

Antenski model mijelinskog živčanog vlakna

Ivana Zulim

Seminar doktoranada/postdoktoranada

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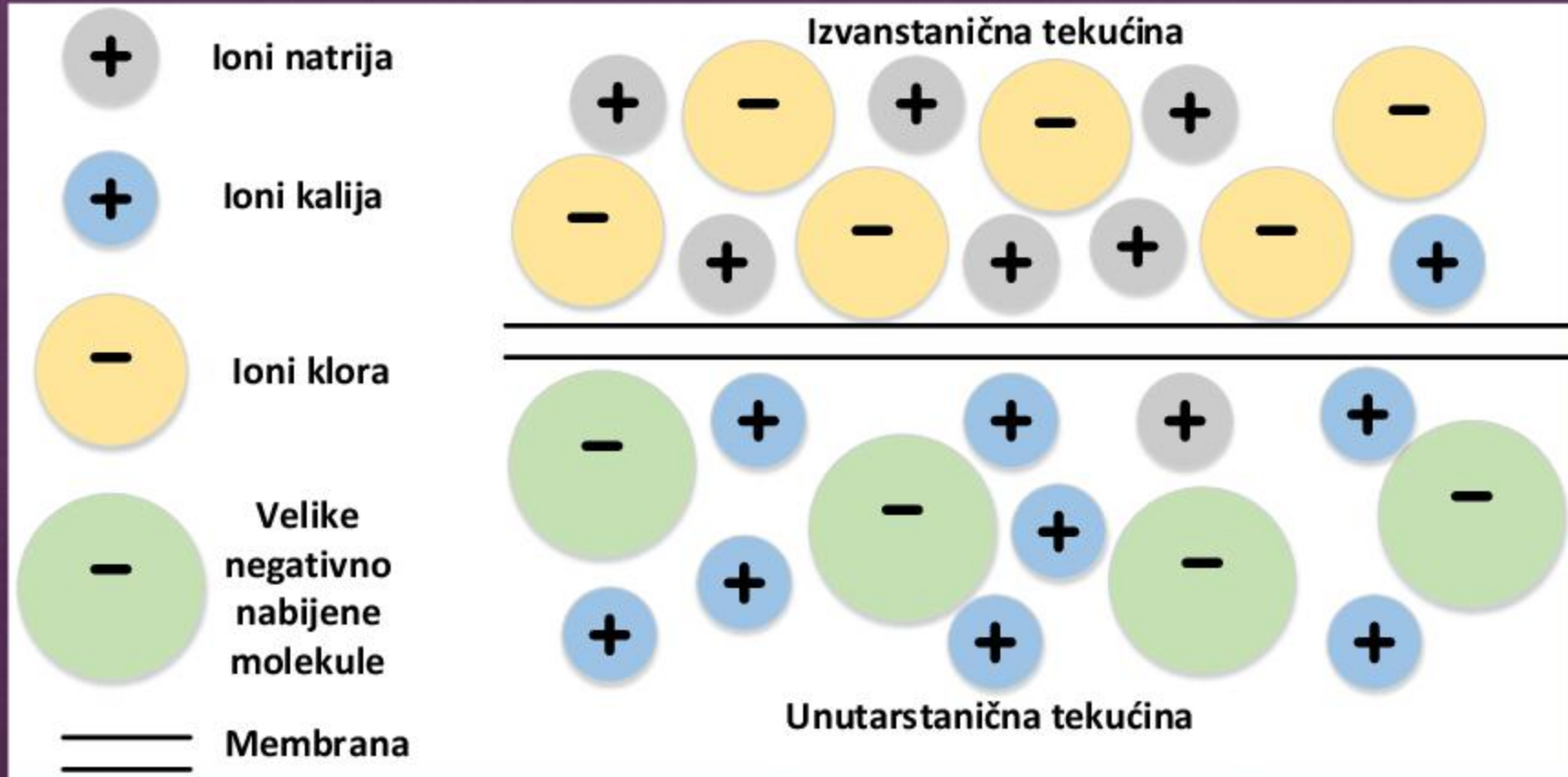
Sadržaj

- ◇ Uvod
 - mijelinsko živčano vlakno
 - načini pobude živčanog vlakna
- ◇ Antenski model mijelinskog živčanog vlakna
 - pasivno vlakno
 - aktivno vlakno
- ◇ Rezultati
- ◇ Zaključak

Uvod – mijelinsko živčano vlakno

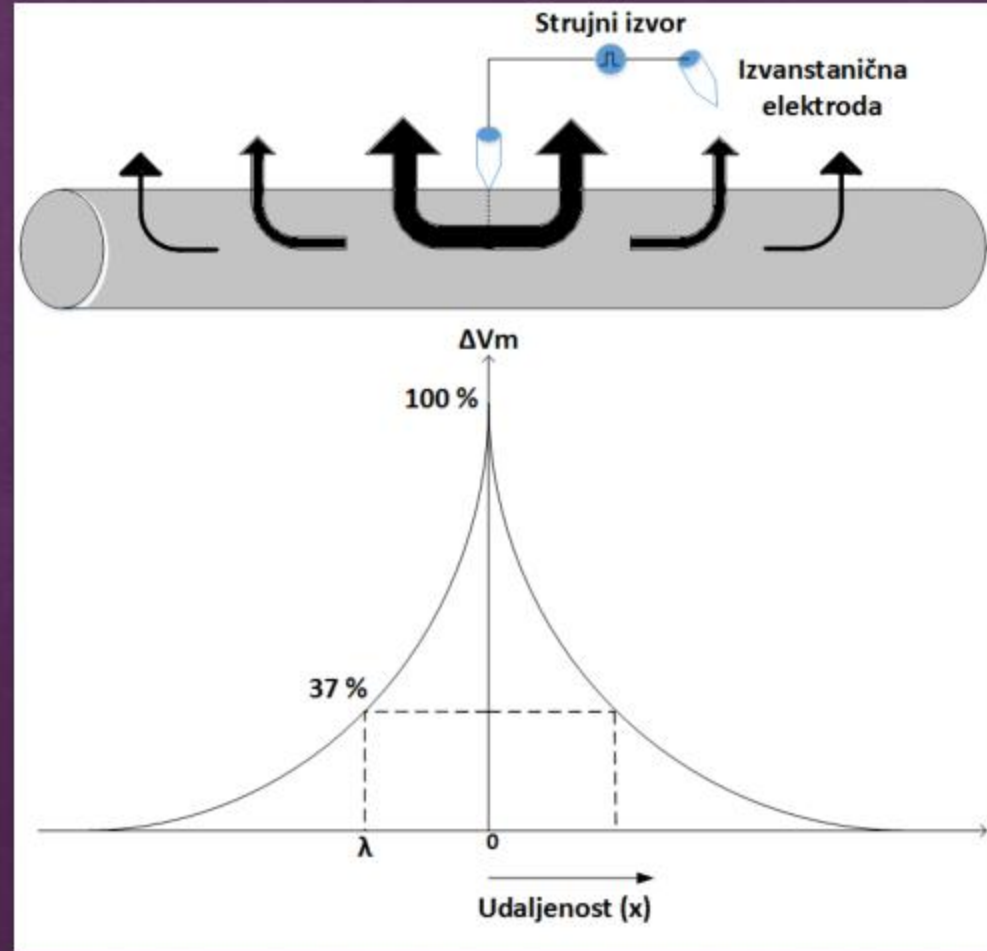


Uvod – mijelinsko živčano vlakno



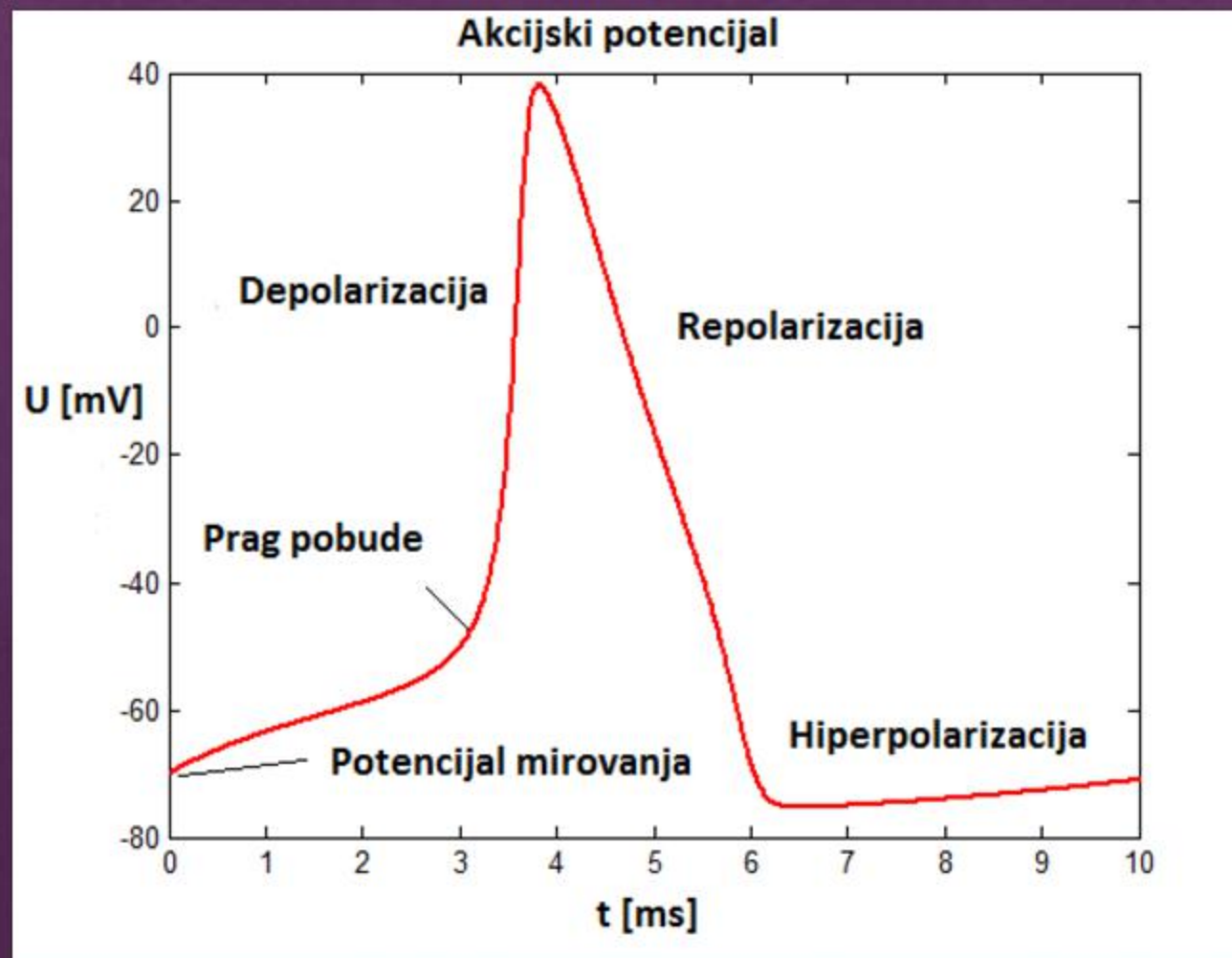
Stanje ravnoteže

Uvod – mijelinsko živčano vlakno



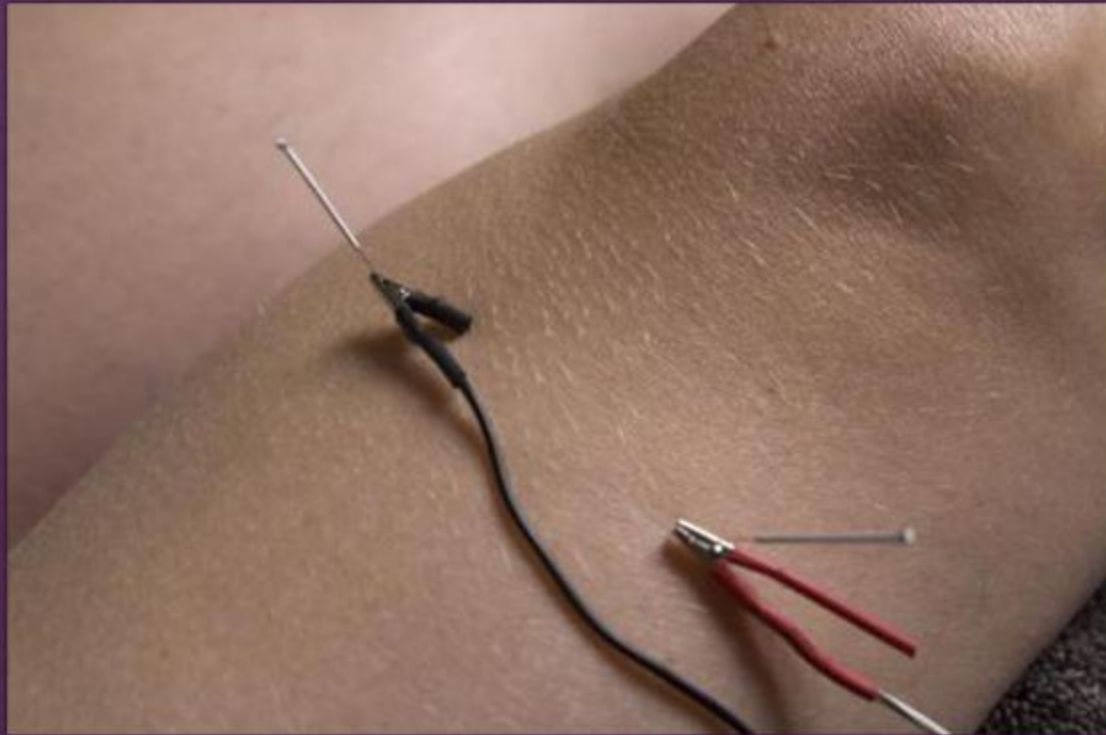
Živčano vlakno u pasivnom stanju

Uvod – mijelinsko živčano vlakno

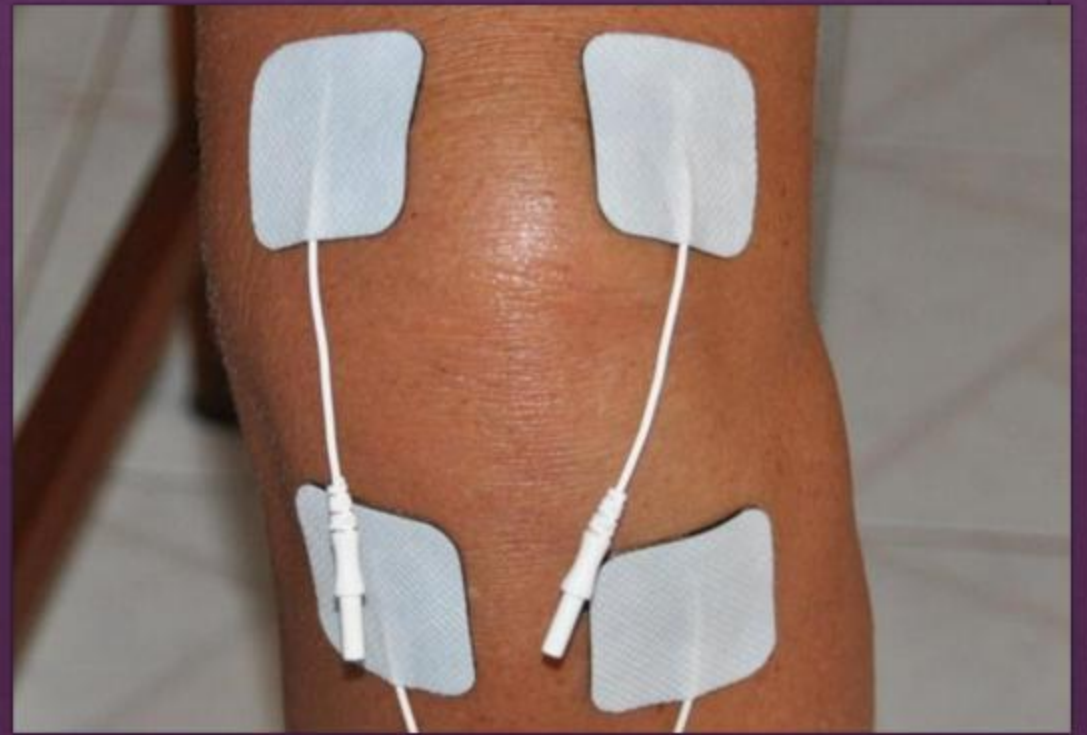


Uvod – načini pobude živčanog vlakna

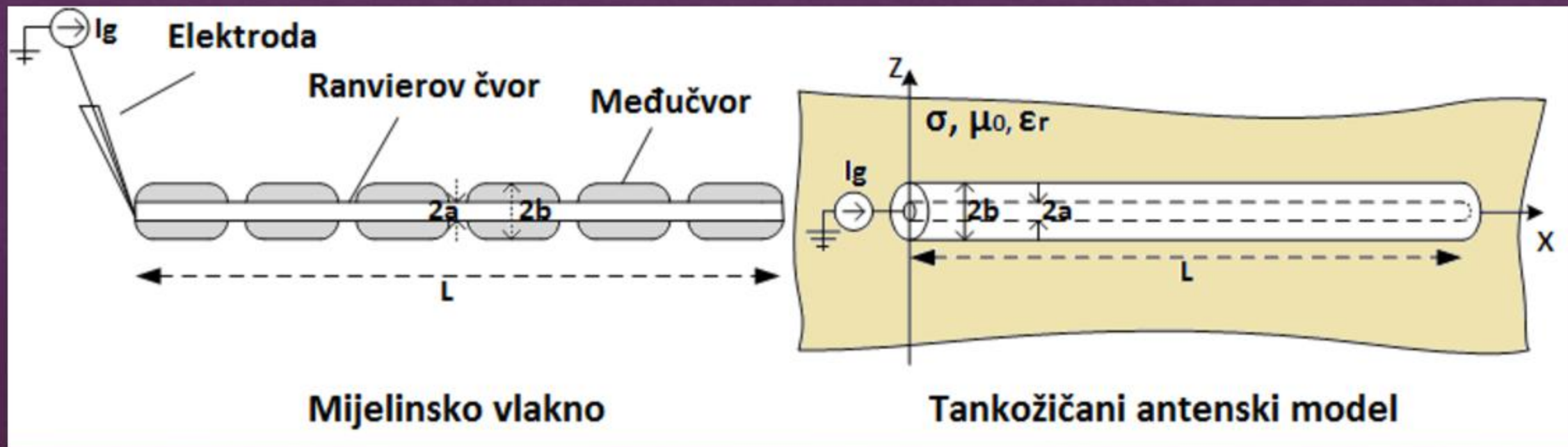
Elektroakupunktura, PENS – (*engl. Percutaneous electrical nerve stimulation*)



TENS – (*engl. Transcutaneous electrical nerve stimulation*)



Antenski model mijelinskog živčanog vlakna



Antenski model mijelinskog živčanog vlakna

Pocklingtonova integro-diferencijalna jednačina

$$-\frac{1}{j4\pi\omega\epsilon_{eff}} \int_0^L \left(\frac{\partial^2}{\partial x^2} - \gamma^2 \right) g(x, x') I_a(x') dx' = 0$$

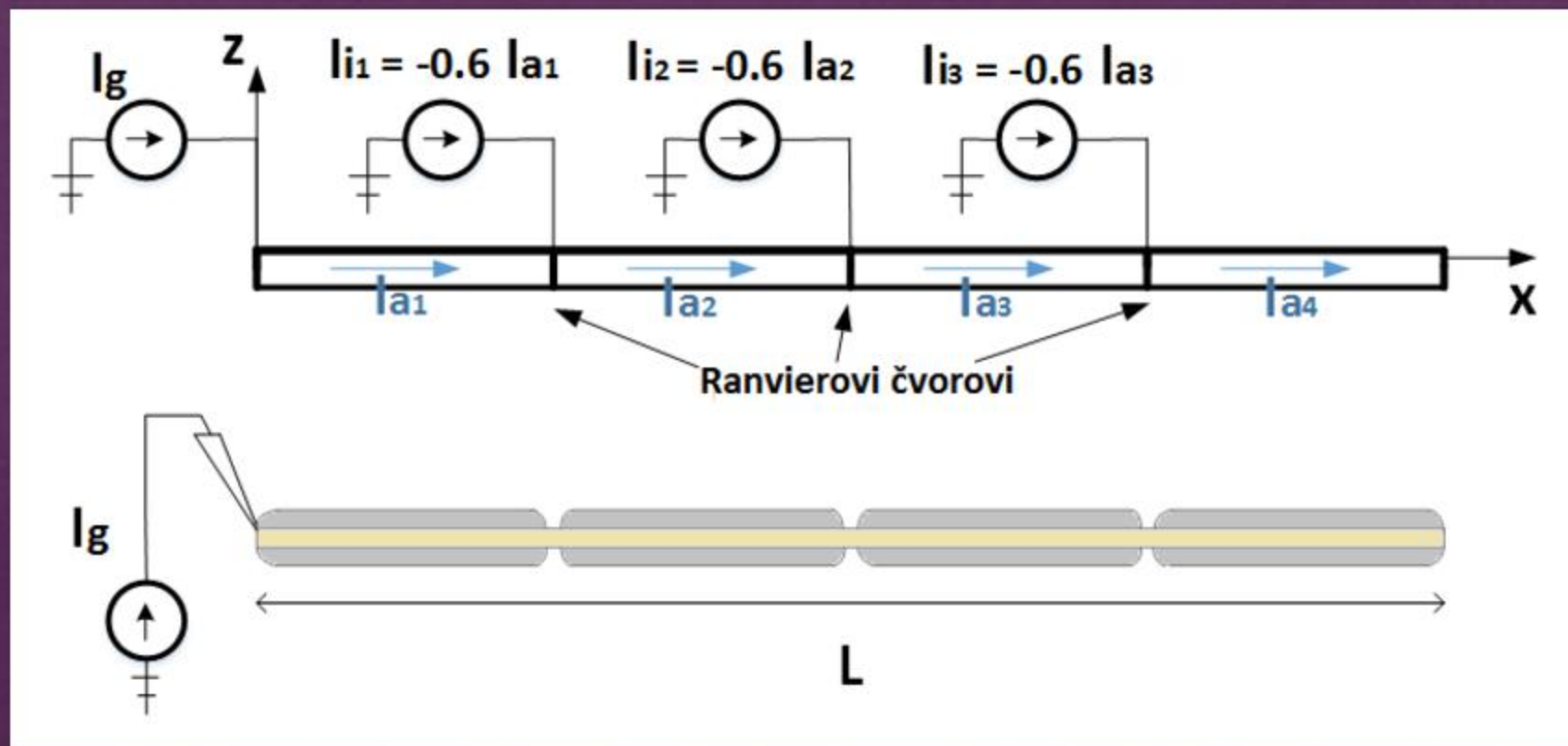
- ◇ ϵ_{eff} - kompleksna permitivnost medija
- ◇ γ - kompleksna konstanta propagacije
- ◇ $g(x, x')$ - Greenova funkcija za medij s gubicima
- ◇ $I_a(x')$ - nepoznata unutarstanična struja

- ◇ Rubni uvjeti:

$$I_a(0) = I_g$$

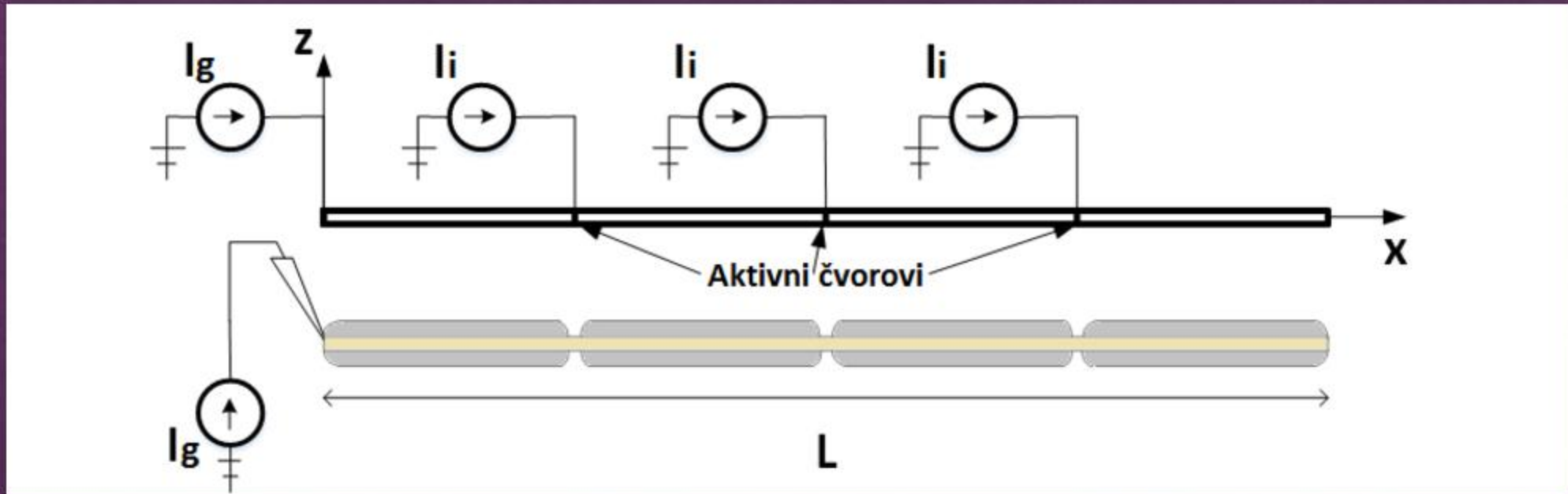
$$I_a(L) = 0$$

Antenski model mijelinskog živčanog vlakna



Modeliranje pasivnog vlakna

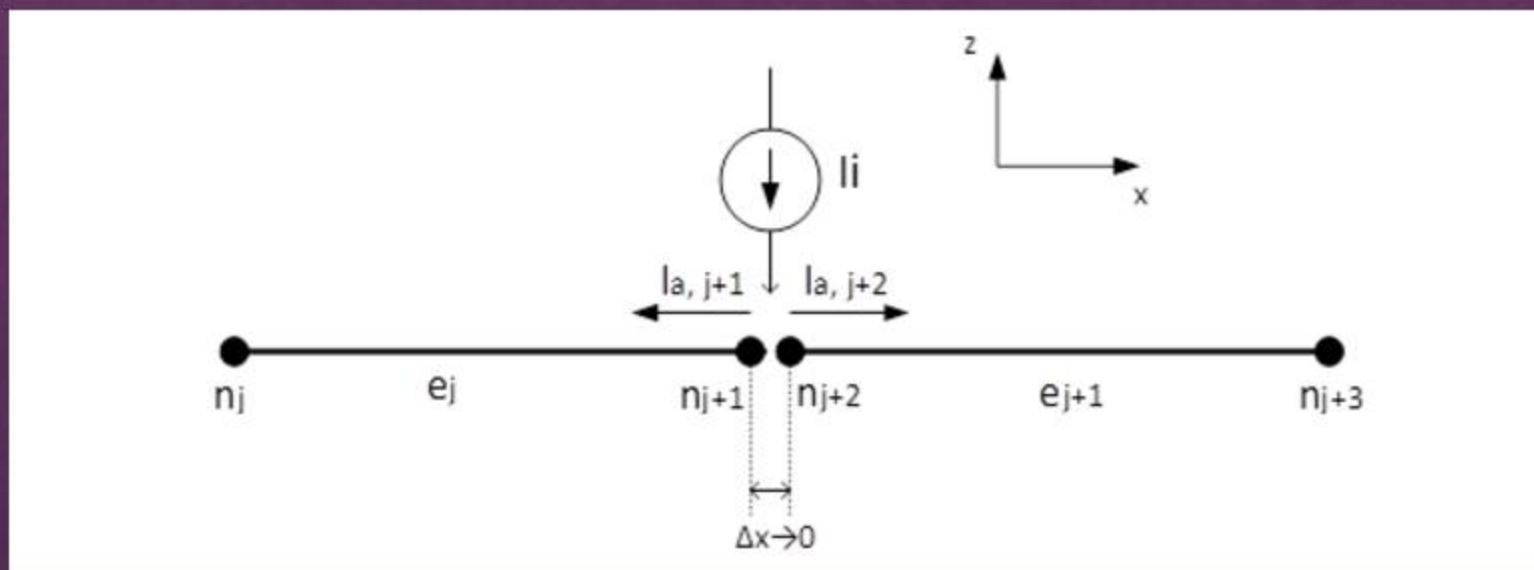
Antenski model mijelinskog živčanog vlakna



Modeliranje aktivnog vlakna

Antenski model mijelinskog živčanog vlakna

Aproksimacija spoja dvije tankožičane antene

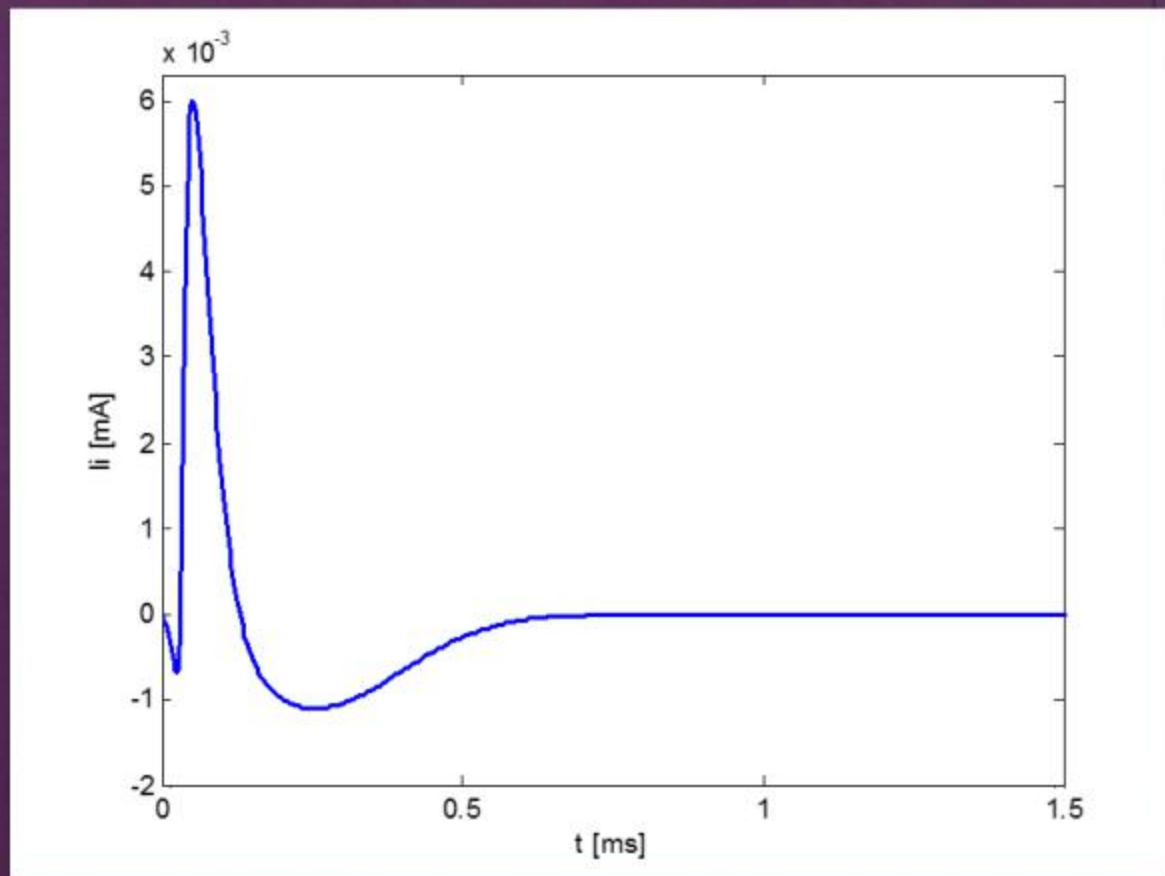


◇ Uvjeti koji trebaju biti zadovoljeni:

$$I_i = I_{a,j+1} + I_{a,j+2}$$

$$Q_{j+1} = Q_{j+2}$$

Antenski model mijelinskog živčanog vlakna



Ionska struja aktivnog Ranvierovog čvora

$$I_i(t) = Au(t - t_1)[e^{-B(t-t_1)} - e^{-D(t-t_1)}] - Eu(t -$$

Rezultati

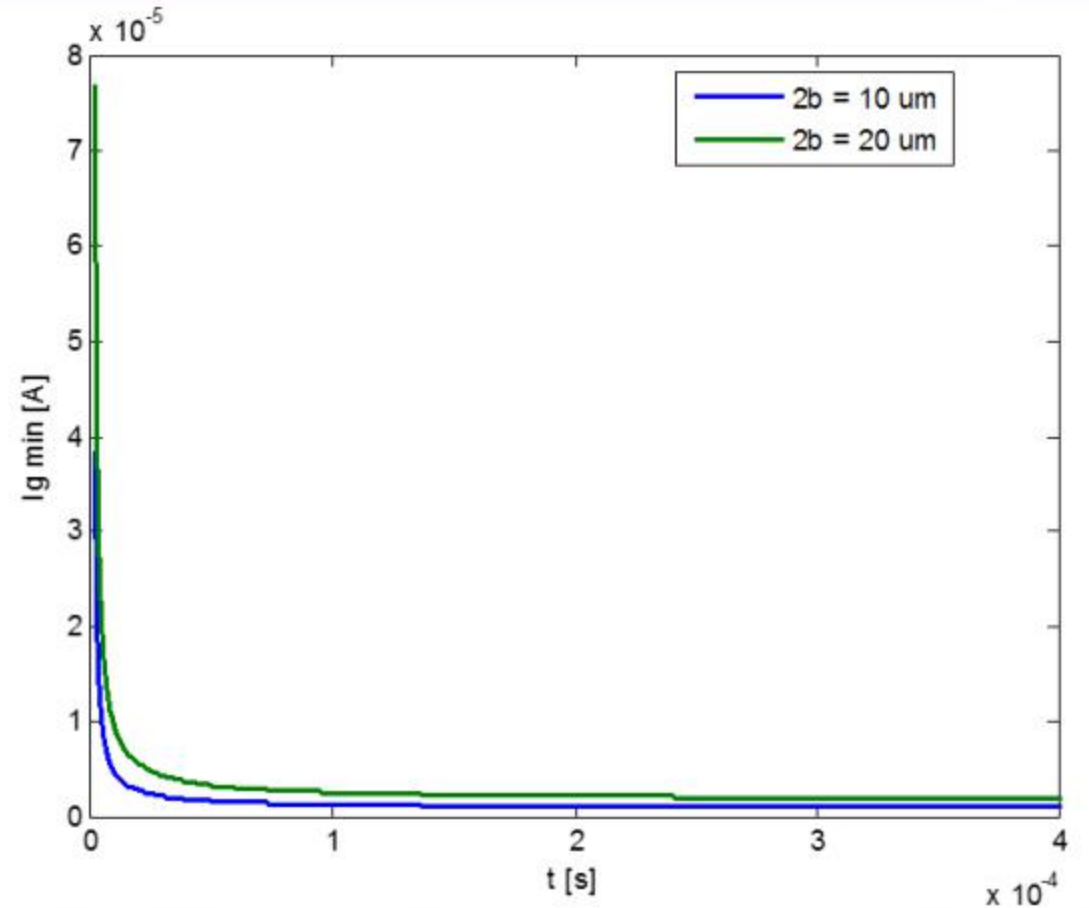
Parametri korišteni u simulacijama

Parametri	Opis	Vrijednost	Jedinica
b	Radijus koji uključuje mijelinsku ovojnicu	$10 \cdot 10^{-6}, 5 \cdot 10^{-6}$	m
a	Radijus aksona	$0.64 \cdot 2b$	m
l_{int}	Duljina međučvora	$100 \cdot 2b$	m
L	Duljina vlakna	$l_{int} \cdot 2, l_{int} \cdot 10$	m
ρ_a	Otpornost aksoplazme	1.1	Ωm
r_m	Otpornost mijelinske ovojnice	10	Ωm^2
C_m	Kapacitet membrane po jedinici površine	$3 \cdot 10^{-5}$	F/m^2

Rezultati

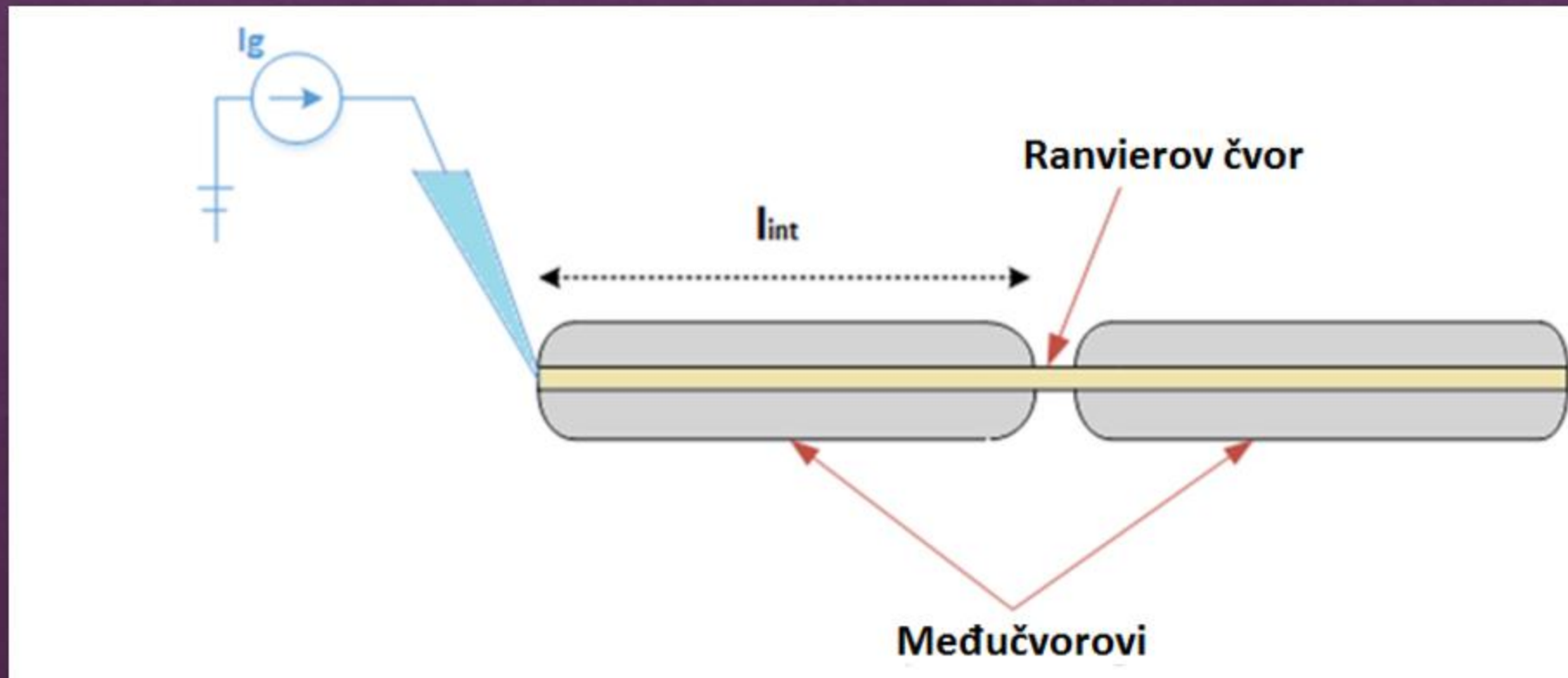
Krivulja praga pobude

- ◇ Vrijeme kronakse: $t_c = 4.08 \cdot 10^{-5} s$
- ◇ Struja reobaze (za promjer vlakna $10 \mu m$):
 $I_r = 0.9 \cdot 10^{-6} A$
- ◇ Struja reobaze (za promjer vlakna $20 \mu m$):
 $I_r = 1.8 \cdot 10^{-6} A$



Rezultati

Vlakno s jednim Ranvierovim čvorom

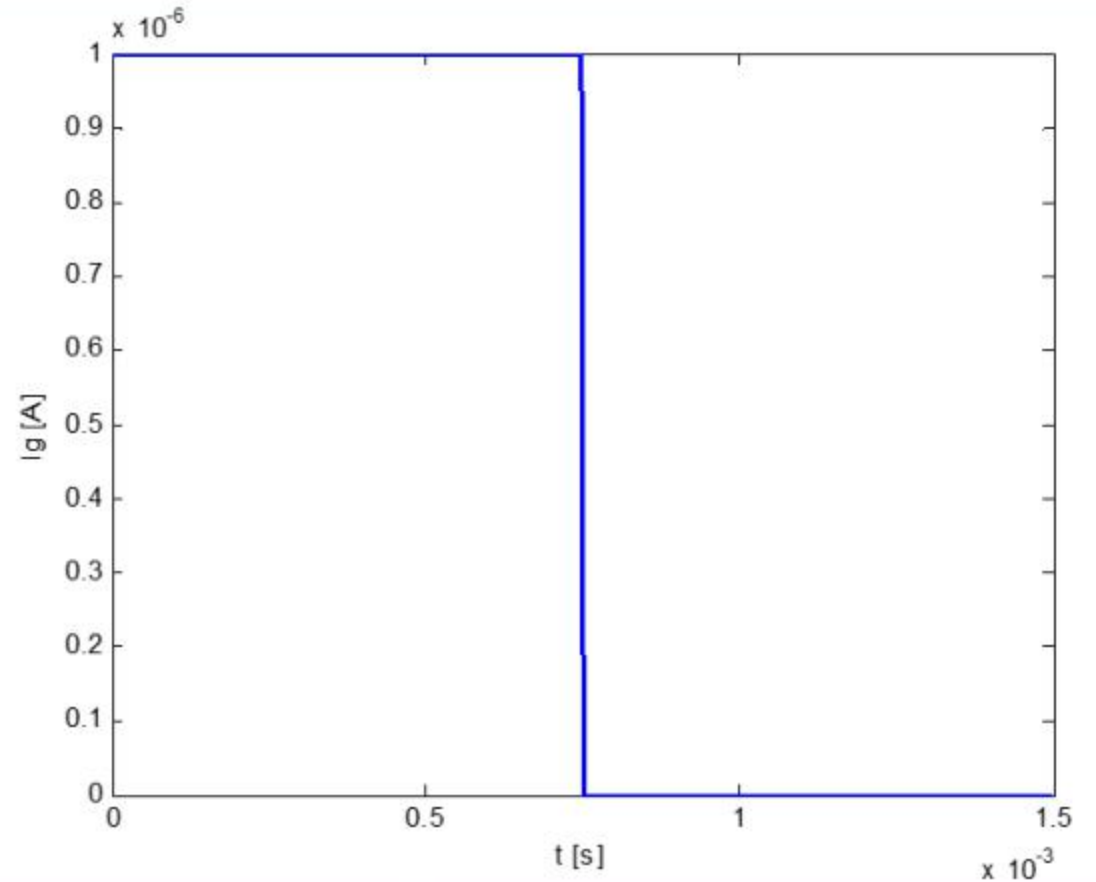


Rezultati

Pasivno stanje

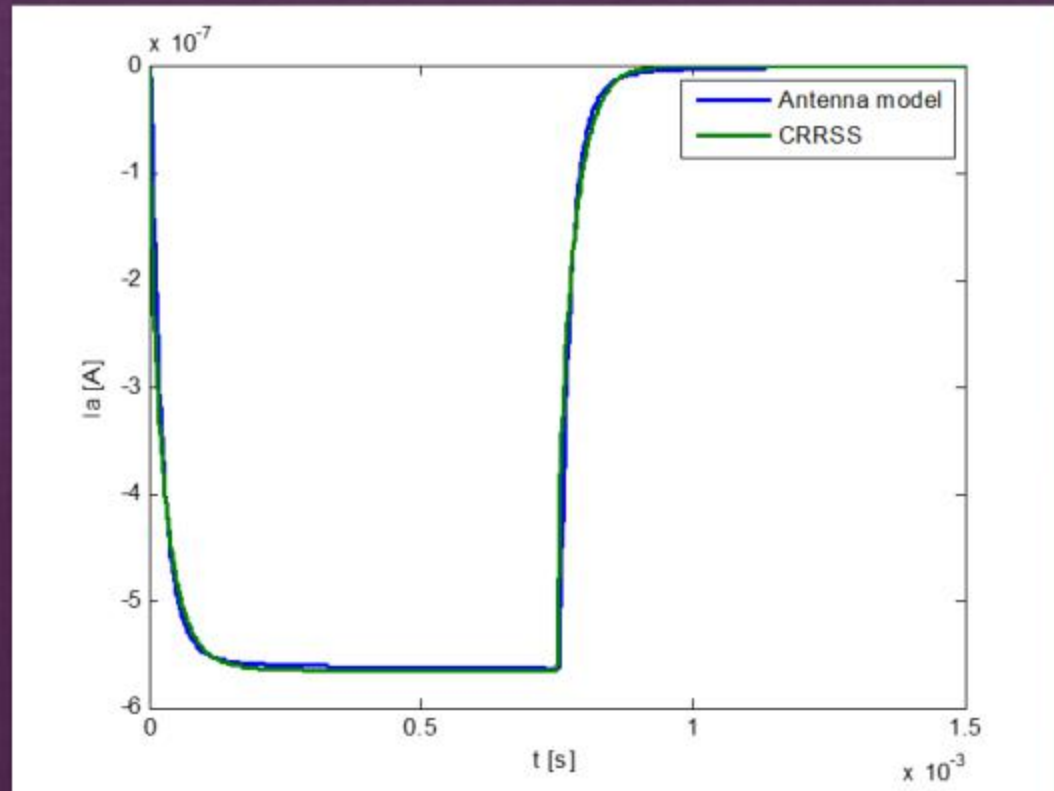
Monofazni pravokutni impuls na početku vlakna:

$$I_g = \begin{cases} 1 \cdot 10^{-6} \text{ A}, & 0 \text{ s} \leq t \leq 0.75 \cdot 10^{-3} \text{ s} \\ 0 \text{ A}, & 0.75 \cdot 10^{-3} \text{ s} < t \leq 1.5 \cdot 10^{-3} \text{ s} \end{cases}$$

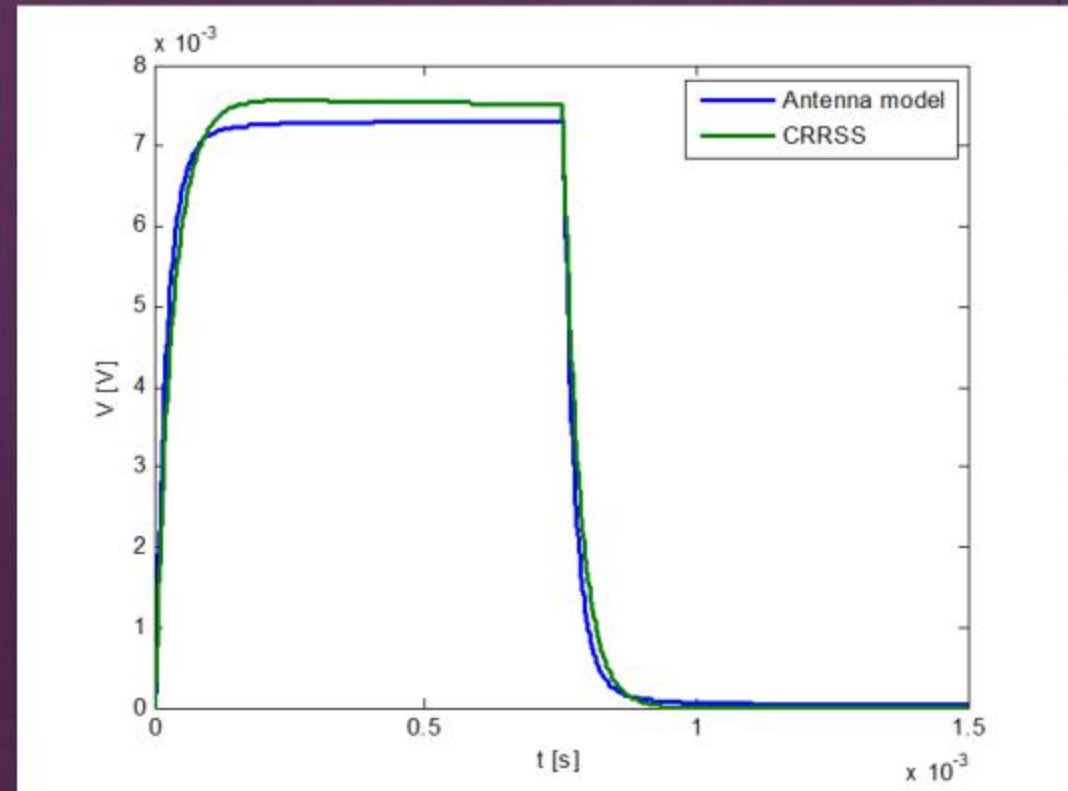


Rezultati

Unutarstanična struja u Ranvierovom čvoru



Potencijal u Ranvierovom čvoru



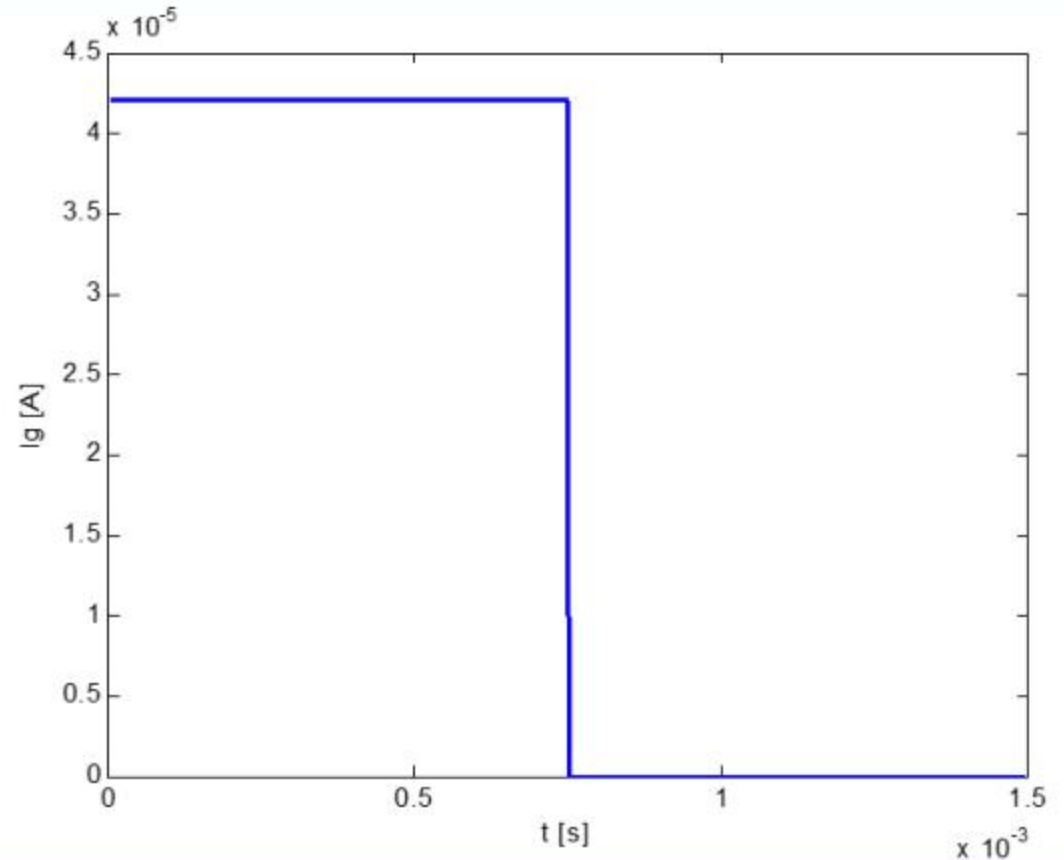
Rezultati

Aktivno stanje

Monofazni pravokutni impuls na početku vlakna:

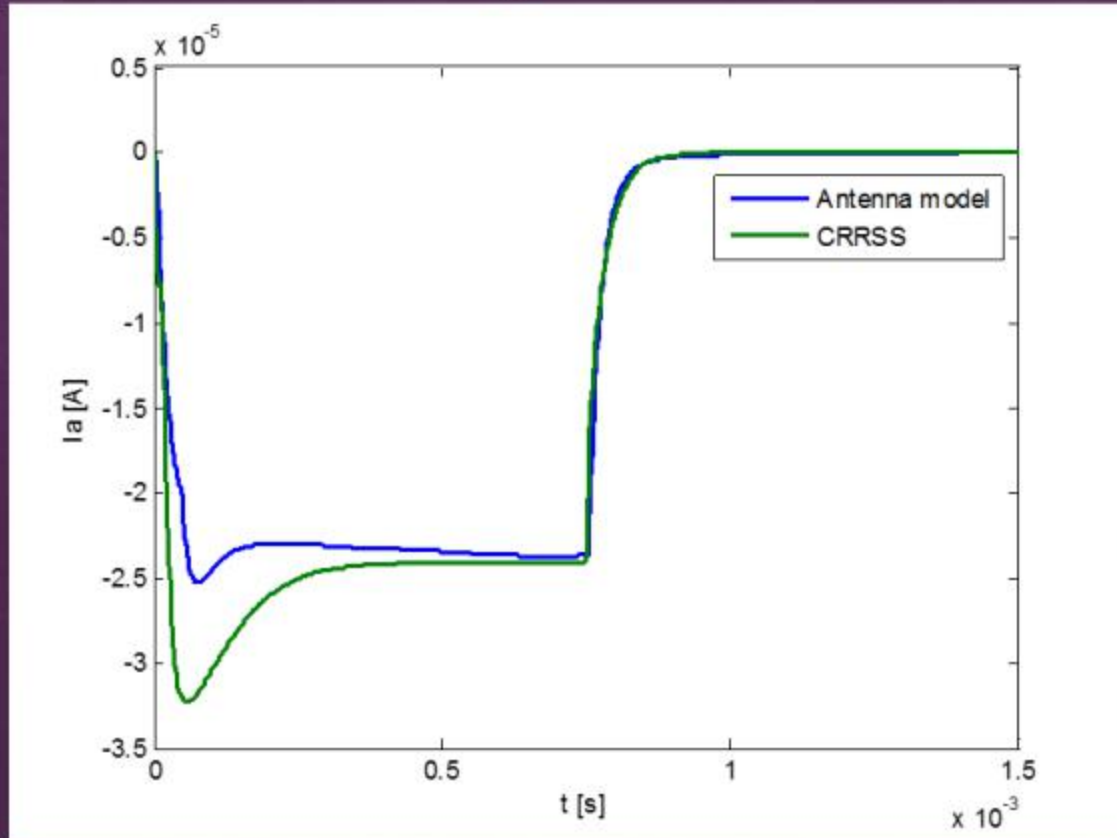
$$I_g = \begin{cases} 4.2 \cdot 10^{-5} A, & 0 \text{ s} \leq t \leq 0.75 \cdot 10^{-3} \text{ s} \\ 0 A, & 0.75 \cdot 10^{-3} \text{ s} < t \leq 1.5 \cdot 10^{-3} \text{ s} \end{cases}$$

Prag pobude: $1.8 \cdot 10^{-6} A$

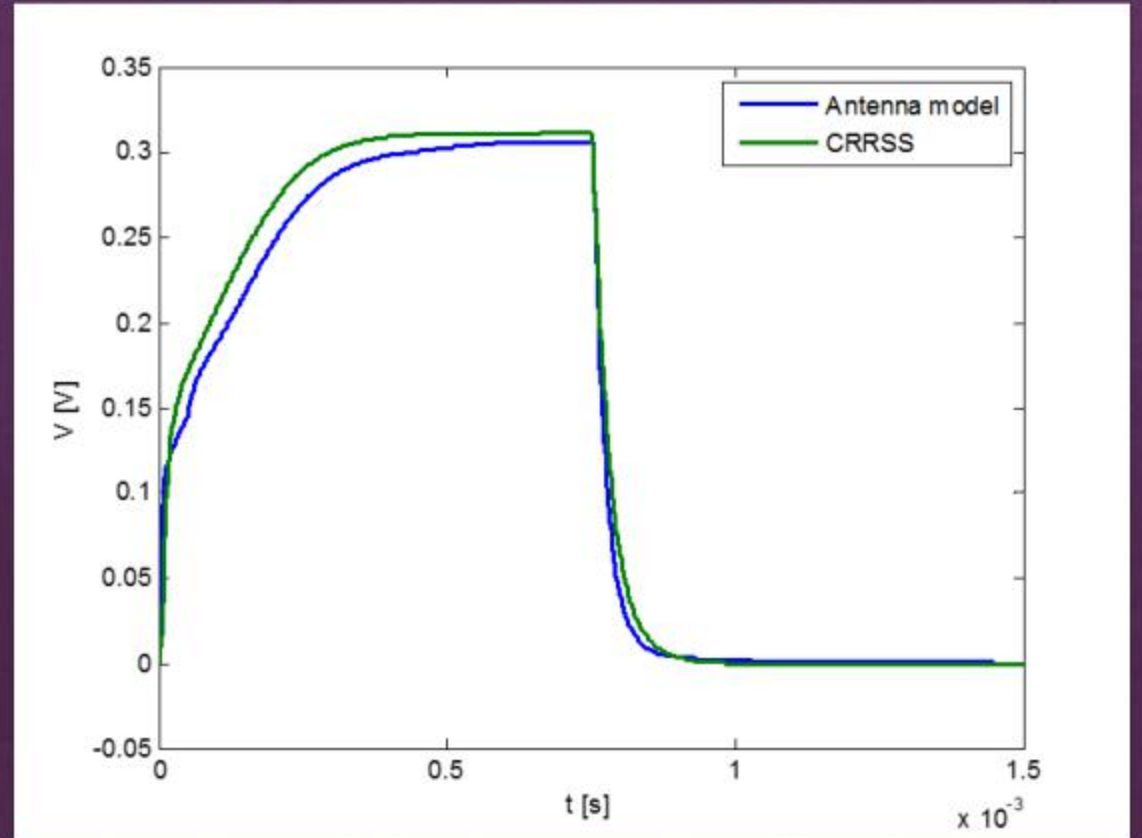


Rezultati

Unutarstanična struja u Ranvierovom čvoru

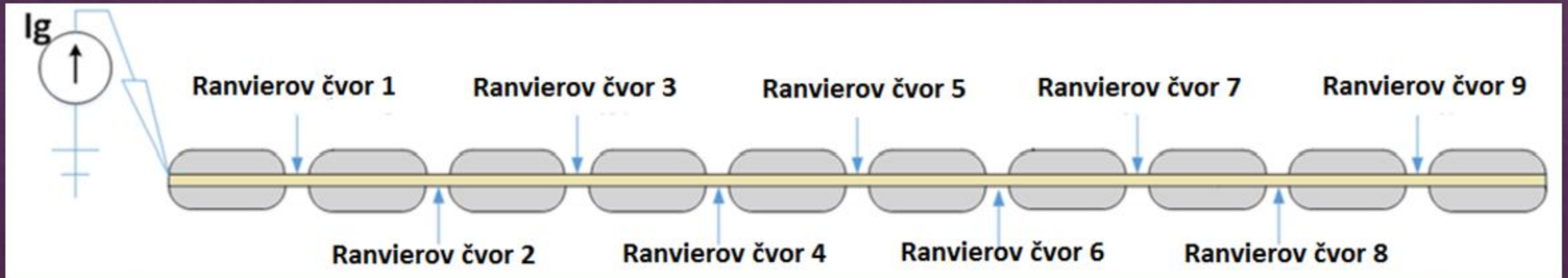


Akcijski potencijal u Ranvierovom čvoru



Rezultati

Vlakno s devet Ranvierovih čvorova i deset međučvorova



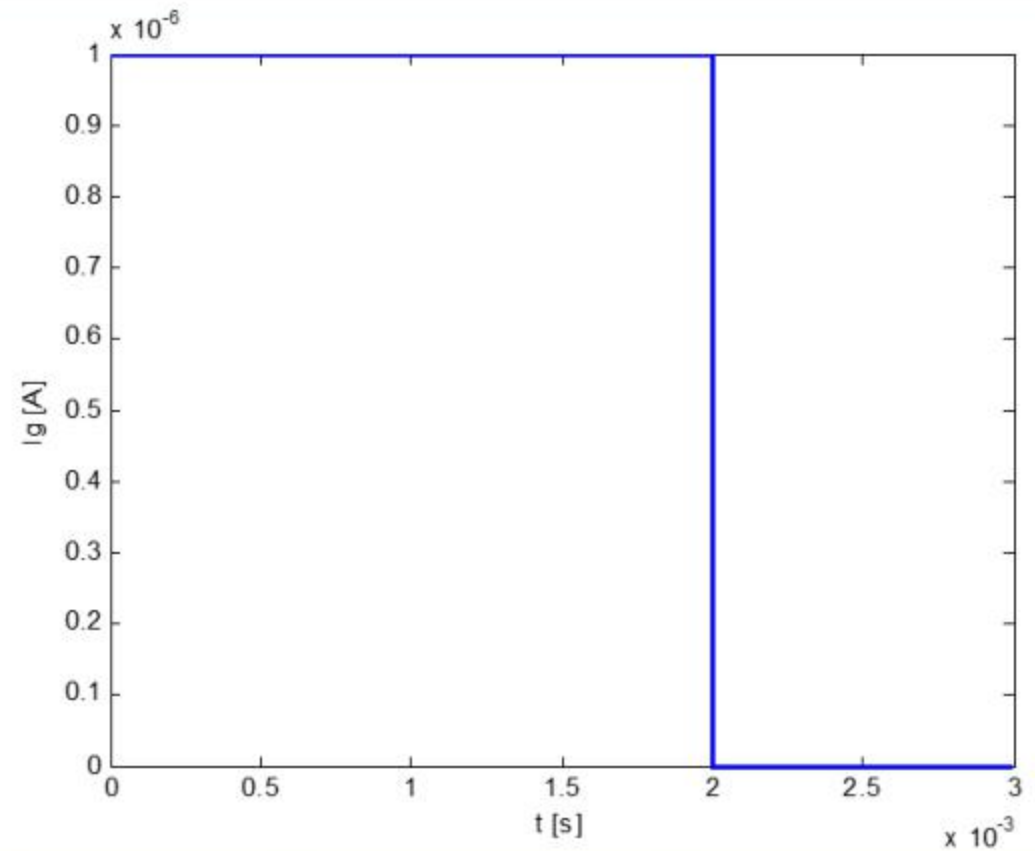
Rezultati

Aktivno stanje

Monofazni pravokutni impuls na početku vlakna:

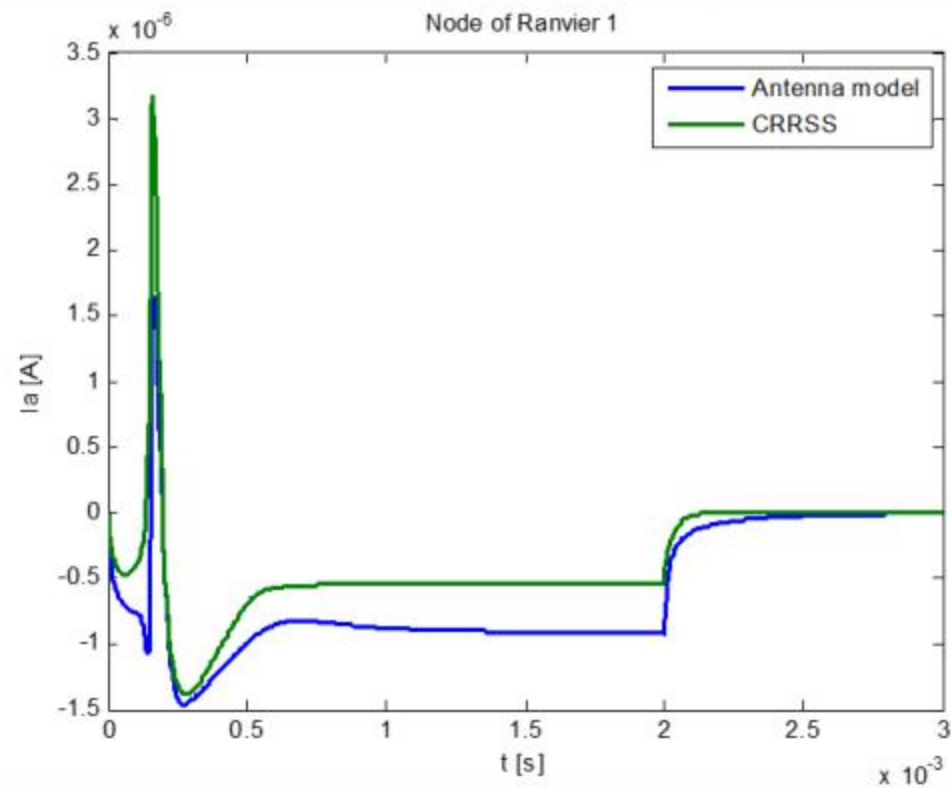
$$I_g = \begin{cases} 1 \cdot 10^{-6} \text{ A}, & 0 \text{ s} \leq t \leq 2 \cdot 10^{-3} \text{ s} \\ 0 \text{ A}, & 2 \cdot 10^{-3} \text{ s} < t \leq 3 \cdot 10^{-3} \text{ s} \end{cases}$$

Prag pobude: $0.9 \cdot 10^{-6} \text{ A}$

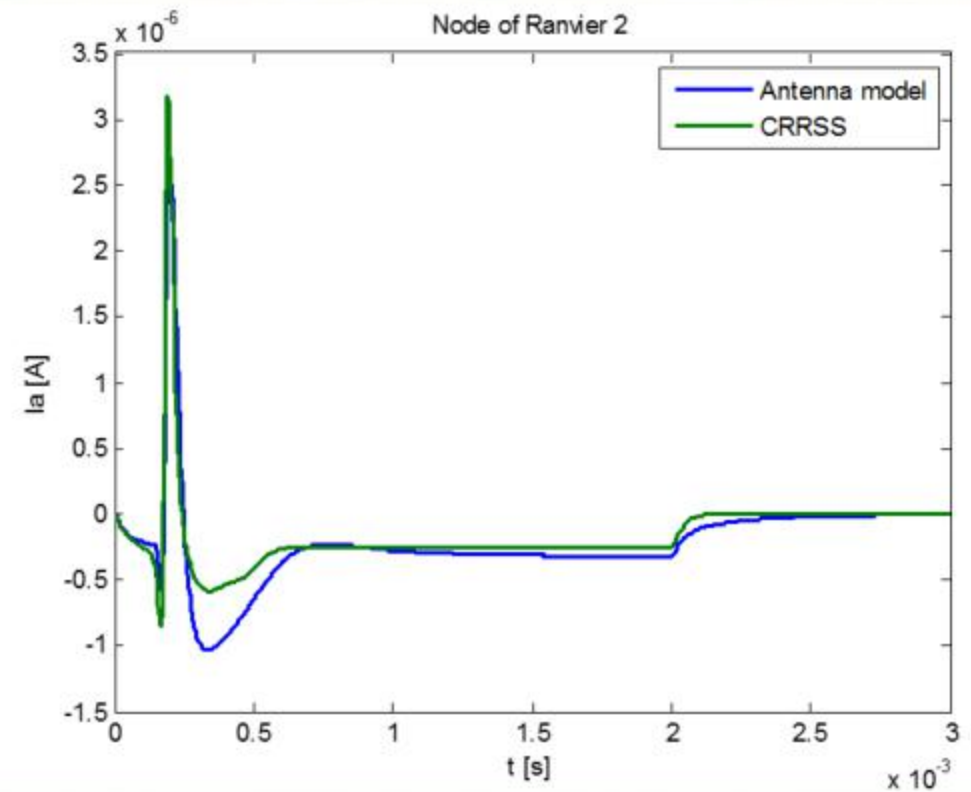


Rezultati

Unutarstanična struja u 1. čvoru

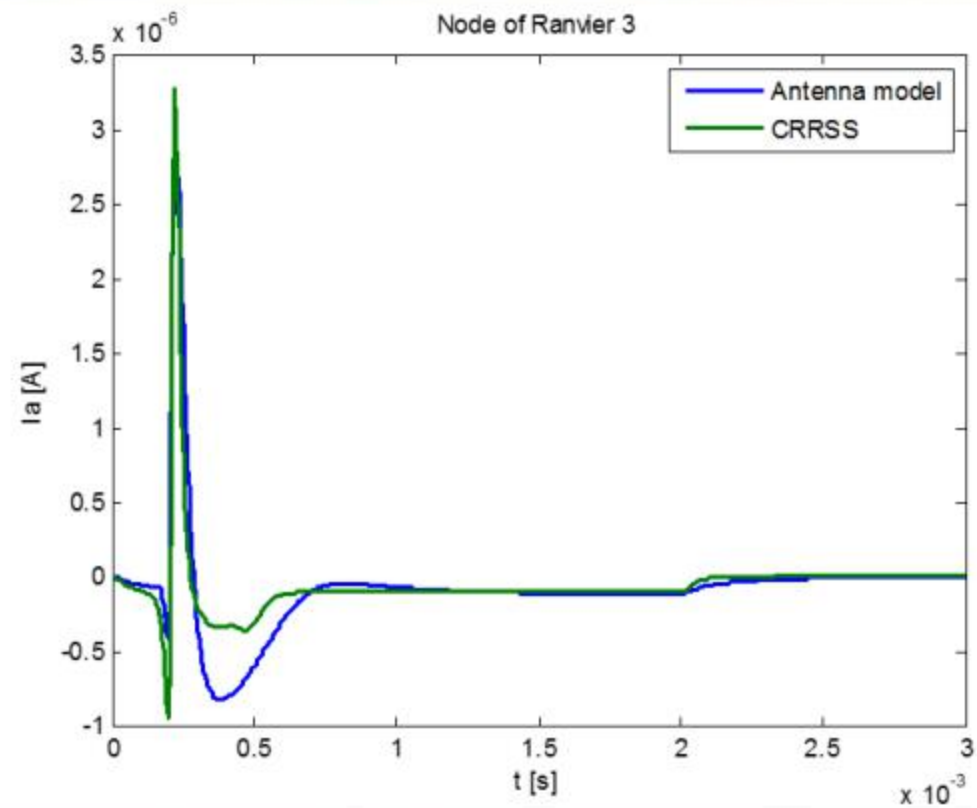


Unutarstanična struja u 2. čvoru

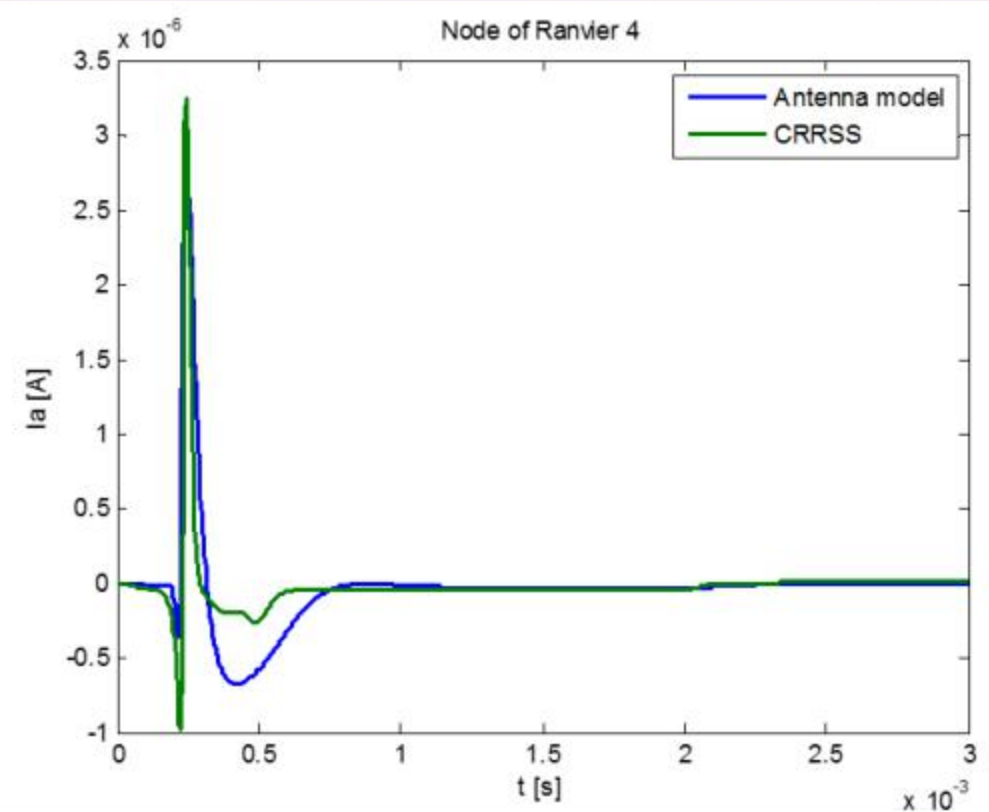


Rezultati

Unutarstanična struja u 3. čvoru

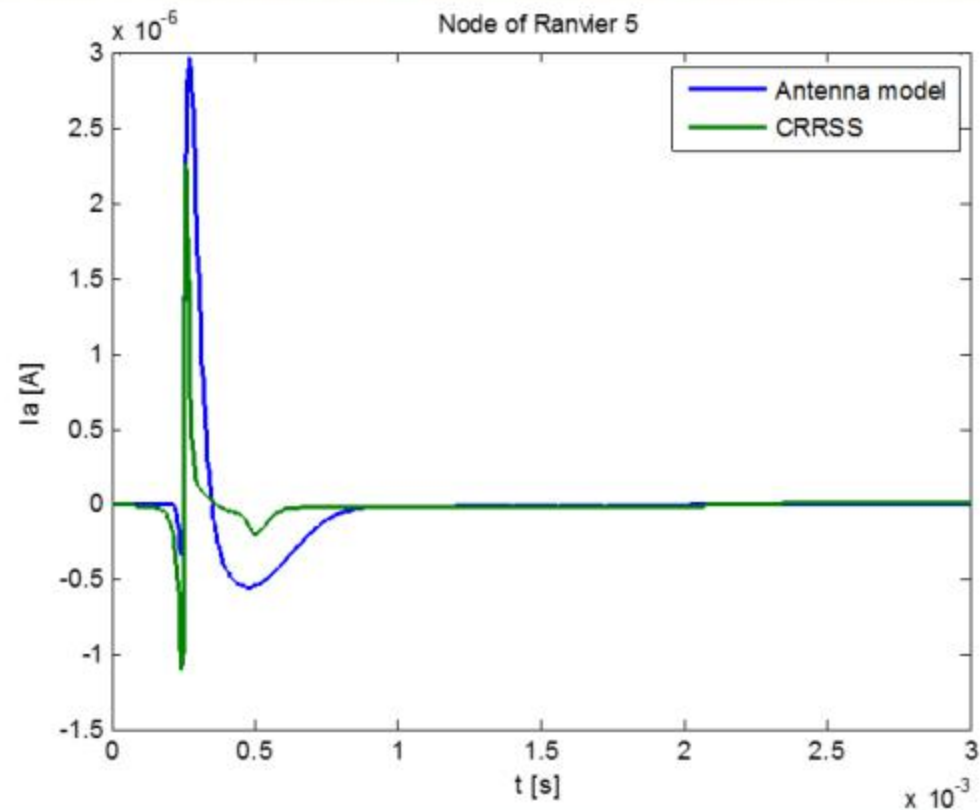


Unutarstanična struja u 4. čvoru

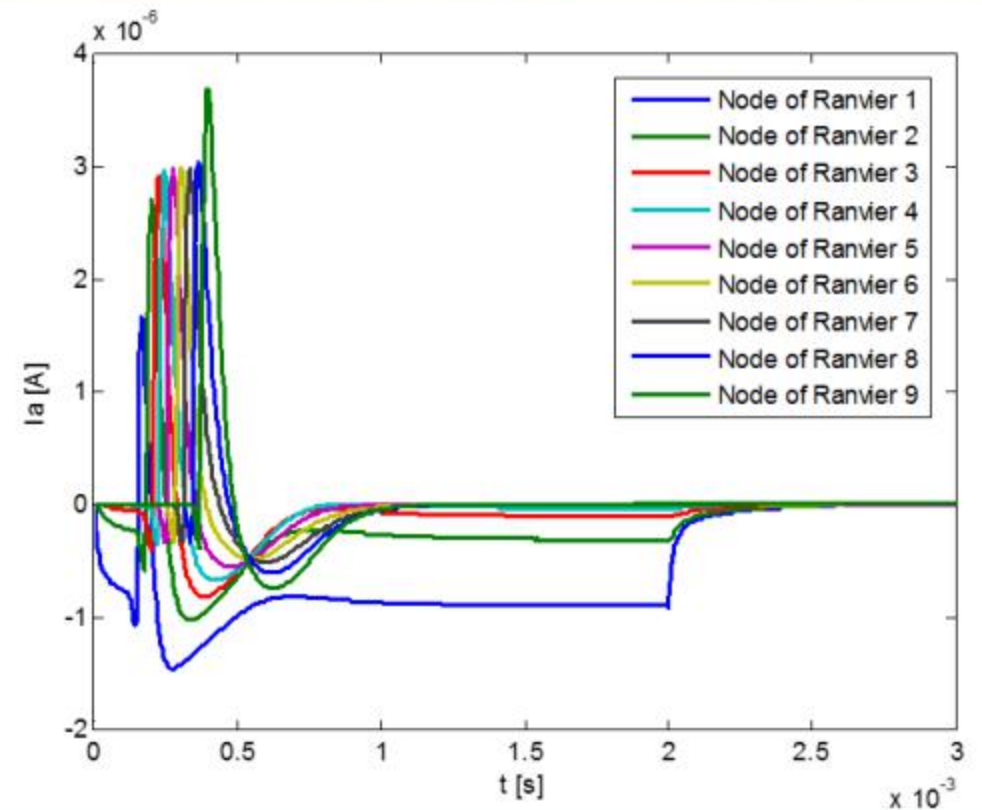


Rezultati

Unutarstanična struja u 5. čvoru



Unutarstanična struja za čvorove 1-9



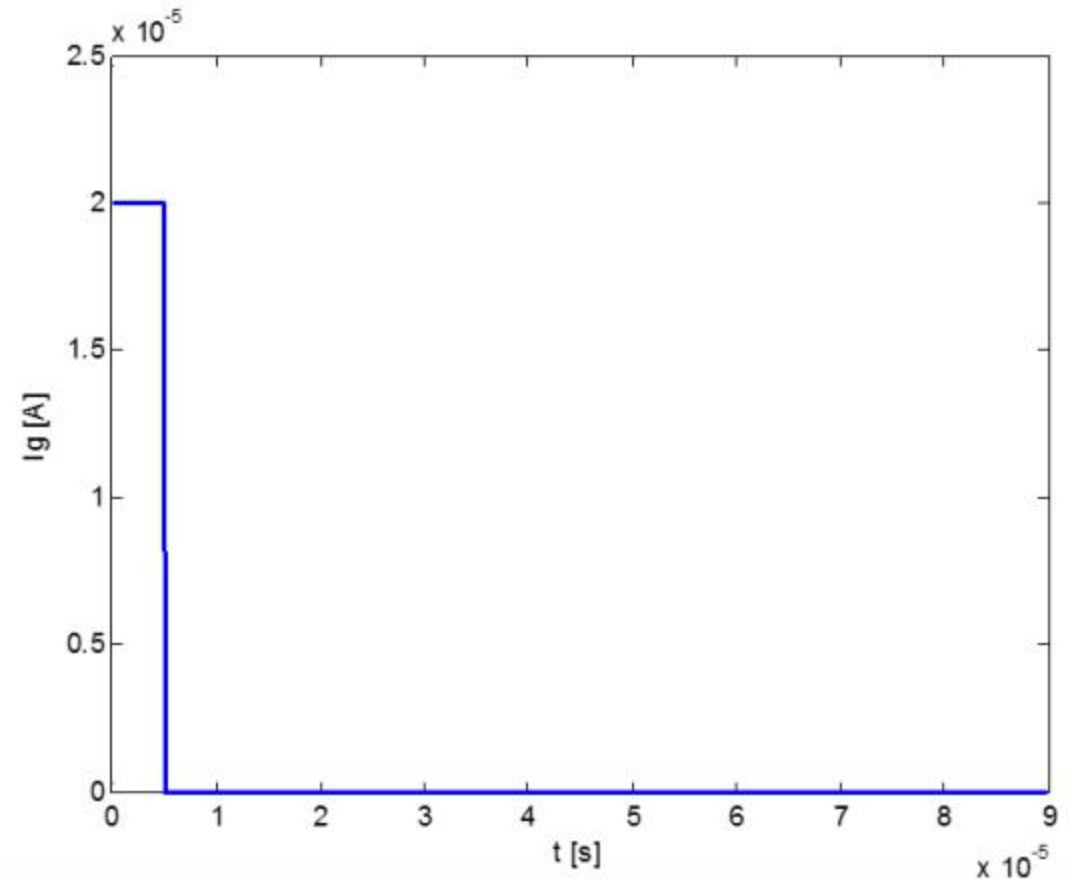
Rezultati

Aktivno stanje

Monofazni pravokutni impuls na početku vlakna:

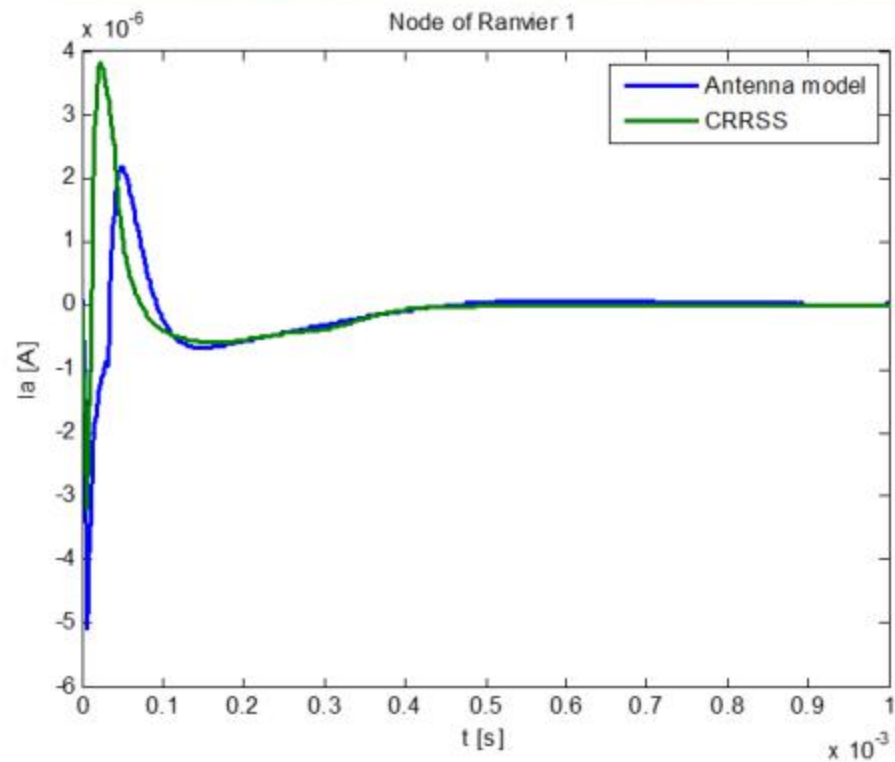
$$I_g = \begin{cases} 20 \cdot 10^{-6} \text{ A}, & 0 \text{ s} \leq t \leq 0.005 \cdot 10^{-3} \text{ s} \\ 0 \text{ A}, & 0.005 \cdot 10^{-3} \text{ s} < t \leq 1 \cdot 10^{-3} \text{ s} \end{cases}$$

Prag pobude: $11 \cdot 10^{-6} \text{ A}$

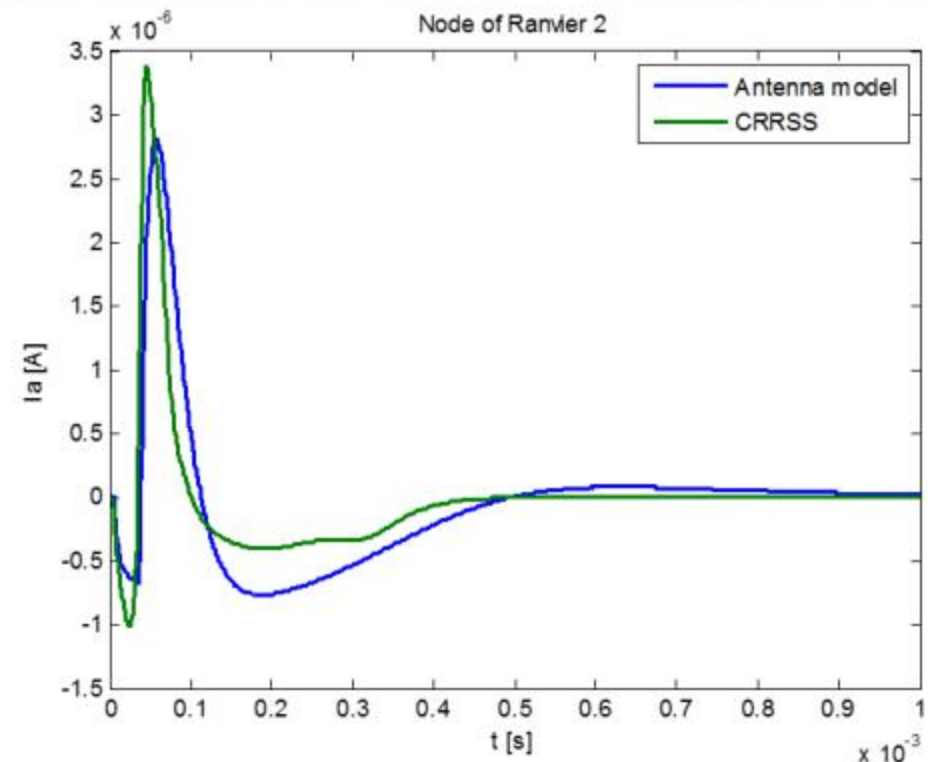


Rezultati

Unutarstanična struja u 1. čvoru

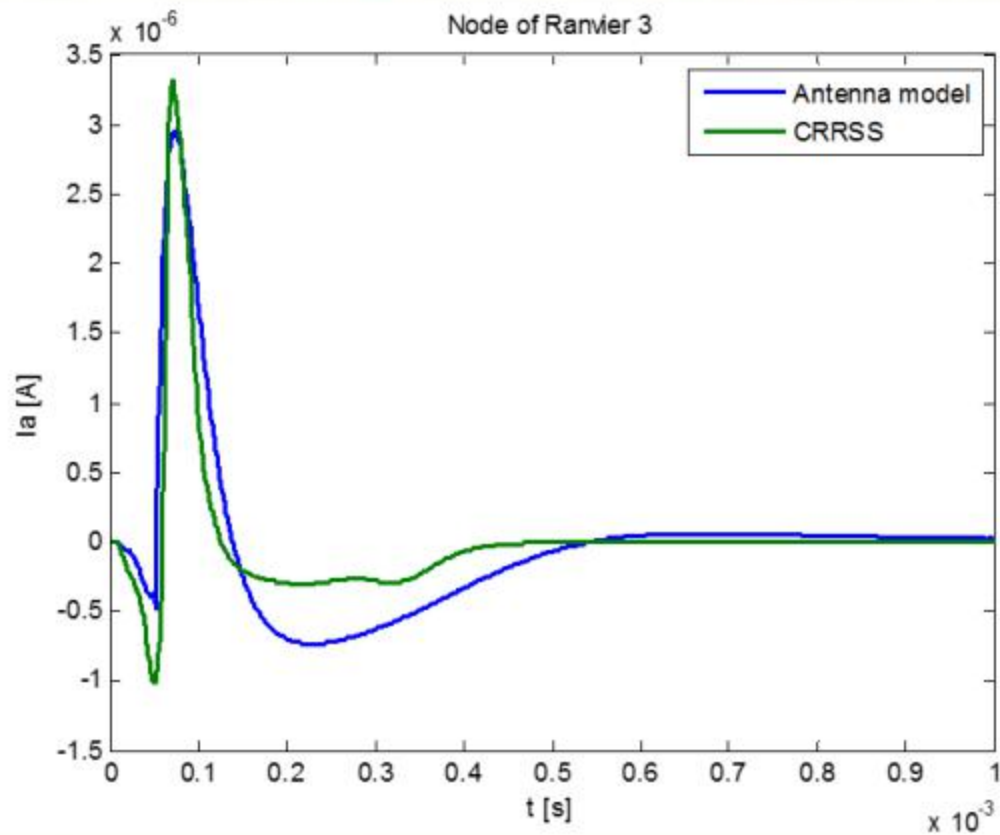


Unutarstanična struja u 2. čvoru

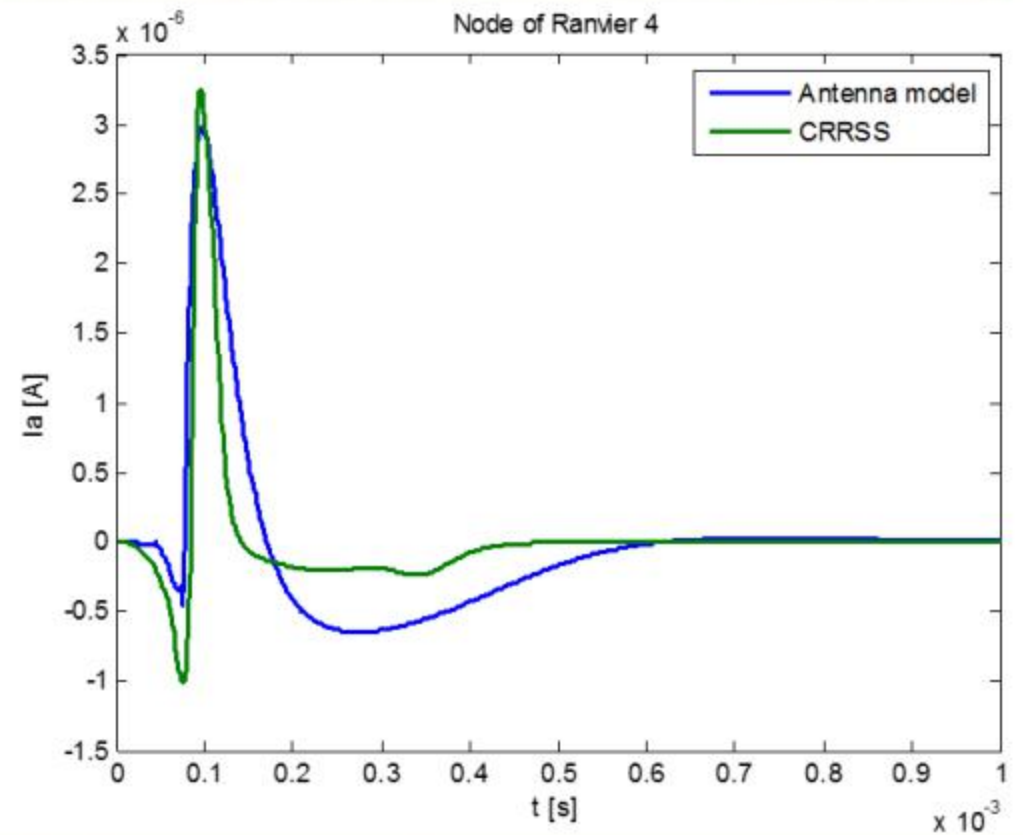


Rezultati

Unutarstanična struja u 3. čvoru

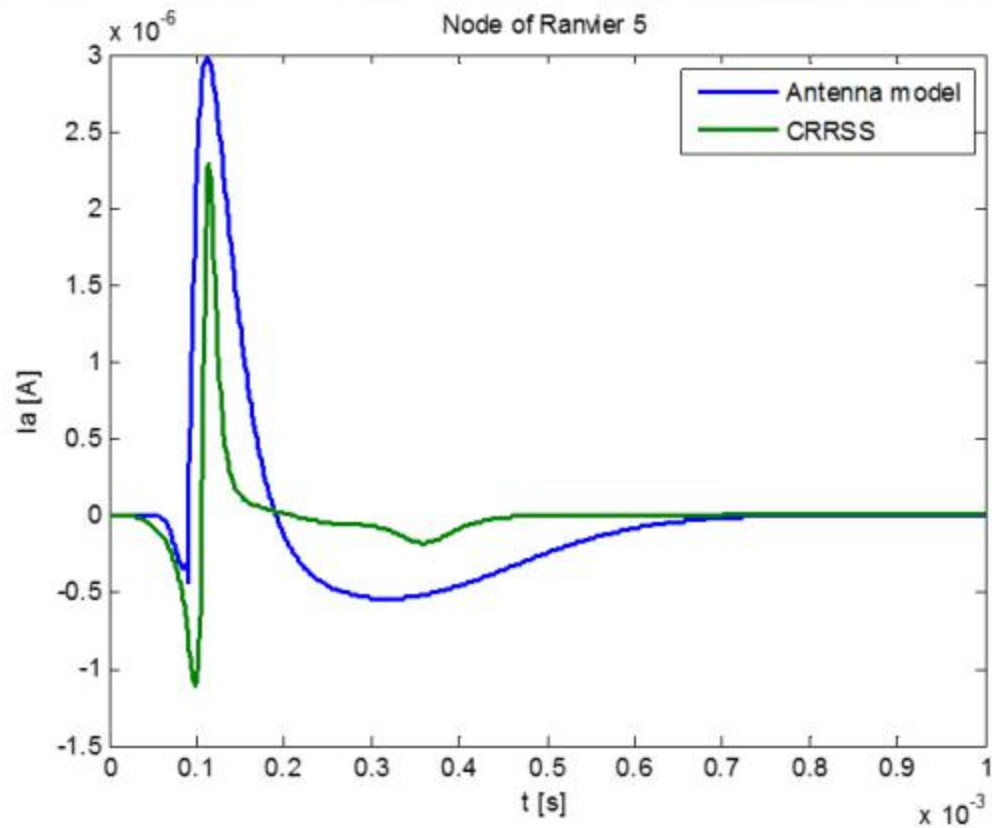


Unutarstanična struja u 4. čvoru

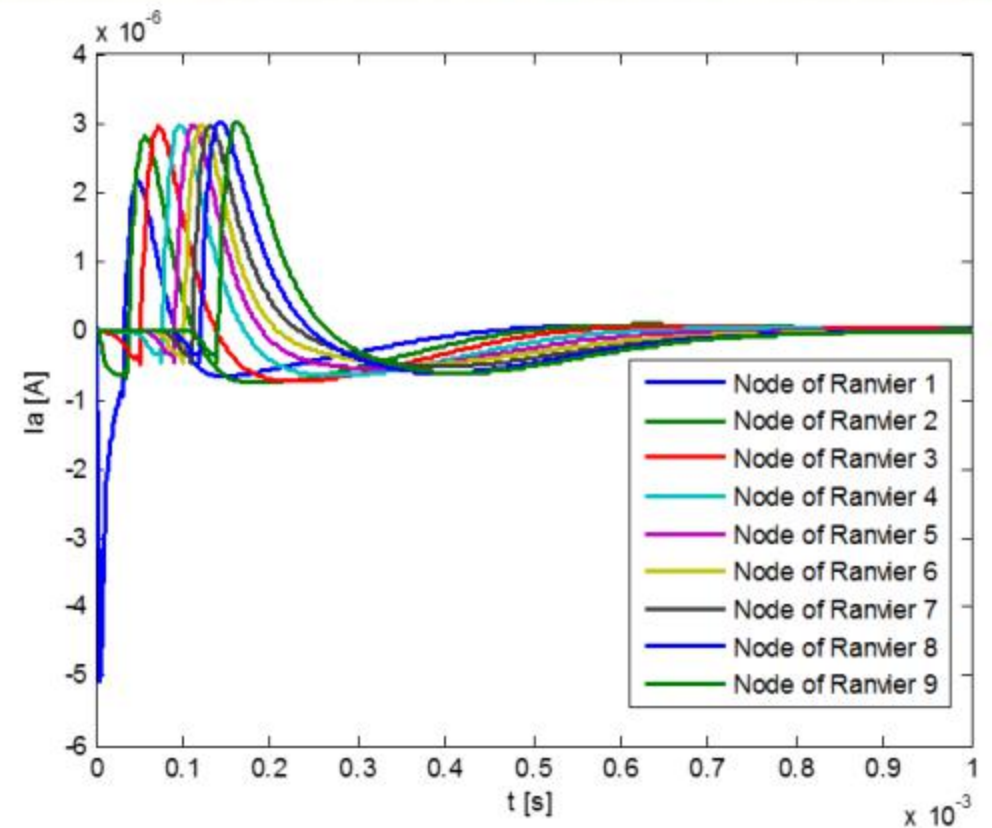


Rezultati

Unutarstanična struja u 5. čvoru



Unutarstanična struja u čvorovima 1-9



Zaključak

- ◆ Antenski model mijelinskog živčanog vlakna može se koristiti za analizu stimuliranja živčanih vlakana strujnim impulsima različitih valnih oblika
- ◆ Direktna primjena modela moguća je kod tehnika elektroakupunkture i PENS-a

Osnovna prednost modela:

- ◆ mogućnost stimulacija vlakna na bilo kojem mjestu duž vlakna
- ◆ modeliranje živčanog vlakna konačne duljine

Hvala na pozornosti!