Whitepaper

NVIDIA SDR (Software Defined Radio) Technology

The modem innovation inside NVIDIA i500 and Tegra 4i

Table of Contents

Introduction 3

Limitations of Fixed Function Hardware modems 3

NVIDIA Software Defined Modem 4

Deep eXecution Processor Architecture 6

Benefits of NVIDIA Software Defined Radio (i500 and Tegra 4i) 7

Conclusion 10

Appendix 11

Document Revision History 12

Introduction

As mobile devices continue to grow in features and functionality, the need for greater computational performance and efficiency is rivaled only by the need for fast, reliable, and seamless connectivity. Smartphones and tablets are quickly becoming primary computing device and are expected to deliver both PC class performance and best of class connectivity for uses such as streaming High-Definition videos, playing multiplayer games, surfing websites and sharing high-resolution media content.

Accelerating the adoption of mobile devices as everyday content creation and consumption platforms is the introduction of high-throughput air interfaces such as Dual-Cell (DC-HSPA+) and more importantly, LTE. The peak bandwidth available with LTE matches, or in many cases, surpasses that of traditional wired solutions such as co-axial or DSL. Consumers are not only voraciously consuming the additional bandwidth delivered by LTE but have also raised their expectations to make LTE connectivity the new norm in the world of mobile data. The advent and continued rise of cloud storage and computing further accentuates the need to support high-performance standards such as LTE.

The **NVIDIA® i500 LTE modem** and NVIDIA Tegra® 4i's processor with integrated i500 modem use a revolutionary **software defined radio technology** that not only supports the latest wireless protocols such as DC-HSPA+ and LTE, but also has the flexibility of being fully programmable to support next generation interfaces and standards. The NVIDIA i500 has a smaller die size, consumes lower power and offers greater implementation flexibility compared to competing LTE modems. Moreover, unlike conventional modems, the software re-configurability of the i500 soft-modem makes it easy for carriers and OEMs to update modem features and to take advantage of performance-improving algorithmic innovations in the field through over-the-air updates.

Limitations of Fixed Function Hardware modems

Conventional modem designs can be termed as 'fixed-function' modems ' because almost all modem functionality in these modems are implemented in silicon resulting in large die sizes and limited flexibility. As the number and complexity of air interfaces increase, so does the challenge involved in planning, designing, manufacturing, testing and maintaining modems. Accommodating ever increasing region and carrier specific modes, bands and protocols require significant resources to test and design modern modems. This results in conventional hard-modem designs that are large, complex and expensive.

More importantly, as wireless standards continue evolving at a rapid pace, the traditional, rigid hard-modem design flow allows for little in terms of flexibility and adaptability. With each new release and ratification of a wireless interface standard, conventional modem designs typically require costly and time consuming silicon re-design and spin to accommodate the new specifications. This greatly impacts the time-to-market of OEMs and carriers who want to support these new wireless standards.

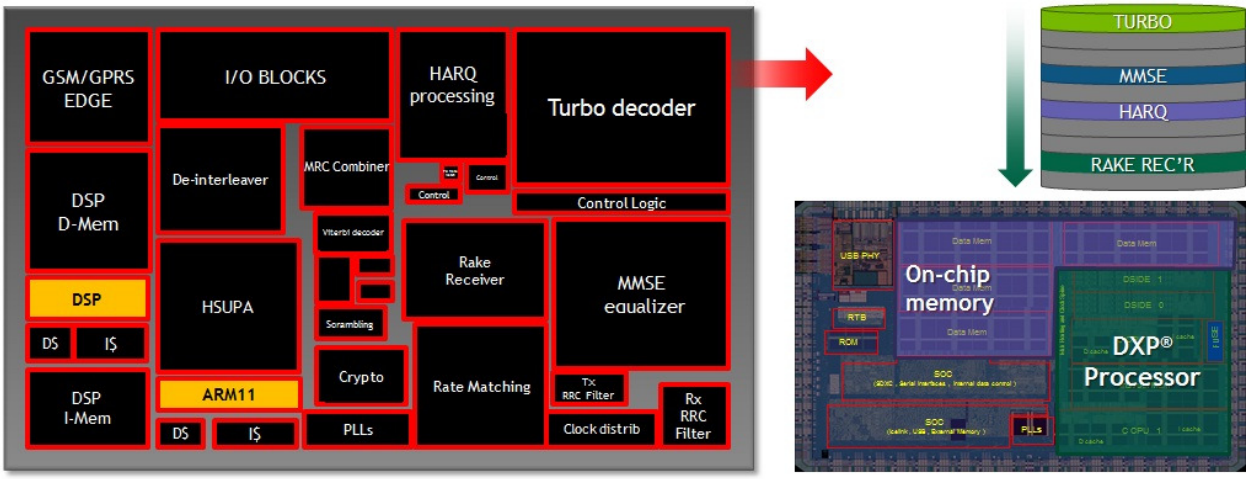

Figure 1 Conventional modem with fixed-function blocks vs. a Programmable soft modem

Moreover, conventional modem designs implement discrete fixed-function blocks for each supported connectivity protocol can result in a larger die sizes and higher power consumption. Ultimately, conventional fixed function modems, with their lengthy design cycles, requirement for discrete fixed function hardware and lack of adaptability results in chips that are large, complex, inefficient and expensive.

For carriers, this results in lower device performance and increased network capital expenditure costs and for vendors it means less competitive products.

For the consumer, this means less than optimal end-user experience, expensive devices, and fewer choices.

NVIDIA Software Defined Modem

The **NVIDIA i500** is a revolutionary and power efficient, multi-mode soft-modem that supports advanced next-generation air interfaces and connectivity technologies. Built on the proven Icera **Software Defined Radio (SDR)** technology, the i500 enables significantly higher user throughput, advanced modem features, better voice quality and lower cost on one of the smallest, most power-efficient footprints in the industry.

Key Specifications of NVIDIA i500:

- Up to 1.3GHz 8 programmable, fully-gated cores (800 Gops/core), NVIDIA DXP® architecture
- 28nm HP High-K Metal Gate process, Ultra-low voltage
- 7 x 7mm package, 40% the size of comparable conventional 4G modem
- Multiband LTE UE Category 3 100Mbps, HSPA+ 42 Mbps, GSM/GPRS/EDGE,
- Fully integrated 2G/3G voice, CSFB and VoLTE support

- Fully capable of LTE UE Category 4 150Mbps with Carrier Aggregation (CA), HSPA+ 84 Mbps
- NVIDIA IceClear® interference-cancellation technology for improved cell edge performance and eICIC support
- Dual SIM, ETWS, CMAS capable

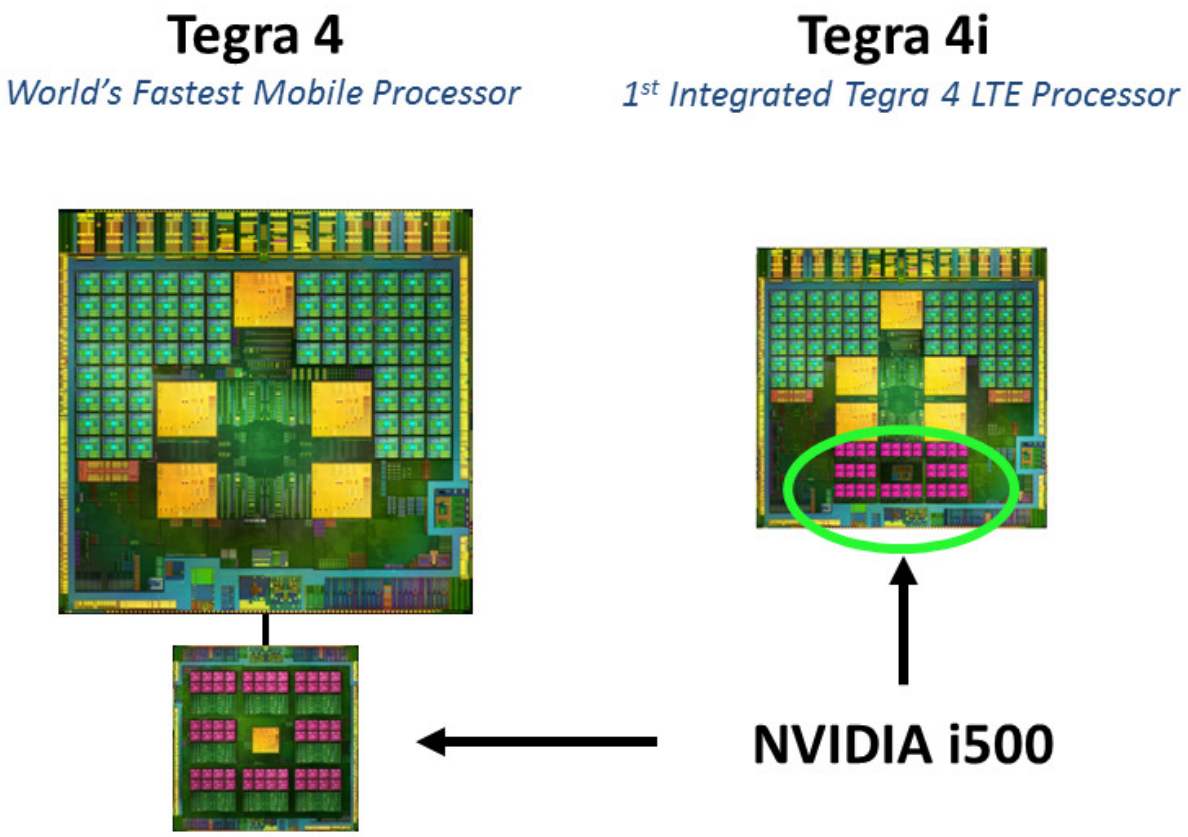

Figure 2 NVIDIA i500 Soft Modem in Tegra 4 and Tegra 4i

The NVIDIA i500, paired with the **ICE9245 low-power, multi-mode RF IC**, fully supports existing 2G/3G/4G specifications, while providing the flexibility and capability to extend available TX-RX and filter paths to new band, mode and application requirements.

The challenge with LTE is the wide range of bandwidths along the huge number of frequency bands and the uncertainty around their deployment. The ICE9245 RF provides the necessary flexibility and efficiency which is essential at this stage in the roll-out of the LTE interface. The flexible TX, RX and diversity port structure, combined with the all-digital interface to the

baseband enables support for a wide variety of LTE and other air interfaces on a low power footprint.

Key Specifications of NVIDIA ICE9245 RFIC:

- FDD/TD LTE, HSPA+ DC and quad-band EDGE Multimode RFIC
- 65nm LP CMOS process, 6.5 x 6.5mm package
- Integrated Low Noise Amplifier (LNA)
- Digital IceLINK to Baseband
- 8 x LTE/3G/2G Tx ports, multi-band RX diversity
- Fully supports converged PA's
- Supports DCXO-based design
- Type 3i Receiver capability

Deep eXecution Processor Architecture

The computational capacity to deliver 100Mbps LTE connectivity is approximately 150 GFLOPS/s. The NVIDIA i500 soft-modem architecture is built around the NVIDIA **Deep eXecution® Processor** (**DXP**) to deliver the performance requirements of high speed LTE connectivity while consuming the least amount of power. The **DXP** is a new class of asymmetric microprocessor that is built from the ground up for wireless signal processing. It includes separate 32-bit and 64-bit register files. The instruction set for the processor includes a set of C-compiler optimized 32-bit instructions and a set of configurable vector instructions along with data memory.

The 32-bit instruction set is designed for the millions of lines of code typically used in the upper layers of the 3GPP protocol stack. It allows sufficient code density and does not need any instruction compression. It includes specific instructions to support voice codecs and data encryption.

The configurable vector instruction set is intended for hand coding of all performance critical PHY layer algorithms. It is not compiler targeted and does not support instructions for flow control, floating point, and error handling. But, it has a number of novel features that are used to optimize the patented algorithms to manage the PHY layers.

The Deep Execution Processor maximizes performance per watt and minimizes overall power consumption through key optimizations in the architecture and silicon implementation. The DXP architecture uses 2-way LIW, multiple vector data paths (SIMD) and compound instruction (in its Deep Execution Unit) to improve performance efficiency. The instruction set of the DXP processor is optimized for baseband signal processing and is designed to minimize hardware costs and power consumption.

At the silicon implementation level, power is further minimized through custom transistor libraries, RAM macro-blocks and manual place-and-rout of key blocks of the design.

Containing fewer transistors than conventional modems, the transistors are run at ultra-low voltages keeping static power very low. This coupled with intelligent clock and power gating nets tangible reduction in overall active power consumption.

Benefits of NVIDIA Software Defined Radio (i500 and Tegra 4i)

The NVIDIA Software Defined Modem compared to conventional hard-modems deliver several important advantages.

Smaller size and lower cost

NVIDIA i500 soft-modem utilizes DXP technology and custom, programmable cores to perform all computation and signal processing tasks. This allows the programmable, hardware blocks are to be efficiently re-used and re-purposed for all stages of signal processing (Viterbi decoders, Turbo decoders, Equalizers etc.), resulting in a smaller, less expensive die. In contrast, conventional hard-modems require discrete computational blocks for most stages (along with associated memory and glue logic) resulting in larger die sizes

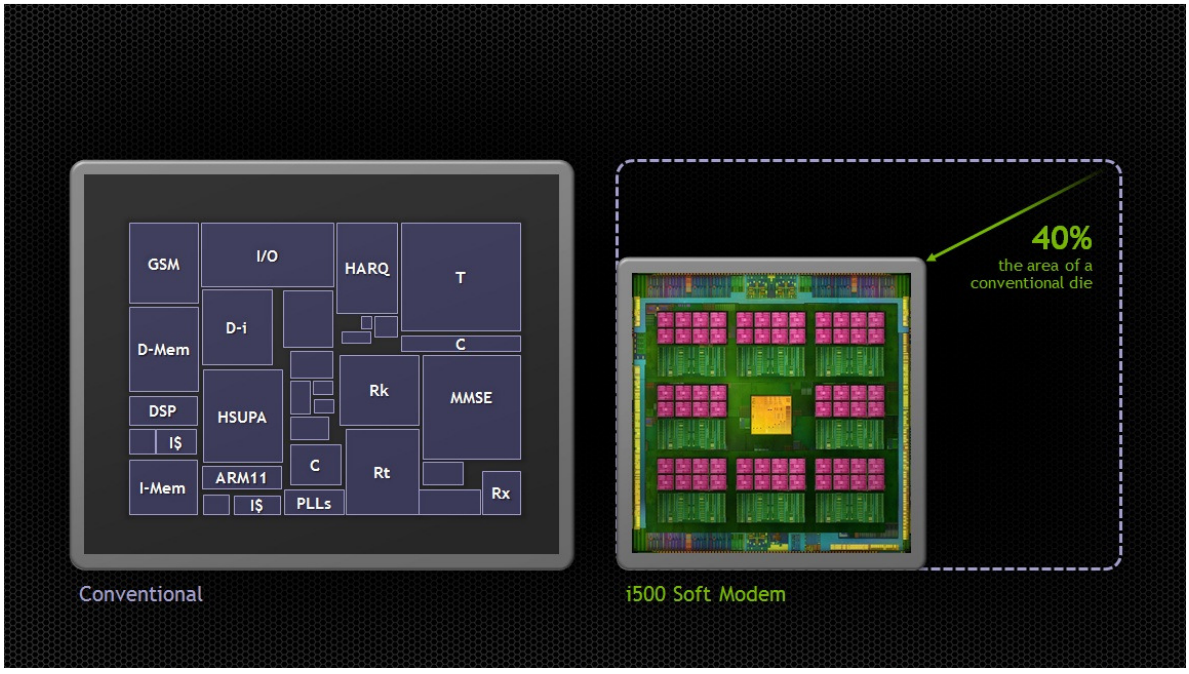

Figure 3 NVIDIA Icera i500 die is 40% the size of a conventional die

The use of programmable core and DXP technology makes NVIDIA i500 soft-modem die size only forty percent the size of a comparable conventional hard-modem design. This helps reduce

silicon costs and this advantage gets even bigger as connectivity standards and interfaces get more complex.

Lower Power

In general fixed-function hardware can perform a specific task more efficiently than general purpose hardware. However, complexity of baseband processing has increased significantly and the number of fixed function blocks required in hard-modems to handle the myriad standards and protocols has not only increased silicon die size and power consumption but also minimized the efficiency of fixed function designs.

In comparison, the NVIDIA i500 is built around the DXP processor that is used run the baseband processing algorithms. The DXP architecture is highly optimized to maximize performance per watt and the hardware is optimized with full custom layout and low power transistor libraries that allow the processor to run at a broad range of operation voltages.

The soft-modem architecture requires significantly fewer transistors compared to hard-modems and is therefore able to use higher performance transistors that run at lower voltages and further reducing power consumption. Since the baseband processing algorithms are software based, these algorithms can be continuously tuned and optimized to minimize power consumption. The i500 design also employs dynamic voltage and frequency scaling based on demand and utilization (2G, 3G, LTE, voice vs data etc.) to optimize performance and power.

Flexibility

NVIDIA i500 soft-modem technology allows the latest technology (new protocols, air interfaces etc.) to be delivered to existing, mainstream platforms. Compared to conventional hard-modems where blocks and associated parameters are mostly rigid and demand agnostic, NVIDIA's SDR stack promotes computational flexibility based on the vendor and market-specific demands and requirements, while allowing performance to be fine-tuned over time. The soft-modem methodology allows for rapid development and deployment of future-proof designs.

Eliminating the need for expensive, fixed function hardware accelerators, DXP technology enables support for advanced modes and features on existing platforms without any architectural changes. Each successive generation provides better computational capabilities to efficiently deal with more complex computation and signal processing. For example, even though i500 will first ship with LTE Category 3 support, it will be upgraded via software to support LTE Category 4 with Carrier Aggregation.

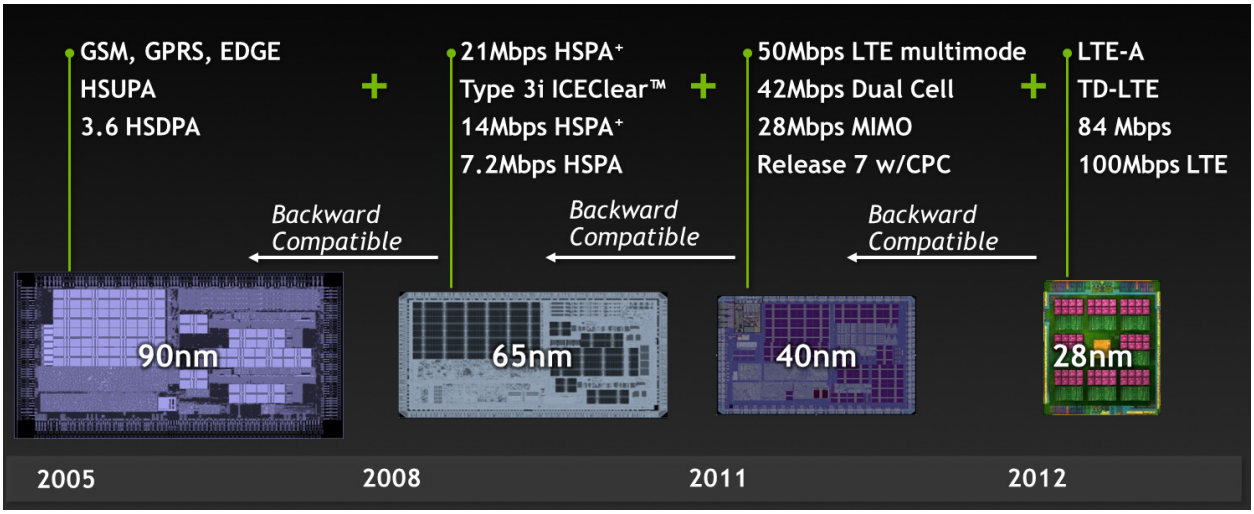

Figure 4 Prior generations are leveraged for fast feature development

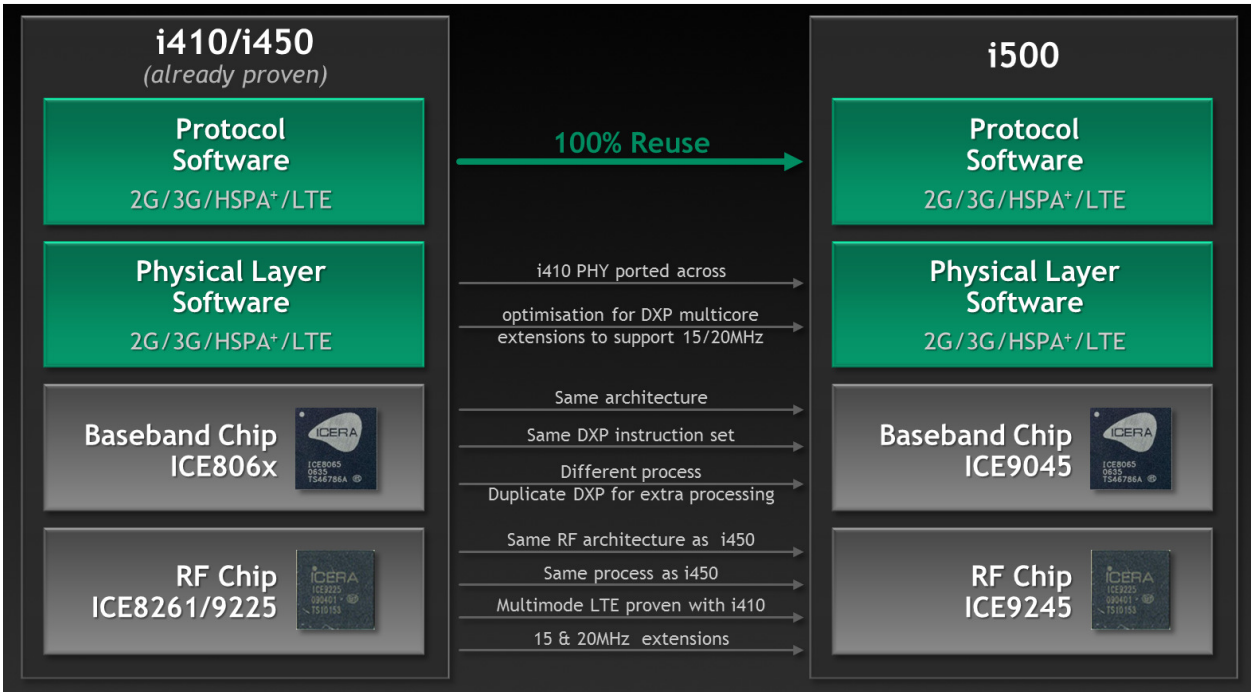

Figure 5 Significant reuse of LTE Multimode software from 4th generation NVIDIA modem

Time-to-Market

Each generation of baseband is leveraged for fast feature development, reducing qualification requirements. This, coupled with the fact that iterations are only in software, accelerates time-to-market and deployment. For example, all LTE Category 2 related IP that has been developed and used in the AT&T LTE-validated NVIDIA i410 is leveraged and built-upon in the i500, accelerating development and qualification

Adaptability

Another advantage of soft-modem technology is the ability to adapt to network conditions in real-time. Based on various channel parameters and conditions (interferences, frequency, geometry), NVIDIA Adaptive Wireless™ technology in the NVIDIA i500 soft-modem can intelligently re-assign available compute resources, vary parameters and select the best RX structure for the current channel condition. The aim is to continuously maximize cell capacity and user throughput, given network conditions, resulting in a better experience for the user and higher revenue for the carrier.

Conclusion

Conventional wisdom, together with the massive amount of legacy investment by traditional modem vendors, dictates a fixed function approach. However the complexity of multi-mode, high-throughput cellular air-interfaces requires a revolution to lift us from convention. This revolution is brought about by the NVIDIA Software Defined modem technology.

NVIDIA modem technology enables a totally new paradigm for modem technology development offering both higher performance and low power consumption; this is brought about by coupling high-performance silicon design techniques together with world-class adaptive algorithm design. NVIDIA is the first silicon company to adopt this approach but it won't be the last, one day all modems will be built this way.

Appendix

	NVIDIA i500	NVIDIA Tegra 4i
Air Interface		
GSM/EDGE	Yes	Yes
WCDMA	Yes	Yes
TD-SCDMA	Yes	Yes
FDD LTE	Yes	Yes
TDD LTE	Yes	Yes
3GPP Release		
Rel 9	Yes	Yes
Rel 10 LTE-A (Carrier Aggregation)	Yes	Yes
HSPA+ Category		
Cat 24 DC-HSPA+ 42Mbps	Yes	Yes
Interference Cancellation	Yes	Yes
LTE		
Cat 3 20Mhz 100/50Mbps DL/UL	Yes	Yes
Cat 4 20MHz 150/50Mbps DL/UL	Yes	Yes
Carrier Aggregation	Yes	Yes
MIMO 2 x 2	Yes	Yes
MIMO 4 x 2	Yes	Yes
2G Voice		
FR, HR, EFR, WB-AMR	Yes	Yes
3G Voice		
3G NB-AMR	Yes	Yes
3G WB-AMR	Yes	Yes
LTE Voice		
CSFB	Yes	Yes
VoLTE with SRVCC	Yes	Yes
Multi MIC AEC NR	Yes	Yes
Package		
Process Technology	28nm	28nm
Package Size	7×7	12×12
Apps Processor		
Integrated AP	No	Yes
RF		
Primary RX ports	8	8

Table 1 NVIDIA i500 Specifications

Document Revision History

Revision Number	Notes

Notice

ALL INFORMATION PROVIDED IN THIS WHITE PAPER, INCLUDING COMMENTARY, OPINION, NVIDIA DESIGN SPECIFICATIONS, REFERENCE BOARDS, FILES, DRAWINGS, DIAGNOSTICS, LISTS, AND OTHER DOCUMENTS (TOGETHER AND SEPARATELY, "MATERIALS") ARE BEING PROVIDED "AS IS." NVIDIA MAKES NO WARRANTIES, EXPRESSED, IMPLIED, STATUTORY, OR OTHERWISE WITH RESPECT TO MATERIALS, AND EXPRESSLY DISCLAIMS ALL IMPLIED WARRANTIES OF NONINFRINGEMENT, MERCHANTABILITY, AND FITNESS FOR A PARTICULAR PURPOSE.

Information furnished is believed to be accurate and reliable. However, NVIDIA Corporation assumes no responsibility for the consequences of use of such information or for any infringement of patents or other rights of third parties that may result from its use. No license is granted by implication or otherwise under any patent or patent rights of NVIDIA Corporation. Specifications mentioned in this publication are subject to change without notice. This publication supersedes and replaces all information previously supplied. NVIDIA Corporation products are not authorized for use as critical components in life support devices or systems without express written approval of NVIDIA Corporation.

Trademarks

NVIDIA, the NVIDIA logo, Adaptive Wireless, DXP, Deep Execution, IceClear, and Tegra are trademarks or registered trademarks of NVIDIA Corporation in the United States and other countries. Other company and product names may be trademarks of the respective companies with which they are associated.

Copyright