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VNA EASES ON-WAFER MM-WAVE MEASUREMENTS

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JACK BROWNE | Technical Contributor

VNA Eases On-Wafer Measurements To 110 GHz

This VNA-based measurement system, with its innovative millimeter-wave modules, brings the measurement power to the wafer, working with low-cost probe stations for S-parameter measurements **through 110 GHz.**

1. The ME7838A Series of broadband VNAs offer single-sweep frequency range of 70 kHz to 110 GHz, and usable frequency range from 40 kHz to 125 GHz.

ON-WAFER MEASUREMENTS at millimeter-wave frequencies were once a "cumbersome luxury." In addition to a vector network analyzer (VNA) with the right frequency range, the measurements required costly millimeter-wave frequency-extension modules that were too large to mount near the test probes needed for on-wafer measurements. But a solution has arrived, in the form of the latest members of the VectorStar™ family of VNAs from Anritsu (www.us.anritsu.com), the ME7838A Series VNAs. With single-sweep frequency range of 70 kHz to 110 GHz, and usable frequency range from 40 kHz to 125 GHz, a ME7838A VNA forms one component of the millimeter-wave on-wafer test solution; the other component is a set of compact frequency-extension modules from Cascade Microtech (www.cmicro.com) that is compatible with on-wafer test probe stations.

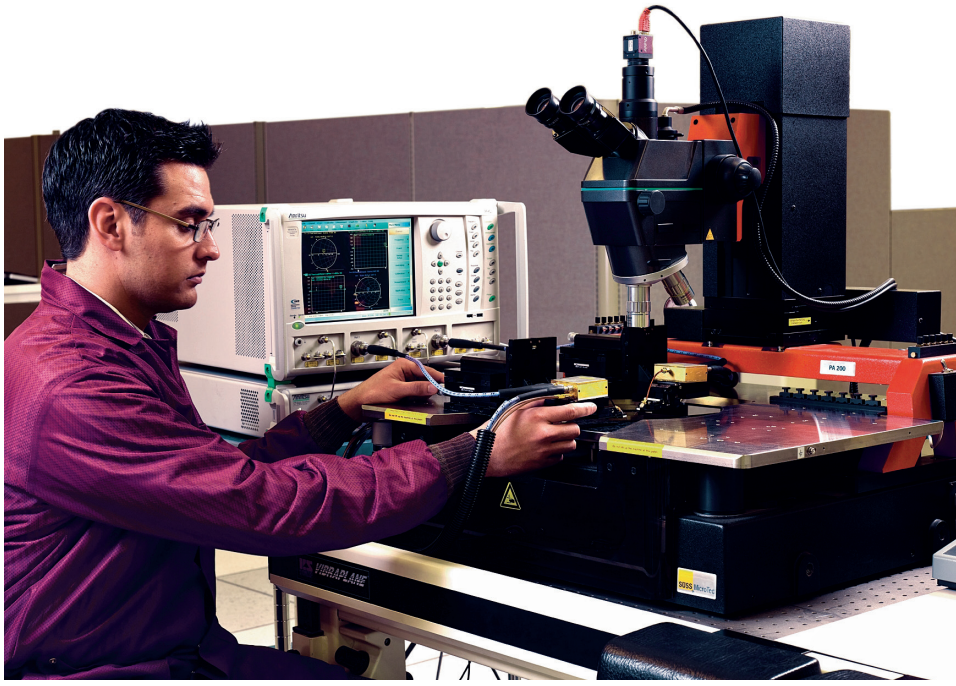
Higher-frequency (millimeter-wave) bands are of growing interest for commercial, industrial, and military users as bandwidth is consumed by the growing number of wireless applications. Commercial cellular systems operators, for example, have found available bandwidth at 60 GHz for line-of-sight backhaul links from cellular towers. Industrial users have enjoyed the benefits of wide-bandwidth millimeter-wave links for sensor and communications links on oil fields. And military users have learned that millimeter-wave frequencies, in addition to serving radar systems, offer reliable battlefield communications for both soldiers and robots: They provide bandwidth to receive full sensor data from drone vehicles, including unmanned aerial vehicles (UAVs) and unmanned ground vehicles (UGVs).

Of course, practical implementation of millimeter-wave electronic products in any market requires affordable semiconductor devices (from sufficiently high yields), as well as accurate and reliable test solutions for characterizing these devices in both research and production environments. VNAs have been available

for measuring transmission and reflection scattering (S) parameters on active and passive devices through 110 GHz. But it is the manner in which most VNAs generate and detect those higher-frequency test signals that offers such challenges for making on-wafer measurements at millimeter-wave frequencies. The VNA itself typically has a frequency range through microwave frequencies, and then employs frequency multiplication in the generation of millimeter-wave test signals and frequency division on the return path when analyzing the signals from a device under test (DUT). Most VNAs employ the multiplication and division circuitry within frequency-extension modules that are remote and connected to the VNA mainframe by means of precision cables or waveguide, depending upon the frequency range.

These frequency-extension modules have traditionally been somewhat bulky because of the necessary components and printed circuits—typically about 7 lbs. or more each. The large size and weight makes them less than ideal for mounting on commercial automatic wafer probe stations, such as those available from Cascade Microtech (www.cmicro.com) and Micromanipulator Company (www.micromanipulator.com). And this is where some of the innovation in the VectorStar ME7838A Series VNAs **(Fig. 1)**, and their extremely compact frequency-extension modules, makes a difference. By leveraging GaAs monolithic-microwave-integrated-circuit (MMIC) technology and integrating multipliers directly in the frequency-extension modules without couplers, Anritsu's engineers were able to dramatically reduce the size and weight of the millimeter-wave modules for the ME7838A Series VNAs.

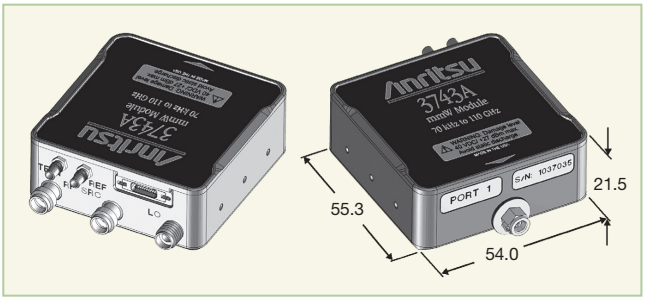
With millimeter-wave modules that weigh only 0.6 lbs each **(Fig. 2)**—compared to 7.6 lbs. each for conventional millimeter-wave modules, and with millimeter-wave frequency-extension modules that are about 1/50th the volume of conventional millimeter-wave modules—the ME7838A Series VNAs literally bring S-parameter measurement power to the wafer, allowing frequency-extension modules to be mounted directly on an automatic wafer probe station for improved ease and accuracy of testing **(Fig. 3)**. The light weight of the model 3743A frequency-extension modules for the ME7838A Series VNAs translates into improved positioning accuracy. In addition, there is no longer a need for long connecting cables or waveguide extensions to make connections between the wafer probes of a probe station and the frequency-extension modules of a VNA. Nor is there a need to perform tedious calibration routines to remove the amplitude and phase effects of those added cables and waveguide from millimeter-wave S-parameter measurements. In fact, because Cascade Microtech has developed adapters for the new millimeter-wave modules for its different lines of probe stations, the frequency-extension modules for the ME7838A Series VNAs can be used with lower-cost probe stations nominally designed for lower-frequency use, providing an economical on-wafer millimeter-wave measurement solution.



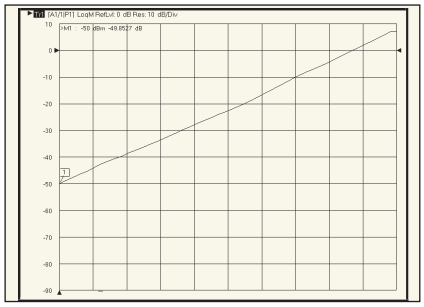
3. The VNAs are designed with compact, light-weight frequency-extension modules that simplify millimeter-wave on-wafer measurements.

In addition to simplifying on-wafer millimeter-wave measurements, the ME7838A Series VectorStar VNAs offer extended low-frequency coverage to 70 kHz (usable to 40 kHz), as well as operational millimeter-wave frequency coverage to 125 GHz. The VNAs feature an advanced power-control technique, with signal processing performed in both the VNA mainframe and in the millimeter-wave modules. The approach employed in the ME7838A takes less time, is less tedious, and is more accurate than the usual method of adjusting power at millimeter-wave frequencies via electronically controlled mechanical attenuators and power linearity correction tables.

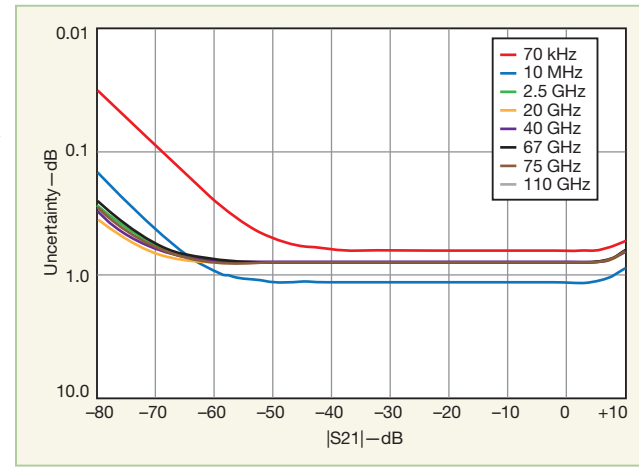
Signal frequencies through 54 GHz are processed in the VNA mainframe, while signals beyond 54 GHz are handled in the millimeter-wave modules. This level of power control results in outstanding calibration and measurement stability that maintains amplitude within 0.1



2. These compact millimeter-wave modules measure just 55.3 x 54.0 x 21.5 mm.



4. This plot shows the sweep power range of the ME7838A VNAs at 94 GHz, with better than 60-dB control range.



5. The transmission magnitude uncertainty of the ME7838A VNA was evaluated at frequencies from 70 kHz to 110 GHz following a SOLT calibration.

dB over a 24-hour period, for confidence in measurement results over time. (The analyzers also boast 0.5° phase stability from 70 kHz to 110 GHz over a 24-hour period.) The power accuracy is within ±1.5 dB through 54 GHz, within ±2 dB from 54 to 90 GHz, within ±3 dB from 90 to 110 GHz, and within ±4 dB from 110 to 125 GHz. Activating the internal power calibration routine with appropriate power sensors results in power accuracy corrected to the accuracy of the power meter. The available test port power (with option 62) ranges from -85 to +8 dBm from 70 kHz to 2.5 GHz, from -85 to +3 dBm from 2.5 to 24.0 GHz, from -90 to -4 dBm from 24 to 54 GHz, from -55 dBm to at least -6 dBm from 54 to 90 GHz, from -55 to 0 dBm from 90 to 105 GHz **(Fig. 4)**, from -50 to -5 dBm from 105 to 110 GHz, and at least -40 to -15 dBm from 110 to 125 GHz. The result is real-time ALC power control of at least -55 to -6 dBm from 70 kHz to 110 GHz. At all power levels, the resolution is 0.01 dB.

Since VNAs are typically used with some form of calibration, the ME7838A Series VNAs were evaluated for essential measurement performance, including directivity, source match, and load match, following a short-open-load-thru (SOLT) and triple-offset-short calibration using the model 3656B calibration kit **(Fig. 5)**. The directivity is 36 dB from 70 kHz to 10 MHz, 40 dB from 10 MHz to 20 GHz, 37 dB or better from 20 to 95 GHz, and 35 dB from 95 to 110 GHz. The source match is 35 dB or better at the low- and high-frequency extremes (70 kHz to 10 MHz and 95 to 110 GHz) and 41 dB or better from 10 MHz through 95 GHz. The ME7838A VNAs achieve similar performance for load match, with reflection tracking of ±0.1 dB from 70 kHz to 10 MHz and ±0.05 dB from 10 MHz through 110 GHz, and transmission tracking of ±0.1 dB from 70 kHz to 10 MHz and ±0.07 dB or better from 10 MHz through 110 GHz (Fig. 3).

The sensitive receiver design in the ME7838A Series VNAs and an instrument architecture that improves noise-floor performance by as much as 20 dB accounts for impressive dynamic range at millimeter-wave frequencies: 108 dB at 65 GHz and 107 dB at 110 GHz. The receiver's compression point is defined as a deviation of at least 0.2 dB in response relative to the normalization level when using a 10-Hz IF bandwidth (IF bandwidths can be set from 10 Hz to 1 MHz). At the lowest frequencies (through 300 kHz), compression doesn't occur until the receiver is hit with +6 dBm power (the available test power is +10 dBm at those frequencies). For most of the ME7838A Series VNAs' receiver frequency range, from 300 kHz to 110 GHz, compression doesn't occur until receiver input power reaches +10 dBm (available test port power is less than that for most of that frequency range). At the highest frequencies, 110 to 125 GHz, receiver compression occurs with input power of +5 dBm. The ME7838A Series VNAs feature fast measurement speed of 55 ms for a 201-point sweep, helping to significantly shorten the time required for swept frequency measurements or any measurements in which a large number of data points are required. This combination of fast measurement speed, wide receiver dynamic range, and innovative power control make the VectorStar ME7838A VNAs ideally suited for broadband swept gain compression measurements on millimeter-wave amplifiers.

In short, the ME7838A Series VNAs and their frequency range of 40 kHz to 125 GHz are ideal for analog millimeter-wave and digital high-speed testing of active and passive devices. They offer excellent raw directivity and wide dynamic range for broadband device characterization for Ka-band satellite-communications (satcom) systems and their components, 40-Gb/s optical networks, 60-GHz backhaul communications links, 77- and 94-GHz automotive radar, E-band point-to-point communications systems, and 94-GHz imaging radar systems. They can also be used for signal-integrity (SI) testing on high-speed digital components, including 28-Gb/s serializer/deserializer (SerDes) transceivers. With the millimeter-wave frequency-extension modules and their test power, it will be a while before the ME7838A Series VNAs run out of bandwidth for most measurements. MWRF

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