Advancing beyond

Distributed Port Approach to Network Analyzer Measurements Over Distance

Introduction

Measuring networks with two ports separated by more than several feet, or in situations where it is hard to place a vector network analyzer (VNA) in close proximity to the ports of a device-under-test (DUT) has always been a challenge. The typical solution to this challenge is to sacrifice measurement completeness and use only a single port network analyzer, use a remote power sensor with a VNA, or to vastly increase the cost of test and use a high performance 2-port VNA and long lengths of low-loss VNA coaxial cables. Any of these methods require measurement quality sacrifices and ultimately degrade the dynamic range of the measurement. Fortunately, there is a new solution that leverages high precision timing synchronization between two 1-port VNAs to create a distributed 2-port VNA. This modular instrument directly connects through standard coaxial connectors to the DUT's ports, which may be separated by over 100 meters.

This paper discusses the historical challenges associated with network measurements over distance, applications where this is a challenge, the unique considerations for these applications, and how this new modular solution addresses these challenges and opens the doors to a new realm of 2-port VNA measurements that are port separation distance agnostic to 100 meters.

Why Make Network Or Transmission Measurements Over A Distance?

In many RF systems the DUT can be much larger or more spread out than what is commonly seen in laboratory testing conditions. For instance, once an RF system is installed, there are often long stretches of transmission lines or waveguides connecting various components of the system, sometimes separated by over 100 meters. These stretches of transmission lines intrinsically impact the RF system and are often installed in such a way that finding faults and troubleshooting poses difficulties. Large test chambers and sites may cover relatively large spaces, and large vehicles, such as aircraft and ships, are themselves large DUTs. The following is a brief description of applications that benefit from transmission measurements over a distance.

Installed Cable Testing

In the case of installed transmission lines, cables, and waveguides, performing precision testing is a challenge given the often long separation distances between the ends of the lines. It is often critical to know the actual loss through a given interconnect routing or to perform periodic maintenance checks, which are only possible to ascertain through direct measurement of the insertion loss over the distance (frequency sweep). In other situations, such as high reflections at one end of the line indicating some type of cable fault/failure, time domain measurements and distance to fault measurements are valuable in determining the exact location of the fault. These measurement methods are especially useful when the installed lines are routed through a vehicle, building, tunnel/mine, or industrial facility where accessing the cable behind walls, bulkheads, conduit, or multi-cable bundles would otherwise potentially obscure a visual inspection of the fault.

Given the lengths of these cables and often complex and difficult to reach routing scenarios, traditional test and measurement equipment isn't well suited to perform these tests. Part of this issue is that these cables need to be tested in place, which requires bringing the test and measurement equipment to the ends of the cabling and any amplitude or phase variation after calibration leads to greater instability. Also, long interface cables add instability to any measurement, as well as contributing significantly to the insertion loss (an issue that is exacerbated at higher frequencies). Not only are these tests somewhat difficult to perform with traditional test and measurement equipment, the often rugged/harsh environments may otherwise lead to increased wear-and-tear on equipment that may be severe enough to limit measurement accuracy to below a usable level.

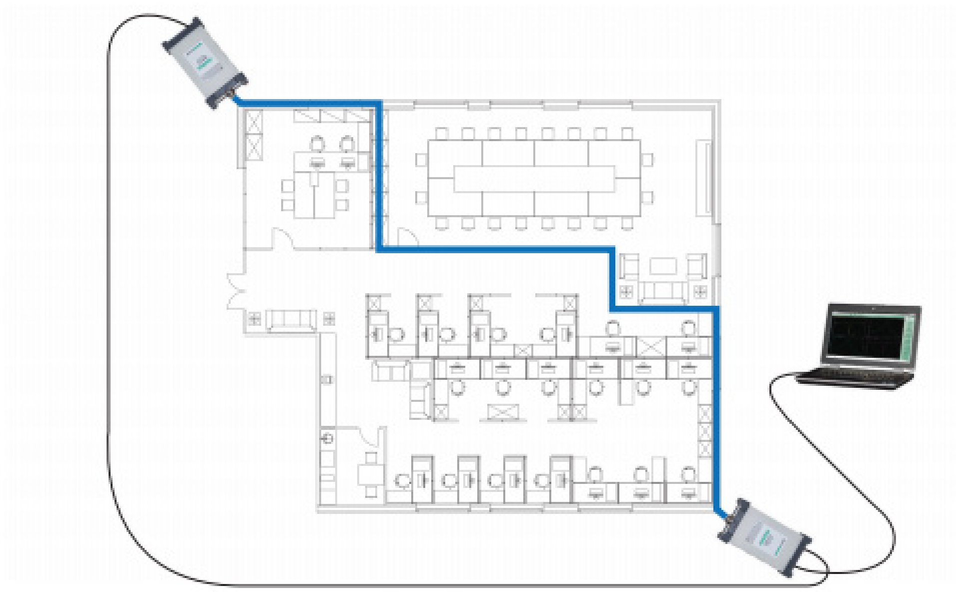


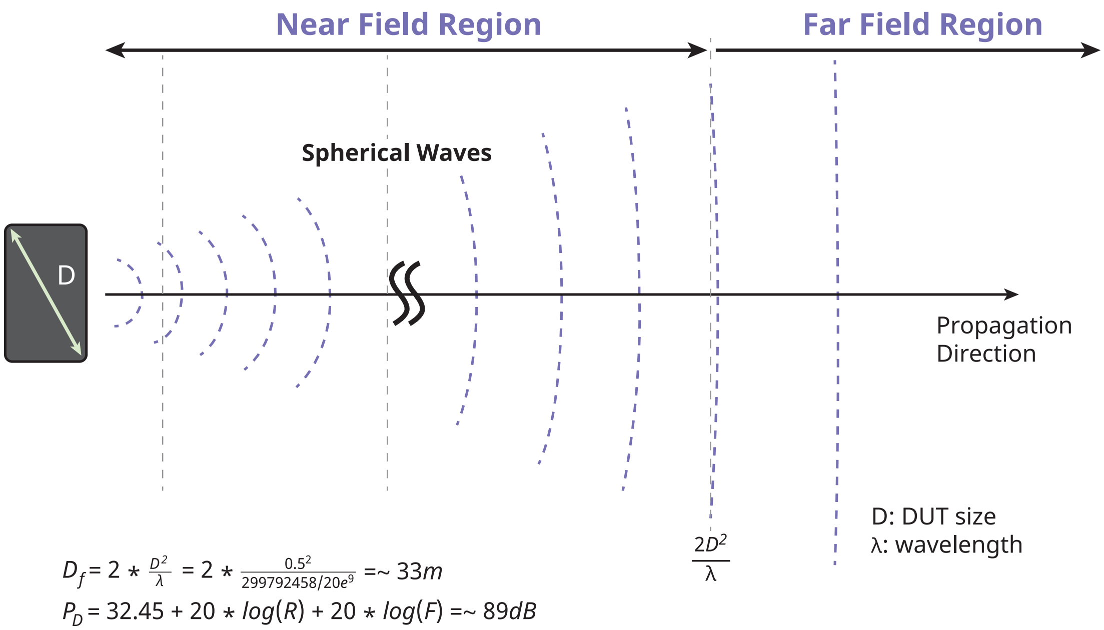
Figure 1. *Example Setup for Testing Insertion Loss of an Installed Cable within a Building*

Over-the-Air (OTA) Antenna Test Setup

OTA test ranges and chambers are often used to make channel measurements, as well as making antenna pattern measurements. Modern antenna pattern measurement applications include measuring 5G active/advanced antenna systems (AAS) that employ beam steering technology, so DUT control is also needed to perform beam steering characterization tests.

Outdoor antenna test ranges are used in similar ways to large RF test chambers, but may be used to test larger/higher power antennas over longer distances. This includes far-field testing for lower frequencies, as the distance from the antenna to the far-field is a function of wavelength. The distances from the antenna to the test port and the desired dynamic range make these measurements difficult with traditional test and measurement methods. Moreover, for antenna null testing and beam steering testing, the measurement antenna may require repositioning that may impact the uncertainty of the measurements.

The factors that come to play with this are atmospheric losses and cable losses, with both of these factors increasing with distance and at greater loss-per-distance at higher frequencies. The total cable loss in conjunction with atmospheric losses, even with lengths of high precision low-loss coaxial cabling, eventually becomes high enough to limit the maximum possible measurable distances for outdoor ranges without large amplifiers or other significant hardware workarounds. See the following:



Note: The path loss for an antenna operating at 20 GHz (λ = speed of light/frequency) with the largest radiator dimension of 0.5 m (D) is over 89 dB after the far field distance (D_f) of roughly 33 m. The free space path loss being a function of the free space loss (PD), the distance (R) in meters, and the test frequency in gigahertz (F). These path loss calculations do not include water absorption, any other material-based atmospheric losses, or antenna gain.

Figure 2. *Antenna signal path loss at far field distance*

Large Vehicle Electromagnetic Testing (Shielding & Propagation)

As aircraft, ships, trains, and other vehicles become increasingly connected, there has been a greater emphasis on developing wireless systems for extra-vehicle and intra-vehicle communications. Moreover, the increased use of highly integrated digital, analog, and RF systems sensitive to interference, makes ensuring the shielding quality of these vehicles a growing requirement. Hence, providing shielding measurements and propagation measurements for modern large vehicles, and even during retrofitting of older large vehicles (i.e., cruise ships), is an application with growing significance that is hampered by traditional test and measurement equipment. Common testing for these vehicles is to measure response nulls and multipath interactions within the vehicle, and these measurements require positioning of the measurement antenna in several locations within and without the vehicle.

The sheer size of modern vehicles and numbers of wireless systems operating at various frequencies poses substantial challenges when attempting to perform measurements externally and internally testing vehicle structures. Many of the issues mentioned above also impact this use case, including high cable attenuation affects limiting dynamic range, measurement stability concerns during cable placement/test antenna positioning, wear and tear on expensive interface cables, and the type of testing needed for these systems requiring stable phase measurements.

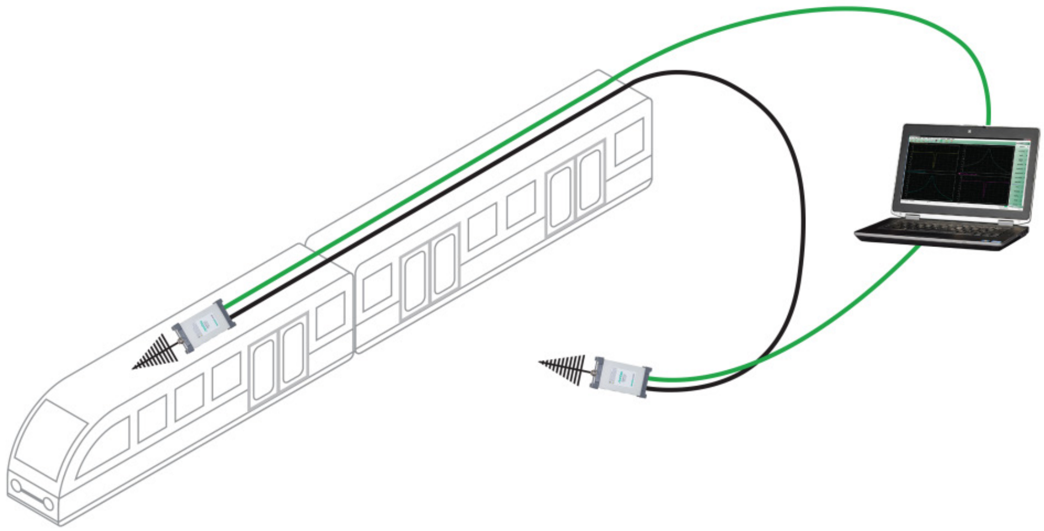


Figure 3. *Large Vehicle Electromagnetic Shielding and Propagation Testing*

Traditional Methods of Making Wide Span Network/Transmission Measurements

Most test and measurement instruments are made for laboratory or testing facility use, and are not necessarily well suited to field testing, testing large DUTs, or testing DUTs with ports separated by distances greater than a few meters. The following is a discussion of the current long cable insertion loss test solutions and the drawbacks of these methods.

1-Port VNA Reflection Measurement

A 1-port VNA reflection measurement technique enables vector reflection measurements from a single DUT port. Distance-to-fault (DTF) measurements, and some other time domain measurements, may be performed with this solution. However, the insertion loss measurements made with a 1-port VNA are not as accurate as the other solutions, and are typically only viable for less than 15 dB of total instrument return loss range and cable's return loss. If the cable's return loss is poor, this directly impacts the measurements as the cable's return loss divided by two is essentially the insertion loss measurement. Hence the poor cable return loss can become the dominant source of error, and precision cabling in good shape is needed to ensure accurate measurements.

Figure 4. *ShockLine MS46131A 1-Port VNA*

Scalar Insertion Loss Measurement

Another solution, though now considered an obsolete method due to availability of equipment, is to use a scalar analyzer to perform scaler insertion loss measurements. This method involves the use of a relatively bulky scalar analyzer that must be setup at either end of the DUT test ports. Another way to perform scalar insertion loss measurements is to use two portable VNAs, which obviously doubles the equipment cost and increases instrumentation setup complexity. Generally, low equipment availability, increased costs, and additional setup difficulties minimize the usefulness of the scalar insertion loss methods.

Traditional 2-Port VNA Measurement

A 2-port VNA setup, which can be done with a high performance VNA solution, can be used to perform all traditional two port S-parameter (magnitude and phase) measurements on a system. These units are generally higher precision and can produce more accurate measurements than scalar solutions, but require interface cables of appropriate lengths to reach between the VNA and the DUT ports. The insertion loss of the interface cables directly reduces the dynamic range of the measurement system, so for very long DUT separation distances, extremely low-loss and phase stable interface cabling and a very high dynamic range VNA are needed to reach a minimum desirable system dynamic range. Moreover, long lengths of interface cable introduce the potential for measurement instability as any changes to the interface cable, or the environment around the interface cable, may result in reduced measurement accuracy.

An option to reduce the RF losses of this setup is to use external mixing to downconvert higher frequency signals to lower frequency signals, as the losses within the interface cables will be less at lower frequencies. This method may aid in limiting the RF losses, but at the expense of requiring additional equipment, system setup complexity, calibration complexity, and increased uncertainty due to the potential for drift errors. This method also turns a previously broadband measurement method into a banded method, as any external mixing hardware will be a banded solution. Hence, additional external mixers would be required to perform wideband measurements that will have intrinsic differences in uncertainty.

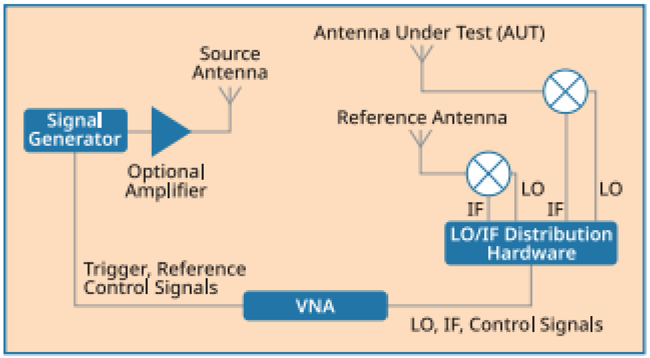


Figure 5. *Example Long Distance OTA Chamber Setup with Traditional VNA*

Another option is to use fiber optic port extensions to replace long runs of VNA interface cables. This option does add complexity and cost, as well as introducing potential signal-to-noise ratio issues with the insertion of active components in the measurement signal path. Depending on the RF/optical converters, this solution may also be banded and require several sets of RF/optical converters to cover the entire frequency spectrum of interest.

Overcoming Long Distance Network/Transmission Testing

As these types of testing situations are likely only to become more common, a new solution to long distance transmission testing would benefit those performing the tests and those in need of long distance transmission testing services. There are several factors that need to be addressed for a solution, which mainly involve replacing current 2-port VNA test equipment with a much more portable, rugged, lower cost, and more flexible solution whose ports can be separated by a wide distance without sacrificing measurement stability or dynamic range.

Necessary Features:

- High-frequency, wide-band coverage (not a banded solution)
- Wide dynamic range (~ 100 dB)
- Elimination of the need for long interface cables
- Full 2-port vector S-parameter measurements
- Enhanced measurement stability

- Reduced test signal attenuation
- Greater portability and equipment ruggedness
- Lower overall setup cost compared to current solutions

Solution Outline

The target solution should be a modularized 2-port VNA with source/receiver circuitry (distributed) that can be placed at the DUT's ports. This system would also comprise a synchronization scheme that enables phase synchronization of the measurement signals over long distances between the VNA modules located at the DUT ports. This solution should also ideally use common computer communication interfaces that can be used to process data and control the VNA with commercially available PCs.

Introducing A Distributed, Modular and Configurable 2-Port/2x 1-Port VNA Solution With Port Synchronization To 100 Meters

Given the challenges with network/transmission measurements over distance, the need for an enhanced solution, and the proposed solution requirements, Anritsu engineers devised a new distributed VNA architecture based on 1-port VNAs that are PC-driven. The choice to base the solution on 1-port VNA stems from the fact that current 1-port VNA designs contain source and measure circuitry within the solution, and these units are already designed to be compact, lightweight, and readily portable. These units are also designed from the ground up to be driven by a PC through a standard interface, such as USB, and are very easy to set up.

The other part of the solution innovated by Anritsu engineers is the synchronization technology to phase synchronize two 1-port VNAs over long distances. The synchronization method developed automatically handles source/receiver phase, frequency reference, acquisition control, and can maintain synchronization of these factors at distances over 100 meters.

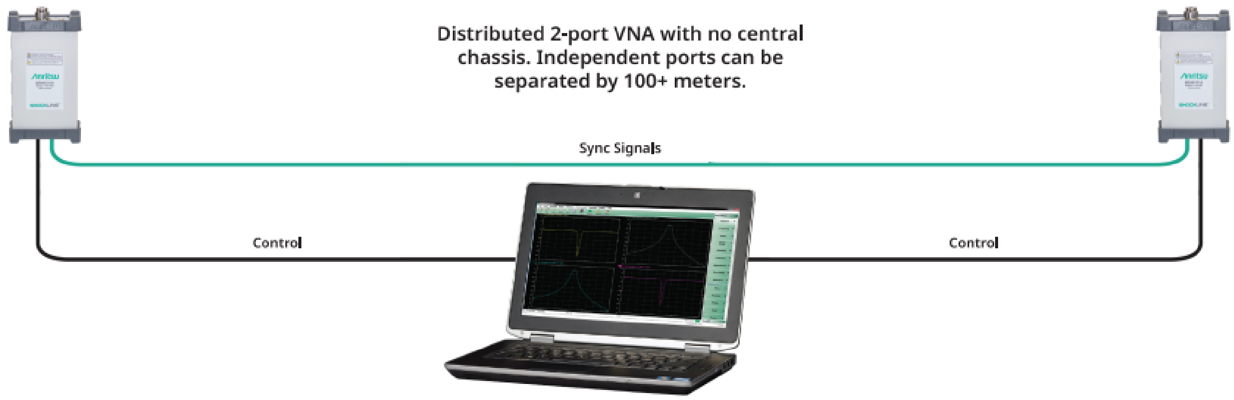


Figure 6. *Long Distance VNA Setup*

Features and Capabilities of ME7868A 2-port Distributed VNA

The solution became the Anritsu ME7868A 2-port VNA based on the 1-port MS46131A VNA. Inheriting the well-established hardware and software developed for previous Anritsu nonlinear transmission line (NLTL) instruments, the ME7868A 2-port VNA is able to provide precision 2-port VNA measurements and meet the portability and measurement over distance goals envisioned for this solution by building upon the 1-port MS46131A VNA.

The modular 1-port VNA MS46131A is able to directly connect to a DUT’s ports through rugged N or K type coaxial connectors, which completely eliminates the need for interface cabling. The design of each modular MS46131A is proven to be rugged and demonstrates excellent reliability. The sync option technology for these modular VNAs allows these devices connected to the same PC to create a fully reversing 2-port VNA, the distributed modular 2-port VNA ME7868A, with full S-parameter measurement capability to distances of 100 meters or more. The only additional equipment required to create the base ME7868A other than two of the MS46131As, are sync cables, USB cables, and an external PC running the latest ShockLine™ software. MS46131A models are available that reach 8 GHz, 20 GHz, and 43.5 GHz, ideal for testing the latest 5G devices. This ME7868A system is able to deliver 100 dB typical dynamic range, three output powers (high, low, and off), and a frequency resolution of 1 Hz. The MS46131A / ME7868A are compatible with Anritsu’s AutoCal and SmartCal units for faster and more efficient calibrations.

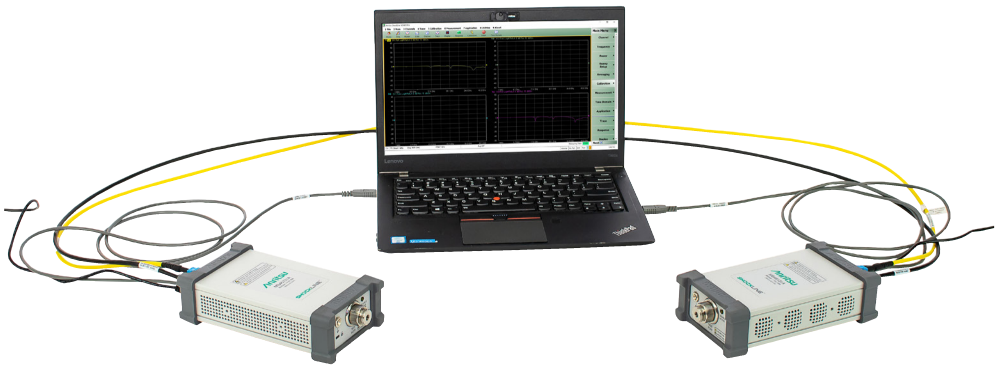


Figure 7. *ShockLine ME7868A 2-Port VNA*

How it works

The backbone to the new synchronization option is Anritsu's PhaseLync™ technology. This is what enables two MS46131A to be synchronized and combined to form a distributed instrument ideal for vector insertion loss measurements over long distances. PhaseLync™ is a combination of hardware and software, including embedded hardware within MS46131A with the sync option, and augmented software features within Anritsu's ShockLine software. The other part is a proprietary set of sync cabling based on fiber optic and other cable technologies, which allows for source/receiver, frequency reference, acquisition timing, and control handshaking all within the same synchronization system.

Conclusion

Addressing the challenges faced by professionals attempting to make network/transmission measurements over long distances with traditional test equipment, Anritsu has developed a modular, distributed 2-Port VNA solution able to make full 2-Port S-parameter measurements at distances to 100 meters. This solution is ideal for insertion loss testing of long, installed cable runs, OTA antenna transmission measurements, and shielding/propagation tests of large DUTs, such as aircraft and ships. This new solution is portable, rugged, and provides enhanced dynamic range at a much lower cost compared to a large high end bench-style VNA instrument and low-loss/phase stable cabling otherwise needed to make long distance network/transmission measurements over distance.

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4. Introducing the MS46131A 1-Port Modular VNA Video
5. ShockLine ME7868A 2-Port VNA System Introduction Video

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11410-02868, Rev A Printed in United States 2021-08