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ONFi: Achieving Breakthrough NAND Performance

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Intel Corporation



Agenda

- ONFi Workgroup Update
 - Mission and membership
 - ONFi 2.0 specification completed
 - NAND connector specification completed
 - JEDEC collaboration established
- High-speed NAND interface details
- Extending the high-speed interface

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Mission... Possible.

- NAND has been the only commodity memory with no standard interface
 - Command set, timings, and pin-out are similar among vendors
- NAND has been ripe for standardization due to a few inflection points:
 - 1) Explosion in use of NAND for MP3 players, phones, caches, and SSDs
 - 2) Increase in number of NAND vendors serving the market (2 to 6+)
- ONFi Workgroup was formed in May 2006 to address “gap”
 - ONFI = Open NAND Flash Interface
- ONFi revision 1.0 delivered in December 2006, defines:
 - Uniform NAND electrical and protocol interface
 - Raw NAND component interface for embedded use
 - Includes timings, electrical, protocol
 - Standardized base command set
 - Uniform mechanism for device to report its capabilities to the host

ONFI 1.0 sets a solid foundation for NAND (r)evolution.

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Members

- | | | |
|-----------------------|----------------------------|--------------------------|
| A-Data | Afa Technologies | Alcor Micro |
| Aleph One | Anobit Tech. | Apacer |
| Arasan Chip Systems | ASMedia Technology | ATI |
| Avid Electronics | BitMicro | Biwin Technology |
| Chipsbank | Cypress | DataFab Systems |
| DataIO | Datalight | Denali Software |
| Entorian | FCI | FormFactor |
| Foxconn | Fusion Media Tech | Genesys Logic |
| Hagiwara Sys-Com | HiperSem | Hitachi GST |
| Hyperstone | InCOMM | Indilinx |
| Inphi | Intelliprop | ITE Tech |
| Jinvani Systech | Kingston Technology | Lauron Technologies |
| Lotes | LSI | Macronix |
| Marvell | Mentor Graphics | Metaram |
| Moai Electronics | Molex | NVidia |
| Orient Semiconductor | P.A. Semi | Powerchip Semi. |
| PQI | Prolific Technology | Qimonda |
| Sandforce | Seagate | Shenzhen Netcom |
| Sigmatel | Silicon Integrated Systems | Silicon Motion |
| Silicon Storage Tech | STEC | Skymedi |
| Smart Modular Tech. | Solid State System | Super Talent Electronics |
| Synopsys | Tandon | Tanisys |
| Teachips | Teradyne, Inc. | Testmetrix |
| Transcend Information | Tyco | UCA Technology |
| University of York | Virident Systems | WinBond |

ONFi continues to grow with over 80 members.

ONFi 2.0 Delivers the Speed You Need

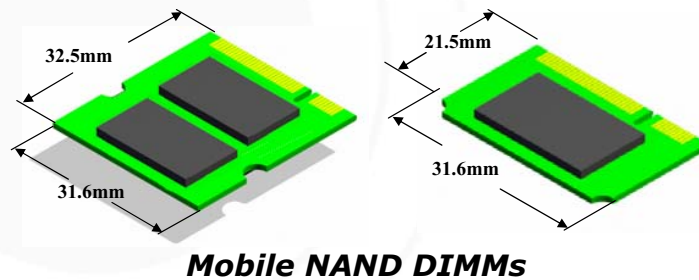
- ONFi 2.0 was published on February 27th
 - Available at www.onfi.org
- Adds a synchronous DDR interface option for high speed
 - Up to 133 MT/s in current generation
 - 3.3V and 1.8V VccQ options
 - BGA package optimized for high speed
- Many more details to come later in the presentation...



ONFi 2.0 triples the legacy NAND interface speed.

Towards NAND Ubiquity in PCs...

- As NAND becomes ubiquitous in PCs, the NAND controller will be integrated with the platform (rather than on a PCIe add-in card)
- It is not necessarily desirable to solder NAND to the platform, though
 - Need to offer customers capacity and feature choices
 - Dynamically changing price of NAND
- Desirable to have an “unregistered, unbuffered DIMM” for NAND
 - Provides a cost effective method to offer choice with the platform



Mobile NAND DIMMs

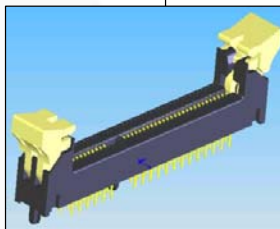
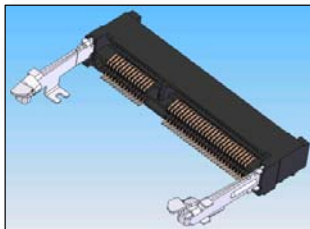
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Connector Specification Complete!

- The ONFi Workgroup published Revision 1.0 of the connector specification on April 23rd
 - Available at www.onfi.org
- The ONFi connector leverages existing memory connectors
 - Avoids major tooling costs
 - Re-uses electrical verification
 - Ensures low cost and fast TTM



ONFi
OPEN NAND
FLASH INTERFACE

**Open NAND Flash Interface Specification:
NAND Connector**

Connector Revision 1.0
23-April-2008

Hynix Semiconductor
Intel Corporation
Micron Technology, Inc.
Phison Electronics Corp.
Sony Corporation
Spansion
STMicroelectronics

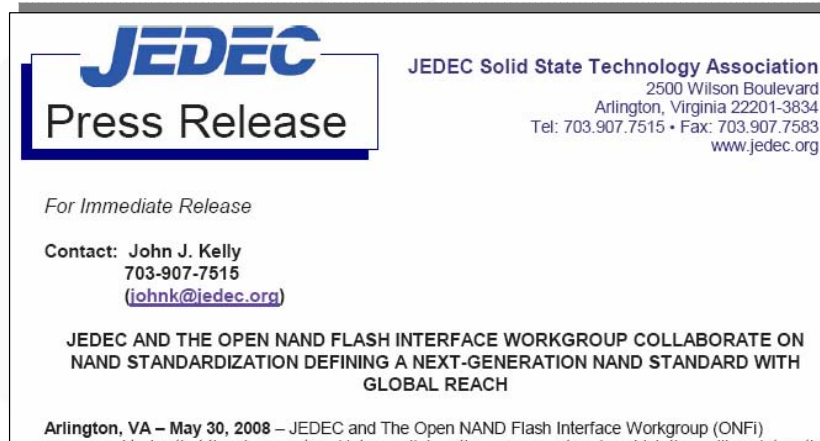
The ONFi connector and module are key building blocks for pervasive use of NAND in PC platforms.

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JEDEC and ONFi Launch Collaboration

- The ONFi Workgroup is pleased to team up with JEDEC on NAND standardization moving forward
- ONFi is submitting the ONFi 2.0 specification as part of the joint effort



JEDEC
Press Release

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For Immediate Release

Contact: John J. Kelly
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(johnk@jedec.org)

JEDEC AND THE OPEN NAND FLASH INTERFACE WORKGROUP COLLABORATE ON NAND STANDARDIZATION DEFINING A NEXT-GENERATION NAND STANDARD WITH GLOBAL REACH

Arlington, VA – May 30, 2008 – JEDEC and The Open NAND Flash Interface Workgroup (ONFi)

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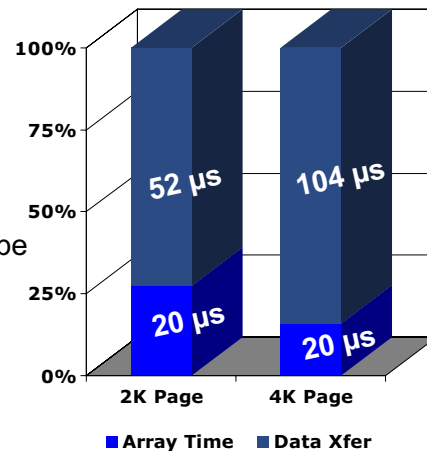
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The Outdated Legacy NAND Interface

- NAND performance is determined by two elements
 - NAND array access time
 - Data transfer time across the bus
- For legacy NAND reads, the dominant factor is the bus!
 - Performance is limited to 40 MB/s
 - With interface improvements data could be read at over 150 MB/s
- The issue gets ***significantly worse*** as page size increases

Legacy NAND Interface Bottleneck



Even with pipelined reads, the NAND array sits idle for 80+ μs while data is transferred to the host...

ONFi 2.0 To The Rescue...

Project Goal

- Develop a scalable and backwards compatible high speed interface that does not require a DLL on the NAND device
 - Performance goal: 133 MT/s initially, with scalability to at least 400 MT/s over several generations

The Result

- ONFi 2.0 source synchronous data interface
 - Scalable
 - Backwards compatible
 - No DLL on the device

Interface Roadmap	
Legacy	40 MB/s
Gen1	~ 133 MB/s
Gen2	~ 266 MB/s
Gen3	400 MB/s +

Enabling a Seamless Transition

- Source synchronous is backwards compatible with the legacy NAND interface to enable:
 - a) An orderly discovery process
 - b) To allow NAND parts to support both interfaces during transition
 - c) To allow host to support either type of NAND easily
- NAND pins are re-purposed when source synchronous is selected
 - WE# is used as a clock for data input and output (clock used when I/O is active)
 - RE# is used to indicate the direction of data transfer and bus ownership
 - A strobe (DQS) is added for latching data input and output (the only new signal)
- The pins were named using traditional DRAM nomenclature to make the interface easier to understand for those with a DRAM background

Symbol		Type	Description
Traditional	Source synchronous		
I/O[7:0]	DQ[7:0]	I/O	Data inputs/outputs
—	DQS	I/O	Data strobe
WE#	CLK	Input	Write enable => Clock
RE#	W/R#	Input	Read enable => Write / Read# direction



Source Synchronous Discovery

- Using asynchronous SDR:
 - Read ID is used to identify the device supports ONFI
 - Read Parameter page identifies that source synchronous is supported
 - The host selects source synchronous using Set Features
- The host then enjoys using the high-speed source synchronous interface

Parameter Page Information

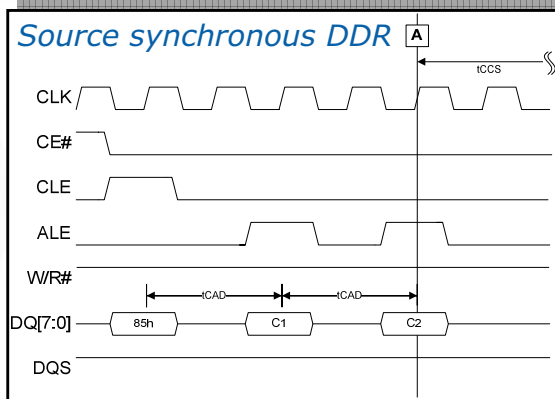
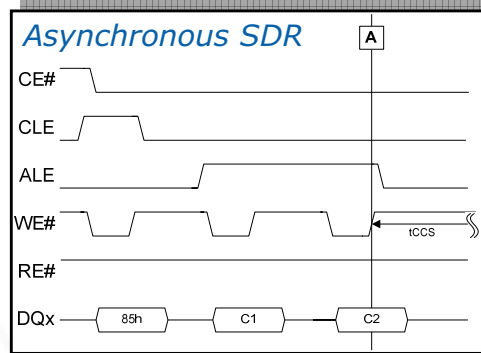
Byte	O/M	Description
6-7	M	Features supported 6-15 Reserved (0) 5 1 = supports source synchronous 4 1 = supports odd to even page Copyback 3 1 = supports interleaved operations 2 1 = supports non-sequential page programming 1 1 = supports multiple LUN operations 0 1 = supports 16-bit data bus width
141-142	O	Source synchronous timing mode support 4-15 Reserved (0) 3 1 = supports timing mode 3 2 1 = supports timing mode 2 1 1 = supports timing mode 1 0 1 = supports timing mode 0
143	O	Source synchronous features 2-7 Reserved (0) 1 1 = typical capacitance values present 0 tCAD value to use
144-145	O	CLK input pin capacitance, typical
146-147	O	I/O pin capacitance, typical
148-149	O	Input pin capacitance, typical
150	M	Input pin capacitance, maximum

Timing Mode	Mode 0	Mode 1	Mode 2	Mode 3	Unit
tCK	50	30	20	15	ns
CLK frequency	~20	~33	~50	~66	MHz
Interface speed	40	66	100	133	MT/s



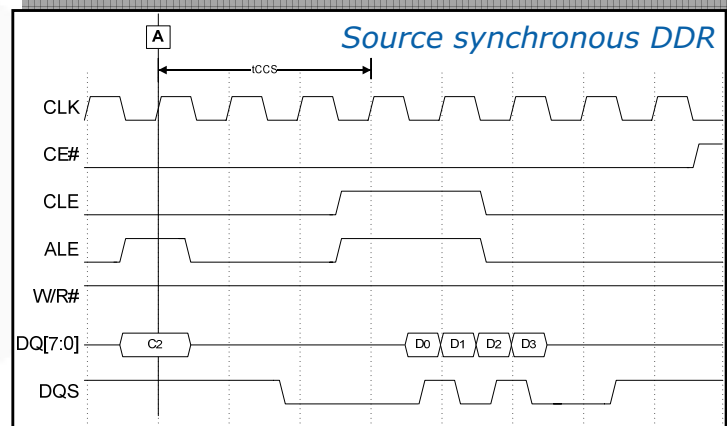
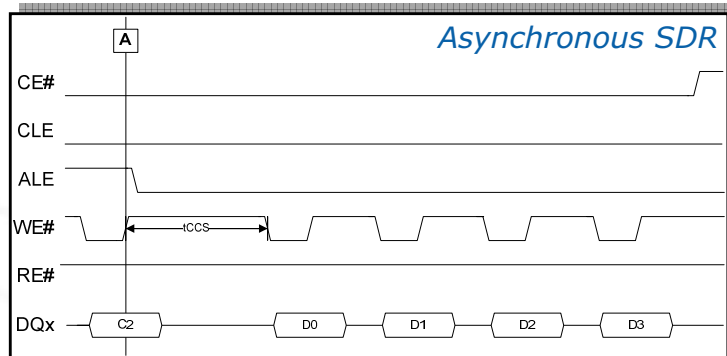
Commands

- Asynchronous SDR and source synchronous DDR command issue is very similar
- tCAD timing parameter ensures 25 ns or 45 ns is provided to process each command and address
 - Avoids redoing command state machine
 - Avoids host needing to pulse WE# at different rates for cmd/addr and data
- Traditional parameters, like tCCS, tRHW, tWHR, etc are still used
- Data strobe (DQS) is not used for command/address cycles
- Reset (FFh) always issued in asynchronous SDR mode to reset the device



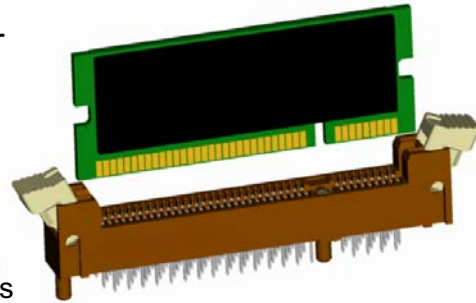
Data Phase

- Data is transferred on each edge of DQS
- DQS marks where the receiver should latch the data
- ALE/CLE takes on new meaning
 - 00b: Idle
 - 11b: Data



Impedance, Slew Rates and Robustness

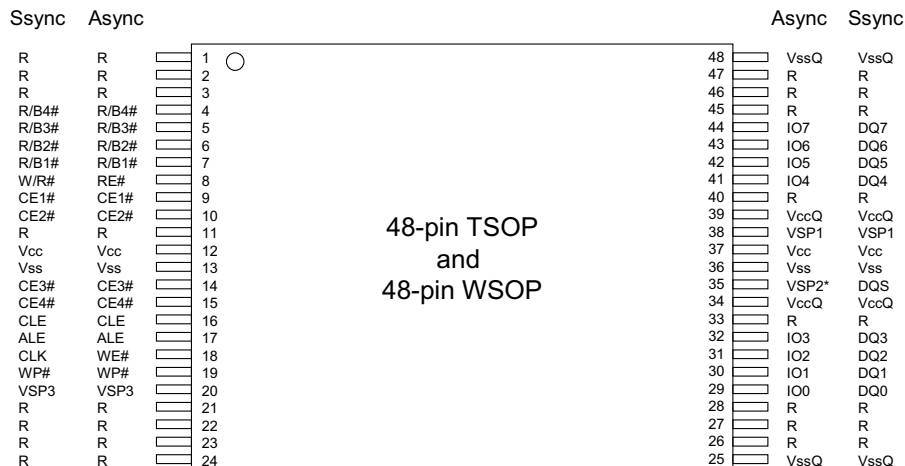
- Interoperability at higher speeds is critical, especially with the connector
 - Important to make sure design can work across long trace lengths and deal with discontinuities introduced
- Input slew rates, output slew rates, and impedance values are specified
 - Ensures robust interoperable designs can be delivered



Description	VOUT to VssQ	Maximum	Nominal	Minimum	Unit
R_pulldown	0.2 x VccQ	95.0	39.0	21.5	Ohms
	0.5 x VccQ	90.0	50.0	26.0	Ohms
	0.8 x VccQ	126.5	66.5	31.5	Ohms
R_pullup	0.2 x VccQ	126.5	66.5	31.5	Ohms
	0.5 x VccQ	90.0	50.0	26.0	Ohms
	0.8 x VccQ	95.0	39.0	21.5	Ohms

TSOP and Its Limitations...

- TSOP was extended in a straightforward manner to support source synchronous
 - DQS was added on pin 35, all other pins in same location
 - VccQ and VssQ locations also defined
- However, TSOP is not suitable as speed continues to scale past 100 MT/s...
 - Package has high input capacitance due to single-sided bond pads
 - Typically up to four die can be stacked in the package leading to higher capacitance
 - Lower cost package construction than DRAM TSOP



BGA Package

- ONFi 2.0 defines a BGA package optimized for source synchronous

Attributes:

- Dual 8-bit interface
- More power/ground balls for lower noise
- Signals arranged with excellent signal integrity in mind
- 1mm ball spacing for low cost PCB assembly
- Two package outline options supported for increasing densities

	1	2	3	4	5	6	7	8	9	10
A	R	R							R	R
B	R									R
C										
D		R	RFT	VSP3-2	WP2#	VSP2-2	VSP1-2	RFT	R	
E		R	RFT	VSP3-1	WP1#	VSP2-1	VSP1-1	RFT	R	
F		VCC	VCC	VCC	VCC	VCC	VCC	VCC	VCC	
G		VSS	VSS	VSS	VSS	VSS	VSS	VSS	VSS	
H		VSSQ	VCCQ	VREFQ2	VREFQ1	R/B2#	R/B4#	VCCQ	VSSQ	
J		DQ0-2	DQ2-2	ALE2	CE4#	R/B#	R/B3#	DQ5-2	DQ7-2	
K		DQ0-1	DQ2-1	ALE1	CE3#	CE2#	CE#	DQ5-1	DQ7-1	
L		VCCQ	VSSQ	VCCQ	CLE2	W/R2#	VCCQ	VSSQ	VCCQ	
M		DQ1-2	DQ3-2	VSSQ	CLE1	W/R1#	VSSQ	DQ4-2	DQ6-2	
N		DQ1-1	DQ3-1	DQS2#	DQS2	CLK2#	CLK2	DQ4-1	DQ6-1	
P		VSSQ	VCCQ	DQS1#	DQS1	CLK1#	CLK1	VCCQ	VSSQ	
R										
T	R									R
U	R	R							R	R

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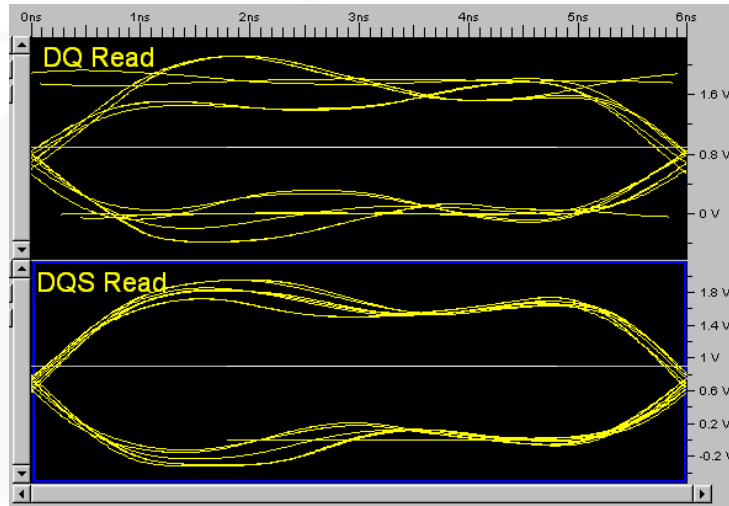
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There is Head Room

- Why stop at 133 MT/s? Successful operation at 166 MT/s for 8 NAND die with a connector!



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Enter ONFi 2.1...

- Work on the 2.1 specification started early this year, with target completion in 2H'08
- Recognizes head room by defining 166 MT/s and 200 MT/s timing modes
- Includes additional new features, like an interleaved read command to continue moving the industry forward

Parameter	Mode 0		Mode 1		Mode 2		Mode 3		Mode 4		Mode 5		Unit
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
	50		30		20		15		12		10		ns
		~20		~33		~50		~66		~83		~100	MHz
tAC	—	20	—	20	—	20	—	20	—	20	—	20	ns
tADL	100	—	100	—	70	—	70	—	70	—	70	—	ns
tCADr	25	—	25	—	25	—	25	—	25	—	25	—	ns
tCADs	45	—	45	—	45	—	45	—	45	—	45	—	ns
tCAH	10	—	5	—	4	—	3	—	2.5	—	2	—	ns
tCALH	10	—	5	—	4	—	3	—	2.5	—	2	—	ns
tCALs	10	—	5	—	4	—	3	—	2.5	—	2	—	ns
tCAS	10	—	5	—	4	—	3	—	2.5	—	2	—	ns
tCH	10	—	5	—	4	—	3	—	2.5	—	2	—	ns
tCK(avg) or tCK	50	—	30	—	20	—	15	—	12	—	10	—	ns
tCK(abs)	Minimum: tCK(avg) + tJIT(per) min Maximum: tCK(avg) + tJIT(per) max												ns

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Summary

- ONFi source synchronous is designed to preserve backwards compatibility, ease NAND transitions, and scale in speed across multiple generations
- Benefits of ONFi 2.0 solution:
 - Delivers 133 MT/s in first generation, scales up to 400 MT/s through straightforward techniques (like complementary signals)
 - Lower power by separating Vcc and VccQ, and lower VccQ (1.8V)
 - Backwards compatible with legacy NAND interface, including with TSOP
 - Standard BGA package designed to overcome speed limitations of TSOP
 - Ensures that NAND controllers can be confidently designed for future NAND devices through mechanisms like Read Parameter Page
- ONFi 2.1 scales performance to 166 MT/s and 200 MT/s

*Achieve breakthrough performance with ONFI 2.0 today!
For more information, visit www.onfi.org.*