第二章 动态电路瞬态特性分析

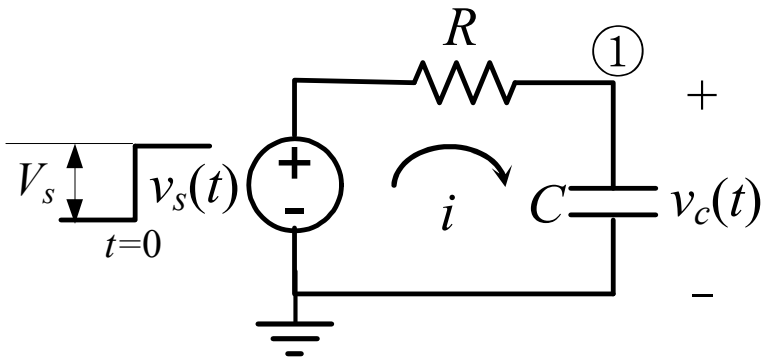
2.5 RC电路充放电

RC电路充放电

- RC电路充电
- RC电路放电
- RC电路充放电仿真

RC电路的充电

阶跃电压激励 $v_i(t) = V_s \cdot u(t) = \begin{cases} 0 & t < 0 \\ V_s & t > 0 \end{cases}$



围绕节点①列写KCL方程

$$C\frac{dv_c(t)}{dt} + \frac{v_c(t) - v_i(t)}{R} = 0$$

设$v_c(0)=0$

$$CsV_c(s) + \frac{V_c(s) - V_s/s}{R} = 0 \rightarrow RCsV_c(s) + V_c(s) - V_s/s = 0$$

$$V_c(s) = \frac{V_s}{s(1+sRC)}$$

RC电路的充电

$$V_c(s)=\frac{V_s}{s(1+sRC)}$$

```
syms RC Vs s;
VS=Vs/s/(1+s*RC)
Vt=ilaplace(VS)
```

```
VS =
Vs/(s*(RC*s + 1))

Vt =
Vs - Vs*exp(-t/RC)
>>
```

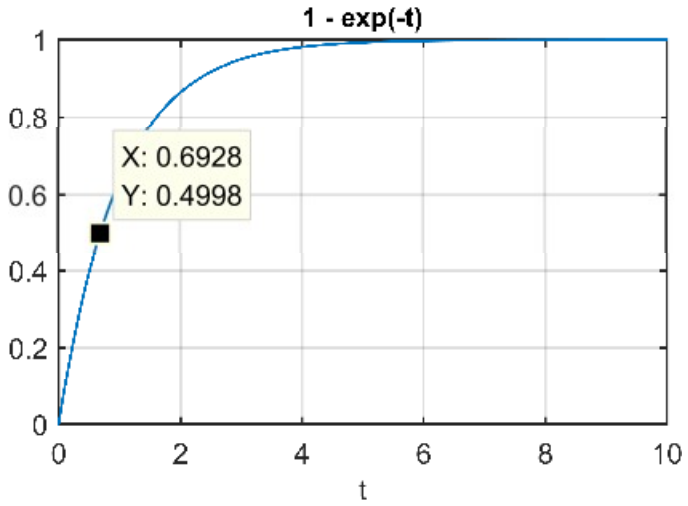
$$V_c(t)=V_s\left(1-e^{-\frac{t}{RC}}\right)=V_s\left(1-e^{-\frac{t}{\tau}}\right),\quad \tau=RC$$

RC电路的充电

$$V_c(t)\big|_{V_s=1,RC=1} = 1 - e^{-t}$$

- Vs=1 （单位阶跃电压）
- RC=1 （归一化）

```
ezplot(Vt, [0, 10]);ylim([0 1]);grid on;
```



电容器电压达到一个特定值 $v_c(t_x) = V_x$ 所需时间

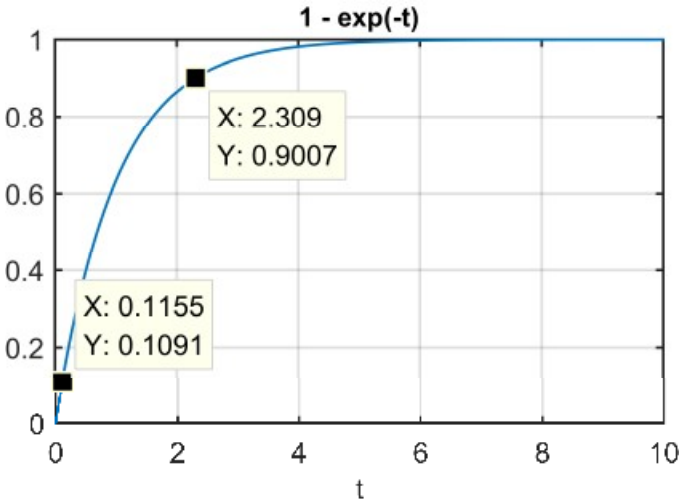
$$t_x = \ln\left(\frac{1}{1-V_x}\right)$$

$$0.5 = 1 - e^{-t_{50\%}} \rightarrow t_{50\%} = \ln\left(\frac{1}{1-0.5}\right) = 0.7$$

RC电路的充电

充电过程中电容器电压上升时间
t_{LH}定义为

$$t_{LH} = t_{90\%} - t_{10\%} = \ln\left(\frac{1}{1-0.9}\right) - \ln\left(\frac{1}{1-0.1}\right) = 2.2$$

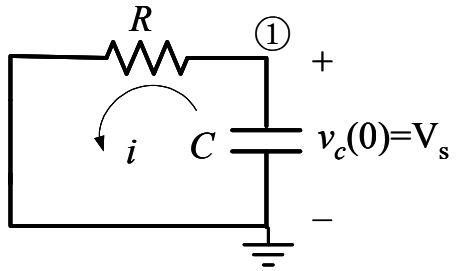


t_{LH}=2.309-0.1155=2.19

RC电路的放电

电源短路，电容初始储能不为零

$$v_c(0^-) = V_s \neq 0$$



$$\frac{v_c(t)}{R} + C\frac{dv_c(t)}{dt} = 0$$

$$f(t) \leftrightarrow F(s)$$

$$\frac{d}{dt}f(t) = sF(s) - f(0^-)$$

$$\frac{V_c(s)}{R} + C\left(sV_c(s) - v_c(0^-)\right) = 0,\ v_c(0^-) = V_s$$

$$V_c(s) = \frac{V_s}{s + \frac{1}{RC}}$$

RC电路的放电

$$V_c(s)=\frac{V_s}{s+\frac{1}{RC}}$$

```
syms RC Vs s;
VS=Vs/(s+1/(RC))
Vt=ilaplace(VS)
```

```
VS =
Vs/(s + 1/RC)

Vt =
Vs*exp(-t/RC)
>>
```

$$v_c(t)=V_s e^{-\frac{t}{RC}}=V_s e^{-\frac{t}{\tau}},\tau=RC$$

RC电路的放电

$$V_c(t)\big|_{V_s=1,RC=1} = e^{-t}$$

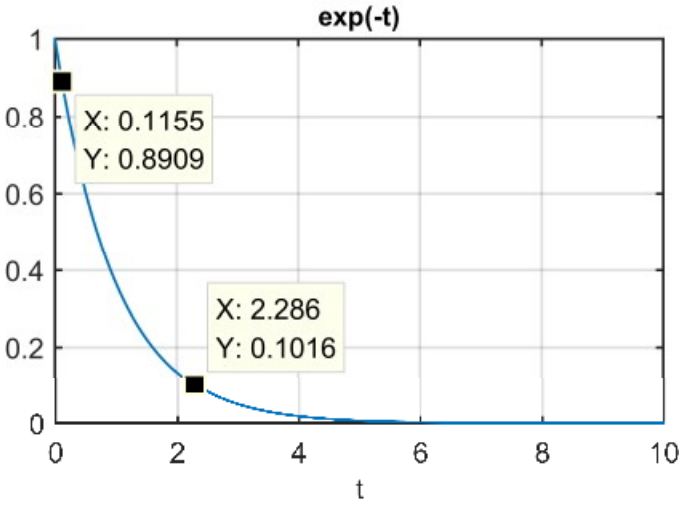
Vs=1 （单位阶跃电压）
RC=1（归一化）

```
ezplot(Vt, [0, 10]);ylim([0 1]);grid on;
```

$$0.5 = e^{-t_{50\%}} \rightarrow t_{50\%} = \ln\frac{1}{0.5} = 0.7$$

$$t_{HL} = t_{10\%} - t_{90\%} = \ln\left(\frac{1}{0.1}\right) - \ln\left(\frac{1}{0.9}\right) = 2.2$$

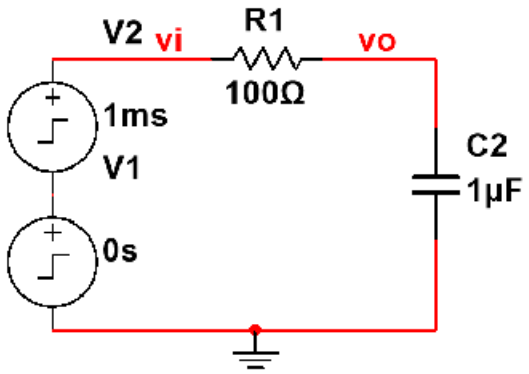
放电过程中电容器电压下降时间t_{HL} $t_{HL} \approx 2.2\tau$



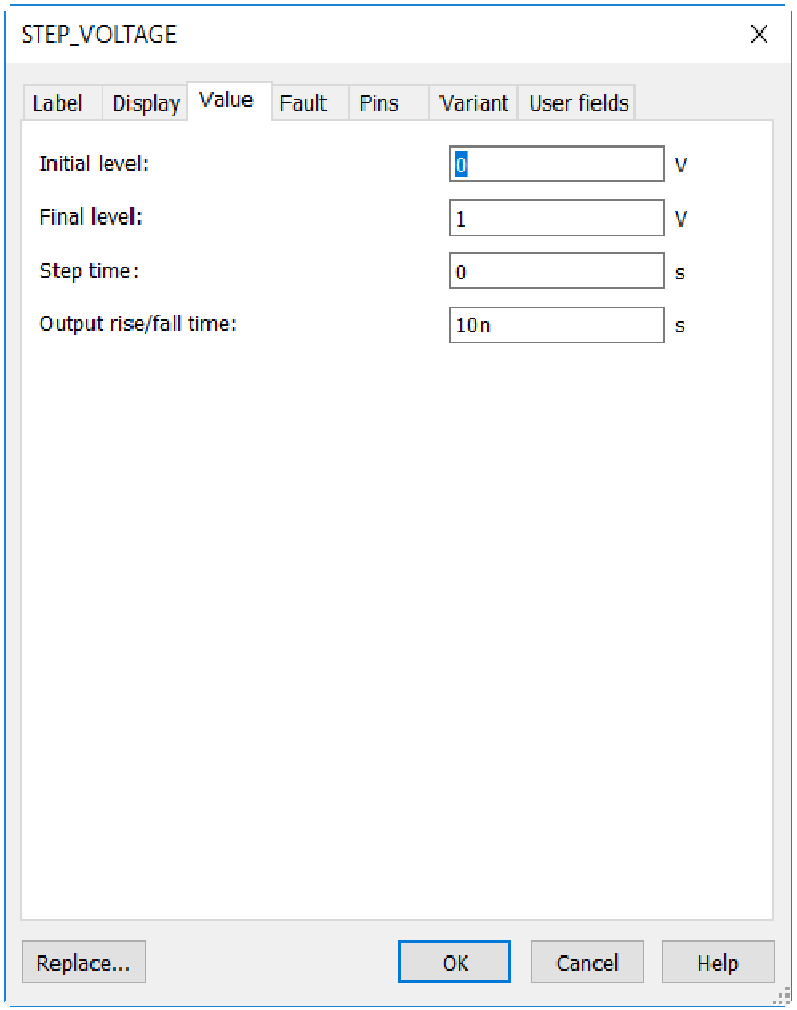
t_{HL}=2.286-0.1155=2.17

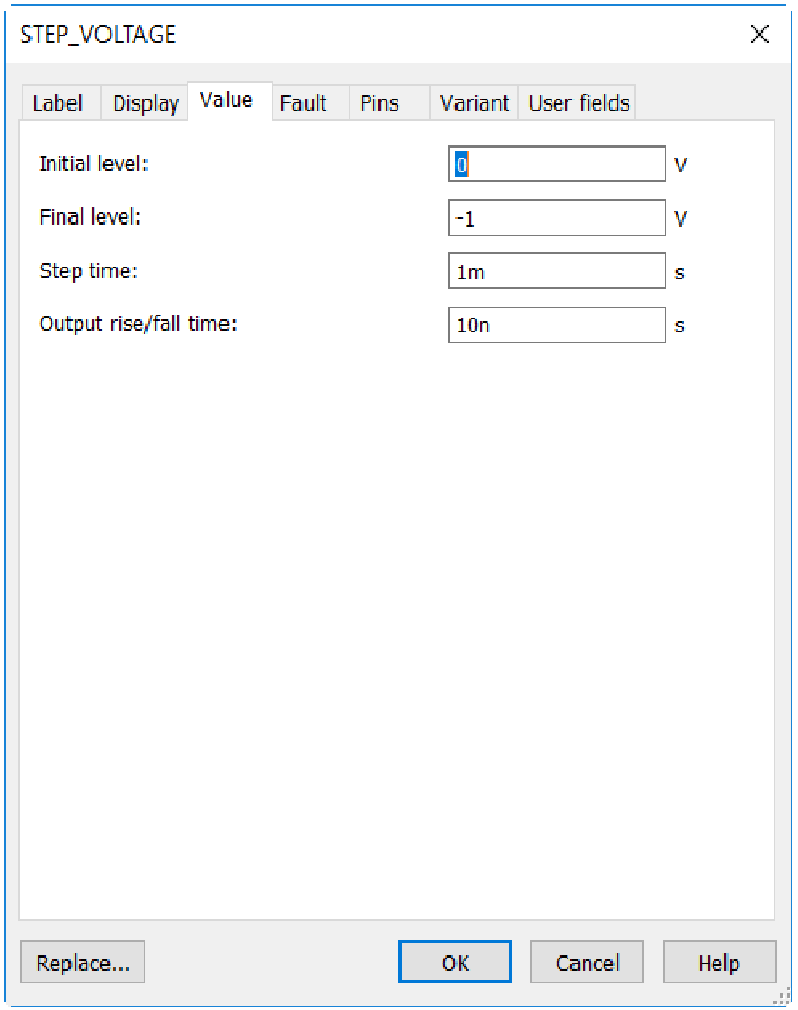
RC电路充放电仿真

- τ =RC=0.1ms，仿真时间2ms（=20*τ）

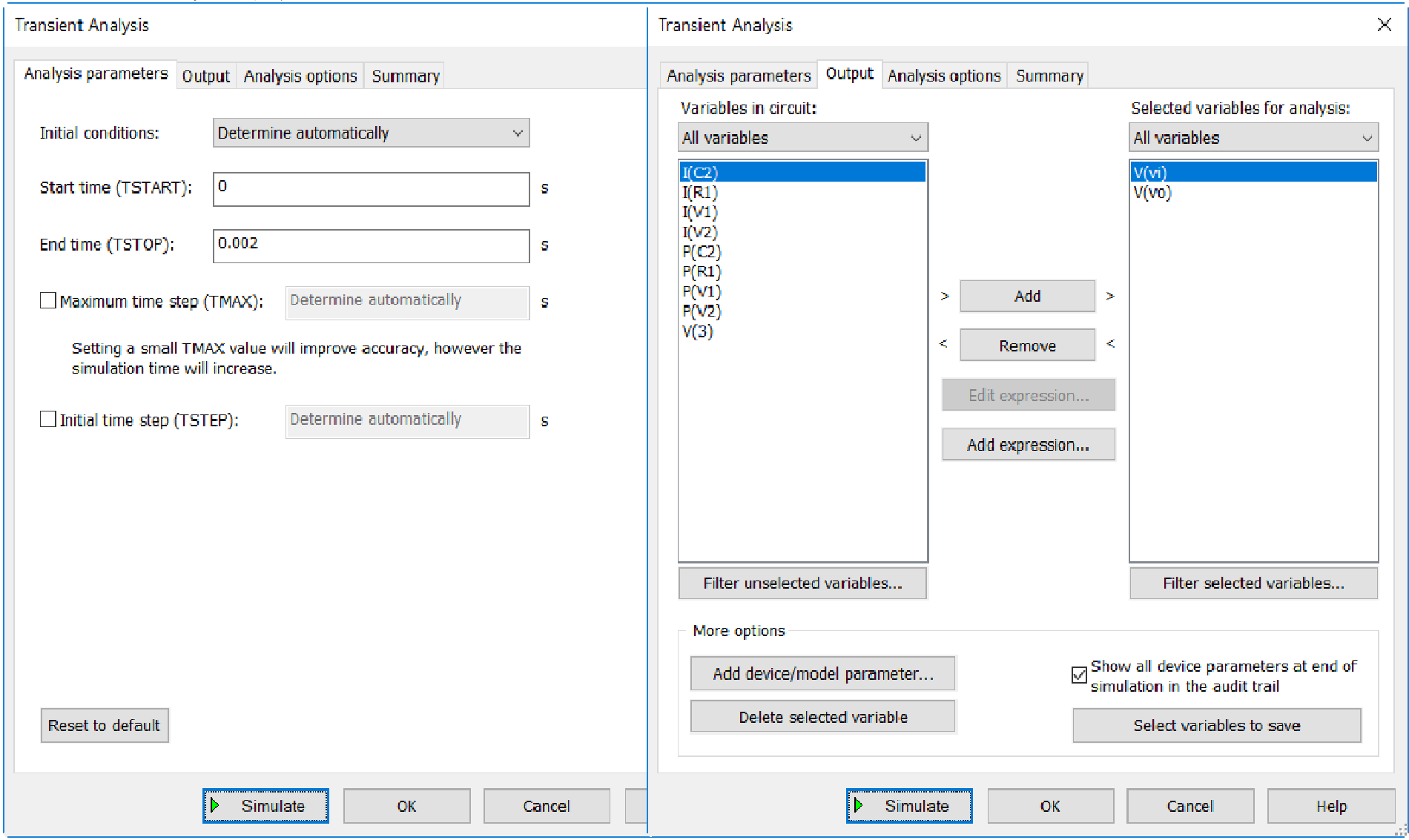


信号源设置


STEP_VOLTAGE
Label
Display
Value
Fault
Pins
Variant
User fields
Initial level:
0
V
Final level:
1
V
Step time:
0
s
Output rise/fall time:
10n
s
Replace...
OK
Cancel
Help

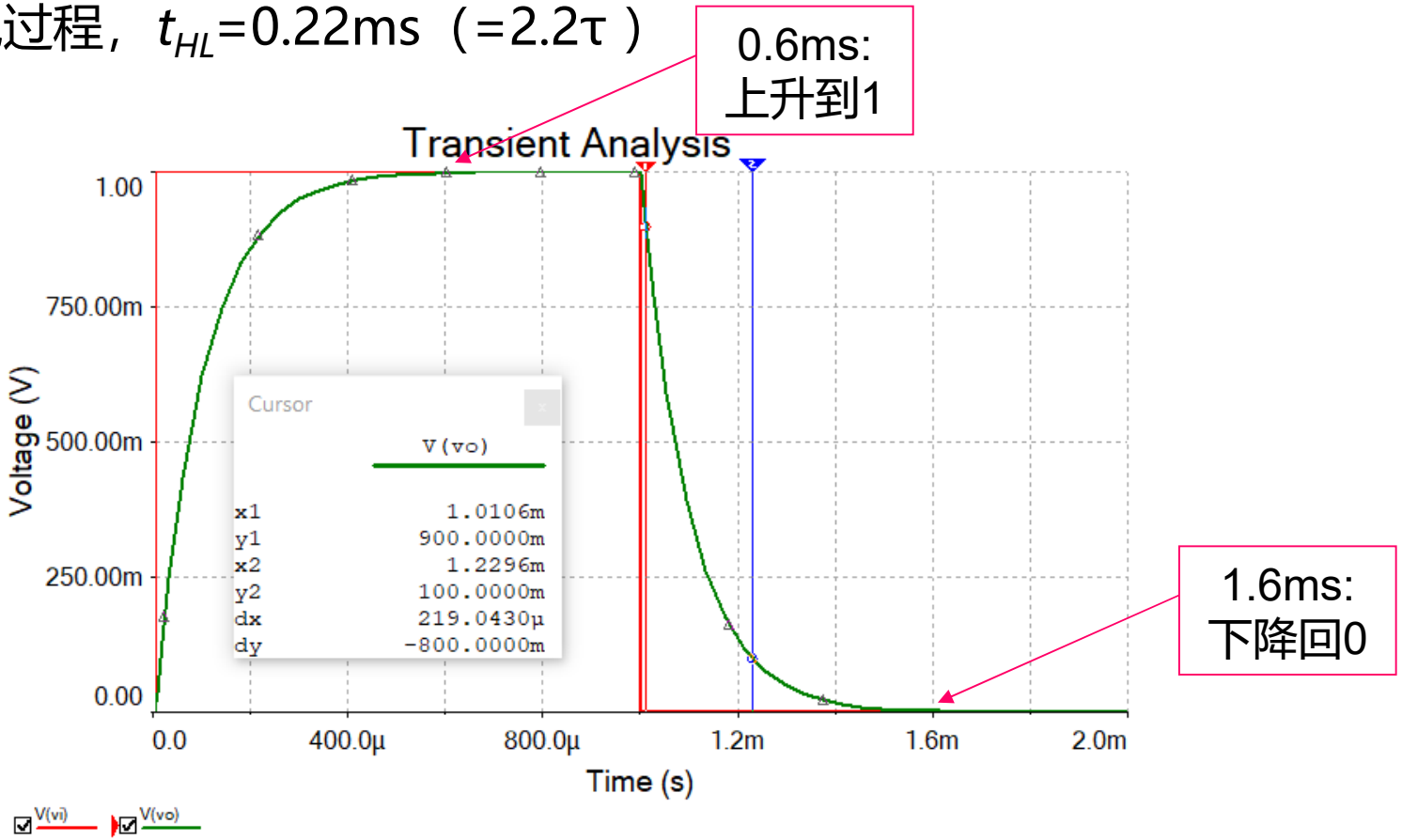

STEP_VOLTAGE
Label
Display
Value
Fault
Pins
Variant
User fields
Initial level:
0
V
Final level:
-1
V
Step time:
1m
s
Output rise/fall time:
10n
s
Replace...
OK
Cancel
Help

仿真设置


Transient Analysis
Analysis parameters
Output
Analysis options
Summary
Initial conditions:
Determine automatically
Start time (TSTART):
0
s
End time (TSTOP):
0.002
s
Maximum time step (TMAX):
Determine automatically
s
Setting a small TMAX value will improve accuracy, however the simulation time will increase.
Initial time step (TSTEP):
Determine automatically
s
Reset to default
Simulate
OK
Cancel
Transient Analysis
Analysis parameters
Output
Analysis options
Summary
Variables in circuit:
All variables
I(C2)
I(R1)
I(V1)
I(V2)
P(C2)
P(R1)
P(V1)
P(V2)
V(3)
Add
Remove
Edit expression...
Add expression...
Selected variables for analysis:
All variables
V(vi)
V(vo)
Filter unselected variables...
Filter selected variables...
More options
Add device/model parameter...
Delete selected variable
Show all device parameters at end of simulation in the audit trail
Select variables to save
Simulate
OK
Cancel
Help

RC电路充放电仿真

- 0~1ms 充电过程；1~2ms放电过程
- 放电过程，t_{HL}=0.22ms（=2.2τ）



小结

- 电容电压不能突变，RC电路
  - 一方面导致**信号有延迟**，另一方面**波形有失真**
  - 信号延迟的大小与波形失真的程度都与时间常数有关

- 实际电路中寄生电容不可避免

- 对于高速或高频电路，必须通过仿真，确认信号延迟与波形失真是否在可以接受的程度之内