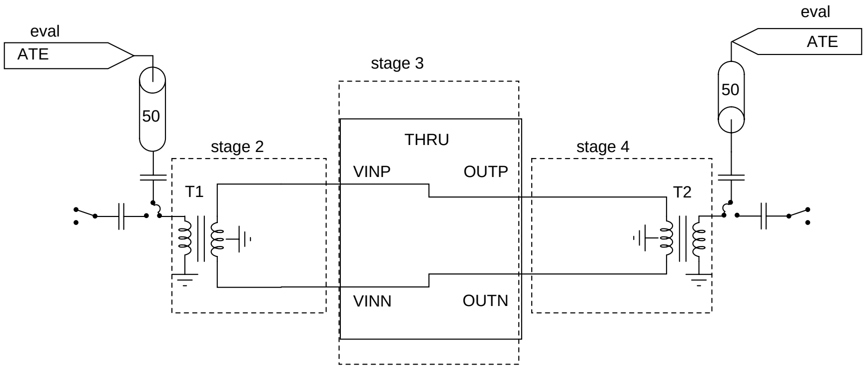

Figure 3. Stage 2-4 Characterization

Figure 3 shows the measurement path to characterize stages 2 to 4. The DUT is replaced with THRU jumpers. This is usually accomplished with direct bond wires in the package or, more crudely, with jumpers at the socket. Also note that the DUT termination match components have been removed so that the balun transformers are matched and symmetric. Characterization of stages 2-4 will measure the stray gain of the path. The fixed gains of the transformers and matching components will be treated as constants independent of frequency

We'll use $G_1..G_5$ to denote gain of stage 1 through stage 5 and $F_1..F_5$ to denote noise factor (linear domain) of stage 1 through 5. Thanks to symmetry G_2 is equal to G_4 and is equal to half of the measured gain of stage 2-4 characterization. This is the stray gain component of G_2 and G_4. The fixed gain component is dependent on the transformer turn ratio and load matching components.

Fixed Gain Components

As an example consider a transformer with a 1:2 turn ratio (1:4 Ω ratio). The DUT matching network would target 200 Ω input termination. Although the transformer cannot produce a power gain it yields a 1:2 voltage gain and there is an effective 6dB power gain due to the DUT's high to low impedance transformation. That's in addition to the DUT's actual gain. As a result, stage 2 gain (G_2) is the sum of measured stray gain and the fixed gain of +6dB. The same analysis applies to the output transformer network G_4. Note that for this example there is an analogous -6dB gain at the output transformer in addition to any matching network attenuation.

With this methodology one can create scalar correction data for each component G_{1a}, G_{1b}, G_{1c}, G_{1d}, G_2, G_4, G_{5a}, G_{5b}, G_{5c} and G_{5d}. The G_{1a} amplifier component has an active amplifier and should also be characterized for NF (or F in linear terms). All the other components are passive and should use the inverse of their measured gain for F ($F = 1/G$, linear terms).

Correction Data Applied

$$G_{SYS} = G_1 + G_2 + G_3 + G_4 + G_5 \qquad \textbf{(1a)}$$

Equation (1a) represents the fixture system gain in logarithmic terms. The DUT is stage 3. DUT input power and DUT output power can be found from equation (1a). DUT gain and linearity parameters can be found using the appropriate correction data for each frequency and component.

Consider the fundamental measurement of a distortion SDR parameter. The c path is selected at the input relay tree and the a path is selected at the output relay tree. Given a target DUT input power P_{IN}, set the ATE $P_{SYSIN} = P_{IN} - G_{1c} - G_2$. Then measure the system out power P_{SYSOUT}. The DUT output power $P_3 = P_{SYSOUT} - G_4 - G_{5a}$.

$$F_{SYS} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3} + \frac{F_5 - 1}{G_1 G_2 G_3 G_4} \qquad \textbf{(1b)}$$

Equation 1b is the cascade noise equation. Noise is usually measured with the Y-factor method. The G_{1a} amplifier is provided to elevate the DUT noise above the ATE noise floor. The ATE measures and calculates NF_{SYS}. DUT gain, G_3 is determined from measurement using equation (1a). And F_3 can be calculated since other variables of equation (1b) are known.

Using this methodology one can accurately correct fixture embedded scalar measurements on differential components.

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