Universidade de Brasília
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Dpto. Ciência da Computação
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Projeto da Disciplina - RISC-V Uniciclo em VHDL

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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, SRA
- Comparação: SLT, SLTu
- Comparação com imediato: SLTi, SLTUi
- Subrotinas: JAL, JALR
- Saltos 1: BEQ, BNE
- Memória: LW, SW

O diagrama esquemático utilizado será o seguinte:

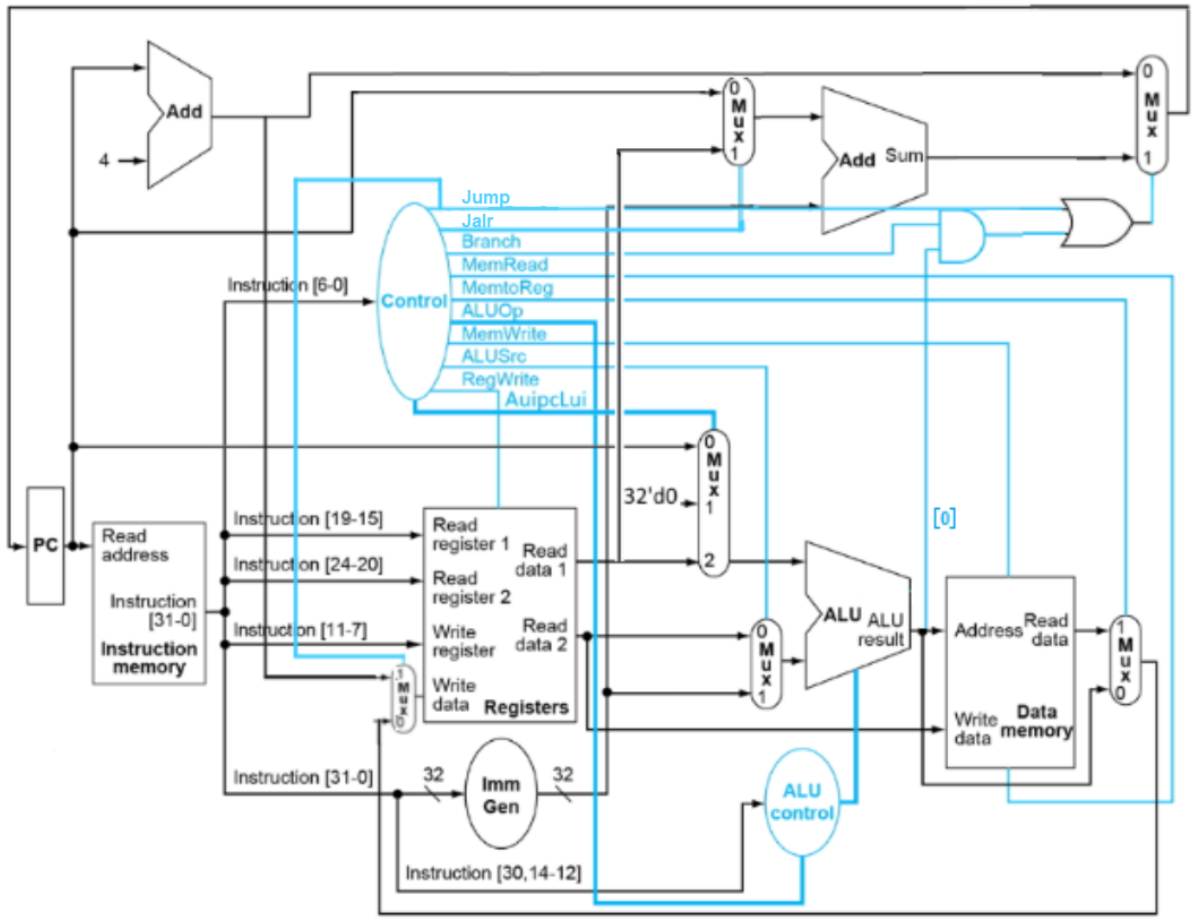


Figura 1.0: *esquema do riscV*

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:

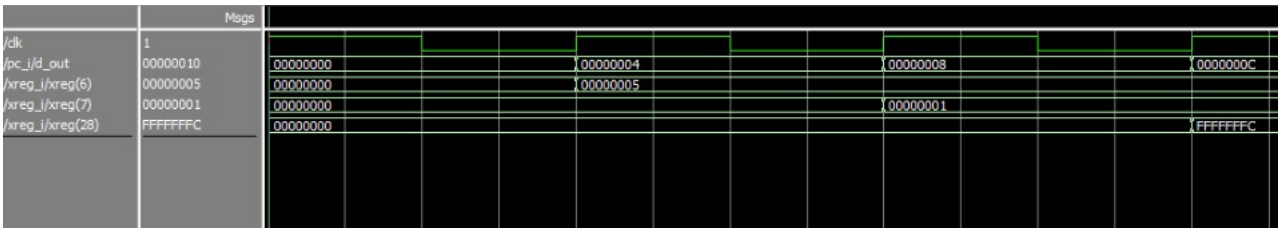


Figura 2.2: *formas de onda geradas pelo processador, obtidas por intermédio do software ModelSim.*

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
        num_test:      .word           0x00000002
.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.

Text Segment

Bkpt	Address	Code	Basic	Source
	0x00000000	0x00430313	addi x6,x6,4	7: addi t1, t1, 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: sll t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25: lui t1, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27: srl t1, t1, 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 t1, 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 t1, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
t1	6	0x00000000
t2	7	0x00000000
s0	8	0x00000000
s1	9	0x00000000
a0	10	0x00000000
a1	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
s11	27	0x00000000
t3	28	0x00000000
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000000

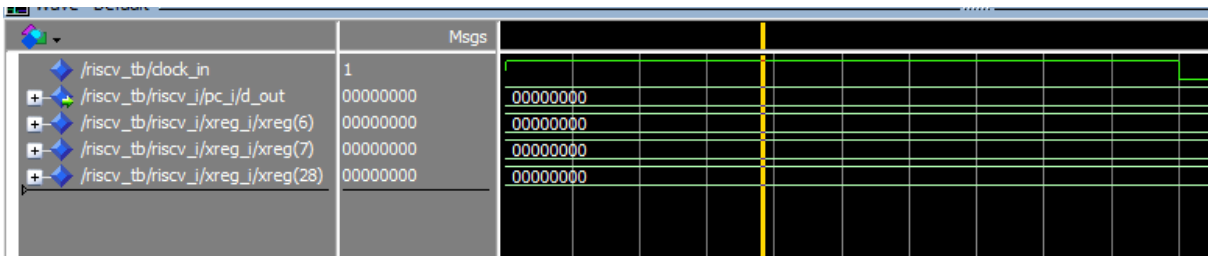


Figura 3.1: *execução da instrução addi t1, t1, 4; estado dos registradores; formas de ondas obtidas.*

Bkpt	Address	Code	Basic	Source
	0x00000000	0x00430313	addi x6,x6,4	7: addi t1, t1, 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: sll t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25: lui t1, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27: srl t1, t1, t2
	0x00000030	0x00000e17	auipc x28,0	29: auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xfffffffcc	31: beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33: addi t1, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xfffffffc4	35: bne t1, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37: jal teste2
	0x00000044	0x00000367	jalr x6,x0,0	41: jalr t1, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
t1	6	0x00000004
t2	7	0x00000000
s0	8	0x00000000
s1	9	0x00000000
a0	10	0x00000000
a1	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
s11	27	0x00000000
t3	28	0x00000000
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000004

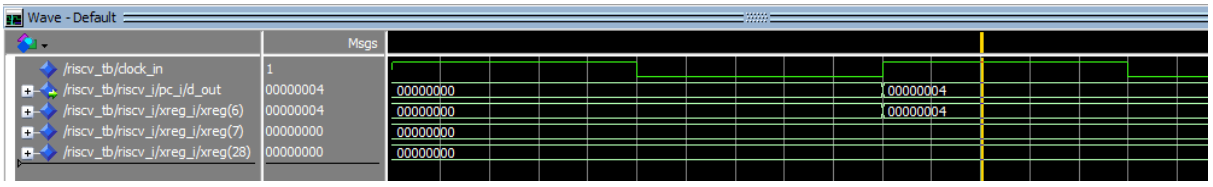


Figura 3.2: *execução da instrução auipc, que calcula o endereço de num_test; estado dos registradores; formas de ondas obtidas.*

Bkpt	Address	Code	Basic	Source
	0x00000000	0x00430313	addi x6,x6,4	7: addi t1, t1, 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: sll t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25: lui t1, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27: srl t1, t1, t2
	0x00000030	0x00000e17	auipc x28,0	29: auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xfffffffcc	31: beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33: addi t1, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xfffffffc4	35: bne t1, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37: jal teste2
	0x00000044	0x00000367	jalr x6,x0,0	41: jalr t1, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
t1	6	0x00000004
t2	7	0x00002004
s0	8	0x00000000
s1	9	0x00000000
a0	10	0x00000000
a1	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
s11	27	0x00000000
t3	28	0x00000000
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000008

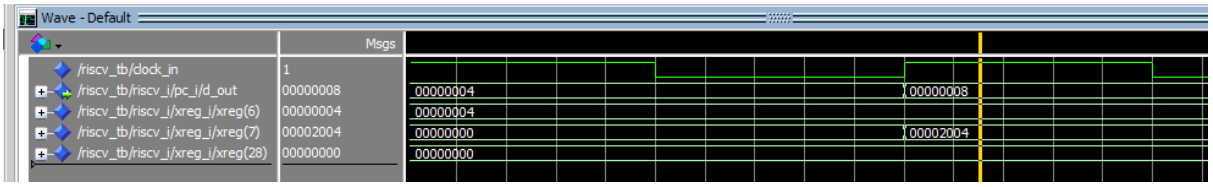


Figura 3.3: *execução da instrução lw t2, num_test; estado dos registradores; formas de ondas obtidas.*

Text Segment

Bkpt	Address	Code	Basic	Source
	0x00000000	0x00430313	addi x6,x6,4	7: addi t1, t1, 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: sll t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25: lui t1, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27: srl t1, t1, 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 t1, 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 t1, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
t1	6	0x00000004
t2	7	0x00000002
s0	8	0x00000000
s1	9	0x00000000
a0	10	0x00000000
a1	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
s11	27	0x00000000
t3	28	0x00000000
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x0000000c

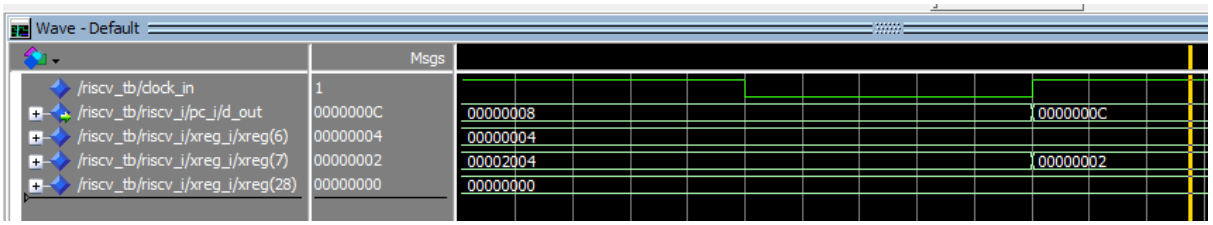


Figura 3.4: *execução da instrução add t3, t1, t2; estado dos registradores; formas de ondas obtidas.*

Text Segment

Bkpt	Address	Code	Basic	Source
	0x00000000	0x00430313	addi x6,x6,4	7: addi t1, t1, 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: sll t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25: lui t1, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27: srl t1, t1, 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 t1, 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 t1, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
t1	6	0x00000004
t2	7	0x00000002
s0	8	0x00000000
s1	9	0x00000000
a0	10	0x00000000
a1	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
s11	27	0x00000000
t3	28	0x00000006
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000010

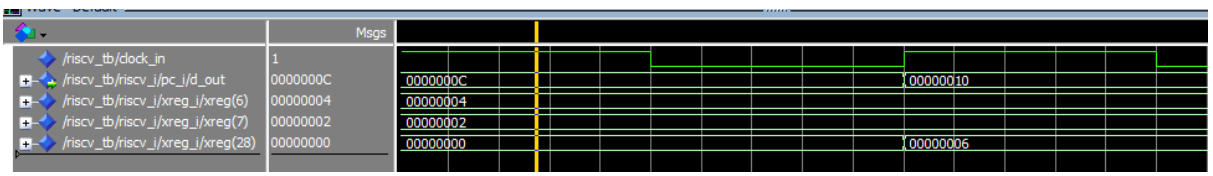


Figura 3.5: *execução da instrução sub t1, t2, t3; estado dos registradores; formas de ondas obtidas.*

Text Segment

Bkpt	Address	Code	Basic	Source
	0x00000000	0x00430313	addi x6,x6,4	7: addi t1, t1, 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: sll t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25: lui t1, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27: srl t1, t1, t2
	0x00000030	0x00000e17	auipc x28,0	29: auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xfffffffcc	31: beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33: addi t1, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xfffffffc4	35: bne t1, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37: jal teste2
	0x00000044	0x00000367	jalr x6,x0,0	41: jalr t1, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
t1	6	0xfffffffc
t2	7	0x00000002
s0	8	0x00000000
s1	9	0x00000000
a0	10	0x00000000
a1	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
s11	27	0x00000000
t3	28	0x00000006
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000014

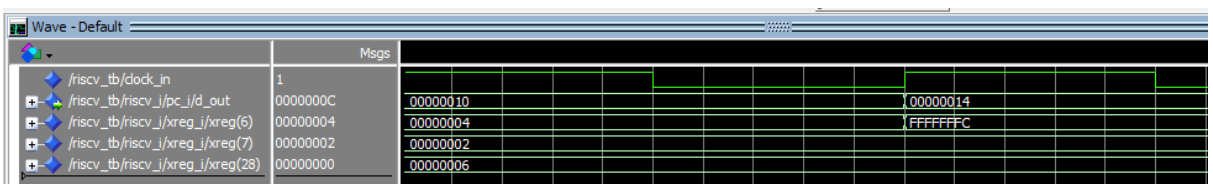


Figura 3.6: *execução da instrução addi t1, t1, 4; estado dos registradores; formas de ondas obtidas.*

Text Segment

Bkpt	Address	Code	Basic	Source
	0x00000000	0x00430313	addi x6,x6,4	7: addi t1, t1, 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: sll t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25: lui t1, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27: srl t1, t1, 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 t1, 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 t1, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
t1	6	0xfffffffc
t2	7	0x00000002
s0	8	0x00000000
s1	9	0x00000000
a0	10	0x00000000
a1	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
s11	27	0x00000000
t3	28	0x00000001
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000018

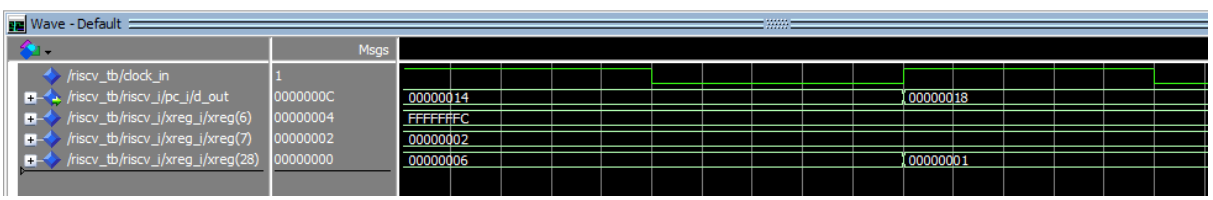


Figura 3.7: *execução da instrução sltu t2, t1, t3; estado dos registradores; formas de ondas obtidas.*

Bkpt	Address	Code	Basic	Source
	0x00000000	0x00430313	addi x6,x6,4	7: addi t1, t1, 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: sll t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25: lui t1, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27: srl t1, t1, 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 t1, 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 t1, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
t1	6	0xfffffffc
t2	7	0x00000000
s0	8	0x00000000
s1	9	0x00000000
a0	10	0x00000000
a1	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
s11	27	0x00000000
t3	28	0x00000001
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x0000001c

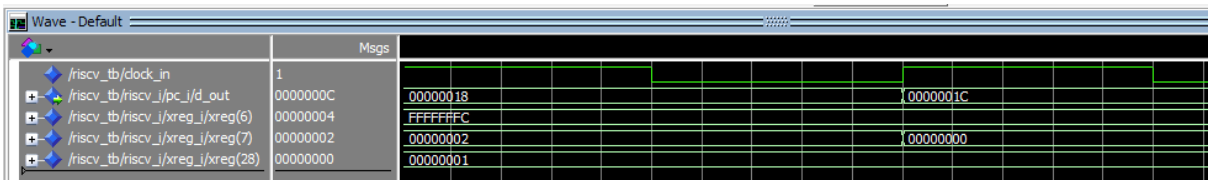
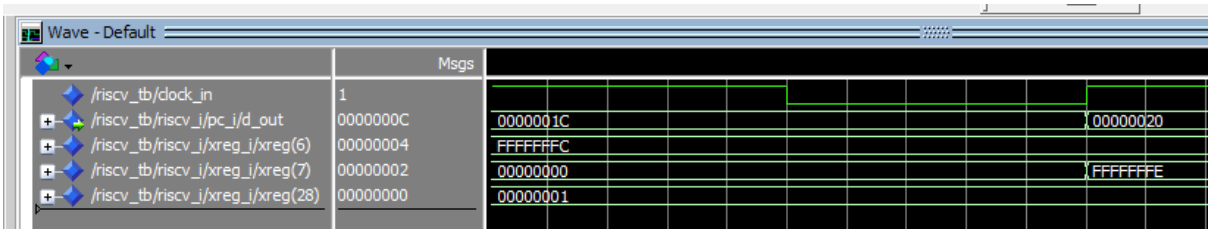


Figura 3.8: *execução da instrução sra t2, t1, t3; estado dos registradores; formas de ondas obtidas.*

Text Segment

Bkpt	Address	Code	Basic	Source
	0x00000000	0x00430313	addi x6,x6,4	7: addi t1, t1, 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: sll t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25: lui t1, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27: srl t1, t1, t2
	0x00000030	0x00000e17	auipc x28,0	29: auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xfffffffcc	31: beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33: addi t1, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xfffffffc4	35: bne t1, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37: jal teste2
	0x00000044	0x00000367	jalr x6,x0,0	41: jalr t1, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
t1	6	0xfffffffc
t2	7	0xfffffffe
s0	8	0x00000000
s1	9	0x00000000
a0	10	0x00000000
a1	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
s11	27	0x00000000
t3	28	0x00000001
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000020



Text Segment

Bkpt	Address	Code	Basic	Source
	0x00000000	0x00430313	addi x6,x6,4	7: addi t1, t1, 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: sll t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25: lui t1, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27: srl t1, t1, t2
	0x00000030	0x00000e17	auipc x28,0	29: auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xfffffffcc	31: beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33: addi t1, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xfffffc4	35: bne t1, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37: jal teste2
	0x00000044	0x00000367	jalr x6,x0,0	41: jalr t1, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
t1	6	0xfffffffc
t2	7	0x00000001
s0	8	0x00000000
s1	9	0x00000000
a0	10	0x00000000
a1	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
s11	27	0x00000000
t3	28	0x00000001
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000024

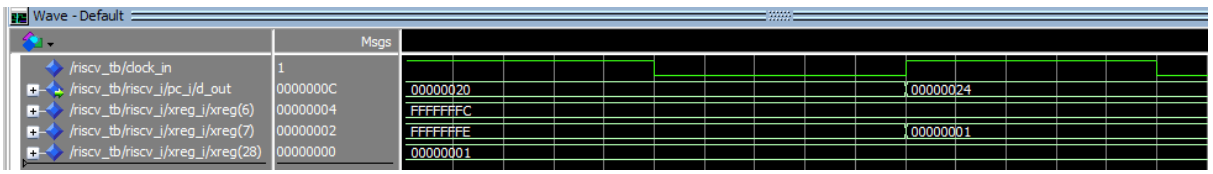


Figura 3.9: *execução da instrução sll t2, t2, t2; estado dos registradores; formas de ondas obtidas.*

Text Segment

Bkpt	Address	Code	Basic	Source
	0x00000000	0x00430313	addi x6,x6,4	7: addi t1, t1, 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: sll t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25: lui t1, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27: srl t1, t1, 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 t1, 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 t1, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
t1	6	0xfffffffc
t2	7	0x00000002
s0	8	0x00000000
s1	9	0x00000000
a0	10	0x00000000
a1	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
s11	27	0x00000000
t3	28	0x00000001
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000028

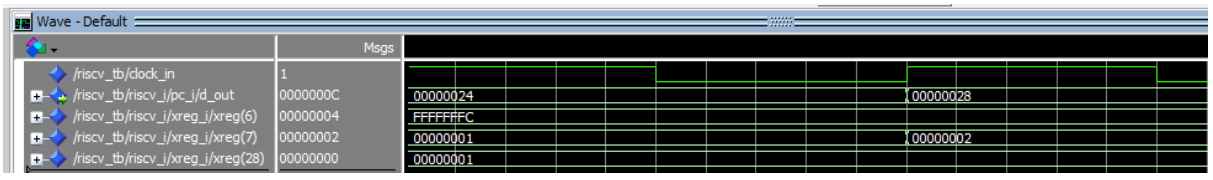


Figura 3.10: *execução da instrução lui t1, x00000; estado dos registradores; formas de ondas obtidas.*

Text Segment

Bkpt	Address	Code	Basic	Source
	0x00000000	0x00430313	addi x6,x6,4	7: addi t1, t1, 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: sll t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25: lui t1, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27: srl t1, t1, t2
	0x00000030	0x00000e17	auipc x28,0	29: auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xfffffffcc	31: beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33: addi t1, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xfffffffc4	35: bne t1, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37: jal teste2
	0x00000044	0x00000367	jalr x6,x0,0	41: jalr t1, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
t1	6	0x00001000
t2	7	0x00000002
s0	8	0x00000000
s1	9	0x00000000
a0	10	0x00000000
a1	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
s11	27	0x00000000
t3	28	0x00000001
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x0000002c

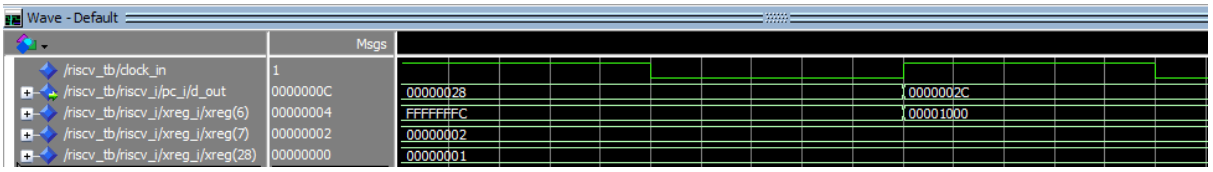


Figura 3.11: *execução da instrução srl t1, t1, t2; estado dos registradores; formas de ondas obtidas.*

Text Segment

Bkpt	Address	Code	Basic	Source
	0x00000000	0x00430313	addi x6,x6,4	7: addi t1, t1, 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: sll t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25: lui t1, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27: srl t1, t1, 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 t1, 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 t1, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
t1	6	0x00000400
t2	7	0x00000002
s0	8	0x00000000
s1	9	0x00000000
a0	10	0x00000000
a1	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
s11	27	0x00000000
t3	28	0x00000001
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000030

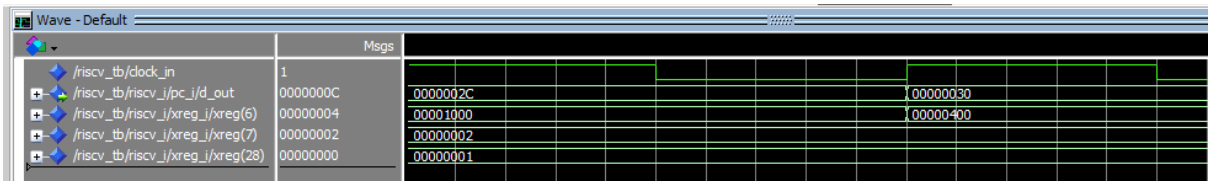


Figura 3.12: *execução da instrução auipc t3, 0x00000; estado dos registradores; formas de ondas obtidas.*

Text Segment

Bkpt	Address	Code	Basic	Source
	0x00000000	0x00430313	addi x6,x6,4	7: addi t1, t1, 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: sll t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25: lui t1, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27: srl t1, t1, t2
	0x00000030	0x00000e17	auipc x28,0	29: auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xfffffffcc	31: beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33: addi t1, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xfffffffc4	35: bne t1, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37: jal teste2
	0x00000044	0x00000367	jalr x6,x0,0	41: jalr t1, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
t1	6	0x00000400
t2	7	0x00000002
s0	8	0x00000000
s1	9	0x00000000
a0	10	0x00000000
a1	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
s11	27	0x00000000
t3	28	0x00000030
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000034

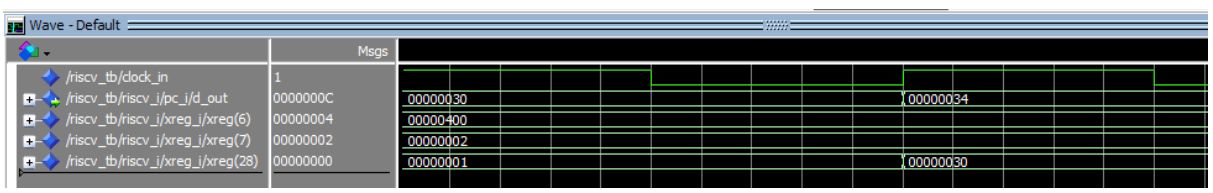


Figura 3.13: *execução da instrução beq t1, t3, teste; estado dos registradores; formas de ondas obtidas.*

Text Segment

Bkpt	Address	Code	Basic	Source
	0x00000000	0x00430313	addi x6,x6,4	7: addi t1, t1, 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: sll t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25: lui t1, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27: srl t1, t1, t2
	0x00000030	0x00000e17	auipc x28,0	29: auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xfffffffc	31: beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33: addi t1, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xfffffffc4	35: bne t1, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37: jal teste2
	0x00000044	0x00000367	jalr x6,x0,0	41: jalr t1, zero, 0

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
t1	6	0x00000400
t2	7	0x00000002
s0	8	0x00000000
s1	9	0x00000000
a0	10	0x00000000
a1	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
s11	27	0x00000000
t3	28	0x00000030
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000038

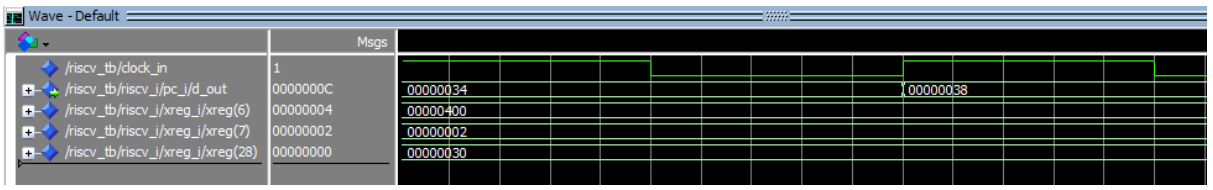


Figura 3.13: *execução de outra instrução addi; estado dos registradores; formas de ondas obtidas.*

Text Segment

Bkpt	Address	Code	Basic	Source
	0x00000000	0x00430313	addi x6,x6,4	7: addi t1, t1, 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: sll t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25: lui t1, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27: srl t1, t1, 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 t1, 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 t1, zero, 0

Registers | Floating Point | Control and Status

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
t1	6	0x00000002
t2	7	0x00000002
s0	8	0x00000000
s1	9	0x00000000
a0	10	0x00000000
a1	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
s11	27	0x00000000
t3	28	0x00000030
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x0000003c

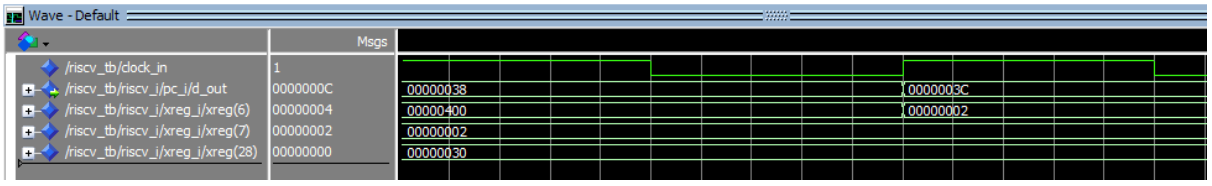


Figura 3.14: *execução da instrução bne t1, t2, teste; estado dos registradores; formas de ondas obtidas.*

Text Segment

Bkpt	Address	Code	Basic	Source
	0x00000000	0x00430313	addi x6,x6,4	7: addi t1, t1, 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: sll t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25: lui t1, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27: srl t1, t1, t2
	0x00000030	0x00000e17	auipc x28,0	29: auipc t3, 0x00000
	0x00000034	0xfdc306e3	beq x6,x28,0xfffffffcc	31: beq t1, t3, teste
	0x00000038	0x00200313	addi x6,x0,2	33: addi t1, zero, 2
	0x0000003c	0xfc7312e3	bne x6,x7,0xfffffffc4	35: bne t1, t2, teste
	0x00000040	0x004000ef	jal x1,0x00000004	37: jal teste2
	0x00000044	0x00000367	jalr x6,x0,0	41: jalr t1, zero, 0

Registers | Floating Point | Control and Status

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000000
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
t1	6	0x00000002
t2	7	0x00000002
s0	8	0x00000000
s1	9	0x00000000
a0	10	0x00000000
a1	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
s11	27	0x00000000
t3	28	0x00000030
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000040

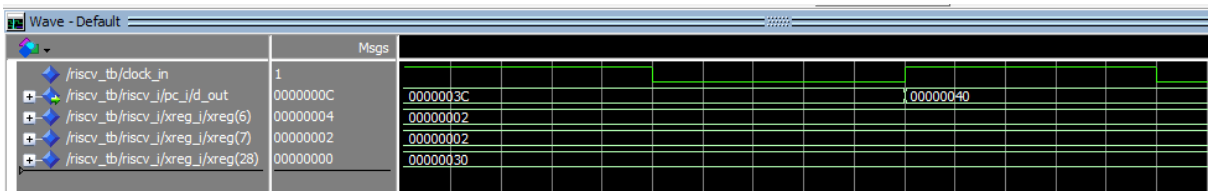


Figura 3.15: *execução da instrução jal zero, teste2; estado dos registradores; formas de ondas obtidas.*

Text Segment

Bkpt	Address	Code	Basic	Source
	0x00000000	0x00430313	addi x6,x6,4	7: addi t1, t1, 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: sll t2, t2, t2
	0x00000028	0x00001337	lui x6,1	25: lui t1, 0x00001
	0x0000002c	0x00735333	srl x6,x6,x7	27: srl t1, t1, 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 t1, 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 t1, zero, 0

Registers | Floating Point | Control and Status

Name	Number	Value
zero	0	0x00000000
ra	1	0x00000044
sp	2	0x00003ffc
gp	3	0x00001800
tp	4	0x00000000
t0	5	0x00000000
t1	6	0x00000002
t2	7	0x00000002
s0	8	0x00000000
s1	9	0x00000000
a0	10	0x00000000
a1	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
s11	27	0x00000000
t3	28	0x00000030
t4	29	0x00000000
t5	30	0x00000000
t6	31	0x00000000
pc		0x00000044

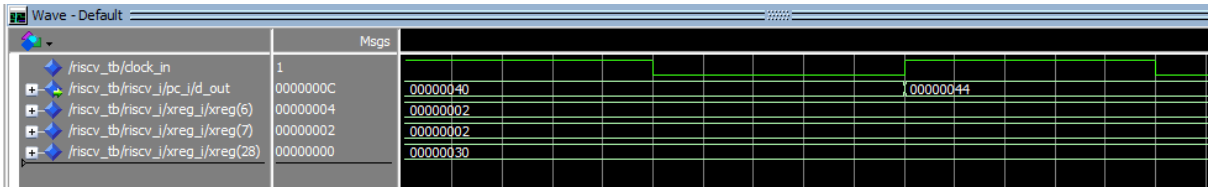


Figura 3.16: *execução da instrução jalr t1, zero, 0; estado dos registradores; formas de ondas obtidas.*