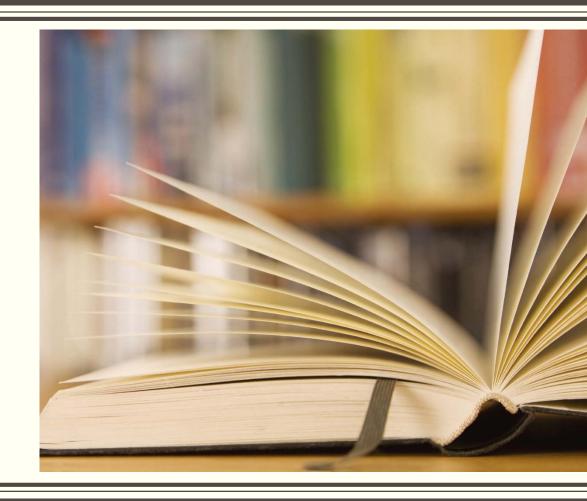
HOW COMPLICATED CAN THE CIRCUIT NETWORK BE WHEN USING CircuitNAV?

Boundaries of Symbolic Circuit Analysis



CircuitNAV's Capability

- CircuitNAV is a symbolic circuit analysis tool
- It generates systems of equations for node voltages based on Kirchhoff's Current Law
- CircuitNAV uses SymPy, a computer algebra system, to solve the systems of equations
- Theoretically, the tool does not have a limitation on how many nodes the circuit netlist can have
- Practically, CircuitNAV does have a boundary how come?

Limitations on Algebraic Solutions for Systems of Equations

- In theory there is no limit on the size of a system or the number of unknowns and equations
- SymPy does not have a limit on the size either
- To get the simplified solution, SymPy could take a significant amount of time when the size grows larger.

system size # of unknowns # of equations	# of product terms	SymPy Calculation Time(sec)
7 or equations	2 (2!)	1
2		1
3	6 (3!)	<u> </u>
4	24 (4!)	7
5	120 (5!)	120 (2 min)
6	720 (6!)	3000 (50 min)

Visual Sense of the Solutions for System Size of Two and Three

For two equations and two unknowns, the solution has a sum of two product terms both in numerator and denominator.

```
Three Unknowns, [x0, x1]; Two Equations:
a00*x0 + a01*x1 = b0
a10*x0 + a11*x1 = b1

SymPy Solution (takes an i7 CPU less than 1 sec):
x0 = (-a01*b1 + a11*b0)/(a00*a11 - a01*a10)
x1 = (a00*b1 - a10*b0)/(a00*a11 - a01*a10)

Three Unknowns, [x0, x1, x2]; Three Equations:
a00*x0 + a01*x1 + a02*x2 = b0
a10*x0 + a11*x1 + a12*x2 = b1
a20*x0 + a21*x1 + a22*x2 = b2

SymPy Solution (takes an i7 CPU about 1 sec):
x0 = (b0*(a11*a22 - a12*a21) - b1*(a01*a22 - a02*a21) + b2*(a01*a12 - a02*a11)/(a00*a11*a22 - a00*a12*a21 - a01*a10*a22 + a01*a12*a20 + a02*a10*a21 - a02*a11*a20)
x1 = (-b0*(a10*a22 - a12*a20) + b1*(a00*a21 - a01*a10*a2) + b2*(a00*a11 - a01*a10)/(a00*a11*a22 - a00*a12*a21 - a01*a10*a22 + a01*a12*a20 + a02*a10*a21 - a02*a11*a20)
x2 = (b0*(a10*a21 - a11*a20) - b1*(a00*a21 - a01*a10*a21 - a01*a10*a22 + a01*a12*a20 + a02*a10*a21 - a02*a11*a20)
```

For three equations and three unknowns, the solution has a sum of six product terms both in numerator and denominator.

Visual Sense of the Solutions for System Size of Four

For four equations and four unknowns, the solution has a sum of 24 product terms both in the numerator and denominator.

```
Four Unknowns, [x0, x1, x2, x3]; Four Equations:
a00*x0 + a01*x1 + a02*x2 + a03*x3 = b0
a10*x0 + a11*x1 + a12*x2 + a13*x3 = b1
a20*x0 + a21*x1 + a22*x2 + a23*x3 = b2
a30*x0 + a31*x1 + a32*x2 + a33*x3 = b3
SymPy Solution (takes an i7 CPU about 7 sec):
x0 = (b0*(a11*a22*a33 - a11*a23*a32 - a12*a21*a33 + a12*a23*a31 + a13*a21*a32 - a13*a22*a31) - b1*(a01*a22*a33 - a01*a23*a32 - a02*a21*a33 + a02*a23*a31 + a13*a21*a32 - a13*a22*a31)
a03*a21*a32 - a03*a22*a31) + b2*(a01*a12*a33 - a01*a13*a32 - a02*a11*a33 + a02*a13*a31 + a03*a11*a32 - a03*a12*a31) - b3*(a01*a12*a23 - a01*a13*a22 - a02*a11*a23 - a01*a13*a22 - a02*a11*a23 - a03*a12*a31) + b2*(a01*a12*a33 - a01*a13*a22 - a02*a11*a33 -
a02*a11*a23*a30 + a02*a13*a20*a31 - a02*a13*a21*a30 - a03*a10*a21*a32 + a03*a10*a22*a31 + a03*a11*a20*a32 - a03*a11*a22*a30 - a03*a12*a20*a31 + a03*a12*a21*a30)
x1 = (-b0*(a10*a22*a33 - a10*a23*a32 - a12*a20*a33 + a12*a23*a30 + a13*a20*a32 - a13*a22*a30) + b1*(a00*a22*a33 - a00*a23*a32 - a02*a20*a33 + a02*a23*a30)
a03*a20*a32 - a03*a22*a30) - b2*(a00*a12*a33 - a00*a12*a33 - a02*a10*a33 + a02*a10*a33 + a02*a10*a30 + a03*a10*a32 - a03*a12*a30) + b3*(a00*a12*a23 - a00*a12*a23 - a02*a10*a23 + a02*
a01*a10*a22*a33 + a01*a10*a23*a32 + a01*a12*a20*a33 - a01*a12*a23*a30 - a01*a12*a23*a30 + a01*a13*a22*a30 + a02*a10*a21*a33 - a02*a10*a23*a31 - a02*a11*a20*a33 + a01*a12*a20*a33 + a01*a12*a20*a31 - a02*a11*a20*a33 + a01*a12*a20*a31 - a02*a11*a20*a33 + a01*a12*a20*a31 - a02*a11*a20*a31 - a02*a11*a2
a02*a11*a23*a30 + a02*a13*a20*a31 - a02*a13*a21*a30 - a03*a10*a21*a32 + a03*a10*a22*a31 + a03*a11*a20*a32 - a03*a11*a22*a30 - a03*a12*a20*a31 + a03*a12*a21*a30)
x2 = (b0*(a10*a21*a33 - a10*a23*a31 - a11*a20*a33 + a11*a20*a33 + a11*a23*a30 + a13*a20*a31 - a13*a21*a30) - b1*(a00*a21*a33 - a00*a23*a31 - a01*a23*a31 + a01*a23*a30 + a11*a23*a30)
a03*a20*a31 - a03*a21*a30) + b2*(a00*a11*a33 - a00*a13*a31 - a01*a10*a33 + a01*a10*a33 + a01*a10*a31 - a03*a10*a31 - a03*a11*a30) - b3*(a00*a11*a23 - a00*a11*a23 - a01*a10*a23 + a01*a10*a23 + a01*a10*a31 - a03*a10*a31 - a03*a11*a30) - b3*(a00*a11*a23 - a00*a11*a23 - a01*a10*a21 - a01*a10*a23 + a01*a10*a21 - a01*a10*a10*a10*a21 - a01*a10*a10*a10*a10
a01*a13*a20 + a03*a10*a21 - a03*a11*a20))/(a00*a11*a22*a33 - a00*a11*a23*a32 - a00*a12*a21*a33 + a00*a12*a23*a31 + a00*a13*a21*a32 - a00*a13*a22*a31
x3 = (-b0*(a10*a21*a32 - a10*a22*a31 - a11*a20*a32 + a11*a22*a30 + a12*a20*a31 - a12*a21*a30) + b1*(a00*a21*a32 - a00*a22*a31 - a01*a20*a32 + a01*a22*a30)
a01*a12*a20 + a02*a10*a21 - a02*a11*a20))/(a00*a11*a22*a33 - a00*a11*a22*a33 - a00*a12*a21*a33 + a00*a12*a23*a31 + a00*a12*a23*a31 + a00*a13*a21*a32 - a00*a13*a22*a31
```

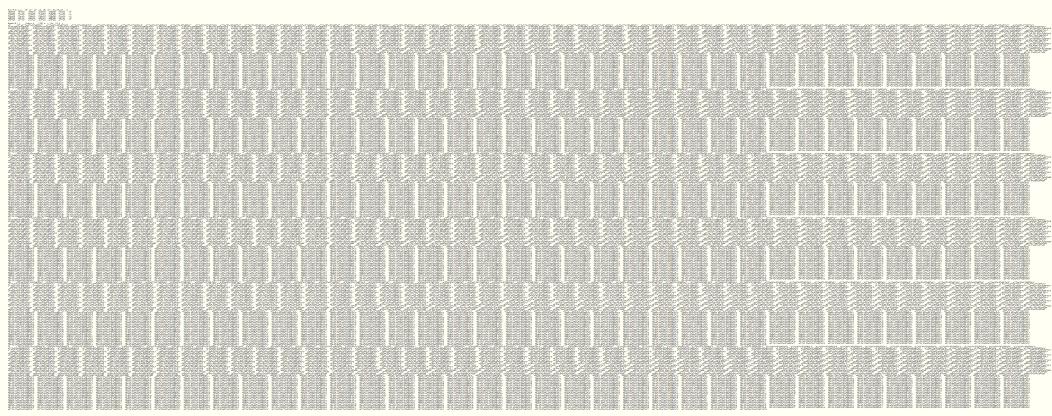
Visual Sense of the Solutions for System Size of Five

For five equations and five unknowns, the solution has a sum of 120 product terms both in numerator and denominator.

```
000*x0 + 001*x1 + 002*x2 + 003*x3 + 004*x4
  a10*e0 + a11*e1 + a12*e2 + a13*e3 + a14*e4 b1
 220*x0 + 221*x1 + 222*x2 + 223*x3 + 224*x4
  a30*e0 + a31*e1 + a32*e2 + a33*e3 + a34*e4 - b3
 440*x0 + 441*x1 + 442*x2 + 443*x3 + 444*x4 - 54
                           (BOT (A)17-0227-0337-049 - 0117-0227-0337-049 - 0117-0227-0327-049 - 0117-0237-0327-049 - 0117-0237-0327-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 0137-0227-0337-049 - 013
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  008*137*22*33**041 + 008*137*22*337*041 + 008*137*22*337*042 - 008*14*227*337*042 - 008*14*227*337*043 + 008*14*227*337*043 + 008*14*227*337*043 + 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*227*337*044 - 008*14*22
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   a04*a12*a21*a33*a40 + a04*a12*a23*a38*a41 - a04*a12*a23*a31*a40 - a04*a12*a23*a31*a40 - a04*a13*a22*a31*a42 + a04*a13*a22*a31*a40)
                         (-56*(a)*a22*a37*a6* - a)*a22*a37*a6* - a)*a22*a37*a6* - a)*a22*a37*a6* (- a)*a22*a3
 302*310*326*343 + 302*313*327*345 - 302*313*327*345 - 302*313*327*345 - 302*313*327*345 - 302*313*327*345 - 302*313*327*345 - 302*313*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*345 - 303*312*327*
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Visual Sense of the Solutions for System Size of Six

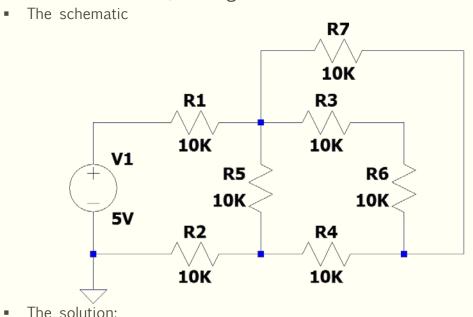
For six equations and six unknowns, the solution has a sum of 720 product terms both in numerator and denominator.



It takes an i7 CPU almost an hour to get the simplified solution!

How Complicated can the Circuit be when using CircuitNAV?

• For a four node circuit, the algebraic solution could be messy.



The netlist:

R1 N001 N003 10K
R2 N005 0 10K
R3 N004 N001 10K
R4 N002 N005 10K
R5 N005 N001 10K
R6 N002 N004 10K
V1 N003 0 5V
R7 N002 N001 10K

- When the netlist has five, six, or more nodes, the algebraic analysis may take minutes to hours to get the simplified result
- The result may not be algebraically meaningful, and hard for humans to make any sense out of it
- Numerical solutions might be the way to go

The Conclusion

- Zooming out on the solutions presented, we conclude:
 - When using the symbolic circuit analysis tool, e.g. CircuitNAV, be cautious when the circuit has more than five nodes. The solution might be too complicated to understand.
 - The limitation does not come from the tool, but from the sophisticated algebraic solution itself.