

Matrix Attenuators—The Unsung Hero of Handover, Mesh, and Other Test Systems



Given the enhanced complexity of wireless/mesh and antenna technologies there are now a myriad of different test systems and technologies from simple modular component systems, handover test systems, to complete all-in-one wireless/mesh test units. These new units are designed to tackle the latest wireless/mesh technologies, such as Wi-Fi 6e/7, Bluetooth, Zigbee, Thread, Matter, cellular (4G and 5G NR/5G Advanced), as well as proprietary wireless technologies and advanced/active antenna systems (AAS). Though the complexity of modern wireless/mesh and antenna technology has exploded, RF attenuators and attenuator matrices have been, and continue to be vital components of modern RF test systems for wireless/mesh, antenna, and other measurement technologies.

This article aims to educate readers on how attenuators and attenuator matrices are used in the latest wireless/mesh and handover test systems, and how modular attenuator matrices and other components can be used to augment existing test systems and can even be used to assemble wholly modular/custom test systems.



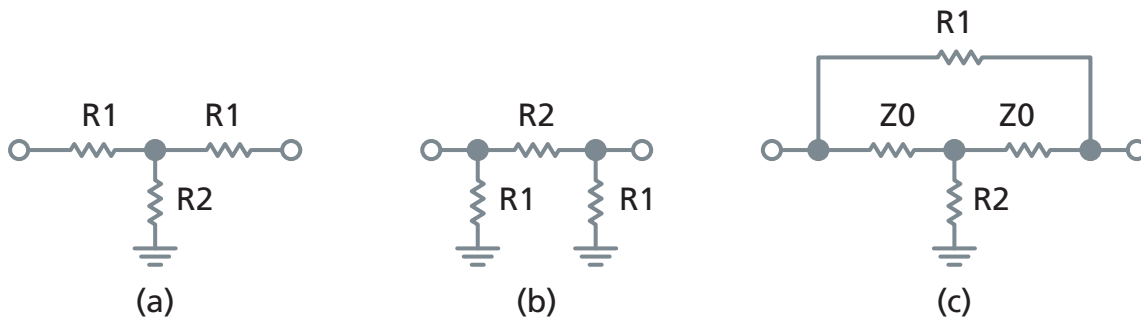
The Venerable RF Attenuator & Attenuator Matrix

At the heart of an RF attenuator is the signal conditioning feature of signal strength reduction. However, most common RF attenuators offer features beyond simple signal strength reduction and include broadband

functionality, precision impedance matching, and in the case of variable attenuators, the ability to set the attenuation level. Attenuator matrices are a set of attenuators with a number of input and output ports, where each RF path includes an attenuator, typically a variable or programmable attenuator.

Common uses for RF attenuators are to augment the dynamic range of test equipment, compensate for poor

impedance matching/mitigate standing wave formation between two reflective nodes, enable calibration techniques for specific test setups, and to control signal levels in a single/several RF path(s). RF attenuators are also used in advanced/active antenna systems (AAS) and active electronically scanned arrays (AESAs) to control the signal strength at the various antenna elements and manipulate the AAS/AESA antenna radiation pattern.



(a) T-type (b) pi-type (c) bridged-T resistive networks that function as absorptive RF attenuator circuits.

The Role of Matrix Attenuators in Handover, Mesh Networking, and Other Wireless System Testing

These functions and features make RF attenuators essential for RF test setups, especially for modern wireless sensing and communication systems. The latest 5G Open Radio Access Network (O-RAN) technology presents a common challenge where the frequency of software releases necessitates near continual testing and certification of wireless base station technology to be compatible with the macro or O-RAN base stations from other providers. Other challenges include prototyping/developing and certifying Internet of Things (IoT) and Industrial Internet of Things (IIoT) devices in the myriad of network topologies these devices may be installed. The sheer diversity of new wireless systems and technologies raises the bar for testing to ensure newly developed devices will be able to compete in the cluttered landscape while conforming to regulatory requirements.

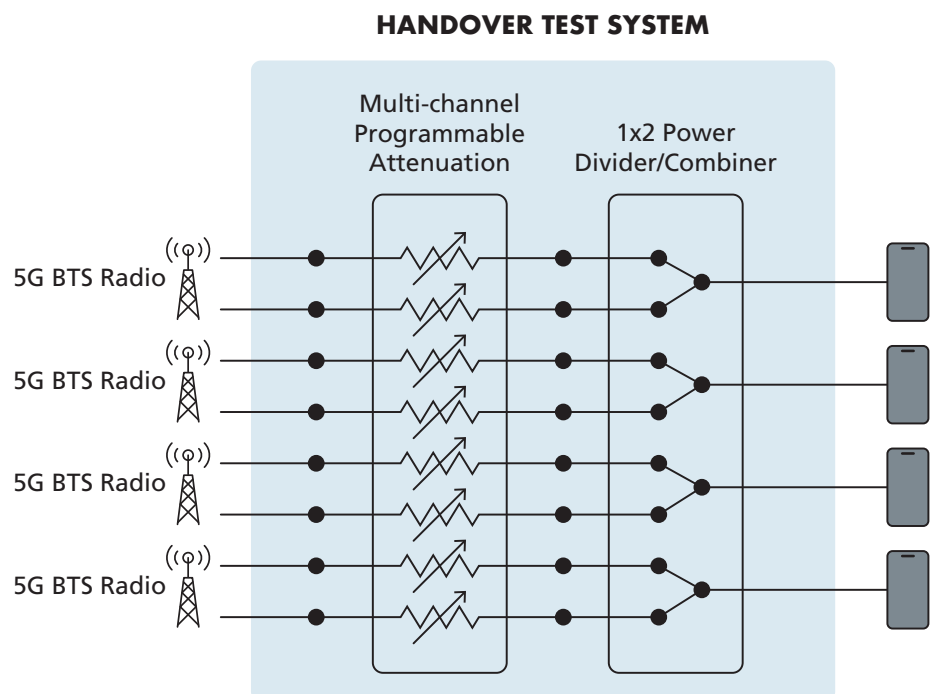
An example 5G handover test system with 4 user devices and 4 base station transceivers (BTSs). A programmable attenuator is used for each of the two channels from the 5G BTSs and power divider/combiners are used to combine these two signals into a single RF path to the user devices.

Attenuators In Handover Test Systems

Handover testing is a common test type that is used in cellular telecommunications, wireless communication networks, wireless mesh networks, and tactical radio systems. Essentially, any radio system that has more than a single possible wireless link among devices in the network where a handover may occur will likely involve handover testing to ensure that key functionality of the network. Handover, however, generally applies to networks with redundancy or moving user equipment (UEs) and/or base stations. Hence, cellular telecommunications and Wi-Fi applications make use of handover test systems as the UE is often mobile, and now, the routers/base stations for these technologies are also sometimes mobile. Many

modern tactical radio systems are designed with mobility of UEs and base stations in mind, so handover testing is also prevalent in modern military/defense and aerospace applications.

A handover is merely when a base station, router, mesh node, or wireless link between two points is handed off to another transceiver to continue the same communication. The role of a handover test system is to provide fading of the wireless link in a laboratory condition to simulate the real-world condition of signal strength reduction as a device passes to the edge of wireless link range. Handover testing can be used to ensure that a device or radio architecture conforms to a specific standard, or to otherwise test the absolute capabilities of a radio system.



A simple handover test system is just an RF attenuator matrix with variable attenuation levels. This could be manual, digital control, or programmable. Typically, a handover test system consists of a programmable attenuator matrix and optionally a fixed attenuator matrix to enhance the signal level reduction through the test system.

With the complexity of modern base stations and wireless router technology, there are also now different varieties of handovers. This includes intra-system, inter-system, vertical handovers, and cellular to Wi-Fi handover. There will also likely be future handover variations between other wireless networking standards and types and possibly even networking typologies, such as handovers between mesh networks and star networks (Wi-Fi) or cellular networks. Future wireless networks may also make use

of cognitive radio technology and include features like adaptable network topologies where the devices on the network self-arrange to form a more optimal wireless network based on the type of devices in the area and the traffic/demand from these devices. These new intelligent networks will also require more sophisticated handover techniques, and hence, much more sophisticated handover testing systems that will necessarily make use of a plethora of RF attenuators.

Attenuators In Mesh Networking Test Systems

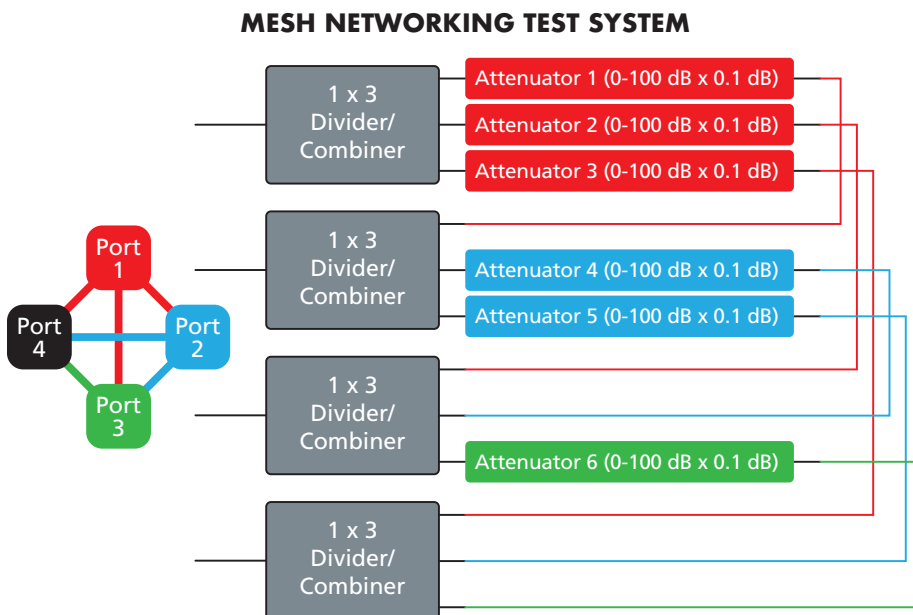
Mesh networking test systems typically provide conductive interconnect paths among the nodes in a mesh network. This removes the need to perform testing with the variability of an air channel, and instead, a more controlla-

ble and reliable conductive channel can be used where signal conditioning hardware, such as attenuators, can be inserted within the conductive channel. Mesh networking test systems require there to be a variety of different transceivers, generally one per node, interconnected in a way that the signals from one node may reach one or more other nodes. Using matrix attenuators and signal routing hardware can allow for a significant part or entire mesh network to be simulated with the various attenuation levels providing simulated signal strength differences based on simulated range or obstructions. Various mesh networking features, such as network initialization, optimization, and healing can be simulated with programmability of the attenuators and signal routing hardware used in these systems.

Other Wireless Network & System Testing

There are also many other types of wireless network and system testing that makes use of attenuators and attenuator matrices. This list includes interoperability, coexistence, beam forming, network equipment validation, inter-band carrier aggregation, regression testing and multi-standard interference testing. The majority of wireless network and system testing leverages signal conditioning, which

A mesh networking test system, sometimes referred to as a transceiver test system or simply mesh test system, that is configured as a “full fan-out” test system. This means that every port has access to every other port via power dividers/combiners and attenuator matrices.



includes signal level adjustment. There are also various types of transceiver and receiver testing that use high precision attenuators for calibration and precise level control to the DUT. The number of connections and attenuators depends on the complexity of the networks and the number of nodes/base station/UEs/transceivers in the network, which could be hundreds or even thousands in dense IoT networks. With modern wireless network and system testing, this can involve tens to hundreds of devices, especially if interference/interoperability/coexistence is being performed where there are multiple transceivers for each wireless standard being tested.

The Growing Complexity of Wireless/Mesh & Antenna Test Systems

The complexity of modern wireless technologies is driving the growing sophistication of test systems needed to qualify, verify, certify, and otherwise

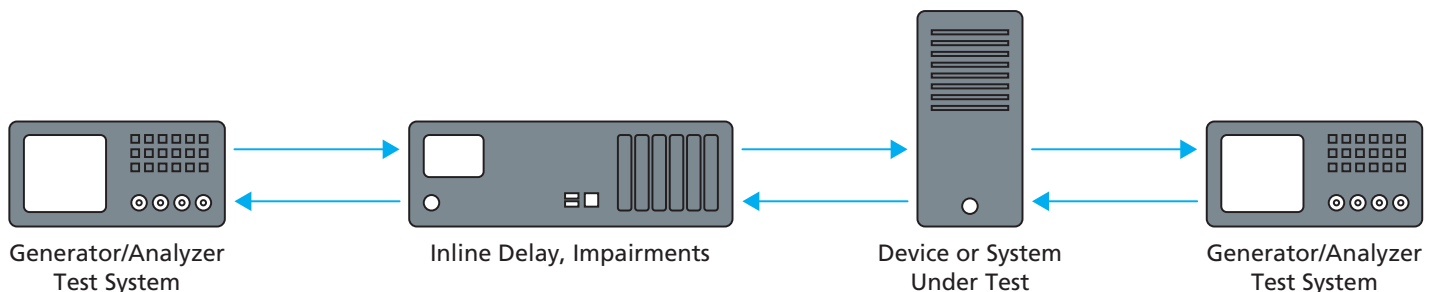
measure these new technologies. There are new wireless/mesh and antenna test systems that are packaged to provide substantial or even turn-key solutions for testing all of the new devices based on specific new wireless standards, protocols, and frequencies. Among these new solutions are transceiver test systems, mesh/mesh network test systems, wireless network test systems, base station test systems, handover test systems, and so on. There are also antenna test systems that provide much of the same features as other wireless test systems. But, these antenna test systems are predominantly designed to also drive AAS in order to ascertain the performance of the antenna itself as opposed to the transceiver hardware or wireless network performance.

At the heart of all of these systems is the humble RF attenuator, as each of these wireless test systems ultimately must provide precision control of signal levels at various stages in the process. In fact, many of the mesh network test systems, wireless network test systems, and even transceiver test systems are merely RF matrix attenuators with some control interface and software/

application programming interface (API) to allow for external control by an automated test system or as integration into a larger wireless test system. The same can be said for many “handover” test systems, that are simply programmable attenuator matrices with external control.

However, there are also more sophisticated wireless test systems that include other RF hardware outside of programmable attenuator matrices. Some wireless test systems include switch matrices for various routing options. Power dividers/combiners are also often included along with switch matrices to allow for even more complex routing and real-world scenario simulation.

Some handover test systems include switch matrices and power dividers/combiners to allow for more complex scenario simulation during conductive testing. One of the distinctions amongst some handover test systems that feature programmable attenuators, is that the systems may provide programmable fading profiles and swept attenuation ramps, amongst other programmable features suited to handover testing. Simple wireless test systems for cellular telecommunica-



tions are also composed of switch matrices, power divider/combiners, and attenuator matrices.

Phase shifters can be used to add delay and increase simulation realism as well as drive AAS based on phased antenna array technology. In some cases wireless test systems also include full transceivers connected to the switch, power divider/combiner, attenuator, and phase shifter matrices to create complete active wireless test systems, router emulators, or base station emulators. A step beyond this in complexity are the wireless test systems that digitize/synthesize real RF test signals to/from the devices-under-test (DUTs) or network-under-test (NUT) and provide extensive signal manipula-

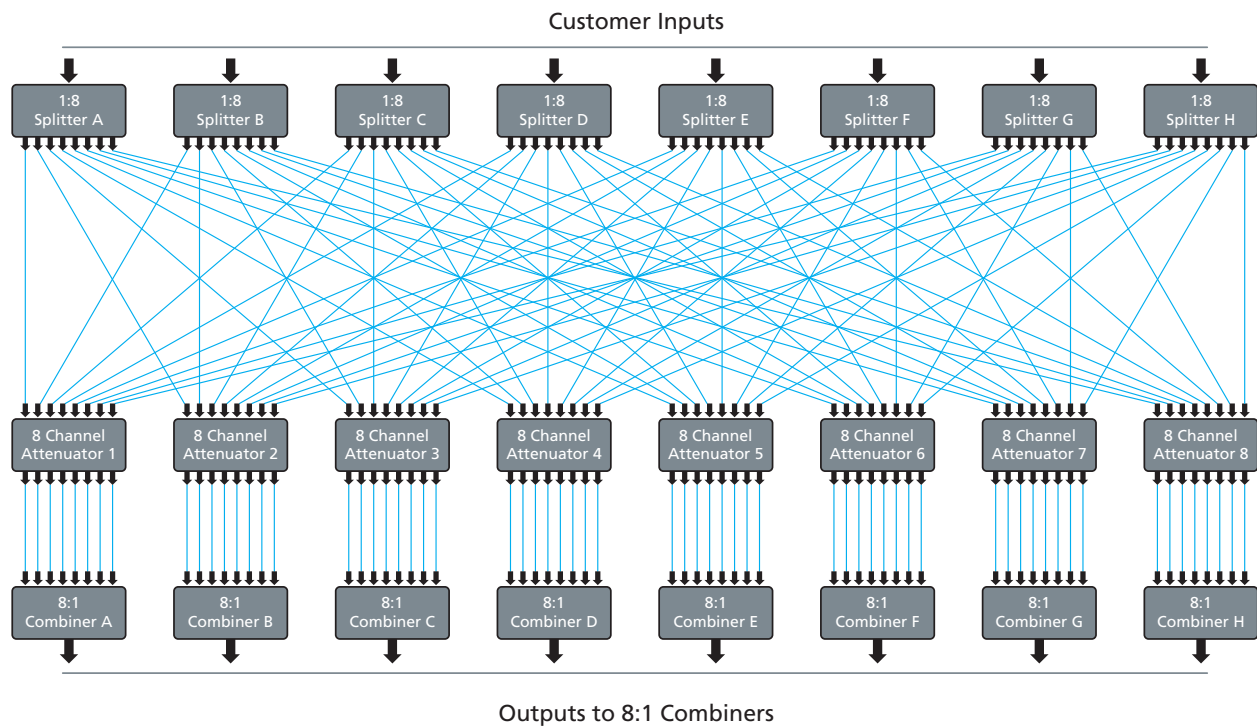
tion functionality in the digital realm. Many of these systems only have specific product names and there isn't standard nomenclature to describe these systems to potential customers. The systems are sometimes called channel emulators, radio channel emulators, wireless network emulators, or the term "simulator" is used instead of "emulators".

There are varying degrees of modularity/customizability with these systems, where some are made of entirely modular components, such as coaxial connectorized parts, while some are highly integrated and specialized. Many of these systems also have various degrees of software control and programmability, and there is no

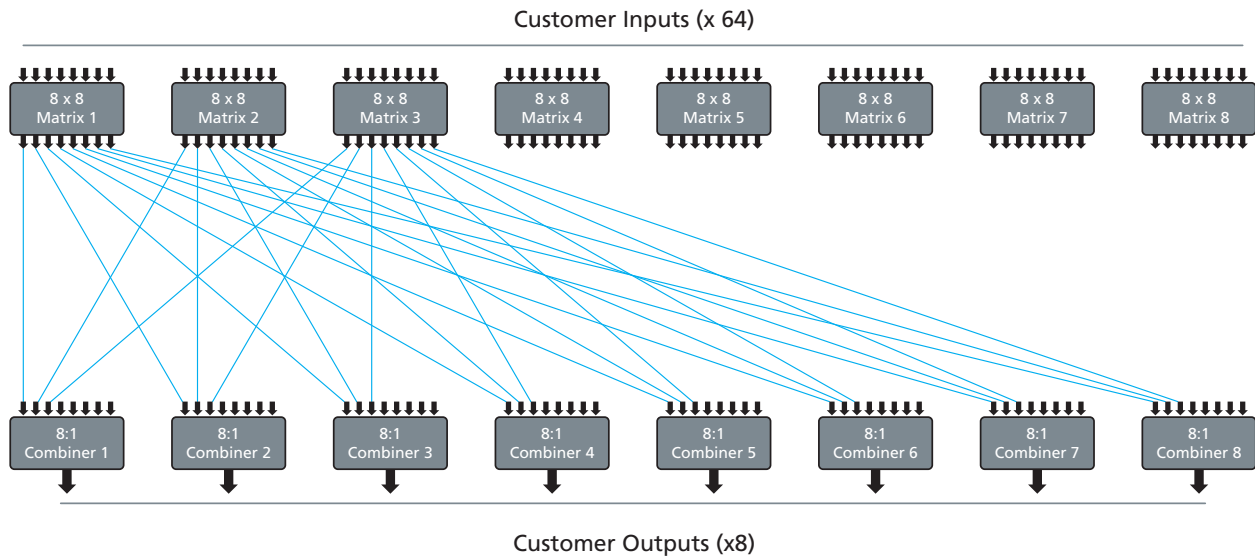
simple rule for determining the extensibility of such systems. The onus is generally on the customer and user to decipher the utility of these systems for a given application, and this approach can be hit or miss.

Using Modular Test Components To Assemble a Complete Test System

The core of conductive test systems for wireless network and system testing are programmable attenuator matrices, power dividers/combiners, and



An 8x8 attenuator matrix with power dividers/combiners at the inputs and outputs, hence a "full fan-out" 8x8 wireless test system. This configuration can be used as a handover test system, transceiver test system, or mesh network test system.



A 64 input to 8 output attenuator matrix that can be used as a handover test system. If the power combiner/dividers and attenuator matrices in this diagram are bidirectional this could also be used as an 8 input to 64 output attenuator matrix or handover test system (bidirectional 64x8).

switch matrices, and interconnect. Properly arranged, these components can be used to create the desired routing scenarios and signal conditioning amongst the various ports of the test system to simulate a variety of different network conditions.

It may also be useful to include programmable phase shifter matrices along with RF attenuators to simulate a programmable delay in addition to the generally slight delay the interconnect and attenuators and other active hardware add. Depending on the

necessary precision of the system and the types of testing being performed, it may be advantageous to add directional couplers and power meters at certain ports. Tunable filters may also be added to channels of the wireless test system to provide additional signal conditioning, such as tunable notch filters for signal removal, and tunable bandpass filters to enhance selectivity of certain frequencies during testing.

With the basic attenuator, switch, and power divider/combiner building blocks it is possible to construct wireless

network/system testing systems to essentially any number of ports. It is important to keep in mind that wireless test systems with greater flexibility require much more interconnect and additional building blocks than less flexible test systems. For instance a wireless test system where the signals from every port are routed to every other port necessarily requires more interconnect and components than a test system where only the input ports are routed to every output port, or only certain input/output ports are routed to each other.

Conclusion

RF attenuators and attenuator matrices, specifically programmable attenuator matrices, are a cornerstone of a variety of different wireless network and system test setups. As wireless systems become more complex with greater numbers of nodes, frequency channels, multi-input multi-output (MIMO) spatial multiplexing channels, network topologies, inter-technology handover/

handoffs, and more, there is a need for higher density programmable attenuator matrices and modular test systems to augment existing test systems and build new test systems. Modular RF test systems are particularly advantageous in the modern landscape of wireless tests as there is a greater demand for flexibility in testing to adapt to new standards and test configurations that continually emerge.

Digital attenuator handover test systems such as these provide the necessary level of reconfigurability, cost-effectiveness, and ease of control offered by modular and efficient USB-based digital attenuators.



Tech Brief Provides Insight on Creating Wireless Handover Tests and Fading Simulations with Low-cost Programmable Devices

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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.

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