

Universidade de Brasília Instituto de Ciências Exatas Dpto. Ciência da Computação Organização e Arquitetura de Computadores

# Projeto da Disciplina - RISC-V Uniciclo em VHDL

José Roberto Interaminense Soares 19/0130008 Emanuel Firmino Abrantes 19/0105747 O trabalho teve o objetivo de desenvolver uma versão do processador Risc-V na arquitetura uniciclo utilizando a linguagem de descrição de hardware VHDL. A ferramenta utilizada para desenvolvimento foi o ModelSim, compilando os arquivos na versão de 1076-2008.

As operações implementadas foram as seguintes:

Geração de constantes: AUIPC, LUI

• Aritméticas: ADD, SUB

Aritméticas com imediato: ADDi

Shift: SLL, SRL, SRAComparação: SLT, SLTu

Comparação com imediato: SLTi, SLTUi

Subrotinas: JAL, JALRSaltos 1: BEQ, BNEMemória: LW, SW

### O diagrama esquemático utilizado será o seguinte:

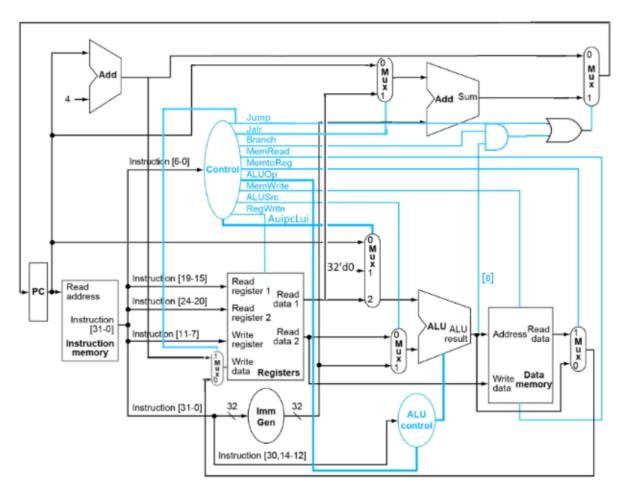


Figura 1.0: esquema do riscV

Existem portanto 10 sinais de controles, onde da arquitetura original, foram adicionados 3: Jump, JalR, e AuipcLui, que habilitam ou desabilitam os componentes para realizar tais operações.

Os módulos desenvolvidos (em VHDL), que compõem o modelo do RISCV Uniciclo ilustrado acima, são:

Somador;

Soma duas entradas e retorna valor da soma em std logic vector.

Multiplexador 2 para 1;

Recebe duas entradas e um seletor, e retorna multiplexação.

Multiplexador 3 para 1;

Recebe três entradas e um seletor, e retorna multiplexação.

Controle da ULA;

Recebe a operação da ULA, funct3 e funct7, retorna opcode.

ULA (Unidade Lógico/Aritmética);

Recebe o opcode do controle, e realiza a operação.

• Gerador de Imediatos de 32 bits;

Recebe instrução, faz máscara e shift e retorna o imediato.

Banco de Registradores (32 registradores de 32 bits);

Escreve ou lê dos registradores.

• Controle de Sinais:

Faz o controle dos mux

PC (Contador de Programa);

Representa o bloco PC.

Memória de Dados;

Lê arquivo de texto que contém memória de dados.

Memória de instruções.

Lê arquivo de texto que contém as instruções a serem executadas.

E cada um foi devidamente testado individualmente.

## Teste inicial para as instruções ADDi e SUB

Com o objetivo de verificar o pleno funcionamento das instruções 'addi' e 'sub', o breve trecho de código apresentado abaixo foi elaborado para tal finalidade:

```
.text

addi t1, t1, 5
addi t2, t2, 1
sub t3, t2, t1
```

Figura 2.1: código de teste para as instruções addi e sub.

Com a utilização do ModelSim, foi possível obter o resultado das formas de ondas geradas pelo RISCV Uniciclo desenvolvido, como apresentado abaixo:

	Msgs							
/dk	1							
/pc_i/d_out	00000010	00000000		00000004		00000008		0000000C
/xreg_i/xreg(6)	00000005	00000000		00000005				
/xreg_i/xreg(7)	00000001	00000000				00000001		
/xreg_i/xreg(28)	FFFFFFFC	00000000						FFFFFFC
· ·								

Figura 2.2: formas de onda geradas pelo processador, obtidas por intermédio do software ModelSim.

### Onde:

xreg(6) equivale ao registrador temporário t1;

xreg(7) equivale ao registrador temporário t2;

xreg(28) equivale ao registrador temporário t3.

### **Teste Geral**

Em um programa real, várias instruções serão utilizadas. Para teste, foi feito um programa com todas as instruções que o processador construído consegue suportar. O programa pode ser visto a seguir:

```
Programa teste
.data
                                     0x00000002
       num_test:
                      .word
.text
teste:
       addi t1, t1, 4
       lw t2, num test
       add t3, t1, t2
       sub t1, t2, t3
       slt t3, t1, t2
       sltu t2, t1, t3
       sra t2, t1, t3
       slti t2, t2, 1
       sll t2, t2, t2
       lui t1, 0x00001
       srl t1, t1, t2
       auipc t3, 0x00000
       beq t1, t3, teste
       addi t1, zero, 2
       bne t1, t2, teste
       jal teste2
teste2:
       jalr t1, zero, 0
```

Os resultados de t1, t2 e t3 a cada instrução foram retirados do Rars e serão comparados com o formato de onda do simulador.

Bkpt	Address	Code	Basic		Source
	0x00000000	0x00430313	addi x6,x6,4	7:	addi tl, tl, 4
	0x00000004	0x00002397	auipc x7,2	9:	lw t2, num_test
	0x00000008	0xffc3a383	lw x7,0xfffffffc(x7)		
	0x0000000c	0x00730e33	add x28,x6,x7	11:	add t3, t1, t2
	0x00000010	0x41c38333	sub x6,x7,x28	13:	sub t1, t2, t3
	0x00000014	0x00732e33	slt x28,x6,x7	15:	slt t3, t1, t2
	0x00000018	0x01c333b3	sltu x7,x6,x28	17:	sltu t2, t1, t3
	0x0000001c	0x41c353b3	sra x7,x6,x28	19:	sra t2, t1, t3
	0x00000020	0x0013a393	slti x7,x7,1	21:	slti t2, t2, 1
	0x00000024	0x007393b3	sll x7,x7,x7	23:	sl1 t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25:	lui tl, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27:	srl tl, tl, t2
	0x00000030	0x00000e17	auipc x28,0	29:	auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xffffffcc	31:	beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33:	addi tl, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xffffffc4	35:	bne tl, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37:	jal teste2
	0x00000044	0x00000367	jalr x6,x0,0	41:	jalr tl, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
ap	2	0x00003ffc
ab	3	0x00001800
tp	4	0x00000000
t0	5	0x000000x0
tl	6	0x00000000
t2	7	0x00000000
30	8	0x00000000
sl	9	0x000000x0
a0	10	0x00000000
al	11	0x00000000
a2	12	0x00000000
a3	13	0x00000000
a 4	14	0x00000000
a5	15	0x00000000
a6	16	0x00000000
a7	17	0x00000000
52	18	0x00000000
53	19	0x00000000
s 4	20	0x00000000
s5	21	0x00000000
s6	22	0x00000000
s7	23	0x00000000
58	24	0x00000000
59	25	0x00000000
s10	26	0x00000000
511	27	0x00000000
t3	28	0x00000000
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000000

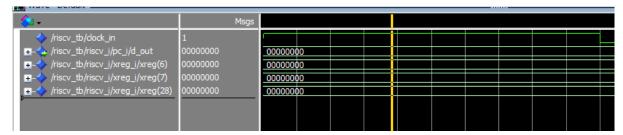


Figura 3.1: execução da instrução addi t1, t1, 4; estado dos registradores; formas de ondas obtidas.

Bkpt	Address	Code	Basic		Source
	0x000000000	0x00430313	addi x6,x6,4	7:	addi tl, tl, 4
	0x00000004	0x00002397	auipc x7,2	9:	lw t2, num_test
	0x00000008	0xffc3a383	lw x7,0xfffffffc(x7)		
	0x0000000c	0x00730e33	add x28,x6,x7	11:	add t3, t1, t2
	0x00000010	0x41c38333	sub x6,x7,x28	13:	sub t1, t2, t3
	0x00000014	0x00732e33	slt x28,x6,x7	15:	slt t3, t1, t2
	0x00000018	0x01c333b3	sltu x7,x6,x28	17:	sltu t2, t1, t3
	0x0000001c	0x41c353b3	sra x7,x6,x28	19:	sra t2, t1, t3
	0x00000020	0x0013a393	slti x7,x7,l	21:	slti t2, t2, 1
	0x00000024	0x007393b3	sll x7,x7,x7	23:	sl1 t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25:	lui tl, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27:	srl tl, tl, t2
	0x00000030	0x00000e17	auipc x28,0	29:	auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xffffffcc	31:	beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33:	addi tl, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xffffffc4	35:	bne t1, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37:	jal teste2
	0x00000044	0x00000367	jalr x6,x0,0	41:	jalr tl, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
tl	6	0x00000004
t2	7	0x00000000
s0	8	0x00000000
sl	9	0x00000000
a0	10	0x00000000
al	11	0x00000000
a2	12	0x00000000
a3	13	0x00000000
a4	14	0x00000000
a5	15	0x00000000
аб	16	0x00000000
a7	17	0x00000000
s2	18	0x00000000
s3	19	0x00000000
s4	20	0x00000000
s5	21	0x00000000
s6	22	0x00000000
<b>s</b> 7	23	0x00000000
s8	24	0x00000000
s9	25	0x00000000
s10	26	0x00000000
sll	27	0x00000000
t3	28	0x00000000
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000004

Wave - Default						- 200000						
<b>≨</b> 1 •	Msgs											
/riscv_tb/clock_in	1											
<pre>#-</pre> /riscv_tb/riscv_i/pc_i/d_out	00000004	000000	00					000000	04			
	00000004	000000	00					000000	04			
_ , _ , _ , _ , _ , _ , _ , _ , _ , _ ,	00000000	000000	00									
	00000000	000000	00									

**Figura 3.2:** execução da instrução auipc, que calcula o endereço de num\_test; estado dos registradores; formas de ondas obtidas.

Bkpt	Address	Code	Basic		Source
	0x00000000	0x00430313	addi x6,x6,4	7:	addi tl, tl, 4
	0x00000004	0x00002397	auipc x7,2	9:	lw t2, num_test
	0x00000008	0xffc3a383	lw x7,0xfffffffc(x7)		
	0x0000000c	0x00730e33	add x28,x6,x7	11:	add t3, t1, t2
	0x00000010	0x41c38333	sub x6,x7,x28	13:	sub t1, t2, t3
	0x00000014	0x00732e33	slt x28,x6,x7	15:	slt t3, t1, t2
	0x00000018	0x01c333b3	sltu x7,x6,x28	17:	sltu t2, t1, t3
	0x0000001c	0x41c353b3	sra x7,x6,x28	19:	sra t2, t1, t3
	0x00000020	0x0013a393	slti x7,x7,l	21:	slti t2, t2, 1
	0x00000024	0x007393b3	sll x7,x7,x7	23:	sl1 t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25:	lui tl, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27:	srl tl, tl, t2
	0x00000030	0x00000e17	auipc x28,0	29:	auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xffffffcc	31:	beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33:	addi tl, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xffffffc4	35:	bne t1, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37:	jal teste2
	0x00000044	0x00000367	jalr x6,x0,0	41:	jalr tl, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
tl	6	0x00000004
t2	7	0x00002004
<b>s</b> 0	8	0x00000000
sl	9	0x00000000
a0	10	0x00000000
al	11	0x00000000
a2	12	0x00000000
a3	13	0x00000000
a4	14	0x00000000
a5	15	0x00000000
a6	16	0x00000000
a7	17	0x00000000
s2	18	0x00000000
s3	19	0x00000000
s4	20	0x00000000
s5	21	0x00000000
s6	22	0x00000000
s7	23	0x00000000
s8	24	0x00000000
s9	25	0x00000000
s10	26	0x00000000
sll	27	0x00000000
t3	28	0x00000000
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000008

Wave - Default					= >>>>=					
<b>€</b> 1 +	Msgs									
<pre>//riscv_tb/clock_in</pre>	1									
_ /riscv_tb/riscv_i/pc_i/d_out	00000008	00000004					000000	08		
	00000004	00000004								
<u>+</u> → /riscv_tb/riscv_i/xreg_i/xreg(7)	00002004	00000000					000020	04		
/riscv_tb/riscv_i/xreg_i/xreg(28)	00000000	00000000								

**Figura 3.3:** execução da instrução lw t2, num\_test; estado dos registradores; formas de ondas obtidas.

Text Segment	1.14	0-4-	Pasia		0
Bkpt	Address 0x000000000	Code 0x00430313	Basic Baddi x6,x6,4	7:	Source addi t1, t1, 4
	0x00000004	0x00002397	auipc x7,2	9:	lw t2, num_test
	0x00000008 0x0000000c		lw x7,0xffffffffc(x7) add x28,x6,x7	11:	add t3, t1, t2
	0x00000000		sub x6,x7,x28	13:	sub t1, t2, t3
	0x00000014 0x00000018		slt x28,x6,x7 sltu x7,x6,x28	15: 17:	slt t3, t1, t2 sltu t2, t1, t3
	0x0000001c		sra x7,x6,x28	19:	sra t2, t1, t3
	0x00000020 0x00000024		3 slti x7,x7,1 3 sl1 x7,x7,x7	21:	slti t2, t2, 1 sl1 t2, t2, t2
	0x00000024	0x00001337		25:	lui t1, 0x00001
	0x0000002c 0x00000030		srl x6,x6,x7 auipc x28,0	27:	srl tl, tl, t2 auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xffffffcc	31:	beq t1, t3, teste
	0x00000038 0x0000003c		addi x6,x0,2 bne x6,x7,0xffffffc4	33: 35:	addi tl, zero, 2 bne tl, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37:	jal teste2
	0x00000044	0x00000367	jalr x6,x0,0	41:	jalr tl, zero, 0
	Name	Num	nber		Value
ero			0		0x000000
a			1		0x000000
р			2		0x00003f
р			3		0x000018
p			4		0x000000
0			5		0x000000
1			6		0x000000
2			7		0x000000
0			8		0x000000
1			9		0x000000
0			10		0x000000
1			11		0x000000
2			12		0x000000
3			13		0x000000
4			14		0x000000
5			15		0x000000
6			16		0x000000
7			17		0x000000
2			18		0x000000
3			19		0x000000
4			20		0x000000
5			21		0x000000
6			22		0x000000
7			23		0x000000
8			24		0x000000
9			25		0x000000
10			26		0x000000
11			27		0x000000
3			28		0x000000
4			29		0x000000
5			30		0x000000
6			31		0x000000
С					0x000000
				_	
Wave - Default ==		Maga		<i>'''''</i> '	
/riscv_tb/clocl	k_in 1	Msgs			
/HSCV_tD/GOG					
- /riscv tb/riscv	/ i/pc i/d out10000000C	00000008			I 0000000C
→ /riscv_tb/riscv  → /riscv_tb/riscv		00000008			(000000C

Figura 3.4: execução da instrução add t3, t1, t2; estado dos registradores; formas de ondas obtidas.

Text Segment	Address	Code Book	Sauras
Bkpt	Address 0x00000000	Code Basic 0x00430313 addi x6,x6,4	7: addi tl, tl, 4
	0x00000004	0x00002397 auipc x7,2	9: lw t2, num_test
	0x00000008 0x0000000c	0xffc3a383 lw x7,0xfffffffc(x7) 0x00730e33 add x28,x6,x7	11: add t3, t1, t2
	0x00000000	0x41c38333 sub x6,x7,x28	13: sub t1, t2, t3
	0x00000014	0x00732e33 slt x28,x6,x7	15: slt t3, t1, t2
	0x00000018 0x0000001c	0x01c333b3 sltu x7,x6,x28 0x41c353b3 sra x7,x6,x28	17: sltu t2, t1, t3 19: sra t2, t1, t3
	0x00000020	0x0013a393 slti x7,x7,1	21: slti t2, t2, 1
	0x00000024 0x00000028	0x007393b3 sll x7,x7,x7 0x00001337 lui x6,1	23: sll t2, t2, t2 25: lui t1, 0x00001
	0x0000002c	0x00735333 srl x6,x6,x7	27: srl tl, tl, t2
	0x00000030	0x00000e17 auipc x28,0	29: auipc t3, 0x00000
	0x00000034 0x00000038	0xfdc306e3 beq x6,x28,0xfffffffcc 0x00200313 addi x6,x0,2	31: beq t1, t3, teste 33: addi t1, zero, 2
	0x0000003c	0xfc7312e3 bne x6,x7,0xffffffc4	35: bne t1, t2, teste
	0x00000040 0x00000044	0x004000ef jal x1,0x00000004 0x00000367 jalr x6,x0,0	37: jal teste2 41: jalr tl, zero, 0
	Nama	Number	Value
	Name	Number	Value
ero		0	0x00000
`a		1	0x00000
p		2	0x00003
p		3	0x00001
p		4	0x00000
0		5	0x00000
1		6	0x00000
2		7	0x00000
0		8	0x00000
1		9	0x00000
10		10	0x00000
1		11	0x00000
2		12	0x00000
. <u> </u>		13	0x00000
4		14	0x00000
5		15	0x00000
.6		16	0x00000
.7		17	0x00000
2		18	0x00000
3		19	0x00000
4		20	0x00000
5		21	0x00000
6		22	0x00000
7		23	
8		24	0x00000
9		25	
10		26	
11		27	0x00000
:3		28	0x00000
.4		29	0x00000
:5		30	0x00000
:6		31	0x00000
С			0x00000

THE PERSON								
<b>≨</b> 1 <b>→</b>	Msgs							
<pre>/riscv_tb/clock_in</pre>	1							
<b>I</b> —	0000000C	000000C			000000	10		
→ /riscv_tb/riscv_i/xreg_i/xreg(6)	00000004	00000004						
_ •	00000002	00000002						
/riscv_tb/riscv_i/xreg_i/xreg(28)	00000000	00000000			000000	06		
<u> </u>								

Figura 3.5: execução da instrução sub t1, t2, t3; estado dos registradores; formas de ondas obtidas.

Bkpt	Address				
	Addless	Code	Basic		Source
	0x00000000	0x00430313	addi x6,x6,4	7:	addi tl, tl, 4
	0x0000004	0x00002397	auipc x7,2	9:	lw t2, num_test
	80000000x0	0xffc3a383	N x7,0xfffffffc(x7)		
	0x000000c	0x00730e33	3 add x28,x6,x7	11:	add t3, t1, t2
	0x00000010	0x41c38333	sub x6,x7,x28	13:	sub t1, t2, t3
	0x00000014	0x00732e33	slt x28,x6,x7	15:	slt t3, t1, t2
	0x00000018	0x01c333b3	sltu x7,x6,x28	17:	sltu t2, t1, t3
	0x0000001c	0x41c353b3	sra x7,x6,x28	19:	sra t2, t1, t3
	0x00000020	0x0013a393	3 slti x7,x7,1	21:	slti t2, t2, 1
	0x00000024	0x007393b3	3 sll x7,x7,x7	23:	sll t2, t2, t2
	0x00000028	0x00001337	7 lui x6,1	25:	lui tl, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27:	srl tl, tl, t2
	0x00000030	0x00000e17	auipc x28,0	29:	auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xffffffcc	31:	beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33:	addi tl, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xffffffc4	35:	bne t1, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37:	jal teste2

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
tl	6	0xffffffc
t2	7	0x00000002
s0	8	0x00000000
sl	9	0x00000000
a0	10	0x00000000
al	11	0x00000000
a2	12	0x00000000
a3	13	0x00000000
a4	14	0x00000000
a5	15	0x00000000
a6	16	0x00000000
a7	17	0x00000000
s2	18	0x00000000
s3	19	0x00000000
s4	20	0x00000000
s5	21	0x00000000
s6	22	0x00000000
s7	23	0x00000000
s8	24	0x00000000
s9	25	0x00000000
s10	26	0x00000000
sll	27	0x00000000
t3	28	0x00000006
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000014

Wave - Default	Wave - Default													
<b>&amp;</b> 1 →	Msgs													
<pre>/riscv_tb/clock_in</pre>	1													
+- /riscv_tb/riscv_i/pc_i/d_out	000000C	000000	10								000000	14		
	00000004	000000	04								FFFFFF	FC		
#- /riscv_tb/riscv_i/xreg_i/xreg(7)	00000002	000000	02											
riscv_tb/riscv_i/xreg_i/xreg(28)	00000000	000000	06											

Figura 3.6: execução da instrução addi t1, t1, 4; estado dos registradores; formas de ondas obtidas.

		0x0000008 0x0000000c 0x00000010	0xffc3a383 w x7,0xfffffffc(x7) 0x00730e33 add x28,x6,x7 0x41c38333 sub x6,x7,x28	11: 13:	add t3, t1, t2 sub t1, t2, t3
		0x00000014	0x00732e33 slt x28,x6,x7	15:	slt t3, t1, t2
		0x0000001c	0x41c353b3 sra x7,x6,x28	19:	sra t2, t1, t3
		0x00000024	0x007393b3 sll x7,x7,x7	23:	s11 t2, t2, t2
		0x00000028	0x00001337 lui x6,1	25:	lui tl, 0x00001
		0x00000030	0x00000e17 auipc x28,0	29:	auipc t3, 0x00000
Name   Number   Value		0x00000038	0x00200313 addi x6,x0,2	33:	addi tl, zero, 2
Name   Number   Value			0xfc7312e3 bne x6,x7,0xffffffc4	37:	bne tl, t2, teste
sero         0         0x00000           ca         1         0x00000           spp         2         0x00000           spp         3         0x00000           spp         4         0x00000           spp         4         0x00000           spp         4         0x00000           spp         5         0x00000           spp         8         0x00000           spp         9         0x00000           spp         0x00000         10         0x00000           spp         0x00000         11         0x00000           spp         0x00000         11         0x00000           spp         0x00000         12         0x00000           spp         0x00000         0x00000         0x00000           spp         0x000000         0x00000           <			0x00000367 ialr x6,x0,0	41:	jalr tl, zero, 0
ra       1       0x000000         rp       2       0x000000         rp       3       0x000000         rp       4       0x000000         rp       5       0x000000         rp       6       0xffffff         rp       7       0x000000         rp       0x000000       8       0x000000         rp       0x000000       10       0x000000         rp       0x000000       11       0x000000         rp       0x000000       11       0x000000         rp       0x000000       11       0x000000         rp       0x000000       12       0x000000         rp       0x000000       12       0x000000         rp       0x0000000       0x000000       0x000000         rp       0x00000000000000000000000000000000000					
					0x0000000
3					0x0000000
tp         4         0x00000           t0         5         0x00000           t1         6         0xfffff           t2         7         0x00000           s0         8         0x00000           s1         9         0x00000           a0         10         0x00000           a1         11         0x00000           a2         12         0x00000           a3         13         0x00000           a4         14         0x00000           a5         15         0x00000           a6         16         0x00000           a7         17         0x00000           s2         18         0x00000           s4         20         0x00000           s4         20         0x00000           s5         21         0x00000           s6         22         0x00000           s7         23         0x00000           s8         24         0x00000           s9         25         0x00000           s10         26         0x00000           s11         27         0x00000           s12	зр				0x00003ff
to         5         0x00000           tl         6         0xfffff           t2         7         0x00000           s0         8         0x00000           s1         9         0x00000           a0         10         0x00000           a1         11         0x00000           a2         12         0x00000           a3         13         0x00000           a4         14         0x00000           a5         15         0x00000           a6         16         0x00000           a7         17         0x00000           s2         18         0x00000           s4         20         0x00000           s5         21         0x00000           s6         22         0x00000           s7         23         0x00000           s8         24         0x00000           s9         25         0x00000           s9         25         0x00000           s11         27         0x00000           t3         28         0x00000           t4         29         0x00000           t5					0x0000180
til 6 0xffffff t2 7 0x00000 s0 8 0x00000 s1 9 0x00000 a0 10 0x00000 a1 11 0x00000 a2 12 0x00000 a3 13 0x00000 a4 14 0x00000 a5 15 0x00000 a6 16 0x00000 a7 17 0x00000 a9 18 0x00000 s2 18 0x00000 s3 19 0x00000 s4 20 0x00000 s5 21 0x00000 s6 22 0x000000 s6 22 0x000000 s6 22 0x000000000000000000000000000000000					0x0000000
t2         7         0x000000           s0         8         0x000000           s1         9         0x000000           a0         10         0x000000           a1         11         0x000000           a2         12         0x00000           a3         13         0x00000           a4         14         0x00000           a5         15         0x00000           a6         16         0x00000           a7         17         0x00000           s2         18         0x00000           s3         19         0x00000           s4         20         0x00000           s5         21         0x00000           s6         22         0x00000           s7         23         0x00000           s8         24         0x00000           s9         25         0x00000           s10         26         0x00000           s11         27         0x00000           t3         28         0x00000           t4         29         0x00000           t5         30         0x00000           t6<					0x0000000
80       8       0x00000         81       9       0x00000         a0       10       0x00000         a1       11       0x00000         a2       12       0x00000         a3       13       0x00000         a4       14       0x00000         a5       15       0x00000         a6       16       0x00000         a7       17       0x00000         s2       18       0x00000         s3       19       0x00000         s4       20       0x00000         s5       21       0x00000         s6       22       0x00000         s7       23       0x00000         s8       24       0x00000         s9       25       0x00000         s10       26       0x00000         s11       27       0x00000         t4       29       0x00000         t5       30       0x00000         t6       31       0x00000					0xfffffff
9     0x00000       a0     10     0x00000       a1     11     0x00000       a2     12     0x00000       a3     13     0x00000       a4     14     0x00000       a5     15     0x00000       a6     16     0x00000       a7     17     0x00000       a2     18     0x00000       a3     19     0x00000       a4     20     0x00000       a5     21     0x00000       a5     22     0x00000       a6     22     0x00000       a5     21     0x00000       a6     22     0x00000       a5     24     0x00000       a6     22     0x00000       a7     23     0x00000       a8     24     0x00000       a9     25     0x00000       a1     27     0x00000       a2     0x00000     0x00000       a3     0x00000     0x00000       a4     29     0x00000       a5     30     0x00000       a5     31     0x00000					0x0000000
a0       10       0x00000         a1       11       0x00000         a2       12       0x00000         a3       13       0x00000         a4       14       0x00000         a5       15       0x00000         a6       16       0x00000         a7       17       0x00000         s2       18       0x00000         s3       19       0x00000         s4       20       0x00000         s5       21       0x00000         s6       22       0x00000         s7       23       0x00000         s8       24       0x00000         s9       25       0x00000         s10       26       0x00000         s11       27       0x00000         t3       28       0x00000         t4       29       0x00000         t5       30       0x00000         t5       30       0x00000					0x0000000
a1       11       0x00000         a2       12       0x00000         a3       13       0x00000         a4       14       0x00000         a5       15       0x00000         a6       16       0x00000         s2       18       0x00000         s3       19       0x00000         s4       20       0x00000         s5       21       0x00000         s6       22       0x00000         s7       23       0x00000         s8       24       0x00000         s9       25       0x00000         s10       26       0x00000         s11       27       0x00000         t3       28       0x00000         t4       29       0x00000         t5       30       0x00000         t6       31       0x00000					0x0000000
a2     12     0x00000       a3     13     0x00000       a4     14     0x00000       a5     15     0x00000       a6     16     0x00000       s2     18     0x00000       s3     19     0x00000       s4     20     0x00000       s5     21     0x00000       s6     22     0x00000       s8     24     0x00000       s9     25     0x00000       s10     26     0x00000       s11     27     0x00000       t3     28     0x00000       t4     29     0x00000       t5     30     0x00000       t5     30     0x00000       t6     31     0x00000					0x0000000
a3       13       0x00000         a4       14       0x00000         a5       15       0x00000         a6       16       0x00000         a7       17       0x00000         s2       18       0x00000         s3       19       0x00000         s4       20       0x00000         s5       21       0x00000         s6       22       0x00000         s7       23       0x00000         s8       24       0x00000         s9       25       0x00000         s10       26       0x00000         s11       27       0x00000         t3       28       0x00000         t4       29       0x00000         t5       30       0x00000         t6       31       0x00000					0x0000000
a4       14       0x00000         a5       15       0x00000         a6       16       0x00000         a7       17       0x00000         s2       18       0x00000         s3       19       0x00000         s4       20       0x00000         s5       21       0x00000         s6       22       0x00000         s7       23       0x00000         s8       24       0x00000         s9       25       0x00000         s10       26       0x00000         s11       27       0x00000         t3       28       0x00000         t4       29       0x00000         t5       30       0x00000         t6       31       0x00000					0x0000000
a5       15       0x00000         a6       16       0x00000         a7       17       0x00000         s2       18       0x00000         s3       19       0x00000         s4       20       0x00000         s5       21       0x00000         s7       23       0x00000         s8       24       0x00000         s9       25       0x00000         s10       26       0x00000         s11       27       0x00000         t3       28       0x00000         t5       30       0x00000         t6       31       0x00000					0x0000000
a6       16       0x00000         a7       17       0x00000         s2       18       0x00000         s3       19       0x00000         s4       20       0x00000         s5       21       0x00000         s7       23       0x00000         s8       24       0x00000         s9       25       0x00000         s10       26       0x00000         s11       27       0x00000         t3       28       0x00000         t4       29       0x00000         t5       30       0x00000         t6       31       0x00000					0x0000000
a7     17     0x00000       s2     18     0x00000       s3     19     0x00000       s4     20     0x00000       s5     21     0x00000       s6     22     0x00000       s8     24     0x00000       s9     25     0x00000       s10     26     0x00000       s11     27     0x00000       t3     28     0x00000       t4     29     0x00000       t5     30     0x00000       t6     31     0x00000					0x0000000
\$2     18     0x00000       \$3     19     0x00000       \$4     20     0x00000       \$5     21     0x00000       \$6     22     0x00000       \$7     23     0x00000       \$9     25     0x00000       \$10     26     0x00000       \$11     27     0x00000       \$13     28     0x00000       \$15     30     0x00000       \$15     30     0x00000       \$16     31     0x00000					0x0000000
\$4     20     0x00000       \$5     21     0x00000       \$6     22     0x00000       \$7     23     0x00000       \$8     24     0x00000       \$9     25     0x00000       \$10     26     0x00000       \$11     27     0x00000       \$13     28     0x00000       \$15     30     0x00000       \$15     30     0x00000       \$16     31     0x00000	52		18		0x0000000
\$5     21     0x00000       \$6     22     0x00000       \$7     23     0x00000       \$8     24     0x00000       \$9     25     0x00000       \$10     26     0x00000       \$11     27     0x00000       \$13     28     0x00000       \$14     29     0x00000       \$15     30     0x00000       \$16     31     0x00000	<b>s</b> 3				0x000000
\$6     22     0x00000       \$7     23     0x00000       \$8     24     0x00000       \$9     25     0x00000       \$10     26     0x00000       \$11     27     0x00000       \$28     0x00000       \$4     29     0x00000       \$5     30     0x00000       \$6     31     0x00000					0x000000
\$7     23     0x00000       \$8     24     0x00000       \$9     25     0x00000       \$10     26     0x00000       \$11     27     0x00000       \$28     0x00000       \$4     29     0x00000       \$5     30     0x00000       \$6     31     0x00000					0x000000
88     24     0x00000       89     25     0x00000       \$10     26     0x00000       \$11     27     0x00000       \$13     28     0x00000       \$14     29     0x00000       \$15     30     0x00000       \$16     31     0x00000	s6		22		0x000000
s9     25     0x00000       s10     26     0x00000       s11     27     0x00000       t3     28     0x00000       t4     29     0x00000       t5     30     0x00000       t6     31     0x00000					0x000000
\$10     26     0x00000       \$11     27     0x00000       \$13     28     0x00000       \$14     29     0x00000       \$15     30     0x00000       \$16     31     0x00000					0x0000000
s11     27     0x00000       t3     28     0x00000       t4     29     0x00000       t5     30     0x00000       t6     31     0x00000					0x0000000
t3         28         0x00000           t4         29         0x00000           t5         30         0x00000           t6         31         0x00000					0x0000000
t4     29     0x00000       t5     30     0x00000       t6     31     0x00000					
t5 30 0x00000 t6 31 0x00000					0x0000000
t6 31 0x00000					0x0000000
					0x0000000
					0x000000
■ Wave - Default ::::::::::::::::::::::::::::::::::::					

Figura 3.7: execução da instrução sltu t2, t1, t3; estado dos registradores; formas de ondas obtidas.

00000001

Bkpt	Address	Code	Basic		Source
	0x00000000	0x00430313	addi x6,x6,4	7:	addi tl, tl, 4
	0x00000004	0x00002397	auipc x7,2	9:	lw t2, num_test
	0x00000008	0xffc3a383	lw x7,0xfffffffc(x7)		
	0x0000000c	0x00730e33	add x28,x6,x7	11:	add t3, t1, t2
	0x00000010	0x41c38333	sub x6,x7,x28	13:	sub t1, t2, t3
	0x00000014	0x00732e33	slt x28,x6,x7	15:	slt t3, t1, t2
	0x00000018	0x01c333b3	sltu x7,x6,x28	17:	sltu t2, t1, t3
	0x0000001c	0x41c353b3	sra x7,x6,x28	19:	sra t2, t1, t3
	0x00000020	0x0013a393	slti x7,x7,l	21:	slti t2, t2, 1
	0x00000024	0x007393b3	sl1 x7,x7,x7	23:	s11 t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25:	lui tl, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27:	srl tl, tl, t2
	0x00000030	0x00000e17	auipc x28,0	29:	auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xffffffcc	31:	beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33:	addi tl, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xffffffc4	35:	bne t1, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37:	jal teste2
	0x00000044	0x00000367	jalr x6,x0,0	41:	jalr tl, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
tl	6	0xfffffffc
t2	7	0x00000000
<b>s</b> 0	8	0x00000000
sl	9	0x00000000
a0	10	0x00000000
al	11	0x00000000
a2	12	0x00000000
a3	13	0x00000000
a4	14	0x00000000
a5	15	0x00000000
a6	16	0x00000000
a7	17	0x00000000
s2	18	0x00000000
<b>s</b> 3	19	0x00000000
<b>s</b> 4	20	0x00000000
<b>s</b> 5	21	0x00000000
<b>s</b> 6	22	0x00000000
<b>s</b> 7	23	0x00000000
<b>s</b> 8	24	0x00000000
<b>s</b> 9	25	0x00000000
s10	26	0x00000000
sll	27	0x00000000
t3	28	0x00000001
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x0000001c

Wave - Default	Wave - Default													
<b>≨1</b> •	Msgs													
<pre>/riscv_tb/clock_in</pre>	1													
☐→ /riscv_tb/riscv_i/pc_i/d_out  ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	0000000C	000000	18								000000	1C		
	00000004	FFFFFF	FC											
/riscv_tb/riscv_i/xreg_i/xreg(7)		000000	02								000000	00		
	00000000	000000	01											

Figura 3.8: execução da instrução sra t2, t1, t3; estado dos registradores; formas de ondas obtidas.

Text Segment					
Bkpt	Address	Code	Basic		Source
	0x000000000	0x00430313	addi x6,x6,4	7:	addi tl, tl, 4
	0x00000004	0x00002397	auipc x7,2	9:	lw t2, num_test
	0x00000008	0xffc3a383	lw x7,0xfffffffc(x7)		
	0x0000000c	0x00730e33	add x28,x6,x7	11:	add t3, t1, t2
	0x00000010	0x41c38333	sub x6,x7,x28	13:	sub t1, t2, t3
	0x00000014	0x00732e33	slt x28,x6,x7	15:	slt t3, t1, t2
	0x00000018	0x01c333b3	sltu x7,x6,x28	17:	sltu t2, t1, t3
	0x0000001c	0x41c353b3	sra x7,x6,x28	19:	sra t2, t1, t3
	0x00000020	0x0013a393	slti x7,x7,1	21:	slti t2, t2, 1
	0x00000024	0x007393b3	sll x7,x7,x7	23:	sl1 t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25:	lui tl, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27:	srl tl, tl, t2
	0x00000030	0x00000e17	auipc x28,0	29:	auipc t3, 0x00000
	0x00000034		beq x6,x28,0xffffffcc	31:	beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33:	addi tl, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xffffffc4	35:	bne t1, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37:	jal teste2
	0x00000044	0x00000367	jalr x6,x0,0	41:	jalr tl, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
tl	6	0xffffffc
t2	7	0xfffffffe
<b>s</b> 0	8	0x00000000
sl	9	0x00000000
a0	10	0x00000000
al	11	0x00000000
a2	12	0x00000000
a3	13	0x00000000
a4	14	0x00000000
a5	15	0x00000000
a6	16	0x00000000
a7	17	0x00000000
s2	18	0x00000000
<b>s</b> 3	19	0x00000000
s4	20	0x00000000
<b>s</b> 5	21	0x00000000
s6	22	0x00000000
<b>s</b> 7	23	0x00000000
<b>s</b> 8	24	0x00000000
<b>s</b> 9	25	0x00000000
s10	26	0x00000000
sll	27	0x00000000
t3	28	0x00000001
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000020

Wave - Default	Wave - Default ::::::::::::::::::::::::::::::::::::											
<b>≨</b> 1 <b>→</b>	Msgs											
/riscv_tb/clock_in	1											
<b></b> /riscv_tb/riscv_i/pc_i/d_out	0000000C	00000	1C								000000	20
<b>I</b> —◆ /riscv_tb/riscv_i/xreg_i/xreg(6)	00000004	FFFFF	FC									
	00000002	00000	000								FFFFFF	FE
<b>I</b> I → /riscv_tb/riscv_i/xreg_i/xreg(28)	00000000	00000	01									
<u> </u>												

Text Segment					
Bkpt	Address	Code	Basic		Source
	0x00000000	0x00430313	addi x6,x6,4	7:	addi tl, tl, 4
	0x00000004	0x00002397	auipc x7,2	9:	lw t2, num_test
	0x00000008	0xffc3a383	lw x7,0xfffffffc(x7)		
	0x0000000c	0x00730e33	add x28,x6,x7	11:	add t3, t1, t2
	0x00000010	0x41c38333	sub x6,x7,x28	13:	sub t1, t2, t3
	0x00000014	0x00732e33	slt x28,x6,x7	15:	slt t3, t1, t2
	0x00000018	0x01c333b3	sltu x7,x6,x28	17:	sltu t2, t1, t3
	0x0000001c	0x41c353b3	sra x7,x6,x28	19:	sra t2, t1, t3
	0x00000020	0x0013a393	slti x7,x7,l	21:	slti t2, t2, 1
	0x00000024	0x007393b3	sll x7,x7,x7	23:	sl1 t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25:	lui tl, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27:	srl tl, tl, t2
	0x00000030	0x00000e17	auipc x28,0	29:	auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xffffffcc	31:	beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33:	addi tl, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xffffffc4	35:	bne t1, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37:	jal teste2
	0x00000044	0x00000367	jalr x6,x0,0	41:	jalr tl, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
tl	6	0xffffffc
t2	7	0x00000001
<b>s</b> 0	8	0x00000000
sl	9	0x00000000
a0	10	0x00000000
al	11	0x00000000
a2	12	0x00000000
a3	13	0x00000000
a4	14	0x00000000
a5	15	0x00000000
a6	16	0x00000000
a7	17	0x00000000
s2	18	0x00000000
s3	19	0x00000000
s4	20	0x00000000
s5	21	0x00000000
s6	22	0x00000000
s7	23	0x00000000
s8	24	0x00000000
s9	25	0x00000000
s10	26	0x00000000
sll	27	0x00000000
t3	28	0x00000001
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000024

Wave - Default	Wave - Default :													
<b>≨</b>	Msgs													
/riscv_tb/clock_in	1													
//riscv_tb/riscv_i/pc_i/d_out	0000000C	00000020								000000	24			
//riscv_tb/riscv_i/xreg_i/xreg(6)		FFFFFFC												
→ /riscv_tb/riscv_i/xreg_i/xreg(7)  →		FFFFFFE								000000	01			
+- /riscv_tb/riscv_i/xreg_i/xreg(28)	00000000	0000001												

Figura 3.9: execução da instrução sll t2, t2, t2; estado dos registradores; formas de ondas obtidas.

	*************************************	*************************		vennennennennen	
Bkpt	Address	Code	Basic		Source
	0x00000000	0x00430313	addi x6,x6,4	7:	addi tl, tl, 4
	0x00000004	0x00002397	auipc x7,2	9:	1w t2, num_test
	0x00000008	0xffc3a383	lw x7,0xfffffffc(x7)		
	0x0000000c	0x00730e33	add x28,x6,x7	11:	add t3, t1, t2
	0x00000010	0x41c38333	sub x6,x7,x28	13:	sub t1, t2, t3
	0x00000014	0x00732e33	slt x28,x6,x7	15:	slt t3, t1, t2
	0x00000018	0x01c333b3	sltu x7,x6,x28	17:	sltu t2, t1, t3
	0x0000001c	0x41c353b3	sra x7,x6,x28	19:	sra t2, t1, t3
	0x00000020	0x0013a393	slti x7,x7,1	21:	slti t2, t2, l
	0x00000024		sll x7,x7,x7	23:	sl1 t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25:	lui tl, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27:	srl tl, tl, t2
	0x00000030	0x00000e17	auipc x28,0	29:	auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xffffffcc	31:	beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33:	addi tl, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xffffffc4	35:	bne t1, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37:	jal teste2
	0x00000044		jalr x6,x0,0	41:	jalr tl, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
tl	6	0xffffffc
t2	7	0x00000002
<b>s</b> 0	8	0x00000000
sl	9	0x00000000
a0	10	0x00000000
al	11	0x00000000
a2	12	0x00000000
a3	13	0x00000000
a4	14	0x00000000
a5	15	0x00000000
a6	16	0x00000000
a7	17	0x00000000
s2	18	0x00000000
s3	19	0x00000000
s4	20	0x00000000
s5	21	0x00000000
s6	22	0x00000000
s7	23	0x00000000
<b>s</b> 8	24	0x00000000
s9	25	0x00000000
s10	26	0x00000000
sll	27	0x00000000
t3	28	0x00000001
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000028

Wave - Default					=					
<b>\$</b> 1 →	Msgs									
/riscv_tb/clock_in	1									
#- /riscv_tb/riscv_i/pc_i/d_out	0000000C	00000024					000000	28		
	00000004	FFFFFFC								
/riscv_tb/riscv_i/xreg_i/xreg(7)	00000002	0000001					000000	02		
	00000000	0000001								

Figura 3.10: execução da instrução lui t1, x00000; estado dos registradores; formas de ondas obtidas.

Text Segment			
Bkpt	Address 0x00000000	Code Basic 0x00430313 addi x6,x6,4	Source 7: addi t1, t1, 4
	0x00000004	0x00002397 auipc x7,2	9: lw t2, num_test
	0x00000008 0x0000000c	0xffc3a383 lw x7,0xffffffffc(x7) 0x00730e33 add x28,x6,x7	11: add t3, t1, t2
	0x00000010 0x00000014	0x41c38333 sub x6,x7,x28 0x00732e33 slt x28,x6,x7	13: sub t1, t2, t3 15: slt t3, t1, t2
	0x00000018	0x01c333b3 sltu x7,x6,x28	17: sltu t2, t1, t3
	0x0000001c 0x00000020	0x41c353b3 sra x7,x6,x28 0x0013a393 slti x7,x7,1	19: sra t2, t1, t3 21: slti t2, t2, 1
	0x00000024 0x00000028	0x007393b3 sll x7,x7,x7 0x00001337 lui x6,1	23: sll t2, t2, t2 25: lui t1, 0x00001
	0x0000002c 0x00000030	0x00735333 <mark>srl x6,x6,x7</mark> 0x00000e17 auipc x28,0	27: srl tl, tl, t2 29: auipc t3, 0x00000
	0x00000034	0xfdc306e3 beq x6,x28,0xffffffcc	31: beq t1, t3, teste
	0x00000038 0x0000003c	0x00200313 addi x6,x0,2 0xfc7312e3 bne x6,x7,0xffffffc4	33: addi tl, zero, 2 35: bne tl, t2, teste
	0x00000040	0x004000ef jal x1,0x00000004 0x00000367 jalr x6.x0.0	37: jal teste2 41: jalr tl. zero. 0
	Name	Number	Value
zero		0	0x00000000
ra		1	0x00000000
sp		2	0x00003ffc
gp		3	0x00001800
tp		4	0x00000000
t0		5	0x0000000
tl		7	0x00001000
t2 s0		8	0x00000002 0x00000000
sl		9	0x00000000
a0		10	0x00000000
al		11	0x00000000
a2		12	0x00000000
a3		13	0x00000000
a4		14	0x00000000
a5		15	0x00000000
a6		16	0x00000000
a7		17	0x0000000
s2 s3		18	0x00000000 0x00000000
s4		20	0x00000000
s5		21	0x0000000
s6		22	0x00000000
s7		23	0x00000000
<b>s</b> 8		24	0x00000000
<b>s</b> 9		25	0x00000000
s10		26	0x00000000
sll		27	0x00000000
t3		28	0x00000001
t4 t5		29	0x00000000
t6		30	0x00000000 0x00000000
pc		31	0x00000000
Wave - Default ======	Msgs		
<pre>/riscv_tb/clock_in</pre>	1		V2222222
riscv_tb/riscv_i/pc friscv_tb/riscv_i/xrc	eg_i/xreg(6) 00000004	00000028 FFFFFFFC	, 000002C , 00001000
+- /riscv_tb/riscv_i/xre		00000002 00000001	
/ilsev_tb/ilsev_l/xi	eg_/xicg(20) 00000000	00000001	

Figura 3.11: execução da instrução srl t1, t1, t2; estado dos registradores; formas de ondas obtidas.

egment					
Bkpt	Address	Code	Basic		Source
	0x00000000	0x00430313	addi x6,x6,4	7:	addi tl, tl, 4
	0x00000004	0x00002397	auipc x7,2	9:	lw t2, num_test
	0x00000008	0xffc3a383	lw x7,0xfffffffc(x7)		
	0x0000000c	0x00730e33	add x28,x6,x7	11:	add t3, t1, t2
	0x00000010	0x41c38333	sub x6, x7, x28	13:	sub t1, t2, t3
	0x00000014	0x00732e33	slt x28,x6,x7	15:	slt t3, t1, t2
	0x00000018	0x01c333b3	sltu x7,x6,x28	17:	sltu t2, t1, t3
	0x0000001c	0x41c353b3	sra x7,x6,x28	19:	sra t2, t1, t3
	0x00000020	0x0013a393	slti x7,x7,1	21:	slti t2, t2, 1
	0x00000024	0x007393b3	sll x7,x7,x7	23:	s11 t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25:	lui tl, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27:	srl tl, tl, t2
	0x00000030	0x00000e17	auipc x28,0	29:	auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xffffffcc	31:	beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33:	addi tl, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xffffffc4	35:	bne t1, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37:	jal teste2
	0x00000044	0x00000367	jalr x6,x0,0	41:	jalr tl, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
tl	6	0x00000400
t2	7	0x00000002
<b>s</b> 0	8	0x00000000
sl	9	0x00000000
a0	10	0x00000000
al	11	0x00000000
a2	12	0x00000000
a3	13	0x00000000
a4	14	0x00000000
a5	15	0x00000000
a6	16	0x00000000
a7	17	0x00000000
s2	18	0x00000000
<b>s</b> 3	19	0x00000000
s4	20	0x00000000
s5	21	0x00000000
s6	22	0x00000000
<b>s</b> 7	23	0x00000000
<b>s</b> 8	24	0x00000000
<b>s</b> 9	25	0x00000000
s10	26	0x00000000
sll	27	0x00000000
t3	28	0x00000001
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
nc		0x00000030

Wave - Default							=					
<b>≨1</b> •	Msgs											
/riscv_tb/clock_in	1											
<b>I</b> — /riscv_tb/riscv_i/pc_i/d_out	0000000C	000000	2C						000000	30		
III  III  III  III  III  III  III	00000004	000010	00						000004	00		
<u>+</u> -  √ /riscv_tb/riscv_i/xreg_i/xreg(7)	00000002	000000	02									
// /riscv_tb/riscv_i/xreg_i/xreg(28)	00000000	000000	01									
								l	l			

**Figura 3.12:** execução da instrução auipc t3, 0x00000; estado dos registradores; formas de ondas obtidas.

Bkpt	Address	Code	Basic		Source
	0x00000000	0x00430313	addi x6,x6,4	7:	addi tl, tl, 4
	0x00000004	0x00002391	auipc x7,2	9:	lw t2, num_test
	0x00000008	0xffc3a383	lw x7,0xfffffffc(x7)		
	0x0000000c	0x00730e33	add x28,x6,x7	11:	add t3, t1, t2
	0x00000010	0x41c38333	sub x6,x7,x28	13:	sub t1, t2, t3
	0x00000014	0x00732e33	slt x28,x6,x7	15:	slt t3, t1, t2
	0x00000018	0x01c333b3	sltu x7,x6,x28	17:	sltu t2, t1, t3
	0x0000001c	0x41c353b3	sra x7,x6,x28	19:	sra t2, t1, t3
	0x00000020	0x0013a393	slti x7,x7,l	21:	slti t2, t2, 1
	0x00000024	0x007393b3	3 sll x7,x7,x7	23:	sl1 t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25:	lui tl, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27:	srl tl, tl, t2
	0x00000030	0x00000e17	auipc x28,0	29:	auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xffffffcc	31:	beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33:	addi tl, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xffffffc4	35:	bne tl, t2, teste
	0x00000040	0x004000e1	jal x1,0x00000004	37:	jal teste2
		0x004000ei			

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
tl	6	0x00000400
t2	7	0x00000002
s0	8	0x00000000
sl	9	0x00000000
a0	10	0x00000000
al	11	0x00000000
a2	12	0x00000000
a3	13	0x00000000
a4	14	0x00000000
a5	15	0x00000000
a6	16	0x00000000
a7	17	0x00000000
s2	18	0x00000000
s3	19	0x00000000
s4	20	0x00000000
s5	21	0x00000000
s6	22	0x00000000
s7	23	0x00000000
s8	24	0x00000000
s9	25	0x00000000
s10	26	0x00000000
sll	27	0x00000000
t3	28	0x00000030
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000034

Wave - Default	Nave - Default																
<b>≨</b> 1 •	Msgs																
<pre>/riscv_tb/clock_in</pre>	1																
	000000C	000000	30									000000	34				
/riscv_tb/riscv_i/xreg_i/xreg(6)	00000004	000004	00														
/riscv_tb/riscv_i/xreg_i/xreg(7)	00000002	000000	02														
- /riscv_tb/riscv_i/xreg_i/xreg(28)	00000000	000000	01									000000	30				

**Figura 3.13:** execução da instrução beq t1, t3, teste; estado dos registradores; formas de ondas obtidas.

Text Segment					
Bkpt	Address	Code	Basic		Source
	0x00000000	0x00430313	addi x6,x6,4	7:	addi tl, tl, 4
	0x00000004	0x00002397	auipc x7,2	9:	lw t2, num_test
	0x00000008	0xffc3a383	lw x7,0xfffffffc(x7)		
	0x0000000c	0x00730e33	add x28,x6,x7	11:	add t3, t1, t2
	0x00000010	0x41c38333	sub x6,x7,x28	13:	sub t1, t2, t3
	0x00000014	0x00732e33	slt x28,x6,x7	15:	slt t3, t1, t2
	0x00000018	0x01c333b3	sltu x7,x6,x28	17:	sltu t2, t1, t3
	0x0000001c		sra x7,x6,x28	19:	sra t2, t1, t3
	0x00000020	0x0013a393	slti x7,x7,1	21:	slti t2, t2, l
	0x00000024	0x007393b3	sll x7,x7,x7	23:	sl1 t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25:	lui tl, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27:	srl tl, tl, t2
	0x00000030	0x00000e17	auipc x28,0	29:	auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xffffffcc	31:	beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33:	addi tl, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xffffffc4	35:	bne t1, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37:	jal teste2
	0x00000044	0x00000367	jalr x6,x0,0	41:	jalr tl, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
tl	6	0x00000400
t2	7	0x00000002
s0	8	0x00000000
sl	9	0x00000000
a0	10	0x00000000
al	11	0x00000000
a2	12	0x00000000
a3	13	0x00000000
a4	14	0x00000000
a5	15	0x00000000
a6	16	0x00000000
a7	17	0x00000000
s2	18	0x00000000
s3	19	0x00000000
s4	20	0x00000000
s5	21	0x00000000
s6	22	0x00000000
s7	23	0x00000000
s8	24	0x00000000
s9	25	0x00000000
s10	26	0x00000000
sll	27	0x00000000
t3	28	0x00000030
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000038

Wave - Default						=					
<b>≨</b> 1 →	Msgs										
<pre>/riscv_tb/clock_in</pre>	1										
riscv_tb/riscv_i/pc_i/d_out	0000000C	000000	34					000000	38		
+ /riscv_tb/riscv_i/xreg_i/xreg(6)	00000004	000004	Ю0								
+	00000002	000000	02								
riscv_tb/riscv_i/xreg_i/xreg(28)	00000000	000000	30								
,											

Figura 3.13: execução de outra instrução addi; estado dos registradores; formas de ondas obtidas.

gment					
Bkpt	Address	Code	Basic		Source
	0x00000000	0x00430313	addi x6,x6,4	7:	addi tl, tl, 4
	0x00000004	0x00002397	auipc x7,2	9:	lw t2, num_test
	0x00000008	0xffc3a383	lw x7,0xfffffffc(x7)		
	0x000000c	0x00730e33	add x28,x6,x7	11:	add t3, t1, t2
	0x00000010	0x41c38333	sub x6,x7,x28	13:	sub t1, t2, t3
	0x00000014	0x00732e33	slt x28,x6,x7	15:	slt t3, t1, t2
	0x00000018	0x01c333b3	sltu x7,x6,x28	17:	sltu t2, t1, t3
	0x0000001c	0x41c353b3	sra x7,x6,x28	19:	sra t2, t1, t3
	0x00000020	0x0013a393	slti x7,x7,1	21:	slti t2, t2, 1
	0x00000024	0x007393b3	sl1 x7,x7,x7	23:	sl1 t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25:	lui tl, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27:	srl tl, tl, t2
	0x00000030	0x00000e17	auipc x28,0	29:	auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xffffffcc	31:	beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33:	addi tl, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xffffffc4	35:	bne t1, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37:	jal teste2
	0x00000044	0x00000367	jalr x6,x0,0	41:	jalr tl, zero, 0

Registers	Floating Point	Control and Status		
	Name	Nun	nber	Value
zero			0	0x00000000
ra			1	0x00000000
sp			2	0x00003ffc
gp			3	0x00001800
tp			4	0x00000000
t0			5	0x00000000
tl			6	0x00000002
t2			7	0x00000002
<b>s</b> 0			8	0x00000000
sl			9	0x00000000
<b>a</b> 0			10	0x00000000
al			11	0x00000000
a2			12	0x00000000
a3			13	0x00000000
a4			14	0x00000000
a5			15	0x00000000
a6			16	0x00000000
a7			17	0x00000000
<b>s</b> 2			18	0x00000000
<b>s</b> 3			19	0x00000000
s4			20	0x00000000
<b>s</b> 5			21	0x00000000
<b>s</b> 6			22	0x00000000
<b>s</b> 7			23	0x00000000
s8			24	0x00000000
<b>s</b> 9			25	0x00000000
s10			26	0x00000000
sll			27	0x00000000
t3			28	0x00000030
t4			29	0x00000000
t5			30	0x00000000
t6			31	0x00000000
pc				0x0000003c

Wave - Default					= 1111111					
<b>≨</b> 1 •	Msgs									
<pre>/riscv_tb/clock_in</pre>	1									
/riscv_tb/riscv_i/pc_i/d_out	0000000C	00000038					000000	3C		
	00000004	00000400					000000	02		
	00000002	00000002								
	00000000	00000030								
·										

**Figura 3.14:** execução da instrução bne t1, t2, teste; estado dos registradores; formas de ondas obtidas.

Bkpt	Address	Code	Basic		Source
	0x00000000	0x00430313	addi x6,x6,4	7:	addi tl, tl, 4
	0x00000004	0x00002397	auipc x7,2	9:	lw t2, num_test
	0x00000008	0xffc3a383	lw x7,0xfffffffc(x7)		
	0x0000000c	0x00730e33	add x28,x6,x7	11:	add t3, t1, t2
	0x00000010	0x41c38333	sub x6,x7,x28	13:	sub tl, t2, t3
	0x00000014	0x00732e33	slt x28,x6,x7	15:	slt t3, t1, t2
	0x00000018	0x01c333b3	sltu x7,x6,x28	17:	sltu t2, t1, t3
	0x0000001c	0x41c353b3	sra x7,x6,x28	19:	sra t2, t1, t3
	0x00000020	0x0013a393	slti x7,x7,1	21:	slti t2, t2, l
	0x00000024		3 sll x7,x7,x7	23:	sl1 t2, t2, t2
	0x00000028	0x00001337	7 lui x6,1	25:	lui tl, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27:	srl tl, tl, t2
	0x00000030		auipc x28,0	29:	auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xffffffcc	31:	beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33:	addi tl, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xffffffc4	35:	bne t1, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37:	jal teste2
	0x00000044	0x00000367	7 jalr x6,x0,0	41:	jalr tl, zero, 0

Registers	Floating Point	Control and Status	
	Name	Number	Value
zero			0x00000000
ra			1 0x00000000
sp			2 0x00003ffc
gp			3 0x00001800
tp			4 0x00000000
t0			5 0x00000000
t1			6 0x00000002
t2			7 0x00000002
<b>s</b> 0			8 0x00000000
sl			9 0x00000000
a0			10 0x00000000
al			11 0x00000000
a2			12 0x00000000
a3			13 0x00000000
a4			14 0x00000000
a5			15 0x00000000
a6			16 0x00000000
a7			17 0x00000000
s2			18 0x00000000
<b>s</b> 3			19 0x00000000
s4			20 0x00000000
<b>s</b> 5			21 0x00000000
s6			22 0x00000000
s7			23 0x00000000
<b>s</b> 8			24 0x00000000
<b>s</b> 9			25 0x00000000
s10			26 0x00000000
s11			27 0x00000000
t3			28 0x00000030
t4			29 0x00000000
t5			30 0x00000000
t6			31 0x00000000
рс			0x00000040

Wave - Default	Vave - Default																					
<b>\$</b> 1 →	Msgs																					
/riscv_tb/clock_in	1																					
<b>- - - -</b> /riscv_tb/riscv_i/pc_i/d_out	000000C	000000	)3C									000000	40									
<b>I</b> → /riscv_tb/riscv_i/xreg_i/xreg(6)	00000004	000000	02																			
	00000002	000000	02																			
	00000000	000000	30																			

**Figura 3.15:** execução da instrução jal zero, teste2; estado dos registradores; formas de ondas obtidas.

egment					
Bkpt	Address	Code	Basic		Source
	0x00000000	0x00430313	addi x6,x6,4	7:	addi tl, tl, 4
	0x00000004	0x00002397	auipc x7,2	9:	lw t2, num_test
	0x00000008	0xffc3a383	lw x7,0xfffffffc(x7)		
	0x000000c	0x00730e33	add x28,x6,x7	11:	add t3, t1, t2
	0x00000010	0x41c38333	sub x6,x7,x28	13:	sub t1, t2, t3
	0x00000014	0x00732e33	slt x28,x6,x7	15:	slt t3, t1, t2
	0x00000018	0x01c333b3	sltu x7,x6,x28	17:	sltu t2, t1, t3
	0x0000001c	0x41c353b3	sra x7,x6,x28	19:	sra t2, t1, t3
	0x00000020	0x0013a393	slti x7,x7,1	21:	slti t2, t2, 1
	0x00000024	0x007393b3	sll x7,x7,x7	23:	sl1 t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25:	lui tl, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27:	srl tl, tl, t2
	0x00000030	0x00000e17	auipc x28,0	29:	auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xffffffcc	31:	beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33:	addi tl, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xffffffc4	35:	bne tl, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37:	jal teste2
	0x00000044	0x00000367	jalr x6,x0,0	41:	jalr tl, zero, 0

Registers	Floating Point	Cont	trol and Status		
	Name		Nur	mber	Value
zero				0	0x00000000
ra				1	0x00000044
sp				2	0x00003ffc
gp				3	0x00001800
tp				4	0x00000000
t0				5	0x00000000
tl				6	0x00000002
t2				7	0x00000002
<b>s</b> 0				8	0x00000000
sl				9	0x00000000
<b>a</b> 0				10	0x00000000
al				11	0x00000000
a2				12	0x00000000
a3				13	0x00000000
a4				14	0x00000000
a5				15	0x00000000
a6				16	0x00000000
a7				17	0x00000000
s2				18	0x00000000
<b>s</b> 3				19	0x00000000
s4				20	0x00000000
s5				21	0x00000000
s6				22	0x00000000
s7				23	0x00000000
<b>s</b> 8				24	0x00000000
<b>s</b> 9				25	0x00000000
s10				26	0x00000000
sll				27	0x00000000
t3				28	0x00000030
t4				29	0x00000000
t5				30	0x00000000
t6				31	0x00000000
pc					0x00000044

Wave - Default =					= 777777					
<b>\$</b> 1 <b>₹</b> 1	Msgs									
/riscv_tb/clock_in	1									
/riscv_tb/riscv_i/pc_i/d_out	000000C	00000040					000000	44		
/riscv_tb/riscv_i/xreg_i/xreg(6)	00000004	00000002								
/riscv_tb/riscv_i/xreg_i/xreg(7)	00000002	00000002								
/riscv_tb/riscv_i/xreg_i/xreg(28)	00000000	00000030								

**Figura 3.16:** execução da instrução jalr t1, zero, 0; estado dos registradores; formas de ondas obtidas.