LVS Using a Customized Resistor Extractor

continuation

Aim:

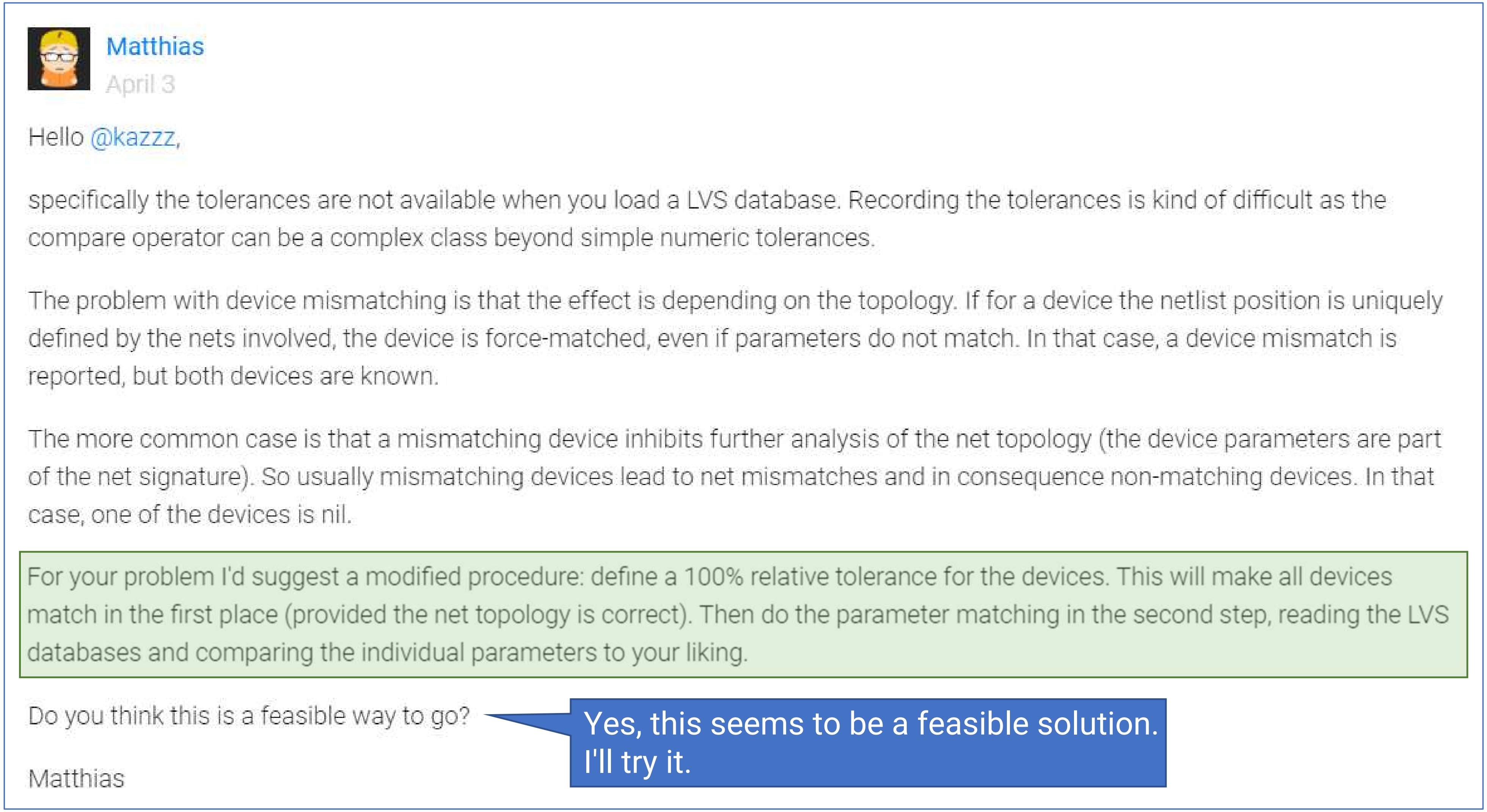
To implement and test a customized resistor extractor for KLayout's LVS

Disclaimer:

This document is for personal records only. There is NO WARRANTY on technical correctness.

By Kazzz-S (2023-04-04)
original (2023-03-31)

0. Discussions and Suggestions



Matthias

April 3

Hello @kazzz,

specifically the tolerances are not available when you load a LVS database. Recording the tolerances is kind of difficult as the compare operator can be a complex class beyond simple numeric tolerances.

The problem with device mismatching is that the effect is depending on the topology. If for a device the netlist position is uniquely defined by the nets involved, the device is force-matched, even if parameters do not match. In that case, a device mismatch is reported, but both devices are known.

The more common case is that a mismatching device inhibits further analysis of the net topology (the device parameters are part of the net signature). So usually mismatching devices lead to net mismatches and in consequence non-matching devices. In that case, one of the devices is nil.

For your problem I'd suggest a modified procedure: define a 100% relative tolerance for the devices. This will make all devices match in the first place (provided the net topology is correct). Then do the parameter matching in the second step, reading the LVS databases and comparing the individual parameters to your liking.

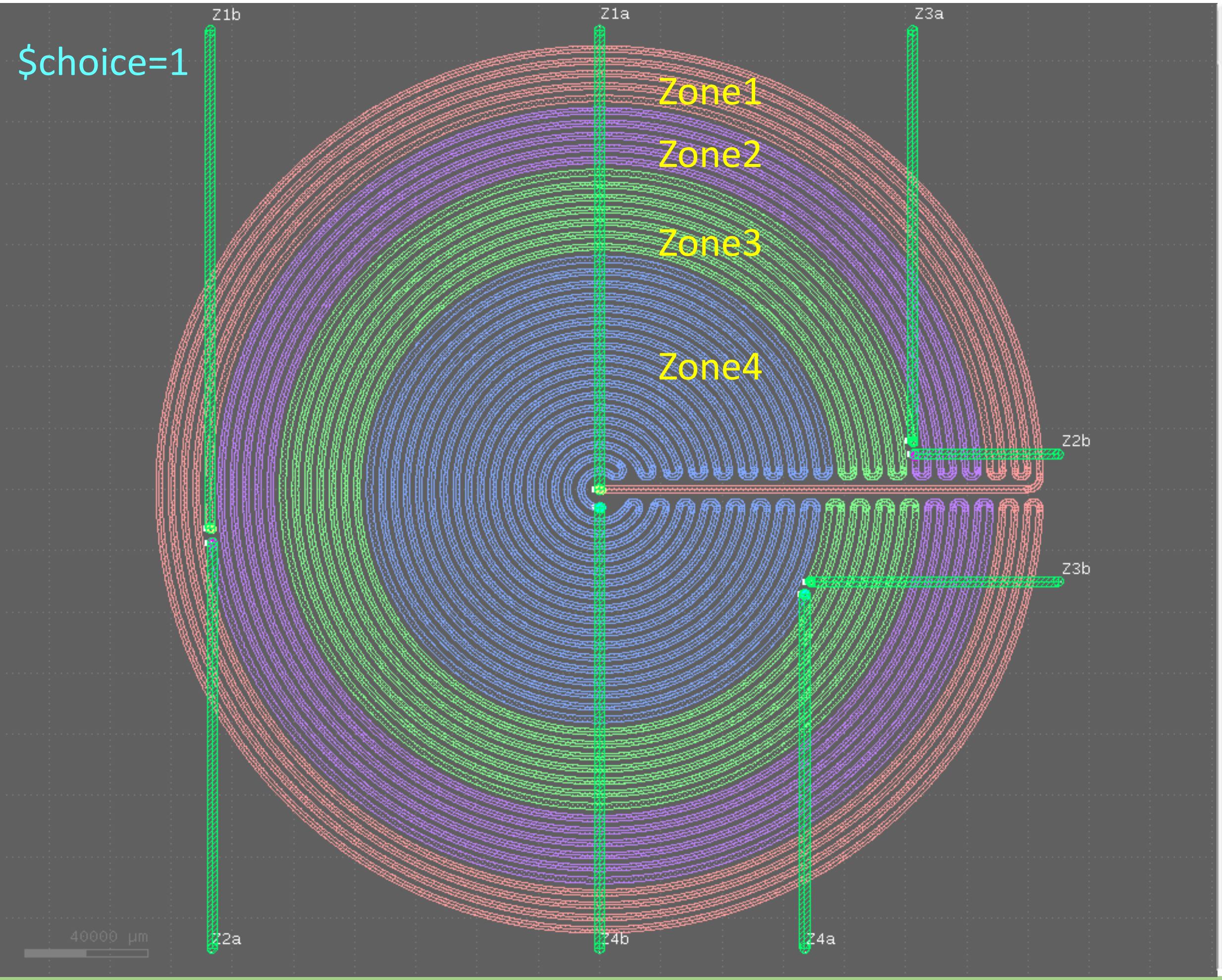
Do you think this is a feasible way to go?

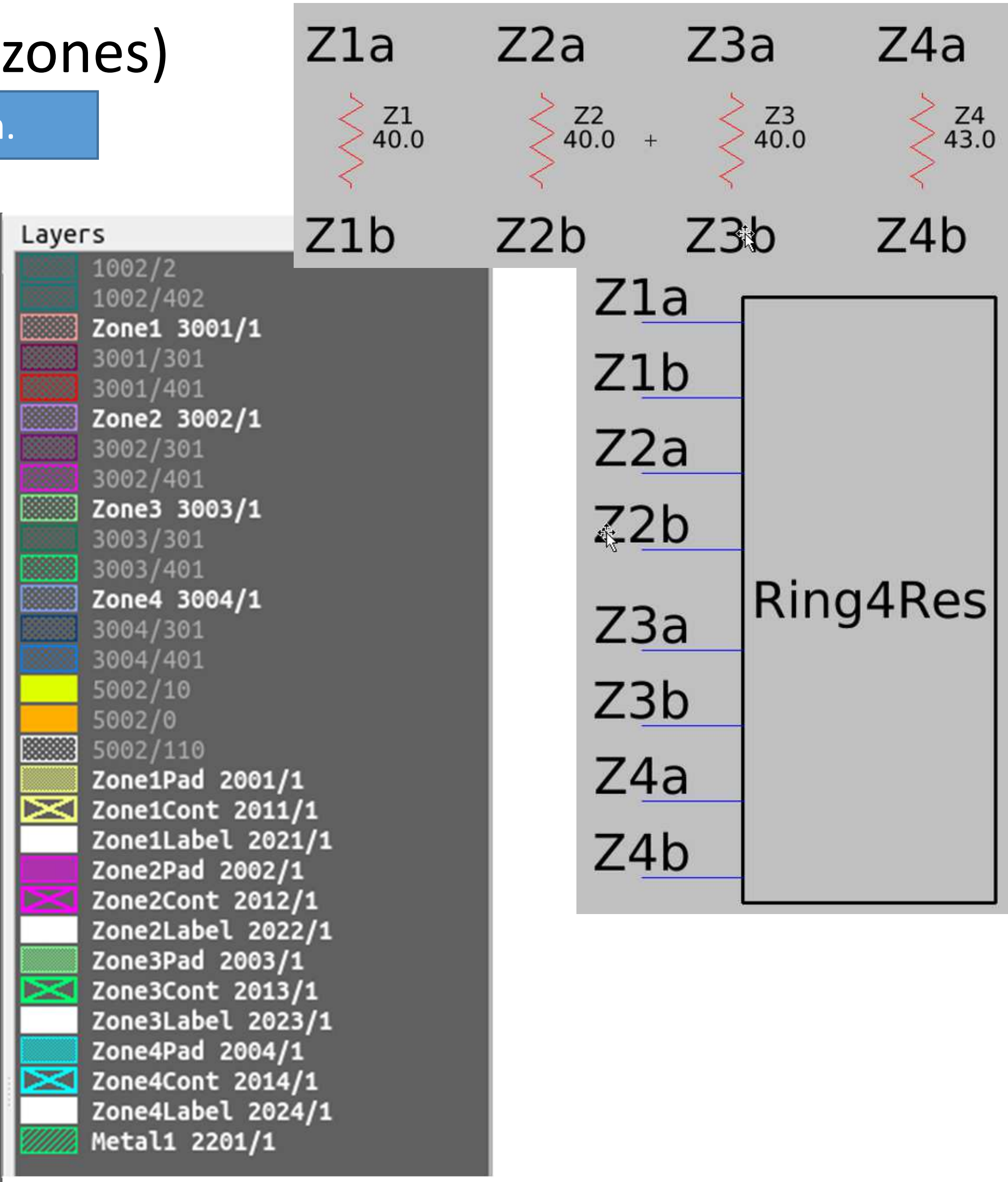
Matthias

Yes, this seems to be a feasible solution. I'll try it.

1. The Design (BBQ hotplate with four heater zones)

- Each zone has a distinct layer set in the standard layout design.

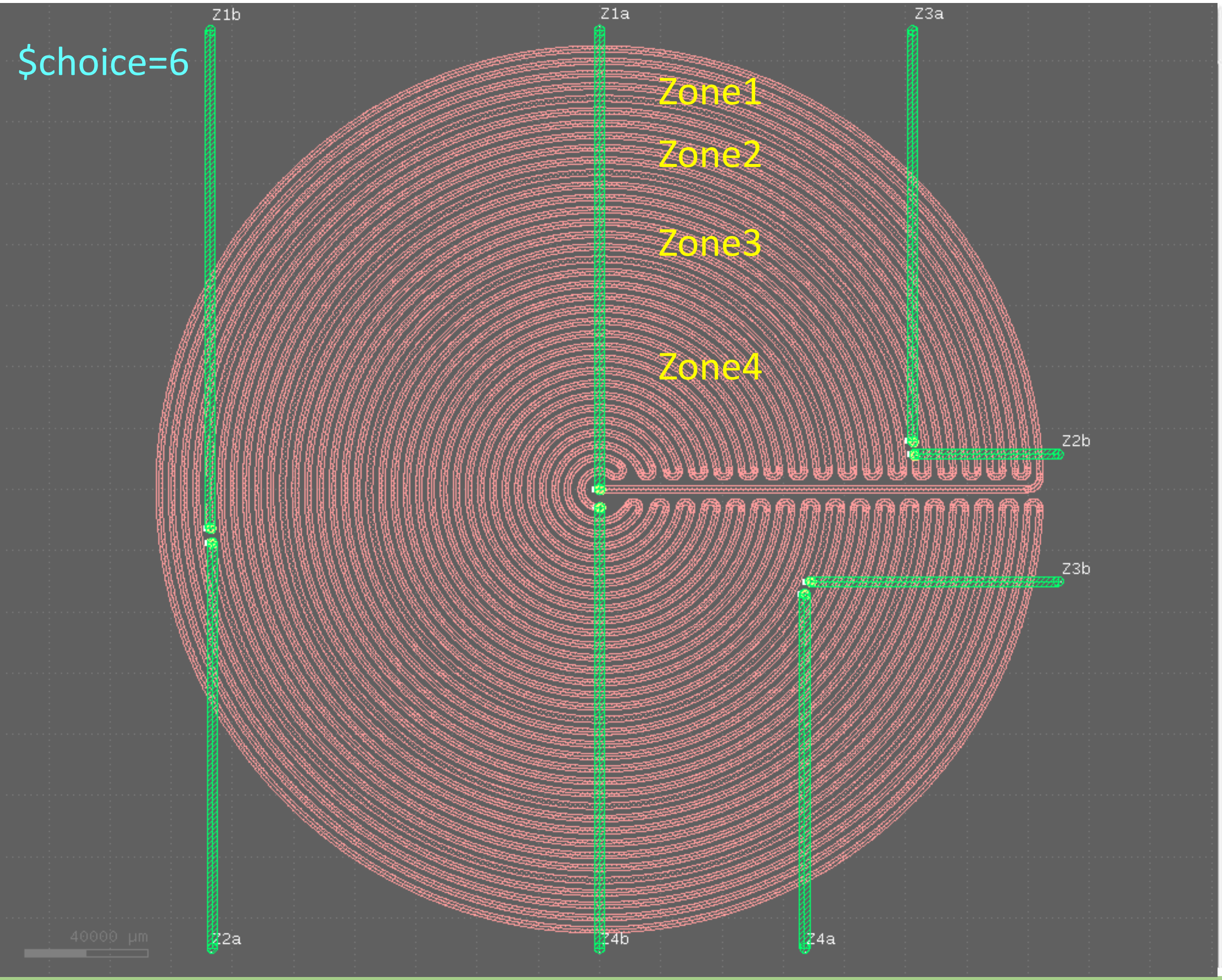


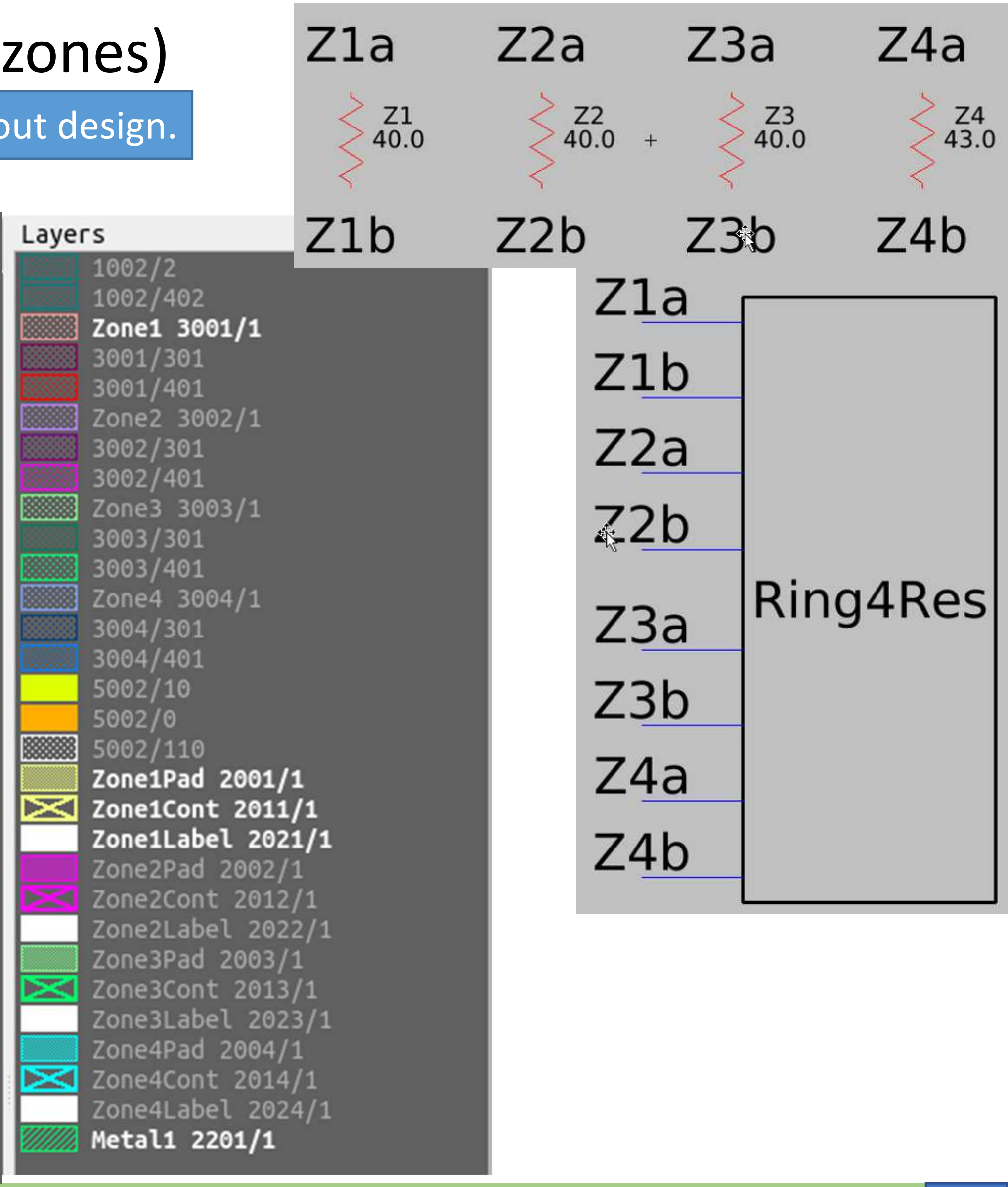

Layers

- 1002/2
- 1002/402
- Zone1 3001/1
- 3001/301
- 3001/401
- Zone2 3002/1
- 3002/301
- 3002/401
- Zone3 3003/1
- 3003/301
- 3003/401
- Zone4 3004/1
- 3004/301
- 3004/401
- 5002/10
- 5002/0
- 5002/110
- Zone1Pad 2001/1
- Zone1Cont 2011/1
- Zone1Label 2021/1
- Zone2Pad 2002/1
- Zone2Cont 2012/1
- Zone2Label 2022/1
- Zone3Pad 2003/1
- Zone3Cont 2013/1
- Zone3Label 2023/1
- Zone4Pad 2004/1
- Zone4Cont 2014/1
- Zone4Label 2024/1
- Metal1 2201/1

1. The Design (BBQ hotplate with four heater zones)

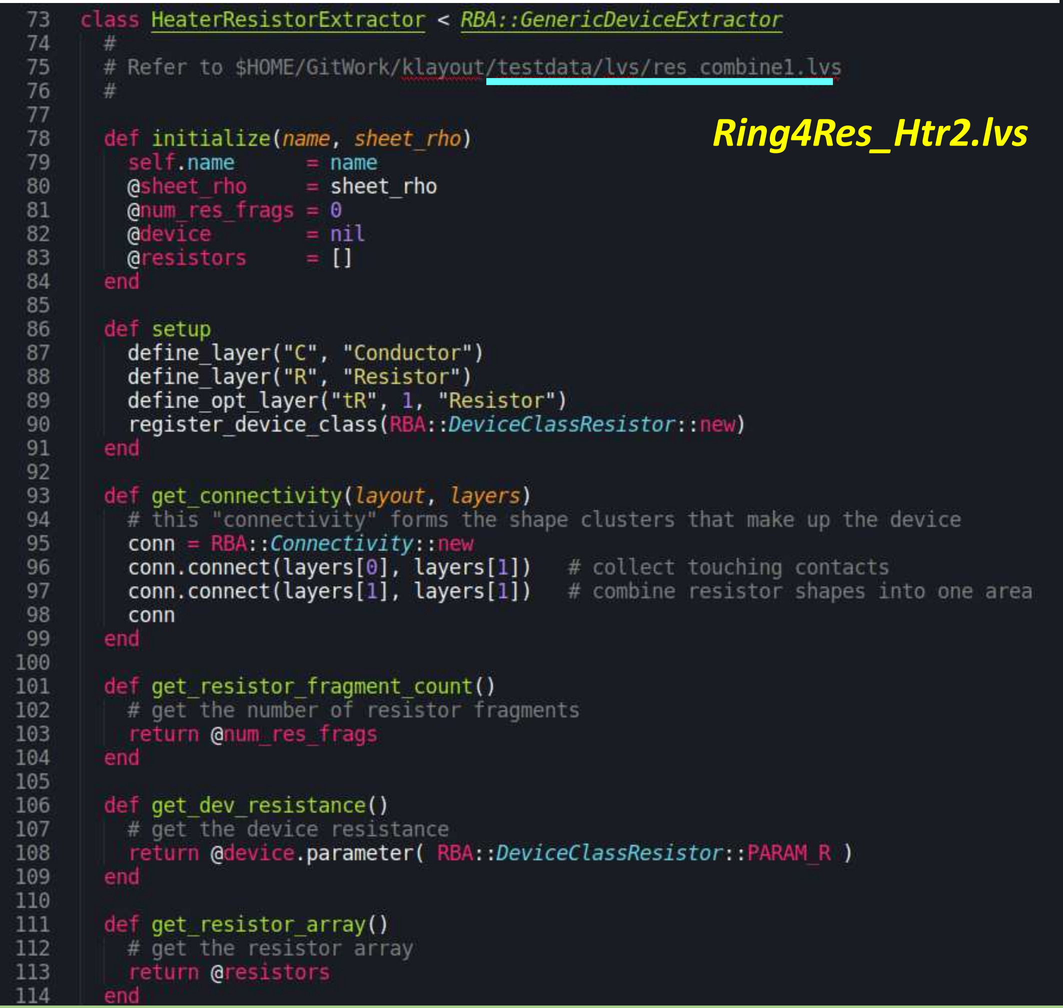
- Four zones may have a common layer set in an alternative layout design.




Layers

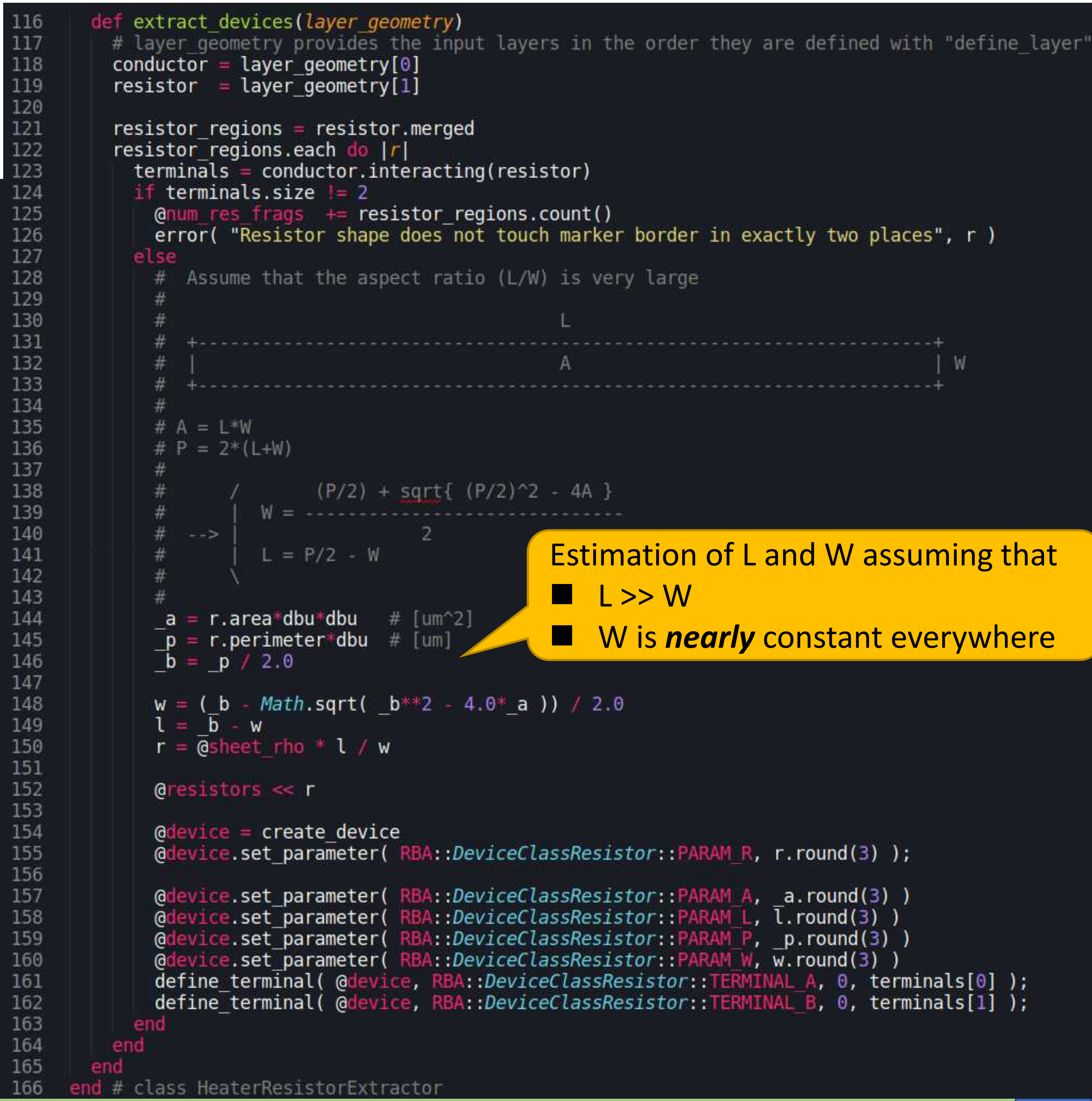
1002/2
1002/402
Zone1 3001/1
3001/301
3001/401
Zone2 3002/1
3002/301
3002/401
Zone3 3003/1
3003/301
3003/401
Zone4 3004/1
3004/301
3004/401
5002/10
5002/0
5002/110
Zone1Pad 2001/1
Zone1Cont 2011/1
Zone1Label 2021/1
Zone2Pad 2002/1
Zone2Cont 2012/1
Zone2Label 2022/1
Zone3Pad 2003/1
Zone3Cont 2013/1
Zone3Label 2023/1
Zone4Pad 2004/1
Zone4Cont 2014/1
Zone4Label 2024/1
Metal1 2201/1

2. The Refactored Customized Resistor Extractor



Ring4Res_Htr2.lvs

```ruby
class HeaterResistorExtractor < RBA::GenericDeviceExtractor
  #
  # Refer to $HOME/GitWork/klayout/testdata/lvs/res_combine1.lvs
  #

  def initialize(name, sheet_rho)
    self.name      = name
    @sheet_rho     = sheet_rho
    @num_res_frags = 0
    @device        = nil
    @resistors     = []
  end

  def setup
    define_layer("C", "Conductor")
    define_layer("R", "Resistor")
    define_opt_layer("tR", 1, "Resistor")
    register_device_class(RBA::DeviceClassResistor::new)
  end

  def get_connectivity(layout, layers)
    # this "connectivity" forms the shape clusters that make up the device
    conn = RBA::Connectivity::new
    conn.connect(layers[0], layers[1])   # collect touching contacts
    conn.connect(layers[1], layers[1])   # combine resistor shapes into one area
    conn
  end

  def get_resistor_fragment_count()
    # get the number of resistor fragments
    return @num_res_frags
  end

  def get_dev_resistance()
    # get the device resistance
    return @device.parameter( RBA::DeviceClassResistor::PARAM_R )
  end

  def get_resistor_array()
    # get the resistor array
    return @resistors
  end
```

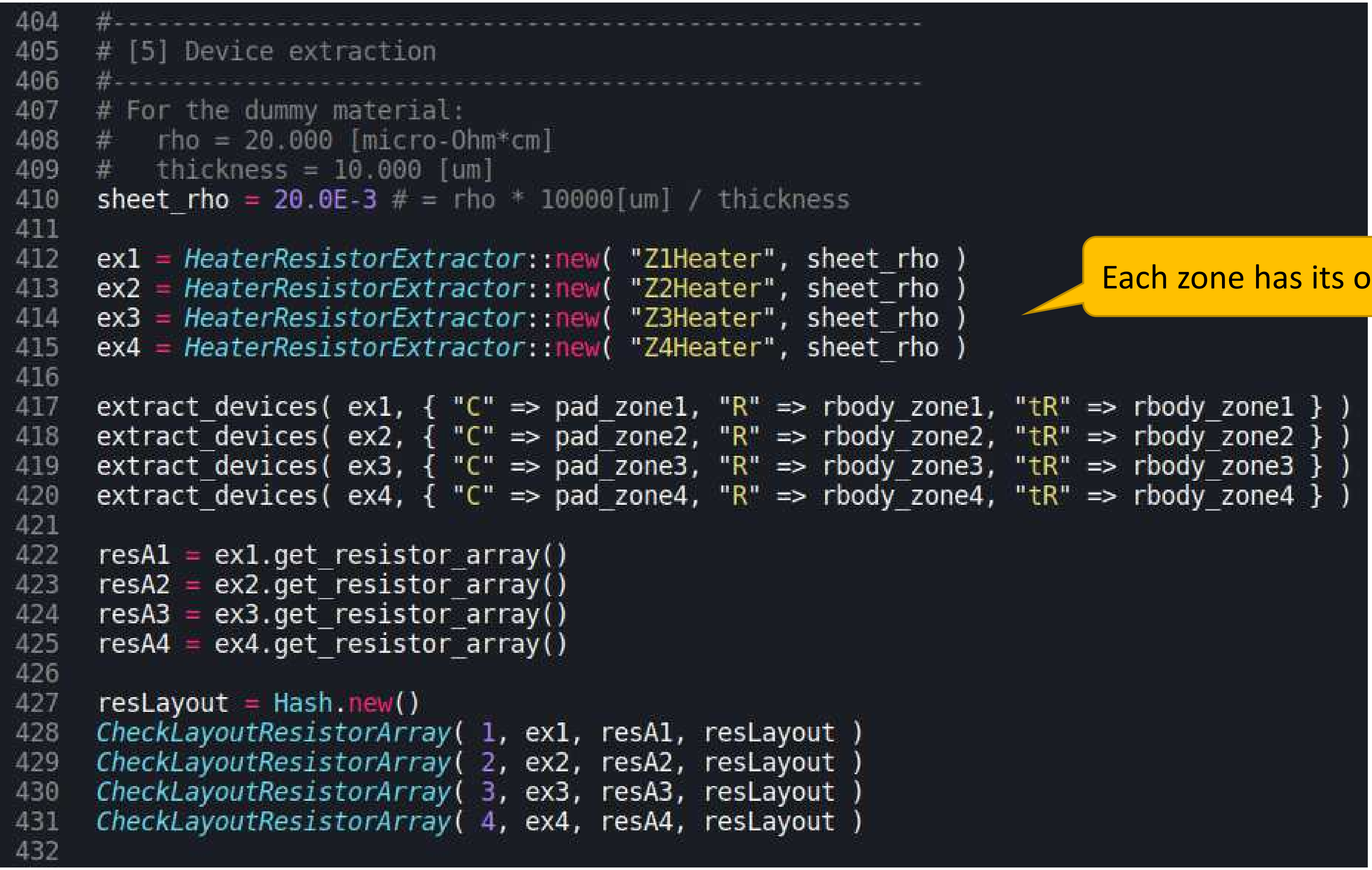


```ruby
  def extract_devices(layer_geometry)
    # layer_geometry provides the input layers in the order they are defined with "define_layer"
    conductor = layer_geometry[0]
    resistor  = layer_geometry[1]

    resistor_regions = resistor.merged
    resistor_regions.each do |r|
      terminals = conductor.interacting(resistor)
      if terminals.size != 2
        @num_res_frags  += resistor_regions.count()
        error( "Resistor shape does not touch marker border in exactly two places", r )
      else
        #  Assume that the aspect ratio (L/W) is very large
        #
        #                                     L
        #  +---------------------------------------------------------------------+
        #  |                                  A                                  | W
        #  +---------------------------------------------------------------------+
        #
        # A = L*W
        # P = 2*(L+W)
        #
        #      /       (P/2) + sqrt{ (P/2)^2 - 4A }
        #      |  W = ------------------------------
        #  --> |                 2
        #      |  L = P/2 - W
        #      \
        #
        _a = r.area*dbu*dbu   # [um^2]
        _p = r.perimeter*dbu  # [um]
        _b = _p / 2.0

        w = ( _b - Math.sqrt( _b**2 - 4.0*_a )) / 2.0
        l = _b - w
        r = @sheet_rho * l / w

        @resistors << r

        @device = create_device
        @device.set_parameter( RBA::DeviceClassResistor::PARAM_R, r.round(3) );

        @device.set_parameter( RBA::DeviceClassResistor::PARAM_A, _a.round(3) )
        @device.set_parameter( RBA::DeviceClassResistor::PARAM_L, l.round(3) )
        @device.set_parameter( RBA::DeviceClassResistor::PARAM_P, _p.round(3) )
        @device.set_parameter( RBA::DeviceClassResistor::PARAM_W, w.round(3) )
        define_terminal( @device, RBA::DeviceClassResistor::TERMINAL_A, 0, terminals[0] );
        define_terminal( @device, RBA::DeviceClassResistor::TERMINAL_B, 0, terminals[1] );
      end
    end
  end
end # class HeaterResistorExtractor
```

Estimation of L and W assuming that

- L >> W
- W is ***nearly*** constant everywhere

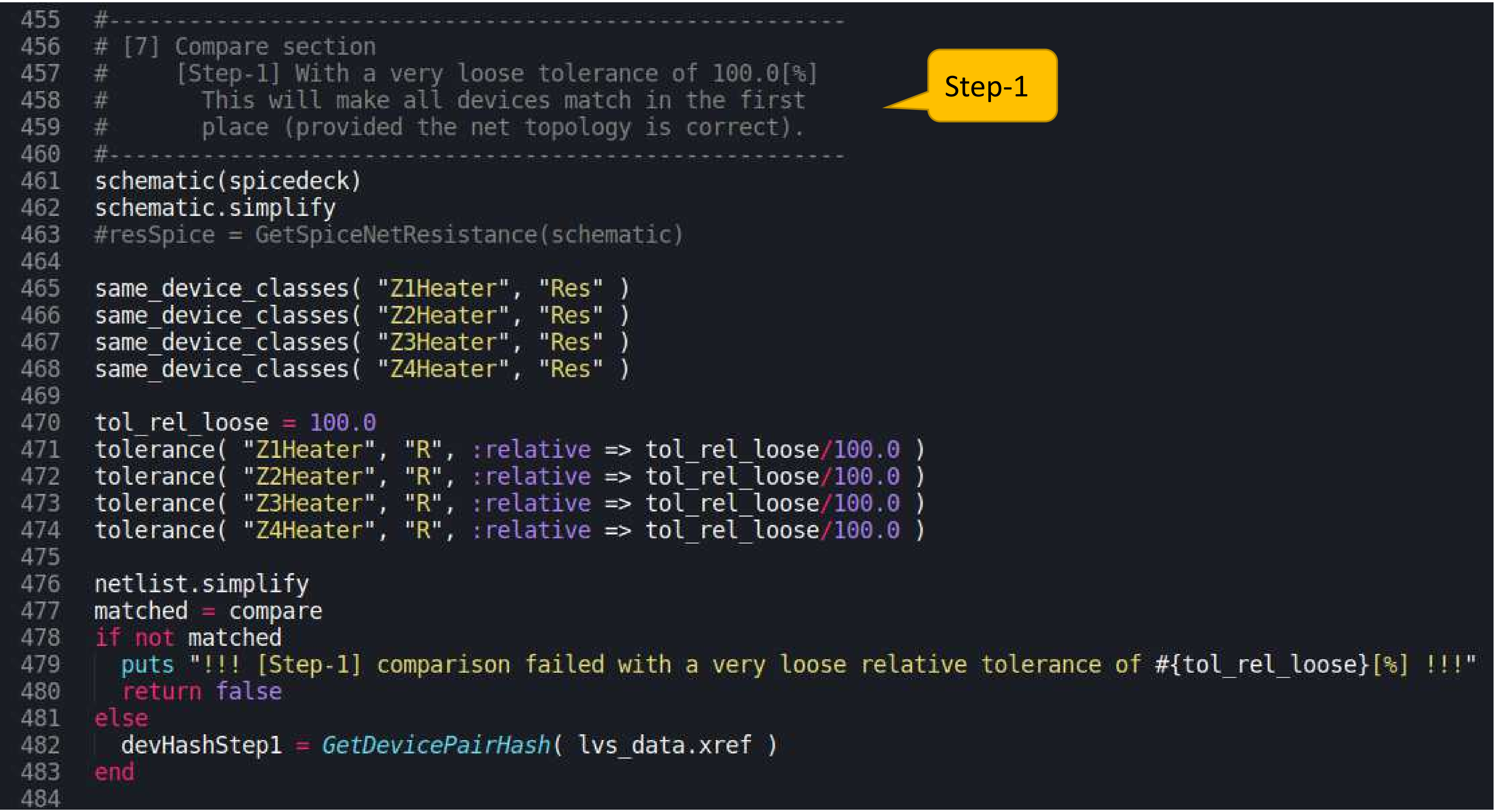
2. The Refactored Customized Resistor Extractor



```
#---------------------------------------------------
# [5] Device extraction
#---------------------------------------------------
# For the dummy material:
#   rho = 20.000 [micro-Ohm*cm]
#   thickness = 10.000 [um]
sheet_rho = 20.0E-3 # = rho * 10000[um] / thickness

ex1 = HeaterResistorExtractor::new( "Z1Heater", sheet_rho )
ex2 = HeaterResistorExtractor::new( "Z2Heater", sheet_rho )
ex3 = HeaterResistorExtractor::new( "Z3Heater", sheet_rho )
ex4 = HeaterResistorExtractor::new( "Z4Heater", sheet_rho )

extract_devices( ex1, { "C" => pad_zone1, "R" => rbody_zone1, "tR" => rbody_zone1 } )
extract_devices( ex2, { "C" => pad_zone2, "R" => rbody_zone2, "tR" => rbody_zone2 } )
extract_devices( ex3, { "C" => pad_zone3, "R" => rbody_zone3, "tR" => rbody_zone3 } )
extract_devices( ex4, { "C" => pad_zone4, "R" => rbody_zone4, "tR" => rbody_zone4 } )

resA1 = ex1.get_resistor_array()
resA2 = ex2.get_resistor_array()
resA3 = ex3.get_resistor_array()
resA4 = ex4.get_resistor_array()

resLayout = Hash.new()
CheckLayoutResistorArray( 1, ex1, resA1, resLayout )
CheckLayoutResistorArray( 2, ex2, resA2, resLayout )
CheckLayoutResistorArray( 3, ex3, resA3, resLayout )
CheckLayoutResistorArray( 4, ex4, resA4, resLayout )

```

Each zone has its own dedicated resistor extractor

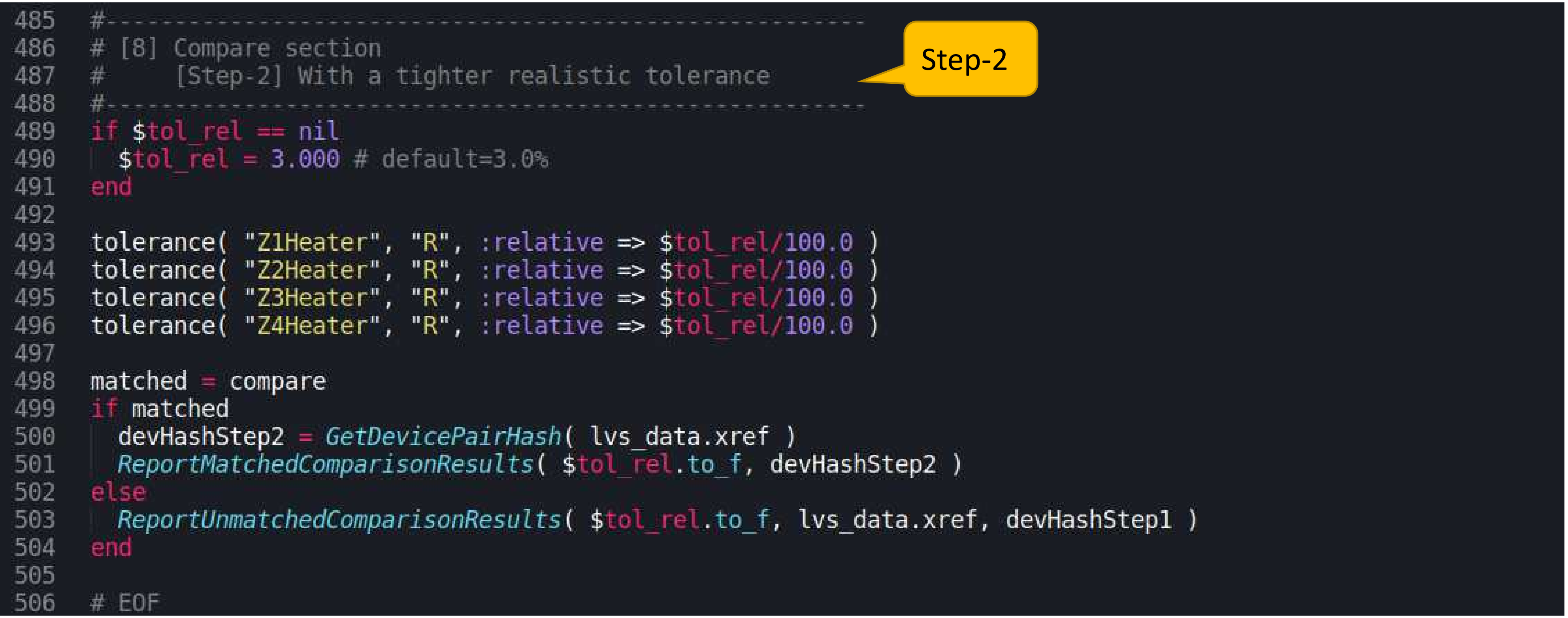
2. The Refactored Customized Resistor Extractor



```
#-------------------------------------------------------
# [7] Compare section
#     [Step-1] With a very loose tolerance of 100.0[%]
#       This will make all devices match in the first
#       place (provided the net topology is correct).
#-------------------------------------------------------
schematic(spicedeck)
schematic.simplify
#resSpice = GetSpiceNetResistance(schematic)

same_device_classes( "Z1Heater", "Res" )
same_device_classes( "Z2Heater", "Res" )
same_device_classes( "Z3Heater", "Res" )
same_device_classes( "Z4Heater", "Res" )

tol_rel_loose = 100.0
tolerance( "Z1Heater", "R", :relative => tol_rel_loose/100.0 )
tolerance( "Z2Heater", "R", :relative => tol_rel_loose/100.0 )
tolerance( "Z3Heater", "R", :relative => tol_rel_loose/100.0 )
tolerance( "Z4Heater", "R", :relative => tol_rel_loose/100.0 )

netlist.simplify
matched = compare
if not matched
  puts "!!! [Step-1] comparison failed with a very loose relative tolerance of #{tol_rel_loose}[%] !!!"
  return false
else
  devHashStep1 = GetDevicePairHash( lvs_data.xref )
end

```

Step-1

2. The Refactored Customized Resistor Extractor

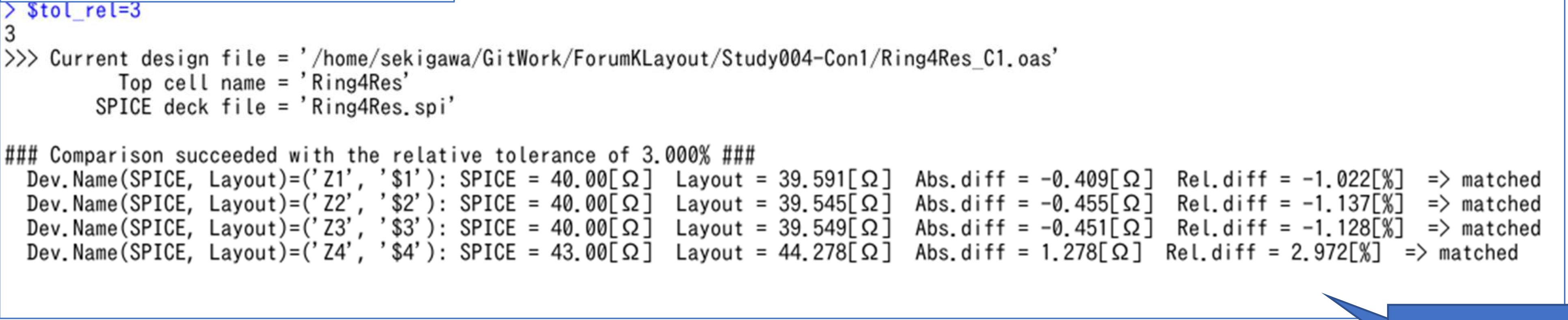


```
#---------------------------------------------------
# [8] Compare section
#     [Step-2] With a tighter realistic tolerance
#---------------------------------------------------
if $tol_rel == nil
  $tol_rel = 3.000 # default=3.0%
end

tolerance( "Z1Heater", "R", :relative => $tol_rel/100.0 )
tolerance( "Z2Heater", "R", :relative => $tol_rel/100.0 )
tolerance( "Z3Heater", "R", :relative => $tol_rel/100.0 )
tolerance( "Z4Heater", "R", :relative => $tol_rel/100.0 )

matched = compare
if matched
  devHashStep2 = GetDevicePairHash( lvs_data.xref )
  ReportMatchedComparisonResults( $tol_rel.to_f, devHashStep2 )
else
  ReportUnmatchedComparisonResults( $tol_rel.to_f, lvs_data.xref, devHashStep1 )
end

# EOF
```

Step-2

3. Test Results of the Standard Layout Design ($choice=1)

$choice = 1 $tol_rel = 3.0%

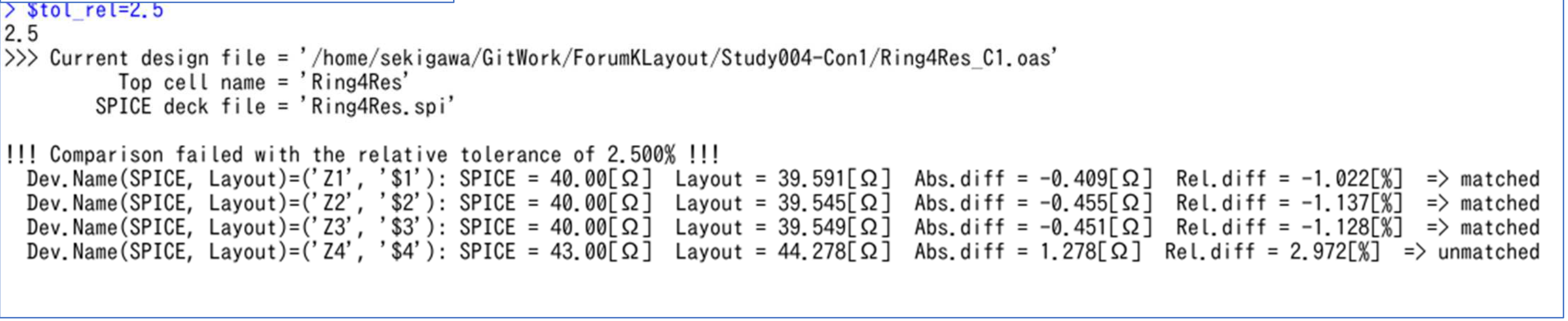


```
> $tol_rel=3
3
>>> Current design file = ’/home/sekigawa/GitWork/ForumKLayout/Study004-Con1/Ring4Res_C1.oas’
          Top cell name = ’Ring4Res’
        SPICE deck file = ’Ring4Res.spi’

### Comparison succeeded with the relative tolerance of 3.000% ###
  Dev.Name(SPICE, Layout)=(’Z1’, ’$1’): SPICE = 40.00[Ω]  Layout = 39.591[Ω]  Abs.diff = -0.409[Ω]  Rel.diff = -1.022[%]  => matched
  Dev.Name(SPICE, Layout)=(’Z2’, ’$2’): SPICE = 40.00[Ω]  Layout = 39.545[Ω]  Abs.diff = -0.455[Ω]  Rel.diff = -1.137[%]  => matched
  Dev.Name(SPICE, Layout)=(’Z3’, ’$3’): SPICE = 40.00[Ω]  Layout = 39.549[Ω]  Abs.diff = -0.451[Ω]  Rel.diff = -1.128[%]  => matched
  Dev.Name(SPICE, Layout)=(’Z4’, ’$4’): SPICE = 43.00[Ω]  Layout = 44.278[Ω]  Abs.diff = 1.278[Ω]  Rel.diff = 2.972[%]  => matched
```

perfect

Became simpler!

$choice = 1 $tol_rel = 2.5%

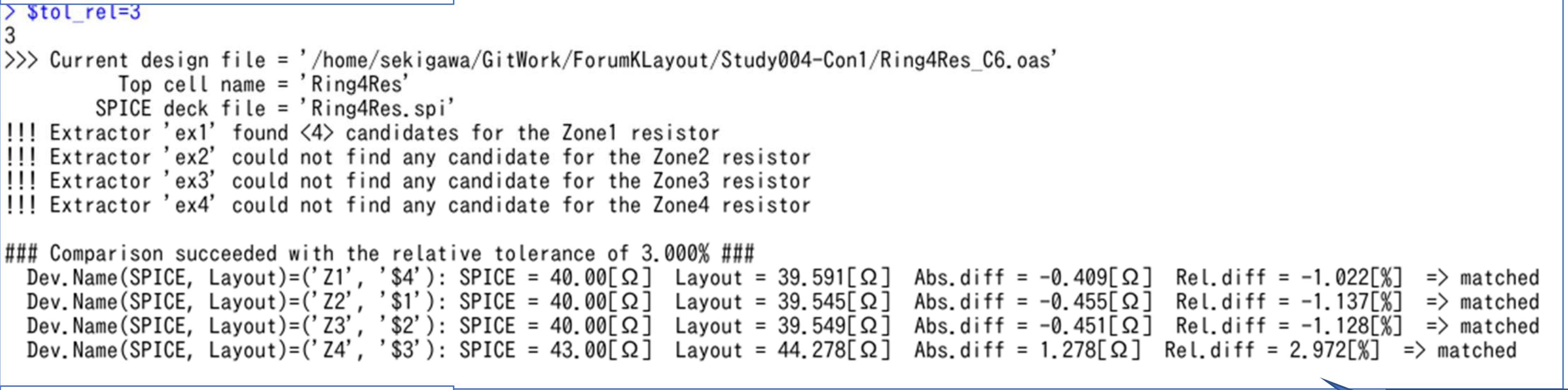


```
> $tol_rel=2.5
2.5
>>> Current design file = ’/home/sekigawa/GitWork/ForumKLayout/Study004-Con1/Ring4Res_C1.oas’
          Top cell name = ’Ring4Res’
        SPICE deck file = ’Ring4Res.spi’

!!! Comparison failed with the relative tolerance of 2.500% !!!
  Dev.Name(SPICE, Layout)=(’Z1’, ’$1’): SPICE = 40.00[Ω]  Layout = 39.591[Ω]  Abs.diff = -0.409[Ω]  Rel.diff = -1.022[%]  => matched
  Dev.Name(SPICE, Layout)=(’Z2’, ’$2’): SPICE = 40.00[Ω]  Layout = 39.545[Ω]  Abs.diff = -0.455[Ω]  Rel.diff = -1.137[%]  => matched
  Dev.Name(SPICE, Layout)=(’Z3’, ’$3’): SPICE = 40.00[Ω]  Layout = 39.549[Ω]  Abs.diff = -0.451[Ω]  Rel.diff = -1.128[%]  => matched
  Dev.Name(SPICE, Layout)=(’Z4’, ’$4’): SPICE = 43.00[Ω]  Layout = 44.278[Ω]  Abs.diff = 1.278[Ω]  Rel.diff = 2.972[%]  => unmatched
```

perfect

4. Test Results of the Alternative Layout Design ($choice=6)

$choice = 6 $tol_rel = 3.0%

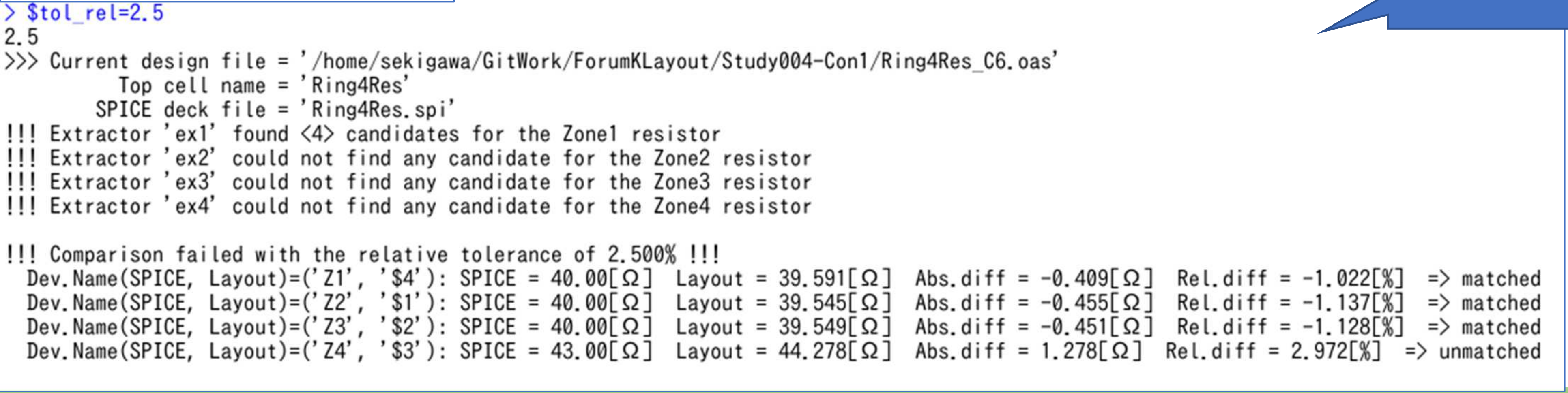


```
> $tol_rel=3
3
>>> Current design file = '/home/sekigawa/GitWork/ForumKLayout/Study004-Con1/Ring4Res_C6.oas'
          Top cell name = 'Ring4Res'
        SPICE deck file = 'Ring4Res.spi'
!!! Extractor 'ex1' found <4> candidates for the Zone1 resistor
!!! Extractor 'ex2' could not find any candidate for the Zone2 resistor
!!! Extractor 'ex3' could not find any candidate for the Zone3 resistor
!!! Extractor 'ex4' could not find any candidate for the Zone4 resistor

### Comparison succeeded with the relative tolerance of 3.000% ###
  Dev.Name(SPICE, Layout)=('Z1', '$4'): SPICE = 40.00[Ω]  Layout = 39.591[Ω]  Abs.diff = -0.409[Ω]  Rel.diff = -1.022[%]  => matched
  Dev.Name(SPICE, Layout)=('Z2', '$1'): SPICE = 40.00[Ω]  Layout = 39.545[Ω]  Abs.diff = -0.455[Ω]  Rel.diff = -1.137[%]  => matched
  Dev.Name(SPICE, Layout)=('Z3', '$2'): SPICE = 40.00[Ω]  Layout = 39.549[Ω]  Abs.diff = -0.451[Ω]  Rel.diff = -1.128[%]  => matched
  Dev.Name(SPICE, Layout)=('Z4', '$3'): SPICE = 43.00[Ω]  Layout = 44.278[Ω]  Abs.diff = 1.278[Ω]  Rel.diff = 2.972[%]  => matched
```

perfect

Became simpler! ☺

$choice = 6 $tol_rel = 2.5%



```
> $tol_rel=2.5
2.5
>>> Current design file = '/home/sekigawa/GitWork/ForumKLayout/Study004-Con1/Ring4Res_C6.oas'
          Top cell name = 'Ring4Res'
        SPICE deck file = 'Ring4Res.spi'
!!! Extractor 'ex1' found <4> candidates for the Zone1 resistor
!!! Extractor 'ex2' could not find any candidate for the Zone2 resistor
!!! Extractor 'ex3' could not find any candidate for the Zone3 resistor
!!! Extractor 'ex4' could not find any candidate for the Zone4 resistor

!!! Comparison failed with the relative tolerance of 2.500% !!!
  Dev.Name(SPICE, Layout)=('Z1', '$4'): SPICE = 40.00[Ω]  Layout = 39.591[Ω]  Abs.diff = -0.409[Ω]  Rel.diff = -1.022[%]  => matched
  Dev.Name(SPICE, Layout)=('Z2', '$1'): SPICE = 40.00[Ω]  Layout = 39.545[Ω]  Abs.diff = -0.455[Ω]  Rel.diff = -1.137[%]  => matched
  Dev.Name(SPICE, Layout)=('Z3', '$2'): SPICE = 40.00[Ω]  Layout = 39.549[Ω]  Abs.diff = -0.451[Ω]  Rel.diff = -1.128[%]  => matched
  Dev.Name(SPICE, Layout)=('Z4', '$3'): SPICE = 43.00[Ω]  Layout = 44.278[Ω]  Abs.diff = 1.278[Ω]  Rel.diff = 2.972[%]  => unmatched
```

perfect

5. Summary

- The proposed two-step approach works very well.
- This homework assignment is done.
- Thank you!

All Files

Ring4Res-Cont1.zi
p