

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: Twos 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

X,Y,Z: Indirect address register (X=R27:R26,
 Y=R29:R28 and Z=R31:R30)
 P: I/O port address
 q: Displacement for direct addressing (6 bit)

I/O Registers

RAMPX, RAMPY, RAMPZ: Registers concatenated with the X, Y and Z registers enabling indirect addressing of the whole SRAM area on MCUs with more than 64K bytes SRAM.

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 literal or byte data (8 bit)
 k: Constant address data for program counter
 b: Bit in the register file or I/O register (3 bit)
 s: Bit in the status register (3 bit)

Stack:

STACK: Stack for return address and pushed registers
 SP: Stack Pointer to STACK

Flags:

\leftrightarrow : 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
$Rd > Rr$	$Z.(N \oplus V) = 0$	BRLT*	$Rd \leq Rr$	$Z+(N \oplus V) = 1$	BRGE*	Signed
$Rd \geq Rr$	$(N \oplus V) = 0$	BRGE	$Rd < Rr$	$(N \oplus V) = 1$	BRLT	Signed
$Rd = Rr$	$Z = 1$	BREQ	$Rd \neq Rr$	$Z = 0$	BRNE	Signed
$Rd \leq Rr$	$Z+(N \oplus V) = 1$	BRGE*	$Rd > Rr$	$Z.(N \oplus V) = 0$	BRLT*	Signed
$Rd < Rr$	$(N \oplus V) = 1$	BRLT	$Rd \geq Rr$	$(N \oplus V) = 0$	BRGE	Signed
$Rd > Rr$	$C + Z = 0$	BRLO*	$Rd \leq Rr$	$C + Z = 1$	BRSH*	Unsigned
$Rd \geq Rr$	$C = 0$	BRSH/BRCC	$Rd < Rr$	$C = 1$	BRLO/BRCS	Unsigned
$Rd = Rr$	$Z = 1$	BREQ	$Rd \neq Rr$	$Z = 0$	BRNE	Unsigned
$Rd \leq Rr$	$C + Z = 1$	BRSH*	$Rd > Rr$	$C + Z = 0$	BRLO*	Unsigned
$Rd < Rr$	$C = 1$	BRLO/BRCS	$Rd \geq Rr$	$C = 0$	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

* Interchange Rd and Rr in the operation before the test. i.e. CP Rd,Rr → CP Rr,Rd



Complete Instruction Set Summary

Mnemonics	Operands	Description	Operation	Flags	#Clock Note
ARITHMETIC AND LOGIC INSTRUCTIONS					
ADD	Rd, Rr	Add without Carry	$Rd \leftarrow Rd + Rr$	Z,C,N,V,H	1
ADC	Rd, Rr	Add with Carry	$Rd \leftarrow Rd + Rr + C$	Z,C,N,V,H	1
ADIW	Rd, K	Add Immediate to Word	$Rd+1:Rd \leftarrow Rd+1:Rd + K$	Z,C,N,V	2
SUB	Rd, Rr	Subtract without Carry	$Rd \leftarrow Rd - Rr$	Z,C,N,V,H	1
SUBI	Rd, K	Subtract Immediate	$Rd \leftarrow Rd - K$	Z,C,N,V,H	1
SBC	Rd, Rr	Subtract with Carry	$Rd \leftarrow Rd - Rr - C$	Z,C,N,V,H	1
SBCI	Rd, K	Subtract Immediate with Carry	$Rd \leftarrow Rd - K - C$	Z,C,N,V,H	1
SBIW	Rd, K	Subtract Immediate from Word	$Rd+1:Rd \leftarrow Rd+1:Rd - K$	Z,C,N,V	2
AND	Rd, Rr	Logical AND	$Rd \leftarrow Rd \cdot Rr$	Z,N,V	1
ANDI	Rd, K	Logical AND with Immediate	$Rd \leftarrow Rd \cdot K$	Z,N,V	1
OR	Rd, Rr	Logical OR	$Rd \leftarrow Rd \vee Rr$	Z,N,V	1
ORI	Rd, K	Logical OR with Immediate	$Rd \leftarrow Rd \vee K$	Z,N,V	1
EOR	Rd, Rr	Exclusive OR	$Rd \leftarrow Rd \oplus Rr$	Z,N,V	1
COM	Rd	One's Complement	$Rd \leftarrow \$FF - Rd$	Z,C,N,V	1
NEG	Rd	Two's Complement	$Rd \leftarrow \$00 - Rd$	Z,C,N,V,H	1
SBR	Rd,K	Set Bit(s) in Register	$Rd \leftarrow Rd \vee K$	Z,N,V	1
CBR	Rd,K	Clear Bit(s) in Register	$Rd \leftarrow Rd \cdot (\$FFh - K)$	Z,N,V	1
INC	Rd	Increment	$Rd \leftarrow Rd + 1$	Z,N,V	1
DEC	Rd	Decrement	$Rd \leftarrow Rd - 1$	Z,N,V	1
TST	Rd	Test for Zero or Minus	$Rd \leftarrow Rd \cdot Rd$	Z,N,V	1
CLR	Rd	Clear Register	$Rd \leftarrow Rd \oplus Rd$	Z,N,V	1
SER	Rd	Set Register	$Rd \leftarrow \$FF$	None	1
CP	Rd,Rr	Compare	$Rd - Rr$	Z,C,N,V,H	1
CPC	Rd,Rr	Compare with Carry	$Rd - Rr - C$	Z,C,N,V,H	1
CPI	Rd,K	Compare with Immediate	$Rd - K$	Z,C,N,V,H	1

√) Not available in base-line microcontrollers

(continued)

Complete Instruction Set Summary (continued)

Mnemonics	Operands	Description	Operation	Flags	#Clock Note
BRANCH INSTRUCTIONS					
RJMP	k	Relative Jump	$PC \leftarrow PC + k + 1$	None	2
IJMP		Indirect Jump to (Z)	$PC \leftarrow Z$	None	2
JMP	k	Jump	$PC \leftarrow k$	None	3
RCALL	k	Relative Call Subroutine	$PC \leftarrow PC + k + 1$	None	3
ICALL		Indirect Call to (Z)	$PC \leftarrow Z$	None	3
CALL	k	Call Subroutine	$PC \leftarrow k$	None	4
RET		Subroutine Return	$PC \leftarrow \text{STACK}$	None	4
RETI		Interrupt Return	$PC \leftarrow \text{STACK}$	I	4
CPSE	Rd,Rr	Compare, Skip if Equal	if (Rd = Rr) $PC \leftarrow PC + 2$ or 3	None	1 / 2 / 3
SBRC	Rr, b	Skip if Bit in Register Cleared	if (Rr(b)=0) $PC \leftarrow PC + 2$ or 3	None	1 / 2 / 3
SBRB	Rr, b	Skip if Bit in Register Set	if (Rr(b)=1) $PC \leftarrow PC + 2$ or 3	None	1 / 2 / 3
SBIC	P, b	Skip if Bit in I/O Register Cleared	if(I/O(P,b)=0) $PC \leftarrow PC + 2$ or 3	None	1 / 2 / 3
SBIS	P, b	Skip if Bit in I/O Register Set	if(I/O(P,b)=1) $PC \leftarrow PC + 2$ or 3	None	1 / 2 / 3
BRBS	s, k	Branch if Status Flag Set	if (SREG(s) = 1) then $PC \leftarrow PC + k + 1$	None	1 / 2
BRBC	s, k	Branch if Status Flag Cleared	if (SREG(s) = 0) then $PC \leftarrow PC + k + 1$	None	1 / 2
BREQ	k	Branch if Equal	if (Z = 1) then $PC \leftarrow PC + k + 1$	None	1 / 2
BRNE	k	Branch if Not Equal	if (Z = 0) then $PC \leftarrow PC + k + 1$	None	1 / 2
BRCS	k	Branch if Carry Set	if (C = 1) then $PC \leftarrow PC + k + 1$	None	1 / 2
BRCC	k	Branch if Carry Cleared	if (C = 0) then $PC \leftarrow PC + k + 1$	None	1 / 2
BRSH	k	Branch if Same or Higher	if (C = 0) then $PC \leftarrow PC + k + 1$	None	1 / 2
BRLO	k	Branch if Lower	if (C = 1) then $PC \leftarrow PC + k + 1$	None	1 / 2
BRMI	k	Branch if Minus	if (N = 1) then $PC \leftarrow PC + k + 1$	None	1 / 2
BRPL	k	Branch if Plus	if (N = 0) then $PC \leftarrow PC + k + 1$	None	1 / 2
BRGE	k	Branch if Greater or Equal, Signed	if (N ⊕ V = 0) then $PC \leftarrow PC + k + 1$	None	1 / 2
BRLT	k	Branch if Less Than, Signed	if (N ⊕ V = 1) then $PC \leftarrow PC + k + 1$	None	1 / 2
BRHS	k	Branch if Half Carry Flag Set	if (H = 1) then $PC \leftarrow PC + k + 1$	None	1 / 2
BRHC	k	Branch if Half Carry Flag Cleared	if (H = 0) then $PC \leftarrow PC + k + 1$	None	1 / 2
BRTS	k	Branch if T Flag Set	if (T = 1) then $PC \leftarrow PC + k + 1$	None	1 / 2
BRTC	k	Branch if T Flag Cleared	if (T = 0) then $PC \leftarrow PC + k + 1$	None	1 / 2
BRVS	k	Branch if Overflow Flag is Set	if (V = 1) then $PC \leftarrow PC + k + 1$	None	1 / 2
BRVC	k	Branch if Overflow Flag is Cleared	if (V = 0) then $PC \leftarrow PC + k + 1$	None	1 / 2
BRIE	k	Branch if Interrupt Enabled	if (I = 1) then $PC \leftarrow PC + k + 1$	None	1 / 2
BRID	k	Branch if Interrupt Disabled	if (I = 0) then $PC \leftarrow PC + k + 1$	None	1 / 2

(continued)



Complete Instruction Set Summary (continued)

Mnemonics	Operands	Description	Operation	Flags	#Clock Note
DATA TRANSFER INSTRUCTIONS					
MOV	Rd, Rr	Copy Register	$Rd \leftarrow Rr$	None	1
LDI	Rd, K	Load Immediate	$Rd \leftarrow K$	None	1
LDS	Rd, k	Load Direct from SRAM	$Rd \leftarrow (k)$	None	3
LD	Rd, X	Load Indirect	$Rd \leftarrow (X)$	None	2
LD	Rd, X+	Load Indirect and Post-Increment	$Rd \leftarrow (X), X \leftarrow X + 1$	None	2
LD	Rd, -X	Load Indirect and Pre-Decrement	$X \leftarrow X - 1, Rd \leftarrow (X)$	None	2
LD	Rd, Y	Load Indirect	$Rd \leftarrow (Y)$	None	2
LD	Rd, Y+	Load Indirect and Post-Increment	$Rd \leftarrow (Y), Y \leftarrow Y + 1$	None	2
LD	Rd, -Y	Load Indirect and Pre-Decrement	$Y \leftarrow Y - 1, Rd \leftarrow (Y)$	None	2
LDD	Rd, Y+q	Load Indirect with Displacement	$Rd \leftarrow (Y + q)$	None	2
LD	Rd, Z	Load Indirect	$Rd \leftarrow (Z)$	None	2
LD	Rd, Z+	Load Indirect and Post-Increment	$Rd \leftarrow (Z), Z \leftarrow Z + 1$	None	2
LD	Rd, -Z	Load Indirect and Pre-Decrement	$Z \leftarrow Z - 1, Rd \leftarrow (Z)$	None	2
LDD	Rd, Z+q	Load Indirect with Displacement	$Rd \leftarrow (Z + q)$	None	2
STS	k, Rr	Store Direct to SRAM	$Rd \leftarrow (k)$	None	3
ST	X, Rr	Store Indirect	$(X) \leftarrow Rr$	None	2
ST	X+, Rr	Store Indirect and Post-Increment	$(X) \leftarrow Rr, X \leftarrow X + 1$	None	2
ST	-X, Rr	Store Indirect and Pre-Decrement	$X \leftarrow X - 1, (X) \leftarrow Rr$	None	2
ST	Y, Rr	Store Indirect	$(Y) \leftarrow Rr$	None	2
ST	Y+, Rr	Store Indirect and Post-Increment	$(Y) \leftarrow Rr, Y \leftarrow Y + 1$	None	2
ST	-Y, Rr	Store Indirect and Pre-Decrement	$Y \leftarrow Y - 1, (Y) \leftarrow Rr$	None	2
STD	Y+q, Rr	Store Indirect with Displacement	$(Y + q) \leftarrow Rr$	None	2
ST	Z, Rr	Store Indirect	$(Z) \leftarrow Rr$	None	2
ST	Z+, Rr	Store Indirect and Post-Increment	$(Z) \leftarrow Rr, Z \leftarrow Z + 1$	None	2
ST	-Z, Rr	Store Indirect and Pre-Decrement	$Z \leftarrow Z - 1, (Z) \leftarrow Rr$	None	2
STD	Z+q, Rr	Store Indirect with Displacement	$(Z + q) \leftarrow Rr$	None	2
LPM		Load Program Memory	$R0 \leftarrow (Z)$	None	3
IN	Rd, P	In Port	$Rd \leftarrow P$	None	1
OUT	P, Rr	Out Port	$P \leftarrow Rr$	None	1
PUSH	Rr	Push Register on Stack	$STACK \leftarrow Rr$	None	2
POP	Rd	Pop Register from Stack	$Rd \leftarrow STACK$	None	2

(continued)

Complete Instruction Set Summary (continued)

Mnemonics	Operands	Description	Operation	Flags	#Clock Note
BIT AND BIT-TEST INSTRUCTIONS					
LSL	Rd	Logical Shift Left	$Rd(n+1) \leftarrow Rd(n), Rd(0) \leftarrow 0, C \leftarrow Rd(7)$	Z,C,N,V,H	1
LSR	Rd	Logical Shift Right	$Rd(n) \leftarrow Rd(n+1), Rd(7) \leftarrow 0, C \leftarrow Rd(0)$	Z,C,N,V	1
ROL	Rd	Rotate Left Through Carry	$Rd(0) \leftarrow C, Rd(n+1) \leftarrow Rd(n), C \leftarrow Rd(7)$	Z,C,N,V,H	1
ROR	Rd	Rotate Right Through Carry	$Rd(7) \leftarrow C, Rd(n) \leftarrow Rd(n+1), C \leftarrow Rd(0)$	Z,C,N,V	1
ASR	Rd	Arithmetic Shift Right	$Rd(n) \leftarrow Rd(n+1), n=0..6$	Z,C,N,V	1
SWAP	Rd	Swap Nibbles	$Rd(3..0) \leftrightarrow Rd(7..4)$	None	1
BSET	s	Flag Set	$SREG(s) \leftarrow 1$	SREG(s)	1
BCLR	s	Flag Clear	$SREG(s) \leftarrow 0$	SREG(s)	1
SBI	P, b	Set Bit in I/O Register	$I/O(P, b) \leftarrow 1$	None	2
CBI	P, b	Clear Bit in I/O Register	$I/O(P, b) \leftarrow 0$	None	2
BST	Rr, b	Bit Store from Register to T	$T \leftarrow Rr(b)$	T	1
BLD	Rd, b	Bit load from T to Register	$Rd(b) \leftarrow T$	None	1
SEC		Set Carry	$C \leftarrow 1$	C	1
CLC		Clear Carry	$C \leftarrow 0$	C	1
SEN		Set Negative Flag	$N \leftarrow 1$	N	1
CLN		Clear Negative Flag	$N \leftarrow 0$	N	1
SEZ		Set Zero Flag	$Z \leftarrow 1$	Z	1
CLZ		Clear Zero Flag	$Z \leftarrow 0$	Z	1
SEI		Global Interrupt Enable	$I \leftarrow 1$	I	1
CLI		Global Interrupt Disable	$I \leftarrow 0$	I	1
SES		Set Signed Test Flag	$S \leftarrow 1$	S	1
CLS		Clear Signed Test Flag	$S \leftarrow 0$	S	1
SEV		Set Two's Complement Overflow	$V \leftarrow 1$	V	1
CLV		Clear Two's Complement Overflow	$V \leftarrow 0$	V	1
SET		Set T in SREG	$T \leftarrow 1$	T	1
CLT		Clear T in SREG	$T \leftarrow 0$	T	1
SEH		Set Half Carry Flag in SREG	$H \leftarrow 1$	H	1
CLH		Clear Half Carry Flag in SREG	$H \leftarrow 0$	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:

$$(i) \quad Rd \leftarrow Rd + Rr + C$$

Syntax:

(i) ADC Rd,Rr

Operands:

$0 \leq d \leq 31, 0 \leq r \leq 31$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

0001	11rd	dddd	rrrr
------	------	------	------

Status Register (SREG) Boolean Formulae:

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

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

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

V: $Rd7 \cdot Rr7 \cdot \overline{Rr7} + \overline{Rd7} \cdot \overline{Rr7} \cdot Rr7$
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: $\overline{Rd7} \cdot \overline{Rr7} \cdot \overline{Rr7} \cdot R7 \cdot R7 \cdot \overline{Rd7}$
Set if the result is \$00; cleared otherwise.

C: $Rd7 \cdot Rr7 + Rr7 \cdot \overline{Rr7} + \overline{Rr7} \cdot Rd7$
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:

$$(i) \quad Rd \leftarrow Rd + Rr$$

Syntax:

(i) ADD Rd,Rr

Operands:

$0 \leq d \leq 31, 0 \leq r \leq 31$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

0000	11rd	dddd	rrrr
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

H: $Rd3 \bullet Rr3 + Rr3 + \overline{R3} + \overline{R3} \bullet Rd3$
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) $R_{dh}:R_{dl} \leftarrow R_{dh}:R_{dl} + K$

Syntax:

(i) ADIW Rdl,K

Operands:

$dl \in \{24,26,28,30\}, 0 \leq K \leq 63$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	0110	KKdd	KKKK
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

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

V: R_{dh}7 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: $\overline{R_{15}} \cdot \overline{R_{14}} \cdot \overline{R_{13}} \cdot \overline{R_{12}} \cdot \overline{R_{11}} \cdot \overline{R_{10}} \cdot \overline{R_9} \cdot \overline{R_8} \cdot \overline{R_7} \cdot \overline{R_6} \cdot \overline{R_5} \cdot \overline{R_4} \cdot \overline{R_3} \cdot \overline{R_2} \cdot \overline{R_1} \cdot \overline{R_0}$
Set if the result is \$0000; cleared otherwise.

C: $\overline{R_{15}} \cdot R_{dh7}$
Set if there was carry from the MSB of the result; cleared otherwise.

R (Result) equals R_{dh}:R_{dl} after the operation (R_{dh}7-R_{dh}0 = R₁₅-R₈, R_{dl}7-R_{dl}0=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) $Rd \leftarrow Rd \bullet Rr$

Syntax:

(i) AND Rd,Rr

Operands:

$0 \leq d \leq 31, 0 \leq r \leq 31$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

0010	00rd	dddd	rrrr
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

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

V: 0
Cleared

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

Z: $R7 \bullet R6 \bullet R5 \bullet R4 \bullet R3 \bullet R2 \bullet R1 \bullet R0$
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) $Rd \leftarrow Rd \bullet K$

Syntax:

(i) ANDI Rd,K

Operands:

$16 \leq d \leq 31, 0 \leq K \leq 255$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

0111	KKKK	dddd	KKKK
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

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

V: 0
Cleared

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

Z: $R7 \bullet R6 \bullet R5 \bullet R4 \bullet R3 \bullet R2 \bullet R1 \bullet R0$
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)

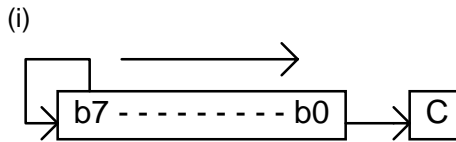
Cycles: 1

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 two's complement value by two without changing its sign. The carry flag can be used to round the result.

Operation:



Syntax:

(i) ASR Rd

Operands:

$0 \leq d \leq 31$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	010d	dddd	0101
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

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

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

Set if (N is set and C is clear) or (N is clear and C is set); Cleared otherwise (for values of N and C after the shift).

N: R7

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

Z: $R7 \cdot R6 \cdot R5 \cdot R4 \cdot R3 \cdot R2 \cdot R1 \cdot R0$

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) $SREG(s) \leftarrow 0$

Syntax:

(i) BCLR s

Operands:

$0 \leq s \leq 7$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	0100	1sss	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

I	T	H	S	V	N	Z	C
\leftrightarrow	\leftrightarrow	\leftrightarrow	\leftrightarrow	\leftrightarrow	\leftrightarrow	\leftrightarrow	\leftrightarrow

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) $Rd(b) \leftarrow T$

Syntax:

(i) BLD Rd,b

Operands:

$0 \leq d \leq 31, 0 \leq b \leq 7$

Program Counter:

$PC \leftarrow PC + 1$

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 ($PC-64 \leq \text{destination} \leq PC+63$). The parameter k is the offset from PC and is represented in two's complement form.

Operation:

- (i) If $SREG(s) = 0$ then $PC \leftarrow PC + k + 1$, else $PC \leftarrow PC + 1$

Syntax:

- (i) BRBC s,k

Operands:

$0 \leq s \leq 7, -64 \leq k \leq +63$

Program Counter:

$PC \leftarrow PC + k + 1$

$PC \leftarrow PC + 1$, 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 ($PC-64 \leq \text{destination} \leq PC+63$). The parameter k is the offset from PC and is represented in two's complement form.

Operation:

- (i) If $SREG(s) = 1$ then $PC \leftarrow PC + k + 1$, else $PC \leftarrow PC + 1$

Syntax:

- (i) BRBS s,k

Operands:

$0 \leq s \leq 7, -64 \leq k \leq +63$

Program Counter:

$PC \leftarrow PC + k + 1$

$PC \leftarrow PC + 1$, 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 ($PC-64 \leq \text{destination} \leq PC+63$). 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 $PC \leftarrow PC + k + 1$, else $PC \leftarrow PC + 1$

Syntax:

- (i) BRCC k

Operands:

$-64 \leq k \leq +63$

Program Counter:

$PC \leftarrow PC + k + 1$

$PC \leftarrow PC + 1$, 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:

```

addr22,r23    ; Add r23 to r22
brccnocarrry ; 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 ($PC-64 \leq \text{destination} \leq PC+63$). 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 $PC \leftarrow PC + k + 1$, else $PC \leftarrow PC + 1$

Syntax:

- (i) BRCS k

Operands:

$-64 \leq k \leq +63$

Program Counter:

$PC \leftarrow PC + k + 1$

$PC \leftarrow PC + 1$, 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 ($PC-64 \leq \text{destination} \leq PC+63$). 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 $PC \leftarrow PC + k + 1$, else $PC \leftarrow PC + 1$

Syntax:

- (i) BREQ k

Operands:

$-64 \leq k \leq +63$

Program Counter:

$PC \leftarrow PC + k + 1$

$PC \leftarrow PC + 1$, 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:

```

cpr1,r0      ; Compare registers r1 and r0
breqequal    ; 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 ($PC-64 \leq \text{destination} \leq PC+63$). 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:

- (i) BRGE k

Operands:

$-64 \leq k \leq +63$

Program Counter:

$PC \leftarrow PC + k + 1$

$PC \leftarrow PC + 1$, 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:

```

cpr11,r12    ; Compare registers r11 and r12
brgegreateq  ; 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 ($PC-64 \leq \text{destination} \leq PC+63$). 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 $PC \leftarrow PC + k + 1$, else $PC \leftarrow PC + 1$

Syntax:

- (i) BRHC k

Operands:

$-64 \leq k \leq +63$

Program Counter:

$PC \leftarrow PC + k + 1$

$PC \leftarrow PC + 1$, if condition is false

16 bit Opcode:

1111	01kk	kkkk	k101
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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 ($PC-64 \leq \text{destination} \leq PC+63$). 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 $PC \leftarrow PC + k + 1$, else $PC \leftarrow PC + 1$

Syntax:

- (i) BRHS k

Operands:

$-64 \leq k \leq +63$

Program Counter:

$PC \leftarrow PC + k + 1$

$PC \leftarrow PC + 1$, if condition is false

16 bit Opcode:

1111	00kk	kkkk	k101
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

Example:

```

    brhshset    ; 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 ($PC-64 \leq \text{destination} \leq PC+63$). 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 $PC \leftarrow PC + k + 1$, else $PC \leftarrow PC + 1$

Syntax:

(i) BRID k

Operands:

$-64 \leq k \leq +63$

Program Counter:

$PC \leftarrow PC + k + 1$

$PC \leftarrow PC + 1$, if condition is false

16 bit Opcode:

1111	01kk	kkkk	k111
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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 ($PC-64 \leq \text{destination} \leq PC+63$). 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 $PC \leftarrow PC + k + 1$, else $PC \leftarrow PC + 1$

Syntax:

(i) BRIE k

Operands:

$-64 \leq k \leq +63$

Program Counter:

$PC \leftarrow PC + k + 1$

$PC \leftarrow PC + 1$, if condition is false

16 bit Opcode:

1111	00kk	kkkk	k111
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

Example:

```

    brieinten    ; 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 ($PC-64 \leq \text{destination} \leq PC+63$). 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 $PC \leftarrow PC + k + 1$, else $PC \leftarrow PC + 1$

Syntax:

- (i) BRLO k

Operands:

$-64 \leq k \leq +63$

Program Counter:

$PC \leftarrow PC + k + 1$

$PC \leftarrow PC + 1$, 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 ($PC-64 \leq \text{destination} \leq PC+63$). 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 $PC \leftarrow PC + k + 1$, else $PC \leftarrow PC + 1$

Syntax:

- (i) BRLT k

Operands:

$-64 \leq k \leq +63$

Program Counter:

$PC \leftarrow PC + k + 1$

$PC \leftarrow PC + 1$, 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 ($PC-64 \leq \text{destination} \leq PC+63$). 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 $PC \leftarrow PC + k + 1$, else $PC \leftarrow PC + 1$

Syntax:

- (i) BRMI k

Operands:

$-64 \leq k \leq +63$

Program Counter:

$PC \leftarrow PC + k + 1$

$PC \leftarrow PC + 1$, if condition is false

16 bit Opcode:

1111	00kk	kkkk	k010
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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 ($PC-64 \leq \text{destination} \leq PC+63$). 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 $Rd \neq Rr$ ($Z = 0$) then $PC \leftarrow PC + k + 1$, else $PC \leftarrow PC + 1$

Syntax:

- (i) BRNE k

Operands:

$-64 \leq k \leq +63$

Program Counter:

$PC \leftarrow PC + k + 1$

$PC \leftarrow PC + 1$, if condition is false

16 bit Opcode:

1111	01kk	kkkk	k001
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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 ($PC-64 \leq \text{destination} \leq PC+63$). 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 $PC \leftarrow PC + k + 1$, else $PC \leftarrow PC + 1$

Syntax:

(i) BRPL k

Operands:

$-64 \leq k \leq +63$

Program Counter:

$PC \leftarrow PC + k + 1$

$PC \leftarrow PC + 1$, if condition is false

16 bit Opcode:

1111	01kk	kkkk	k010
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

Example:

```

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

Words: 1 (2 bytes)

Cycles: 1 if condition is false

2 if condition is true

BRSR - 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 ($PC-64 \leq \text{destination} \leq PC+63$). 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 $Rd \geq Rr$ ($C = 0$) then $PC \leftarrow PC + k + 1$, else $PC \leftarrow PC + 1$

Syntax:

- (i) BRSR k

Operands:

$-64 \leq k \leq +63$

Program Counter:

$PC \leftarrow PC + k + 1$

$PC \leftarrow PC + 1$, 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:

```

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 ($PC-64 \leq \text{destination} \leq PC+63$). 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 $PC \leftarrow PC + k + 1$, else $PC \leftarrow PC + 1$

Syntax:

- (i) BRTC k

Operands:

$-64 \leq k \leq +63$

Program Counter:

$PC \leftarrow PC + k + 1$

$PC \leftarrow PC + 1$, 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 ($PC-64 \leq \text{destination} \leq PC+63$). 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 $PC \leftarrow PC + k + 1$, else $PC \leftarrow PC + 1$

Syntax:

(i) BRTS k

Operands:

$-64 \leq k \leq +63$

Program Counter:

$PC \leftarrow PC + k + 1$

$PC \leftarrow PC + 1$, 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 ($PC-64 \leq \text{destination} \leq PC+63$). 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 $PC \leftarrow PC + k + 1$, else $PC \leftarrow PC + 1$

Syntax:

- (i) BRVC k

Operands:

$-64 \leq k \leq +63$

Program Counter:

$PC \leftarrow PC + k + 1$

$PC \leftarrow PC + 1$, if condition is false

16 bit Opcode:

1111	01kk	kkkk	k011
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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 ($PC-64 \leq \text{destination} \leq PC+63$). 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 $PC \leftarrow PC + k + 1$, else $PC \leftarrow PC + 1$

Syntax:

- (i) BRVS k

Operands:

$-64 \leq k \leq +63$

Program Counter:

$PC \leftarrow PC + k + 1$

$PC \leftarrow PC + 1$, if condition is false

16 bit Opcode:

1111	00kk	kkkk	k011
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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) $SREG(s) \leftarrow 1$

Syntax:

(i) BSET s

Operands:

$0 \leq s \leq 7$

Program Counter:

$PC \leftarrow PC + 1$

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) $T \leftarrow Rd(b)$

Syntax:

(i) BST Rd,b

Operands:

$0 \leq d \leq 31, 0 \leq b \leq 7$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1111	101d	dddd	xbbb
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

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).

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:

- (i) CALL k

Operands:

0 ≤ k ≤ 64K

Program Counter:Stack

PC ← kSTACK ← PC+2
SP ← SP-2, (2 bytes, 16 bits)

- (ii) CALL k

0 ≤ k ≤ 4M

PC ← kSTACK ← 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 Formulae:

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

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) $I/O(P,b) \leftarrow 0$

Syntax:

(i) CBI P,b

Operands:

$0 \leq P \leq 31, 0 \leq b \leq 7$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	1000	pppp	pbbb
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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) $Rd \leftarrow Rd \cdot (\$FF - K)$

Syntax:

(i) CBR Rd,K

Operands:

$16 \leq d \leq 31, 0 \leq K \leq 255$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode: See ANDI with K complemented.

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: $R7 \bullet R6 \bullet R5 \bullet R4 \bullet R3 \bullet R2 \bullet R1 \bullet R0$
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:

(i) CLC

Operands:

None

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	0100	1000	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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) $H \leftarrow 0$

Syntax:

(i) CLH

Operands:

None

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	0100	1101	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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) $I \leftarrow 0$

Syntax:

(i) CLI

Operands:

None

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	0100	1111	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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) $N \leftarrow 0$

Syntax:

(i) CLN

Operands:

None

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	0100	1010	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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:

(i) CLR Rd

Operands:

$0 \leq d \leq 31$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode: (see EOR Rd,Rd)

0010	01dd	dddd	dddd
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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) $S \leftarrow 0$

Syntax:

(i) CLS

Operands:

None

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	0100	1100	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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) $T \leftarrow 0$

Syntax:

(i) CLT

Operands:

None

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	0100	1110	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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) $V \leftarrow 0$

Syntax:

(i) CLV

Operands:

None

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	0100	1011	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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) $Z \leftarrow 0$

Syntax:

(i) CLZ

Operands:

None

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	0100	1001	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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) $Rd \leftarrow \$FF - Rd$

Syntax:

(i) COM Rd

Operands:

$0 \leq d \leq 31$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	010d	dddd	0000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

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

V: 0
Cleared.

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

Z: $R7 \bullet R6 \bullet R5 \bullet R4 \bullet R3 \bullet R2 \bullet R1 \bullet R0$
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:

(i) CP Rd,Rr

Operands:

$0 \leq d \leq 31, 0 \leq r \leq 31$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

0001	01rd	dddd	rrrr
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

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: $Rd7 \bullet \overline{Rd7} \bullet \overline{Rr7} + \overline{Rd7} \bullet Rr7 \bullet R7$
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: $Rd7 \bullet Rr7 + Rr7 \bullet R7 + R7 \bullet \overline{Rd7}$
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:

(i) CPC Rd,Rr

Operands:

$0 \leq d \leq 31, 0 \leq r \leq 31$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

0000	01rd	dddd	rrrr
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

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:

(i) CPI Rd,K

Operands:

$16 \leq d \leq 31, 0 \leq K \leq 255$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

0011	KKKK	dddd	KKKK
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

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: $\overline{Rd7} \bullet \overline{K7} + K7 \bullet R7 + R7 \bullet \overline{Rd7}$
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:

(i) CPSE Rd,Rr

Operands:

$0 \leq d \leq 31, 0 \leq r \leq 31$

Program Counter:

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 Formulae:

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

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:

(i) DEC Rd

Operands:

$0 \leq d \leq 31$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	010d	dddd	1010
------	------	------	------

Status Register and Boolean Formulae:

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

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

V: $R7 \bullet R6 \bullet R5 \bullet R4 \bullet R3 \bullet R2 \bullet R1 \bullet R0$
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: $R7 \bullet R6 \bullet R5 \bullet R4 \bullet R3 \bullet R2 \bullet R1 \bullet R0$
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

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:

(i) EOR Rd,Rr

Operands:

$0 \leq d \leq 31, 0 \leq r \leq 31$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

0010	01rd	dddd	rrrr
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

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

V: 0
Cleared

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

Z: $R7 \bullet R6 \bullet R5 \bullet R4 \bullet R3 \bullet R2 \bullet R1 \bullet R0$
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

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 current 64K words (128K bytes) section in the program memory space.

Operation:

- (i) $PC(15-0) \leftarrow Z(15-0)$ Devices with 16 bits PC, 128K bytes program memory maximum.
- (ii) $PC(15-0) \leftarrow Z(15-0)$ Devices with 22 bits PC, 8M bytes program memory maximum.
PC(21-16) is unchanged

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

16 bit Opcode:

1001	0101	XXXX	1001
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

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 current 64K words (128K bytes) section of program memory.

Operation:

- (i) $PC \leftarrow Z(15 - 0)$ Devices with 16 bits PC, 128K bytes program memory maximum.
- (ii) $PC(15-0) \leftarrow Z(15-0)$ Devices with 22 bits PC, 8M bytes program memory maximum.
PC(21-16) is unchanged

	Syntax:	Operands:	Program Counter:	Stack
(ii)	IJMP	None	See Operation	Not Affected
(iii)	IJMP	None	See Operation	Not Affected

16 bit Opcode:

1001	0100	XXXX	1001
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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 Port to Register

Description:

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

Operation:

(i) $Rd \leftarrow P$

Syntax:

(i) IN Rd,P

Operands:

$0 \leq d \leq 31, 0 \leq P \leq 63$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1011	0PPd	dddd	PPPP
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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:

(i) INC Rd

Operands:

$0 \leq d \leq 31$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	010d	dddd	0011
------	------	------	------

Status Register and Boolean Formulae:

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

S: $N \oplus V$

For signed tests.

V: $R7 \bullet R6 \bullet R5 \bullet R4 \bullet R3 \bullet R2 \bullet R1 \bullet R0$

Set if two's complement overflow resulted from the operation; cleared otherwise. Two's complement overflow occurs if and only if Rd was \$7F before the operation.

N: R7

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

Z: $R7 \bullet R6 \bullet R5 \bullet R4 \bullet R3 \bullet R2 \bullet R1 \bullet R0$

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) $PC \leftarrow k$

Syntax:

(i) JMP k

Operands:

$0 \leq k \leq 4M$

Program Counter:

$PC \leftarrow k$

Stack

Unchanged

32 bit Opcode:

1001	010k	kkkk	110k
kkkk	kkkk	kkkk	kkkk

Status Register (SREG) and Boolean Formulae:

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 SRAM to Register using Index X

Description:

Loads one byte indirect from SRAM to register. The SRAM location is pointed to by the X (16 bits) pointer register in the register file. Memory access is limited to the current SRAM page of 64K bytes. To access another SRAM page the RAMPX in register in the I/O area has to be changed.

The X pointer register can either be left unchanged after the operation, or it can be incremented or decremented. These features are especially suited for accessing arrays, tables, and stack pointer usage of the X pointer register.

Using the X pointer:

	Operation:	Comment:	
(i)	$Rd \leftarrow (X)$		X: Unchanged
(ii)	$Rd \leftarrow (X)$	$X \leftarrow X + 1$	X: Post incremented
(iii)	$X \leftarrow X - 1$	$Rd \leftarrow (X)$	X: Pre decremented
	Syntax:	Operands:	Program Counter:
(i)	LD Rd, X	$0 \leq d \leq 31$	$PC \leftarrow PC + 1$
(ii)	LD Rd, X+	$0 \leq d \leq 31$	$PC \leftarrow PC + 1$
(iii)	LD Rd, -X	$0 \leq d \leq 31$	$PC \leftarrow PC + 1$

16 bit Opcode :

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

Status Register (SREG) and Boolean Formulae:

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

Example:

```

clr   r27           ; Clear X high byte
ldi   r26,$20      ; Set X low byte to $20
ld    r0,X+        ; Load r0 with SRAM loc. $20(X post inc)
ld    r1,X         ; Load r1 with SRAM loc. $21
ldi   r26,$23      ; Set X low byte to $23
ld    r2,X         ; Load r2 with SRAM loc. $23
ld    r3,-X        ; Load r3 with SRAM loc. $22(X pre dec)

```

Words: 1 (2 bytes)

Cycles: 2

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

Description:

Loads one byte indirect with or without displacement from SRAM to register. The SRAM location is pointed to by the Y (16 bits) pointer register in the register file. Memory access is limited to the current SRAM page of 64K bytes. To access another SRAM page the RAMPY register in the I/O area has to be changed.

The Y pointer register can either be left unchanged after the operation, or it can be incremented or decremented. These features are especially suited for accessing arrays, tables, and stack pointer usage of the Y pointer register.

Using the Y pointer:

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

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

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 Formulae:

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

Example:

```

clr r29 ; Clear Y high byte
ldi r28,$20 ; Set Y low byte to $20
ld r0,Y+ ; Load r0 with SRAM loc. $20(Y post inc)
ld r1,Y ; Load r1 with SRAM loc. $21
ldi r28,$23 ; Set Y low byte to $23
ld r2,Y ; Load r2 with SRAM loc. $23
ld r3,-Y ; Load r3 with SRAM loc. $22(Y pre dec)
ldd r4,Y+2 ; Load r4 with SRAM loc. $24
    
```

Words: 1 (2 bytes)

Cycles: 2

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

Description:

Loads one byte indirectly with or without displacement from SRAM to register. The SRAM location is pointed to by the Z (16 bits) pointer register in the register file. Memory access is limited to the current SRAM page of 64K bytes. To access another SRAM page the RAMPZ register in the I/O area has to be changed.

The Z pointer register can either be left unchanged after the operation, or it can be incremented or 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.

For using the Z pointer for table lookup in program memory see the LPM instruction.

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	$0 \leq d \leq 31$	$PC \leftarrow PC + 1$
(ii)	LD Rd, Z+	$0 \leq d \leq 31$	$PC \leftarrow PC + 1$
(iii)	LD Rd, -Z	$0 \leq d \leq 31$	$PC \leftarrow PC + 1$
(iiii)	LDD Rd, Z+q	$0 \leq d \leq 31, 0 \leq q \leq 63$	$PC \leftarrow PC + 1$

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 Formulae:

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

Example:

```

clr r31 ; Clear Z high byte
ldi r30,$20 ; Set Z low byte to $20
ld r0,Z+ ; Load r0 with SRAM loc. $20(Z post inc)
ld r1,Z ; Load r1 with SRAM loc. $21
ldi r30,$23 ; Set Z low byte to $23
ld r2,Z ; Load r2 with SRAM loc. $23
ld r3,-Z ; Load r3 with SRAM loc. $22(Z pre dec)
ldd r4,Z+2 ; Load r4 with SRAM loc. $24
    
```

Words: 1 (2 bytes)

Cycles: 2

LDI - Load Immediate

Description:

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

Operation:

(i) $Rd \leftarrow K$

Syntax:

(i) LDI Rd,K

Operands:

$16 \leq d \leq 31, 0 \leq K \leq 255$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1110	KKKK	dddd	KKKK
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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 SRAM

Description:

Loads one byte from the SRAM to a Register. A 16-bit address must be supplied. Memory access is limited to the current SRAM Page of 64K bytes. The LDS instruction uses the RAMPZ register to access memory above 64K bytes.

Operation:

(i) $Rd \leftarrow (k)$

Syntax:

(i) LDS Rd,k

Operands:

$0 \leq d \leq 31, 0 \leq k \leq 65535$

Program Counter:

$PC \leftarrow PC + 2$

32 bit Opcode:

1001	000d	dddd	0000
kkkk	kkkk	kkkk	kkkk

Status Register (SREG) and Boolean Formulae:

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

Example:

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

Words: 2 (4 bytes)

Cycles: 3

LPM - Load Program Memory

Description:

Loads one byte pointed to by the Z register into register 0 (R0). This instruction features a 100% space effective constant initialization or constant data fetch. The program memory is organized in 16 bits words and the LSB of the Z (16 bits) pointer selects either low byte (0) or high byte (1). This instruction can address the first 64K bytes (32K words) of program memory.

Operation:
(i) $R0 \leftarrow (Z)$

Comment:
Z points to program memory

Syntax:
(i) LPM

Operands:
None

Program Counter:
 $PC \leftarrow PC + 1$

16 bit Opcode:

1001	0101	110X	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

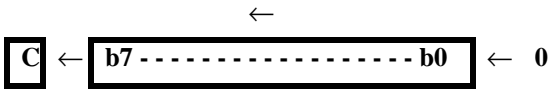
LSL - Logical Shift Left

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 an unsigned value by two.

Operation:

(i)



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

16 bit Opcode: (see ADD Rd,Rd)

0000	11dd	dddd	dddd
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

H: Rd3

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

V: $N \oplus C$ (For N and C after the shift)
Set if (N is set and C is clear) or (N is clear and C is set); Cleared otherwise (for values of N and C after the shift).

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

Z: $R7 \cdot R6 \cdot R5 \cdot R4 \cdot R3 \cdot R2 \cdot R1 \cdot R0$
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)

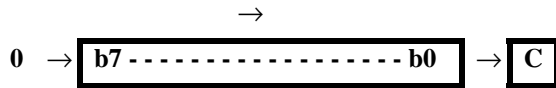
Cycles: 1

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:



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

16 bit Opcode:

1001	010d	dddd	0110
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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)
Set if (N is set and C is clear) or (N is clear and C is set); Cleared otherwise (for values of N and C after the shift).

N: 0

Z: $R7 \cdot R6 \cdot R5 \cdot R4 \cdot R3 \cdot R2 \cdot R1 \cdot R0$
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) $Rd \leftarrow Rr$

Syntax:

(i) MOV Rd,Rr

Operands:

$0 \leq d \leq 31, 0 \leq r \leq 31$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

0010	11rd	dddd	rrrr
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

```

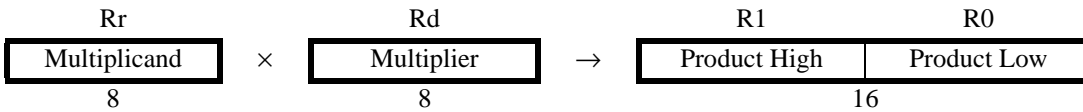
Words: 1 (2 bytes)

Cycles: 1

MUL - Multiply

Description:

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



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

Operation:

(i) $R1, R0 \leftarrow Rr \times Rd$

Syntax:

(i) MUL Rd,Rr

Operands:

$0 \leq d \leq 31, 0 \leq r \leq 31$

Program Counter:

$PC \leftarrow PC + 1$

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.

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

Example:

```
mulr6,r5; Multiply r6 and r5
movr6,r1; Copy result back in r6:r5
movr5,r0; Copy result back in r6:r5
```

Words: 1 (2 bytes)

Cycles: 2

Not available in base-line microcontrollers.



NEG - Two's Complement

Description:

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

Operation:

$$(i) \quad R_d \leftarrow \$00 - R_d$$

Syntax:

(i) NEG Rd

Operands:

$$0 \leq d \leq 31$$

Program Counter:

$$PC \leftarrow PC + 1$$

16 bit Opcode:

1001	010d	dddd	0001
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

H: $R_3 \bullet \overline{R_3}$
Set if there was a borrow from bit 3; cleared otherwise

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

V: $R_7 \bullet \overline{R_6} \bullet \overline{R_5} \bullet \overline{R_4} \bullet \overline{R_3} \bullet \overline{R_2} \bullet \overline{R_1} \bullet \overline{R_0}$
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: R_7
Set if MSB of the result is set; cleared otherwise.

Z: $\overline{R_7} \bullet \overline{R_6} \bullet \overline{R_5} \bullet \overline{R_4} \bullet \overline{R_3} \bullet \overline{R_2} \bullet \overline{R_1} \bullet \overline{R_0}$
Set if the result is \$00; Cleared otherwise.

C: $R_7 + R_6 + R_5 + R_4 + R_3 + R_2 + R_1 + R_0$
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:

(i) NOP

Operands:

None

Program Counter:

PC ← PC + 1

16 bit Opcode:

0000	0000	0000	0000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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) $Rd \leftarrow Rd \vee Rr$

Syntax:

(i) OR Rd,Rr

Operands:

$0 \leq d \leq 31, 0 \leq r \leq 31$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

0010	10rd	dddd	rrrr
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

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

V: 0
Cleared

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

Z: $R7 \cdot R6 \cdot R5 \cdot R4 \cdot R3 \cdot R2 \cdot R1 \cdot R0$
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:

(i) ORI Rd,K

Operands:

$16 \leq d \leq 31, 0 \leq K \leq 255$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

0110	KKKK	dddd	KKKK
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

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

V: 0
Cleared

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

Z: $R7 \cdot R6 \cdot R5 \cdot R4 \cdot R3 \cdot R2 \cdot R1 \cdot R0$
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 port

Description:

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

Operation:

(i) $P \leftarrow Rr$

Syntax:

(i) OUT P,Rr

Operands:

$0 \leq r \leq 31, 0 \leq P \leq 63$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1011	1PPr	rrrr	PPPP
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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.

Operation:

(i) $Rd \leftarrow \text{STACK}$

Syntax:

(i) POP Rd

Operands:

$0 \leq d \leq 31$

Program Counter:Stack

$PC \leftarrow PC + 1$ $SP \leftarrow SP + 1$

16 bit Opcode:

1001	000d	dddd	1111
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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.

Operation:

(i) $STACK \leftarrow Rr$

Syntax:

(i) PUSH Rr

Operands:

$0 \leq r \leq 31$

Program Counter:Stack:

$PC \leftarrow PC + 1$ $SP \leftarrow SP - 1$

16 bit Opcode:

1001	001d	dddd	1111
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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:

Calls a subroutine within $\pm 2K$ words (4K bytes). The return address (the instruction after the RCALL) is stored onto the stack. (See also CALL).

Operation:

- (i) $PC \leftarrow PC + k + 1$ Devices with 16 bits PC, 128K bytes program memory maximum.
- (ii) $PC \leftarrow PC + k + 1$ Devices with 22 bits PC, 8M bytes program memory maximum.

	Syntax:	Operands:	Program Counter:	Stack
(i)	RCALL k	$-2K \leq k \leq 2K$	$PC \leftarrow PC + k + 1$	STACK $\leftarrow PC+1$ SP $\leftarrow SP-2$ (2 bytes, 16 bits)
(ii)	RCALL k	$-2K \leq k \leq 2K$	$PC \leftarrow PC + k + 1$	STACK $\leftarrow PC+1$ SP $\leftarrow SP-3$ (3 bytes, 22 bits)

16 bit Opcode:

1101	kkkk	kkkk	kkkk
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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



RET - Return from Subroutine

Description:

Returns from subroutine. The return address is loaded from the STACK.

Operation:

- (i) PC(15-0) ← STACKDevices with 16 bits PC, 128K bytes program memory maximum.
- (ii) PC(21-0) ← STACKDevices with 22 bits PC, 8M bytes program memory maximum.

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

16 bit Opcode:

1001	0101	0XX0	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

RETI - Return from Interrupt

Description:

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

Operation:

- (i) PC(15-0) ← STACKDevices with 16 bits PC, 128K bytes program memory maximum.
- (ii) PC(21-0) ← STACKDevices 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	0XX1	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

RJMP - Relative Jump

Description:

Relative jump to an address within PC-2K 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:

(i) RJMP k

Operands:

$-2K \leq k \leq 2K$

Program Counter:

$PC \leftarrow PC + k + 1$

Stack

Unchanged

16 bit Opcode:

1100	kkkk	kkkk	kkkk
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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)

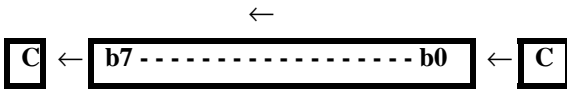
Cycles: 2

ROL - Rotate Left through 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.

Operation:



Syntax: ROL Rd
Operands: $0 \leq d \leq 31$
Program Counter: $PC \leftarrow PC + 1$

16 bit Opcode: (see ADC Rd,Rd)

0001	11dd	dddd	dddd
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

H: Rd3

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

V: $N \oplus C$ (For N and C after the shift)
 Set if (N is set and C is clear) or (N is clear and C is set); Cleared otherwise (for values of N and C after the shift).

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

Z: $R7 \bullet R6 \bullet R5 \bullet R4 \bullet R3 \bullet R2 \bullet R1 \bullet R0$
 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:

```

rolr15          ; Rotate left
brcsoneenc      ; Branch if carry set
...
oneenc:  nop    ; Branch destination (do nothing)
    
```

Words: 1 (2 bytes)

Cycles: 1

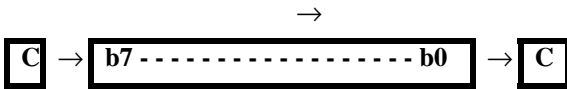


ROR - Rotate Right through Carry

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.

Operation:



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

16 bit Opcode:

1001	010d	dddd	0111
------	------	------	------

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)
Set if (N is set and C is clear) or (N is clear and C is set); Cleared otherwise (for values of N and C after the shift).

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

Z: $R7 \cdot R6 \cdot R5 \cdot R4 \cdot R3 \cdot R2 \cdot R1 \cdot R0$
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:

```

rorr15      ; Rotate right
brcczeroenc ; Branch if carry cleared
...
zeroenc:    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:

$$(i) \quad R_d \leftarrow R_d - R_r - C$$

Syntax:

(i) SBC Rd,Rr

Operands:

$0 \leq d \leq 31, 0 \leq r \leq 31$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

0000	10rd	dddd	rrrr
------	------	------	------

Status Register and Boolean Formulae:

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

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:

$$(i) \quad Rd \leftarrow Rd - K - C$$

Syntax:

(i) SBCI Rd,K

Operands:

$16 \leq d \leq 31, 0 \leq K \leq 255$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

0100	KKKK	dddd	KKKK
------	------	------	------

Status Register and Boolean Formulae:

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

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

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

V: $Rd7 \cdot \overline{K7} \cdot \overline{R7} + \overline{Rd7} \cdot K7 \cdot R7$
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: $\overline{R7} \cdot \overline{R6} \cdot \overline{R5} \cdot \overline{R4} \cdot \overline{R3} \cdot \overline{R2} \cdot \overline{R1} \cdot \overline{R0} \cdot Z$
Previous value remains unchanged when the result is zero; cleared otherwise.

C: $\overline{Rd7} \cdot \overline{K7} + K7 \cdot R7 + R7 \cdot \overline{Rd7}$
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) $I/O(P,b) \leftarrow 1$

Syntax:

(i) SBI P,b

Operands:

$0 \leq P \leq 31, 0 \leq b \leq 7$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	1010	pppp	pbbb
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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 $I/O(P,b) = 0$ then $PC \leftarrow PC + 2$ (or 3) else $PC \leftarrow PC + 1$

Syntax:

- (i) SBIC P,b

Operands:

$0 \leq P \leq 31, 0 \leq b \leq 7$

Program Counter:

$PC \leftarrow PC + 1$, If condition is false, no skip.
 $PC \leftarrow PC + 2$, If next instruction is one word.
 $PC \leftarrow PC + 3$, If next instruction is JMP or CALL

16 bit Opcode:

1001	1001	pppp	pbbb
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

Example:

```
e2wait: sbic $1C,1      ; Skip next inst. if EWE 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)

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 $I/O(P,b) = 1$ then $PC \leftarrow PC + 2$ (or 3) else $PC \leftarrow PC + 1$

Syntax:

- (i) SBIS P,b

Operands:

$0 \leq P \leq 31, 0 \leq b \leq 7$

Program Counter:

$PC \leftarrow PC + 1$, Condition false - no skip
 $PC \leftarrow PC + 2$, Skip a one word instruction
 $PC \leftarrow PC + 3$, Skip a JMP or a CALL

16 bit Opcode:

1001	1011	pppp	pbbb
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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)

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) $R_{dh}:R_{dl} \leftarrow R_{dh}:R_{dl} - K$

Syntax:

(i) SBIW Rdl,K

Operands:

$dl \in \{24,26,28,30\}, 0 \leq K \leq 63$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	0111	KKdd	KKKK
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

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

V: $R_{dh7} \bullet \overline{R15}$
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 ($R_{dh7}-R_{dh0} = R_{15}-R_8, R_{dl7}-R_{dl0}=R_7-R_0$).

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) $Rd \leftarrow Rd \vee K$

Syntax:

(i) SBR Rd,K

Operands:

$16 \leq d \leq 31, 0 \leq K \leq 255$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

0110	KKKK	dddd	KKKK
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

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

V: 0
Cleared

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

Z: $R7 \cdot R6 \cdot R5 \cdot R4 \cdot R3 \cdot R2 \cdot R1 \cdot R0$
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 $PC \leftarrow PC + 2$ (or 3) else $PC \leftarrow PC + 1$

Syntax:

- (i) SBRC Rr,b

Operands:

$0 \leq r \leq 31, 0 \leq b \leq 7$

Program Counter:

$PC \leftarrow PC + 1$, If condition is false, no skip.
 $PC \leftarrow PC + 2$, If next instruction is one word.
 $PC \leftarrow PC + 3$, If next instruction is JMP or CALL

16 bit Opcode:

1111	110r	rrrr	Xbbb
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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)

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 $PC \leftarrow PC + 2$ (or 3) else $PC \leftarrow PC + 1$

Syntax:

- (i) SBRS Rr,b

Operands:

$0 \leq r \leq 31, 0 \leq b \leq 7$

Program Counter:

$PC \leftarrow PC + 1$, Condition false - no skip
 $PC \leftarrow PC + 2$, Skip a one word instruction
 $PC \leftarrow PC + 3$, Skip a JMP or a CALL

16 bit Opcode:

1111	111r	rrrr	Xbbb
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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)

SEC - Set Carry Flag

Description:

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

Operation:

(i) $C \leftarrow 1$

Syntax:

(i) SEC

Operands:

None

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	0100	0000	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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) $H \leftarrow 1$

Syntax:

(i) SEH

Operands:

None

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	0100	0101	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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) $I \leftarrow 1$

Syntax:

(i) SEI

Operands:

None

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	0100	0111	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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) $N \leftarrow 1$

Syntax:

(i) SEN

Operands:

None

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	0100	0010	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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) $Rd \leftarrow \$FF$

Syntax:

(i) SER Rd

Operands:

$16 \leq d \leq 31$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1110	1111	dddd	1111
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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) $S \leftarrow 1$

Syntax:

(i) SES

Operands:

None

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	0100	0100	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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) $T \leftarrow 1$

Syntax:

(i) SET

Operands:

None

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	0100	0110	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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) $V \leftarrow 1$

Syntax:

(i) SEV

Operands:

None

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	0100	0011	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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:

(i) SEZ

Operands:

None

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	0100	0001	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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. When an interrupt wakes up the MCU from a sleep state, the instruction following the SLEEP instruction will be executed before the interrupt handler is executed.

Operation:

Syntax:

SLEEP

Operands:

None

Program Counter:

PC ← PC + 1

16 bit Opcode:

1001	0101	100X	1000
------	------	------	------

Status Register (SREG) and Boolean Formulae:

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

Example:

```

mov    r0,r11      ; Copy r11 to r0
sleep                ; Put MCU in sleep mode
    
```

Words: 1 (2 bytes)

Cycles: 1

ST - Store Indirect From Register to SRAM using Index X

Description:

Stores one byte indirect from Register to SRAM. The SRAM location is pointed to by the X (16 bits) pointer register in the register file. Memory access is limited to the current SRAM Page of 64K bytes. To access another SRAM page the RAMPX register in the I/O area has to be changed.

The X pointer register can either be left unchanged after the operation, or it can be incremented or decremented. These features are especially suited for stack pointer usage of the X pointer register.

Using the X pointer:

	Operation:		Comment:
(i)	$(X) \leftarrow Rr$		X: Unchanged
(ii)	$(X) \leftarrow Rr$	$X \leftarrow X+1$	X: Post incremented
(iii)	$X \leftarrow X - 1$	$(X) \leftarrow Rr$	X: Pre decremented
	Syntax:	Operands:	Program Counter:
(i)	ST X, Rr	$0 \leq r \leq 31$	$PC \leftarrow PC + 1$
(ii)	ST X+, Rr	$0 \leq r \leq 31$	$PC \leftarrow PC + 1$
(iii)	ST -X, Rr	$0 \leq r \leq 31$	$PC \leftarrow PC + 1$

16 bit Opcode :

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

Status Register (SREG) and Boolean Formulae:

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

Example:

```

clr    r27           ; Clear X high byte
ldi    r26,$20       ; Set X low byte to $20
st     X+,r0         ; Store r0 in SRAM loc. $20(X post inc)
st     X,r1          ; Store r1 in SRAM loc. $21
ldi    r26,$23       ; Set X low byte to $23
st     r2,X          ; Store r2 in SRAM loc. $23
st     r3,-X         ; Store r3 in SRAM loc. $22(X pre dec)

```

Words: 1 (2 bytes)

Cycles: 2

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

Description:

Stores one byte indirect with or without displacement from Register to SRAM. The SRAM location is pointed to by the Y (16 bits) pointer register in the register file. Memory access is limited to the current SRAM Page of 64K bytes. To access another SRAM page the RAMPY register in the I/O area has to be changed.

The Y pointer register can either be left unchanged after the operation, or it can be incremented or decremented. These features are especially suited for stack pointer usage of the Y pointer register.

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	$0 \leq r \leq 31$	$PC \leftarrow PC + 1$
(ii)	ST Y+, Rr	$0 \leq r \leq 31$	$PC \leftarrow PC + 1$
(iii)	ST -Y, Rr	$0 \leq r \leq 31$	$PC \leftarrow PC + 1$
(iiii)	STD Y+q, Rr	$0 \leq r \leq 31, 0 \leq q \leq 63$	$PC \leftarrow PC + 1$

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 Formulae:

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

Example:

```

clr    r29        ; Clear Y high byte
ldi    r28,$20    ; Set Y low byte to $20
st     Y+,r0      ; Store r0 in SRAM loc. $20(Y post inc)
st     Y,r1       ; Store r1 in SRAM loc. $21
ldi    r28,$23    ; Set Y low byte to $23
st     Y,r2       ; Store r2 in SRAM loc. $23
st     -Y,r3      ; Store r3 in SRAM loc. $22(Y pre dec)
std    Y+2,r4     ; Store r4 in SRAM loc. $24
    
```

Words: 1 (2 bytes)

Cycles: 2



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

Description:

Stores one byte indirect with or without displacement from Register to SRAM. The SRAM location is pointed to by the Z (16 bits) pointer register in the register file. Memory access is limited to the current SRAM Page of 64K bytes. To access another SRAM page the RAMPZ register in the I/O area has to be changed.

The Z pointer register can either be left unchanged after the operation, or it can be incremented or decremented. These features are very suited for stack pointer usage of the Z pointer register, but 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.

Using the Z pointer:

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

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

16 bit Opcode :

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

Status Register (SREG) and Boolean Formulae:

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

Example:

```

clr    r31        ; Clear Z high byte
ldi    r30,$20    ; Set Z low byte to $20
st     Z+,r0      ; Store r0 in SRAM loc. $20(Z post inc)
st     Z,r1       ; Store r1 in SRAM loc. $21
ldi    r30,$23    ; Set Z low byte to $23
st     Z,r2       ; Store r2 in SRAM loc. $23
st     -Z,r3      ; Store r3 in SRAM loc. $22(Z pre dec)
std    Z+2,r4     ; Store r4 in SRAM loc. $24

```

Words: 1 (2 bytes)

Cycles: 2

STS - Store Direct to SRAM

Description:

Stores one byte from a Register to the SRAM. A 16-bit address must be supplied. Memory access is limited to the current SRAM Page of 64K bytes. The SDS instruction uses the RAMPZ register to access memory above 64K bytes.

Operation:

(i) $(k) \leftarrow Rr$

Syntax:

(i) STS k,Rr

Operands:

$0 \leq r \leq 31, 0 \leq k \leq 65535$

Program Counter:

$PC \leftarrow PC + 2$

32 bit Opcode:

1001	001d	dddd	0000
kkkk	kkkk	kkkk	kkkk

Status Register (SREG) and Boolean Formulae:

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

Example:

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

Words: 2 (4 bytes)

Cycles: 3

SUB - Subtract without Carry

Description:

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

Operation:

(i) $Rd \leftarrow Rd - Rr$

Syntax:

(i) SUB Rd,Rr

Operands:

$0 \leq d \leq 31, 0 \leq r \leq 31$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

0001	10rd	dddd	rrrr
------	------	------	------

Status Register and Boolean Formulae:

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

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:

(i) SUBI Rd,K

Operands:

$16 \leq d \leq 31, 0 \leq K \leq 255$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

0101	KKKK	dddd	KKKK
------	------	------	------

Status Register and Boolean Formulae:

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

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:

```

subir22,$11      ; Subtract $11 from r22
brnnoteq        ; 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) $R(7-4) \leftarrow R(3-0)$, $R(3-0) \leftarrow R(7-4)$

Syntax:

(i) SWAP Rd

Operands:

$0 \leq d \leq 31$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

1001	010d	dddd	0010
------	------	------	------

Status Register and Boolean Formulae:

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) $Rd \leftarrow Rd \cdot Rd$

Syntax:

(i) TST Rd

Operands:

$0 \leq d \leq 31$

Program Counter:

$PC \leftarrow PC + 1$

16 bit Opcode:

0010	00dd	dddd	dddd
------	------	------	------

Status Register and Boolean Formulae:

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

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

V: 0
Cleared

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

Z: $R7 \cdot R6 \cdot R5 \cdot R4 \cdot R3 \cdot R2 \cdot R1 \cdot R0$
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:

- (i) WDR

Operands:

None

Program Counter:

PC ← PC + 1

16 bit Opcode:

1001	0101	101X	1000
------	------	------	------

Status Register and Boolean Formulae:

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

Example:

```
wdr ; Reset watchdog timer
```

Words: 1 (2 bytes)

Cycles: 1