

Enhanced **RFCMOS** Paves the Way for **UWB** Systems

UWB circuit topologies using low-cost 180 nm RFCMOS allows system components to achieve high performance with low power in a compact design.

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Recent Ultra Wideband (UWB) product demonstrations have illustrated the many varied applications that will employ this technology including wireless and wired data communications systems with both mobile and fixed devices. This allows increased data rates and distances for personal area networks (PANs), wireless USB (WUSB) and high definition multimedia systems. Applications in wireless printers, hard disk drives, cameras, wireless HDMI and hybrid wireless-coax HD content delivery will change the way we connect our devices together. UWB technology promises to untether us from our cables.

Along with these new applications and untethered freedom come design challenges that result from the unique requirements of the UWB system. UWB is designed to operate across a large frequency range that is higher and wider (3.1 to 10.6 GHz) than most wireless systems use today [1]. The system also uses low transmitted power that doesn't interfere with other RF systems, but requires high performance receivers to operate at

such low signal levels. The RFIC design challenge is to achieve the required performance while still maintaining product size, power and cost for these applications.

The RFICs, including the LNA, VCO, and frequency synthesizer, are critical system components because of their significant impact on performance and cost. Using enhanced RFCMOS, optimized across the wide UWB frequency range, solves analog integration issues above 6 GHz where UWB performance is most critical and most challenging. This technology, along with novel UWB RFIC circuit topologies, provides the cost effective solutions that are needed to compete for tomorrow's connectivity.

The UWB Front End — An Analog Intensive Mixed-signal (AIMS) Application

The RFICs employed in the front-end of a UWB system are analog-intensive, mixed-signal (AIMS) devices because they provide high performance analog functions and integrate more complex mixed-signal cir-



cuitry. In AIMS applications, there can be no compromise between analog performance and the ability to integrate mixed-signal circuitry. The analog performance is crucial to the system and cannot be degraded. This challenge requires an advanced combination of design tools, IC technologies and circuit topologies.

The UWB front end is especially challenging because of the system requirements. Not only is the bandwidth larger than most wireless and wired communications systems, but the signal power is <1 mW, below the noise floor of other protocols to eliminate interference as shown in Figure 1.

The UWB approach provides a data rate up to 480 Mb/s which is greater than all of the protocols in Figure 1 and requires the most analog-intensive designs and technologies. And while performance is of paramount importance, cost and integration are still significant design challenges. Many different design approaches and IC technologies have been investigated to solve the UWB challenges.

As with most analog-intensive mixed-signal applications, the system can be optimized by choosing the best combination of circuit topology and IC technology. Because of the stringent system performance requirements, UWB applications require some novel circuit designs and the most advanced AIMS technology to implement these circuits in a cost-effective solution.

The ideal RFIC technology must include the following features:

- High speed, low-noise transistor characteristics at low bias currents required for high performance and low power dissipation
- High Q inductors and varactors required for accurate frequencies
- Dense analog integration capability for small die area without degrading performance or inducing noise
- Substrate isolation and accurate substrate noise models.

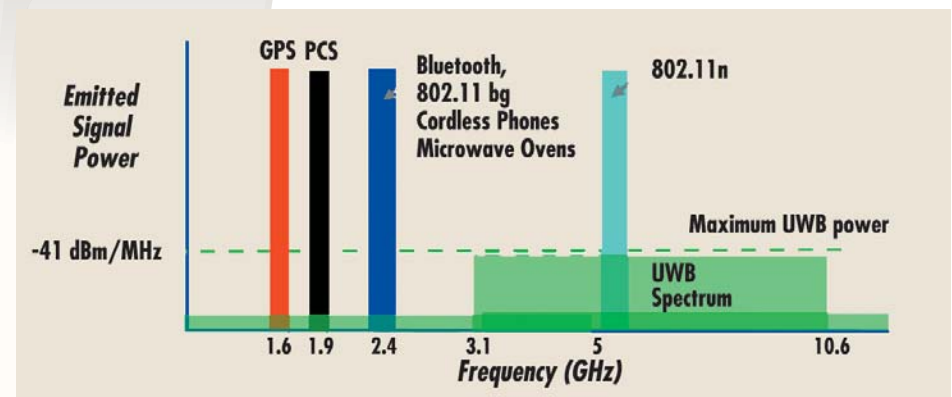
There are significant challenges to providing this

high performance analog technology in a low-cost manufacturing environment that supports mixed-signal integration. Many CMOS IC technologies provide a low-cost digital platform that can be applied in these analog applications with some trade-offs. However, implementing UWB analog-intensive functions requires RFIC technology optimized for performance and integration, not just digital gate density. A 180 nm enhanced RFCMOS can provide all of the IC components necessary to achieve performance, cost and power dissipation design goals in these systems.

Analog-intensive Mixed-signal (AIMS) RFIC Technologies

The 180 nm RFCMOS technology node has been demonstrated to meet the UWB system requirements and, combined with advanced circuit implementations, provides some of the smallest, lowest power consumption components. Key to this success is that the RFIC technology is optimized for AIMS applications. Because of the stringent analog performance requirements, the technology must combine all of the characteristics above with advanced tools designed for analog applications. An enhanced RFCMOS technology includes devices, models and layouts optimized for RF performance along with design tools that improve the art of RF design.

Figure 1. Frequency range and power levels of various wireless protocols.



The optimum RFIC technology for the UWB front end must provide CMOS transistors with $F_t > 60$ GHz and low NF_{min} and $1/f$ noise, both improved with high transconductance. Inductor specifications require $Q > 20$ at 5 GHz in a compact layout in addition to varactors with tuning range of $>20\%$ /volt. Analog integration requires substrate isolation >40 dB in order to facilitate compact layouts without inducing undesired noise components.

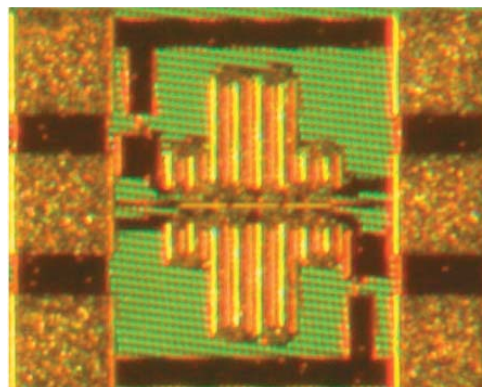
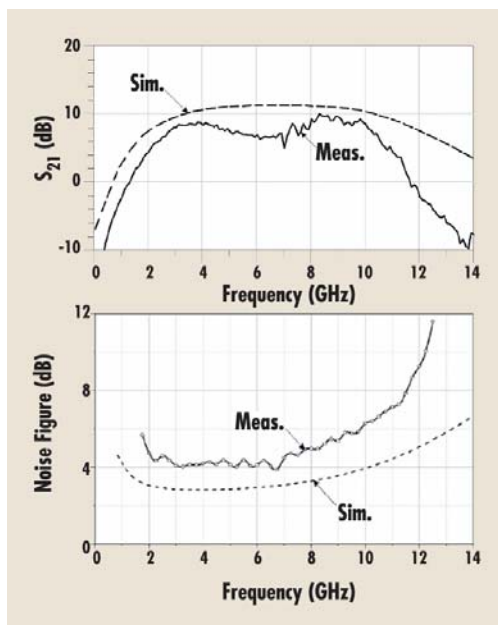
Another important technology consideration is the trade-off between performance and cost. UWB front end circuits have been implemented using different CMOS technology nodes including 180 nm enhanced RFCMOS, 130 nm RFCMOS and 180 nm SiGe BiCMOS. The 180 nm enhanced RFCMOS technology is the least expensive and optimized for analog-intensive designs up to 10 GHz. Other technologies provide too much performance and integration to provide low cost solutions with Cu metals and HBT devices that add unnecessary expenses.

Enhanced RFCMOS also provides advanced models that are critical in UWB designs. The new PSP CMOS model and new MOS varactor models improve the simulation accuracy of RFCMOS and enable first pass design success. These models can be further improved when combined with accurate layout parasitic elements.

Custom design tools also provide significant design improvements in AIMS products. Inductor synthesis tools speed the design cycle and optimize the inductors critical to the frequency of the VCO. Enhanced statistical simulation tools allow the designer to easily investigate designs over the entire or partial distribution of process parameters with physical models that provide unique insight into not just how the circuits will perform, but also how they work. Analog yield estimation tools take some of the black magic out of the art of RF design and improve the manufacturability of products by predicting a product yield and allowing designers to optimize performance and yield. This is something that has existed in the digital design world using defect densities and is now available in enhanced RFCMOS for analog products.

UWB Circuit Implementations

In addition to AIMS technologies, novel design techniques are also necessary to produce high performance, low cost UWB front end circuitry. As described previously, the enhanced RFCMOS provides an ideal technology and design environment for the challenging front end components. Some recent examples of 180 nm RFCMOS circuits include the LNA, VCO and integrated LNA-mixer.



Top, figure 2. Gain and noise figure of shunt feedback LNA for UWB. Bottom, figure 3. Chip photograph of 0.08 mm² distributed LNA.

Details of how the enhanced RFCMOS technology has facilitated these designs are described below.

An LNA has been designed using a shunt feedback approach operating over the entire UWB range of 3.1 to 10.6 GHz. Gain of approximately 9 dB across the band with good linearity and low noise figure are achieved because of the high performance CMOS transistor characteristics. This performance is required in the only demonstration of resistive feedback to cover the entire UWB range. Measured results are presented in Figure 2.

The resulting design is smaller than lumped element designs and uses less power than multi-stage designs. The final design requires only 9 mW from a 1.8 V supply and occupies only 0.22 mm² die area. Similar performance to 130 nm CMOS is obtained using this approach at a lower cost and smaller die size.

Another LNA implementation uses a novel multi-layer inductor to reduce the area even further in a distributed LNA design. The approach uses high performance inductors found in the enhanced RFCMOS technology to replace transmission lines as distributed elements. The inductors occupy much less area than traditional inductors and transmission lines and exhibit enhanced quality factor. Compacting the layout even further improves mutual coupling between these already small inductors to further reduce the die size. This allows a complete distributed LNA to occupy only 0.08 mm², a 90% die shrink, with 6 dB of gain and 2.7 dB noise figure. A chip photograph of this distributed LNA using multilayer inductors is shown in Figure 3. This approach has also been used to demonstrate an integrated front end consisting of an LNA and mixer, using the inherently wideband properties of the distributed topology.

The enhanced RFCMOS high performance inductors are also critical in low phase noise VCOs for UWB applications. A 1 nH inductor with Q-factor up to 20 at 5 GHz has been successfully implemented in a MB-OFDM frequency synthesizer with phase noise < -120 dBc/Hz at 1 MHz offset. The VCO is also improved by the reduced $1/f$ noise of the enhanced RFCMOS transistors.

Conclusion

It is clear that Ultra Wideband technology will find a home in a variety of applications, both wireless and wireline. Despite the many different types of communications systems, some things are constant in all of the applications, including the need for lower cost, lower power dissipation and sufficient performance to meet the stringent UWB standards.

New advances in analog-intensive mixed-signal IC technologies and design techniques allow UWB systems to meet these challenges and future system requirements.

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About the Author

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