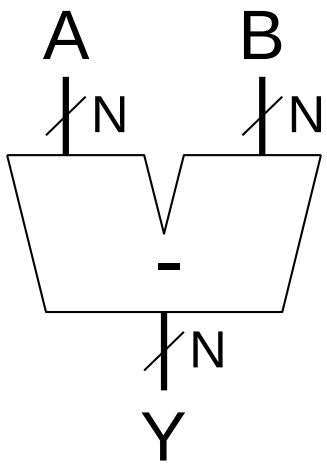
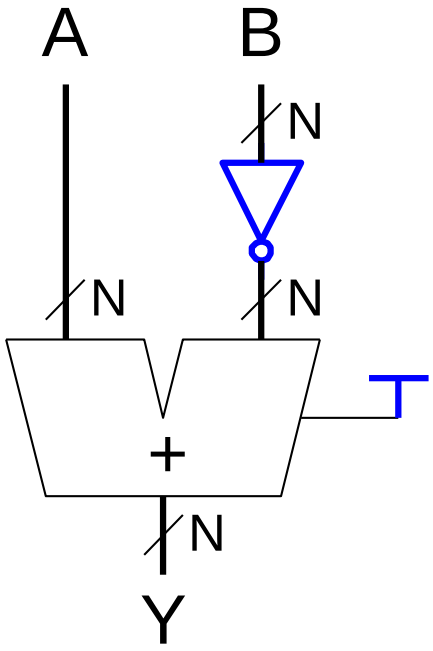
Subtracter

Symbol

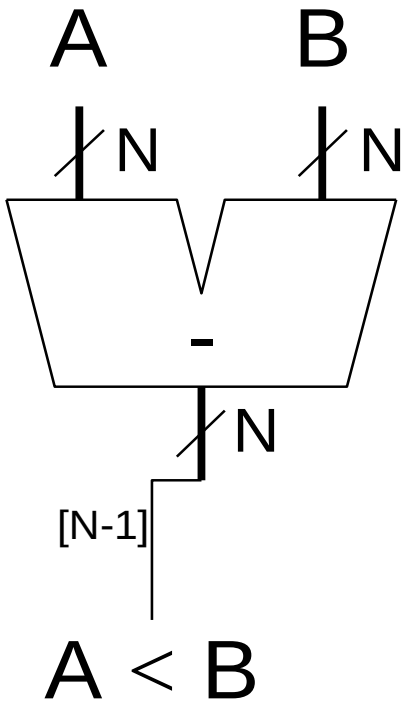


Implementation

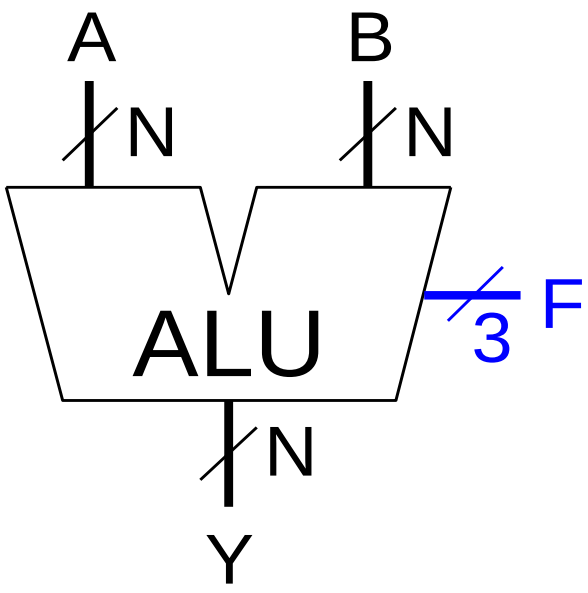


Comparator: Less Than

- For unsigned numbers

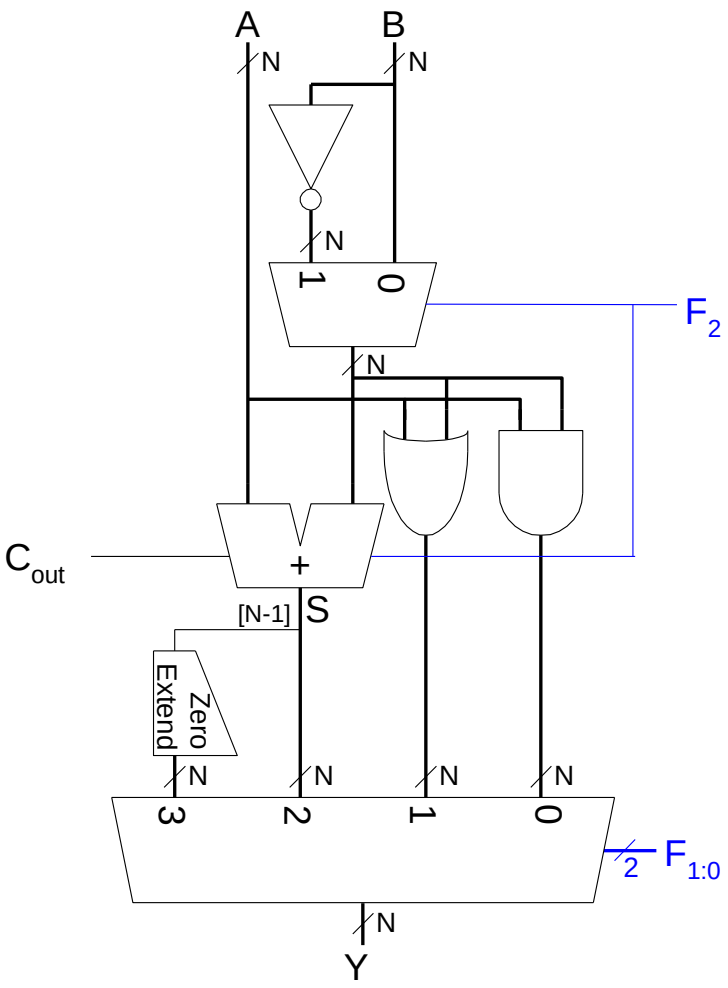


Arithmetic Logic Unit (ALU)



$F_{2:0}$	Function
000	A & B
001	A | B
010	A + B
011	not used
100	A & ~B
101	A | ~B
110	A - B
111	SLT

ALU Design



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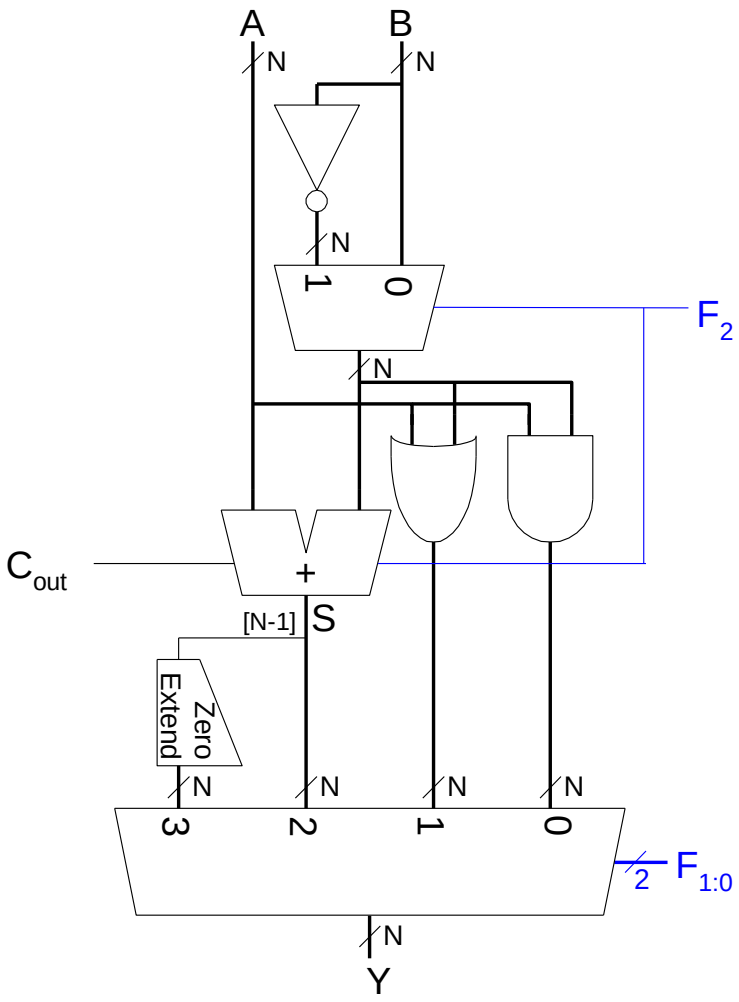
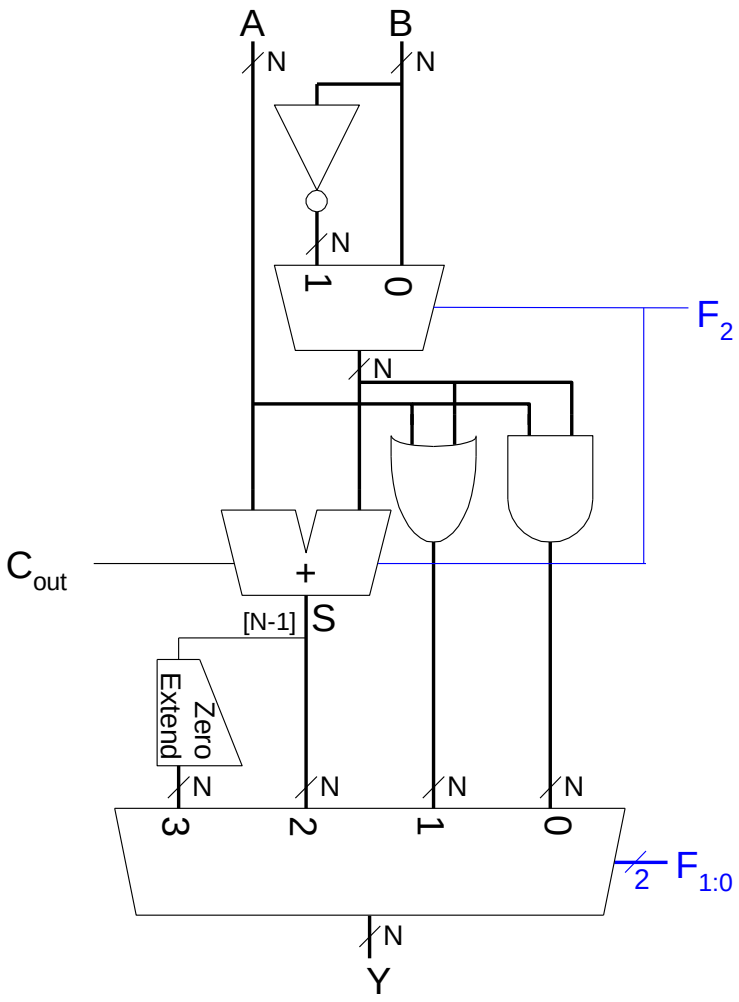
Set Less Than (SLT) Example



- Configure a 32-bit ALU for the set if less than (SLT) operation. Suppose $A = 25$ and $B = 32$.

Set Less Than (SLT) Example



- Configure a 32-bit ALU for the set if less than (SLT) operation. Suppose $A = 25$ and $B = 32$.
  - A is less than B, so we expect Y to be the 32-bit representation of 1 (0x00000001).
  - For SLT, $F_{2:0} = 111$.
  - $F_2 = 1$ configures the adder unit as a subtracter. So 25 - 32 = -7.
  - The two's complement representation of -7 has a 1 in the most significant bit, so $S_{31} = 1$.
  - With $F_{1:0} = 11$, the final multiplexer selects $Y = S_{31}$ (zero extended) = 0x00000001.

Shifters

- **Logical shifter:** shifts value to left or right and fills empty spaces with 0's
  - Ex: 11001 >> 2 =
  - Ex: 11001 << 2 =

- **Arithmetic shifter:** same as logical shifter, but on right shift, fills empty spaces with the old most significant bit (msb).
  - Ex: 11001 >>> 2 =
  - Ex: 11001 <<< 2 =

- **Rotator:** rotates bits in a circle, such that bits shifted off one end are shifted into the other end
  - Ex: 11001 ROR 2 =
  - Ex: 11001 ROL 2 =

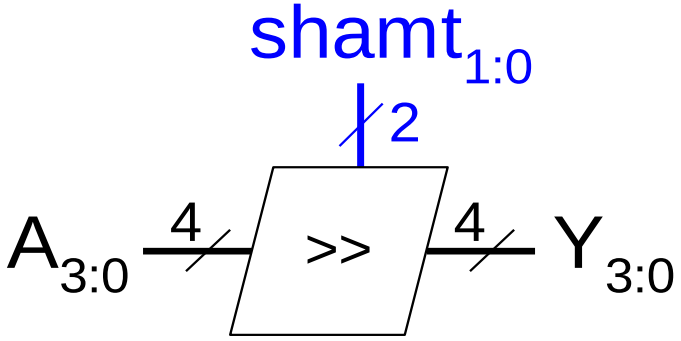
Shifters

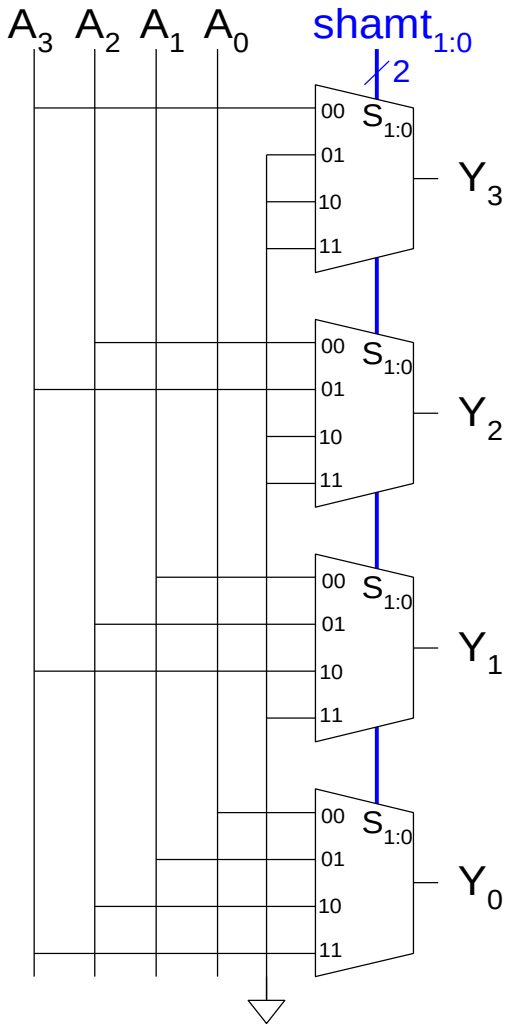
- **Logical shifter:** shifts value to left or right and fills empty spaces with 0's
  - Ex: 11001 >> 2 = 00110
  - Ex: 11001 << 2 = 00100

- **Arithmetic shifter:** same as logical shifter, but on right shift, fills empty spaces with the old most significant bit (msb).
  - Ex: 11001 >>> 2 = **11**110
  - Ex: 11001 <<< 2 = 00100

- **Rotator:** rotates bits in a circle, such that bits shifted off one end are shifted into the other end
  - Ex: 11001 ROR 2 = 01110
  - Ex: 11001 ROL 2 = 00111

Shifter Design





Shifters as Multipliers and Dividers

- A left shift by *N* bits multiplies a number by 2^N
  - Ex: 00001 << 2 = 00100 ($1 \times 2^2 = 4$)
  - Ex: 11101 << 2 = 10100 ($-3 \times 2^2 = -12$)

- The arithmetic right shift by *N* divides a number by 2^N
  - Ex: 01000 >>> 2 = 00010 ($8 \div 2^2 = 2$)
  - Ex: 10000 >>> 2 = 11100 ($-16 \div 2^2 = -4$)

Multipliers

- Steps of multiplication for both decimal and binary numbers:
  - Partial products are formed by multiplying a single digit of the multiplier with the entire multiplicand
  - Shifted partial products are summed to form the result

Decimal		**Binary**
230	multiplicand	0101
x 42	multiplier	x 0111
460	partial products	0101
+ 920		0101
		0101
		+ 0000
9660	result	0100011

230 x 42 = 9660

5 x 7 = 35