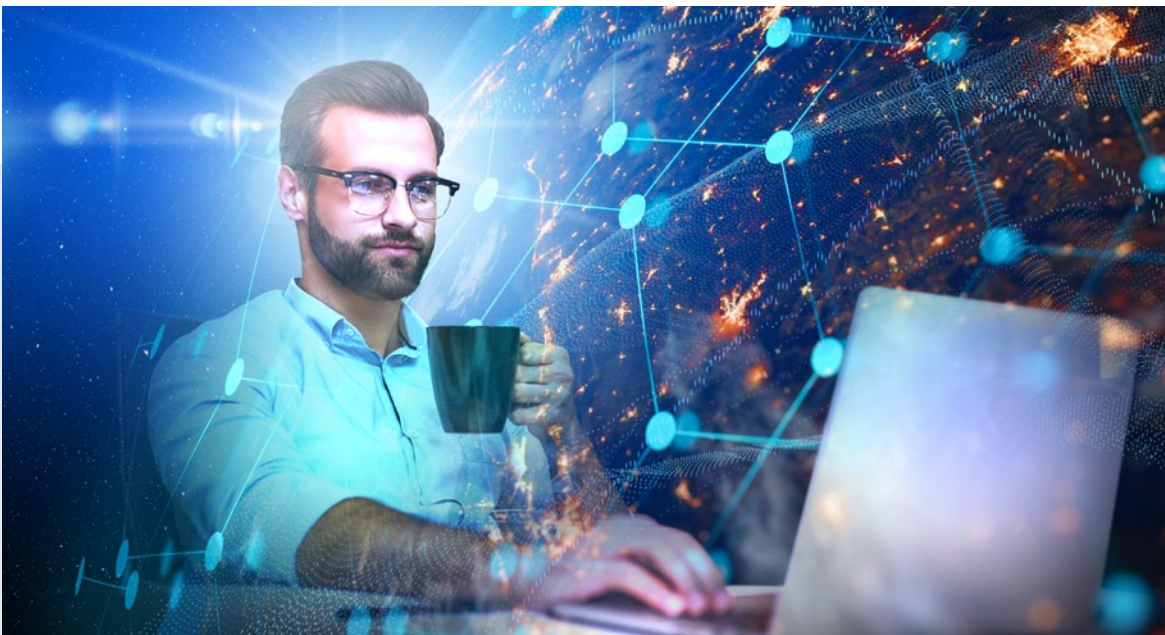
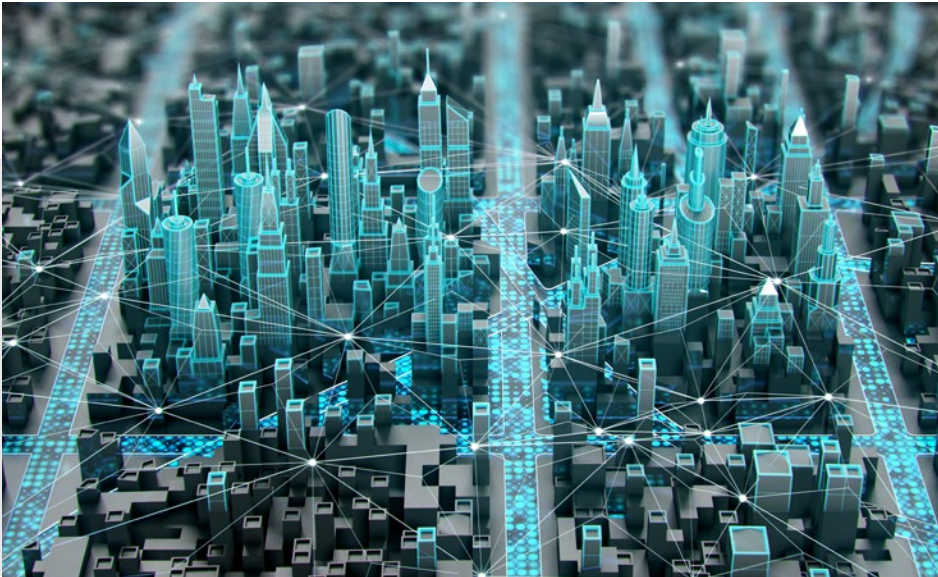


# Considerations for Creating Microwave and Millimeter-wave Automated Test Systems



Automated test systems are cornerstone to high frequency testing for 5G, next generation Wi-Fi, satellite communications systems. Programmable RF devices such as digital step attenuators, phase shifters, and signal generators form the building blocks to these systems. RF network simulation is necessary in the test and measurement of 5G and Wi-Fi 6/6e systems where MIMO, handover and various wireless systems testing enables engineers to test out next generation wireless systems in the lab environment. This tech brief dives into specific considerations around the buildout of programmable RF systems.



## RF Network Simulation, Fading Simulation, Handover and MIMO Test Systems

RF network simulators, handover test systems, fading simulators, and MIMO test systems will often leverage a matrix of programmable RF components in order to recreate the complexities of any propagation environment with conductive test equipment. Customized handover test systems are often designed for fast-moving platforms such as a high speed train or aircraft that moves in the range of multiple base stations during transit (**Figure 1**). In these

scenarios, the test system will have to utilize particular attenuation ramps based upon the speed of the train's (or plane) onboard transceiver and the location of the device relative to the base station covering that particular

area. The test system can simulate a downlink from multiple base stations via the inputs of the matrix attenuation unit where the outputs would be the ultimate signal arriving at the transceiver.

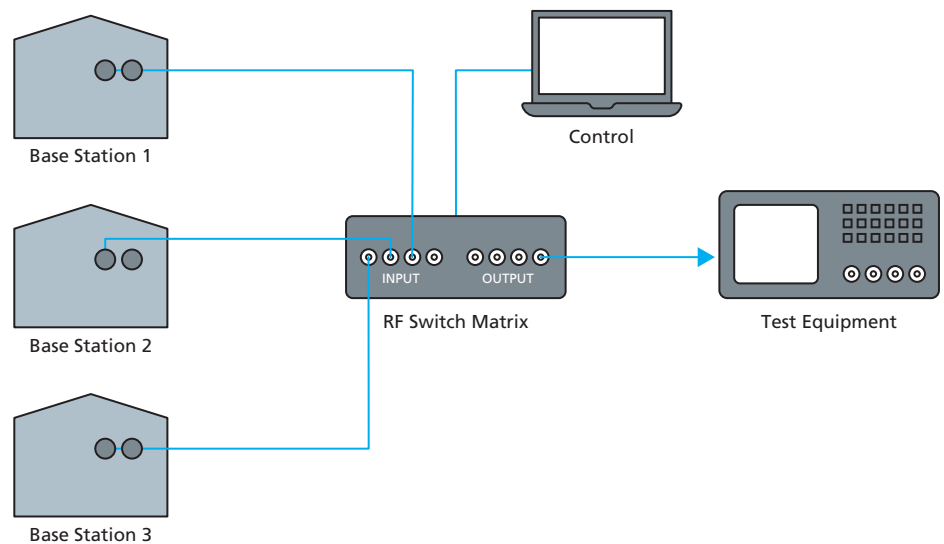


**Figure 1.** Handover test systems leverage attenuator matrices to simulate the rapid fading that occurs between the base station(s) and the onboard transceiver. In this setup, the base stations provide the input signals that are then attenuated according to a fading profile to be received at the output, or the transceiver.

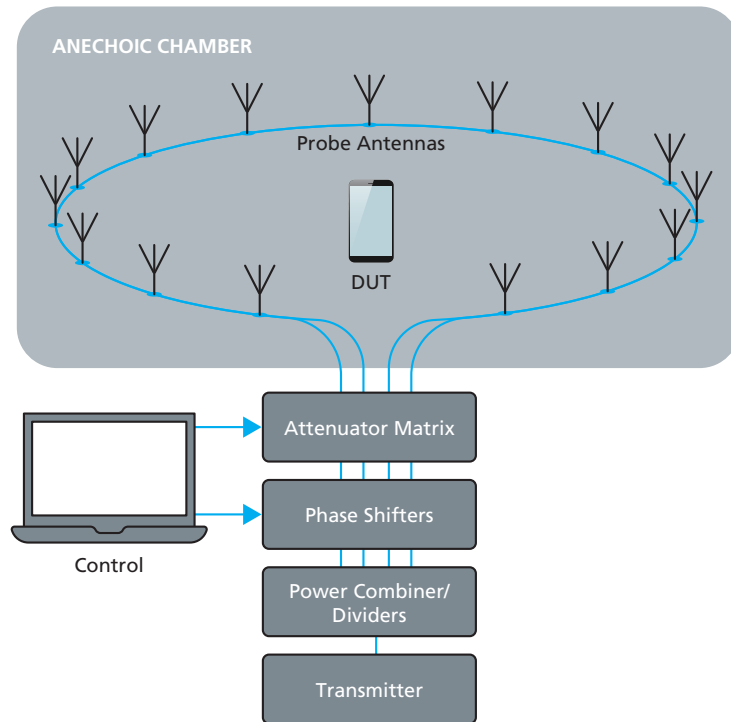


**Figure 2.** Test method for evaluating the channel properties of 4x4 MIMO with spatial fading emulation performed by an array of programmable phase shifters and attenuators.

Fading simulators must effectively mimic the multipath and fading that occurs when a transmitted signal is attenuated and dispersed through the various propagation obstacles in the environment. In multipath fading, the final signals arriving at the receiver will be the original shifted in phase, at varying amplitudes, and with different delays. The doppler effect, or a shift in frequency will also occur according to

the relative speed between the transmitter and receiver. The combination of all these effects can be seen in mathematical models such as Rayleigh distribution or Rician distribution where the signal amplitude varies in time. This effect is also critical to test in MIMO systems that take advantage of multipath in spatial diversity for a more reliable link. These effects can be simulated with programmable attenua-

tor and phase shifter matrices in order to reduce both the signal strength and shift it in phase. The test setup in **Figure 2** illustrates this in a spatial fading emulator setup where the RF signal from the base station is fed into a power divider to split the signal into multiple signals that is equal to the number probe antennas in the anechoic chamber. These signals are phase shifted by individual phase shifters and then attenuated by programmable RF attenuators. The phase and amplitude adjusted signal is sent off the probe antennas where the device under test measures the signals from each antenna probe and outputs the data to a computer for further analysis. Leveraging programmable phase shifters and digital attenuators is much more cost-effective over a channel simulator.

MIMO test systems for Wi-Fi and cellular systems might require a pulsed test signal to be sent to a MIMO device to transmit multiple signals to a number of test antennas in order to test the integrity of the transmitted data (**Figure 3**). A similar setup can be

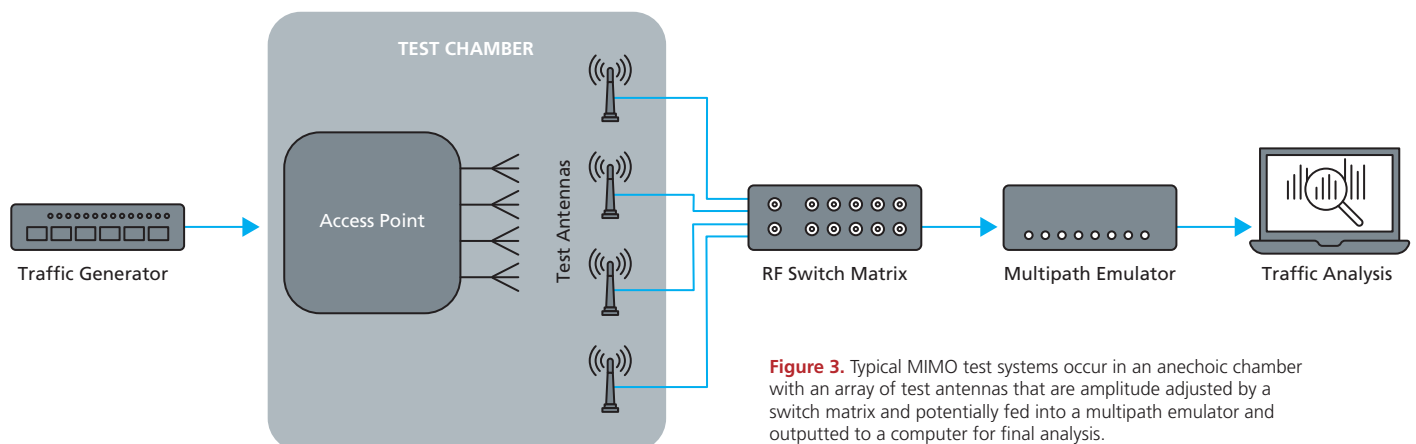


**Figure 3.** Typical MIMO test systems occur in an anechoic chamber with an array of test antennas that are amplitude adjusted by a switch matrix and potentially fed into a multipath emulator and outputted to a computer for final analysis.

performed to measure received data to a MIMO device under test (DUT) where the test antennas are configured to transmit uplink signals and the MIMO DUT receives the combined downlink signals. In these test setups fading profiles, or more basic signal attenuation are often performed with RF switch matrices. A multipath emulator can be added for additional realism in order to gauge how these devices perform in various RF environments.

The beauty of these test systems is that the basic programmable RF devices within them can be scaled up or scaled down. Utilizing an array of attenuators and/or phase shifters can allow an engineer to precisely customize multiple input signals as per their specifications. And, with software programmability these systems can be ideated and developed remotely, prior to any physical construction. Prototyping smaller systems to scale up is a

relatively straightforward process; once the base configuration is established, the larger system can be easily generated, upgraded, and adjusted accordingly.

## Considerations for RF Switched Matrices—Blocking or Non-Blocking?

Switched RF matrices are necessary in order to properly affect an environment for a moving handset or radio transceiver. These systems incorporate a series of programmable digital attenuators that carefully attenuate the amplitude of the signals running through them according to a “fading profile”, an “attenuation ramp”, or even simply provide a fixed attenuation. At the input of these systems, a

series of power dividers will split the signal sending the split output signal down to an input of the multi-channel digital attenuator. The attenuator will then impede the signal according to a preprogrammed attenuation profile. The outputs of the attenuators are then fed into power combiners to generate the final output signals.

**Figure 4** shows the components and interconnection of “non-blocking” 8x8 switch matrix. In non-blocking configuration, splitters and combiners are used at the inputs at outputs in order to connect all the inputs with all the outputs, simultaneously. This is sometimes referred to as the “full fan-out” configuration.

In practice, this allows engineers to run an input signal through different outputs with varying attenuation profiles, or run varying input signals to the same output. In a MIMO system, this means two devices with a dissimilar antenna count can be connected via arbitrarily selected input and output paths of the RF simulator. On the other hand, a blocking switch matrix would use switches at the inputs and outputs (or both) to “select” which input will connect to which output. In the industry, this can be referred to as a limited fan-out configuration. Each of these configurations will provide the test engineer with a level of flexibility to test their system. Depending on the choice of topology, there are certain performance bottlenecks to consider. Oftentimes, this boils down to the subcomponents used to build out the test system.

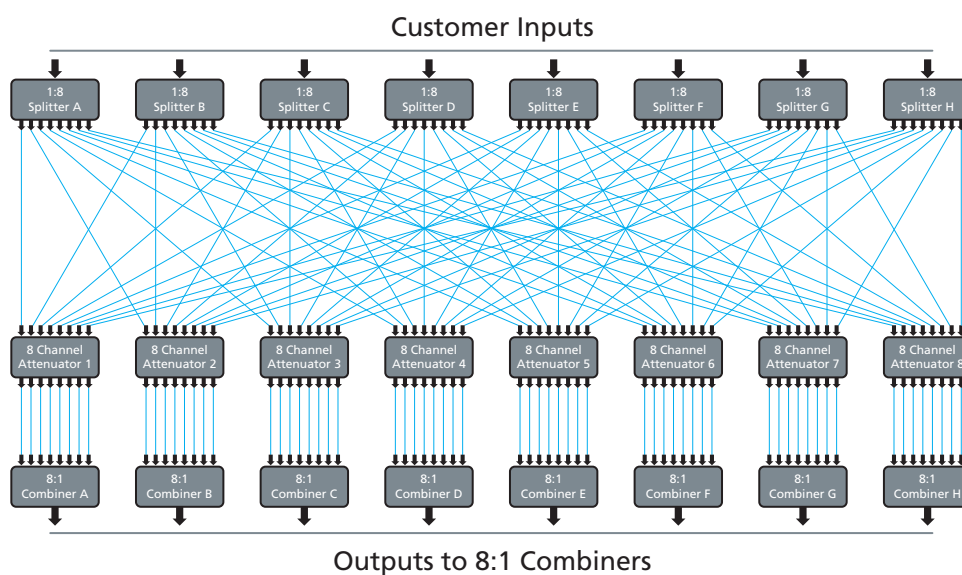


**Figure 4.** 8x8 non-blocking attenuation matrix.

# How product specifications will impact your test system's functionality

## Passives, Switches, Power Combiners, and Interconnects

In the blocking topology, the use of switches offers more isolation between different signals and less insertion loss from the input to the output. In this version of the RF switch matrix, the exclusive employment of absorptive switches are preferred over the reflective switch counterpart. This way, the a 50  $\Omega$  load termination in the absorptive switch offers a low VSWR to all switch paths in both their on and off state.

In the non-blocking matrix configurations, the isolation between the output ports is often determined by the isolation of the power combiners. The higher the isolation, the less likely it is for signals to interfere with each other—a parameter that will invariably impact the accuracy of test results. In the instance where two output signals are being fed from the same power combiner, the isolation is capped at the isolation between adjacent ports of the combiner. This can be 20 dB for adjacent ports and up to 25 dB for distant ports in a power combiner. For your standard SPDT switch, this falls between 60 dB to 65 dB.

For engineers designing a switched matrix, the insertion loss of the power dividers will depend heavily on whether or a resistive or reactive power splitter/combiner is used. Resistive power splitters will offer a wider operating bandwidth, however the isolation between the output ports

and the insertion loss of the component are both considerably worse than that of a reactive power splitter. The resistive power splitters offer no common ports, the signal entering a singular arbitrary port will be split up equally between the rest of the ports. More often than not, RF attenuator matrices will employ RF splitters and combiners as there are distinct “inputs” and “outputs” to work with and the overall system insertion loss is kept to a minimum while the isolation between output ports is maximized. The insertion loss of the power dividers will also increase with the number of outputs (**Figure 5**). These are serious considerations for a switch matrix buildout that might include the use of active RF signal conditioning components such as amplifiers and mixers. These components are not bidirectional and will ultimately limit the utility of the system based upon the end-user's test requirements.

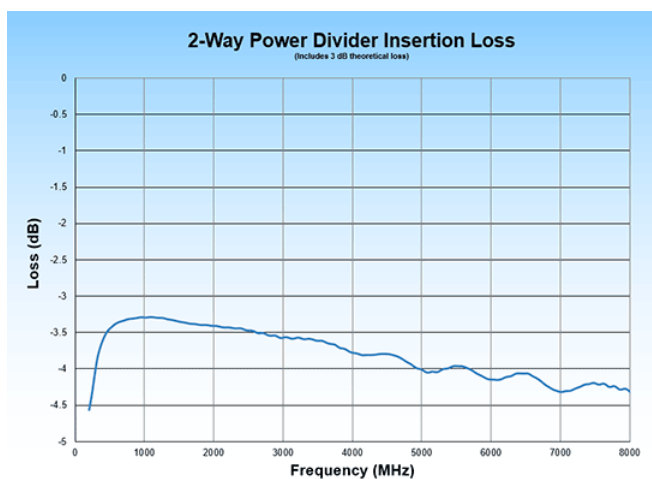
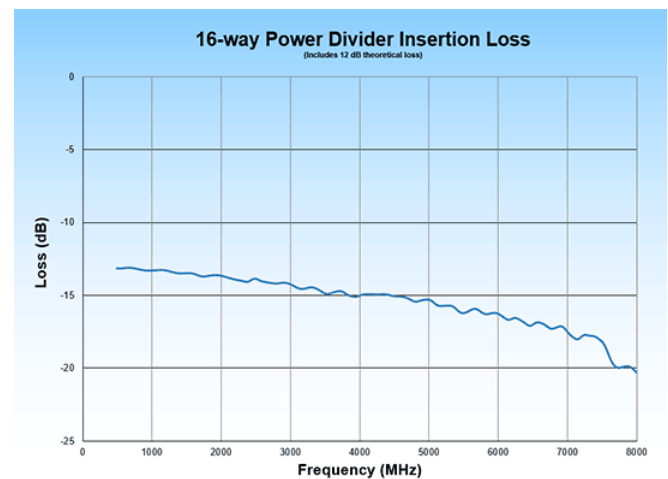


**Figure 5.** The insertion loss of the power combiner/divider used will increase with the number of ports.

### Picking the Right Coax

Using the shortest possible signal path between components and the inputs/ outputs on the switched matrix is critically important to minimizing the insertion loss of the entire system. The more passive components introduced from point A to point B, the more signal attenuation will occur. In order to minimize this, using low loss passive components and the short lengths of coax are necessary. The coax used within switched matrices are typically semi-rigid cables due to their inherently low attenuation, or insertion loss per unit length. Semi-rigid coaxial assemblies feature a solid sheath outer conductor and a solid inner conductor that allow the coax to be formed to the preferred length and shape after which, the connector heads are soldered on. This type of fabrication creates both a phase and amplitude stable coax with an extremely low VSWR and insertion loss as compared to the flexible coax alternatives.

### Choosing the Right Programmable Attenuators and Phase Shifters

RF attenuators are resistive devices that can impede a signal according to a specific attenuation level; this can come in the form of a fixed RF attenuator, a variable attenuator, or a programmable RF attenuation. Programmable RF attenuators use switches in discrete attenuation states through semiconductor devices

including PIN diodes and various transistor topologies (e.g., MOSFET, MESFET). Programmable phase shifters, on the other hand, adjust the phase of a high frequency signal while keeping its amplitude constant. Both these devices are typically controlled via transistor-transistor logic (TTL) inputs which can be controlled via a serial interface such as RS232. However, modern-day programmable devices can include the use of a USB and/or LAN interface for ease of accessibility. This way, the device can readily connect to virtually every commonly used device such as laptops, tablets, and PCs. An Ethernet interface allows for network control over a web interface for remote control (Figure 6).

The parameters of the programmable attenuator and phase shifter will ultimately limit specific parameters of a

test system. The bandwidth is the first parameter to ascertain as it ultimately determines the range of frequencies a test can be performed at. This can be critical when performing fading simulations that include the doppler effect. For both a programmable attenuator and phase shifter a rapid response time is important for proper fast fading emulation and mobile transceiver test systems where the transceiver might be moving at a fast speed relative to the base station. A small step size of 0.1 dB for a programmable attenuator or 1 degree for the programmable phase shifter will allow the test to have a much higher resolution with a more precision test system. The accuracy of the test system will be limited by the phase and attenuation accuracy of these components as well. While a phase shifter will generally

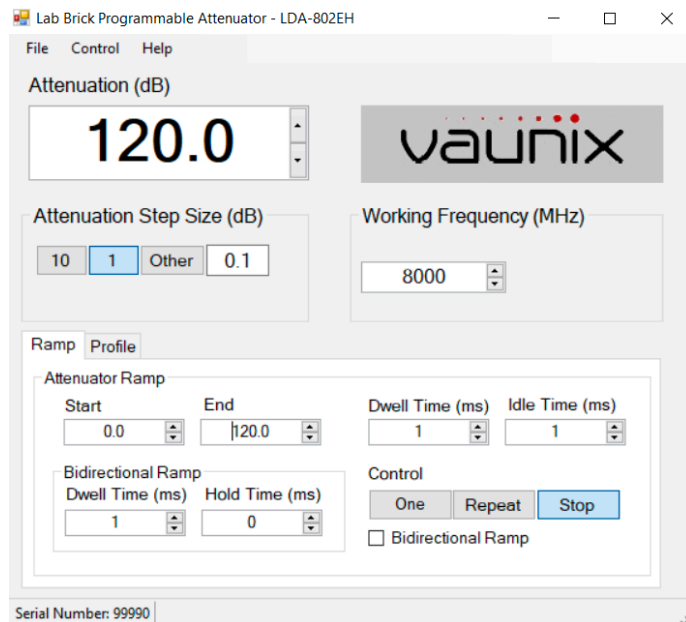


**Figure 6.** Vaunix Lab Brick phase shifters connect via USB. Lab Brick digital attenuators connect via USB or USB/Ethernet. Both can be easily programmed with free software.

have a phase control range from 1° to 360°, a programmable attenuator might have an attenuation range from 30 dB up to 120 dB. A programmable RF attenuator with a high channel count (4 and beyond) would inevitably save space in a switched attenuation matrix, a serious consideration for portable test setups. Programmable phase shifters can also vary in channel counts and size, all of which are parameters to consider when implementing a test system.

As stated earlier, minimizing the system's insertion loss is key to developing the best RF network simulator possible. Whenever possible, insertion loss and VSWR should be minimized by selecting the right components. However, it is more important to ensure that the test required even can be performed by ensuring that programmable RF attenuators and phase shifters offer the right range of operating frequency, attenuator range, attenuation step and phase control range.

## Big Decisions: Going for a big box or building a system from the ground up

The arena of programmable RF measurement has traditionally been

dominated by big-box test systems where all the switches, attenuators, phase shifters, and power combiner/dividers as well as all their relevant interconnections come readily encased in a rack mountable, metallic enclosure. There is merit to purchasing a pre-built solution – these boxes sidestep the headache of putting together a massive test system, allowing the test engineer to focus on putting together a production test setup on the system level rather than a device level. Selecting adequate equipment that both fills the needs of ongoing testing and is future testing would be optimal. Oftentimes, this might mean leveraging a full-fanout, non-blocking matrix that operates over a wide enough bandwidth – a solution that loses feasibility in terms of cost when multiple test systems are required.

There is, however, the alternative solution of implementing smaller modules in any configuration in order to satisfy a particular set of test requirements. This allows test facilities to more readily scale their tests up (or down) and run through several iterations of test setups to progressively optimize a modular rack mount system. Both of these methods of building a larger test system hold merit. A pre-built, large rack mount system might speedup the testing timeline of a specific prototype. However, for a company looking to build in a number of more specific

functions on a budget, building a test system at the component level might be more desirable. More often than not, the test system's functionality (e.g., bandwidth, accuracy, resolution, response time) is a much stronger driver than its performance (e.g., insertion loss, isolation, etc); the ability to custom-tailor these functions to suit an application might be the best option.

## Designing a scalable test system that can be custom-designed and upgraded remotely

Regardless of the choice of conductive test system, the importance of programmability cannot be understated. This means that there should be continuity in programmability between RF devices over the same software platform. Regardless of whether an engineer is operating a signal generator, phase shifter, attenuator, or switch individually or as a group, adjustments should be performed almost identically and with ease. The same can be said for configuring the device(s). This should be able to occur from a single interface rather than through layers of menus. Much of these issues can be

## TECHNICAL BRIEF

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bypassed by ensuring that components are purchased from a quality vendor with a decent selection of programmable devices. This also helps mitigate the risk of spending more for extraneous test features that are just not necessary.

Both USB- and Ethernet-controlled programmable RF devices have the ability to be accessed with the standard equipment, allowing users to set-up, adjust, and upgrade devices with ease. The Ethernet interface also allows for software development, upgrades, and test equipment control to be performed remotely; lowering the barriers for global enterprises. This way, a modular rack-mount test system can be ideated across the world and a prototype can be built, programmed and tested to be readily scaled up for more complex testing.

## Conclusion

Programmable RF test systems can be built modularly from individual components or bought as a large rackmount system. Each of these choices come with their own myriad of considerations. However, regardless of the test system, engineer's intending to obtain these programmable RF test systems must thoroughly consider the functional requirements of the particular test they wish to undertake. This will ultimately determine the optimal type of test system to go for. In many cases, scaling up a programmable RF test system from individual programmable attenuators, phase shifters, switches, and power combiners/splitters is also manageable and often desirable in order to tailor the various aspects of a programmable RF test system.

Vaunix lab bricks are readily programmable, remotely upgradeable and easy to build out to a larger test system.



# vaunix

*Vaunix offers a strong portfolio of programmable RF components including digital attenuators, phase shifters, signal generators, switches and power combiner/splitters. All of these USB-controlled components come readily programmable out of the box and can also be developed with other programs such as LabVIEW and Python.*

→ **Lab Bricks are Available for Immediate Delivery From Stock**