AUTOMATIC SYNTHESIS OF ELECTRICAL CIRCUITS USING DEVELOPMENTAL GENETIC PROGRAMMING

PART 4 — NOVELTY-DRIVEN EVOLUTION

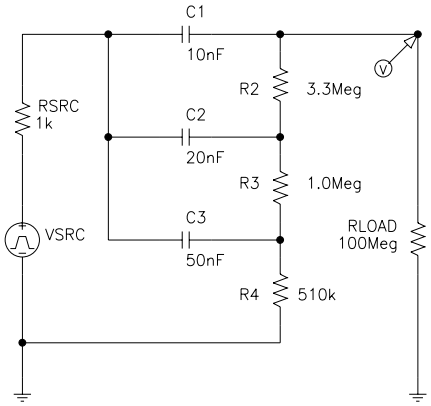
SEARCHING FOR THE IMPOSSIBLE

• In his regular column in *Electronic Design* in 1996, Robert Pease, the legendary analog design engineer and chief scientist at National Semiconductor, posed the question of whether it is possible to design an electrical circuit composed only of resistors and capacitors that delivers a gain of greater than one. Pease observed that most electrical engineers would say that it is "absurd" to try to build such a circuit using only resistors and capacitors. As Pease observed,

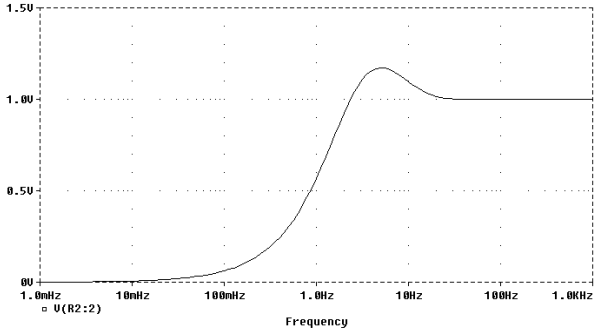
> **"Resistors are passive. How can you take a network of Rs and Cs and generate a gain of greater than one? That's impossible!"**

SEARCHING FOR THE IMPOSSIBLE — CONTINUED

PHILBRICK 1956 CIRCUIT

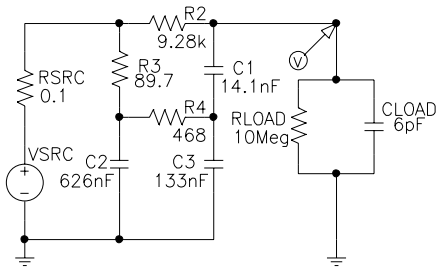


FREQUENCY DOMAIN BEHAVIOR

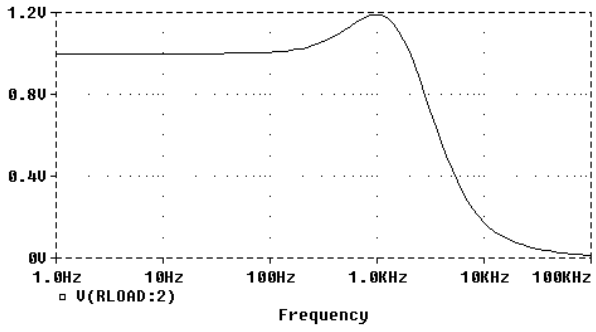


SEARCHING FOR THE IMPOSSIBLE — CONTINUED

EVOLVED RC CIRCUIT WITH GAIN GREATER THAN 1.0 — GENERATION 15

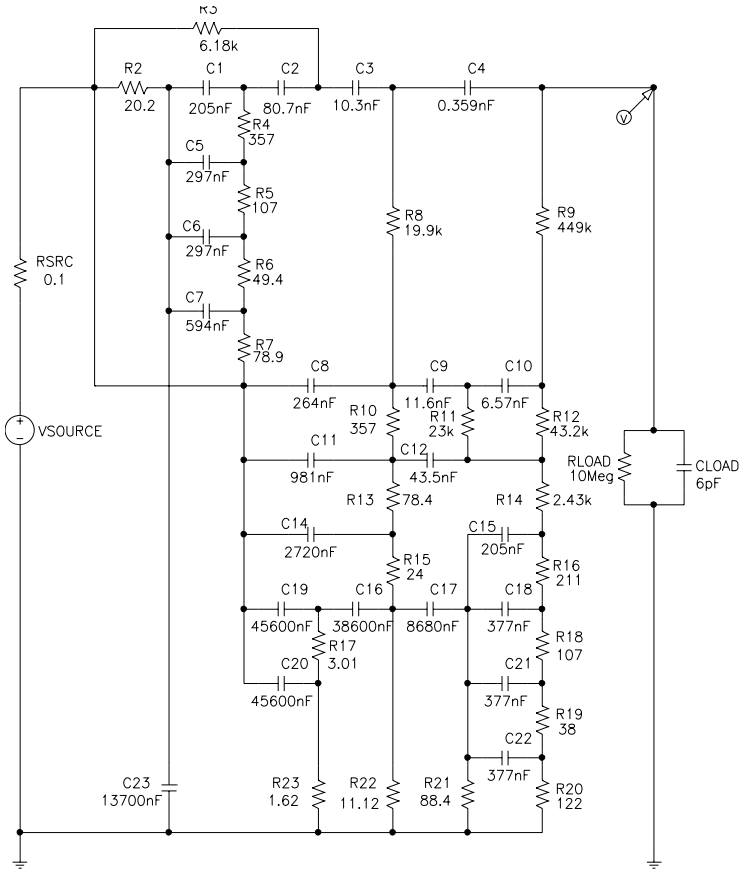


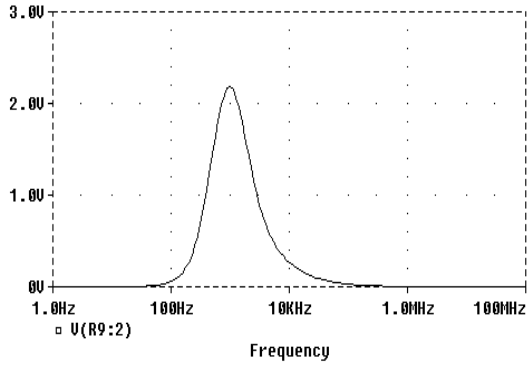
FREQUENCY DOMAIN BEHAVIOR



SEARCHING FOR THE IMPOSSIBLE — CONTINUED

GENERATION 927

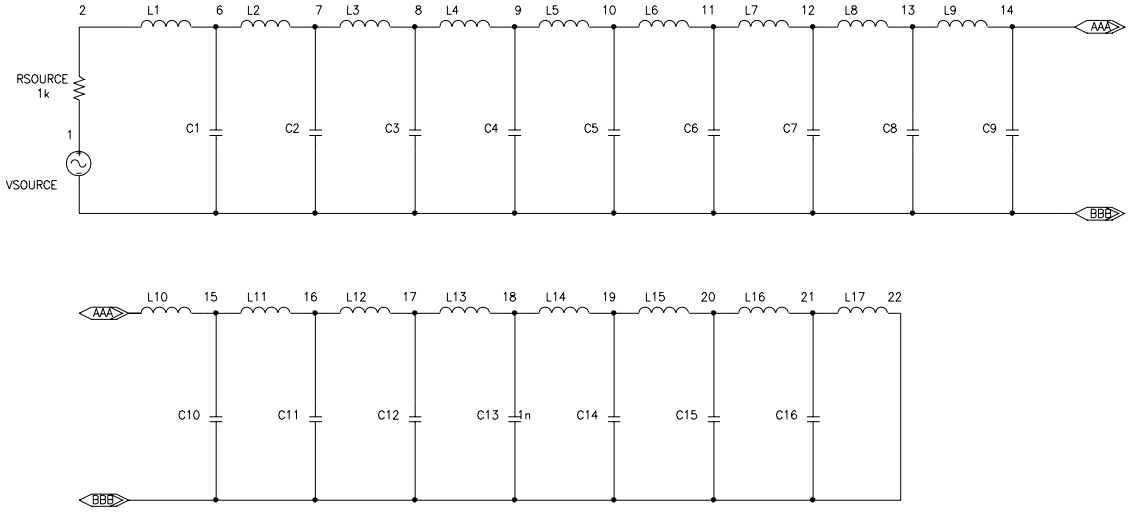




NOVELTY-DRIVEN FITNESS

- **Two factors.**
  - Circuit's behavior in the frequency domain
  - Largest number of nodes and edges (circuit components) of a subgraph of the given circuit that is isomorphic to a subgraph of a template representing the prior art Graph isomorphism algorithm with the cost function being based on the number of shared nodes and edges (instead of just the number of nodes).

PRIOR ART TEMPLATE

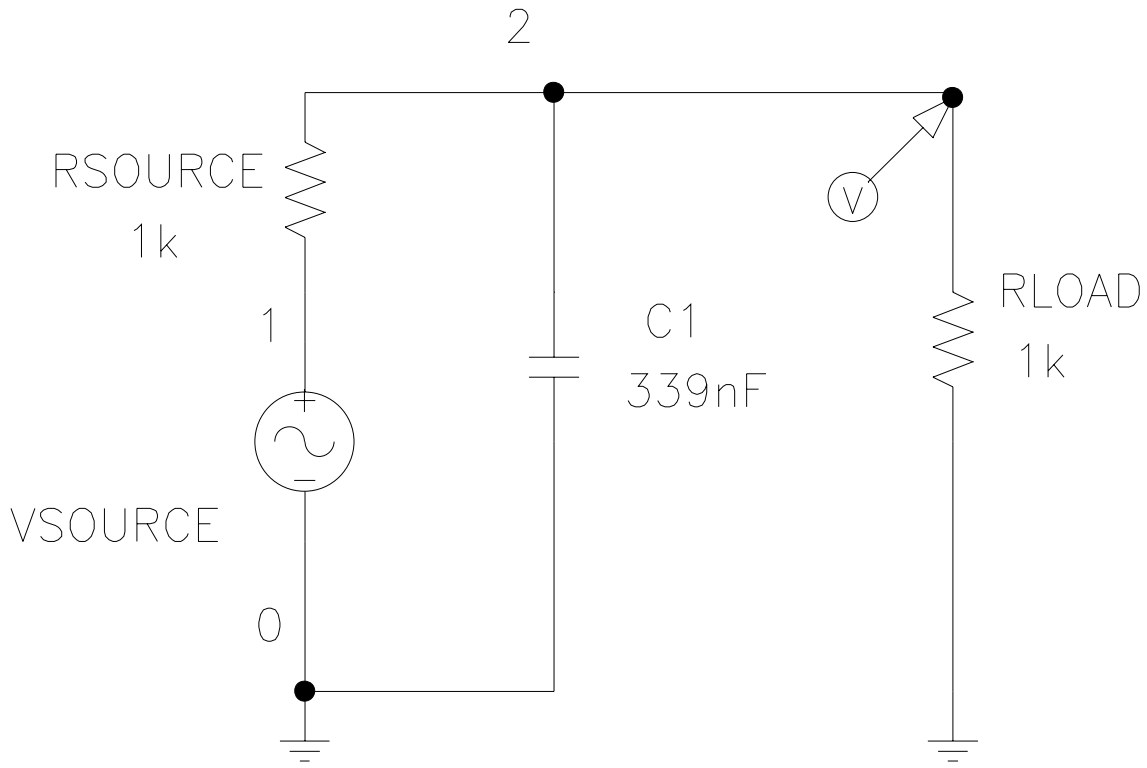


NOVELTY-DRIVEN FITNESS — CONTINUED

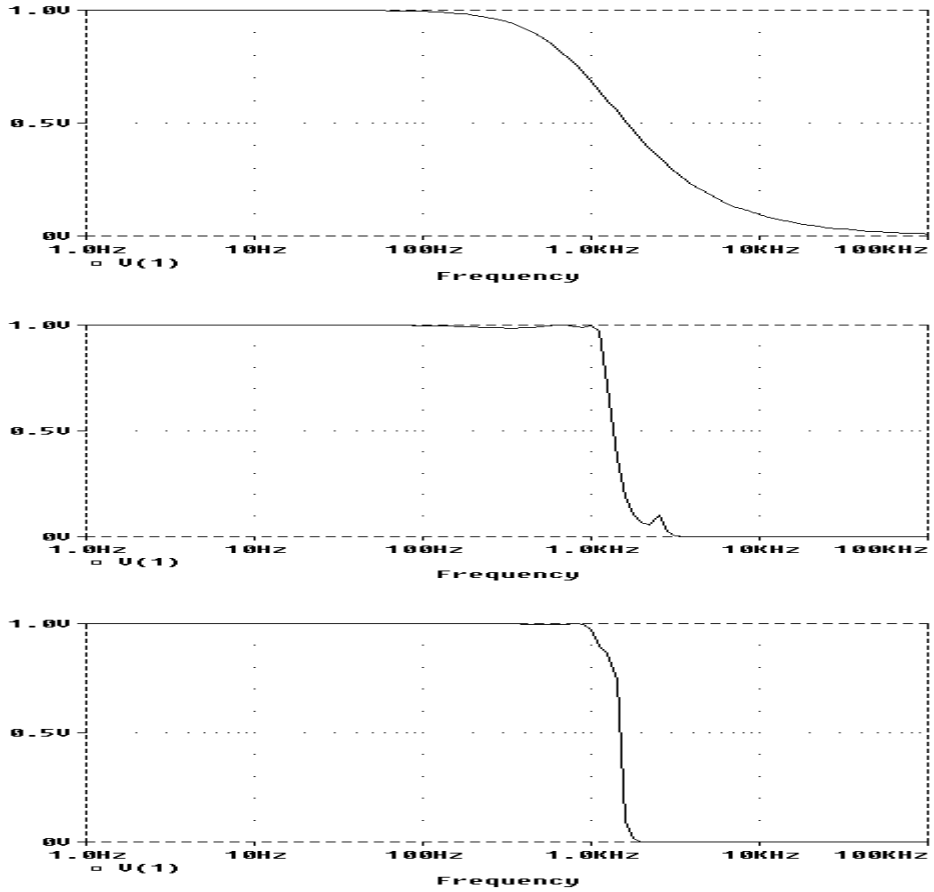
- **For circuits not scoring the maximum number (101) of hits, the fitness of a circuit is the product of the two factors.**
- **For circuits scoring 101 hits (100%-compliant individuals), fitness is the number of shared nodes and edges divided by 10,000.**

BEST CIRCUIT OF GENERATION 0

- **52 hits (out of 101).**
- **Overall fitness is 296.5 because the factor pertaining to this circuit's frequency response is 59.30 and because this circuit's isomorphism factor is 5.**

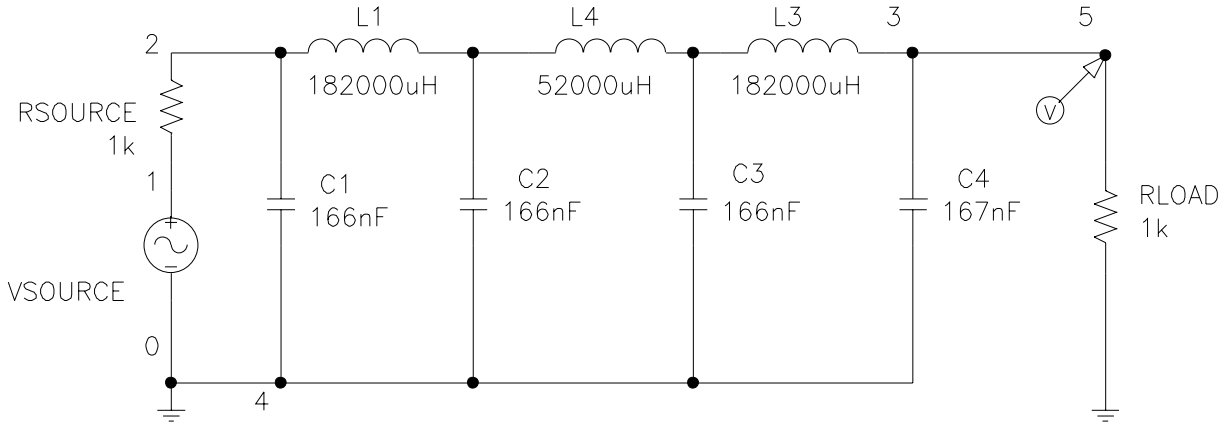


FREQUENCY DOMAIN BEHAVIOR OF BEST CIRCUITS FROM GENERATIONS 0, 16, AND SOLUTION NO. 8 (100%-COMPLIANT CIRCUIT WITH ONE FORM OF THE ELLIPTIC TOPOLOGY)



BEST-OF-GENERATION CIRCUIT FROM GENERATION 16

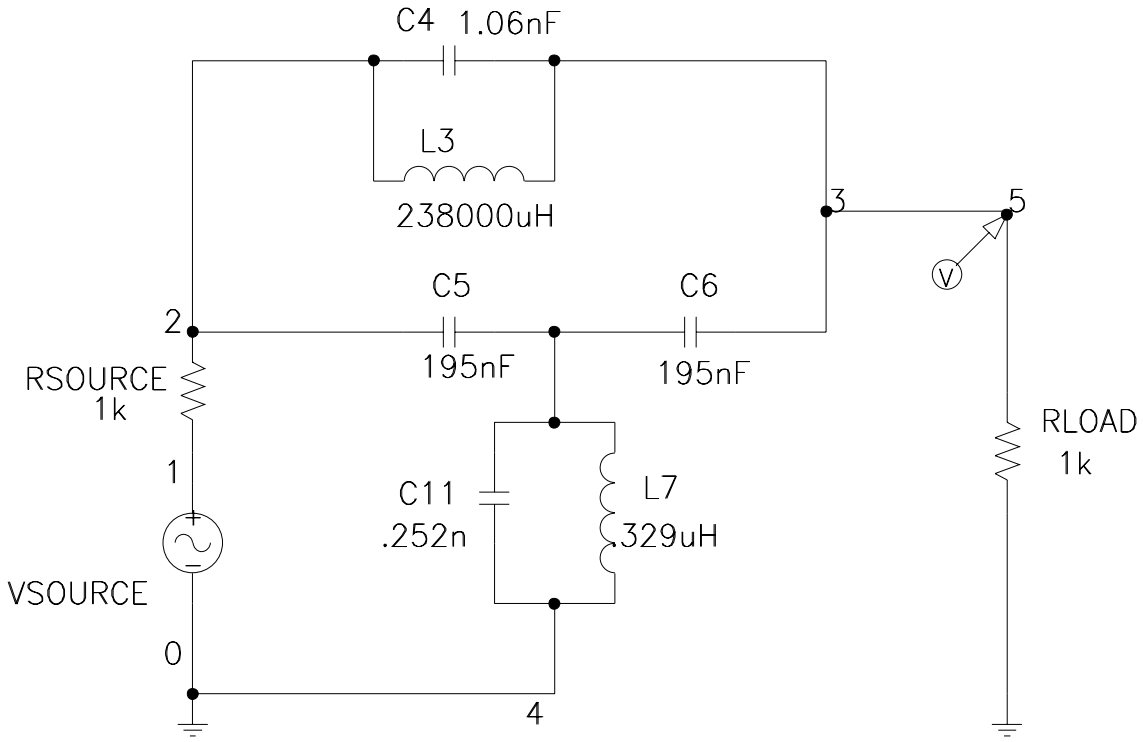
- **95 hits.**
- **Rediscovery of the Campbell ladder topology**
- **Overall fitness is 32.32 because the factor pertaining to this circuit's frequency response is 2.694 and this circuit's isomorphism factor is 12.**



TWO PACE-SETTING CIRCUITS FROM GENERATION 18 ILLUSTRATING THE COMPETITIVE TENSION BETWEEN THE TWO FACTORS OF THE FITNESS MEASURE

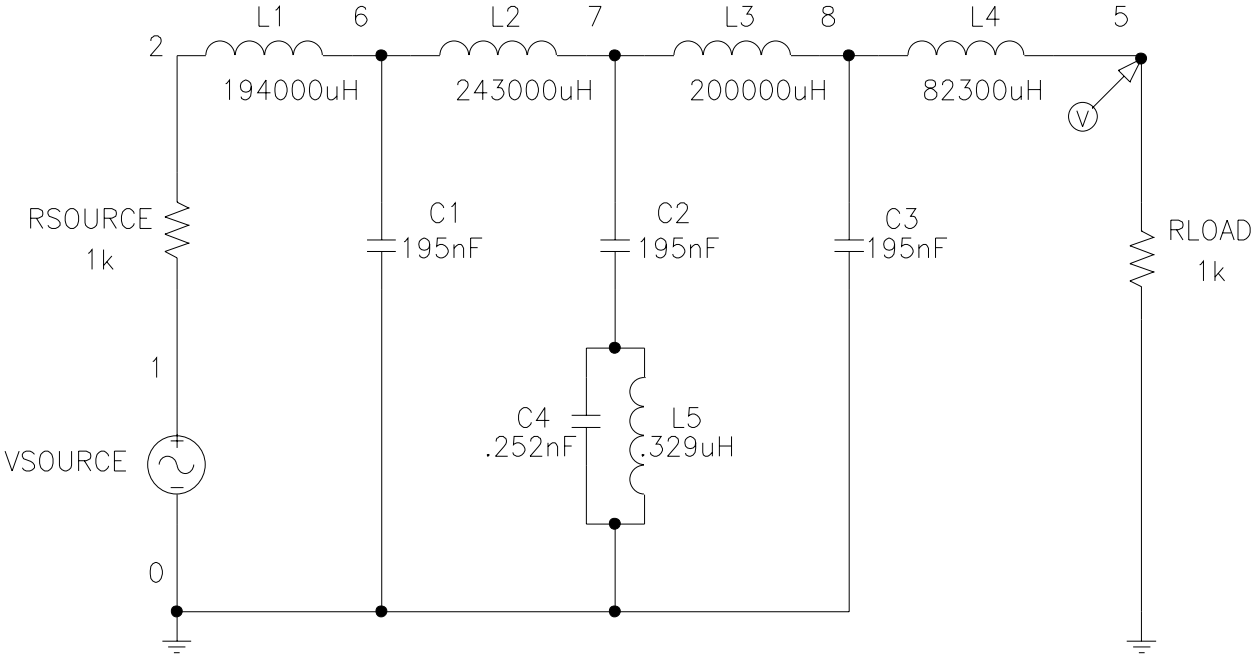
CIRCUIT A FROM GENERATION 18

- **Fitness is 30.585. The factor of the fitness measure pertaining to this circuit's frequency response is 6.117 and its isomorphism factor is only 5.**



CIRCUIT B FROM GENERATION 18

- **Five inductors and four capacitors**
- **Fitness is 11.556 because the factor pertaining to this circuit's frequency response is 0.7704 and this circuit's isomorphism factor is 15.**



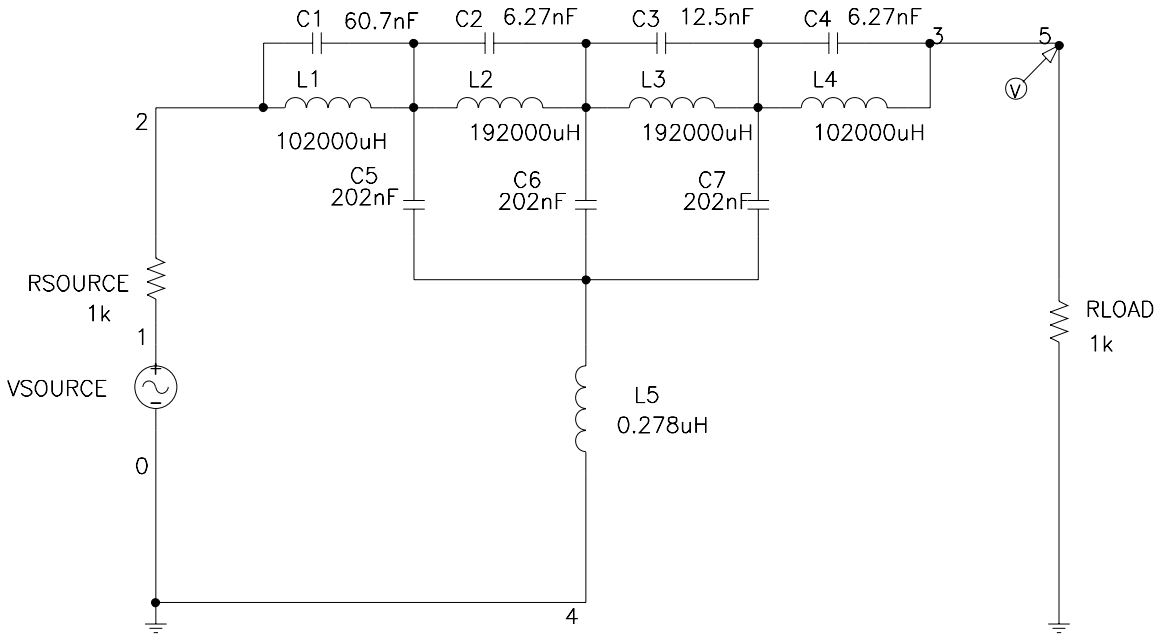
EXPLANATION OF ISOMORPHISM FACTOR OF 15 FOR CIRCUIT B FROM GENERATION 18

Node or edge of best circuit B	Node or edge of template
Node 0	Node0
VSOURCE	VSOURCE
Node 1	Node 1
RSOURCE	RSOURCE
Node 2	Node 2
L1	L1
C1	C1
Node 6	Node 6
L2	L2
Node 7	Node 7
L3	L3
Node 8	Node 8
C3	C3
L4	L4
Node5	Node 9

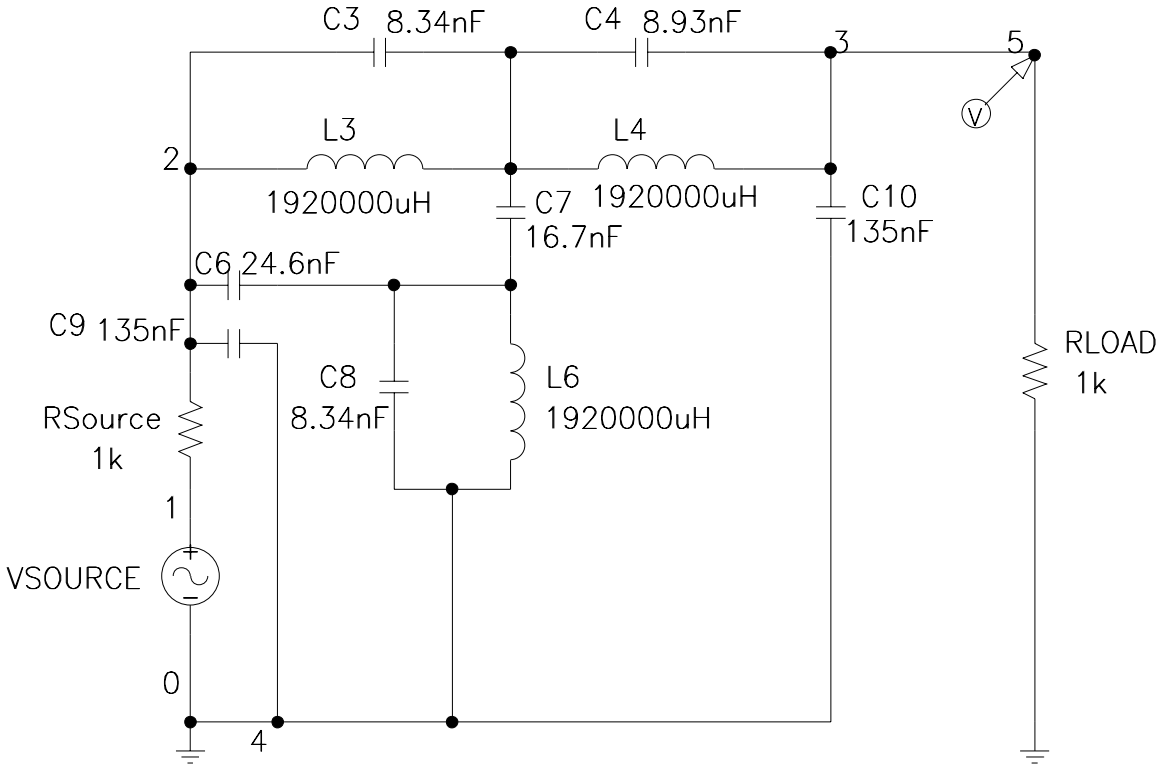
FITNESS OF EIGHT 100%-COMPLIANT CIRCUITS

Solution	Frequency factor	Isomorphism factor	Fitness
1	**0.051039**	**7**	**0.357273**
2	**0.117093**	**7**	**0.819651**
3	**0.103064**	**7**	**0.721448**
4	**0.161101**	**7**	**1.127707**
5	**0.044382**	**13**	**0.044382**
6	**0.133877**	**7**	**0.937139**
7	**0.059993**	**5**	**0.299965**
8	**0.062345**	**11**	**0.685795**

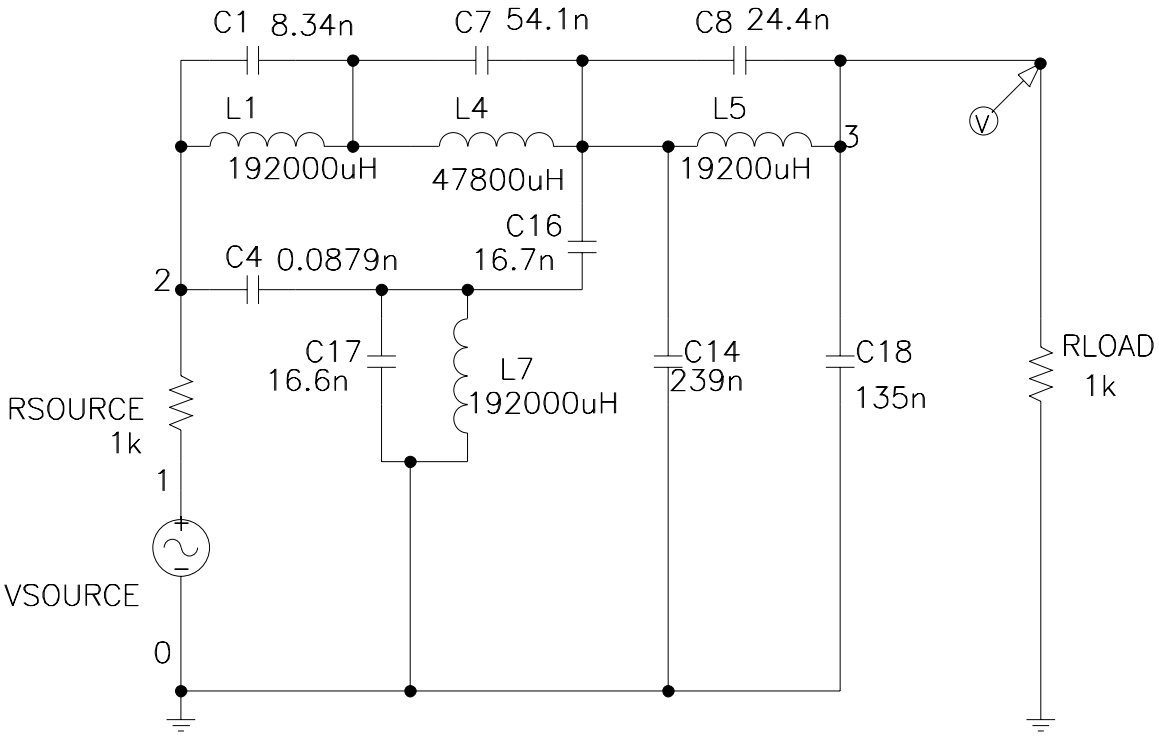
SOLUTION NO. 1



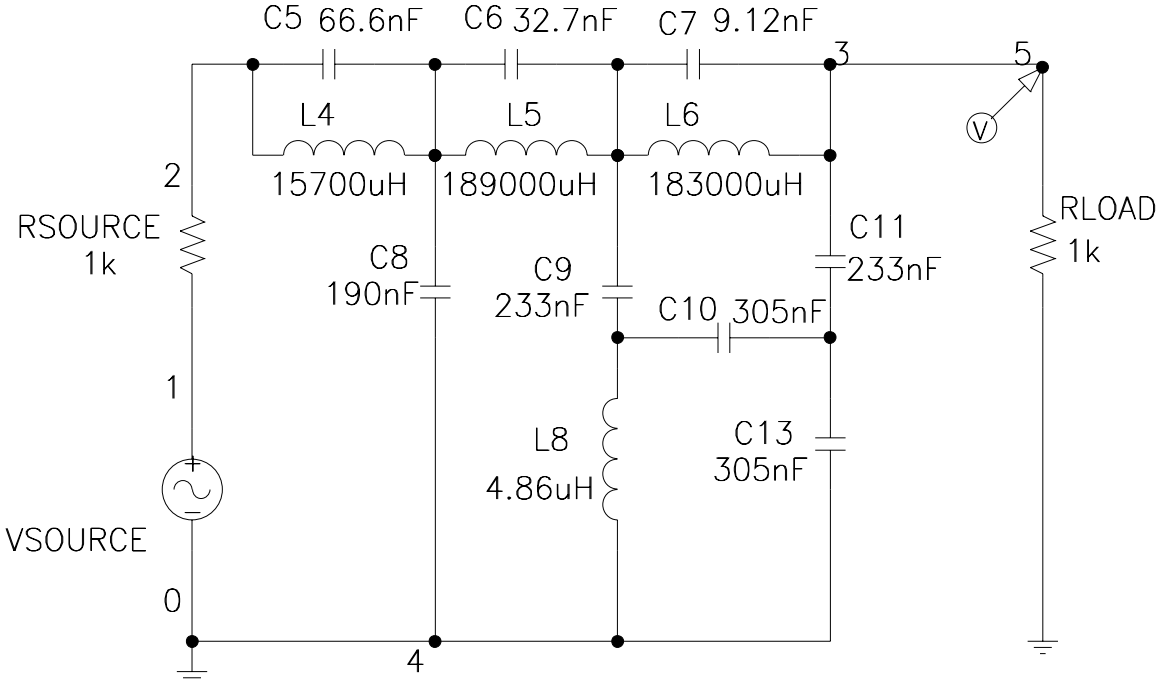
SOLUTION NO. 2



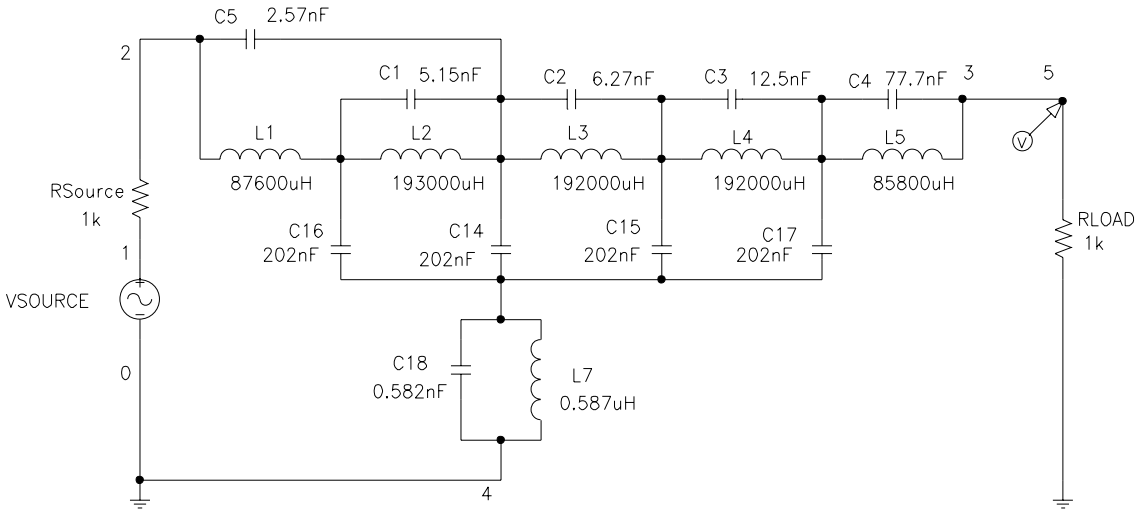
SOLUTION NO. 3



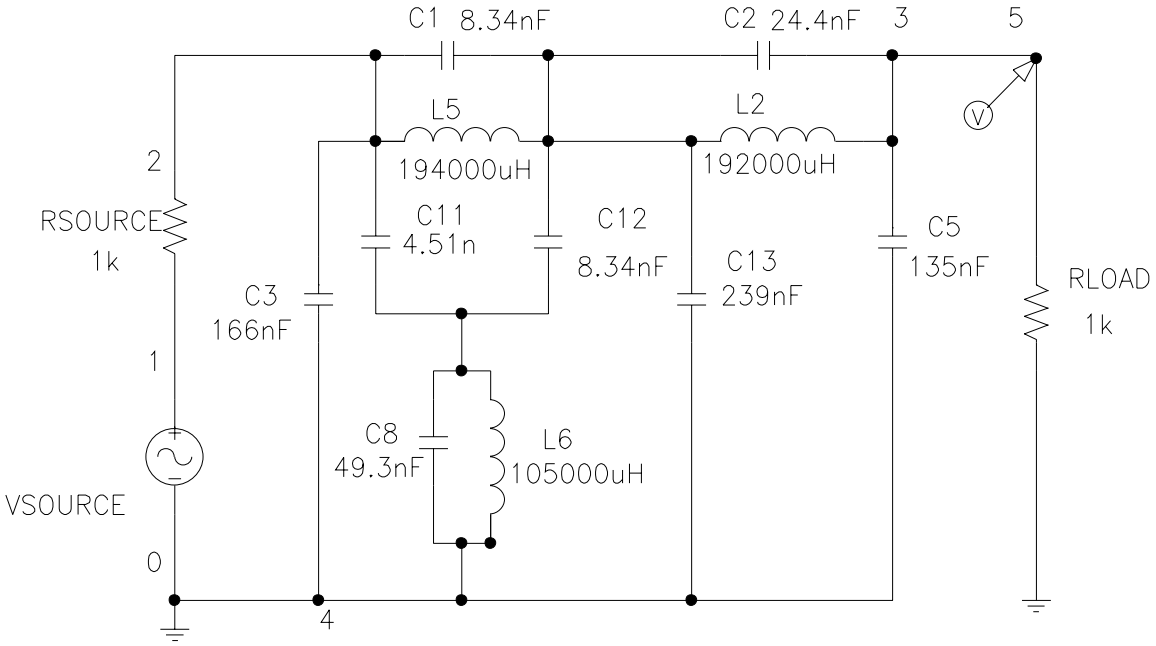
SOLUTION NO. 4



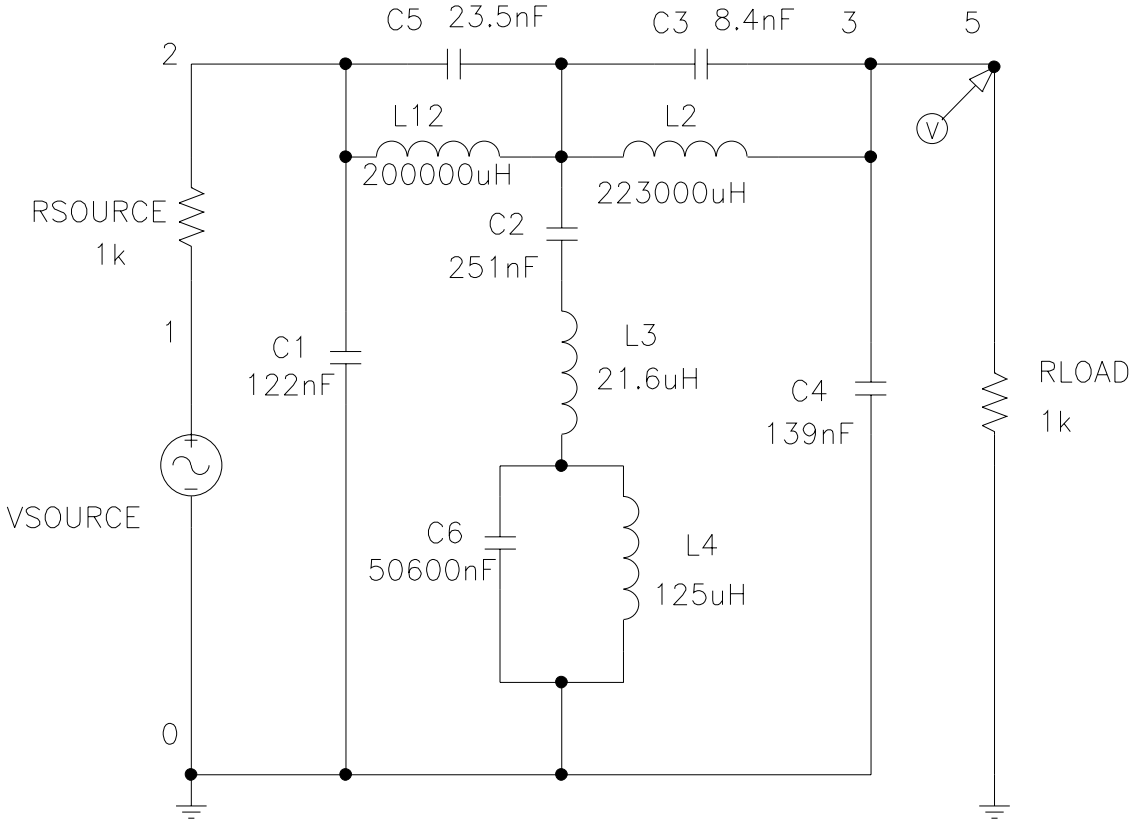
SOLUTION NO. 5



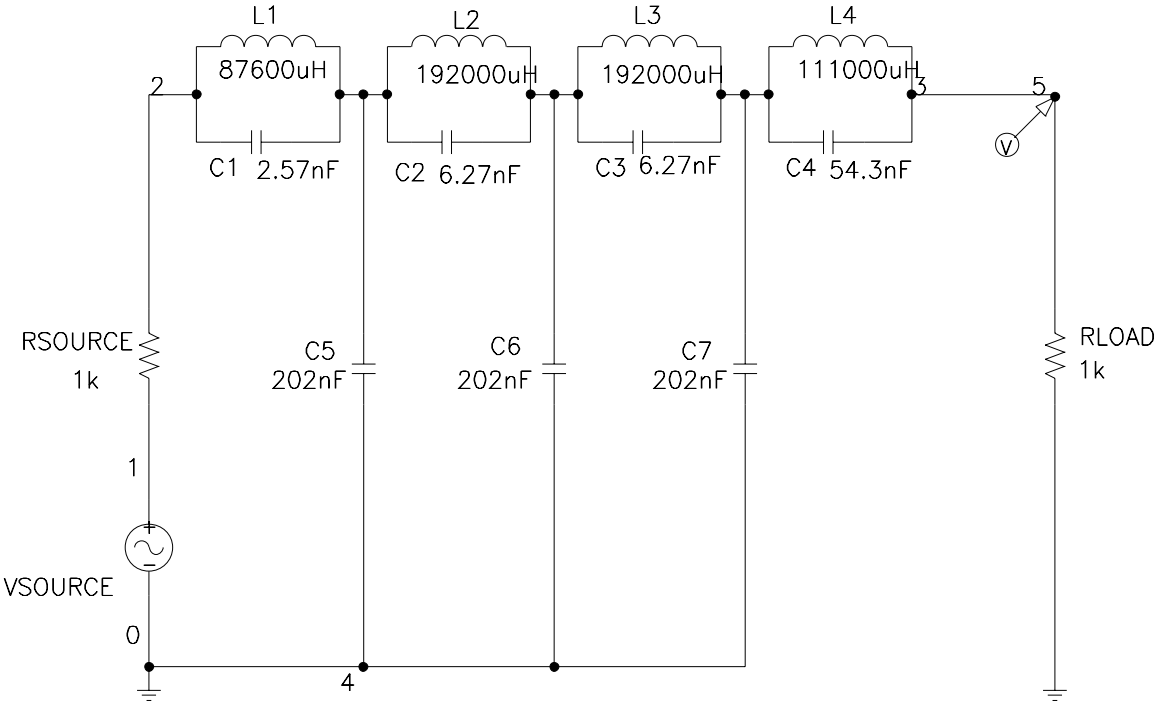
SOLUTION NO. 6



SOLUTION NO. 7

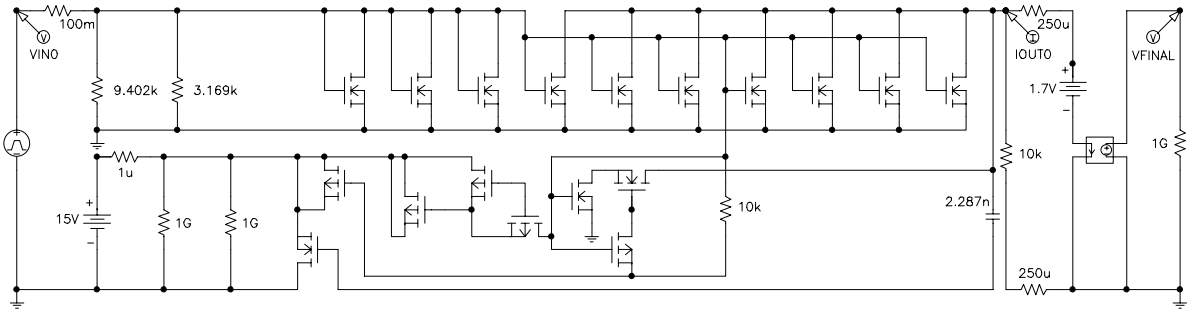


SOLUTION NO. 8



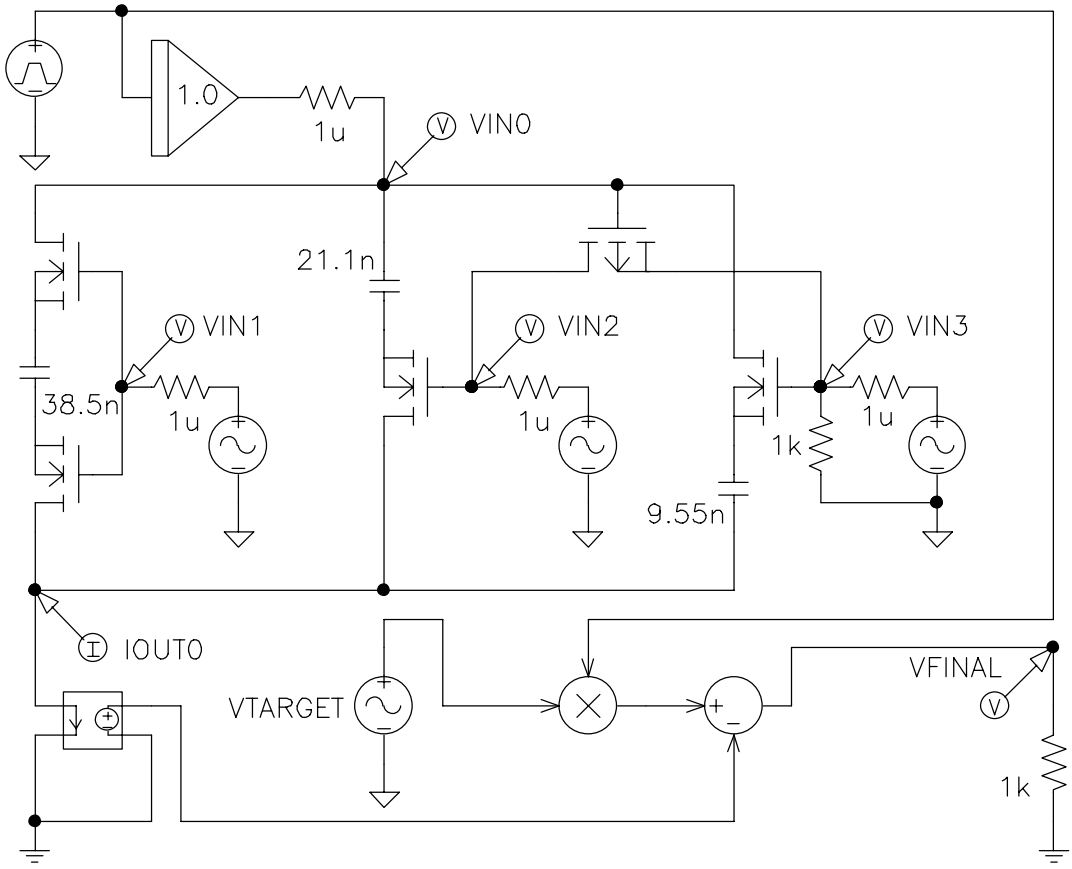
POST-2000 PATENTED INVENTIONS

BEST-OF-RUN HIGH CURRENT LOAD CIRCUIT FROM GENERATION 114



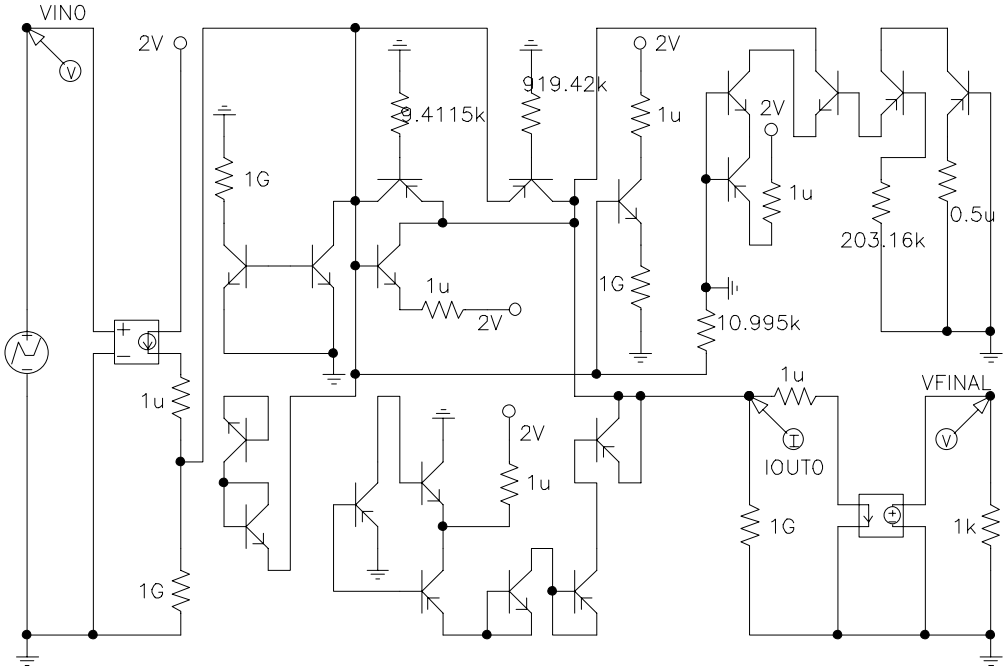
POST-2000 PATENTED INVENTIONS

SMALLEST COMPLIANT REGISTER-CONTROLLED CAPACITOR CIRCUIT FROM GENERATION 98



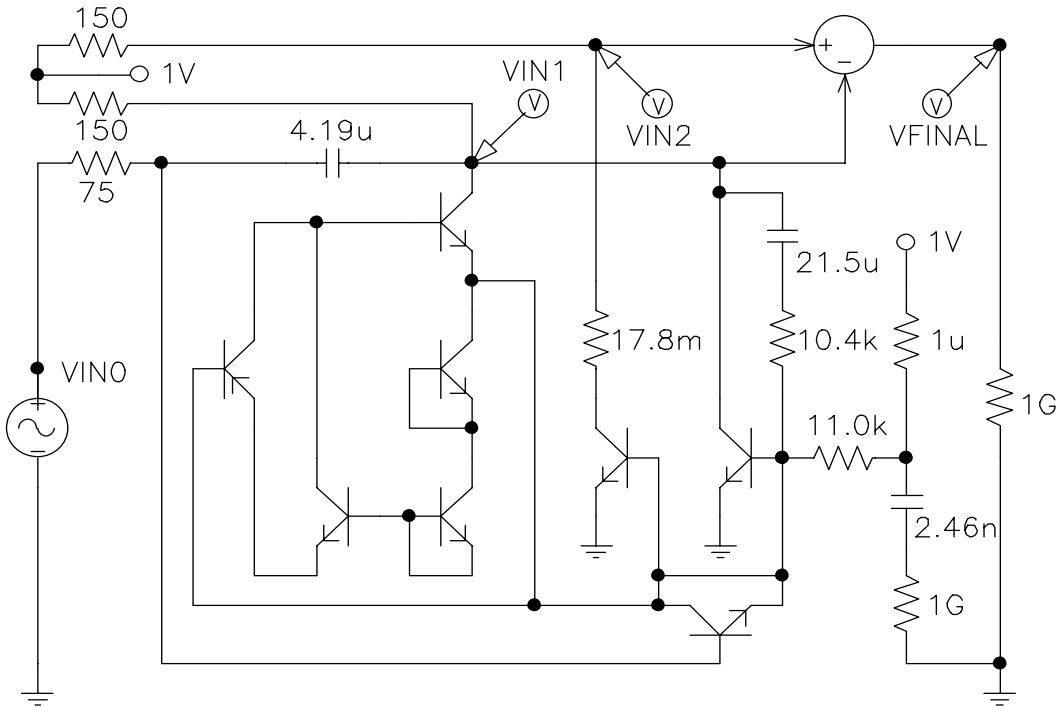
POST-2000 PATENTED INVENTIONS

BEST-OF-RUN CUBIC SIGNAL GENERATION CIRCUIT FROM GENERATION 182



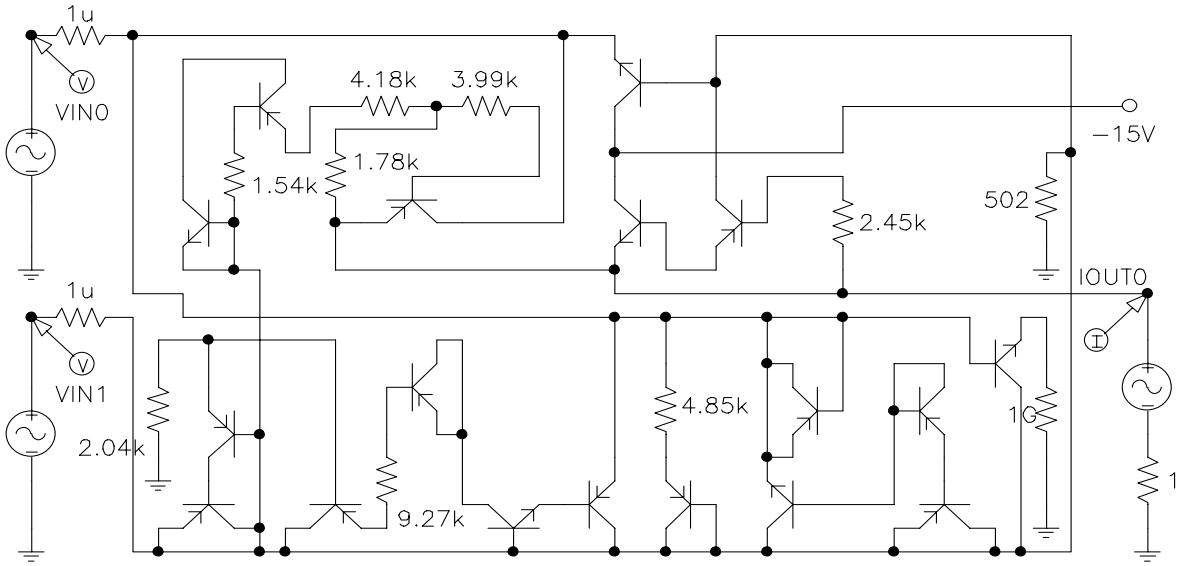
POST-2000 PATENTED INVENTIONS

BEST EVOLVED BALUN CIRCUIT FROM GENERATION 84



POST-2000 PATENTED INVENTIONS

BEST-OF-RUN VOLTAGE-CURRENT-CONVERSION CIRCUIT FROM GENERATION 109



PATENTS

"Patentability shall not be negatived by the manner in which the invention was made." 35 *United States Code* 103a

GENETIC PROGRAMMING AS AN INVENTION MACHINE