Repeatable and Reproducible Measurements Using the octoBox Personal Testbed

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Test measurements should be both repeatable and reproducible

Wireless testing should be both repeatable and reproducible, and the octoBox personal testbed delivers on both goals. Although the two concepts are different, the words are sometimes used interchangeably. For the sake of clarity, we will provide our definitions of them here.

Repeatability refers to the variation in measurements as seen in a single test environment under the same conditions. So, for example, repeatability is what we get if we run a test in the octoBox and, without changing anything, we run that same test again. In addition, we define repeatability to include taking measurements on a device under test ("DUT") at one time, and then running the same test again a significant time later using the same testbed. A repeatable testing environment will give the same results for each test (provided the DUT's adaptation behavior is consistent under the same airlink conditions, as discussed in more detail below.)

Reproducibility, on the other hand, refers to the ability to set up two separate testbeds, run the same measurement, and get the same results. In this case we are referring to the ability to, for example, describe the test setup to someone else, have them configure a different set of equipment in the same way, run the same tests, and get the same results.

Challenges to achieving repeatability and reproducibility

Repeatable/reproducible measurements require a stable device under test

A prerequisite to being able to get repeatable measurements in the octoBox is that the DUT should behave in the same way under the same conditions. Although this may seem an obvious statement, it is often the case, especially in the earlier phases of product development, that the DUTs themselves are inherently unstable. Wireless devices are complicated and the more advanced they are the more adaptive behavior mechanisms they contain. At octoScope we have seen situations in which products, especially in the earlier phases of their development, have inconsistent behavior even under the same external conditions. This can be due, for example, to immature or unstable algorithms, or hysteresis behavior in which the device behavior under some conditions is dependent on the immediately preceding conditions.

That being said, however, when the DUT itself behaves in a consistent manner under the same airlink conditions, it is possible to get repeatable test results in the octoBox testbed. In what follows we will implicitly assume the consistent behavior of the DUT.

Repeatable/reproducible measurements require a repeatable/reproducible test environment

In many cases, even when the DUT is stable, wireless testing is neither repeatable nor reproducible. Much wireless testing is done in an open-air environment (so called "walk-tests" or "drive-tests") and those tests are neither repeatable nor reproducible. The reason is that the wireless environment is often extremely variable, so even tests repeated back-to-back will face very different conditions and return different results.

Reproducibility is even harder to achieve, since if a test can't even be reliably repeated, it won't matter how precisely the test setup is reproduced. The results will not match.

This is not to say that walk-testing and drive-testing are not valuable techniques. They are, and they are widely used. But they provide results that need to be examined in the

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averages. They can tell you how a network performs on average, over a given area, at a given time, under given conditions. And these average results should be repeatable (and, to the extent that it makes sense, reproducible.) But if the need is to examine specific device behaviors, these techniques are not appropriate.

Repeatable measurements are what the octoBox does best

Repeatable testing is at the heart of the octoBox value proposition. The octoBox testbed provides a completely isolated, controlled RF environment, which does not change from test to test. And the impairments that the system creates (path loss via controllable attenuation, multipath via multipath emulation, interference via interference generation) are precisely repeated from test to test. When running a test in the octoBox, it is always the case that when no changes are made to the system, the RF environment will be identical.

When attempting to repeat a test after significant time has elapsed, more care should be taken to get consistent results. It is important to verify that the system has not changed in any significant way between tests, or that the system has been returned to the original configuration.

For example, the antennas, attenuations, and other system parameters must be the same between tests. In addition, care should be taken to place the device under test in the same location and orientation. In fact, repeating a test after a significant time gap is much like the process of reproducing results in a different environment. However, as described in the following section, when appropriate care is taken, the results will be consistent.

Reproducible measurements require careful use of the system

By far the more complicated goal to achieve is that of reproducibility. That is, if you do a test in the octoBox and your team around the world wants to reproduce those results, can they? Or, as discussed above, if you do a test in the octoBox and then, one month later you want to do it again, can the environment reproduce those original results? It is important to understand how various test conditions can make the goal of reproducibility easier or harder to achieve, and specifically what conditions make reproducibility easy.

Here we will discuss some of the most important issues that affect reproducibility and how best to manage them. These effects are

(1) the orientation of the device under test (DUT orientation), and
(2) the position of the device under test with respect to the probe antennas (DUT position).

DUT orientation matters

Imagine first, a test that might be done outside of the octoScope system, that is, a test that could be done in an open-air environment. An example is shown in Figure 1, in which we have a device under test (DUT) communicating with a test device.

Figure 1: Example of an open-air test configuration

This is test which, for example, would look at the signal strength (or other related parameter, like data rate) between the DUT and the testing device.

If we look at what is happening at the DUT, it is radiating a signal based on its overall radiation pattern, which is made up of the antennas themselves, and the material surrounding and

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interacting with those antennas. In Figure 2 we show a classic dipole antenna pattern to illustrate the point that the radiating field will have some shape, with more signal radiated in some directions than in others.

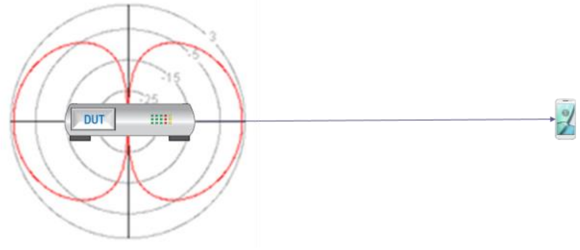

Figure 2: The open-air test, with an example radiation pattern for the DUT

Now imagine that we change the orientation of the DUT.

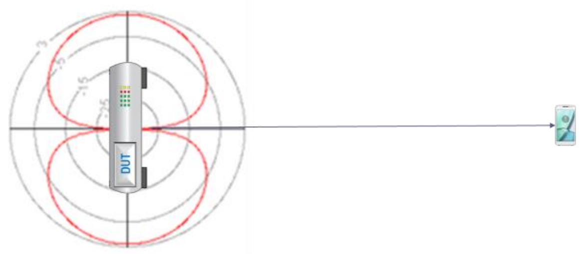

Figure 3: Open-air test with a rotated DUT, and the resulting radiation pattern

If we were to do such a test using a DUT with the radiation pattern shown in Figure 3, we would expect to get different results in our test, since the test device is now in the direction of a null in the DUT's radiation pattern. If we ran the same test(s), different results would be exactly what we would expect.

Now imagine that we move this test into an octoScope testbed. It is important to recognize that ***tests in the octoBox are over-the-air tests***, so the relative orientations of the DUT antennas (radiation pattern) and the test antennas is still quite important. The tests are in a *controlled* environment, but still an *over-the-air* environment.

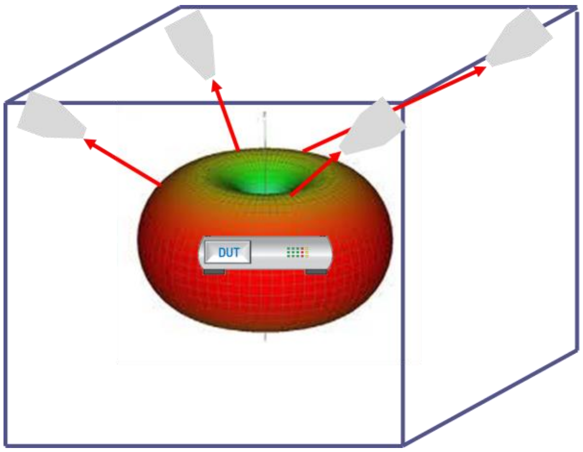

Figure 4: Test in an octoBox, with an example (3D) radiation pattern shown for the DUT

We would not be surprised to find that a test done in the configuration of Figure 5 would produce different results from a test done using the configuration of Figure 4.

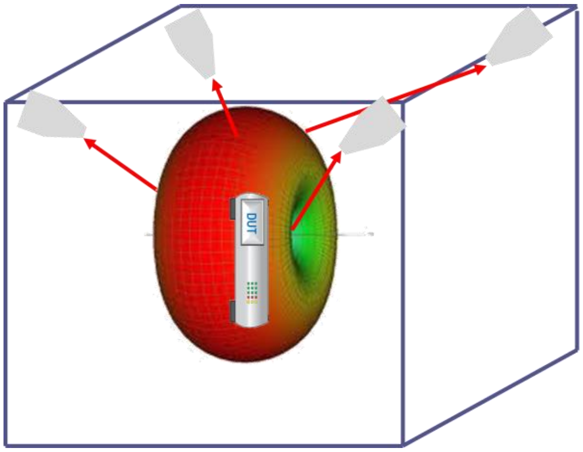

Figure 5: Test in an octoBox, with an example (3D) radiation pattern shown for the rotated DUT

It is for this reason that we do not expect tests with random, different orientations of the DUT in the chamber to give the same results.

DUT position can have several effects

DUT position and test-antenna gain

Reasonable care should be taken to position the DUT in the same location each time, and to avoid changing the orientation of the test antennas. This is because, especially when the test antennas being used are the octoScope high gain antennas, the antennas have about 8 dB of gain in their main lobe, and are directional. (The 3 dB beamwidth is about 60°.) Changes in the position of the antennas or in the position of the DUT can result in changes to the amount of signal received by one or more of the test antennas, which can result in changes to the test results.

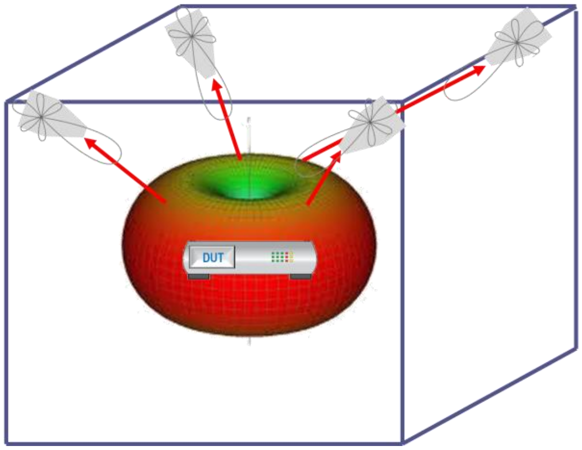

Figure 6: Test configuration in the octoBox, showing high-gain test antennas

Short distances (low path losses) challenge reproducibility

The second major consideration regarding DUT position is related to the distance between the DUT and the test antennas. There is no additional attenuation of the signal inside the test chamber (no clutter, no absorption, etc.), so the path loss between the DUT and the test antennas will be free-space path loss. Free space path loss is a function of the square of the distance between the devices. The equation for the path loss, measured in dB, is:

$$PL(dB) = 20*\log_{10}(f_{GHz}) + 20*\log_{10}(d_m) + 32.45$$

In this equation, d_m is the distance between the transmitter and receiver measured in meters.

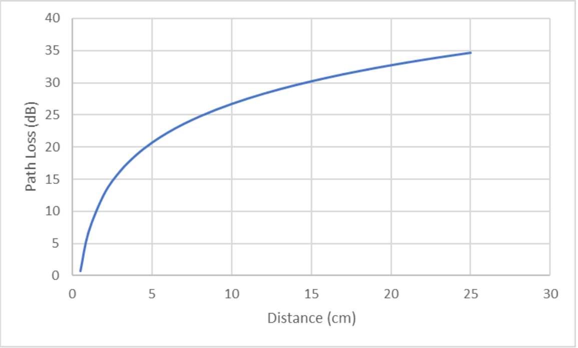

Figure 7: Free space path loss as a function of distance

At short distances the path loss changes rapidly. See Figure 7. Looked at another way, the change in the pathloss as a function of changing distance can be very high when there is a short distance between the antennas. See Figure 8.

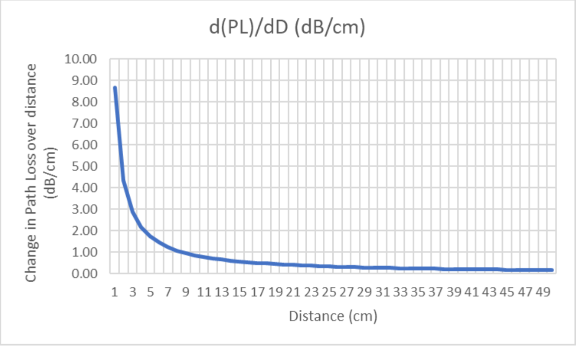

Figure 8: The rate of change in path loss as a function of distance

This means that if a test is done with a very short separation between the Tx and Rx antennas the results can be sensitive to the position of the DUT. Making some assumptions about the Tx power, 802.11 mode being tested, etc. we can map changes in path loss to changes in data rate. See Figure 9.

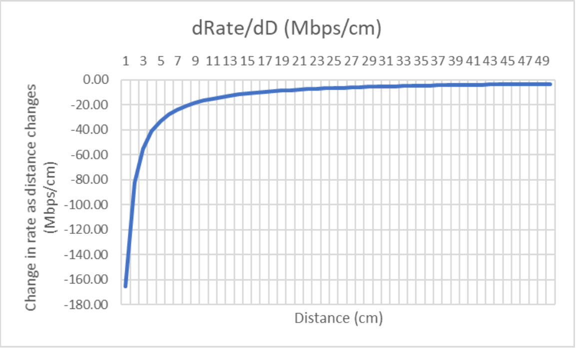

Figure 9: The rate of change of data rate as a function of distance

The important lesson here, though, ***is not*** that the measurements can be sensitive to DUT position at very short distances. The lesson here is that while a test using very short Tx-to-Rx distances may be very sensitive to DUT position, this sensitivity decreases rapidly. Once the distance is about 10 cm, we have reached the region of easy repeatability/reproducibility. At these distances, there are only very limited effects on the results due to changing the DUT position.

To help explain this better, we present the results of three simulations below. In these simulations we model the case in which the DUT is placed, data is taken, and then the DUT is moved by one (1) centimeter and the measurements are taken again. In this simulation we are modeling only the effect of the changing path loss at various distances.

(1) First, we look at the change in the results when the DUT is very close to the test antennas.
(2) Next, we look at the change in the results when the DUT is further from the test antennas.
(3) Last, we look at the change in the results when the DUT is very close to the test antennas, but the measured data is averaged over a 360° rotation of the DUT.

Sensitivity at short DUT-to-antenna distances

In our first simulation, we place the DUT close to the test antennas, so the Rx-to-Tx separation is only 3 cm. We then simulate changing the attenuation between the DUT and the receiver and measuring the throughput. When we repeat the test, however, the distance between the DUT and the test antennas is changed to 4 cm (representing an imprecise attempt to place the DUT), and a second set of data is taken. The results of the simulation are shown in Figure 10.

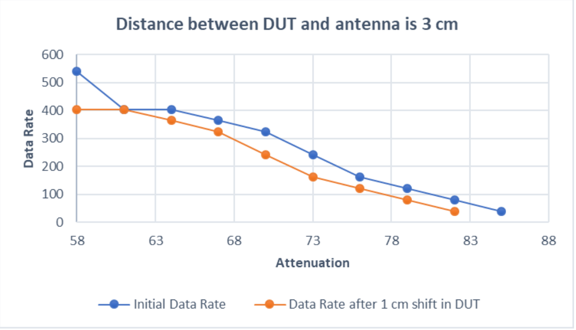

Figure 10: Theoretical data rates seen when the DUT is at 3 cm and then 4 cm from the test antennas

As can be seen, there can be changes of tens of Mbps when the DUT is moved.

Sensitivity at longer DUT-to-antenna distances

However, if the test above is done with a 12 cm Tx-to-Rx separation, there is *no effect at all* seen when there is a 1 cm change in the DUT position. That is, if we take the data with the DUT at 12 cm, and then take the data with the DUT at 13 cm, the data is the same, so only a single curve appears on the plot. See Figure 11.

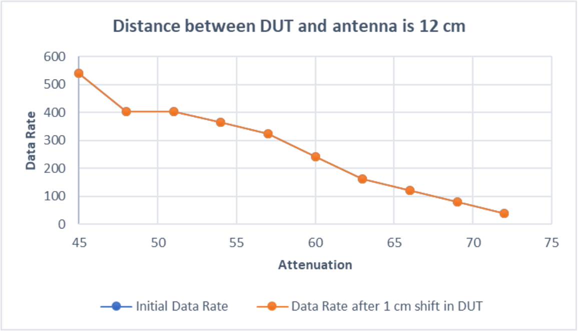

Figure 11: Theoretical data rates seen when the DUT is at 12 cm and then 13 cm from the test antennas

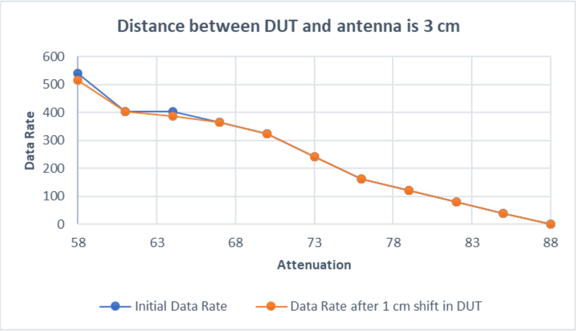

Figure 12: Theoretical short distance data rate results with the data averaged over rotation

Sensitivity at short DUT-to-antenna distances, but with data averaged over DUT orientation

If we return to the first test, at short Tx-to-Rx separation, we find that reproducible results can be obtained when the turntable is used to gather data over a full rotation of the device, and that data is then averaged together. When this is done the effect of changes in the DUT position may be reduced.

For example, we repeat the measurements for which the initial Tx-to-Rx separation is only 3 cm. As shown in Figure 10, this can show large data rate variation when the DUT is moved by 1 cm. However, if the data is averaged over a full rotation of the DUT, then a change in the DUT position has virtually no effect on the measurement results. See Figure 12.

The reason for this is that when the DUT is moved by 1 cm from its initial position, the rotation will sometimes bring it close to the antennas, and sometimes further from the antennas, and the averaging of these measurements removes the sensitivity to the initial DUT placement.[1]

Summary

It has been verified by users worldwide that, with appropriate care, both repeatable and reproducible results can be achieved using the octoBox personal testbed. Among the precautions that should be taken:

- Placing the DUT in roughly the same orientation for each test,
- Keeping the high gain antennas in the same positions/orientations,
- Placing the DUT as far from the test antennas as possible (which may reduce throughput),
- Rotating the device under test to average out the sensitivity to the DUT position and orientation.

[1] The simulation discussed here looks only at the effects of rotation on smoothing out the variability due to path loss issues. There are other good reasons to use rotation averaging of results, such as reduced sensitivity to the specifics of the MIMO environment. These will be discussed in a separate whitepaper.

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