Frequency Extenders Elevate Network Analyzers to mm-Wave Test Capability

By Eravant

A highly capable VNA usually represents a major investment in future productivity.

It can be nearly impossible to perform many kinds of high-frequency testing at an acceptable pace without the aid of certain tools. Perhaps foremost among RF test equipment are automatic Vector Network Analyzers (VNAs). These versatile instruments enable the rapid characterization of myriad devices, from Amplifiers to Zinc-oxide transistors.

A highly capable VNA usually represents a major investment in future productivity. In addition to the instrument's cost, weeks of research may be necessary to appreciate the value of many available options. Considerations should include whether Millimeterwave (mm-wave) frequency (30 to 300 GHz) coverage is needed, and whether such coverage is built into the instrument or achieved by adding external frequency-extension hardware.

Eravant (Torrance, CA) offers a series of frequency extender systems covering waveguide bands from 50 to 170 GHz (Fig. 1). Precision calibration kits with NIST traceability are also available. When choosing among these and other options for mm-wave coverage, it helps to understand some of the history surrounding the VNA as well as the background of those manufacturing the instruments and their various accessories.

VNA History

It's impossible to appreciate the privilege of measuring network parameters automatically, without having had to measure them without the aid of a modern VNA. Long before VNAs became ubiquitous in engineering labs, reflection, and transmission coefficients, known as scattering parameters or [S] parameters, were typically measured using amplitude detectors and isolation devices such as hybrid junctions, directional couplers, bridge circuits, and circulators. Before accurate quadrature signal detection became commonplace, slotted transmission lines, six-port networks, and a host of tedious measurement techniques were needed to capture hard-won phase information. A component's scattering parameters over frequency took a lot of time and talent to produce.

Starting in the late 1970's, the computer-controlled network-measurement systems were developed by instrument manufacturers such as Hewlett-Packard (later Agilent and Keysight) and Wiltron (acquired by Anritsu), and later, joined by Rohde & Schwarz, and Copper Mountain Technologies. Hewlett-Packard's 8510 Vector Analyzer was the flagship VNA and dominated this space for decades. Meantime, VNA product development and improvement has been continually advancing, incorporating every applicable breakthrough in electronics and computer technology along the way. Eventually, the modern automatic and more affordable VNA became one of the most powerful, productive, essential and easy-to-use instrument available for high-frequency product engineering and manufacturing.

By combining multiple test signals and applying advanced signal-processing technologies, higher-end VNAs can measure amplifier compression, intermodulation products, mixer conversion efficiency, noise figure, and a host of other system parameters in additional to [S]

Figure 1 • The STO series of frequency extenders cover waveguide bands from 50 to 170 GHz.

parameter measurement. In well-equipped microwave labs or production lines, VNAs automatically control external calibration devices that switch between various impedance and transmission standards. As a result, modern VNAs largely free engineers from having to become experts in operating cumbersome test systems and applying complex error-correction algorithms. They offer reliable and complete [S] parameters and other critical data in device and component characterizations at both engineering and production stages.

mm-Wave VNAs

When working at high frequencies, particularly those mm-wave frequencies above 50 GHz, the cost of VNA measurement capability can be a major hurdle. It can be difficult sometimes for an engineering or manufacturing team to justify such an investment. Alternatively, lower-cost and less capable measurement systems can be constructed from stand-alone signal generators, signal analyzers, and collections of cables and other components. Such test systems are often more economical than a fully integrated VNA when addressing an immediate need. But in many cases, this custom-built approach leads to a longer-term reliance on clumsy collections of dissimilar equipment that must be reconfigured, reprogrammed, or otherwise enhanced for new measurement tasks. Over time the resulting setup and measurement procedures can become increasingly time-consuming and error-prone when compared to a more integrated and capable test system, thus cancelling any short-term cost savings over the long run.

When considering the many VNA solutions available for the high frequencies, such as mm-wave bands, it is important to evaluate all options for covering different frequency ranges. Continuous frequency coverage from RF to about 50 GHz is readily available in both new and fairly recent equipment. Above 50 GHz, the cost of wideband electrical components tends to grow exponentially, with similar increases applicable to instrumentation costs. In many situations, the continuous coverage from 10 MHz to 110 GHz, for instance, may not be necessary, instead, a waveguide frequency extender, which offers segment frequency coverage for interested frequency range may be more predominant. Therefore, the waveguide band based VNA extension for mm-wave band applications is the most economical and practical approach perhaps for many circumstances. In addition, the smallest available coaxial connectors operating above 110 GHz is still very limited and extremely expensive, thus making waveguide connections inherently superior.

Waveguide VNA Frequency Extenders

Waveguide VNA frequency extenders have been around for many years. A typical system uses a chain of frequency multipliers and amplifiers to generate test signals from the VNA's native output signals. In most implementations, a tracking Local Oscillator (LO) is also used. In many test systems the LO signal is obtained conveniently from a VNA having dual-source capability. However a range of options can supply a suitable LO signal depending on the instrument being extended.

Frequency extender systems require a heterodyne VNA that provides access to its Intermediate Frequency (IF) signal-processing channels. A single extender unit

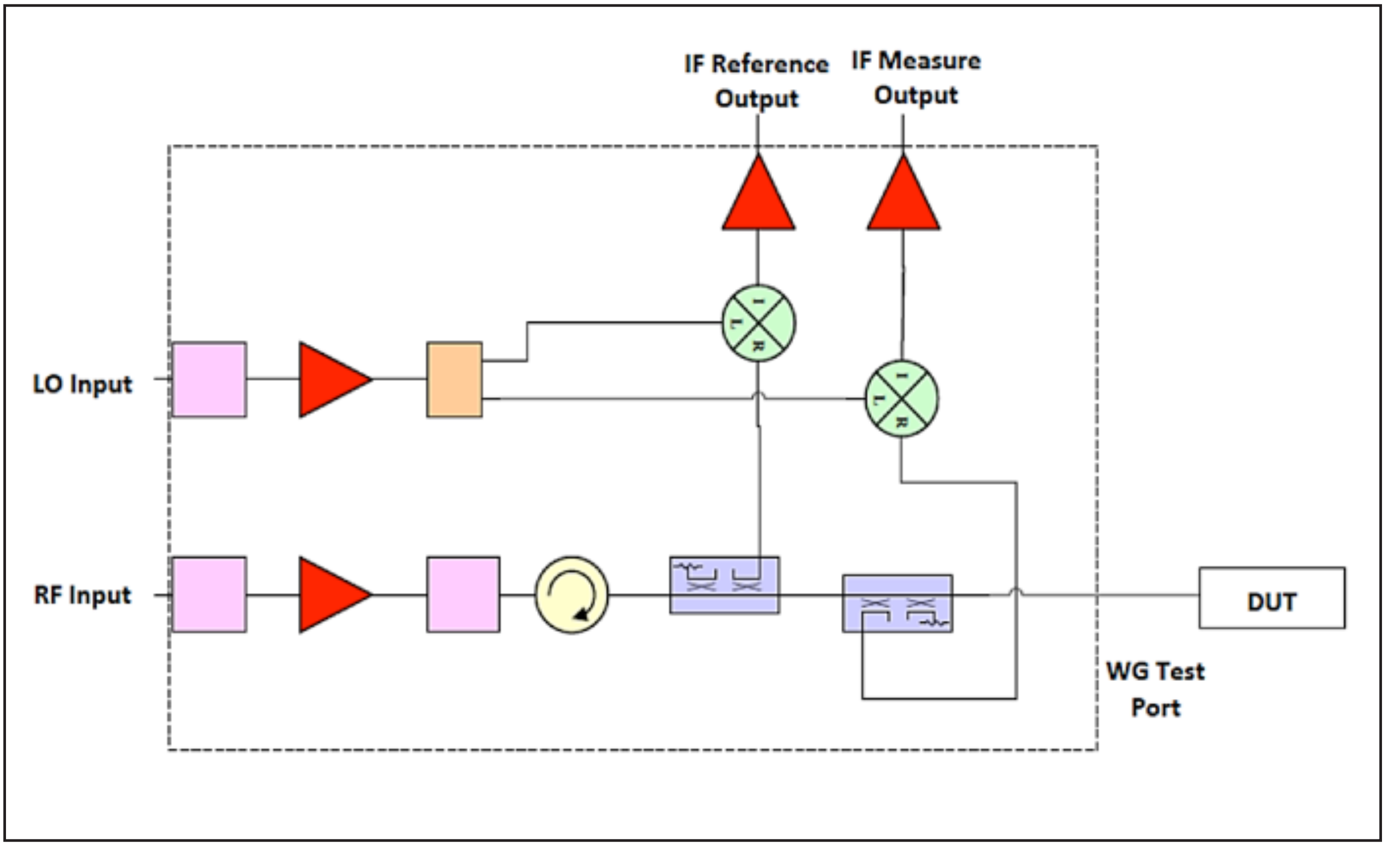

Figure 2 • The simplified block diagram of a typical VNA frequency extender unit showing half of the system necessary to perform full 2-port network [S] parameter measurements.

feeds a pair of Reference and Test input channels on the VNA. By itself, one extender can only measure S11.

Within each extender unit a directional coupler and a balanced mixer produce a down-converted sample of the incident Reference signal (Fig. 2). Another directional coupler and mixer supply the down-converted Test signal returned by the device under test. For full 2-port [S] parameter measurements (S11, S12, S21, S22), a pair of frequency extender units are required.

Dynamic range is partially determined by the VNA's RF and LO signals. The purity of these signals affects the levels of sideband noise that are down-converted to the IF channels. One possible strategy for reducing the IF noise floor is to increase the LO offset and thereby reduce the amplitude of overlapping noise sidebands. However any improvement to the achievable dynamic range is likely to be modest if the RF and LO signals are spurious-free. Dynamic range relies more heavily on the selection of low-noise frequency multipliers and amplifiers, having well-balanced and efficient mixers, and using high-quality directional couplers with high directivity and good impedance matching on all ports. In addition, special efforts of radiation suppression between the components within the extender assembly is needed to maintain the dynamic range. Fig. 3 shows a typical dynamic range of Eravant WR-12 band VNA extender.

Engineers at Eravant have a long history of designing, developing, and manufacturing high performance mm-wave components and subsystem up to 325 GHz. They also designed and implemented various frequency extenders for its product development, to support their manufacturing operations and fulfill many customers' special measurement requirements. Stable and reliable performance of the test equipment is critical to meeting customer demands for accuracy, reliability, and performance. Controlling manufacturing costs demands finding the most economical test solutions that yield satisfactory results. Eravant's VNA frequency extender designs have been proven by years of heavy usage and are backed by an engineering team who understands the high-performance mm-wave component and sub-system design and manufacturing process challenges surrounding the use and maintenance of high-performance measurements systems.

Extender Options

Eravant's standard VNA frequency extenders are offered in five waveguide bands, namely WR-15, WR-12,

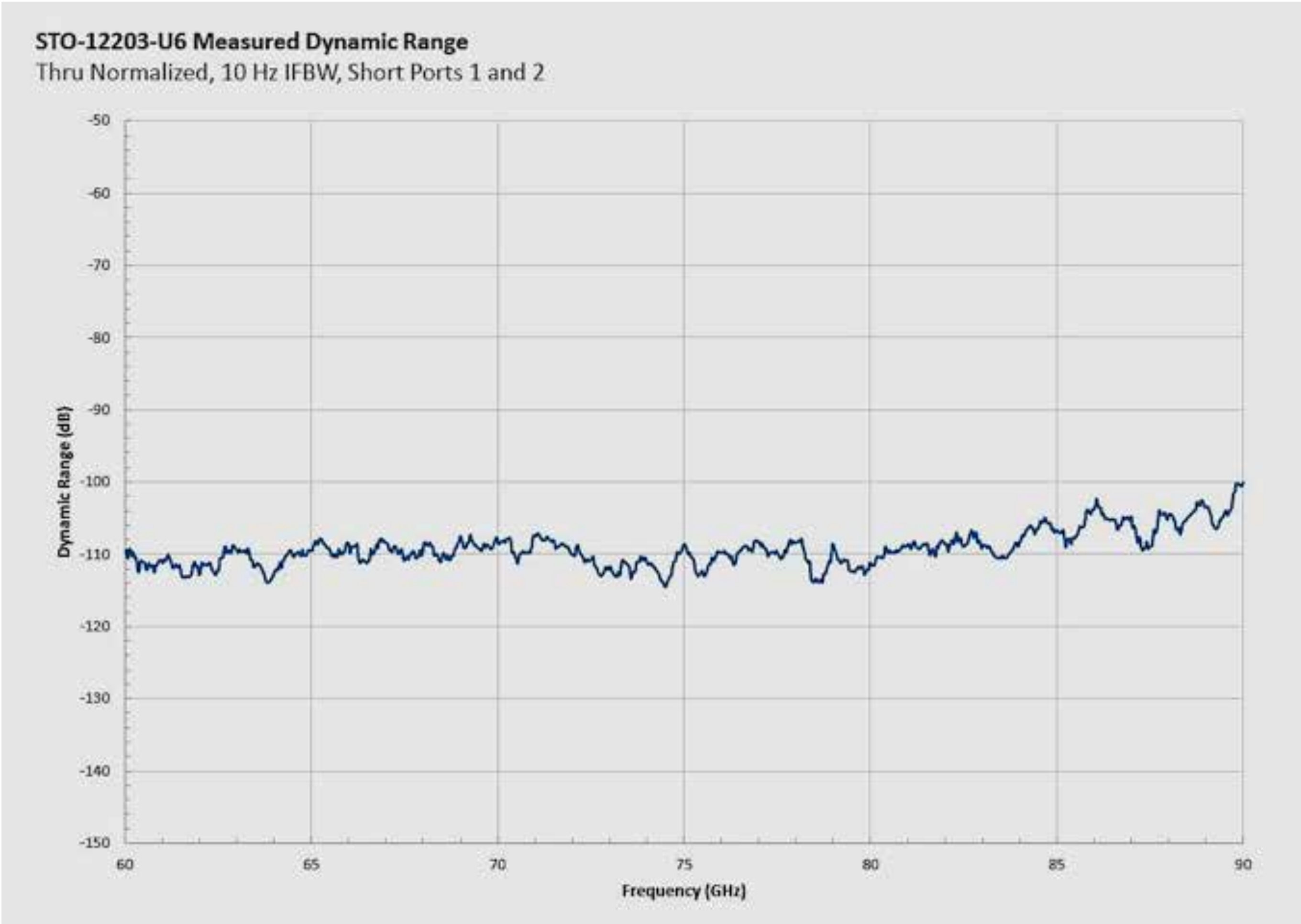

Fig. 3 • STO-12203-U6 Measured Dynamic Range.

WR-10, WR-08, and WR-06 to cover 50 to 170 GHz, and the WR-05 through WR-03 bands, covering 140 to 325 GHz are under development. They are compatible with modern vector network analyzers such as the Rohde & Schwarz ZVA series, the Anritsu VectorStar, the Keysight PNA-X series, and the Copper Mountain CobaltFx models. For other VNA brands, certain configuration options must be selected and examined to ensure compatibility.

Eravant's STO series of frequency extenders display high system dynamic range up to 110 dB and test port power levels up to +5 dBm (Table 1). In addition, the output power can be adjusted to enhance the amplifier measurement capabilities for WR-15, WR-12 and WR-10 models. These models include an integrated variable attenuator to optionally reduce test port power by up to 20 dB. This feature is provided to prevent the saturation of high-gain amplifiers and other active devices having low input P-1 dB.

Test port return loss is 30 dB or better while directivity reaches 35 or higher, enabling accurate measurements of return loss (S11) for applications such as antenna arrays where uniform impedance matching is critical to achieving optimum performance or high directivity directional couplers where the directivity is a crucial specification.

There are several competing manufacturers of frequency extender systems. Electrical performance is generally comparable among the available options. Notable differences include how well impedance-matching is controlled on the waveguide test ports, which can affect the measured performance of some amplitude- and phase-sensitive devices.

Dynamic range for S12 and S21 measurement is usually defined as the IF signal power seen when a through-line is connected between the extender units, relative to the noise floor measured when shorted waveguide terminations are attached to each test port. Dynamic range is typically 100 to 110 dB for an IF bandwidth of 10 Hz.

For any VNA system, good amplitude and phase stability are required to maintain calibration integrity.

Model Number	Waveguide Band	Test Frequency (GHz)	VNA RF/LO Range (GHz)	Test Port Power (dBm)	Power Control Range (dB)	Dynamic Range (dB)
STO-15203-U6	V	50 - 75	8 - 12	+5	0 to 20	100 to 110
STO-12203-U6	E	60 - 90	10 - 15	+5	0 to 20	100 to 110
STO-10203-U6	W	75 - 100	12 - 18	+5	0 to 20	100 to 110
STO-08203-U6	F	90 - 140	7 - 12	+1	N/A	100 to 110
STO-06203-U6	D	110 - 170	9 - 14	+1	N/A	100 to 110

Table 1• Eravant frequency extender options.

Eravant extenders control amplitude variations to within +/- 0.15 dB while phase stability stays within +/- 1.5 degrees or better.

Installation of VNA frequency extenders is straightforward. The RF and LO signal channels require instrumentation-grade coaxial cables to minimize phase and amplitude variations.

Eravant recommends model SCW-SMSM040-F1-A-PM instrumentation-grade coaxial cables. They feature 40-inch length, SMA male connectors, and 1.6 dB insertion loss at 18 GHz. Phase matching between cables is better than +/- 10 degrees at 26.5 GHz. To the extent possible, cable positions should remain unchanged for all calibration and test conditions.

In most cases, the VNA setup is a fairly simple task. Frequency multiplication factors must be provided, along with the LO offset or an IF signal frequency. RF and LO power levels must be specified as well. Calibration options and procedures are generally unchanged, and operator functions for measuring scattering parameters are mostly unaffected by the presence of the frequency extenders.

Each extension unit includes a straight section of metrology-grade waveguide for the DUT connection. When an adapter or a waveguide transition is required, Eravant provides instructions for moving the calibration test plane to the other side of the adapter to compensate for its electrical characteristics. This calibration step yields more accurate results for components having square or circular waveguide ports, for which calibration devices are not generally available.

Each VNA extender is packaged in a rugged equipment box with additional hardware and tools.

Calibration Kits

The precision of any VNA test system relies on the quality of its calibration devices. Eravant provides metrology grade waveguide calibration kits with optional NIST traceability (Fig. 4). Each kit includes a USB memory stick containing calibration data used by the VNA.

Eravant waveguide calibration kits are available for frequencies ranging from 18 to 220 GHz. Each kit includes a matched load, a fixed short, and reference waveguide segments for 1/8, 1/4, and 3/8 wavelengths. Also included is a pair of Eravant's novel Waveguide Quick-Connect clamps (Fig. 5). They eliminate the need for screws when temporarily joining waveguide components. The Quick-Connect devices achieve excellent alignment with minimal effort. A pair of thumb screws applies uniform mating forces to eliminate gaps and avoid damage to waveguide flange surfaces.

Eravant also provides high-quality coaxial calibration kits. Connector sizes include 1.85, 2.4, 2.92, and 3.5 mm. These kits may be used with frequency extenders and waveguide-to-coaxial adapters to support coaxial VNA operation up to 67 GHz.

Figure 4 • Eravant metrology-grade waveguide calibration kits in eleven standard waveguide sizes to span the frequency range covering 18 to 220 GHz.

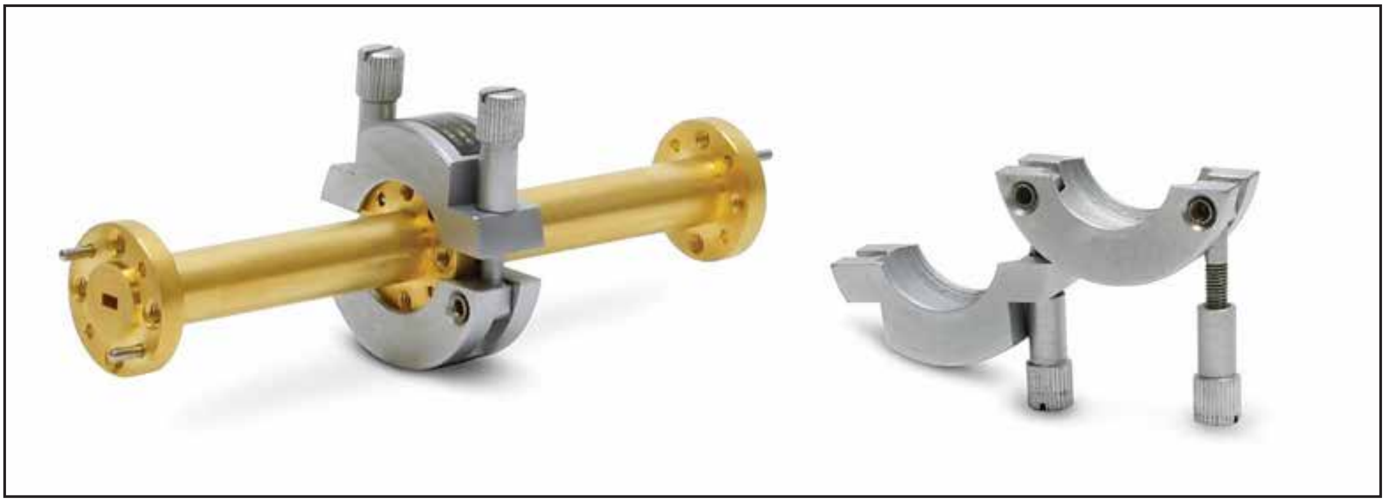

Fig.5. Waveguide Quick-Connect.

mm-Wave VNA Applications

VNA measurements at mm-wave frequencies can provide the sensitivity and dynamic range needed to develop components and systems having high levels of isolation or attenuation. Examples include waveguide ortho-mode transducers (OMTs) and duplexers that must provide low insertion loss and high isolation between antenna ports.

In communication and radar systems, filter responses must often demonstrate low in-band losses while rejecting unwanted signals by 80 dB or more. Without the error-correction capabilities of a VNA, component measurement over such wide dynamic ranges can be much more difficult and time-consuming.

Antenna measurement ranges are another common application for VNAs. With their wide dynamic range, fast response, and compatibility with motion-control and data-acquisition systems, VNAs are a common choice for characterizing antenna performance.

High-quality VNA measurements of individual components are often desired to more accurately model complex networks found in radar transceivers, MIMO communication front ends, and steerable antenna arrays. Amplitude and phase relationships at critical points in these systems can be easier to characterize and control when individual components are more faithfully modeled in software.

Another useful capability of VNAs is their ability to display measurement results in the time domain. Parameters such as group delay and localized wave impedance can be derived from vector data measured in the frequency domain. Such information can be used to understand the effects of structural discontinuities and help optimize the wide-band performance of transitions, junctions, and tuning elements.

As new applications for mm-wave VNA measurements emerge and the need for cost-effective solutions grows, Eravant will continue to build upon its commitment to offer high-quality solutions and back them up with solid technical support and high-quality component and subsystem hardware. For more information please visit www.eravant.com, call us at 424-757-0168, or send a message to support@eravant.com.