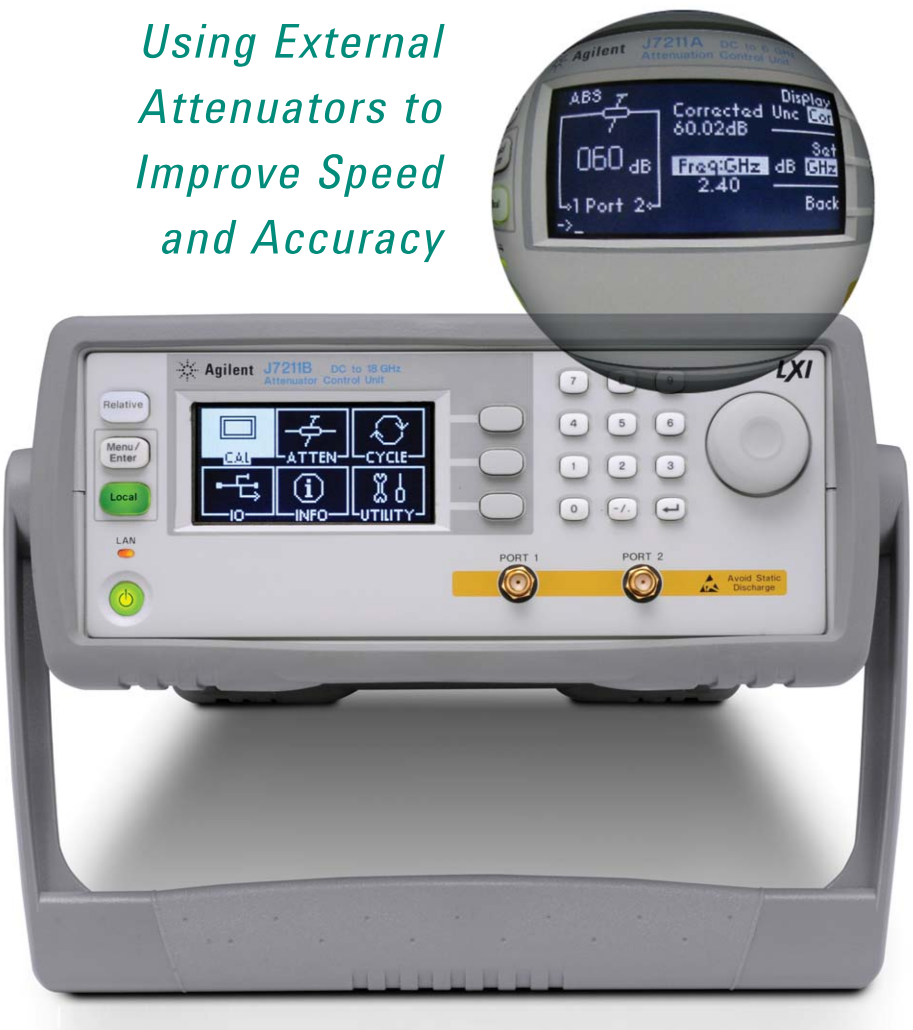
Power Accuracy in Receiver Test –

Using External Attenuators to Improve Speed and Accuracy



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Introduction

Wireless communication is rapidly advancing. The era of circuit switched telecommunication is slowly falling behind as packet switched telecommunication moves ahead steadily. GSM technology has enabled massive cellular and mobile networks worldwide that are rapidly evolving towards higher data rates through W-CDMA and HSDPA/HSUPA technologies. Wi-Fi, which exploits the wired LAN in its last miles to provide wireless internet connection, is now advancing towards greater mobility and coverage with the introduction of mobile WiMAX™.

The seemingly unceasing consumer demand for higher data rates for multimedia products transforms a luxurious want into a metropolitan need that forces service providers and device manufacturers to employ extensive new technologies and deploy sophisticated networks. In addition to these challenges, service providers and manufacturers face intense competition with user satisfaction of services a pivotal key for success.

Overall system performance and user satisfaction rely heavily on the RF performance of network devices. Designers must ensure that devices conform fully and accurately to the designated standards and specifications. Manufacturers must produce reliable devices by verifying their performance. A large portion of manufacturing time is often devoted to calibration as this optimizes yield. Both device characterization during the design stage as well as test system calibration in the manufacturing stage require highly accurate measurements. In addition, manufacturing test times need to be kept as short as possible to ensure efficient use of testing resources and to maintain high profitability.

This application note discusses mobile device receiver testing in conformance with various wireless connectivity standards including WiFi, and fixed and mobile WiMAX. The principles covered in this note can also be applied to other applications such as *Bluetooth*®, ZigBee or UWB. This note explains the importance of the power accuracy of the test signal, as well as the role external variable attenuators play in ensuring fast and accurate test system calibration and device testing.

Receiver Tests

Typical RF measurements for mobile communication receivers include RF sensitivity, dynamic range, and adjacent-channel and alternate-channel rejection. Extensive conformance tests are performed during the development stages of the mobile devices. In manufacturing, tests verify the workability of devices produced in large quantities by covering a wide range of tests within a short amount time.

Receiver sensitivity test

Receiver sensitivity tests measure a receiver's performance using known signal conditions including modulation and coding type, signal-to-noise ratio (SNR) and input level.

Using these specified conditions, receivers must be able to perform to the specified parameter of the conformance standard, for instance in fixed WiMAX, the IEEE 802.16d Conformance Standard.[1]

The receiver sensitivity test setup for this standard is shown in Figure 1.[1] A connection is made between the test base station (test BS) and the receiver under test. The attenuator value is increased until the minimum operable value is reached while maintaining a BER of at least 1×10^{-6}. The power of the received signal is measured and recorded. This is the receiver sensitivity of the receiver.

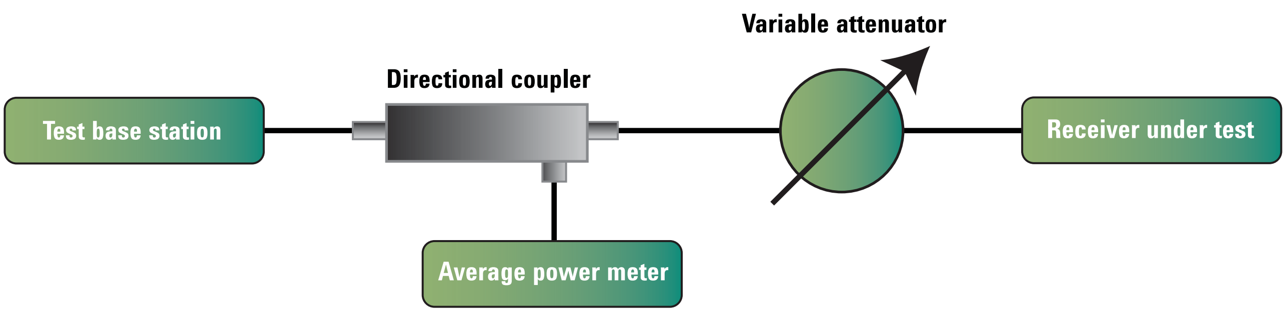

Figure 1. Test setup for receiver sensitivity and dynamic range

Under the IEEE 802.16-2004 WiMAX conformance standards, wireless devices must be able to achieve a BER of at least 1×10^{-6} in accordance with the specified data patterns and bandwidth.[2] Table 1 summarizes the test conditions for a variety of bandwidths and modulation types.

Table 1. BER specifications for receiver sensitivity (dBm)[2]

Bandwidth	Modulation and coding rate						
	BPSK	QPSK		16 QAM		64 QAM	
	1/2	1/2	3/4	1/2	3/4	2/3	3/4
1.75 MHz	–93.7	–90.7	–88.9	–83.7	–81.9	–77.4	–75.7
3.5 MHz	–90.7	–87.7	–85.9	–80.7	–78.9	–74.4	–72.7
7.0 MHz	–87.6	–84.6	–82.8	–77.6	–75.8	–71.3	–69.6
10.0 MHz	–86.1	–83.1	–81.3	–76.1	–74.3	–69.8	–68.1
20.0 MHz	–83.0	–80.0	–78.2	–73.0	–71.2	–66.7	–65.0
Rx SNR (dB)	6.4	9.4	11.2	16.4	18.2	22.7	24.4

Receiver dynamic range test

To test the receiver's dynamic range, the attenuator is then decreased until the maximum operable value is reached. The power is measured and recorded. The difference between the two power values is the receiver's dynamic range. The receiver dynamic range must be >40 dB to meet the conformance standard.

Adjacent channel interference test

This parameter tests the receiver's immunity to unwanted signals located one or two channels away from the dedicated channel.

Figure 2 shows a setup example for the first adjacent channel rejection test (1 dB degradation) in fixed WiMAX. In this setup [1], a signal generator is used to create an interference signal, the interfering signal is transmitted on the first adjacent channel to the useful signal (the carrier signal). The useful signal is transmitted from the base test station.

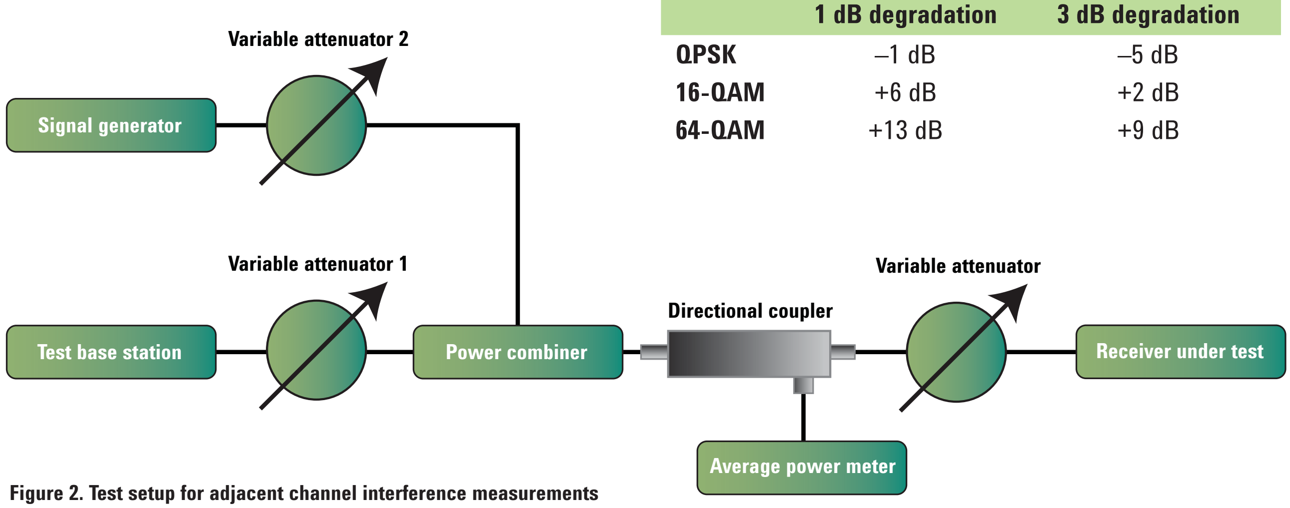

Figure 2. Test setup for adjacent channel interference measurements

First, the signal power is measured. Next, the signal generator is turned off and attenuator 2 is set to maximum attenuation. Attenuator 1 is then adjusted to BER = 1 x 10^{-3} or 1 x 10^{-6}. The signal power is increased by 1 dB or 3 dB and the power is measured.

The signal generator is then switched on and attenuator 2 is decreased until BER of 1 x 10^{-3} or 1 x 10^{-6} is achieved. The test BS is turned off and the power of the interfering signal is measured. The carrier-to-interference (C/I) power values need to be within the parameters listed in Table 2.

Table 2. Specifications for adjacent channel interference[1]

1st Adjacent channel interference (BER=1x10^{-3})		
	1 dB degradation	**3 dB degradation**
QPSK	–5 dB	–9 dB
16-QAM	+2 dB	–2 dB
64-QAM	+9 dB	+5 dB
1st Adjacent channel interference (BER=1x10^{-6})		
	1 dB degradation	**3 dB degradation**
QPSK	–1 dB	–5 dB
16-QAM	+6 dB	+2 dB
64-QAM	+13 dB	+9 dB

Test Signal Generation and Power Inaccuracy

In manufacturing test, particularly in mobile WiMAX test, vector signal generators and signal analysis tools are often integrated into one-box test sets that incorporate flexible base station emulation and RF parametric tests. This expands the test set's capability enabling complete component verification from development through manufacturing.

Whether as a stand-alone signal generator or as part of a one-box communication test set, a vector signal generator is used in complex systems to deliver adjustable, accurate amounts of RF power at different frequencies, with or without modulation, and with as few spurious signals or other distortions as possible. One of the prime specification parameters of a vector signal generator is the RF output level accuracy. To provide accurate output signal levels the automatic level control (ALC) system compensates for the insertion loss between the output amplifier and the output connector. Many other factors including the variations of insertion loss as the frequency varies, ALC linearity and output VSWR must also be taken into account.

The problem becomes more complex as the RF power level is reduced to lower levels where the receiver sensitivity of mobile devices is tested (Table 1). At these levels, when the vector signal generator's internal attenuator pads are switched on, they are unlikely to be accurate. As a result, additional correction data is applied to correct for the pads across different frequency and attenuation values. The large amount and high density of calibration data points are taxing to a signal generator which must calibrate and compensate for each and every power level across the frequency range. This causes some uncertainties in the power level accuracy of the vector signal generator. For instance, the power accuracy of a good vector signal generator can be as good as ±0.5 dB at high power levels of around –50 dBm. However, at low power levels of –80 dBm, the inaccuracy can be as high as 1.0 dB or more.

A signal generator with poor output VSWR and tight RF level accuracy can also cause problems.

For example:
If the source has an output VSWR specifcation of 1.4 and the load VSWR is 1.1, then the level uncertainty of a perfect power meter is ±0.07 dB.

The uncertainty level gets worse if the source or load impedance VSWR is higher.

For instance:
If the source has an output VSWR of 1.8 (which is typical for many vector signal generators) and the load VSWR is 1.3, then the level uncertainty of a perfect power meter becomes 0.33 dB.

Mobile device BER is extremely sensitive to even 1 dB difference in power. The inaccuracy in test signals can easily decrease the manufacturing yield and create false constraints for the designers of mobile devices.

In product development environments, this can be overcome with meticulous measurement of the low output power from the vector signal generators. In manufacturing environments, a large portion of manufacturing test time must be dedicated to the calibration process. To overcome the problem of the power inaccuracy from signal generators, you need to use power measurement equipment to calibrate the output power of the signal generators before running any receiver tests.

As seen in Table 1, there are different specifications for the different bandwidths, modulation and coding rates of WiMAX signals. Receiver sensitivity, for example may vary from -65 dBm to more than -94 dBm. It is not feasible to calibrate the power level of the signal generator or wireless test set at each and every power level. Hence, a faster, more accurate and more reliable solution is needed.

MIMO testing and signal level consistency at multiple test paths

Multiple input, multiple output (MIMO) is the latest trend in wireless connectivity for both WiMAX and WiFi. MIMO employs multiple antennas at both transmitter and receiver to increase the capacity of a wireless link. A few test methodologies are used to test MIMO-enabled devices in R&D and manufacturing environments. In R&D, multiple vector signal generators and signal analyzers are used with a software package to analyze MIMO devices. In manufacturing, a fast switching method switches the input test signal from a vector signal generator to the different antennas of the device or a composite test method uses a combiner or splitter which splits the input test signal to different antennas of the receiver under test.

In both methods, there is a power level consistency issue across the multiple paths/ports. The fast switching method typically employs solid state switches which might have different insertion loss values at different ports of the switch. Solid state switches also have different distortion performances at different power levels. In the composite method, the power splitters or dividers have a certain amount of amplitude variations across different output paths making it impossible to split of the power evenly at each output path. Generally, the greater the number of paths, the greater the variation.

It is time-consuming and troublesome to fully calibrate all the power level and paths/ports in MIMO testing. Adding a variable attenuator with stored calibration data enables a single, one-time calibration method for receiver sensitivity testing.

Power Measurement Inaccuracy

Unfortunately power measurements and test system calibration are not straightforward processes, especially for WiMAX device test. The WiMAX signal has a very high crest factor, 12 dB peak-to-average power, and fast-changing amplitude behavior, where the preamble of WiMAX frame is 3 dB higher than data part. Thus it is not as easy as connecting a power meter to the signal to calibrate the signal generator. A sophisticated power meter with gating capability or a programmable signal analyzer with application software is needed to measure the preamble or data part of the signal. The preamble part is used for received signal strength indication (RSSI) measurements.

Thermoelectrical-type sensors are more accurate than diode-type sensors but they have extremely slow settling time. Diode-type sensors have a faster settling time but they have limited dynamic range causing problems with signals with high peak-to-average (crest) factor. This can be overcome with longer calibration times or by using different power sensors for different areas of the dynamic range, then the lower limit of the measureable power value through a power meter-sensor becomes the ultimate limitation for calibrating the low power level of the signal generator.

With a power sensor, however, it is almost impossible to find one that is able to measure signal strength of anything less than –90 dBm. So then, you would need a very high performance signal analyzer with low noise floor for the measurement.

The complexity of measuring WiMAX signals comes up again. Typical WiMAX signals have a bandwidth in MHz. Even with the best signal analyzer, it is impossible to have the necessary noise floor for the power values needed in receiver sensitivity test. A setting of a mere 2 MHz resolution bandwidth in a typical spectrum analyzer will raise the noise floor range to –60 dB.

How then do you verify that the power level of the signal generator is, for instance, 90 dBm? How can you be sure that the exact power level is not –91 dBm or –89 dBm, when you factor in the loose accuracy specification of signal generators at low power? This problem can be resolved by inserting a variable attenuator with known calibration data into the test system. This enables the signal generator to function at higher power levels where its accuracy is easily assured. It also reduces calibration time and increases test speeds.

Why Accurate Power Measurement is Important

The accuracy of the power meter can have a significant impact on the overall performance depending on the application.

For manufacturers who test the receiver's sensitivity, a 1.5 dB inaccuracy in the test signal can severely affect the yield. This is more prominent in WiMAX where tight power control and high receiver sensitivity is critical. A study [3] made on how the signal-to-noise ratio of the receiver's received signal affects the BER of a WiMAX receiver is shown in Figure 3. As you can see, a small dB change in the SNR (signal strength versus the noise level, in dB) has a large effect on the BER rate.

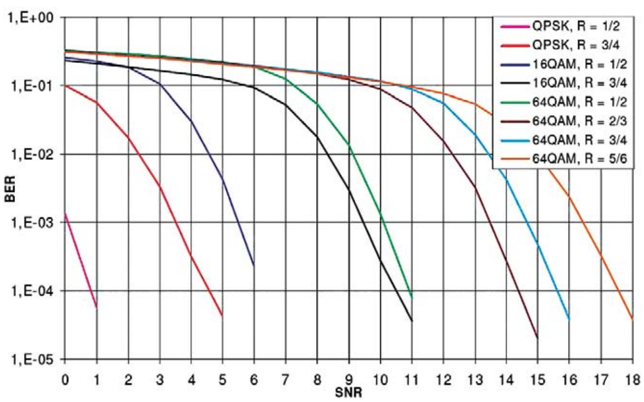

Figure 3. Performance of MIMO Matrix A systems (with MRC at the receiver) on ITU pedestrian B channel with a pedestrian speed of 3 km/h

For network planning, you can see this from the free space path loss versus the distance. If a base station is operating at 2.4 GHz and has an effective radiated power (ERP) of 40 dBm and the receiver has a sensitivity of -80 dBm, then the user can be 9.995 kilometers away from the base station. If the receiver has only –79 dBm of minimum sensitivity, the user can not stand at more than 8.908 kilometers away from the base station. Assuming that the coverage area is proportional to the square of the distance, then a mere 1 dB of measurement error or wrong interpretation of the receiver sensitivity is equivalent to a 24.79 percent error in the coverage area.

Because power from the base station reaching the receiver is inversely proportional to the square of the distance, even a small error in power or a small incorrect interpretation in receiver sensitivity can result in a significant error in coverage area. This causes a considerable amount of inconvenience and uncertainties in network deployment and will affect the user satisfaction of the whole mobile network environment.

Accurate Low Power Level Calibration Using External Variable Attenuators

In receiver testing, using a variable external attenuator with stored calibration data will remove the problems associated with the power measurements discussed in this application note. The attenuator is used to step down the signal generated from the test base station emulating the distance from the base station to the mobile devices. The same applies to other wireless applications where variable attenuators are used to step down the power from the test base station. In WiFi testing, this is called the golden ratio[1] method. Power level control for the golden ratio method is provided by an external variable attenuator.

What is the role of an external variable attenuator when a signal generator or wireless test set comes with an internal variable attenuator and adjustable power value down to –110 dBm? Does this make the attenuator redundant? The answer is no as explained on page 10.

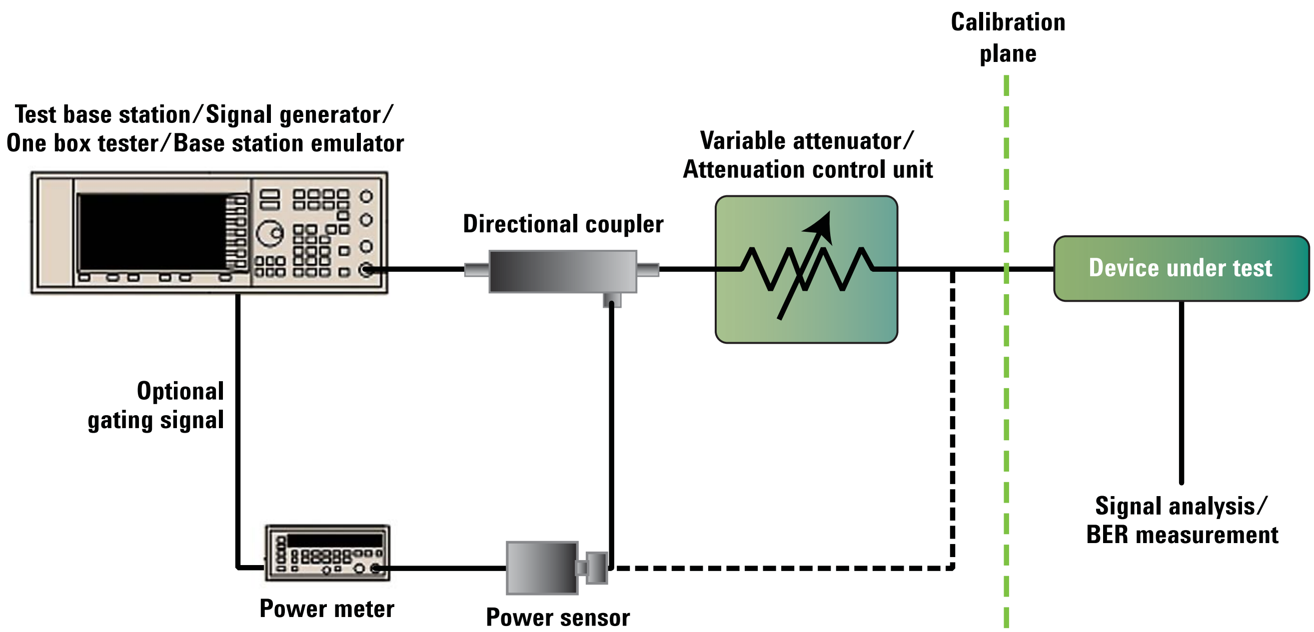

Figure 4: Test setup for efficient power calibration using external attenuators

1. The signal source and receiver for the system is provided by a golden ratio. The golden ratio is used to generate RF signals to test the DUT receiver, as well as to receive packets from the DUT.

Figure 4. shows the test setup for the calibration and measurement of a receiver sensitivity test. By placing the coupler-power meter combination before the external variable attenuator, the loss of the coupler as well as the inaccuracy of the signal generator can be calibrated at only high power levels where the signal generator is more accurate. The rest of the power levels, including very low power levels, can be stepped down using the external variable attenuator. Furthermore, with J7211A/B/C attenuation control units you can perform one power level calibration and use it to accurately measure multiple power levels and frequencies.

External attenuators do not have the exact nominal values at each and every attenuation value either, but Agilent attenuators provide accurate calibration data with reference to 0 dB attenuation across their frequency range. Agilent's new J7211A/B/C attenuation control units not only display the corrected attenuation value on the LCD screen for each and every attenuation level across the frequency range, it provides you with embedded calibration data file to use in your test systems for accurate power levels computation.

Figure 5. LCD display of Agilent Attenuation Control Unit

In Figure 5, the display of Agilent J7211A attenuation control unit clearly shows the corrected attenuation value at 60 dB attenuation at 2.40 GHz, 60.02 dB in this case. The corrected data can be observed on the LCD or extracted through GPIB, LAN or a USB interface.

Calibration steps using an J7211A attenuation control unit

1) Assume that a maximum signal level of 0 dBm[1] is needed for the receiver test.

2) Set the attenuation of the J7211A attenuation control unit to 0 dB (no attenuation).

3) Then measure the power value at calibration plane with a power meter that has gating capability or a signal analysis tool. The calibration plane is just before the device under test.

4) Next, gradually increase the signal level of the signal generator to compensate for the loss of the directional coupler, connectors, cables and the variable attenuator until the power meter reads 0 dBm.

5) Record the power level of the signal generator. This value actually reads the loss in magnitude of the setup, from the output of the signal generator to the calibration plane. In the measurement example below, a 2.47 dB loss is observed.

- The power sensor and power meter are then removed from the calibration plane, and are then connected to the coupled port of the directional coupler.
- The measurement setup is now ready for accurate and fast receiver sensitivity testing.

If a signal level at –80 dB is needed, set the attenuation of the attenuation control box to 80 dB. Now, you simply use the corrected attenuation value[2] for the measurement results. If the corrected attenuation value shown on the display is 80.2 dB, as in this example, then the input signal level of the DUT is exactly –80.2 dBm.

1. Any other power level can be set as the initial power setting.
2. Corrected attenuation values are normalized to a loss of 0 dB attenuation setting.

Table 3: Corrected attenuation values for Agilent J7211A attenuation control unit

Attenuation setting (dB)	Displayed corrected value (dB)	Normalized to 0dB	Generator output (dBm) at 3GHz	Power meter reading (dBm)	Error (dB)
0	0.95	0.00	2.47	0	0
10	9.99	9.99	2.47	10.03	0.04
20	19.98	19.98	2.47	20.02	0.04
30	29.99	29.99	2.47	30.03	0.04
40	40.30	40.30	2.47	40.34	0.04
50	50.30	50.30	2.47	50.33	0.03
60	60.28	60.28	2.47	60.32	0.04

A similar setup using an Agilent J7211A attenuation control unit was used to verify the steps shown in Table 3. Table 3 shows the measurement results. The absolute error is a mere 0.04 dB. This small error is a composite effect of the non-linearity of the power sensor and power meter, the repeatability of the external attenuator[1] as well as the measurement uncertainty of the test system.

If a smaller resolution than the 1-dB resolution of the variable attenuator is needed, you can simply adjust the output power level of the signal generator. If a -80 dBm signal level is needed at the input port of the device under test, simply increase the power level of the signal generator by 0.2 dB and you will get –80 dBm at the calibration plane. The power linearity[2] of a typical signal generator is very good at small steps (0.2 dB in this case) and is therefore negligible.

The power meter and power sensor are connected to verify the small step change and to give real-time feedback to the source of signal analysis tool. Whether or not you need it to be there depends on your application.

Using an external attenuator, with exact attenuation values, lets you to vary the input signal to the DUT and provides the following benefits.

- Eliminates the need to calibrate every power level coming from the signal generator by providing an exact, known attenuation value.
- Eliminates complications of power level accuracy and uncertainty, especially at low power levels.
- Overcomes the inability to measure and calibrate low power levels from the signal generator.
- Resolves power level linearity[2] problems across a wide range of power levels.
- Reduces the number of calibration cycles needed as power only needs to be calibrated at one power level.
- Significantly shortens calibration and test time.

The method presented here provides fast, accurate power level calibration for mobile receiver tests in manufacturing without having to measure and calibrate the power at many different power levels. Also, complications at low power levels are eliminated.

1. The repeatability of the external attenuator is 0.03 dB per section.
2. Linearity measures the signal generator's relative level accuracy which is the accuracy of a step change from any power level to any other power level

Conclusion

For accurate receiver sensitivity measurements, you need to make sure that the power coming from the source is exactly what is displayed. This is not possible as the typical accuracy of a vector signal generator at low power levels can be as high as ±1.0 dB or more. Inaccuracy in receiver testing has substantial negative impact to the yield and mobile network planning, as the BER or PER performance of the receiver is very sensitive to input power levels.

To overcome this, a large amount of time and effort is needed to calibrate the power levels of the test signals. With increased complexity of wireless signals, such as high crest factors and extremely wide bandwidth, accurate power measurements can be complicated, long and tedious, leading to higher cost of test.

Although high-performance vector signal generators may have better accuracy and power linearity specifications, they are costly and it is difficult to find one with a better than 0.4 dB accuracy for unmodulated CW signals. By using the method described in this application note, you can calibrate the whole test system with a single, accurate power measurement at a higher power level, modulated or unmodulated. Once this is done, you can easily generate different power levels, including lower power levels, to the DUT using external attenuators without having to worry about the power accuracy or linearity. The precision, speed and ease of this method greatly reduce cost of test.

References

[1] IEEE Std 802.16/Conformance03-2004- Part 3: Radio Conformance Tests (RCT) for 10–66 GHz WirelessMAN-SC Air Interface

[2] WiMAX Concepts and RF Measurements

[3] Diversity, Interference Cancellation and Spatial Multiplexing in MIMO Mobile WiMAX Systems, paper 1-4244-0957-8/07/ ©2007 IEEE, pp 78..

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