APPLICATION NOTE

Switch Matrix Configurations for RF Signal Routing

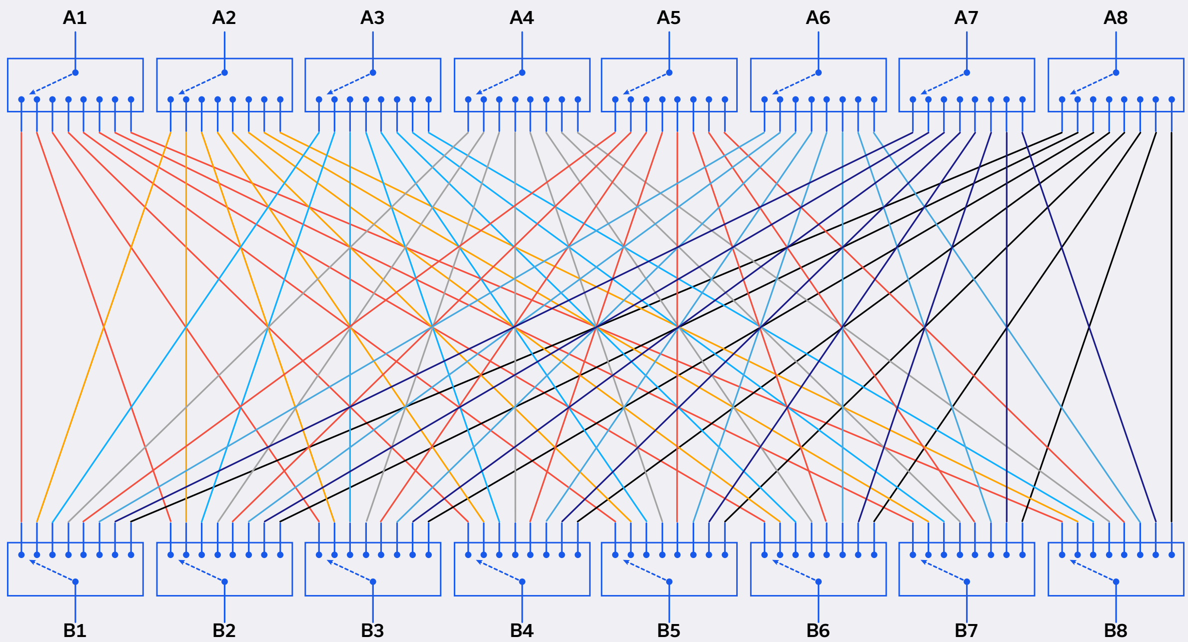

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TABLE OF CONTENTS

1. OVERVIEW 03

2. BLOCKING SWITCH MATRICES 04–07

2.1. Switch Path Options 04–05
2.2. Benefits / Trade-Offs 05–06
2.3. Applications 06
2.4. Mini-Circuits' Solutions 06–07

3. NON-BLOCKING 08–12

3.1. Fan-In 09
3.2. Fan-Out 09
3.3. Switch Path Options 09–10
3.4. Benefits / Trade-Offs 10
3.5. Applications 11
3.6. Mini-Circuits' Solutions 11–12

4. FULLY NON-BLOCKING / FULL FAN-OUT 12–15

4.1. Switch Path Options 13
4.2. Benefits / Trade-Offs 13
4.3. Applications 13
4.4. Mini-Circuits' Solutions 14
4.5. Mesh Network Emulators 15

5. CONCLUSION 16

6. CONTACT 16

1. Overview

Switch matrices are an essential tool for control of RF signal routing in any environment where there is a recurring need to change how systems interconnect. The addition of Ethernet and USB interfaces with flexible software and APIs (application programming interfaces) makes switch matrices particularly useful in automated test environments, allowing test sequences to be scheduled to run with no user intervention, switching between multiple devices under test (DUT), input / output ports and test equipment.

This application note aims to summarize the different switch matrix variations available to the user, along with the key considerations, specifications and benefits of each approach. For convenience, switch matrix ports are referred to below as either “inputs” or “outputs” but in most cases, switch matrices operate bi-directionally so that all ports can be used as both input and output.

Mini-Circuits offers a wide range of switch matrix configurations to support any application from DC to 67 GHz, drawing on our extensive catalog of switches, programmable attenuators and power splitter / combiners. A non-exhaustive summary of existing switch matrix configurations is available on our website at:

minicircuits.com/WebStore/RF-NxM-Switch.html

Please contact us to discuss your requirements:

testsolutions@minicircuits.com

2. Blocking Switch Matrices

1. Features:

- Switches on input and output ports
- One-to-one configuration
- Multiple paths
- Bi-directional operation

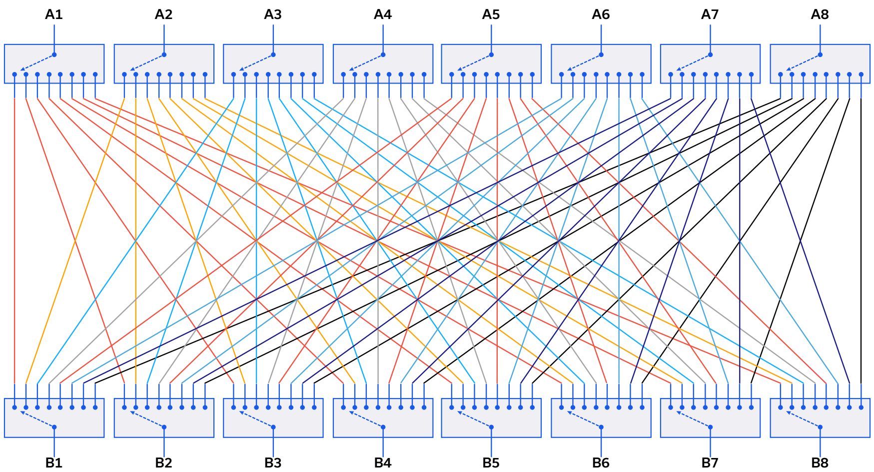


***Figure 1**: 8 x 8 Blocking Switch Matrix Configuration.*

Blocking switch matrices are constructed using switches on the inputs and outputs, as shown in Figure 1. They are called "blocking" because once a path is set between any pair of ports, those 2 ports are not available (blocked) for use by any other path. Multiple paths can be active in parallel, up to the number of input ports or the number of output ports (whichever is fewer), with each path connecting a different pair of ports.

2.1. Switch Path Options

The example in Figure 1 is an 8 x 8 blocking switch matrix, which allows 8 individual paths to be active in parallel. The configuration is described as "one to one" since each of the active paths can only connect a single input port to a single output port. Any combination of 8 active paths is possible, as shown in Figures 2-3.

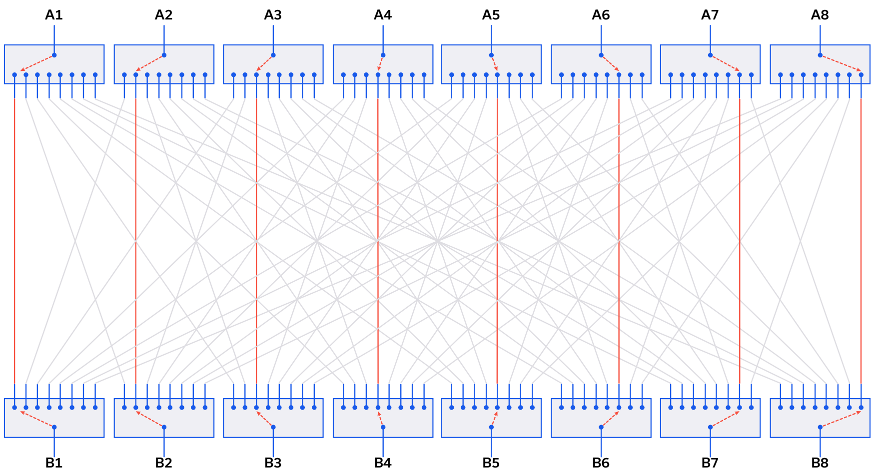


Figure 2: *Example blocking matrix paths (A1<>B1; A2<>B2; A3<>B3; A4<>B4; A5<>B5; A6<>B6; A7<>B7; A8<>B8).*

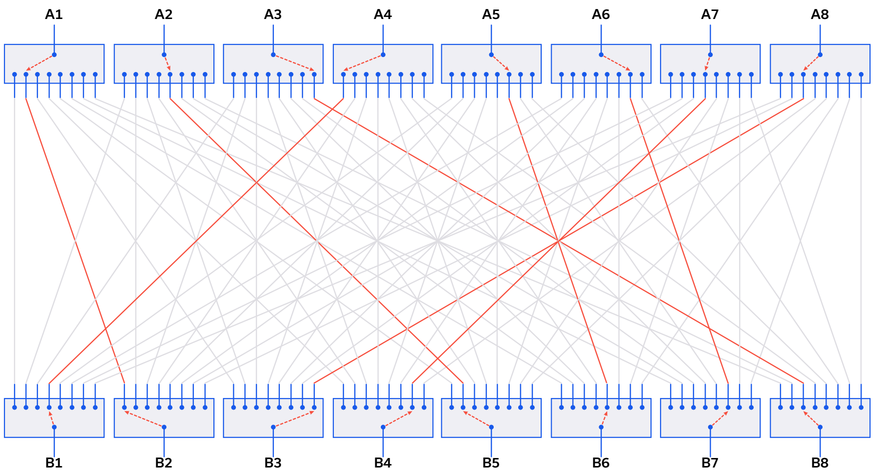


Figure 3: *Example blocking matrix paths (A1<>B2; A2<>B5; A3<>B8; A4<>B1; A5<>B6; A6<>B7; A7<>B4; A8<>B3).*

2.2. Benefits / Trade-Offs

One key advantage of blocking switch matrices over other configurations is the inherent performance of the discrete RF switches used in their construction. A blocking switch matrix built using mechanical switches is the closest approximation to physically connecting and disconnecting a cable between 2 devices. Mini-Circuits has mechanical switch components available with very low insertion loss for the active path, very high isolation for the disconnected path, high power rating and exceptionally wide bandwidths, from DC up to as high as 50 GHz, making them ideal for blocking matrix designs.

While mechanical switches are optimized for reliability with switching lifetimes specified on the order of millions of switching cycles, the moving parts will wear out eventually, so for applications requiring an exceptional number of switch operations (for example, semi-conductor testing), a solid-state blocking matrix may be more appropriate. Matrices built with solid-state switches also have the advantages of a physically smaller package for the matrix and a faster switching time (subject to delays in the Ethernet / USB control interface).

Mini-Circuits has a range of high-performance solid-state switch modules available for use in switch matrix designs, which successfully combine some of the performance benefits more often associated with mechanical switches, including very high isolation and ultra-wide bandwidths.

The notable trade-off for a blocking switch matrix configuration in comparison to the other matrix types summarized below is the limitation that each path can only provide a one-to-one connection. For applications requiring multiple signals to be routed to the same port simultaneously, a non-blocking or full fan-out configuration would be required.

2.3. Applications

The one-to-one nature of blocking switch matrices, with minimum loss on active paths and maximum isolation of disconnected paths, makes the configuration perfectly suited to expansion of automated test and measurement environments. The matrix can be used to switch signal sources, signal analyzers and any other test equipment between input / output ports of 1 or more devices under test (DUT), with minimum interference in the measurement. The ability to automate this switching through software, rather than requiring someone to be available to change the physical cable connections, allows for test sequences to be automated and run unattended, maximizing throughput and utilization of test equipment.

A special case of this is Mini-Circuits' ZTVX series 2 x n blocking switch matrices (available from 2 x 8 up to 2 x 32). The 2 "input" ports can be connected to a standard 2-port VNA to expand the capability of the test setup, either for testing of multiple 2-port devices, or for testing of devices with a larger number of ports.

2.4. Mini-Circuits' Solutions

Mini-Circuits' ZT-8X8B and ZT-8X8B-1835 are summarized below as examples of 8 x 8 blocking switch matrices. ZT-8X8B operates from 10 MHz to 6 GHz, using solid-state switches for high-throughput, fast-switching applications. ZT-8X8B-1835 offers the same configuration implemented with mechanical switches, offering a wider bandwidth, from DC to 18 GHz and very low insertion loss. Both models can be controlled via Ethernet or USB, using the included GUI or comprehensive API for automation in most modern programming environments.

ZT-8X8B

- 8 x 8 blocking switch matrix
- Solid-state switch design
- 19″ rack-mount chassis, 3U, 20″ depth
- SMA female connectors (front & rear)
- Ethernet & USB control

Parameter	Conditions	Min	Typ	Max	Units
Frequency	-	10	6.5	6000	MHz
Path Loss	10 MHz – 2 GHz	-	9.0	-	dB
	2 – 4 GHz	-	11.0	-	
	4 – 6 GHz	-	80	-	
Isolation	Ax<>Ay & Bx<>By	-	60	-	dB
	Ax<>By (disconnected)	-	12	-	
Return Loss	-	-	-	-	dB
Input Power	Through path	-	-	+27	dBm
	Hot switching	-	-	+17	
	Into terminations	-		+17	

ZT-8X8B-1835

- 8 x 8 blocking switch matrix
- Mechanical switch design
- 19″ rack-mount chassis, 4U, 20″ depth
- 3.5 mm female connectors (front & rear)
- Ethernet & USB control

Parameter	Conditions	Min	Typ	Max	Units
Frequency	-	DC	-	18	GHz
Path Loss	DC – 6 GHz	-	1.3	1.8	dB
	6 – 12 GHz	-	2.0	2.5	
	12 – 18 GHz	-	2.6	3.1	
Isolation	Ax<>Ay & Bx<>By	80	100	-	dB
	Ax<>By (disconnected)	80	100	-	
Return Loss	DC – 6 GHz	-	24	-	dB
	6 – 12 GHz	-	20	-	
	12 – 18 GHz	-	15	-	
Input Power	Cold Switching	-	-	+40	dBm
	Into terminations	-	-	+30	

3. Non-Blocking

2. Features:

- Fan-In:
    - Switches on input ports and combiners on outputs
    - Many to one configuration
- Fan-Out:
    - Splitters on input ports and switches on outputs
    - One to many configuration
- Multiple paths
- Bi-directional operation

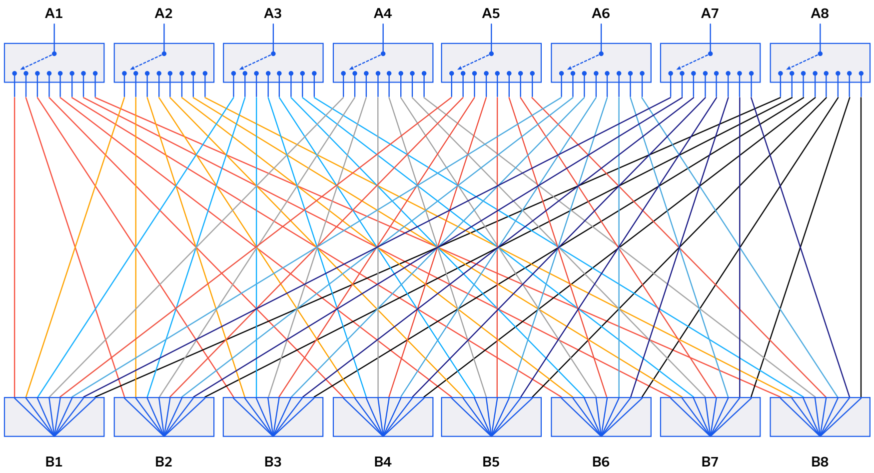


***Figure 4**: 8x8 Non-blocking Switch Matrix Configuration.*

Non-blocking switch matrices are constructed using switches on one set of ports and passive splitter / combiners on the other. They are referred to as non-blocking (sometimes partially non-blocking) since the splitter / combiner component allows a single port to be connected concurrently to multiple ports on the opposite side. Hence the path is not blocking any other ports from connecting, as would be the case with a blocking switch matrix.

Non-blocking matrices are often characterized as either fan-in or fan-out depending on the orientation of the splitter / combiners relative to the input ports.

3.1. Fan-In

Fan-in matrices have switches on the input side, connecting each individual input port to only one output port at a time. The splitter / combiners on the output ports, allow multiple inputs to be combined or fanned in simultaneously to a single output. This is a “many to one” configuration as multiple inputs can be switched simultaneously into the same output. The number of paths that can be active at once is dictated by the number of input ports.

3.2. Fan-Out

Fan-out matrices have the orientation reversed, with the splitter / combiner components on the input ports permanently fanning out each input concurrently to every output. The switches on the output ports then allow each output to select only one of those input ports at a time. This is a “one to many” configuration as a single input can be switched into multiple outputs ports at once. The number of paths that can be active at once is dictated by the number of output ports.

3.3. Switch Path Options

The example in Figure 4 is an 8x8 non-blocking configuration, allowing 8 paths to be active simultaneously in a range of possible configurations. The figures below demonstrate the flexibility of the non-blocking configuration, with Figure 5 showing a routing that could also be achieved in a blocking matrix, Figure 6 showing all inputs connected concurrently to the same output, and Figure 7 showing a combination of paths.

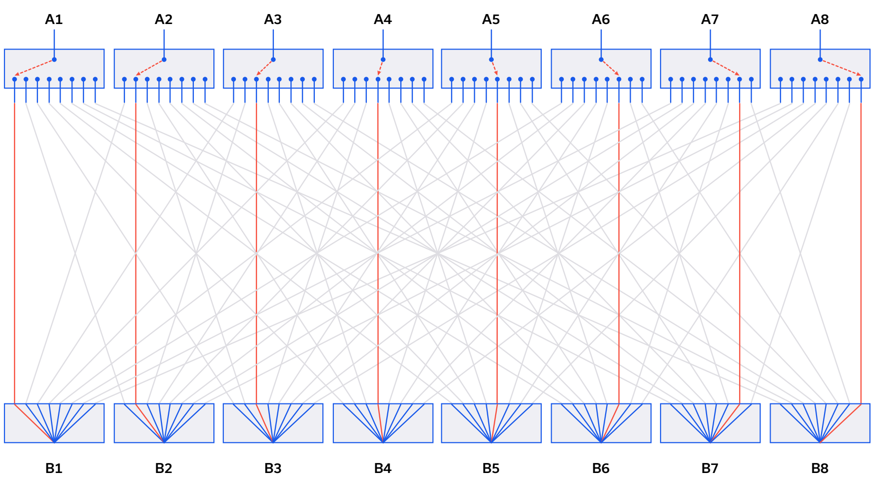


***Figure 5**: Example non-blocking matrix paths (A1<>B1; A2<>B2; A3<>B3; A4<>B4; A5<>B5; A6<>B6; A7<>B7; A8<>B8).*

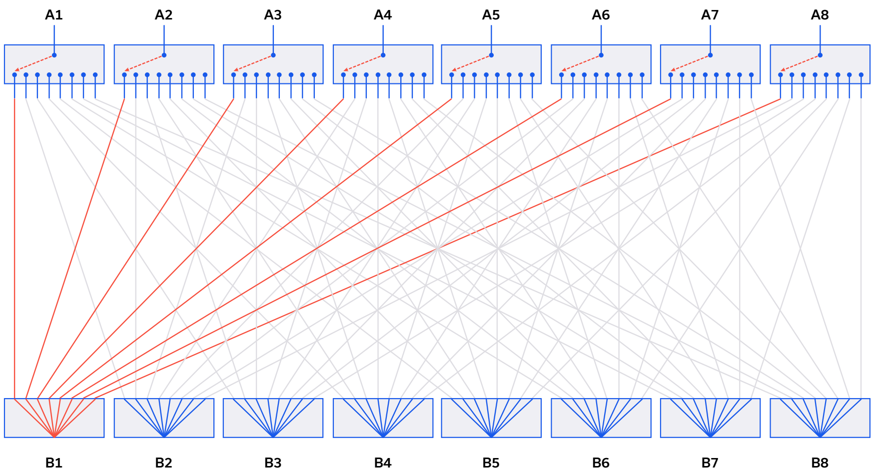


***Figure 6**: Example non-blocking matrix paths (A1-8 <> B1).*

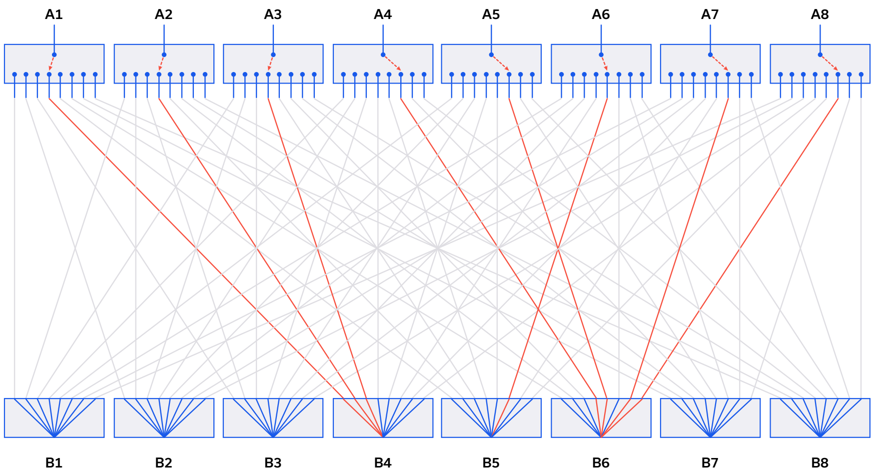


***Figure 7**: Example non-blocking matrix paths (A1-3 <> B4; A4-7 & A8 <> B6; A6 <> B5).*

3.4. Benefits / Trade-Offs

The key advantage of a non-blocking matrix over a blocking version is the ability to have multiple ports connected to the same input / output at once. The use of splitters in place of switches for one bank can also help to reduce cost, since these components are typically lower cost than switches. The trade-off is that the use of splitter / combiner components can be limiting for the overall RF parameters of the matrix, typically resulting in higher insertion loss, limited isolation between ports routed into the same splitter / combiner, and a reduction in RF bandwidth.

Mini-Circuits has an industry-leading catalog of splitter / combiner components available with frequency ranges up to 65 GHz combined with the flexibility and in-house expertise to create non-blocking switch matrices for a wide range of applications.

3.5. Applications

The ability to combine multiple inputs concurrently into a single output or to share a single input into multiple outputs makes a non-blocking switch matrix configuration ideally suited to test applications based around wireless devices, or any other system based on a transmitter or receiver. Non-blocking matrices also provide the option to open up test resources by allowing multiple users or systems to share resources and run multiple tests in parallel.

For testing of a transmitter or signal source, it can be convenient to share the source to multiple devices or test stations. Routing the source into the input (splitter side) of a matrix makes the signal available to all devices / test stations connected at the outputs to the matrix, with each able to choose whether to connect that signal or a different one.

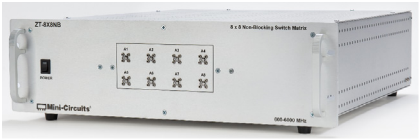
For receiver test applications the fan-in orientation may be advantageous, allowing multiple signal sources to be switched on and off in combination into the receiver DUT. This configuration allows the receiver to be evaluated in the presence of signals simulating multiple base stations for example, as well as co-located interfering signals.

3.6. Mini-Circuits' Solutions

Two examples of Mini-Circuits' non-blocking switch matrix designs are summarized below, both operating from 600 MHz to 6 GHz. ZT-8X8NB is an 8 x 8 matrix in a compact 3U rack chassis, developed using solid-state switches and passive splitter / combiners. ZT-20X6NB is a 20 x 6 matrix, with 20 inputs fanning out to 6 outputs, developed using a combination of solid-state and mechanical switches to gain the advantages of both. Both models can be controlled via Ethernet or USB, using the included GUI, or comprehensive API for automation in most modern programming environments.

ZT-8X8NB

- 8 x 8 non-blocking switch matrix
- 19" rack-mount chassis, 3U, 20" depth
- SMA female connectors (front & rear)
- Ethernet & USB control



ZT-20X6NB

- 20 x 6 non-blocking switch matrix
- 19" rack-mount chassis, 5U, 20" depth
- N-type female connectors (front)
- Ethernet, USB & touchscreen control

Parameter	Conditions	Min	Typ	Max	Units
Frequency	-	0.6	-	6	GHz
Path Loss	0.6 – 3 GHz	-	14	16	dB
	3 – 6 GHz	-	17	19	
Isolation	Ax<>Ay (connected to Bz)	90	100	-	dB
	Bx<>By (connected to Az)	25	30	-	
	Ax<>By (disconnected)	80	100	-	
Return Loss	-	-	15	-	dB
Input Power	A ports	-	-	+25	dBm
	B ports	-	-	+15	

Parameter	Conditions	Min	Typ	Max	Units
Frequency	-	0.6	-	6	GHz
Path Loss	0.6 – 3 GHz	-	15	-	dB
	3 – 6 GHz	-	18	-	
Isolation	Ax<>Ay (connected to Bz)	-	80	-	dB
	Bx<>By (connected to Az)	-	30	-	
	Ax<>By (disconnected)	-	100	-	
Return Loss	-	-	12	-	dB
Input Power	A ports	-	-	+33	dBm
	B ports	-	-	+26	

4. Fully Non-Blocking / Full Fan-Out

3. Features:

- Splitter / combiners on input & output ports
- Programmable attenuators for path control
- Many to many configuration
- Bi-directional operation

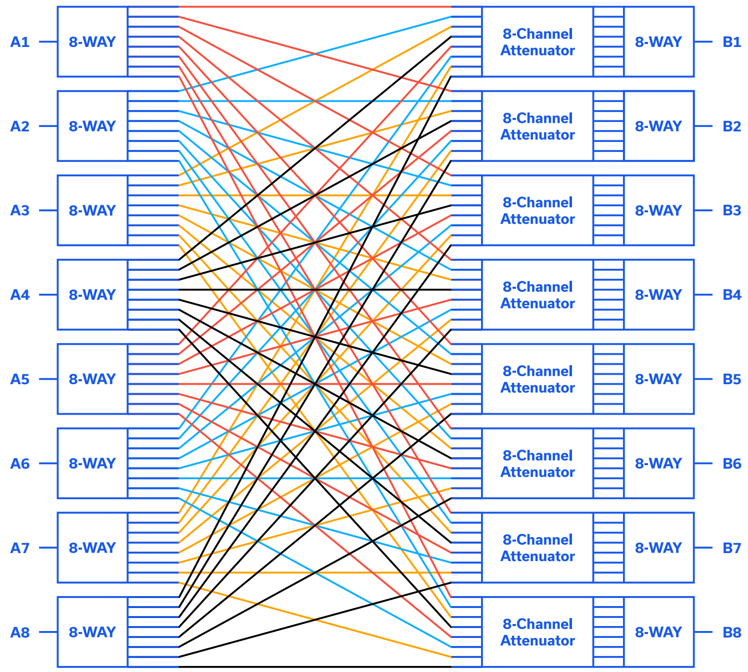


***Figure 8**: 8 X 8 Fully Non-Blocking / Full Fan-Out Matrix Configuration*

Fully non-blocking matrices (sometimes referred to as full fan-out matrices) are constructed with splitter / combiners on all input and output ports to allow every possible internal path between the group of input ports and the group of output ports. Switches could be used internally to allow each path to be individually connected / disconnected but more commonly, programmable attenuators are used for enhanced functionality. A programmable attenuator with 0-63 dB attenuation range can be considered a type of switch with an “on” state (0 dB) and an “off” state (63 dB), plus the additional benefit of being able to set any path loss within that range. This allows the matrix to go further than just connecting / disconnecting the internal signal paths, with the ability to combine signals at precise levels.

4.1. Switch Path Solutions

Since every input-to-output port combination is possible, the total number of active paths available within the matrix is equal to the number of inputs multiplied by the number of outputs. The 8 x 8 matrix example of figure 10 permits up to 64 concurrent active paths. All 8 inputs could be simultaneously connected to all 8 outputs in a “many to many” configuration. The use of programmable attenuators as the control element also allows the signal level to be varied independently on each of those 64 paths.

4.2. Benefits / Trade-Offs

The benefit of the fully non-blocking matrix is clearly in its complete flexibility of input / output path combinations. This configuration can replace blocking and non-blocking (both fan-out and fan-in) switch matrices, performing all functions simultaneously and open up additional test applications requiring signal level control. The key trade-off is the higher insertion loss since each path would pass through 2 splitter / combiners and a programmable attenuator.

4.3. Applications

Full fan-out / fully non-blocking matrices are an ideal configuration for transceiver testing, with a particular focus on cellular handover and eNodeB test systems. By connecting a bank of wireless devices on one side of the matrix with a bank of radio nodes on the other, a wide range of common scenarios can be simulated in the test environment.

For characterization of wireless devices such as cellular handsets, the matrix allows multiple radios and interfering signals to be present at each handset, as they would be in the real world. Adjusting the programmable attenuation on any path, simulates a change in the signal strength between device and radio. Ramping up the attenuation on one path while ramping down the attenuation on the other allows the handover scenario to be tested, where the device switches from one radio to the other as if it was physically moving between base stations.

The same setup can also be used for the opposite use case, testing of the radios / base stations against a bank of cellular handset simulators.

4.4. Mini-Circuits' Solutions

The two models summarized below demonstrate Mini-Circuits' range of fully non-blocking matrices. ZT-8RFX8 is a compact 8 x 8 matrix covering 0.5 to 7.2 GHz, encompassing most of the common IoT applications, including the 5G FR1, WiFi 6E and ISM bands. ZT-24RFX8 offers a larger port count, with a 24 x 8 configuration and frequency coverage from 0.5 to 6 GHz. Both matrices use a combination of solid-state switches, passive splitter / combiners and programmable attenuators (each with 0-63 dB range) with control via Ethernet or USB and Mini-Circuits' comprehensive software support

ZT-8RFX8-6E

- 8 x 8 fully non-blocking matrix
- 0-63 dB attenuation per path
- 19″ rack-mount chassis, 3U, 20″ depth
- SMA female connectors (front & rear)
- Ethernet & USB control

Parameter	Conditions	Min	Typ	Max	Units
Frequency	-	10	6.5	6000	MHz
Path Loss	10 MHz – 2 GHz	-	9.0	-	dB
	2 – 4 GHz	-	11.0	-	
	4 – 6 GHz	-	80	-	
Isolation	Ax<>Ay & Bx<>By	-	60	-	dB
	Ax<>By (disconnected)	-	12	-	
Return Loss	-	-	-	-	dB
Input Power	Through path	-	-	+27	dBm
	Hot switching	-	-	+17	
	Into terminations	-		+17	

ZT-24RFX8

- 24 x 8 fully non-blocking matrix
- 0-63 dB attenuation per path
- 19″ rack-mount chassis, 5U, 30″ depth
- SMA female connectors (front & rear)
- Ethernet & USB control

Parameter	Conditions	Min	Typ	Max	Units
Frequency	-	DC	-	18	GHz
Path Loss	DC – 6 GHz	-	1.3	1.8	dB
	6 – 12 GHz	-	2.0	2.5	
	12 – 18 GHz	-	2.6	3.1	
Isolation	Ax<>Ay & Bx<>By	80	100	-	dB
	Ax<>By (disconnected)	80	100	-	
Return Loss	DC – 6 GHz	-	24	-	dB
	6 – 12 GHz	-	20	-	
	12 – 18 GHz	-	15	-	
Input Power	Cold Switching	-	-	+40	dBm
	Into terminations	-	-	+30	

4.5. Mesh Network Emulators

Mesh network emulators are an extension of the fully non-blocking / full fan-out concept, also constructed from a combination of power splitter / combiners and programmable attenuators. The distinction for a mesh network is that all ports are interconnected to all other ports, with the programmable attenuators providing signal control. This contrasts with the matrices discussed above, which are each defined with a bank of input ports which can only be interconnected with a separate bank of output ports. The mesh network emulator concept is particularly useful for testing of devices which operate in a mesh configuration in the real world. Mesh networks comprise a set of devices which can each communicate directly with any other device in range, rather than all communicating back to a central base-station or hub. Mesh configurations are commonly used for IoT (Internet of Things) applications such as wireless "smart" devices using Zigbee or Z-Wave, as well as a range of military mesh radios.

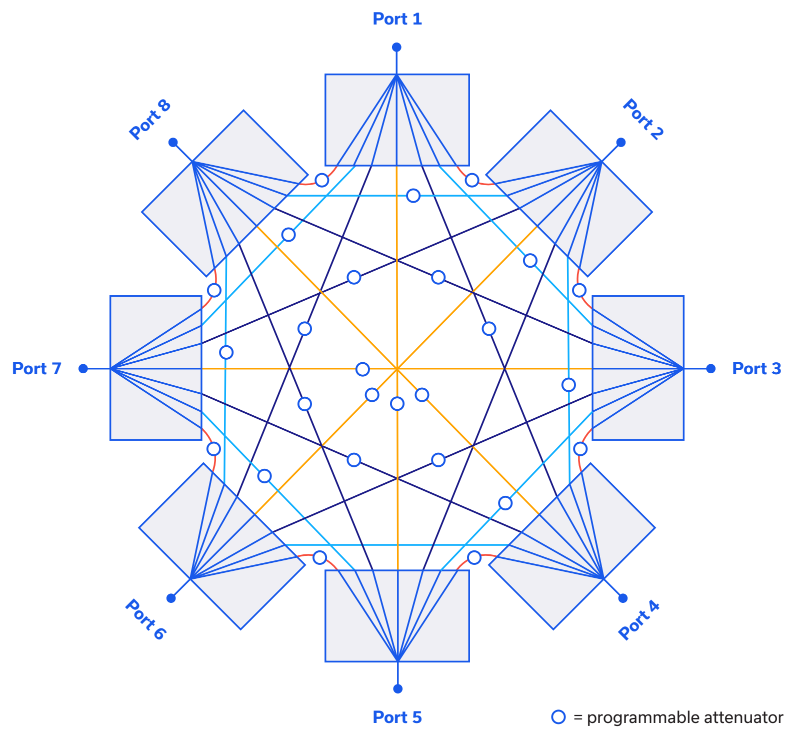


***Figure 9**: 8-Port Mesh Network Emulator Showing Interconnections Between All Ports*

For more information on mesh network emulators, please refer to our application note:

blog.minicircuits.com/mesh-network-simulators-for-wireless-device-testing/

A sample of the mesh network emulators available from Mini-Circuits can be found on our website at:

minicircuits.com/WebStore/RF-Mesh-Network-Systems.html

5. Conclusion

Switch matrices are available in blocking, non-blocking and full fan-out configurations to suit the requirements of any RF signal routing application. The key differentiators / advantages of each configuration are:

Feature	Blocking	Non-Blocking	Full Fan-Out
Single input to single output (per path)	Yes	Yes	Yes
Single input to multiple outputs (per path)	No	Yes	Yes
Multiple inputs to multiple outputs (per path)	No	No	Yes
Bi-directional	Yes	Yes	Yes
Adjustable path loss	No	No	Yes
Insertion loss	Lowest	Medium	Highest
Power rating	Highest	Medium	Medium

Mini-Circuits offers a wide range of switch matrix configurations to support any application from DC to 67 GHz, drawing on our extensive catalog of switches, programmable attenuators and power splitter / combiners.

A non-exhaustive summary of existing switch matrix configurations is available on our website at:

minicircuits.com/WebStore/RF-NxM-Switch.html

Please contact us to discuss your requirements:

testsolutions@minicircuits.com

6. Contact

13 Neptune Avenue
Brooklyn, NY 11235
Phone: +1-718-934-4500
Email: testsolutions@minicircuits.com
Web: minicircuits.com