White Paper

Speed Up Radio System Development for Defense Applications

Channel Emulation Advances Bring Innovative Technology to Lab Testing

Why is RF Design So Demanding?

Whether you are designing battlefield radio hardware or software-defined radio (SDR) software, building a military IoT device with a radio frequency (RF) module, buying or evaluating devices, or developing network applications that use radios, you are probably grappling with the real-world challenges of successfully getting radio-frequency signals from point A to point B.

Testing radio systems at a controlled range might be considered the most realistic methodology, but in practice it has its own challenges. Range testing can only replicate a small subset of the variables of a scenario, and it is difficult to replicate the congested and contested environments that mirror the tactical edge. It can also be expensive to implement, and scheduling restrictions often adversely impact the ability to debug and iterate designs.

Fortunately, the world of **Channel Emulation** has advanced rapidly over just the past few years. Today's channel emulators (sometimes just called **Faders**, even though that's a bit of a misnomer), allow you to put your waveforms, your RF hardware and software, and your network and application software into complex simulation environments. They can handle 5G, Wi-Fi and custom waveforms with massive MIMO and beamforming/tracking antenna systems. Realistic sensitivity, range, error rate and other performance results are achieved in the lab at a small fraction of the time and cost of testing in the field or on the range, and with the added benefits of being highly repeatable to aid in debug and performance evaluation.

The connected battlefield requires a new level of testing and assurance that depends on close collaboration between government defense agencies and private enterprise. In this

paper, Spirent shares our industry expertise on the technical challenges that military radio system designers, integrators and buyers face, and shows how state-of-the-art channel emulation has become so beneficial in getting today's complex RF systems proven in faster and at much lower cost than previously achievable.

What's Between Point A and Point B?

An RF channel is a path through the air between a transmitting and a receiving radio antenna. Many things can affect the quality of a channel and can therefore affect the network that we are building on top of the radio. Considering each of these challenges is critical as we create our testing environments and plans.

Channel Basics

Distance, Reflections, Blockers. Anything and everything in the environment can cause reflections. Known as multipath propagation, reflections typically arrive with different delays and power levels and from various angles of arrival. Even in the simplest case where we have an unobstructed line-of-sight, there are still ground reflections that arrive at the receiving antenna in-phase or out-of-phase with the primary signal and thereby cause higher or lower received power levels. Some obstructions may block signals entirely, while others may partially absorb RF energy. Barriers such as structures, weapon systems and armored vehicles have a wide variety of reflectivity and absorption characteristics, which also may vary considerably depending on frequency. And distance, of course, affects received power (every doubling of distance cuts the received power by a factor of four).

Interference and Noise

Interference and noise can come from many sources. Another radio system (anything from a far-off base station to a multitude of near-by sources such as Wi-Fi routers or IOT devices) may be operating on a nearby frequency. Sources on different frequencies could be creating harmonics or spurious noise that appear in our band. Non-wireless electronic devices in the area (compute devices, on-board electronics, weapon systems, etc.) may be creating RF emissions. Atmospheric disturbances can affect the signals we receive as well.

Three Types of Motion

There are at least three types of motion to consider as we're testing our system. Handovers happen when a moving endpoint needs to shift its RF link from one transmitting station to another. Endpoints must monitor power levels from available stations to decide when to handover and to avoid hanging on to a weakening signal for too long. Movement also causes highly variable fading: even at low speeds and over short distances, a receiver experiences widely fluctuating power levels as the phasing of reflections add up constructively or destructively.

When endpoints are moving at higher speeds, Doppler effects come into play and shift the frequency of the received signal.

Special Challenges for Defense and Mission Critical Communications

When we enter the domain of mission critical communications, several more challenges may emerge.

Mesh Network Architecture

Most fielded cellular networks are hierarchical. Each handset communicates with base stations, which carry traffic back into the network core. Mesh networks, on the other hand, are non-hierarchical. Endpoints can communicate with each other without the aid of a central coordinator. They can communicate directly in pairwise fashion, or by using intermediary endpoints that receive traffic and pass it along toward the destination endpoint.

The implications for test are significant. Each endpoint is typically handling multiple simultaneous connections. The channel conditions for each connection may be different, and connections will be arriving from different directions, especially if some of the endpoints are airborne. With n endpoints under test, there are n * (n-1) unidirectional connections to be modelled.

Frequency Hopping

Radio systems designed for secure communications often employ a spread spectrum scheme that rapidly "hops" among various frequencies to make it more difficult for an adversarial system to listen in on the communication. Even though the required communications bandwidth may be narrow, a wideband channel is used to accommodate all the hop bands. The designer must ensure performance across the entire wideband, and the test engineer must consider wideband channel propagation effects such as frequency-dependent fading.

High Speed Doppler

With consumer cellular technology the highest speed scenarios involve trains topping out at a few hundred miles per hour. In aerospace and defense applications the speeds are much higher. An aircraft moving at Mach 4 and operating on a 5 GHz band, for example, will see a Doppler frequency shift of 10 kHz. As it moves past a base station, the radios need to track a rapid shift as the carrier frequency is distorted by +10 kHz when approaching to -10 kHz when receding.

Low Earth Orbit Delay

Communications via Low Earth Orbit (LEO) satellites introduce yet another issue to be tested: delay. A communications path to an LEO satellite at 800 km adds 2.7 msec on each leg. This delay should be modelled in test setups to assess the impact on protocols and to understand achievable data rates.

Phase Array Antennas

Antenna systems in modern communications are more often made up of multiple elements. 4G smartphones typically employ MIMO (multiple input multiple output) schemes of two or four antennas, as do the base stations they communicate with. This sort of 4x4 MIMO arrangement can be used on one of two ways: to improve the ability to receive a signal (if one of the antennas receives a path that is blocked for the others), or to transmit data to multiple endpoints simultaneously on the same frequency.

With the rapid improvement in signal processing speeds, massive MIMO is becoming the standard in aero/defense applications. With a horizontal array of, say, 16 or 32 antennas, phase can be tightly controlled to create and steer beams, rather than the roughly omnidirectional propagation that a single antenna produces. Beamforming allows a station to communicate on the same frequency and at the same time with many endpoints by pointing (i.e., spatially) independent beams at each. Two-dimensional antenna arrays (e.g., 32 antennas arranged in four rows of eight) can produce distinct beams in both azimuth and altitude dimensions. Because this allows for steering horizontally (in the x-y plane) and vertically (in the z dimension), it is known as 3D beamforming.

Bad Actors: Jamming & Spoofing

Distinguishing good signals from bad is yet another challenge area, especially in tactical situations. An adversary may attempt to override, or jam, friendly signals with a higher-power signal on the same frequency. Jamming systems might use a static signal or might sweep through bands to disrupt communications.

Spoofing is more sophisticated. Spoofers attempt to trick a friendly system into thinking that a bad actor is an authorized connection. One method of defense against spoofing is to use multiple antennas to determine the direction from which signals are arriving. When combined with knowledge of where friendly sources are located, spoofing sources can be ignored.

Three Test Environments | Range, Chamber and Bench

Broadly speaking, there are three places where we test our radio systems. Out on the test range, in the lab on a bench, and in an RF chamber. How should we think about aligning our test needs and methodologies to each environment?

The Open-Air Test Range

Range testing has the strong advantage that radio signal propagation is real (that is, it is not simulated in any fashion), and that gives us confidence in the validity of test results. When we are able to create realistic scenarios on a test range we can easily measure receiver range, noise sensitivity, data throughput, and other characteristics.

However, testing in open-air brings some significant limitations as well.

1. Range testing is typically the most expensive option available from a whole cost perspective, and it has the greatest negative impact on deployment schedules. This is because it is logistically challenging. Arranging for time on the range and getting all the devices-under-test and other gear there can take time. Sometimes weeks or longer. This makes it especially difficult when it comes to debugging issues that are found, as iterating to solve an issue can burn through the schedule allocated to testing.
2. Lack of repeatability is another issue to wrestle with. If the open-air range is not well isolated from unexpected noise and outside radio traffic, then results can vary from one test run to the next.
3. The most critical issue with range testing is that trouble lives in the corner cases. Each of the above factors presents a challenge to the RF design when at the extremes of the design parameters. The real-world stress points, however, come when these factors combine. The corner cases of high Doppler plus high delay plus high noise environments, for example, are the kinds of scenarios that can cause design issues to surface in the hands of actual users. Creating these and the myriad of other corner case scenarios on the range is quite difficult.

Despite these limitations, testing out in the real world is an absolutely essential part of any test methodology. But if we could create the corner cases and execute them repeatably indoors, we would be able to improve our outcomes (and lower costs and speed our test cycles as well).

Chamber Tests

RF Isolation chambers are widely used when we need to evaluate the performance of an antenna system. *Reverb* chambers have a reflective interior, and often feature a slowly rotating metallic “stirrer” to change the reflection pattern in the chamber over time. This arrangement allows us to measure the average transmit power and average receive power characteristics of an antenna, as it exposes the antenna to many angles, reflections, and power levels.

Anechoic chambers are lined with RF-absorbing material to provide a controlled RF “quiet” space. Anechoic chambers are especially important for phased array (M-MIMO and beamforming) antenna systems, as they allow for controlling the angle of departure and/or angle of arrival of signals.

Reverb and anechoic chambers are the tools of choice when we need to evaluate an antenna design, or to optimize antenna placement on a device or vehicle.

Bench Testing

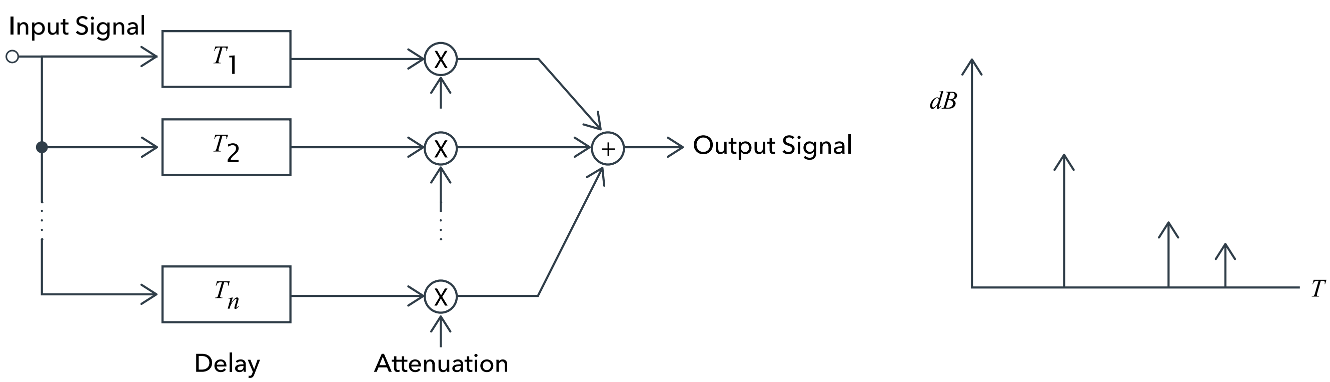
In the lab, we can perform extensive functional and performance testing in “conducted mode.” Using cables to connect our transceivers instead of antennas allows for rapid validation of much of the RF design. The challenge on the bench is to be able to create meaningful and realistic test scenarios. After all, with only a simple RF cable between transceivers, we are restricted to a highly idealized operating environment. Adding attenuation into the path to allows us to simulate some distance, but what else can we do to recreate more complex environments?

The next sections will introduce two models for creating lab-based scenarios: discrete components and the channel emulator.

Bench Testing with Basic Channel Fading

Two of the most fundamental characteristics of RF channels that transceivers must cope with are the wide change in received power level as distance increases, and the multitude of multipath signals as a result of reflection, refraction and scattering. Both conditions can be modeled easily and inexpensively with a tapped delay line.

Multipath propagation results in numerous copies of the original signal, each arriving at the receiving antenna at slightly different times and with different power levels. The tapped delay line starts with the original signal, and then adds some delay and some attenuation to create a second copy of the signal, simulating a reflection. By adding successive stages of delay and attenuation, a power delay profile is created that mimics multipath behavior.



A tapped delay line uses stages of delay and attenuation to model multipath reflections.

Benefits

The tapped delay line can be built from readily available components and at relatively small costs. By simulating distance vs. power effects and simple multipath effects, we can test the basic **sensitivity** and **range** of our receiver, and we can establish our best-case **link throughput** data rate. The setup gives us a way to rapidly iterate on a design, as it is highly repeatable and easily available.

Challenges

While more repeatable, faster and less expensive than testing out on the open range, the tapped delay line lab setup suffers from a critical problem: it isn't realistic. Since so many of the challenges that receivers face are left untested in the lab, the burden largely remains on range testing to characterize the performance of our radio system. Worse yet, there is no way to scale the approach to meet the complexity of modern systems such as 5G that use many (dozens or more) RF channels simultaneously.

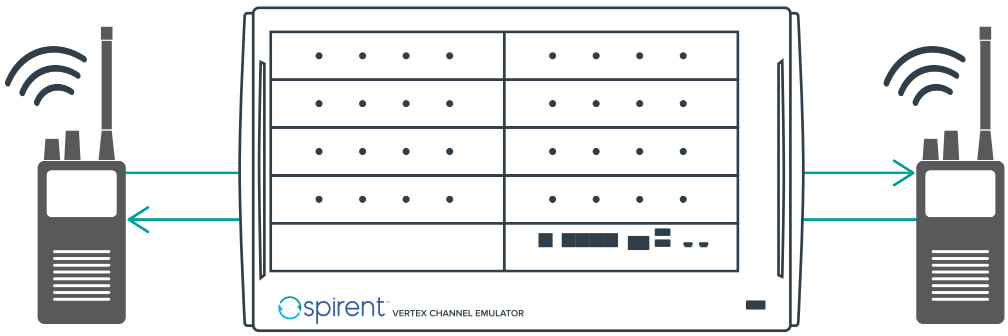
Speed Up Radio System Development for Defense Applications

Channel Emulation Advances Bring Innovative Technology to Lab Testing

Bench Testing with Channel Modeling and Emulation

To move beyond simple channel power and delay characteristics we need to employ some serious math. Channel models are mathematical descriptions of radio signal propagation. Channel modeling can be used to describe multipath effects such as reflections and refraction; pedestrian and high-speed motion; antenna height and associated ground reflections; and 3D geometries including angles of departure and angles of arrival. These effects can be combined to create complete scenarios, such as urban and rural models.

These models are then executed in a channel emulator. At its simplest, a channel emulator takes in an RF signal, uses digital signal processing to implement the mathematics of a channel model and apply it to the input signal, and outputs the resulting signal.



A channel emulator creates a simulation environment for real RF signals.

Over the past decade, the world of channel modeling has moved forward in two important ways. First, the mathematical modeling of conditions and scenarios has gotten more sophisticated. Frequency dependent fading, complex multi-antenna-element phasing for beam forming and beam tracking, and arbitrarily complex motion paths can all be modeled mathematically. Secondly, the power of the channel emulator hardware has vastly improved. Today's channel emulators can operate over a broad range of radio frequencies (from VHF to millimeter wave), employ state of the art DSP and FPGAs to implement complex channel models, and can support large numbers of RF connections to simulate multiple endpoint scenarios.

A benchtop setup with a state-of-the-art channel emulator is a hardware-in-the-loop environment for modern radio systems. It is capable of emulating urban, rural, indoor and custom propagation models. It can model ground-to-ground RF channels as well as ground-to-air and air-to-air channels. It allows the user to simulate macro cell (large radius high-power) and micro cell (small radius low power) architectures, with antenna placements at arbitrary heights. It can implement frequency-dependent fading effects that are especially important in wide bandwidth and frequency-hopping channels. It can simulate the doppler effects of high-speed motion, with user-defined motion paths for transmitters, receivers and reflectors. And it can handle peer-to-peer and mesh network scenarios where a dozen or more endpoints are communicating with each other, each with a different propagation model comprised of the above effects.

Benefits

With the channel emulator on our bench we can still test the **sensitivity** and **range** of our receiver. But now, we effectively have a simulated **drive/fly route** in our hands for development, performance tuning, trouble-shooting, and regression testing. **Automated** testing can be created to cycle through many different challenge scenarios. In addition to **link throughput** we can implement multiple nodes of a network and measure **network throughput** as well. With support for wide bandwidth channels we can validate **frequency hopping** designs. With multiple base stations and devices, we can model **network handovers** to evaluate the performance of **resiliency and recovery** algorithms. We can use additional RF inputs to mix in noise, **interference and jamming** signals. We can take advantage of the channel emulator's ability to manipulate phasing to test **anti-spoofing** techniques. We can use r**ecord and playback to record real-world** channel environments and recreate them on the bench. And finally, we can move up the protocol stack to evaluate **voice quality, speech intelligibility, video and positioning performance** to see how end applications behave under adverse conditions.

Challenges

A modern channel emulator that is stuffed with high power DSPs and high-frequency RF ports may be expensive. Budget constraints can be mitigated, though, with a modular channel emulator that can start by supporting a few ports and DSPs and scale up along with radio and system design complexity and testing needs. Feature complexity is another issue to be wary of. A channel emulator with too many software 'knobs and buttons' can be difficult to use. User interfaces must streamline creating scenarios, while still allowing for power users.

About Spirent Communications

Spirent Communications (LSE: SPT) is a global leader with deep expertise and decades of experience in testing, assurance, analytics and security, serving developers, service providers, and enterprise networks.

We help bring clarity to increasingly complex technological and business challenges.

Spirent's customers have made a promise to their customers to deliver superior performance. Spirent assures that those promises are fulfilled.

For more information, visit: www.spirent.com

Conclusion: Better, Faster and Less Expensive, By a Wide Margin

As technology continues to speed ahead at record pace, addressing critical and highly complex RF communication channels and specialized military scenarios has become increasingly demanding. Fortunately, RF channel modeling and emulation solutions have also progressed rapidly over just the past few years, helping to simplify and accelerate radio system development and testing.

Spirent's state-of-the-art solutions can replicate the comprehensive impairment and spatial conditions of even the most complex wireless channels, making it possible to conduct repeatable lab tests that have real-world relevance, lower costs, and improve test program outcomes while minimizing risk.

The Spirent Vertex Channel Emulator provides the modularity, flexibility and high density needed for a myriad of challenging test configurations, while the graphical user interface of the Advanced Channel Modeling software simplifies the design of your propagation scenarios and allows creation of downloadable 3D channel models.

A trusted provider for over 25 years, Spirent has led the definition of complex fading with multiple radios spanning several generations of mobile technologies. Our team of world- renowned experts are here to help. To learn more about assuring RF performance and channel emulation advancements, Contact Us.

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