Economics of the Chip Business

Key Principles

- Time value of money (ROI)
- Cost vs. price
- Product cost vs. design cost (NRE)
- Business models

Acknowledgments

Time Value of Money
Money is a commodity, just like anything else
- Investors buy/sell it
- Investors have many choices

Risk vs. Reward
- Bank CD: low risk, low reward
- S&P 500: moderate risk, moderate reward
- Venture capital: high risk, high reward

Return on investment (ROI)
- Profit = (amount invested) + time period, e.g.
  \((40\text{M$} + 200\text{M$} \times 4 \text{ yrs}) = 5.0\%\)
  (there are more precise ways for compounding interest, e.g. daily)

Cost vs. Price
Price – what you can charge for an item
- Set based on law of supply and demand
- Not an exact science

Cost – what you spend to design & manufacture
- Design: non-recurring engineering (NRE) Cost
  Personnel: salary, benefits, equipment (~3x salary)
  Prototyping
  Main driver: design complexity
- Product cost
  Manufacture, test, assemble, distribute
  Main driver: chip area

Total Product Cost
\[ \text{Cost}_{\text{tot}} = \frac{NRE}{\text{volume}} + \text{Cost}_{\text{manufacture}} \]

Expected volume determines design philosophy
- Low volume (e.g. IBM): minimize NRE
- High volume (e.g. Intel): minimize Cost_{manufacture}
Manufacturing Cost
Functional Silicon Die
- Die Size
- Process Maturity
Package & Assembly
- Substrate vs. Lead Frame
Yield
- Functional
- Frequency

Yield as Function of Die Size

Functional Die Cost

*Assumption: 200mm (8 inch) wafers at $3,000 each
Example #1: Graphics Chip

- 63% Functional Yield ($3.72)
- BGA Package ($4.00)
- Assembly ($0.60)
- 1% Fallout ($0.15)
- Test ($1.00)
- Total: $16.31

Assumption: 200mm (8 inch) wafers at $3,000 each, defect density 0.8

Example #2: After Shrink

- 79% Functional Yield ($0.82)
- BGA Package ($4.00)
- Assembly ($0.60)
- 1% Fallout ($0.08)
- Test ($1.00)
- Total: $9.68

Assumption: 200mm (8 inch) wafers at $3,000 each, defect density 0.8

Process Variation

- Low Volume ASIC Device
- Mass Production Device
- Equivalent Speed ASIC

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Example #3: Speed Sorted

- 63% Functional Yield ($3.72)
- 85% Speed Yield ($2.79)
- 1% Fallout ($0.15)
- Test ($1.00)
- Assembly ($0.60)
- BGA Package ($4.00)

Total: $18.62

*Assumption: 200mm (8 inch) wafers at $3,000 each, defect density 0.8

Design Cost

- Time
  - How Long Until Revenue
- Resources
  - No. People, Expertise, CAD Tools, ...
- Risk
  - Schedule Slip
  - Performance Irregularities
  - Reliability Problems

Typical Project Schedule

- Architecture: 9 months
- Logical Design (RTL): 6.75 years
- Logical Verification
- Physical Design (Synthesis, P&R): 9 months
- Physical Verification (Timing)
- Prototype Fabrication, Package
- Silicon Debug
- In-System Verification
- 2nd Physical Design
- 2nd Physical Verification
- Production Fabrication

Variations:
- Startup: Architecture -6
- Big Company: System Verif. +6

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Typical Manpower Requirements

- Performance: 2 – 10
- Logical Design: 5 – 25
- Logical Verification: 5 – 50
- Physical Design: 2 – 30
- Physical Verification: 1 – 30
- Package Design: 1 – 5
- Reference Board Design: 1 – 5
- In-System Verification: 2 – 10
- 2nd Physical Design: 1 – 5
- 2nd Physical Verification: 1 – 5
- Documentation: 1 – 5

Range: Startup – Mature Company

Design Cost Summary

$333K per Person Year
- Low: 20p x 3y = $20M
- High: 150p x 3.5y = $175M

Amortize
- High Volume
  - Demand Generation
  - Derivative Products
- High-Value System Product

*Compensation $150K + 50% Benefits + 50% Equipment + 20% Facilities

Example #1: PC Graphics Chip

Price: $46

*Highest volume PC OEM product line shipped several million in year 2000
Example #2: High-End Router

- NRE $20M
- 100K parts ($200)
- BGA Package ($50)
- Asm+Test ($10)
- 400mm Die ($51)
- 9% Functional Yield ($519)

10% Sales Cost ($83)
15% Profit ($137)

Price: $1,050

*Chip revenue stream $100M. System revenue stream $1B?

Return On Investment (ROI)

#1: PC Graphics Chip
$4M Profit + $20M + 4yr = 5%
Do better by investing in S&P 500

#2: High-End Router
$14M Profit + $20M + 4yr = 18%
Can afford R&D for future
Derivative designs help
$16M Profit + $25M + 7yr = 9%

Big Picture

Business Models
- Deep Pocket
  - Demand Generation + Forward Pricing
e.g. Nintendo, Sony Video Game Consoles
- System Subsidy
  - System Sales + Support Cost
e.g. Sun Microsystems, Hewlett-Packard Microprocessors

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Model #1: Deep Pocket

- Architecture
- Design
- Proto Fab (600mm² in 0.12µm)
- HW Debug/Qual
- Mass Production (400mm² in 0.10µm)
- Sales Channel
  - 1st Shrink (300mm² in 0.09µm)
  - 2nd Shrink (150mm² in 0.06µm)
- Software Development
- Promotion Campaign

Forward Pricing

- Process Generation
- Proto Fab (600mm² in 0.12µm)
- Mass Production (400mm² in 0.10µm)
- 1st Shrink (300mm² in 0.09µm)
- 2nd Shrink (150mm² in 0.06µm)
- Mature Process (0.06µm)
- Units Shipped
- Revenue, Price = $250
- Net Gain: $1.8B
- ROI: ($1.8B – $175M) ÷ $175M = 100% (– cost of $7.5B × 2yr, ...)

Model #2: System Subsidy

- Example:
  - 16-Processor Server
  - Price: $7,000
  - Cost: $6,000
  - Volume: 50,000 units × 2 years
  - NRE: Chip $20M + System $20M
  - Recovery: $400 per system
  - "Profit": $600 per system
  - ROI: $60M ÷ $40M ÷ 5yr = 30%

*Note*

System Sales + Support Cost > Chip Sales Cost

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