Instruction Set Nomenclature:

Status Register (SREG)

SREG: Status register
C: Carry flag in status register
Z: Zero flag in status register
N: Negative flag in status register
V: Two's complement overflow indicator
S: $N \oplus V$, For signed tests
H: Half Carry flag in the status register
T: Transfer bit used by BLD and BST instructions
I: Global interrupt enable/disable flag

Registers and Operands

Rd: Destination (and source) register in the register file
Rr: Source register in the register file
R: Result after instruction is executed
K: Constant data
k: Constant address
b: Bit in the register file or I/O register (3 bit)
s: Bit in the status register (3 bit)
X,Y,Z: Indirect address register
(X=R27:R26, Y=R29:R28 and Z=R31:R30)
A: I/O location address
q: Displacement for direct addressing (6 bit)

AVR®
Instruction Set

Rex. 0856B-06/99

I/O Registers

RAMPX, RAMPY, RAMPZ

Registers concatenated with the X, Y and Z registers enabling indirect addressing of the whole data space on MCUs with more than 64K bytes data space, and constant data fetch on MCUs with more than 64K bytes program space.

RAMPD

Register concatenated with the Z register enabling direct addressing of the whole data space on MCUs with more than 64K bytes data space.

EIND

Register concatenated with the instruction word enabling indirect jump and call to the whole program space on MCUs with more than 64K bytes program space.

Stack

STACK: Stack for return address and pushed registers

SP: Stack Pointer to STACK

Flags

⇔: Flag affected by instruction

0: Flag cleared by instruction

1: Flag set by instruction

-: Flag not affected by instruction

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

Complete Instruction Set Summary

Notes: 1. Not all instructions are available in all devices. Refer to the device specific instruction summary.

2. Cycle times for data memory accesses assume internal memory accesses, and are not valid for accesses via the external RAM interface. For LD, ST, LDS, STS, PUSH, POP, add one cycle plus one cycle for each wait state. For CALL, ICALL, EICALL, RCALL, RET, RETI in devices with 16 bit PC, add three cycles plus two cycles for each wait state. For CALL, ICALL, EICALL, RCALL, RET, RETI in devices with 22 bit PC, add five cycles plus three cycles for each wait state.

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
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
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
MULS	Rd,Rr	Multiply Signed	R1:R0 ← Rd × Rr (SS)	Z,C	2
MULSU	Rd,Rr	Multiply Signed with Unsigned	R1:R0 ← Rd × Rr (SU)	Z,C	2
FMUL	Rd,Rr	Fractional Multiply Unsigned	R1:R0 ← (Rd × Rr)<<1 (UU)	Z,C	2
FMULS	Rd,Rr	Fractional Multiply Signed	R1:R0 ← (Rd × Rr)<<1 (SS)	Z,C	2
FMULSU	Rd,Rr	Fractional Multiply Signed with Unsigned	R1:R0 ← (Rd × Rr)<<1 (SU)	Z,C	2

Instruction Set Summary (Continued)

Mnemonics	Operands	Description	Operation	Flags	#Clock Note
		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
EIJMP		Extended Indirect Jump to (Z)	PC(15:0) ← Z, PC(21:16) ← EIND	None	2
JMP	k	Jump	PC ← k	None	3
RCALL	k	Relative Call Subroutine	PC ← PC + k + 1	None	3 / 4
ICALL		Indirect Call to (Z)	PC(15:0) ← Z, PC(21:16) ← 0	None	3 / 4
EICALL		Extended Indirect Call to (Z)	PC(15:0) ← Z, PC(21:16) ← EIND	None	4
CALL	k	Call Subroutine	PC ← k	None	4 / 5
RET		Subroutine Return	PC ← STACK	None	4 / 5
RETI		Interrupt Return	PC ← STACK	I	4 / 5
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

Instruction Set Summary (Continued)

Mnemonics	Operands	Description	Operation	Flags	#Clock Note
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
Data Transfer Instructions					
MOV	Rd, Rr	Copy Register	Rd ← Rr	None	1
MOVW	Rd, Rr	Copy Register Pair	Rd+1:Rd ← Rr+1:Rr	None	1
LDI	Rd, K	Load Immediate	Rd ← K	None	1
LDS	Rd, k	Load Direct from data space	Rd ← (k)	None	2
LD	Rd, X	Load Indirect	Rd ← (X)	None	2
LD	Rd, X+	Load Indirect and Post-Increment	Rd ← (X), X ← X + 1	None	2
LD	Rd, -X	Load Indirect and Pre-Decrement	X ← X - 1, Rd ← (X)	None	2
LD	Rd, Y	Load Indirect	Rd ← (Y)	None	2
LD	Rd, Y+	Load Indirect and Post-Increment	Rd ← (Y), Y ← Y + 1	None	2
LD	Rd, -Y	Load Indirect and Pre-Decrement	Y ← Y - 1, Rd ← (Y)	None	2
LDD	Rd,Y+q	Load Indirect with Displacement	Rd ← (Y + q)	None	2
LD	Rd, Z	Load Indirect	Rd ← (Z)	None	2
LD	Rd, Z+	Load Indirect and Post-Increment	Rd ← (Z), Z ← Z+1	None	2
LD	Rd, -Z	Load Indirect and Pre-Decrement	Z ← Z - 1, Rd ← (Z)	None	2
LDD	Rd, Z+q	Load Indirect with Displacement	Rd ← (Z + q)	None	2
STS	k, Rr	Store Direct to data space	Rd ← (k)	None	2
ST	X, Rr	Store Indirect	(X) ← Rr	None	2
ST	X+, Rr	Store Indirect and Post-Increment	(X) ← Rr, X ← X + 1	None	2
ST	-X, Rr	Store Indirect and Pre-Decrement	X ← X - 1, (X) ← Rr	None	2
ST	Y, Rr	Store Indirect	(Y) ← Rr	None	2
ST	Y+, Rr	Store Indirect and Post-Increment	(Y) ← Rr, Y ← Y + 1	None	2
ST	-Y, Rr	Store Indirect and Pre-Decrement	Y ← Y - 1, (Y) ← Rr	None	2
STD	Y+q,Rr	Store Indirect with Displacement	(Y + q) ← Rr	None	2
ST	Z, Rr	Store Indirect	(Z) ← Rr	None	2
ST	Z+, Rr	Store Indirect and Post-Increment	(Z) ← Rr, Z ← Z + 1	None	2

Instruction Set Summary (Continued)

Mnemonics	Operands	Description	Operation	Flags	#Clock Note
ST	-Z, Rr	Store Indirect and Pre-Decrement	Z ← Z - 1, (Z) ← Rr	None	2
STD	Z+q,Rr	Store Indirect with Displacement	(Z + q) ← Rr	None	2
LPM		Load Program Memory	R0 ← (Z)	None	3
LPM	Rd, Z	Load Program Memory	Rd ← (Z)	None	3
LPM	Rd, Z+	Load Program Memory and Post-Increment	Rd ← (Z), Z ← Z + 1	None	3
ELPM		Extended Load Program Memory	R0 ← (RAMPZ:Z)	None	3
ELPM	Rd, Z	Extended Load Program Memory	Rd ← (RAMPZ:Z)	None	3
ELPM	Rd, Z+	Extended Load Program Memory and Post-Increment	Rd ← (RAMPZ:Z), Z ← Z + 1	None	3
SPM		Store Program Memory	(Z) ← R1:R0	None	-
ESPM		Extended Store Program Memory	(RAMPZ:Z) ← R1:R0	None	-
IN	Rd, A	In From I/O Location	Rd ← I/O(A)	None	1
OUT	A, Rr	Out To I/O Location	I/O(A) ← Rr	None	1
PUSH	Rr	Push Register on Stack	STACK ← Rr	None	2
POP	Rd	Pop Register from Stack	Rd ← STACK	None	2
		Bit and Bit-test Instructions			
LSL	Rd	Logical Shift Left	Rd(n+1)←Rd(n),Rd(0)←0,C←Rd(7)	Z,C,N,V,H	1
LSR	Rd	Logical Shift Right	Rd(n)←Rd(n+1),Rd(7)←0,C←Rd(0)	Z,C,N,V	1
ROL	Rd	Rotate Left Through Carry	Rd(0)←C,Rd(n+1)←Rd(n),C←Rd(7)	Z,C,N,V,H	1
ROR	Rd	Rotate Right Through Carry	Rd(7)←C,Rd(n)←Rd(n+1),C←Rd(0)	Z,C,N,V	1
ASR	Rd	Arithmetic Shift Right	Rd(n) ← Rd(n+1), n=0..6	Z,C,N,V	1
SWAP	Rd	Swap Nibbles	Rd(3..0) ↔ Rd(7..4)	None	1
BSET	s	Flag Set	SREG(s) ← 1	SREG(s)	1
BCLR	s	Flag Clear	SREG(s) ← 0	SREG(s)	1
SBI	A, b	Set Bit in I/O Register	I/O(A, b) ← 1	None	2
CBI	A, b	Clear Bit in I/O Register	I/O(A, b) ← 0	None	2
BST	Rr, b	Bit Store from Register to T	T ← Rr(b)	T	1
BLD	Rd, b	Bit load from T to Register	Rd(b) ← T	None	1
SEC		Set Carry	C ← 1	C	1
CLC		Clear Carry	C ← 0	C	1
SEN		Set Negative Flag	N ← 1	N	1
CLN		Clear Negative Flag	N ← 0	N	1
SEZ		Set Zero Flag	Z ← 1	Z	1
CLZ		Clear Zero Flag	Z ← 0	Z	1

Instruction Set Summary (Continued)

Mnemonics	Operands	Description	Operation	Flags	#Clock Note
SEI		Global Interrupt Enable	I ← 1	I	1
CLI		Global Interrupt Disable	I ← 0	I	1
SES		Set Signed Test Flag	S ← 1	S	1
CLS		Clear Signed Test Flag	S ← 0	S	1
SEV		Set Two's Complement Overflow	V ← 1	V	1
CLV		Clear Two's Complement Overflow	V ← 0	V	1
SET		Set T in SREG	T ← 1	T	1
CLT		Clear T in SREG	T ← 0	T	1
SEH		Set Half Carry Flag in SREG	H ← 1	H	1
CLH		Clear Half Carry Flag in SREG	H ← 0	H	1
NOP		No Operation		None	1
SLEEP		Sleep	(see specific descr. for Sleep)	None	1
WDR		Watchdog Reset	(see specific descr. for WDR)	None	1

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 Formulae:

I	T	H	S	V	N	Z	C
-	-	⇔	⇔	⇔	⇔	⇔	⇔

H: $Rd3 \bullet Rr3 + Rr3 \bullet \overline{R3} + \overline{R3} \bullet Rd3$
Set if there was a carry from bit 3; cleared otherwise

S: $N \oplus V$, For signed tests.

V: $Rd7 \bullet Rr7 \bullet \overline{R7} + \overline{Rd7} \bullet \overline{Rr7} \bullet R7$
Set if two's complement overflow resulted from the operation; cleared otherwise.

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is \$00; cleared otherwise.

C: $Rd7 \bullet Rr7 + Rr7 \bullet \overline{R7} + \overline{R7} \bullet Rd7$
Set if there was carry from the MSB of the result; cleared otherwise.

R (Result) equals Rd after the operation.

Example:

```
                ; Add R1:R0 to R3:R2
    add   r2,r0     ; Add low byte
    adc   r3,r1     ; Add with carry high byte
```

Words: 1 (2 bytes)
Cycles: 1

ADD - Add without Carry

Description:

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

	Operation:
(i)	$Rd \leftarrow Rd + Rr$

	Syntax:	**Operands:**	**Program Counter:**
(i)	ADD Rd,Rr	$0 \le d \le 31, 0 \le r \le 31$	$PC \leftarrow PC + 1$

16-bit Opcode:

0000	11rd	dddd	rrrr

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
-	-	⇔	⇔	⇔	⇔	⇔	⇔

H: $Rd3 \bullet Rr3 + Rr3 \bullet \overline{R3} + \overline{R3} \bullet Rd3$
Set if there was a carry from bit 3; cleared otherwise

S: $N \oplus V$, For signed tests.

V: $Rd7 \bullet Rr7 \bullet \overline{R7} + \overline{Rd7} \bullet \overline{Rr7} \bullet R7$
Set if two's complement overflow resulted from the operation; cleared otherwise.

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is $00; cleared otherwise.

C: $Rd7 \bullet Rr7 + Rr7 \bullet \overline{R7} + \overline{R7} \bullet Rd7$
Set if there was carry from the MSB of the result; cleared otherwise.

R (Result) equals Rd after the operation.

Example:

```
add   r1,r2     ; Add r2 to r1 (r1=r1+r2)
add   r28,r28   ; Add r28 to itself (r28=r28+r28)
```

Words: 1 (2 bytes)
Cycles: 1

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.

	Operation:
(i)	Rd+1:Rd ← Rd+1:Rd + K

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

16-bit Opcode:

1001	0110	KKdd	KKKK

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
-	-	-	⇔	⇔	⇔	⇔	⇔

S: $N \oplus V$, For signed tests.

V: $\overline{Rdh7} \bullet R15$
Set if two's complement overflow resulted from the operation; cleared otherwise.

N: R15
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R15} \bullet \overline{R14} \bullet \overline{R13} \bullet \overline{R12} \bullet \overline{R11} \bullet \overline{R10} \bullet \overline{R9} \bullet \overline{R8} \bullet \overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is $0000; cleared otherwise.

C: $\overline{R15} \bullet Rdh7$
Set if there was carry from the MSB of the result; cleared otherwise.

R (Result) equals Rdh:Rdl after the operation (Rdh7-Rdh0 = R15-R8, Rdl7-Rdl0=R7-R0).

Example:

```
adiw  r24,1     ; Add 1 to r25:r24
adiw  r30,63    ; Add 63 to the Z pointer(r31:r30)
```

Words: 1 (2 bytes)

Cycles: 2

AND - Logical AND

Description:

Performs the logical AND between the contents of register Rd and register Rr and places the result in the destination register Rd.

Operation:

(i) Rd ← Rd • Rr

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

16-bit Opcode:

0010	00rd	dddd	rrrr

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
-	-	-	⇔	0	⇔	⇔	-

S: $N \oplus V$, For signed tests.

V: 0
Cleared

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is \$00; cleared otherwise.

R (Result) equals Rd after the operation.

Example:

```
and   r2,r3     ; Bitwise and r2 and r3, result in r2
ldi   r16,1     ; Set bitmask 0000 0001 in r16
and   r2,r16    ; Isolate bit 0 in r2
```

Words: 1 (2 bytes)
Cycles: 1

ANDI - Logical AND with Immediate

Description:

Performs the logical AND between the contents of register Rd and a constant and places the result in the destination register Rd.

Operation:

(i) Rd ← Rd • K

	Syntax:	Operands:	Program Counter:
(i)	ANDI Rd,K	$16 \le d \le 31$, $0 \le K \le 255$	PC ← PC + 1

16-bit Opcode:

0111	KKKK	dddd	KKKK

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
-	-	-	⇔	0	⇔	⇔	-

S: $N \oplus V$, For signed tests.

V: 0
Cleared

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is \$00; cleared otherwise.

R (Result) equals Rd after the operation.

Example:

```
andi  r17,$0F   ; Clear upper nibble of r17
andi  r18,$10   ; Isolate bit 4 in r18
andi  r19,$AA   ; Clear odd bits of r19
```

Words: 1 (2 bytes)
Cycles: 1

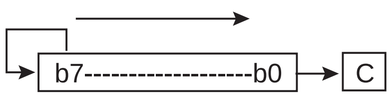
ASR - Arithmetic Shift Right

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	$0 \le d \le 31$	$PC \leftarrow PC + 1$

16-bit Opcode:

1001	010d	dddd	0101

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
-	-	-	⇔	⇔	⇔	⇔	⇔

S: $N \oplus V$, For signed tests.

V: $N \oplus C$ (For N and C after the shift)

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is \$00; cleared otherwise.

C: Rd0
Set if, before the shift, the LSB of Rd was set; cleared otherwise.

R (Result) equals Rd after the operation.

Example:

```
ldi   r16,$10   ; Load decimal 16 into r16
asr   r16       ; r16=r16 / 2
ldi   r17,$FC   ; Load -4 in r17
asr   r17       ; r17=r17/2
```

Words: 1 (2 bytes)
Cycles: 1

BCLR - Bit Clear in SREG

Description:

Clears a single flag in SREG.

	Operation:
(i)	SREG(s) ← 0

	Syntax:	**Operands:**	**Program Counter:**
(i)	BCLR s	0 ≤ s ≤ 7	PC ← PC + 1

16-bit Opcode:

1001	0100	1sss	1000

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
⇔	⇔	⇔	⇔	⇔	⇔	⇔	⇔

I: 0 if s = 7; Unchanged otherwise.

T: 0 if s = 6; Unchanged otherwise.

H: 0 if s = 5; Unchanged otherwise.

S: 0 if s = 4; Unchanged otherwise.

V: 0 if s = 3; Unchanged otherwise.

N: 0 if s = 2; Unchanged otherwise.

Z: 0 if s = 1; Unchanged otherwise.

C: 0 if s = 0; Unchanged otherwise.

Example:

```
bclr   0       ; Clear carry flag
bclr   7       ; Disable interrupts
```

Words: 1 (2 bytes)
Cycles: 1

BLD - Bit Load from the T Flag in SREG to a Bit in Register.

Description:

Copies the T flag in the SREG (status register) to bit b in register Rd.

	Operation:
(i)	Rd(b) ← T

	Syntax:	**Operands:**	**Program Counter:**
(i)	BLD Rd,b	$0 \leq d \leq 31, 0 \leq b \leq 7$	PC ← PC + 1

16 bit Opcode:

1111	100d	dddd	0bbb

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
                  ; Copy bit
    bst   r1,2    ; Store bit 2 of r1 in T flag
    bld   r0,4    ; Load T flag into bit 4 of r0
```

Words: 1 (2 bytes)
Cycles: 1

BRBC - Branch if Bit in SREG is Cleared

Description:

Conditional relative branch. Tests a single bit in SREG and branches relatively to PC if the bit is cleared. This instruction branches relatively to PC in either direction (PC - 63 ≤ destination ≤ PC + 64). The parameter k is the offset from PC and is represented in two's complement form.

Operation:

(i) If SREG(s) = 0 then PC ← PC + k + 1, else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	BRBC s,k	0 ≤ s ≤ 7, -64 ≤ k ≤ +63	PC ← PC + k + 1 PC ← PC + 1, if condition is false

16-bit Opcode:

1111	01kk	kkkk	ksss

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
cpi   r20,5     ; Compare r20 to the value 5
brbc  1,noteq   ; Branch if zero flag cleared
...
noteq:nop       ; Branch destination (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false
2 if condition is true

BRBS - Branch if Bit in SREG is Set

Description:

Conditional relative branch. Tests a single bit in SREG and branches relatively to PC if the bit is set. This instruction branches relatively to PC in either direction (PC - 63 ≤ destination ≤ PC + 64). The parameter k is the offset from PC and is represented in two's complement form.

Operation:

(i) If SREG(s) = 1 then PC ← PC + k + 1, else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	BRBS s,k	0 ≤ s ≤ 7, -64 ≤ k ≤ +63	PC ← PC + k + 1 PC ← PC + 1, if condition is false

16-bit Opcode:

1111	00kk	kkkk	ksss

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
        bst   r0,3     ; Load T bit with bit 3 of r0
        brbs  6,bitset ; Branch T bit was set
        ...
bitset: nop            ; Branch destination (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false
2 if condition is true

BRCC - Branch if Carry Cleared

Description:

Conditional relative branch. Tests the Carry flag (C) and branches relatively to PC if C is cleared. This instruction branches relatively to PC in either direction (PC - 63 ≤ destination ≤ PC + 64). The parameter k is the offset from PC and is represented in two's complement form. (Equivalent to instruction BRBC 0,k).

Operation:

(i) If C = 0 then PC ← PC + k + 1, else PC ← PC + 1

	Syntax:	**Operands:**	**Program Counter:**
(i)	BRCC k	-64 ≤ k ≤ +63	PC ← PC + k + 1 PC ← PC + 1, if condition is false

16-bit Opcode:

1111	01kk	kkkk	k000

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
           add   r22,r23    ; Add r23 to r22
           brcc  nocarry    ; Branch if carry cleared
           ...
  nocarry: nop              ; Branch destination (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false
2 if condition is true

BRCS - Branch if Carry Set

Description:

Conditional relative branch. Tests the Carry flag (C) and branches relatively to PC if C is set. This instruction branches relatively to PC in either direction (PC - 63 ≤ destination ≤ PC + 64). The parameter k is the offset from PC and is represented in two's complement form. (Equivalent to instruction BRBS 0,k).

Operation:

(i) If C = 1 then PC ← PC + k + 1, else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	BRCS k	-64 ≤ k ≤ +63	PC ← PC + k + 1 PC ← PC + 1, if condition is false

16-bit Opcode:

1111	00kk	kkkk	k000

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
        cpi   r26,$56   ; Compare r26 with $56
        brcs  carry     ; Branch if carry set
        ...
carry:  nop             ; Branch destination (do nothing)
```

Words: 1 (2 bytes)
Cycles: 1 if condition is false
2 if condition is true

BREQ - Branch if Equal

Description:

Conditional relative branch. Tests the Zero flag (Z) and branches relatively to PC if Z is set. If the instruction is executed immediately after any of the instructions CP, CPI, SUB or SUBI, the branch will occur if and only if the unsigned or signed binary number represented in Rd was equal to the unsigned or signed binary number represented in Rr. This instruction branches relatively to PC in either direction (PC - 63 ≤ destination ≤ PC + 64). The parameter k is the offset from PC and is represented in two's complement form. (Equivalent to instruction BRBS 1,k).

Operation:

(i) If Rd = Rr (Z = 1) then PC ← PC + k + 1, else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	BREQ k	-64 ≤ k ≤ +63	PC ← PC + k + 1 PC ← PC + 1, if condition is false

16-bit Opcode:

1111	00kk	kkkk	k001

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
        cp    r1,r0     ; Compare registers r1 and r0
        breq  equal     ; Branch if registers equal
        ...
equal:  nop             ; Branch destination (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false
2 if condition is true

BRGE - Branch if Greater or Equal (Signed)

Description:

Conditional relative branch. Tests the Signed flag (S) and branches relatively to PC if S is cleared. If the instruction is executed immediately after any of the instructions CP, CPI, SUB or SUBI, the branch will occur if and only if the signed binary number represented in Rd was greater than or equal to the signed binary number represented in Rr. This instruction branches relatively to PC in either direction ($PC - 63 \leq destination \leq PC + 64$). The parameter k is the offset from PC and is represented in two's complement form. (Equivalent to instruction BRBC 4,k).

Operation:

(i) If $Rd \geq Rr$ ($N \oplus V = 0$) then $PC \leftarrow PC + k + 1$, else $PC \leftarrow PC + 1$

	Syntax:	Operands:	Program Counter:
(i)	BRGE k	$-64 \leq k \leq +63$	$PC \leftarrow PC + k + 1$ $PC \leftarrow PC + 1$, if condition is false

16-bit Opcode:

1111	01kk	kkkk	k100

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
          cp    r11,r12     ; Compare registers r11 and r12
          brge  greateq     ; Branch if r11 ≥ r12 (signed)
          ...
greateq:  nop               ; Branch destination (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false

2 if condition is true

BRHC - Branch if Half Carry Flag is Cleared

Description:

Conditional relative branch. Tests the Half Carry flag (H) and branches relatively to PC if H is cleared. This instruction branches relatively to PC in either direction (PC - 63 ≤ destination ≤ PC + 64). The parameter k is the offset from PC and is represented in two's complement form. (Equivalent to instruction BRBC 5,k).

Operation:

(i) If H = 0 then PC ← PC + k + 1, else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	BRHC k	-64 ≤ k ≤ +63	PC ← PC + k + 1 PC ← PC + 1, if condition is false

16-bit Opcode:

1111	01kk	kkkk	k101

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
        brhc hclear     ; Branch if half carry flag cleared
        ...
hclear: nop             ; Branch destination (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false
2 if condition is true

BRHS - Branch if Half Carry Flag is Set

Description:

Conditional relative branch. Tests the Half Carry flag (H) and branches relatively to PC if H is set. This instruction branches relatively to PC in either direction (PC - 63 ≤ destination ≤ PC + 64). The parameter k is the offset from PC and is represented in two's complement form. (Equivalent to instruction BRBS 5,k).

Operation:

(i) If H = 1 then PC ← PC + k + 1, else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	BRHS k	-64 ≤ k ≤ +63	PC ← PC + k + 1 PC ← PC + 1, if condition is false

16-bit Opcode:

1111	00kk	kkkk	k101

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
        brhs   hset        ; Branch if half carry flag set
        ...
hset:   nop                ; Branch destination (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false
2 if condition is true

BRID - Branch if Global Interrupt is Disabled

Description:

Conditional relative branch. Tests the Global Interrupt flag (I) and branches relatively to PC if I is cleared. This instruction branches relatively to PC in either direction (PC - 63 ≤ destination ≤ PC + 64). The parameter k is the offset from PC and is represented in two's complement form. (Equivalent to instruction BRBC 7,k).

Operation:

(i) If I = 0 then PC ← PC + k + 1, else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	BRID k	-64 ≤ k ≤ +63	PC ← PC + k + 1 PC ← PC + 1, if condition is false

16-bit Opcode:

1111	01kk	kkkk	k111

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
        brid intdis     ; Branch if interrupt disabled
        ...
intdis: nop             ; Branch destination (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false
2 if condition is true

BRIE - Branch if Global Interrupt is Enabled

Description:

Conditional relative branch. Tests the Global Interrupt flag (I) and branches relatively to PC if I is set. This instruction branches relatively to PC in either direction (PC - 63 ≤ destination ≤ PC + 64). The parameter k is the offset from PC and is represented in two's complement form. (Equivalent to instruction BRBS 7,k).

Operation:

(i) If I = 1 then PC ← PC + k + 1, else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	BRIE k	-64 ≤ k ≤ +63	PC ← PC + k + 1 PC ← PC + 1, if condition is false

16-bit Opcode:

1111	00kk	kkkk	k111

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
            brie   inten       ; Branch if interrupt enabled
            ...
    inten:  nop                ; Branch destination (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false
2 if condition is true

BRLO - Branch if Lower (Unsigned)

Description:

Conditional relative branch. Tests the Carry flag (C) and branches relatively to PC if C is set. If the instruction is executed immediately after any of the instructions CP, CPI, SUB or SUBI, the branch will occur if and only if the unsigned binary number represented in Rd was smaller than the unsigned binary number represented in Rr. This instruction branches relatively to PC in either direction (PC - 63 ≤ destination ≤ PC + 64). The parameter k is the offset from PC and is represented in two's complement form. (Equivalent to instruction BRBS 0,k).

Operation:

(i) If Rd < Rr (C = 1) then PC ← PC + k + 1, else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	BRLO k	-64 ≤ k ≤ +63	PC ← PC + k + 1 PC ← PC + 1, if condition is false

16-bit Opcode:

1111	00kk	kkkk	k000

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
        eor   r19,r19     ; Clear r19
loop:   inc   r19         ; Increase r19
        ...
        cpi   r19,$10     ; Compare r19 with $10
        brlo  loop        ; Branch if r19 < $10 (unsigned)
        nop               ; Exit from loop (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false
2 if condition is true

BRLT - Branch if Less Than (Signed)

Description:

Conditional relative branch. Tests the Signed flag (S) and branches relatively to PC if S is set. If the instruction is executed immediately after any of the instructions CP, CPI, SUB or SUBI, the branch will occur if and only if the signed binary number represented in Rd was less than the signed binary number represented in Rr. This instruction branches relatively to PC in either direction (PC - 63 ≤ destination ≤ PC + 64). The parameter k is the offset from PC and is represented in two's complement form. (Equivalent to instruction BRBS 4,k).

Operation:

(i) If Rd < Rr ($N \oplus V = 1$) then PC ← PC + k + 1, else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	BRLT k	-64 ≤ k ≤ +63	PC ← PC + k + 1 PC ← PC + 1, if condition is false

16-bit Opcode:

1111	00kk	kkkk	k100

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
            cp    r16,r1        ; Compare r16 to r1
            brlt  less          ; Branch if r16 < r1 (signed)
            ...
    less:   nop                 ; Branch destination (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false
2 if condition is true

BRMI - Branch if Minus

Description:

Conditional relative branch. Tests the Negative flag (N) and branches relatively to PC if N is set. This instruction branches relatively to PC in either direction (PC - 63 ≤ destination ≤ PC + 64). The parameter k is the offset from PC and is represented in two's complement form. (Equivalent to instruction BRBS 2,k).

Operation:

(i) If N = 1 then PC ← PC + k + 1, else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	BRMI k	-64 ≤ k ≤ +63	PC ← PC + k + 1 PC ← PC + 1, if condition is false

16-bit Opcode:

1111	00kk	kkkk	k010

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
            subi    r18,4       ; Subtract 4 from r18
            brmi    negative    ; Branch if result negative
            ...
negative:   nop                 ; Branch destination (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false
2 if condition is true

BRNE - Branch if Not Equal

Description:

Conditional relative branch. Tests the Zero flag (Z) and branches relatively to PC if Z is cleared. If the instruction is executed immediately after any of the instructions CP, CPI, SUB or SUBI, the branch will occur if and only if the unsigned or signed binary number represented in Rd was not equal to the unsigned or signed binary number represented in Rr. This instruction branches relatively to PC in either direction (PC - 63 ≤ destination ≤ PC + 64). The parameter k is the offset from PC and is represented in two's complement form. (Equivalent to instruction BRBC 1,k).

Operation:

(i) If Rd ≠ Rr (Z = 0) then PC ← PC + k + 1, else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	BRNE k	-64 ≤ k ≤ +63	PC ← PC + k + 1 PC ← PC + 1, if condition is false

16-bit Opcode:

1111	01kk	kkkk	k001

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
        eor   r27,r27   ; Clear r27
loop:   inc   r27       ; Increase r27
        ...
        cpi   r27,5     ; Compare r27 to 5
        brne  loop      ; Branch if r27<>5
        nop             ; Loop exit (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false
2 if condition is true

BRPL - Branch if Plus

Description:

Conditional relative branch. Tests the Negative flag (N) and branches relatively to PC if N is cleared. This instruction branches relatively to PC in either direction (PC - 63 ≤ destination ≤ PC + 64). The parameter k is the offset from PC and is represented in two's complement form. (Equivalent to instruction BRBC 2,k).

Operation:

(i) If N = 0 then PC ← PC + k + 1, else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	BRPL k	-64 ≤ k ≤ +63	PC ← PC + k + 1 PC ← PC + 1, if condition is false

16-bit Opcode:

1111	01kk	kkkk	k010

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
            subi  r26,$50       ; Subtract $50 from r26
            brpl  positive      ; Branch if r26 positive
            ...
positive:   nop                 ; Branch destination (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false
2 if condition is true

BRSH - Branch if Same or Higher (Unsigned)

Description:

Conditional relative branch. Tests the Carry flag (C) and branches relatively to PC if C is cleared. If the instruction is executed immediately after execution of any of the instructions CP, CPI, SUB or SUBI the branch will occur if and only if the unsigned binary number represented in Rd was greater than or equal to the unsigned binary number represented in Rr. This instruction branches relatively to PC in either direction (PC - 63 ≤ destination ≤ PC + 64). The parameter k is the offset from PC and is represented in two's complement form. (Equivalent to instruction BRBC 0,k).

Operation:

(i) If Rd ≥Rr (C = 0) then PC ← PC + k + 1, else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	BRSH k	-64 ≤ k ≤ +63	PC ← PC + k + 1 PC ← PC + 1, if condition is false

16-bit Opcode:

1111	01kk	kkkk	k000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
          subi  r19,4         ; Subtract 4 from r19
          brsh  highsm        ; Branch if r19 >= 4 (unsigned)
          ...
highsm:   nop                 ; Branch destination (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false
2 if condition is true

BRTC - Branch if the T Flag is Cleared

Description:

Conditional relative branch. Tests the T flag and branches relatively to PC if T is cleared. This instruction branches relatively to PC in either direction (PC - 63 ≤ destination ≤ PC + 64). The parameter k is the offset from PC and is represented in two's complement form. (Equivalent to instruction BRBC 6,k).

Operation:

(i) If T = 0 then PC ← PC + k + 1, else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	BRTC k	-64 ≤ k ≤ +63	PC ← PC + k + 1 PC ← PC + 1, if condition is false

16-bit Opcode:

1111	01kk	kkkk	k110

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
            bst     r3,5      ; Store bit 5 of r3 in T flag
            brtc    tclear    ; Branch if this bit was cleared
            ...
tclear:     nop               ; Branch destination (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false
2 if condition is true

BRTS - Branch if the T Flag is Set

Description:

Conditional relative branch. Tests the T flag and branches relatively to PC if T is set. This instruction branches relatively to PC in either direction (PC - 63 ≤ destination ≤ PC + 64). The parameter k is the offset from PC and is represented in two's complement form. (Equivalent to instruction BRBS 6,k).

Operation:

(i) If T = 1 then PC ← PC + k + 1, else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	BRTS k	-64 ≤ k ≤ +63	PC ← PC + k + 1 PC ← PC + 1, if condition is false

16-bit Opcode:

1111	00kk	kkkk	k110

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
         bst   r3,5      ; Store bit 5 of r3 in T flag
         brts  tset      ; Branch if this bit was set
         ...
tset:    nop             ; Branch destination (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false
2 if condition is true

BRVC - Branch if Overflow Cleared

Description:
Conditional relative branch. Tests the Overflow flag (V) and branches relatively to PC if V is cleared. This instruction branches relatively to PC in either direction (PC - 63 ≤ destination ≤ PC + 64). The parameter k is the offset from PC and is represented in two's complement form. (Equivalent to instruction BRBC 3,k).

Operation:

(i) If V = 0 then PC ← PC + k + 1, else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	BRVC k	-64 ≤ k ≤ +63	PC ← PC + k + 1 PC ← PC + 1, if condition is false

16-bit Opcode:

1111	01kk	kkkk	k011

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
            add   r3,r4       ; Add r4 to r3
            brvc  noover      ; Branch if no overflow
            ...
  noover:   nop               ; Branch destination (do nothing)
```

Words: 1 (2 bytes)
Cycles: 1 if condition is false
2 if condition is true

BRVS - Branch if Overflow Set

Description:

Conditional relative branch. Tests the Overflow flag (V) and branches relatively to PC if V is set. This instruction branches relatively to PC in either direction (PC - 63 ≤ destination ≤ PC + 64). The parameter k is the offset from PC and is represented in two's complement form. (Equivalent to instruction BRBS 3,k).

Operation:

(i) If V = 1 then PC ← PC + k + 1, else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	BRVS k	-64 ≤ k ≤ +63	PC ← PC + k + 1 PC ← PC + 1, if condition is false

16-bit Opcode:

1111	00kk	kkkk	k011

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
            add     r3,r4       ; Add r4 to r3
            brvs    overfl      ; Branch if overflow
            ...
overfl:     nop                 ; Branch destination (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false
2 if condition is true

BSET - Bit Set in SREG

Description:

Sets a single flag or bit in SREG.

Operation:

(i) SREG(s) ← 1

	Syntax:	Operands:	Program Counter:
(i)	BSET s	$0 \le s \le 7$	PC ← PC + 1

16-bit Opcode:

1001	0100	0sss	1000

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
⇔	⇔	⇔	⇔	⇔	⇔	⇔	⇔

I: 1 if s = 7; Unchanged otherwise.

T: 1 if s = 6; Unchanged otherwise.

H: 1 if s = 5; Unchanged otherwise.

S: 1 if s = 4; Unchanged otherwise.

V: 1 if s = 3; Unchanged otherwise.

N: 1 if s = 2; Unchanged otherwise.

Z: 1 if s = 1; Unchanged otherwise.

C: 1 if s = 0; Unchanged otherwise.

Example:

```
bset   6          ; Set T flag
bset   7          ; Enable interrupt
```

Words: 1 (2 bytes)

Cycles: 1

BST - Bit Store from Bit in Register to T Flag in SREG

Description:

Stores bit b from Rd to the T flag in SREG (status register).

	Operation:
(i)	T ← Rd(b)

	Syntax:	**Operands:**	**Program Counter:**
(i)	BST Rd,b	$0 \le d \le 31, 0 \le b \le 7$	PC ← PC + 1

16-bit Opcode:

1111	101d	dddd	0bbb

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	⇔	-	-	-	-	-	-

T: 0 if bit b in Rd is cleared. Set to 1 otherwise.

Example:

```
                ; Copy bit
    bst   r1,2  ; Store bit 2 of r1 in T flag
    bld   r0,4  ; Load T into bit 4 of r0
```

Words: 1 (2 bytes)
Cycles: 1

CALL - Long Call to a Subroutine

Description:

Calls to a subroutine within the entire program memory. The return address (to the instruction after the CALL) will be stored onto the stack. (See also RCALL). The stack pointer uses a post-decrement scheme during CALL.

	Operation:	
(i)	PC ← k	Devices with 16 bits PC, 128K bytes program memory maximum.
(ii)	PC ← k	Devices with 22 bits PC, 8M bytes program memory maximum.

	Syntax:	Operands:	Program Counter	Stack:
(i)	CALL k	$0 \leq k < 64K$	PC ← k	STACK ← PC+2 SP ← SP-2, (2 bytes, 16 bits)
(ii)	CALL k	$0 \leq k < 4M$	PC ← k	STACK ← PC+2 SP ← SP-3 (3 bytes, 22 bits)

32-bit Opcode:

1001	010k	kkkk	111k
kkkk	kkkk	kkkk	kkkk

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
        mov     r16,r0        ; Copy r0 to r16
        call    check         ; Call subroutine
        nop                   ; Continue (do nothing)
        ...
check:  cpi     r16,$42       ; Check if r16 has a special value
        breq    error         ; Branch if equal
        ret                   ; Return from subroutine
        ...
error:  rjmp    error         ; Infinite loop
```

Words: 2 (4 bytes)

Cycles: 4, devices with 16 bit PC
5, devices with 22 bit PC

CBI - Clear Bit in I/O Register

Description:

Clears a specified bit in an I/O register. This instruction operates on the lower 32 I/O registers - addresses 0-31.

Operation:

(i) I/O(A,b) ← 0

	Syntax:	Operands:	Program Counter:
(i)	CBI A,b	$0 \leq A \leq 31$, $0 \leq b \leq 7$	PC ← PC + 1

16-bit Opcode:

1001	1000	AAAA	Abbb

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
cbi     $12,7           ; Clear bit 7 in Port D
```

Words: 1 (2 bytes)

Cycles: 2

CBR - Clear Bits in Register

Description:

Clears the specified bits in register Rd. Performs the logical AND between the contents of register Rd and the complement of the constant mask K. The result will be placed in register Rd.

Operation:

(i) Rd ← Rd • ($FF - K)

	Syntax:	Operands:	Program Counter:
(i)	CBR Rd,K	16 ≤ d ≤ 31, 0 ≤ K ≤ 255	PC ← PC + 1

16-bit Opcode: (see ANDI with K complemented)

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	⇔	0	⇔	⇔	-

S: N ⊕ V, For signed tests.

V: 0
Cleared

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is $00; cleared otherwise.

R (Result) equals Rd after the operation.

Example:

```
cbr     r16,$F0   ; Clear upper nibble of r16
cbr     r18,1     ; Clear bit 0 in r18
```

Words: 1 (2 bytes)
Cycles: 1

CLC - Clear Carry Flag

Description:

Clears the Carry flag (C) in SREG (status register).

Operation:

(i) $C \leftarrow 0$

	Syntax:	Operands:	Program Counter:
(i)	CLC	None	$PC \leftarrow PC + 1$

16-bit Opcode:

1001	0100	1000	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	0

C: 0
Carry flag cleared

Example:

```
add   r0,r0   ; Add r0 to itself
clc           ; Clear carry flag
```

Words: 1 (2 bytes)
Cycles: 1

CLH - Clear Half Carry Flag

Description:

Clears the Half Carry flag (H) in SREG (status register).

Operation:

(i) H ← 0

	Syntax:	Operands:	Program Counter:
(i)	CLH	None	PC ← PC + 1

16-bit Opcode:

1001	0100	1101	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	0	-	-	-	-	-

H: 0
Half Carry flag cleared

Example:

```
clh          ; Clear the Half Carry flag
```

Words: 1 (2 bytes)

Cycles: 1

CLI - Clear Global Interrupt Flag

Description:

Clears the Global Interrupt flag (I) in SREG (status register).

Operation:

(i) I ← 0

	Syntax:	Operands:	Program Counter:
(i)	CLI	None	PC ← PC + 1

16-bit Opcode:

1001	0100	1111	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
0	-	-	-	-	-	-	-

I: 0
Global Interrupt flag cleared

Example:

```
cli             ; Disable interrupts
in     r11,$16  ; Read port B
sei             ; Enable interrupts
```

Words: 1 (2 bytes)
Cycles: 1

CLN - Clear Negative Flag

Description:

Clears the Negative flag (N) in SREG (status register).

Operation:

(i) N ← 0

	Syntax:	**Operands:**	**Program Counter:**
(i)	CLN	None	PC ← PC + 1

16-bit Opcode:

1001	0100	1010	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	0	-	-

N: 0
Negative flag cleared

Example:

```
add     r2,r3     ; Add r3 to r2
cln               ; Clear negative flag
```

Words: 1 (2 bytes)
Cycles: 1

CLR - Clear Register

Description:

Clears a register. This instruction performs an Exclusive OR between a register and itself. This will clear all bits in the register.

Operation:

(i) $Rd \leftarrow Rd \oplus Rd$

	Syntax:	Operands:	Program Counter:
(i)	CLR Rd	$0 \leq d \leq 31$	$PC \leftarrow PC + 1$

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

0010	01dd	dddd	dddd

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	0	0	0	1	-

S: 0
Cleared

V: 0
Cleared

N: 0
Cleared

Z: 1
Set

R (Result) equals Rd after the operation.

Example:

```
        clr   r18       ; clear r18
loop:   inc   r18       ; increase r18
        ...
        cpi   r18,$50   ; Compare r18 to $50
        brne  loop
```

Words: 1 (2 bytes)
Cycles: 1

CLS - Clear Signed Flag

Description:

Clears the Signed flag (S) in SREG (status register).

Operation:

(i) S ← 0

	Syntax:	Operands:	Program Counter:
(i)	CLS	None	PC ← PC + 1

16-bit Opcode:

1001	0100	1100	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	0	-	-	-	-

S: 0
Signed flag cleared

Example:

```
add   r2,r3     ; Add r3 to r2
cls             ; Clear signed flag
```

Words: 1 (2 bytes)
Cycles: 1

CLT - Clear T Flag

Description:

Clears the T flag in SREG (status register).

Operation:

(i) T ← 0

	Syntax:	Operands:	Program Counter:
(i)	CLT	None	PC ← PC + 1

16-bit Opcode:

1001	0100	1110	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	0	-	-	-	-	-	-

T: 0
T flag cleared

Example:

```
clt             ; Clear T flag
```

Words: 1 (2 bytes)
Cycles: 1

CLV - Clear Overflow Flag

Description:

Clears the Overflow flag (V) in SREG (status register).

Operation:

(i) V ← 0

	Syntax:	Operands:	Program Counter:
(i)	CLV	None	PC ← PC + 1

16-bit Opcode:

1001	0100	1011	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	0	-	-	-

V: 0
Overflow flag cleared

Example:

```
add   r2,r3   ; Add r3 to r2
clv           ; Clear overflow flag
```

Words: 1 (2 bytes)
Cycles: 1

CLZ - Clear Zero Flag

Description:

Clears the Zero flag (Z) in SREG (status register).

Operation:

(i) Z ← 0

	Syntax:	Operands:	Program Counter:
(i)	CLZ	None	PC ← PC + 1

16-bit Opcode:

1001	0100	1001	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	0	-

Z: 0
Zero flag cleared

Example:

```
add    r2,r3    ; Add r3 to r2
clz             ; Clear zero
```

Words: 1 (2 bytes)
Cycles: 1

COM - One's Complement

Description:

This instruction performs a one's complement of register Rd.

Operation:

(i) Rd ← $FF - Rd

	Syntax:	Operands:	Program Counter:
(i)	COM Rd	$0 \le d \le 31$	PC ← PC + 1

16-bit Opcode:

1001	010d	dddd	0000

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
-	-	-	⇔	0	⇔	⇔	1

S: $N \oplus V$
For signed tests.

V: 0
Cleared.

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is $00; Cleared otherwise.

C: 1
Set.

R (Result) equals Rd after the operation.

Example:

```
        com   r4    ; Take one's complement of r4
        breq  zero  ; Branch if zero
        ...
zero:   nop         ; Branch destination (do nothing)
```

Words: 1 (2 bytes)
Cycles: 1

CP - Compare

Description:

This instruction performs a compare between two registers Rd and Rr. None of the registers are changed. All conditional branches can be used after this instruction.

Operation:

(i) Rd - Rr

	Syntax:	Operands:	Program Counter:
(i)	CP Rd,Rr	$0 \le d \le 31, 0 \le r \le 31$	$PC \leftarrow PC + 1$

16-bit Opcode:

0001	01rd	dddd	rrrr

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	⇔	⇔	⇔	⇔	⇔	⇔

H: $\overline{Rd3} \bullet Rr3 + Rr3 \bullet R3 + R3 \bullet \overline{Rd3}$
Set if there was a borrow from bit 3; cleared otherwise

S: $N \oplus V$, For signed tests.

V: $Rd7 \bullet \overline{Rd7} \bullet \overline{R7} + \overline{Rd7} \bullet Rr7 \bullet R7$
Set if two’s complement overflow resulted from the operation; cleared otherwise.

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is $00; cleared otherwise.

C: $\overline{Rd7} \bullet Rr7 + Rr7 \bullet R7 + R7 \bullet \overline{Rd7}$
Set if the absolute value of the contents of Rr is larger than the absolute value of Rd; cleared otherwise.

R (Result) after the operation.

Example:

```
        cp    r4,r19    ; Compare r4 with r19
        brne  noteq     ; Branch if r4 <> r19
        ...
noteq:  nop             ; Branch destination (do nothing)
```

Words: 1 (2 bytes)
Cycles: 1

CPC - Compare with Carry

Description:

This instruction performs a compare between two registers Rd and Rr and also takes into account the previous carry. None of the registers are changed. All conditional branches can be used after this instruction.

Operation:

(i) Rd - Rr - C

	Syntax:	Operands:	Program Counter:
(i)	CPC Rd,Rr	$0 \le d \le 31$, $0 \le r \le 31$	$PC \leftarrow PC + 1$

16-bit Opcode:

0000	01rd	dddd	rrrr

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	⇔	⇔	⇔	⇔	⇔	⇔

H: $\overline{Rd3} \bullet Rr3 + Rr3 \bullet R3 + R3 \bullet \overline{Rd3}$
Set if there was a borrow from bit 3; cleared otherwise

S: $N \oplus V$, For signed tests.

V: $Rd7 \bullet \overline{Rr7} \bullet \overline{R7} + \overline{Rd7} \bullet Rr7 \bullet R7$
Set if two's complement overflow resulted from the operation; cleared otherwise.

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0} \bullet Z$
Previous value remains unchanged when the result is zero; cleared otherwise.

C: $\overline{Rd7} \bullet Rr7 + Rr7 \bullet R7 + R7 \bullet \overline{Rd7}$
Set if the absolute value of the contents of Rr plus previous carry is larger than the absolute value of Rd; cleared otherwise.

R (Result) after the operation.

Example:

```
                           ; Compare r3:r2 with r1:r0
          cp      r2,r0    ; Compare low byte
          cpc     r3,r1    ; Compare high byte
          brne    noteq    ; Branch if not equal
          ...
   noteq: nop              ; Branch destination (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1

CPI - Compare with Immediate

Description:

This instruction performs a compare between register Rd and a constant. The register is not changed. All conditional branches can be used after this instruction.

	Operation:
(i)	Rd - K

	Syntax:	**Operands:**	**Program Counter:**
(i)	CPI Rd,K	$16 \leq d \leq 31$, $0 \leq K \leq 255$	$PC \leftarrow PC + 1$

16-bit Opcode:

0011	KKKK	dddd	KKKK

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	⇔	⇔	⇔	⇔	⇔	⇔

H: $\overline{Rd3} \bullet K3 + K3 \bullet R3 + R3 \bullet \overline{Rd3}$
Set if there was a borrow from bit 3; cleared otherwise

S: $N \oplus V$, For signed tests.

V: $Rd7 \bullet \overline{K7} \bullet \overline{R7} + \overline{Rd7} \bullet K7 \bullet R7$
Set if two's complement overflow resulted from the operation; cleared otherwise.

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is \$00; cleared otherwise.

C: $\overline{Rd7} \bullet K7 + K7 \bullet R7 + R7 \bullet \overline{Rd7}$
Set if the absolute value of K is larger than the absolute value of Rd; cleared otherwise.

R (Result) after the operation.

Example:

```
         cpi     r19,3     ; Compare r19 with 3
         brne    error     ; Branch if r19<>3
         ...
error:   nop               ; Branch destination (do nothing)
```

Words: 1 (2 bytes)
Cycles: 1

CPSE - Compare Skip if Equal

Description:

This instruction performs a compare between two registers Rd and Rr, and skips the next instruction if Rd = Rr.

Operation:

(i) If Rd = Rr then PC ← PC + 2 (or 3) else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	CPSE Rd,Rr	$0 \le d \le 31$, $0 \le r \le 31$	PC ← PC + 1, Condition false - no skip PC ← PC + 2, Skip a one word instruction PC ← PC + 3, Skip a two word instruction

16-bit Opcode:

0001	00rd	dddd	rrrr

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
inc    r4      ; Increase r4
cpse   r4,r0   ; Compare r4 to r0
neg    r4      ; Only executed if r4<>r0
nop            ; Continue (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false (no skip)
2 if condition is true (skip is executed) and the instruction skipped is 1 word
3 if condition is true (skip is executed) and the instruction skipped is 2 words

DEC - Decrement

Description:

Subtracts one -1- from the contents of register Rd and places the result in the destination register Rd.

The C flag in SREG is not affected by the operation, thus allowing the DEC instruction to be used on a loop counter in multiple-precision computations.

When operating on unsigned values, only BREQ and BRNE branches can be expected to perform consistently. When operating on two's complement values, all signed branches are available.

Operation:

(i) $Rd \leftarrow Rd - 1$

	Syntax:	Operands:	Program Counter:
(i)	DEC Rd	$0 \le d \le 31$	$PC \leftarrow PC + 1$

16-bit Opcode:

1001	010d	dddd	1010

Status Register and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	⇔	⇔	⇔	⇔	-

S: $N \oplus V$
For signed tests.

V: $\overline{R7} \bullet R6 \bullet R5 \bullet R4 \bullet R3 \bullet R2 \bullet R1 \bullet R0$
Set if two's complement overflow resulted from the operation; cleared otherwise. Two's complement overflow occurs if and only if Rd was $80 before the operation.

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is $00; Cleared otherwise.

R (Result) equals Rd after the operation.

Example:

```
        ldi   r17,$10   ; Load constant in r17
loop:   add   r1,r2     ; Add r2 to r1
        dec   r17       ; Decrement r17
        brne  loop      ; Branch if r17<>0
        nop             ; Continue (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1

EICALL - Extended Indirect Call to Subroutine

Description:

Indirect call of a subroutine pointed to by the Z (16 bits) pointer register in the register file and the EIND register in the I/O space. This instruction allows for indirect calls to the entire program memory space. This instruction is not implemented for devices with 2 bytes PC, see ICALL. The stack pointer uses a post-decrement scheme during EICALL.

Operation:

(i) PC(15:0) ← Z(15:0)
PC(21:16) ← EIND

	Syntax:	Operands:	Program Counter:	Stack:
(i)	EICALL	None	See Operation	STACK ← PC + 1 SP ← SP - 3 (3 bytes, 22 bits)

16-bit Opcode:

1001	0101	0001	1001

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
ldi     r16,$05   ; Set up EIND and Z pointer
out     EIND,r16
ldi     r30,$00
ldi     r31,$10
eicall            ; Call to $051000
```

Words: 1 (2 bytes)
Cycles: 4 (only implemented in devices with 22 bit PC)

EIJMP - Extended Indirect Jump

Description:

Indirect jump to the address pointed to by the Z (16 bits) pointer register in the register file and the EIND register in the I/O space. This instruction allows for indirect jumps to the entire program memory space.

Operation:

(i) PC(15:0) ← Z(15:0)
PC(21:16) ← EIND

	Syntax:	Operands:	Program Counter:	Stack:
(i)	EIJMP	None	See Operation	Not Affected

16-bit Opcode:

1001	0100	0001	1001

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
ldi     r16,$05   ; Set up EIND and Z pointer
out     EIND,r16
ldi     r30,$00
ldi     r31,$10
eijmp             ; Jump to $051000
```

Words: 1 (2 bytes)
Cycles: 2

ELPM - Extended Load Program Memory

Description:

Loads one byte pointed to by the Z register and the RAMPZ register in the I/O space, and places this byte in the destination register Rd. This instruction features a 100% space effective constant initialization or constant data fetch. The program memory is organized in 16 bit words and the least significant bit of the Z pointer selects either low byte (0) or high byte (1). This instruction can address the entire program memory space. The Z pointer register can either be left unchanged by the operation, or it can be incremented. The incrementation applies to the entire 24-bit concatenation of the RAMPZ and Z pointer registers.

The result of these combinations is undefined:

ELPM r30, Z+
ELPM r31, Z+

	Operation:		**Comment:**
(i)	R0 ← (RAMPZ:Z)		RAMPZ:Z: Unchanged, R0 implied destination register
(ii)	Rd ← (RAMPZ:Z)		RAMPZ:Z: Unchanged
(iii)	Rd ← (RAMPZ:Z)	(RAMPZ:Z) ← (RAMPZ:Z) + 1	RAMPZ:Z: Post incremented

	Syntax:	**Operands:**	**Program Counter:**
(i)	ELPM	None, R0 implied	PC ← PC + 1
(ii)	ELPM Rd, Z	0 ≤ d ≤ 31	PC ← PC + 1
(iii)	ELPM Rd, Z+	0 ≤ d ≤ 31	PC ← PC + 1

16 bit Opcode:

(i)	1001	0101	1101	1000
(ii)	1001	000d	dddd	0110
(iii)	1001	000d	dddd	0111

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
clr   r16          ; Clear RAMPZ
out   RAMPZ, r16
clr   r31          ; Clear Z high byte
ldi   r30,$F0      ; Set Z low byte
elpm  r16, Z+      ; Load constant from program
                   ; memory pointed to by RAMPZ:Z (r31:r30)
```

Words: 1 (2 bytes)
Cycles: 3

EOR - Exclusive OR

Description:

Performs the logical EOR between the contents of register Rd and register Rr and places the result in the destination register Rd.

Operation:

(i) $Rd \leftarrow Rd \oplus Rr$

	Syntax:	Operands:	Program Counter:
(i)	EOR Rd,Rr	$0 \le d \le 31, 0 \le r \le 31$	$PC \leftarrow PC + 1$

16-bit Opcode:

0010	01rd	dddd	rrrr

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	⇔	0	⇔	⇔	-

S: $N \oplus V$, For signed tests.

V: 0
Cleared

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is \$00; cleared otherwise.

R (Result) equals Rd after the operation.

Example:

```
eor     r4,r4      ; Clear r4
eor     r0,r22     ; Bitwise exclusive or between r0 and r22
```

Words: 1 (2 bytes)
Cycles: 1

ESPM - Extended Store Program Memory

Description:

ESPM can be used to erase a page in the program memory, to write a page in the program memory (that is already erased), and to set boot loader lock bits. In some devices, the program memory can be written one word at a time, in other devices an entire page can be programmed simultaneously after first filling a temporary page buffer. In all cases, the program memory must be erased one page at a time. When erasing the program memory, the RAMPZ and Z registers are used as page address. When writing the program memory, the RAMPZ and Z registers are used as page or word address, and the R1:R0 register pair is used as data. When setting the boot loader lock bits, the R1:R0 register pair is used as data. Refer to the device documentation for detailed description of ESPM usage. This instruction can address the entire program memory.

	Operation:	Comment:
(i)	(RAMPZ:Z) ← $ffff	Erase program memory page
(ii)	(RAMPZ:Z) ← R1:R0	Write program memory word
(iii)	(RAMPZ:Z) ← R1:R0	Write temporary page buffer
(iv)	(RAMPZ:Z) ← TEMP	Write temporary page buffer to program memory
(v)	BLBITS ← R1:R0	Set boot loader lock bits

	Syntax:	Operands:	Program Counter:
(i)-(v)	ESPM	None	PC ← PC + 1

16-bit Opcode:

1001	0101	1111	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
; This example shows ESPM write of one word for devices with page write
clr   r31          ; Clear Z high byte
clr   r30          ; Clear Z low byte
ldi   r16,$F0      ; Load RAMPZ register
out   RAMPZ, r16   ;
ldi   r16, $CF     ; Load data to store
mov   r1, r16
ldi   r16, $FF
mov   r0, r16
ldi   r16,$03      ; Enable ESPM, erase page
out   SPMCR, r16   ;
espm               ; Erase page starting at $F00000
ldi   r16,$01      ; Enable ESPM, store R1:R0 to temporary buffer
out   SPMCR, r16   ;
espm               ; Execute ESPM, store R1:R0 to temporary buffer location $F00000
ldi   r16,$05      ; Enable ESPM, write page
out   SPMCR, r16   ;
espm               ; Execute SPM, store temporary buffer to program memory page starting at $F00000
```

Words: 1 (2 bytes)

Cycles: depends on the operation

FMUL - Fractional Multiply Unsigned

Description:

This instruction performs 8-bit × 8-bit → 16-bit unsigned multiplication and shifts the result one bit left.

Rd		Rr		R1	R0
Multiplicand	×	Multiplier	→	Product High	Product Low
8		8		16	

Let (N.Q) denote a fractional number with N binary digits left of the radix point, and Q binary digits right of the radix point. A multiplication between two numbers in the formats (N1.Q1) and (N2.Q2) results in the format ((N1+N2).(Q1+Q2)). For signal processing applications, the format (1.7) is widely used for the inputs, resulting in a (2.14) format for the product. A left shift is required for the high byte of the product to be in the same format as the inputs. The FMUL instruction incorporates the shift operation in the same number of cycles as MUL.

The multiplicand Rd and the multiplier Rr are two registers containing unsigned fractional numbers where the implicit radix point lies between bit 6 and bit 7. The 16-bit unsigned fractional product with the implicit radix point between bit 14 and bit 15 is placed in R1 (high byte) and R0 (low byte).

Operation:

(i) R1:R0 ← Rd × Rr (unsigned (1.15) ← unsigned (1.7) × unsigned (1.7))

	Syntax:	**Operands:**	**Program Counter:**
(i)	FMUL Rd,Rr	16 ≤ d ≤ 23, 16≤ r ≤ 23	PC ← PC + 1

16-bit Opcode:

0000	0011	0ddd	1rrr

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	⇔	⇔

C: R16

Set if bit 15 of the result before left shift is set; cleared otherwise.

Z: $\overline{R15} \bullet \overline{R14} \bullet \overline{R13} \bullet \overline{R12} \bullet \overline{R11} \bullet \overline{R10} \bullet \overline{R9} \bullet \overline{R8} \bullet \overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$

Set if the result is $0000; cleared otherwise.

R (Result) equals R1,R0 after the operation.

Example:

```
fmul  r23,r22   ; Multiply unsigned r23 and r22 in (1.7) format, result in (1.15) format
movw  r22,r0    ; Copy result back in r23:r22
```

Words: 1 (2 bytes)

Cycles: 2

FMULS - Fractional Multiply Signed

Description:

This instruction performs 8-bit × 8-bit → 16-bit signed multiplication and shifts the result one bit left.

Rd		Rr		R1	R0
Multiplicand	×	Multiplier	→	Product High	Product Low
8		8		16	

Let (N.Q) denote a fractional number with N binary digits left of the radix point, and Q binary digits right of the radix point. A multiplication between two numbers in the formats (N1.Q1) and (N2.Q2) results in the format ((N1+N2).(Q1+Q2)). For signal processing applications, the format (1.7) is widely used for the inputs, resulting in a (2.14) format for the product. A left shift is required for the high byte of the product to be in the same format as the inputs. The FMULS instruction incorporates the shift operation in the same number of cycles as MULS.

The multiplicand Rd and the multiplier Rr are two registers containing signed fractional numbers where the implicit radix point lies between bit 6 and bit 7. The 16-bit signed fractional product with the implicit radix point between bit 14 and bit 15 is placed in R1 (high byte) and R0 (low byte).

Operation:

(i) R1:R0 ← Rd × Rr (signed (1.15) ← signed (1.7) × signed (1.7))

	Syntax:	Operands:	Program Counter:
(i)	FMUL Rd,Rr	16 ≤ d ≤ 23, 16≤ r ≤ 23	PC ← PC + 1

16-bit Opcode:

0000	0011	1ddd	0rrr

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	⇔	⇔

C: R16

Set if bit 15 of the result before left shift is set; cleared otherwise.

Z: $\overline{R15} \bullet \overline{R14} \bullet \overline{R13} \bullet \overline{R12} \bullet \overline{R11} \bullet \overline{R10} \bullet \overline{R9} \bullet \overline{R8} \bullet \overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$

Set if the result is $0000; cleared otherwise.

R (Result) equals R1,R0 after the operation.

Example:

```
fmuls r23,r22   ; Multiply signed r23 and r22 in (1.7) format, result in (1.15) format
movw  r22,r0    ; Copy result back in r23:r22
```

Words: 1 (2 bytes)

Cycles: 2

FMULSU - Fractional Multiply Signed with Unsigned

Description:

This instruction performs 8-bit × 8-bit → 16-bit signed multiplication and shifts the result one bit left.

Rd		Rr		R1	R0
Multiplicand	×	Multiplier	→	Product High	Product Low
8		8		16	

Let (N.Q) denote a fractional number with N binary digits left of the radix point, and Q binary digits right of the radix point. A multiplication between two numbers in the formats (N1.Q1) and (N2.Q2) results in the format ((N1+N2).(Q1+Q2)). For signal processing applications, the format (1.7) is widely used for the inputs, resulting in a (2.14) format for the product. A left shift is required for the high byte of the product to be in the same format as the inputs. The FMULSU instruction incorporates the shift operation in the same number of cycles as MULSU.

The multiplicand Rd and the multiplier Rr are two registers containing fractional numbers where the implicit radix point lies between bit 6 and bit 7. The multiplicand Rd is a signed fractional number, and the multiplier Rr is an unsigned fractional number. The 16-bit signed fractional product with the implicit radix point between bit 14 and bit 15 is placed in R1 (high byte) and R0 (low byte).

Operation:

(i) R1:R0 ← Rd × Rr (signed (1.15) ← signed (1.7) × unsigned (1.7))

	Syntax:	Operands:	Program Counter:
(i)	FMULSU Rd,Rr	16 ≤ d ≤ 23, 16≤ r ≤ 23	PC ← PC + 1

16-bit Opcode:

0000	0011	1ddd	1rrr

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	⇔	⇔

C: R16

Set if bit 15 of the result before left shift is set; cleared otherwise.

Z: $\overline{R15} \bullet \overline{R14} \bullet \overline{R13} \bullet \overline{R12} \bullet \overline{R11} \bullet \overline{R10} \bullet \overline{R9} \bullet \overline{R8} \bullet \overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$

Set if the result is $0000; cleared otherwise.

R (Result) equals R1,R0 after the operation.

Example:

```
fmulSU  r23,r22 ; Multiply signed r23 with unsigned r22 in (1.7) format, signed result in (1.15) format
movw    r22,r0  ; Copy result back in r23:r22
```

Words: 1 (2 bytes)

Cycles: 2

ICALL - Indirect Call to Subroutine

Description:

Indirect call of a subroutine pointed to by the Z (16 bits) pointer register in the register file. The Z pointer register is 16 bits wide and allows call to a subroutine within the lowest 64K words (128K bytes) section in the program memory space. The stack pointer uses a post-decrement scheme during ICALL.

	Operation:	
(i)	PC(15:0) ← Z(15:0)	Devices with 16 bits PC, 128K bytes program memory maximum.
(ii)	PC(15:0) ← Z(15:0) PC(21:16) ← 0	Devices with 22 bits PC, 8M bytes program memory maximum.

	Syntax:	Operands:	Program Counter:	Stack:
(i)	ICALL	None	See Operation	STACK ← PC + 1 SP ← SP - 2 (2 bytes, 16 bits)
(ii)	ICALL	None	See Operation	STACK ← PC + 1 SP ← SP - 3 (3 bytes, 22 bits)

16-bit Opcode:

1001	0101	0000	1001

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
mov     r30,r0    ; Set offset to call table
icall             ; Call routine pointed to by r31:r30
```

Words: 1 (2 bytes)
Cycles: 3 devices with 16 bit PC
4 devices with 22 bit PC

IJMP - Indirect Jump

Description:

Indirect jump to the address pointed to by the Z (16 bits) pointer register in the register file. The Z pointer register is 16 bits wide and allows jump within the lowest 64K words (128K bytes) section of program memory.

	Operation:	
(i)	PC ← Z(15:0)	Devices with 16 bits PC, 128K bytes program memory maximum.
(ii)	PC(15:0) ← Z(15:0) PC(21:16) ← 0	Devices with 22 bits PC, 8M bytes program memory maximum.

	Syntax:	**Operands:**	**Program Counter:**	**Stack:**
(i),(ii)	IJMP	None	See Operation	Not Affected

16-bit Opcode:

1001	0100	0000	1001

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
mov     r30,r0    ; Set offset to jump table
ijmp              ; Jump to routine pointed to by r31:r30
```

Words: 1 (2 bytes)

Cycles: 2

IN - Load an I/O Location to Register

Description:

Loads data from the I/O Space (Ports, Timers, Configuration registers etc.) into register Rd in the register file.

Operation:

(i) Rd ← I/O(A)

	Syntax:	Operands:	Program Counter:
(i)	IN Rd,A	0 ≤ d ≤ 31, 0 ≤ A ≤ 63	PC ← PC + 1

16-bit Opcode:

1011	0AAd	dddd	AAAA

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
        in      r25,$16     ; Read Port B
        cpi     r25,4       ; Compare read value to constant
        breq    exit        ; Branch if r25=4
        ...
exit:   nop                 ; Branch destination (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1

INC - Increment

Description:

Adds one -1- to the contents of register Rd and places the result in the destination register Rd.

The C flag in SREG is not affected by the operation, thus allowing the INC instruction to be used on a loop counter in multiple-precision computations.

When operating on unsigned numbers, only BREQ and BRNE branches can be expected to perform consistently. When operating on two's complement values, all signed branches are available.

Operation:

(i) $Rd \leftarrow Rd + 1$

	Syntax:	Operands:	Program Counter:
(i)	INC Rd	$0 \le d \le 31$	$PC \leftarrow PC + 1$

16-bit Opcode:

1001	010d	dddd	0011

Status Register and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	⇔	⇔	⇔	⇔	-

S: $N \oplus V$
For signed tests.

V: $R7 \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if two's complement overflow resulted from the operation; cleared otherwise. Two's complement overflow occurs if and only if Rd was $7F before the operation.

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is $00; Cleared otherwise.

R (Result) equals Rd after the operation.

Example:

```
        clr    r22        ; clear r22
loop:   inc    r22        ; increment r22
        ...
        cpi    r22,$4F    ; Compare r22 to $4f
        brne   loop       ; Branch if not equal
        nop               ; Continue (do nothing)
```

Words: 1 (2 bytes)
Cycles: 1

JMP - Jump

Description:

Jump to an address within the entire 4M (words) program memory. See also RJMP.

	Operation:
(i)	PC ← k

	Syntax:	**Operands:**	**Program Counter:**	**Stack:**
(i)	JMP k	$0 \le k < 4M$	PC ← k	Unchanged

32-bit Opcode:

1001	010k	kkkk	110k
kkkk	kkkk	kkkk	kkkk

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
        mov     r1,r0     ; Copy r0 to r1
        jmp     farplc    ; Unconditional jump
        ...
farplc: nop               ; Jump destination (do nothing)
```

Words: 2 (4 bytes)

Cycles: 3

LD - Load Indirect from data space to Register using Index X

Description:

Loads one byte indirect from the data space to a register. For parts with SRAM, the data space consists of the register file, I/O memory and internal SRAM (and external SRAM if applicable). For parts without SRAM, the data space consists of the register file only. The EEPROM has a separate address space.

The data location is pointed to by the X (16 bits) pointer register in the register file. Memory access is limited to the current data segment of 64K bytes. To access another data segment in devices with more than 64K bytes data space, the RAMPX in register in the I/O area has to be changed.

The X pointer register can either be left unchanged by the operation, or it can be post-incremented or pre-decremented. These features are especially suited for accessing arrays, tables, and stack pointer usage of the X pointer register. Note that only the low byte of the X pointer is updated in devices with no more than 256 bytes data space. For such devices, the high byte of the pointer is not used by this instruction and can be used for other purposes. The RAMPX register in the I/O area is updated in parts with more than 64K bytes data space.

The result of these combinations is undefined:

LD r26, X+
LD r27, X+
LD r26, -X
LD r27, -X

Using the X pointer:

	Operation:		**Comment:**
(i)	Rd ← (X)		X: Unchanged
(ii)	Rd ← (X)	X ← X + 1	X: Post incremented
(iii)	X ← X - 1	Rd ← (X)	X: Pre decremented

	Syntax:	**Operands:**	**Program Counter:**
(i)	LD Rd, X	$0 \le d \le 31$	PC ← PC + 1
(ii)	LD Rd, X+	$0 \le d \le 31$	PC ← PC + 1
(iii)	LD Rd, -X	$0 \le d \le 31$	PC ← PC + 1

16-bit Opcode:

(i)	1001	000d	dddd	1100
(ii)	1001	000d	dddd	1101
(iii)	1001	000d	dddd	1110

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
clr   r27          ; Clear X high byte
ldi   r26,$60      ; Set X low byte to $60
ld    r0,X+        ; Load r0 with data space loc. $60(X post inc)
ld    r1,X         ; Load r1 with data space loc. $61
ldi   r26,$63      ; Set X low byte to $63
ld    r2,X         ; Load r2 with data space loc. $63
ld    r3,-X        ; Load r3 with data space loc. $62(X pre dec)
```

Words: 1 (2 bytes)

Cycles: 2

LD (LDD) - Load Indirect from data space to Register using Index Y

Description:

Loads one byte indirect with or without displacement from the data space to a register. For parts with SRAM, the data space consists of the register file, I/O memory and internal SRAM (and external SRAM if applicable). For parts without SRAM, the data space consists of the register file only. The EEPROM has a separate address space.

The data location is pointed to by the Y (16 bits) pointer register in the register file. Memory access is limited to the current data segment of 64K bytes. To access another data segment in devices with more than 64K bytes data space, the RAMPY in register in the I/O area has to be changed.

The Y pointer register can either be left unchanged by the operation, or it can be post-incremented or pre-decremented. These features are especially suited for accessing arrays, tables, and stack pointer usage of the Y pointer register. Note that only the low byte of the Y pointer is updated in devices with no more than 256 bytes data space. For such devices, the high byte of the pointer is not used by this instruction and can be used for other purposes. The RAMPY register in the I/O area is updated in parts with more than 64K bytes data space, and the displacement is added to the entire 24-bit address on such devices.

The result of these combinations is undefined:

LD r28, Y+
LD r29, Y+
LD r28, -Y
LD r29, -Y

Using the Y pointer:

	Operation:		**Comment:**
(i)	Rd ← (Y)		Y: Unchanged
(ii)	Rd ← (Y)	Y ← Y + 1	Y: Post incremented
(iii)	Y ← Y - 1	Rd ← (Y)	Y: Pre decremented
(iiii)	Rd ← (Y+q)		Y: Unchanged, q: Displacement

	Syntax:	**Operands:**	**Program Counter:**
(i)	LD Rd, Y	$0 \le d \le 31$	PC ← PC + 1
(ii)	LD Rd, Y+	$0 \le d \le 31$	PC ← PC + 1
(iii)	LD Rd, -Y	$0 \le d \le 31$	PC ← PC + 1
(iiii)	LDD Rd, Y+q	$0 \le d \le 31$, $0 \le q \le 63$	PC ← PC + 1

16-bit Opcode:

(i)	1000	000d	dddd	1000
(ii)	1001	000d	dddd	1001
(iii)	1001	000d	dddd	1010
(iiii)	10q0	qq0d	dddd	1qqq

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
clr   r29        ; Clear Y high byte
ldi   r28,$60    ; Set Y low byte to $60
ld    r0,Y+      ; Load r0 with data space loc. $60(Y post inc)
ld    r1,Y       ; Load r1 with data space loc. $61
ldi   r28,$63    ; Set Y low byte to $63
ld    r2,Y       ; Load r2 with data space loc. $63
ld    r3,-Y      ; Load r3 with data space loc. $62(Y pre dec)
ldd   r4,Y+2     ; Load r4 with data space loc. $64
```

Words: 1 (2 bytes)

Cycles: 2

LD (LDD) - Load Indirect From data space to Register using Index Z

Description:

Loads one byte indirect with or without displacement from the data space to a register. For parts with SRAM, the data space consists of the register file, I/O memory and internal SRAM (and external SRAM if applicable). For parts without SRAM, the data space consists of the register file only. The EEPROM has a separate address space.

The data location is pointed to by the Z (16 bits) pointer register in the register file. Memory access is limited to the current data segment of 64K bytes. To access another data segment in devices with more than 64K bytes data space, the RAMPZ in register in the I/O area has to be changed.

The Z pointer register can either be left unchanged by the operation, or it can be post-incremented or pre-decremented. These features are especially suited for stack pointer usage of the Z pointer register, however because the Z pointer register can be used for indirect subroutine calls, indirect jumps and table lookup, it is often more convenient to use the X or Y pointer as a dedicated stack pointer. Note that only the low byte of the Z pointer is updated in devices with no more than 256 bytes data space. For such devices, the high byte of the pointer is not used by this instruction and can be used for other purposes. The RAMPZ register in the I/O area is updated in parts with more than 64K bytes data space, and that the displacement is added to the entire 24-bit address on such devices. For devices with more than 64K bytes program memory and up to 64K bytes data memory, the RAMPZ register is only used by the ELPM and ESPM instructions. Hence, RAMPZ is not affected by the ST instruction.

For using the Z pointer for table lookup in program memory see the LPM and ELPM instructions.

The result of these combinations is undefined:

LD r30, Z+
LD r31, Z+
LD r30, -Z
LD r31, -Z

Using the Z pointer:

	Operation:	Comment:	
(i)	Rd $\leftarrow$ (Z)		Z: Unchanged
(ii)	Rd $\leftarrow$ (Z)	Z $\leftarrow$ Z + 1	Z: Post increment
(iii)	Z $\leftarrow$ Z -1	Rd $\leftarrow$ (Z)	Z: Pre decrement
(iiii)	Rd $\leftarrow$ (Z+q)		Z: Unchanged, q: Displacement

	Syntax:	Operands:	Program Counter:
(i)	LD Rd, Z	$0 \le d \le 31$	PC $\leftarrow$ PC + 1
(ii)	LD Rd, Z+	$0 \le d \le 31$	PC $\leftarrow$ PC + 1
(iii)	LD Rd, -Z	$0 \le d \le 31$	PC $\leftarrow$ PC + 1
(iiii)	LDD Rd, Z+q	$0 \le d \le 31$, $0 \le q \le 63$	PC $\leftarrow$ PC + 1

16-bit Opcode:

(i)	1000	000d	dddd	0000
(ii)	1001	000d	dddd	0001
(iii)	1001	000d	dddd	0010
(iiii)	10q0	qq0d	dddd	0qqq

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
clr   r31      ; Clear Z high byte
ldi   r30,$60  ; Set Z low byte to $60
ld    r0,Z+    ; Load r0 with data space loc. $60(Z post inc)
ld    r1,Z     ; Load r1 with data space loc. $61
ldi   r30,$63  ; Set Z low byte to $63
ld    r2,Z     ; Load r2 with data space loc. $63
ld    r3,-Z    ; Load r3 with data space loc. $62(Z pre dec)
ldd   r4,Z+2   ; Load r4 with data space loc. $64
```

Words: 1 (2 bytes)
Cycles: 2

LDI - Load Immediate

Description:

Loads an 8 bit constant directly to register 16 to 31.

Operation:

(i) Rd ← K

	Syntax:	Operands:	Program Counter:
(i)	LDI Rd,K	16 ≤ d ≤ 31, 0 ≤ K ≤ 255	PC ← PC + 1

16-bit Opcode:

1110	KKKK	dddd	KKKK

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
clr   r31       ; Clear Z high byte
ldi   r30,$F0   ; Set Z low byte to $F0
lpm             ; Load constant from program
                ; memory pointed to by Z
```

Words: 1 (2 bytes)

Cycles: 1

LDS - Load Direct from data space

Description:

Loads one byte from the data space to a register. For parts with SRAM, the data space consists of the register file, I/O memory and internal SRAM (and external SRAM if applicable). For parts without SRAM, the data space consists of the register file only. The EEPROM has a separate address space.

A 16-bit address must be supplied. Memory access is limited to the current data segment of 64K bytes. The LDS instruction uses the RAMPD register to access memory above 64K bytes. To access another data segment in devices with more than 64K bytes data space, the RAMPD in register in the I/O area has to be changed.

Operation:

(i) Rd ← (k)

	Syntax:	Operands:	Program Counter:
(i)	LDS Rd,k	$0 \leq d \leq 31$, $0 \leq k \leq 65535$	PC ← PC + 2

32-bit Opcode:

1001	000d	dddd	0000
kkkk	kkkk	kkkk	kkkk

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
lds   r2,$FF00     ; Load r2 with the contents of data space location $FF00
add   r2,r1        ; add r1 to r2
sts   $FF00,r2     ; Write back
```

Words: 2 (4 bytes)

Cycles: 2

LPM - Load Program Memory

Description:

Loads one byte pointed to by the Z register into the destination register Rd. This instruction features a 100% space effective constant initialization or constant data fetch. The program memory is organized in 16 bit words and the least significant bit of the Z pointer selects either low byte (0) or high byte (1). This instruction can address the first 64K bytes (32K words) of program memory. The Z pointer register can either be left unchanged by the operation, or it can be incremented. The incrementation does not apply to the RAMPZ register.

The result of these combinations is undefined:

LPM r30, Z+
LPM r31, Z+

	Operation:		**Comment:**
(i)	R0 ← (Z)		Z: Unchanged, R0 implied destination register
(ii)	Rd ← (Z)		Z: Unchanged
(iii)	Rd ← (Z)	Z ← Z + 1	Z: Post incremented

	Syntax:	**Operands:**	**Program Counter:**
(i)	LPM	None, R0 implied	PC ← PC + 1
(ii)	LPM Rd, Z	0 ≤ d ≤ 31	PC ← PC + 1
(iii)	LPM Rd, Z+	0 ≤ d ≤ 31	PC ← PC + 1

16-bit Opcode:

(i)	1001	0101	1100	1000
(ii)	1001	000d	dddd	0100
(iii)	1001	000d	dddd	0101

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
clr   r31          ; Clear Z high byte
ldi   r30,$F0      ; Set Z low byte
lpm                ; Load constant from program
                   ; memory pointed to by Z (r31:r30)
```

Words: 1 (2 bytes)

Cycles: 3

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)

←

C ← b7 - - - - - - - - - - - - - - - - - - b0 ← 0

	Syntax:	Operands:	Program Counter:
(i)	LSL Rd	$0 \le d \le 31$	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
-	-	⇔	⇔	⇔	⇔	⇔	⇔

H: Rd3

S: $N \oplus V$, For signed tests.

V: $N \oplus C$ (For N and C after the shift)

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is $00; cleared otherwise.

C: Rd7
Set if, before the shift, the MSB of Rd was set; cleared otherwise.

R (Result) equals Rd after the operation.

Example:

```
add    r0,r4    ; Add r4 to r0
lsl    r0       ; Multiply r0 by 2
```

Words: 1 (2 bytes)
Cycles: 1

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:

→

0 → | b7 - - - - - - - - - - - - - - - - - - b0 | → | C |

	Syntax:	**Operands:**	**Program Counter:**
(i)	LSR Rd	$0 \le d \le 31$	$PC \leftarrow PC + 1$

16-bit Opcode:

1001	010d	dddd	0110

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	⇔	⇔	0	⇔	⇔

S: $N \oplus V$, For signed tests.

V: $N \oplus C$ (For N and C after the shift)

N: 0

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is $00; cleared otherwise.

C: Rd0
Set if, before the shift, the LSB of Rd was set; cleared otherwise.

R (Result) equals Rd after the operation.

Example:

```
add     r0,r4     ; Add r4 to r0
lsr     r0        ; Divide r0 by 2
```

Words: 1 (2 bytes)
Cycles: 1

MOV - Copy Register

Description:

This instruction makes a copy of one register into another. The source register Rr is left unchanged, while the destination register Rd is loaded with a copy of Rr.

	Operation:
(i)	Rd ← Rr

	Syntax:	Operands:	Program Counter:
(i)	MOV Rd,Rr	$0 \le d \le 31$, $0 \le r \le 31$	PC ← PC + 1

16-bit Opcode:

0010	11rd	dddd	rrrr

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
        mov     r16,r0    ; Copy r0 to r16
        call    check     ; Call subroutine
        ...
check:  cpi     r16,$11   ; Compare r16 to $11
        ...
        ret               ; Return from subroutine
```

Words: 1 (2 bytes)

Cycles: 1

MOVW - Copy Register Word

Description:

This instruction makes a copy of one register pair into another register pair. The source register pair Rr+1:Rr is left unchanged, while the destination register pair Rd+1:Rd is loaded with a copy of Rr + 1:Rr.

Operation:

(i) Rd+1:Rd ← Rr+1:Rr

	Syntax:	Operands:	Program Counter:
(i)	MOVW Rd,Rr	d ∈ {0,2,...,30}, r ∈ {0,2,...,30}	PC ← PC + 1

16-bit Opcode:

0000	0001	dddd	rrrr

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
        movw    r16,r0     ; Copy r1:r0 to r17:r16
        call    check      ; Call subroutine
        ...
check:  cpi     r16,$11    ; Compare r16 to $11
        ...
        cpi     r17,$32    ; Compare r17 to $32
        ...
        ret                ; Return from subroutine
```

Words: 1 (2 bytes)

Cycles: 1

MUL - Multiply Unsigned

Description:

This instruction performs 8-bit × 8-bit → 16-bit unsigned multiplication.

Rd		Rr		R1	R0
Multiplicand	×	Multiplier	→	Product High	Product Low
8		8		16	

The multiplicand Rd and the multiplier Rr are two registers containing unsigned numbers. The 16-bit unsigned product is placed in R1 (high byte) and R0 (low byte). Note that if the multiplicand or the multiplier is selected from R0 or R1 the result will overwrite those after multiplication.

Operation:

(i) R1:R0 ← Rd × Rr (unsigned ← unsigned × unsigned)

	Syntax:	**Operands:**	**Program Counter:**
(i)	MUL Rd,Rr	$0 \le d \le 31$, $0 \le r \le 31$	PC ← PC + 1

16-bit Opcode:

1001	11rd	dddd	rrrr

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	⇔	⇔

C: R15
Set if bit 15 of the result is set; cleared otherwise.

Z: $\overline{R15} \bullet \overline{R14} \bullet \overline{R13} \bullet \overline{R12} \bullet \overline{R11} \bullet \overline{R10} \bullet \overline{R9} \bullet \overline{R8} \bullet \overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is $0000; cleared otherwise.

R (Result) equals R1,R0 after the operation.

Example:

```
    mul   r5,r4     ; Multiply unsigned r5 and r4
    movw  r4,r0     ; Copy result back in r5:r4
```

Words: 1 (2 bytes)
Cycles: 2

MULS - Multiply Signed

Description:

This instruction performs 8-bit $\times$ 8-bit $\rightarrow$ 16-bit signed multiplication.

Rd		Rr		R1	R0
Multiplicand	$\times$	Multiplier	$\rightarrow$	Product High	Product Low
8		8		16	

The multiplicand Rd and the multiplier Rr are two registers containing signed numbers. The 16-bit signed product is placed in R1 (high byte) and R0 (low byte).

Operation:

(i) R1:R0 $\leftarrow$ Rd $\times$ Rr (signed $\leftarrow$ signed $\times$ signed)

	Syntax:	Operands:	Program Counter:
(i)	MULS Rd,Rr	$16 \le d \le 31$, $16 \le r \le 31$	PC $\leftarrow$ PC + 1

16-bit Opcode:

0000	0010	dddd	rrrr

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	⇔	⇔

C: R15
Set if bit 15 of the result is set; cleared otherwise.

Z: $\overline{R15} \bullet \overline{R14} \bullet \overline{R13} \bullet \overline{R12} \bullet \overline{R11} \bullet \overline{R10} \bullet \overline{R9} \bullet \overline{R8} \bullet \overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is $0000; cleared otherwise.

R (Result) equals R1,R0 after the operation.

Example:

```
muls  r21,r20   ; Multiply signed r21 and r20
movw  r20,r0    ; Copy result back in r21:r20
```

Words: 1 (2 bytes)
Cycles: 2

MULSU - Multiply Signed with Unsigned

Description:

This instruction performs 8-bit × 8-bit → 16-bit multiplication of a signed and an unsigned number.

Rd		Rr		R1	R0
Multiplicand	×	Multiplier	→	Product High	Product Low
8		8		16	

The multiplicand Rd and the multiplier Rr are two registers. The multiplicand Rd is a signed number, and the multiplier Rr is unsigned. The 16-bit signed product is placed in R1 (high byte) and R0 (low byte).

Operation:

(i) R1:R0 ← Rd × Rr (signed ← signed × unsigned)

	Syntax:	**Operands:**	**Program Counter:**
(i)	MULSU Rd,Rr	16 ≤ d ≤ 23, 16 ≤ r ≤ 23	PC ← PC + 1

16-bit Opcode:

0000	0011	0ddd	0rrr

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	⇔	⇔

C: R15
Set if bit 15 of the result is set; cleared otherwise.

Z: $\overline{R15} \bullet \overline{R14} \bullet \overline{R13} \bullet \overline{R12} \bullet \overline{R11} \bullet \overline{R10} \bullet \overline{R9} \bullet \overline{R8} \bullet \overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is $0000; cleared otherwise.

R (Result) equals R1,R0 after the operation.

Example:

```
mulsu r21,r20   ; Multiply signed r21 with unsigned r20, signed result
movw  r20,r0    ; Copy result back in r21:r20
```

Words: 1 (2 bytes)
Cycles: 2

NEG - Two's Complement

Description:

Replaces the contents of register Rd with its two's complement; the value $80 is left unchanged.

Operation:

(i) Rd ← $00 - Rd

	Syntax:	Operands:	Program Counter:
(i)	NEG Rd	$0 \le d \le 31$	PC ← PC + 1

16-bit Opcode:

1001	010d	dddd	0001

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	⇔	⇔	⇔	⇔	⇔	⇔

H: R3 + Rd3
Set if there was a borrow from bit 3; cleared otherwise

S: $N \oplus V$
For signed tests.

V: $R7 \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if there is a two's complement overflow from the implied subtraction from zero; cleared otherwise. A two's complement overflow will occur if and only if the contents of the Register after operation (Result) is $80.

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is $00; Cleared otherwise.

C: R7 + R6 + R5 + R4 + R3 + R2 + R1 + R0
Set if there is a borrow in the implied subtraction from zero; cleared otherwise. The C flag will be set in all cases except when the contents of Register after operation is $00.

R (Result) equals Rd after the operation.

Example:

```
           sub   r11,r0       ; Subtract r0 from r11
           brpl  positive     ; Branch if result positive
           neg   r11          ; Take two's complement of r11
positive:  nop                ; Branch destination (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1

NOP - No Operation

Description:

This instruction performs a single cycle No Operation.

	Operation:
(i)	No

	Syntax:	**Operands:**	**Program Counter:**
(i)	NOP	None	PC ← PC + 1

16-bit Opcode:

0000	0000	0000	0000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
clr     r16       ; Clear r16
ser     r17       ; Set r17
out     $18,r16   ; Write zeros to Port B
nop               ; Wait (do nothing)
out     $18,r17   ; Write ones to Port B
```

Words: 1 (2 bytes)

Cycles: 1

OR - Logical OR

Description:

Performs the logical OR between the contents of register Rd and register Rr and places the result in the destination register Rd.

Operation:

(i) Rd ← Rd v Rr

	Syntax:	Operands:	Program Counter:
(i)	OR Rd,Rr	$0 \le d \le 31$, $0 \le r \le 31$	PC ← PC + 1

16-bit Opcode:

0010	10rd	dddd	rrrr

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	⇔	0	⇔	⇔	-

S: $N \oplus V$, For signed tests.

V: 0
Cleared

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is $00; cleared otherwise.

R (Result) equals Rd after the operation.

Example:

```
        or      r15,r16     ; Do bitwise or between registers
        bst     r15,6       ; Store bit 6 of r15 in T flag
        brts    ok          ; Branch if T flag set
        ...
ok:     nop                 ; Branch destination (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1

ORI - Logical OR with Immediate

Description:

Performs the logical OR between the contents of register Rd and a constant and places the result in the destination register Rd.

Operation:

(i) $Rd \leftarrow Rd \vee K$

	Syntax:	Operands:	Program Counter:
(i)	ORI Rd,K	$16 \leq d \leq 31, 0 \leq K \leq 255$	$PC \leftarrow PC + 1$

16-bit Opcode:

0110	KKKK	dddd	KKKK

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	⇔	0	⇔	⇔	-

S: $N \oplus V$, For signed tests.

V: 0
Cleared

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is \$00; cleared otherwise.

R (Result) equals Rd after the operation.

Example:

```
ori     r16,$F0   ; Set high nibble of r16
ori     r17,1     ; Set bit 0 of r17
```

Words: 1 (2 bytes)
Cycles: 1

OUT - Store Register to I/O Location

Description:

Stores data from register Rr in the register file to I/O Space (Ports, Timers, Configuration registers etc.).

	Operation:
(i)	I/O(A) ← Rr

	Syntax:	**Operands:**	**Program Counter:**
(i)	OUT A,Rr	$0 \le r \le 31$, $0 \le A \le 63$	PC ← PC + 1

16-bit Opcode:

1011	1AAr	rrrr	AAAA

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
clr  r16        ; Clear r16
ser  r17        ; Set r17
out  $18,r16    ; Write zeros to Port B
nop             ; Wait (do nothing)
out  $18,r17    ; Write ones to Port B
```

Words: 1 (2 bytes)

Cycles: 1

POP - Pop Register from Stack

Description:

This instruction loads register Rd with a byte from the STACK. The stack pointer is pre-incremented by 1 before the POP.

Operation:

(i) Rd ← STACK

	Syntax:	Operands:	Program Counter:	Stack:
(i)	POP Rd	$0 \le d \le 31$	PC ← PC + 1	SP ← SP + 1

16-bit Opcode:

1001	000d	dddd	1111

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
            call    routine   ; Call subroutine
            ...
routine:    push    r14       ; Save r14 on the stack
            push    r13       ; Save r13 on the stack
            ...
            pop     r13       ; Restore r13
            pop     r14       ; Restore r14
            ret               ; Return from subroutine
```

Words: 1 (2 bytes)

Cycles: 2

PUSH - Push Register on Stack

Description:

This instruction stores the contents of register Rr on the STACK. The stack pointer is post-decremented by 1 after the PUSH.

Operation:

(i) STACK $\leftarrow$ Rr

	Syntax:	Operands:	Program Counter:	Stack:
(i)	PUSH Rr	$0 \leq r \leq 31$	PC $\leftarrow$ PC + 1	SP $\leftarrow$ SP - 1

16-bit Opcode:

1001	001d	dddd	1111

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
            call    routine ; Call subroutine
            ...
routine:    push    r14     ; Save r14 on the stack
            push    r13     ; Save r13 on the stack
            ...
            pop     r13     ; Restore r13
            pop     r14     ; Restore r14
            ret             ; Return from subroutine
```

Words: 1 (2 bytes)

Cycles: 2

RCALL - Relative Call to Subroutine

Description:

Relative call to an address within PC - 2K + 1 and PC + 2K (words). The return address (the instruction after the RCALL) is stored onto the stack. (See also CALL). In the assembler, labels are used instead of relative operands. For AVR microcontrollers with program memory not exceeding 4K words (8K bytes) this instruction can address the entire memory from every address location. The stack pointer uses a post-decrement scheme during RCALL.

	Operation:	
(i)	PC ← PC + k + 1	Devices with 16 bits PC, 128K bytes program memory maximum.
(ii)	PC ← PC + k + 1	Devices with 22 bits PC, 8M bytes program memory maximum.

	Syntax:	Operands:	Program Counter:	Stack:
(i)	RCALL k	-2K ≤ k < 2K	PC ← PC + k + 1	STACK ← PC + 1 SP ← SP - 2 (2 bytes, 16 bits)
(ii)	RCALL k	-2K ≤ k < 2K	PC ← PC + k + 1	STACK ← PC + 1 SP ← SP - 3 (3 bytes, 22 bits)

16-bit Opcode:

1101	kkkk	kkkk	kkkk

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
            rcall   routine     ; Call subroutine
            ...
routine:    push    r14         ; Save r14 on the stack
            ...
            pop     r14         ; Restore r14
            ret                 ; Return from subroutine
```

Words: 1 (2 bytes)

Cycles: 3 devices with 16-bit PC
4 devices with 22-bit PC

RET - Return from Subroutine

Description:

Returns from subroutine. The return address is loaded from the STACK. The stack pointer uses a pre-increment scheme during RET.

	Operation:	
(i)	PC(15:0) ← STACK	Devices with 16 bits PC, 128K bytes program memory maximum.
(ii)	PC(21:0) ← STACK	Devices with 22 bits PC, 8M bytes program memory maximum.

	Syntax:	**Operands:**	**Program Counter:**	**Stack:**
(i)	RET	None	See Operation	SP←SP + 2, (2bytes,16 bits)
(ii)	RET	None	See Operation	SP←SP + 3, (3bytes,22 bits)

16-bit Opcode:

1001	0101	0000	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
               call    routine    ; Call subroutine
               ...
    routine:   push    r14        ; Save r14 on the stack
               ...
               pop     r14        ; Restore r14
               ret                ; Return from subroutine
```

Words: 1 (2 bytes)

Cycles: 4 devices with 16-bit PC
5 devices with 22-bit PC

RETI - Return from Interrupt

Description:

Returns from interrupt. The return address is loaded from the STACK and the global interrupt flag is set.

Note that the status register is not automatically stored when entering an interrupt routine, and it is not restored when returning from an interrupt routine. This must be handled by the application program. The stack pointer uses a pre-increment scheme during RETI.

	Operation:	
(i)	PC(15:0) ← STACK	Devices with 16 bits PC, 128K bytes program memory maximum.
(ii)	PC(21:0) ← STACK	Devices with 22 bits PC, 8M bytes program memory maximum.

	Syntax:	**Operands:**	**Program Counter:**	**Stack**
(i)	RETI	None	See Operation	SP ← SP + 2 (2 bytes, 16 bits)
(ii)	RETI	None	See Operation	SP ← SP + 3 (3 bytes, 22 bits)

16-bit Opcode:

1001	0101	0001	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
1	-	-	-	-	-	-	-

I: 1
The I flag is set.

Example:

```
            ...
extint:     push    r0      ; Save r0 on the stack
            ...
            pop     r0      ; Restore r0
            reti            ; Return and enable interrupts
```

Words: 1 (2 bytes)

Cycles: 4 devices with 16-bit PC
5 devices with 22-bit PC

RJMP - Relative Jump

Description:

Relative jump to an address within PC - 2K +1 and PC + 2K (words). In the assembler, labels are used instead of relative operands. For AVR microcontrollers with program memory not exceeding 4K words (8K bytes) this instruction can address the entire memory from every address location.

Operation:

(i) $PC \leftarrow PC + k + 1$

	Syntax:	Operands:	Program Counter:	Stack
(i)	RJMP k	$-2K \leq k < 2K$	$PC \leftarrow PC + k + 1$	Unchanged

16-bit Opcode:

1100	kkkk	kkkk	kkkk

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
         cpi     r16,$42   ; Compare r16 to $42
         brne    error     ; Branch if r16 <> $42
         rjmp    ok        ; Unconditional branch
error:   add     r16,r17   ; Add r17 to r16
         inc     r16       ; Increment r16
ok:      nop               ; Destination for rjmp (do nothing)
```

Words: 1 (2 bytes)

Cycles: 2

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:

←

C ¨ b7 - - - - - - - - - - - - - - - - - - b0 ← C

	Syntax:	**Operands:**	**Program Counter:**
(i)	ROL Rd	$0 \leq d \leq 31$	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
-	-	⇔	⇔	⇔	⇔	⇔	⇔

H: Rd3

S: $N \oplus V$, For signed tests.

V: $N \oplus C$ (For N and C after the shift)

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is $00; cleared otherwise.

C: Rd7
Set if, before the shift, the MSB of Rd was set; cleared otherwise.

R (Result) equals Rd after the operation.

Example:

```
          lsl   r18         ; Multiply r19:r18 by two
          rol   r19         ; r19:r18 is a signed or unsigned two-byte integer
          brcs  oneenc      ; Branch if carry set
          ...
oneenc:   nop               ; Branch destination (do nothing)
```

Words: 1 (2 bytes)
Cycles: 1

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:

→

C → b7 - - - - - - - - - - - - - - - - - - b0 → C

	Syntax:	**Operands:**	**Program Counter:**
(i)	ROR Rd	$0 \le d \le 31$	$PC \leftarrow PC + 1$

16-bit Opcode:

1001	010d	dddd	0111

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	⇔	⇔	⇔	⇔	⇔

S: $N \oplus V$, For signed tests.

V: $N \oplus C$ (For N and C after the shift)

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is \$00; cleared otherwise.

C: Rd0
Set if, before the shift, the LSB of Rd was set; cleared otherwise.

R (Result) equals Rd after the operation.

Example:

```
            lsr   r19           ; Divide r19:r18 by two
            ror   r18           ; r19:r18 is an unsigned two-byte integer
            brcc  zeroenc1      ; Branch if carry cleared
            asr   r17           ; Divide r17:r16 by two
            ror   r16           ; r17:r16 is a signed two-byte integer
            brcc  zeroenc2      ; Branch if carry cleared
            ...
zeroenc1:   nop                 ; Branch destination (do nothing)
            ...
zeroenc1:   nop                 ; Branch destination (do nothing)
```

Words: 1 (2 bytes)
Cycles: 1

SBC - Subtract with Carry

Description:

Subtracts two registers and subtracts with the C flag and places the result in the destination register Rd.

Operation:

(i) $Rd \leftarrow Rd - Rr - C$

	Syntax:	Operands:	Program Counter:
(i)	SBC Rd,Rr	$0 \le d \le 31, 0 \le r \le 31$	$PC \leftarrow PC + 1$

16-bit Opcode:

0000	10rd	dddd	rrrr

Status Register and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	⇔	⇔	⇔	⇔	⇔	⇔

H: $\overline{Rd3} \bullet Rr3 + Rr3 \bullet R3 + R3 \bullet \overline{Rd3}$
Set if there was a borrow from bit 3; cleared otherwise

S: $N \oplus V$, For signed tests.

V: $Rd7 \bullet \overline{Rr7} \bullet \overline{R7} + \overline{Rd7} \bullet Rr7 \bullet R7$
Set if two's complement overflow resulted from the operation; cleared otherwise.

N: $R7$
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0} \bullet Z$
Previous value remains unchanged when the result is zero; cleared otherwise.

C: $\overline{Rd7} \bullet Rr7 + Rr7 \bullet R7 + R7 \bullet \overline{Rd7}$
Set if the absolute value of the contents of Rr plus previous carry is larger than the absolute value of the Rd; cleared otherwise.

R (Result) equals Rd after the operation.

Example:

```
                        ; Subtract r1:r0 from r3:r2
        sub     r2,r0   ; Subtract low byte
        sbc     r3,r1   ; Subtract with carry high byte
```

Words: 1 (2 bytes)
Cycles: 1

SBCI - Subtract Immediate with Carry

Description:

Subtracts a constant from a register and subtracts with the C flag and places the result in the destination register Rd.

	Operation:
(i)	Rd ← Rd - K - C

	Syntax:	**Operands:**	**Program Counter:**
(i)	SBCI Rd,K	16 ≤ d ≤ 31, 0 ≤ K ≤ 255	PC ← PC + 1

16-bit Opcode:

0100	KKKK	dddd	KKKK

Status Register and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	⇔	⇔	⇔	⇔	⇔	⇔

H: $\overline{Rd3} \bullet K3 + K3 \bullet R3 + R3 \bullet \overline{Rd3}$
Set if there was a borrow from bit 3; cleared otherwise

S: N ⊕ V, For signed tests.

V: $Rd7 \bullet \overline{K7} \bullet \overline{R7} + \overline{Rd7} \bullet K7 \bullet R7$
Set if two’s complement overflow resulted from the operation; cleared otherwise.

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0} \bullet Z$
Previous value remains unchanged when the result is zero; cleared otherwise.

C: $\overline{Rd7} \bullet K7 + K7 \bullet R7 + R7 \bullet \overline{Rd7}$
Set if the absolute value of the constant plus previous carry is larger than the absolute value of Rd; cleared otherwise.

R (Result) equals Rd after the operation.

Example:

```
                    ; Subtract $4F23 from r17:r16
     subi  r16,$23  ; Subtract low byte
     sbci  r17,$4F  ; Subtract with carry high byte
```

Words: 1 (2 bytes)
Cycles: 1

SBI - Set Bit in I/O Register

Description:

Sets a specified bit in an I/O register. This instruction operates on the lower 32 I/O registers - addresses 0-31.

Operation:

(i) I/O(A,b) ← 1

	Syntax:	Operands:	Program Counter:
(i)	SBI A,b	$0 \leq A \leq 31, 0 \leq b \leq 7$	PC ← PC + 1

16-bit Opcode:

1001	1010	AAAA	Abbb

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
out   $1E,r0    ; Write EEPROM address
sbi   $1C,0     ; Set read bit in EECR
in    r1,$1D    ; Read EEPROM data
```

Words: 1 (2 bytes)

Cycles: 2

SBIC - Skip if Bit in I/O Register is Cleared

Description:

This instruction tests a single bit in an I/O register and skips the next instruction if the bit is cleared. This instruction operates on the lower 32 I/O registers - addresses 0-31.

Operation:

(i) If I/O(A,b) = 0 then PC ← PC + 2 (or 3) else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	SBIC A,b	$0 \le A \le 31$, $0 \le b \le 7$	PC ← PC + 1, Condition false - no skip PC ← PC + 2, Skip a one word instruction PC ← PC + 3, Skip a two word instruction

16-bit Opcode:

1001	1001	AAAA	Abbb

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
e2wait:  sbic  $1C,1       ; Skip next inst. if EEWE cleared
         rjmp  e2wait      ; EEPROM write not finished
         nop               ; Continue (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false (no skip)
2 if condition is true (skip is executed) and the instruction skipped is 1 word
3 if condition is true (skip is executed) and the instruction skipped is 2 words

SBIS - Skip if Bit in I/O Register is Set

Description:

This instruction tests a single bit in an I/O register and skips the next instruction if the bit is set. This instruction operates on the lower 32 I/O registers - addresses 0-31.

Operation:

(i) If I/O(A,b) = 1 then PC ← PC + 2 (or 3) else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	SBIS A,b	$0 \leq A \leq 31$, $0 \leq b \leq 7$	PC ← PC + 1, Condition false - no skip PC ← PC + 2, Skip a one word instruction PC ← PC + 3, Skip a two word instruction

16-bit Opcode:

1001	1011	AAAA	Abbb

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
waitset: sbis  $10,0      ; Skip next inst. if bit 0 in Port D set
         rjmp  waitset    ; Bit not set
         nop              ; Continue (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false (no skip)
2 if condition is true (skip is executed) and the instruction skipped is 1 word
3 if condition is true (skip is executed) and the instruction skipped is 2 words

SBIW - Subtract Immediate from Word

Description:

Subtracts an immediate value (0-63) from 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.

Operation:

(i) Rd+1:Rd ← Rd+1:Rd - K

	Syntax:	Operands:	Program Counter:
(i)	SBIW Rd,K	$d \in \{24,26,28,30\}$, $0 \le K \le 63$	PC ← PC + 1

16-bit Opcode:

1001	0111	KKdd	KKKK

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	⇔	⇔	⇔	⇔	⇔

S: $N \oplus V$, For signed tests.

V: $Rdh7 \bullet \overline{R15}$
Set if two's complement overflow resulted from the operation; cleared otherwise.

N: R15
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R15} \bullet \overline{R14} \bullet \overline{R13} \bullet \overline{R12} \bullet \overline{R11} \bullet \overline{R10} \bullet \overline{R9} \bullet \overline{R8} \bullet \overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is $0000; cleared otherwise.

C: $R15 \bullet \overline{Rdh7}$
Set if the absolute value of K is larger than the absolute value of Rd; cleared otherwise.

R (Result) equals Rdh:Rdl after the operation (Rdh7-Rdh0 = R15-R8, Rdl7-Rdl0=R7-R0).

Example:

```
sbiw   r24,1      ; Subtract 1 from r25:r24
sbiw   r28,63     ; Subtract 63 from the Y pointer(r29:r28)
```

Words: 1 (2 bytes)
Cycles: 2

SBR - Set Bits in Register

Description:

Sets specified bits in register Rd. Performs the logical ORI between the contents of register Rd and a constant mask K and places the result in the destination register Rd.

Operation:

(i) Rd ← Rd v K

	Syntax:	Operands:	Program Counter:
(i)	SBR Rd,K	$16 \le d \le 31$, $0 \le K \le 255$	PC ← PC + 1

16-bit Opcode:

0110	KKKK	dddd	KKKK

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	⇔	0	⇔	⇔	-

S: $N \oplus V$, For signed tests.

V: 0
Cleared

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is \$00; cleared otherwise.

R (Result) equals Rd after the operation.

Example:

```
sbr   r16,3     ; Set bits 0 and 1 in r16
sbr   r17,$F0   ; Set 4 MSB in r17
```

Words: 1 (2 bytes)
Cycles: 1

SBRC - Skip if Bit in Register is Cleared

Description:

This instruction tests a single bit in a register and skips the next instruction if the bit is cleared.

Operation:

(i) If Rr(b) = 0 then PC ← PC + 2 (or 3) else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	SBRC Rr,b	$0 \le r \le 31$, $0 \le b \le 7$	PC ← PC + 1, Condition false - no skip PC ← PC + 2, Skip a one word instruction PC ← PC + 3, Skip a two word instruction

16-bit Opcode:

1111	110r	rrrr	0bbb

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
sub   r0,r1     ; Subtract r1 from r0
sbrc  r0,7      ; Skip if bit 7 in r0 cleared
sub   r0,r1     ; Only executed if bit 7 in r0 not cleared
nop             ; Continue (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false (no skip)
2 if condition is true (skip is executed) and the instruction skipped is 1 word
3 if condition is true (skip is executed) and the instruction skipped is 2 words

SBRS - Skip if Bit in Register is Set

Description:

This instruction tests a single bit in a register and skips the next instruction if the bit is set.

Operation:

(i) If Rr(b) = 1 then PC ← PC + 2 (or 3) else PC ← PC + 1

	Syntax:	Operands:	Program Counter:
(i)	SBRS Rr,b	$0 \le r \le 31$, $0 \le b \le 7$	PC ← PC + 1, Condition false - no skip PC ← PC + 2, Skip a one word instruction PC ← PC + 3, Skip a two word instruction

16-bit Opcode:

1111	111r	rrrr	0bbb

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
sub     r0,r1   ; Subtract r1 from r0
sbrs    r0,7    ; Skip if bit 7 in r0 set
neg     r0      ; Only executed if bit 7 in r0 not set
nop             ; Continue (do nothing)
```

Words: 1 (2 bytes)

Cycles: 1 if condition is false (no skip)
2 if condition is true (skip is executed) and the instruction skipped is 1 word
3 if condition is true (skip is executed) and the instruction skipped is 2 words

SEC - Set Carry Flag

Description:

Sets the Carry flag (C) in SREG (status register).

Operation:

(i) C ← 1

	Syntax:	Operands:	Program Counter:
(i)	SEC	None	PC ← PC + 1

16-bit Opcode:

1001	0100	0000	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	1

C: 1
Carry flag set

Example:

```
sec             ; Set carry flag
adc     r0,r1   ; r0=r0+r1+1
```

Words: 1 (2 bytes)
Cycles: 1

SEH - Set Half Carry Flag

Description:

Sets the Half Carry (H) in SREG (status register).

Operation:

(i) H ← 1

	Syntax:	Operands:	Program Counter:
(i)	SEH	None	PC ← PC + 1

16-bit Opcode:

1001	0100	0101	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	1	-	-	-	-	-

H: 1
Half Carry flag set

Example:

```
seh     ; Set Half Carry flag
```

Words: 1 (2 bytes)

Cycles: 1

SEI - Set Global Interrupt Flag

Description:

Sets the Global Interrupt flag (I) in SREG (status register).

Operation:

(i) I ← 1

	Syntax:	**Operands:**	**Program Counter:**
(i)	SEI	None	PC ← PC + 1

16-bit Opcode:

1001	0100	0111	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
1	-	-	-	-	-	-	-

I: 1
Global Interrupt flag set

Example:

```
cli              ; Disable interrupts
in    r13,$16    ; Read Port B
sei              ; Enable interrupts
```

Words: 1 (2 bytes)

Cycles: 1

SEN - Set Negative Flag

Description:

Sets the Negative flag (N) in SREG (status register).

Operation:

(i) N ← 1

	Syntax:	Operands:	Program Counter:
(i)	SEN	None	PC ← PC + 1

16-bit Opcode:

1001	0100	0010	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	1	-	-

N: 1
Negative flag set

Example:

```
add   r2,r19    ; Add r19 to r2
sen             ; Set negative flag
```

Words: 1 (2 bytes)

Cycles: 1

SER - Set all bits in Register

Description:

Loads $FF directly to register Rd.

Operation:

(i) Rd ← $FF

	Syntax:	Operands:	Program Counter:
(i)	SER Rd	$16 \leq d \leq 31$	PC ← PC + 1

16-bit Opcode:

1110	1111	dddd	1111

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
clr   r16        ; Clear r16
ser   r17        ; Set r17
out   $18,r16    ; Write zeros to Port B
nop              ; Delay (do nothing)
out   $18,r17    ; Write ones to Port B
```

Words: 1 (2 bytes)

Cycles: 1

SES - Set Signed Flag

Description:

Sets the Signed flag (S) in SREG (status register).

Operation:

(i) S ← 1

	Syntax:	Operands:	Program Counter:
(i)	SES	None	PC ← PC + 1

16-bit Opcode:

1001	0100	0100	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	1	-	-	-	-

S: 1
Signed flag set

Example:

```
add   r2,r19    ; Add r19 to r2
ses             ; Set negative flag
```

Words: 1 (2 bytes)
Cycles: 1

SET - Set T Flag

Description:

Sets the T flag in SREG (status register).

Operation:

(i) T ← 1

	Syntax:	**Operands:**	**Program Counter:**
(i)	SET	None	PC ← PC + 1

16-bit Opcode:

1001	0100	0110	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	1	-	-	-	-	-	-

T: 1
T flag set

Example:

```
set          ; Set T flag
```

Words: 1 (2 bytes)
Cycles: 1

SEV - Set Overflow Flag

Description:

Sets the Overflow flag (V) in SREG (status register).

Operation:

(i) V ← 1

	Syntax:	Operands:	Program Counter:
(i)	SEV	None	PC ← PC + 1

16-bit Opcode:

1001	0100	0011	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	1	-	-	-

V: 1
Overflow flag set

Example:

```
add   r2,r19      ; Add r19 to r2
sev               ; Set overflow flag
```

Words: 1 (2 bytes)
Cycles: 1

SEZ - Set Zero Flag

Description:

Sets the Zero flag (Z) in SREG (status register).

Operation:

(i) $Z \leftarrow 1$

	Syntax:	Operands:	Program Counter:
(i)	SEZ	None	$PC \leftarrow PC + 1$

16-bit Opcode:

1001	0100	0001	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	1	-

Z: 1
Zero flag set

Example:

```
add   r2,r19    ; Add r19 to r2
sez             ; Set zero flag
```

Words: 1 (2 bytes)
Cycles: 1

SLEEP

Description:

This instruction sets the circuit in sleep mode defined by the MCU control register.

Operation:

Refer to the device documentation for detailed description of SLEEP usage.

Syntax:	Operands:	Program Counter:
SLEEP	None	PC ← PC + 1

16-bit Opcode:

1001	0101	1000	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
mov     r0,r11        ; Copy r11 to r0
ldi     r16,(1<<SE)   ; Enable sleep mode
out     MCUCR, r16
sleep                 ; Put MCU in sleep mode
```

Words: 1 (2 bytes)
Cycles: 1

SPM - Store Program Memory

Description:

SPM can be used to erase a page in the program memory, to write a page in the program memory (that is already erased), and to set boot loader lock bits. In some devices, the program memory can be written one word at a time, in other devices an entire page can be programmed simultaneously after first filling a temporary page buffer. In all cases, the program memory must be erased one page at a time. When erasing the program memory, the Z register is used as page address. When writing the program memory, the Z register is used as page or word address, and the R1:R0 register pair is used as data. When setting the boot loader lock bits, the R1:R0 register pair is used as data. Refer to the device documentation for detailed description of SPM usage. This instruction can address the first 64K bytes (32K words) of program memory.

	Operation:	Comment:
(i)	(Z) ← $ffff	Erase program memory page
(ii)	(Z) ← R1:R0	Write program memory word
(iii)	(Z) ← R1:R0	Write temporary page buffer
(iv)	(Z) ← TEMP	Write temporary page buffer to program memory
(v)	BLBITS ← R1:R0	Set boot loader lock bits

	Syntax:	Operands:	Program Counter:
(i)-(v)	SPM	None	PC ← PC + 1

16-bit Opcode:

1001	0101	1110	1000

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
; This example shows SPM write of one word for devices with word write
ldi   r31, $F0     ; Load Z high byte
clr   r30          ; Clear Z low byte
ldi   r16, $CF     ; Load data to store
mov   r1, r16
ldi   r16, $FF
mov   r0, r16
ldi   r16,$03      ; Enable SPM, erase page
out   SPMCR, r16   ;
spm                ; Erase page starting at $F000
ldi   r16,$01      ; Enable SPM, store to program memory
out   SPMCR, r16   ;
spm                ; Execute SPM, store R1:R0 to program memory location $F000
```

Words: 1 (2 bytes)

Cycles: depends on the operation

ST - Store Indirect From Register to data space using Index X

Description:

Stores one byte indirect from a register to data space. For parts with SRAM, the data space consists of the register file, I/O memory and internal SRAM (and external SRAM if applicable). For parts without SRAM, the data space consists of the register file only. The EEPROM has a separate address space.

The data location is pointed to by the X (16 bits) pointer register in the register file. Memory access is limited to the current data segment of 64K bytes. To access another data segment in devices with more than 64K bytes data space, the RAMPX in register in the I/O area has to be changed.

The X pointer register can either be left unchanged by the operation, or it can be post-incremented or pre-decremented. These features are especially suited for accessing arrays, tables, and stack pointer usage of the X pointer register. Note that only the low byte of the X pointer is updated in devices with no more than 256 bytes data space. For such devices, the high byte of the pointer is not used by this instruction and can be used for other purposes. The RAMPX register in the I/O area is updated in parts with more than 64K bytes data space.

The result of these combinations is undefined:

ST X+, r26
ST X+, r27
ST -X, r26
ST -X, r27

Using the X pointer:

	Operation:		Comment:
(i)	(X) ← Rr		X: Unchanged
(ii)	(X) ← Rr	X ← X+1	X: Post incremented
(iii)	X ← X - 1	(X) ← Rr	X: Pre decremented

	Syntax:	Operands:	Program Counter:
(i)	ST X, Rr	$0 \le r \le 31$	PC ← PC + 1
(ii)	ST X+, Rr	$0 \le r \le 31$	PC ← PC + 1
(iii)	ST -X, Rr	$0 \le r \le 31$	PC ← PC + 1

16-bit Opcode :

(i)	1001	001r	rrrr	1100
(ii)	1001	001r	rrrr	1101
(iii)	1001	001r	rrrr	1110

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
clr     r27         ; Clear X high byte
ldi     r26,$60     ; Set X low byte to $60
st      X+,r0       ; Store r0 in data space loc. $60(X post inc)
st      X,r1        ; Store r1 in data space loc. $61
ldi     r26,$63     ; Set X low byte to $63
st      X,r2        ; Store r2 in data space loc. $63
st      -X,r3       ; Store r3 in data space loc. $62(X pre dec)
```

Words: 1 (2 bytes)

Cycles: 2

ST (STD) - Store Indirect From Register to data space using Index Y

Description:

Stores one byte indirect with or without displacement from a register to data space. For parts with SRAM, the data space consists of the register file, I/O memory and internal SRAM (and external SRAM if applicable). For parts without SRAM, the data space consists of the register file only. The EEPROM has a separate address space.

The data location is pointed to by the Y (16 bits) pointer register in the register file. Memory access is limited to the current data segment of 64K bytes. To access another data segment in devices with more than 64K bytes data space, the RAMPY in register in the I/O area has to be changed.

The Y pointer register can either be left unchanged by the operation, or it can be post-incremented or pre-decremented. These features are especially suited for accessing arrays, tables, and stack pointer usage of the Y pointer register. Note that only the low byte of the Y pointer is updated in devices with no more than 256 bytes data space. For such devices, the high byte of the pointer is not used by this instruction and can be used for other purposes. The RAMPY register in the I/O area is updated in parts with more than 64K bytes data space, and the displacement is added to the entire 24-bit address on such devices.

The result of these combinations is undefined:

ST Y+, r28
ST Y+, r29
ST -Y, r28
ST -Y, r29

Using the Y pointer:

	Operation:		Comment:
(i)	$(Y) \leftarrow Rr$		Y: Unchanged
(ii)	$(Y) \leftarrow Rr$	$Y \leftarrow Y+1$	Y: Post incremented
(iii)	$Y \leftarrow Y - 1$	$(Y) \leftarrow Rr$	Y: Pre decremented
(iiii)	$(Y+q) \leftarrow Rr$		Y: Unchanged, q: Displacement

	Syntax:	Operands:	Program Counter:
(i)	ST Y, Rr	$0 \le r \le 31$	$PC \leftarrow PC + 1$
(ii)	ST Y+, Rr	$0 \le r \le 31$	$PC \leftarrow PC + 1$
(iii)	ST -Y, Rr	$0 \le r \le 31$	$PC \leftarrow PC + 1$
(iiii)	STD Y+q, Rr	$0 \le r \le 31, 0 \le q \le 63$	$PC \leftarrow PC + 1$

16-bit Opcode:

(i)	1000	001r	rrrr	1000
(ii)	1001	001r	rrrr	1001
(iii)	1001	001r	rrrr	1010
(iiii)	10q0	qq1r	rrrr	1qqq

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
clr     r29         ; Clear Y high byte
ldi     r28,$60     ; Set Y low byte to $60
st      Y+,r0       ; Store r0 in data space loc. $60(Y post inc)
st      Y,r1        ; Store r1 in data space loc. $61
ldi     r28,$63     ; Set Y low byte to $63
st      Y,r2        ; Store r2 in data space loc. $63
st      -Y,r3       ; Store r3 in data space loc. $62(Y pre dec)
std     Y+2,r4      ; Store r4 in data space loc. $64
```

Words: 1 (2 bytes)

Cycles: 2

ST (STD) - Store Indirect From Register to data space using Index Z

Description:

Stores one byte indirect with or without displacement from a register to data space. For parts with SRAM, the data space consists of the register file, I/O memory and internal SRAM (and external SRAM if applicable). For parts without SRAM, the data space consists of the register file only. The EEPROM has a separate address space.

The data location is pointed to by the Z (16 bits) pointer register in the register file. Memory access is limited to the current data segment of 64K bytes. To access another data segment in devices with more than 64K bytes data space, the RAMPZ in register in the I/O area has to be changed.

The Z pointer register can either be left unchanged by the operation, or it can be post-incremented or pre-decremented. These features are especially suited for stack pointer usage of the Z pointer register, however because the Z pointer register can be used for indirect subroutine calls, indirect jumps and table lookup, it is often more convenient to use the X or Y pointer as a dedicated stack pointer. Note that only the low byte of the Z pointer is updated in devices with no more than 256 bytes data space. For such devices, the high byte of the pointer is not used by this instruction and can be used for other purposes. The RAMPZ register in the I/O area is updated in parts with more than 64K bytes data space, and the displacement is added to the entire 24-bit address on such devices. For devices with more than 64K bytes program memory and up to 64K bytes data memory, the RAMPZ register is only used by the ELPM and ESPM instructions. Hence, RAMPZ is not affected by the ST instruction.

The result of these combinations is undefined:

ST Z+, r30
ST Z+, r31
ST -Z, r30
ST -Z, r31

Using the Z pointer:

	Operation:		**Comment:**
(i)	(Z) ← Rr		Z: Unchanged
(ii)	(Z) ← Rr	Z ← Z+1	Z: Post incremented
(iii)	Z ← Z - 1	(Z) ← Rr	Z: Pre decremented
(iiii)	(Z+q) ← Rr		Z: Unchanged, q: Displacement

	Syntax:	**Operands:**	**Program Counter:**
(i)	ST Z, Rr	$0 \le r \le 31$	PC ← PC + 1
(ii)	ST Z+, Rr	$0 \le r \le 31$	PC ← PC + 1
(iii)	ST -Z, Rr	$0 \le r \le 31$	PC ← PC + 1
(iiii)	STD Z+q, Rr	$0 \le r \le 31$, $0 \le q \le 63$	PC ← PC + 1

16-bit Opcode :

(i)	1000	001r	rrrr	0000
(ii)	1001	001r	rrrr	0001
(iii)	1001	001r	rrrr	0010
(iiii)	10q0	qq1r	rrrr	0qqq

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
clr   r31       ; Clear Z high byte
ldi   r30,$60   ; Set Z low byte to $60
st    Z+,r0     ; Store r0 in data space loc. $60(Z post inc)
st    Z,r1      ; Store r1 in data space loc. $61
ldi   r30,$63   ; Set Z low byte to $63
st    Z,r2      ; Store r2 in data space loc. $63
st    -Z,r3     ; Store r3 in data space loc. $62(Z pre dec)
std   Z+2,r4    ; Store r4 in data space loc. $64
```

Words: 1 (2 bytes)
Cycles: 2

STS - Store Direct to data space

Description:

Stores one byte from a Register to the data space. For parts with SRAM, the data space consists of the register file, I/O memory and internal SRAM (and external SRAM if applicable). For parts without SRAM, the data space consists of the register file only. The EEPROM has a separate address space.

A 16-bit address must be supplied. Memory access is limited to the current data segment of 64K bytes. The STS instruction uses the RAMPD register to access memory above 64K bytes. To access another data segment in devices with more than 64K bytes data space, the RAMPD in register in the I/O area has to be changed.

	Operation:
(i)	$(k) \leftarrow Rr$

	Syntax:	**Operands:**	**Program Counter:**
(i)	STS k,Rr	$0 \le r \le 31$, $0 \le k \le 65535$	$PC \leftarrow PC + 2$

32-bit Opcode:

1001	001d	dddd	0000
kkkk	kkkk	kkkk	kkkk

Status Register (SREG) and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
lds     r2,$FF00    ; Load r2 with the contents of data space location $FF00
add     r2,r1       ; add r1 to r2
sts     $FF00,r2    ; Write back
```

Words: 2 (4 bytes)

Cycles: 2

SUB - Subtract without Carry

Description:

Subtracts two registers and places the result in the destination register Rd.

	Operation:
(i)	Rd ← Rd - Rr

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

16-bit Opcode:

0001	10rd	dddd	rrrr

Status Register and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	⇔	⇔	⇔	⇔	⇔	⇔

H: $\overline{Rd3} \bullet Rr3 + Rr3 \bullet R3 + R3 \bullet \overline{Rd3}$
Set if there was a borrow from bit 3; cleared otherwise

S: $N \oplus V$, For signed tests.

V: $Rd7 \bullet \overline{Rr7} \bullet \overline{R7} + \overline{Rd7} \bullet Rr7 \bullet R7$
Set if two's complement overflow resulted from the operation; cleared otherwise.

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is $00; cleared otherwise.

C: $\overline{Rd7} \bullet Rr7 + Rr7 \bullet R7 + R7 \bullet \overline{Rd7}$
Set if the absolute value of the contents of Rr is larger than the absolute value of Rd; cleared otherwise.

R (Result) equals Rd after the operation.

Example:

```
        sub     r13,r12     ; Subtract r12 from r13
        brne    noteq       ; Branch if r12<>r13
        ...
noteq:  nop                 ; Branch destination (do nothing)
```

Words: 1 (2 bytes)
Cycles: 1

SUBI - Subtract Immediate

Description:

Subtracts a register and a constant and places the result in the destination register Rd. This instruction is working on Register R16 to R31 and is very well suited for operations on the X, Y and Z pointers.

Operation:

(i) $Rd \leftarrow Rd - K$

	Syntax:	Operands:	Program Counter:
(i)	SUBI Rd,K	$16 \le d \le 31$, $0 \le K \le 255$	$PC \leftarrow PC + 1$

16-bit Opcode:

0101	KKKK	dddd	KKKK

Status Register and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	⇔	⇔	⇔	⇔	⇔	⇔

H: $\overline{Rd3} \bullet K3 + K3 \bullet R3 + R3 \bullet \overline{Rd3}$
Set if there was a borrow from bit 3; cleared otherwise

S: $N \oplus V$, For signed tests.

V: $Rd7 \bullet \overline{K7} \bullet \overline{R7} + \overline{Rd7} \bullet K7 \bullet R7$
Set if two's complement overflow resulted from the operation; cleared otherwise.

N: $R7$
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is $00; cleared otherwise.

C: $\overline{Rd7} \bullet K7 + K7 \bullet R7 + R7 \bullet \overline{Rd7}$
Set if the absolute value of K is larger than the absolute value of Rd; cleared otherwise.

R (Result) equals Rd after the operation.

Example:

```
        subi   r22,$11   ; Subtract $11 from r22
        brne   noteq     ; Branch if r22<>$11
        ...
noteq:  nop              ; Branch destination (do nothing)
```

Words: 1 (2 bytes)
Cycles: 1

SWAP - Swap Nibbles

Description:

Swaps high and low nibbles in a register.

Operation:

(i) R(7:4) ← Rd(3:0), R(3:0) ← Rd(7:4)

	Syntax:	Operands:	Program Counter:
(i)	SWAP Rd	$0 \le d \le 31$	PC ← PC + 1

16-bit Opcode:

1001	010d	dddd	0010

Status Register and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

R (Result) equals Rd after the operation.

Example:

```
inc     r1    ; Increment r1
swap    r1    ; Swap high and low nibble of r1
inc     r1    ; Increment high nibble of r1
swap    r1    ; Swap back
```

Words: 1 (2 bytes)

Cycles: 1

TST - Test for Zero or Minus

Description:

Tests if a register is zero or negative. Performs a logical AND between a register and itself. The register will remain unchanged.

Operation:

(i) $Rd \leftarrow Rd \bullet Rd$

	Syntax:	Operands:	Program Counter:
(i)	TST Rd	$0 \le d \le 31$	$PC \leftarrow PC + 1$

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

0010	00dd	dddd	dddd

Status Register and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	⇔	0	⇔	⇔	-

S: $N \oplus V$, For signed tests.

V: 0
Cleared

N: R7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R7} \bullet \overline{R6} \bullet \overline{R5} \bullet \overline{R4} \bullet \overline{R3} \bullet \overline{R2} \bullet \overline{R1} \bullet \overline{R0}$
Set if the result is $00; cleared otherwise.

R (Result) equals Rd.

Example:

```
            tst   r0        ; Test r0
            breq  zero      ; Branch if r0=0
            ...
    zero:   nop             ; Branch destination (do nothing)
```

Words: 1 (2 bytes)
Cycles: 1

WDR - Watchdog Reset

Description:

This instruction resets the Watchdog Timer. This instruction must be executed within a limited time given by the WD prescaler. See the Watchdog Timer hardware specification.

Operation:

(i) WD timer restart.

	Syntax:	Operands:	Program Counter:
(i)	WDR	None	PC ← PC + 1

16-bit Opcode:

1001	0101	1010	1000

Status Register and Boolean Formula:

I	T	H	S	V	N	Z	C
-	-	-	-	-	-	-	-

Example:

```
wdr         ; Reset watchdog timer
```

Words: 1 (2 bytes)

Cycles: 1

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