Models are Always Wrong, Right? What's the Difference Between an $85 Model and a $2,000,000 Model

Colin McAndrew

April 4, 2002

Australia, not Austria

Australia, not Austria

Taz

Taz

Tassie, not Taz

Taz

Laws of Simulation and Modeling

- A simulation is only as accurate as the models it is based on
- A model is (mostly) useless unless it is embedded in a simulator
- Models are, by definition, inaccurate; it's just a matter of degree
- Models generally trade off complexity (simulation time) for accuracy

Zeroeth Law of Modeling

Physics (reality) trumps Mathematics

Zeroeth Law of Modeling

Measurements trump Models

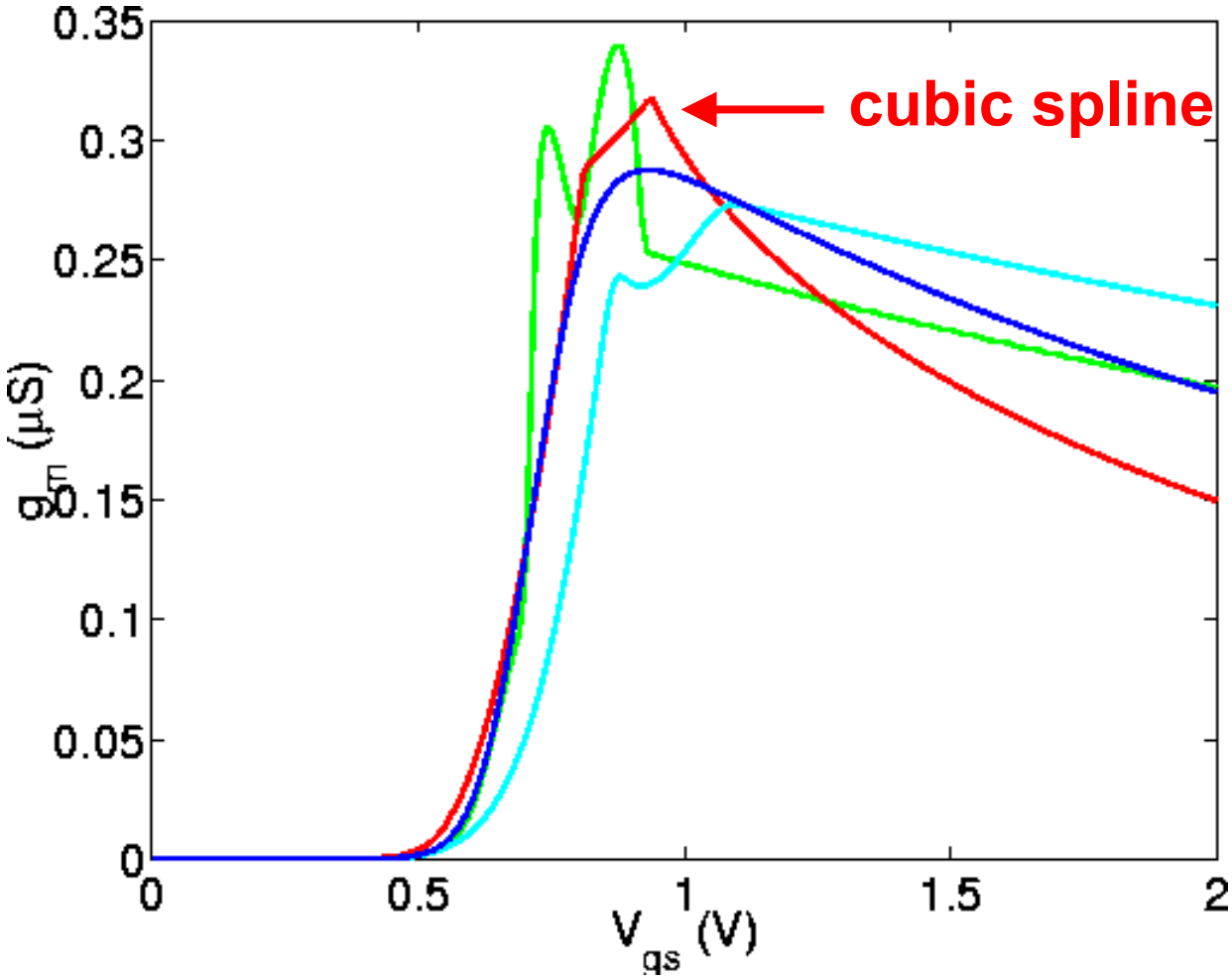
Zeroeth Law of Modeling

Measurements trump Models

Especially when Engineers Use Polynomials

Colin McAndrew
NACDM, April 2002

Numerical Tricks May not Work

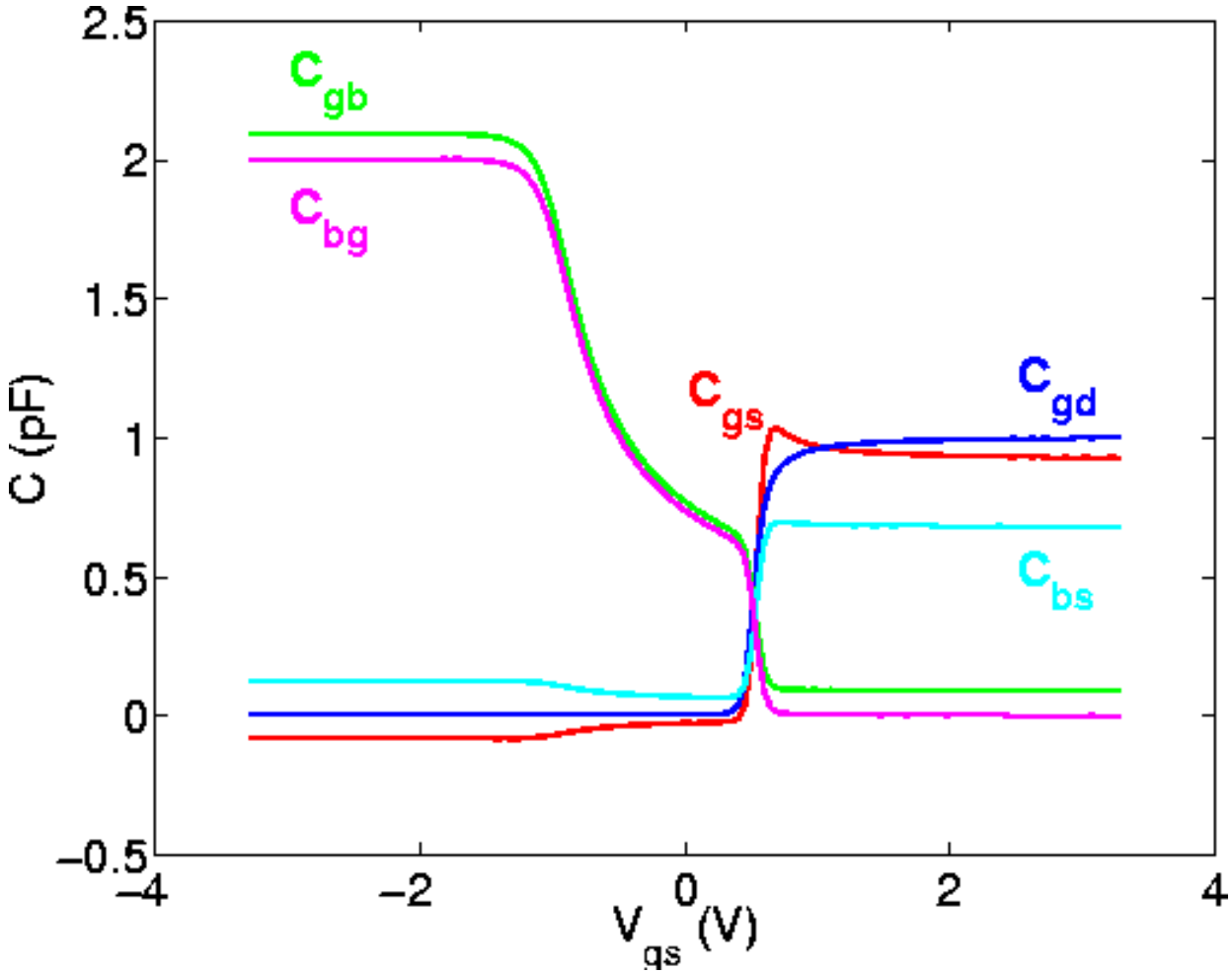


Zeroeth Law of Modeling

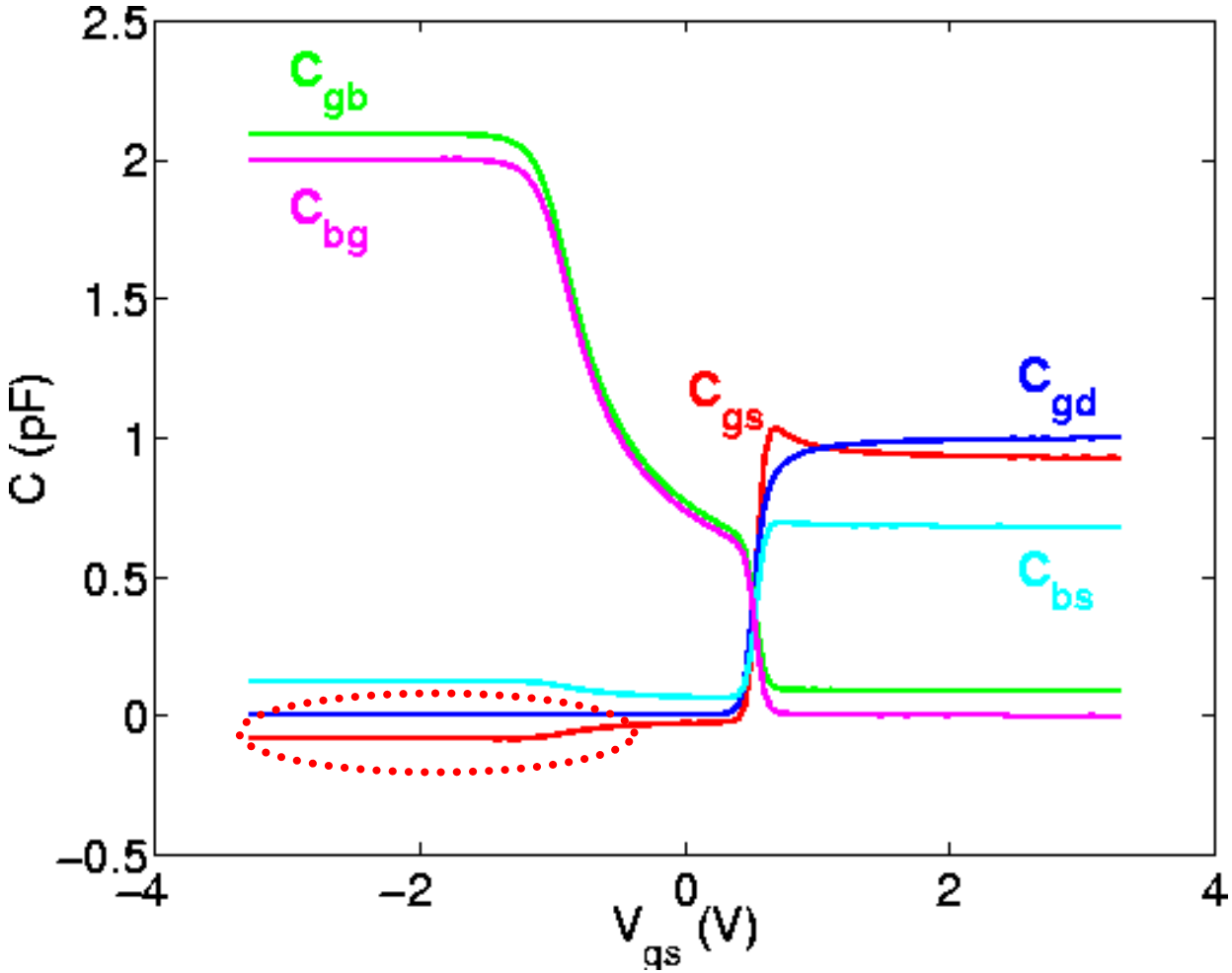
Measurements trump Models

Just be careful you know what you are measuring

Negative Capacitance Blooper



Negative Capacitance Blooper



Simple way to Get Capacitance

- **Terminal currents from AC analysis**

$$i_i = (g_{ik} + j\omega C_{ik})v_k$$

- **Sequentially excite terminals k with $1+j0$ volts at $\omega=1$, i.e. $f=1/(2\pi)$**

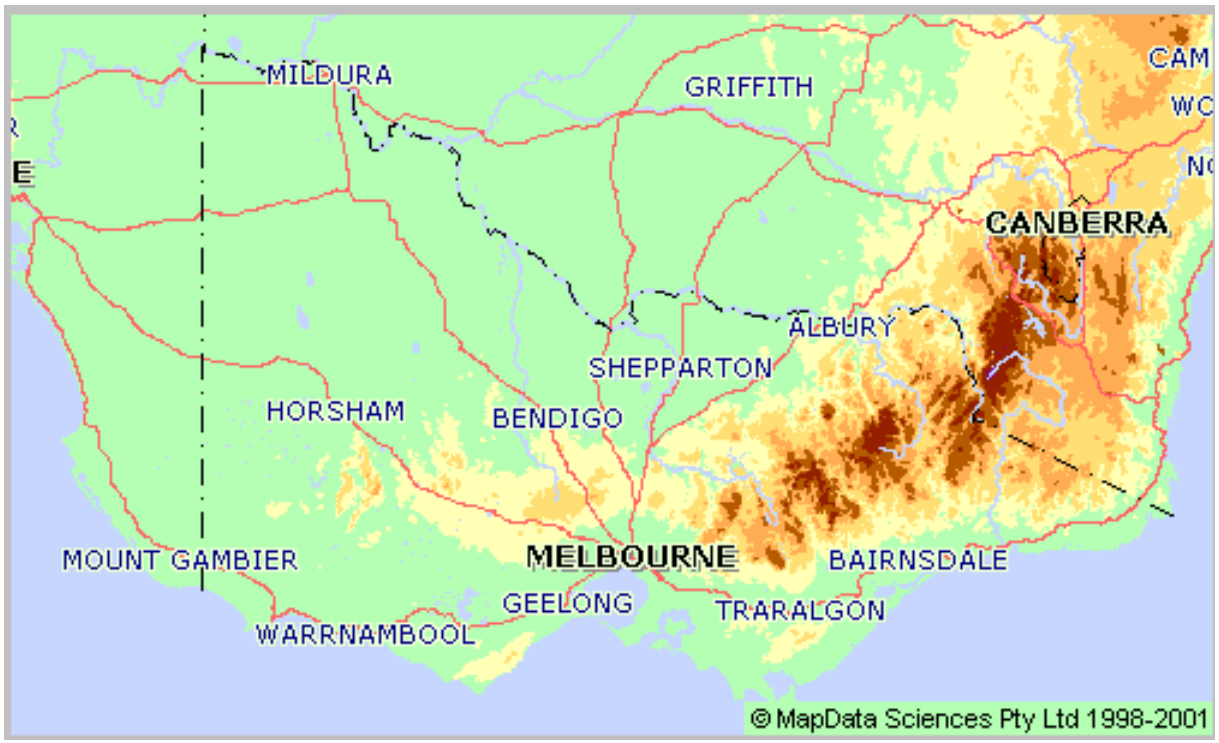
$$C_{ik} = im(i_i)$$

- **Change sign if $i \neq k$**

Oz is Acceptable

Aussie, not Ozzie

Victoria


MILDURA
GRIFFITH
CANBERRA
ALBURY
SHEPPARTON
HORSHAM
BENDIGO
MOUNT GAMBIER
MELBOURNE
BAIRNSDALE
GEELONG
TRARALGON
WARRNAMBOOL
© MapData Sciences Pty Ltd 1998-2001

Charge or Capacitance?

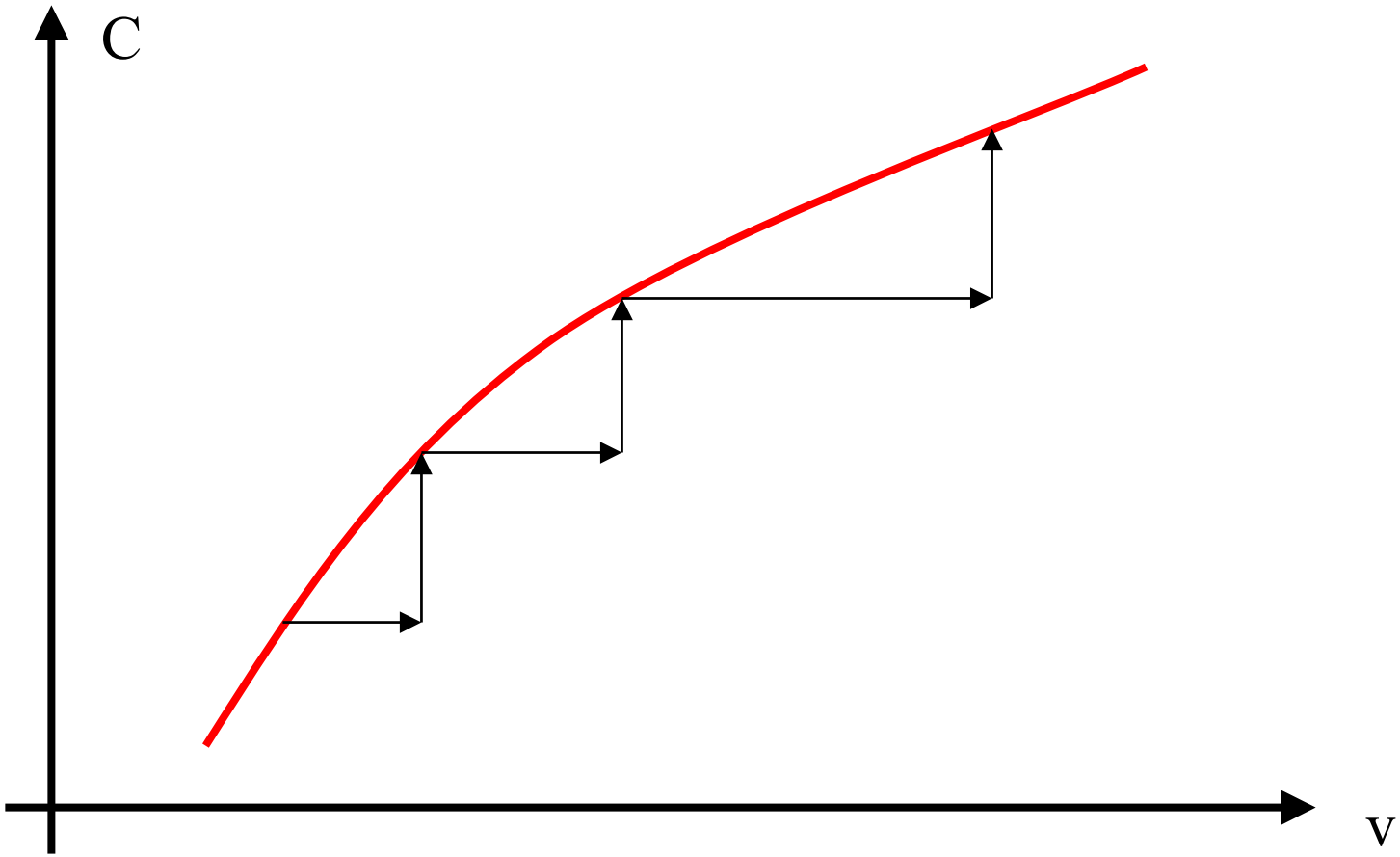
- **They're really the same, right?**

$$q = Cv(t)$$

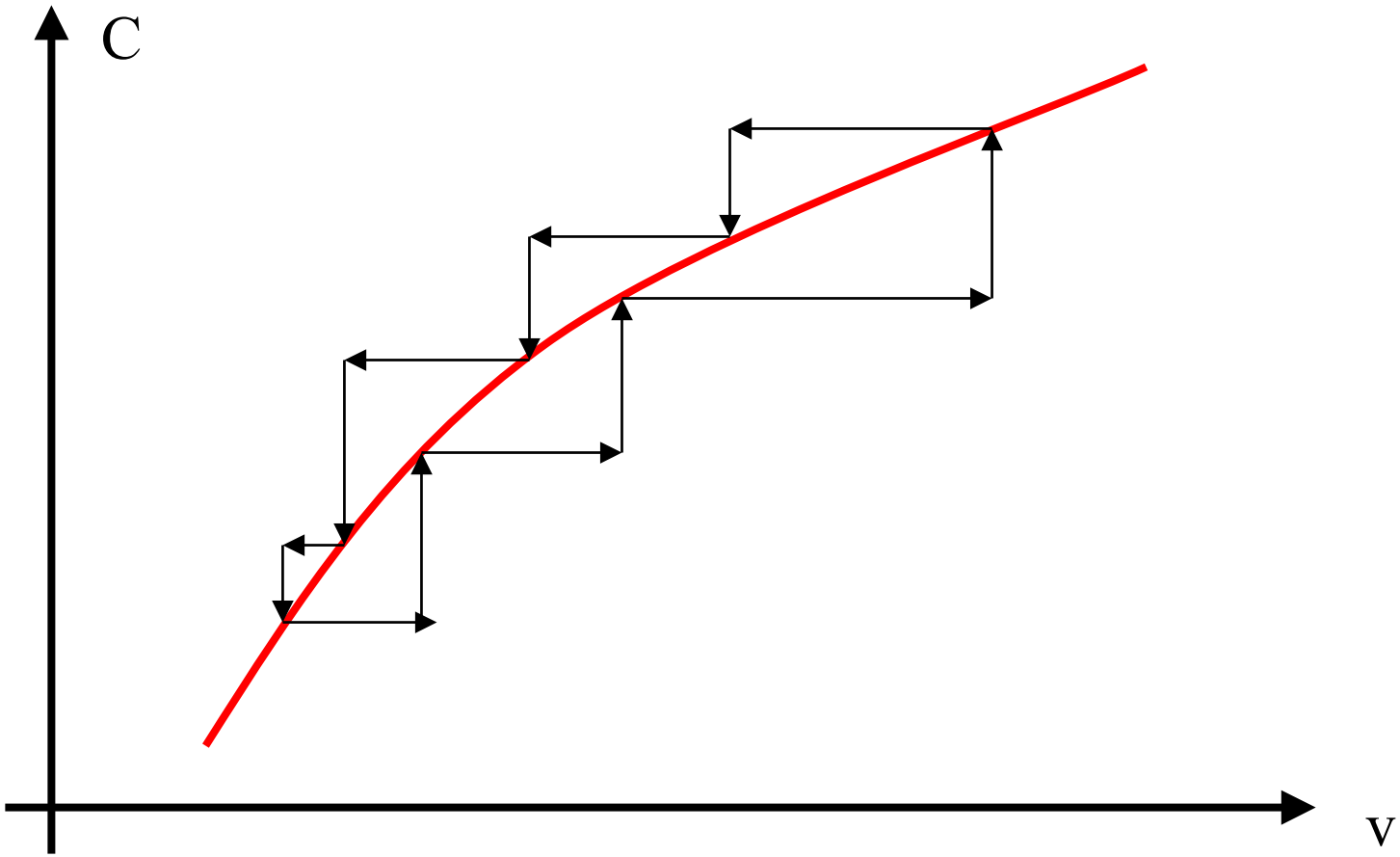
$$i = \frac{\partial q}{\partial t} = \frac{q_{k+1} - q_k}{t_{k+1} - t_k}$$

$$i = C\frac{\partial v}{\partial t} \approx C_k \frac{v_{k+1} - v_k}{t_{k+1} - t_k}$$

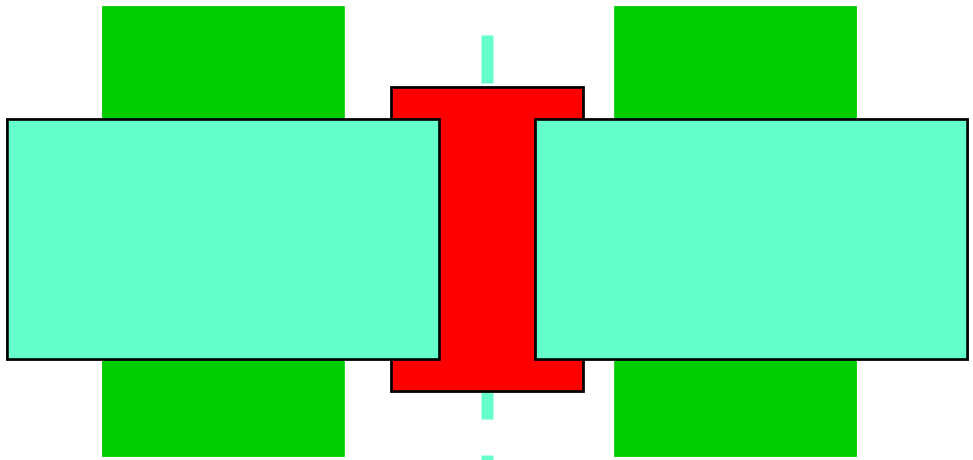
Charge or Capacitance?



Charge or Capacitance?

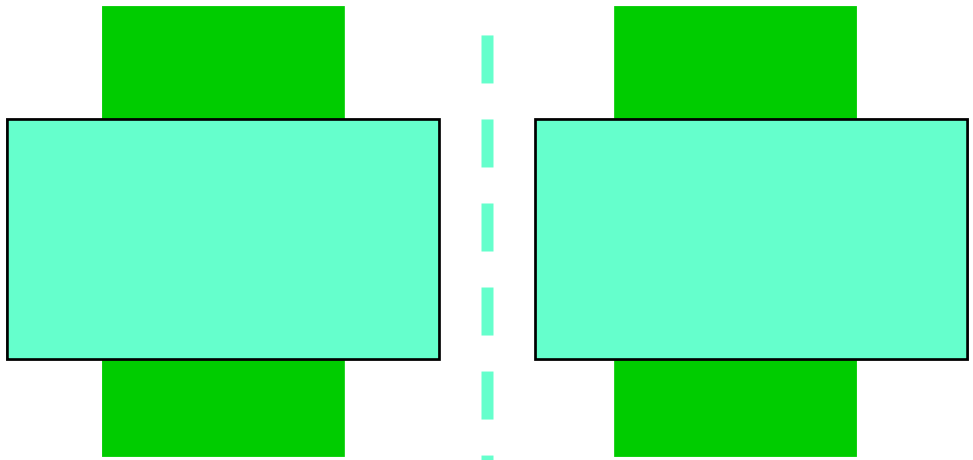


Will the IC Fail?



Protection circuitry **Real circuitry**

Metal Routing Missing

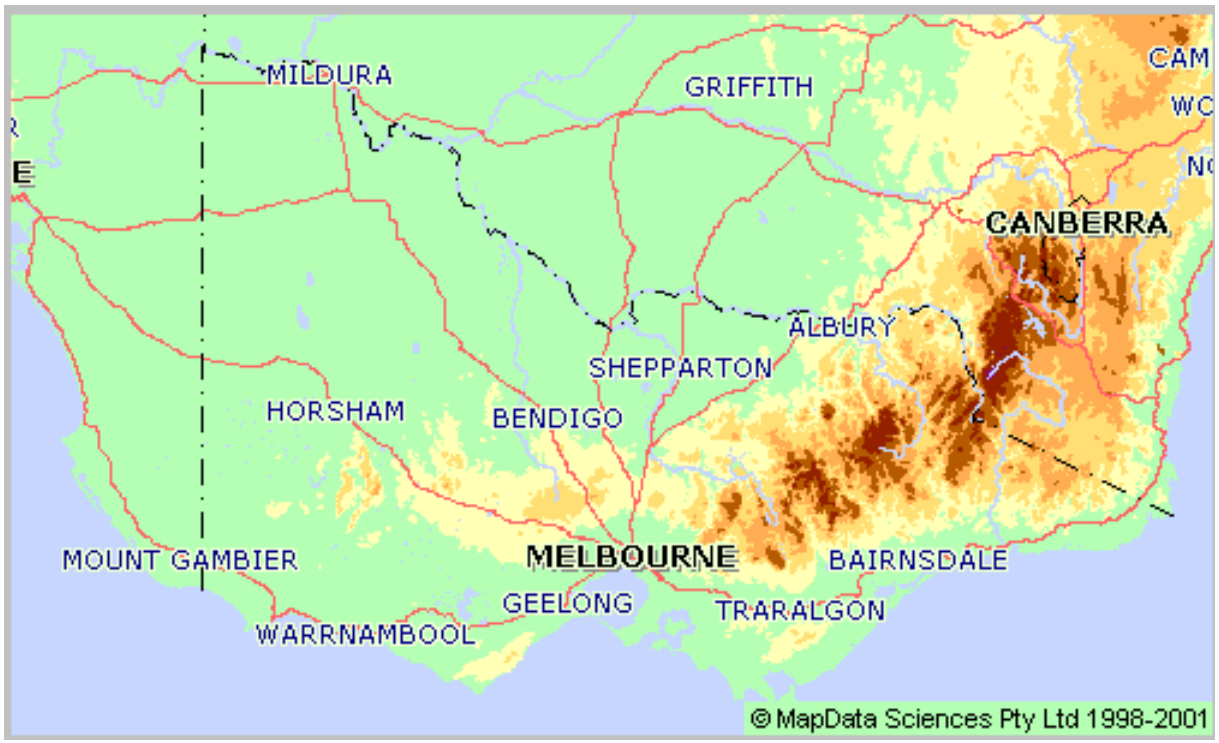


Protection circuitry **Real circuitry**

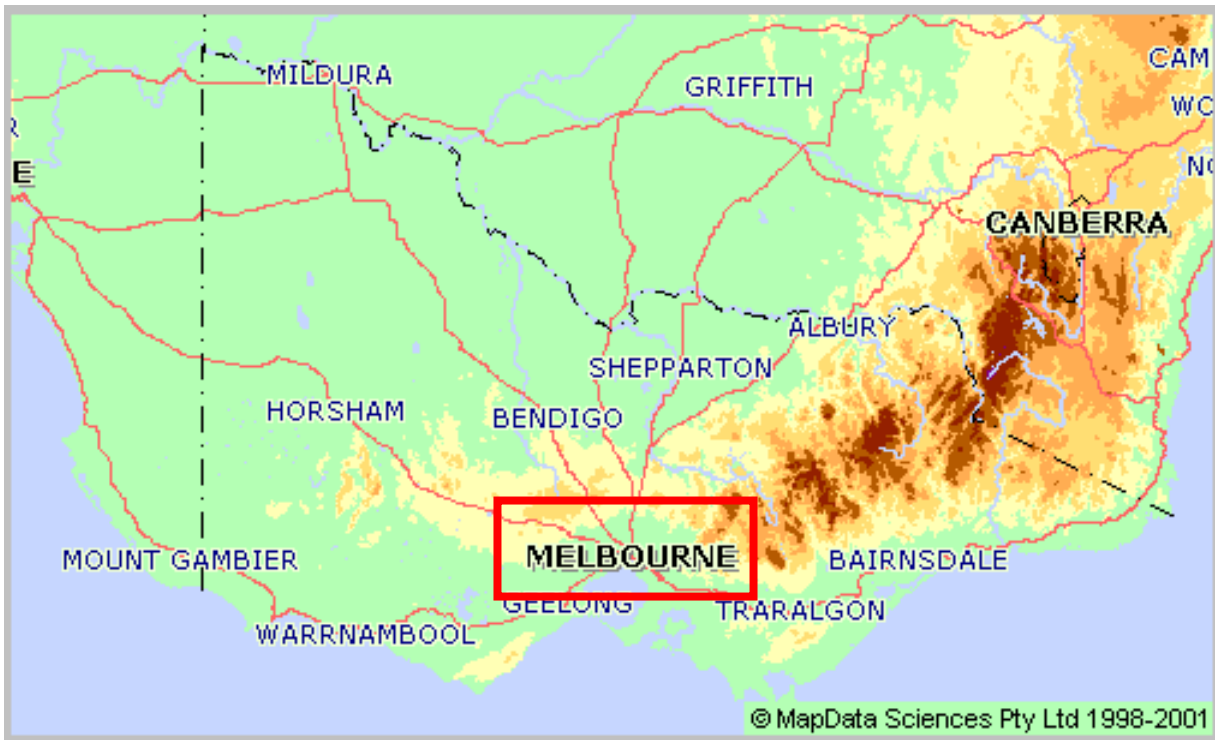
Simulation Results

- Capacitance based model did not conserve charge, isolated protection circuitry voltage ramped to infinity!
- Charge based model showed the missing metal would NOT cause the protection circuitry to trigger
- $2,000,000 of already manufactured parts were shipped and not scrapped

Victoria


MILDURA
GRIFFITH
CANBERRA
ALBURY
SHEPPARTON
HORSHAM
BENDIGO
MOUNT GAMBIER
MELBOURNE
BAIRNSDALE
GEELONG
TRARALGON
WARRNAMBOOL
© MapData Sciences Pty Ltd 1998-2001

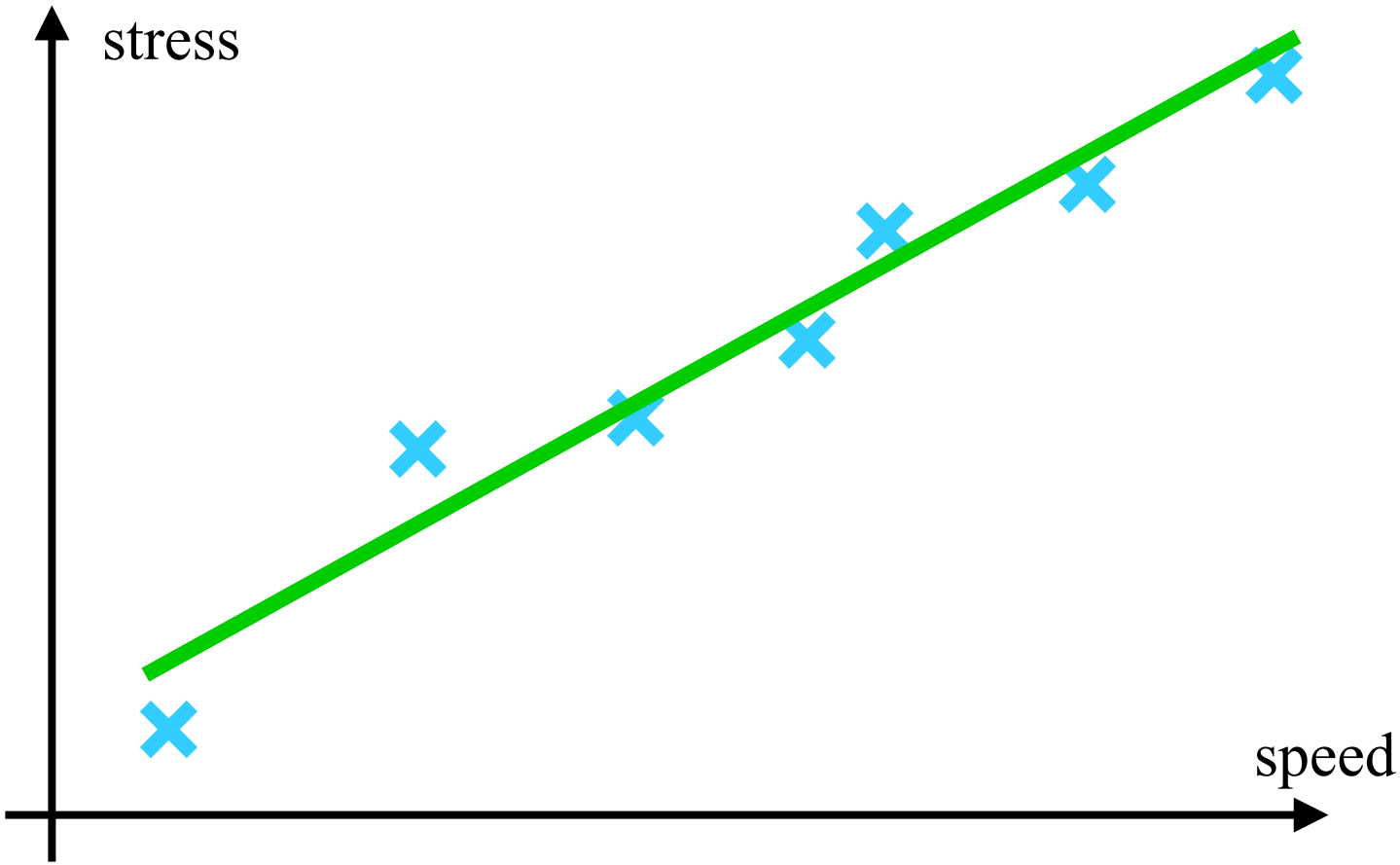
Victoria


MILDURA
GRIFFITH
CANBERRA
ALBURY
SHEPPARTON
HORSHAM
BENDIGO
MELBOURNE
MOUNT GAMBIER
BAIRNSDALE
TRARALGON
WARRNAMBOOL
© MapData Sciences Pty Ltd 1998-2001

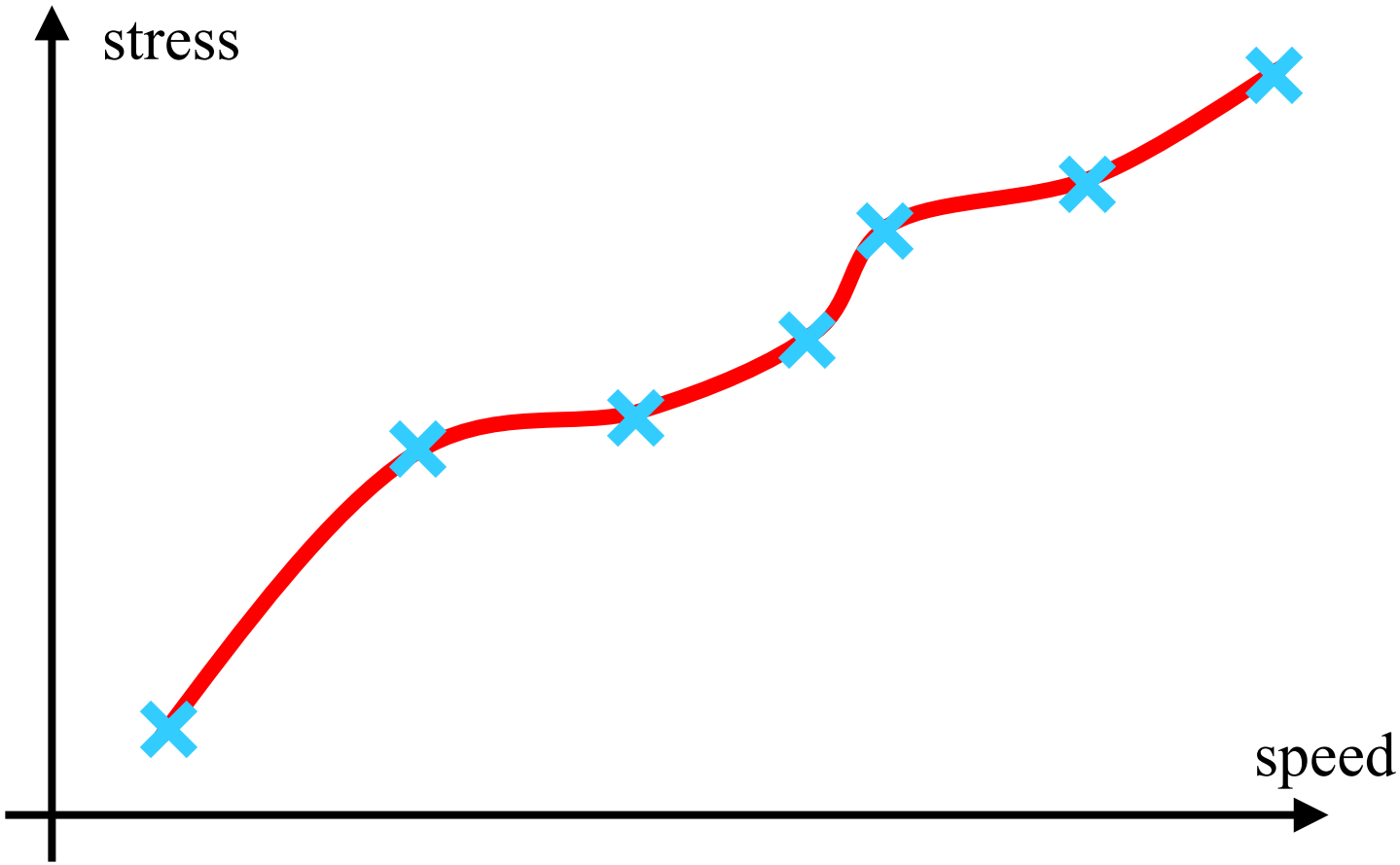
Melb’n, not Mell-born

Milling Coal for the SECV

Milling Coal for the SECV



Milling Coal for the SECV



Melb’n, not Mell-born

Melb’n, not Mell-born

Eastern Suburbs

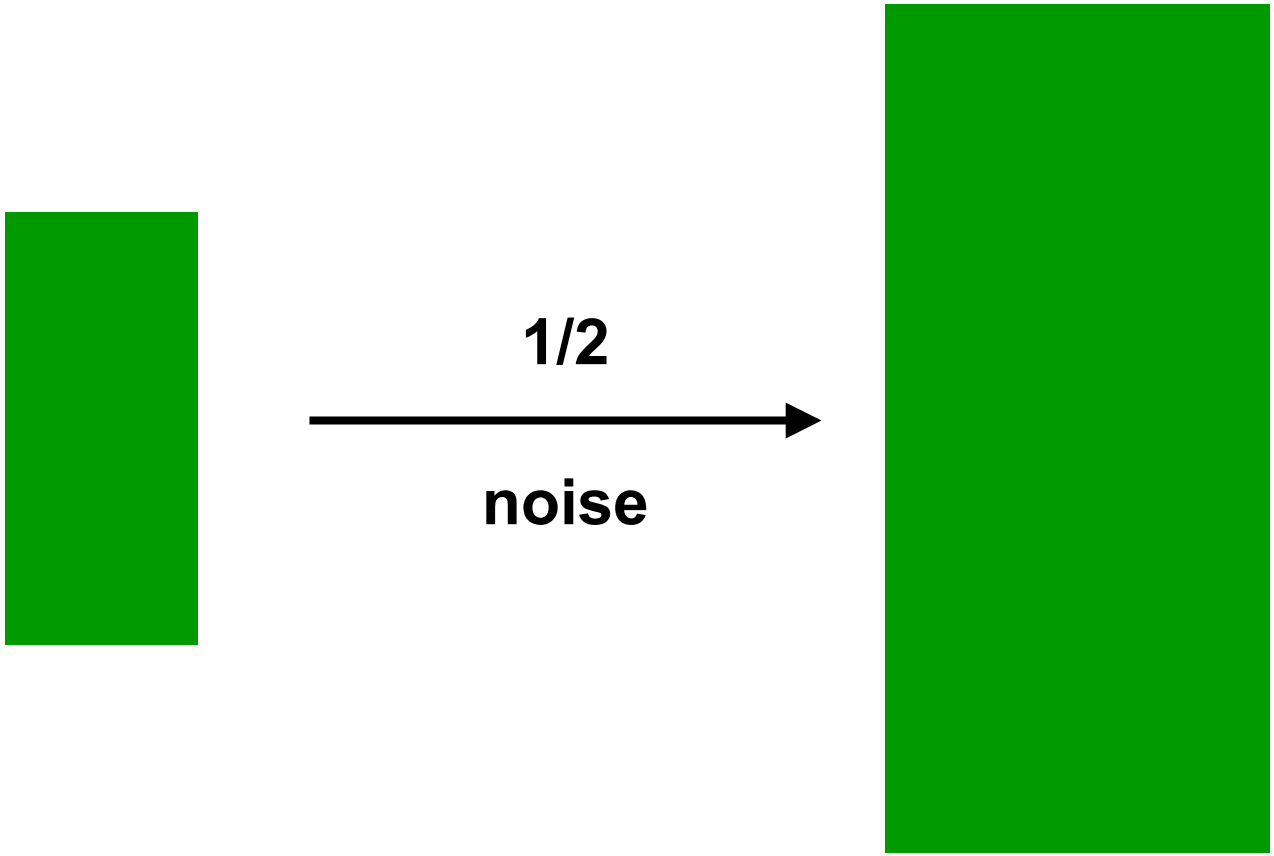
Asymptotic Correctness

- Any model should give physically correct and reasonable behavior as any controlling parameter approaches an extreme
  - Temperature going very cold or hot
  - Geometry getting very large
- It is amazing how infrequently this simple principle is applied
  - 1/W and 1/L preferred to L and W

Universal SPICE 1/f Noise Model

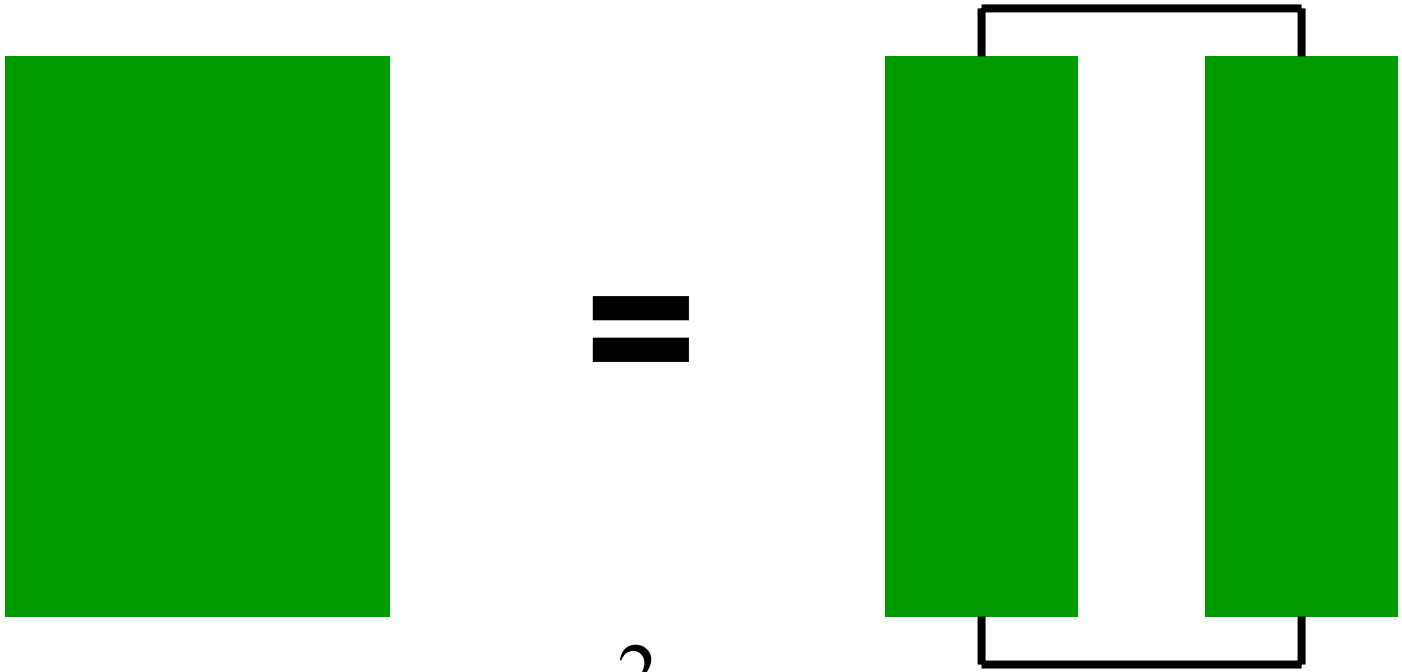
$$\frac{\Delta i^2}{\Delta f} = \frac{K_F (I_{ds})^{A_F}}{LWf}$$

Universal SPICE 1/f Noise Model



(at a fixed total current)

Universal SPICE 1/f Noise Model



$$\frac{\Delta i^2}{\Delta f} \propto W$$

Universal SPICE 1/f Noise Model

$$\frac{\Delta i^2}{\Delta f} = \frac{K_F (I_{ds})^{A_F}}{LWf}$$

$$I_{ds} = I_{ds}^0 \frac{W}{L}$$

$$\frac{\Delta i^2}{\Delta f} = \frac{K_F W^{A_F - 1} (I_{ds}^0)^{A_F}}{L^{A_F + 1} f}$$

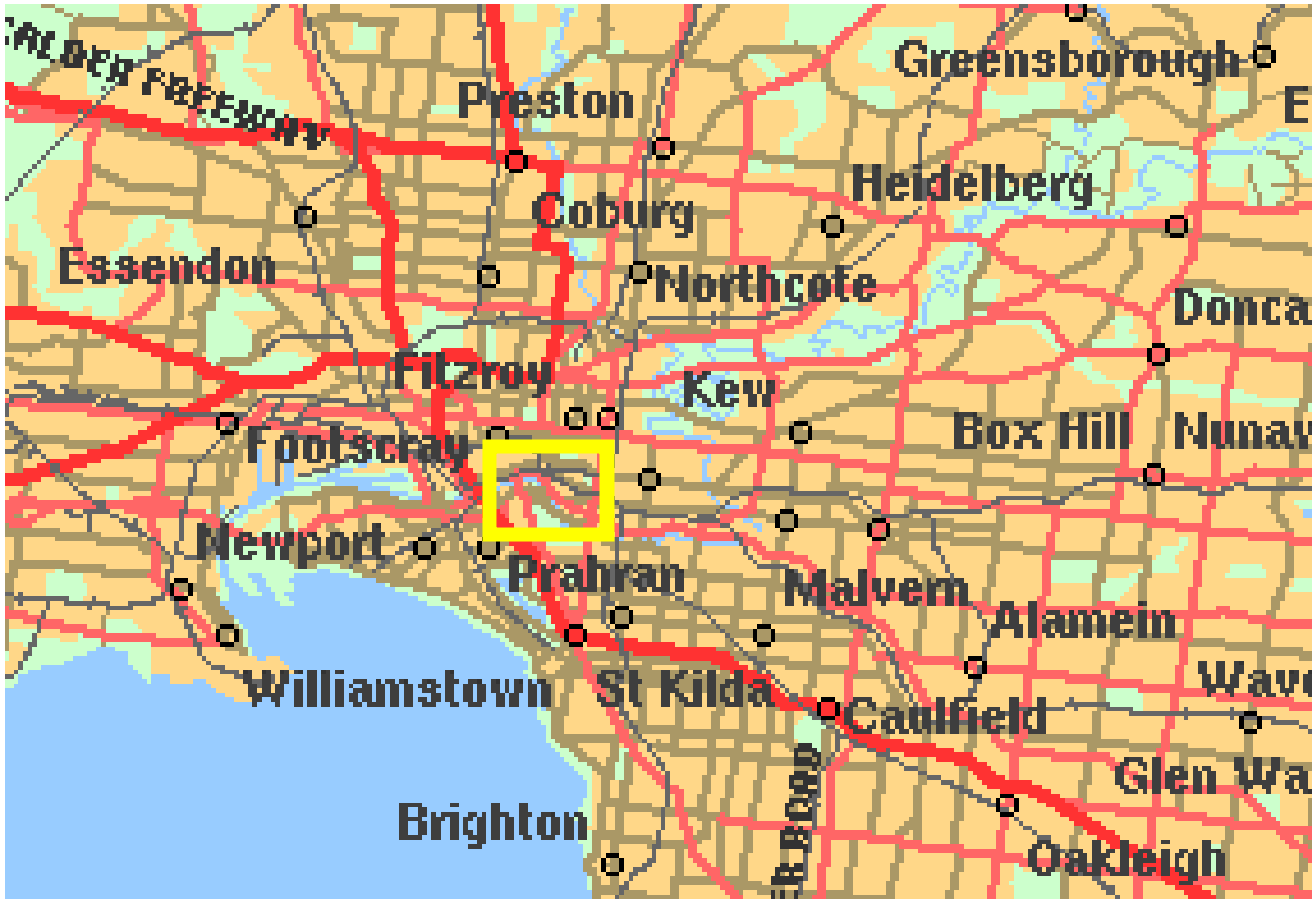
Symmetry

- Most MOSFET and resistor models are cast in the form $I_{ds}=GV_{ds}$
- $G(V_{sb},V_{db},V_{gb})$ is the effective conductance of the MOSFET or resistor
- Consider symmetric biasing $V_{db}=V_{db0}+V_x$, $V_{sb}=V_{sb0}-V_x$, $V_{ds}=2V_x$
- I_{ds} MUST be an odd function of V_x
- G MUST be an even function of V_x
- Limiting of V_{ds} to V_{sat} MUST be odd

Eastern Suburbs

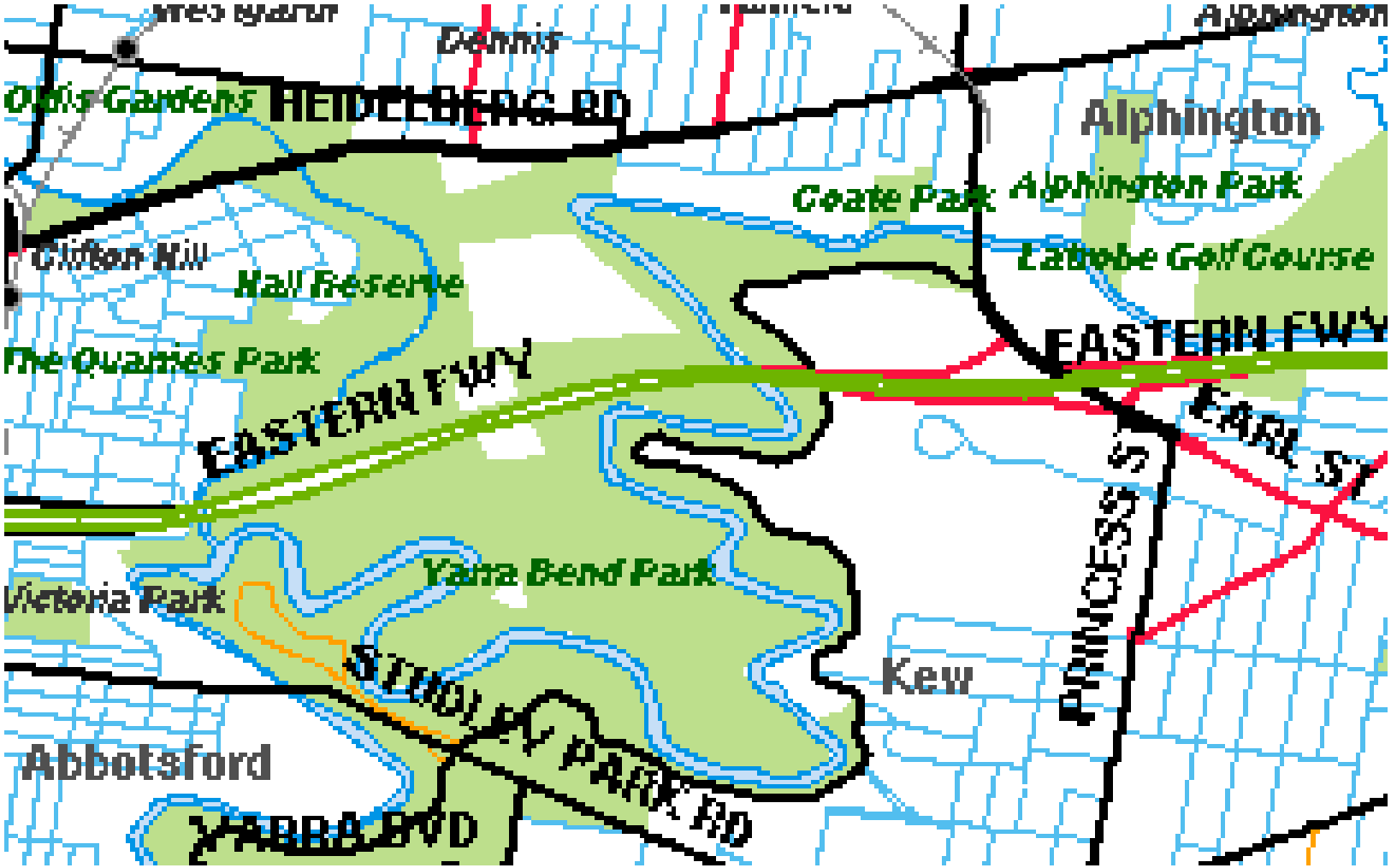
Eastern Suburbs

Eastern Suburbs

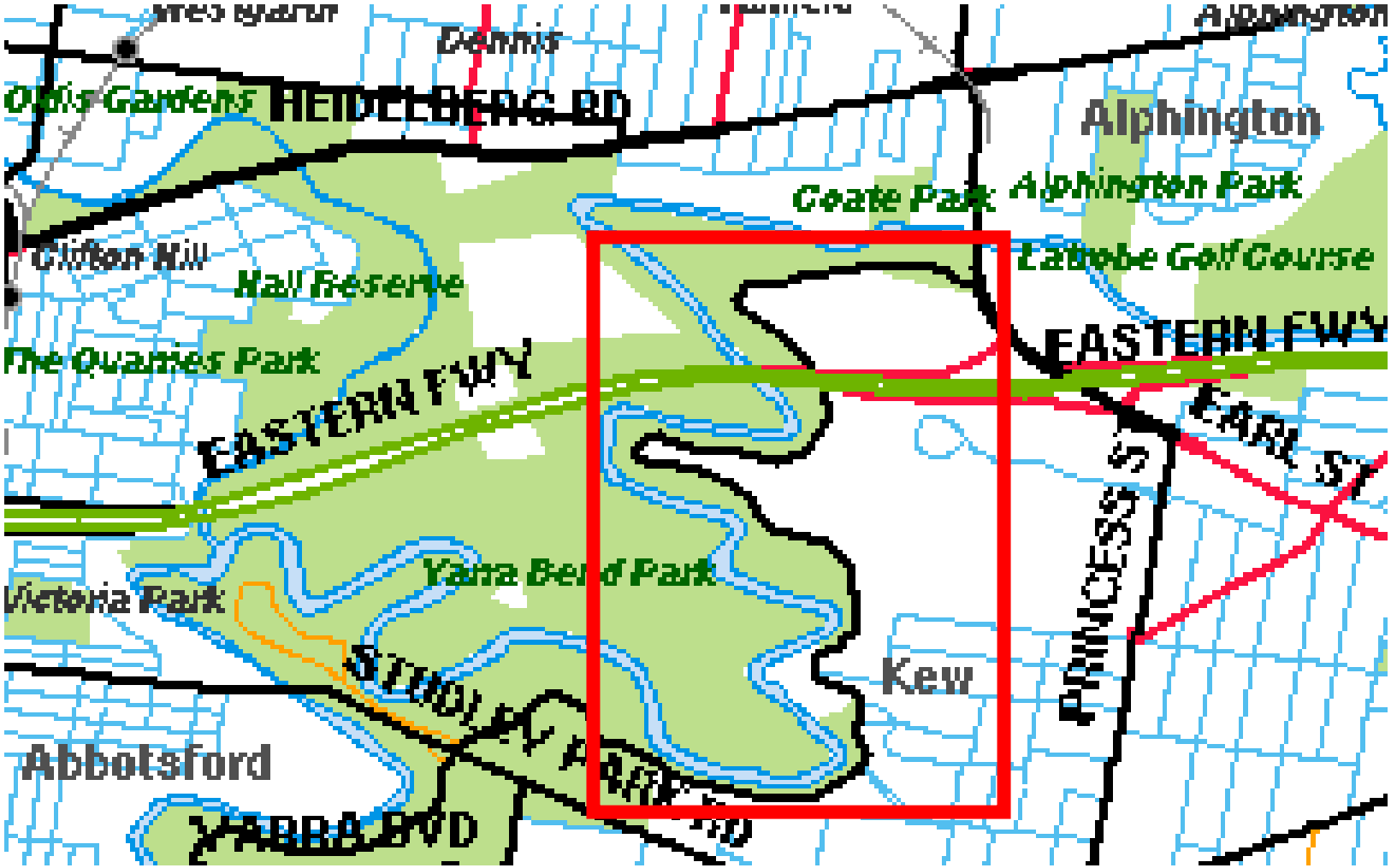


Eastern Suburbs

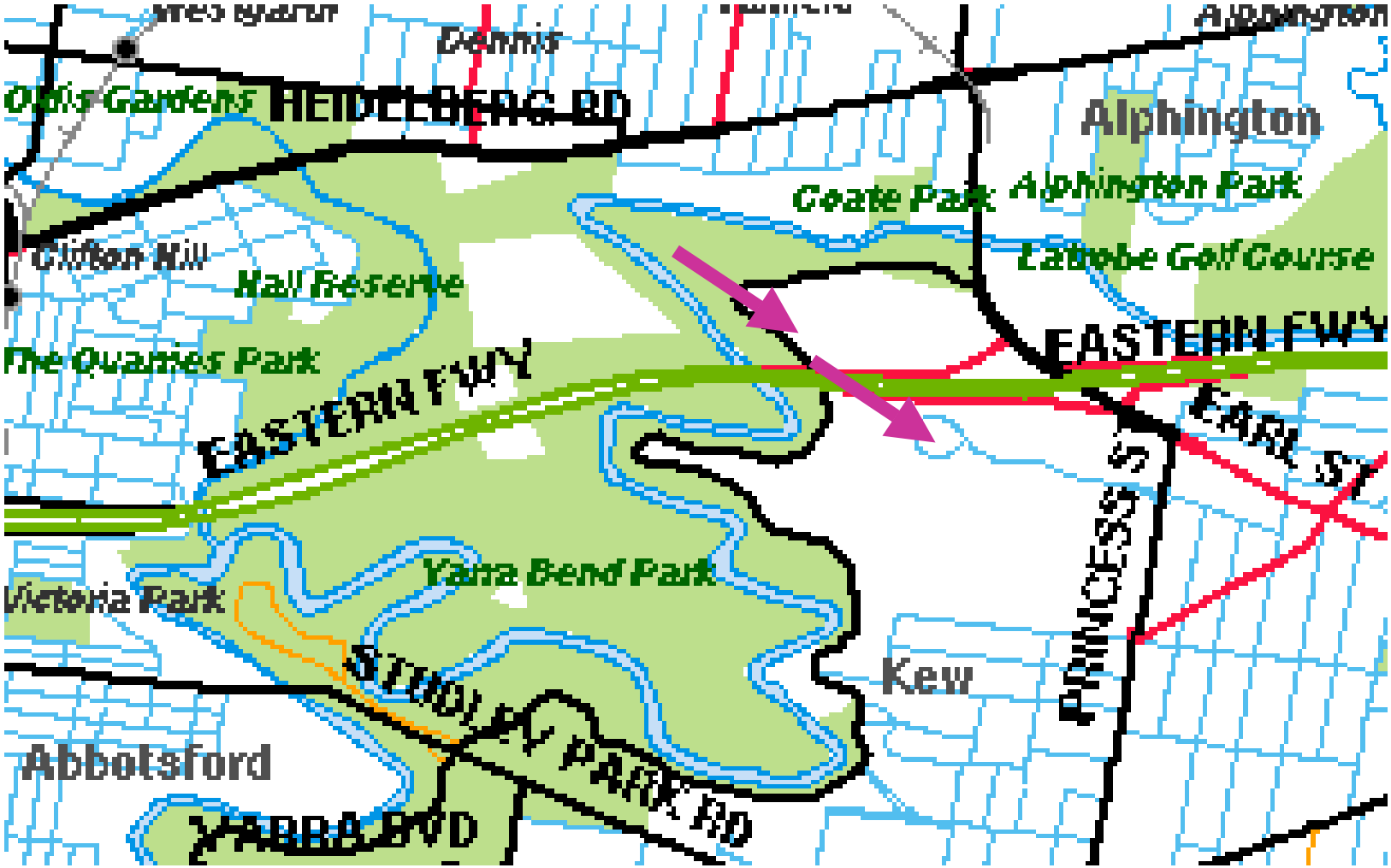
Kew


Dennis
Alphington
Ollis Gardens
HEIDELBERG RD
Alphington
Coate Park
Alphington Park
Clifton Hill
Hall Reserve
Latrobe Golf Course
The Quarries Park
EASTERN FWY
EASTERN FWY
EARL ST
Yarra Bend Park
Victoria Park
KINGS WAY
Kew
STRODE PARK RD
Abbotsford
YARRA BVD

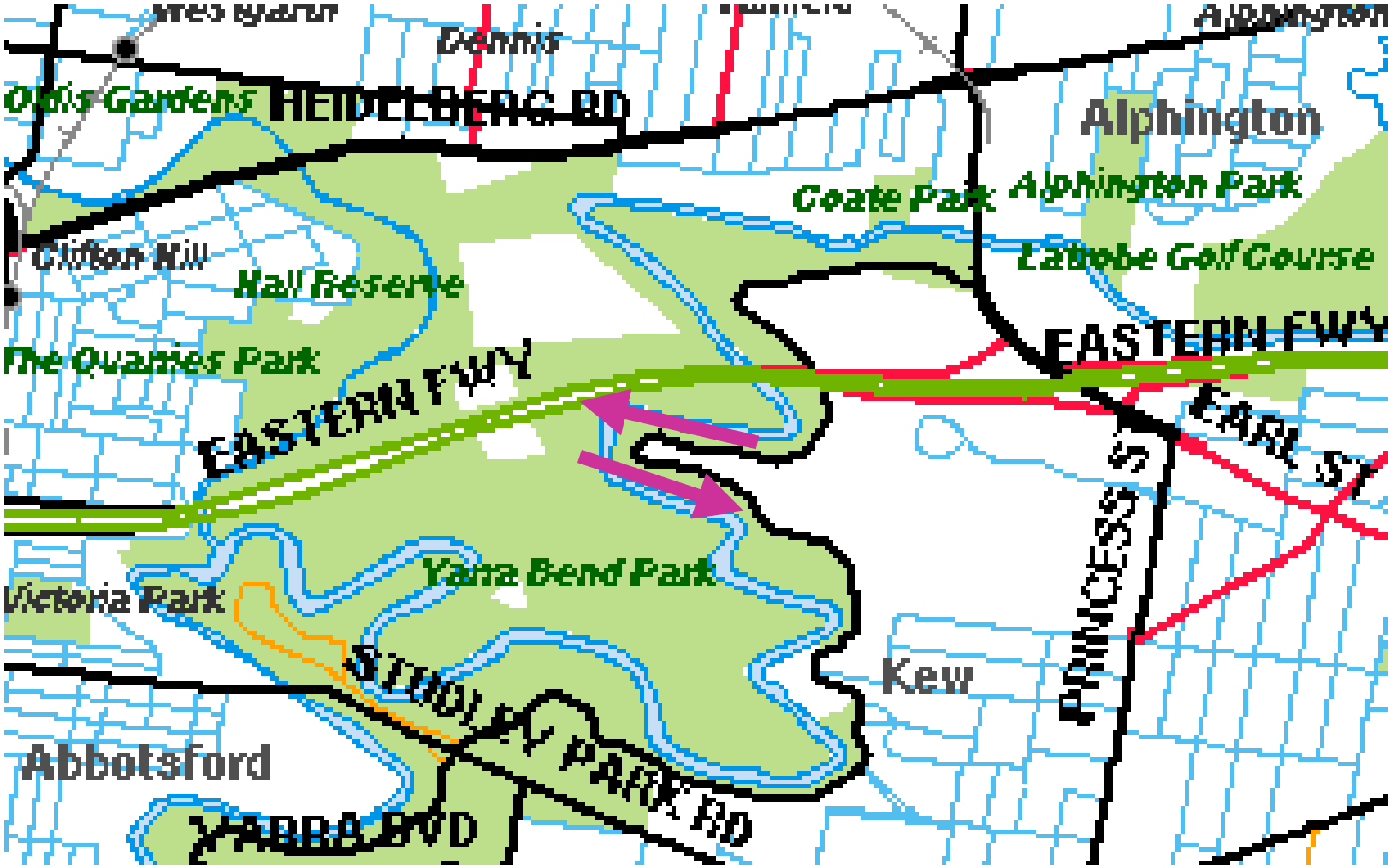
Kew


Dennis
Alphington
Otto's Gardens
HEIDELBERG RD
Alphington
Coate Park
Alphington Park
Clifton Hill
Hall Reserve
Latrobe Golf Course
The Quarries Park
EASTERN FWY
EASTERN FWY
EARL ST
PRINCES ST
Yarra Bend Park
Victoria Park
Kew
Abbotsford
YARRA BVD

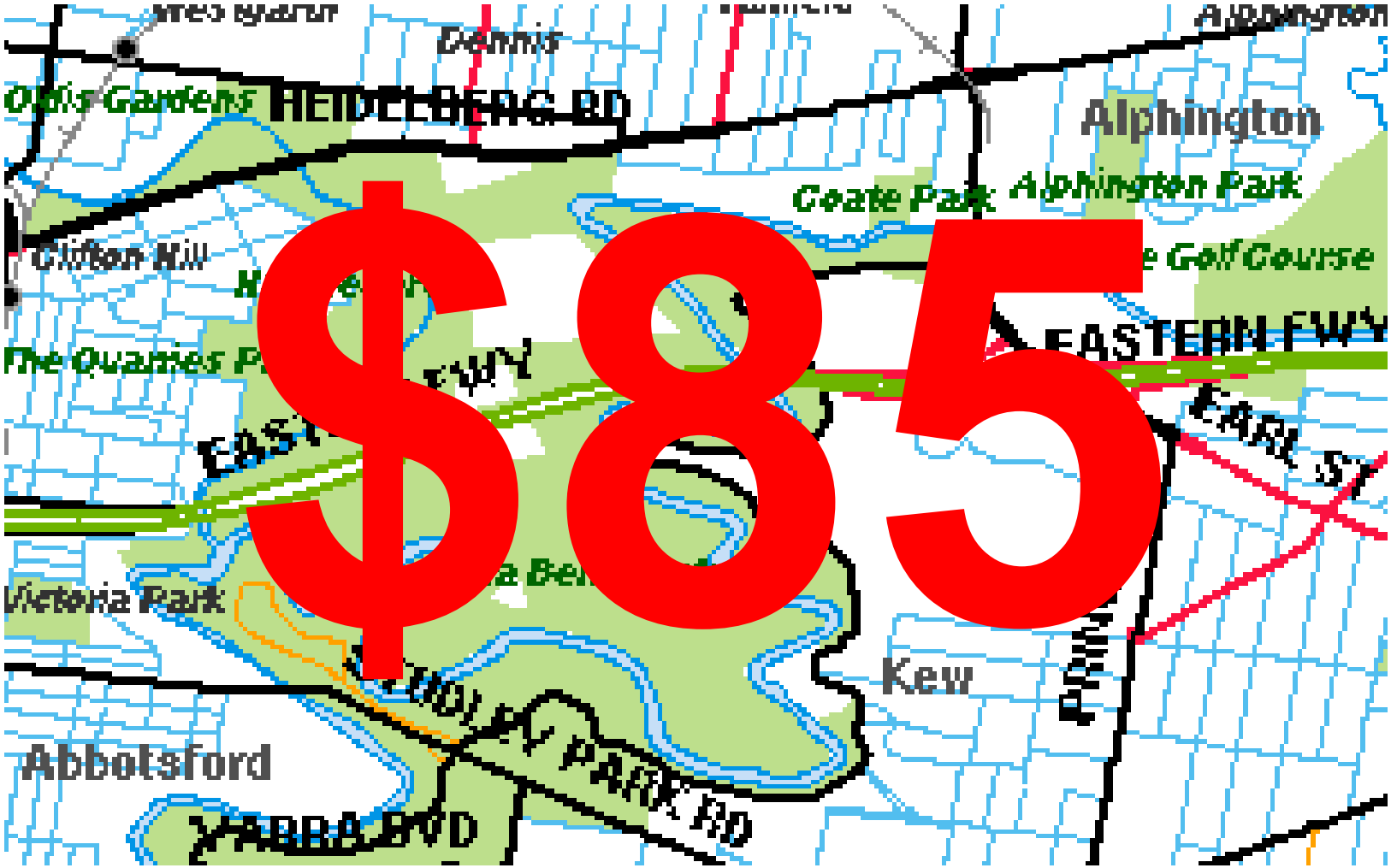
Kew


Dennis
Alphington
Ollis Gardens
HEIDELBERG RD
Alphington
Coate Park
Alphington Park
Clifton Hill
Hall Reserve
Latrobe Golf Course
The Quarries Park
EASTERN FWY
EASTERN FWY
EARL ST
Yarra Bend Park
Victoria Park
KINGS WAY
Kew
STRADA PARK RD
Abbotsford
YARRA BVD

Kew


Dennis
Alphington
Ollis Gardens
HEIDELBERG RD
Alphington
Coate Park
Alphington Park
Clifton Hill
Hall Reserve
Latrobe Golf Course
EASTERN FWY
The Quarries Park
EASTERN FWY
EARL ST
PRINCES ST
Yarra Bend Park
Victoria Park
Kew
STRADA PARK RD
Abbotsford
YARRA BVD

Kew


Dennis
Alphington
Alphington Park
Clifton Hill
EASTERN FWY
Victoria Park
Kew
Abbotsford
YARRA BVD
$85