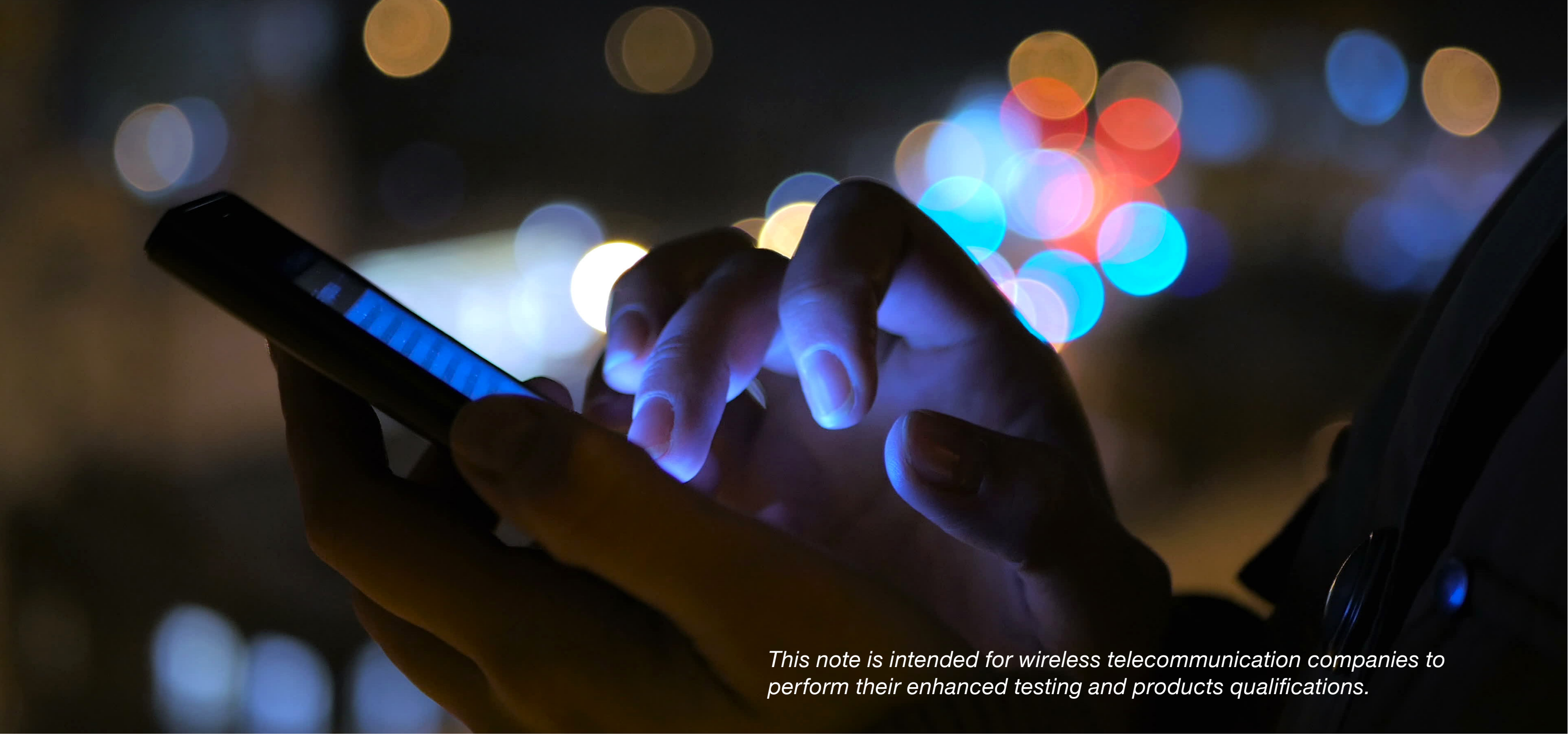
Application Note

Weinschel
BY SPECTRUM CONTROL™

Wireless Test

Test Solutions
Butler Matrix

Multichannel MIMO testing for 4×4, 8×8, and 16×16 ports over a large frequency range for both transceiver and receive applications.



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Introduction

Spectrum Control's 8401, 8401-8, and 8401-16 series Butler Matrices are a beamforming network which are typically used for wireless test applications. It is available in several frequency bands from 0.5 to 7.25 GHz. Butler Matrices are used in multiple-input and multiple-output (MIMO) testing to simulate real-world, over-the-air conditions in a conductive test environment. A Butler Matrix can transfer a signal reciprocally from any of its n-input ports to any of of its n-output ports, with high phase accuracy, amplitude balance, low insertion loss, and high port-to-port isolation.

Using a Butler matrix in a RF MIMO test environment ensures the signal optimally conditioned for highest throughput. With high port count a user can test up to 16×16 channel MIMO or multiple lower order devices concurrently.

MIMO testing for Bluetooth and Wi-Fi

Spectrum Control's series of Butler Matrices supports MIMO testing for 4×4, 8×8, and 16×16 configurations over a wide frequency range . The matrix can support conventional Bluetooth and Wi-Fi bands at 2.4 and 5.8 GHz, as well as operational bands up to 7.25 GHz. Tables 1, 2, and 3 show the detailed specifications of the 4, 8, and 16 channels Butler Matrices.

A Butler Matrix emulates an environment in which the gain in bit-rate from a MIMO configuration is maximized. This enables throughput testing of customer premises equipment (CPE) and Wi-Fi access points.

While a Butler Matrix emulates an ideal environment, it can be combined with programmable attenuators and phase shifters to produce channel conditions equivalent to real world and worst case conditions.

Models

16X16 Model

Part Number	Fmin (GHz)	Fmin (GHz)	Insertion Loss (dB)	VSWR	Output Phase Accuracy	RF Input Power (dBm)	Isolation (dB)	Dimension (inch)
8401-16-5	0.7 2.0	2.0 6.0	14 typ. / 18 max 18 typ. / 24 max	2.0:1 max 2.2:1 max	± 20° max at 3.25 GHz	37	20 typ. / 10 min 17 typ. / 10 min*	19 × 20 × 1.75

Isolation: * *3.4 – 4.0 GHz: 17 typ. / 8 dB min // 5.6 – 6.0 GHz: 17 typ. / 8 dB min*

8X8 Model

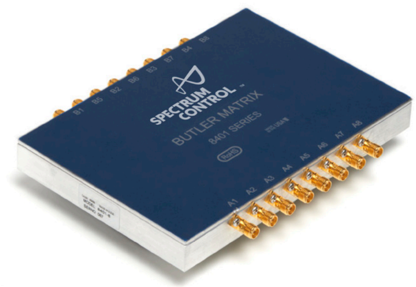
Part Number	Fmin (GHz)	Fmin (GHz)	Insertion Loss (dB)	VSWR	Output Phase Accuracy	RF Input Power (dBm)	Isolation (dB)
8401-8-6	0.5	2.5	10 typ / 14 max	1.6:1 max	±20° max at 3.4 GHz	37	20 typ / 12 min
	2.5	6.0	12 typ / 17 max	2.2:1 max			
8401-8E	2.4	7.25	13.5 typ / 16 max	1.8:1 typ 2.2:1 max	±20° max at 6.5 GHz	37	20 typ / 12 min

4X4 Model

Part Number	Fmin (GHz)	Fmin (GHz)	Insertion Loss (dB)	Max. VSWR	Output Phase Accuracy	RF Input Power (dBm)	Isolation (dB)
8401-6	0.5	2.0	7 typ / 10 max	1.7:1	±15° max at 3.25 GHz	37	25 typ / 16 min
	2.0	6.0	7 typ / 12 max	2.0:1			20 typ / 11 min
8401E	2.4	7.25	8.5 typ / 11 max	2.0:1	±15° max at 6.5 GHz	37	20 typ / 11 min

Impedance	50 Ohms
Connectors	SMA (F) all ports
Temperature Range, Operating	-20° to +70°C

4x4 **Butler Matrix**



8x8 **Butler Matrix**

16x16 **Butler Matrix**

The channel condition number is an important metric which describes the gain in bit-rate that can be achieved from a MIMO configuration. It characterizes the quality of the channel, and its value determines whether a channel can be considered well conditioned or ill conditioned. This metric is also employed to analyze the potential causes for throughput issues and implemented to formulate novel spectrum sensing algorithms in cognitive radio applications for MIMO systems [1].

In practice, a well-conditioned matrix has low condition number, which is close to 1 (or 0 dB). A well-conditioned MIMO system is able to achieve a higher rank, where more data streams can be spatially multiplexed. In contrast, a high condition number (over 19 dB) indicates an ill-conditioned channel matrix, where the small changes in the input cause the drastic changes in the output [2]. Thus, the system will be more vulnerable to channel noise and other interference issues. At a given signal to noise ratio, the bit-rate will increase as the channel condition number decreases.

Table 4. Channel Condition Number Indications

Condition Number	Indication
0 dB	Totally independent channels ideal condition to maximize throughput
≤ 13 dB	Favorable condition enables higher throughput than SIMO/MISO systems
13 – 19 dB	Medium correlation provides marginal throughput improvement
≥ 19 dB	High correlation the MIMO would not be able to increase throughput

Spectrum Control's Butler Matrices enable a user to connect access points to user devices with a low channel condition number. Devices with a dissimilar number of antenna ports can be interconnected using a Butler Matrix. Figure 1 illustrates a simple RF testbed which allow for testing the throughput of a number of wireless devices (5G, Wi-Fi, LTE,…) at various transmit and receive power levels [3].

The 8401, 8401-8 and 8401-16 series Butler Matrices offer excellent condition number to maximize the throughput over wide frequency range. Figure 2 depicts the typical measured condition number of model 8401-8-5. The device maintains great channel condition number (less than 6 dB) across the entire operating frequency, reaching as low as 0.1 dB. This means that the matrix will represent a channel condition that is close to ideal, and will maximize the gain in bit-rate from the MIMO configuration.

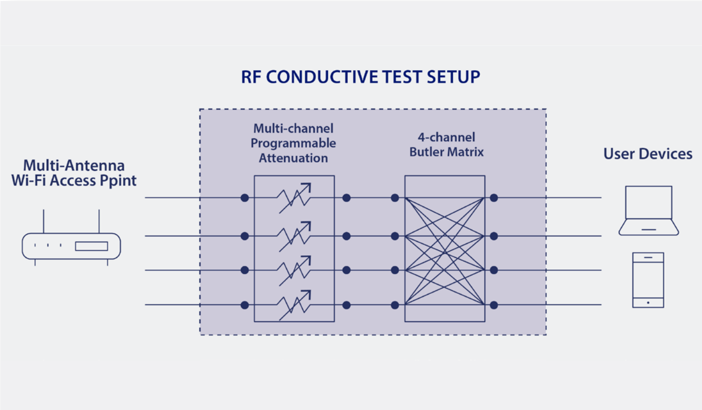


Figure 1. RF Conductive Test Setup

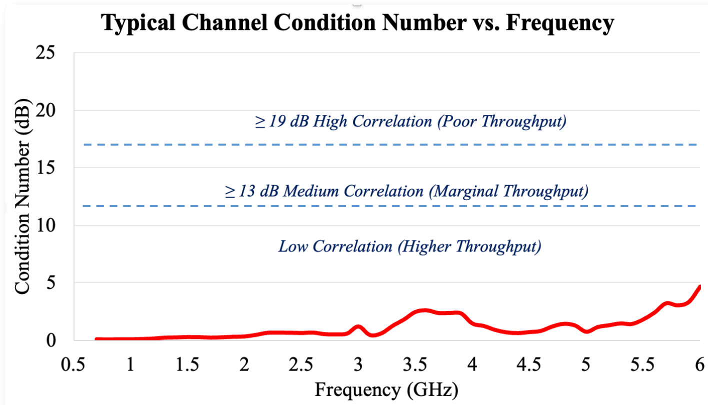


Figure 2. Typical Channel Condition Number of the 8×8 Butler Matrix

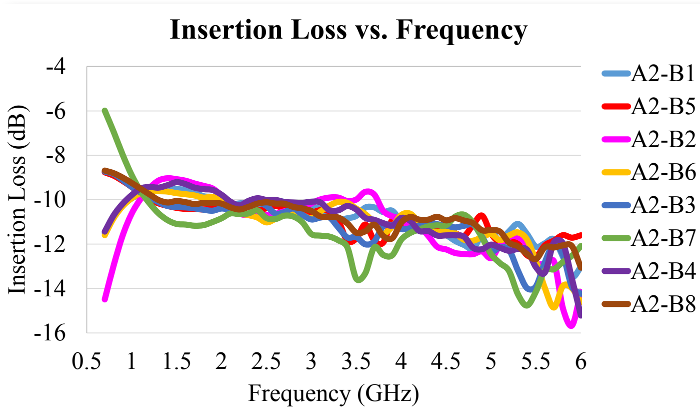


Figure 3. Typical Insertion Loss of the 8×8 Butler Matrix

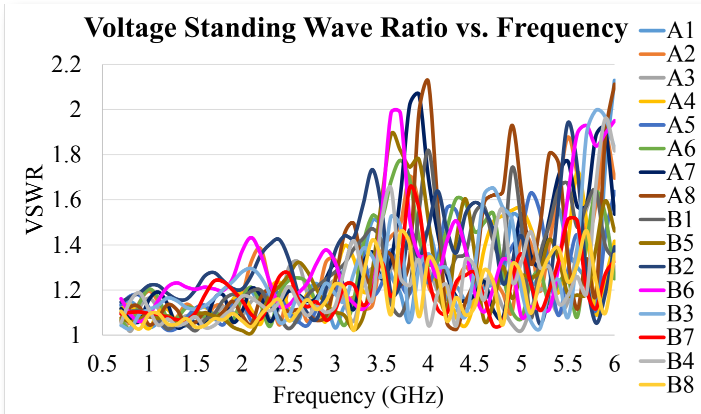


Figure 4. Typical VSWR of the 8×8 Butler Matrix

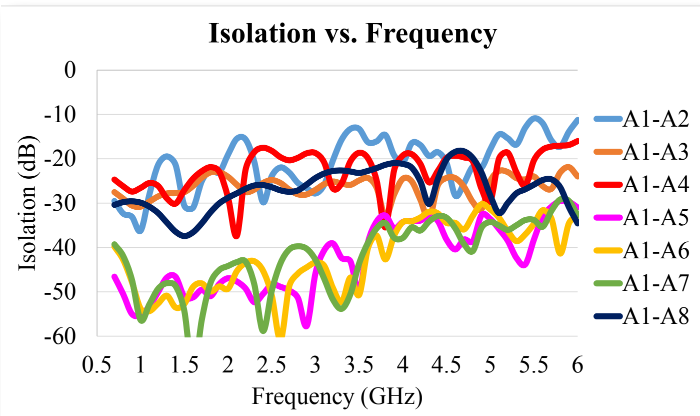


Figure 5. Typical Isolation of the 8×8 Butler Matrix

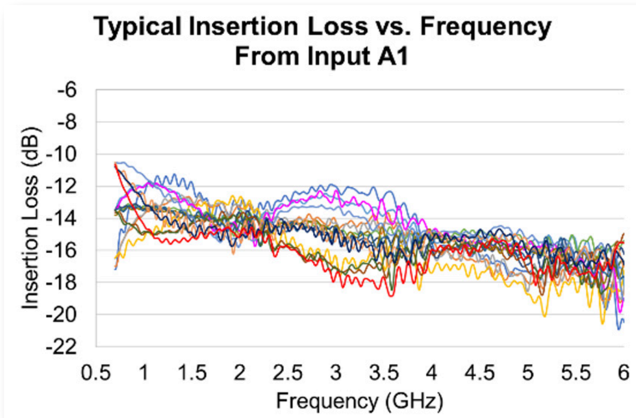


Figure 6. Typical Insertion Loss of the 16x16 Butler Matrix

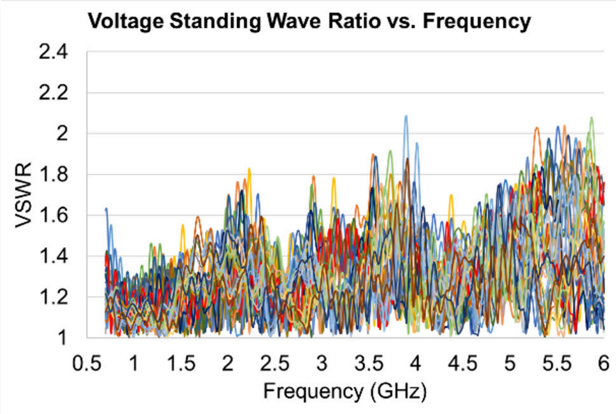


Figure 7. Typical VSWR of the 16×16 Butler Matrix

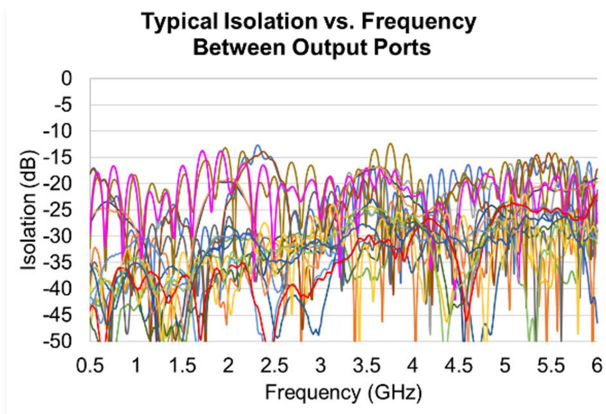


Figure 7. Typical Isolation of the 16x16 Butler Matrix

Along with the excellent channel condition number, the 8401 and 8401-8 series Butler Matrices also provide exceptional performance with progressive phase differences between elements, high phase accuracy, amplitude balance, low insertion loss, and high port-to-port isolation. Figure 2 to 8 clearly show the typical measured data of model 401-8-5 and 8401-16-5. .

With competitive features, Spectrum Controls Butler Matrices can be utilized in various applications, such as:

- **MIMO system level performance verification (firmware version, competitive benchmarking, UE conformance testing)**
- **Wi-Fi / WiMAX / LTE / 5G testing**
- **Key component of Spectrum Control's RF channel emulation platform**
- **Antenna array beamforming**
- **Interferometer system simulation and testing**
- **Addition of programmable attenuators allows easy degradation of the channel number for Throughput vs. Channel Testing**

In addition, since the Butler Matrix is passive and reciprocal, the device can be employed for both transceiver and receiver applications. Butler matrices deliver maximum power with progressive phase shift to the output in the transmitting mode and collect signals from all beam directions in the receiving mode.

References:

[1] J. Lota, et. al., "5G Uniform Linear Arrays With Beamforming and Spatial Multiplexing at 28, 37, 64, and 71 GHz for Outdoor Urban Communication: A Two-Level Approach," IEEE Trans. On Vehicular Tech., Vol. 66, No. 11, Nov. 2017.

[2] P. K. Pal. "MIMO Channel Capacity using Covariance Matrix and Configuration Selection for Switched Parasitic Antennas," Ph.D. dissertation, University of Reading, UK, 2018.

[3] "Cookbook For RF Testbed Design," Spectrum Control, Inc, 2021.

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