ISSUE SIX • 2008

Agilent Measurement Journal

Agilent Technologies

Using a Few Words to Convey a Deeply-Held Spirit

Darlene J.S. Solomon
Chief Technology Officer, Agilent Technologies
Vice President, Agilent Laboratories

Three-word (tripartite) mottos are a common — and succinct — way to convey the essence of a larger idea. For example, the spirit of the Olympics is captured in Latin as *Citius, Altius, Fortius* or Faster, Higher, Stronger in English.

For Agilent Labs, the three-word motto "Depth, Synergy, Contribution" captures the essence of our work. This comes from a deep base of technical expertise, the synergy we create across multiple technologies and businesses, and our contributions to Agilent's business results as well as the larger scientific and engineering communities.

The results of our work also create synergy with Agilent's customers and make meaningful contributions to their work. Labs research aims for the technical challenges, which, if solved, will contribute significant and sustained customer value. Several examples are documented in this issue of *Agilent Measurement Journal* as specific contributions to China and the Olympic Games.

One example is the TD-SCDMA, WiMAX™ and Wi-Fi services that were available during the Beijing Games in cities that hosted Olympic events. In preparation for the Games, Agilent was there to provide equipment and timely technical support at each customer site.

The underlying innovations for these measurements first appeared during the 1980s and '90s within developments such as the modulation domain analyzer, which was based on a picosecond time-digitizer IC. Other Agilent innovations have been used inside cellular phones, ranging from the world's smallest duplexer to space-saving filters, both of which were implemented using film-bulk acoustic resonators created with micromachining technology.

Dating back to the 1972 Munich Games, Agilent (then part of Hewlett-Packard) has been a leader in doping-testing — instrumentation and methods — to help ensure a level playing field for all participants. During the Beijing Games, we supplied 37 analytical systems — 18 liquid chromatograpy/mass spectrometry (LC/MS) and 19 gas chromatography/ mass spectrometry (GC/MS). These were used to examine more than 4,500 samples from the participating athletes. The director of the China Anti-Doping Agency believes this equipment helped make testing at the Games "the most technically advanced yet."

Our history of innovation in analytical instrumentation dates back to the early 1970s and quadrupole MS for chemical analysis. Today, advances such as time-of-flight (TOF) and triple-quadrupole (QQQ) MS are combined with LC or GC to provide highly sensitive screening and confirmation in testing for sports doping. Microfluidics technologies enable separations of complex samples at reduced sample size, improved sensitivity and simplified ease-of-use for these applications. In the future, new developments may enable reliable detection of gene therapy or "gene doping," which is currently very difficult to catch.

At every Games, the pursuit of *Citius, Altius, Fortius* leads to new achievements in athletic performance. Inspired by this example, Agilent and Agilent Labs will continue to pursue Depth, Synergy, Contribution in communications, electronics, life sciences, and chemical analysis to the benefit of our customers and the people they serve.

WiMAX is a trademark of the WiMAX Forum

Visit the *Journal's* online version to listen to Darlene's podcast interview at **www.agilent.com/go/journal**
Interviewer: Frank Elsesser, *eMarketing Manager, Agilent Technologies*

Charting a Unique Path to Technology Innovation

Ron Nersesian
Vice President of Agilent's Wireless Business Unit, Agilent Technologies

Professional athletes — whether competing in the Olympics or other major sporting events — often follow their own unique training path to push beyond their limits. Likewise, Agilent and China are each charting a unique path in the wireless communications industry.

Today, this industry is being driven by an insatiable need for increased data. Two key trends have resulted: the convergence of cellular and wireless connectivity, and an increase in data rates, requiring faster signal speeds and development of technologies with more complex encoding schemes. Increasing mobile-handset complexity (e.g., from the inclusion of eight to ten radios per handset) is another result of the demand for data. Software-defined radios (SDRs) offer one way of dealing with this complex environment.

As an enabler of emerging industries and a supporter of technology commercialization, Agilent is uniquely qualified to address the needs of increasingly complex mobile-communication devices and networks. Unlike other vendors who support a single wireless standard, Agilent provides solutions in support of all major wireless standards across the entire product lifecycle including China-specific standards such as TD-SCDMA and TD-LTE. Remaining technology neutral, Agilent retains an unbiased view of emerging standards and is therefore able to offer a unique perspective on different technologies as the industry evolves from 2.5G to 3.9/4G networks.

China — in a quest to develop its own intellectual property for communications standards — has chosen TD-SCDMA over other global 3G standards (e.g., W-CDMA) for its initial rollout of 3G multimedia services. This service has now been deployed in eight Olympics cities across China. For 3.9G data services, China is working with the international standards committees to develop TD-LTE, a more advanced time-domain-duplexed standard that maintains strong Chinese technical contribution but is more integrated into the global LTE standard. As the leading test-and-measurement vendor in China, Agilent worked to help define these standards and created TD-SCDMA-specific measurement solutions which have been used by the majority of all TD-SCDMA equipment providers to develop their products. Agilent maintains large R&D and marketing teams in China and their responsibilities include creating and supporting test solutions for China-specific communications standards. These teams have been integral to Agilent's success with customers who create and provide equipment for these standards. Agilent created the first test solutions for TD-SCDMA and recently released the industry's first TD-LTE product to the market.

Agilent's role in China's wireless-communications industry was recently spotlighted during the 2008 Beijing Olympics. Prior to the event, the Beijing Olympic organizing committee granted China Mobile the right to provide WiMAX™, Wi-Fi and 3G (TD-SCDMA) network services. The WiMAX mobile terminals were offered by Samsung and provided voice, data and wireless networking services. A temporary trial WiMAX network was deployed in Qingdao, China to test this service. A TD-SCDMA commercial trial has also been deployed with over 40,000 TD-SCDMA mobile phones in use during the Olympic Games.

Agilent provided China Mobile with both WiMAX and TD-SCDMA test solutions and over 60 percent of all test equipment needed to deploy the TD-SCDMA base-station network in the Olympic host cities. Agilent even provided 24-hour technical support for the TD-SCDMA network prior to and during the Olympic Games.

Agilent's decision to take a unique path in supporting all leading wireless standards has enabled it to play a key role in moving China's vision of the wireless-communications industry forward. Whatever unique path China chooses to take in the future, Agilent will be there with the necessary technology and solutions to make it a reality.

Agilent Measurement Journal

Contents

TABLE OF CONTENTS

Insight
Department

1 Using a Few Words to Convey a Deeply-Held Spirit

Three-word mottos are a common — and succinct — way to convey the essence of a larger idea, the pursuit of which often leads to new achievements in technology or otherwise.

Visit the *Journal's* online version to listen to Darlene's podcast interview at **www.agilent.com/go/journal**

Interviewer: Frank Elsesser
eMarketing Manager, Agilent Technologies

2 Charting a Unique Path to Technology Innovation

Following a unique path in support of all leading wireless standards is helping Agilent enable China's vision of the wireless-communications industry.

Emerging Innovations
Department

5

- **Assessing nonlinear behavior**
- **Testing combines form and function**
- **Testing multiplay networks**
- **Announcing first commercial GC/MS metabolites library**
- **Higher sensitivity LC/MS**
- **Easing military radio test**
- **3GPP tool supports TS 36 standards**
- **Stepping up calibration accuracy**
- **Increasing spectrum analyzer bandwidth**

7 The Olympic Story Spotlights Agilent's Continuing Contribution to Technology Innovation

Agilent's support of the 2008 Olympic Games came in many forms including helping to provide advanced and reliable wireless services and ensuring timely and accurate drug testing.

11 Ensuring a Level Playing Field in Competitive Sports

While liquid chromatography/gas chromatography (LC/GC) coupled to mass spectrometry (MS) has long been the core technology used in doping testing, this application poses many challenges and opportunities.

15 GPS: Coming of Age

Simulating GPS signals with a high-performance RF source provides great flexibility in creating an accurate and repeatable test environment for evaluating GPS receivers.

Visit the *Journal's* online version to listen to a podcast concerning this article.
www.agilent.com/go/journal

25 Resolving Design Issues in HSPA Mobile Devices

An effective test strategy that mimics real-world scenarios addresses the key challenges of testing and validating HSPA mobile phones.

Visit the *Journal's* online version to listen to a podcast concerning this article.
www.agilent.com/go/journal

Subscribe to *Agilent Measurement Journal*

Give yourself an edge in today's dynamic world of technology: Subscribe to the *Journal* and receive your own copy of the print edition in the mail.

To activate your free subscription, go to **www.agilent.com/go/journal** and look for the link "Manage your *Agilent Measurement Journal* subscription."

While at this site, check out the latest digital edition of *Agilent Measurement Journal*. Also, please help us improve and enhance future issues of the *Journal* by completing the survey located at the end of the digital edition.

Issue Six | 2008

33 Achieving Accurate Results with Oscilloscope-Based Jitter-Analysis Software

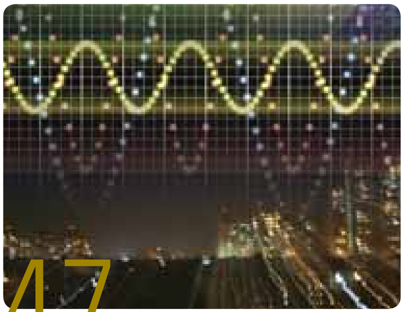
Large memory depth enhances the accuracy of scope-based jitter analysis and provides a viable alternative to BERT-based testing.

41 RF Handheld Testers Guarantee Traffic Stability Under Olympic-Sized Stress Conditions

Optimizing a network's signal transmission quality during long periods of time and in remote locations can be challenging and require the adoption of new processes and handheld testers.

Correction
On page 38 of *Agilent Measurement Journal*, Issue Five: "400,000 seconds, which is over 111 days!" should have read: "400,000 seconds, which is over 111 hours!"

www.agilent.com/go/journal



47 Utilizing LAN-Based Instrumentation to Measure Total Harmonic Distortion in Remote Facilities

An enhanced-performance digital multimeter provides an accurate means of measuring power-generation total harmonic distortion and allows for remote data monitoring via LAN or WAN.

51 IMT-Advanced: 4G Wireless Takes Shape in an Olympic Year

The extent to which 4G can address capacity and coverage issues in a cost-effective manner will determine if it will be the enabler of the mobile broadband revolution.

Campus Connection *Department*

61 EPO Doping: A Speed Engine, Turbo-Charged by Chemistry

Researchers at Peking University, in collaboration with Agilent, have undertaken a research project to discover the biomarkers associated with an EPO injection.

AGILENT MEASUREMENT JOURNAL

William P. Sullivan | President and Chief Executive Officer

Darlene J.S. Solomon | Agilent Chief Technology Officer and Vice President, Agilent Laboratories

Heidi Garcia | Editor-in-Chief

EDITORIAL

Please e-mail inquiries and requests to journal@agilent.com

Agilent Measurement Journal

Emerging Innovations

New software assesses microwave networks' nonlinear behavior

Agilent has upgraded the PNA-X microwave network analyzer with nonlinear vector network analyzer (NVNA) capabilities. The software converts a four-port PNA-X into a high-performance nonlinear analyzer and measures calibrated amplitude and cross-frequency relative phase of measured spectra from 10 MHz to 26.5 GHz. New features for nonlinear component characterization, nonlinear scattering parameters (X-parameters) and nonlinear pulse envelope domain capabilities were incorporated to help RF engineers and component designers accurately characterize the nonlinear behavior of active devices such as high-power amplifiers and frequency doublers.

Form and function combine in new family of compact instruments

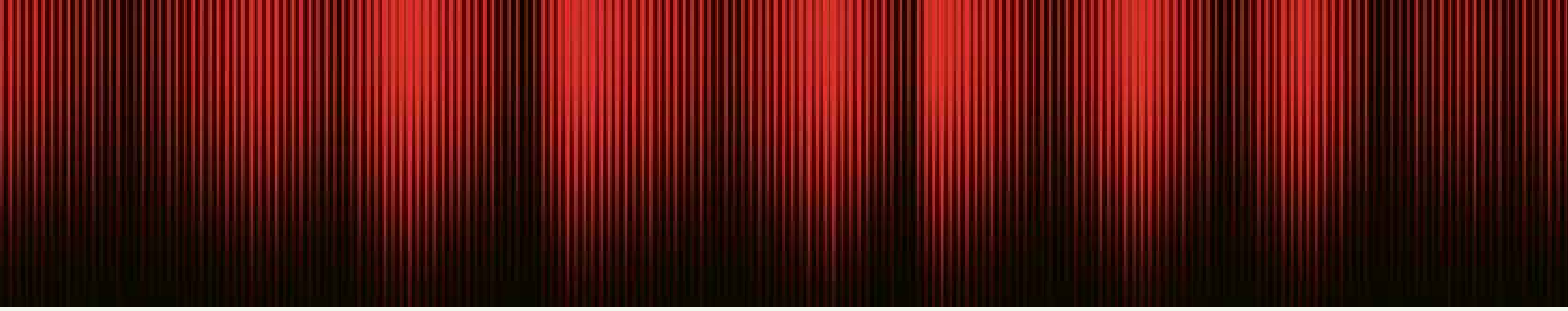
Engineers who troubleshoot electronics products and processes outside the office have new tools to make their jobs easier. Two oscilloscopes, a function generator, a source/measure unit and a switch matrix represent Agilent's new U2700A family of USB-based modular instruments. Each device is about the size of a paperback book, allowing users to carry two or three devices in a briefcase along with their laptop PC. The 100- and 200-MHz oscilloscopes feature two channels, eight-bit sampling and 500 MSA per channel. The function generator provides six standard waveforms, while the three-channel source/measure unit offers four-quadrant capabilities for parametric tests. The instrument front panel is on the PC screen: the Agilent Measurement Manager (AMM) software provides a familiar, instrument-like interface for each of the modular devices.

Multiplay network testing capabilities on a single port

The N2X multiservice test system combines multiplay network test measurements for video, voice and data on the same port. Each test port can concurrently display real-time video media quality metrics and IPTV channel-zapping times along with voice mean opinion score (MOS) and data-forwarding measurements on a per-subscriber basis. The result is an accurate gauge of how the number and behavior of multiplay subscribers and a mix of service traffic affects subscriber quality of experience (QoE). Another noteworthy enhancement to the N2X is the industry-first ANCP/L2CP protocol emulation, which allows service providers and network equipment manufacturers to validate the topology-discovery and line-configuration capabilities of ANCP-enabled routers and switches.

First GC/MS library hits the market

Agilent announced the first commercially-available gas chromatography/mass spectrometry (GC/MS) library for identifying metabolites. The Fiehn Metabolomics Retention Time Locked (RTL) Library, developed in cooperation with metabolomics scientist Oliver Fiehn, contains preprogrammed methods for further analyses. Additionally, data results can be imported into Agilent's GeneSpring MS bioinformatics software for mass spectrometry, enabling users to compare large data sets for the discovery of metabolite biomarkers. The library complements Agilent's METLIN personal metabolite database used for liquid chromatography/mass spectrometry (LC/MS) analysis.



New LC/MS system features high sensitivity, quick data acquisition

High-definition time-of-flight (TOF) technology anchors the new Agilent 6530 accurate-mass quadrupole TOF LC/MS system, providing users with high sensitivity and data quality. Ideal for proteomics, metabolomics, impurity profiling, and environmental screening, the 6530 incorporates new Agilent Jet Stream thermal-gradient focusing technology. Further, the system offers exceptional mass accuracy across a wide range of concentrations and at high data-acquisition rates of up to 40 spectra/second. Other unique specifications include better than 1-ppm MS mass accuracy, better than 3-ppm MS/MS mass accuracy, and a 10x improvement in in-spectrum dynamic range without loss of sensitivity.

Ruggedized, streamlined military radio tester

Testing military radios just got easier with Agilent's new, one-button portable radio tester for FM and SINCGARS (SINgle Channel Ground Air Radio System) equipment. The L4600A radio test set is designed for quicker troubleshooting while in the field and includes a built-in spectrum analyzer, network analyzer, signal generator, or signal analyzer per testing requirements. Its rugged, weather-proof construction seals out moisture and dust, ensuring continual uptime even in adverse conditions. Operating in a wide frequency range — between 2 MHz and 2.5 GHz — the test set is also upgradeable to ensure it will accommodate the latest technologies, including JTRS radios up to 2.5 GHz.

New 3GPP measurement tool supports latest TS 36 standards

A new 3GPP LTE measurement solution for Agilent X-Series signal analyzers highlights signal problems for improved troubleshooting. The Agilent N9080A embedded LTE measurement application enables physical-layer testing of uplink and downlink LTE signals, including single-channel MIMO analysis, at the test rack. The system supports all LTE bandwidths and modulation formats outlined in the latest 3GPP TS 36 standards. Specific measurements include EVM per OFDM carrier, EVM per OFDM symbol, EVM per slot, and Agilent's proprietary EVM per resource block.

A step up in machine tool calibration accuracy

Machine tool manufacturers, operators and calibration service providers have a new device for measuring machine-tool and coordinate-measuring-machine (CMM) accuracy. The Agilent 5530 dynamic calibrator is a laser-based calibration system featuring accuracy to 0.4 ppm, a 20 percent improvement over other systems on the market. The system works with Agilent 5519A and 5519B lasers and features basic components such as laser source, optics, PC-based electronics, and Microsoft® Windows®-based software.

Increased bandwidth for PSA spectrum analyzer

Agilent's PSA high-performance spectrum analyzer and mid-range MXA signal analyzer boast advanced functionality that will allow engineers to tackle the most difficult application challenges. The E4446A and E4448A PSAs now feature up to 80-MHz analysis bandwidth, enabling analysis of complex signals with higher symbol rates in millimeter-wave digital communications. The addition of two-channel analog baseband analysis to the N9020A MXA signal analyzer permits R&D engineers to use one instrument for both baseband and RF analysis.

Microsoft and Microsoft Windows are U.S. registered trademarks of Microsoft Corporation

The Olympic Story Spotlights Agilent's Continuing Contribution to Technology Innovation

Liu Ning
Application Support Engineer, Agilent Technologies
ning_liu@agilent.com

The 2008 Olympic Games gave people from all over the world an opportunity to experience Beijing, the vibrant capital city of China. Beijing is both a tribute to China's proud history and gateway to China's future. The capital city during the Liao, Yuan, Ming, and Qing Dynasties, Beijing has long been the political, cultural and diplomatic center of China. It is now an international metropolis, home to 11 million people from all walks of life.

Figure 1. Beijing is home to 7,300 cultural relics and historic sites, and more than 200 scenic spots — including the world's largest palace, the Forbidden City, as well as the Summer Palace, Temple of Heaven and part of the Great Wall.

Alongside its many cultural antiquities, Beijing boasts an impressive modern skyline — a reflection of its rapid economic development (Figure 1). The recently expanded Beijing Capital International Airport, for example, is China's largest and most advanced airport. The National Stadium, known as the "Bird's Nest," served as the main venue of the 2008 Olympic Games. China's National Aquatics Center, or "Water Cube," is another famous Olympic venue. These two buildings have become Beijing landmarks and today stand as a tribute to the admiration of the Chinese people for the Olympic purpose and principles. It is China's hope that the 2008 Olympic Games carried forward those principles — promoting world peace, enhancing friendships among people of the world and allowing the Olympic spirit to flourish.

Agilent Technologies and China have a strong relationship with roots that stretch back to the establishment of China-Hewlett-Packard 23 years ago. Both Agilent and China have prospered, with Agilent becoming the world's premier measurement company and China achieving some of the most spectacular economic gains of any country in history. With its world-leading solutions for wireless test and measurement, doping testing and food safety — backed by local support — Agilent worked to help ensure China delivered a successful 2008 Olympics on many fronts.

Inspiring innovation

To create awareness for its role in the Beijing Olympics and to spotlight its contributions to local industry and markets, Agilent China recently presented Agilent Technology Day — the first such event it has ever held in China. This two-day celebration included product exhibitions, technology forums and seminars reflecting Agilent's support for the growing local economy, environmental sustainability and the 2008 Olympic Games. Agilent's President and CEO, Bill Sullivan, kicked off the event's opening ceremony on April 24 at the Agilent China headquarters in Beijing (Figure 2). This was followed by exhibits on Agilent China's history and its achievements in innovation. The event also showcased the key milestones Agilent China has made since its establishment. The most popular presentation was the company's anti-doping instrumentation, used for various important sports events including the Olympic Games.

Figure 2. Representatives from Agilent, its customers and the Chinese government helped unveil the Technology Day logo by placing blocks into the 24 slots on the face of a sundial. When Bill Sullivan, president and chief executive officer of Agilent Technologies, inserted the last block, the face was lit, fireworks went off and the Technology Day logo banner was unfurled. The sundial was chosen to for the ceremony because it is one of the oldest known tools of measurement.

Another way in which Agilent is contributing to China's industry, while also supporting the recent Olympic Games, comes from its work with testing wireless technologies such as TD-SCDMA, WiMAX™ and Wi-Fi. As mandated by the government of China, deployment of TD-SCDMA networks is occurring now in at least eight cities and was undertaken to provide wireless technology support for the 2008 Olympic Games. The deployment is being handled by China Mobile, China's largest mobile phone operator. Since April 4, 2008, China Mobile has invited 20,000 clients from all walks of industry to participate in the test of TD-SCDMA terminals, networks and services. The clients received free test terminals and an allowance to cover the mobile phone fee. Now, more and more people are getting a chance to use the TD-SCDMA phones and experience the service of TD-SCDMA.

The Beijing Olympics also provided WiMAX/Wi-Fi service to hot spots in Olympic cities. The Beijing Olympic Organizing Committee granted China Mobile the contract to provide WiMAX/Wi-Fi network service as a supplement to the existing 3G system. The mobile terminals were provided by Samsung and the service included voice, data and wireless networking. China Mobile has already tested a WiMAX network consisting of ten base stations in the 2.5-GHz frequency band in Qing Dao. It has also deployed a WiMAX test network in Wangdian in Jiaxing city, Zhejiang province. The WiMAX network covered the whole town and 1,000 terminals were provided. Using this network, townspeople are able to surf the Web much faster than was previously possible. According to China Mobile, the quality of the system was fine but the WiMAX signals were affected by adverse weather conditions and electromagnetic interference (EMI). Never the less, it was a successful trial and better prepared China Mobile to provide faster, more stable WiMAX service to the 2008 Beijing Olympic Games.

Over the years, Agilent has worked hard to establish itself as a preferred supplier of wireless test and measurement solutions to China Mobile. To bolster its position, Agilent's China Communications Operation (CCO) marketing and field sales teams joined together to participate in many customer meetings with China Mobile, Huawei and ZTE. The intent of the meetings was to provide these companies with a full understanding of Agilent's wireless solutions. The Agilent team also delivered seminars at various events including Wireless Test World, a mini-solo show and the "Best of Next" seminar. Many wireless engineers and students attended these seminars and learned how to choose and use Agilent equipment in their daily work (Figure 3).

Agilent's team also loaned test equipment to China Mobile and provided timely technical support at each customer site. When questions arose, the team responded quickly to help customers solve their technical problems. Since the CCO R&D teams are located in Beijing, they were able to step in to quickly fix any problems involving software bugs. This rapid response time was a major strategic advantage for Agilent in China.

Figure 3. The engineers and students attending one of Agilent's seminars gained a better understanding of the value of Agilent's test and measurement solutions in their various industries.

Agilent now has a dominant market share in the base-station test business at China Mobile, Huawei and ZTE. In addition to securing the base-station test business, Agilent's signal monitoring systems were used in the Beijing Olympic Village and other Olympic facilities to help with radio detecting, wireless troubleshooting and technical support.

Keeping the Olympic Games clean

For more than 30 years, Agilent has developed a strong reputation in analytical instruments and methods for drug testing in sports. In 1972, Agilent supplied analytical instrumentation to the lab serving the first-ever Olympic Games in which testing was required. Since then, Agilent's technology has played a role with the drug-testing labs serving each of the subsequent Olympic Games, as well as major events such as the FIFA World Cup and *Le Tour de France*.

One key way in which Agilent contributed to the success of the 2008 Beijing Olympic Games was by supplying instruments and solutions for doping-testing in partnership with the China Anti-Doping Testing Center. The China Anti-Doping Agency is today one of the largest and most technologically advanced testing facilities in the world (Figure 4). During the 2008 Olympic Games it was estimated that it examined more than 4,500 samples from participating athletes. The agency equipped its Beijing lab with Agilent's liquid chromatography (LC), gas chromatography (GC) and mass spectrometry (MS) instruments. These instruments were used to confirm the chemical identity of suspected banned substances found in testing samples. Agilent also provided a total of 18 LC/MS and 19 GC/MS units for drug testing at the 2008 Olympic Games.

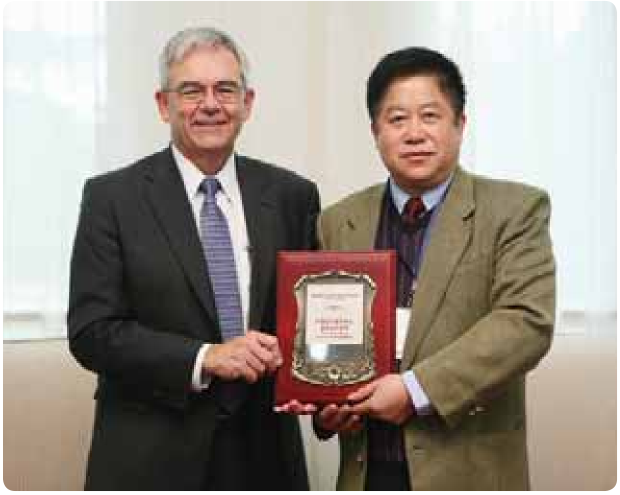


Figure 4. The China Anti-Doping Agency recently presented Agilent China with a "Best Partner" award for providing world-class instruments and service for the 2008 Olympic Games.

Conclusion

The ability to provide advanced and reliable wireless services and ensure timely and accurate drug testing for the 2008 Olympic Games are two of the exciting stories surrounding China's commitment to fostering Olympic spirit. Agilent fully supports this effort and through its many instruments, service and support worked diligently to contribute to the success of the 2008 Beijing Olympic Games.

WiMAX is a trademark of the WiMAX Forum.

Ensuring a Level Playing Field in Competitive Sports

Tom Gluodenis
Marketing Manager, Forensics and Toxicology, Agilent Technologies
tom_gluodenis@agilent.com

Stephen B. Crisp
International Business Development Manager, Agilent Technologies
steve_crisp@agilent.com

Testing for performance-enhancing substances is now an accepted part of sporting life in major international competitions such as the Olympics, and even during events at the national and collegiate levels. The ability to fight the use of banned drugs in sports — and ensure a level playing field for all participants — depends on tough sanctions supported by a reliable and reproducible scientific system for doping testing.

Liquid chromatography/gas chromatography (LC/GC) coupled to mass spectrometry (MS) has long been the core technology used in doping testing. This is an application that poses many challenges — and opportunities — for scientists and chromatographers. Even as the demands on (and from) regulatory agencies continue to evolve, “underground chemists” try to stay one step ahead by synthesizing new and harder-to-detect compounds that can give athletes an unfair advantage.

Scaling the problem

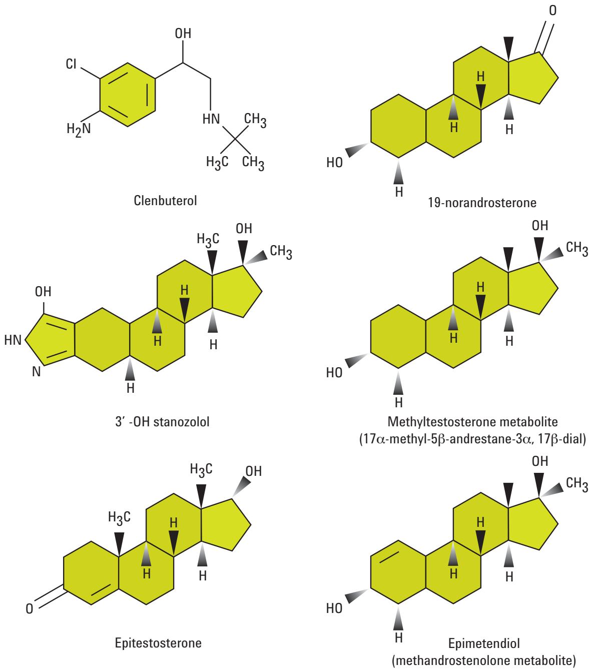
The death of British cyclist Tommy Simpson during the 1967 *Tour de France* focused tremendous attention on the issue of doping in sports. It was later discovered that Simpson had taken amphetamines, which caused his heart to give out during his ascent of the formidable 1,909-meter Mount Ventoux. Stimulants such as amphetamines increase stamina and endurance but also have serious side effects such as dependency, depression and exhaustion. Their use in cycling had become widespread by the end of the 1960s and continued through the 1970s, even though the International Cycling Union introduced a list of banned substances shortly after Simpson’s death.

In 1972, doping testing was introduced at the Munich Olympics. Testing at the international level is now overseen by the World Anti-Doping Agency (WADA), which was established in 2000.[1] Doping testing is also carried out by all the major sporting industry bodies, including Major League Baseball, the National Football League and the National Collegiate Athletic Association in the United States.

As a result, demand for doping testing is expanding. In the 33 WADA-accredited labs around the world, the number of tests increased by more than 14,000 between 2004 and 2005, from 169,187 to 183,337. The corresponding increase in adverse analytical findings — the presence of prohibited substances — grew from 2,909 to 3,909, a 34.4-percent rise.

Adhering to protocol

Currently, WADA lists 11 categories that include more than 400 banned substances: anabolic agents (Figure 1); hormones and related substances; beta-2 agonists; agents with anti-estrogenic activity; diuretics and other masking agents; stimulants; narcotics; cannabinoids; glucocorticosteroids; alcohol; and beta-blockers. For most of these, LC/GC coupled with some form of MS is the preferred analytical technology. Agilent, as a leader in these technologies, has a long involvement in doping testing (see sidebar), having developed the GC nitrogen-phosphorus detector (GC/NPD) specifically for use at the Munich Olympics.



Clenbuterol

19-norandrosterone

3′ -OH stanozolol

Methyltestosterone metabolite (17α-methyl-5β-andrestane-3α, 17β-dial)

Epitestosterone

Epimetendiol (methandrostenolone metabolite)

Figure 1. Chemical structures of common anabolic substances

Testing done under the auspices of WADA follows a specific procedure. The athlete provides a urine or blood sample in the presence of an anti-doping official; the sample is split, by the athlete, into two — the A and B samples — and these are sealed. The samples are then handled within a strict chain of custody similar to that applied to forensic samples.

Testing starts with the A sample. An aliquot is extracted and derivatized as necessary to leave a residue that contains the compound or metabolites of interest. The exact procedure depends on the class of drug being tested for in the sample. If the initial test is negative, no further action is taken. With a positive test, a second aliquot of the A sample is taken and subjected to a more-detailed analysis. If this test is positive, the B sample is tested, but only after informing the athlete, who can be present and can also bring along their own expert observer. If the B sample generates a positive result, then the matter is referred to the anti-doping authority. No further action is taken if the B sample test is negative.

Applying appropriate tools and methods

The optimal choice of analytical techniques and instruments varies depending on the target substance and the task (e.g., screening or confirmation). As a general statement, GC is well suited to the separation of small, volatile compounds while LC is best for larger, non-volatile substances. In recent years, the utility of these separation techniques has been further expanded by the advent of robust tandem MS technologies such as LC or GC combined with a triple-quadrupole mass spectrometer (LC/QQQ and GC/QQQ).

To be more specific, doping control labs typically use GC/NPD for screening of narcotics and some classes of stimulants, while GC/MS is used for broader screens including anabolic steroids, marijuana, marijuana metabolites, and opiates. Larger molecules, such as beta-blockers and glucocorticoids, are often screened for using tandem LC/MS. More recently, laboratories have been applying the rapid, full-scan capability of LC time-of-flight (LC/TOF) and LC quadrupole time-of-flight (LC/QTOF) to screen for presumptive positives. Because TOF instruments always operate in full-scan mode, which collects "all the data, all the time," these technologies also provide laboratories with the ability to perform retrospective analysis. Immunoassays are used to screen for peptides and hormones such as human chorionic gonadotropin (hCG) and insulin. Isoelectric focusing (IEF) with chemiluminescence detection is used to screen for erythropoietin (EPO), which has become popular for boosting an athlete's oxygen-carrying capacity.

Confirmation tests are often performed using GC/MS or some form of tandem LC/MS such as LC/QQQ. Recently, some have been using LC/MS ion-trap technology for target confirmation due to its unique ability to generate multiple MS (MS^n) spectra and provide a "spectral audit trail." Similarly, some laboratories leverage the superb mass accuracy of LC/TOF or LC/QTOF to confirm the presence of a target compound through empirical formula determination.

Whatever the method, testing for sports doping places tremendous demands on analytical instruments. Above all, the equipment must be reliable because downtime is unacceptable, especially during a major event. The instrument must be able to process large numbers of samples in the lab with a rapid turnaround time: Those athletes being tested have a right to a prompt result. Day-to-day reproducibility is also crucial, particularly where confirmatory analyses are concerned, to ensure confidence in results that may be challenged.

Testing for steroids

Steroids are the most commonly abused drugs because they increase muscle growth (mass) and decrease recovery time. More than 70 are on the banned list, the most common of which are stanozolol, testosterone, nandrolone, clenbuterol, and the new "designer steroid" tetrahydrogestrinone (THG) — but new ones are constantly emerging (Figure 2).

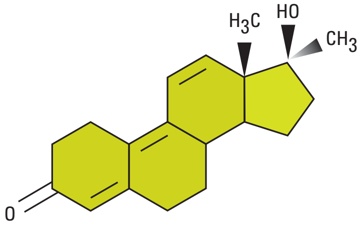


Figure 2. Chemical structure of the designer steroid THG

Honoring Excellence in Doping Control

To underline its commitment to the field, Agilent set up the Manfred Donike Award for scientific excellence in doping control in 1997. Professor Donike was a pioneer in doping tests, setting up one of the earliest dedicated labs in time for the Munich Games.

The 2008 award went to Ulrich Flenker, a research scientist at the Institute of Biochemistry, German Sport University, Cologne, Germany. Flenker was honored for his continuous technical and scientific improvements in detecting doping with synthetic steroids by identifying the ratios of stable isotopes 13C to 12C in samples using gas chromatography-combustion-isotope ratio mass spectrometry (GC-C-IRMS).

Although there are standard techniques, analytical protocols and measurement technology must constantly evolve to keep pace with new trends and demands in doping testing. Examples include the designer steroids clandestine labs synthesize by making a slight chemical modification to a known compound. Consequently, the synthetic steroid has a molecular weight that falls outside the target mass range monitored for anti-doping purposes. One way to detect these compounds is to capitalize on advances in GC/MS technology that allow for simultaneous collection of both selected ion monitoring (SIM) and scan data. This provides an abundance of information to assist in elucidating the molecular structure of the designer steroid. Another useful tool is ion-trap LC/MS with its inherent ability to collect MS^n spectra, which provides excellent elucidation of molecular structure.[2]

Another challenge for doping labs is that some steroids, such as nandrolone and its metabolites, can occur at very low endogenous levels. Consequently, WADA has established a 2 ng/ml threshold for these compounds: any concentration above the 2 ng/ml level is considered to be suspicious (Figure 3). Traditionally, high-resolution magnetic sector (HRMS) instruments are used to determine these low-level concentrations of steroids.

Some laboratories, however, would prefer to avoid HRMS devices due to their complexity and expense. One alternative is GC/QQQ, an older technology that is experiencing a revival because the instrumentation has become more robust — and because it can meet the demanding requirements of steroid testing. Additional alternatives include LC/TOF, LC/QTOF and high-resolution ion traps, which many labs are currently using to detect steroids.[3]

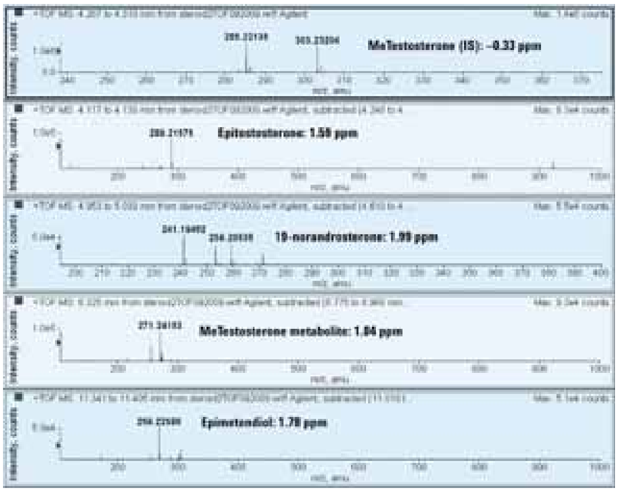


Figure 3. Example spectra from accurate mass LC/TOF analysis of 2 ng/ml urine extract (1 ng/ml 19-norandrosterone), mass accuracy was better than 2 ppm for each analyte.[3]

Conclusion

Many challenges remain in the quest to ensure a level playing field in competitive sports. For example, it is still difficult to distinguish between endogenous and exogenous levels of substances such as human growth hormone (hGH) and EPO. Both natural and recombinant versions of these hormones are popular doping agents.

In the future, athletes may be tempted to try "gene doping." Research at the University of Pennsylvania has shown that mice administered with the insulin-like growth factor gene (IGF-1) have muscle strength and power up to 30 percent greater than normal animals, and they also respond better to resistance training. Gene therapy is very difficult to detect — IGF-1, EPO and growth factor are already present in the human body — but test labs are working on ways to detect these forms of doping, too.

Sadly, dopers and cheaters will always try to stay ahead of the game. As a result, some form of testing will remain a fact of life in competitive sports. Fortunately, though, these forces will continue to stimulate the creation of new developments in measurement science and technology.

References

1. Learn more about the World Anti-Doping Agency at www.wada-ama.org.

2. Agilent Application, *Detection of 23 Corticosteroids, Anabolic Steroids, and ß2-Agonist in Athens Doping Control Lab During Athens 2004 Olympic Games Using Agilent 1100 LC/MSD Trap Mass Spectrometers.* Publication number 5989-3395EN available from www.chem.agilent.com.

3. Agilent Application, *Screening and Confirmation of Anabolic Steroids Using Accurate Mass LC/MS*. Publication number 5989-4738EN available from www.chem.agilent.com.

Portions of this article were published in October 2007 in *Chromatography Online*, www.chromatographyonline.com, the website of *LC/GC North America*.

GPS:
Coming of Age

Michael Griffin
Asia Market Development Manager, Agilent Technologies
mike_griffin2@agilent.com

John Kikuchi
Application Expert, Agilent Technologies
johnnny_kikuchi@agilent.com

GPS navigation technology has today become common in every facet of our lives (see the sidebar, *GPS at a glance*). Personal navigation devices (PNDs), for example, were very popular gift items during the 2007 holiday season and navigation systems are becoming more ubiquitous in all classes of automobiles. As GPS ICs become faster, smaller, cheaper, and consume less power, the technology will expand beyond the typical functionalities of personal navigation and into other areas such as geotagging, social networking and location-based services (LBS). These applications represent only a small portion of the ever-expanding role that GPS technology will play in our lives.

The recent 2008 Olympic Games in Beijing showcased an explosion of GPS-related technologies and applications. The Shanghai World Expo in 2010 is expected to do the same. Considering the fact that China accounted for more than 70 percent of portable GPS shipments in 2007 and also hosts the largest mobile-handset manufacturing sector in the world, this should come as no surprise. Events like these, and the new products and applications they feature, will play a role in keeping GPS increasingly on the minds of consumers. ABI Research estimates that over 550 million GPS-enabled mobile handsets will be shipping by 2012.

In today's "connect at anytime, anywhere, to anyone" society, we have witnessed the rapid acceleration of technology integration into mobile devices. Additionally, quality of service improvements and higher data rates to support content-rich mobile applications are driving a continual evolution of wireless access technologies. Many mobile devices now support cellular voice/data, wireless networking (e.g., PAN, LAN, MAN, and WAN) and digital audio/video broadcasting services. The integration of GPS into mobile handsets is an additional catalyst and will enable GPS-related applications that take advantage of both GPS and the other resident wireless technologies.

While for consumers the potential for exciting new applications is high, the constant evolution in wireless technologies and increasing demand for multi-format devices creates unique test challenges. It is also spurring new test strategies in R&D and manufacturing. Today's mobile devices require comprehensive verification and test solutions for multiple wireless technologies. Flexible test environments that are easily adaptable to changing test requirements are essential, since dedicated test equipment does not scale well with increased integration and quickly becomes cost prohibitive. This article will highlight some of the test engineering challenges for GPS and introduce a cost-effective solution that meets the demands of today's new test environment.

Understanding GPS technology

Before characterizing the test challenges and solutions for verifying and testing GPS receivers, it is necessary to first gain a clear understanding of the technology. The United States Department of Defense manages the GPS-satellite constellation that includes 24 orbiting satellites (32 satellites if you include backups and Block II/IIA/IIR/IIR-M satellites). The satellite orbits are arranged such that at least six satellites are always visible from any line-of-sight point on earth (Figure 1). Each satellite broadcasts navigation data that includes ephemeris data (precise orbital data for itself) and almanac data (coarse orbit and status information on all satellites). This data is transmitted using a distinct spread-spectrum code, coarse/acquisition (C/A), which is unique for each individual satellite (Figure 2). All GPS satellites are also equipped with onboard atomic clocks that allow GPS receivers to perform the precise time measurements required for calculating signal travel time.

Using its knowledge of the satellite positions and their C/A codes, the GPS receiver correlates the incoming GPS-satellite signals to identify and calculate the signal travel time from each satellite in view. It then calculates the distance to the satellite based on this travel time. The distance D to the satellite can be determined by $D = \Delta\tau$ x c, where $\Delta\tau$ is the calculated signal travel time and c is the speed of light (approximately 300,000 km/s).

GPS receivers calculate their position using the signals from at least four GPS satellites. By calculating the distance from these satellites, the GPS receiver is able to solve for four unknowns: longitude, latitude, altitude, and time. Using a principle known as trilateration, it then uses geometry and trigonometry to determine its actual location.

Figure 1. The orbiting GPS constellation includes 24 satellites

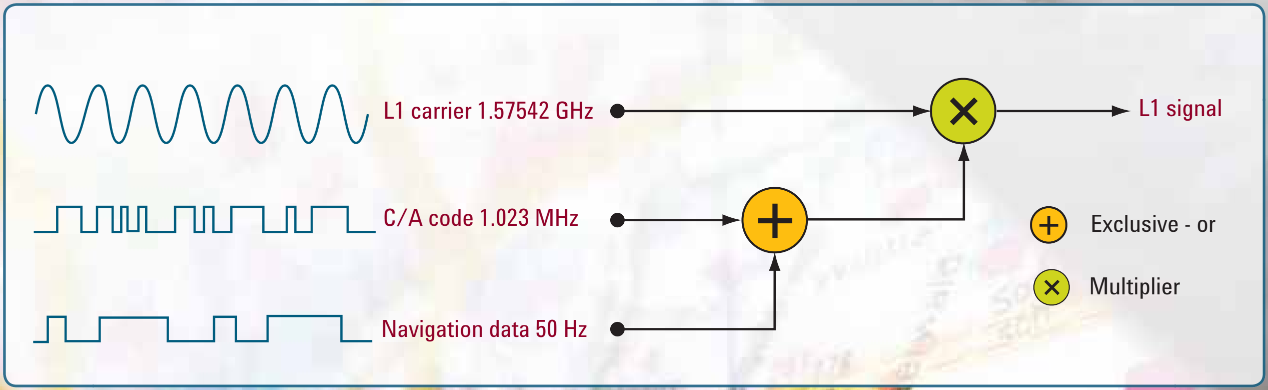


Figure 2. Satellite-signal block diagram for GPS link 1 (L1) frequency

Several types of augmentation systems have been created to improve the accuracy and reliability of the GPS receiver (Table 1). These systems provide additional information beyond what is available from the individual GPS satellites. Some systems use additional satellites to transmit external information to the GPS receivers, others use ground-based reference stations, and still others integrate navigation systems to calculate location fixes.

Table 1. GNSS augmentation systems

Augmentation system	System features

Satellite-based augmentation system (SBAS)	• Provides correction data (clock errors, atmospheric attenuation) for increased accuracy
	    • Many regional systems currently are active
	    • Wide Area Augmentation System (WAAS) USA
	    • European Geostationary Navigation Overlay Service (EGNOS)
	    • Quasi-Zenith Satellite System (QZSS) Japan
	    • Multi-functional Satellite Augmentation System (MSAS) Japan
	    • Commercial systems, StarFire, OmniSTAR

Differential GPS	• Fixed ground-based reference stations • Broadcast differences between measured and computed pseudoranges
Inertial navigation systems	• Uses computer, accelerometers, gyroscopes, and other motion-sensing devices • Typically used in automotive and missile guidance systems

Assisted GPS	• A-GPS leverages existing base stations of telecom systems
	• Incorporates “Assistance Server” to enhance performance such as time to first fix (TTFF) and signal sensitivity
	• Assistance Server provides:
	    • General location information based on cellular network
	    • Location information by comparing fragmentary cell phone GPS signals and its own satellite signal
	    • Orbital data for the GPS satellites enabling the handset to lock quickly (TTFF)
	    • Known ionospheric conditions

Identifying the test requirements

Even as GPS technology becomes more common, GPS receiver manufacturers, OEM integrators and contract manufacturers struggle for standard tests to verify receiver performance. Verification is required both to validate GPS receiver functionality and to objectively evaluate competing GPS IC performance. Verification procedures require a controlled environment that facilitates

precise repeatability. In most cases, using actual GPS-satellite signals received through an antenna does not provide this type of environment. A real-time GPS signal simulation, generated by a metric-grade RF signal generator, offers an excellent starting point for creating a calibrated and repeatable test environment.

As GPS receivers are incorporated into mobile consumer products (e.g., cellular phones) it also becomes important to have a flexible test environment. The source should therefore be flexible enough to generate not only GPS signals, but other wireless standards as well.

A series of six tests, described below, is not all-encompassing but can help in the evaluation of GPS receiver performance and provide a validation technique for GPS products in a controlled environment: time to first fix, warm start-time to fix, reacquisition time, static-navigation accuracy, radio-frequency interference, and receiver sensitivity.

For the purposes of this discussion, the GPS receiver used for these tests is the U-blox AEK-4T evaluation kit with U-center software. The GPS signals were created by the E4438C ESG vector signal generator with Option 409 GPS personality (Figure 3). The E4438C is a high performance, general-purpose RF signal generator capable of providing comprehensive support for today's wireless signal formats. The GPS personality provides up to eight real-world GPS satellite signals that are based on pre-configured scenario files. These signals, including Doppler shifts, are synchronized with the actual satellite orbits so that they are consistent with the navigation message contained in the satellite signals (see the sidebar, *Scenario generator and verification*).

Figure 3. The Agilent Technologies E4438C ESG

The user interface of the E4438C-409 GPS personality is shown in Figure 4. This GPS signal simulator provides the following capabilities:

- Multi-satellite GPS configuration (maximum eight satellites)
- Simulation of real-world scenarios (multiple scenarios available)
- Real satellite data (synchronized satellites with Doppler shifts and navigation messages)
- Adjustable number of visible satellites between one and eight
- Automation of signal generation through SCPI commands

Location: KONA
Start Date: 21-May-2007
Start Time: 01:00:00
Altitude (m): 100
Latitude: 19.818888
Longitude: -155.988055
Filename: HAWAII
GPS Ref (f0): 1.023000Mcps
GPS Ref Clk: Int
IQ Phase: Normal
Scenario State: Running
Signal Play Duration: 00:02:34 of 00:30:00
Satellites in View: 27, 8, 25, 4, 13, 20, 23, 2

Figure 4. E4438C-409 GPS personality user interface

Setting up the tests

The test setup is shown in Figure 5. Specific test scenarios are selected from the E4438C-409 application. The real-time GPS signal is created by the E4438C and the RF output is sent to the GPS receiver. The GPS receiver is connected to the PC through a USB cable and to the GPS receiver evaluation software.

Unless otherwise noted, the following default assumptions are made for each of the test measurements:

- No ionospheric- or tropospheric-range delay
- Zero clock and ephemeris error
- No multipath fading
- UTC time
- Minimum of eight visible satellites
- Static GPS receiver (e.g., not moving in relation to the rotating globe)

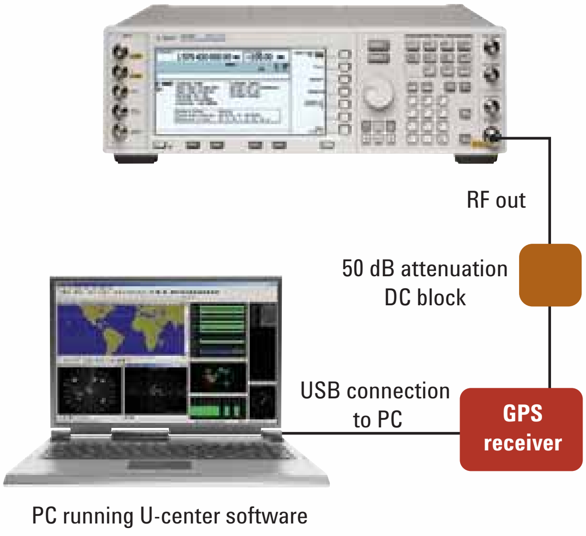


Figure 5. Test configuration

GPS at a glance

Global Positioning System (GPS) is a Global Navigation Satellite System (GNSS). It is one of five operational or planned systems and today is the only worldwide fully-operational system. Table 1 lists the other existing or planned GNSSs.

Table 1. A current list of global navigation satellite systems

System name	Country of origin	Date of full operation	Comments
GPS	USA	1995	Only worldwide fully operational GNSS system
GLONASS	Russia	2009	Initially completed in 1995. Currently not fully operational worldwide
Galileo	European Union	2013	Scheduled for full operation in 2013 Interoperability with GPS
Beidou or Compass	China	Unknown	Experimental Beidou-1 locally available for Beijing Olympics
IRNSS	India	Unknown	Only available locally around India

Making the measurements

Given the test setup and instrumentation previously described, the following tests can be performed to help evaluate GPS receiver performance and validate GPS products in a controlled environment.[1]

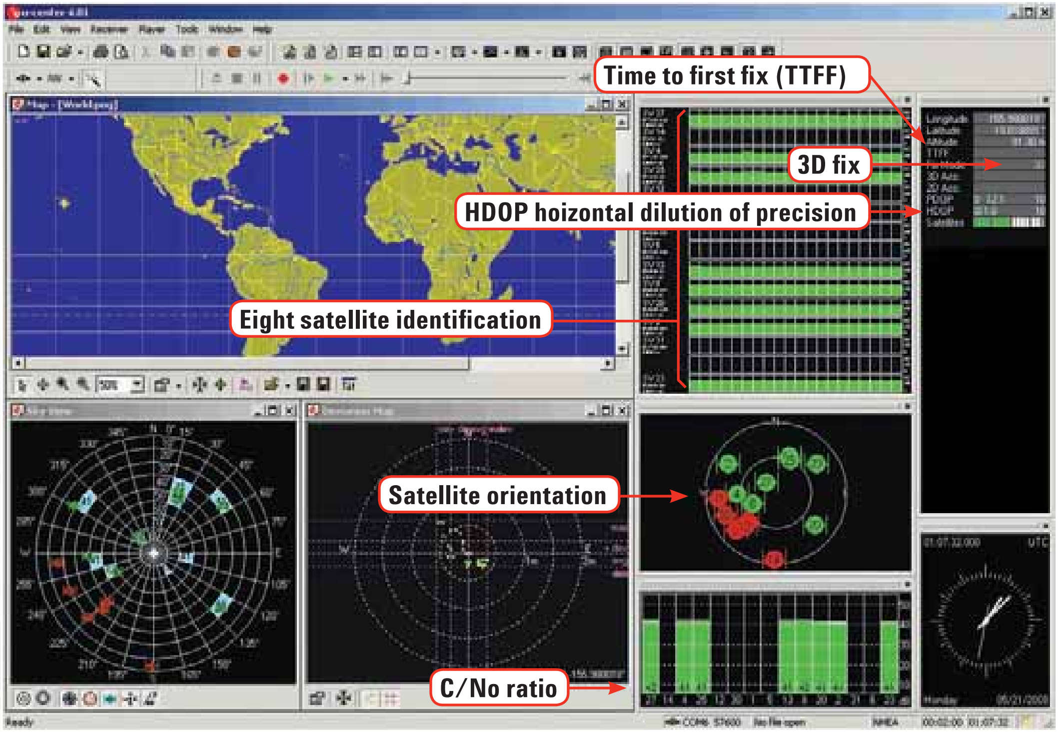
Time to first fix (TTFF): The test objective here is to measure the time required by the GPS receiver to achieve a GPS navigation fix from a cold start. A cold start is defined as a receiver that is turned on without current ephemeris data. Typically, a cold start can be achieved by a receiver that has been turned off for at least two hours. The TTFF is defined as the time interval between the GPS receiver startup (power up) and the first-valid navigation 3D-data point, derived from the simulation (Figure 6).

The GPS simulation is first started on the E4438C before the GPS receiver is turned on. At least 20 valid sample TTFFs should be collected. The mean, minimum and maximum values for these samples are analyzed and the standard deviation computed.

Warm start time to first fix: The objective is to measure the time required by the GPS receiver to achieve a GPS navigation fix from a warm start. This is similar to the cold-start TTFF test but, in this case, the receiver contains current ephemeris data for all satellites in the simulation. Typically, this can be achieved by a receiver that had previously been on and was then turned off for a short period of time.

The GPS simulation is first started on the E4438C. The GPS receiver is turned on and allowed to achieve a location fix. This ensures the presence of current ephemeris data in the GPS receiver. Next, the GPS receiver is turned off for a short period of time and then on again. The time interval from this turn-on to a valid 3D location fix is the TTFF. At least 50 valid sample TTFFs should be collected. The mean, minimum and maximum values for these samples are analyzed and the standard deviation computed.

Figure 6. U-center software, printed with written permission from U-blox



Reacquisition time: This test establishes the time required to reacquire a navigation fix following a short blockage of all GPS signals during normal operation. The method of blockage can be achieved in a number of ways. The two most common ways would be to attenuate the signal by inserting an attenuation of at least 60 dB in the feed line or to disconnect the feed line from the simulator to the receiver. Measurement data is similar to the TTFF measurement.

The GPS simulation is first started on the E4438C. The GPS receiver is turned on and allowed to achieve a location fix. Next the GPS signal is interrupted by pressing the RF On/Off button on the E4438C. The signal is then restarted by pressing the RF On/Off button to simulate a short signal blockage. The reacquisition time is the interval between the reconnection of the GPS signal and the first-valid navigation data point derived from the simulation. At least 50 valid reacquisition samples should be collected. The mean, minimum and maximum values for these samples are analyzed and the standard deviation computed.

Static navigation accuracy: The objective is to characterize the accuracy of the receiver location fix with respect to the simulated location. In this test, a static (non-moving) scenario is used as the GPS simulated signal.

The GPS simulation is first started on the E4438C. The GPS receiver is turned on and allowed to achieve a location fix. Valid 2D or 3D navigation data points, as defined by the GPS receiver, are counted over the GPS simulation period. The interval of the data collection is based solely on the receiver's output-navigation data rate.

Typical GPS receiver evaluation software provides location fix information. This data, usually longitude, latitude and altitude information, can be converted to Earth-centered, Earth-fixed (ECEF) Cartesian coordinates for evaluation of the simulated, versus calculated, GPS receiver locations.

ECEF coordinates (x, y and z) of a point P can be determined from its geodetic coordinates (Φ, λ and h) using the following algorithms.[2]

$$x = (R + h) \cos \Phi \cos \lambda$$
$$y = (R + h) \cos \Phi \sin \lambda$$
$$z = (R + h - e^2 R) \sin \Phi$$

where $R = a/(1 - e^2 \sin^2 \Phi)^{1/2}$

Φ is the geodetic latitude

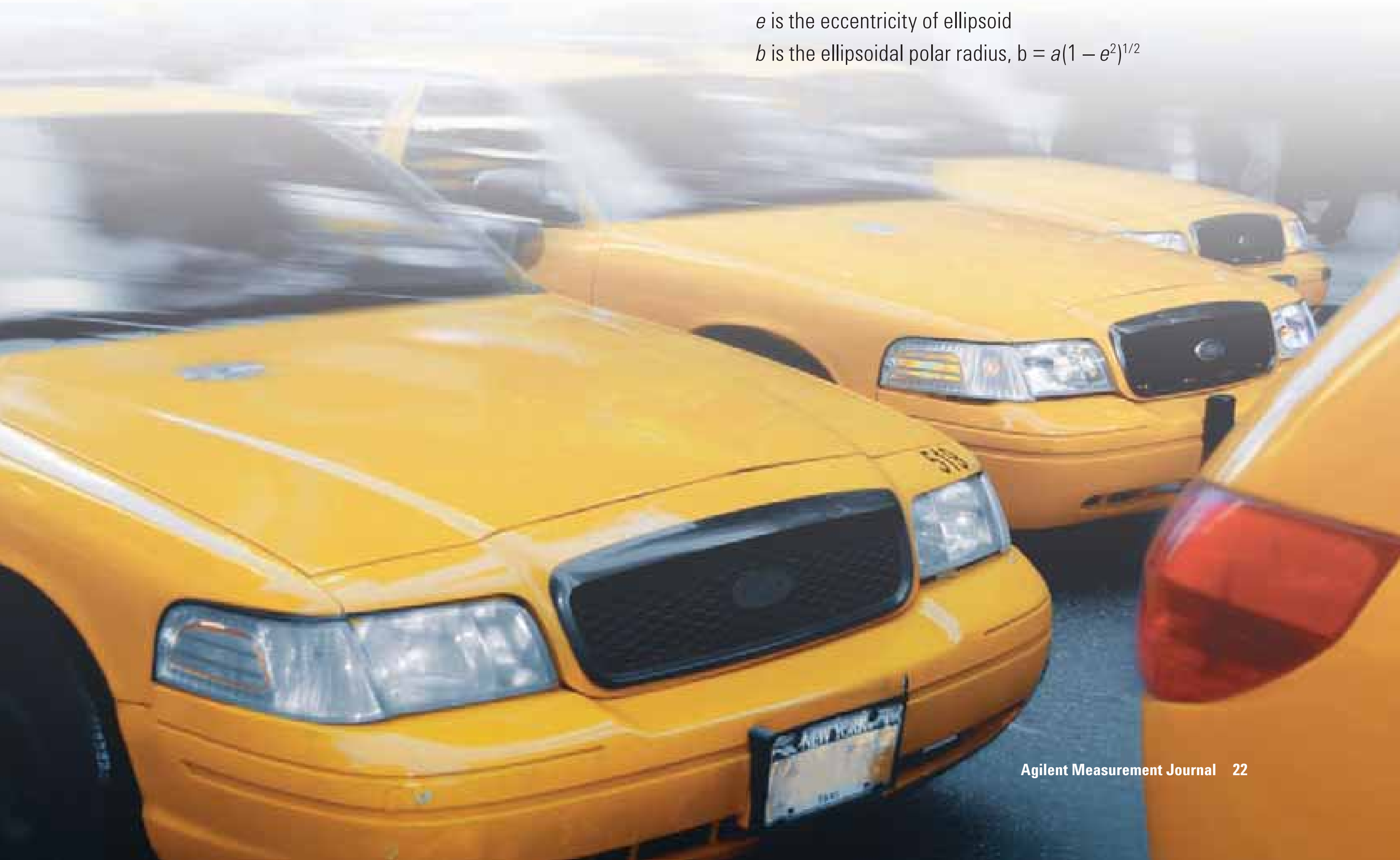
λ is the geodetic longitude

h is the altitude

a is the ellipsoidal equatorial radius

e is the eccentricity of ellipsoid

b is the ellipsoidal polar radius, $b = a(1 - e^2)^{1/2}$



Note that further information on data analysis, including a complete definition of measurement methodologies to evaluate accuracy performance for this test, can be found in the second edition of the *GPS Standard Positioning Service Signal Specification.*[3]

Radio-frequency interference: This test measures the ability of the GPS receiver to operate in the presence of interfering (jamming) signals that may be received through its input. In this test, the jamming-signal power level is increased in 1-dB increments until the first degradation of the GPS satellite-signal tracking is detected. The jamming-signal power level is again slowly increased until the GPS receiver losses its 3D navigation fix. The setup required for this test is shown in Figure 7.

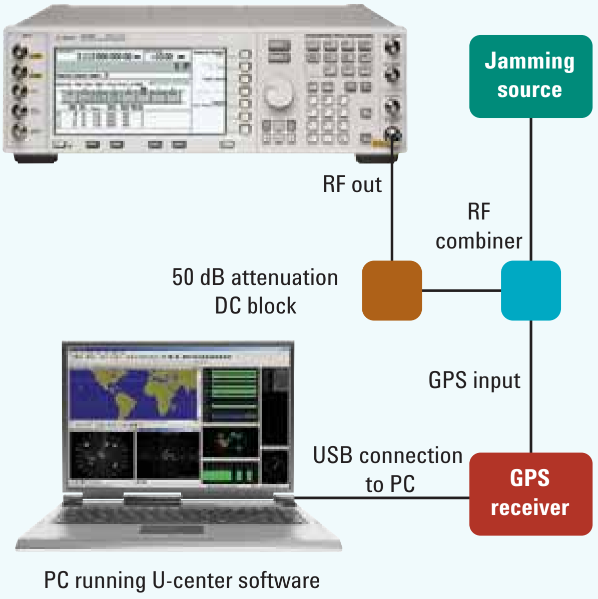


Figure 7. RF interference test configuration

The GPS simulation is first started on the E4438C. The GPS receiver is turned on and allowed to achieve a location fix. The jamming signal is then added to the GPS signal at a level that is discernible to the GPS receiver and is increased in 1-dB steps. The typical data collected for this interference test includes four key items:

- First satellite loss threshold (dB)
- 3D navigation loss threshold (dB)
- Jammer center frequency
- Jammer bandwidth

Receiver sensitivity: The test objective here is to verify receiver sensitivity by measuring signal strength (C/No) under various GPS-signal power levels.

To obtain an accurate power level for the GPS satellite signal, the number of visible satellites should be set to one on the E4438C-409 application. The power level on the front panel of the E4438C will then accurately reflect the total power in the single satellite signal.

The GPS simulation is first started on the E4438C. The power level on the E4438C is set such that the GPS receiver can identify the single GPS satellite signal. The power level of the GPS satellite signal is then decreased until the GPS receiver loses tracking of the single satellite. This power level, and the corresponding GPS-receiver C/No ratio, is collected as data.

Another receiver sensitivity test is to measure the power level and C/No ratio level at which the 3D location fix is lost. This requires a minimum of four satellite GPS simulations. In this test, the GPS simulation is started on the E4438C with all eight satellites visible. The GPS receiver is turned on and allowed to achieve a location fix. The power level of the E4438C is then decreased until the 3D location fix is lost. The power level and the corresponding GPS-receiver C/No ratio is collected as data.

Conclusion

The ability to simulate GPS signals easily with a high-performance RF source provides great flexibility in creating an accurate and repeatable test environment for evaluating GPS receivers. Although the tests mentioned in this article are not all encompassing, they can be used as a basis for verification of GPS receivers. The characteristic performance information gathered from these tests enables not only verification of GPS receiver performance, but comparisons between them as well. The test equipment used for these tests is all standard commercial off-the-shelf (COTS) equipment and can be easily modified to suit the changing test requirements of the wireless industry.

References

1. ION STD 101: *Recommended Test Procedures for GPS Receivers, Revision C*. 1997. Institute of Navigation. ISBN: 0936406046.

2. Zhu, J. 1994. *Conversion of Earth-Centered Earth-Fixed Coordinates* to Geodetic Coordinates. IEEE Log No. T-AES/30/30/16661.

3. *Global Positioning System Standard Positioning Service Signal Specification*, Second Edition, June 2, 1995, available online at www.navcen.uscg.gov.

Scenario generator and verification

Each scenario included in the E4438C-409 application was generated by the NAVSYS Corporation GPS-Signal Simulation Toolbox. A script was created to generate specific satellite information based on a given location (e.g., longitude, latitude and altitude), specific time and period, and corresponding Yuma almanac file. The satellite information includes satellite-navigation data, as well as power levels and Doppler shifts for each visible satellite during that time period.

Verification of the accuracy of the scenario files was performed by NAVSYS Corporation. Actual measurements of carrier frequency and pseudo range were collected with the NAVSYS High Gain Advanced GPS Receiver (HAGR) over a period of 12 hours. A scenario file was generated using the Signal Simulation Toolbox over the same period for comparison. A comparison between simulated values and actual received signals is shown in Figure 8. The solid blue line is actual data from the HAGR. The red dashed line represents simulated data from the scenario generator. The two lines overlay each other exactly. The comparisons were made for all visible satellites during the 12-hour period. Excellent accuracy between simulated and captured GPS signals was observed on all visible satellites.

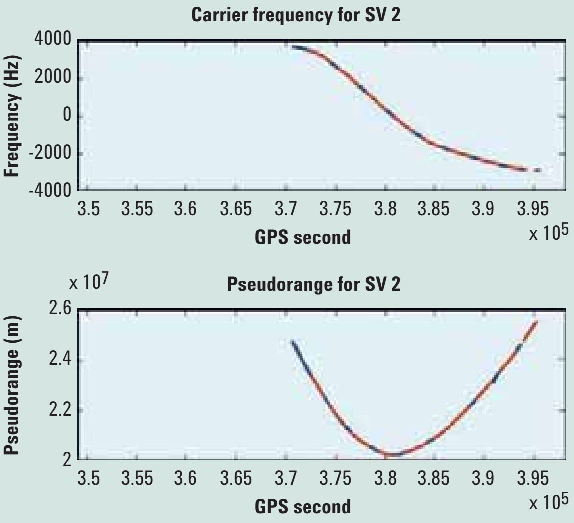
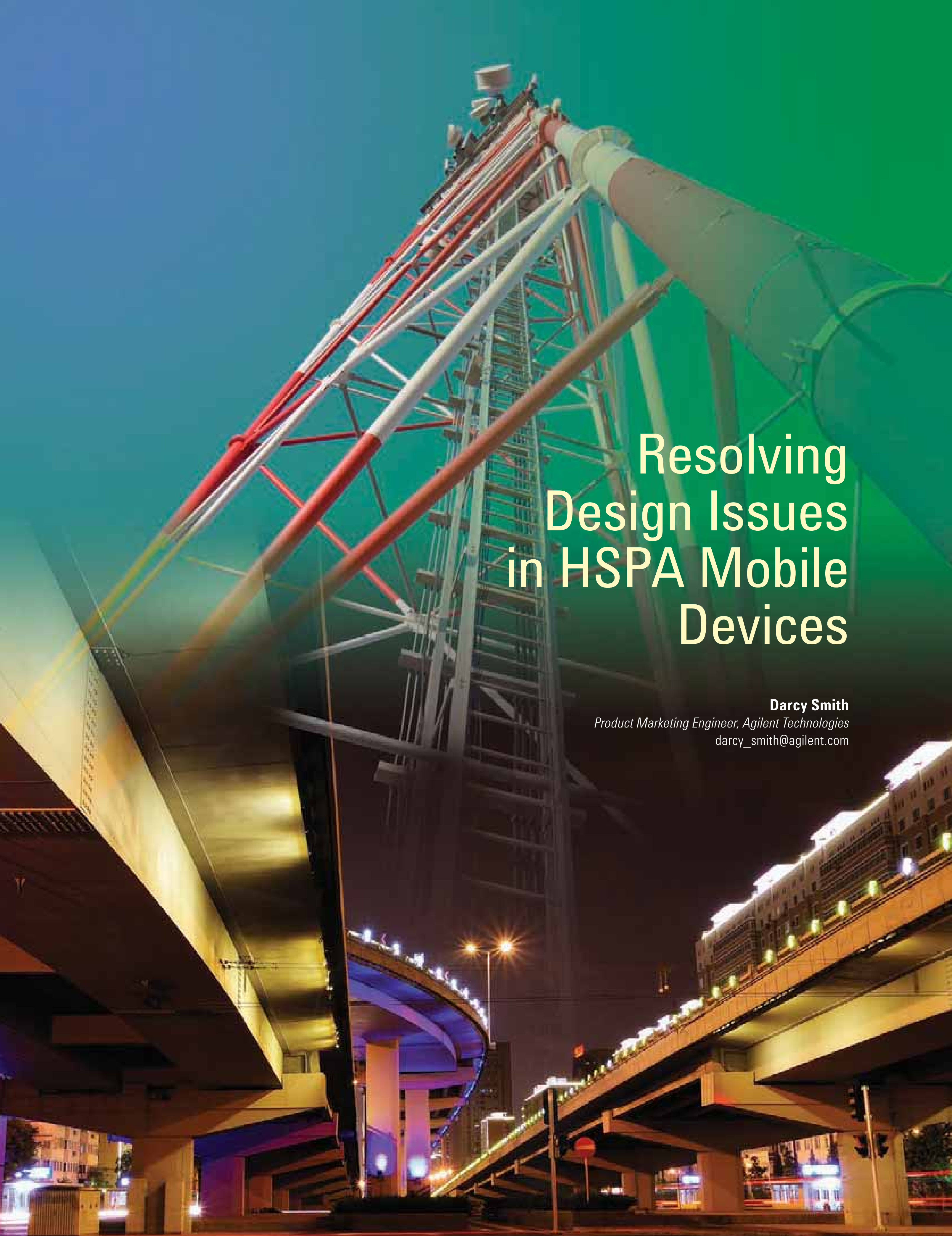


Figure 8. Scenario verification



Resolving Design Issues in HSPA Mobile Devices

Darcy Smith
Product Marketing Engineer, Agilent Technologies
darcy_smith@agilent.com

High-speed packet access (HSPA) is a collection of mobile telephony protocols which are today being deployed quickly around the world (see the sidebar, *HSPA review*). According to a March 2008 survey from the Global Mobile Suppliers Association (www.gsacom.com), seven in eight commercial W-CDMA operators have already launched HSPA and more than 1.1 billion GSM and W-CDMA subscribers now receive service on commercial HSPA-enabled networks. As further evidence of HSPA's emergence on the commercial scene, consider that the 2008 Beijing Olympics are being touted as the first broadband Olympics. In support of this designation, China Mobile has committed to launch its HSPA network this year as a way to provide high-speed wireless communications to the masses.

The benefits of adding HSPA to a wireless network include much higher data rates in the downlink and uplink, lower latency and expanded coverage areas for high-speed data. By deploying HSPA, operators can offer a wider array of revenue-generating data services such as VoIP and mobile gaming. Any new technology, however, comes with a price. In the case of HSPA, its evolving standards, complex protocol stacks and embedded applications require far greater software and hardware performance. A prime example is the HSPA mobile phone, which must carry voice and high-speed data while managing handovers, power output and responses to the RF environment. This workload places tough demands on the device's transmitter, processor, internal buses, and memory allocation — and this calls for more testing and verification in the design lab. Fortunately, test and measurement suppliers have introduced products to help mobile phone designers catch problems early in the development cycle, when the problems are easier and less costly to fix. This article details some of the key challenges of testing and validating HSPA mobile phones and proposes an effective test strategy that mimics real-world scenarios.

Weighing the design tradeoffs

There are several reasons why today's mobile phones are so functionally complex. The growing presence of multimedia and mobile Internet applications is the greatest factor driving capability requirements. Less obvious perhaps is the requirement for mobile phones to support network-optional features. Additionally, phones have to work globally across many network configurations — even as new designs incorporate new functionality; remain small, attractive, affordable, and easy to use; and provide the longest possible battery life.

Under the weight of these expectations, mobile phone designers are often forced to make difficult design tradeoffs to provide the right amount of processing capability to meet current requirements and expected future needs. They attempt to minimize power usage and anticipate the worst-case scenarios that software and applications might encounter in real network environments. Moreover, they try to meet design goals using the fewest, smallest and least-expensive chips — all the while reusing existing hardware designs and software modules as much as possible.

Because of these tradeoffs, there are literally hundreds of W-CDMA and HSPA devices on the market today, each with its own distinct size, shape, feature set, and method of operation. Consequently, there is no "typical" HSPA mobile phone and, therefore, no simple, one-time test process for ensuring a phone delivers the required performance. Instead, testing is iterative. It begins when the core components of the mobile device (e.g., RF and baseband chipsets, operating system, protocol stack, and applications) are first integrated into a working unit. It ends when a reliable, quality product has been delivered successfully to the end user.

Surveying the design challenges

The challenges posed in implementing HSPA's new performance enhancements in high-speed downlink packet access (HSDPA) and high-speed uplink packet access (HSUPA) often become evident during the integration process. Here the designer brings together the hardware, operating system, protocol stack, and applications, and tests them at a system level. Power control is often an issue. At the physical layer, adding HSPA to the technology mix introduces larger power variations — for example, in the uplink at transmission time interval (TTI) boundaries when HSUPA is turned on and off. In this case, relative differences in code channels also can be large. The dynamic nature of the HSUPA uplink makes construction of proper code channels in the phone more difficult and can lead to increased out-of-channel interference and poorer modulation quality.

Figure 1 shows an HSPA waveform in the time domain. It illustrates the power level changes that occur when HSDPA and HSUPA transmission are added to the W-CDMA signal. Note that in segment A, the HSUPA dominates because the Absolute Grant is set to a high level.

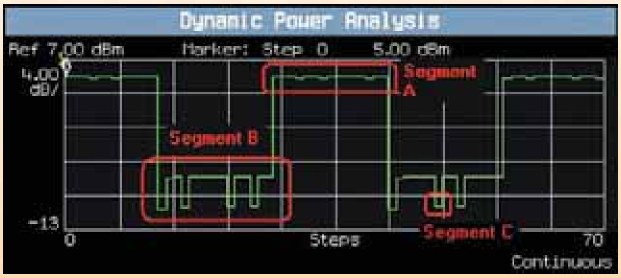


Figure 1. HSPA waveform showing (A) HSUPA, HSDPA and W-CDMA combined; (B) HSDPA control channel and W-CDMA; and (C) W-CDMA signal only

Another challenge is protocol design. The fast scheduling first introduced in HSDPA requires the mobile phone to respond with "correct" messages in terms of content, length, order of delivery, and delivery time. Moreover, the mobile phone needs to ignore messages from the network pertaining to any functionality it doesn't support. Protocol errors can cause problems with handovers, resulting in lost data and dropped calls. Figure 2 shows a protocol log from a situation in which a message was missing certain content (e.g., the message length) and, as a result, all subsequent messages were misinterpreted.

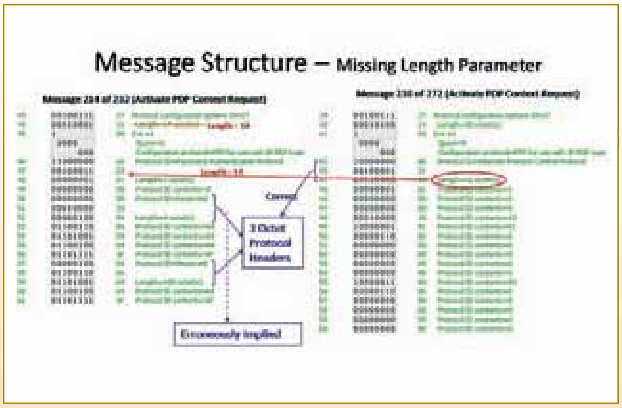


Figure 2. Protocol log showing the effect of a missing parameter

Memory management is yet another challenge for HSPA mobile phone designers. Because most applications deal with some type of data transfer, memory buffers must be kept optimally loaded. Any large changes in throughput or delay degrade the application's performance. If a drop in bandwidth occurs, for example, the mobile phone is instructed to request a lower rate of data from the server. However, before the server receives the request and acts on it, the network will have continued to buffer data, awaiting delivery. Because a mobile phone operates on in-sequence delivery, the data being stored could create a bottleneck that, when cleared, floods the mobile phone with data.

It's also worth noting that in a mobile environment, extreme changes of bandwidth are likely and often occur rapidly as a mobile device roams between networks. These large, dynamic variations are difficult to model and even more challenging to compensate. Similarly, as a mobile phone moves between networks, large delays can build up as a result of the time required to process handover protocols and re-establish data flow. Test techniques that mimic real-world scenarios are therefore the best way to ensure that the phone continues to perform correctly in a challenging environment.

Improving test effectiveness

There is no simple, one-step method of testing mobile phones for every performance issue associated with HSPA. However, a useful approach can be devised to test mobile phones during the integration and validation stages of development.

Testing at the physical layer is the first step in evaluating the performance of a mobile device or application. Physical-layer data throughput gives an initial indication of how well the mobile phone is performing, although it doesn't point directly to the root cause of any errors that may occur. Building on the results of physical layer testing, the next step is to validate the radio link control (RLC) protocol, driver and IP. This begins to tell the developer how the HSPA device will perform on a live network. Application-layer data throughput tests can also be carried out at this time to see how well the mobile phone performs from an end user's perspective.

The next step is to add an application that places a moderate load on the device's processors. Then, to fully stress the system from a data throughput perspective, a packet-switched call can be set up and a data file transferred. Using FTP, for example, can simulate the running of an application that requires acknowledgment of received packets.

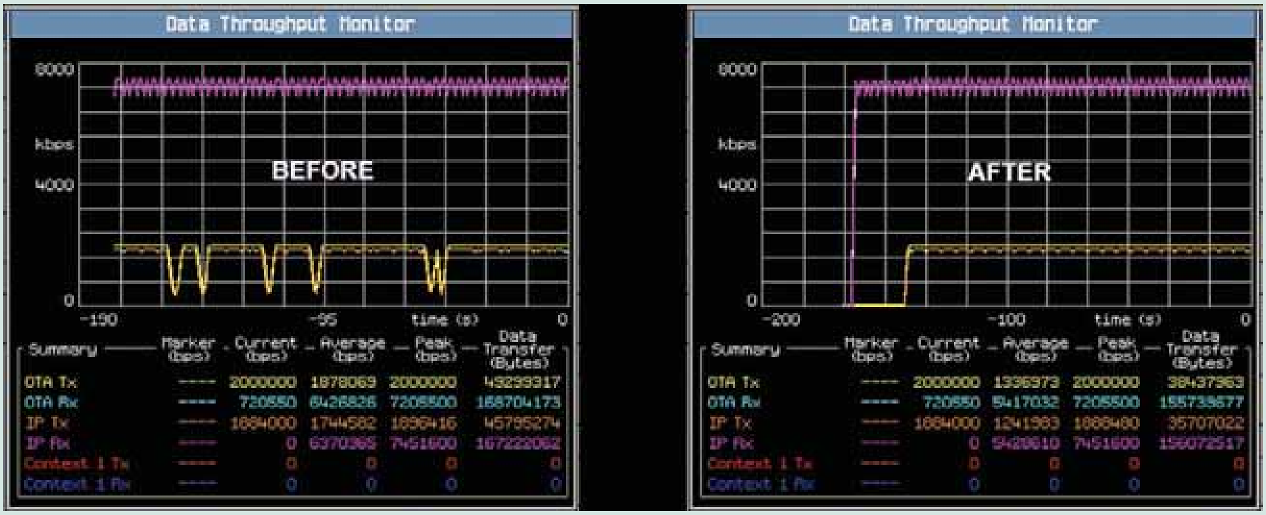
Following these steps maximizes the amount of data flowing through the HSPA mobile phone to verify that everything is working together. Two additional techniques can be used to push the mobile phone to its performance limit:

- Emulating a live network and exposing the phone to scenarios that could be expected in the real world.
- Subjecting the phone to the most stressful of these usage scenarios to find any weak (or breaking) points in the design.

Finally, the importance of handover testing must be noted. Handover errors are some of the most common causes of dropped calls and data loss. Valuable network resources are required to manage handovers and this explains why so many HSPA conformance tests require testing with more than one cell. It is critical to test handovers while running other services and features on the phone such as SMS, MMS, FTP throughput, Web browsing, and video and voice calls. Additionally, it's important to test scenarios in which the phone hands over from a cell that supports HSPA to one that does not. Base station emulators that support HSPA can be used for testing most of these cases.

Resolving HSPA issues

Mobile phone designers can identify and resolve many HSPA issues using the test methodology described, along with enhanced measurement tools provided by test and measurement suppliers. As an example, consider a situation uncovered during physical layer testing (Figure 3). In this case, the designer wanted the device to process HSDPA and HSUPA data simultaneously at the maximum capability of the device — 7.2 Mbps on the downlink and 2 Mbps on the uplink. Although the downlink data appeared to work correctly, the uplink data was occasionally being dropped. Setting up a packet-switched data call, the designer initiated a flood of user datagram protocol (UDP) traffic to and from the device and observed the results on the data throughput monitor provided by the Agilent 8960 Wireless Communications Test Set.



Summary	Marker (bps)	Current (bps)	Average (bps)	Peak (bps)	Data Transfer (Bytes)
OTA Tx	----	2000000	1878069	2000000	49239317
OTA Rx	----	720550	6426826	7205500	168704173
IP Tx	----	1884000	1744582	1896416	45795274
IP Rx	----	0	6370365	7451600	167222062
Context 1 Tx	----	0	0	0	0
Context 1 Rx	----	0	0	0	0

Summary	Marker (bps)	Current (bps)	Average (bps)	Peak (bps)	Data Transfer (Bytes)
OTA Tx	----	2000000	1336373	2000000	38437363
OTA Rx	----	720550	5417032	7205500	155739677
IP Tx	----	1884000	1241983	1888480	35707022
IP Rx	----	0	5428610	7451600	156072517
Context 1 Tx	----	0	0	0	0
Context 1 Rx	----	0	0	0	0

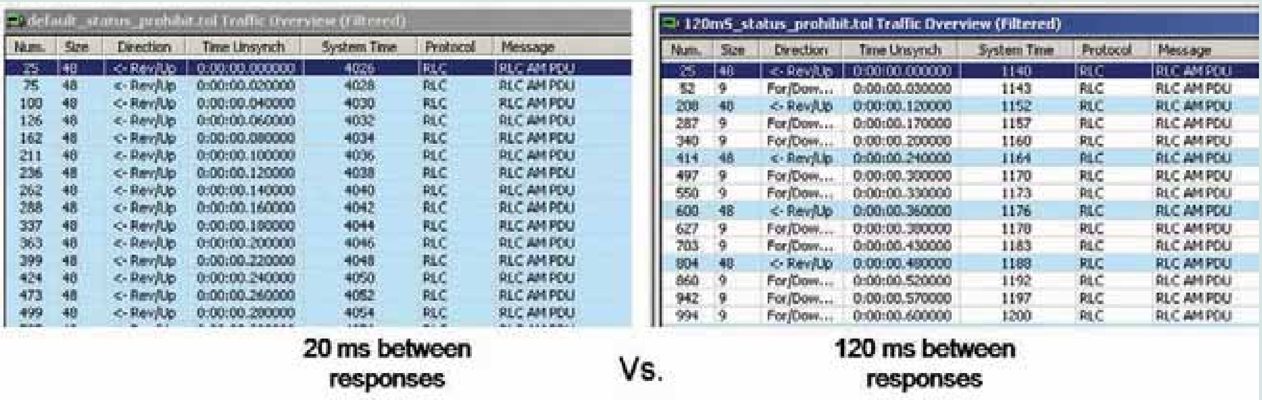
Figure 3. Data "drop outs" identified during physical layer integration

The "before" measurement in Figure 3 suggested that the phone had detected a change in its power allocation for transmitting data. The designer explored this suggestion further by first turning off the relative grant channel (E-RGCH) power. Because this did not affect the user equipment (UE) uplink data throughput, the next step was to signal that the relative grant channel power was "off." This gave the correct results, as shown in the "after" measurement in Figure 3. Further investigation showed that the phone was interpreting a "HOLD" sent on the E-RGCH as a "DOWN," resulting in the drop-outs. The problem could then be fixed.

In another example, a designer observed that data calls on the mobile phone were being disconnected whenever the serving grant varied widely over a period of time. This occurred when a video-streaming application was running. The environment was replicated using a packet-switched data call. Agilent's Wireless Test Manager software was used to control the 8960 Test Set measurements and absolute grant pattern setups. The results were reviewed on the E-TFCI recording screen. Figure 4 shows the results after the test was run for several minutes. The behavior was determined to be caused by buffer overflow in the mobile phone.

Figure 4. Calls being disconnected during a video streaming application

Frequently during application integration, HSPA phones are found to have difficulty delivering maximum data rates to the application layer. The reasons are many. In the example illustrated in Figure 5, the designer was able to determine that his device could not handle the standard RLC polling rate. This determination was made by viewing the data throughput monitor and wireless protocol advisor protocol logs from an Agilent 8960 Test Set. The log on the left shows that the phone's responses, occurring at 20-ms intervals, dominate the available resources. When the RLC polling rate was decreased, the phone was able to maintain higher data rates in a more stable manner. The protocol log on the right shows that the phone is less stressed by responding to polling at 120-ms intervals.



default_status_prohibit.tol Traffic Overview (Filtered)

Num.	Size	Direction	Time Unsynch	System Time	Protocol	Message
25	48	<- Rev/Up	0:00:00.000000	4026	RLC	RLC AM PDU
75	48	<- Rev/Up	0:00:00.020000	4028	RLC	RLC AM PDU
100	48	<- Rev/Up	0:00:00.040000	4030	RLC	RLC AM PDU
126	48	<- Rev/Up	0:00:00.060000	4032	RLC	RLC AM PDU
162	48	<- Rev/Up	0:00:00.080000	4034	RLC	RLC AM PDU
211	48	<- Rev/Up	0:00:00.100000	4036	RLC	RLC AM PDU
236	48	<- Rev/Up	0:00:00.120000	4038	RLC	RLC AM PDU
262	48	<- Rev/Up	0:00:00.140000	4040	RLC	RLC AM PDU
288	48	<- Rev/Up	0:00:00.160000	4042	RLC	RLC AM PDU
337	48	<- Rev/Up	0:00:00.180000	4044	RLC	RLC AM PDU
363	48	<- Rev/Up	0:00:00.200000	4046	RLC	RLC AM PDU
399	48	<- Rev/Up	0:00:00.220000	4048	RLC	RLC AM PDU
424	48	<- Rev/Up	0:00:00.240000	4050	RLC	RLC AM PDU
473	48	<- Rev/Up	0:00:00.260000	4052	RLC	RLC AM PDU
499	48	<- Rev/Up	0:00:00.280000	4054	RLC	RLC AM PDU

120mS_status_prohibit.tol Traffic Overview (Filtered)

Num.	Size	Direction	Time Unsynch	System Time	Protocol	Message
25	48	<- Rev/Up	0:00:00.000000	1140	RLC	RLC AM PDU
52	9	For/Dow...	0:00:00.030000	1143	RLC	RLC AM PDU
208	48	<- Rev/Up	0:00:00.120000	1152	RLC	RLC AM PDU
287	9	For/Dow...	0:00:00.170000	1157	RLC	RLC AM PDU
340	9	For/Dow...	0:00:00.200000	1160	RLC	RLC AM PDU
414	48	<- Rev/Up	0:00:00.240000	1164	RLC	RLC AM PDU
497	9	For/Dow...	0:00:00.300000	1170	RLC	RLC AM PDU
550	9	For/Dow...	0:00:00.330000	1173	RLC	RLC AM PDU
600	48	<- Rev/Up	0:00:00.360000	1176	RLC	RLC AM PDU
627	9	For/Dow...	0:00:00.380000	1178	RLC	RLC AM PDU
703	9	For/Dow...	0:00:00.430000	1183	RLC	RLC AM PDU
804	48	<- Rev/Up	0:00:00.480000	1188	RLC	RLC AM PDU
860	9	For/Dow...	0:00:00.520000	1192	RLC	RLC AM PDU
942	9	For/Dow...	0:00:00.570000	1197	RLC	RLC AM PDU
994	9	For/Dow...	0:00:00.600000	1200	RLC	RLC AM PDU

Figure 5. A 20-ms RLC polling rate interferes with the mobile phone's ability to sustain maximum data rates

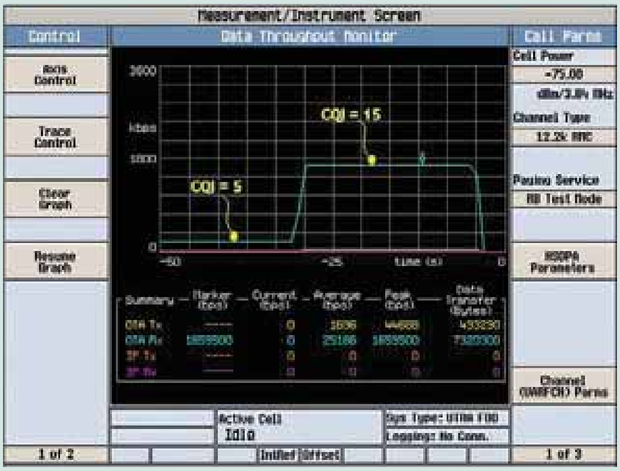
Taking the final step: validation

Before releasing a mobile phone design for certification testing, field tests or manufacturing, designers want to be absolutely certain that their designs will withstand the rigors of the real world. Consequently, during final in-house validation, the phone should be put through a series of "user-experience" tests and stress testing. Wherever possible, these tests should be incorporated even earlier in the design process to get the greatest benefit.

As an example, consider the testing of a video streaming application intended to keep video playback smooth, regardless of inconsistencies in the mobile network. To accomplish this goal, the application is supposed to enable fast responses to channel-quality indication (CQI) changes. However, when the phone was tested running the application, it failed to respond as quickly to the CQI changes as was required. Figure 6 shows the test results on the data throughput monitor display. To troubleshoot the problem, protocol logs were examined. The final analysis led to a redesign of the server buffering algorithm. This example illustrates, yet again, the challenge of designing a phone that is able to accommodate the bandwidth changes and delays so prevalent in the mobile Internet environment.

Conclusion

Advanced HSPA mobile phones — and the networks they use — are designed and built based on certain tradeoffs. Any testing strategy must therefore begin with the 3GPP standards, while also including critical steps for verifying the performance of each unique phone design in the dynamic HSPA environment. Physical layer variables, as well as the design of the protocol stack, can affect the final application-layer throughput delivered to the end user. Thorough testing at all stages of integration and validation helps ensure that the phone performs as designed, network resources are allocated most efficiently, and, most importantly, that users have a satisfying experience.



Summary	Marker (bps)	Current (bps)	Average (bps)	Peak (bps)	Data Transfer (Bytes)
OTA Tx	-----	0	1636	44688	433230
OTA Rx	1659500	0	25186	1659500	7320300
IP Tx	-----	0	0	0	0
IP Rx	-----	0	0	0	0

Figure 6. Testing an application under real-world conditions

HSPA review

HSPA is an evolution of 3GPP W-CDMA Release 99 and works with existing spectrum and carriers. However, it adds high-speed downlink packet access (HSDPA) for enhanced performance in the downlink, and an enhanced uplink, more commonly known as high-speed uplink packet access (HSUPA), for improved data-rate performance in the uplink. The new features of HSDPA and HSUPA are summarized in Tables 1 and 2, respectively.

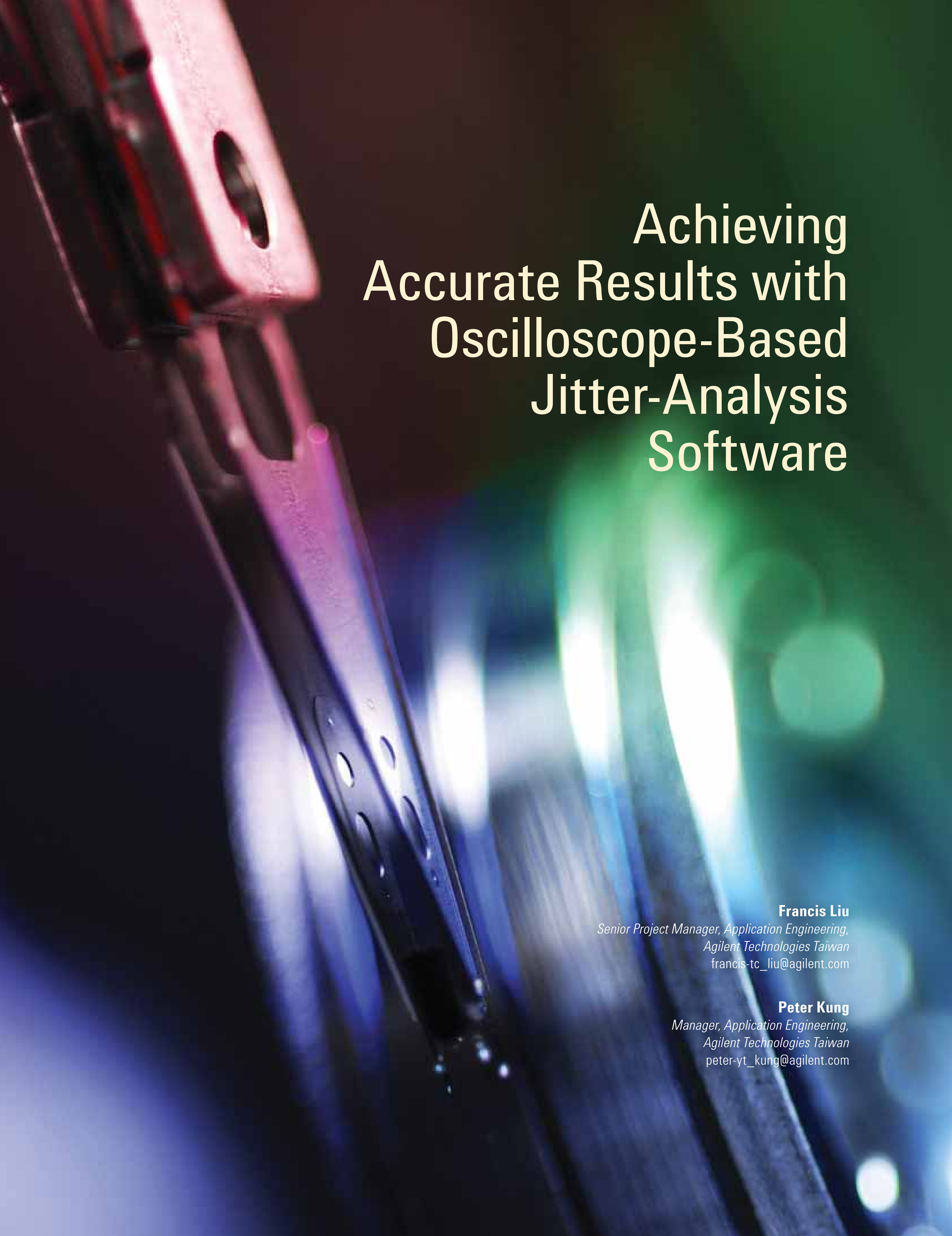
Table 1. Key features of HSDPA

Feature	Purpose
High-speed downlink shared channel (HS-DSCH)	New shared downlink transport channel that allows certain channel codes and transmission power in a cell to be considered a common resource to be shared among users and allocated dynamically for greater efficiency.
2 ms transmission time interval (TTI)	Downlink transmission time interval is much shorter than the 10, 20 and 40 ms TTI specified in W-CDMA. Channel codes are allocated dynamically every 2 ms, a total of 500 times per second, thus reducing roundtrip time for an IP packet. Allows other features to change rapidly.
16QAM modulation	Higher-order modulation using 16QAM in addition to QPSK, the modulation format currently used in W-CDMA. 16QAM can provide twice the peak data rate of QPSK but requires better radio-channel conditions.
Link adaptation	Fast method of compensating for varying RF conditions in the downlink by adjusting the transmitted data rate up or down while maintaining transmission power at a constant rate.
Fast packet scheduling	Technique that estimates the instantaneous radio conditions of the downlink channel to each mobile phone in the serving area and determines to which phone the shared channel resource will be directed during each TTI.
Hybrid automatic repeat request (HARQ)	Method by which the mobile phone can request retransmissions of missing data to be combined with the original transmission, allowing original transmission to be decoded as quickly as possible.
MAC-hs	New MAC sub-layer that supports HSDPA transmission with minimal impact on the existing radio interface protocol architecture.

Table 2. Key features of HSUPA

Feature	Purpose
Enhanced dedicated channel (E-DCH)	New transport channel that is dedicated to a single user and supports transmission of up to four codes to increase the uplink data rate.
2 or 10 ms transmission time interval (TTI)	Uplink TTI is much shorter than the 10, 20 and 40 ms TTI specified in W-CDMA. Reduces roundtrip time for an IP packet. Allows other features to change rapidly.
Scheduling	Technique for enabling fast reallocation of uplink resources among mobile phones by exploiting the bursty nature of packet data transmissions. Allows the system to support more high-data-rate users.
Hybrid automatic repeat request (HARQ)	Method by which the base station can request retransmissions of missing data to be combined with the original transmission, allowing original transmission to be decoded as quickly as possible.

HSPA-enabled phones must be able to handle the new features. Therefore, different UE categories have been specified to accommodate low-end and high-end implementations. Each category supports a different combination of features. For example, the 12 UE categories for HSDPA support different numbers of codes, modulation formats, TTI, and peak data rates — from 1.2 Mbps at the low end to the maximum of 14.4 Mbps at the high end. For HSUPA, six UE categories combine different numbers of codes, spreading factors, TTI, and peak rates. A maximum data rate of 5.76 Mbps with 2-ms TTI is specified at the high end.



Achieving Accurate Results with Oscilloscope-Based Jitter-Analysis Software

Francis Liu
Senior Project Manager, Application Engineering,
Agilent Technologies Taiwan
francis-tc_liu@agilent.com

Peter Kung
Manager, Application Engineering,
Agilent Technologies Taiwan
peter-yt_kung@agilent.com

The Beijing Summer Olympic Games were viewable through unprecedented amounts of television- and Internet-based coverage, including over 3,600 hours delivered by U.S. network NBC. Capturing, storing and delivering the seemingly countless hours of events and ceremonies required terabytes worth of digital storage devices, many of which were Serial Advanced Technology Attachment (SATA) hard disc drives.

The ability to move ever-larger data files requires fast, dependable data transfers. To meet these demands in media servers, desktop PCs and other applications, data rates are increasing for most serial-bus standards and designs. For engineers designing serial chipsets and characterizing or debugging serial devices, a technique called jitter analysis is becoming an increasingly important and useful tool.

The reason is simple: As serial data rates increase, the timing budget for jitter decreases. For example, the third-generation SATA interface (SATA Revision 3.x) will provide a data rate of up to 6 Gbps. In the "SATA 6 Gb/s+" draft standard, the total jitter (TJ) specification is 0.37 unit intervals (UI) where 1 UI is 166.6 ps. Thus, designers must manage all contributions to jitter to ensure that TJ doesn't exceed 61.64 ps (0.37x166.6).

Measuring total jitter

Total jitter is the most important indicator of jitter performance in a device at a given bit-error-rate level (e.g., 10^{-12}). In principle, TJ should be measured directly with a bit-error-rate tester (BERT) because it is the most accurate method. However, when performing a bit-error-ratio (BER) measurement at a low level (e.g., 10^{-12}) it takes a long time to perform a typical bathtub scan. Even with enhanced algorithms such as fast total jitter (FTJ) that shorten the measurement time, designers must set up clock data recovery (CDR) parameters that ensure compliance with an individual application's jitter transfer function.

One alternative is Agilent's EZJIT Plus jitter-analysis software, which runs in an oscilloscope for TJ estimation and separation of random and deterministic jitter (RJ/DJ). This solution is widely accepted and is being applied to advanced applications such as PCI Express, HDMI and DisplayPort. With its jitter-analysis functionality, EZJIT Plus makes it easy for engineers to analyze jitter components such as periodic jitter (PJ), inter-symbol interference (ISI) and duty-cycle distortion (DCD).

The EZJIT Plus software also provides a friendly user interface with single-display views of multiple windows (Figure 1). Each window provides multiple perspectives of a device under test (DUT) and its performance.[1]

Figure 1. Four-window display includes composite histogram, data-dependent jitter (DDJ) versus bit, BER bathtub plot, and RJ, PJ spectrum

Evaluating analysis results

Getting good results depends, of course, on proper configuration of the EZJIT Plus software. The setup wizard is a good place to start because it can provide good initial settings for edge thresholds, CDR parameters and memory size. Additional considerations are ISI filter parameters and RJ bandwidth settings.[2,3]

Adjusting memory size is one way to optimize jitter measurements. In many cases, changing the memory size setting will produce different jitter results. This phenomenon is shown in Figures 2 and 3, which use 512 Kpts and 2 Mpts, respectively, to measure the same DUT. In such a case, the logical question is, "Which one is correct?"

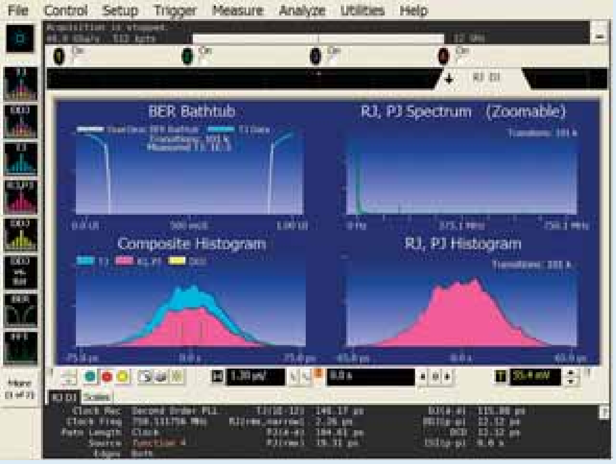


Figure 2. With memory size set to 512 Kpts, TJ = 148.17 ps and RJ (rms) = 2.26 ps

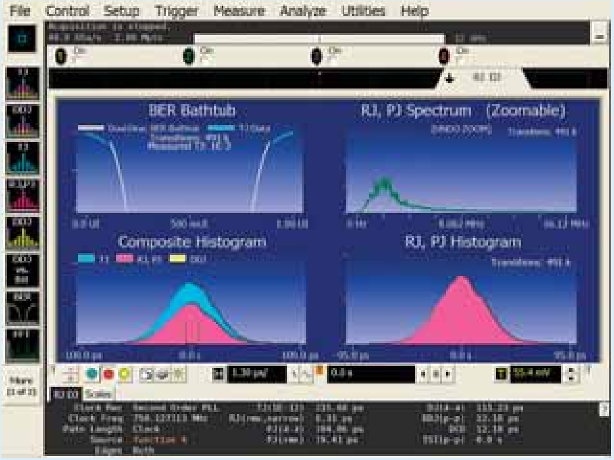


Figure 3. With memory size of 2 Mpts, TJ = 231.68 ps and RJ (rms) = 8.31 ps

It is tempting to focus on the jitter numbers, but useful information is contained in each of the four displays. Comparing Figures 2 and 3, there are clear differences in the BER bathtub, RJ, PJ spectrum and composite histogram traces. An experienced engineer will also notice the broken segments in the BER bathtub window between the measured (blue) and extrapolated (gray) sections (Figure 4). These are a few examples of the useful clues for further study that are revealed by the EZJIT Plus software.

Figure 4. Breaks in the BER bathtub trace exist between the measured and extrapolated sections

Varying the memory size

The example measurements shown in this article were made on a prototype SATA 3 Gb/s+ (SATA Revision 2.x) chipset. It was able to generate a high-frequency test pattern (HFTP) with large RJ at 1.5 Gbps. The design team was having trouble finding the true TJ and RJ values of this device while using conventional scope jitter software.

Initial clues were provided by the measurements shown in Figures 2 and 3. This led to follow-on measurements using the wider range of memory sizes available in the Agilent Infiniium 90000A digital sampling oscilloscope (DSO).

Table 1 summarizes the range of memory sizes — from 512 Kpts to 32 Mpts — along with associated measurement results. These show that, as memory size increased, RJ became larger and TJ increased along with RJ. The results reveal another key point: the RJ values converged to approximately 20 ps.

Table 1. As memory size increased, RJ converged around 20 ps

Memory size	RJ (ps)	PJ (ps)	TJ (ps)
512 Kpts	2.26	104.6	148.17
512 Kpts	2.14	84.78	126.78
2 Mpts	4.64	134.48	210.96
2 Mpts	8.31	104.06	231.68
4 Mpts	7.35	106.38	220.73
8 Mpts	20.23	0	296
8 Mpts	16.83	43.87	289.82
16 Mpts	19.77	12.7	299.4
16 Mpts	20.46	0	295.64
16 Mpts	18.68	18.18	291.05
32 Mpts	20.68	0	305.79
32 Mpts	20.14	14.88	308.59

The other three windows provided additional clues about what was happening inside the DUT. Figure 5 shows a series of RJ, PJ spectrum measurements made with increasing memory size (along with the second-order CDR and 1.55-MHz bandwidth settings). Looking across the four measurements, the spectrum resolution appears greater when memory size is increased. The other observation worth considering in the higher-resolution spectra is the waveform itself, which tends to resemble a noise curve rather than a typical PJ spike curve. In such cases, the EZJIT Plus software will treat the waveform as a primary RJ component when memory size is set to 32 Mpts.

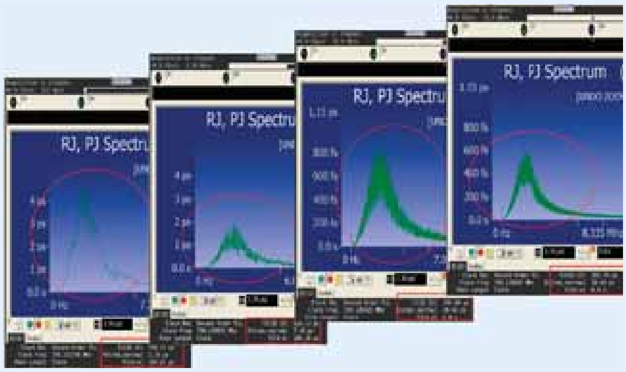
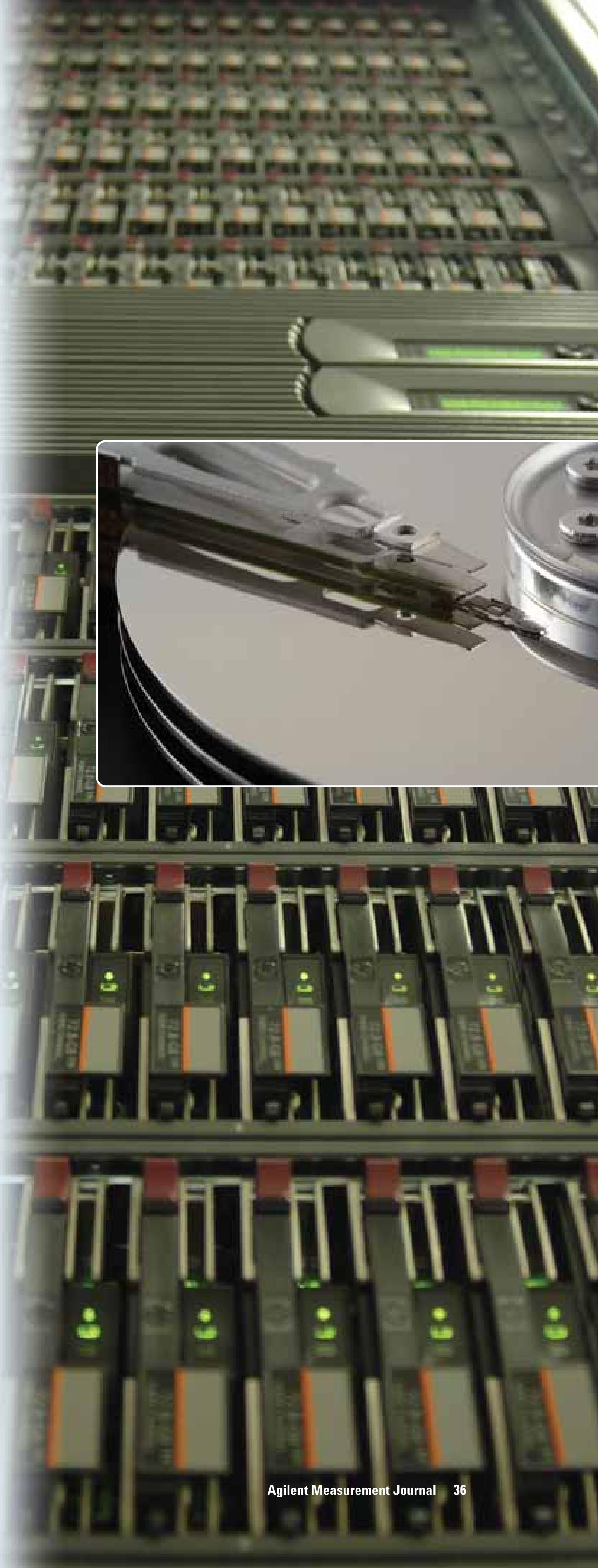
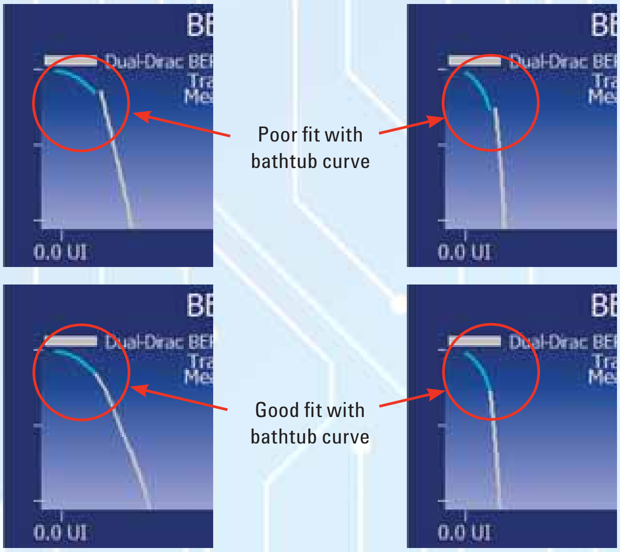


Figure 5. Increased memory size produced higher-resolution RJ, PJ spectra and larger RJ (rms) values



Another interesting point is the concentration of spectrum energy in the frequency range below 6 MHz. Increasing the memory size reveals that this jitter is low-frequency RJ and not low-frequency PJ.

Additional information can be gleaned from the BER bathtub window. As shown in Figure 6, the EZJIT Plus software first analyzes the RJ (rms) value from the jitter spectrum. It then uses that value to extrapolate the bathtub curve to achieve the desired BER level.



Poor fit with bathtub curve

Good fit with bathtub curve

Figure 6. With increased memory size, the larger RJ (rms) value enables a smoother fit between measured and extrapolated sections of the BER bathtub curve

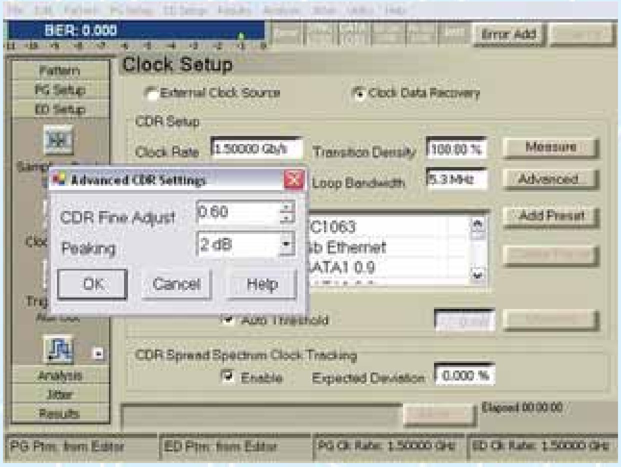
In the BER bathtub diagrams, the blue curves at the top show the measured sections of the histogram database. The light gray curve is the extrapolation section. As mentioned earlier, the RJ (rms) value is calculated from the jitter spectrum. If the waveform parametrics cannot be modeled, or measured well enough, then the extrapolation section will not be properly aligned with the measured section of the curve. In contrast, a correct RJ (rms) value extracted from the jitter spectrum will provide an accurate fit with the measured histogram tail.

Making accurate TJ measurements

Measurements showed that the SATA DUT generated a large RJ component in the lower frequency range, but there were doubts about the accuracy of the jitter software. The best way to judge the accuracy is to compare a direct jitter measurement with the estimated TJ from the EZJIT Plus software.

A BERT is the only instrument that can measure TJ directly. To ensure valid comparisons between different instruments (e.g., a BERT and a scope), it is important to use either the CDR function or the observed jitter transfer function (OJTF) of the CDR. Because the SATA device cannot provide a reference clock to both the scope and the BERT, it is necessary to use similar settings for the tunable CDR in the BERT and the CDR function in the EZJIT Plus software.

In this case, the BERT was an Agilent J-BERT N4903A high-performance serial BERT. In the EZJIT Plus software, the CDR function was set to the second order with 1.55-MHz bandwidth and 0.707 damping factor. To create comparable measurements, the hardware parameters inside the J-BERT were adjusted as closely as possible to the EZJIT Plus settings (Figure 7).



○ External Clock Source ● Clock Data Recovery

CDR Setup

Clock Rate 1.50000 Gb/s

Transition Density 100.00 %

Loop Bandwidth 5.3 MHz

CDR Fine Adjust 0.60

Peaking 2 dB

C1063

b Ethernet

ATA1 0.9

☑ Auto Threshold

CDR Spread Spectrum Clock Tracking

☑ Enable

Expected Deviation 0.000 %

Elapsed 00:00:00

PG Ptrn: from Editor

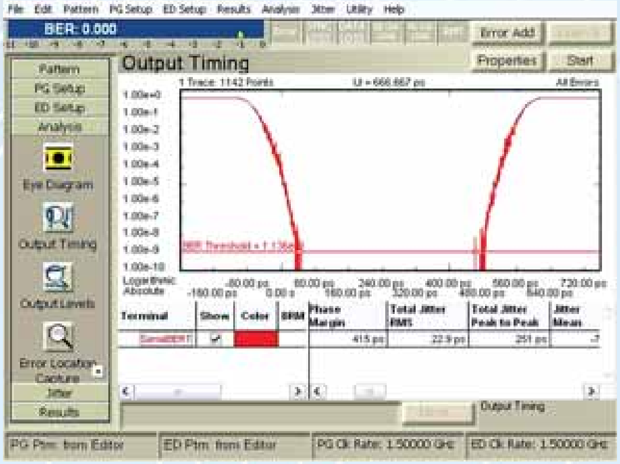
ED Ptrn: from Editor

PG Clk Rate: 1.50000 GHz

ED Clk Rate: 1.50000 GHz

Figure 7. Hardware CDR setup parameters within the J-BERT

The results are shown in Figures 8 and 9. To minimize the long wait associated with measurements made at the 10^{-12} BER level, both the J-BERT and EZJIT Plus measurements were made with a 10^{-9} BER level. Comparing the results, the J-BERT measured a TJ of 251 ps while the EZJIT Plus software calculated a TJ of 259.67 ps.



Terminal	Show	Color	BRM	Phase Margin	Total Jitter RMS	Total Jitter Peak to Peak	Jitter Mean
SerialBERT	☑	🟥		415 ps	22.9 ps	251 ps	-7

Figure 8. The J-BERT measured a TJ of 251 ps at BER level of 1.136x10^{-9}

Figure 9. With memory size set to 32 Mpts, the EZJIT Plus software measured a TJ of 259.67 ps at a BER level of 10^{-9}

Because the CDR characteristics of these two instruments aren't exactly the same, it is reasonable that the results will have minor differences. Referring back to Figures 8 and 9, the J-BERT direct bathtub scan and the Infiniium oscilloscope agree within 3 percent when the EZJIT Plus TJ measurement has a memory size of 16 or 32 Mpts.

Performing further analysis

For these measurements, CDR bandwidth was set to 1.55 MHz and, as a consequence, some parts of the jitter below 1.55 MHz in the RJ, PJ spectrum were removed. However, when CDR is set to a constant frequency, an analysis of the SATA DUT's signal produces a complete RJ, PJ spectrum.

As seen in Figure 10, the jitter spectrum shows that the energy is strong in the low-frequency range, but it is inversely proportional to an increase in frequency. This effect is typically called flicker noise. Flicker noise normally happens inside a chipset's phase-locked loop (PLL) circuit, and this is typically related to either intrinsic material characteristics or the PLL design itself.

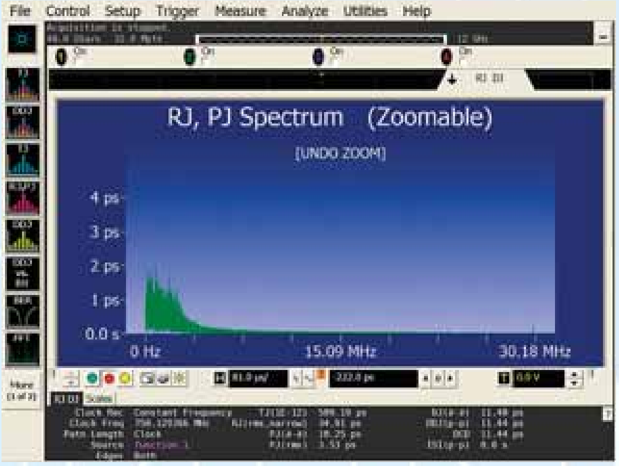


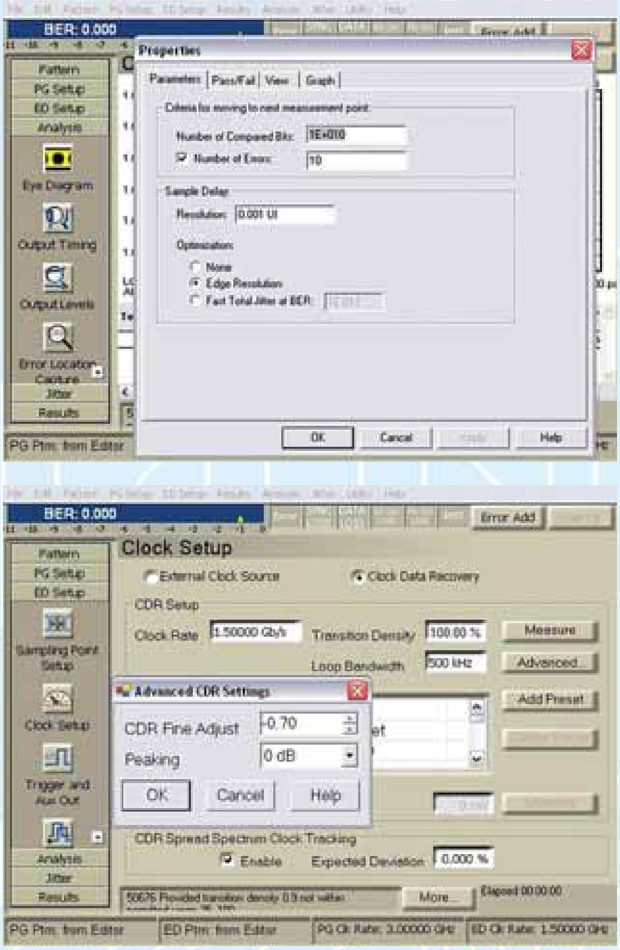
Figure 10. With constant-frequency CDR, the RJ, PJ spectrum exhibits a large flicker noise effect (TJ is 509.19 ps)

Whenever the 3 Gb/s+ SATA device produced strong flicker noise, it showed up as large spectrum density in the low-frequency range (low-frequency RJ). When making measurements on this type of device, it is better to choose larger memory size in the scope, enabling the software algorithm to correctly calculate RJ (rms). There is one caveat: Choosing an unnecessarily large memory size causes a longer measurement time and will provide only a minimal improvement in jitter accuracy.

Comparing TJ results between two instruments

Setting CDR to a constant frequency is a good way to compare the accuracy of TJ measurements made with different instruments. This is useful because the jitter applications offered by various vendors will produce different OJTFs, even if the same values are used for CDR bandwidth and damping factor.

In this case, our comparison was again between the EZJIT Plus software and the J-BERT with a 10^{-9} BER level. The J-BERT cannot produce a 0-Hz bandwidth (due to its hardware design) so we used its lowest setting, which is 500 kHz (Figure 11).



Criteria for moving to next measurement point

Number of Compared Bits: 1E+010

☑ Number of Errors: 10

Sample Delay

Resolution: 0.001 UI

Optimization:

○ None

● Edge Resolution

○ Fast Total Jitter at BER:

Clock Setup

○ External Clock Source ● Clock Data Recovery

CDR Setup

Clock Rate 1.50000 Gb/s

Transition Density 100.00 %

Loop Bandwidth 500 kHz

Advanced CDR Settings

CDR Fine Adjust -0.70

Peaking 0 dB

CDR Spread Spectrum Clock Tracking

☑ Enable Expected Deviation 0.000 %

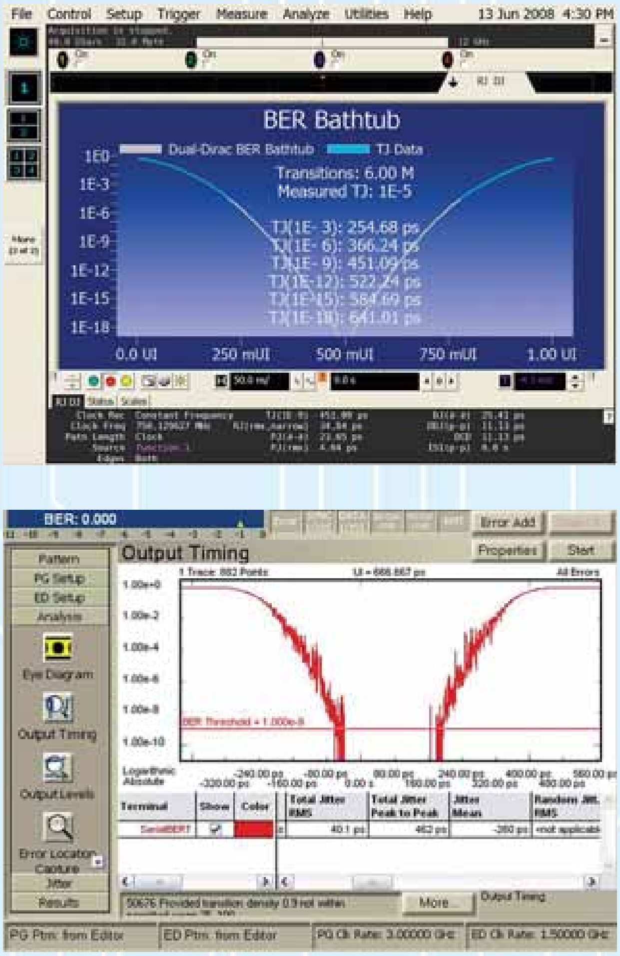
50676 Provided transition density 0.3 not within

Elapsed 00:00:00

PG Ptrn: from Editor | ED Ptrn: from Editor | PG Clk Rate: 3.00000 GHz | ED Clk Rate: 1.50000 GHz

Figure 11. Bathtub scan settings and CDR setup for the J-BERT

The reference measurement was a bathtub scan with the J-BERT. To create the comparison, we connected the same signal to a DSO90000A scope running the EZJIT Plus software and estimated the TJ. Figure 12 shows the two results.



Transitions: 6.00 M

Measured TJ: 1E-5

TJ(1E- 3): 254.68 ps

TJ(1E- 6): 366.24 ps

TJ(1E- 9): 451.09 ps

TJ(1E-12): 522.24 ps

TJ(1E-15): 584.69 ps

TJ(1E-18): 641.01 ps

UI = 666.667 ps

Terminal	Show	Color	Total Jitter RMS	Total Jitter Peak to Peak	Jitter Mean	Random Jitt. RMS
SerialBERT	☑	🟥	40.1 ps	462 ps	-280 ps	<not applicable

50676 Provided transition density 0.3 not within

PG Ptrn: from Editor | ED Ptrn: from Editor | PG Clk Rate: 3.00000 GHz | ED Clk Rate: 1.50000 GHz

Figure 12. TJ was 451 ps with EZJIT Plus (top) and 462 ps with the J-BERT (bottom)

As shown, the respective TJ measurements were within 11 ps (2.38 percent) of each other. One important cause of the delta is the difference in CDR bandwidth settings (0 Hz versus 500 kHz). Of course, the respective intrinsic noise levels within each instrument also contribute to the difference. In summary, the EZJIT Plus result is validated by the J-BERT's direct TJ bathtub scan measurement.

Conclusion

Whether working with today's SATA 3Gb/s+ devices or ever-faster serial links of the future, jitter analysis will be an indispensable tool. Even though BERTs provide precise jitter measurements, scope-based jitter analysis software provides an accurate alternative.

When making such measurements with a scope-based application, greater memory depth enables measurement of lower-frequency jitter components. The example presented here shows that measurements on a device with large flicker noise will need sufficient memory to produce an accurate result. However, there is a tradeoff between memory size and measurement time: As seen here, setting the memory size to its optimum — not maximum — value is the best way to achieve an accurate result.

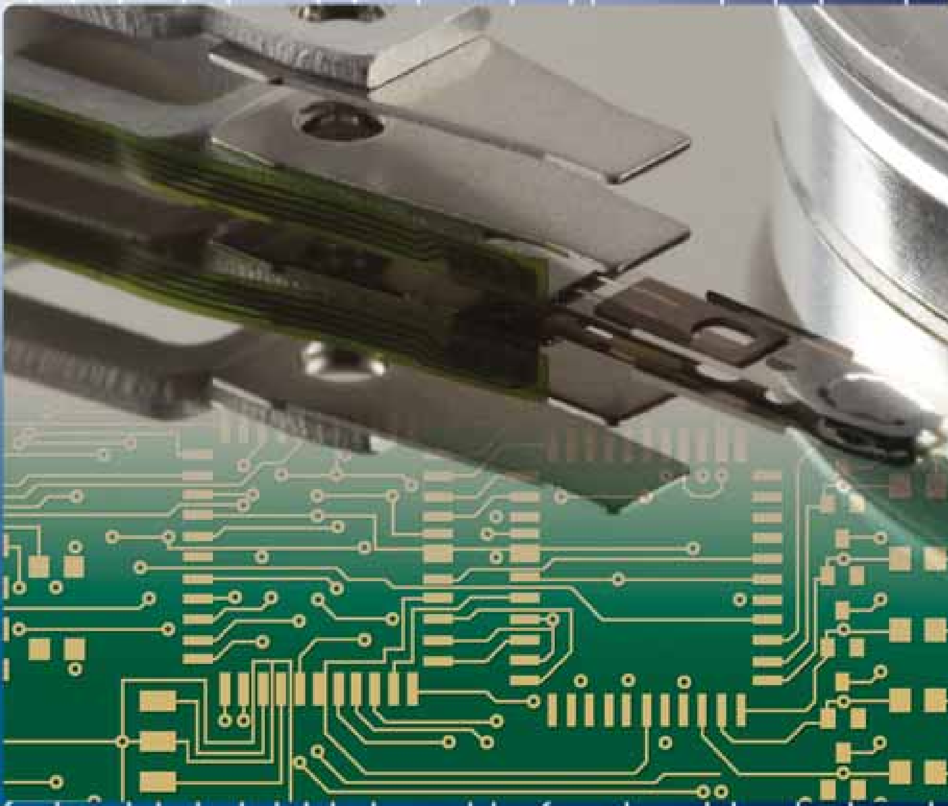
If there are any lingering doubts about the measurements produced by jitter analysis software such as EZJIT Plus, a direct bathtub scan with a BERT or J-BERT is the best way to validate measurement accuracy. The comparisons made in this article show that the results can be impressively similar.

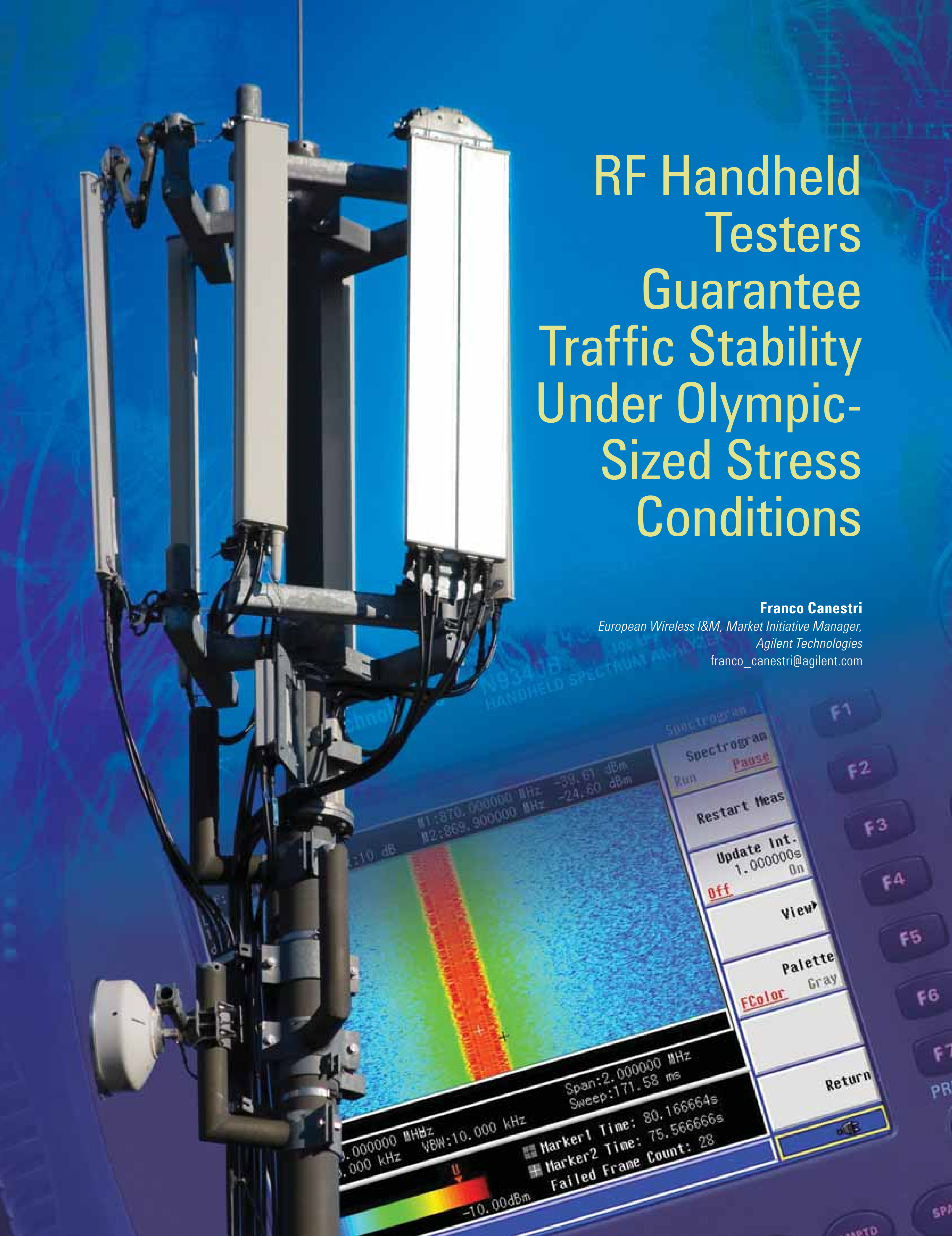
References

1. Agilent Application Note 1563, *Analyzing Jitter Using Agilent EZJIT Plus Software*. Publication number 5989-3776EN available from www.agilent.com.

2. Agilent Application Note 1574, *Choosing the ISI Filter Size for EZJIT Plus Arbitrary Data Jitter Analysis*. Publication number 5989-4974EN available from www.agilent.com.

3. Agilent Application Note 1577, *Selecting RJ Bandwidth in EZJIT Plus Software*. Publication number 5989-5056EN available from www.agilent.com.





RF Handheld Testers Guarantee Traffic Stability Under Olympic-Sized Stress Conditions

Franco Canestri
European Wireless I&M, Market Initiative Manager,
Agilent Technologies
franco_canestri@agilent.com

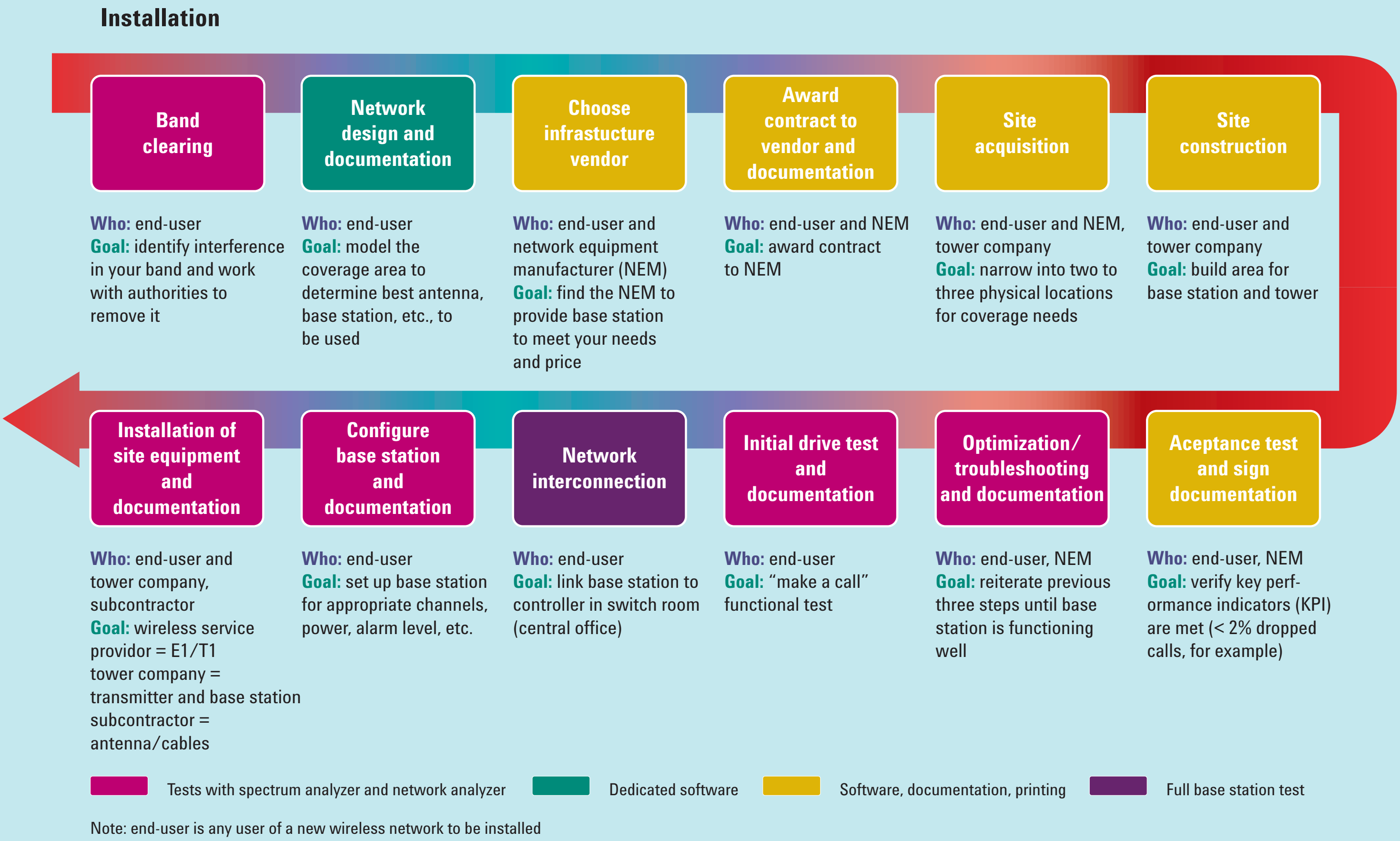
Today's wireless service providers (WSPs) face a critical challenge — optimizing a network's signal transmission quality during long periods of time and in remote locations where RF base stations are beyond the reach of a control center. The challenge is greater when the network is under stress, such as during high traffic flow. Traffic overflow is prone to occur during mass events such as the 2008 Olympics where WSPs provided coverage to the large number of visitors arriving in the region all at once. They also had to continue to support coverage to the large population of China.

One way for WSPs to ensure the necessary level of optimization is through the adoption of installation and maintenance (I&M) processes. Successfully implementing these processes requires the use of suitable I&M tools, such as the handheld signal analyzer and cable and antenna tester (CAT). Both instruments are today essential for remotely ensuring optimized installation and operation of wireless networks in the field.

Monitoring RF networks

The great influx of people into China to attend the 2008 Beijing Olympics tested the current mobile telephony infrastructure and made appropriate network testing — especially in the field — absolutely critical. Such testing is necessary to ensure continuity and stability of service at a high level of signal quality and bandwidth. Because the Olympics were watched online by a very large worldwide audience, the risk of network downtime had to be avoided at all costs. Whether at the WSP's central location or in the most remote field locations, the network transmission quality and sustainability had to be kept under tight control around the clock.

I&M routines play a critical role in ensuring service continuity and stability. Figures 1 and 2 highlight, step-by-step, the procedures to be implemented in the physical design, creation and installation of an RF wireless network's hardware infrastructure (e.g., antennae, base stations and cabling) in the outdoor environment. Continuity testing ensures that end-to-end connectivity is established and the logical setup is correct, while long-term monitoring tests ensure network stability and verify its ability to deliver long-term, error-free operation. When performed without the proper equipment, these test routines can prove overly complex and cumbersome.



Installation

Band clearing

Who: end-user
Goal: identify interference in your band and work with authorities to remove it

Network design and documentation

Who: end-user
Goal: model the coverage area to determine best antenna, base station, etc., to be used

Choose infrastructure vendor

Who: end-user and network equipment manufacturer (NEM)
Goal: find the NEM to provide base station to meet your needs and price

Award contract to vendor and documentation

Who: end-user and NEM
Goal: award contract to NEM

Site acquisition

Who: end-user and NEM, tower company
Goal: narrow into two to three physical locations for coverage needs

Site construction

Who: end-user and tower company
Goal: build area for base station and tower

Installation of site equipment and documentation

Who: end-user and tower company, subcontractor
Goal: wireless service providor = E1/T1
tower company = transmitter and base station
subcontractor = antenna/cables

Configure base station and documentation

Who: end-user
Goal: set up base station for appropriate channels, power, alarm level, etc.

Network interconnection

Who: end-user
Goal: link base station to controller in switch room (central office)

Initial drive test and documentation

Who: end-user
Goal: "make a call" functional test

Optimization/ troubleshooting and documentation

Who: end-user, NEM
Goal: reiterate previous three steps until base station is functioning well

Aceptance test and sign documentation

Who: end-user, NEM
Goal: verify key performance indicators (KPI) are met (< 2% dropped calls, for example)

🟪 Tests with spectrum analyzer and network analyzer
🟩 Dedicated software
🟨 Software, documentation, printing
🟪 Full base station test

Note: end-user is any user of a new wireless network to be installed

Figure 1. The flow of network installation routines

Among the I&M routines used for RF wireless networks, four are especially important:

- Configuring the hardware elements and software algorithms in a base station
- Testing the network interconnections of the hardware parts and their respective optimizations
- Conducting initial drive tests whereby a vehicle travels into the field to check the quality of received base station signals prior to authorization of network operation
- Final optimization, troubleshooting and documentation for acceptance tests

RF wireless networks are not the only emerging application requiring I&M procedures and each market segment (e.g., aerospace/defense, mobile and general purpose) is driven by its own unique set of needs (Figure 3). Therefore, all I&M procedures demand high levels of precision, reliability and timely execution to accommodate the emerging range of field applications.

Identifying suitable I&M solutions

According to a recent study, the current worldwide market for 3- to 4-GHz handheld signal analyzers is estimated to be around US$100 million. As a handheld solution, these simple, general-purpose tools are well suited to address the needs of the large population of users in wireless I&M applications and, in particular, RF networks. A prime example is the LAN-remote controlled spectrum analyzer, which offers a fast and efficient way to monitor key network parameters over long period. The data obtained from this instrument can later be recalled and analyzed using computer-assisted algorithms to provide an immediate and intuitive overview of the situation during installation of a network's hardware components. Because such instruments can be used to ensure broadcasting service quality in the field — during long periods of time and in critical situations — they are uniquely qualified to address the critical I&M routines previously detailed.

Problem found Consult documentation

Choose maintenance vendor
Who: end-user
Goal: find the best company to meet the needs

Activate internal installation and maintenance department
OR
Award contract to external vendor
Who: end-user, NEM, crew
Goal: award contract to vendor or allocate internal crew

Visit site Problem evaluation Review documentation
Who: end-user, crew
Goal: narrow into the physical location(s) for repair needs

Installation of on-site maintenance equipment
Who: end-user, crew
Goal: set-up the on-site test lab

Run onsite tests on hardware and documentation
Who: crew
Goal: test base station for traffic, find interferences, losses, distance-to-fault in cables/connections

Go operational Archive documentaion
Who: end-user
Goal: restore traffic

Acceptance test of hardware and software Sign, update doc.
Who: end-user
Goal: verify KPI are met (< 2% dropped calls, for example)

Optimization troubleshooting Update documentation
Who: end-user, crew
Goal: reiterate previous two steps until base station is functioning well

Drive test on software Review documentation
Who: end-user, crew
Goal: "make a call" functional test

Test network interconnection
Who: crew, end-user, and NEM
Goal: link base station to controller in switch room (central office) and start traffic

Locate and repair
Who: crew
Goal: replace hardware, reload software, reboot local units

🟥 Tests with spectrum analyzer and network analyzer 🟩 Dedicated software 🟨 Software, documentation, printing 🟪 Full base station test

Note: end-user is any user of a new wireless network to be installed

Figure 2. The flow of network maintenance routines, used as a main living document for multiple needs

Figure 3. Drivers in key installation and maintenance markets

Installation	Maintenance	
Sites and documentation are classified Highest accuracy and reliability in acceptance tests Fastest evolution of software and hardware Increase protection of data management	Super-fast maintenance procedures Preventive maintenance Constant data monitoring Increasing satellite/antenna accuracy Protection and classified issues	**Aerospace and defense**
Multiple technologies, challenging installation and maintenance procedures Base station becomes smaller, but more complex Operating frequency is getting higher	More complex functional tests are needed More applications More cell maintenance More antennas in a single site	**Mobile**
Five- to seven-year replacement period Basic technology only, preference on desk-tops	Low budget for repair	**General purpose** Education Low-cost NEMs
Low-cost bundles Fast throughput in production at lowest up-front investments	Longest warranty at best conditions Low-cost repair – extended warranty	ESMOG environmental medical telemetry Palmtop terminals Emergency services

When selecting an appropriate signal analyzer, I&M companies and subcontractors often look for a number of key features:

- Portability
- Light weight
- Ruggedized
- Superior testing quality
- Modern connectivity for easy data transfer
- Battery operated
- Low cost

The Agilent N9340B handheld spectrum analyzer is an example of one solution that effectively meets these requirements. In addition to these features, it differentiates itself with a range of measurement and monitoring capabilities that prove especially useful in wireless network I&M applications. The first such capability, the spectrogram, allows the service provider's field engineer to monitor transient signals that cause traffic interruption and disturbances, whenever and wherever desired. In the LAN-remote-controlled spectrum analyzer, color-coded spectrogram functionality saves data in both the frequency and time domains and collects sudden transient signals that interfere with the main carrier, causing severe and very costly interference to regular WSP traffic.

A spectrogram measurement and spectrum trace from an Agilent N9340B handheld spectrum analyzer is shown in Figure 4. The color-coded image of a recorded transient signal is depicted on the screen, with frequency range and monitoring time displayed on the horizontal and vertical axes, respectively. Color coding denotes the power associated with the recorded signal.

By activating and moving a marker on the spectrogram, either vertically (indicating a past moment in time) or horizontally (indicating a different frequency), the engineer can easily mark a portion of the signal of interest. With a single keystroke, the engineer can then toggle between the spectrogram and the actual spectral trace recorded at the moment of interest. In the left-most graphics in Figure 4 (the spectrogram), it is easy to find the intermittent interference signals at 1.806993478 GHz. A marker is placed on one interference signal. Using the spectrum trace view on the right, it is then possible to view the spectrum trace at that specific time. A spectrogram, therefore, is a powerful tool for the handheld spectrum analyzer, allowing the user to capture interference, especially intermittent signals.

Another useful capability for implementing I&M procedures is the spectrum emission mask (SEM), defined relative to in-channel power, which allows the engineer to monitor out-of-channel emissions. For added measurement flexibility, the user can specify a range of parameters including the main channel, out-of-channel frequency bands and tolerance limits.

Other important signal analyzer capabilities include the electrical field strength measurement and USB power sensor support, as well as demodulation analysis, which allows the engineer to see the service customer's actual demodulated signal. These capabilities, together with the ones previously cited, enable the engineer to perform a global field-test session on a signal for the purposes of monitoring, at very narrow resolution bandwidth (e.g., just a few hertz), the presence of disturbances next to the main carrier. When disturbances are identified, corrective measures can then be quickly and properly deployed.

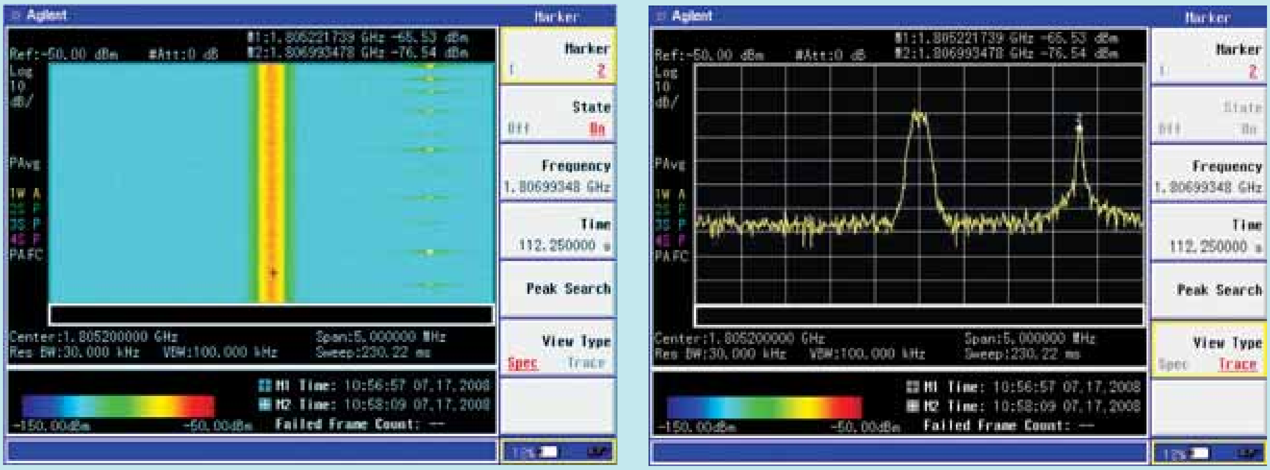


Figure 4. Spectrogram functionality as implemented in an Agilent N9340B handheld spectrum analyzer

Analyzing the CAT's role

The handheld cable and antenna tester plays a vital role in guaranteeing the quality of transmitted signals in the field to support wireless communications traffic. Working together with the handheld signal analyzer, it completes the full set of tools required to provide optimized hardware installation of cables and parts of the antennas (Figure 5).

One basic requirement for the ideal CAT is the ability to measure return loss in the field. Return loss is a measure of the signal reflection characteristics of the cable and antenna system. In S-parameter terms, it is referred to as an S_{11} measurement. To make the measurement, the handheld CAT (e.g., the Agilent N9330B) uses a signal generator to generate a swept RF signal which is sent to the cable and antenna system under test. A portion of the incident power is reflected back to the source from each transmission fault and the antenna. The ratio of the reflected voltage to the incident voltage is called the reflection coefficient — a complex number containing both magnitude and phase information. By measuring the signal reflection, the handheld CAT can identify the parameters of the cable and antenna system.

Another key requirement of the ideal CAT is to provide the return-loss measurement in both the frequency and time domains. In the frequency domain, the CAT uses an inverse Fourier transformation of the time domain signal to identify the fault point location. It also supports standing wave ratio (SWR), return loss and cable loss tests. SWR and cable loss are two measurements which can be derived from the return-loss measurement. In the time domain, the CAT supports return-loss and cable-loss tests. These frequency- and time-domain test functions have today become the standard in test for the cable and antenna system.

Processing the data

All I&M wireless network procedures require the utilization of a fast and agile post-processing and reporting tool (Figure 6). The Agilent N9330 PC software offers powerful post-analysis of test data. In addition to providing a good user interface, the PC-based post-analysis tool can provide Smith chart displays and analysis functions. It also supports powerful printing functions that make report writing convenient. A database function even provides an organized file management feature.

Conclusion

The successful implementation of I&M routines is critical to ensuring around-the-clock service continuity and network stability over an extended period of time and under stress conditions. Use of proper test equipment such as the handheld signal analyzer and CAT, coupled with a suitable post-processing tool, can aid in this process by greatly simplifying the engineer's performance of these typically complex and cumbersome test routines.

The author would like to thank Marco Kong, HH Product Manager, Agilent Technologies, ChengDu Division, People's Republic of China, for his support given during the preparation of this article.

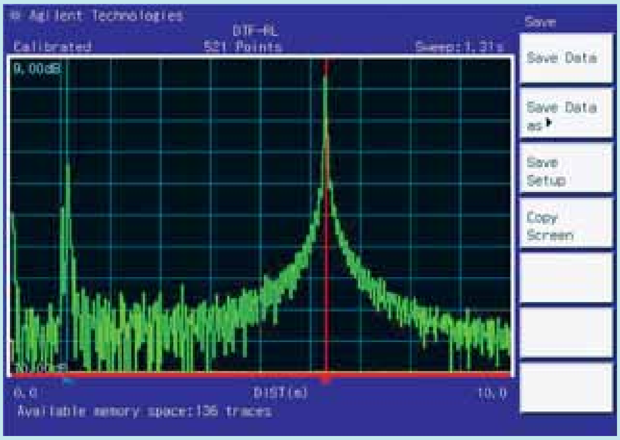


Figure 5. Example measurement screen from a cable and antenna tester system

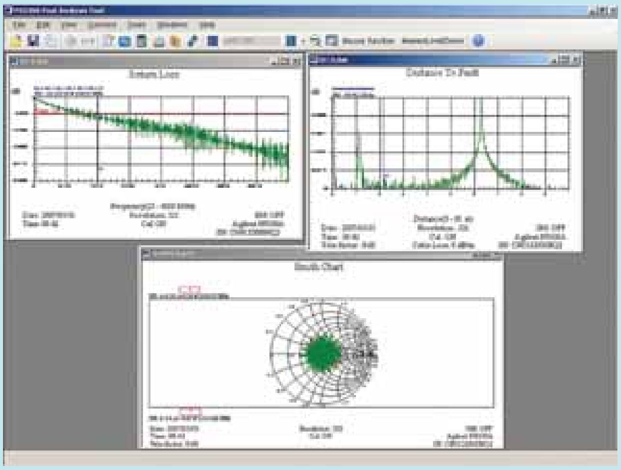
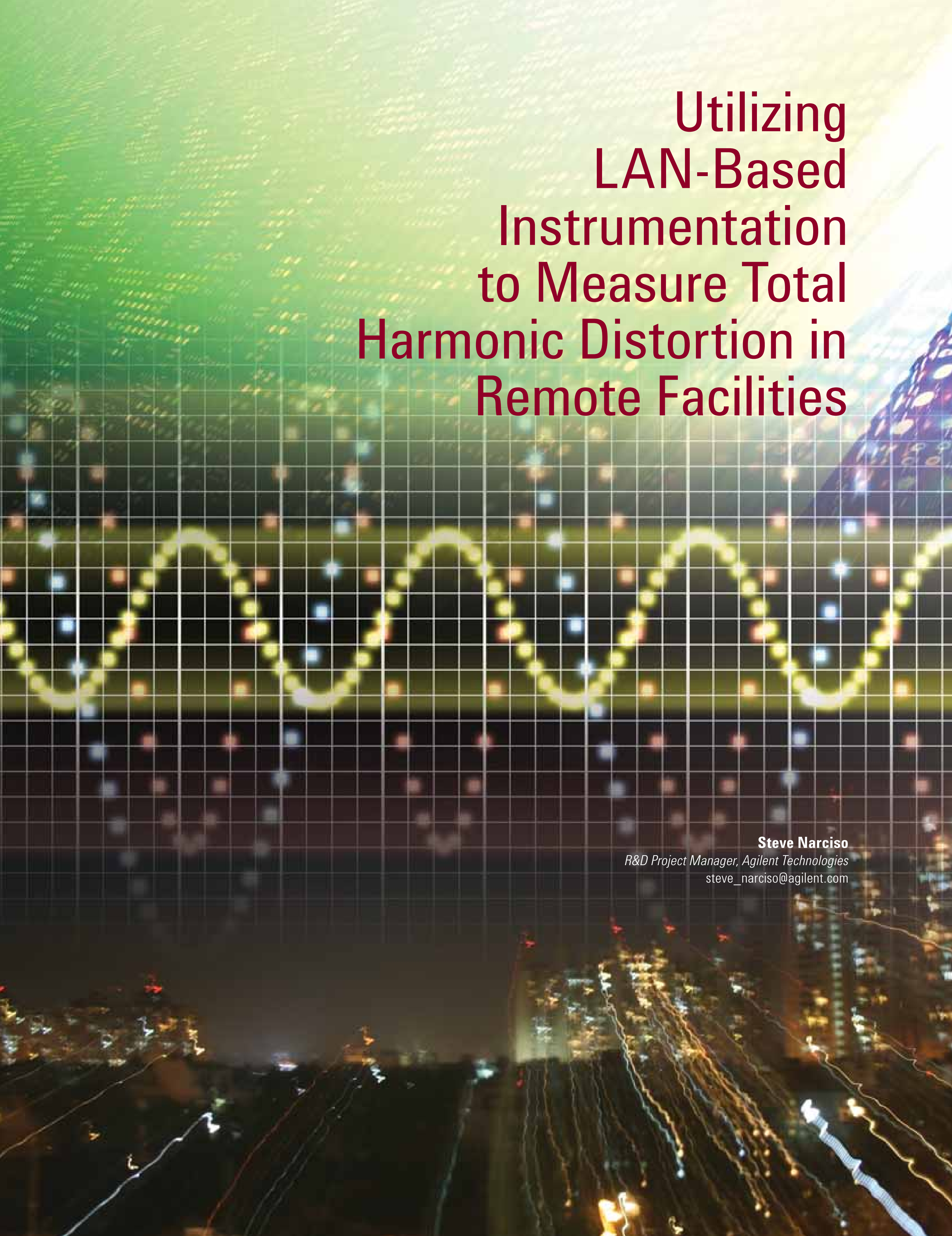


Figure 6. The Agilent Technologies N9330A post-analysis tool



Utilizing LAN-Based Instrumentation to Measure Total Harmonic Distortion in Remote Facilities

Steve Narciso
R&D Project Manager, Agilent Technologies
steve_narciso@agilent.com

Ensuring a stable and reliable supply of electrical power is essential to the successful operation of any city. Stability is especially critical when a city expects that its maximum power supply will be exceeded, such as during the 2008 Beijing Olympic Games (see the sidebar, *Powering the 2008 Olympic Games*). However, the production of high-quality electrical power requires more than simply providing the proper voltage and sufficient current. It also requires the proper shape of the voltage waveform. One critical specification of wave shape is total harmonic distortion (THD).

The delivery of low-distortion electrical power is important since too much distortion can cause tripping of overcurrent protection devices. It can also cause overheating and reduced reliability of equipment such as capacitors, transformers and motors. Higher-order harmonics can even couple into communication systems, thereby generating interference. For these reasons it is important to measure AC power THD as it provides a means of verifying that power quality is within an acceptable range. This article describes a method of measuring power-generation THD that allows for remote data monitoring from a local-area network (LAN) or wide-area network (WAN).

Defining THD

THD is defined as the ratio of the root-mean-square (RMS) value of the harmonically-related signal components to the fundamental frequency (not including the fundamental frequency). Mathematically, we square the amplitudes of harmonics 2 through N, sum them, take the square root, and then divide by the amplitude of the fundamental. It is usually expressed in terms of a percent. For example, if 100 harmonics are to be considered, then THD is calculated in Equation 1 as:

Equation 1.

$$THD=\frac{\sqrt{\sum_{i=2}^{100} a_i^2}}{a_1}$$

In practice, measurements are either made by monitoring taps (electrical connections in power lines that provide low-voltage monitoring points) in power-generation facilities or directly on line power at customer premises. While a digital multimeter (DMM) can offer a convenient method to measure the AC voltage of the line, until recently this type of instrument did not have the capability to measure THD. Also, it is difficult to configure a traditional DMM to be monitored remotely.

New generations of DMMs now provide the ability to digitize waveforms with sufficient bandwidth to calculate THD. Some of these DMMs also offer remote monitoring and control using a LAN or WAN connection. Such capabilities enable technical personnel in a central location to evaluate the operation of power-grid components over a wide area.

Answering the call for remote functionality

The Agilent 34411A 6½-digit, enhanced-performance DMM offers the remote monitoring and control capabilities that producers of electrical power require. In addition to this capability, the 34411A provides classic multimeter functionality such as the ability to measure AC RMS voltage directly and a convenient new method to display the peak-to-peak value of the AC waveform concurrently with the AC RMS voltage (Figure 1).

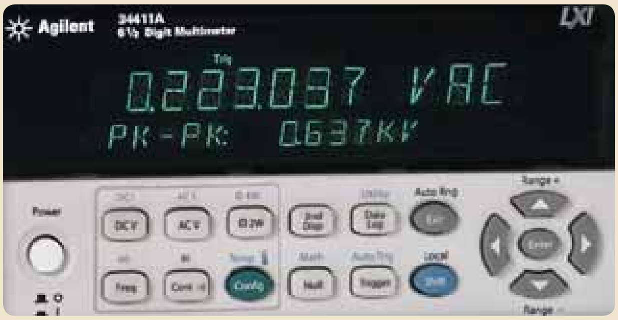


Figure 1. The Agilent 34411A measuring 223 V in the main display and 637 V_{pp} in the lower display

The ability to compare simultaneous RMS and peak measurements provides the user with an indication of crest factor, the peak-to-RMS ratio of the waveform. Since the crest factor of a pure sine wave is 1.414, a high ratio might indicate a "peaking" type of distortion. In contrast, a low ratio might indicate a "clipping" type of distortion.

To obtain more detailed information about harmonic distortion, the DMM can be set to digitize the waveform in DC voltage (DCV) mode. In this mode it can support up to 50,000 readings/second with 4½-digit precision. Because the DMM is a LAN eXtensions for Instrumentation (LXI) instrument, it can easily be connected to a LAN and controlled and monitored from a remote PC.

As previously mentioned, producers of electrical power are today required to deliver power with a voltage waveform that meets local specifications. It is critical, therefore, to have a reliable compliance test. The ability to monitor the testing of remote sites from a central location is an added convenience. Software applications have been developed that can control a remote 34411A DMM and calculate THD. These applications can also display the waveform, its frequency spectrum and the amplitudes of the individual harmonics. A typical signal and its frequency spectrum for one such application are shown in Figure 2.

These software applications can compare the resulting THD and amplitudes of individual harmonics to industry limits, perhaps generating an alarm if the limits are exceeded. The Institute of Electrical and Electronics Engineers (IEEE) has established such voltage-distortion limits from 1 to 5 percent, depending on the location of the measurement in the power distribution network.[1] These limits are applicable for normal, continuous power operation. For shorter periods, such as during system start up or other unusual conditions, these limits may be temporarily exceeded. In this case, the application may be modified to show the variation of distortion with time, as is illustrated in Figure 3, and the limit-checking temporarily modified or suspended.

The LAN connection built into the 34411A allows the same measurements to be made in the same fashion in laboratories, or in generation facilities and substations, over a broad region.

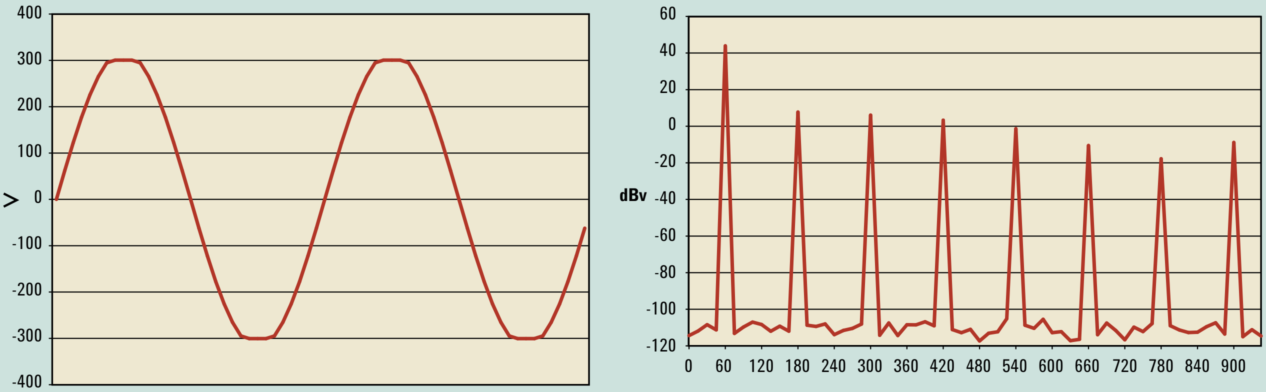


Figure 2. A typical THD signal and its associated spectrum

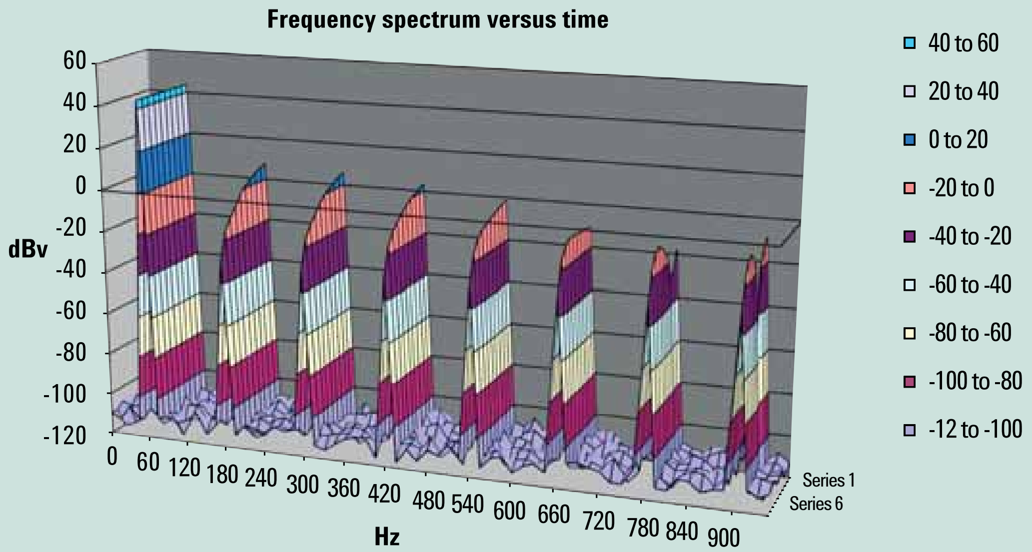


Figure 3. A THD signal, showing its variation of distortion with time

Conclusion

The Agilent 34411A enhanced-performance DMM provides users with the ability to monitor the testing of remote sites from a central location. It can be used to not only calculate THD, but also to display the waveform, its frequency spectrum and the amplitudes of the individual harmonics. The development of this type of application is an innovative use of networking and measurement automation in the deployment and maintenance of widely-distributed, electrical-power generation and transmission systems. It also demonstrates the true flexibility of modern LAN-based (LXI) instrumentation. When coupled with application-specific software, such instrumentation provides a powerful solution for the monitoring and control of electrical-power requirements. This solution goes beyond simply providing the proper voltage and sufficient current to also providing the proper shape of the voltage waveform — a critical specification in verifying that power quality is within an acceptable range.

References

1. IEEE Std519-1992, *IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*, June 2004.

Powering the 2008 Olympic Games

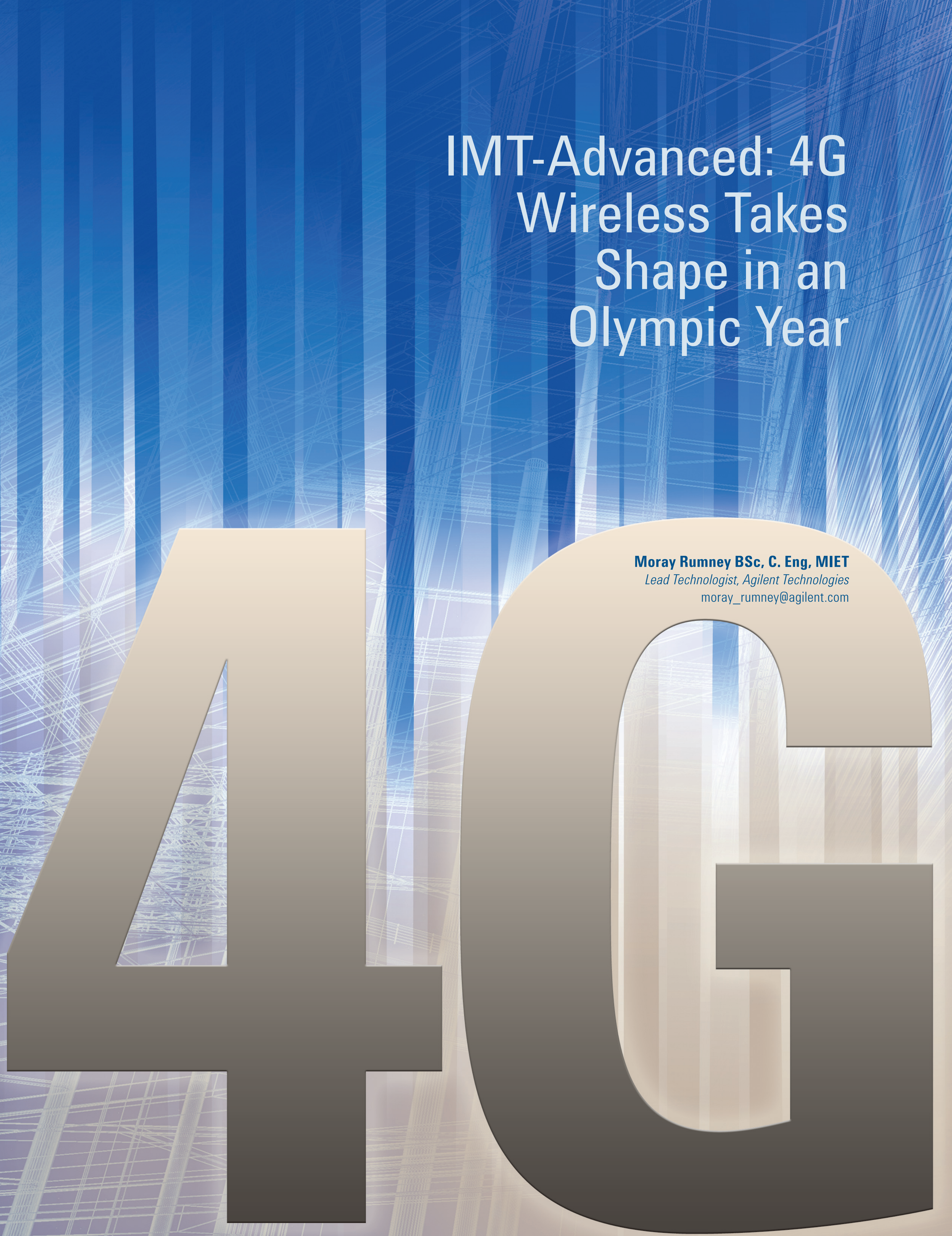
As China prepared for the Summer Olympics, it had to ensure a safe and stable supply of electricity to stadiums and arenas. Prior to the Games, Beijing Municipal Electric Power Corporation projected record power consumption of 14.6 million kilowatts when event demand added onto the city's summertime peak in electric consumption. The problem was that Beijing had a maximum power supply of just 52 million kilo-volt amperes (KVA).

To address the shortfall, Beijing invested roughly US$3.05 billion (22.1 billion yuan) in network upgrades. Completed on January 1, 2008, the 18-month Beijing State Grid's "0811" project encompassed, among other things, an Olympic project, a state-grid safety project and a state-grid emergency contingency project. Existing equipment and technology were employed in the state grid to safely, and in a stable manner, handle extreme heat and humidity, rainstorms and other severe weather conditions.

The "0811" project added 70 additional 110-KV transformer substations to the power grid, bringing the total to 337 and increasing power-supply capacity by 33 percent. The grid reached a reliability rate of 99.9382 percent in the city and 99.795 percent in the countryside. With a maximum power supply of 68.9 million KVA, the city was able to reliably supply enough power to meet total demand during the Olympic Games.

IMT-Advanced: 4G Wireless Takes Shape in an Olympic Year

Moray Rumney BSc, C. Eng, MIET
Lead Technologist, Agilent Technologies
moray_rumney@agilent.com



It has been well over a decade since the International Telecommunications Union (ITU) launched its International Mobile Telephony-2000 (IMT-2000) third-generation (3G) framework for mobile wireless communications. In more recent times there has been much anticipation of the fourth generation (4G) with development of so-called 3.5G, 3.75G and 3.9G standards. However, in this Olympic year, it was perhaps appropriate that China was the venue for a landmark workshop on 4G wireless that took place in Shenzhen following the April meetings of the working groups from the Third Generation Partnership Project (3GPP).

The purpose of the workshop was to start planning 3GPP's response to the ITU's 4G program, which the ITU has named "IMT-Advanced." There were around 200 delegates in attendance from all the major wireless industry players. Nearly 60 technical papers were presented espousing corporate views on the provisional 4G requirements and potential 4G solutions.

The article "What Next for Mobile Telephony: Examining the trend towards high-data-rate networks" in Issue Three of *Agilent Measurement Journal* introduced some of the concepts further developed in this article. From here forward, the terms 3G and 4G will be used interchangeably to refer to IMT-2000 and IMT-Advanced.

Putting 4G in context

Reviewing previous wireless generations will help put 4G in context. The first generation came of age in the 1980s, offering for the first time a relatively affordable (though expensive by today's standards) mobile wireless telephony service. 1G was characterized by a multiplicity of incompatible regional analog standards that kept the market fragmented, expensive and without international roaming.

In the early 1990s, GSM, the first of the digital second generation, arrived to provide telephony plus text messaging and limited circuit-switched data services. For GSM, everything lined up: technology; demand; supply; pricing; value; and delivery costs. The result remains an enormous international industry that in 15 years grew from nothing to being owned by more than half the people on the planet, revolutionizing the way the world communicates. GSM's success can be traced back to a few key factors: sufficient scale (17 European countries); the focus of basic telephony (text messaging was an unexpected bonus); and value (providing affordable services people wanted to use). The other main 2G system was CDMA, which offered services similar to GSM but in different geographies. In essence, 2G wireless brought the niche 1G to the mass market.

Following the phenomenal and unexpected success of 2G there was heightened anticipation of what 3G would bring, but 3G's contribution to date is a very mixed bag. On a technical level, 3G met the increased single-user data rates mandated by the IMT-2000 requirements, but the uptake of much-hyped 3G services such as video telephony has been poor.

One key challenge in moving from telephony to data services has been the complexity and diversity of the possible services, compounded by the difficult issue of pricing. Also, services requiring higher data rates are less available than 2G voice: radio conditions mean that it is normal to experience a 10:1 variation in data rates across a cell, even before loading is considered. This largely explains why 3G in mobile phones has not lived up to expectations. 3G subscriptions are just over 7 percent of 2G subscriptions and many of these are primarily using telephony and basic messaging rather than 3G-specific data services.[1]

Real uptake of data services didn't start until the c.2005 introduction of the so-called 3.5G packet-based data services (HSDPA on UMTS and 1xEV-DO on cdma2000). Dedicated data-only devices with flat-rate tariffs (e.g., USB dongles used with laptops) are showing strong growth in some markets with good performance, at least for early adopters. Whether there is demand backed by network coverage, capacity and sufficient revenue to allow such services to become mainstream is yet to be seen, meaning 3G's impact is currently much less significant than the step from the first to the second generation.

Given the experience so far with 3G, how should we evaluate the targets being set for 4G? Will 4G make mobile broadband a reality for the masses? This should surely be the hope of the industry and is the reason why it is so important to correctly define the fourth generation. At this stage in the planning process, opportunities still exist to identify those critical elements that will make 4G a success.

Scanning the IMT-Advanced timeline

The ITU's 3G program took some 12 years to complete, with work having started as far back as 1985 under its original project name of Future Public Land Mobile Telephone System (FPLMTS). Not so with IMT-Advanced, which has a much contracted timeline — and a pronounceable name. The 4G work started in 2005 and Figure 1 shows the projected ITU timeline and links into 3GPP.

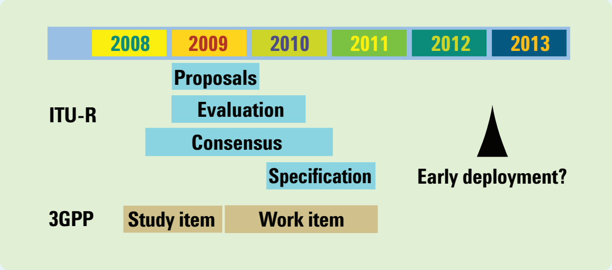


Figure 1. Overall IMT-Advanced timeline

The ITU's goal is to approve candidate 4G technologies by the end of 2009 with standards development and implementation to follow. This puts 4G about two years behind 3GPP's Long Term Evolution (LTE) project, suggesting that 4G commercial service will be available no earlier than 2012. By any standard, and particularly by 3G standards, this is an aggressive timeline. It is made possible, however, because the two most likely 4G candidate technologies — IEEE's 802.16e standard (Mobile WiMAX™) and 3GPP's LTE — are already considered 3.9G technologies and the enhancements required to meet 4G's requirements are not considered major. This is a significant point: Unlike with 3G, the advent of 4G is not going to result in a major rethinking of existing air-interface technologies.

In some ways, IMT-2000 led the development of 3G standards; however, in the case of IMT-Advanced, it is playing catch-up with the many developments that have taken place since the IMT-2000 requirements were established in 1997. 3GPP's submission to the ITU, planned for September 2009, will be a backwards-compatible enhancement of LTE Release 8, to be known generally as LTE-Advanced, and will probably be fully specified in 3GPP release 10.[2] For the IEEE, it is likely any submission will be based on the 802.16m standard, which is an evolution of 802.16e.

What's in a 4G name?

In naming its 4G initiative IMT-Advanced, the ITU has consciously reused the first part — "IMT" — from the 3G IMT-2000 program. This naming is significant because it has been agreed that spectrum currently allocated for exclusive use by IMT-2000 technologies will now be known as just "IMT" spectrum and will also be made available for IMT-Advanced. Crucially, there are no plans for exclusive IMT-Advanced spectrum. This is pragmatic since spectrum is scarce and largely occupied.

Reviewing IMT-2000 (3G) requirements and deployment

The requirements for 3G systems can largely be summarized by the following peak single-user data rates:

- 2048 kbps: indoor office
- 384 kbps: outdoor to indoor and pedestrian
- 144 kbps: vehicular
- 9.6 kbps: satellite

It is unfortunate that 2 Mbps dominated early 3G marketing and it was a long time before the limited reality of early 3G deployments became clear. Since the emergence of HSDPA in 2006, the original 3G data rates have long been surpassed. Even so, these figures have always lacked the caveats that translate headline rates into typical end-user experience. The two biggest culprits are coverage and capacity. Coverage falls into a couple of categories: locations where, for commercial reasons, there is simply no 3G service; and performance within the coverage area, which is highly dependent on radio conditions (indoor performance being particularly challenging). The other major issue is capacity. The IMT-2000 figures represent single-user peak data rates and say nothing about the number of users who can expect to see such performance in any given cell. The requirements may have ignored coverage and capacity factors but the end-user certainly cannot because these directly drive quality of experience (QoE). Shortcomings with coverage and capacity — along with difficulty in pricing and presenting value-added services — are the main reasons why the uptake of 3G has been much slower than predicted.

There are similar differences between peak and average performance in other industries where claims are designed to grab the eye and the wallet — but a growing list of caveats in the small print speaks more to the QoE. For example, getting the quoted performance out of a modern laptop battery requires tactics such as slowing the CPU to a fraction of its peak performance, dimming the display and switching off wireless features. Without regulations such as those that control claims about automobile gas mileage, the reality of wireless will continue to lag the hype. Peak-rate marketing in telecommunications is not unique to cellular wireless — as many DSL and Wi-Fi users will testify — but the gap between the peak and average for cellular is larger and growing faster than for wired or hotspot services.

Another point worth noting about 3G, as evidenced by its now six members*, is that it would be easy to conclude that 3G was a happy family of specifications. However, the ITU chose to define 3G only in terms of performance requirements and did not provide guidance on any technical implementation that might have created a stronger bond between the technologies. Thus, although 3G technologies share a common minimum performance level, the 3G label did not ease interworking between them.

When we consider the scope of the 4G requirements it will be interesting to see what they say about interworking and the factors limiting 3G in the areas of capacity and coverage.

Sketching preliminary IMT-Advanced requirements

The preliminary requirements for IMT-Advanced are shown in the sidebar *Key features of IMT-Advanced* and can be found on the ITU's IMT-Advanced website.[3] The first seven of the eight requirements are "soft," largely being pursued by the industry already. However, when it comes to defining what 4G is all about, the final target for data rates leaves no room for doubt: 100 Mbps high mobility and 1 Gbps low mobility. Thus, the headline requirements for 4G are nailed to the same mast as that of 3G: the continued growth in single-user peak data rates.

The intent of most of the softer requirements is to create a more integrated family of technologies than was ever the case for 3G. These good intentions, however, will always be subject to commercial reality and it seems evident from 4G contenders LTE and WiMAX™ that they will have little in common by the time the electromagnetic waves hit the air. Consequently, we are likely to end up with a repeat of 3G where interworking within the 4G "family" may still feel more like *The Simpsons* than *The Waltons.*

The 1-Gbps headline figure is likely to grab attention in the same way that 2 Mbps did for 3G ten years earlier. Like its 3G predecessor, the 1-Gbps peak figure is not without qualification since it applies only for low mobility in ideal radio conditions and requires up to 100 MHz of spectrum. Nevertheless, these caveats may be overlooked, and, as with 3G, expectations of 4G may outstrip reality for what could be a long time.

Key features of IMT-Advanced

ITU-R M.[IMT-TECH] August 8, 2008

- A high degree of commonality of functionality world wide while retaining the flexibility to support a wide range of services and applications in a cost-efficient manner
- Compatibility of services within IMT and with fixed networks
- Capability of interworking with other radio access systems
- High-quality mobile services
- User equipment suitable for worldwide use
- User-friendly applications, services and equipment
- Worldwide roaming capability
- Enhanced peak data rates to support advanced services and applications (100 Mbps for high and 1 Gbps for low mobility were established as targets for research)

---

* W-CDMA FDD, W-CDMA TDD, TD-SCDMA, cdma2000, UWC-136 and Mobile WiMAX

Reviewing detailed 4G performance requirements

Besides the headline peak data rates, 4G — unlike 3G — is setting targets for average spectral efficiency and cell-edge performance. This is a welcome development and these figures can be seen in Table 1.

The first point of note is that the peak efficiency targets for LTE-Advanced are substantially higher than the targets for 4G — thus the focus on peak performance is maintained despite the averages being very similar. That said, 3GPP have emphasized that the average and cell-edge targets are more important than the peaks. The LTE targets are based on 2x to 4x improvements to Release 6 HSPA (single-stream downlink with diversity UE receiver), which produces a microcell average efficiency of around 0.53 b/s/Hz/cell.[4] At 2.6 b/s/Hz/cell the targets for 4G and LTE-Advanced are around five times higher and, should they be met, would truly be worth the investment. However, we are still some way from demonstrating cost-effective technology that can deliver on the lower 1.69 b/s/Hz/cell LTE target. The industry knows how to increase the peak figures by adding more bandwidth or higher-level modulation and less coding (with consequential negative impact on coverage), but with targets for average performance there is nowhere to hide.

Consider this automotive example: Let's say the average speed of metropolitan rush-hour traffic is 20 mph. Compare the difficulty of designing a car that can travel at ten times the average speed with no environmental restrictions (e.g., assume perfect roads and no traffic) versus designing an entire traffic system — not just a car — that can double the average speed during rush hour. This offers a qualitative feel for the enormity of the challenge 4G is setting in improving on today's average wireless performance by a factor of five.

Aggregating bandwidth

Those familiar with today's spectrum allocations might well be wondering where space for the 100-MHz channels needed for 1 Gbps will be found. Some new IMT spectrum was identified at the World Radio Conference in 2007 (WRC-07) but there are still only a few places where continuous blocks of 100 MHz might be found (e.g., at 2.6 GHz or 3.5 GHz). One possibility would be to encourage network sharing, which reduces fragmentation caused by splitting one band between several operators; however, sharing the spectrum, as opposed to just the sites and towers, is a considerable step up in difficulty. The ITU recognizes the challenge that wide-bandwidth channels present and so it is an expectation that the required 100 MHz can be created by the aggregation of non-contiguous channels from different bands in a multi-transceiver mobile device.

Table 1. LTE, LTE-Advanced and IMT-Advanced performance requirements

Item	Sub-category	LTE (3.9G) target[4]	LTE-Advanced (4G) target[2]	IMT-Advanced (4G) requirement[5]
Peak spectral efficiency (b/s/Hz)	Downlink	16.3 (4x4 MIMO)	30 (up to 8x8 MIMO)	15 (4x4 MIMO)
	Uplink	4.32 (64QAM SISO)	15 (up to 4x4 MIMO)	6.75 (2x4 MIMO)
Downlink cell spectral efficiency (b/s/Hz/cell) Microcellular 3 km/h	(2x2 MIMO)	1.69	2.4	
	(4x2 MIMO)	1.87	2.6	2.6
	(4x4 MIMO)	2.67	3.7	
Downlink cell-edge spectral efficiency (b/s/Hz/user)*	(2x2 MIMO)	0.05	0.07	
	(4x2 MIMO)	0.06	0.09	0.075
	(4x4 MIMO)	0.08	0.12	

---

*5 percentile, 10 users

The beginnings of such aggregation techniques are already showing up in established technologies, first with EDGE Evolution, for which standards are being written to aggregate two non-adjacent 200-kHz channels to potentially double the single-user data rates possible with standard EDGE. Along similar lines, there are 3GPP proposals for "dual-carrier" High Speed Downlink Packet Access (HSDPA) to try to close the "bandwidth" gap between 5-MHz UMTS and 20-MHz LTE. Multi-carrier cdma2000 has also been considered, although its use of adjacent channels avoids the need for multiple transceivers.

There is clearly precedence for the ITU's bandwidth aggregation proposals but there are unanswered questions about the viability of such solutions at 100 MHz due to the implications for user equipment (UE) cost and complexity. This is compounded by the fact that commercially-viable applications for 1-Gbps data rates to a single mobile device have yet to be articulated. It should also be noted that bandwidth-aggregation does not increase network capacity. Taking all these factors into account suggests a very uncertain future for 100-MHz multi-transceiver bandwidth aggregation as a means of delivering extreme single-user peak data rates.

Summarizing 4G solution proposals

During the 4G workshop there were numerous proposals from the industry as to how LTE-Advanced might deliver and even exceed 4G requirements. Space does not permit detailed analysis but the proposals included the following:

- Higher-order multiple-input/multiple-output (MIMO) and beamforming (up to 8x8)
- Co-operative MIMO
- Cell-edge interference coordination and cancellation
- Advanced coding and scheduling
- In-channel relay for backhaul
- Femtocell / Home Node B using self-configuring/ self-optimizing networks

Further details can be found in the workshop report and documents.[6]

Evaluating 4G

So how should 4G be evaluated given the history of previous generations? We could analyze many factors — but one undeniable truth supporting the phenomenal growth in the wireless market has been the parallel growth in system capacity. This should be no surprise since capacity is the raw material required to deliver value-added services. If capacity is not growing then neither is the industry. Most of the capacity in today's infrastructure is consumed with telephony and messaging, with demand being fueled by growth in subscriptions of typical voice usage, which averages globally at around three hours per user per month. However, the advent of higher-rate data services changes this model and it is now possible for one user to demand far more capacity from the system than was possible with voice. If higher-rate 3G and 4G services are to be viable there has to be a corresponding growth in system capacity.

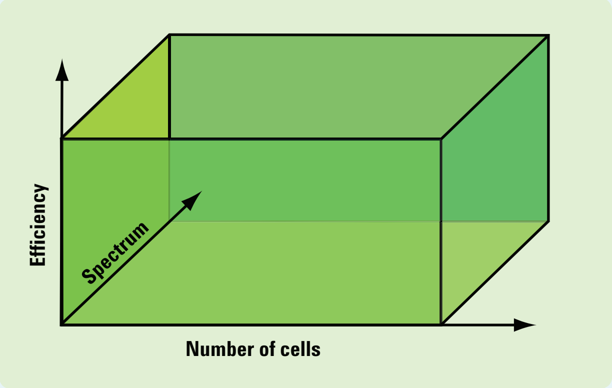


Figure 2. Volume model for wireless system capacity

Figure 2 presents a simple model for evaluating system capacity with three axes: spectrum, spectral efficiency and number of cells (which is a form of frequency reuse). The product of these three axes represents the volume or capacity of the system. Over the last 50 years there has been phenomenal capacity growth of around one million. Further analysis shows that efficiency has improved 20x and spectrum by around 25x, but the number of cells has grown by a staggering 2000x, making this axis 80 to 100x more significant.

Figure 3 shows a more detailed view of how peak data rates and system capacity have grown, spanning 1992 (2G) to 2015 (4G projections). The trends shown are based on a European model and are valid in general, though not necessarily in the fine detail. The Y scale is the peak data rate in kbps and the other traces (normalized to single-band GSM in 1992) are: average efficiency (b/s/Hz/cell); spectrum; and their product, which is cell capacity (b/s/cell). The efficiency figures are taken from various sources with the value in 2015 being projected at 1.3 b/s/Hz/cell, which is a safer figure to use than the 2.6 b/s/Hz/cell 4G target based on 4x2 MIMO. The spectrum growth follows the GSM900, DCS1800, E-GSM, UMTS2100 historical progression with projections for 700 MHz, 2.6 GHz and 3.5 GHz leading to a total of 680 MHz by 2015.

In the early days, 2G systems were deployed to operate at a peak rate of around 10 kbps at the cell edge, enabling uniform, if somewhat inefficient, service. In later generations, many techniques have been used to increase average efficiency by exploiting better radio conditions further into the cell. The result is better efficiency — but service coverage is no longer uniform.

Until about 2002, the peak data rates tracked the growth in cell capacity, meaning that, on average, a loaded cell could deliver the higher rates to its users. The number of users will obviously vary depending on the service, but if we take as a reference the number of users in the original GSM cell at its capacity, then these same users would experience a nearly 50x growth in data rates in ten years — quite impressive! However, after 2002 we see a growing gap between cell capacity and the peak rates possible for single users. This is significant because our same set of users will, on average, see only one-tenth of the possible peak data rates today's unloaded systems can deliver. Using the projections for LTE and 4G, we can see the gap widening such that by 2015 the peak rates of the system will have outpaced system capacity by 100x. This means that, on average, the cell's set of users will experience only one percent of the headline data rates. Even these figures are optimistic since Figure 3 is simplified by assuming constant load, ideal scheduling and the absence of deployed legacy terminals.

There are many ways 4G systems could be analyzed, but the fundamentals of capacity and coverage are essential. In addition to the predicted capacity limitations, the delivery of very high data rates in a macrocell radio environment is restricted to a small area near the center of the cell (as discussed in Issue Three of *Agilent Measurement Journal*). If mobile broadband is to become a reality, both the capacity and coverage limitations of current macrocell systems need to be addressed, otherwise the result will be a continuation of the trend towards inconsistent service provision known to have held back the adoption of 3G.

Although projected capacity growth through additional spectrum and improvements in efficiency are real, neither can deliver the substantial growth that is required for the mobile broadband revolution. To meet this challenge we must turn to the third axis in Figure 2, that being growth in cell numbers.

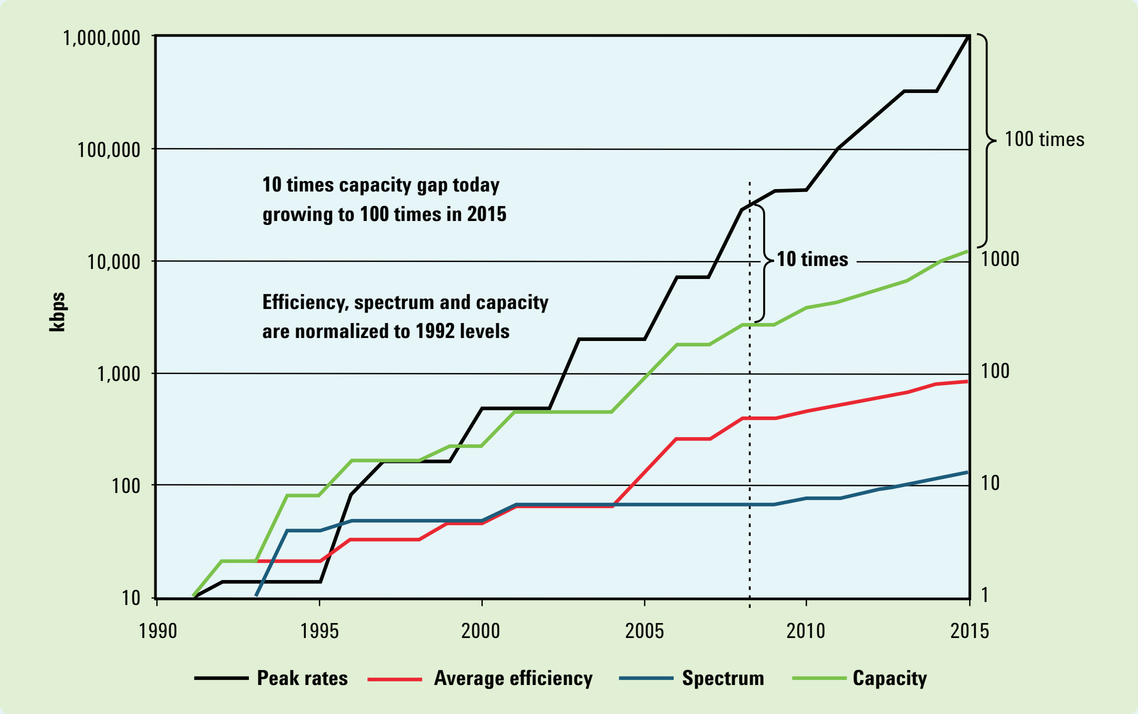


Figure 3. Growth in peak data rates and system capacity

Growing capacity by increasing cell numbers

Today there are approximately 1,000 subscribers per macro base station. Reducing this ratio has historically been the way system capacity has grown to meet demand. However, it seems evident from operators that making more than a token increase in macrocell density is not economically viable and thus the primary growth mechanism that has served us since wireless began seems to be nearing its end. There are ongoing efforts to deploy picocells and in-building systems but these too have practical limits. Breaking through to the next 10x or 100x of capacity growth means a dramatic increase in cell numbers is required — but the current centrally-managed deployment model will not scale due to costs and environmental factors such as planning and site availability.

The time now seems right for the home base station or femtocell. With a femtocell in every second home it is possible to imagine a 100x growth in cell numbers compared to the current macrocellular model. With this femtocell assumption, a comparison of the capacity potential of the three axes in the capacity model from today through 2015 is shown in Figure 4. It is interesting to note that the outlook for capacity growth is much like the previous 50 years, with cell number upside being 100x more significant than growth in either spectrum or efficiency.

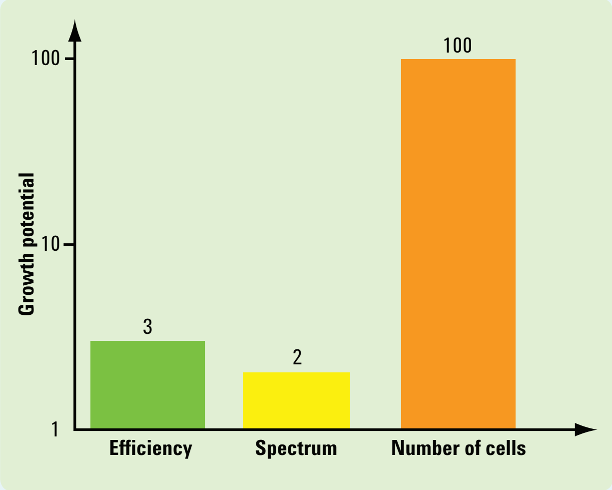


Figure 4. Capacity growth potential 2008 through 2015

How well are the 4G requirements addressing the need for capacity growth to match the demand from higher peak-data rates? Taking spectrum first, this will always be mired in the slow-moving politics of international regulation. There are no expectations that the existence (or absence) of 4G will make much change in the projected 2x spectrum growth through 2015, which will be available for 3G as well. Next we have efficiency, which is the focus of most of the study into 4G, but as we have seen the targets are very challenging and the upside remains low. Finally, regarding the number of cells, there were some encouraging discussions at the Shenzhen workshop on femtocells, although this is not currently seen as a major 4G initiative. For this reason it is perhaps fortuitous that 3GPP is already standardizing femtocell technology for both UMTS and LTE. The significance of this cannot be underestimated since the potential upside from a femtocell deployment will address both the capacity and coverage limitations of current systems, plus the better radio conditions experienced in hotspot femtocell environments go hand in hand with delivering higher data rates.

Femtocells: Enabling mobile broadband?

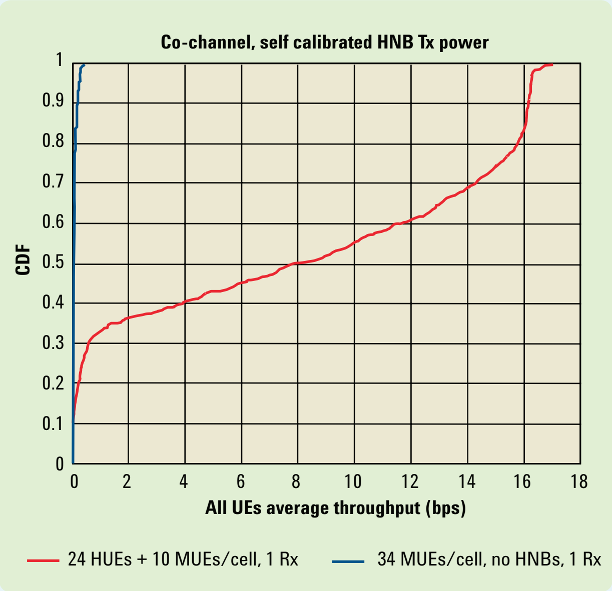


Figure 5. Average throughput per user with and without femtocells

The potential of femtocells is illustrated in Figure 5. This data was presented in June 2008 at 3GPP RAN WG4 as part of a femtocell study that included a simulation of user data rates with and without femtocells.[7] The air interface is 5-MHz HSDPA using a single receiver with equalizer, 64QAM and 15 codes. For the macrocell case (blue trace), 34 UEs are evenly distributed across the cell and the median throughput is 40 kbps with the peak at 400 kbps. When the 96 femtocells are enabled, 24 UE choose to switch to the femtocells, leaving only 10 UE on the macrocell.

The new median data rate (red trace) is 8 Mbps with the peak around 17 Mbps. In addition, by offloading users to the femtocells, the remaining macrocell users see their median data rate move from 50 kbps to around 170 kbps.

This simulation clearly shows the difference between trying to improve capacity and median data rates by enhancing a single macro cell versus adding femtocells. This macrocell with 34 distributed users has a capacity of around 1.3 Mbps (0.26 b/s/Hz/cell), resulting in the median of 40 kbps. Note that the macrocell is capable of supporting 17 Mbps, but only for one user near the cell center. If efficiency gains of 3x were realized, the median would rise to around 120 kbps, but this is a difficult and expensive task with no guarantee of success. In contrast, by deploying low-cost femtocells using existing less-sophisticated technology, median data rates, due to better radio conditions and lower cell loading, are seen to rise a massive 200x to 8 Mbps.

Looking briefly at femtocells

A femtocell differentiates itself from the traditional centrally-deployed model according to the attributes in Table 2.

It is easy to assume that femtocells are just a further progression down the macro/micro/picocellular model of decreasing cell radius. This is true in terms of the coverage area, which for picocells and femtocells is in the range of 10 m, but it should be evident from Table 2 that the femtocell approach is fundamentally different from today's cellular. A closer model would be that of a cellular version of Wi-Fi hotspots but with much better control over QoS through use of cognitive radio techniques inherent to cellular's awareness of its environment, and the ability of the operator to remotely control the femtocell via the Internet-based backhaul. Note that the 200x femtocell improvement is delivered with a peak rate of 17 Mbps, well within range of evolving end-user backhaul.

To be fair, femtocells have been tried — unsuccessfully — several times in the past, with the focus having been on telephony. Understanding those failures, and embracing the new potential for data services, will determine if femtocells have now come of age. To this end, one crucial factor now making a big difference is the Femtoforum, which is addressing many of the issues necessary to ensure commercial femtocell success.[8] The challenges remain significant and include aspects of end-to-end service — such as backhaul network neutrality

Table 2. Comparison of traditional cellular and femtocellular

Attribute	Traditional cellular	Femtocellular
Infrastructure cost	\$10,000 - \$100,000	\$100 - \$200
Infrastructure finance	Operator	End user
Backhaul	Expensive leased E1/T1 lines	Existing end-user DSL or cable broadband
Planning	Operator	End-user (no central planning)
Deployment	Operator truck roll	End-user one-touch provisioning
Quality of Service (QoS)	Operator controlled	Best effort
Control	Operator via O&M	Operator via Internet
Mobility	Good/excellent	Nomadic/best effort
Performance	Limited	Excellent

and commercial roaming agreements — that are outside the scope of traditional standards bodies. The prize, however, if these obstacles can be overcome, is that femtocells have the potential to deliver massive capacity gains and corresponding increases in average data rates for the nomadic data-using community — gains that could never be achieved with macrocell improvements alone. It will be some time before femtocells are as prevalent as Wi-Fi is today, but the outlook is good and the next two years will be key for this fledgling technology.

Offering a 4G prognosis

Let's repeat two key points. First, the provision of higher data rates drives up expectations but does not significantly increase system capacity or median data rates. Second, with the projected efficiency and spectrum gains, median data rates in a loaded network may reach only one percent of the designed peak. If we accept these hypotheses, then it seems evident that 4G's spectrum and efficiency gains are insignificant compared to what could be achieved by enabling a femtocell deployment.

4G is aiming to be a low-cost solution for mobile broadband, but high efficiency and high data rates mitigate against this. Ever-higher peak rates drive up the cost of infrastructure and terminals, and high-efficiency systems are inherently complex and therefore also drive up costs. If there is neither the demand for extreme high-rate services, nor the ability to deliver them uniformly, 4G could be in danger of becoming an expensive white elephant. In reality, subscribers pay for peak performance but experience the average. With current plans, the top end of 4G at 100:1 will have the highest peak-to-average performance ratio of any wireless system to date. The contrast with today's most successful and ubiquitous wireless services — voice telephony with a 1:1 ratio and highly inefficient text messaging — could not be starker.

The pursuit of capacity gains through efficiency will have a positive effect — and the engineering challenge this presents is both fascinating and formidable. However, the question the industry must ask itself is whether efficiency should be a primary goal. The 100x capacity gains that might be realized using a high-mobility macro network complemented by a femtocell network for nomadic use in the locations of highest demand cannot be ignored.

Conclusion

The door is not yet shut on the definition of 4G, but it is closing fast. The extent to which 4G can address the capacity and coverage issues in a cost-effective manner will determine if it will be the enabler of the mobile broadband revolution — or if it will compound the issues that have hindered 3G. One thing is certain: The market will select, in Darwinian fashion, the lowest-cost way to realize the mobile broadband opportunity. If 4G does not address the bottlenecks in today's systems then several alternative technologies — all based on existing and evolving 2G and 3G standards — are ready to step up and clear the way. In particular, femtocells (based on simpler, existing air-interface technology) and even evolving Wi-Fi technologies have the potential to deliver high-performance, cost-effective alternatives to enable the mobile broadband revolution.

References

1. http://www.gsacom.com/news/statistics.php4.

2. 3GPP TR 36.913 V8.0.0: *Requirements for further enhancements to E-UTRA (LTE-Advanced).*

3. ITU-R IMT-Advanced website: www.itu.int/ITU-R/go/rsg5-imt-advanced.

4. 3GPP RAN Tdoc RP-070466: *LTE Performance verification work.*

5. ITU-R M.[IMT-TECH].

6. ftp://ftp.3gpp.org/tsg_ran/TSG_RAN/TSGR_40/LTE-Advanced%20workshop.

7. 3GPP RAN WG4 Tdoc R4-081344 Qualcomm: *HNB and Macro Downlink performance with Calibrated HNB Transmit Power.*

8. For more information, see the Femtoforum website at www.femtoforum.org.

EPO Doping: A Speed Engine, Turbo-Charged by Chemistry

Xia Yang, Ph.D.
Post-Doctoral Researcher, College of Chemistry and Molecular Engineering, Peking University, Beijing, China
xyangpku@gmail.com

Hongfeng Yin, Ph.D.
Scientist, Agilent Technologies
hongfeng_yin@agilent.com

Huwei Liu, Ph.D.
Professor of Chemistry, College of Chemistry and Molecular Engineering, Peking University, Beijing, China
hwliu@pku.edu.cn

Erythropoietin (EPO) is a glycoprotein hormone, produced by the kidneys, which stimulates the formation of red blood cells by stem cells in bone marrow. Because of its ability to boost endurance, illegal EPO doping by athletes in endurance sports such as cycling has become more prevalent through the years — likely starting in the late 1980s when the first synthetic version of EPO, recombinant human EPO (rhEPO), became commercially available. No official test method for EPO doping existed until the 2000 Summer Olympics in Sydney, Australia, and even today the search for better tests continues.

During sporting events, officials have relied on a blood test to analyze any given athlete's red blood-cell (RBC) count and the quantity of RBC precursors. An increase in the EPO level triggers the bone marrow to overproduce the precursors, some of which may leak into the main circulatory system. A high ratio of precursors versus the RBC count indicates a recent spike in the athlete's EPO level.[1]

Knowing these factors, researchers at Peking University, in collaboration with Agilent Technologies and the Agilent Technologies Foundation, have undertaken a research project to discover the biomarkers associated with an EPO injection.* Biomarkers are compounds that serve as an indicator for a certain disease or body condition. Essentially, researchers are looking for the proverbial "needle in a haystack," which, in this case, is the biomarkers present in blood and urine samples. Their tools are high-performance liquid chromatography coupled directly to mass spectrometry (HPLC/MS) and data-mining software. This article highlights some of the ongoing efforts to create an effective test for EPO doping.

Examining EPO doping

Before examining the ongoing research into testing for EPO doping, it is important to first answer two critical questions:

- Why are top athletes using EPO to improve their performance?
- Why it is so hard to detect EPO doping?

The answer to both questions lies with oxygen. Since the human body releases energy through oxidation processes, oxygen is a critical component in this discussion. In many endurance sports, the amount of available oxygen carried by red blood cells to the muscle's cells often limits the amount of energy that can be released. Increasing the RBC count generally means the availability of more oxygen to the muscle's cells. Consequently, more energy can be released at a faster rate, just like a turbo-charged car engine.

There are two ways to artificially boost the RBC count in a human. One is typically called "blood doping" or "blood packing." An athlete can draw and store a certain amount of his or her blood in the offseason and then re-inject it via transfusion prior to an important sporting event. Nowadays, though, athletes looking for a way to boost their RBC counts might prefer an alternate option to a messy blood transfusion — an injection of EPO.

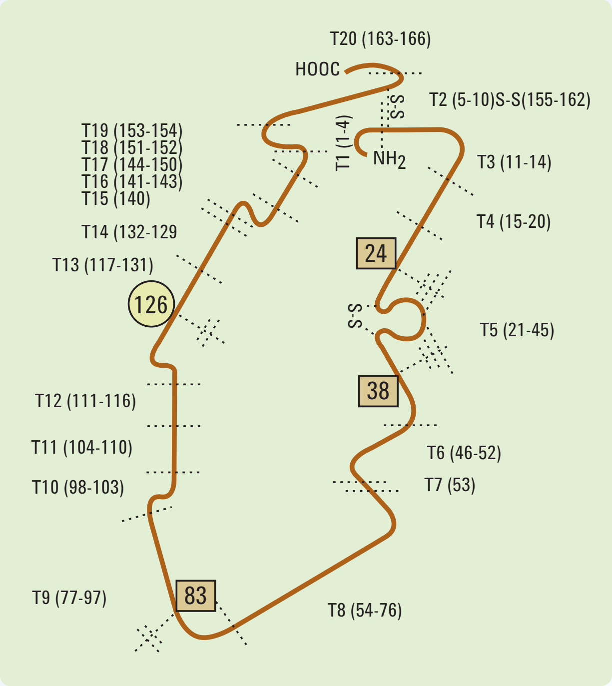


Figure 1. This graphic shows the predicted structure of rhEPO. Here, T1 through T20 are peptides generated by tryptic. The amino acid residue numbers are indicated in parentheses.

---

* The research is funded by the National Science Foundation of China (NSFC) and the Agilent Technologies Foundation.

As a peptide hormone produced in the kidneys, EPO stimulates the production of red blood cells and is released in response to decreased levels of oxygen in body tissue. It is a highly glycosylated protein with a 30 to 34 kDa molecular weight, 40 percent of which amounts to carbohydrate chains (Figure 1). The rhEPO is one of the top selling biopharmaceutical products for treating anemia caused by kidney failure. In fact, its amino acid sequence is identical to human endogenous EPO (Figure 2). One of the current EPO tests approved by the International Olympics Committee (IOC) relies on the differences in the glycosylation patterns between the recombinant EPO and the endogenous EPO.[3] This test calls for the separation of the different forms of glycoproteins using isoelectric-focusing gel electrophoresis. An anti-EPO antibody helps visualize the separated gel band.

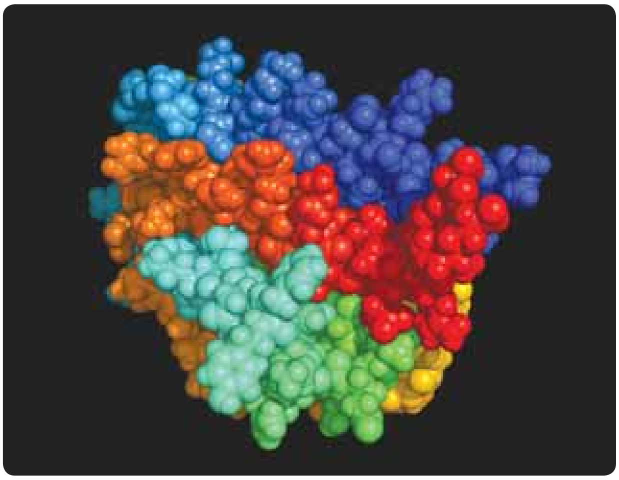


Figure 2. rhEPO, as pictured here in its 3D structure, has led to the disqualification of athletes from endurance sports competitions such as cycling.[2]

Closing in on an answer

At Peking University's College of Chemistry and Molecular Engineering, an alternative method of separating the various EPO glycoforms — capillary electrophoresis technology — is now under investigation.[4] Capillary electrophoresis is widely used for the separation of protein mixtures based on their ionic charge differences. Due to the high voltage used, the separation process is generally much faster than traditional slab-gel electrophoresis. However, when it comes to using this technology for EPO testing, there are still several issues that must be addressed.

Happy collaboration

Huwei Liu

My relationship with chromatography and Agilent's (formerly Hewlett-Packard's (HP's)) chromatographic instrumentation began in the early '80s when I was a college student. It was further cemented in 1990, when I joined Peking University (PKU) after having received my doctorate from the Beijing Institute of Technology. There I met Hongfeng Yin, a Ph.D. student who later graduated and joined Agilent China where he was responsible for setting up a chemical analysis training center for Agilent customers. We formed a strong relationship and, in 1997, Agilent donated four sets of chromatographic instruments that were used to establish the PKU-Agilent (formerly PKU-HP) Chemical Analysis Laboratory. Today, we train Agilent customers in the area of capillary electrophoresis and test their GC and LC columns.

Since 2005, PKU has received two Agilent Technologies Foundation grants and I am lucky to serve as the resident mentor for each. Thanks to the flexibility of Agilent management, the happy collaboration between PKU and Agilent continues to flourish.

The first challenge to overcome is the interaction of protein molecules with the capillary wall. Such interaction can dramatically affect the separation performance. Our ongoing research has found that dynamically-coated, fused-silica capillaries with carboxymethyl chitosan can minimize the protein-to-capillary wall interaction.

The second issue that requires attention is the inherent lack of detection sensitivity, when compared with antibody blotting, and the selectivity of the UV detector. A better alternative for high-sensitivity analysis is laser-induced fluorescence detection. Since the EPO molecules are not inherently fluorescent, they must also be derivatized from the sample. Although fluorescein isothiocyanate (FITC) is a common fluorescence reagent and has been used for pre-column labeling of peptides and proteins in the capillary electrophoresis with laser-induced fluorescence detection (CE-LIF) method, we have found that its reaction with rhEPO is slow. In addition, FITC exhibits a high-fluorescence property and pre-capillary derivatization with a higher concentration of FITC results in high background from the excess reagent. The fluorescence background of FITC obscures a large portion of the baseline, making it difficult to detect the analytes at low concentration.

We recently discovered that on-capillary derivatization of the amino group of EPO's lysine residues with the fluorogenic dye 5-furoylquinoline-3-carboxaldehyde (FQ) offers a fast and easy method of derivatizing EPO. For this research, a plug of FQ solution was first loaded into the capillary followed by an injection of the EPO sample. Applying a relatively low voltage of –3 kV for five minutes allowed the sample to mix and then react with the fluorescence dye. A high separation voltage of up to –30 kV was next applied across the capillary to achieve separation of the EPO isoforms in 20 minutes.

With continued improvements in analytical instrumentation and the hard work of analytical chemists, one can be assured that the detection sensitivity and specificity of recombinant EPO will only get better over time. However, in the fight against illegal sports doping, another challenge comes from the short half-life of recombinant EPO in the human body. After the recombinant EPO injection, the hormone only presents in the urine or blood for a few days. The effect of an EPO injection, on the other hand, lasts much longer. In fact, if an athlete decides to take an injection of recombinant EPO a few days prior to a sporting event, by the time the event starts it is already impossible to detect the substance in the athlete's body. The detection of recombinant EPO is therefore most useful in out-of-competition testing when the samples are collected during unannounced visits prior to the sporting event.[5]

Trust: The foundation for a successful collaboration

Hongfeng Yin

My initial collaboration with Professor Liu from Peking University dates back to the early 1990s when I was setting up a customer training center at Agilent China (formerly HP China). Our friendship continued after I joined Agilent Labs (formerly HP Labs) in the United States. Professor Liu has been collaborating with Agilent China ever since. I feel fortunate that we were able to receive a research grant from the Agilent Technologies Foundation to support Professor Liu's team of bright, young students as they work on such an exciting and challenging project — a project that may one day change the face of EPO doping as we now know it.

Conclusion

Because of its ability to boost endurance and defy detection after just a few days, recombinant EPO is gaining popularity within the professional sports community. By uncovering the biomarkers associated with an EPO injection, researchers hope to one day be able to successfully detect EPO doping in blood and urine. While this approach must understandably involve large numbers of samples and therefore be extremely painstaking, the prospect that it will one day result in the discovery of long-lasting biomarkers which can be used to measure EPO doping presents an exciting prospect — one that continues to drive our research efforts forward.

References

1. Parisotto, R. et al. 2000. *Haematologica*, Volume 85, 2000: 564-572.

2. Cotes P.M., Downing M.R., Oliver D.O., Pippard M.J., Reid C. and Winearls C.G. 1986. *Lancet*, 2 (8517), November 1986: 1175-1186.

3. Ceaurriz, J. de and Lanse, L. 2000. *Nature*, Volume 405, 2000: 635.

4. Yang, X., Zhang, L., Fu, X., Yin, H., Liao, Y. and Liu, H. 2008. *Anal. Bioanal. Chem.*, in revision.

5. Abbott, A. 2000. *Nature*, Volume 407, 2000: 125.

Contact Agilent

Email Update Service

Get the latest information and newest test skills
Subscribe to our free Email Update Service for the latest Agilent product, support and application information — customized for your interests and preferences.

Only the information you want, when you want it
Easily identify your specific interests from a selection of more than 100 product and application areas and specify the types of information you would like to receive:

- **Support information** such as new-product information and specifications; application notes; tradeshows, events, and live or virtual seminars.
- **What's New**, including education/training and consulting services; firmware and software upgrades; and warranty, calibration and repair.

Total commitment to privacy
Agilent is proud to participate in the Better Business Bureau On-Line Privacy Program, and we adhere to all of the program's standards.

Agilent Email Updates

www.agilent.com/find/emailupdates

Agilent Test and Measurement RSS Feeds

Subscribing to Agilent´s RSS feeds lets you receive Agilent news as soon as it is published. With over 50 topics — ranging from "AC Power Sources/Power Analyzers" to "Wireless Test Systems" — you may find several feeds of interest.

www.agilent.com/find/rss

Additional Agilent Resources

Agilent Direct Store

- Quickly build and place your order, secure transactions 24x7
- Easily select and configure your products
- Flexible payment options
- Order basic instruments, general purpose test accessories, microwave test accessories and replacement parts online today (available to U.S. customers only)

Agilent Direct

www.agilent.com/find/onlinestore

Infoline

Your online source for Agilent repair and calibration information

Infoline

www.agilent.com/find/service

Electronic Measurement Promotions

Current product and service savings in one convenient location

www.agilent.com/find/promotions

Agilent Trade-in

Migrate towards new test equipment with Agilent Trade-in

Agilent Trade-in

www.agilent.com/find/trade

Agilent CertiPrime

Your source for Agilent CertiPrime premium used equipment

Agilent
CertiPrime

www.agilent.com/find/certiprime


4G

www.agilent.com/go/journal

Printed in U.S.A. September 1, 2008

5989-9379EN

Agilent Technologies