Critical to the quality of communication between a base-station transmitter and a mobile receiver is the signal's propagation channel. As it is transmitted over the air, the signal is subject to fading. The signal can be absorbed or reflected by obstacles such as buildings, mountains, and trees, and the resulting fading can influence its amplitude and phase significantly.

**Figure 1**: Signals experience fading during transmission. Obstacles such as buildings and mountains reflect or absorb the signals, influencing the signals' amplitude and phase.

Reflection, diffraction, and local scattering can cause a signal to take multiple paths from base station to receiver (**Figure 1**). In a so-called multipath scenario, several copies of the same signal arrive at the receiver with different path lengths at different times and with varying amplitudes and phases. With a moving receiver, additional challenges occur such as maxima and minima of signal strength and Doppler shift.

Wireless devices such as mobile phones must be tested under real-world conditions to guarantee their performance. For this purpose, the ITU (International Telecommunication Union) has specified fading that simulates diverse propagation conditions and also some special receiving conditions.
But fading is not limited to mobile radio networks. Another area where fading is critical is in military communications systems based on SDRs (software-defined radios). Such systems use time-critical complex waveforms that can have extremely short synchronization sequences.

Airborne radios are especially subject to extreme conditions. Long distances introduce considerable delays into the transmitted signals. Radio waves propagate at the speed of light, leading to time delays of about 1 ms per 300-km distance between communicating radios. Thus, the performance of hopping radio systems under worst-case conditions needs to be verified by radio manufacturers so they can optimize their designs, and it also must be evaluated by test houses to verify whether a radio complies with the specification.

By using a vector signal generator with a fading option in conjunction with a signal analyzer—both of which are equipped with a digital baseband interface—you can create repeatable, real-world test scenarios in a time-saving and cost-efficient manner. You can use the combined instruments to check the performance of receivers during development and acceptance testing in order to uncover areas that need adjustment prior to costly field tests.

**General methods of fading simulation**

There are several methods for performing fading simulation. Normally, the optimum method is to generate fading within the digital baseband section of a signal generator that is used to test a receiver. This method is widely used and is cost-effective, and it ensures the best performance and repeatable signal quality. Another method operates on an RF-in/RF-out basis. But stand-alone RF fading simulators that work with this method are expensive. Plus, the signal quality may be degraded by the effects of the necessary multiple conversions from IF to baseband and vice versa.

For some applications, however, there is no alternative to RF fading because the baseband signal is not available. For example, fading tests performed on actual transmissions from mobile radio base stations including signaling require a simulator for RF fading. The same is true for military radio links with frequency hopping. In addition, TV signals and even simple FM signals must be tested under fading conditions.

For mobile radio testing, the ITU has specified fading profiles, such as the channel models for GSM and UMTS/WCDMA standards. GSM defines three propagation models: typical urban, hilly terrain, and rural area. UMTS/WCDMA channel models are derived from the ITU channel model for indoor, pedestrian, and vehicular environments. All these channel models simulate the propagation conditions in different environments by modeling the expected impact of the environment. The ITU channel models are based on a tapped delay-line channel model and differ, for instance, in the number and distribution of fading paths and delay spread of the channel. Besides the actual fading profile, the models require that the relative movement of the receiver with respect to the transmitter in the form of a Doppler frequency shift be simulated as well.

When a receiver or any of the reflectors in the receiver's environment are moving, the receiver's relative velocity causes a shift in the frequency of the signal transmitted along each signal path. Signals take different paths and can have different Doppler shifts, corresponding to different rates of change in phase.

**Setting up an RF fading simulator**
You can build a versatile simulator for RF fading by combining a signal analyzer that has a digital baseband interface with an RF vector signal generator that has digital baseband inputs and a fading option. If a suitable signal generator and signal analyzer are already available in a lab, this solution is more cost-effective than investing in a stand-alone RF fading simulator.

To use this setup, you feed the RF signal to be faded into the signal analyzer's RF input. The signal analyzer works as a downconverter and digitizes the signal's IF. (The R&S FSQ signal analyzer, for example, enables a real-time bandwidth of up to 28 MHz.) The digital baseband interface in the signal analyzer must send a continuous digital data stream that is compatible with the signal generator's digital I/Q input; the data stream should be fed into the I/Q input via an LVDS (low-voltage differential-signaling) cable (Figure 2).

The signal generator will deliver an RF signal at its RF output with the same level, modulation, and frequency as the signal fed into the signal analyzer's RF input. The baseband fading functions of the signal generator, along with superimposed AWGN (additive white Gaussian noise), can be applied to the baseband signal before upconversion to the RF. The combination of the R&S FSQ signal analyzer and R&S SMU signal generator provides an RF fading simulator with a real-time bandwidth of up to 28 MHz and an RF frequency up to 6 GHz. It covers all current digital radio standards for both uplink and downlink signals.

**Setting up fading tests**

The most important tests on digital mobile radio receivers are fading tests, which ensure that communications between a base station and a mobile device can be maintained even under adverse conditions. Figure 3 shows how to set up fading tests on a mobile radio receiver. Using a power attenuator, feed the base station's RF signal into the RF input of the signal analyzer. Then, connect the digital baseband output of the signal analyzer to the digital baseband input of the vector signal generator. Next, feed the signal generator's output signal to the mobile radio receiver input at the required level. Some vector signal generators, such as the R&S SMU200A, permit you to implement a fading scenario according to the mobile radio standard to be tested (such as GSM, 3GPP, or LTE).
Fading tests for military airborne transceivers require a different setup. Military communication systems based on SDRs use complex waveforms that can have extremely short synchronization sequences. In addition, wideband fast frequency-hopping schemes are employed as electronic protective measures. Such hopping sequences cover frequency bandwidths beyond 100 MHz with hopping rates of up to thousands of hops per second. Before secure communication can take place, all radio systems involved are synchronized to a master clock. Subsequently, each radio follows the same master-defined hopping scheme, relying solely on its internal system clock.

The synchronization window for establishing a connection between two radios is very short. Time delays and the accuracy of the individual system clocks can become critical. System clocks are frequently resynchronized through the master. But the radios always must be able to cope with the time delays as well as with the signal’s characteristics resulting from the arbitrary hopping schemes.

Airborne radios are especially subject to extreme conditions. Long distances between radios can cause signal delays of up to several milliseconds, and in the worst cases, a communication link cannot be established at all. In addition, the supersonic speed of the aircrafts create significant Doppler shift on the received signals, which may create problems.

The performance of hopping radio systems under worst-case conditions needs to be verified by radio manufacturers so they can optimize their designs and verify the compliance of a radio to the system specifications. Usually, test houses rent helicopters, an airfield, and antennas to carry out “real-world” tests, which are costly and time-consuming. The test results of this conventional approach can be corrupted by many known and unknown sources of errors, such as antenna placement and other parameters. Figure 4 shows a setup for testing military fast-frequency-hopping airborne transceivers.
The synchronization of the receiver under test (lower device) to the transmitter (upper device) can be tested by introducing signal delays of several milliseconds to the transmitted signal set by the fading section of the signal generator. These delays occur in real-world conditions when two aircraft communicating with each other are several hundred kilometers apart.

For the test, the reference transceiver sends an RF signal to the signal analyzer, where it is downconverted to the baseband. The resulting digital I/Q stream is forwarded in real time to the vector signal generator. The generator's fading option applies the intended delay, fading, and Doppler speed scenario to the signal to simulate a real-world environment, such as when two aircraft are traveling at significantly different speeds. The test signal is upconverted to RF before being passed to the transceiver under test for demodulating the signal content. Correct synchronization is checked by comparing the synchronization signals from the two transceivers with an oscilloscope. If the hopping waveforms exceed the bandwidth of the signal analyzer, you should be able to test the waveforms by using reduced bandwidth hopping schemes provided by the radio manufacturer.

A test setup that makes use of both a signal analyzer and a vector signal generator to perform RF fading can eliminate unknown sources of errors, enable manufacturers to optimize their radio designs, and allow test houses, military radio users, and system integrators to verify compliance with international standards and the supplier radio specifications based on realistic environmental conditions.

FOR FURTHER READING


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**Roland Minihold** received a degree in high-frequency engineering from the Technical University of Munich in 1976. In the same year, he started working as a development engineer at Rohde & Schwarz in Munich, where he was responsible for development projects for RF signal generators and for modulation, spectrum, and signal analyzers. Since 1997, he has been working as a senior application engineer in the application development department of the Test and Measurement Division at Rohde & Schwarz.