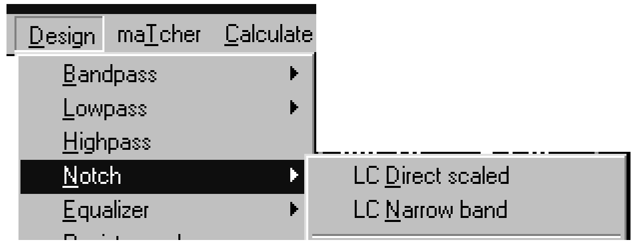
Lumped component band reject filters



Direct scaled notch

The direct scaled notch is the most basic notch circuit. It is a wide bandwidth circuit consisting of a highpass filter with the cutoff frequency equal to the desired width of the notch scaled up to the center frequency by resonating each element at Fo with a component of the opposite type.

```
                                   ┌─── L ───┐
                              ─────┤         ├─────
 ─────┬──── C ────┬─────        |  └─── C ───┘  |
      |           |             C               C
      L           L    ----->   |               |
 ─────┴───────────┴─────        L               L
                              ──┴───────────────┴──
```

As the width of the notch is reduced, the cutoff frequency of the lowpass filter becomes lower making its values larger. As the Fo of the notch becomes higher, the components necessary to resonate each element becomes smaller. These two factors conspire to make a narrow notch at a high frequency consist of a huge value resonated by a tiny one at every section.

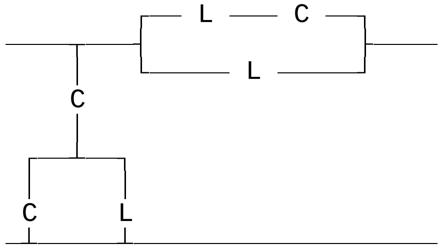
Narrow band L-C notch

The L-C narrow band notch module designs a notch filter that yields element values that are realizable down to bandwidths much narrower than are possible using the direct scaled method. The idea was proposed by Phillip R. Geffe in an article published in PROCEEDINGS OF THE IEEE INTERNATIONAL SYMPOSIUM ON CIRCUITS AND SYSTEMS (May 5-7, 1986).

The basic form of this notch filter circuit is derived from the combination of a narrow direct scaled notch and a lowpass filter of the same order and passband characteristics in such a way as to reduce the unreasonable parts value problem associated with the direct scaled circuit alone. The procedure is illustrated below for the case of a second order design:

```
      ┌─── L ───┐                                             ┌─── L ───┐
 ──┬──┤         ├──                        ─────┬────┬── L ───┤         ├────
   |  └─── C ───┘       ──┬── L ───             |    |        └─── C ───┘
   C                      |                     |    C
   |   -- plus -->        C        ----->       C    |
   L                    ──┴────────             |    L
 ──┴───────────────                        ─────┴────┴──────────────────────
```

The lowpass is simply inserted into the direct scaled notch, as shown above. A dipole transform is then applied generating the circuit shown to the right. By picking the cutoff frequency of the lowpass by means of an iteration, the value spread can be reduced. The passband will resemble that of the lowpass.



This implementation provides for any combination of three variations in the basic scheme described above.

1 - The all-pole lowpass and notch may also be replaced by an elliptic function notch and all-pole lowpass to improve the notch shape factor. The elliptic option has a somewhat wider parts value spread than the all-pole notch but is still useful. This choice is made from the reference values menu from the new design menu.

2 - The inserted lowpass filter may be replaced with a highpass filter. This will change the passband characteristics of the notch from that of a lowpass to a highpass. The choice of a highpass versus a lowpass passband will also allow the choice of which way the response of the notch will skew.

Passband type   (H=Hp L=Lp) L

3 - Two Hybrid options allows the addition of 1/4 wave series transmission lines between each "section".

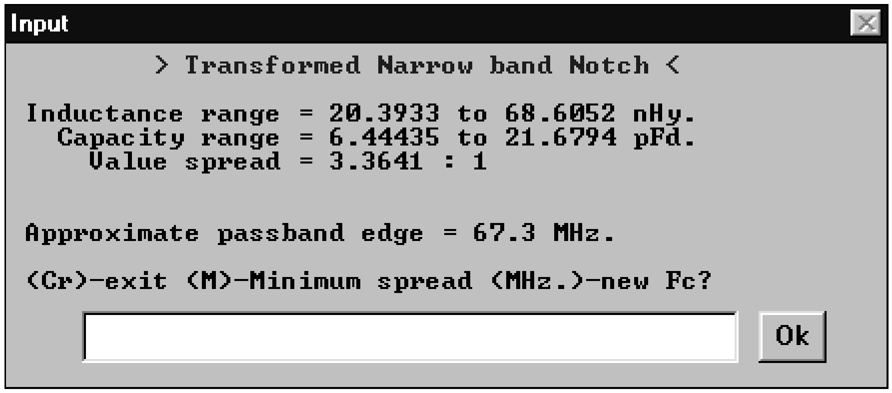
confIg: Ser Par hybrid: A B A

Below is the specifications for a practical 500 MHz notch having only a 4% relative width and a highpass passband.

```
File name = GEFFE1
Design = Narrow band notch
order N                        3
passband Ripple (0=Butt. dB) 0.05
Define pass / stop      (dB) 3
arithmetic Fo.          MHz. 500
Bandwidth               MHz. 20
design Zo.                   50
confIg: Ser Par  hybrid: A B P
tYpe: 1=sing 2=doub 3=ratio  2
Passband type    (H=Hp L=Lp) H
```

The [CALCULATE] button brings up this dialog box. The parts value spread and passband cutoff (of the inserted highpass) is displayed.

Because the passband limit is set by the cutoff of the lowpass or highpass filter used to transform it, you are given the option to change this parameter from that chosen by the iteration if the passband is unsatisfactory. With some designs, the passband upper limit may actually fall within the notch itself. If this happens, a warning will show indicating that the passband is limited. You may also return to the minimum spread iterated passband edge frequency using the (M) command.




```
 0  ┌─ Termination ─┐          50 Ohms
 1. ├─── L ┐       │       20.393 nHy.
 2  ├─── C ┴── L ──┤       6.4478 pFd.       68.605 nHy.
    │            ┌─┴─┐
 4. │            L   │       20.404 nHy.
    │            │   │
 5  │            C   C       6.4444 pFd.       21.679 pFd.
    │            └─┬─┘
 7. ├─── L ┐       │       20.393 nHy.
 8  ├─── C ┴── L ──┤       6.4478 pFd.       68.605 nHy.
10  └──── Source ──┘          50 Ohms
11  Fc = 499.9 MHz.
```

The "Hybrid" notch

The "Hybrid" notch simply adds 1/4 wave transmission lines between sections of the transformed notch causing each series section to be inverted to a parallel one. The procedure is a little different when designing the "Hybrid" type "A" notch because the passband shaping action of the transforming highpass or lowpass is masked by the series line inverters. In this case, the passband edge can be adjusted at will to get the L/C ratio you want without regard to the passband performance. The actual passband is affected mostly by the choice of highpass or lowpass transformation. Network analysis should be used to monitor the passband performance as the cutoff is changed however as it is also affected by the cutoff to some degree.

With a single change to the "confIg:" parameter:

confIg: Ser Par hybrid: A B A

The same design becomes:

```
 0  ┌─ Termination ─┐          50 Ohms
 1  │               │     Ref. freq. = 499.9 MHz.
 2. ├─── L ┐        │       20.393 nHy.
 3  ├─── C ┴── L ───┤       6.4478 pFd.       68.605 nHy.
    │               │
 5. ║ + + + + + + + ║          50 Ohms            90 Deg.
    │               │
 7. ├─── C ┐        │       8.1617 pFd.
 8  ├─── L ┴── L ───┤       16.111 nHy.       54.199 nHy.
    │               │
10. ║ + + + + + + + ║          50 Ohms            90 Deg.
    │               │
12. ├─── L ┐        │       20.393 nHy.
13  ├─── C ┴── L ───┤       6.4478 pFd.       68.605 nHy.
15  └──── Source ───┘          50 Ohms
16  Fc = 499.9 MHz.
```

Note that the transmission lines that form the inverters may consist of L-C 90 degree phase shifters taking the form of a 3 or 5 element artificial line or a lowpass filter. This makes the "Hybrid" notch configuration usable at extremely low frequencies with even lower parts value spread than the series or parallel input type.

Hybrid type "B" notch / bandpass

An additional type of notch is provided which is useful as an upper or lower sideband bandpass filter. This is done by setting the passband edge very close to the notch. Simply ignore the warning message telling you that the passband is restricted. This type filter uses the conversion lowpass (or highpass) cutoff frequency to control the skewing of the notch shape to form a bandpass with one very sharp skirt on one side of the filter. The L/C ratio is NOT affected by the lowpass cutoff frequency as it is with the other designs of this type, therefore, the minimum spread iteration is bypassed.

The sample design shown below has the conversion lowpass passband edge set at 2000 MHz with the notch at 2250 MHz. This would imply that the notch is outside the passband of the conversion lowpass. The actual passband limit will be quite different from the theoretical cutoff of the conversion lowpass. The actual passband limits must be determined by analysis.

```
File name = TYPE_B
Design = Narrow band notch
order N                       3
passband Ripple (0=Butt. dB) 0.05
Define pass / stop      (dB) 3
arithmetic Fo.          MHz. 2250
Bandwidth               MHz. 1200
design Zo.                    50
confIg: Ser Par hybrid: A B  B  <--- hybrid type "B"
tYpe: 1=sing 2=doub 3=ratio  2
Passband type    (H=Hp L=Lp) L
```

```
 0  ┌─ Termination ─┐            50 Ohms
 1  │               │        Ref. freq. = 2168.52 MHz.
 2  ├────── C ──────┤           2.1151 pFd.
 3. ├─── L ─── C ───┤             4.99 nHy.       1.0795 pFd.  Fx = 2168.5 MHz.
    │               │
 5. ║ + + + + + + + ║              50 Ohms            90 Deg.
    │               │
 7  ├────── C ──────┤           2.6773 pFd.
 8. ├─── L ─── C ───┤           3.9421 nHy.       1.3664 pFd.  Fx = 2168.5 MHz.
    │               │
10. ║ + + + + + + + ║              50 Ohms            90 Deg.
    │               │
12  ├────── C ──────┤           2.1151 pFd.
13. ├─── L ─── C ───┤             4.99 nHy.       1.0795 pFd.  Fx = 2168.5 MHz.
15  └──── Source ───┘              50 Ohms
16  Fc = 2168.5 MHz.
```

By programming the L-C to stub generator (from the Utilities menu) the transmission line version shown below can be made. By using the dipole transform feature ([MIS3:] Dipole) of the circuit editor and by controlling the L-C to stub generator from within the editor many variations are possible. The physical dimensions of the transmission lines may be monitored simultaneously for microstrip by doing the entire design from the mechanical dimensions and spacing menu (also from the Utilities menu).

The width of the notch will determine the impedance of the 90 Degree "z" stubs while the impedance of the open stubs forming the shunt capacitors can be set directly on the L-C to stub generator menu. The length is a function of the passband cutoff. A filter with a highpass response will have shorted stubs in place of the open stubs in this example.

```
  0  ┌─ Termination ─┐            50 Ohms
  1  │               │     Ref. freq. = 2168.52 MHz.
  2. ╞═════:   :═════╡            20 Ohms       29.958 Deg.
  4. ╞═════: z :═════╡        135.98 Ohms           90 Deg.
     │               │
  6. ║ + + + + + + + ║            50 Ohms           90 Deg.
     │               │
  8. ╞═════:   :═════╡            20 Ohms       36.114 Deg.
 10. ╞═════: z :═════╡        107.42 Ohms           90 Deg.
     │               │
 12. ║ + + + + + + + ║            50 Ohms           90 Deg.
     │               │
 14. ╞═════:   :═════╡            20 Ohms       29.958 Deg.
 16. ╞═════: z :═════╡        135.98 Ohms           90 Deg.
 18  └──── Source ───┘            50 Ohms
 19   Fc = 2168.5 MHz.
```

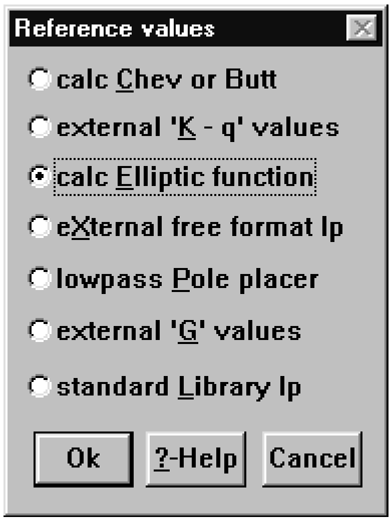
An implementation which allows all the line impedances to be specified can also be done by a different setting of the L-C to stub generator. Lumped component capacitors are required with this variation.

```
  0  ┌─ Termination ─┐            50 Ohms
  1  │               │     Ref. freq. = 2168.52 MHz.
  2. ╞═════:   :═════╡            20 Ohms       29.958 Deg.
  4. ╞═══:───:═══*─C─┤           100 Ohms       34.212 Deg.       1.0795 pFd.
     │               │
  7. ║ + + + + + + + ║            50 Ohms           90 Deg.
     │               │
  9. ╞═════:   :═════╡            20 Ohms       36.114 Deg.
 11. ╞═══:───:═══*─C─┤           100 Ohms       28.241 Deg.       1.3664 pFd.
     │               │
 14. ║ + + + + + + + ║            50 Ohms           90 Deg.
     │               │
 16. ╞═════:   :═════╡            20 Ohms       29.958 Deg.
 18. ╞═══:───:═══*─C─┤           100 Ohms       34.212 Deg.       1.0795 pFd.
 21  └──── Source ───┘            50 Ohms
 22   Fc = 2168.5 MHz.
```

Elliptic function narrow band notch

In addition to converting an all-pole direct scaled notch by inserting a highpass or lowpass, an elliptic function direct scaled notch may be converted in the same way. The resulting notch will not have equal rejection across the bottom as is normally the case with elliptic filters but rather has a "tilt" that must be accepted. This tilt will have opposite slope with a highpass passband than it will have with a lowpass passband. Below is an elliptic version of the same notch filter used as an example earlier in this section:

The choice of elliptic response is made on the reference values menu:




```
Design file: ELLIP-N
Design = Narrow band notch
order N                         3
passband Ripple (0=Butt. dB) 0.05
Define pass / stop      (dB) 3
required Attenuation    (dB) 30
arithmetic Fo.          MHz. 500
Bandwidth               MHz. 20
design Zo.                   50
confIg: Ser Par hybrid: A B  P
tYpe: 1=sing 2=doub 3="C"    2
Passband type    (H=Hp L=Lp) H
```

```
 0  ┌─ Termination ─┐              50 Ohms
 1. ├──── L ─┐     │          14.541 nHy.
 2  ├──── C ─┴─ L ─┤          8.5687 pFd.       63.425 nHy.
    │            ┌─┴─┐
 4. │            L   │        14.979 nHy.
    │            │   │
 5  │            C   C        8.2871 pFd.       40.988 pFd.
    │            └─┬─┘
    │            ┌─┴─┐
 7. │            L   │         12.83 nHy.
    │            │   │
 8  │            C   C        9.6425 pFd.       39.633 pFd.
    │            └─┬─┘
10. ├──── L ─┐     │          14.541 nHy.
11  ├──── C ─┴─ L ─┤          8.5687 pFd.       63.425 nHy.
13  └───── Source ─┘             50 Ohms
14   Fc = 499.9 MHz.
```

Note that the "hybrid A or B" topology is also available for elliptic notch filters. Below is the same filter done using the type "A" confIg:

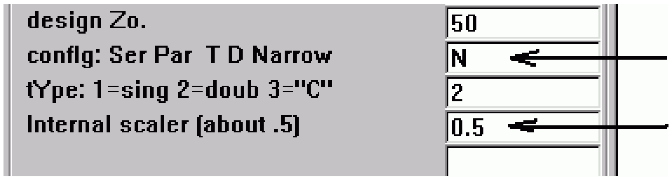
```
  0 ┌─ Termination ─┐          50 Ohms
  1 │               │      Ref. freq. = 499.9 MHz.
  2.├─── L ┐        │         14.541 nHy.
  3 ├─── C ┴── L ───┤         8.5687 pFd.       63.425 nHy.
    │               │
  5.║ + + + + + + + ║          50 Ohms             90 Deg.
  7.├─── L ┐        │         20.718 nHy.
  8 ├─── C ┴── L ───┤         5.9915 pFd.       102.47 nHy.
 10.├─── L ┐        │         24.106 nHy.
 11 ├─── C ┴── L ───┤          5.132 pFd.       99.082 nHy.
    │               │
 13.║ + + + + + + + ║          50 Ohms             90 Deg.
 15.├─── L ┐        │         14.541 nHy.
 16 ├─── C ┴── L ───┤         8.5687 pFd.       63.425 nHy.
 18 └──── Source ───┘          50 Ohms
 19  Fc = 499.9 MHz.
```

Dual dipole transformed narrow notch

For elliptic notch filters that are somewhat wider than those described for the Geffe transformation a double dipole transformation can be applied. The example below shows the element values for a direct scaled notch 10% wide. The inductor at branch 6 is large but manageable. The elements at branches 3 and 4 however are not. By applying a dipole transformation on the parts at branches 3,4 and 5, then splitting out one of the capacitors to make two, a second dipole transformation can be done to actually force the inductor at branch 4 to be whatever value you like.

```
Design file: NOTCH2 ... Design parameters
Design = Basic direct scaled notch
order N                         3
passband Ripple (0=Butt. dB) 0.05
Define pass / stop      (dB) 1
required Attenuation    (dB) 40
arithmetic Fo.          MHz. 500
Bandwidth               MHz. 50
design Zo.                   50
confIg: Ser Par  T D Narrow  T
tYpe: 1=sing 2=doub 3="C"    2


Date / time = Wed May 24 17:57:22 2006
Design file: NOTCH2 ... Schematic diagram
  0 ┌─ Termination ─┐          50 Ohms
    │             ┌─┴─┐
  1.│             C   L       58.926 pFd.   1.7238 nHy.  Fx = 499.37 MHz.
    │             └─┬─┘
  3.├─ C ┐          │         1080.9 pFd.
  4 ├─ L ┴── C ─ L ─┤       0.093973 nHy.  0.86159 pFd.    117.89 nHy.
    │             ┌─┴─┐
  7.│             C   L       58.926 pFd.   1.7238 nHy.  Fx = 499.37 MHz.
    │             └─┬─┘
  9 └──── Source ───┘          50 Ohms
 10  Fc = 499.37 MHz.
```



So that the value of the second inductor can be controlled an additional parameter will appear when the “config:” parameter is set to “N”. This will sets the ratio of the second inductor to the large value that appears at branch 6 in the direct scaled network. The normal value for this inductor is about .5. Smaller values will allow the associated capacitors to be come larger.

Here is the resulting filter:

```
Design file: NOTCH2 ... Schematic diagram
  0  ┌─ Termination ─┐            50 Ohms
     │               │
  1. │             C   L     58.926 pFd.       1.7238 nHy.  Fx = 499.37 MHz.
     │               │
  3. ├─ L ─┐          │     58.946 nHy.
  4  ├─ C ─┴─ C ┐     │     1.6902 pFd.     0.034401 pFd.
  6  ├──── C ───┘ L ─┤    0.82719 pFd.       117.89 nHy.
     │               │
  8. │             C   L     58.926 pFd.       1.7238 nHy.  Fx = 499.37 MHz.
     │               │
 10  └──── Source ───┘            50 Ohms
 11   Fc = 499.37 MHz.
```

The capacitor at branch 5 is very small but is not critical. Reducing the scale factor to .1 results in these values:

```
Design file: NOTCH2 ... Schematic diagram
  0  ┌─ Termination ─┐            50 Ohms
     │               │
  1. │             C   L     58.926 pFd.       1.7238 nHy.  Fx = 499.37 MHz.
     │               │
  3. ├─ L ─┐          │     11.789 nHy.
  4  ├─ C ─┴─ C ┐     │     8.5459 pFd.     0.076924 pFd.
  6  ├──── C ───┘ L ─┤    0.78467 pFd.       117.89 nHy.
     │               │
  8. │             C   L     58.926 pFd.       1.7238 nHy.  Fx = 499.37 MHz.
     │               │
 10  └──── Source ───┘            50 Ohms
 11   Fc = 499.37 MHz.
```