Reinventing the Transmit Chain for Next-Generation Multimode Wireless Devices

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Upcoming generations of radio access standards are placing high demands on the RF transmit chain, requiring significant improvements in size, integration, and functionality while improving power efficiency for multimode wireless devices. To date, trends in RF integration have been to add redundant circuits to accommodate new standards, packing more complexity into the circuit, and then shrinking it. However, this approach often requires a necessary compromise in performance and yield, with physical limits in terms of overall size reductions. A new approach is needed that incorporates a streamlined architecture to accommodate the additional levels of complexity due to multimode functionality, while improving efficiency, yield, and size, and meeting regulatory compliance.

Increasing Complexity

The need for more integration in multi-mode wireless devices is undisputed. The news media and wireless service providers have done an excellent job of raising consumer expectations, so that subscribers now expect instant access to voice, text, web, location-based, and mobile TV services in their handsets—without sacrificing battery life, form factor, or convenience.

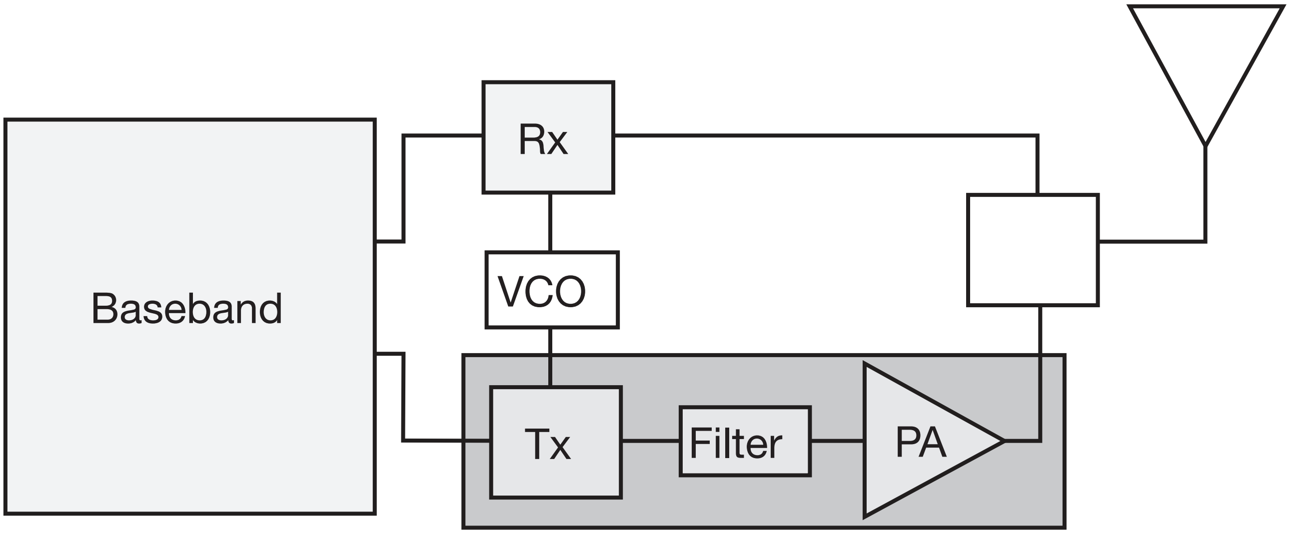
In a traditional design, each service requires its own dedicated signal chain. So, as each feature is added, the pressure to integrate and include chips with small footprints intensifies. In response, the semiconductor industry has leveraged its expertise in design, foundry process improvements, packaging, and manufacturing to shrink radio modems to smaller and smaller form factors. However, high-power device structures, such as those found in RF power amplifiers (PAs), do not benefit from CMOS geometry shrinks as digital and small signal structures do. Instead, GaAs materials are typically used to support the necessary voltage swings that are required for adequate output power and linearity in RF PAs. Unfortunately, the continuing pressure for smaller circuitry raises important concerns, specifically the tradeoffs between efficient use of power and acceptable linearity.

Conventional approaches have practical limitations. In multimode handsets, the compromise is usually the use of multiple transmitters and power amplifiers, each optimized for specific modes of operation. In its place, an advanced transmit chain architecture is needed that is inherently designed to provide smaller size, higher integration, better thermal performance, and higher efficiency. One way to achieve this is to use a unified RF architecture that handles all transmit and power amplification functions for multiple access technologies, such as cellular, UMTS, WiMAX, and LTE, regardless of modulation type. Of course, this new architecture must be compliant with regulatory and industry standards, and be efficient in its use of power. In addition, it would ideally use common, narrow-band-gap bulk materials that would facilitate an integration roadmap to common silicon semiconductor materials.

The good news is that commercialization is now underway to incorporate the advantages of this type of solution. A new architecture, referred to as an "agile" radio, features a single unified architecture that handles all modulation schemes. Production ready silicon of agile radios are now being demonstrated, and the initial measured results are very promising. This new architecture is now poised for volume production.

Agile Radio Architecture

The new transmit architecture replaces the entire transmitter in a conventional radio



architecture, as shown in Figure 1.

Figure 1: Agile Radio Transmit Process Replaces the Transmitter in a Conventional Radio Architecture

In Figure 2, the conventional transmit IQ modulation and amplification chain (2a) is contrasted with the agile-radio transmit process, referred to as the d2p™ RF Power Modulator (2b). In the conventional transmit process, accurate preservation of the directly modulated AM/PM waveform requires linear amplification to preserve the integrity of the modulation; excellent linearity and high efficiency are inversely correlated. The d2p process combines and re-organizes the functions of traditional transmitters and power amplifiers to present a single unified multimode non-linear architecture that handles numerous access technologies. In one step, an agile radio converts a signal from baseband data to modulated RF at the desired output power with no intermediate frequency (IF) stages and no interstage support of the complex RF waveform.

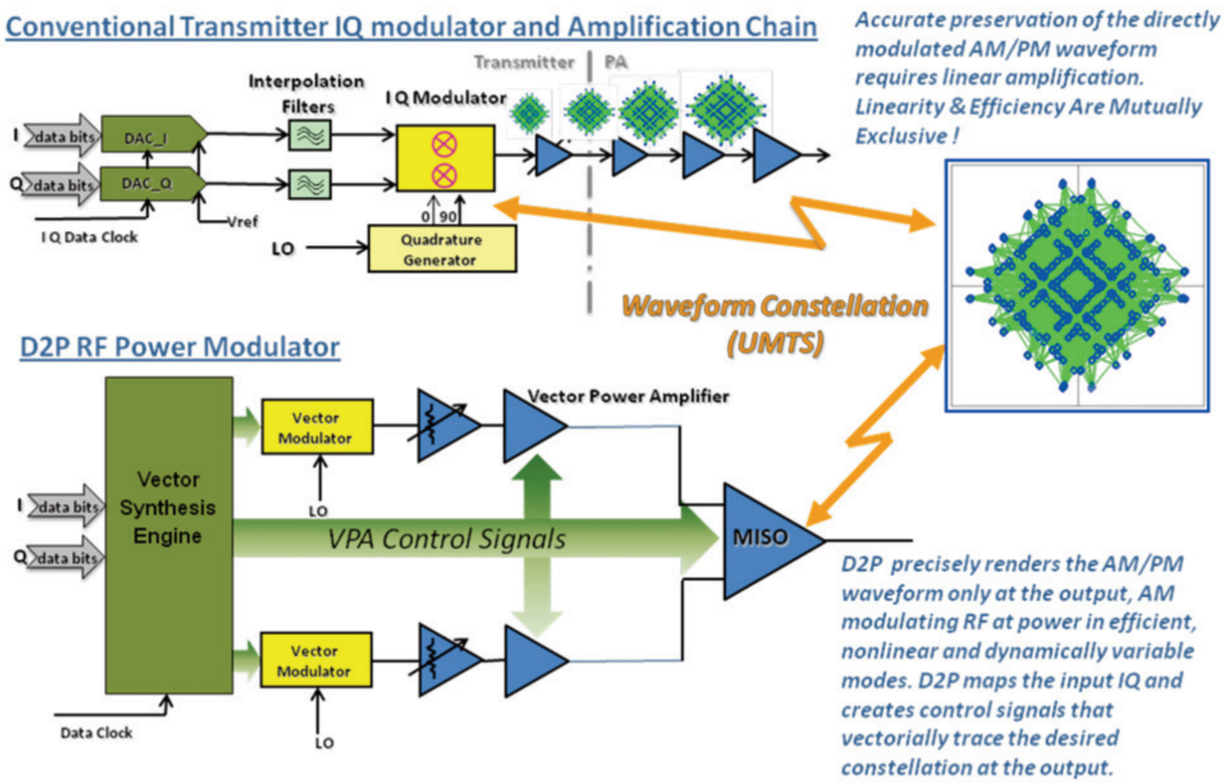


Figure 2: Conventional Transmitter IQ Modulator and Amplification Chain (a) vs. the d2p RF Power Modulator (b)

Specifically, this agile radio architecture decomposes and converts baseband in-phase and quadrature (I/Q) signals into data streams for non-linear vector-power-amplifier (VPA) control signals. d2p maps the input I/Q data and creates control signals that vectorially map the desired constellation at the output of the VPA.
These non-linear controls allow the VPA to run in high saturation through the final processing and gain stages. Modulation and final amplification take place simultaneously at the RF output of the VPA. In this process, d2p precisely renders the composite AM/PM waveform only at the output, AM modulating RF at power using efficient, nonlinear and dynamically variable classes of amplification. This is a key difference between agile radios and traditional architectures, which attempt to linearly amplify and preserve the completely modulated RF waveform, starting in the small signal domain.

Figure 3 shows an application where d2p technology is being used to replace a traditional RF transmitter and PA. In this 3G application, the entire solution, including power management and synthesizer circuitry, is packaged in 100 square millimeters with a minimal number of passive external components. The d2p package in this figure replaces all of the components in the outlined area on the original board.

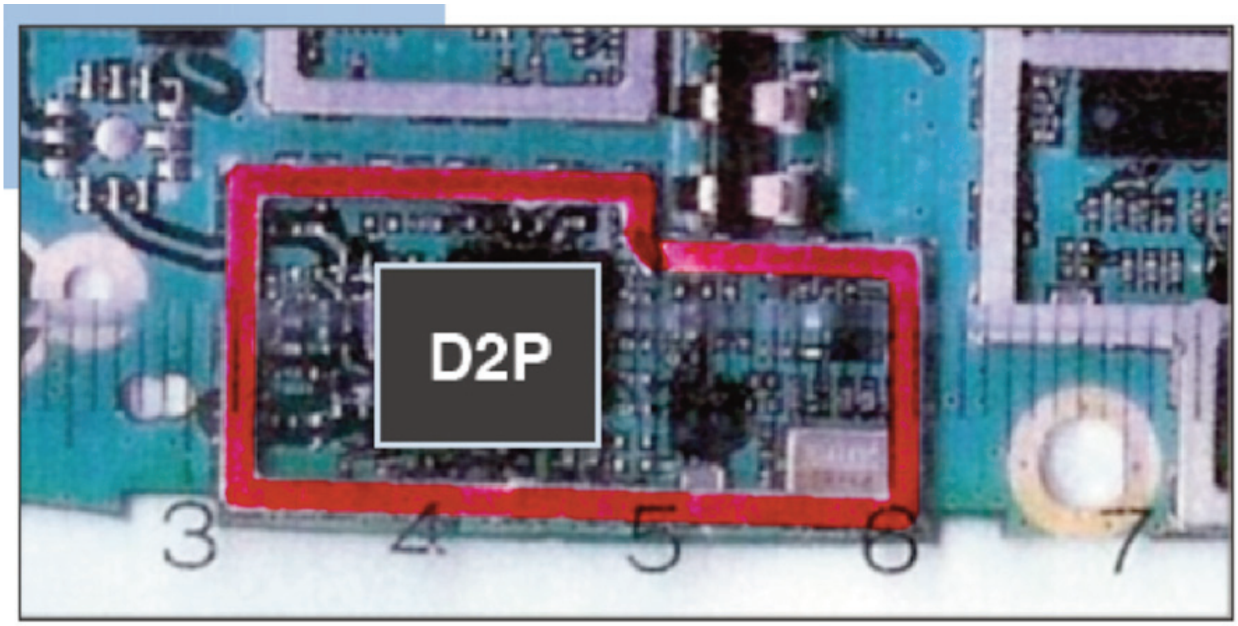


Figure 3: In this 3G application, all functionality from I/Q data to modulated RF at full power is contained within a single module using silicon-based semiconductor materials.

To more fully understand the d2p agile radio architecture, it can be helpful to understand what it is not. The d2p agile radio architecture should not be confused with predistortion, which is a technique to improve linearity so that radios can handle more complex waveforms. Predistortion attempts to cancel any nonlinearities imparted to the modulated waveform due to the amplification process after it passes from the modulator and moves to the transmitter output. A d2p agile radio does not have a fully modulated waveform within the active circuitry, allowing operation in a nonlinear mode without the use of conventional predistortion. d2p agile radio is also not driven by a power-hungry digital signal processor. Instead, characteristic nonlinear mapping functions are embedded within a simple state machine, the Vector Synthesis Engine (VSE), that interprets the desired response based on the input IQ data and manipulates the VPA using the control signals or vectors. Performance may be optimized or corrected to accommodate manufacturing variations over a wide range or performance goals or yield, respectively, by programming a small block of memory registers at the time of manufacture. d2p does not require complex or real-time feedback loops or output combiners, nor does it perform polar or envelope tracking.

Figure 4 shows a system level flow for d2p technology, the device on the left is a d2p vector synthesis engine, manufactured in CMOS, which integrates a small digital state machine, non-volatile memory (NVM), fast static random-access memory (SRAM), and digital-to-analog converters (DACs) to control the vector power amplifier (VPA) upper and lower branch phase, amplitude, and bias. The digital baseband I/Q data enters the vector synthesis engine, then it passes to the chip on the right, which is a d2p VPA manufactured in SiGe, where the modulation and amplification occur. As with traditional systems, this architecture uses a conventional synthesizer.

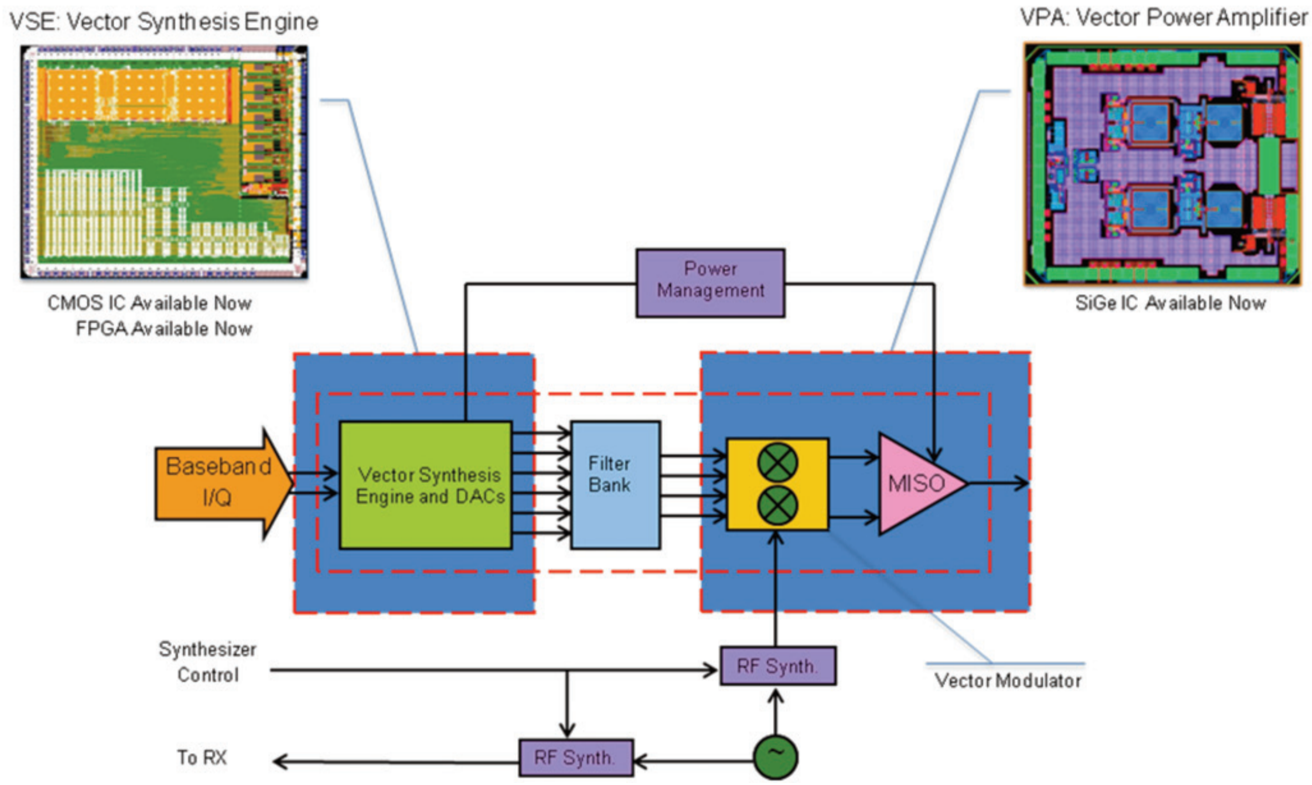


Figure 4: System level diagram using agile radio architecture.

Functionality

Developmental systems and applications boards for d2p agile radios are available, now, which support any radio access standard with a single circuit over a wide frequency band. For example, a low-band VPA can support UMTS/EUTRA bands 5, 6, and 8 (824-915 MHz), while the high-band VPA can accommodate UMTS/EUTRA bands 1, 2, and 3 (1710 MHz to 1980 MHz). The VPAs are capable of passing all types of waveforms, including GSM, EDGE, WCDMA, cdma2000, TD-SCDMA, HSUPA, LTE, and mobile WiMAX, while meeting regulatory requirements and improving efficiency over legacy linear transmitter-PA chains. The following performance graphics highlight EDGE, HSUPA, WCDMA, and LTE performance. All of these measurements were made using the same 180nm SiGe VPA chip. Note that these waveforms represent the combined modulation and amplification functions of d2p with the device operating at full output power.

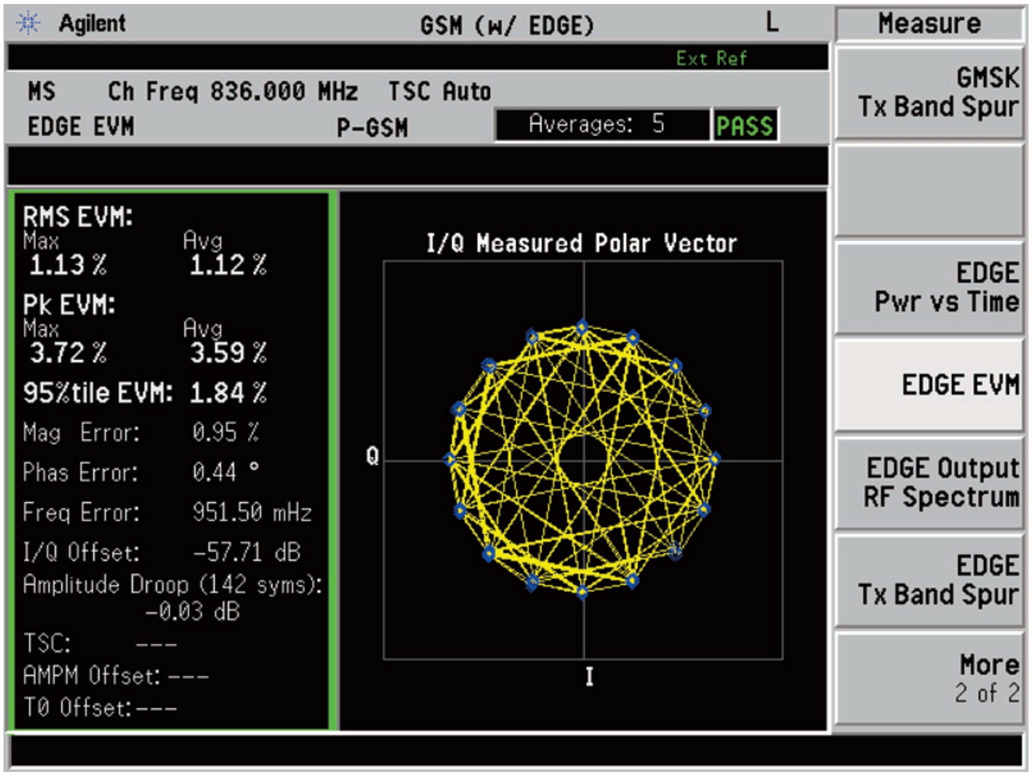


Figure 5: Measured EDGE Modulation Accuracy for a Multimode d2p VPA.

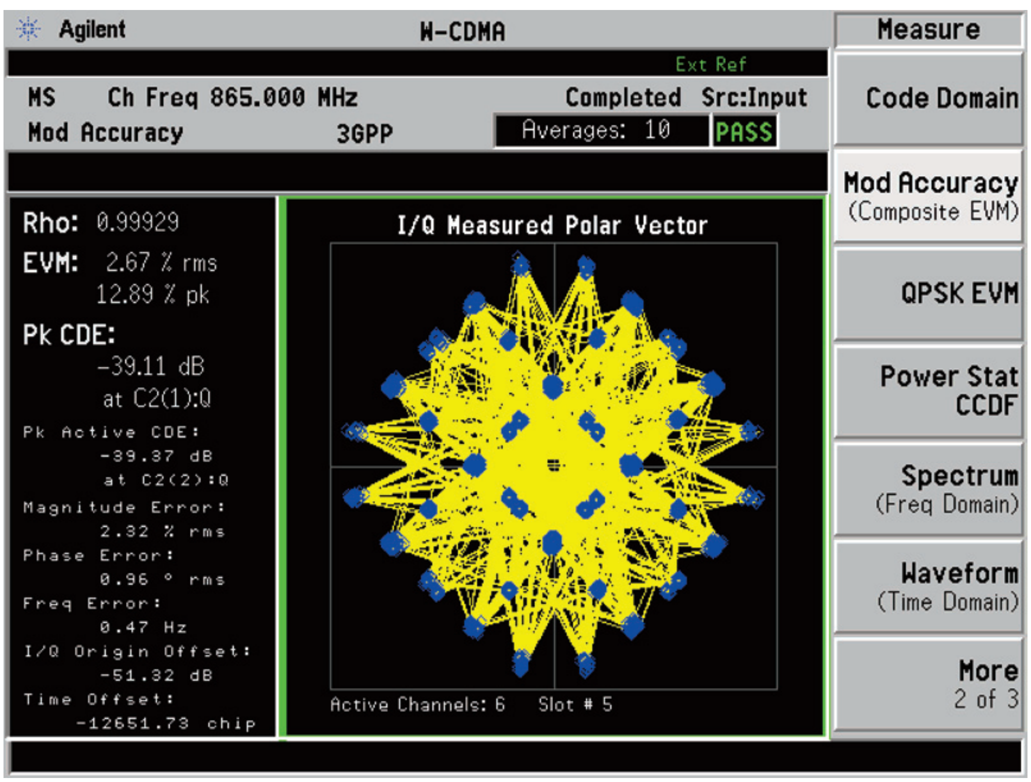


Figure 6: Measured HSUPA Modulation Accuracy from a Multimode d2pVPA.

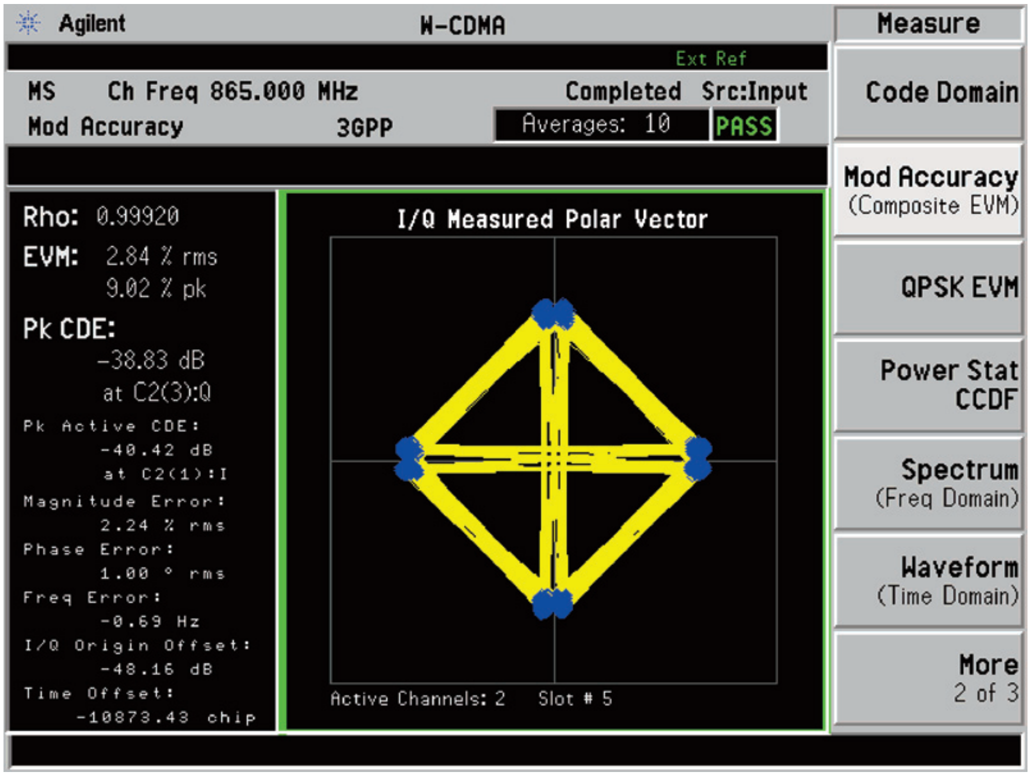


Figure 7: slide Measured WCDMA Modulation Accuracy for a WCDMA Multimode VPA

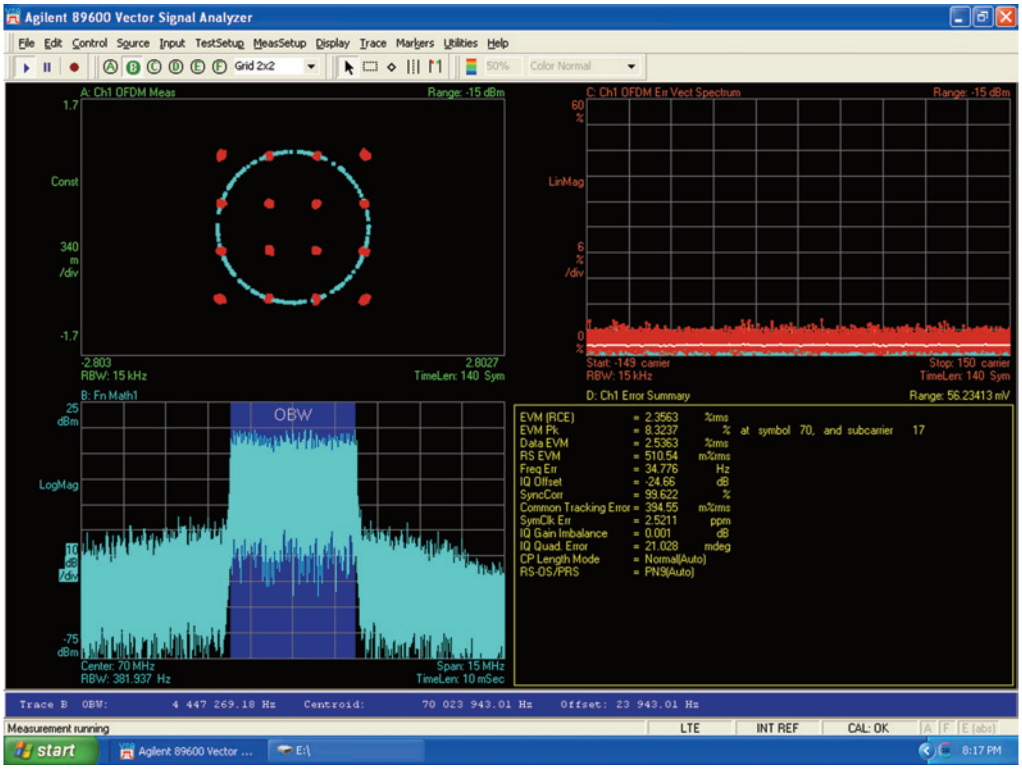


Figure 8: slide 18 Measured LTE 16 QAM

In Figures 5-8, the same d2p device provides exemplary modulation accuracy for 2G, 3G, and 4G signals without any additional hardware or circuitry. Figure 5 shows the measured performance of the D2P device for a EDGE signal. In Figure 6, the VPA is moduating an HSUPA signal, and in Figure 7, it is producing a WCDMA signal. Figure 8 shows a 16-QAM LTE signal produced by the same d2p device.

Efficiency

Any device used in a mobile handset needs to have high power efficiency in order to preserve battery life. It is most important and challenging to achieve high power-added efficiency (PAE) in the RF PA in the presence of high peak-to-average-ratio (PAPR) carrier signals, such as those found in the 3G, 3.9G, and 4G standards. Any new architecture that boosts efficiency could have the potential to dramatically change battery life expectations in mobile handsets and data devices. The agile radio architecture regularly demonstrates higher PAE than traditional architectures; these gains improve even more with increasing peak-to-average-power-ratios in the waveforms.

Figure 9 shows measured PAE vs. output power for a d2p VPA, when handling a WCDMA signal. This figure also compares the VPA performance to three commonly used PAs currently available on the market from leading manufacturers. Note that the traditional approaches have a sharper drop off in performance, particularly in the area of 40mW (+16dBm) output power. (These efficiency measurements were taken at the same time as the constellation diagrams in Figures 5, 6, 7, and 8.) The traditional PAs that spike back up in efficiency after the drop off actually have architectures that switch to a smaller PA that is optimized for lower power levels or an alternate low-power bias arrangement.

Unlike traditional PA approaches, when the waveform becomes more complex and the PAPR increases, the agile radio performs better relative to linear techniques. This is because the agile radio dynamically and continuously varies the load line of the VPA from saturated switching conditions at the higher amplitudes to increasingly linear conditions as the amplitude decreases, providing both excellent efficiency and linearity. As a result, when compared to traditional PAs, a d2p VPA demonstrates relative PAE improvements of more than 30% for WCDMA over a wide output-power range. In Figure 9, note that very high efficiency is sustained over a broad output power range for the agile radio VPA,which demonstrates 46 and 57.4% PAE at 100 and 600 mW respectively

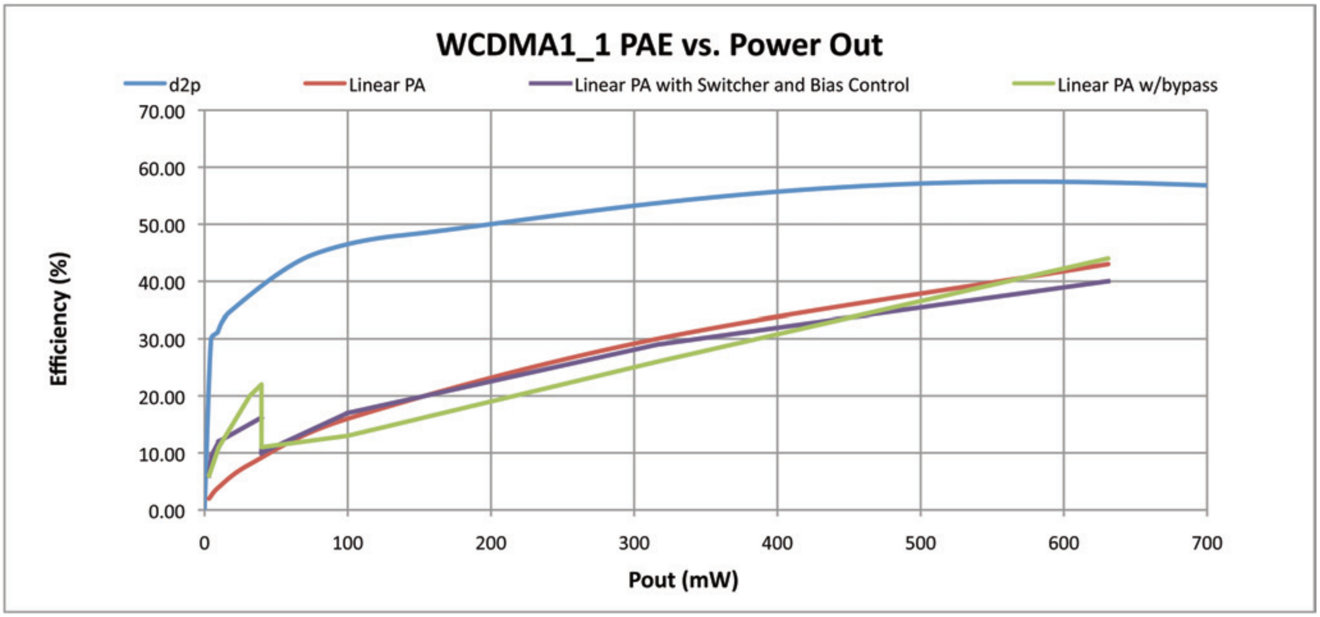


Figure 9: PAE vs WCDMA Measured Output Power comparing a d2p VPA to various available amplifier technologies.

Yield

In d2p agile radio, the VPA operates in nonlinear modes with high saturation through the amplification process until the final modulation step occurs. This is unlike a traditional architecture, which attempts to preserve linear signals throughout the entire radio transmitter. This is significant because an agile radio is not constrained by the need to sustain a linear signal, which improves the overall robustness of the system. Because an agile radio combines the modulation and amplification functions and manages them using many different simple control points, there are several degrees of freedom before transmission, allowing the system to be calibrated to account for yield or compensate for non-ideal components in the system, such as surface acoustic wave (SAW) filters.

In addition to improvements to system performance, the agile radio reduces component level testing requirements. For instance, because the agile radio can be calibrated, system designers could choose to integrate much of the radio front end within the same module, where the VSE could be programmed to compensate for the other components in the system. With traditional architectures, a battery of overlapping functional tests is typically run on the transceiver and, separately, on the PA. The d2p agile radio architecture allows for a single set of tests, eliminating many redundant manufacturing tests, reducing overall test time and increasing yield.

Regulatory Compliance

One of the challenges that advanced agile radio architectures have faced is achieving a high degree of waveform flexibility, while successfully meeting a wide range of compliance requirements, which may be different for each standard. The fundamental d2p technology has been developed to meet the rigorous specifications for compliance with the GSM, EDGE, CDMA, WCDMA, HSUPA, WiMAX, LTE, and TD-SCDMA mobility standards. When operating in these systems, it has been in compliance with all of the required specifications for every waveform, including full power output, power control, noise floor and spurious content, robustness over VSWR conditions, stability over temperature, stability over voltage range, and stability over broad frequency range.

For example, a common challenge for systems that try to operate in the nonlinear domain is spectral performance and noise. This has been addressed in d2p technology, and Figure 10 shows a noise profile of a d2p VPA. At 882MHz, with +31.4dBm output power, the transmitter noise is -133dBm at 45MHz offset from the carrier. This level is consistent with those of traditional radio architectures for FDD applications and would be near thermal noise at the RX port of a typical duplexer.

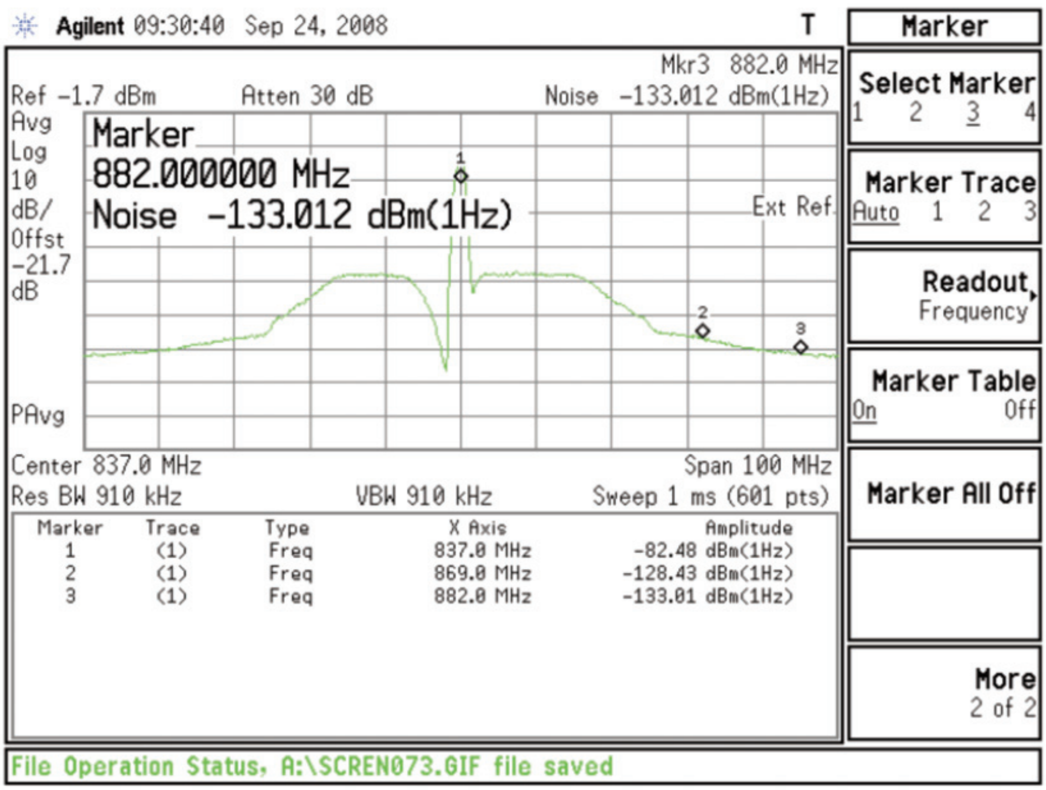


Figure 10: slide 28: The spurious noise performance of an agile radio architecture is comparable to that of traditional radio architectures.

Size

It is no secret that the real estate available inside of mobile handsets continues to shrink. As multiple modes, features, and services are packed into the handset, the need for higher integration and smaller bills of materials (BOMs) is reaching a critical level. And, in addition to reduced system footprint, a side benefit of higher integration is improved reliability.

An agile radio inherently reduces the BOM for a multi-mode cellular phone, because it eliminates the need for special purpose transmitters and multiple narrowband PAs. In traditional architectures, a WCDMA and GSM world-phone, for instance, requires separate PAs for the TDD frequency channels and more complex, UMTS waveforms. In an agile radio, both WCDMA and GSM signals are handled with a single transmit chain.

No discussion of integration is complete without addressing semiconductor processing technology. An agile radio could be built using any semiconductor process. ParkerVision's d2p technology uses CMOS and SiGe for lower cost, and superior integration options, as compared to GaAs. These options include co-packaging and integration of the d2p agile radio transmit chain with the receiver and the baseband processor. If desired, agile radios can also be realized using GaAs or standard CMOS.

The Future of Multimode Design

Agile radios in general and d2p technology in particular offer viable alternatives for designers looking to meet the needs of next-generation multimode wireless devices. This new approach focuses on simplifying the architecture rather than making it more complex, by dynamically manipulating a single circuit to handle a wide range of waveforms and frequencies. By turning a perceived disadvantage, nonlinearity, into an advantage, agile radios offer designers greater flexibility in compensating for all of the components in the RF signal chain, from the baseband to the antenna, while bringing significant increases in power efficiency and, consequently, talk time.

Once designers adopt this architecture, they can easily adapt to new standards, as they are developed. The highly reusable d2p sub-system requires relatively simple modifications for use in new designs, which will help reduce future design cycles and speed time to market. Reference designs are available from ParkerVision for select customer prospects, and commercial engagements are underway.