The Application of RESCUER Software to Modelling of Coupled Problems in Modern Devices

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ABSTRACT

The paper presents a application of RESCUER software to the fast multidomain model developing for the modern behavioural simulators such as PSPICE, ICAP, ELDO, AdvanceMS. The micro-channel cooling systems for modern integration systems has been presented as the example.

Keywords: RESCUER, PDAE, VLSI, micro-channel cooling system

1 INTRODUCTION

The simulation of modern electronic devices requiring taking into account physical phenomena of different nature such as electrical, mechanical, thermal or fluidic ones. The most of processes are governed by multidimensional partial differential-algebraic equations (PDAEs). The analytical approach is often insufficient to describe all necessary details of modern devices. On the other hand, using classical finite element analysis (FEA) and boundary element method (BEM) it is difficult to model multidomain devices together with real electrical circuits containing different devices, such as OPAMPs, low voltage or high power devices [1]. The interfacing of these simulators to purely electrical ones requires creating special synchronisers, but then the simulation time and memory requirements may become unacceptable. In order to simplify the modelling and simulation of recently developed multidomain silicon structures (MEMS, MOEMS and others) [2-5], the RESCUER programming tool has been proposed and developed [6,7].

The advantage of proposed approach consists in creation of new generation of compiler, which can translate and optimize specified distributed problems described in the high-level abstraction language into a destination language or equivalent SPICE circuit. The exemplary application of RESCUER to the coupled problems modelling and simulation has been shown using the electro-thermal model of heat transfer in the cooling pipes and micro-channels.

2 SLOW CIRCULATION COOLING SYSTEM

The slow circulation cooling system based on the micro-channel in modern integration systems (VLSI, Smart Power systems) will be presented as the example. This problem is similar to the problem of the heat transfer in pipe-type high voltage power cable systems with slow circulation of dielectric fluid (oil) has been detailed presented in [8,9].

The micro-channel cooling systems can be decomposed to particular cooling pipe described by the set of Navier-Stokes, the cooling fluid continuity and Fourier-Kirchhoff equation

$$\frac{\partial\theta}{\partial t}+\left(\mathbf{w}\nabla\right)\theta= =\frac{q_v}{c_p\rho_m}+\frac{1}{c_p\rho_m}\left\{\nabla\left[k\nabla\theta\right]+\frac{\partial p}{\partial x}+\left(\mathbf{w}\nabla\right)p\right\} \quad (1)$$

$$\frac{\partial\mathbf{w}}{\partial t}+\left(\mathbf{w}\nabla\right)\mathbf{w}=\mathbf{K}-\frac{\nabla p}{\rho_m}+\nu\nabla^2\mathbf{w}+\frac{\nu}{3}\nabla\left(\nabla\mathbf{w}\right) \quad (2)$$

$$\frac{\partial\rho_m}{\partial t}+\rho_m\nabla\mathbf{w}=0 \quad (3)$$

where $\theta=\theta(x,y,z,t)=\theta(\mathrm{r,t})$ - temperature distribution of the cooling fluid; $\mathbf{w}=\mathbf{w}(x,y,z,t)=\mathbf{w}(r,t)$ - cooling medium velocity; q_v - internal heat sources (0); c_p - specific heat; ρ_m - fluid density; k,p - thermal conductivity and kinematic viscosity; $\mathbf{K}$ - gravitation vector; ν -- dynamic viscosity.

This problem description can be simplified taking into account the following assumptions:

- the quasi steady-state ($\partial\bullet/\partial t=0$),
- no-internal heat sources ($q_\mathrm{v}=0$),
- the laminar fluid flow (Re <<1000),
- the dominance of forced-convection over the free-convection ($\mathrm{Gr}<<0.06\,(\mathrm{Re})^2$),
- the region of hydrodynamic stability ($x>d_\mathrm{h}\cdot \mathrm{Re}/20$).
- the circular cross-section of the microfluid-channel (see Fig. 1).

The heat transfer can be expressed in simplified form

$$r^+\frac{d^2\theta^+}{d\left(r^+\right)^2}+\frac{d\theta^+}{dr^+}=\frac{r^+w^+}{2}\frac{d\theta^+}{dx^+}+\frac{1}{\left(Pe\right)_f^2}\frac{d^2\theta^+}{d\left(x^+\right)^2} \quad (4)$$

with boundary condition

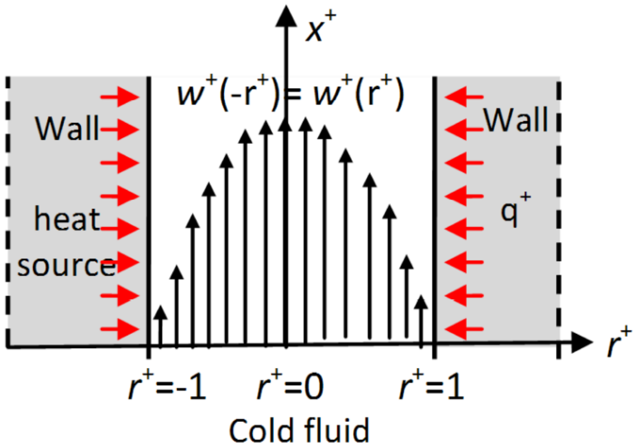

Figure 1: Fluid velocity profile w^+ and micro-fluid cross-section.

$$\left.\frac{d\theta^+}{dr^+}\right|_{r^+=1}=q^+,\left.\frac{d\theta^+}{dr^+}\right|_{r^+=0}=0,\left.\theta^+\right|_{x=0}=0 \qquad (5)$$

and fluid velocity profile

$$w=w^+\cdot\langle w\rangle \qquad (6)$$

$$w^+=2\langle w\rangle\cdot\left\{1-\left(r^+\right)^2\right\} \qquad (7)$$

where $<w>$ - average fluid speed; θ^+ - normalised fluid temperature; Pe_f - averaged Peclet number; S -- oil transport cross-section; $w^+=w^+(r)$ - non-dimensional oil velocity; r^+ - non-dimensional radius, $r^+=r/D_d \in <\beta,1>$; d_h - channel external diameter.

Presented problem can be solved using following Green's function:

$$\theta^+\left(r^+,x^+\right)=\sum_{i=1}^{\infty}\frac{1}{r^+}\cdot\left\{C_{1,i}M_{\frac{\zeta_i}{4},0}\left(\zeta_i\cdot\left(r^+\right)^2\right)+\right.$$
$$\left.+C_{2,i}W_{\frac{\zeta_i}{4},0}\left(\zeta_i\cdot\left(r^+\right)^2\right)\right\}\cdot\exp\left(-\zeta_i\cdot x^+\right) \qquad (8)$$

where $M_{k,\mu}(z)$, $W_{k,\mu}(z)$ - Whittaker special function; $C_{1,i}$,$C_{2,i}$ - particular constants; ζ_i - eigenvalues.

Unfortunately, this form is not effective for small x as-well as a transient simulation. The following problem can be directly written in RESCUER language and translated to SPICE circuit ([4,6,7]):

Listing 1

```
-- q is used as input signal
object 2D MyModel{      -- y is used as r
  option
    DP_NPOINTS=40, TR_PRECISION=18,
    TR_COMMENTS=10;

  const Pe=1000.0,          --Peclet number
        wc =0.01;           -- fluid-speed

  var theta, w;

  equ r1(w):w== wc*(1-Y_0*Y_0),
    r2(theta):Y_0*diff[theta,y,y]     +diff[theta,y]==
    Y_0*w*diff[theta,x]/2+diff[theta,x,x]/(Pe*Pe);

    import 'points.txt';

    object BoundaryCond1 {
    equ r1(theta): diff[theta,y]== -q;

    import 'points2.txt'; -- for r==1
  };

  object BoundaryCond2
  {
    equ r1(theta): diff[theta,y]==0;

    import 'points3.txt'; -- for r==0
  };

  object BoundaryCond3
  {
    equ r1(theta):  theta==0;

   import 'points3.txt'; -- for x==0
  };

}
```

and translated to SPICE circuit (1576 elements RGVE for domain <0,1>x<0,1> and mesh mod 0.1x0.1).The dimension-less solution has been presented in figure 2.

3 SUMMARY

The RESCUER tools allows for fast generation of distributed multi-domain models for the circuital and behavioural simulators such as PSPICE, ICAP, ELDO, AdvanceMS and others. The developed models are full-integrated with electronic circuits (e.g. VLSI circuits) and simulator resources (e.g. implemented functions and predefined signals). The solution approximation and simulation convergence should be verified for each analised model.

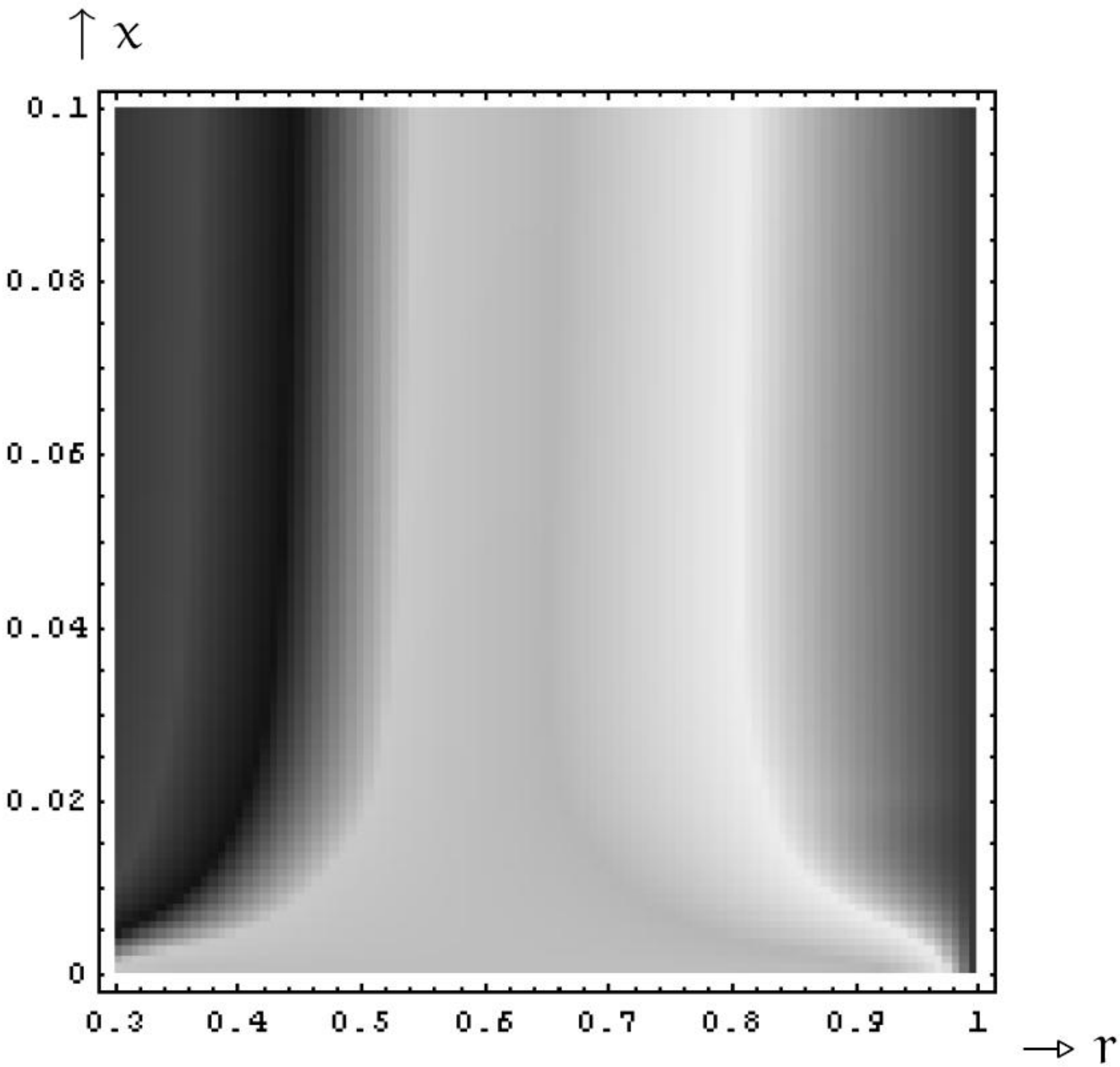

Figure 2: Dimension-less solution $\theta^{+}(r^{+},x^{+})$ for β=0.3.

4 ACKNOWLEDGMENT

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