Keysight Technologies

E5071C ENA Calibration Down to 9 kHz Using the N4431A/B 4-Port ECal Modules

Firmware 9.1 and Later

Technical Overview

Introduction

For the Keysight Technologies, Inc. E5071C ENA network analyzer with firmware revision 8.12 or below, calibration in the frequency range of 9 kHz to 300 kHz can only be achieved using a mechanical calibration kits. Firmware revision 9.1 enables calibration in this frequency range via Keysight's electronic calibration (ECal) modules. This note explains the theory behind this new technique and shows how to calibrate the E5071C down to 9 kHz using the firmware revision 9.1 and the N4431A/B 4-port ECal modules. An example using a 3.5 mm thru adapter is given.

Theory

The N4431A/B ECal modules have a definition value of standards down to 300 kHz and which has limited the calibration from 9 kHz to 300 kHz on the E5071C. The new method of calibrating the ENA down to 9 kHz now available with firmware rev. 9.10 models the N4431A/B ECal standards value using its 300 kHz to 1 MHz data, and then uses that model to extract the lower frequency data. The extraction is done in the ENA firmware, thus no additional procedures are necessary. Extracting calibration data using modeling is an appropriate method as long as the model is deemed valid. Modeling is especially valid at low frequencies because of its ability to ignore parasitic effects.

Note: The calibration technique described in this note only applies to the N4431A/B 4-port ECal modules with factory characterized data, with the E5071C ENA Options 9 or 100 kHz to 3, 4.5, or 8.5 GHz, firmware revision A.09.10 or higher. User characterization data of the N4431A/B is unaffected by this new technique. The latest ENA firmware is available at **http://www.keysight.com/find/ena_support**.

Error Term Difference

Figure 1 shows the difference in error terms between error terms using a 85033D DC to 9 GHz mechanical calibration kit with an unknown thru[1] method, and error terms of the N4431B with a defined thru[2] using the modeling method. Letter number combinations like Et21 designate each error term of each port, and the difference is calculated as 20 * log10 (abs (Err_A – Err_B)). As you can see, the difference of error terms at 9 kHz to 300 kHz is below –50 dB, which is small and comparable to that of error terms in the 300 kHz and above range.

Figure 2 shows the difference in error terms between error terms using a 85033D DC to 9 GHz mechanical calibration kit with an unknown thru, and error terms using a N4431B with an unknown thru using the modeling method. The difference at 9 kHz to 300 kHz is approximately –55 dB, and comparable to that of error terms in the 300 kHz and above range, too.

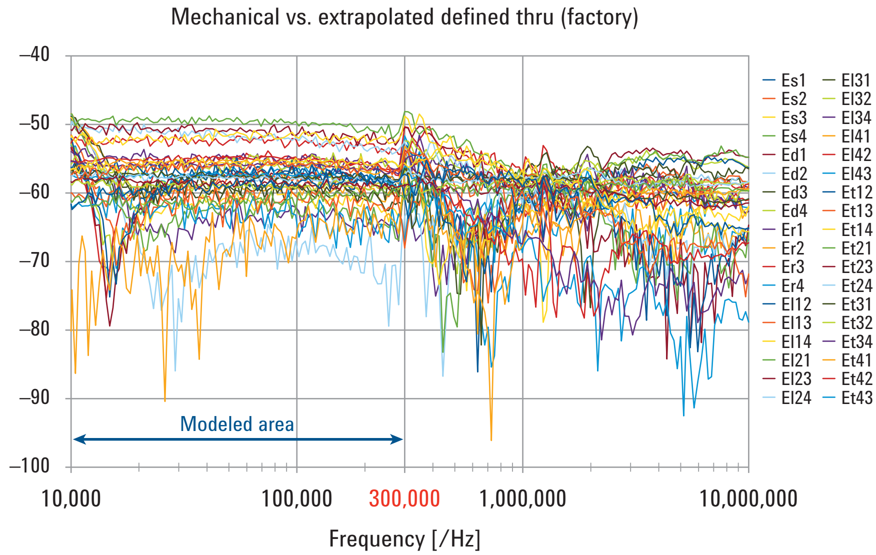

Figure 1. Error term difference between the 85033D (unknown thru) and N4431B ECal (defined thru)

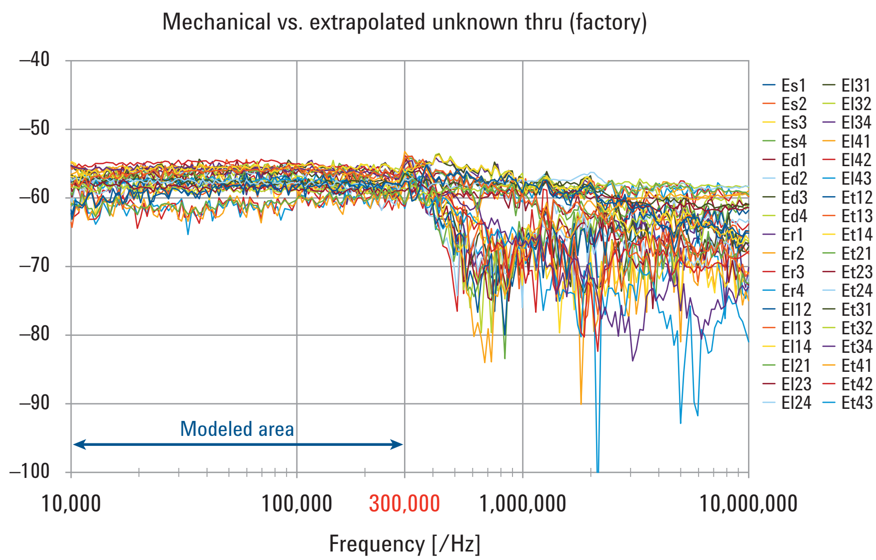

Figure 2. Error term difference between the 85033D (unknown thru) and N4431B ECal (unknown thru)

1. *The "unknown thru" method is available for ENA firmware revision 7.00. It allows you to use a THRU adapter without a precise definition, but with good accuracy.*
2. *The "defined thru" is a traditional calibration method which uses a pre-defined definition measured with a THRU standard.*

Residual Error Comparison

Figure 3 (defined thru) and Figure 4 (unknown thru) show how the residual errors of the modeling method compare with that of an ECal that has been characterized using a mechanical calibration kit (induced upon the directivity, source match, and load match terms). In conclusion, the errors are less than 60 dB and regarded as negligible. The largest errors that occur are the transmission tracking errors, which are about ~0.02 dB. And, the transmission tracking error can be further reduced to ~0.005 dB by using the “unknown thru” method.

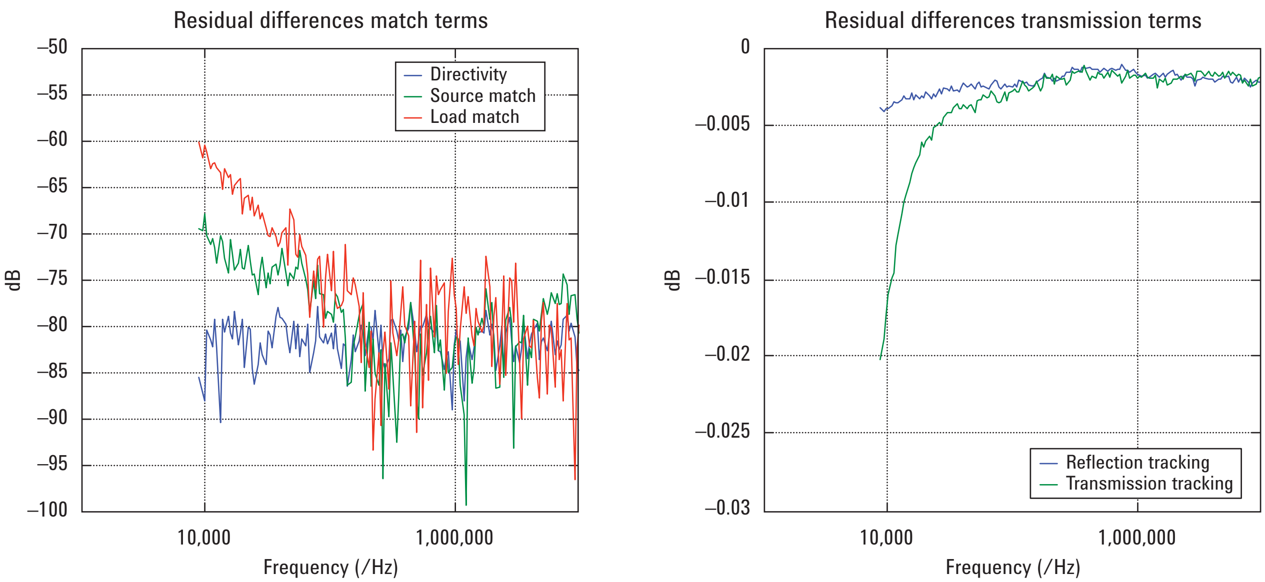

Figure 3. Log plot calibration difference between ECal characterization using a mechanical cal kit and ECal using the modeling method from 300 kHz to 9 kHz using a “defined thru”

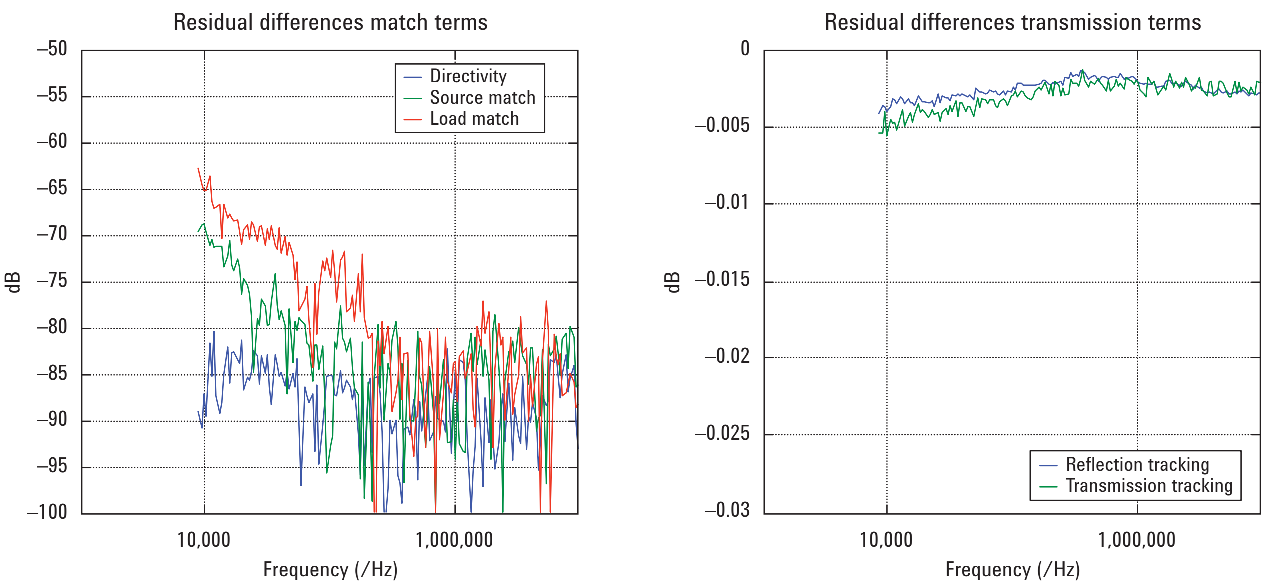

Figure 4. Log plot calibration difference between ECal characterization using a mechanical cal kit and ECal using the modeling method from 300 kHz to 9 kHz using an “unknown thru”

Residual Error Comparison *(continued)*

These errors are small relative to the characteristic performance of the N4431A/B ECal module at low frequencies, and can be absorbed into the performances which are shown in Table 1.

Table 1. Residual error term specifications of the N4431A/B ECal module (3.5 mm)

Error term	Residual error (300 kHz to 10 MHz)
Directivity	45 dB
Source match	36 dB
Reflection tracking	±0.10 dB
Transmission tracking	±0.078 dB
Load match	39 dB

Conclusion

In this paper, both the theory and the reliable performance of the ECal modeling method of calibration down to 9 kHz for the ENA has been shown. The ENA performance calibrated using this method is proved reliable. The modeling method has consistent and expected behavior for the N4431A/B ECal modules from 9 kHz to 300 kHz using the defined thru method. Also, this methodology is referred by the production documents of the N4431B in Keysight, which means that the ECal module has characteristic performance down to 9 kHz.

Example Using a 3.5 mm Thru Adapter as the DUT

To see the effect of the modeling method from a customer's perspective, a 3.5 mm thru adapter was measured. This measurement lets you to see the error term differences more easily. A measurement result (taken after calibration using mechanical calibration kit) is used as a reference value, and the differences (from the reference value) between the new modeling method supported by the E5071C firmware rev. 9.1, and the extrapolated method supported by firmware rev. 8.12 are evaluated.

Figure 5 shows the result of a THRU adapter measured with the modeling method (E5071C rev. 9.1) and by the extrapolated method (E5071C rev. 8.12). The label **UT_ON** in the figure means using an unknown thru, and **UT_OFF** means using a defined thru.

For a 3.5 mm adapter at 9 kHz, the magnitude should be ~0 dB with ~0 degrees of phase. The difference from the reference value of the magnitude measurement result using the modeling method (rev. 9.1) is small, approximately ~0.010 dB less than the result of the mechanical cal kit. The difference from the reference value using the extrapolated method (rev. 8.12) is ~0.020 dB and has some ripples below 300 kHz.

The majority of the errors occur in the phase measurements. The results of the extrapolated method (rev. 8.12) causes the most phase error of ~1.0 degrees, while the modeling method (rev. 9.1) results using the "defined thru" produces less ~0.2 degrees. However, by using rev. 9.1 with the "unknown thru" an error of less than ~0.05 degrees, negligible in most ranges, is obtained.

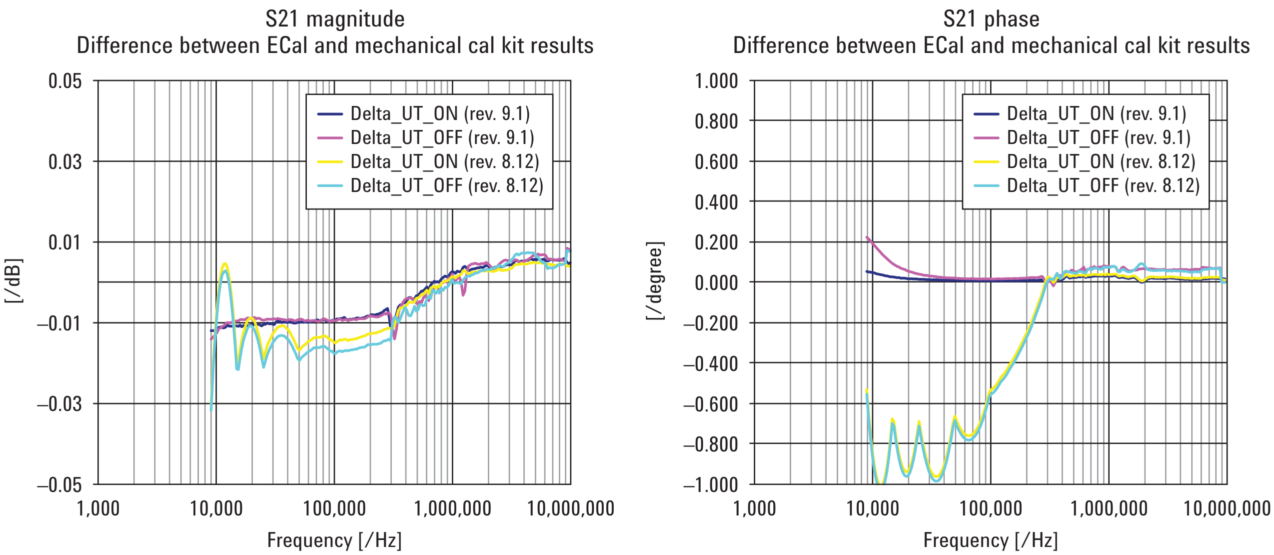

Figure 5. Measurement of a 3.5 mm thru adapter by ECal and mechanical calibration kit

Related Keysight Literature

Publication title	Pub number
85033D Specifications: 85033D User's and Service Guide	85033-90027
Electronic Calibration Modules Reference Guide	N4693-90001

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