Integration-by-parts: An approach to the RFIC market

One semiconductor manufacturer is applying a basic concept to wireless integrated circuits, starting at the antenna rather than the baseband side for its integration efforts.

By Dan Nobbe

A concept learned in freshman calculus, but now applied to wireless integrated circuits, “integration-by-parts” is the classical approach Peregrine is taking to wireless integration. The wireless precedent has been established by companies like Analog Devices, RF Micro Devices and Maxim, which constantly create building blocks, then create custom versions for specific customers or applications. These application-specific devices are then introduced into an expanded standard products catalog, which themselves become building blocks for more highly integrated, complex products. Digital IC companies have followed this model since the 1960s. RFIC semiconductor manufacturers applied it in the 1990s, creating an abundance of RF integrated circuits (RFIC) companies and solutions.

Integration-by-parts simply implies that cycles of learning start with building blocks, create variations, and then combine them into higher levels of integration. The success of the first wave of RF integration companies validated the business model.

RFIC companies sprouted right and left, leading into the Dotcom era. Funding was relatively easy (certainly by today’s standards), and fabless semiconductor companies were the preferred model. These companies often pursued highly integrated communications products such as RF or photonics transceivers, enabled by the research at universities and rapidly emerging standards such as Bluetooth, 802.11x and OC-48/192. These companies did not employ the integration-by-parts strategy. Instead, they typically focused on one distinct application with a goal to go public or be acquired rapidly. While initially successful, several factors combined to constrain this era—the Dotcom bubble burst, the economy suffered a severe and protracted downturn, and the traditional investment

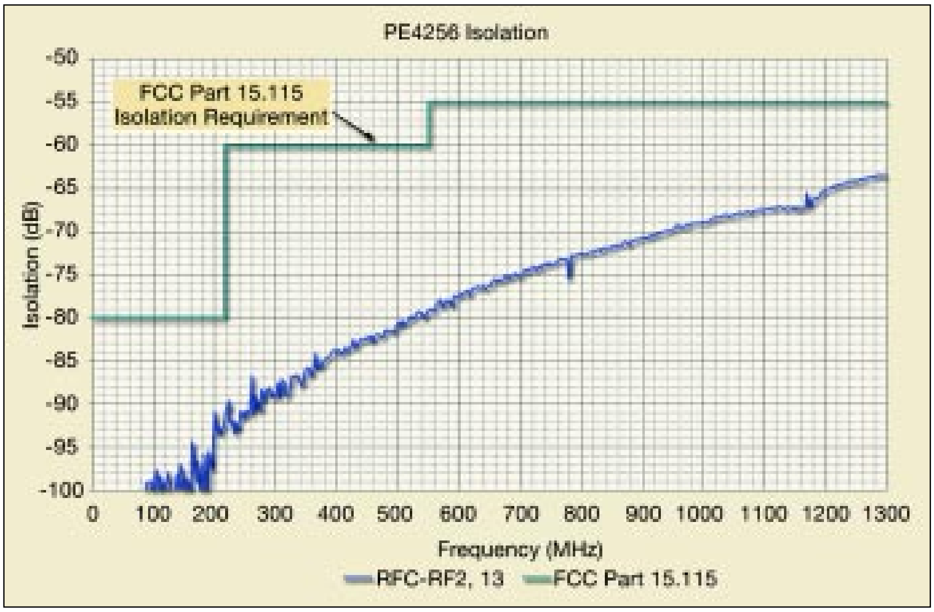


Figure 1. PE4256 switch isolation.

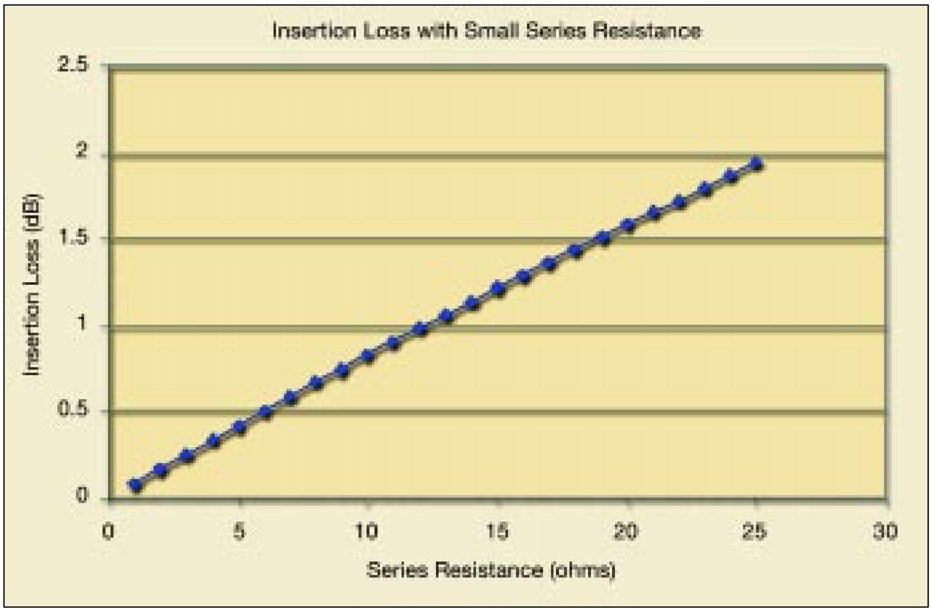
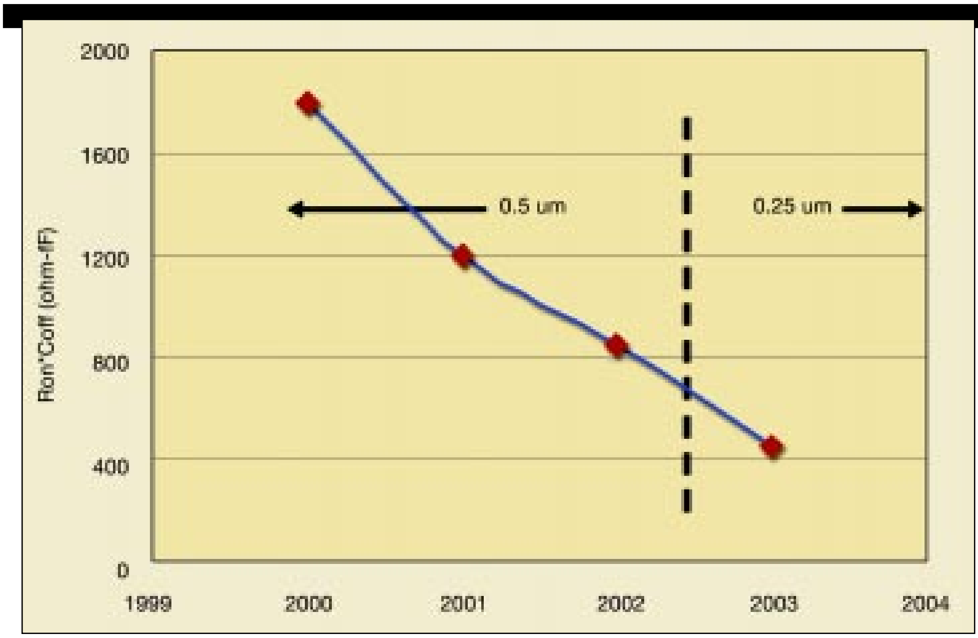


Figure 2. Insertion loss vs. series resistance in a 50 Ω network.



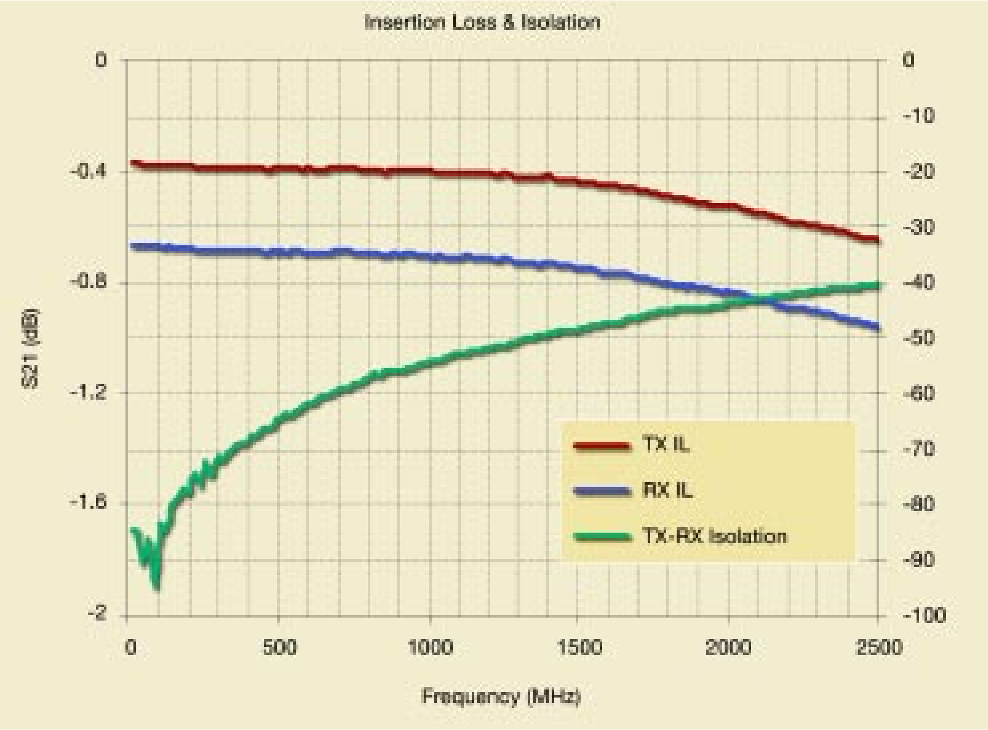


Figure 4. Insertion loss and isolation of a Peregrine SP6T antenna switch.

values returned with a vengeance. The bottom line is important after all. With high levels of integration and global competition, the margins on RFICs for standards like Bluetooth and 802.11 are very thin. This is because everyone in the world is fighting for the few design sockets in cell phones. Due to overcapacity today, one can assume that the pattern has been set and these chipsets will remain cheap.

The large numbers of new companies pursuing a single market like Bluetooth or 802.11 forced business models where perceived technology advantages were only good for a six-month spin of hardware and were quickly passed by someone else. Too many apparent successes and the low barrier to entry quickly led to a condition of overcapacity. Ultimately, such companies were expected to make money on their products, but their products sold into consumer electronics markets with infamously razor-thin margins. In other words, the RFIC integration business model had broken down. In addition, the global nature of the consumer electronics market increased the knowledge base on how to design an IC, making it an insufficient single capability upon which to found a successful company. Intersil's sale of its wireless local area networking (WLAN) business, a business in which it had the majority of the market, was a striking event underscoring the difficulty in making money in consumer electronics.

Tempting as it was to join the Dotcom trend, Peregrine instead stuck to the traditional approach to building a company's product line: the integration-by-parts model of earlier generations. However, its approach is different. Rather than start at the baseband side of the radio for integration efforts, it started at the antenna, integrating functions dominated by gallium arsenide (GaAs) technology.

Integration

Integration can offer many advantages, such as cost reduction, size reduction, performance improvements, reduced part count and associated vendor management issues, and added features. Digital circuits went through the large-scale integration (LSI) and very large scale integration (VLSI) evolutions of the 1980s and 1990s, taking functions previously in separate chips and pulling them into a single part. Technology improvements, design tools and high-volume markets were the enablers. The improved performance and smaller devices—along with hardware description language (HDL)—moving to a higher level of abstraction moved technology from under the desk and the trunk of the car into the briefcase, backpack, and the belt clip. RF integration is still in the early stages, largely because the HDL approach has not been established for RFICs.

However, outstanding achievements have been made in RFICs. The RF community has made tremendous improvements in the last decade, from conventional heterodyne high intermediate frequency (IF) and dual conversion receivers to low IF receivers to direct conversion. Likewise, the demodulation process moved into the digital domain with sampled IFs and multichannel receivers. Transmitters went from direct analog modulation of voltage-controlled oscillators (VCOs) to offset in-phase and quadrature (IQ) modulation to direct launch IQ modulation. Now polar modulation is becoming a common transmit architecture.

Many radio architecture improvements have been known for decades, but the technology couldn't support them. It seemed like the changes have all rolled out in the last few years, but the research has been underway for many years. It just took a while for the advanced silicon processes to catch up.

Integration roadblocks

Handset transceivers are integrated using a variety of technologies. However, the front end of the handset is still fragmented. This is primarily the power amplifier and associated control circuitry, the switches, the electrostatic discharge (ESD) protection, and the filters. One big area of research is the implementation of the power amplifier in silicon technologies, whether silicon germanium (SiGe) bipolar complementary metal oxide semiconductor (BiCMOS) or bulk CMOS. Today, it can be done, but it doesn't match the performance of III-V compound semiconductors. The primary motivation is cost reduction.

Once this circuit design obstacle is cleared and the power amplifier (PA) is implemented with reasonable efficiency in a silicon technology, another technology roadblock to integration will appear. This roadblock is an isolation limitation. It will be difficult to keep the transceiver's spurious signals from coupling onto the PA output and transmitter signals out of the receiver in frequency duplexed radios such as code-division multiple access (CDMA). Limited isolation will impede further integration.

Why not put the radio on the baseband chip? It is hard to keep the digital circuitry from contaminating the fidelity of the RF functions. Peregrine's silicon-on-sapphire RF CMOS technology does not suffer from the isolation limitations of the conducting and semiconducting substrates of other silicon technologies.

GaAs does operate on a semi-insulating substrate but lacks the complementary devices required for levels of integration realized in silicon. While GaAs was found in numerous areas of RF and photonics systems, it is now found only in the high-performance front-end components that are not yet available in Si-based solutions. However, these last redoubts of GaAs are under attack and GaAs is quickly on its way out. The limited integration potential of GaAs, largely because it lacks a complementary device, has it on the retreat. GaAs has also been dominant at microwave frequencies, but again silicon technologies are gaining ground. In handsets, GaAs is typically used in the PA and antenna switch. This is about to change.

Peregrine's RF CMOS components

Peregrine's standard components, the building blocks for integration-by-parts, compete against the silicon and III-V parts in the industry. In switches, Peregrine competes head-to-head against the handset antenna switches, even though the GaAs industry had at least a 10-year head start. Peregrine also makes high isolation switches that are marketed for the cable television (CATV) market. A monolithic switch like the PE4256 can replace a mechanical relay for CATV applications, allowing remotely addressable CATV distribution systems, reducing the number of service trucks that roll every time a college student starts a year's residency at the dorm. The PE4256's isolation response is shown in Figure 1. The switch easily exceeds the stringent requirements of the Federal Communications Commission (FCC) 15.115 limit for CATV systems, taking advantage of the outstanding isolation properties of the sapphire substrate.

The switch core can also be applied to digital step attenuators that integrate serial and parallel interfaces for 5-bit and 6-bit offerings. An added feature is the ability to preset a power-up attenuation setting that gets applied before the microprocessor takes control of the part, made possible by the Peregrine RF CMOS process.

Market demands for integration

Peregrine has developed a line of multithrow handset antenna switches that achieve 10W compression points in RF CMOS. Unlike GaAs, Peregrine can integrate the CMOS control logic. Peregrine also offers improved ESD performance and doesn't require an array of capacitors to float the switch for positive control logic. Until now, GaAs pseudomorphic high electron mobility transport (pHEMT) and positive intrinsic negative (PIN) diodes have been the only technology that could meet the performance requirements of the market. Bipolars cannot make switches, and bulk CMOS devices suffer insertion losses through the substrate and problems meeting the power-handling requirements. Low 'on' resistances are required for a low insertion loss switch, as illustrated in Figure 2 and simple equation relating insertion loss to series resistance.

IL = -10*log((4Rl^2/(Rs+Rl)^2)

An important figure-of-merit for switching devices is the $R_{on}*C_{off}$ product. This is the product of the on-resistance of a device times its off capacitance. One could make the on-resistance of a device small by increasing the device size, but the off-capacitances would increase at the same rate, reducing the usable bandwidth and degrading high-frequency isolation. Figure 3 shows the rapid improvements in this switch figure-of-merit for Peregrine's ultra-thin silicon (UTSi) RF CMOS technology. UTSi switches have made tremendous improvements in the last three years, with many more improvements in the queue.

With performance that equals GaAs on an SP4T and superior performance for higher number of throws, RF CMOS technology will become more important as the complexity of the multiband and multimode phones increases. Because the multithrow switches are literally the first device after the antenna, they serve as a springboard for integration of the adjacent functions, such as filters, matching networks, PAs and LNAs. Figures 4 and 5 show the performance of the Peregrine SP6T antenna switch.

Peregrine's roadmap points to further integration by incorporating functions that

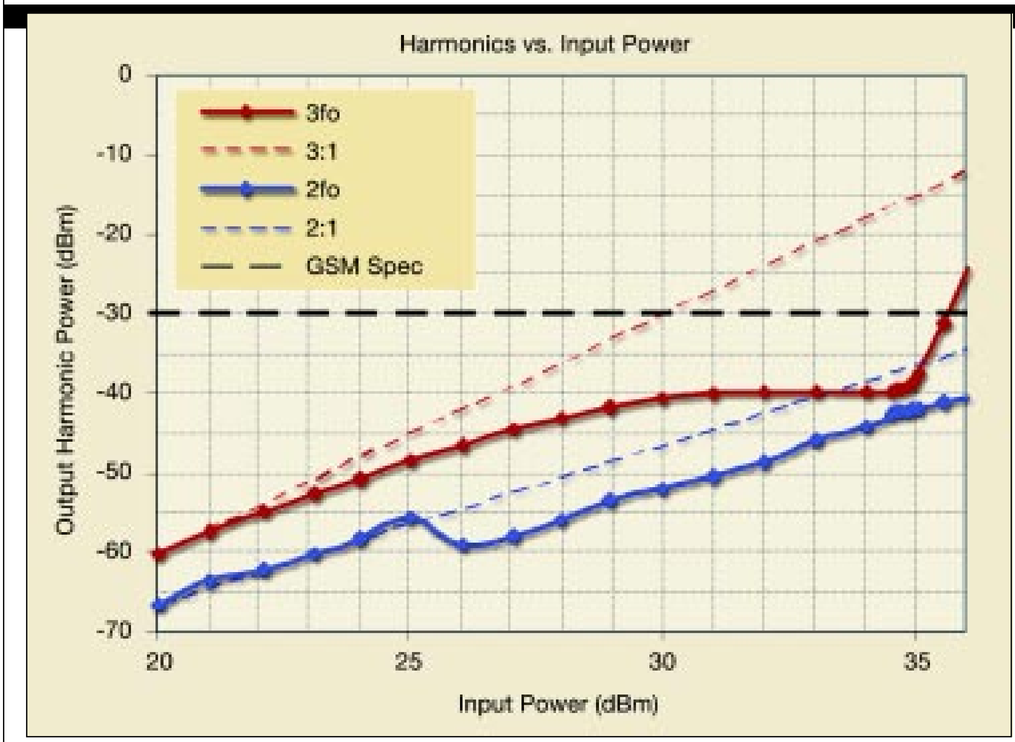


Figure 5. Second and third harmonic power performance of a Peregrine SP6T antenna switch.

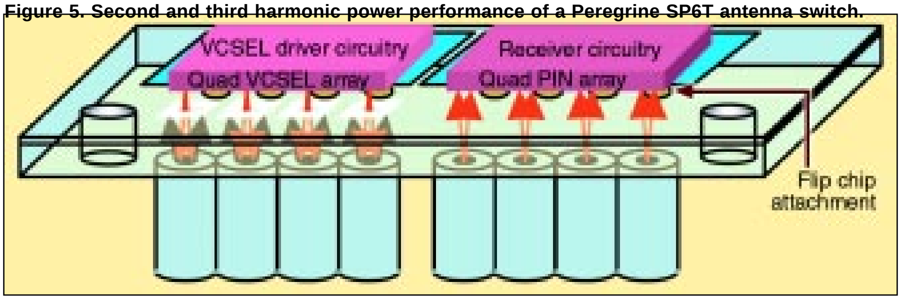


Figure 6. Flipped optical chips on UTSi, FOCUTS, consists of VCSEL arrays and photodetector arrays flip chip attached to their respective driver circuits.

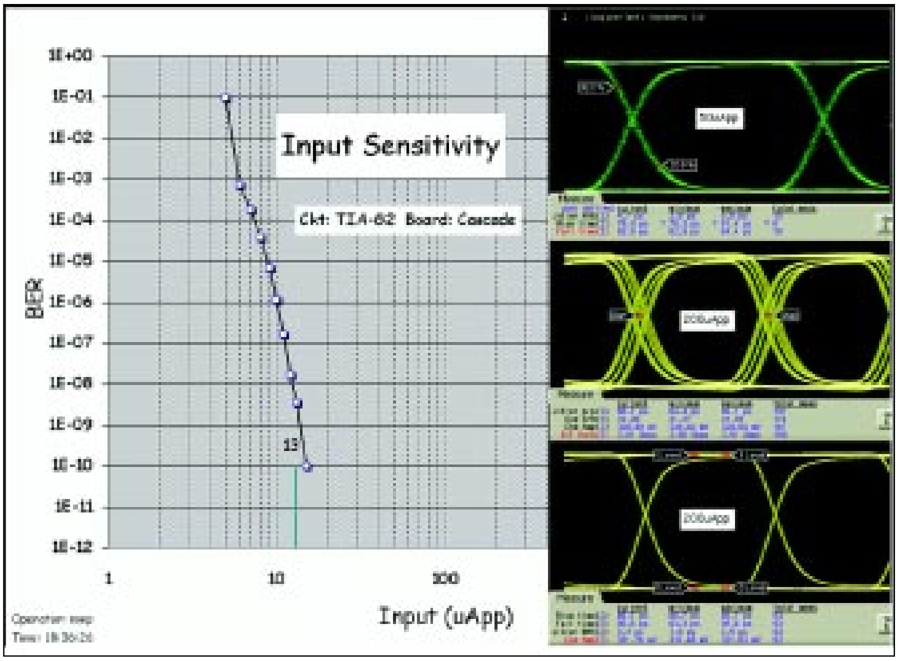


Figure 7. Waterfall chart of BER in an optical link using FOCUTs.

are now part of the PA module. RF, passive and digital circuitry within the PA module, including the bias circuitry, output match, and the power control circuits can be monolithically integrated with the antenna switch. The fully insulating sapphire substrate allows for the creation of high-quality factor passives with no voltage coefficients or capacitive substrate coupling. Electrically erasable programmable read-only memory (EEPROM) can also be added with no additional mask steps, which allows the calibration coefficients of the PA to be stored locally. This E^2 capability is already in production in the form of a PLL with integrated E^2, perfect for fixed frequency applications. The roadmap shows the integration of the PA driver and can enable new classes of PAs that rely on E^2 look-up tables for pre-distortion or polar modulation.

Because sapphire is transparent from ultraviolet (UV) to far infrared (IR), UTSi CMOS has been applied to make high-performance parallel optical interconnects. Figure 6 shows a module that is a 10 Gbps bi-directional (transmit and receive) parallel optical module made on UTSi CMOS. By flip-chipping vertical cavity surface emitting laser (VCSEL) lasers and P-i-N photodetectors onto circuits designed to drive them (laser drivers and TIA/LA, respectively), virtually all bonding parasitics and alignment issues are resolved. Laser cutting of alignment holes in the sapphire substrate provides a mechanical self-alignment feature that ensures reliable optical coupling.

The RF parts are best-of-class performance leaders; all in a CMOS process using standard tools, manufacturing flows and models.

A waterfall chart is shown in Figure 7 from a 2.5 Gbps optical link of Figure 6 with a bit error rate of 1x10^{-10} at input optical power of -13 dBm. Each channel consumes about 100 mW of power. The entire module is 0.5x1x2 cm and can be configured in any combination of transmit (TX) and receive (RX) for each of the 12 channels. Two dimensional arrays such as 2x12 are also possible in the same basic configuration.

The RF parts are best-of-class performance leaders; all in a CMOS process using standard tools, manufacturing flows and models. The integration is currently in areas that are conventionally hybrid solutions, offering unprecedented size and cost reductions without sacrificing the performance. The radio in consumer electronics is a commodity. A few integration holdouts exist in these radio platforms, but Peregrine is developing technologies to address these markets. RFD

ABOUT THE AUTHOR

Dan Nobbe is the vice president of engineering for Peregrine Semi-conductor (www.peregrine-semi.com). He received his B.S.E.E. degree from the University of Missouri-Rolla and his M.S.E.E. from the University of Texas-Arlington. Nobbe previously worked for Motorola designing ICs for cellular handsets, as well as cellular handset and infrastructure products. He has three patents issued and three patent applications. He can be reached at dnobbe@peregrine-semi.com.