Speed, Precision, Accuracy

How Keithley’s test equipment is revolutionizing the industry
Our Assignment: Several years ago my team was given an assignment to measure RF radiation from Low Power CMOS ICs. In this article I’ll describe the setup we designed and some of the problems we overcame to measure the weak radiation from CMOS Imager ICs.

Radiation

By David Cuthbert, EEWeb Contributing Author

Switches and switch matrices are widely used for the routing of RF and microwave signals in high-speed ATE systems. As today’s devices and products become more complex, there is an increasing need for the speed and flexibility of switching systems capable of connecting multiple signals or instruments to multiple devices-under-test (DUTs).

On a smaller scale, the same is true in R&D and design validation when developing RF and microwave products or when creating test routines that will be used in manufacturing. Even on the bench or in a small system, dependable switching can improve efficiency and save time. For day-to-day testing, USB-based single-pole / double-throw (SPDT) coaxial switches provide a solution that offers excellent RF performance and convenient connectivity.
Switches and switch matrices are widely used for the routing of RF and microwave signals in high-speed ATE systems. As today’s devices and products become more complex, there is an increasing need for the speed and flexibility of switching systems capable of connecting multiple signals or instruments to multiple devices-under-test (DUTs).

On a smaller scale, the same is true in R&D and design validation when developing RF and microwave products or when creating test routines that will be used in manufacturing. Even on the bench or in a small system, dependable switching can improve efficiency and save time. For day-to-day testing, USB-based single-pole / double-throw (SPDT) coaxial switches provide a solution that offers excellent RF performance and convenient connectivity.
Comparing Switch Topologies

Several factors are important in the selection of an appropriate switch for a specific application: frequency range, switching speed, settling time, power handling and operating life are often among the key attributes. Additional considerations include electrical characteristics such as insertion loss, return loss, repeatability, isolation, voltage standing-wave ratio (VSWR) and termination.

Less obvious is the effect of switch topology. Either of two types may be used: the switch ports are either on the same electrical plane or on different electrical planes. Each has plusses and minuses.

In conventional designs, all connector ports are on the same plane. This is commonly found in the large, front-mounted switch matrices used in complex ATE systems. Placing all the ports on the same plane saves space and thereby reduces the size of the resulting switch matrices.

Figure 1 shows two typical connections between a conventional switch and an instrument: both methods require the use of one or more RF cables between the switch, the instrument and the DUT. If a semi-rigid or flexible cable is used, its length and bend angle must be taken into consideration. If cable pairs are used, as shown on the right in Figure 1, they must be equal in length to ensure phase accuracy.

For some applications, good measurement results can be obtained when the switch ports are on different planes. This topology makes it possible to add switching to a test instrument or system without requiring additional RF cables. While this may simplify setups and eliminate the issues described above, it limits the breadth and complexity of the switching solution: creating multi-tier switching or a switch matrix would take up considerable space and require use of long interconnect cables.

Utilizing a Convenient Alternative

The Agilent U1810B USB coaxial switch puts solid RF performance and the convenience of USB connectivity in a small package. Operating from DC to 18 GHz, this SPDT device is configured to route signals between one common port and a pair of switched ports. The unit connects directly to instruments such as network analyzers and spectrum analyzers using a rugged Type-N connector; the switched ports use female SMA connectors (Figure 2).

Using solid-state technology, the switch offers an operating life of five million cycles or repeatability of measurement results.

Figure 2. A USB coaxial switch can simplify test setups while enabling greater versatility.

During calibration or compensation, the process typically requires a series of connections and disconnections involving the reference unit and the DUT. With a pair of USB switches, the reference can remain connected and be measured as needed while a series of DUTs is connected and measured.

To increase throughput with a four-port network analyzer, the addition of four USB switches enables connection of up to eight devices—DUTs, calibration units, references, etc.—to the analyzer (Figure 4).

Enhancing Cable-and-Antenna Testing

Installation and maintenance of specialized systems—radio networks, satellite ground stations, radars—often requires field verification or adjustment of cables, antennas, filters, diplexers and duplexers. When engineers or technicians travel to remote locations in potentially harsh conditions, they want to carry very little equipment and complete their measurement tasks as quickly as possible.

Figure 3. Switching saves time in network analysis when comparing DUTs or when performing calibration or compensation.

Figure 4. A quartet of USB switches doubles the number of devices that can be connected to a four-port network analyzer.

Illustrating Example Applications

Three simple measurement scenarios demonstrate what can be done with a USB switch: network analysis, cable-and-antenna testing and spectrum analysis.

Simplifying Network Analysis

Adding a pair of USB switches to a two-port network analyzer can enable comparisons between two devices or simplify calibration or compensation (Figure 3). In this configuration, one connection can be used to measure two devices in either the frequency or time domain.
With capabilities such as cable-and-antenna testing (CAT) and network analysis, the Agilent FieldFox handheld analyzers provide bench-caliber RF and microwave measurement results in the field. Adding a USB switch to these analyzers can reduce the time spent connecting, disconnecting and reconnecting cables or devices. As shown in Figure 5, two cables can be connected through the switch to the analyzer (power is provided by either of analyzer’s USB ports). This could be used to quickly compare a known-good cable to one or more potentially damaged cables, and this scenario can include distance-to-fault measurements with a suitably configured analyzer. Measurements such as return loss and cable loss also can be performed.

**Extending Spectrum Analysis**

A variety of systems use multiple transmitters and receivers. Examples include multi-channel radar systems and wireless LAN or mobile communications systems that use multiple-input/multiple-output (MIMO) technology.

Even though the addition of a USB switch to a signal analyzer won’t enable correlated measurements between signals, it will accelerate back-and-forth comparisons between a pair of connected transmitters, antennas or other DUTs up to 18 GHz (Figure 6).

**Conclusion**

Even in small-scale test configurations, high-quality switching offers convenience and efficiency by reducing the number of connects, disconnects and reconnects needed to accomplish common day-to-day measurements. Because the USB switch described here utilizes solid-state switching technology, it can be expected to provide long life and excellent electrical performance in a variety of applications.

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**Figure 5.** A single USB switch unit is a useful and time-saving addition to a field measurement kit.

**Figure 6.** In spectrum analysis applications, a USB coaxial switch enables quick comparisons between different signals or antennas.

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Measuring Signal Source Phase Noise

Why You Can’t Just Use a Spectrum Analyzer

Industry has an increasing demand for spectrally pure signals in applications such as imaging radar, mobile communications, satellite communications, weather monitoring, etc. This requires fast, accurate and reproducible characterization of signal generation devices. Dedicated phase noise and amplitude noise measurement systems are needed with typically better than a -180 dBc/Hz measurement noise floor. What is needed are instruments to measure the Absolute Phase Noise of crystal oscillators (VCXO, OCXOs), SAW Oscillators, synthesizers, Phase Locked loops and VCOs (locked, or free-run high-Q), as well as the Additive Phase Noise of Amplifiers, Mixers, Frequency Dividers, and Multipliers.

Alan Lowne
CEO Saelig Company Inc.
Though a spectrum analyzer can be used to yield some characteristics, it is not very helpful for distinguishing amplitude and phase noise. Not only is separating amplitude and phase noise impossible, spectrum analyzers have inadequate dynamic range and noise floor; the phase noise of the internal local oscillator in spectrum analyzers is too high, and they lack resolution bandwidth. For this reason, a dedicated system that demodulates and then analyzes amplitude and phase noise separately is required.

**SOLUTION**

Swiss-based Anapico has produced the APPH series of automated signal source analyzers which separate amplitude modulation and phase modulation measurements, measuring both independently to very low noise levels (below -180 dBc/Hz) with the capability of measuring additive noise of active and passive components. Offering a measurement capability up to 30GHz, with a fully integrated, cross correlation system that responds to the most common issues of phase, amplitude and base-band noise measurements, APPH analyzers provide high accuracy and reproducibility, fast measurement speed, high dynamic range with low system noise floors, and still remaining affordable for labs and production environments.

**SYSTEM ARCHITECTURE**

The core engine of the APPH series combines low-noise analog receiver channels with advanced digital signal processing technology to provide fast and repeatable noise measurements. The proprietary FPGA-based FFT cross-analyzer handles 125Msamples/s in real-time, allowing thousands of correlations and sub -170dBc/Hz measurements within seconds. The LAN- or USB-controlled APPH series can use a PC, laptop or tablet as the controller, so there is no need for a display to be incorporated, which minimizes product costs while increasing reliability.

**ACCURATE CALIBRATION**

Enclosing the system in a compact, fanless chassis further eliminates spurious signals and ground and power line loops. Another very important consideration is precise calibration. Before shipment, each instrument is calibrated against a traceable noise standard to guarantee high precision, consistent and repeatable results. Optionally, a calibration standard can be supplied with the instrument to enable a user’s on-site performance verification at any time.

**MEASUREMENT CAPABILITY**

Measurements supported for Anapico’s APPH instruments include: additive or absolute phase noise measurement using internal or external references, amplitude noise measurements and other automated measurements for evaluating RF signal sources. 358 phase noise, amplitude noise, AM noise measurement, additive or residual noise characterization, and baseband noise measurements up to 30GHz can easily be made for sources such as crystal oscillators, PLL synthesizers, clocks, phase-locked VCOs, DROs, and many others.

The phase noise data shown in Figure 2 is data gathered from a low noise 100 MHz OCXO reference. The three traces shown are after first correlation (green, after 12 s measurement time), 10 correlations (blue, after 120 s) and 100 correlations (red, after 20 min), respectively. The noise floor of the DUT at -180 dBc/Hz is reached just after 10 correlations or two minutes. For this ultra-low noise measurement, even faster results can be obtained with external reference sources. The sensitivity of the system operated with the internal references is dependent on both the carrier frequency of the DUT and the frequency offset range.

Figure 3 shows the APPH’s typical sensitivity when using the internal source to make a measurement, assuming an approximate 24 second measurement with an offset from 1Hz to 10MHz. However, the APPH signal source analyzers can also measure additive phase noise of amplifiers under different drive conditions, and the phase noise of frequency translating devices like prescalers or mixers. Additionally, amplitude noise measurements are also supported.

Figure 4 shows the amplitude noise obtained from one of Anapico’s signal generators at 4GHz, showing a trace with user defined markers and spurious list. The APPH also offers direct access to the FFT analyzer, which enables noise analysis of supply and control voltages. The APPH6040 with extended offset range as well as the APPH20G provide bandwidth beyond 40 MHz and transient measurement capability.

**CONCLUSION**

The APPH series of phase noise testers offers complete measurement functions for evaluating a wide range RF signal sources. They provide comprehensive measurements such as phase and amplitude noise measurement, residual noise characterization with direct access to the FFT analyzer for baseband signal and LF noise analysis. Using proven cross-correlation measurement procedures and self-calibration routines, reproducible and accurate measurements are obtained even under changing environmental conditions. Fully automated frequency acquisition and self-calibration greatly simplify use and applicability of the instrument, resulting in fast measurements and ease of operation.
How Keithley’s test equipment is revolutionizing the industry.

Linda Rae, President of Keithley Instruments

Keithley Instruments is one of the leading test and measurement companies on the market today. In 2010, Keithley was acquired by Tektronix to round out their already impressive product line, opening up new sales opportunities for the company. Although a part of a larger company, the innovative spirit at Keithley has remained constant—its rich history and legacy of accurate and fast measurements remain driving forces within the organization and help ensure continuing customer loyalty.

We spoke with Linda Rae, president of Keithley, about some of the revolutionary test and measurement products Keithley is producing, the biggest markets and technologies for potential growth, and what it takes to get young students into the engineering field.
The only way we can identify how we are going to add value and deliver a good return on investment is to understand the applications. That’s been the core of our strategy for decades now.”

You are both the president of Keithley and the commercial president of Tektronix. What motivates you to push these companies forward in your current roles?

First, let me explain my roles. My role as the president of Keithley is to manage that particular product line—the R&D, product marketing, and applications engineering teams. This is the role I assumed after our acquisition by Danaher.

My commercial president role is to manage the sales teams for my regions to sell our entire Tektronix plus Keithley portfolio. This role provides me the opportunity to gain exposure to the Tektronix product lines and to leverage the experience I have had in these regions during my work with Keithley. They really are two different roles, but there are definitely some overlaps.

The primary motivation for both roles is to drive growth. The challenges, however, are somewhat different. On the Keithley side, our focus now is on accelerating our growth by ensuring we are making good choices about how we are spending our R&D and marketing dollars, and getting good leverage from our R&D teams. We are also always looking for opportunities for more collaboration between the Keithley product line and other product lines within Tektronix.

On the commercial side, it’s also about growth. Each region has its own economic challenges that we have to work through. The economic situation in Japan has been challenging this year, and the Americas have been challenging with the government sequestration and shutdowns, but we still have numbers that we have to hit. We need to be smart about our leverage of our total platform and wide variety of products. In many cases, we have a stronger story to tell when we tell a story across multiple products and across both brands. That’s been an interesting challenge and opportunity.

How has the Tektronix acquisition affected the way Keithley does business?

As I mentioned, we are not a separate company anymore—we are now part of Tektronix and we represent an important product line within the company. All functions other than R&D and marketing have been completely integrated. This has changed peripheral aspects of our business and our go-to-market strategy, but it has opened a lot of new opportunities for partnerships and distribution that we didn’t have when we were a smaller, separate company.

In many ways, the acquisition hasn’t changed us, particularly in our focus on R&D and innovation and the types of applications that we serve. Our strategy is still to understand our customers’ application needs deeply and feed that information back into our products. The nice part about the Tektronix acquisition is that our products are very complementary with each other—there was almost no overlap. Our combined portfolio includes products that can and do get purchased and used together, so there’s a lot of synergy in that regard. Plus, the companies have similar cultures—both were started in 1946 by visionaries who were leaders in their technical fields at the time. Both place a high priority on innovation and bringing cutting-edge technology to our customers. In that regard, we just reinforced what was already important to us and gained greater access to resources than when we were a separate company.

The acquisition hasn’t hurt us a bit from an innovation standpoint. In fact, we just received our 23rd “R&D 100” award and a “Product of the Year” award from Electronic Products Magazine, so we are still putting the edge with innovation and technology within our own product line, but we are now doing that within the context of a larger organization.

What are some emerging trends that will shape the test instruments of the future?

One of the trends we’ve been seeing is that the nature of our customer base is changing. Today’s customer base is a younger generation used to a different, more intuitive user interface. We’ve taken this to heart. For example, we just launched a new product, our Model 2450 SourceMeter SMU instrument, which has an intuitive touchscreen graphical user interface. The entire focus of that product, from a user experience, has been on simplifying startup and getting our customers to their answers more quickly. That starts with having something that is intuitive to use by someone comfortable with touching a screen. We’re definitely ahead of the trend with this product—it’s the first touchscreen SMU on the market. It’s not just the screen itself—the whole user interface has been re-architected to be much easier and more intuitive to use.

Measurement speed is also something that continues to be an important trend. This is the test and measurement equivalent of Moore’s Law—we are always going to be looking for more speed. But it’s not just speed; it’s really cost of test. We focus on the total value we provide, but a lot of the time it just comes down to raw measurement speed. In addition, as we look at how the electronics industry is evolving, there’s a lot of movement in the power area requiring a much wider dynamic range in instrumentation than was required five years ago. These demands create challenges for instrumentation manufacturers—to be able to reach the higher power ranges while maintaining the accuracy of very low current measurements and doing it all at faster measurement speeds.

What new technologies are coming out that have the most potential for growth?

Any kind of component or device that’s associated with mobility—mobile phones, tablets, or smartphones—is an area that will continue to grow. I mentioned the power area—within that broad label of “power,” there are new materials being used for power semiconductor devices that increase their efficiency. The power efficiency category also includes a number of alternative lighting technologies such as organic LEDs; there’s a lot of innovation going on in that area.

We are also seeing growth in electrical measurements being made within non-electronic departments or labs. For example, in the electro-chemistry space or the material sciences space, as companies are pushing the envelope on power requirements, they are introducing a whole new set of materials. That, in turn, introduces a whole set of electrical measurements being made by chemists rather than EE’s. This opens opportunities for us to move beyond electrical engineers and give non-EE’s the tools they need to make good electrical measurements.

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“My message to younger engineers is that if you want to touch and enable the entire electronics industry, then test and measurement is the field for you.”

How do you get engineers to see the real value in buying new test and measurement equipment?

It starts with really understanding our customers’ applications. The only way we can identify how we are going to add value and deliver a good return on investment is to understand the applications. That’s been the core of our strategy for decades now. Then, once we have a good understanding of an application, we look for ways to optimize customers’ cost of test because it all comes back to dollars—we need to prove to them that by spending x dollars on a new piece of equipment or upgrading what they have, they will end up saving time and money. The return is only generated if I can add financial value to our customers in addition to the measurement value. We have to be clear on how that economic equation works and then we need to make sure we have a close enough partnership with customers so we get the information we need from them in order to play that equation out.

I think that one of the things that makes the Keithley brand so valuable to customers is that we took our legacy of accurate measurements and we merged it with this core capability of fast measurements without sacrificing accuracy. Relatively few instrumentation companies can combine them successfully. For the customer, that combination of speed and accuracy delivers a multiplicative effect because it allows them to achieve higher yields with faster throughput.

The last piece is flexibility. Sometimes, the answer is you don’t need to buy a new piece of equipment because you can do more with a piece of equipment that you already have. If that’s the case, then that’s what we tell customers. We help them get the maximum return out of what they’ve already bought, because that’s one of the important ways we can add value as a vendor. This helps build trust in the vendor-customer relationship, which can help customers feel confident about subsequent purchases. We architect our products to have multiple functions. Our SourceMeter SMU line is the perfect example of that. We’ve integrated a DMM with a programmable power supply and a load, so engineers can do a lot of things with it. Our newer SourceMeter SMU instruments are designed with the flexibility to create scalable test solutions by combining multiple units. We have both single- and dual-channel versions, all of which are designed with embedded test script processor technology. Once they’re integrated into a system, any of them can control the other units in the system with a fast, easy-to-use test script.

How do you get young people into electrical engineering and test and measurement in particular?

First of all, I look for opportunities to talk with students. I’ve been involved in programs where we talk to high school students to convey the message that engineering is a very exciting field. The first thing I do with these students is ask what an engineer is. The answer always comes back to this: an engineer is a problem solver. From there, we go through the different types of engineering. These different types of engineering consist of solving problems by using different fields of science. In terms of electrical engineering, we solve problems using physics. We are people who have an interest in math and science and in how to apply these sciences to do something great.

How do we get people interested in test and measurement? Well, test and measurement is cool because you don’t have to pick one industry; you don’t have to be designing smartphones your whole life: you get to touch many different electrical industries throughout the course of your career, test and measurement is at the hub of the wheel in the electronics industry. We stay abreast of what’s going on in diverse segments, such as automotive electronics, medical devices, and consumer products, and enable innovation and technology advances in all of these fields. My message to younger engineers is that if you want to touch and enable the entire electronics industry, then test and measurement is the field for you.

In terms of getting more women involved in electrical engineering, we have to go back to middle school. To get more women into math and science and ultimately engineering, we need them to stick with math and science through middle and high school. There are studies that show that girls in elementary school don’t think in terms of whether or not they should be good at math or science. But something happens in those middle school years and too many girls end up deciding they’re not good at those subjects or they just don’t like them. As a result, they tend to select a path from middle school to high school that is not in line with math or science. By that point, it’s almost impossible for them to pursue engineering. What we’re trying to do is reach out to those 12- to 14-year-old girls and keep them engaged in math and science so they can be part of the pool of future engineers.
Keithley’s NEW SourceMeter SMU

The Model 2450 SourceMeter SMU addresses the current trends in the Test & Measurement industry.
That’s the view of Jonathan Tucker, a senior marketing and product manager at Keithley Instruments. Tucker reports that over the last few years, three common refrains have surfaced:

• A need for simplicity: Users want instruments that are simple to understand and use without dozens of front panel buttons or confusing menu structures. They also want instruments they can operate without the need to refer to a manual constantly.

• A need for speed: Instrument users are under increasing time pressure, so they need solutions that are simple to set up and deliver results quickly.

• A need to focus on what’s important to them: Increasingly, those using instruments are experts in fields other than test and measurement. They want instruments that are easy to learn and use.

Keithley executives are also taking into account some other significant challenges that customers are facing, including shrinking product design cycles (down by 13 percent over the last three years) and fewer dedicated test engineers on staff. At the same time, a growing number of engineers from non-EE disciplines are being asked to perform testing, but they often have limited experience configuring electrical measurements.

To address the needs of the changing test and measurement market and help users of all levels of sophistication learn faster, work smarter, and invent easier, Keithley has developed a new design philosophy based on three principles:

• Touch: Allow the instrument’s user to reach out and literally touch the data.

• Test: Help the user to perform a test accurately and get results quickly.

• Invent: Give the user the time needed to focus on his or her next breakthrough.

The result was Keithley’s first instrument with a touchscreen interface. Touchscreens put interactive control at the user’s fingertips and anyone who owns a smartphone or tablet computer is already familiar with interacting with them. Rather than forcing personnel who are juggling new responsibilities to configure measurement functions using cumbersome, multilayer menu structures and confusing multifunction buttons, the Model 2450 SourceMeter® Source Measure Unit (SMU) Instrument (Figure 1) has a full-color, five-inch touchscreen user interface that offers gestural operation, much like a smartphone or tablet computer.

Keithley’s design team replaced the complex, multilayer menu structures common in earlier instrument designs with a set of intuitive icons, dialog boxes, and QuickSet modes to make configuring measurements faster and more intuitive (Figure 2). Only the options relevant to a specific function are displayed on the screen, minimizing “clutter” and eliminating confusion.

The Model 2450 combines the functionality of a power supply, true current source, 6-1/2-digit multimeter, electronic load, and trigger controller in one tightly integrated, half-rack instrument. These multiple functions allow the Model 2450 to integrate the capabilities of I-V systems, curve tracers, and semiconductor analyzers at a fraction of their cost. However, unlike any of those instruments, its touchscreen GUI allows both configuring measurements and displaying results right on the instrument itself, so users get actionable information rather than simply raw results. See a video demonstration here.

Keithley’s Model 2450 SourceMeter SMU Instrument has a full-color, five-inch, capacitive touchscreen that allows users to configure measurements and display results in numerical or graphical form.

Optimized for Both Benchtop and Rack-Based Applications

Source Measure Units (SMUs) are widely used on the benchtop in lab environments, and the Model 2450 offers a variety of features that optimize its use in those settings. For example, the touchscreen’s full-color display and large on-screen characters enhance legibility in lab environments. The intuitive icon-based menu structure allows users to reach any measurement set-up panel with just two touches. Also, banana jack inputs on the front panel enable convenient signal connections.
The Model 2450 provides GPIB, USB 2.0, and LXI/Ethernet interfaces, a digital I/O port, interlock, and TSP-Link connections to simplify integrating it into automated production test systems.

On-screen buttons work in conjunction with the instrument’s physical pushbuttons and quick-navigation control knob to help users operate the Model 2450 with confidence. The pushbuttons provide ready access to menus, quick configurations and function selection, triggering, and the context-sensitive on-screen help function that minimizes the need to consult a manual. The control knob lets users operate the on-screen controls mechanically, without the need to touch the display for situations in which screen contact is impractical. The knob also allows selecting menus, tabbing through editable fields, and increasing or decreasing values.

Extended measurement ranges provide the superior low-level performance R&D applications often demand. Both low current (100nA, 10nA) and voltage (20mV) ranges are included, which make it unnecessary to add separate low-level instruments to create a benchtop system. Back-panel triax cable connections eliminate the need for expensive cable adaptors, which can degrade low-level measurement performance.

New SMU users will appreciate Keithley’s new instrument control non-programming start-up software called KickStart, which makes it possible to start taking measurements in minutes. For more complex analyses, data can be easily stored to disk, and then exported to Microsoft Excel® or another software environment.

Because they combine sourcing and measurement functions in one instrument, SMUs are common choices for automated production test applications. The Model 2450 includes a variety of features designed to simplify integrating it into larger, rack-based systems. Onboard Test Script Processor (TSP®) technology embeds complete test programs into non-volatile memory within the instrument itself to provide higher test throughput by eliminating the GPIB traffic problems common to systems dependent on an external PC controller. The TSP-Link® channel expansion bus connects multiple Model 2450 instruments and other TSP-enabled instruments in a master-slave configuration that operates as one integrated system.

A built-in SCPI programming mode allows taking full advantage of all the Model 2450’s new features. A separate SCPI 2400 mode provides backwards compatibility with the popular Model 2400 SourceMeter SMU Instrument, which was introduced in 1995 but is still widely used in production test applications today. Not only does this mode preserve current Model 2400 users’ investments in application software, but it eliminates the re-work normally associated with adding a new instrument to an existing system.

Rear panel triax connectors, multiple instrument communication interfaces (GPIB, USB 2.0, and LXI/Ethernet), a D sub 9-pin digital I/O port (for internal/external trigger signals and handler control), instrument interlock control, and TSP-Link® jacks simplify configuring multi-instrument test setups.

Conclusion
The next generation of test and measurement instrument users has already arrived. In order to help these users do their jobs effectively, instrument vendors must rethink their instrument design strategies to deliver the easy-to-use solutions that users want without sacrificing the measurement accuracy that their work demands.

Front view of the Model 2450
Our Assignment: Several years ago my team was given an assignment to measure RF radiation from Low Power CMOS ICs. In this article I’ll describe the setup we designed and some of the problems we overcame to measure the weak radiation from CMOS Imager ICs.
The IC Antenna and Transmitter

IC RF radiation occurs when RF charge flows through the antenna formed by the IC package. Depending on the IC package design the RF charge flow is through the lead frame and bond wires or through the substrate and bond wires. These structures form electrically small loop antennas and the bigger the loop area the higher the RF field strength. The transmitter, which is the source of RF current, consists of the signals driven to the IC or the signals driven out of the IC Clock and DQ pins. Both of these sources can be comparable in amplitude. Additionally, there is RF Power Pin current due to processes internal to the IC.

The Challenge

Our most challenging measurement was a CMOS imager producing RF noise in the 800 MHz Cell Phone band. In the Cell phone the dominant noise source was a harmonic of the system clock signal driven to the CMOS Imager. This harmonic could be attenuated by filtering the system clock and that left the CMOS Imager as the dominant RF noise source. Even though the CMOS Imager RF noise amplitude was relatively weak it was enough to interfere with a cell channel. This tight coupling between the IC and the receiver is due to the Imager being mounted to the cell phone PCB. The challenge for us was measuring the weak CMOS imager signal accurately enough to gauge various experimental changes to the IC. In our test setup the 825 MHz signal strength from the IC was just -20 dBuV/m measured at a distance of 180 mm.

Test Setup

Due to the weak signals to be measured a quiet RF environment was needed. Fortunately, our semi-anechoic EMC chamber provided more than enough attenuation of outside cell phone signals so that all we received inside the chamber was our EMI receiver noise floor. But placing the lab signal generator and digital pattern generator inside the chamber obscured the IC signal. Our two choices to fix this noise were:

1. Place the IC inside a TEM Cell
2. Place the generators outside the EMC chamber and route the stimulus signals through the EMC Chamber bulkhead using double-shielded coaxial cables.
3. House the generators inside a well-shielded enclosure inside the chamber.

We choose (3) with the setup shown in Fig. 1 to house the generators, power supply, and an oscilloscope inside an enclosure in the chamber for two reasons: it allowed us to more easily get the IC and equipment working together and we also avoided issues with connector and cable RF leakage. The TEM Cell was rejected because NEC simulations showed that the dominant radiation mechanism was cable shield radiation due to common-mode current. This would cover up what we wanted to measured, radiation from the IC package itself.

To completely contain RF noise the test equipment was mounted inside a TEMPEST cabinet having RF gaskets on all panels and the front access door. Additionally, the cabinet had a TEMPEST EMI filter for AC power and an RF attenuating honeycomb cooling air access. Clock harmonics were eliminated by using a clean 25 MHz sine wave rather than a square wave.

The Test PCB

To mount the Test PCB to the cabinet a 3” x 3” hole was cut in the top of the cabinet and the paint around the hole was sanded off. This arrangement allowed cabling to the Test PCB from inside the cabinet with the IC soldered to the top of the Test PCB to freely radiate into the EMC Chamber. We found that SMB connectors were ideal for connecting the many signal lines and DC power cables to the IC. The SMB connector provides the ease of push-on/pull-off connectivity while maintaining good signal integrity. An eight layer PCB was used with the top and bottom layers forming gold plated ground layers for shielding. The ground layers were stitched together with via’s every 0.2 inches. To ensure excellent isolation a wire mesh RF gasket was placed between the cabinet top and the PCB bottom. The PCB was pressed against the gasket using four Destaco brand manual clamps hold the PCB against the RF gasket.

Receive Antenna

After analyzing our large EMC Log Periodic antenna we decided that a simple half wavelength dipole antenna would be better for receiving the small signal from our ICs. The advantage of the dipole is that it can be placed close to the IC where the RF noise field...
strength is higher. We placed the dipole a very close \(\frac{1}{2}\) wavelength above the IC so that the relatively weak signal could be accurately measured. To explore the effects of antenna placement we used a NEC (Numerical Electromagnetics Code) simulation to prove that that placing the dipole close would not significantly corrupt the measurement. In fact, the measurement error caused by the close antenna placement is only 1 dB. By turning the dipole in the azimuth we could to plot the IC radiation pattern and “see” the orientation of the bond wires.

**Spectrum Analyzer & Clock Generator**

The receive antenna was cabled to a battery powered preamp having a noise figure of 3 dB. This fed a spectrum analyzer having an RBW (Resolution Bandwidth) of 10 Hz. With an antenna-to-preamp coax loss of 3 dB and the preamp the measurement noise floor was -156 dBm, allowing us to accurately measure IC radiation down to approximately -150 dBm.

Between clock generator and the spectrum analyzer frequency error and drift, and the narrow RBW, finding the signal was a challenge. We fixed this issue by phase locking the clock generator and the spectrum analyzer together. To accomplish this, the clock generator 10 MHz reference output was cabled to the spectrum analyzer reference input through a BNC bulkhead connector on the cabinet.

**Test Results**

Our work to obtain adequate signal-to-noise ratio and eliminate clock harmonics allowed us to measure various IC treatments including DQ load impedance and DQ strength changes.

**About the Author**

David Cuthbert is a consultant with expertise in EMC Design, Signal Integrity, RF, Antennas, Design Review, Power Electronics and Instrumentation and Measurement. In other words, everything analog with no microprocessor or software. He holds 27 patents including an antenna patent.

David is a NARTE Certified EMC Engineer with several years of experience in Military EMC including DC and AC EMI Filter and TEMPEST filter design. His EMI filter designs meet all specifications including conducted noise, conducted susceptibility, AC Power Factor, THD, Inrush Current, and Middlebrook criterion. David also has expertise in semiconductor EMC.