MC404

ORGANIZAÇÃO BÁSICA DE COMPUTADORES E LINGUAGEM DE MONTAGEM

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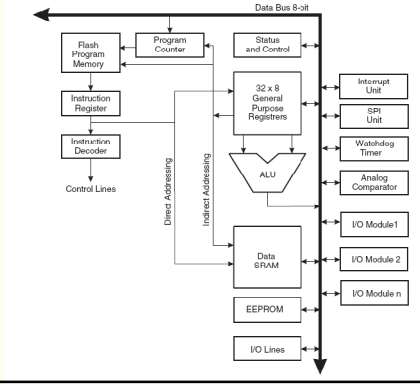
"Organização de Memória
e
Modos de Endereçamento"

Organização de Memória e Modos de Endereçamento Sumário

- Organização de Memória do Atmega88
  - Memória de Programa – Flash
  - Memória de Dados
    - SRAM
    - EEPROM
- Modos de Endereçamento

Table 2-1. Memory Size Summary

Device	Flash	EEPROM	RAM	Interrupt Vector Size
ATmega48	4K Bytes	256 Bytes	512 Bytes	1 instruction word/vector
ATmega88	8K Bytes	512 Bytes	1K Bytes	1 instruction word/vector
ATmega168	16K Bytes	512 Bytes	1K Bytes	2 instruction words/vector



The AVR Status Register

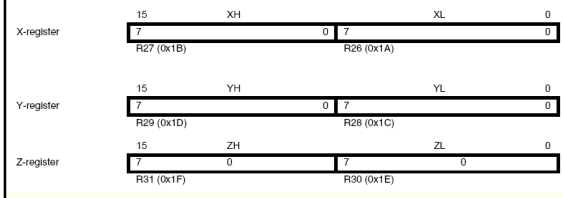
Bit	7	6	5	4	3	2	1	0	
	I	T	H	S	V	N	Z	C	SREG
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 7 - I: Global Interrupt Enable:**
  - Habilita a ocorrência de interrupções. O controle de cada interrupção é realizado por um grupo diferente de registradores, mas se este bit estiver desabilitado, todas as interrupções estarão desabilitadas.
- **Bit 6 - T: Bit Copy Storage**:
  - Operações de cópia de bits (BLD, BST) utilizam este bit como fonte ou destino.
- **Bit 5 - H: Half Carry Flag**:
  - Indica ocorrência de Half Carry (Carry do bit 3 para o 4) em algumas operações aritméticas (útil em aritmética BCD).
- **Bit 4 - S: Sign Bit**:
  - Sempre é um "ou exclusivo' entre o Bit 2 e Bit 3.
- **Bit 3 - V: Two's Complement Overow Flag**:
  - Indica overflow em operações aritméticas com complemento a 2.
- **Bit 2 - N: Negative Flag**:
  - Indica um resultado negativo em uma operação lógica/aritmética.
- **Bit 1 - Z: Zero Flag**:
  - Indica um resultado igual a zero em uma operação lógica/aritmética.
- **Bit 0 - C: Carry Flag**:
  - Indica ocorrência de carry em uma operação lógica/aritmética.

Figure 4-2. AVR CPU General Purpose Working Registers

	7 0	Addr.	
General Purpose Working Registers	R0	0x00	
	R1	0x01	
	R2	0x02	
	...		
	R13	0x0D	
	R14	0x0E	
	R15	0x0F	
	R16	0x10	
	R17	0x11	
	...		
	R26	0x1A	X-register Low Byte
	R27	0x1B	X-register High Byte
	R28	0x1C	Y-register Low Byte
	R29	0x1D	Y-register High Byte
	R30	0x1E	Z-register Low Byte
	R31	0x1F	Z-register High Byte

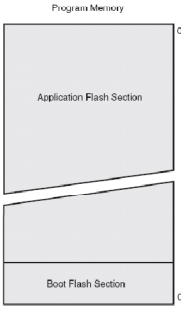
Figure 4-3. The X-, Y-, and Z-registers



AVR ATmega48/88/168 Memories

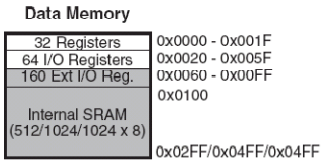
In-System Reprogrammable Flash Program Memory

Figure 5-2. Program Memory Map, ATmega88 and ATmega168



SRAM Data Memory

Figure 5-3. Data Memory Map



EEPROM Data Memory

The EEPROM Address Register – EEARH and EEARL

Bit	15	14	13	12	11	10	9	8	
	–	–	–	–	–	–	–	EEAR8	EEARH
	EEAR7	EEAR6	EEAR5	EEAR4	EEAR3	EEAR2	EEAR1	EEAR0	EEARL
	7	6	5	4	3	2	1	0	
Read/Write	R	R	R	R	R	R	R	R/W	
	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	X	
	X	X	X	X	X	X	X	X	

The EEPROM Data Register – EEDR

Bit	7	6	5	4	3	2	1	0	
	MSB							LSB	EEDR
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

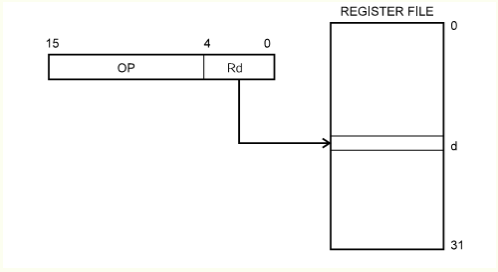
The EEPROM Control Register – EECR

Bit	7	6	5	4	3	2	1	0	
	–	–	EEPM1	EEPM0	EERIE	EEMPE	EEPE	EERE	EECR
Read/Write	R	R	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	X	X	0	0	X	0	

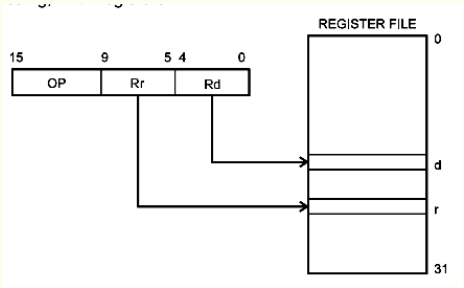
Table 5-1. EEPROM Mode Bits

EEPM1	EEPM0	Programming Time	Operation
0	0	3.4 ms	Erase and Write in one operation (Atomic Operation)
0	1	1.8 ms	Erase Only
1	0	1.8 ms	Write Only
1	1	–	Reserved for future use

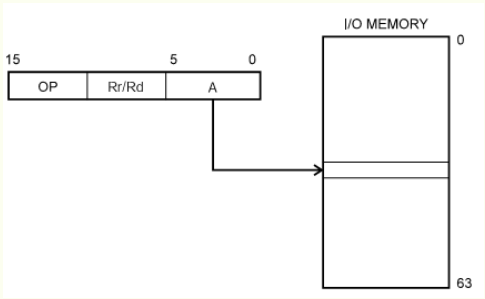
Direct Single Register Addressing



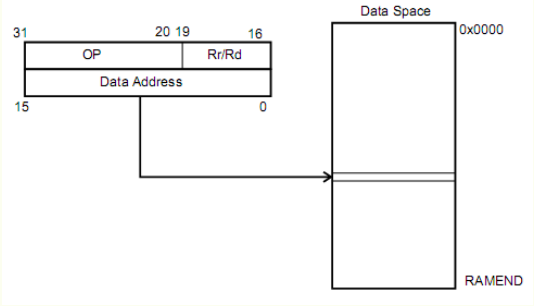
Direct Register Addressing, Two Registers



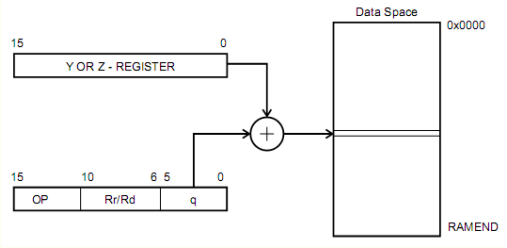
I/O Direct Addressing



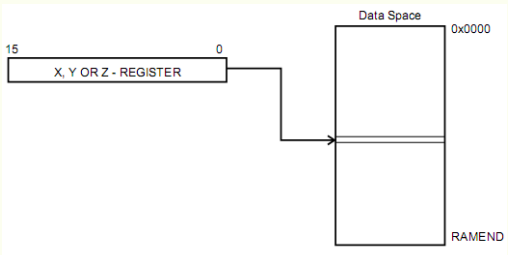
Direct Data Addressing



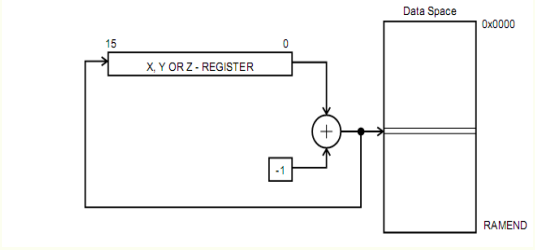
Data Indirect with Displacement



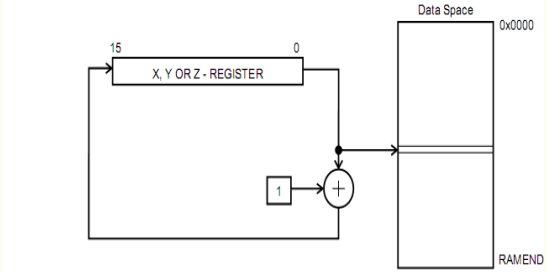
Data Indirect Addressing



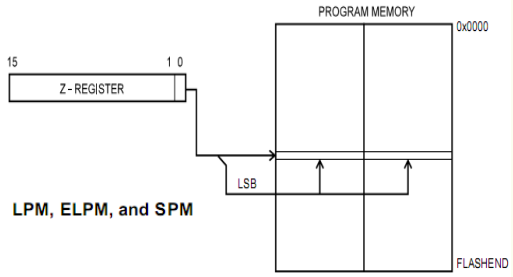
Data Indirect Addressing with Pre-decrement



Data Indirect Addressing with Post-increment

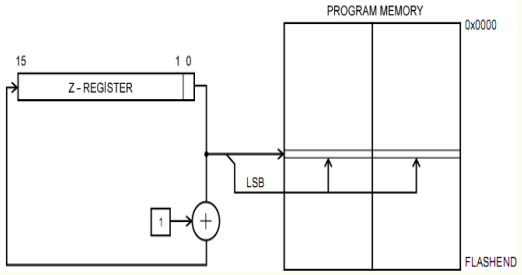


Program Memory Constant Addressing



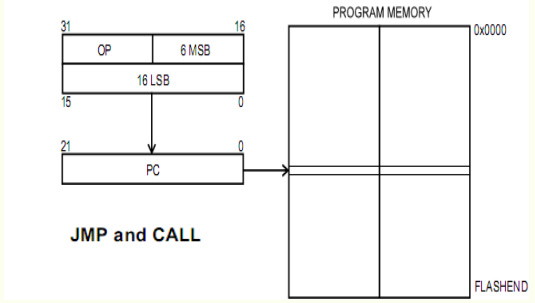
LPM, ELPM, and SPM

Program Memory Addressing with Post-increment



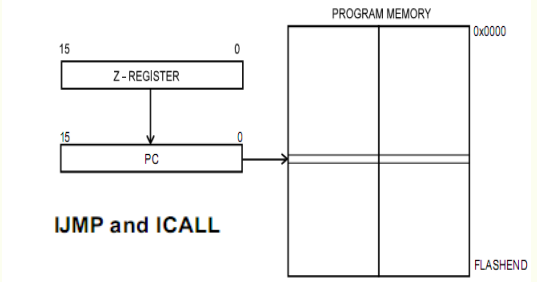
LPM Z+ and ELPM Z+

Direct Program Memory Addressing



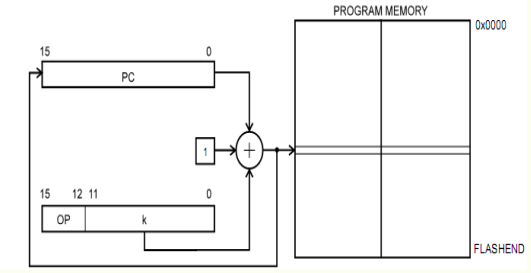
JMP and CALL

Indirect Program Memory Addressing



IJMP and ICALL

Relative Program Memory Addressing



RJMP and RCALL

Conditional Branch Summary

Test	Boolean	Mnemonic	Complementary	Boolean	Mnemonic	Comment
Rd > Rr	Z•(N ⊕ V) = 0	BRLT[1]	Rd ≤ Rr	Z+(N ⊕ V) = 1	BRGE*	Signed
Rd ≥ Rr	(N ⊕ V) = 0	BRGE	Rd < Rr	(N ⊕ V) = 1	BRLT	Signed
Rd = Rr	Z = 1	BREQ	Rd ≠ Rr	Z = 0	BRNE	Signed
Rd ≤ Rr	Z+(N ⊕ V) = 1	BRGE[1]	Rd > Rr	Z•(N ⊕ V) = 0	BRLT*	Signed
Rd < Rr	(N ⊕ V) = 1	BRLT	Rd ≥ Rr	(N ⊕ V) = 0	BRGE	Signed
Rd > Rr	C + Z = 0	BRLO[1]	Rd ≤ Rr	C + Z = 1	BRSH*	Unsigned
Rd ≥ Rr	C = 0	BRSH/BRCC	Rd < Rr	C = 1	BRLO/BRCS	Unsigned
Rd = Rr	Z = 1	BREQ	Rd ≠ Rr	Z = 0	BRNE	Unsigned
Rd ≤ Rr	C + Z = 1	BRSH[1]	Rd > Rr	C + Z = 0	BRLO*	Unsigned
Rd < Rr	C = 1	BRLO/BRCS	Rd ≥ Rr	C = 0	BRSH/BRCC	Unsigned
Carry	C = 1	BRCS	No carry	C = 0	BRCC	Simple
Negative	N = 1	BRMI	Positive	N = 0	BRPL	Simple
Overflow	V = 1	BRVS	No overflow	V = 0	BRVC	Simple
Zero	Z = 1	BREQ	Not zero	Z = 0	BRNE	Simple

Note: 1. Interchange Rd and Rr in the operation before the test, i.e., CP Rd,Rr → CP Rr,Rd

Instruction Set Summary

Mnemonics	Operands	Description	Operation	Flags	#Clock Note
Arithmetic and Logic Instructions					
ADD	Rd, Rr	Add without Carry	Rd ← Rd + Rr	Z,C,N,V,S,H	1
ADC	Rd, Rr	Add with Carry	Rd ← Rd + Rr + C	Z,C,N,V,S,H	1
ADIW	Rd, K	Add Immediate to Word	Rd+1:Rd ← Rd+1:Rd + K	Z,C,N,V,S	2 (1)
SUB	Rd, Rr	Subtract without Carry	Rd ← Rd - Rr	Z,C,N,V,S,H	1
SUBI	Rd, K	Subtract Immediate	Rd ← Rd - K	Z,C,N,V,S,H	1
SBC	Rd, Rr	Subtract with Carry	Rd ← Rd - Rr - C	Z,C,N,V,S,H	1
SBCI	Rd, K	Subtract Immediate with Carry	Rd ← Rd - K - C	Z,C,N,V,S,H	1
SBIW	Rd, K	Subtract Immediate from Word	Rd+1:Rd ← Rd+1:Rd - K	Z,C,N,V,S	2 (1)
AND	Rd, Rr	Logical AND	Rd ← Rd • Rr	Z,N,V,S	1
ANDI	Rd, K	Logical AND with Immediate	Rd ← Rd • K	Z,N,V,S	1
OR	Rd, Rr	Logical OR	Rd ← Rd v Rr	Z,N,V,S	1
ORI	Rd, K	Logical OR with Immediate	Rd ← Rd v K	Z,N,V,S	1
EOR	Rd, Rr	Exclusive OR	Rd ← Rd ⊕ Rr	Z,N,V,S	1
COM	Rd	One's Complement	Rd ← $FF - Rd	Z,C,N,V,S	1
NEG	Rd	Two's Complement	Rd ← $00 - Rd	Z,C,N,V,S,H	1
SBR	Rd,K	Set Bit(s) in Register	Rd ← Rd v K	Z,N,V,S	1
CBR	Rd,K	Clear Bit(s) in Register	Rd ← Rd • ($FFh - K)	Z,N,V,S	1
INC	Rd	Increment	Rd ← Rd + 1	Z,N,V,S	1
DEC	Rd	Decrement	Rd ← Rd - 1	Z,N,V,S	1
TST	Rd	Test for Zero or Minus	Rd ← Rd • Rd	Z,N,V,S	1
CLR	Rd	Clear Register	Rd ← Rd ⊕ Rd	Z,N,V,S	1
SER	Rd	Set Register	Rd ← $FF	None	1
MUL	Rd,Rr	Multiply Unsigned	R1:R0 ← Rd × Rr (UU)	Z,C	2 (1)
MULS	Rd,Rr	Multiply Signed	R1:R0 ← Rd × Rr (SS)	Z,C	2 (1)
MULSU	Rd,Rr	Multiply Signed with Unsigned	R1:R0 ← Rd × Rr (SU)	Z,C	2 (1)
FMUL	Rd,Rr	Fractional Multiply Unsigned	R1:R0 ← (Rd × Rr)<<1 (UU)	Z,C	2 (1)
FMULS	Rd,Rr	Fractional Multiply Signed	R1:R0 ← (Rd × Rr)<<1 (SS)	Z,C	2 (1)
FMULSU	Rd,Rr	Fractional Multiply Signed with Unsigned	R1:R0 ← (Rd × Rr)<<1 (SU)	Z,C	2 (1)

Branch Instructions					
RJMP	k	Relative Jump	PC ← PC + k + 1	None	2
IJMP		Indirect Jump to (Z)	PC(15:0) ← Z, PC(21:16) ← 0	None	2 (1)
EIJMP		Extended Indirect Jump to (Z)	PC(15:0) ← Z, PC(21:16) ← EIND	None	2 (1)
JMP	k	Jump	PC ← k	None	3 (1)
RCALL	k	Relative Call Subroutine	PC ← PC + k + 1	None	3 / 4 (4)
ICALL		Indirect Call to (Z)	PC(15:0) ← Z, PC(21:16) ← 0	None	3 / 4 (1)(4)
EICALL		Extended Indirect Call to (Z)	PC(15:0) ← Z, PC(21:16) ← EIND	None	4 (1)(4)
CALL	k	Call Subroutine	PC ← k	None	4 / 5 (1)(4)
RET		Subroutine Return	PC ← STACK	None	4 / 5 (4)
RETI		Interrupt Return	PC ← STACK	I	4 / 5 (4)
CPSE	Rd,Rr	Compare, Skip if Equal	if (Rd = Rr) PC ← PC + 2 or 3	None	1 / 2 / 3
CP	Rd,Rr	Compare	Rd - Rr	Z,C,N,V,S,H	1
CPC	Rd,Rr	Compare with Carry	Rd - Rr - C	Z,C,N,V,S,H	1
CPI	Rd,K	Compare with Immediate	Rd - K	Z,C,N,V,S,H	1
SBRC	Rr, b	Skip if Bit in Register Cleared	if (Rr(b)=0) PC ← PC + 2 or 3	None	1 / 2 / 3
SBRS	Rr, b	Skip if Bit in Register Set	if (Rr(b)=1) PC ← PC + 2 or 3	None	1 / 2 / 3
SBIC	A, b	Skip if Bit in I/O Register Cleared	if(I/O(A,b)=0) PC ← PC + 2 or 3	None	1 / 2 / 3
SBIS	A, b	Skip if Bit in I/O Register Set	If(I/O(A,b)=1) PC ← PC + 2 or 3	None	1 / 2 / 3
BRBS	s, k	Branch if Status Flag Set	if (SREG(s) = 1) then PC ←PC+k + 1	None	1 / 2
BRBC	s, k	Branch if Status Flag Cleared	if (SREG(s) = 0) then PC ←PC+k + 1	None	1 / 2
BREQ	k	Branch if Equal	if (Z = 1) then PC ← PC + k + 1	None	1 / 2
BRNE	k	Branch if Not Equal	if (Z = 0) then PC ← PC + k + 1	None	1 / 2
BRCS	k	Branch if Carry Set	if (C = 1) then PC ← PC + k + 1	None	1 / 2
BRCC	k	Branch if Carry Cleared	if (C = 0) then PC ← PC + k + 1	None	1 / 2
BRSH	k	Branch if Same or Higher	if (C = 0) then PC ← PC + k + 1	None	1 / 2
BRLO	k	Branch if Lower	if (C = 1) then PC ← PC + k + 1	None	1 / 2
BRMI	k	Branch if Minus	if (N = 1) then PC ← PC + k + 1	None	1 / 2

BRPL	k	Branch if Plus	if (N = 0) then PC ← PC + k + 1	None	1 / 2
BRGE	k	Branch if Greater or Equal, Signed	if (N ⊕ V= 0) then PC ← PC + k + 1	None	1 / 2
BRLT	k	Branch if Less Than, Signed	if (N ⊕ V= 1) then PC ← PC + k + 1	None	1 / 2
BRHS	k	Branch if Half Carry Flag Set	if (H = 1) then PC ← PC + k + 1	None	1 / 2
BRHC	k	Branch if Half Carry Flag Cleared	if (H = 0) then PC ← PC + k + 1	None	1 / 2
BRTS	k	Branch if T Flag Set	if (T = 1) then PC ← PC + k + 1	None	1 / 2
BRTC	k	Branch if T Flag Cleared	if (T = 0) then PC ← PC + k + 1	None	1 / 2
BRVS	k	Branch if Overflow Flag is Set	if (V = 1) then PC ← PC + k + 1	None	1 / 2
BRVC	k	Branch if Overflow Flag is Cleared	if (V = 0) then PC ← PC + k + 1	None	1 / 2
BRIE	k	Branch if Interrupt Enabled	if (I = 1) then PC ← PC + k + 1	None	1 / 2
BRID	k	Branch if Interrupt Disabled	if (I = 0) then PC ← PC + k + 1	None	1 / 2

ADC – Add with Carry

Description:

Adds two registers and the contents of the C Flag and places the result in the destination register Rd.

Operation:

(i) Rd ← Rd + Rr + C

Syntax: **Operands:** **Program Counter:**

(i) ADC Rd,Rr $0 \le d \le 31, 0 \le r \le 31$ PC ← PC + 1

16-bit Opcode:

0001	11rd	dddd	rrrr

Status Register (SREG) Boolean Formula:

I	T	H	S	V	N	Z	C
–	–	⇔	⇔	⇔	⇔	⇔	⇔

ADD – Add without Carry

Description:

Adds two registers without the C Flag and places the result in the destination register Rd.

Operation:

(i) Rd ← Rd + Rr

	Syntax:	Operands:	Program Counter:
(i)	ADD Rd,Rr	0 ≤ d ≤ 31, 0 ≤ r ≤ 31	PC ← PC + 1

16-bit Opcode:

0000	11rd	dddd	rrrr

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
–	–	⇔	⇔	⇔	⇔	⇔	⇔

ADIW – Add Immediate to Word

Description:

Adds an immediate value (0 - 63) to a register pair and places the result in the register pair. This instruction operates on the upper four register pairs, and is well suited for operations on the pointer registers.

This instruction is not available in all devices. Refer to the device specific instruction set summary.

Operation:

(i) Rd+1:Rd ← Rd+1:Rd + K

	Syntax:	Operands:	Program Counter:
(i)	ADIW Rd+1:Rd,K	d ∈ {24,26,28,30}, 0 ≤ K ≤ 63	PC ← PC + 1

16-bit Opcode:

1001	0110	KKdd	KKKK

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
–	–	–	⇔	⇔	⇔	⇔	⇔

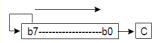
ASR – Arithmetic Shift Right

Description:

Shifts all bits in Rd one place to the right. Bit 7 is held constant. Bit 0 is loaded into the C Flag of the SREG. This operation effectively divides a signed value by two without changing its sign. The Carry Flag can be used to round the result.

Operation:

(i)



	Syntax:	Operands:	Program Counter:
(i)	ASR Rd	0 ≤ d ≤ 31	PC ← PC + 1

16-bit Opcode:

1001	010d	dddd	0101

Status Register (SREG) and Boolean Formula:

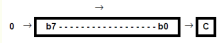
I	T	H	S	V	N	Z	C
–	–	–	⇔	⇔	⇔	⇔	⇔

LSR – Logical Shift Right

Description:

Shifts all bits in Rd one place to the right. Bit 7 is cleared. Bit 0 is loaded into the C Flag of the SREG. This operation effectively divides an unsigned value by two. The C Flag can be used to round the result.

Operation:



	Syntax:	Operands:	Program Counter:
(i)	LSR Rd	0 ≤ d ≤ 31	PC ← PC + 1

16-bit Opcode:

1001	010d	dddd	0110

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
–	–	–	⇔	⇔	0	⇔	⇔

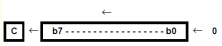
LSL – Logical Shift Left

Description:

Shifts all bits in Rd one place to the left. Bit 0 is cleared. Bit 7 is loaded into the C Flag of the SREG. This operation effectively multiplies signed and unsigned values by two.

Operation:

(i)



	Syntax:	Operands:	Program Counter:
(i)	LSL Rd	0 ≤ d ≤ 31	PC ← PC + 1

16-bit Opcode: (see ADD Rd,Rd)

0000	11dd	dddd	dddd

Status Register (SREG) and Boolean Formula:

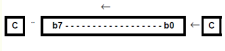
I	T	H	S	V	N	Z	C
–	–	⇔	⇔	⇔	⇔	⇔	⇔

ROL – Rotate Left trough Carry

Description:

Shifts all bits in Rd one place to the left. The C Flag is shifted into bit 0 of Rd. Bit 7 is shifted into the C Flag. This operation, combined with LSL, effectively multiplies multi-byte signed and unsigned values by two.

Operation:



	Syntax:	Operands:	Program Counter:
(i)	ROL Rd	0 ≤ d ≤ 31	PC ← PC + 1

16-bit Opcode: (see ADC Rd,Rd)

0001	11dd	dddd	dddd

Status Register (SREG) and Boolean Formula:

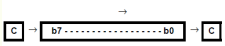
I	T	H	S	V	N	Z	C
–	–	⇔	⇔	⇔	⇔	⇔	⇔

ROR – Rotate Right through Carry

Description:

Shifts all bits in Rd one place to the right. The C Flag is shifted into bit 7 of Rd. Bit 0 is shifted into the C Flag. This operation, combined with ASR, effectively divides multi-byte signed values by two. Combined with LSR it effectively divides multi-byte unsigned values by two. The Carry Flag can be used to round the result.

Operation:



	Syntax:	Operands:	Program Counter:
(i)	ROR Rd	0 ≤ d ≤ 31	PC ← PC + 1

16-bit Opcode:

1001	010d	dddd	0111

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
–	–	–	⇔	⇔	⇔	⇔	⇔