Reconfiguration of the Coupling Matrix

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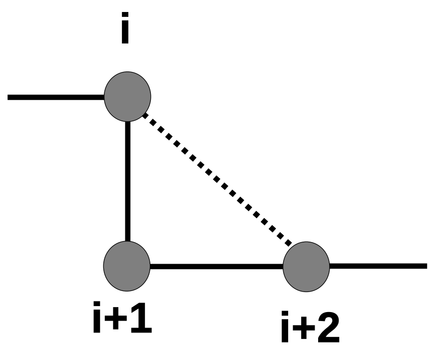
Topologies of practical interest

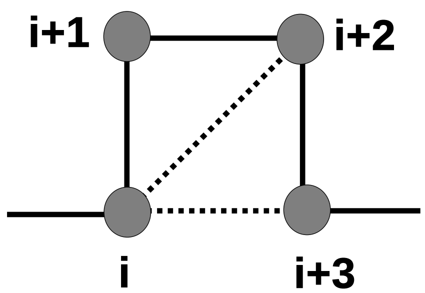
- Canonical prototype are rarely adopted in the practice because their topology poses often several problems, such as:
  - Too many couplings starting from load or source
  - Load and source at the same side
  - Each transmission zero may be influenced by several couplings
- Other topologies have been then devised, which overcome most of the above drawbacks and increase the flexibility of the filter design
- Being such topologies non-canonical, specific rules are needed for associating the number and type of transmission zeros to the prototype topology, in order to guarantee the feasibility

Cascaded-block topology

- The prototype is obtained by the cascade of basic building blocks, each associated which one or more imposed transmission zeros
- The main blocks are the *triplet* and *quadruplet*, the former extracting 1 (imaginary) transmission zero and the latter extracting 2 transmission zeros (imaginary or complex with opposite real part)



Triplet



Quadruplet

Sign of the couplings

- The couplings in a block are classified as *main couplings* (i,i+1) and *cross couplings* (the others)
- It is assumed that the sign of the main coupling is always positive (reference)
- The sign of cross couplings depends on the transmission zero to be extracted:

Triplet

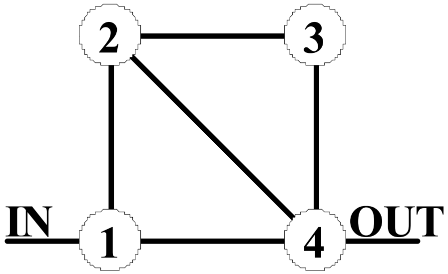
Transmission Zero	*Cross Coupling*
Imaginary positive	Positive
Imaginary negative	Negative

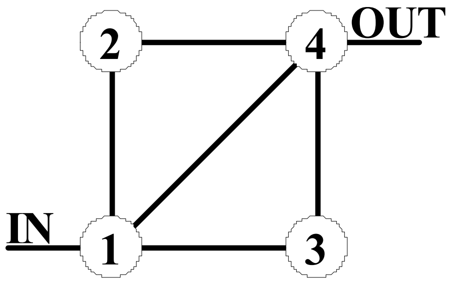
Sign of couplings (quadruplet)

Imposed Transmission zero	Cross coupling Horizontal	Cross coupling Oblique
Imaginary (both negative)	+	-
Imaginary (both positive)	+	+
Imaginary (One positive and one negative)	-	+/-
Complex (positive imaginary part)	+	+
Complex (negative imaginary part)	+	-

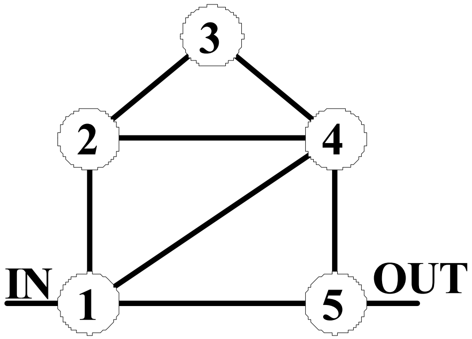
Other blocks of possible use

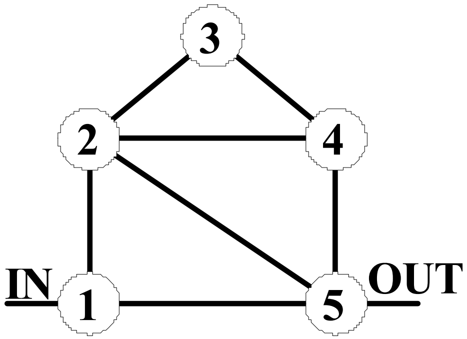
- Alternative quadruplets (2 zeros extracted):

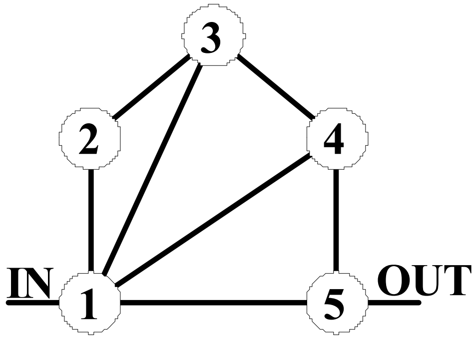




- Quintuplet (3 zeros extracted):

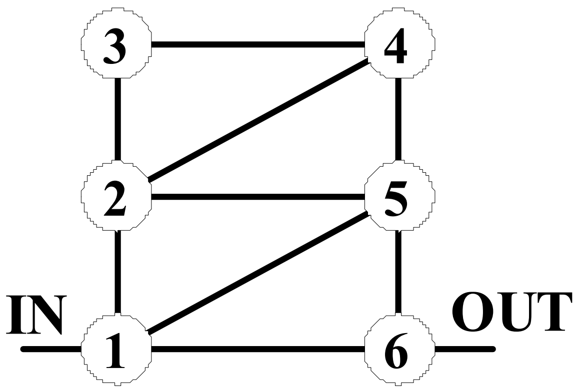


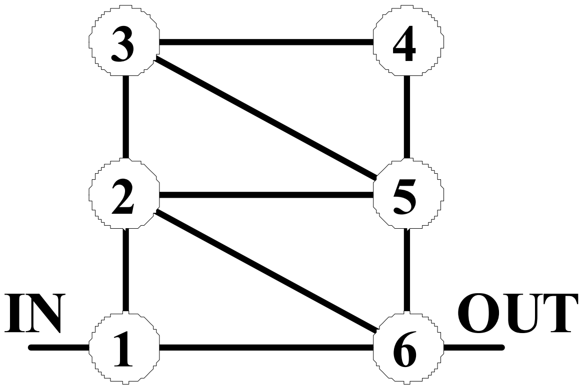


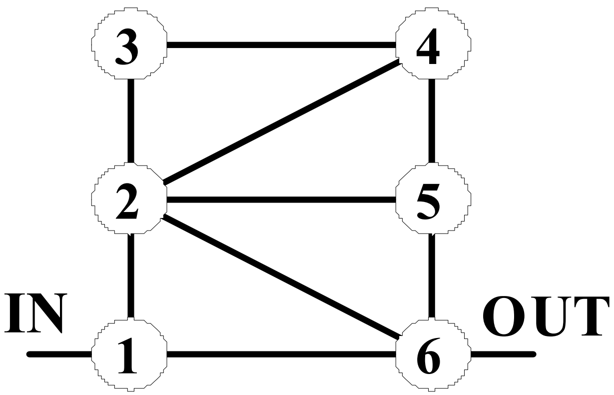


Other blocks

- Sestuplets (4 zeros extracted)

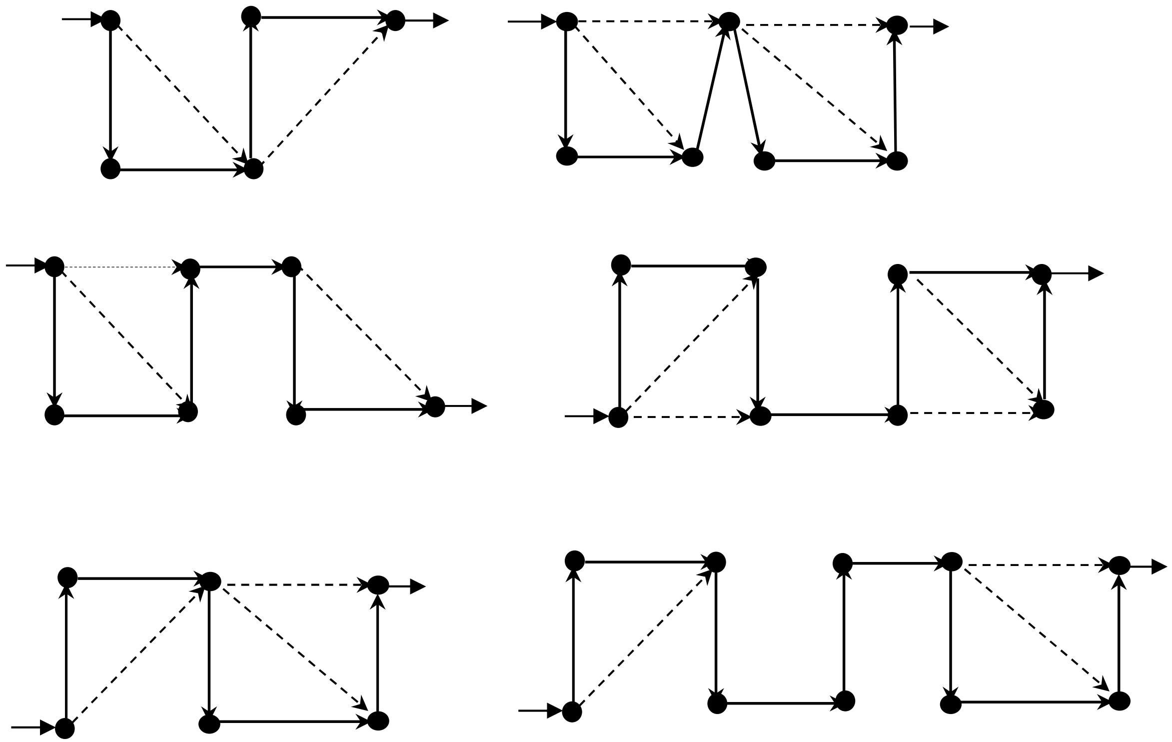


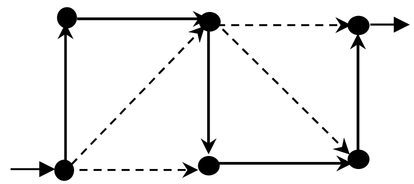




Rule for cascading the blocks

- Blocks can be directly cascaded but can share one node at maximum. They can by separated by one or more nodes.





ALLOWED

NOT ALLOWED

Drawback of the cascaded-block topology

- The number of transmission zeros which can be allocated is lower than the maximum allowed by the filter order:
  - in case source and load are not used for cross-couplings, $nz_{max} = n/2$ (n even), $nz_{max} = (n-1)/2$ (n odd)
  - if source and load are used for cross couplings, $nz_{max} = (n+2)/2$ (n even), $nz_{max} = (n+1)/2$ (n odd)

How to get the coupling matrix of the cascaded-block topology?

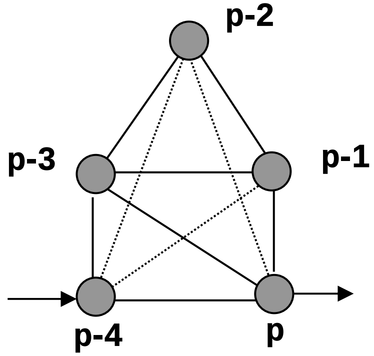
Reconfiguration of the coupling matrix of a canonical prototype with matrix rotations can be used.
But:

- The selected blocks must be able to extract the imposed transmission zeros
- The overall topology must obey the cascading rules
- The sequence of rotations could be obtained through optimizations of the rotation angles
- A far efficient procedure, which does not rely on optimization, is available in the literature :

S. Tamiazzo, G. Macchiarella *An Analytical Technique for the Synthesis of Cascaded N-Tuplets Cross-Coupled Resonators Microwave Filters Using Matrix Rotations* IEEE Trans. Microwave Theory Tech., Vol. MTT-53, n.5, May 2005, pp.1693-1698

Formation of quintuplets and box sections

Quintuplet (3 TZ)



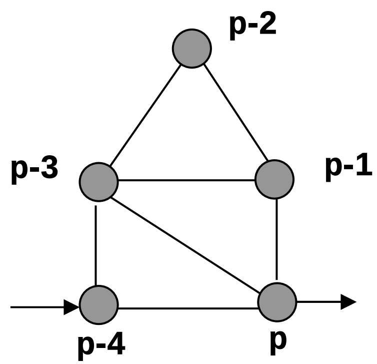
Lattice

pivot (*p-3, p-1*), $\theta_1 = -\tan^{-1}\left(M^{(k)}_{p-4,p-1} / M^{(k)}_{p-4,p-3}\right)$

pivot (*p-3, p-2*), $\theta_2 = -\tan^{-1}\left(M^{(k)}_{p-4,p-2} / M^{(k)}_{p-4,p-3}\right)$

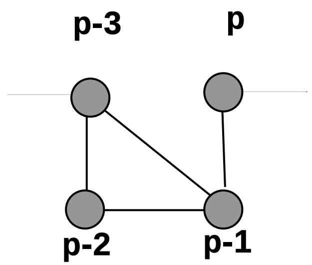
pivot (*p-2, p-1*), $\theta_3 = \tan^{-1}\left(M^{(k)}_{p-2,p} / M^{(k)}_{p-1,p}\right)$

Lattice is generated by extraction of 3 overlapping triplets



quintuplet

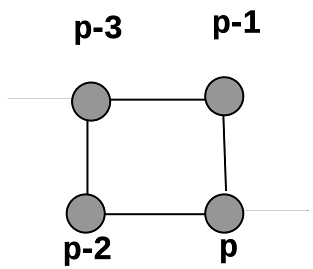
Box Section (1 TZ)



Triplet + 1 node

pivot (*p-2,p-1*)

$$\theta_r = 0.5 \cdot \tan^{-1}\left(2M^{(n-p+1)}_{p-2,p-1} \Big/ \left(M^{(n-p+1)}_{p-1,p-1} - M^{(n-p+1)}_{p-2,p-2}\right)\right)$$



Box section

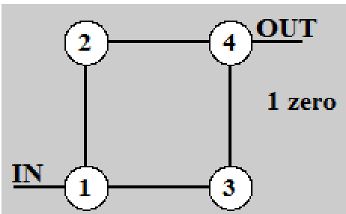
Extraction of complex TZ

Complex transmission zeros are typically employed for phase equalizing purposes. They appear in the filter transfer function as complex pair with opposite real part ($s_z = \pm f_{zr} + j f_{zi}$).

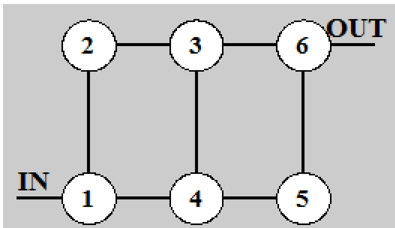
These zeros can be extracted, with the proposed method, as the pure imaginary ones. Actually, during the formation of a block allowing multiple zeros (as the quadruplet or the quintuplet), couplings with complex values may be obtained. However, when the final block is generated, all the elements in the coupling matrix become pure real (physical feasibility assured).

Other topologies of practical interest

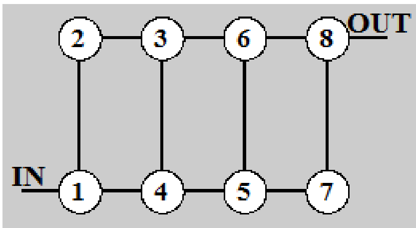
- In some cases it is requested that the selected topology <u>does not present oblique cross-couplings</u> even with asymmetric zeros. This can be achieved with two configurations proposed by Cameron:
  - <u>The box sections</u> (max n. of zeros: (n-2)/2))



1 zero

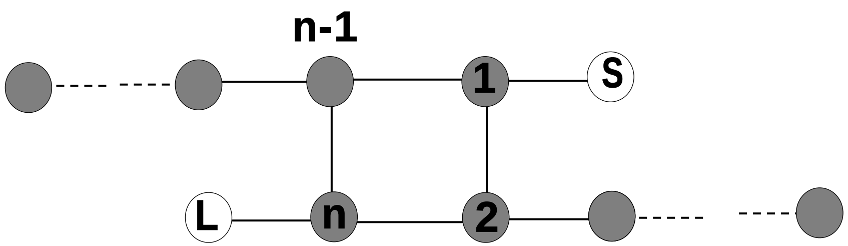


2 zeros



3 zeros

  - <u>The cul-de-sac</u> (max n. of zeros: (n-3))



Notes on box sections

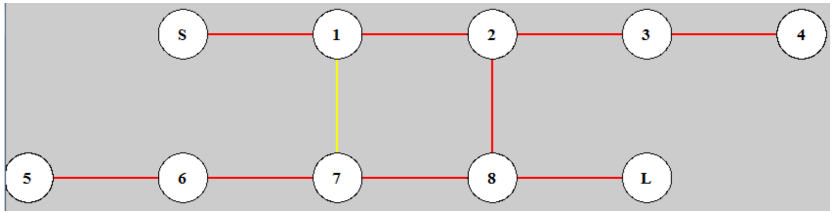
- The sequence of rotations, starting from the folded prototype, is in general obtained through optimization
- Can accommodate both imaginary and complex (pairs) zeros
- Transmission zeros change sign, if the sign of $M_{i,i}$ elements are reverted (with the other elements of M unchanged)
- Can be cascaded each others or with other blocks (sharing one node at maximum)
- For a given set of characteristic polynomials, there are several possible box section topologies differing for at least the sign of one element of M

Notes on cul-de-sac

- The sequence of requested rotations (starting from the transversal prototype) can be programmatically defined
- Can accommodate both imaginary and complex (pair) zeros
- It allows the absolute minimum number of couplings for a given number of transmission zeros
- An higher sensitivity to the couplings variation is obtained (with respect to other cascaded-blocks configurations)

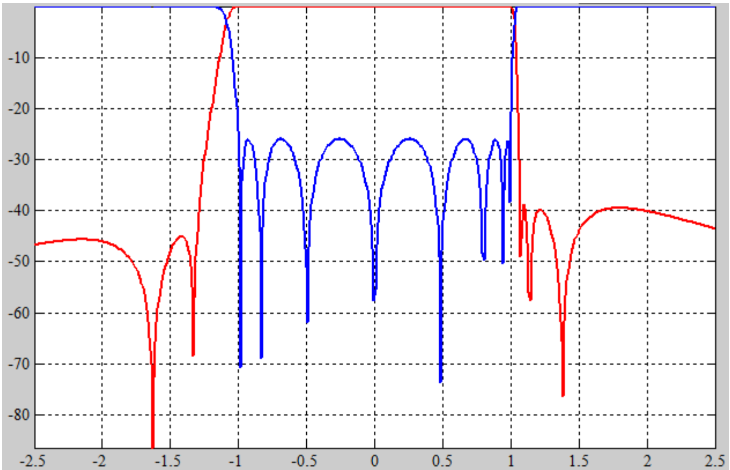
Example: Cul-de-sac (8+5)

n=8, RL=26, fz=1.075i, 1.138i, 1.38i, -1.33i, -1.63i



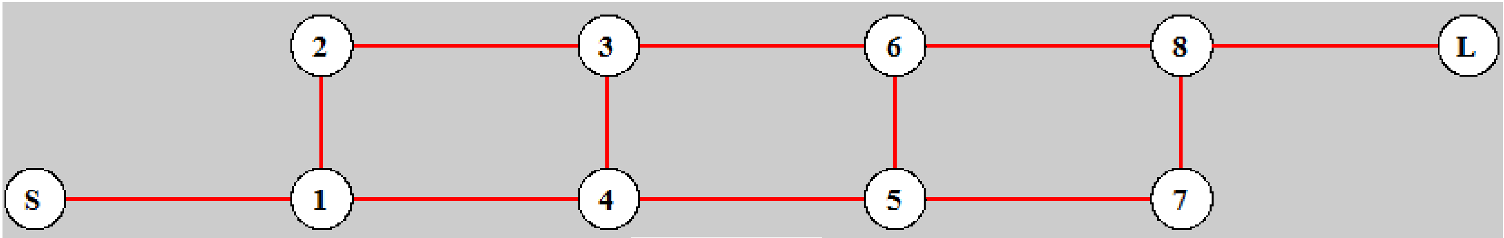
Coupling Matrix (Cul-de-Sac):

0	1.095	0	0	0	0	0	0	0	0
1.095	0.01256	0.665	0	0	0	0	-0.6215	0	0
0	0.665	-0.006616	0.4562	0	0	0	0	0.665	0
0	0	0.4562	0.07835	0.909	0	0	0	0	0
0	0	0	0.909	-0.009366	0	0	0	0	0
0	0	0	0	0	-0.9976	0.1211	0	0	0
0	0	0	0	0	0.1211	-0.03429	0.749	0	0
0	-0.6215	0	0	0	0	0.749	0.03601	0.6215	0
0	0	0.665	0	0	0	0	0.6215	0.01256	1.095
0	0	0	0	0	0	0	0	1.095	0



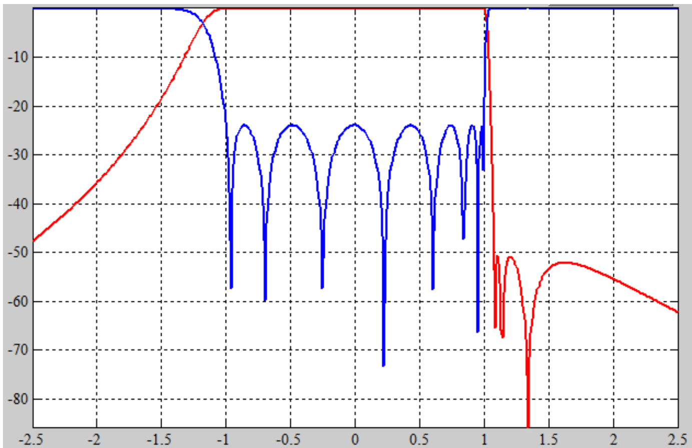
Example: box section (8+3)

n=8, RL=24, fz=1.084i, 1.138i, 1.34i

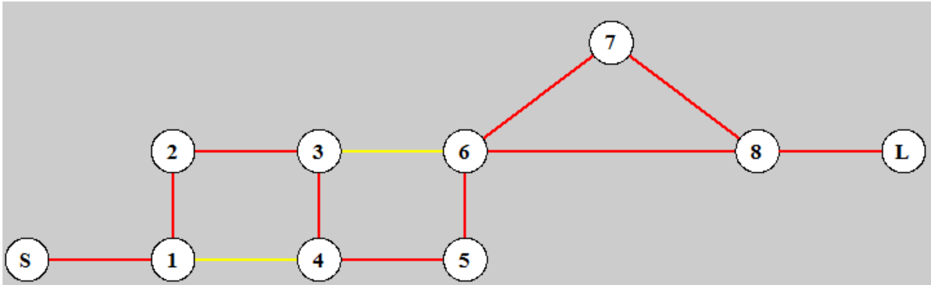


Coupling Matrix (cascaded blocks):

0	1.07	0	0	0	0	0	0	0	0
1.07	0.03396	0.1957	0	-0.8734	0	0	0	0	0
0	0.1957	-1.01	0.02262	0	0	0	0	0	0
0	0	0.02262	-0.8423	0.3072	0.2227	-0.07138	0	0	0
0	-0.8734	0	0.3072	0.09178	0.504	0	0	0	0
0	0	0	0.2227	0.504	0.1828	0.2914	0.4457	0	0
0	0	0	-0.07138	0	0.2914	-0.7103	0	-0.5565	0
0	0	0	0	0	0.4457	0	0.5114	0.701	0
0	0	0	0	0	0	-0.5565	0.701	0.03396	1.07
0	0	0	0	0	0	0	0	1.07	0

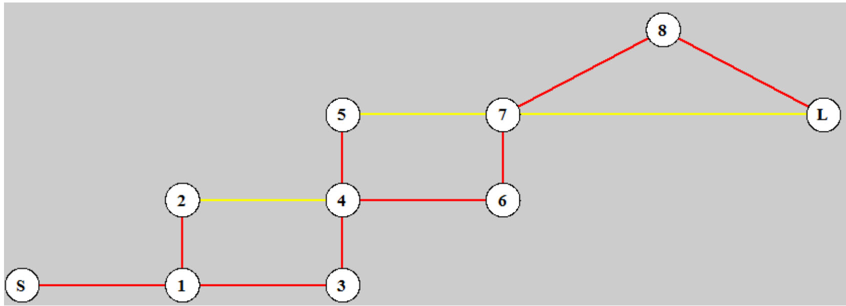


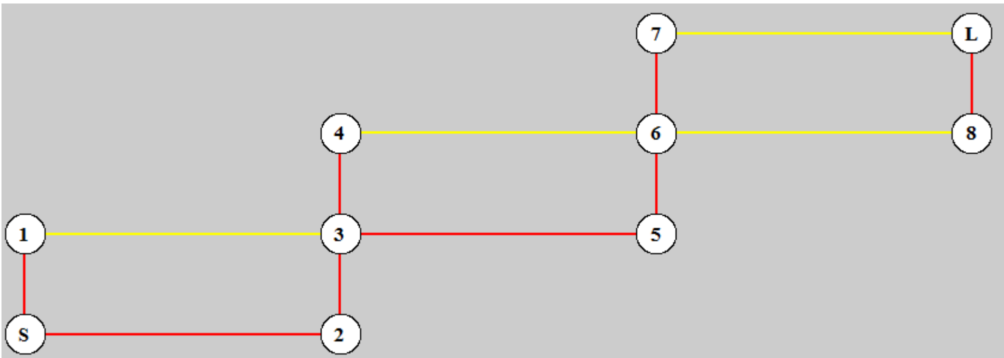
Example: cascaded box sections



Box-section 6 + Triplet

2 Box-sections 4 + Triplet





3 Box-sections 4