TESTING PASSIVE NETWORKS IN DISTRIBUTED ANTENNA SYSTEMS (DAS)

White paper | Version 02.00 | Keith Cobler

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CONTENTS

1 INTRODUCTION

Worldwide consumer demand for cellular services has driven network operators to strive for better network coverage and within that coverage footprint, better network capacity. Since more than 80% of cellular traffic comes from inside a building of some sort, in-building coverage and in-building capacity have become a focus of this effort [1]. In addition, in many countries emergency service providers require cellular access in all areas of large buildings, adding to the importance of in-building coverage. This emphasis is regional and particularly prevalent in Asia and North America [2]. Overall, global growth in the DAS market is projected to be above 10% CAGR through 2023, reflecting an increase from around USD 8 billion to about USD 14 billion by 2023 [3].

This has created a thriving infrastructure of contractors who install and test DAS and work with the often complex cable and antenna systems. This white paper focuses on these DAS-oriented cable and antenna tests.

2 DAS TESTING OVERVIEW

Network operators and public safety providers who rely on DAS need to know that the DAS they use will work for their specific RF bands and technologies providing the necessary capacity and coverage. Given the complex nature of a DAS RF system, the need to cover multiple RF bands, and challenges with physical access to the cables, the DAS installation industry has mostly moved to a "test first" philosophy. It has proven to be cost-efficient to test these systems thoroughly and completely during installation.

There are a lot of RF testing steps in a typical DAS installation, starting with cable and antenna tests, PIM, branch tests and system level tests and then moving on to RF leveling and walk testing. This is all done with the intent of optimizing capacity.

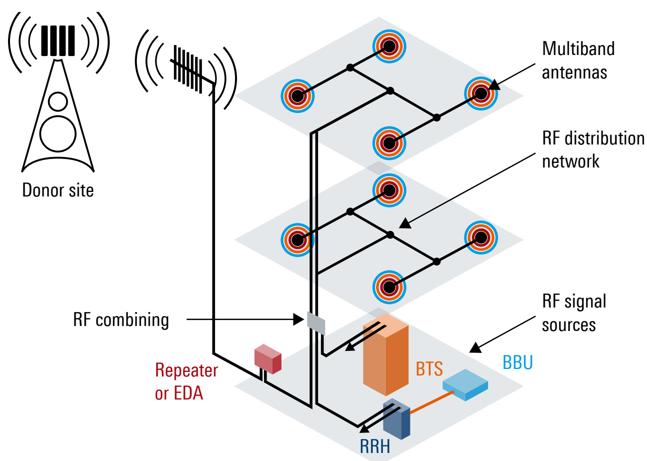
Installations in larger venues, such as a sports stadium or a large convention center, can require literally tens of thousands of measurements. Testing in medium-size installations, such as might be found in a multistory office building or hotel, can still generate thousands of measurements. But why are so many measurements required? To answer this question, we will need to take a look at the different DAS types and how they are tested.

3 DAS CATEGORIES

DAS can be grouped into general categories, depending on the signal source, amplification and signal transport media. Since the testing requirements vary greatly within a given category, let us take a brief look at several types of common DAS installations.

3.1 Passive DAS

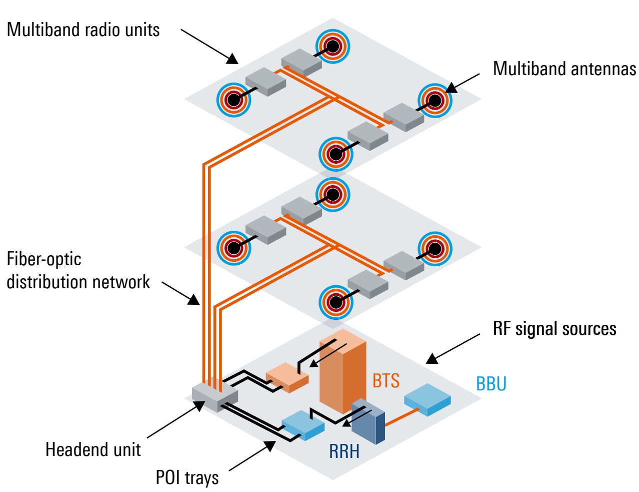
Figure 3-1: Passive DAS with a macro cell donor



A passive DAS is intended to provide a simple coverage solution for smaller buildings. The central idea of a passive DAS is that it takes the signal from an external macro tower or perhaps an internal source and repeats it through a passive network of splitters, cables and antennas inside the building. In turn, it receives the user equipment signals from inside the building and repeats them for the external tower or other cellular RF interface. If the design allows, network operators and public safety can share a passive DAS system, implementing multiple technologies and frequency bands through the passive cable, splitter and antenna network, much like they do over-the-air with longer range radio systems. A passive DAS can be expensive to install and test as well as difficult to modify. This is due to the long length of semi-rigid coax cables used and the limited ways to adjust power at each antenna, which is necessary to ensure good coverage. To make matters more interesting, whatever is done to adjust power at one antenna will affect power levels at other antennas.

3.2 Active DAS

Figure 3-2: An active DAS layout



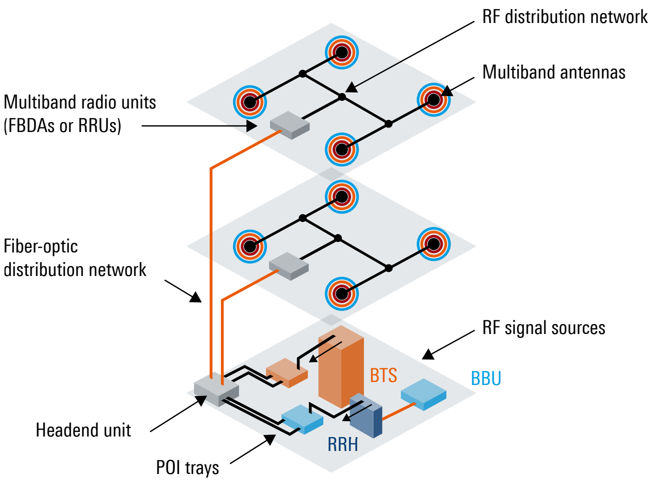
An active DAS may be created in many different configurations, but the one pictured above is very common. A variety of transceivers create RF signals on various bands. The RF signals are converted to optical analog signals, distributed on fiber to multiband radio units, converted back to RF and then transmitted from the local antennas. The terminal antennas and radio units may be either integrated into one physical unit or separate.

Active DAS systems offer the greatest installation flexibility, since fiber is much easier to install and route than RF cable, and it is much easier to adjust power at each antenna for good coverage. There is a lot of flexibility in the selection of RF signal sources when adjusting cellular sectors.

However, active DAS systems are expensive. The equipment is significantly more costly than the equipment for a passive DAS and the multiband radio units take up a lot more space for the antenna location at the real estate. An active DAS offers flexibility and, in some cases, may be the best solution.

3.3 Hybrid DAS

Figure 3-3: Hybrid DAS configuration



A hybrid DAS combines these two technologies. The idea is to combine the flexibility of an active DAS with lower cost. The hybrid approach can be cost-effective and at the same time, it improves cellular capacity. This is the most common type of installation in larger buildings and sports venues. In this case, the RF signal sources can be located in an equipment room somewhere on the premises and use fiber for the longer signal runs. Once the fiber gets to the desired floor, stadium section or other endpoint, a multiband radio unit is used to convert the analog optical signals back to RF. Then, the RF carriers are routed through a local RF cable, splitter and antenna network. This section, from the multiband radio units to the antennas, is often referred to in the industry as a branch. The base of the branch, the multiband radio unit, is referred to as either an FBDA or an RRU.

While a hybrid DAS is less flexible than an active DAS and will have a somewhat higher noise figure, it is better on both counts than a passive DAS, and it is less costly than an active DAS.

4 OTHER DAS TYPES

While not as prevalent, there are other ways to implement DAS:

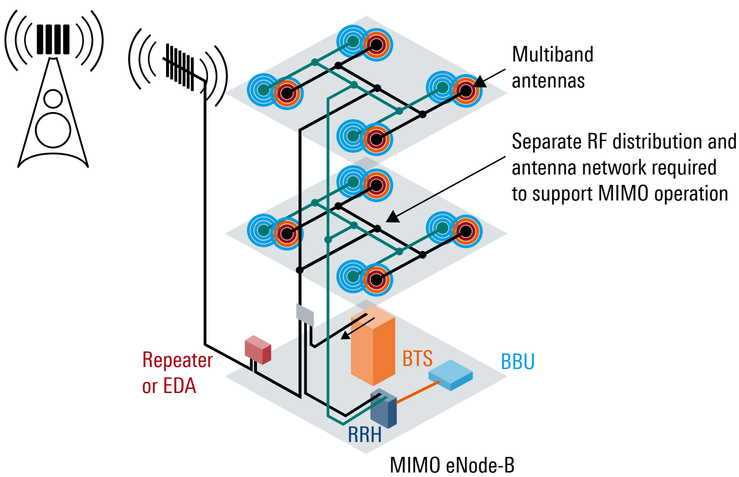
- A **digital DAS** uses the CPRI digital communications protocol on the fiber link and a number of multiband radio units with integrated antennas at the terminal locations. This is cost-efficient and flexible, including the ability to dynamically reallocate capacity, but is sometimes hindered by compatibility issues between various vendors' equipment. Incompatible firmware updates, for instance, can cause serious issues.
- A **DRS** provides much the same capability as a DAS, but uses NEM radio units with integrated antennas. One NEM builds all of the equipment in the system, and the communications links may be proprietary. Initially, this sort of system has been limited to one frequency, one technology and one network operator, making multiple installations necessary for each technology and operator.
- **Distributed small cells** are another way to install a DAS. In this case, the small cells are installed locally at the desired antenna site, in much the same way as they would be on the street. This is primarily a single operator solution, which means that costs may be the biggest issue.

5 VARIATIONS ON A THEME

5.1 MIMO considerations

As shown in the figure below, MIMO technology doubles the requirement for cables, splitters and antennas. In the case of a passive DAS (illustrated), this means a complete duplicate cable, splitter and antenna installation, greatly increasing the complexity, hardware and testing costs. In a similar manner, MIMO also doubles the branch hardware requirement for a hybrid DAS.

Figure 5-1: Effects of LTE's MIMO technology on a DAS



5.2 Neutral host considerations

A neutral host system is designed to work for any desired cellular band and with all communications technologies. It may also work for emergency services and with Wi-Fi. This complicates testing, since a neutral host system must be tested on each certified frequency band, and if one of the technologies is LTE, it may also involve MIMO. The costs of the system can be shared between network operators, thus reducing the financial burden on a single operator.

5.3 Outdoor DAS

Figure 5-2: One node of an outdoor DAS installation near a sports venue

Another concept of interest is that DAS can be created as either an iDAS or oDAS. Our discussion has focused on iDAS. An oDAS will typically be installed to enhance the capacity outside a venue. While an iDAS tends to be quite large, oDAS is similar to a small cell tower with remote radio heads for each sector and frequency accessed by fiber from a remote location. Once configured, this design is often replicated for each outdoor location. In this case, testing will be repetitive and done quickly, though the rigor of the tests does not change.

5.4 Emergency services DAS

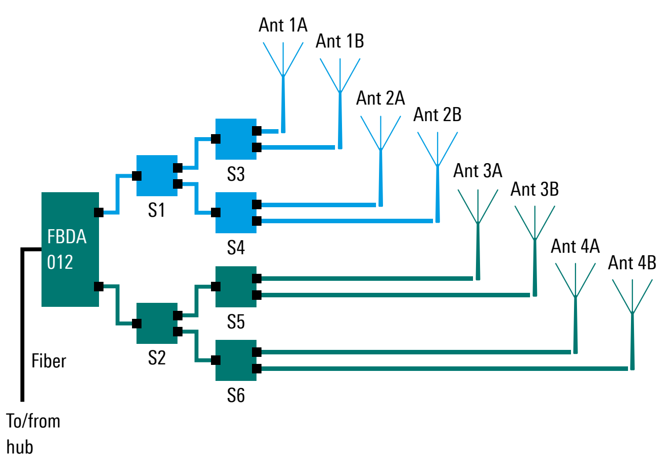
Emergency services may choose to share infrastructure with the network operators as part of a neutral host DAS or, in some cases, may require installation of a separate DAS. The public safety DAS requirement is often the responsibility of the building owner to install, similar to building safety requirements such as sprinklers and emergency exits.

6 DAS BRANCH TESTING

The major goals of a DAS installation are to make sure that coverage is even between antennas, handover locations are precisely defined to control sector loading, and distortion is minimized. This allows maximum cellular traffic capacity. A walk test is often used to verify that these goals have been achieved. A successful walk test requires accurate RF power at each antenna, in each frequency band and with good signal quality. Achieving accuracy at the antennas requires accurate knowledge of the cable, splitter and antenna network in each branch and in each frequency band. Accurate knowledge of the cable, splitter and antenna network requires comprehensive testing of the cable, antenna and splitter network (the branch) in each deployed band.

To understand the implications of these test needs, let us take a look at an example. We will select a common installation, a hybrid DAS branch as shown in Figure 6-1. As part of the example, we will assume that this is a neutral host installation with three required frequency bands. In the United States, this might be frequency bands from 698 MHz to 960 MHz, 1695 MHz to 2200 MHz and 2200 MHz to 2700 MHz. The latter two frequency bands may be combined into one band for testing or tested separately depending on the end-customer's requirements. We will assume they are combined in our example. It is worth noting that this method of testing reduces the total number of bands that need to be tested, saving time and complexity. An example of this is the frequency band from 2200 MHz to 2700 MHz, which can contain public safety, Wi-Fi and cellular bands.

Figure 6-1: MIMO hybrid DAS branch example



Much of the RF testing is concentrated in the branches, the part of the hybrid DAS between the final RF transceiver and the air interface. When considering the test needs of this network, one key point is that most of the RF cable in a branch comes in large spools and the connectors are mated to the cable on site. This means that the cables undergo final assembly on site and therefore should be fully tested. In addition to the cable tests, antennas may also have required tests. For example, antennas can be defective and/or interact with nearby metal or corrosion in the surrounding environment.

In the case of a hybrid DAS system, the multiband radio unit at the base of the branch is often an FBDA or an RRU. Branch build and test normally starts at the FBDA or RRU (the base of the branch) and proceeds towards the antennas. The tests can be divided into tests for each cable, for each antenna, for the cable and splitter assembly with a load in place of the antennas, and for the fully assembled branch including antennas. Specific branch tests include return loss, cable loss, distance-to-fault and PIM. After passing these tests, the complete DAS will undergo RF leveling tests and walk tests.

In the case of a MIMO branch, the number of tests will multiply, as explained before, along with the numbers of cables, splitters and antennas.

Each cable in every band must be certified to be defect-free before use. These tests include return loss, cable loss and measuring PIM in the extreme bands. These specific tests are explained in the next section. In our example, there are only two frequency bands, but in general up to five frequency bands may be required. All of this is done with the goal of making the RF leveling test and walk tests run smoother, as it can be painful to fix issues in those phases of the build-out.

7 BRANCH TESTING

Branch testing can be separated into per-cable, per-antenna, per-branch and per-system tests. Per-cable tests are run on each cable assembled on site. Per-branch tests are run from the base of a branch with precision loads, instead of antennas at the other end of the cable assembly. Per-system tests are run from the base of the branch with antennas installed.

7.1 Per-cable tests

Specific per-cable tests typically include:

Return loss

This test spots any defects in the cable or connector that causes reflections or standing waves. Excessive reflections rob power from the signal, add distortions and can cause the RF transceiver to shut down when very large. Return loss is normally measured for each frequency band used. This test is done with a precision load at the far end of the cable.

Figure 7-1: Return loss measurement on an RG-58C cable with source power at 0 dBm using an R&S®ZVH cable and antenna analyzer

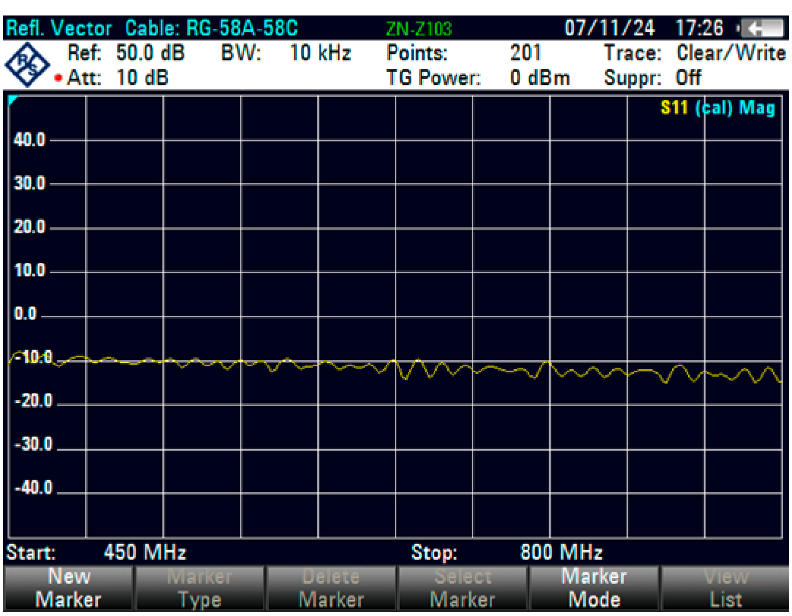
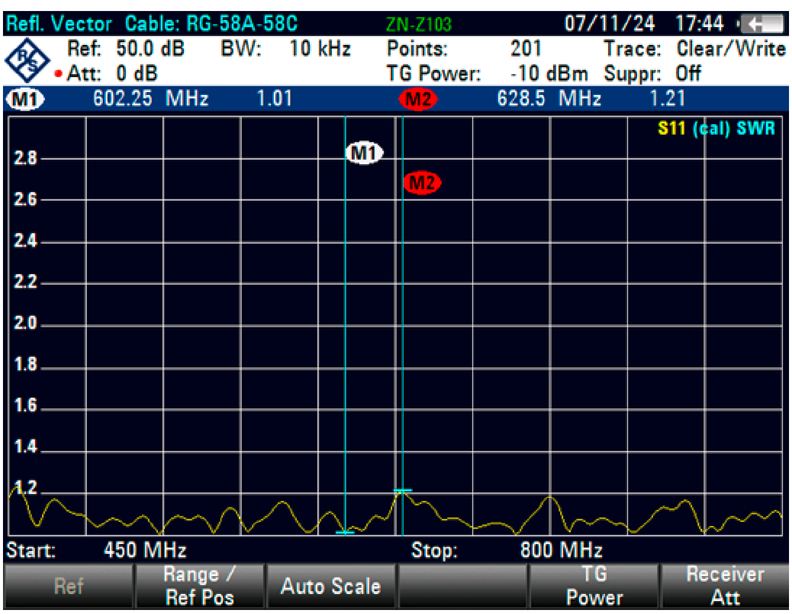


Figure 7-2: Return loss measurement on an RG-58C cable with source power at –10 dBM using an R&S®ZVH cable and antenna analyzer

Figure 7-3: VSWR measurement



DTF

This test provides the distance to any abnormality in the cable that generates a significant return loss. This might be a cable defect, a minimum bend radius violation in the cable (a kink), an improperly installed connector or a crimp due to a tight clamp. This test is often done only for the lowest frequency band to be used, but may be done over the full frequency range in which the cable is to be used. This test is done with a precision load at the far end of the cable.

Figure 7-4: DTF measurement: The result shows that the cable had faults at 8.87 m and 23.6 m

Cable loss

One-port cable loss is a measure of signal attenuation in the cable. Cable loss varies with frequency, cable type and cable length and is taken into account as part of the DAS design. Excessive cable loss can make the cable unusable or make it impossible to balance the RF power at the antennas. Cable loss is normally measured for each frequency band in use. This test is done with a precision short at the far end of the cable.

Figure 7-5: Cable loss measurement across a 25 m long cable

7.2 Per-antenna tests

Antennas may or may not be tested prior to being assembled to the branch. This decision depends on the confidence the engineering team has in the particular antenna brand and model used. If the antennas are tested individually, specific per-antenna tests include:

Antenna return loss

These tests are normally made for each band the antenna covers, which may include up to five measurements per antenna. If the antenna bands are contiguous, the number of return loss measurements may be reduced.

7.3 Per-branch tests

The next stage of testing is to check the assembled branch (without the antennas connected). Instead, a precision load is used in place of the antennas for the return loss and DTF testing, and a 50 Ω load is used in place of the antennas for the branch. A commonly used term for this phase of testing is "branch testing".

Branch return loss

This test is normally done in each implemented band. This is different than the cable return loss, since now all the cables and splitters are connected. This test can catch loose connections or mismatches that would lead to a transmitter VSWR alarm. Caution is needed, as inherently lossy components such as couplers and splitters can mask return loss faults in an assembled cable branch. This is why return loss testing for each cable is so important.

Branch DTF

This test can be used to identify the location of mismatches in a branch. However, some branch topologies may put multiple antennas at the same electrical distance from the test point, so be careful when interpreting the results. For this reason, a branch DTF measurement is most useful when recorded during construction and used to spot changes at a later date. Branch DTF is normally done in the lowest contiguous frequency range.

7.4 Per-system tests

The final stage of branch testing is the system test. For this test set, the branch is fully assembled with antennas, properly torqued and tested as a whole:

- System return loss: This may be required in each contiguous band once the antennas are installed. As in the branch tests, faults may be masked by inherently lossy components
- System DTF: This may be used to record the final location of components (good reference for later troubleshooting)

8 SIMPLIFYING THE PROCESS

8.1 Branch testing example [1)]

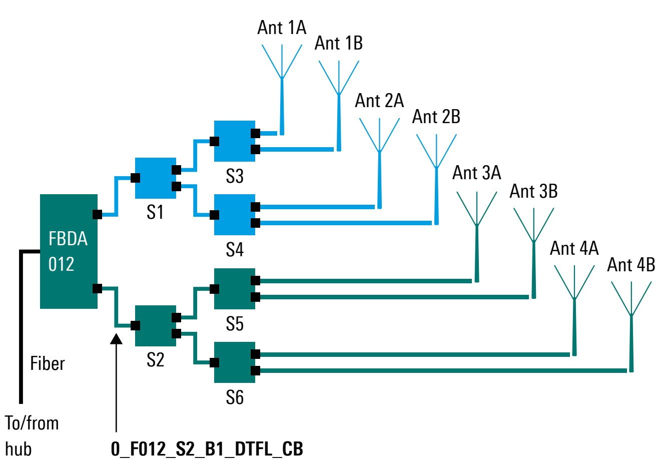
To appreciate how branch testing works in practice, let us go back to our neutral host MIMO hybrid branch example with two aggregated frequency bands for testing. In this case:

- For each cable, we need to make 2 return loss, 2 cable loss, 1 DTF and 2 PIM tests. This amounts to 7 tests per cable. With 14 cables in our example branch, that means 98 cable tests
- If antennas need to be tested, we will likely need 2 return loss and 2 PIM tests per antenna for 32 antenna tests
- The branch tests will require 2 return loss, 1 DTF and 2 PIM tests for a total of 5 branch tests
- The system test will also require 2 return loss, 1 DTF and 2 PIM tests for another 5 system tests

Figure 8-1: DAS antennas may be difficult to reach after installation

This works out to either 103 or 135 total tests for our small example of a neutral host MIMO branch with two discrete RF bands and four MIMO antenna pairs. With some venues requiring dozens or hundreds of branches, it is easy to see that branch testing and keeping track of the branch tests deserve special attention.

Figure 8-2: Example cable name



1) PIM test details not included.

Major time sinks when running branch tests include:

- Getting physical access to both ends of the cable and getting equipment and personnel in place to gain access to both ends of the cable can be expensive and time-consuming. This often involves man-lifts and catwalks
- Measurement naming issues
  - Typing the trace name into the instrument can take a significant amount of time and is an error-prone process
  - For example, an actual trace name might be 0_F012_S2_B1_DFTL_CB. To expand this name, let us use the example in Figure 8-2. This name would indicate that this trace is for stadium section 0 in the FBDA 012 (F012) branch, connected to the FBDA side of splitter 02 (S2) in RF band 1. The test would be a DTF with a load on the far end of the cable (DTFL) and it would be a cable test, not a branch or system test (CB). Test names are highly specific
- Mislabeling or otherwise losing the trace, requiring rework
- Improper measurement setup, requiring rework
- Submitting a failed trace as good, requiring rework
- Lack of trace naming standards is extremely inefficient
- Rework requiring the crew to return to the site will likely delay payment by weeks or months

It is clear that branch testing needs to be done right the first time.

8.2 Naming measurements

While test equipment cannot address all of these issues, the proper selection and use of test equipment can address some of them. Measurement naming, in particular, can be a significant time sink. Not only can misnaming create lost traces and rework, it can also take quite a bit of time to type in filenames (in some cases, this takes more time than the actual measurement). Remember that a measurement can take a few seconds, but typing a complex filename is slow.

Figure 8-3: Quick name feature in the R&S®ZVH handheld analyzers saves the measurements in sequence by keeping the prefix of the assigned name constant and incrementing the sequence on every measurement

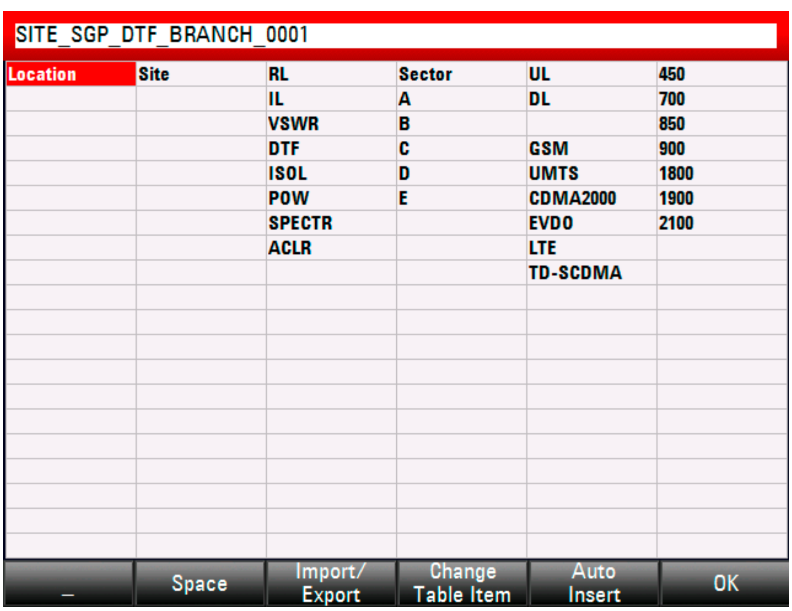
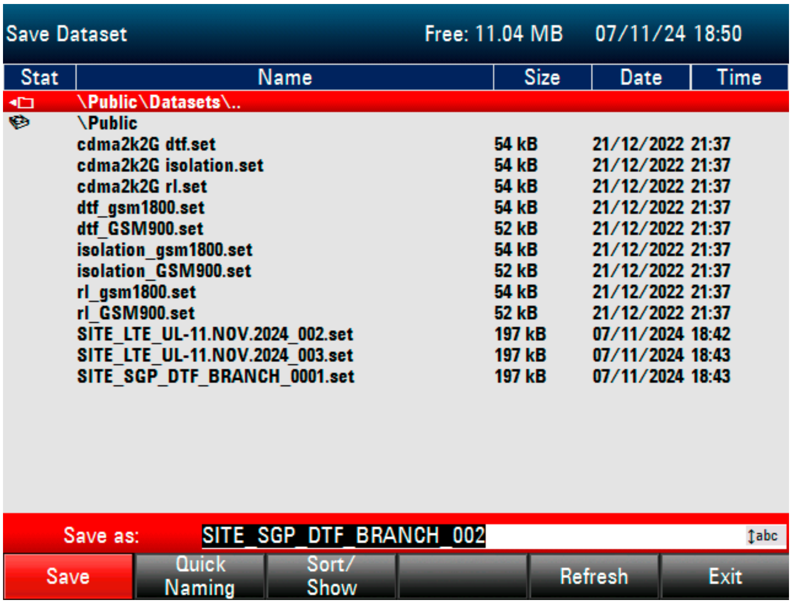


Figure 8-4: Auto generated name in sequence

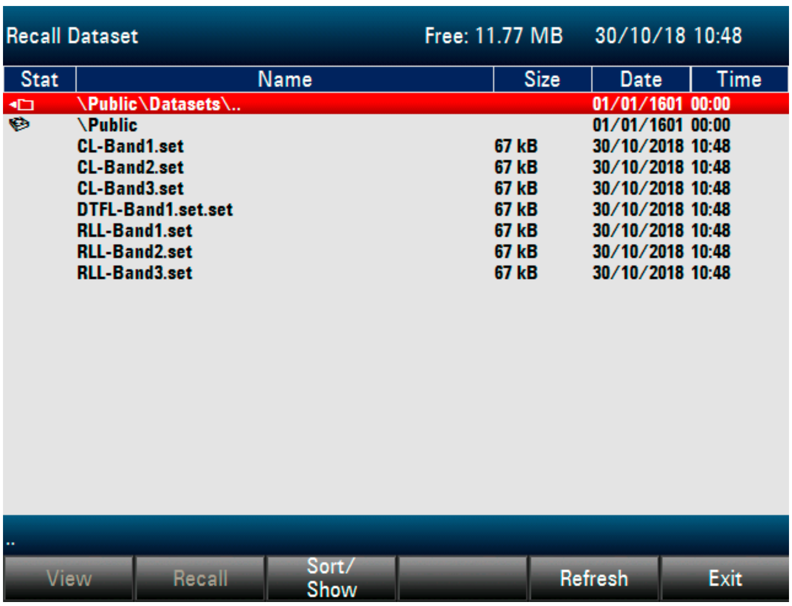


The quick name table editor in the R&S®ZVH cable and antenna analyzer software can dramatically shorten this time, while also helping to reduce errors. Figure 8-4 shows a screenshot of a set of quick name selections in the R&S®InstrumentView software from an R&S®ZVH8 cable and antenna analyzer. When creating a filename for a trace, the user simply selects the filename segments, one from each column, and the name is created. An underscore or space can automatically be added between naming segments. Using this technique, a filename like 0_F012_S2_B1_RLL_CB can be quickly and accurately created. Sets of quick names can be stored on the R&S®ZVH8 and recalled as needed.

9 SAMPLE DATA SETS

Setting up the instrument from the front panel can be tedious and error-prone if done for each measurement. A simple solution is to create sample data sets ahead of time. In Figure 9-1, three cable loss, three return loss and one DTF data set(s) have been created and stored on the test equipment. When a test is needed, the generic test can be recalled, executed and then saved as a specific result using the quick name matrix. This eliminates error-prone repetitive setups, provides consistency and speeds up the overall process. It also gives the user flexibility to modify setups on a one-time basis if, for instance, the particular cable being tested is longer than the default DTF length.

Figure 9-1: Sample cable test setups on the R&S®ZVH8



10 WIZARD APPLICATION AND REPORT GENERATION

Considering a multistory building that has a large network of identical DAS mesh for each floor, testing of such a site may be cumbersome and manual intervention more prone to human errors. In addition, the site supervisor/engineer may find it difficult to compare the same test results provided by different technicians as they may use different settings for the same measurement. Measurement compilation errors may also be a cause of concern that is time-consuming for the supervisor. In such a situation, a small error would be like searching for a pin in a haystack.

To overcome this situation, Rohde & Schwarz came up with an innovative solution to maintain parity among different tests by introducing a free of charge wizard application. In the wizard application, each measurement is saved in the form of a .set file. These .set files may be prefixed with the respective measurement header. To create the wizard, the user needs to install the R&S®InstrumentView software from the Rohde & Schwarz website, select the desired instrument and choose: Preparation ▶ Wizard Sets.

Figure 10-1: R&S®InstrumentView with the list of available .set files

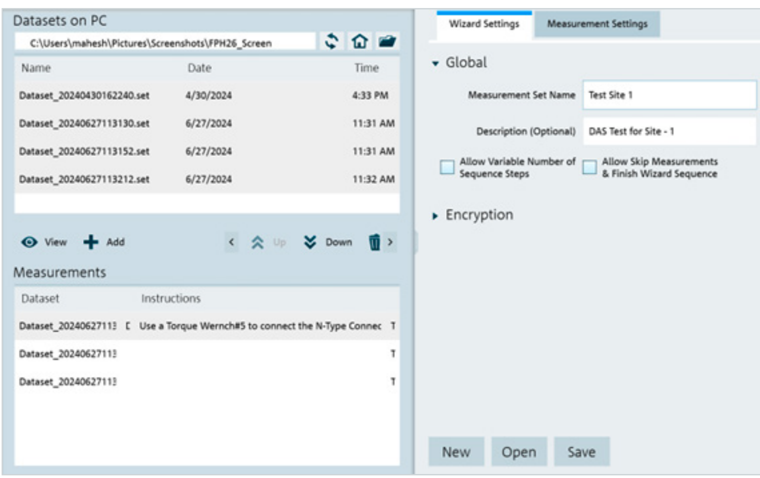
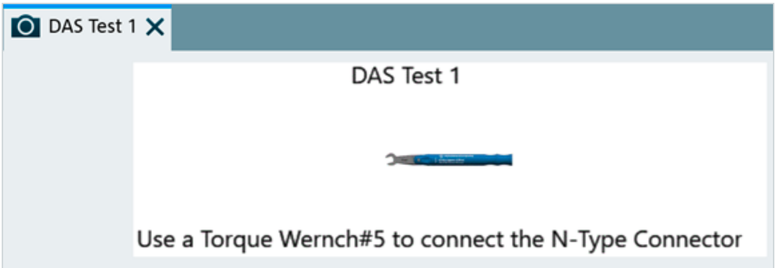


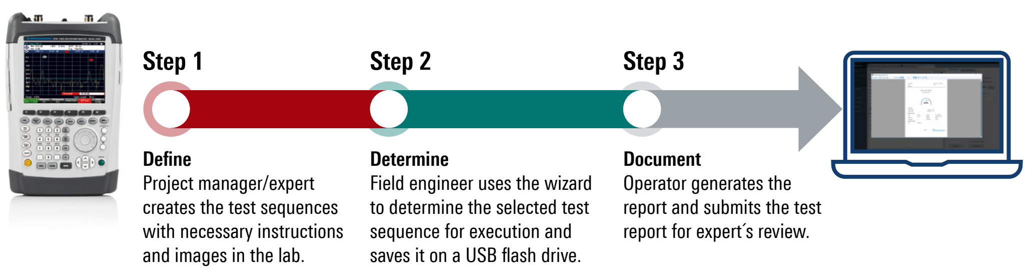
Figure 10-2: Definition of a specific measurement with instruction and image

Figure 10-3: Preview of the uploaded image (the same instruction and image are shown to the user while executing the measurement result)



When the supervisor/engineer has completed the preparation of the wizard file, it can be saved on a USB flash drive and shared with the field technicians. In the field, the technician just needs to insert the USB flash drive and load the wizard application, which then gives a step-by-step procedure for the defined measurement.

Figure 10-4: Definition of a specific measurement with instruction and image



11 SUMMARY

In-building cellular coverage has become important for both emergency services and high-speed cellular data communications. This has generated a surge in DAS installations, particularly in North America and Asia.

The complexity of DAS and the expense of rework have led to a climate where it is generally accepted that complete testing must occur during installation. The side effect of this policy is that even simple systems, such as our four paired antenna MIMO examples, can require dozens or hundreds of documented tests. The payoff of the "do it right the first time" philosophy is immense and thus has resulted in the need to simplify the testing process as much as possible.

DAS physical component access, trace naming, load swapping, repetitive instrument setups and report generation are all considerable time sinks. Use of the R&S®InstrumentView application coupled with an R&S®ZVH cable and antenna analyzer can greatly simplify the test process and reduce costly rework.

The examples in this white paper were created using the R&S®ZVH8 cable and antenna analyzer. While we have focused on the cable and antenna test requirements, Rohde & Schwarz has a full line of handheld and portable test and measurement equipment ideally suited for DAS in-building and outdoor testing and turn-up. To learn more about these and other products, visit www.rohde-schwarz.com or contact your local Rohde & Schwarz sales office.

Keith Cobler, Rohde & Schwarz USA, Inc.

12 REFERENCES

Number	Reference
[1]	In-Building Mobile Data Traffic Forecast; ABI Research, January 2016
[2]	Global Distributed Antenna Market Research Report – Forecast 2022; Market Research Future, September 2018
[3]	Distributed Antenna System (DAS) Market by Offering (Components and Services), Coverage (Indoor and Outdoor), Ownership (Carrier, Neutral-Host, and Enterprise), User Facility, Vertical (Commercial, Public Safety), and Geography – Global Forecast to 2023; MarketsandMarkets, June 2018

13 ABBREVIATIONS

BBU	baseband unit
BTS	base transceiver station
CPRI	common public radio interface
DAS	distributed antenna system
DRS	distributed radio system
DTF	distance to fault
EDA	electronic directional amplifier
FBDA	fiber bidirectional transceiver
iDAS	indoor DAS
LTE	long term evolution
MIMO	multiple input multiple output
NEM	network equipment manufacturer
oDAS	outdoor DAS
PIM	passive intermodulation
POI	point of interface
RF	radio frequency
RRH	remote radio head
RRU	remote radio unit
VSWR	voltage standing wave ratio

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Data without tolerance limits is not binding | Subject to change