CHAPTER XI

DATAPATH ELEMENTS

READ DATAPATH ELEMENTS FREE-DOC ON COURSE WEBPAGE

DATAPATH ELEMENTS

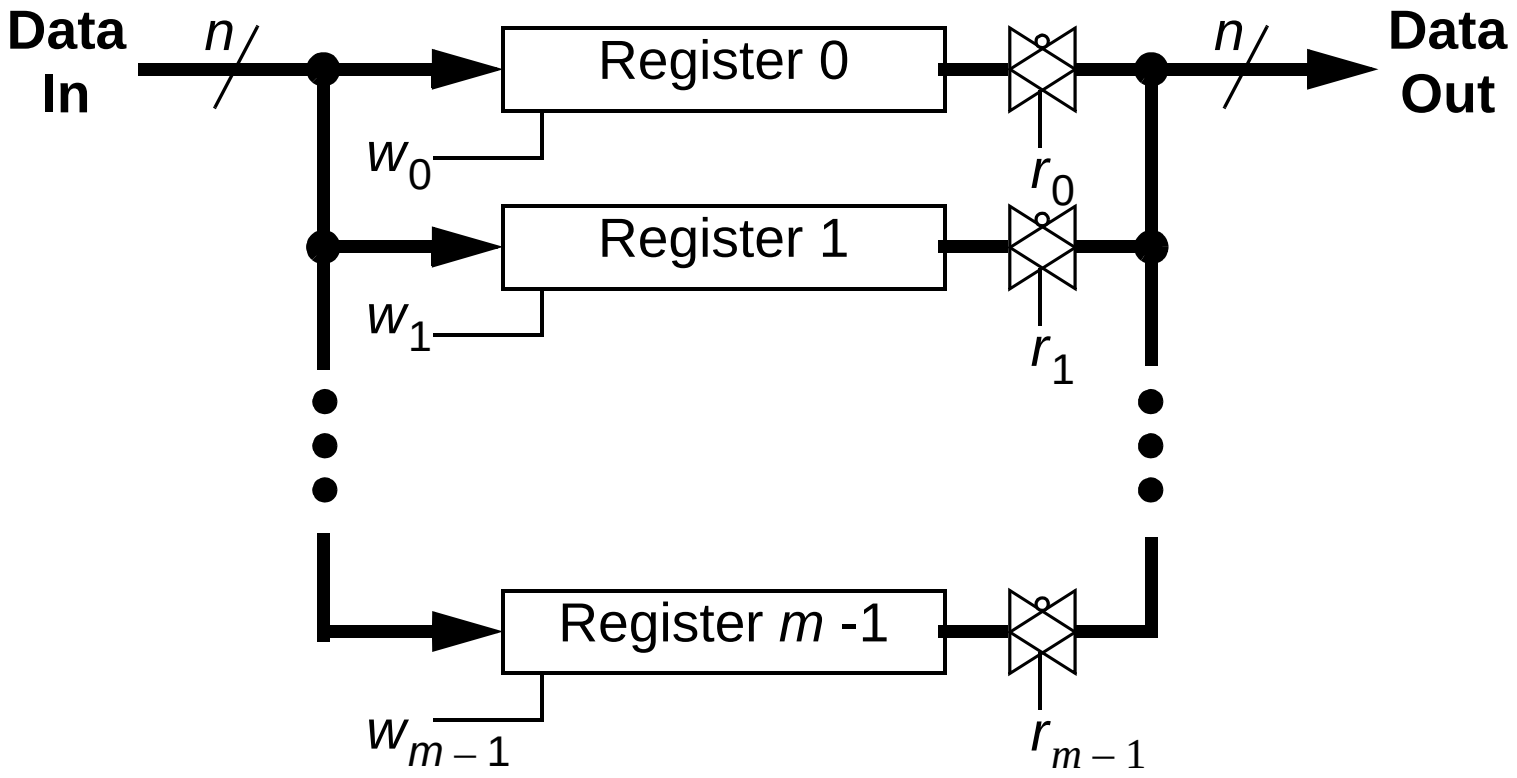
INTRODUCTION

- **So far we have discussed many small components and building blocks.**
- **One final step in our building blocks before we can start to piece together a microprocessor is various datapath elements.**
  - We have already discussed portions of these datapath elements in terms of other components and building blocks.
  - We will now consider some of these components and building blocks in ways that will make the design of a microprocessor a little easier in the next chapter.

REGISTER FILES

REGISTER LAYOUT

- **A general $m \times n$ register file with m registers that are each n-bits wide is illustrated below.**

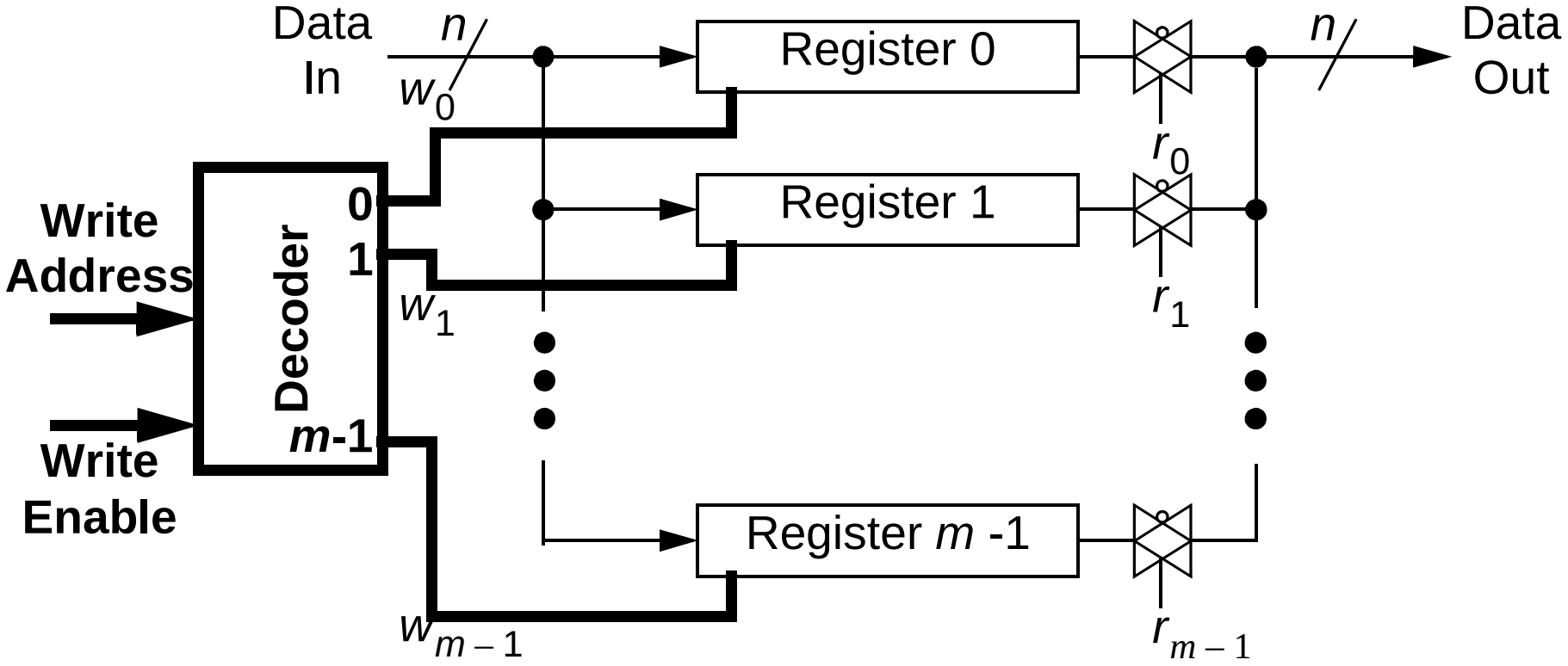


- The r_k and w_j signals indicate which register to read/write, respectively.

REGISTER FILES

WRITE DECODER

- **For writing to a register, we include a write address with decoder.**

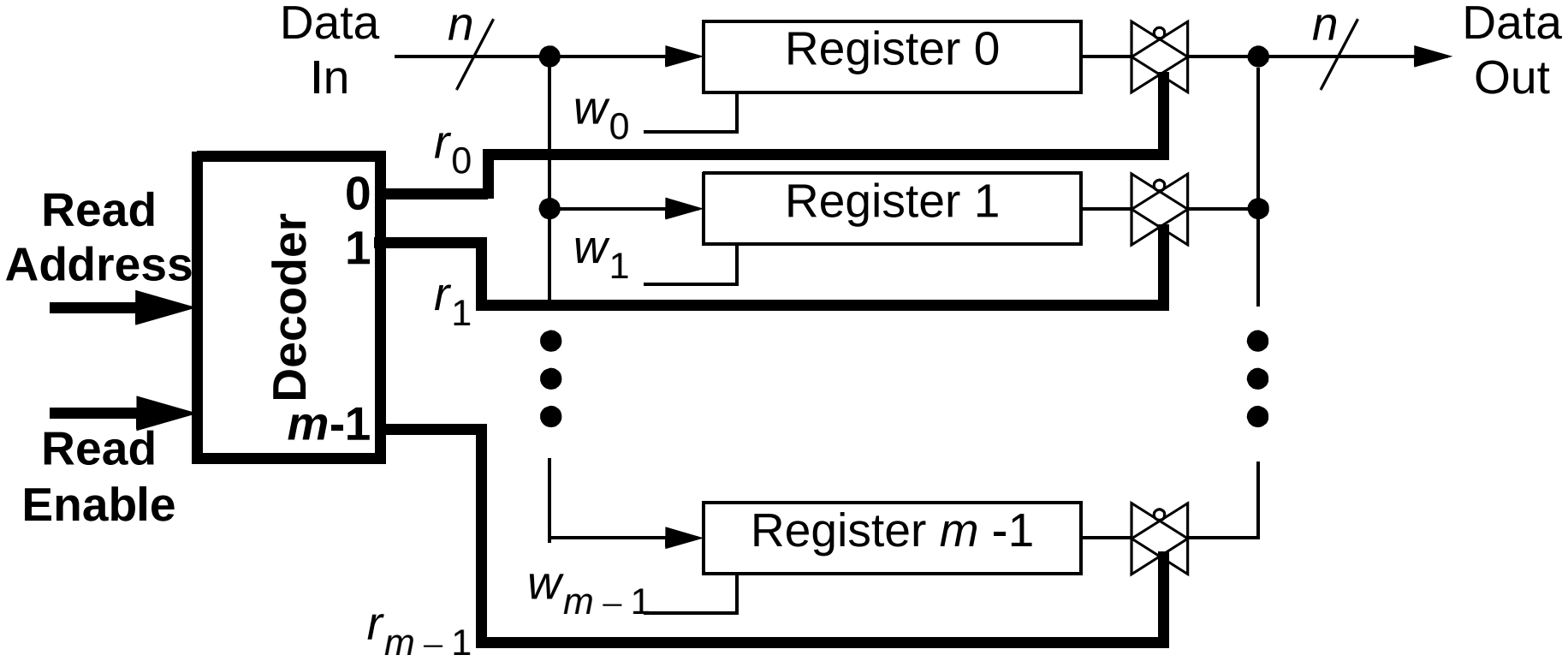


- A given **Write Address** (with **Write Enable = 1**) selects which register, 0 through *m* - 1, to store the input from Data In.

REGISTER FILES

READ DECODER

- **For reading from a register, we include a read address with decoder.**



- A given **Read Address** (with **Read Enable = 1**) selects which register, 0 through *m* - 1, to read from and output to Data Out.
- Could have multiple **data outputs** with multiple **read address** decoders.

REGISTER FILES

32-BIT WORD, 32 REGISTERS

- **For the upcoming datapath designs in the next chapter, we want to have a 32x32 register file with one write input and two read outputs.**

X_{ra} - X read address

Y_{ra} - Y read address

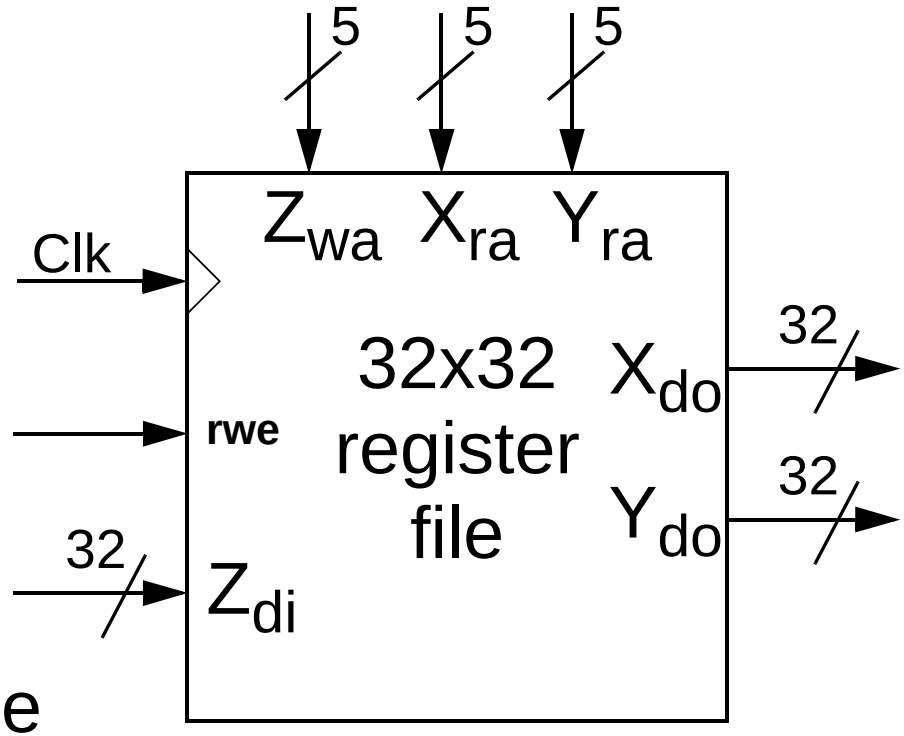
Z_{wa} - Z write address

X_{do} - X data out

Y_{do} - Y data out

Z_{di} - Z data in

rwe - register write enable

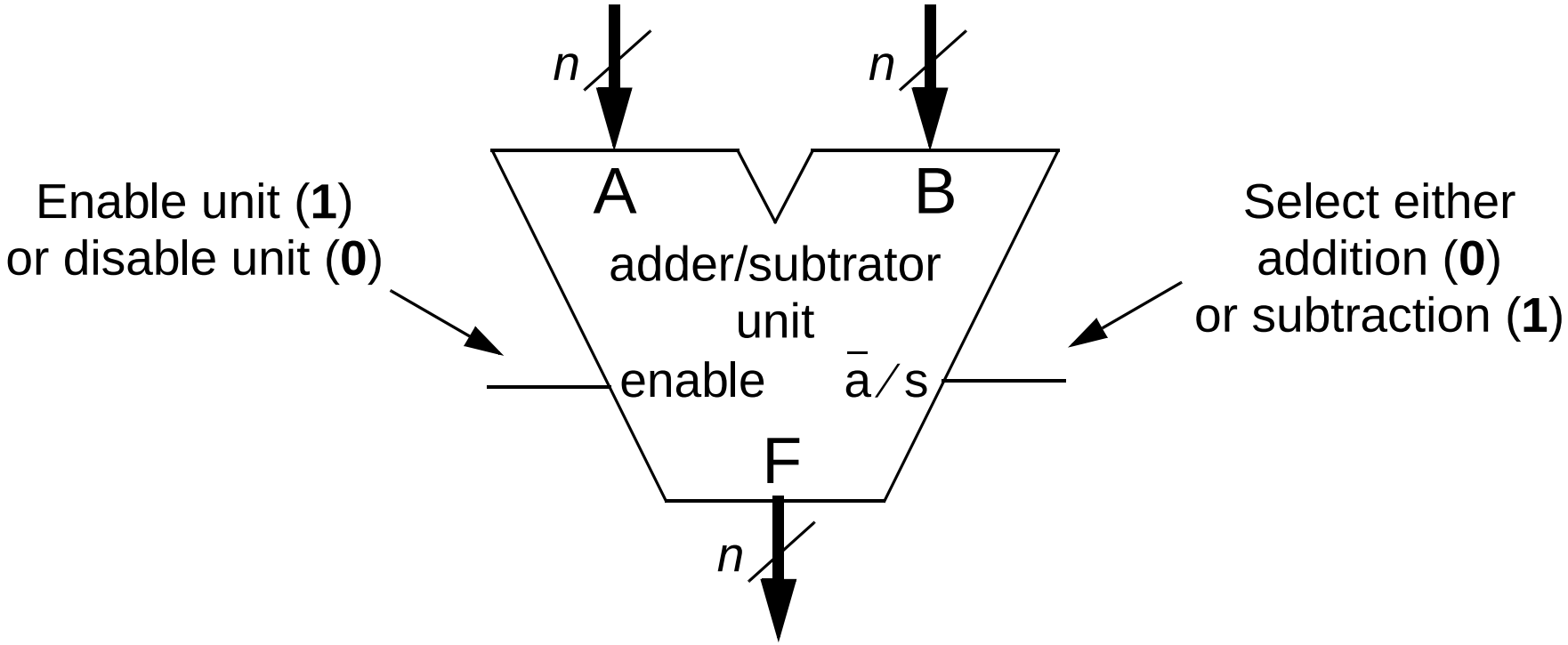


- Note: Two data outputs implemented with two read address decoders.

ADDER/SUBTRACTOR

GENERAL UNIT DIAGRAM

- **An *n*-bit adder/subtractor unit is often illustrated as follows.**

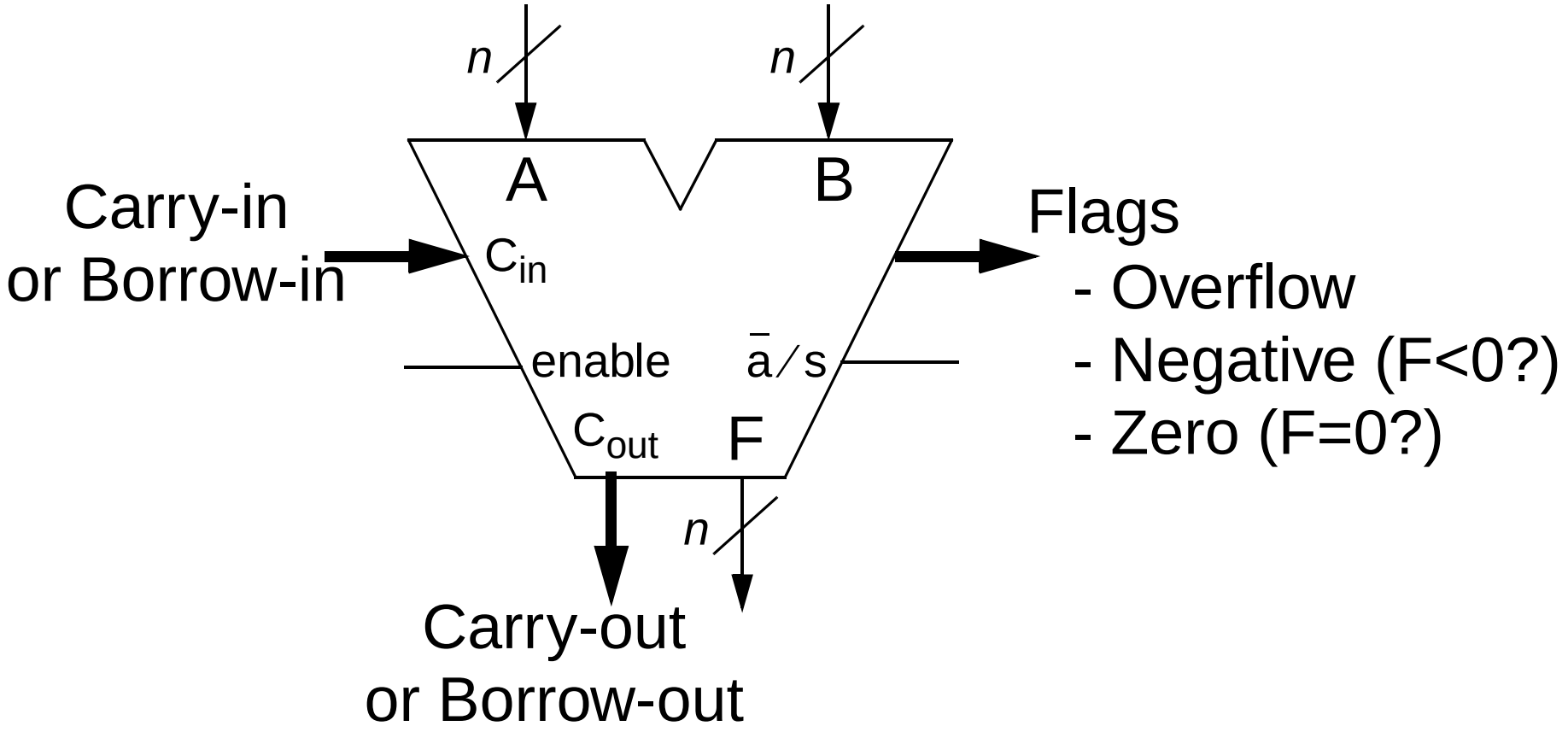


- This unit would have *n* full-adders internally.

ADDER/SUBTRACTOR

OTHER UNIT SIGNALS

- **Other signals often included with an adder/subtractor are shown below.**



LOGICAL UNIT

INTRODUCTION

- **A useful unit would be one that can take two *n*-bit inputs and perform some logical operation between each of the bits to get an *n*-bit output.**
  - For example, given the 8-bit values **0001 1110** and **1001 1000**, we might want to find the **bit-wise logical OR**.

	0001 1110
bit-wise logical OR	**1001 1000**
	1001 1110

  - Or similarly, the **bit-wise logical AND** of the two 8-bit values.

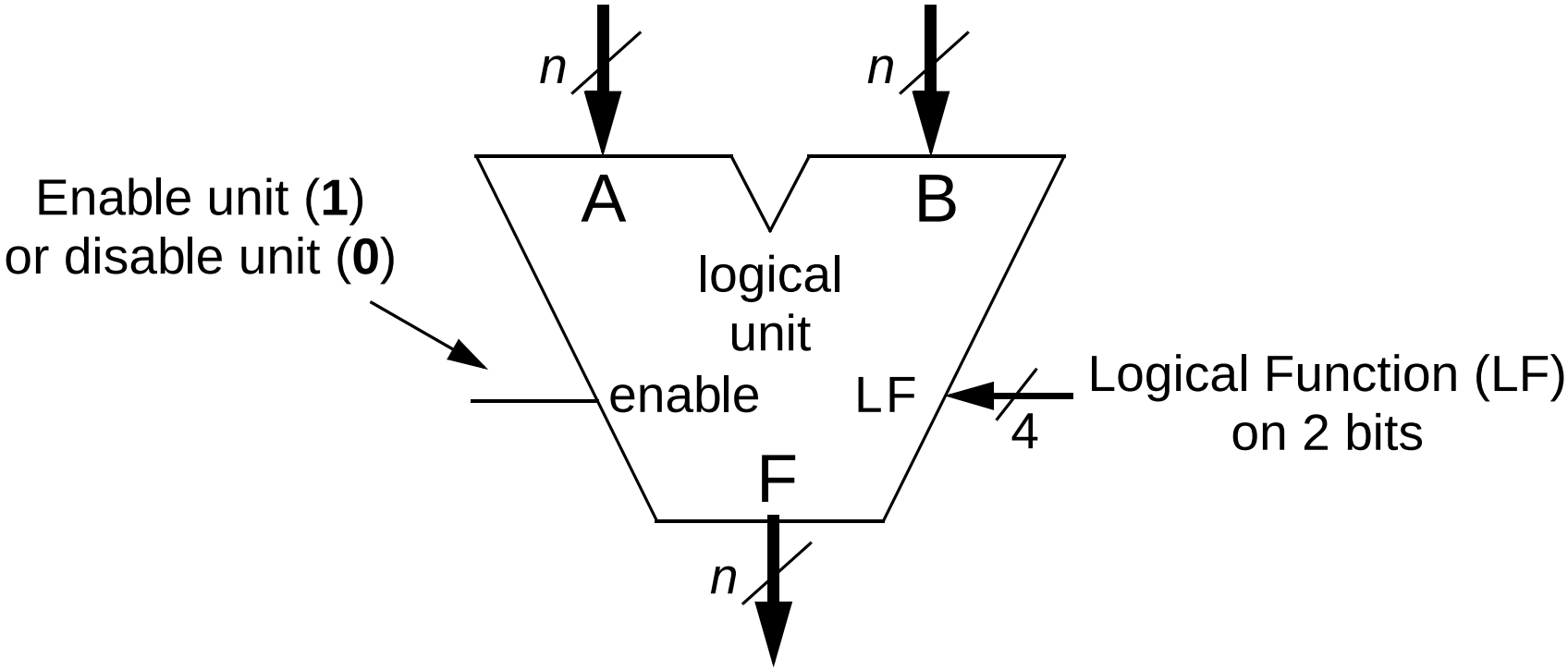
	0001 1110
bit-wise logical AND	**1001 1000**
	0001 1000

  - These types of operations are often used for masking and setting bits.

LOGICAL UNIT

GENERAL UNIT DIAGRAM

- **Below is a general unit diagram for an *n*-bit logical unit.**



- Logical operations, such as **AND/OR/NOT/NAND/NOR**/etc., are done for each bit of **A** and **B** to form **F**.

LOGICAL UNIT

4-BIT LOGICAL FUNCTIONS (LF)

- **Recall the possible logic functions for two bits, A and B.**
  - We can use the column $\mathbf{F_n}$ as the 4-bit LF input for the logical unit.

A	B	F_0	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}	F_{11}	F_{12}	F_{13}	F_{14}	F_{15}
0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
0	1	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
1	0	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1

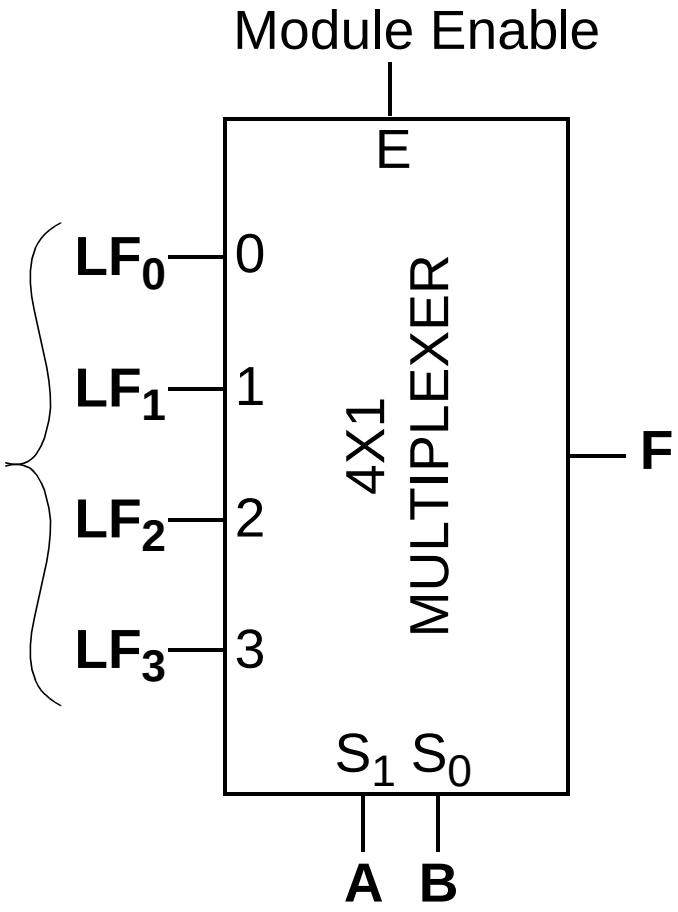
0 Null | AB | Inhibition | A | | B | $A \oplus B$ | A + B | $\overline{A + B}$ | $\overline{A \oplus B}$ | $\overline{B}$ | Implication | $\overline{A}$ | | $\overline{AB}$ | 1 Identity

LOGICAL UNIT

BIT SLICE IMPLEMENTATION

- **A number of internal implementations exist for the logical unit.**
  - The easiest is to use a **4-to-1 multiplexer** for **each bit** as follows

Take F_n column from previous slide as LF input



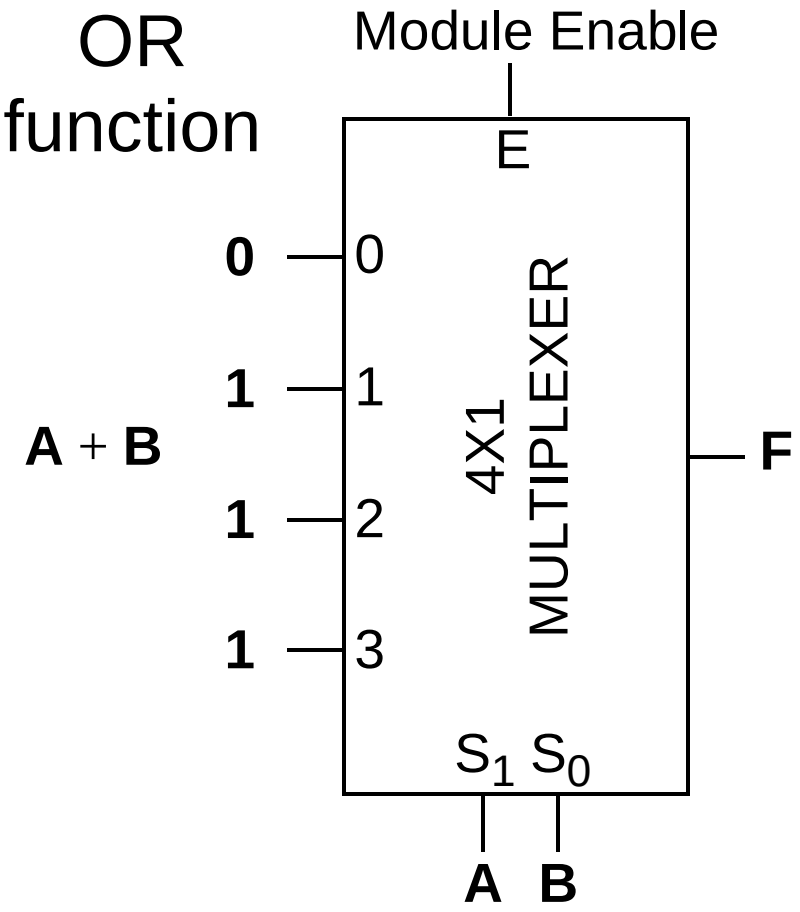
Require *n* of these to form our *n*-bit logical unit.

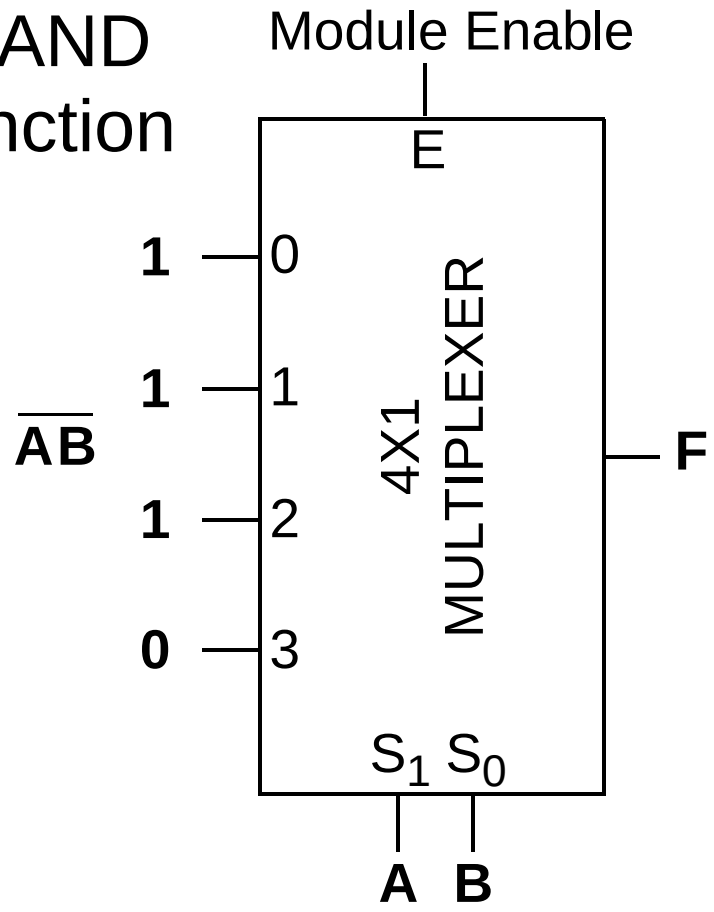
Note: When you look at a design for each bit, it is known as a bit slice

LOGICAL UNIT

BIT SLICE IMPLEMENTATION

- **The following are example LF inputs for a logical unit bit slice.**





SHIFT UNIT

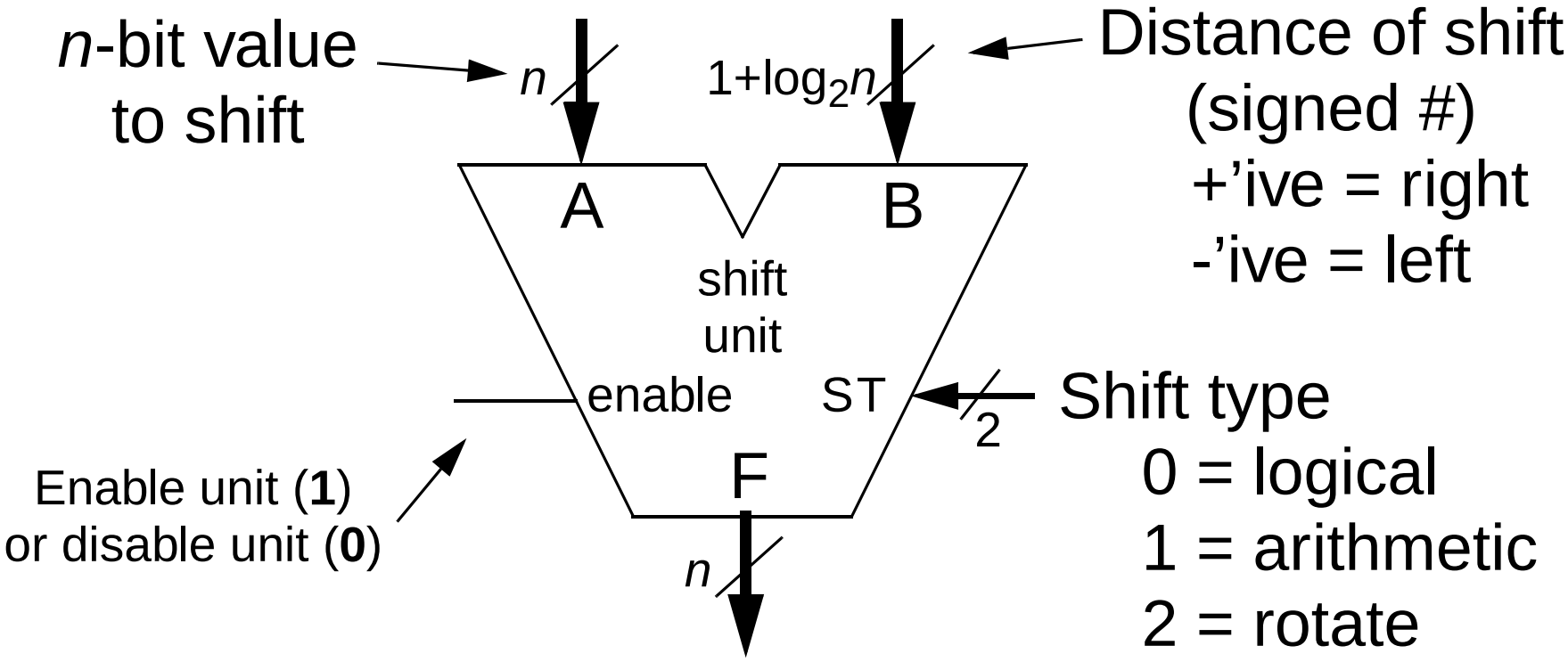
INTRODUCTION

- **We have already discussed the bulk about shift units in previous chapters.**
- **As given in the Free-Doc, there are different types of shift units.**
  - Logical shift
  - Arithmetic shift
  - Circular shift (this is just a rotate unit)
- **We want to discuss an implementation, the barrel shifter, that will be useful in our single cycle datapath computer we will design next chapter.**

SHIFT UNIT

GENERAL UNIT DIAGRAM

- **Below is a general unit diagram for an *n*-bit shift unit.**

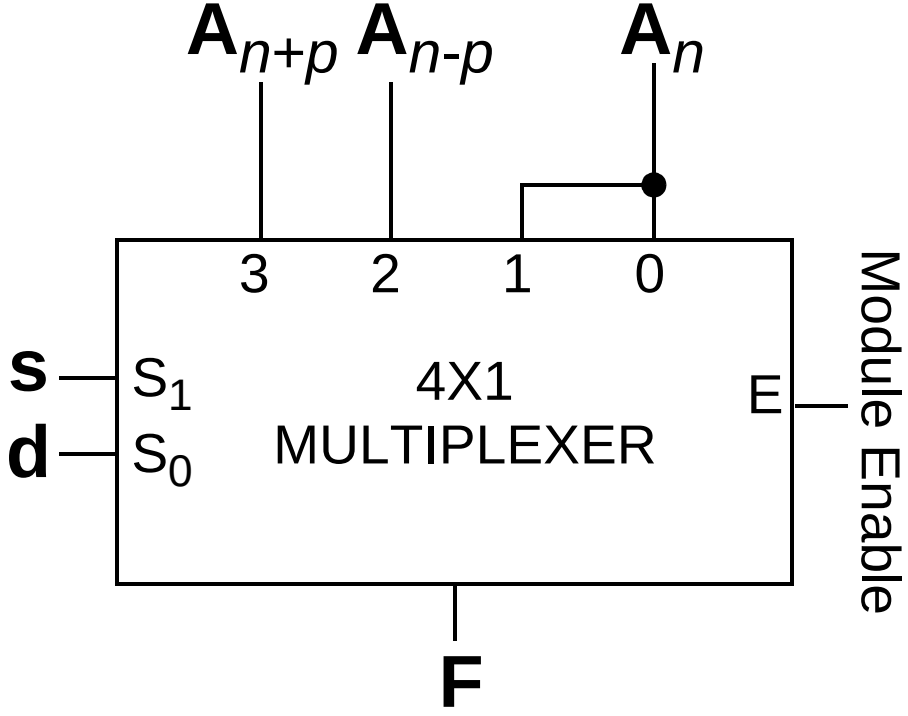


- Notice that the *n*-bit value **A** will be shifted according to the distance indicated with signed number **B**.

SHIFT UNIT

P-SHIFTER BIT SLICE

- **Previously, we discussed the *p*-shifter but not its implementation.**
  - A *p*-shifter shifts the value to the left or right by *p*-bits.
  - A bit slice view of a *p*-shifter for *n*th bit could be as follows.



s

0 = no shift

1 = shift

d

0 = left

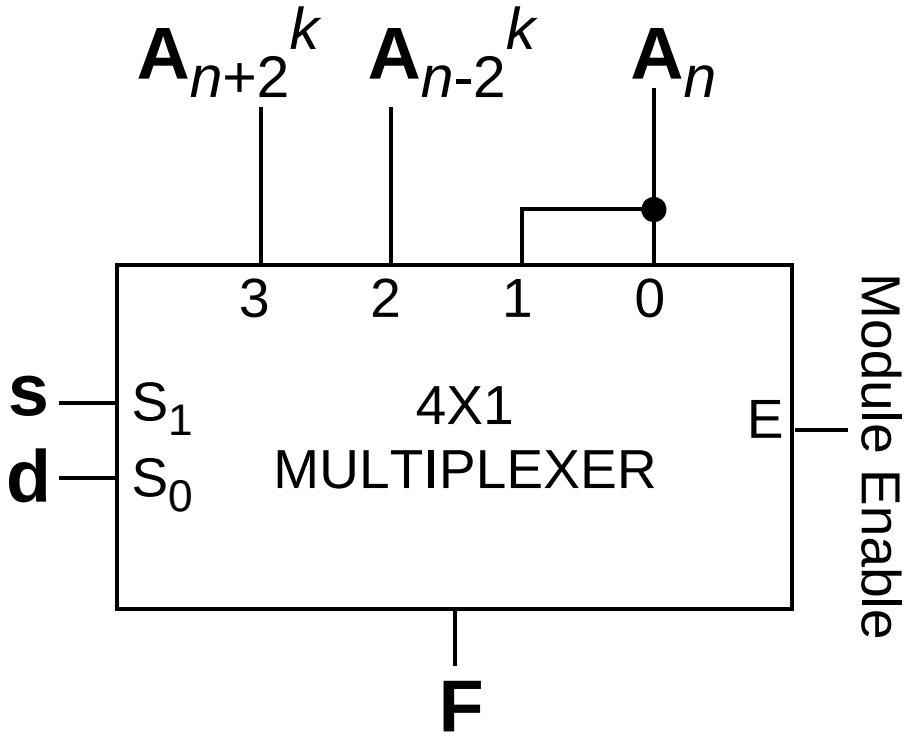
1 = right

- Notice that this can **ONLY** shift by *p*-bits. It is **hardwired** to shift *p*-bits.

SHIFT UNIT

2^K-SHIFTER BIT SLICE

- **A useful type of *p*-shifter is when p = 2^k for some positive integer *k*.**



s

0 = no shift

1 = shift

d

0 = left

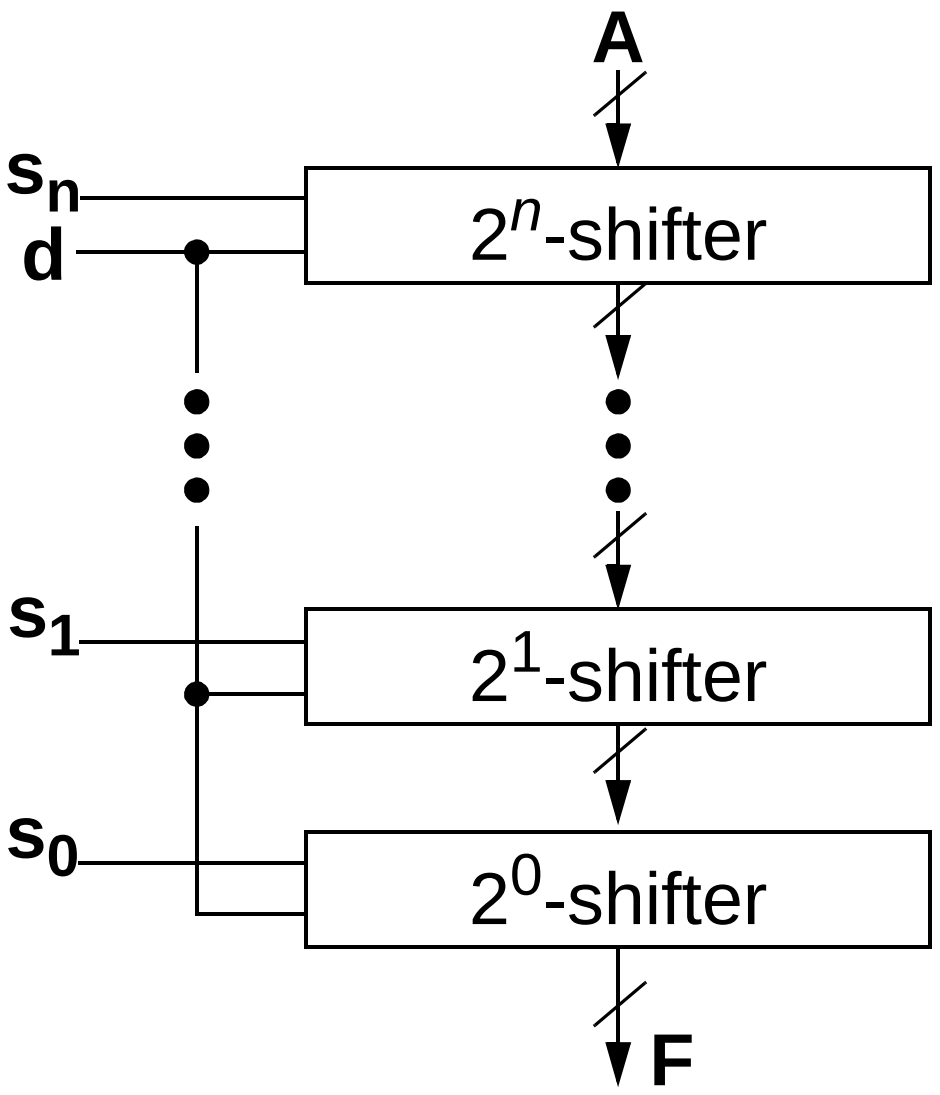
1 = right

- A 2^k-shifter allows use to build a barrel shifter.

SHIFT UNIT

BARREL SHIFTER

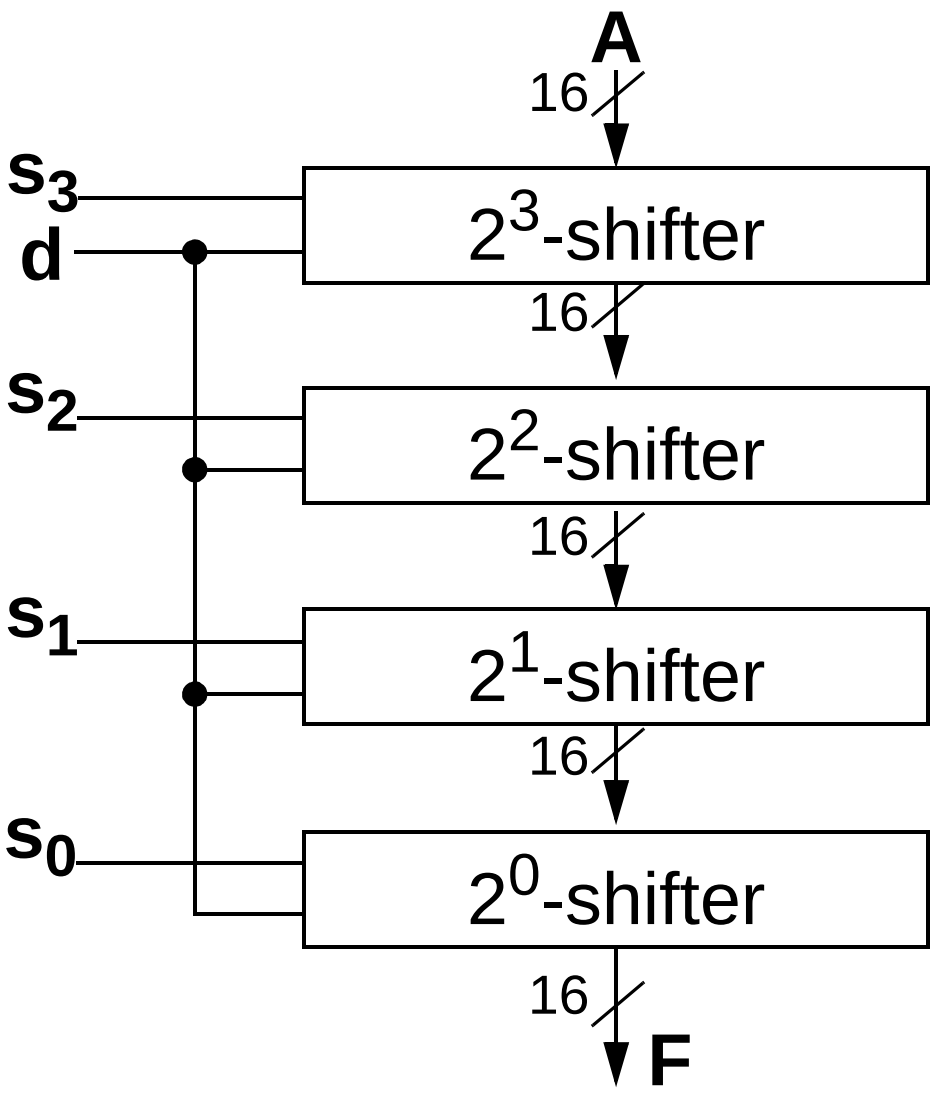
- **We want to be able to shift a vector by an arbitrary distance instead of hardwired like the *p*-shifter and 2^k-shifter.**
  - The top level can shift **A** by *n* bits, depending on s_n.
  - Subsequent levels can shift result by *n*/2 bits, depending on their input s_q.



SHIFT UNIT

SAMPLE BARREL SHIFTER

- **We will do some examples with the following arbitrary *n*-shifter on a 16-bit input.**
- **Note that this barrel shifter can shift the input by 15 bits in either direction.**



SHIFT UNIT

BARREL SHIFTER: EXAMPLE #1

- **For example, consider the input of**

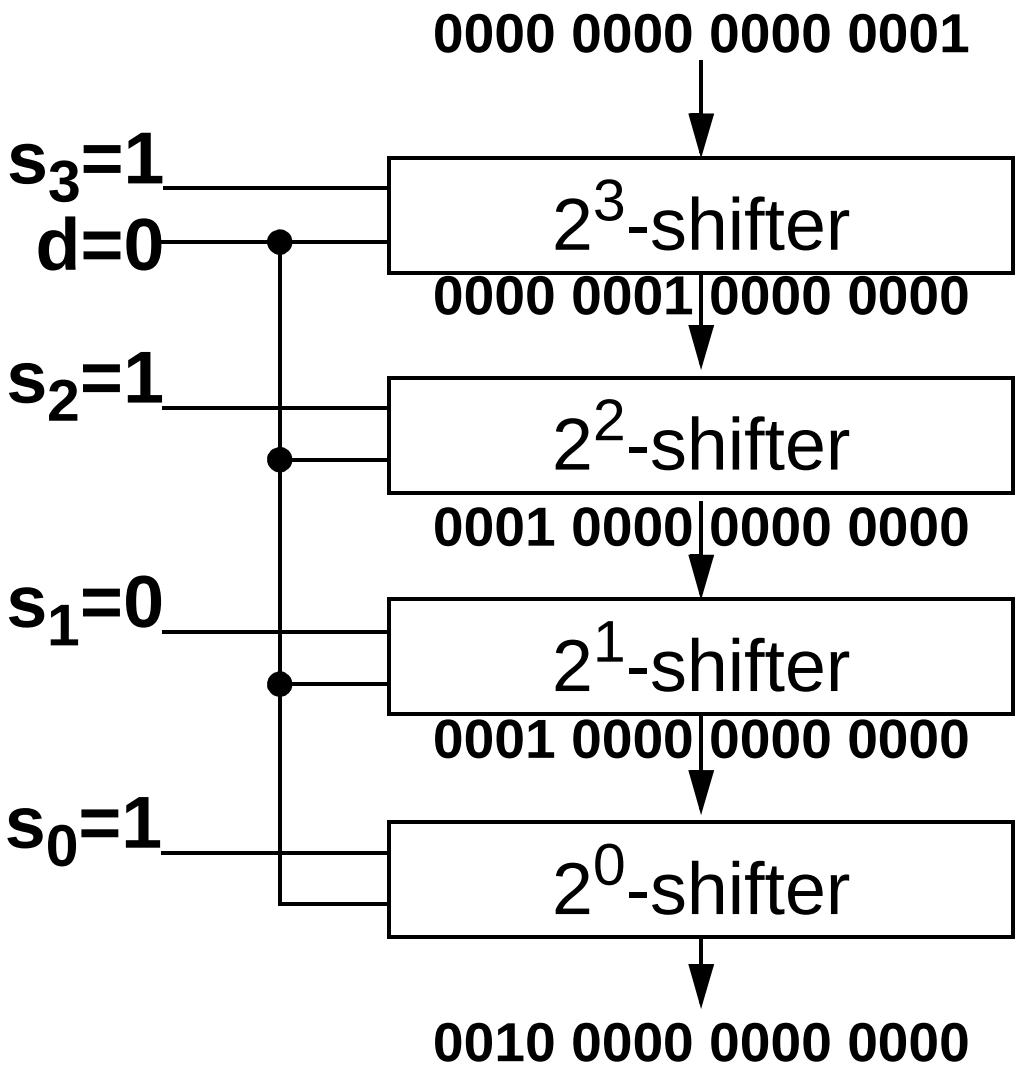
  0000 0000 0000 0001

  - If we want to shift this value to the **left** by **13**, we need the input

    d = 0

    s = ($s_3s_2s_1s_0$) = 1101

  - Note: This example is for a logical shift.



SHIFT UNIT

BARREL SHIFTER: EXAMPLE #2

- **As another example,**

  consider the input of

  1001 0100 1110 0001

  - If we want to shift this value to the **right** by **6**, we need the input

    d = 1

    s = ($s_3s_2s_1s_0$) = 0110

  - Note: This example is for a logical shift.