White Paper

Modern Architecture Advances Vector Network Analyzer Performance

Vector Network Analyzers (VNAs) are based on the use of either mixers or samplers. In traditional sampling VNAs, samplers are gated by pulses generated with a Step-Recovery Diode (SRD) circuit, with the Local Oscillator (LO) and RF source phase locked to a common frequency reference. An alternative architecture is a VNA based on Nonlinear Transmission Line (NLTL) samplers and distributed harmonic generators. NLTL-based samplers configured to provide scalable operation characteristics now offer a more beneficial alternative. Not only do they allow for a simplified VNA architecture, but they also enable VNAs that are much more cost effective than those employing fundamental mixing.

This paper provides an overview of the high-frequency technology deployed in Anritsu's VNA families. It is shown that NLTL technology results in miniature VNA reflectometers that provide enhanced performance over broad frequency ranges, and reduced measurement complexity when compared with existing solutions. These capabilities, combined with the frequency-scalable nature of the reflectometers provide VNA users with a unique and compelling solution for their current and future high-frequency measurement needs.

Limitations of Prior VNA Architectures

VNAs make use of samplers, harmonic mixers, or combinations thereof to down-convert measurement signals to intermediate frequencies (IF) before digitizing them. Such down-conversion components play a critical role in VNAs because they set bounds on important parameters like conversion efficiency, receiver compression, isolation between measurement channels, and spurious generation at the ports of a device under test (DUT).

Mixers tend to be the down converters of choice at RF frequencies, due mainly to their simpler local oscillator (LO) drive system and enhanced spur-management advantages.

At microwave and millimeter wave frequencies (where receiver compression and cost are of major concern), harmonic sampling is often used. VNAs have traditionally relied on Schottky diodes as switches and on SRDs for pulse generation. Implementations have been used extensively in a range of instrumentation, including microwave VNAs, sampling oscilloscopes, and frequency counters.

In an SRD-based sampling VNA, the dynamic range of transmission measurements is often limited by the bandwidth of devices used for isolating test channels. Channel isolation can be best understood by considering the SRD-gated sampling reflectometer shown in Fig. 1. Note that suppression of leaky signals requires the use of broadband isolation devices in the output arms of the power divider.

Leakage Between Test Channels

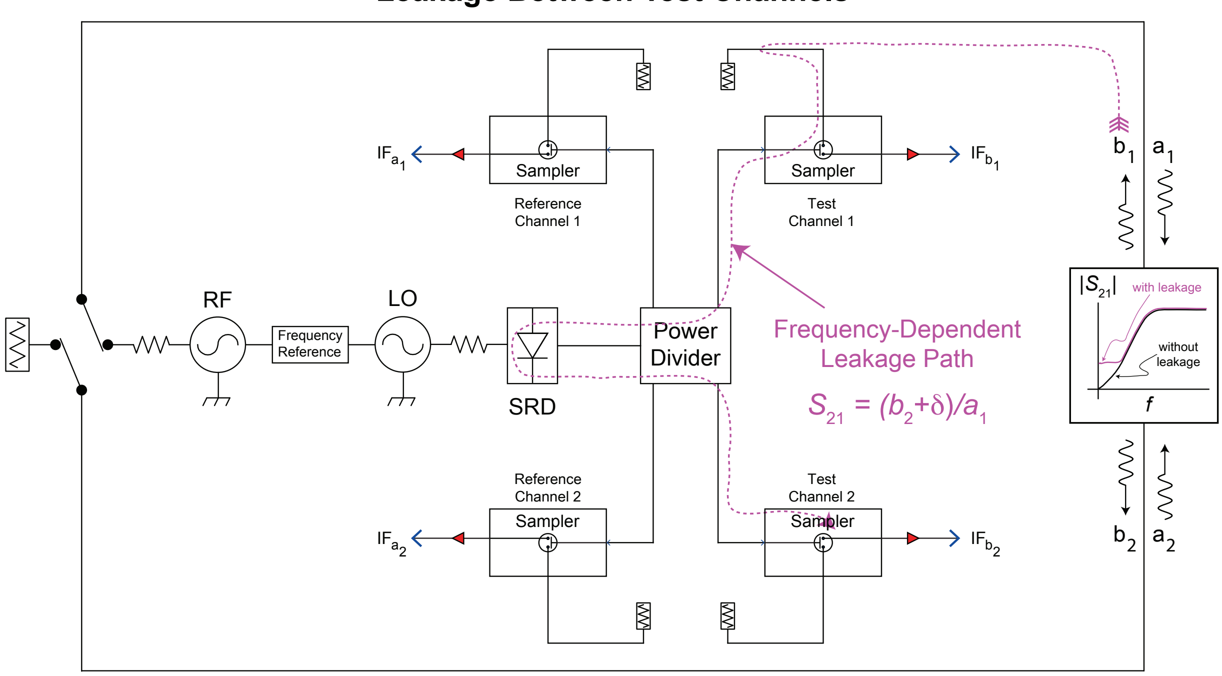


Figure 1. A VNA based on a step-recovery diode (SRD) often has leakage between test channels that limits the VNA's dynamic range.

Furthermore, these leaky signals are frequency dependent and cannot be removed via calibration. Therefore, they impose limitations on the dynamic range of an SRD-based sampling VNA. Consequently, the limited dynamic range prevents full characterization of highly reflective devices such as high-pass filters, as well as devices where weak coupling among constituents must be measured as a function of frequency (e.g. weak crosstalk).

In addition to design issues and RF bandwidth limitations of SRD-based VNAs, the short- and long-term stability and quality of broadband VNA measurements may also be challenged due to the following:

- Physically large and inhomogeneous measurement structures utilizing discrete components such as reflectometers, receivers, signal conditioning devices, interconnect cables, waveguides, etc.;
- High-frequency multiplexing schemes;
- Complex receiver structures such as harmonic frequency converters and complex LO distribution networks.

Introducing Nonlinear Transmission Lines (NLTL)

Nonlinear Transmission Line (NLTL) technology has historically been used for pulse shaping applications and in digitizing oscilloscopes. Over the years it has proven itself to be a highly credible, robust technology. It has been refined by Anritsu for high-frequency use, and complemented with novel monolithic broadband directional bridges, multiplexers, and other key components, resulting in NLTL-based samplers and distributed harmonic generators that

1. Overcome the aforementioned limitations of SRD-based sampling VNAs;
2. Meet the needs for a high-performance frequency-scalable VNA architecture.

In general terms, NLTLs are distributed devices that support the propagation of nonlinear electrical waves such as shocks and solitons. Shock wave propagation along an NLTL closely mimics the motion of water waves just before breaking on the seashore. In their most basic form, NLTLs consist of high-impedance transmission lines loaded with varactor diodes that form a propagation medium whose phase velocity, and thus time delay are a function of the instantaneous voltage across the diodes (Figure 2). The lower the voltage, the lower the phase velocity and the longer the time delay of a waveform propagating along the nonlinear transmission line. Conversely, the higher the voltage, the greater the phase velocity and the shorter the time delay. When acting on a section of a trapezoidal voltage waveform applied to its input, an NLTL compresses the waveform's front, resulting in a step-like voltage that is highly rich in harmonics.

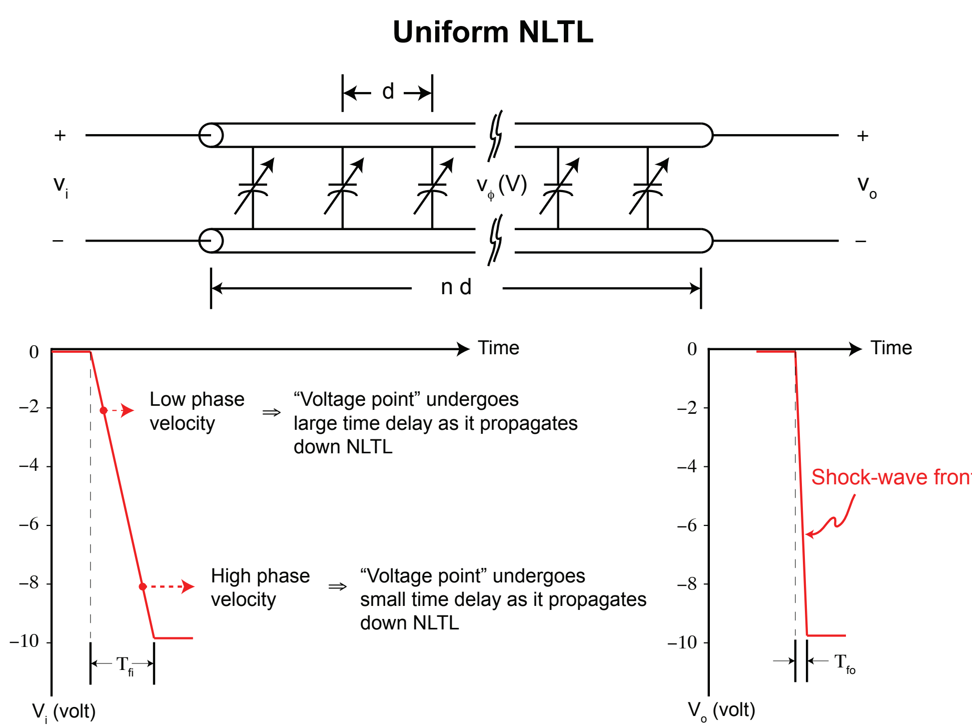


Figure 2. The falling edge of an electrical wave undergoes compression as the wave propagates along the nonlinear transmission line. This effect is analogous to that of a water wave before breaking on the seashore.

By leveraging the fall-time compression characteristics of an NLTL, a train of very narrow gating pulses can be generated at microwave and mm-wave frequencies for sampling receivers starting from a CW signal (Figure 3). An essential ingredient in the pulse formation process is a differentiator circuit (not shown) that transforms the step-like output of an NLTL into a pulse. On the other hand, broadband distributed harmonic generation is achieved by leveraging the "harmonic growth" characteristics of NLTLs. Since two primary functions of any VNA are generating signals and sampling them, NLTL technology is especially well suited for use in such instruments.

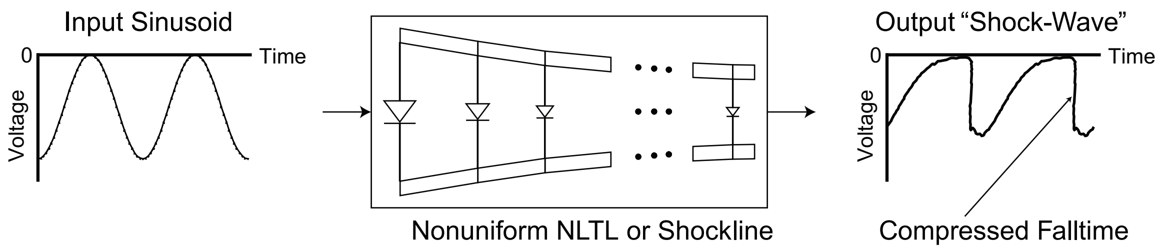


Figure 3. Non-uniform NLTLs enhance fall time compression, and result in a train of step-like waveforms when driven by a CW signal. Step differentiation results in a train of pulses that are used for sampler gating.

Due to their attractive features, NLTL-based samplers have been developed for use in multiple families of Anritsu VNAs. These features include RF and LO frequency scalability, and high channel-to-channel isolation. High isolation is key to achieving high dynamic range. It is carried out by means of amplifiers, filters, and other isolation elements (Figure 4). The isolation between test channels 1 and 2, for example, may be enhanced further by adding additional isolation elements

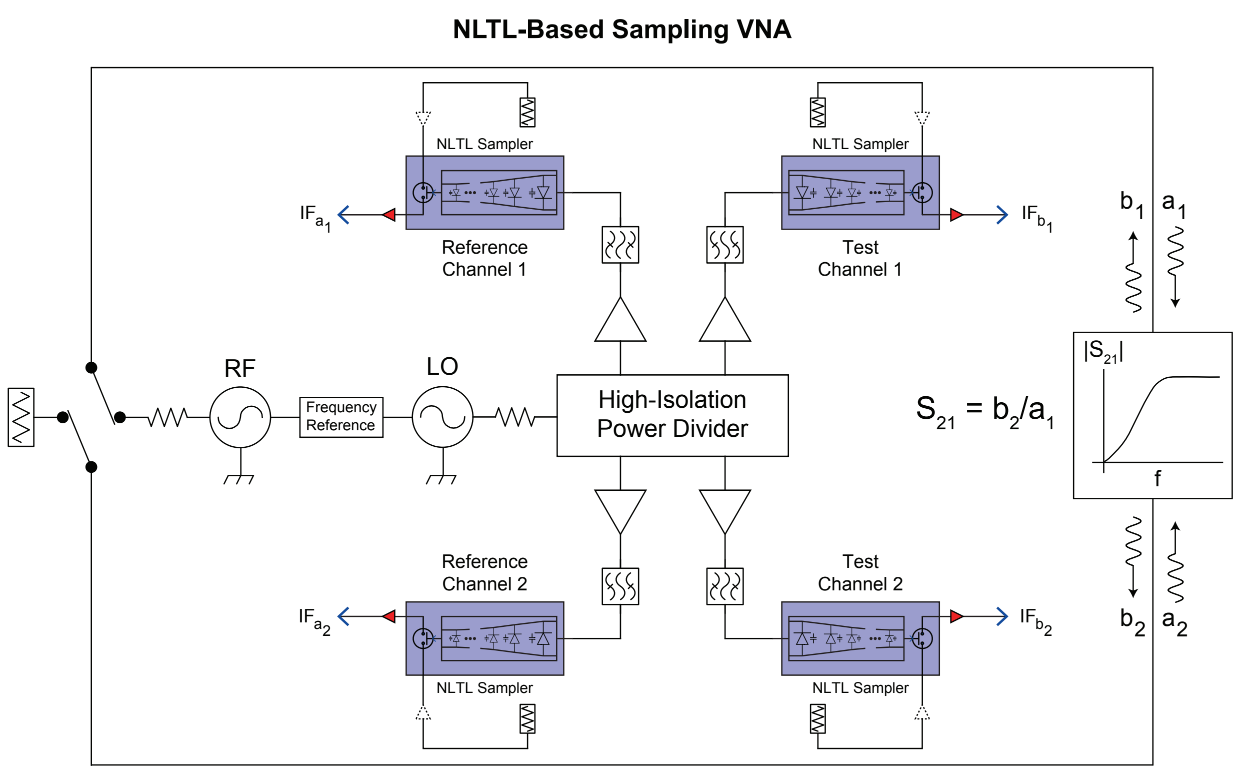


Figure 4. A sampling VNA based on nonlinear-transmission-line (NLTL) samplers. Leakage between channels is suppressed by means of devices such as amplifiers, filters, and isolators

Benefits of NLTL Technology

The use of NLTL-based samplers offers a number of benefits to modern VNA architectures (Table 1). These benefits provide customers with an unparalleled value per GHz for their investments.

Table 1. NLTL Technology Advantages and Benefits

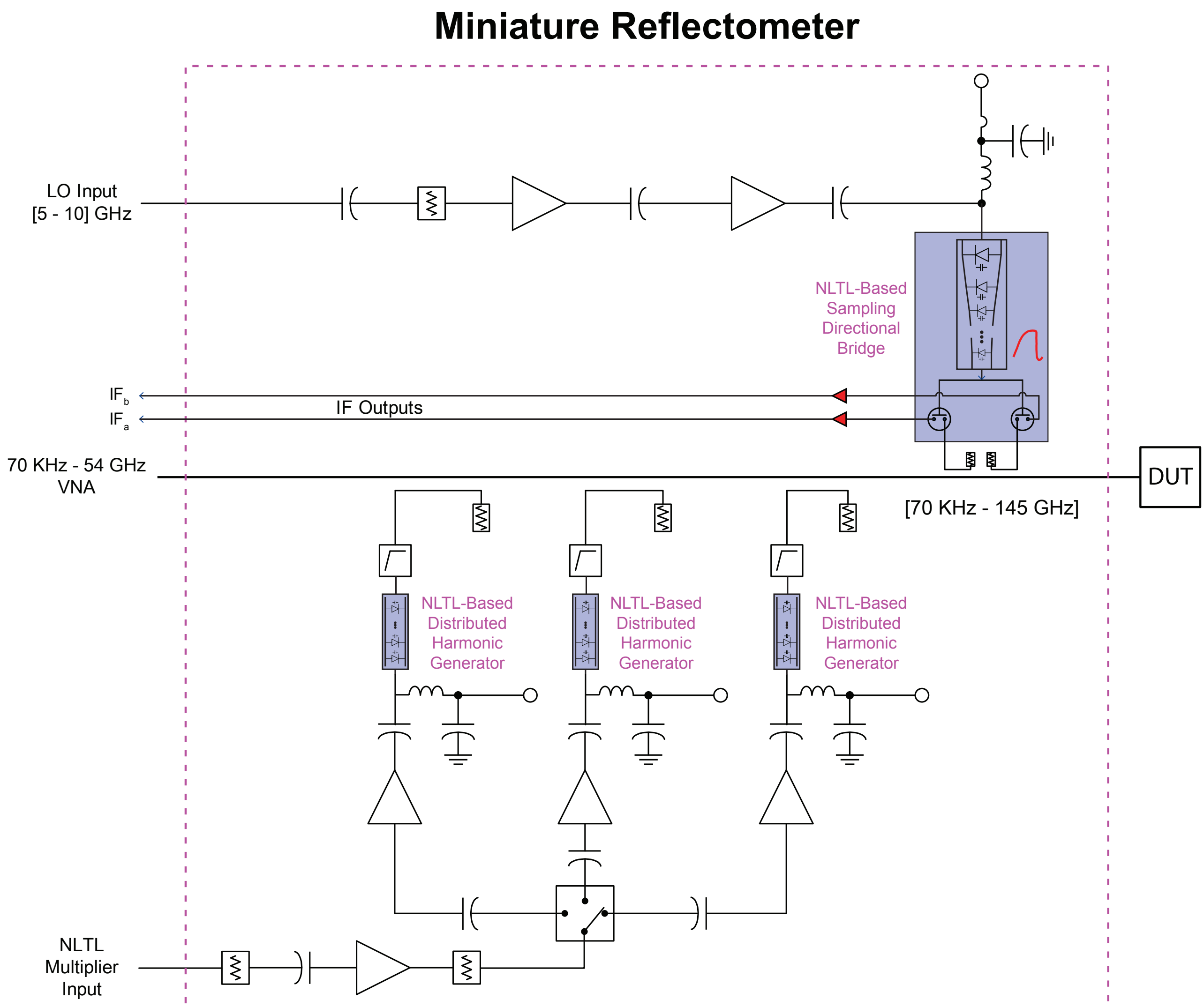
Parameter	NLTL-Based VNA Advantage	Customer Benefit
Simplified VNA architecture	Monolithic reflectometer design reduces number of discrete parts and connectors	Lower maintenance cost, reduced down time and operating costs.
Stability	Integrated chip design greatly reduces the temperature variation across reflectometer constituents	Longer intervals between calibrations, better measurement accuracy and repeatability
Bandwidth	Extremely wide RF sampler bandwidth allows one sampler to cover broad frequency range	Lower cost for making high-performance measurements over broader frequency ranges
Dynamic Range	Over 100 dB across all frequency ranges	Better characterization of highly reflective devices and weak crosstalk.
Size	High performance in a very small form factor	Direct connection to wafer probes, smaller footprint in manufacturing, light weight field solutions
Cost	Improved capability-to-cost ratio enables new applications	Dramatic cost reduction for high frequency testing in engineering, manufacturing and field

Miniature Reflectometers

A major advantage of NLTL based VNAs is the high level of monolithic integration of the various constituents. These include the sampling receivers, distributed harmonic generators, directional bridges, and other key components. The resulting reflectometer modules share the same thermally stable mass, and are miniature in size (Figure 5), thus greatly reducing temperature variations. These in turn, result in highly optimized short- and long-term stability, and less frequent VNA calibration. In addition, the elimination of microwave connectors between the various reflectometer components enhances performance (e.g. lower loss, less reflections) while improving system reliability and stability.

The compact nature of the NLTL-based reflectometers enables several key applications for VNAs such as:

- High-frequency on-wafer testing with the prime advantage of locating the VNA closest to the DUT. By directly connecting the reflectometer to the wafer probe, directivity, port power, and system stability are enhanced.
- Dense multi-port on-wafer measurements.
- Very low cost solutions for testing components in production environments.
- High-frequency handheld VNAs for field applications.



(a) A simplified block diagram of the NLTL-based miniature frequency-extension reflectometer.

(b) An NLTL-based frequency extension module operating to 145 GHz at 0.8 lb and 1/50 the volume of traditional millimeter-wave modules.

Figure 5. NLTL technology reduces component count and greatly minimizes temperature variations in reflectometers resulting in improved reliability and stability.

Maximize Dynamic Range across Broad Frequency Ranges

NLTL samplers exhibit extremely wide RF bandwidth (Figure 6) that is scalable to sub-millimeter-wave frequencies. The continuous frequency coverage is limited only by the bandwidth of the coaxial connector and the number of NLTL frequency multiplier chains (Figure 5-a). When combined with a directional bridge, NLTL samplers enhance VNA directivity.

In contrast, older architectures require implementing a large external combiner to concatenate two frequency bands to extend frequency range of a VNA. Such implementation deteriorates the VNA's raw directivity and output power.

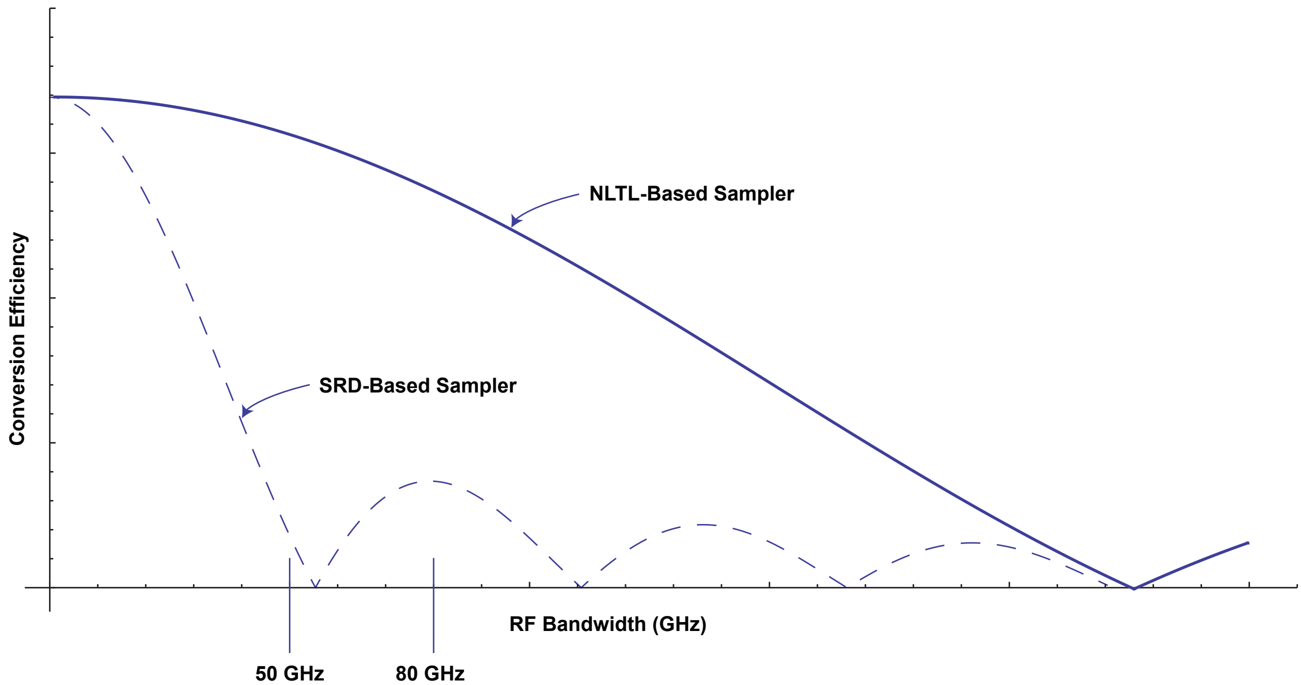


Figure 6. An NLTL-based sampler exhibits extremely wide RF bandwidth that far exceeds that of an SRD based one.

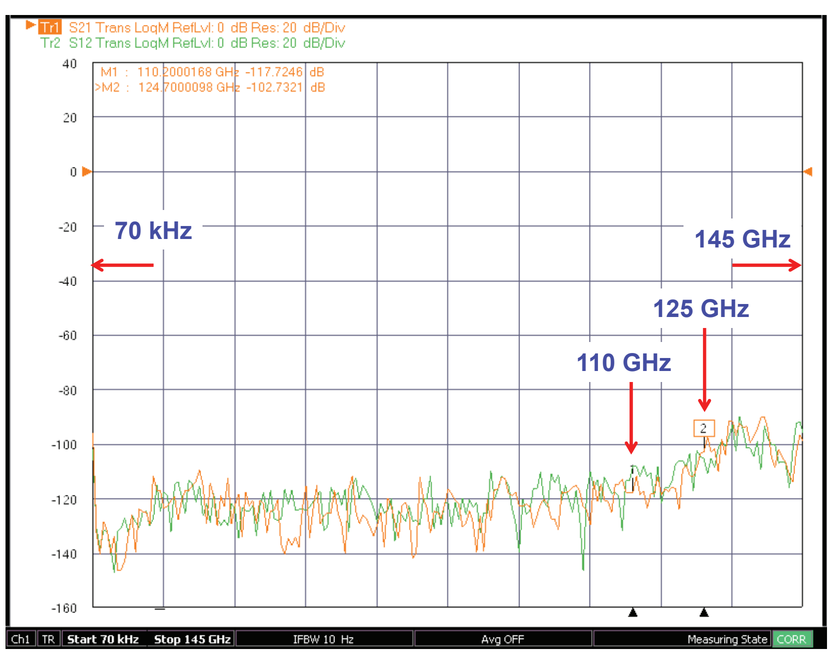


Figure 7. The measured dynamic range of the NLTL-based VNA typically exceeds 100 dB up to 125 GHz and 95 dB up to 145 GHz.

Unmatched Stability

A key advantage of the NLTL-based reflectometer is its inherent temperature and time stability, which makes obtaining stable, quality measurements easier (Figure 8). The stability is a result of the monolithic construction of the NLTL-based sampler and reflectometer components. Monolithic integration results in a vanishing thermal gradient across the reflectometer module and the sampling directional bridge, thus delivering improved measurement stability and lower temperature drift when compared with SRD samplers and classical mixers.

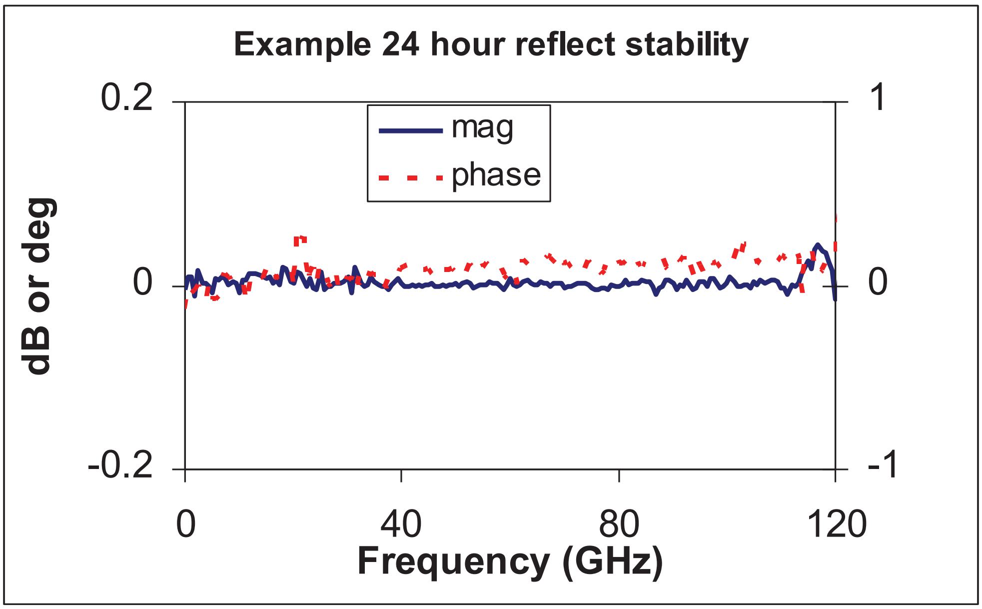


Figure 8. The integrated design of an NLTL-based VNA maintains excellent stability across very wide frequency ranges as shown in this 24-hour reflection measurement.

Improving Capability-to-Cost Ratio

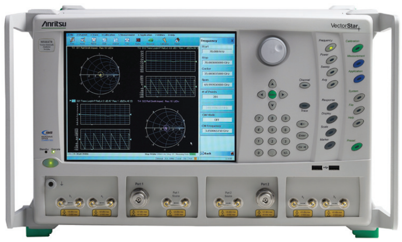
The NLTL-based VNA-on-a-chip advances the capabilities of a VNA and introduces a number of new application spaces. Price sensitive component manufacturers face increasing demand but must meet lower price points to enable lower cost components. NLTL-based VNA's offer component manufacturers very low cost VNA's without compromising performance.

The need for portable microwave solutions for field testing is growing due to demands for high capacity microwave backhaul. The NLTL-based VNA-on-a-chip enables portable VNAs to achieve frequencies as high as 40 GHz in the same form factor as lower-frequency models while preserving battery life.

Anritsu Leverages NLTL Technology across VNA Families

NLTL technology has proven itself to be a highly credible, robust technology for VNAs since its first commercial introduction in 2009. Anritsu employs NLTL technology in many of its latest VNA solutions – ranging from the highest levels of performance to solutions for cost-sensitive applications including testing of microwave systems in field applications.

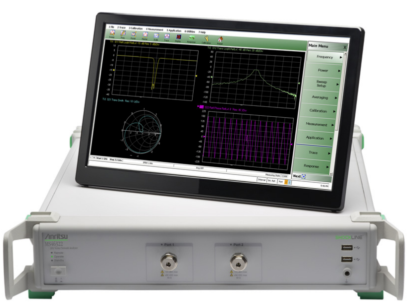
VectorStar MS4640B Series



Anritsu first employed NLTL technology in its high-performance VectorStar VNA because of its effectiveness and functionality. It utilizes four NLTL-based samplers, which helped achieve a much smaller sampling pulse width (approximately 1/6 that of a Step Recovery Diode (SRD)), and to use LO frequencies in excess of 10 GHz.

The small size and lightweight high-frequency reflectometers enhance maneuverability and probe positioning in applications such as on-wafer measurements and near-field scanning of antennas and circuits. Connecting the reflectometer directly (i.e. without a cable) to a wafer probe brings the "VNA" yet closer to the DUT, thus enhancing raw directivity and port power.

ShockLine™ VNA Family



ShockLine™ Vector Network Analyzer family is the latest generation of low cost RF, Microwave and banded Millimeter VNA's from Anritsu Company. These VNAs employ NLTL technology to extend operating frequency to 92 GHz, reduce instrument cost, enhance accuracy and minimize measurement uncertainty. These VNAs are ideal for simple engineering, manufacturing and cost-sensitive education applications.

Microwave Site Master™ S820E Family

Microwave Site Master S820E, the world's first handheld cable and antenna analyzer with frequency coverage up to 40 GHz. This NLTL-based design provides the widest frequency coverage of 1 MHz to 40 GHz. The Site Master S820E offers field technicians, engineers, and wireless network installers industry-leading dynamic range, directivity, and durability so that they can conduct highly accurate measurements during the installation, maintenance, and troubleshooting of microwave communications systems.

Additional Resources

Anritsu Company NLTL VNA Patents

8,417,189 Frequency-scalable shockline-based VNA

8,278,944 Vector network analyzer having multiplexed reflectometers for improved directivity

8,027,390 Method and system to extend a useable bandwidth of a signal generator

7,764,141 Interleaved non-linear transmission lines for simultaneous rise and fall time compression

7,683,633 Apparatus for extending the bandwidth of vector network analyzer receivers

7,088,111 Enhanced isolation level between sampling channels in a vector network analyzer

6,894,581 Monolithic nonlinear transmission lines and sampling circuits with reduced shock-wave-to-surface-wave coupling

Publications

M.J.W. Rodwell et al., "GaAs nonlinear transmission lines for picosecond pulse generation and millimeter-wave sampling," IEEE Trans. on Microwave Theory and Tech., vol. MTT-39,

pp. 1194-1204, July 1991.

K. M. Noujeim, Christian Sattler, "Miniature frequency-scalable reflectometers for vector network analyzers," Session WS3, GeMiC 2011, Darmstadt, Germany, March 14-16, 2011.

K. M. Noujeim, "Miniature frequency-scalable reflectometers for vector network analyzers," Millimeter-Wave Users Group, University of Glasgow, Scotland, March 31, 2011.

K. M. Noujeim, J. Martens, and Tom Roberts, "Frequency-scalable nonlinear-transmission-line-based vector network analyzers," ARMMS 2011 Conference, Milton Mill House, Steventon, Oxfordshire, UK, April 5-6, 2011.

J. Martens, K. Noujeim, and T. Roberts, "Millimeter-wave linearity measurements: sensitivities and uncertainties," Millimeter Wave Days, Espoo, Finland, May 23-25, 2011.

J. Martens, K. Noujeim, and T. Roberts, "An improved stability broadband/mm-wave VNA structure," 77th ARFTG Microwave Measurement Conference, Baltimore, Maryland, June 10, 2011.

K. M. Noujeim, J. Martens, and Tom Roberts, "A frequency-scalable NLTL-based signal-source extension," EuMC 2011, Manchester, UK, October 9-14, 2011.

K. M. Noujeim, "Frequency-multiplexed source and receiver extensions," GeMiC 2012, Ilmenau, Germany, 2012.

Specifications are subject to change without notice.

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