LEGv8 Reference Data Card (“Green Card”) 1. Pull along perforation to separate card 2. Fold bottom side (columns 3 and 4) together

①

LEGv8 Reference Data

CORE INSTRUCTION SET in Alphabetical Order by Mnemonic

NAME	MNEMONIC	FOR-MAT	OPCODE (9) (Hex)	OPERATION (in Verilog)	Notes
ADD	ADD	R	458	R[Rd] = R[Rn] + R[Rm]	
ADD Immediate	ADDI	I	488-489	R[Rd] = R[Rn] + ALUImm	(2,9)
ADD Immediate & Set flags	ADDIS	I	588-589	R[Rd] , FLAGS = R[Rn] + ALUImm	(1,2,9)
ADD & Set flags	ADDS	R	558	R[Rd] , FLAGS = R[Rn] + R[Rm]	(1)
AND	AND	R	450	R[Rd] = R[Rn] & R[Rm]	
AND Immediate	ANDI	I	490-491	R[Rd] = R[Rn] & ALUImm	(2,9)
AND Immediate & Set flags	ANDIS	I	790-791	R[Rd] , FLAGS = R[Rn] & ALUImm	(1,2,9)
AND & Set flags	ANDS	R	750	R[Rd] , FLAGS = R[Rn] & R[Rm]	(1)
Branch	B	B	0A0-0BF	PC = PC + BranchAddr	(3,9)
Branch conditionally	B.cond	CB	2A0-2A7	if(FLAGS==cond) PC = PC + CondBranchAddr	(4,9)
Branch with Link	BL	B	4A0-4BF	R[30] = PC + 4; PC = PC + BranchAddr	(3,9)
Branch to Register	BR	R	6B0	PC = R[Rt]	
Compare & Branch if Not Zero	CBNZ	CB	5A8-5AF	if(R[Rt]!=0) PC = PC + CondBranchAddr	(4,9)
Compare & Branch if Zero	CBZ	CB	5A0-5A7	if(R[Rt]==0) PC = PC + CondBranchAddr	(4,9)
Exclusive OR	EOR	R	650	R[Rd] = R[Rn] ^ R[Rm]	
Exclusive OR Immediate	EORI	I	690-691	R[Rd] = R[Rn] ^ ALUImm	(2,9)
LoaD Register Unscaled offset	LDUR	D	7C2	R[Rt] = M[R[Rn] + DTAddr]	(5)
LoaD Byte Unscaled offset	LDURB	D	1C2	R[Rt]={56’b0, M[R[Rn] + DTAddr](7:0)}	(5)
LoaD Half Unscaled offset	LDURH	D	3C2	R[Rt]={48’b0, M[R[Rn] + DTAddr] (15:0)}	(5)
LoaD Signed Word Unscaled offset	LDURSW	D	5C4	R[Rt] ={ 32{ M[R[Rn] + DTAddr] [31]}, M[R[Rn] + DTAddr] (31:0)}	(5)
LoaD eXclusive Register	LDXR	D	642	R[Rd] = M[R[Rn] + DTAddr]	(5,7)
Logical Shift Left	LSL	R	69B	R[Rd] = R[Rn] << shamt	
Logical Shift Right	LSR	R	69A	R[Rd] = R[Rn] >>> shamt	
MOVe wide with Keep	MOVK	IM	794-797	R[Rd] (Instruction[22:21]*16: Instruction[22:21]*16-15) = MOVImm	(6,9)
MOVe wide with Zero	MOVZ	IM	694-697	R[Rd] = { MOVImm << (Instruction[22:21]*16) }	(6,9)
Inclusive OR	ORR	R	550	R[Rd] = R[Rn] | R[Rm]	
Inclusive OR Immediate	ORRI	I	590-591	R[Rd] = R[Rn] | ALUImm	(2,9)
STore Register Unscaled offset	STUR	D	7C0	M[R[Rn] + DTAddr] = R[Rt]	(5)
STore Byte Unscaled offset	STURB	D	1C0	M[R[Rn] + DTAddr](7:0) = R[Rt](7:0)	(5)
STore Half Unscaled offset	STURH	D	3C0	M[R[Rn] + DTAddr](15:0) = R[Rt](l5:0)	(5)
STore Word Unscaled offset	STURW	D	5C0	M[R[Rn] + DTAddr](31:0) = R[Rt](31:0)	(5)
STore eXclusive Register	STXR	D	640	M[R[Rn] + DTAddr] = R[Rt]; R[Rm] = (*atomic*) ? 0 : 1	(5,7)
SUBtract	SUB	R	658	R[Rd] = R[Rn] – R[Rm]	
SUBtract Immediate	SUBI	I	688-689	R[Rd] = R[Rn] – ALUImm	(2,9)
SUBtract Immediate & Set flags	SUBIS	I	788-789	R[Rd] , FLAGS = R[Rn] – ALUImm	(1,2,9)
SUBtract & Set flags	SUBS	R	758	R[Rd] , FLAGS = R[Rn] – R[Rm]	(1)

(1) FLAGS are 4 condition codes set by the ALU operation: Negative, Zero, oVerflow, Carry
(2) ALUImm = { 52’b0, ALU_immediate }
(3) BranchAddr = { 36{BR_address [25]}, BR_address, 2’b0 }
(4) CondBranchAddr = { 43{COND_BR_address [25]}, COND_BR_address, 2’b0 }
(5) DTAddr = { 55{DT_address [8]}, DT_address }
(6) MOVImm = { 48’b0, MOV_immediate }
(7) Atomic test&set pair; R[Rm] = 0 if pair atomic, 1 if not atomic
(8) Operands considered unsigned numbers (vs. 2’s complement)
(9) Since I, B, and CB instruction formats have opcodes narrower than 11 bits, they occupy a range of 11-bit opcodes
(10) If neither is operand a NaN and Value1 == Value2, FLAGS = 4’b0110;
If neither is operand a NaN and Value1 < Value2, FLAGS = 4’b1000;
If neither is operand a NaN and Value1 > Value2, FLAGS = 4’b0010;
If an operand is a Nan, operands are unordered

ARITHMETIC CORE INSTRUCTION SET ②

NAME	MNEMONIC	FOR-MAT	OPCODE/ SHAMT (Hex)	OPERATION (in Verilog)	Notes
Floating-point ADD Single	FADDS	R	0F1 / 0A	S[Rd] = S[Rn] + S[Rm]	
Floating-point ADD Double	FADDD	R	0F3 / 0A	D[Rd] = D[Rn] + D[Rm]	
Floating-point CoMPare Single	FCMPS	R	0F1 / 08	FLAGS = (S[Rn] vs S[Rm])	(1,10)
Floating-point CoMPare Double	FCMPD	R	0F3 / 08	FLAGS = (D[Rn] vs D[Rm])	(1,10)
Floating-point DIVide Single	FDIVS	R	0F1 / 06	S[Rd] = S[Rn] / S[Rm]	
Floating-point DIVide Double	FDIVD	R	0F3 / 06	D[Rd] = D[Rn] / D[Rm]	
Floating-point MULtiply Single	FMULS	R	0F1 / 02	S[Rd] = S[Rn] * S[Rm]	
Floating-point MULtiply Double	FMULD	R	0F3 / 02	D[Rd] = D[Rn] * D[Rm]	
Floating-point SUBtract Single	FSUBS	R	0F1 / 0E	S[Rd] = S[Rn] – S[Rm]	
Floating-point SUBtract Double	FSUBD	R	0F3 / 0E	D[Rd] = D[Rn] – D[Rm]	
LoaD Single floating-point	LDURS	R	7C2	S[Rt] = M[R[Rn] + DTAddr]	(5)
LoaD Double floating-point	LDURD	R	7C0	D[Rt] = M[R[Rn] + DTAddr]	(5)
MULtiply	MUL	R	4D8 / 1F	R[Rd] = (R[Rn] * R[Rm]) (63:0)	
Signed DIVide	SDIV	R	4D6 / 02	R[Rd] = R[Rn] / R[Rm]	
Signed MULtiply High	SMULH	R	4DA	R[Rd] = (R[Rn] * R[Rm]) (127:64)	
STore Single floating-point	STURS	R	7E2	M[R[Rn] + DTAddr] = S[Rt]	(5)
STore Double floating-point	STURD	R	7E0	M[R[Rn] + DTAddr] = D[Rt]	(5)
Unsigned DIVide	UDIV	R	4D6 / 03	R[Rd] = R[Rn] / R[Rm]	(8)
Unsigned MULtiply High	UMULH	R	4DE	R[Rd] = (R[Rn] * R[Rm]) (127:64)	(8)

CORE INSTRUCTION FORMATS

R	opcode (31–21) | Rm (20–16) | shamt (15–10) | Rn (9–5) | Rd (4–0)
I	opcode (31–22) | ALU_immediate (21–10) | Rn (9–5) | Rd (4–0)
D	opcode (31–21) | DT_address (20–12) | op (11–10) | Rn (9–5) | Rt (4–0)
B	opcode (31–26) | BR_address (25–0)
CB	Opcode (31–24) | COND_BR_address (23–5) | Rt (4–0)
IW	opcode (31–21) | MOV_immediate (20–5) | Rd (4–0)

PSEUDOINSTRUCTION SET

NAME	MNEMONIC	OPERATION
CoMPare	CMP	FLAGS = R[Rn] – R[Rm]
CoMPare Immediate	CMPI	FLAGS = R[Rn] – ALUImm
LoaD Address	LDA	R[Rd] = R[Rn] + DTAddr
MOVe	MOV	R[Rd] = R[Rn]

REGISTER NAME, NUMBER, USE, CALL CONVENTION

NAME	NUMBER	USE	PRESERVED ACROSS A CALL?
X0 – X7	0-7	Arguments / Results	No
X8	8	Indirect result location register	No
X9 – X15	9-15	Temporaries	No
X16 (IP0)	16	May be used by linker as a scratch register; other times used as temporary register	No
X17 (IP1)	17	May be used by linker as a scratch register; other times used as temporary register	No
X18	18	Platform register for platform independent code; otherwise a temporary register	No
X19-X27	19-27	Saved	Yes
X28 (SP)	28	Stack Pointer	Yes
X29 (FP)	29	Frame Pointer	Yes
X30 (LR)	30	Return Address	Yes
XZR	31	The Constant Value 0	N.A.

OPCODES IN NUMERICAL ORDER BY OPCODE ③

Instruction Mnemonic	Instruction Format	Opcode Width (bits)	Opcode Binary	Shamt Binary	11-bit Opcode Range (1) Start (Hex)	11-bit Opcode Range (1) End (Hex)
B	B	6	000101		0A0	0BF
FMULS	R	11	00011110001	000010	0F1	
FDIVS	R	11	00011110001	000110	0F1	
FCMPS	R	11	00011110001	001000	0F1	
FADDS	R	11	00011110001	001010	0F1	
FSUBS	R	11	00011110001	001110	0F1	
FMULD	R	11	00011110011	000010	0F3	
FDIVD	R	11	00011110011	000110	0F3	
FCMPD	R	11	00011110011	001000	0F3	
FADDD	R	11	00011110011	001010	0F3	
FSUBD	R	11	00011110011	001110	0F3	
STURB	D	11	00111000000		1C0	
LDURB	D	11	00111000010		1C2	
B.cond	CB	8	01010100		2A0	2A7
STURH	D	11	01111000000		3C0	
LDURH	D	11	01111000010		3C2	
AND	R	11	10001010000		450	
ADD	R	11	10001011000		458	
ADDI	I	10	1001000100		488	489
ANDI	I	10	1001001000		490	491
BL	B	6	100101		4A0	4BF
SDIV	R	11	10011010110	000010	4D6	
UDIV	R	11	10011010110	000011	4D6	
MUL	R	11	10011011000	011111	4D8	
SMULH	R	11	10011011010		4DA	
UMULH	R	11	10011011110		4DE	
ORR	R	11	10101010000		550	
ADDS	R	11	10101011000		558	
ADDIS	I	10	1011000100		588	589
ORRI	I	10	1011001000		590	591
CBZ	CB	8	10110100		5A0	5A7
CBNZ	CB	8	10110101		5A8	5AF
STURW	D	11	10111000000		5C0	
LDURSW	D	11	10111000100		5C4	
STURS	R	11	10111100000		5E0	
LDURS	R	11	10111100010		5E2	
STXR	D	11	11001000000		640	
LDXR	D	11	11001000010		642	
EOR	R	11	11001010000		650	
SUB	R	11	11001011000		658	
SUBI	I	10	1101000100		688	689
EORI	I	10	1101001000		690	691
MOVZ	IM	9	110100101		694	697
LSR	R	11	11010011010		69A	
LSL	R	11	11010011011		69B	
BR	R	11	11010110000		6B0	
ANDS	R	11	11101010000		750	
SUBS	R	11	11101011000		758	
SUBIS	I	10	1111000100		788	789
ANDIS	I	10	1111001000		790	791
MOVK	IM	9	111100101		794	797
STUR	D	11	11111000000		7C0	
LDUR	D	11	11111000010		7C2	
STURD	R	11	11111100000		7E0	
LDURD	R	11	11111100010		7E2	

(1) Since I, B, and CB instruction formats have opcodes narrower than 11 bits, they occupy a range of 11-bit opcodes, e.g., the 6-bit B format occupies 32 (2^5) 11-bit opcodes.

IEEE 754 FLOATING-POINT STANDARD ④

$(-1)^S \times (1 + \text{Fraction}) \times 2^{(\text{Exponent - Bias})}$

where Single Precision Bias = 127, Double Precision Bias = 1023

IEEE 754 Symbols

Exponent	Fraction	Object
0	0	± 0
0	≠ 0	± Denorm
1 to MAX - 1	anything	± Fl. Pt. Num.
MAX	0	± ∞
MAX	≠ 0	NaN

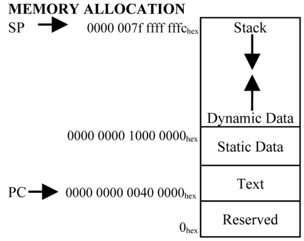
S.P. MAX = 255, D.P. MAX = 2047

IEEE Single Precision and Double Precision Formats:

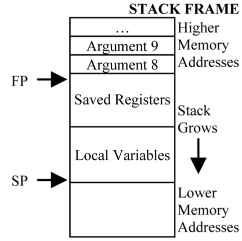
S	Exponent	Fraction
31	30 – 23	22 – 0

S	Exponent	Fraction
63	62 – 52	51 – 0

MEMORY ALLOCATION



STACK FRAME



DATA ALIGNMENT

Double Word							
Word				Word			
Halfword		Halfword		Halfword		Halfword	
Byte	Byte	Byte	Byte	Byte	Byte	Byte	Byte
0	1	2	3	4	5	6	7

Value of three least significant bits of byte address (Big Endian)

EXCEPTION SYNDROME REGISTER (ESR)

Exception Class (EC)	Instruction Length (IL)	Instruction Specific Syndrome field (ISS)
31 – 26	25	24 – 0

EXCEPTION CLASS

EC	Class	Cause of Exception	Number	Name	Cause of Exception
0	Unknown	Unknown	34	PC	Misaligned PC exception
7	SIMD	SIMD/FP registers disabled	36	Data	Data Abort
14	FPE	Illegal Execution State	40	FPE	Floating-point exception
17	Sys	Supervisor Call Exception	52	WPT	Data Breakpoint exception
32	Instr	Instruction Abort	56	BKPT	SW Breakpoint Exception

SIZE PREFIXES AND SYMBOLS

SIZE	PREFIX	SYMBOL	SIZE	PREFIX	SYMBOL
10^3	Kilo-	K	2^{10}	Kibi-	Ki
10^6	Mega-	M	2^{20}	Mebi-	Mi
10^9	Giga-	G	2^{30}	Gibi-	Gi
10^{12}	Tera-	T	2^{40}	Tebi-	Ti
10^{15}	Peta-	P	2^{50}	Pebi-	Pi
10^{18}	Exa-	E	2^{60}	Exbi-	Ei
10^{21}	Zetta-	Z	2^{70}	Zebi-	Zi
10^{24}	Yotta-	Y	2^{80}	Yobi-	Yi
10^{-3}	milli-	m	10^{-15}	femto-	f
10^{-6}	micro-	μ	10^{-18}	atto-	a
10^{-9}	nano-	n	10^{-21}	zepto-	z
10^{-12}	pico-	p	10^{-24}	yocto-	y

LEGv8 Reference Data Card ("Green Card") 1. Pull along perforation to separate card 2. Fold bottom side (columns 3 and 4) together