R 0.8

March 2011

Randy Cochran, Phil Knights, Jarek Lucek

Optimizing High Performance RF components for LTE and LTE Advanced Base Stations

0.0 Introduction – Trends in Wireless Systems

Increasing mobile phone minutes and mobile data usage continues to transform wireless base transceiver stations (BTS). As the number of users and higher data usage requirements increase, higher capacity networks require the deployment of more BTS systems, resulting in more transmit and receive channels per BTS system and in increasing medium to small cell sizes. Cellular providers, municipalities across the globe, and wireless original equipment manufacturers (OEM) are pushing for higher level integration and system efficiencies. Therefore, next generation BTS systems require proven and innovative high performance RF components to optimize cost, size and power efficiency.

1.0 NXP – Trends in Wireless Base Transceiver Station Systems

As air interface standards have evolved from Advanced Mobile Phone System (AMPS) in the eighties to the high-performance 3G and 4G systems of today and tomorrow, so have the architectures of BTS system transceivers.

The high-speed data converters used in Base Transceiver Stations are evolving rapidly as radio transceiver design engineers drive to add LTE and LTE-Advanced functionality, as well as strive to reduce power and system size. These dynamics lead to data converters with more channels (moving from dual to quad), higher sampling rates (to 250 Msps and beyond for ADCs, to 1.25 Gsps and beyond for DACs). ADC input bandwidths are increasing to 100 MHz and potentially higher, and ADC linearity demands are getting higher; SFDR requirements reach as high as 95 dBc. DAC noise figures are required to be -163 dBm/Hz or lower, with 85 dBc SFDR linearity. ADC power consumption is driving to approximately 1 mW / Msps, while DAC power consumption is driving well below 1 mW / Msps.

Gone are the days of up-convert mixers driving four or five amplifiers on a transmitter that connects to a power amplifier (PA) (i.e. class A or Feed-forward Power Amplifier). These transceiver transmit chains have been replaced by ZIF architectures using high-performance quadrature modulators followed by a fixed gain amplifier then a variable gain amplifier (VGA) before going into the final power amplifier (PA). Variable gain amplifiers have higher gain, wider attenuation range and finer step control than ever before. Pre-driver amplifier devices that were previously only possible in Gallium

Arsenide (GaAs) are being replaced by similar performing but significantly more cost effective Silicon Germanium (SiGe) devices that enable the next step in transmit channel integration.

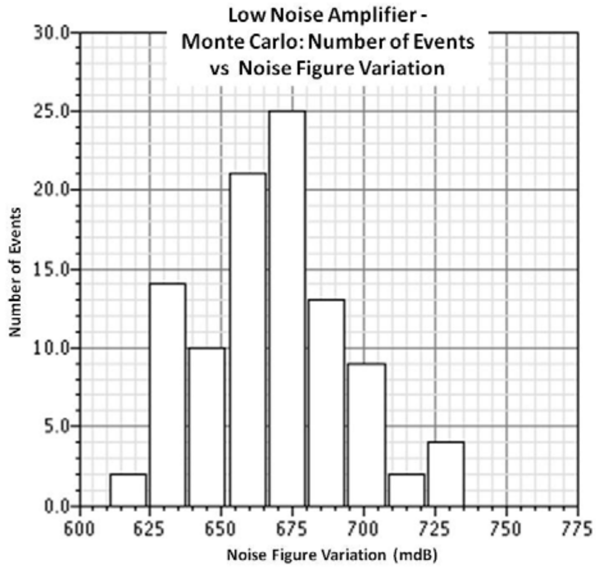
Receivers have continued to change as technologies have enabled evolution from super-heterodyne receivers to low-IF sampling receivers or zero-IF sub-sampling receivers. Technology developments have enabled Tower Mount Amplifiers (TMA) to decrease in size and weight due to power efficient devices, which do not require massive heat slug and allow passive cooling and multiple stage LNAs and passives to be combined into smaller modules. Improved SiGe BiCMOS process technologies with improved minimum NF and high break down voltage have enabled the integration of mixers and differential intermediate frequency (IF) amplifiers that can handle wider instantaneous bandwidths and higher order modulation schemes (16QAM, 64QAM) signals demanded by today's leading air interface standards. IF VGAs now offer outstanding linearity performance plus smaller gain control steps that directly drive SAW or ceramic filters into Analog-to-Digital Converters (ADCs), enabling higher performing IF receiver chains.

At the end of the wired signal transmit chain comes the Power Amplifier (PA), either mounted at ground level, next to the BTS or close to the antenna, as in Tower Mounted Amplifier (TMA). Next generation systems (LTE) will occupy frequency bands from 700 MHz to 3600 MHz, with ever-increasing requirements for power density, efficiency and cost. PA architectures will continue to evolve around Doherty derivatives, both symmetrical and asymmetrical, with power transistor designs to suit. PAs performance will also be stretched in terms of linearization, as digital pre-distortion (DPD) techniques evolve and diverge. Within the next 5-10 years the industry will see the emergence of Switched Mode PAs (SMPA) in commercial systems, necessary to reach new levels of power density and efficiency performance.

2.0 Technology Enablers

What enables these high performance quadrature modulators, variable gain amplifiers, low noise amplifiers and mixers is innovative SiGe processes like NXP's latest bipolar SiGe:C flavor in the QUBIC4-family processes. With multiple process nodes available, QUBIC4 allows optimal technology matching based on functionality and increased integration on-chip utilizing reduced board space. Devices having smaller footprints also mean more competitive costs. Adding and increasing functionality on a single chip improves reliability and gives significant manufacturing advantages.

NXP's state-of-the-art QUBiC4 technology speeds the migration from Gallium-Arsenide (GaAs) to Silicon (Si) by offering comparable or better linearity, noise figures, DC power consumption, immunity against out-of-band signals, spurious emission performance and increased output power. Available since 2002, QUBIC4 (QUality BIpolar and CMOS 4th generation) continues to evolve to meet today's system performance by meeting the most demanding RF requirements with amplifiers reaching more than 44 dBm OIP3 level or LNA with noise figures below 0.7 dB. This extensively tested process that is widely deployed in the field offers consistent parametric RF performance and reliability from wafer-to-wafer and lot-to-lot. For instance, the noise figure (NF) spread of the low-noise amplifier (LNA) is shown in the figure below. It shows the process variation using Monte Carlo simulation. The vertical axis shows the number of events that a certain NF occurs and the horizontal axis shows the NF variation in mdBs. This Monte Carlo simulation has 100 runs and it shows a mean NF of 0.67 dB according to measurements and a standard deviation (1σ) of 25mdB. In case the (3σ) is used as figure of merit then the total spread is 75mdB. This gives a max value for the noise due to process spread of 0.7 dB.



For high-speed data converters, the CMOS14 process technology node has been a sweet spot for high performance mixed-signal design, especially when enhanced with linearized capacitors, typically using metal-insulator-metal structures. Maximum voltage supply swing impacts analog performance, particularly for ADCs, so the 3.3V capability of CMOS14 is helpful in this regard.

NXP offers RF modules; multiple integrated circuits and passives which are combined on a laminate then assembled into HVQFN or BGA footprint compatible packages. These modules, utilizing existing dies can be re-used, with or without changes. The service results in a shorter time to market and allows customers to quickly respond to different system partitioning requests (rapid prototyping) sometimes imposed by changing and smaller form factor radio boards.

NXP’s GEN6 and GEN7 LDMOS technologies ensures RF power solutions with the highest efficiencies possible, enabling system cost reductions and greener base station solutions. NXP LDMOS also offers superior ruggedness and is optimized for use in Doherty high efficiency architectures. NXP’s RF power technical team provides unrivalled applications support including access to a library of proven symmetrical and asymmetrical Doherty solutions for all the dominant mobile communications standards from 700 MHz to 3.8 GHz. These demonstrators come with full documentation including data on DPD performance. To complement NXP’s full-range of LDMOS power transistors, a new portfolio of products has been introduced which uses GaN technology. The technology is being developed with first product releases targeted for the end of 2011. NXP will be the first mainstream supplier to offer industry leading portfolios in both LDMOS and GaN.

3.0 NXP – The Most Efficient Signal Chain

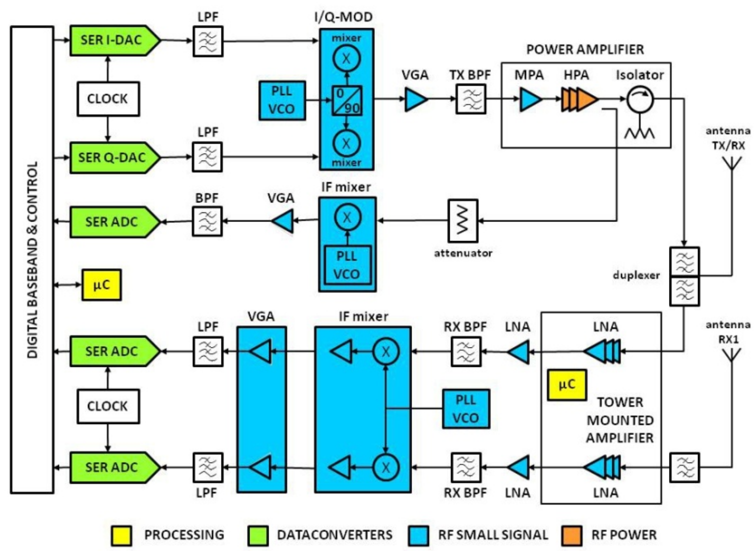
As wireless OEMs continue to push for higher efficiency, higher throughput and smaller sized systems, they continue to look to suppliers that offer a broader product portfolio from multiple semiconductor technologies. NXP is uniquely positioned in the vendor base as a supplier to wireless infrastructure

OEMs that is able to provide components and enabling technologies to construct the entire signal path from bits to the antenna and from the antenna back to bits.

NXP's unique product offering covers:

1. High-Performance Analog Mixed Signal components like Digital-to-Analog Converters (DACs) and Analog-to-Digital Converters (ADCs);
2. Radio Frequency Small Signal components for transmit lineups from quadrature modulators to MPAs and LNAs to IF VGAs and LO Synthesizers for receive chains, and devices in between; and
3. RF Power devices with industry-leading LDMOS technology.

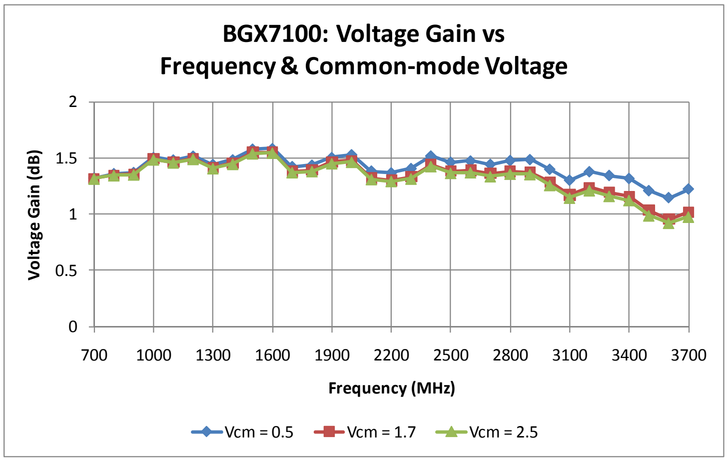
With a complete portfolio of proven RF and converter capabilities for 3G and 4G, NXP provides a broad portfolio of high performance RF components that enable a wide array of OEM integration paths to drive cost, size and power efficiency.



High-speed DACs for BTS are typically dual channel devices. They currently utilize LVDC parallel data interfaces, but the industry is expected to migrate to the new JEDEC JESD204A and emerging JESD204B high-speed serial interface, where NXP has been a leader in terms of new product introductions. The DACs typically include an embedded IF modulator driven by a numerically-controlled oscillator. These DACs also offer 2x, 4x, and 8x digital interpolation filters to simplify the system-level analog filtering challenge.

NXP delivers an industry leading direct quadrature modulator or I/Q modulator. With respect to linearity, flexibility and power consumption, the BGX7100 stands alone covering from 700 MHz to 3800 MHz. The BGX7100 includes an innovative power control function which allows the designer to control the power output of the modulator, as well as turn the component to an on-to-off or off-to-on mode in less than 1.5 µsec bringing the power consumption from 180mA in active mode to a level as low as 8mA in off mode. As shown in the figure on the following page, the BGX7100 performance is agnostic to common-mode input voltage, therefore allowing the designer the freedom to choose the appropriate common-mode voltage for the DAC. The BGA7100 is available in an HVQFN24 leadless package.

The BGX7300 synthesizer is a high performance frequency synthesizer having 3 integrated VCOs and PLL. This device is capable of generating Local Oscillator (LO) frequencies of 625 MHz to 5219 MHz, and it is also possible to use an external VCO if preferred by the customer. The phase noise performance at 1 MHz offset is as low as -144 dBc/Hz at RF below 1 GHz. The BGX7300 also supports innovative power down and sleep functions, as well as adjustable output power from -5 dBm to +5 dBm with 1 dB step control. The BGX7300 is available in an HVQFN32 leadless package.



The BGA720x products are a family of transmit variable gain amplifiers offering 27 dB and 32 dB of attenuation control. The BGA7202 and BGA7203 offer output 3rd order intercept (OIP3) of +45 dBm and 27 dB of analog attenuation control. The BGA7204 provides OIP3 of +37 dBm and 32 dB of digital attenuation control. In addition, the BGA7204s gain curve can be programmed via a SPI interface. The BGA720x VGAs are available in an HVQFN32 leadless package.

The BGA7x2x and BGA7030 series of medium power amplifiers (MPAs) offer output power levels from +24 dBm (or 1/4 Watt) to +30 dBm (or 1 Watt) covering 400 to 2700 MHz. This family of products offers similar performance to competing GaAs products. The BGA7124 and BGA7127 devices also offer the added functionality of a shutdown pin for device power control and an externally programmed current adjust input in order to make the tradeoff between power consumption and RF performance. The BGA7024 and BGA7027 are available in the SOT89 package. The BGA7124, BGA7127 and BGA7130 are available in the HVSON8 leadless package.

For the digital pre-distortion (DPD) feedback or transmitter observation path, NXP offers the BGX7210 I/Q modulator device family, which combines a high performance, highly linear down-convert mixer with an LO generator. The family of devices covers the frequency range from 700 to 3700 MHz. The mixer provides an input 1 dB compression point (P1dB) above 12 dBm, with an Output Third Order Intercept Point (OIP3) of 32 dBm. The BGX7210 is available in the HVQFN32 leadless package.

For the receive side of the transceiver, NXP offers the BGU706x LNA module to be utilized in the Tower Mount Amplifier (TMA). This module family offers an easy to use and highly integrated LNA. The devices include a low noise amplifier, analog variable attenuator, and a highly linear 2nd stage. The noise figure of this device is below 0.7 dB. These modules offer a minimum gain of 15 dB and a maximum gain of 35 dB and 25 dBm of input third-order intercept (IIP3). The BGU706x are available in the HVQFN16 leadless package.

The BGU705x series of low noise amplifiers (LNAs) provide low noise figure (NF) of 0.6 dB and high linearity output third-order intercept point of 30 dBm. This 50 ohm internally matched LNA family has high input return loss and is designed to operate between 500 MHz and 3800 MHz in 4 pin compatible products. This family of products is ESD protected on all terminals, and is housed in HVSON10 leadless packages.

The BGX7220 device family combines a pair of high performance, high linearity down-convert mixers for use in receivers having a common local oscillator, along with main and diversity paths. The family of devices covers the frequency range from 700 to 3700 MHz. Each mixer provides an input 1 dB compression point (P1dB) above 12 dBm, with an Output Third Order Intercept Point (OIP3) of 32 dBm. The small-signal noise figure (NF) is below 10 dB and the isolation between mixers is a minimum of 40 dB. The BGX7220 family is available in the HVQFN36 leadless package.

The BGA735x are dual independently digitally controlled IF Variable Gain Amplifiers (VGA) operating from 50 MHz to 250 MHz. Each IF VGA amplifies within a gain range of 24 dB and 28 dB, respectively. At their maximum gain setting each delivers 18 dBm output power at 1 dB gain compression (P1dB) with superior linear performance and overdrive performance up to +20 dBm. The gain controls of each amplifier are separate digital gain-control, which is provided externally through two sets of 5 bits. The BGA735x are housed in a HVQFN32 leadless package.

High-speed ADCs in base stations being designed in 2011 are often quad channel devices, utilizing an LVDS parallel output interface, or the new JESD204A or JESD204B high-speed serial output interface, which can dramatically reduce PCB design effort, IC package size, BOM cost and engineering development costs. Some of these ADCs include an input buffer, which can simplify the external analog interface circuit, making the ADC easier to use. Most current generation ADCs (and DACs) use an SPI control/status interface for parameter setting and over-range monitoring. To preserve the highest analog performance at the system level, high-speed ADCs generally use differential inputs.

For the sub-1 GHz end of the spectrum NXP is developing new over-molded plastic (OMP) products to complement the traditional ceramic packages used for RF power transistors. Both package styles will continue to feature in new product developments in the years to come. For 2011 NXP will launch Gen7 LDMOS products in OMP and ceramic packages: BLP7G10S-140 a 140W single-ended device, packaged in OMP and BLF7G10LS-250, a 250W single-ended device – both optimized for performance around 900 MHz and with excellent ruggedness. At the higher frequencies many customers are now using a combined pair of LDMOS devices in asymmetrical Doherty formation: the BLF7G24LS-100/140 (for 2300 to 2500 MHz) and the BLF7G27LS-100/140 (for 2600 to 2700 MHz). NXP LDMOS products are also found at the highest LTE frequencies with products like the successful BLF6G38LS-50 (3400 to 3800 MHz). This end of the spectrum is the entry point for NXP's GaN products.

4.0 Conclusions

Increased mobile data usage will be a driver for integration and size reduction of BTS transmit and receive line-ups. This integration will drive the component performance and reliability requirements to higher levels. NXP, with its proprietary QUBiC4 SiGe:C processes and RF Intellectual Property (IP) portfolio as well as module packaging techniques is well positioned to support OEMS in order to meet these demands on the individual component level, as well as on a system integration level. With the announcement of NXP's new product portfolio that enables full radio design, NXP supports Base Transceiver Station System designers as they conquer the challenges set by the demanding signals of today's and tomorrow's leading wireless air interface standards.

5.0 Resources – Wireless Infrastructure Technical Information

NXP offers a wealth of technical information for development and system engineers involved in Wireless Infrastructure Base Transceiver Station development:

http://www.nxp.com/campaigns/high-performance-rf/index.php?sub=wireless-infrastructure

http://www.nxp.com/acrobat_download2/literature/9397/75016837.pdf

NXP offers a fully functional transceiver demo board, as pictured below (Photo 1).

Caption: Photo 1. NXP XVCR EVB