FLUKE®

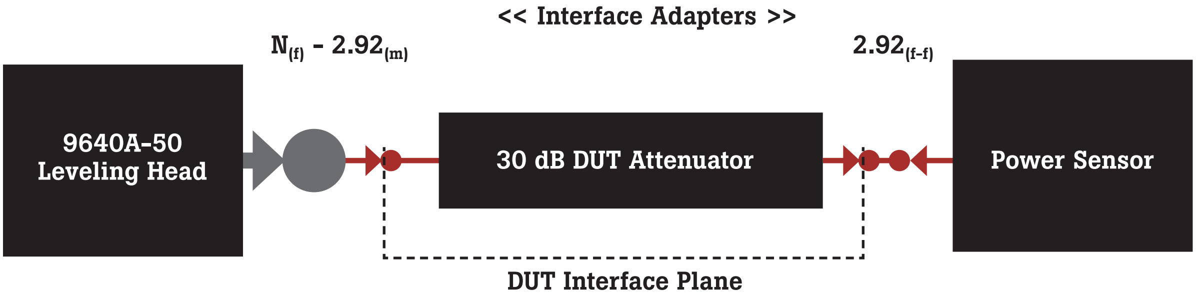
Calibration

Calibrating attenuators using the 9640A RF Reference

Application Note

The precision, continuously variable attenuator within the 9640A can be used as a reference in the calibration of other attenuators, or in the calibration of gain or loss of other RF components or paths. This application note will concentrate upon the calibration of fixed and switched attenuators; the method for other components or paths would be similar.

The calibration method to be described compares the unknown attenuator with a nominally equal Reference value within the 9640A and uses the 9640A unique “Offset” capability to determine in a direct readout either a value for the unknown attenuator or its error from nominal value.



Basic method

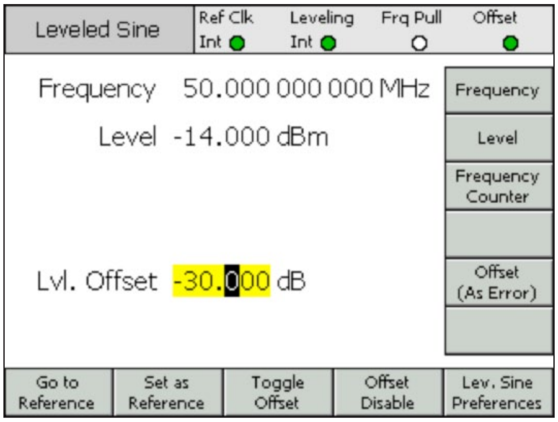
Using the example of a 30 dB fixed attenuator, for which we will assume a different connector series to illustrate the application of inter-series adapters. Our device under test (DUT) will be a female-to-male attenuator in 2.92 mm connectors.

1. In this case we need to adapt the 9640A output to 2.92 mm using an $N_{(f)}$ to $2.92_{(m)}$ adapter. Connect the unknown attenuator in series, and its output to a power measuring instrument e.g. a power sensor, again adapting interfaces as necessary.
2. Set an output level of say +16 dBm at the desired test frequency, very commonly 50 MHz.
3. Turn the 9640A output on and note the resulting power reading, in this case about -14 dBm (~40 µW).

The next step that you take depends upon the desired result format....

To determine attenuation value:

1. To find the unknown attenuation value, use the 9640A Offset feature to reduce the output level by -30 dBm, as shown here.

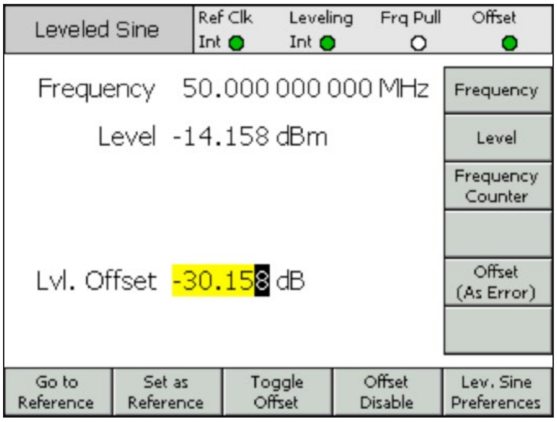


Frequency 50.000 000 000 MHz

Level -14.000 dBm

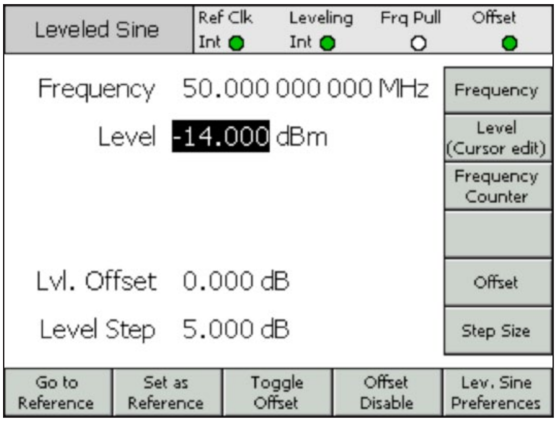
Lvl. Offset -30.000 dB

2. Remove the unknown attenuator (only) leaving both adapters in place (dotted connection above). Note here that it might important to reduce 9640A output (as above) before removing the attenuator to avoid overloading the measuring sensor.
3. We now adjust the 9640A offset to achieve exactly the same measured power level. The 9640A offset value then matches the insertion loss of the unknown attenuator; in this case -30.158 dB.

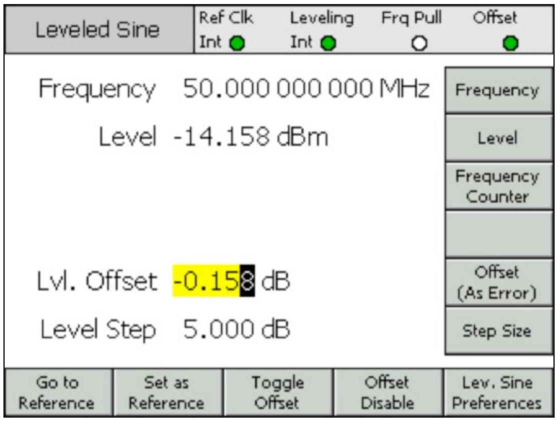

Leveled Sine
Frequency 50.000 000 000 MHz
Level -14.158 dBm
Lvl. Offset -30.158 dB

To determine attenuation error from nominal:

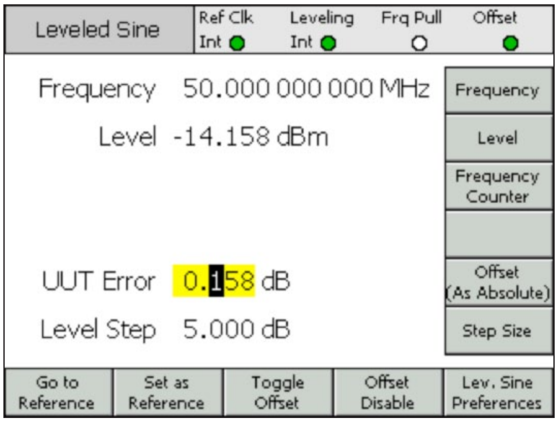
1. To find the unknown attenuation error from nominal, first select the Level Offset function, leaving the Offset value at 0 dB. Then use the 9640A Level control to reduce the output level by the nominal attenuator value -30 dB, as shown here. The 9640A "Step Level" edit mode may be valuable here. In this example a 5dB step has been set, 10dB steps could also be used. This feature is particularly valuable when a range of equi-spaced values needs to be calibrated (e.g. a switched attenuator or a set of attenuators).


Leveled Sine
Frequency 50.000 000 000 MHz
Level -14.000 dBm
Lvl. Offset 0.000 dB
Level Step 5.000 dB

2. Remove the unknown attenuator (only) leaving any adapters in place. Note here that it might important to reduce 9640A output before removing the attenuator to avoid overloading the measuring sensor. We now adjust the 9640A Offset to achieve exactly the same measured power level (in this case -0.158 dB).


Leveled Sine
Frequency 50.000 000 000 MHz
Level -14.158 dBm
Lvl. Offset -0.158 dB
Level Step 5.000 dB

3. By now pressing the "Offset as UUT error" key, we conveniently display the error of the insertion loss from the nominal attenuator value (+0.158 dB or, if we wish, +3.705 %).


Leveled Sine
Frequency 50.000 000 000 MHz
Level -14.158 dBm
UUT Error 0.158 dB
Level Step 5.000 dB

Multiple attenuators in a set, or a switched attenuator can be calibrated quickly, efficiently and accurately using the above method, which is much less prone to error than traditional methods. The 9640A "Step Edit" and "Offset" features significantly simplify and speed the task, providing, as they do, a direct readout of the unknown attenuator value or error from nominal.

Coping with large value attenuators

Use of a power sensor as the comparison measurement instrument will limit the largest attenuation value that can be determined. Typically repeatable measurement using a thermal power sensor will only be possible down to about -10 dBm. Assuming the same 16 dBm start point the largest measurable attenuation value would be around 26 dB. A single path diode sensor might support comparison readings down to around -50 dBm or attenuation values to 66 dB. A multipath diode sensor might gain another 20 dB of useful range. Beyond these we must use the tuned measurement of a spectrum analyzer or a measuring receiver. With the best of these we can make comparisons down to -130 dBm or lower and can potentially resolve attenuation values of 120 dB or more. Note that for very large attenuation values isolation of input and output to prevent signal leakage around the DUT is vital. High integrity components, sensor/receiver and correct connector torque must be used.

Consideration of test signal spectral content

We do not have to consider the spectral content of our comparison measurement so long as the measurement is at a fixed comparison level and the source spectral content does not substantially change throughout the test. The 9640A being of very low and consistent spectral content at all output levels, negates the need for further consideration.

The danger of using high input power

It will not be lost on readers that the use of a higher input power will extend the usable attenuation measurement range of any given comparison sensor and the 9640A could deliver up to +24 dBm to the attenuator input. There are however two dangers here:

1. That with low attenuator values the comparison power at the sensor may be too high and may damage the sensor.
2. That self heating of the DUT may cause its attenuation value to change. This will depend upon the temperature rise (°C/W) of the attenuator resistive elements and the Temperature Coefficient of the total attenuation value; which may or may not be the same under self heating as under ambient heating. Attenuators are generally inadequately specified in this respect and we often cannot establish a good value for the error that may occur. It is likely that high power attenuators will be less susceptible to this form of non-linearity than lower power or smaller devices. Fluke recommends that for a 1 W attenuator (+30 dBm max) no more than 16 dBm should be used at Calibration.

Optimizing accuracy

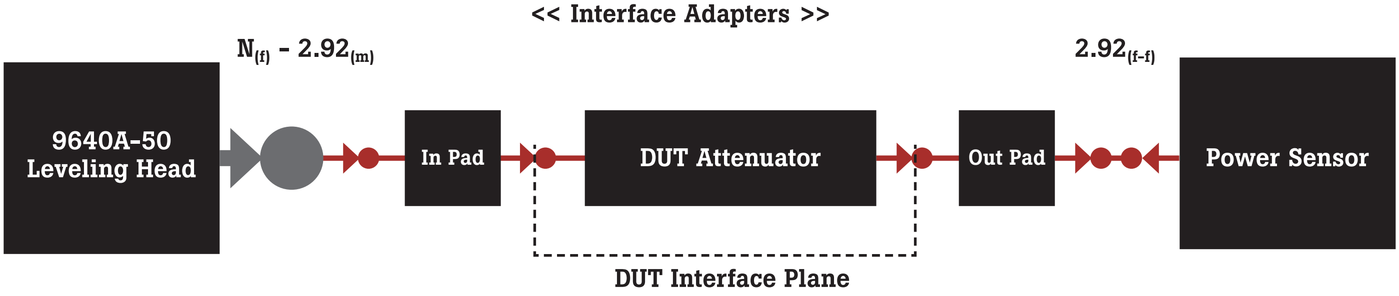
There are three key opportunities to optimize attenuation measurement accuracy:

1). Optimize match conditions.
The attenuator must be driven from and loaded with accurate and stable match to minimize mismatch errors. The 9640A is well specified and certified in this respect, but its output match does change with level range switching and a small additional uncertainty results. Best practice would be to apply a small value attenuator or pad between the 9640A and the DUT to reduce this mismatch switching uncertainty and to move the match defining resistor closer to the DUT interface plane.

Whilst not generally necessary when measuring with a typically well matched power sensor, best practice when comparing at lower levels would be to also insert a small value pad between the DUT attenuator and a less well matched receiver or spectrum analyzer. Clearly pads reduce measured signal level and may equally be impacted by self heating if we were to raise source level to compensate. An ideal match pad would theoretically improve match (reflection coefficient) by twice its attenuation value, however there is a sharply diminishing return for increasing pad values as their own match error limits the improvement.

9640A source mismatch is specified at VSWR of 1.1 : 1 at frequencies <500 MHz. Attenuation is generally measured in this frequency band so we will use this value in an example evaluation of mismatch uncertainty. A good power sensor may be specified at 1.05 : 1 at frequencies <1 GHz. If we were to pad the source and the sensor in this case, optimum results would be achieved if the source were padded more heavily (twice as heavily) than the sensor.

However, the best attenuator match is unlikely to be better than 1.02 : 1 to 100 MHz. In fact it is likely that we would have to measure the attenuator to be certain that it was this good, such tight specification is rarely found. The extent to which the pad can improve match at the DUT attenuator plane is thus limited.



The table below evaluates uncertainty due to source and load mismatch when measuring a 10 dB (nominal) attenuator with hi quality Input and Output pads of various attenuation values and at a match of 1.02 : 1. Two examples are given, that for a DUT with ideal match and a more realistic case, a match of 1.05 : 1. In comparison with the specified attenuation accuracy of the 9640A the additional uncertainty is relatively small in all cases. It is unlikely that anymore than a 3 dB source pad would be deemed valuable to uncertainty reduction. In practice, a reflection measurement would be likely to show the power sensor match, inclusive of any good quality adapter fitted, to be somewhat lower than specified and to be repeatable with connection matings. Further reducing the need for, or improvement that could be gained by using an output matching pad.

A further consideration in the presence of such small benefits in uncertainty would be the increase in uncertainty that might result from a comparison measurement at lower level. In this case -24 dBm would be a small signal for most thermal power sensors.

Nominal Attenuator Value	Input Pad Value	Output Pad Value	Nominal Output Level	Uncertainty due to Mismatch		9640A Specification
				DUT Match Ideal	DUT Match 1.05 : 1	
10 dB	No Pad	No Pad	6 dBm	± 0.0035 dB	± 0.0110 dB	± 0.02 dB
10 dB	1 dB	No Pad	5 dBm	± 0.0030 dB	± 0.0090 dB	± 0.02 dB
10 dB	3 dB	No Pad	3 dBm	± 0.0017 dB	± 0.0075 dB	± 0.02 dB
10 dB	6 dB	3 dB	-3 dBm	± 0.0006 dB	± 0.0035 dB	± 0.02 dB
10 dB	10 dB	6 dB	-10 dBm	± 0.00035 dB	± 0.0030 dB	± 0.02 dB
10 dB	20 dB	10 dB	-24 dBm	± 0.00025 dB	± 0.0025 dB	± 0.02 dB

The tables above and below are derived from Monte Carlo statistical simulation of the suggested mismatch specifications and representative transmission line lengths between them. All specifications and results are assumed to be of 99 % confidence. All results are consistent up to a frequency of 80 MHz, heavier padding of the source (the longest line length in the measurement) raises the frequency to which these values apply up to 200 MHz (6 dB) and 400 MHz (20 dB). The uncertainties are relatively independent of DUT attenuator value but do improve at lower values, as shown below.

Nominal Attenuator Value	Source Pad Value	Load Pad Value	Nominal Output Level	Uncertainty due to Mismatch		9640A Specification
				DUT Match Ideal	DUT Match 1.05:1	
1 dB	6 dB	3 dB	6 dBm	± 0.00015 dB	± 0.00015 dB	± 0.02 dB
3 dB	6 dB	3 dB	4 dBm	± 0.0004 dB	± 0.0035 dB	± 0.02 dB
10 dB	6 dB	3 dB	-3 dBm	± 0.0006 dB	± 0.0035 dB	± 0.02 dB
60 dB	6 dB	3 dB	-53 dBm	± 0.0006 dB	± 0.0008 dB	± 0.03 dB

2) Optimize comparison measurement noise and repeatability. Assuming fixed input level (+16 dBm) the only benefit that can be made is to reduce measurement noise and drift in the comparison measurement. Good practices such as averaging or filtering the measurement, maintaining fixed and quiet environment, careful handling and correct torque on connections, and minimizing the handling of thermal sensors in particular will all help. It is also important to select the best available measurement for the comparison level. The table on the right indicates typical repeatability of measurement that can be achieved against comparison level for thermal and diode power sensors and high end measuring receivers. These results are measured values in a controlled temperature production calibration environment and include contributions such as connector repeatability.

	Typically Achievable Measurement Repeatability 10 MHz** to 300 MHz, inclusive noise, stability and connection repeatability		
Comparison Level	Thermal Sensor e.g. R&S NRP-Z51	Diode Sensor e.g. R&S NRP-Z4	Measuring Receiver/ Spectrum Analyzer e.g. R&S FSU26 with pre-amp option
10 dBm to 20 dBm	0.005 dB	0.005 dB	0.009 dB
0 dBm to <10 dBm	0.005 dB	0.005 dB	0.009 dB
-10 dBm to <0 dBm	0.005 dB	0.005 dB	0.009 dB
-20 dBm to <-10 dBm		0.005 dB	0.01 dB
-30 dBm to <-20 dBm		0.005 dB	0.01 dB
-40 dBm to <-30 dBm		0.006 dB	0.01 dB
-48 dBm to <-40 dBm		0.008 dB	0.01 dB
-57 dBm to <-47 dBm			0.012 dB
-67 dBm to <-57 dBm			0.02 dB
-77 dBm to <-67 dBm			0.02 dB
-87 dBm to <-77 dBm			0.045 dB
-97 dBm to <-87 dBm			0.04 dB (use pre-amp)
-107 dBm to <-97 dBm			0.06 dB (use pre-amp)
-117 dBm to <-107 dBm			0.08 dB (use pre-amp)
-124 dBm to <-117 dBm			0.15 dB (use pre-amp)

** At lower levels it may be necessary to offset measurement from 10 MHz and harmonic multiples to reduce interference from distributed 10 MHz reference clock often found in a calibration lab. +50 kHz offset is often used.

3). Optimize application of 9640A specification.

The 9640A specification is optimized in the frequency band 10 MHz to 128 MHz and for an initial level of +16 dBm as shown below. Other Reference levels can be used, but relative to calibration standards, an uncertainty for both the DUT and Reference measurements must be included in the uncertainty summation, as indicated in the lower section of the 9640A Attenuation specification below.

Attenuation	**50 Ω Output**	
Attenuation	Relative to +16 dBm ouput	
10 Hz(1) to 128 MHz	0 dB to 56 dB 56 dB to 64 dB 64 dB to 74 dB 74 dB to 100 dB 100 dB to 116 dB	± 0.02 dB ± 0.03 dB ± 0.05 dB ± 0.07 dB ± 0.15 dB
Cumulative and incremental attentuation	Relative to any level between +16 dBm and -100 dBm, 10 Hz to 128 MHz	
To determine the attenuation specification between any two output levels, apply RSS(2) summation of the dB values listed for each output level.	+16 dB to -40 dB -40 dB to -48 dB -48 dB to -58 dB -58 dB to -84 dB -84 dB to -100 dB	± 0.02 dB ± 0.03 dB ± 0.05 dB ± 0.07 dB ± 0.15 dB

Total uncertainty in an attenuation measurement derives from the combination of 9640A specification, mismatch uncertainty at the DUT interface and repeatability in the comparison measurement.

Using an example DUT of 10 dB at a match of 1.05 : 1, and the use of a 3 dB source pad, at 99 % confidence we have: (converting to and combining as power uncertainty and converting back to dB)

9640A specification (+16 dBm reference)	± 0.02 dB	± 0.46 % pwr
Mismatch uncertainty	± 0.0075 dB	± 0.17% pwr
Comparison uncertainty at 3 dBm	± 0.005 dB	± 0.12 % pwr (thermal or diode sensor)
RSS total	± 0.0219 dB	± 0.505 % pwr

Had we used a +10 dBm reference instead …

9640A specification (+10 dBm reference level)	± 0.02 dB	± 0.46 % pwr
9640A specification (+0 dBm attenuated level)	± 0.02 dB	± 0.46 % pwr
Mismatch uncertainty	± 0.0075 dB	± 0.17 % pwr
Comparison uncertainty at -3 dBm	± 0.005 dB	± 0.12 % pwr (thermal or diode sensor)
RSS total	± 0.0296 dB	± 0.683 % pwr

Conclusion

The 9640A RF Reference simplifies and streamlines the calibration of attenuators and, by providing direct readout of either attenuation value or error from nominal value, reduces errors in the recording and certification process. 9640A attenuation specification supports low uncertainty measurements and additional uncertainties due to mismatch or comparison measurement repeatability can readily be kept small or insignificant. In practice, given the mix and magnitude of contributing uncertainties, the benefits of padding the measurements are minimal and in practice only rarely would padding greater than an input pad of 3 dB be justifiable.

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