

Configuring an Optimal RF/Microwave Switch System

Introduction

Given the explosive growth of the communications industry, a tremendous amount of testing is being performed on the various components that make up different communications systems. These components range from active components such as Radio Frequency Integrated Circuits (RFICs) and Microwave Monolithic Integrated Circuits (MMICs) to space communication systems. While the testing requirements and procedures for these components differ widely, all are tested at very high frequencies, typically at gigahertz or higher. The main components in a typical test system may include DC bias, DC measurement, RF power meter, network analyzer, etc. Automating the test process and improving test efficiency demands integrating RF/microwave and low frequency switching systems into the test system.

The purpose of a switch is to route signals from measurement instruments to the Device Under Test (DUT). With the help of a switch, an instrument can measure multiple DUTs with increased efficiency. Multiple tests with different instruments can be run on the same DUT or multiple instruments can test multiple DUTs. With the help of a switch system, the test process can

also be automated. For example, in the typical DUT (in this example, mobile phone) lifetime test illustrated in *Figure 1*, the DUT can be stressed at an elevated level for a specified period, then its electrical characteristics can be measured. The DUT can be stressed even further and the electrical characteristics can be measured again. Automated switching allows this process to be performed very efficiently.

This note will briefly discuss several important aspects of configuring a high frequency switch system, including the system configurations and the critical switch specifications.

Configuration of a Switch System

Switch systems can be very simple or quite elaborate. For example, a Single Pole Double Throw (SPDT) switch can be used to route signals to two different DUTs. It can be expanded further into a “multiplexer” configuration so that a single instrument can be routed to many different DUTs. Multiple instruments can be routed to multiple DUTs. In this case, the switch system is known either as a Multiplexer-Demultiplexer or a blocking matrix—only one signal path is active at any given time. *Figure 2* shows the application of an SPDT and a 1×16 multiplexer.

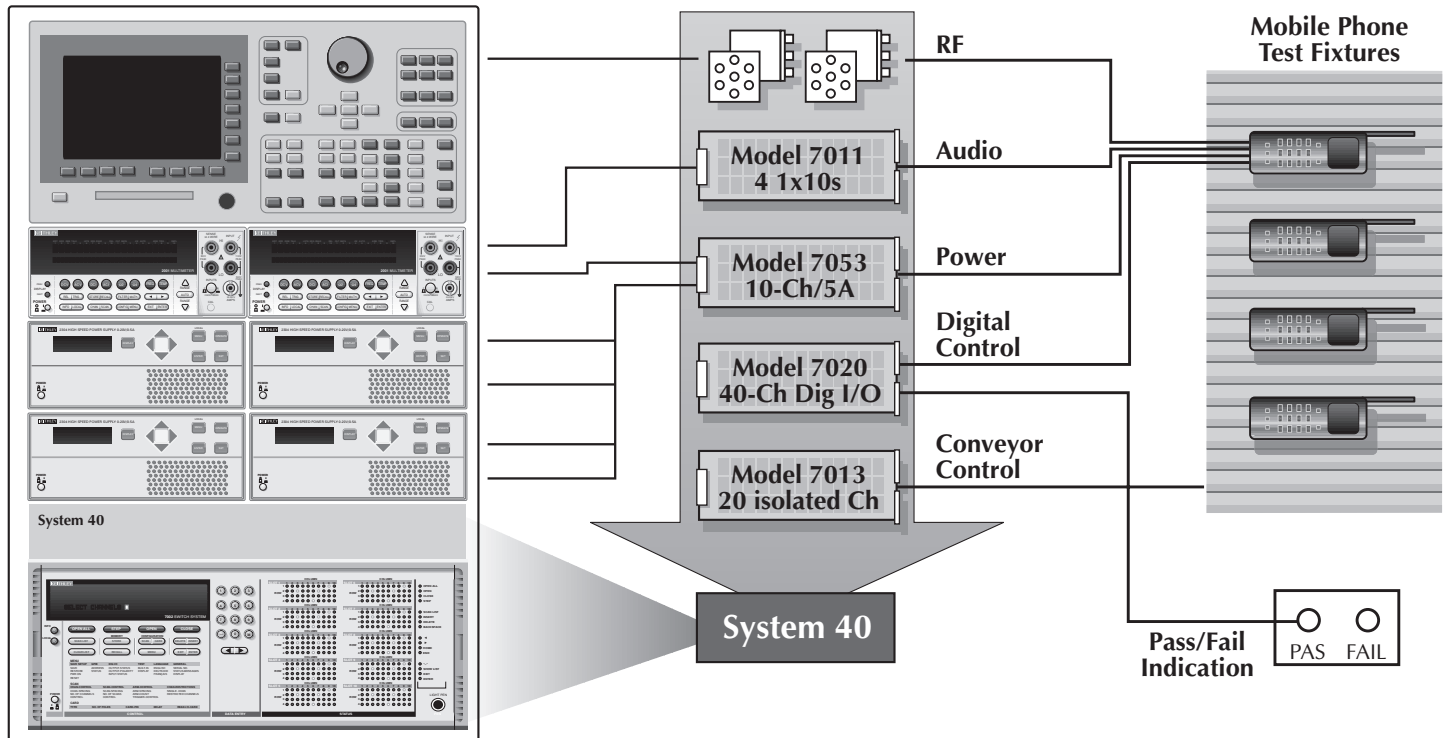


Figure 1

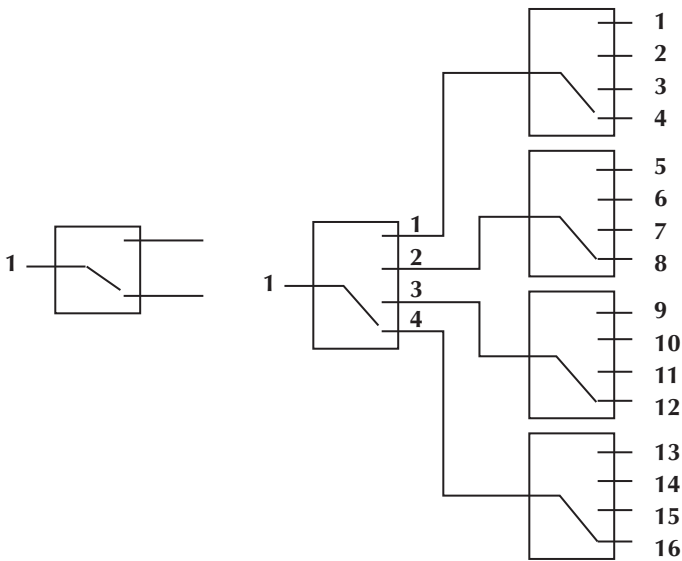


Figure 2a.) SPDT

Figure 2b.) 1-to-16 Multiplexer

To improve testing flexibility, a switch system can connect multiple instruments to multiple DUTs. This is the “blocking” configuration. Any instrument can be connected to only one output at a time. **Figure 3** shows a 4x4 blocking switch system.

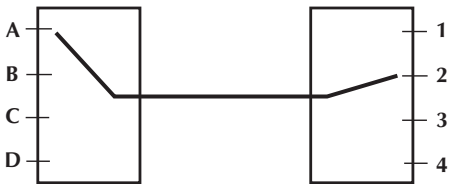


Figure 3. 4x4 Blocking switch

In order to switch any signal to any DUT at any time, a “non-blocking” configuration (sometimes called a switch matrix) can be used. While this switch configuration has the highest flexibility, it is also the most expensive. **Figure 4** shows a 4x4 non-blocking switch configuration and **Figure 5** shows an expanded 4x6 switch configuration.

Critical Switch Specifications

The use of a switch will inevitably degrade the performance of the measurement system, so it is important to consider several critical parameters that may affect system performance significantly. Two types of specifications are very important when configuring a switch: electrical and mechanical. These switches are complex to design and manufacture, so they tend to be significantly more expensive than lower frequency switch systems. During the design phase, the costs and benefits are often weighed against each other to achieve an optimal solution. The following section will briefly discuss some specifications that are critical to RF/microwave switch systems.

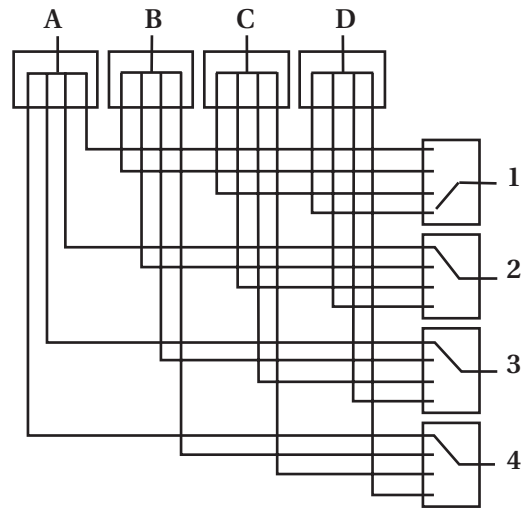


Figure 4. 4x4 Non-blocking switch

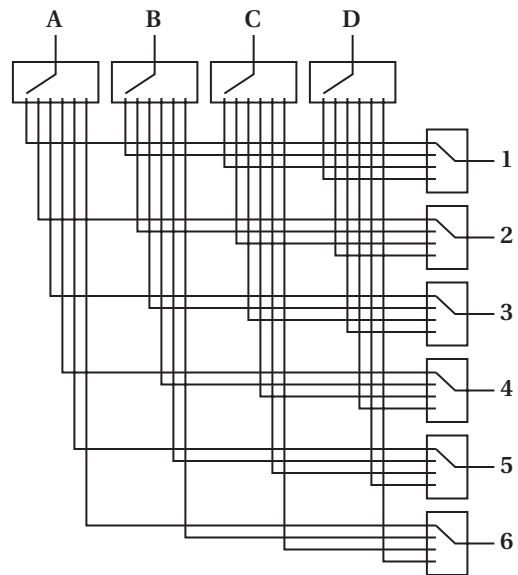


Figure 5. 4x6 Non-blocking switch

Electrical Specifications

Impedance Matching: The switch is positioned between the measurement instruments and the DUT, so it's critical to match the impedance levels of all three system elements. For optimal signal transfer, the impedance of the source has to be equal to that of the switch and the DUT. In RF testing, different impedance levels are used to achieve different purposes. The most commonly used impedance level is 50Ω. For better power transfer, the impedance could be lowered to 30Ω. To provide less RF signal attenuation, the typical impedance used is 75Ω. Whichever impedance level is required, matching impedances properly will ensure the overall system integrity.

Insertion Loss: Any component added to the signal path will cause some degree of loss. The amount of loss is especially severe at higher or resonant frequencies. When signal level is

low or noise is high, insertion loss is particularly important. The insertion loss is reflected as a decrease in the available power on the DUT as compared to the test instrument source value. Normally, it is specified as the ratio of output power over the input power in dB at a certain frequency or over a frequency range.

$$\text{Insertion Loss (dB)} = -10\log(P_{\text{out}}/P_{\text{in}})$$

Path Isolation: At higher frequencies, signals traveling on different paths can interfere with each other due to capacitive coupling between the paths or through electromagnetic radiation. This is especially severe when signal paths are not properly shielded or de-coupled from each other. Sometimes, this is referred to as “crosstalk.” Crosstalk is particularly problematic when a weak signal is physically adjacent to a very strong signal. When maintaining signal path isolation is critical, additional isolation measures should be used.

Voltage Standing Wave Ratio (VSWR): Any component added to the high frequency signal path will not only cause insertion loss, but will also cause an increase in the standing wave in the signal path. This standing wave is formed by the interference of the transmitting electromagnetic wave with the reflected wave. This interference is often the result of mismatched impedances in different parts of the system or connecting points in the system, such as connectors. VSWR is specified as the ratio of the standing wave's highest voltage amplitude to the lowest voltage amplitude in the signal. VSWR is often also expressed as Return Loss:

$$\text{Return Loss (dB)} = -20 \log[(\text{VSWR}-1)/(\text{VSWR}+1)]$$

Signal Filter: Signal filters can be useful in a number of circumstances, such as when spurious noise is inadvertently added to the signal as it travels through the switch. They can also be helpful if the original signal frequency does not fit the DUT testing frequency. In these cases, filters can be added to the switch to modify the signal frequency bandwidth or spurious signals at unwanted frequencies can be eliminated from the signal to the DUT.

Phase Distortion: As a test system expands in size, signals from the same source may travel to the DUT via different paths of different lengths. This specification is often referred to as propagation delay. For a given conducting medium, the delay is proportional to the length of the signal path. Different signal path lengths will cause the signal phase to shift. This phase shift may cause erroneous measurement results. Therefore, techniques to ensure the same phase or path length can be used to compensate for such effects.

Reliability and Repeatability: Obviously, the reliability of the switch is a major concern when designing a switch system. Typically, a switch relay should provide a lifetime of at least one million closures; many relays offer rated lifetimes of five million closures.

The repeatability of the switch performance is an equally important issue. Repeatability is the measure of the changes in

the insertion loss or phase change from repeated use of the switch system. In RF measurement, it is not easy to eliminate the effects from the cycle-to-cycle change in the switch relay closure.

Mechanical Specifications

Physical Form Factor: Depending on the application involved, the switch's physical form factor may limit the choice of the switch system. For a small switch, a simple box will do the job. For example, Keithley's Model 7999-4 Microwave Switch is an RS-232 controllable SPDT switch with a small metal enclosure. For a switch system with a medium number of signal pathways, a system based on the Model 7001 two-slot switch mainframe would be appropriate. For a large-scale switch system, a system based on the Model 7002 10-slot mainframe would be required.

Connectors and Cables: Many different types of connectors and cables can be used in RF/microwave switch systems. The signal frequency, the system impedance, power rating, and test fixture/handler compatibility, etc. should all be taken into consideration when choosing connectors and cables.

Relay Status Visual Feedback: Switch mainframes that provide an LED display to indicate the open/closed status of the switch relays are very useful during system setup and troubleshooting.

Considerations When Specifying an RF/Microwave Switch System

In addition to electrical and mechanical specifications for an RF/microwave switch system, several factors need to be considered carefully. These factors can easily degrade the system performance even when the best parts are used.

Termination: At high frequencies, all signals must be properly terminated or the electromagnetic wave will be reflected from the terminating point. This, in turn, can cause an increase in VSWR. It may even cause damage in the source if the reflected portion is large enough. Typically, the coaxial cables used are terminated at 50Ω. For other types of communication systems, signals may terminate at 75Ω.

Bandwidth: Most switch system users would like to have as wide and as flat a bandwidth switch as possible. However, wide bandwidth switches are costly. If it is not absolutely needed, a narrow band switch can achieve the same objectives at a significantly lower cost. Another factor to consider is that when higher frequency is used, the bandwidth will depend on the type of connectors and cables used. More expensive types of these products are typically needed to ensure adequate system performance.

Power Transmission: Another important consideration is the system's ability to transfer the RF power from instrument to DUT. Due to insertion loss, the signal may require amplification. In some applications, it may be necessary to reduce the signal power to the DUT. The use of either an amplifier or attenuator may be needed to ensure that the accurate level of power is transmitted through the switch.

Conclusion

In this note, we briefly discussed some typical applications of switching in communication testing. When specifying a switch system, the first step is to consider the system configuration. In order to achieve an optimal, yet cost-effective system, system designers must weigh a variety of electrical and mechanical parameters. Understanding these parameters makes it possible to make informed tradeoffs between switch flexibility and system cost.

Specifications are subject to change without notice.

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