6502 Interrupt and Bus

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What Makes the Cursor Blink?

- 6502 CPU processes sequence of instructions
- But: general maintenance needed, e.g.,
  - cursor blinking
  - storage I/O
  - process key strokes
- Regular scheduled program must be interrupted

Multi-Process Operating Systems

- Modern operating systems manage multiple processes
- Scheduler in kernel switches between them
- Process state for each must be preserved
- But 6502 operation systems used simpler approach

Interrupt

- Idea
  - interrupt regularly scheduled code every once in a while
  - take care of maintenance tasks

- 6502 implementation
  - FFFE/FFFF contain address for interrupt routine
  - triggered by a hardware clocks
  - RTI: instruction to return from interrupt
  - SEI: disable interrupts
  - CLI: enable interrupts

Commodore C64 Interrupt Code

- Interrupt vector FFFE/FFFE points to FF48

- Save registers

Address	Bytes	Command
FF48	48	PHA
FF49	8A	TXA
FF4A	48	PHA
FF4B	98	TYA
FF4C	48	PHA

Online reference: http://unusedino.de/ec64/technical/aay/c64/romff48.htm

Software and Hardware Interrupts

- Hardware interrupt: triggered by clock
- Software Interrupt: caused by BRK instruction (sets break flag)
- Interrupt call pushes status register to stack
- Detect what kind of interrupt

```
Address  Bytes      Command
  FF4D   BA         TSX ; get stack pointer
  FF4E   BD 04 01   LDA $0104,X ; load stored status register
  FF51   29 10      AND #$10 ; is the break flag set?
  FF53   F0 03      BEQ $FF58
  FF55   6C 16 03   JMP ($0316) ; software (BRK) interrupt
  FF58   6C 14 03   JMP ($0314) ; hardware interrupt
```

Redirect Interrupts

- Jump to hardware interrupt routine

```
Address  Bytes      Command
  FF58   6C 14 03   JMP ($0314) ; hardware interrupt
```

- This is a pointer

→ can be modified to your own routine

Making the Cursor Blink

- Pointer at 0314/0315 points to EA31
- Subroutine call for real time clock increment

```
Address  Bytes      Command
  EA31   20 EA FF   JSR $FFEA ; increment Real-Time Clock
```

- Cursor blinking code

```
Address  Bytes  Command
  EA34   A5 CC  LDA $CC ; is the cursor in blink mode?
  EA36   D0 29  BNE $EA61 ; no → skip all this
  EA38   C6 CD  DEC $CD ; count down cursor blink timer
  EA3A   D0 25  BNE $EA61 ; not at 0 → done
  EA3C   A9 14  LDA #$14
  EA3E   85 CD  STA $CD ; reset timer
```

Making the Cursor Blink

```
Address   Bytes       Command
  EA40    A4 D3       LDY $D3      ; cursor column
  EA42    46 CF       LSR $CF      ; currently solid → set carry
  EA44    AE 87 02    LDX $0287    ; load color under cursor
  EA47    B1 D1       LDA ($D1),Y  ; retrieve character from screen memory
  EA49    B0 11       BCS $EA5C    ; earlier check:  branch if solid
  EA4B    E6 CF       INC $CF      ; set cursor status "solid"
  EA4D    85 CE       STA $CE      ; store character value under cursor
  EA4F    20 24 EA    JSR $EA24    ; synchronize color pointer
  EA52    B1 F3       LDA ($F3),Y  ; load color from screen color memory
  EA54    8D 87 02    STA $0287    ; set color under cursor
  EA57    AE 86 02    LDX $0286    ; get current color
  EA5A    A5 CE       LDA $CE      ; get character code under cursor
  EA5C    49 80       EOR #$80     ; invert character code
  EA5E    20 1C EA    JSR $EA1C    ; print character to screen
```

Return from Interrupt

- Restore registers

Address	Bytes	Command
EA81	68	PLA
EA82	A8	TAY
EA83	68	PLA
EA84	AA	TAX
EA85	68	PLA

- Return from interrupt

```
EA86  40  RTI
```

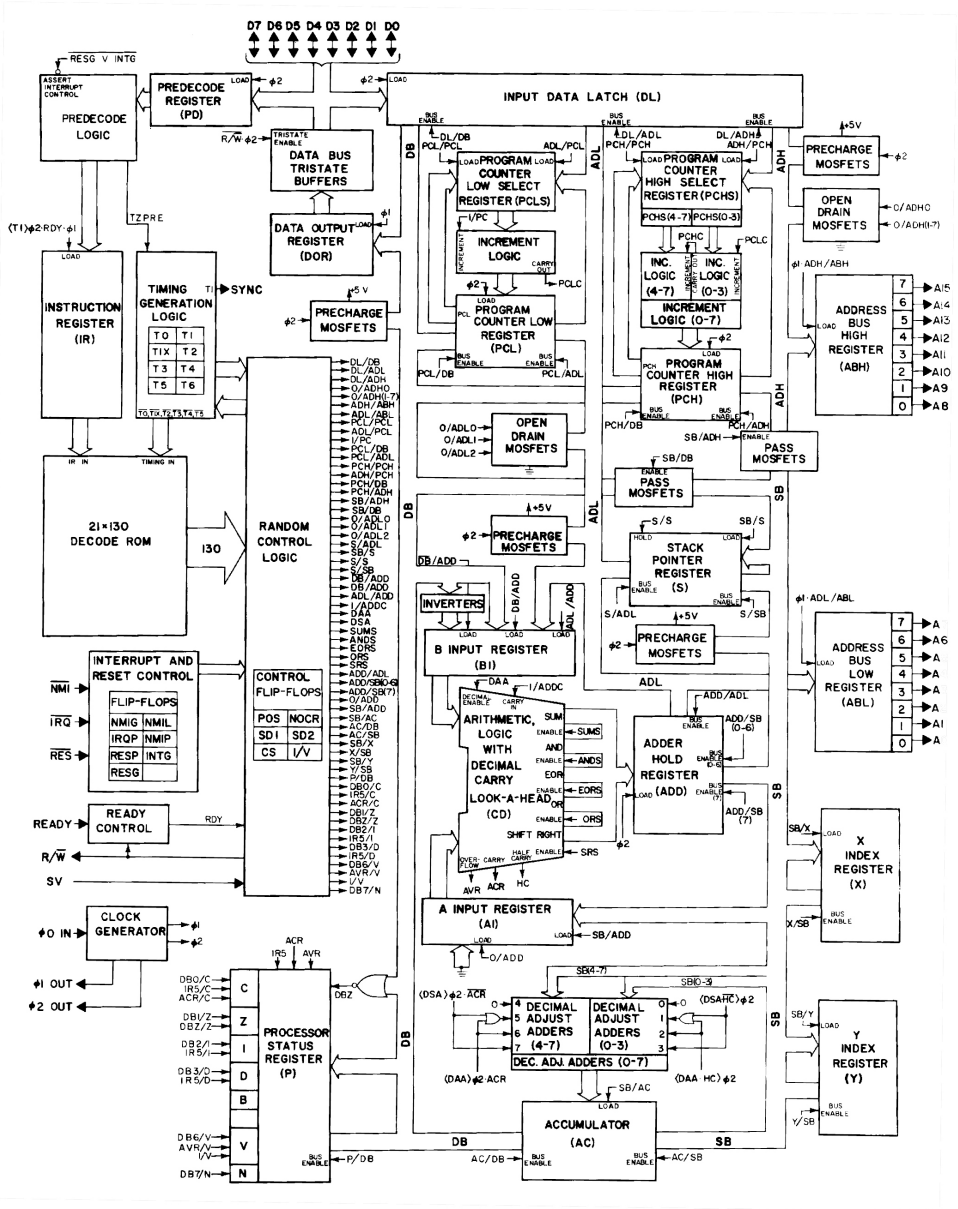
Example: Redirect Interrupt

- Border color is set in D020
- Change border color at each interrupt

```
Address   Bytes       Command
  4000    78          SEI       ; no interrupt while we change pointer
  4001    A9 0D       LDA #0D
  4003    8D 14 00    STA 0314
  4006    A9 40       LDA #40
  4008    8D 15 03    STA 0315  ; redirect interrupt to 400D
  400B    58          CLI
  400C    00          RTS
-------------------------------------------------------------------------
  400D    EE 20 D0    INC D020
  4010    4C 31 EA    JMP EA31  ; jump to regular interrupt reoutine
```

bus

6502 Diagram



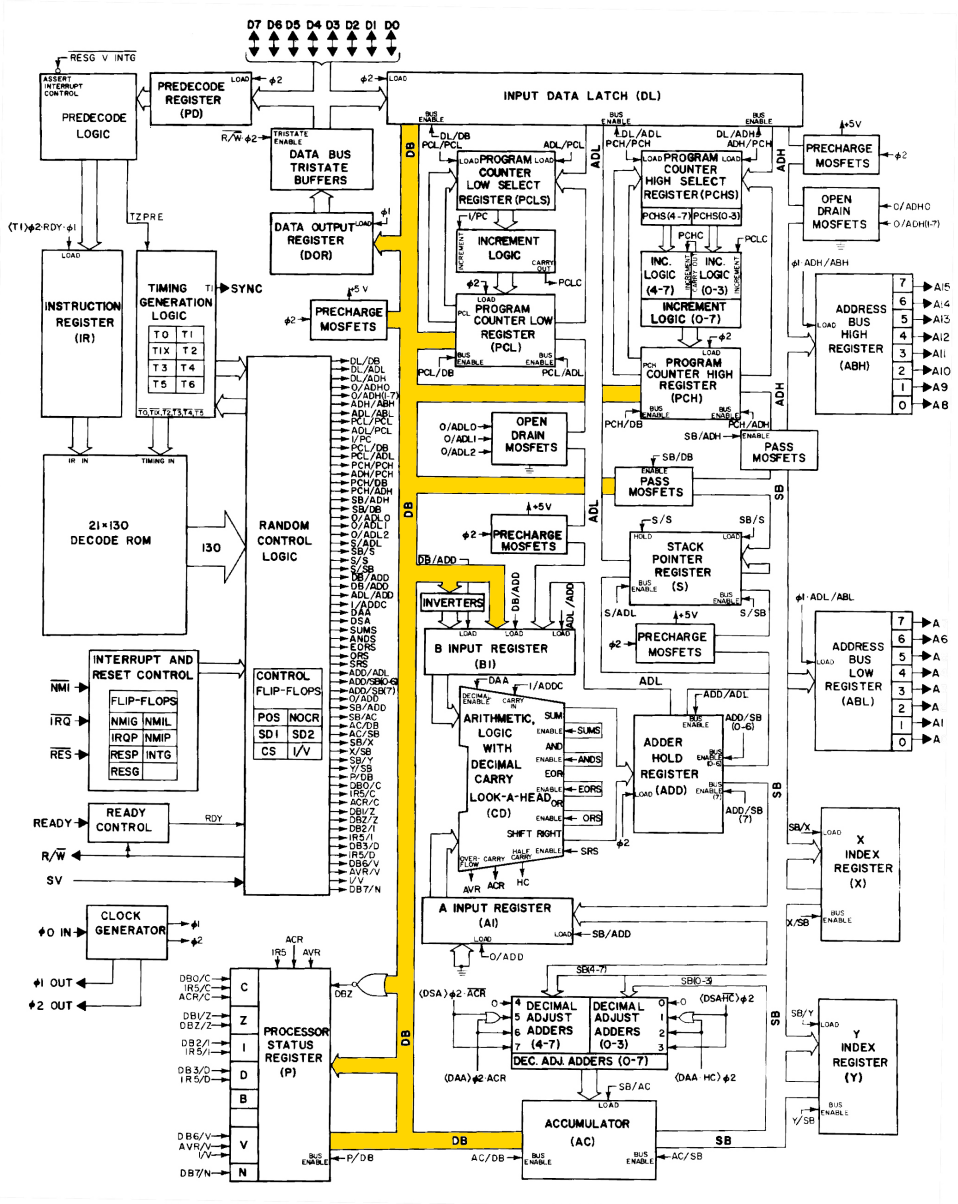
Many Components, Many Data Paths

- Problem: Increasing number of components
  - multiple registers
  - program counter
  - stack pointer
  - arithmetic logic unit
  - memory
- More components, more data paths
- Some components are outside the CPU
  - main memory
  - video processing
  - keyboard
  - tape drive and other storage

Bus

- Bus: shared data paths
- Example: data bus connects
  - accumulator
  - program counter
  - status register
  - arithmetic logic unit (ALU)
  - also (indirectly) connected to pins of chip
- Microprogram instructions
  - AC/DB: place accumulator value on bus
  - DB/ADD: read add input to ALU from bus

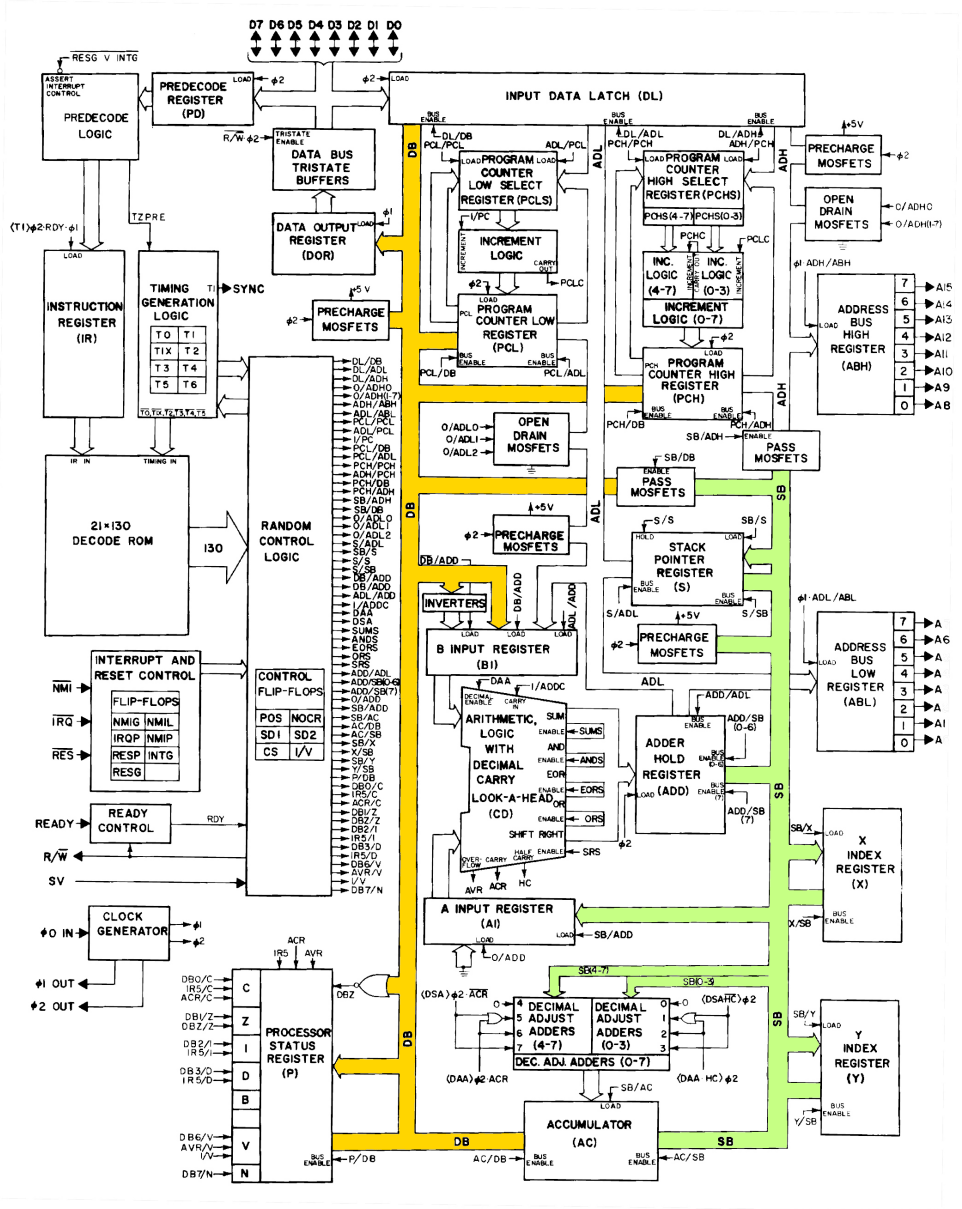
Data Bus (DB)


D7 D6 D5 D4 D3 D2 D1 D0
INPUT DATA LATCH (DL)
PREDECODE REGISTER (PD)
PREDECODE LOGIC
DATA BUS TRISTATE BUFFERS
DATA OUTPUT REGISTER (DOR)
INSTRUCTION REGISTER (IR)
TIMING GENERATION LOGIC
SYNC
21×130 DECODE ROM
130
RANDOM CONTROL LOGIC
INTERRUPT AND RESET CONTROL
FLIP-FLOPS
CONTROL FLIP-FLOPS
READY CONTROL
CLOCK GENERATOR
PROCESSOR STATUS REGISTER (P)
PROGRAM COUNTER LOW SELECT REGISTER (PCLS)
PROGRAM COUNTER HIGH SELECT REGISTER (PCHS)
INCREMENT LOGIC
PROGRAM COUNTER LOW REGISTER (PCL)
PROGRAM COUNTER HIGH REGISTER (PCH)
PRECHARGE MOSFETS
OPEN DRAIN MOSFETS
PASS MOSFETS
ADDRESS BUS HIGH REGISTER (ABH)
ADDRESS BUS LOW REGISTER (ABL)
STACK POINTER REGISTER (S)
INVERTERS
B INPUT REGISTER (BI)
ARITHMETIC, LOGIC WITH DECIMAL CARRY LOOK-A-HEAD (CD)
ADDER HOLD REGISTER (ADD)
A INPUT REGISTER (AI)
DECIMAL ADJUST ADDERS (4-7)
DECIMAL ADJUST ADDERS (0-3)
DEC. ADJ. ADDERS (0-7)
ACCUMULATOR (AC)
X INDEX REGISTER (X)
Y INDEX REGISTER (Y)
DB
ADL
ADH
SB

Internal Buses

- Data bus (DB)
  - accumulator
  - program counter
  - status register
  - arithmetic logic unit (ALU)
  - also (indirectly) connected to pins of chip
- Special bus (SB)
  - registers (A, X, Y)
  - arithmetic logic unit (ALU)
  - stack pointer
  - only internal

Special Bus (SB)



Address Bus (ABL/ABH)

- Addresses are 16 bits

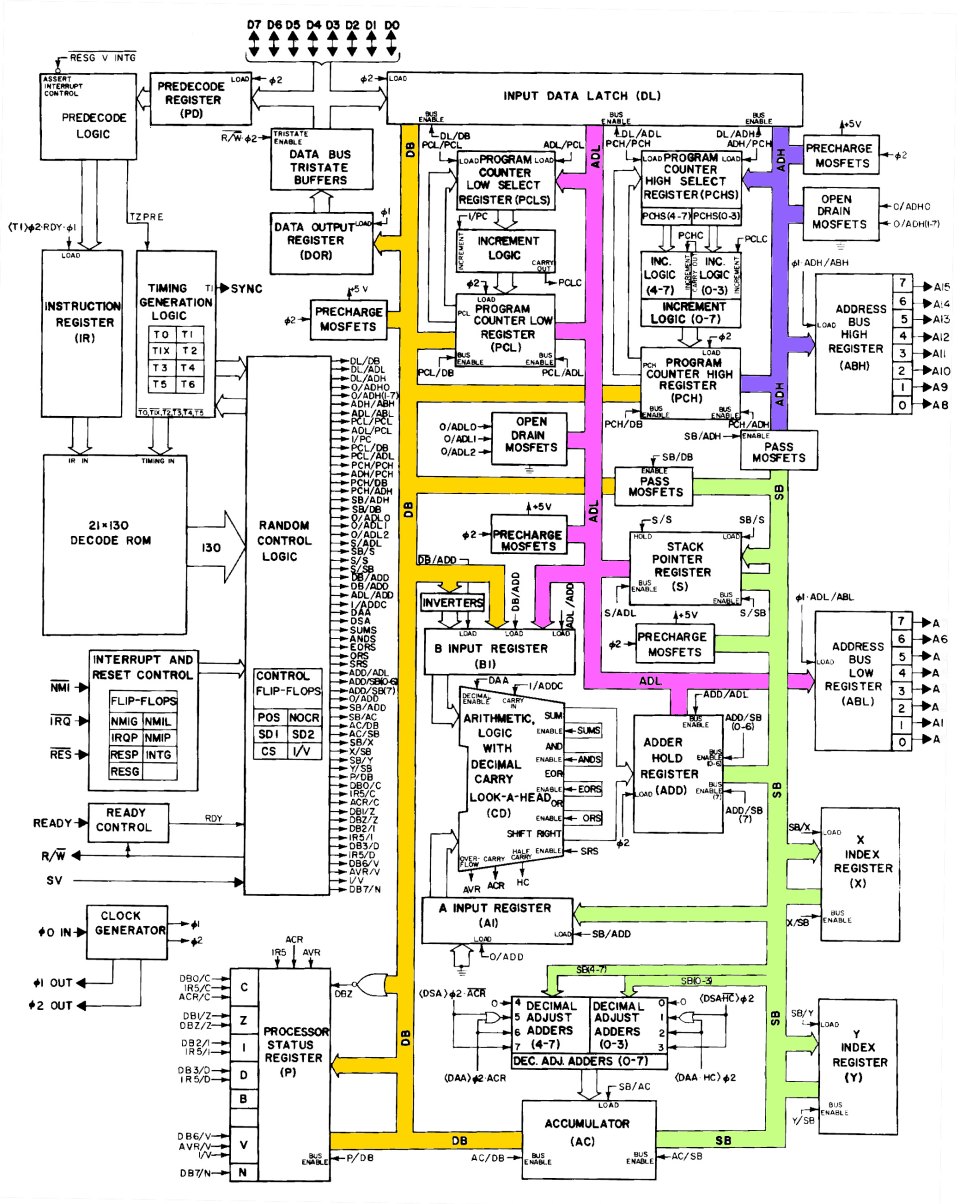
- Memory is based on 8 bit

$\Rightarrow$ 2 buses for memory addresses

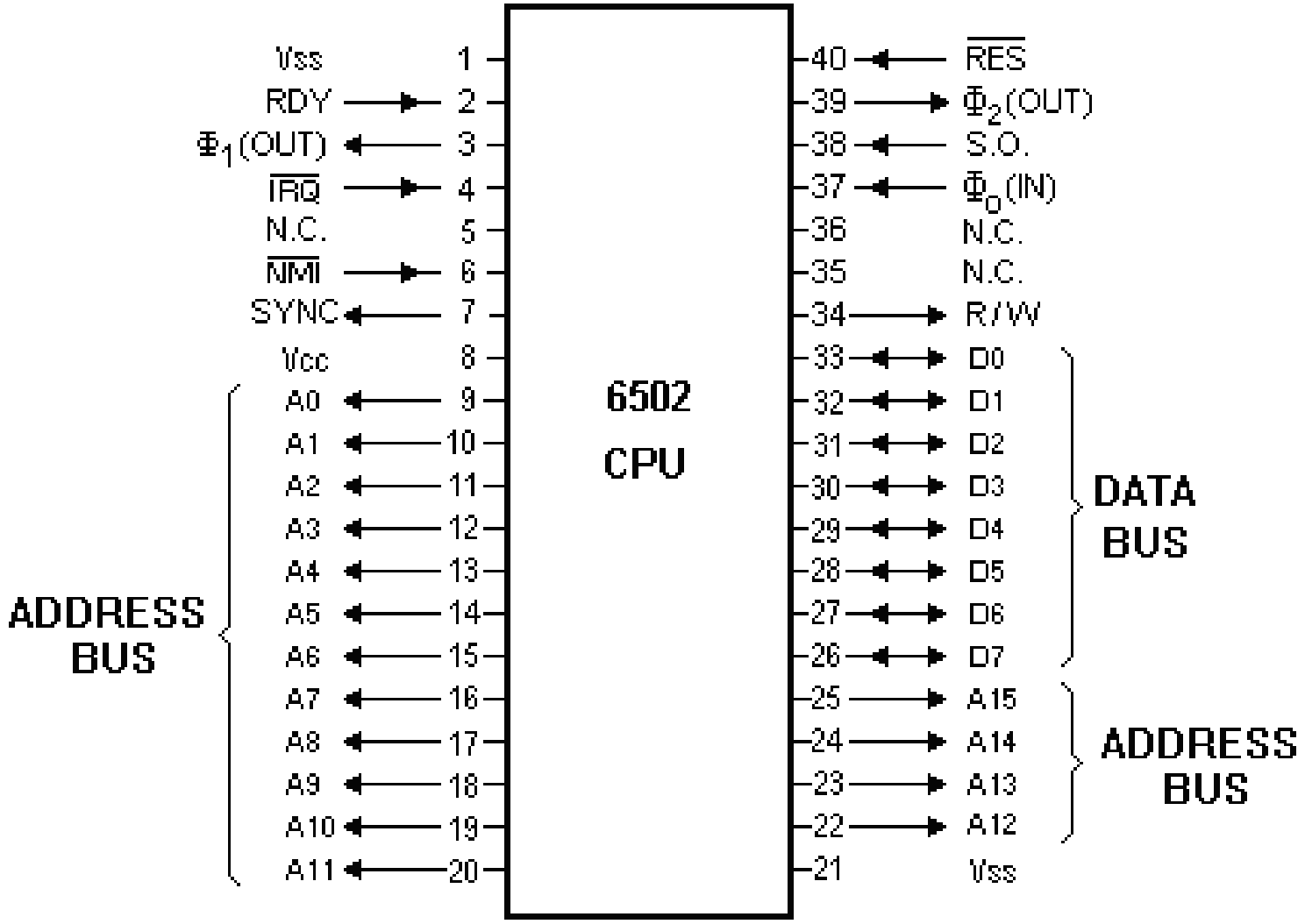
  - ABL: address bus low
  - ABH: address bus high

- Pin connection to memory (outside CPU)

Address Bus (ABL/ABH)



6502 Pins


6502
CPU
Vss 1
RDY 2
Φ1(OUT) 3
IRQ 4
N.C. 5
NMI 6
SYNC 7
Vcc 8
A0 9
A1 10
A2 11
A3 12
A4 13
A5 14
A6 15
A7 16
A8 17
A9 18
A10 19
A11 20
40 RES
39 Φ2(OUT)
38 S.O.
37 Φ0(IN)
36 N.C.
35 N.C.
34 R/W
33 D0
32 D1
31 D2
30 D3
29 D4
28 D5
27 D6
26 D7
25 A15
24 A14
23 A13
22 A12
21 Vss
ADDRESS BUS
DATA BUS
ADDRESS BUS

Internal vs External Bus

- Internal bus
  - operates within the same motherboard
  - 6502: data and special bus
  - system bus connects CPU and memory
- External bus
  - connects to external devices

Universal Serial Bus (USB)

- Popular bus today: universal serial bus (USB)
- Breaks up data into series of bytes
- Protocol defines what each message means
- Also contains power line
  $\rightarrow$ cell phone charging

Bus Speed

- Different buses may operate at different speeds
  - within same chip: very fast
  - on same motherboard: fast
  - external bus: slowest

- Some speed numbers today
  - CPU speed: 3 GHz
  - System bus (CPU to memory): 100-200 MHz
  - USB 3.0 (2013) maximum speed: up to 2.4 GHz