Synchronized Vector Network Measurements Over Long Distances

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[Summary] The RF/microwave wireless industry has an increasing number of applications where synchronized vector network measurements over distance are required. Traditionally, elaborate systems involving long front-end cables have been employed to make these measurements. These historic systems are inherently unstable and therefore inaccurate. This article reports on a new vector network analyzer (VNA) architecture that dramatically improves measurement stability and accuracy for port separation distances of up to 200 meters.

1 Introduction

A key aspect of microwave VNA testing is minimizing the measurement effect of the physical interface to a device under test (DUT). Using high stability, low insertion loss test port cables and applying techniques like reference plane extension and fixture de-embedding, VNA users have been very successful for years in minimizing the effect of the path from the VNA port to the DUT on typical microwave and millimeter wave VNA s-parameter measurements. These techniques are less successful with longer distances or larger DUTs at high frequency as cable insertion loss and instability grows significantly over distance making it more difficult to compensate for the path using typical bench techniques.

Long cable runs between the VNA port and the DUT occur in applications like Over-the-Air (OTA) testing in chambers and outdoor ranges as well as measuring RF and microwave characteristics of large vehicles like ships and aircraft. One key issue to overcome in these types of applications is the insertion loss of the cable affecting the stability and accuracy of the VNA measurements.

2 Modular VNA

To overcome the loss issues, many have used external mixing structures[1)-3)] linked back to a parent VNA. While this can be successful, the setups can be quite complicated and stability can still be an issue. A novel solution to this issue is the concept of a modular (or distributed) VNA[4)]. Instead of having a single chassis instrument where its ports are co-located (and possibly an elaborate external mixing setup), a modular VNA has independent portable modules which allow them to get close to the DUT with minimal cabling (see Figure 1). With source and measurement capability in the port modules, the main issue of insertion loss and distortion due to long coax or fiber interconnect disappears, and stability and accuracy of the measurements improves.

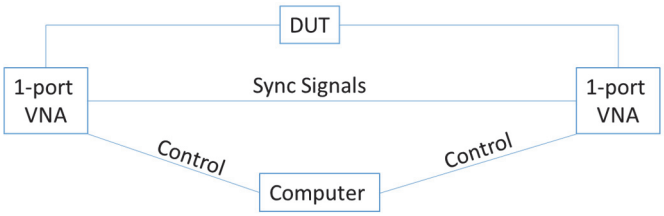

Figure 1 Modular VNA block diagram

Setup of a long-distance measurement is simplified as portable ports make it possible to move the VNA to the DUT eliminating the need for long interconnect cables. Calibration becomes much easier as the calibration plane moves close to or at the port rather than at the end of meters of cable through active components. Without active mixing or fiber optic translation in the measure path, attaining the DUT performance with a modular VNA is straightforward without requiring complex de-embedding.

While portable independent VNA ports eliminate the interconnect issues of long-distance measurement, it does create a major hurdle of providing the precise synchronization required between ports needed to support microwave vector (magnitude and phase) S-parameter measurements.

3 Practical Implementation

Assuming one is not driving both ports simultaneously in some forced phase, the main objectives for synchronizing the modules are:

1. A common LO for both transmit and receive modules
2. A means of sharing frequency references between modules so ADC clocks can be synchronous

The latter objective is met by one module, the Base module, that is defined at start-up time. The Base module supplies a

frequency reference for the other module's synthesizers, and ADC synchronization. The former objective is met by literally sharing an LO between modules as shown in the diagram below. This is possible with an optical link (E/O conversion at one end and O/E conversion at the other) between modules to keep insertion loss to a minimum as shown in Figure 2. Not all of the details are shown in this figure for simplicity:

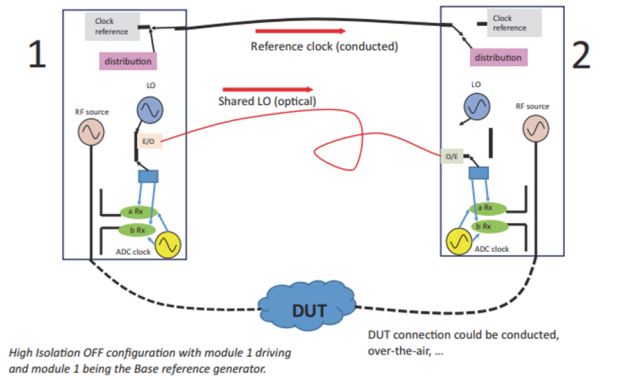

Figure 2 The basic assembly of two modular VNAs is shown here. A cable harness connects the ADC synchronizing signal (and control signals) from one module to the other (the module sourcing these signals is defined at startup) and an optical fiber allows the sharing of an LO. USB cables connecting each module to the PC are not shown here.

This LO connection is an analog signal link so the phase and amplitude information embedded in the LO is transferred (although the amplitude information is limited due to a strong limiting operation). While the insertion loss is low in the fiber link, the optical fiber is not immune to dielectric constant changes with temperature and/or flexure (although less than that observed with a typical coaxial cable) so there could be phase shift in the measured transmission response. To understand this, consider how (for example) S_{21} is constructed from the raw measurement data in an initial state with no LO path electrical length change:

$$S_{21}^{original} = \frac{b_2}{a_1} \approx \frac{Ke^{j\theta_{LO}}Be^{-j\theta_{RF}}}{Ke^{j\theta_{LO}}Ae^{-j\theta_{RF}}} = \frac{B}{A}$$

If, now the phase on the LO path between the modules changes by ϕ, the relationship changes to:

$$S_{21}^{new} = \frac{\widetilde{b_2}}{\widetilde{a_1}} \approx \frac{Ke^{j(\theta_{LO}+\varphi)}Be^{-j\theta_{RF}}}{Ke^{j\theta_{LO}}Ae^{-j\theta_{RF}}} = \frac{Be^{j\varphi}}{A}$$

Had the phase change been common to both the test and reference paths, the phase would have cancelled out. Since the receivers are separate and the longer run exposed, this kind of un-cancelled phase change is a possibility. There are unique methods on the MS46131A to minimize effects of changes to the link.

4 Phase Compensation

Because of the potential large separation of modules (over 100 m in some cases) and the dependence of optical fiber dielectric constant on temperature, pressure, etc., noticeable environmentally-induced phase change is possible. While this might not present too much of a problem in some measurements (e.g., magnitude-only antenna pattern measurements), it can be an issue in others (near-field measurements, for example). A phase compensation algorithm is available where an additional measurement of just the LO path is made periodically and compared to an initial measurement and the phase difference (on a per frequency basis) is computed and used to correct the data. The baseline 'initial' measurement can be re-initialized at any time. Thus monitor measurements are used to periodically assess the state (in an electrical length sense) of the optical fiber link. When this mode is turned on and a new user RF calibration is performed, the baseline phase is automatically re-initialized. Again, because it is the relative LO phase between modules that is of concern here, it is mainly transmission phase that is affected. In highly transmissive devices, there is a coupling to load match so reflection measurements in that class can also be affected.

As an example, consider a setup where a localized cold source is positioned near the optical fiber cable. S_{21} of a transmissive device is being measured and a reading is taken before the temperature change occurs and then again after a two-second blast of ~ –40°C cold spray. Admittedly this is not a precise thermal experiment but it is a bounding case for thermal shock events that can occur in practical measurement setups. The results with and without phase compensation applied (the optical cable was allowed to return to its initial starting temperature between the experiments) are shown in Figure 3.

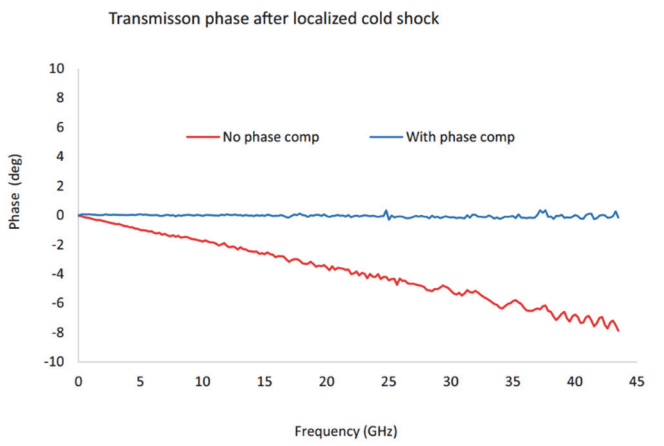

Figure 3 The stabilizing effect of the phase compensation process is illustrated here during thermal shock experiments.

Note that the measurement was done with two different calibrations and at two different points in time but the data is suggestive of the improvement. The algorithm is not limited to handling small phase excursions and can be useful in more thermally and mechanically dynamic environments.

It should be pointed out that, had conventional coaxial cables been used between the modules, not only would the separation distance have been more limited (due to cable loss) but the temperature sensitivity could have been similar or greater. In contrast, the LO sharing cable of the distributed VNA is only subject to phase drift (which can be compensated for as discussed); amplitude stays virtually unaffected.

5 Distributed Power and USB Technology

There exists a control module in this distributed VNA system which is located near the control PC running the VNA application software. This control module provides both power and USB communication to the individual port modules located x meters away. USB communication is over fiber and uses standard commercial technology. Distance for this link is not a limiting factor. Dual isolated floating 36 V supply voltages are transported to the individual VNA modules x meters away. Once received, each VNA module internally regulates the 36 V DC to 12.5 V DC needed for VNA operation. 36 V DC allows up to 200 m of power cable before IR drop prevents regulation at the VNA head. The DC voltage from the control module is supplied through a shielded coax cable and is floating with respect to control module ground. There is a 1 Meg Ohm resistance and 20 nF capacitance to control module ground which prevents power return current from traveling along the PhaseLync™ Electrical (PLE) return shield. The DC voltage is derived from a switching power supply operating at 500 kHz. A 50 mV 500 kHz filtered sin wave ripple voltage is present on the 36 V DC. There are no 500 kHz magnetic fields emanating from the shielded power cable as the equal and opposite fields cancel due to the floating source.

6 Conclusion

For VNA applications over distance like far-field antenna measurements and large vehicle shielding and propagation characterization, several methods exist to deal with the insertion loss and other negative aspects of long interconnect cables. A new modular VNA architecture solves the issue by bringing the VNA port to the DUT eliminating most if not all of the cable interconnect for long distance applications. Measurement stability and accuracy are improved by removing the significant insertion loss due to long cables and by providing a compensation algorithm for the residual phase drift present in the fiber optic LO distribution cable. Setup and calibration are simplified by bringing the calibration plane to the VNA port and removing any active signal conditioning in the measurement path.

References

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4) US patent 11,846,663, "Remote multiport modular vector analyzer system and method of use," and preceding patents.

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