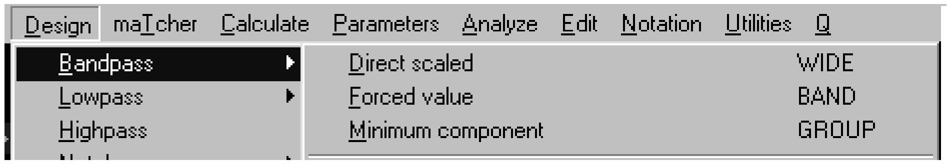
Direct scaled bandpass filters



WIDE BAND GROUP

Direct scaled

The direct scaled filter is the basis for most of the Chebyshev and elliptic function filters designed by the system. Even the narrow band filters are initially direct scaled designs with impedance inverters added. Each element of a reference lowpass is scaled into a specific bandpass section type. The notch sections will be scaled in one of two ways depending on the setting of the (*) confIg: option selected on the parameters menu. The reference lowpass can be calculated internally or it can be provided in the form of normalized "G" values, "k & q" values or as a "free format" external lowpass. The scaling of the reference lowpass to a bandpass is done like this:

```
REFERENCE LOWPASS                    FINAL BANDPASS

**** Using S-Series or P-Parallel configuration:
Series trap            ---->    Two series traps, one in each stopband
Parallel trap          ---->    Two shunt traps, one in each stopband
Series inductor        ---->    Series tuned section
Capacitor to ground    ---->    Parallel tuned section
```

```
0  ┌─ Termination ─┐
1  ├────── C ──────┤
   │               │
2  │               L
   │               │
3. ├── C ── L ─────┤
   │               │
   │              ┌┴─┐
5. │              C  L
   │              └┬─┘
7  └──── Source ───┘
8  Fc = 1 Rad.
```

---->

```
0   ┌─ Termination ─┐
1   ├────── C ──────┤
2   ├────── L ──────┤
3   │               C
    │               │
4   │               L
    │               │
5.  ├─── C ── L ────┤
7.  ├─── C ── L ────┤
    │               │
    │              ┌┴─┐
9.  │              L  C
    │              └┬─┘
    │              ┌┴─┐
11. │              L  C
    │              └┬─┘
13  └──── Source ───┘
14  Fc = ###.###
```

```
**** Using T-Tee or D-Delta configuration:
Series trap            ---->    A 4 part combination, series connected
Parallel trap          ---->    A 4 part combination, parallel connected
Series inductor        ---->    Series tuned section
Capacitor to ground    ---->    Parallel tuned section
```

```
                                    0  ┌─ Termination ─┐
0 ┌─ Termination ─┐                 1  ├────── C ──────┤
1 ├────── C ──────┤                 2  ├────── L ──────┤
                  │                                    │
2                 L                 3                  C
                  │                                    │
3.├── C ── L ─────┤       ---->     4                  L
                  │                 5. ├─ L ┐          │
                 ┌┴─┐               6  ├─ C ┴─ L ─ C ──┤
5.               C  L                            ┌──┬──┤
                 └┬─┘               9.           L  │  │
7 └──── Source ───┘                              │  │  │
8  Fc = 1 Rad.                      10           C  L  C
                                                 └──┴──┘
                                    13 └──── Source ───┘
                                    14  Fc = ##.###
```

The Tee and Delta configurations are actually selecting Ser./ Par. input while activating the alternate type of notch sections. Because the program must pick the correct one of two "dual" circuits to make the input configuration what you have selected, the final design may have the opposite type of notch sections than the reference lowpass. This will happen when the reference lowpass has the opposite type source end than you have requested.

All-pole filters designed using this method simply resonate each element of the reference lowpass filter at Fo with an additional component of the opposite type. This method is fine for wide bandwidths, but will result in a filter that has unreasonable element values as bandwidths become smaller. The example shown below is of a filter with 20% bandwidth that clearly illustrates this effect.

```
                                          0  ┌─ Termination ─┐         50 Ohms
 File name = default                         │               │
 Design = Basic direct scaled bandpass    1  │               L     487.51 nHy.
 order N                      4              │               │
 passband Ripple (0=Butt. dB) 0.05        2  │               C     5.2484 pFd.
 Define pass / stop      (dB) 3              │               │
 arithmetic   Fo.        MHz. 100         3  ├────── C ──────┤      263.8 pFd.
 Bandwidth               MHz. 20          4  ├────── L ──────┤     9.6992 nHy.
 design Zo.                   50             │               │
  Source zo.                  50          5  │               C     3.1297 pFd.
  Termination zo.             50             │               │
 Input config:  S-Ser. P-Par. P           6  │               L     817.52 nHy.
 tYpe: 1=sing 2=doub 3=ratio  2              │               │
                                          7  ├────── C ──────┤     157.31 pFd.
                                          8  ├────── L ──────┤     16.265 nHy.
                                          9  └──── Source ───┘      61.98 Ohms
                                         10   Fc = 99.499 MHz.
```

In order to overcome the problem of unreasonable element values in the direct scaled bandpass filter, Norton transforms may be used to raise and lower the impedance at each section causing the L/C ratio to change. This can be done manually by the circuit editor module (see the NT and FB commands of the editor) but two much faster methods are provided.

Forced value

The forced shunt method of transformation allows the shunt capacitors associated with the Norton transforms to be forced to the nearest standard values. The design is done using a window where the main elements of the filter that are affected by the transforms are displayed and identified by branch number.

```
           0 ┌─ Termination ─┐         1.668 Ohms <--------------------,
             │               │                                         |
      ,-->1  │               L        16.265 nHy.                      |
      |      │               │                                         |
      |    2 ├────── C ──────┤        135.12 pFd.<---------------,     |
      |      │               │                                   |     |
      |    3 │               C        22.189 pFd.                |     |
      |      │               │                                   |     |
      |    4 ├────── C ──────┤        107.71 pFd.<------------------,  |
      |    5 ├────── L ──────┤        16.265 nHy.                |  |  |
      |      │               │                                   |  |  |
      |    6 │               C        34.269 pFd.                |  |  |
      |      │               │                                   |  |  |
      |    7 ├────── C ──────┤        280.35 pFd.                |  |  |
      |      │               │                                   |  |  |
,---------|-->8  │               L        16.265 nHy.            |  |  |
|     |      │               │                                   |  |  |
|     |    9 ├────── C ──────┤        270.24 pFd.                |  |  |
|     |      │               │                                   |  |  |
|     |   10 │               C        44.377 pFd.                |  |  |
|     |      │               │                                   |  |  |
|     |   11 ├────── C ──────┤        119.19 pFd.                |  |  |
|     |   12 ├────── L ──────┤        16.265 nHy.                |  |  |
|     |   13 └──── Source ───┘         61.98 Ohms                |  |  |
|     |   14  Fc = 99.499 MHz.                                   |  |  |
|     |                                                          |  |  |
|  ╒══════|═════> Force Shunt Norton Transformation <══════════╕ |  |  |
|  │ Br. |   Section L   Br.     Shunt C     Br. Par. Section C │ |  |  |
|  │  1 ( )  16.265 nHy.  2 ( ) 135.120 pFd.-----------------------'  |  |
|  │  5 ( )  16.265 nHy.  7 ( ) 280.348 pFd.  4 107.713 pFd. ---------'  |
`----- 8 ( )  16.265 nHy.  9 ( ) 270.240 pFd.                  │       |
   │ L1  =   16.265 nHy. C1 was 157.308 pFd. Zt   1.668 Ohms ------------'
   └─ Local changes Mode ──────────────────────────────────────┘
 S-Shunt  L-section L  P-Param.  E-Edit  X-eXit  M-Mode   R-Restore L = L1
```

The window shown above is displaying the values for the same 20% bandwidth filter as shown earlier for the basic direct scaled method.

Comparing the branches identified in the window with the branches as shown by the editor schematic of the design will show that they are identical. Notice that the values of the first section of the basic circuit L1 and C1 are also given (compare L1 and C1 with branches 7 and 8 of the basic direct scaled design schematic). The initial design impedance of 50 ohms on the direct scaled design was on the termination end. Because the even order filter required unequal terminations, the 50-Ohm level is lost after the transformation as the source end impedance level is the reference for the design.

Initially, all the inductors have been transformed to equal the first one (16.265 nHy). In this case, the value of L1 (determined by the design Zo on the parameters menu) has not been a very good choice. By using the menu options displayed below the window, the design can be improved.

The menu buttons are:

`back	Section L.	Shunt C	Parameters	Edit
?-help	eXit	Mode	Restore	

S-Shunt C

This option causes the * cursor to jump to the bottom shunt capacitor in the window (br 9 in this case). The value of this shunt can be set directly. Each time a shunt value is forced, the * will move up the network to the next shunt. The shunt capacitor values should be forced last, after the design Zo and inductors have been brought into range.

L-section L

The L option will place the * cursor on the bottom inductor (br 8 in the example) so that its value may be set directly. The value of the first inductor (L1) can not be changed here, it is set by the design Zo (on the parameters menu). Each time an inductor value is forced, the position of the * cursor will move up to the next inductor. Do this initially to all the inductors to get the L/C ratios where you want them before forcing the shunt values. You will most likely find that you will want to raise the inductor values higher on the series resonant sections and lower on the parallel ones. This will reduce the range of cap values associated with adjacent sections.

P-Parameters.

This allows access to the parameters menu without exiting from the module. The initial setting of Zo may be changed this way to adjust the value of L1.

E-Edit

The circuit editor and all of its commands may be used as desired during the design. Any changes made by the editor will be reflected in the window upon exit from the editor. You will use this option mostly just to see the schematic, but it will also be required to manually transform any notch sections present in the network.

X-eXit

Allows exit from the module to the main control menu.

M-Mode

Two different modes are provided. When a Norton transform is used in a network, every component from the transform up to and including the termination is scaled by the impedance ratio chosen. This effect can be seen using the "└ Network scale Mode ———". This mode can be used to set the value of all the inductors in the network together in the event the design Zo can't be changed.

When the "└ Local changes Mode ———" is active, the following sections are automatically scaled by the next transform to bring the impedance (and therefore the parts values) back to where they were. The effect is to allow changes to be made to one section at a time. This mode is the default.

The M command will toggle between these two modes.

R-Restore

Use this option to restore the initial "all inductors equal L1" condition. This is an "I goofed, let's start over" option. Any time you want to return the value of an individual section inductor to that of L1, rather than all of them, a simple (Cr) (or 0) in place of a value will do it.

Direct scaled filters containing notch sections

Bandpass filters containing notch sections (an equal number on low side and high side) are desirable because of their low passband loss, sharp skirts and reliable ultimate rejection. This type of filter can also be transformed using this module. As with the all-pole example done before, the bandwidth is 20%, but this time the lowpass reference will have 4 transmission zeros at infinity, 1 finite zero located at 1.2 radians and will be generated using the pole placer.

```
       The design parameters for the filter are:
File name = default
Design = Forced shunt direct scaled
passband Ripple (0=Butt. dB) 0.05
arithmetic Fo.          MHz. 100
Bandwidth               MHz. 20
design Zo.                   15
 Source zo.                  50
 Termination zo.             50
confIg: (input)  Ser.  Par.  S
tYpe: 1=sing 2=doub 3=ratio  2
  --- POLE PLACER DATA ---
Zeros at Infinity = 4
Finite transmission zero frequencies:
    1.200
Finite transmission zero sequence: 1

Lowpass reference used:
  ├───── R ─────┤      1
  ├───── C ─────┤      1.04391
  │             L      1.45137
  ├───── C ─────┤      1.41895
  │           ┌─┴─┐
  │           L   C    0.655261  1.0598  f = 1.2
  │           └─┬─┘
  ├───── C ─────┤      1.19247
  │             L      0.842126
  ├───── R ─────┤      0.806701
```

The initial equal inductor design and corresponding window display generated for the design are shown below:

```
╒═══════════════> Force Shunt Norton Transformation <═══════════════╕
│  Br.     Section L   Br.     Shunt C     Br. Par. Section C       │
│   2 ( ) 100.521 nHy.  4 ( )  42.594 pFd.  1  18.498 pFd.          │
│   5 ( ) 100.521 nHy.  6 ( )  43.129 pFd.                          │
│   -- Notch sections --                                            │
│  14 ( ) 100.521 nHy. 17 ( )  20.348 pFd. 15  21.372 pFd.          │
│  L1  =  100.521 nHy. C1 was  25.453 pFd. Zt 326.368 Ohms          │
└─ Local changes Mode ──────────────────────────────────────────────┘
S-Shunt  L-section L  P-Param.  E-Edit  X-eXit  M-Mode   R-Restore L = L1
```

Note that the notch section values are NOT shown in the window.

```
 0  ┌─ Termination ─┐         326.4 Ohms
 1  ├────── C ──────┤        18.498 pFd.
 2  ├────── L ──────┤        100.52 nHy.
    │               │
 3  │               C        8.3132 pFd.
    │               │
 4  ├────── C ──────┤        42.594 pFd.
    │               │
 5  │               L        100.52 nHy.
    │               │
 6  ├────── C ──────┤        43.129 pFd.
    │               │
 7  │               C        7.7781 pFd.
    │               │
 8  ├────── C ──────┤        23.698 pFd.
 9  ├────── L ──────┤        84.477 nHy.
    │             ┌─┴─┐
10. │             L   C      49.781 nHy.       40.405 pFd.  Fx = 112.22 MHz.
    │             └─┬─┘
    │             ┌─┴─┐
12. │             L   C      63.324 nHy.       51.397 pFd.  Fx = 88.22 MHz.
    │             └─┬─┘
14  ├────── L ──────┤        100.52 nHy.
15  ├────── C ──────┤        21.372 pFd.
    │               │
16  │               C        5.1056 pFd.
    │               │
17  ├────── C ──────┤        20.348 pFd.
    │               │
18  │               L        100.52 nHy.
    │               │
19  └──── Source ───┘          12.1 Ohms
20  Fc = 99.499 MHz.
```

Using the "S" command, force the shunt cap at branch 17 to 22 pFd.

```
╒═══════════════> Force Shunt Norton Transformation <═══════════════╕
│  Br.     Section L   Br.     Shunt C     Br. Par. Section C       │
│   2 ( ) 100.521 nHy.  4 ( )  42.594 pFd.  1  18.498 pFd.          │
│   5 ( ) 100.521 nHy.  6 ( )  45.646 pFd.                          │
│   -- Notch sections --                                            │
│  14 ( ) 219.707 nHy. 17 ( )  22.000 pFd. 15   8.661 pFd.          │
│  L1  =  100.521 nHy. C1 was  25.453 pFd. Zt 326.368 Ohms          │
└─ Local changes Mode ──────────────────────────────────────────────┘
S-Shunt  L-section L  P-Param.  E-Edit  X-eXit  M-Mode   R-Restore L = L1
```

```
 0  ┌─ Termination ─┐          326.4 Ohms
 1  ├────── C ──────┤          18.498 pFd.
 2  ├────── L ──────┤          100.52 nHy.
    │               │
 3  │               C          8.3132 pFd.
    │               │
 4  ├────── C ──────┤          42.594 pFd.
    │               │
 5  │               L          100.52 nHy.
    │               │
 6  ├────── C ──────┤          45.646 pFd.
    │               │
 7  │               C          5.2612 pFd.
    │               │
 8  ├────── C ──────┤          9.1399 pFd.
 9  ├────── L ──────┤          184.64 nHy.
    │             ┌─┴─┐
10. │             L   C        108.81 nHy.       18.486 pFd.  Fx = 112.22 MHz.
    │             └─┬─┘
    │             ┌─┴─┐
12. │             L   C        138.41 nHy.       23.515 pFd.  Fx = 88.22 MHz.
    │             └─┬─┘
14  ├────── L ──────┤          219.71 nHy.
15  ├────── C ──────┤          8.6607 pFd.
    │               │
16  │               C          3.4535 pFd.
    │               │
17  ├────── C ──────┤              22 pFd. <-- Standard value forced
    │               │
18  │               L          100.52 nHy.
    │               │
19  └──── Source ───┘            12.1 Ohms
20   Fc = 99.499 MHz.
```

The next section is a notch section. At this point we must use the circuit editor to do the transforms. The IT command could be used to automatically add an additional L-C "tank" at the junction of the two series notches and iterate for minimum parts value spread (an example of that procedure is given in the section on the circuit editor that describes the IT command). Rather than using the iterated method, we will add a small shunt capacitor to the junction of the two notches to absorb any stray capacity in that sensitive area.

Enter the circuit editor with the [Edit] button. With the editor, highlight the capaictor at branch 10 (above) and select the CP command from the [Nort:] menu. Enter 1.0 pFd. Into the prompt:

```
 8  ├────── C ──────┤          14.474 pFd.
 9  ├────── L ──────┤          118.89 nHy.
    │             ┌─┴─┐
10. │             C   L        24.031 pFd.         83.7 nHy.  Fx = 112.22 MHz.
    │             └─┬─┘
12  ├────── C ──────┤               1 pFd.
    │             ┌─┴─┐
13. │             C   L        25.893 pFd.        125.7 nHy.  Fx = 88.22 MHz.
    │             └─┬─┘
15  ├────── L ──────┤          261.71 nHy.
16  ├────── C ──────┤          6.2832 pFd.
```

The CP editor command can be used again, at the same branch number to change the value to something other than 1 pFd if you like. Once the shunt capacitor has been inserted initially, you may also specify the branch number of the parallel capacitor directly. That is, either branch 10 or branch 12 will work equally well in this example.

To delete the capacitor from the circuit in the event the results are not satisfactory, you can simply specify a value of zero pFd or just press the <Enter> key at the input prompt.

Now we can exit from the editor and save the results. The design can now be finished by forcing the last 2 shunt caps at branches 4 and 6 (33 pFd. might be nice there). The initial design parameters called for 50 ohms to be the source and termination Zo. The matcher can be used from the utilities menu (T and S options) to get back to 50 ohms. The matcher could also have been reset at the main control menu before doing the design, which is the preferred method.

```
      ╒════════════> Force Shunt Norton Transformation <════════════╕
      │  Br.     Section L   Br.     Shunt C     Br. Par. Section C  │
      │   2 ( ) 180.067 nHy.  4 ( )  33.000 pFd.  1   9.573 pFd.     │
      │   5 ( ) 133.282 nHy.  6 ( )  33.000 pFd.                     │
      │   -- Notch sections --                                       │
      │  15 ( ) 261.710 nHy. 18 ( )  22.000 pFd. 16   6.283 pFd.     │
      │  L1  =  100.521 nHy. C1 was  25.453 pFd. Zt 584.635 Ohms     │
      └─ Local changes Mode ─────────────────────────────────────────┘
   S-Shunt  L-section L  P-Param.  E-Edit  X-eXit  M-Mode   R-Restore L = L1
```

Press "X" to exit. The results will look like this:

```
  0  ┌─ Termination ─┐         584.6 Ohms
  1  ├────── C ──────┤        9.5729 pFd.
  2  ├────── L ──────┤        180.07 nHy.
     │               │
  3  │               C        5.3941 pFd.
     │               │
  4  ├────── C ──────┤            33 pFd.
     │               │
  5  │               L        133.28 nHy.
     │               │
  6  ├────── C ──────┤            33 pFd.
     │               │
  7  │               C        5.3941 pFd.
     │               │
  8  ├────── C ──────┤        16.412 pFd.
  9  ├────── L ──────┤        118.89 nHy.
     │             ┌─┴─┐
 10. │             C   L      24.031 pFd.         83.7 nHy.  Fx = 112.22 MHz.
     │             └─┬─┘
 12  ├────── C ──────┤             1 pFd.
     │             ┌─┴─┐
 13. │             C   L      25.893 pFd.        125.7 nHy.  Fx = 88.22 MHz.
     │             └─┬─┘
 15  ├────── L ──────┤        261.71 nHy.
 16  ├────── C ──────┤        6.2832 pFd.
     │               │
 17  │               C        3.4535 pFd.
     │               │
 18  ├────── C ──────┤            22 pFd.
     │               │
 19  │               L        100.52 nHy.
     │               │
 20  └──── Source ───┘          12.1 Ohms
 21  Fc = 99.499 MHz.
```

Minimum component

The second method of applying Norton transforms to the basic direct scaled bandpass is by the minimum component method where the capacitor that is associated with each parallel tuned section is eliminated except the last. This method will reduce the parts count in a large network but does not have the flexibility of the forced shunt method.

The design is done using a window display similar to the other method but with a few variations. All of the menu options shown below the window in this module have the same function as those for the forced value module. The [Shunt] button is missing however because the shunt values can not be forced. Only the inductor values may be forced.

Take special note of the warning ── `Source matching bypassed ─┘` that appears in the lower right hand corner of the window border. It tells you that the source impedance of any final design you come up with can NOT be matched to some other impedance using the matcher module. Any matching to the source end of this type of network must be done BEFORE any transformations are done. This action is automatic unless the matcher is bypassed. If you see this warning and you are going to use the matcher, reset the matcher. This can be done from the parameters menu that is accessible via the [P-Parameters] button. The termination impedance however must be matched AFTER all transformations are complete.

The following example is the all-pole 20% bandwidth case again. File name = default

```
Design = Min. component direct scaled
order N                       6
passband Ripple (0=Butt. dB) 0.05
Define pass / stop      (dB) 3
arithmetic   Fo.        MHz. 100
Bandwidth               MHz. 20
design Zo.                   300
 Source zo.                  50
 Termination zo.             50
Input config:  S-Ser. P-Par. P
tYpe: 1=sing 2=doub 3=ratio  2
```

```
       The initial window will look like this:
      ╒═══════════> Minimum Component Norton Transform <═══════════╕
      │  Br.     Section L     Br. +Adjacent     Br. -Adjacent Cap.  │
      │   1 ( ) 104.535 nHy.    2  20.822 pFd.                       │
      │   5 ( ) 104.535 nHy.    6   2.978 pFd.    4  18.713 pFd.     │
      │   8 ( ) 104.535 nHy.    9 208.956 pFd.    7  24.367 pFd.     │
      │  11 ( ) 104.535 nHy.   12   3.054 pFd.   10  24.283 pFd.     │
      │  14 ( ) 104.535 nHy.   15 163.931 pFd.   13  24.984 pFd.     │
      │  L1  =  104.535 nHy.   C1  24.476 pFd.   Zt  11.484 Ohms     │
      └─ Local changes Mode ────────────── Source matching bypassed ─┘
   L-section L   P-Parameters   X-eXit  E-Edit  M-Mode   R-Restore L = L1
```

The schematic drawing of the design with no changes other than resetting the matcher shows that 2 capacitors have been eliminated over the forced value circuit.

```
 0  ┌─ Termination ─┐             50 Ohms
 1  ├────── C ──────┤         58.586 pFd.  <-- Added by matcher.
    │               │
 2  │               L         104.53 nHy.
    │               │
 3  ├────── C ──────┤         30.702 pFd.
    │               │
 4  │               C         5.3887 pFd.
    │               │
 5  ├────── C ──────┤         17.233 pFd.
 6  ├────── L ──────┤         104.53 nHy.
    │               │
 7  │               C         2.9843 pFd.
    │               │
 8  ├────── C ──────┤         24.416 pFd.
    │               │
 9  │               L         104.53 nHy.
    │               │
10  ├────── C ──────┤         205.49 pFd.
    │               │
11  │               C         23.881 pFd.
    │               │
12  ├────── L ──────┤         104.53 nHy.  <-- Cap removed here.
    │               │
13  │               C         3.4586 pFd.
    │               │
14  ├────── C ──────┤         28.296 pFd.
    │               │
15  │               L         104.53 nHy.
    │               │
16  ├────── C ──────┤         90.838 pFd.
    │               │
17  │               C         15.943 pFd.
    │               │
18  ├────── L ──────┤         104.53 nHy.  <-- Cap removed here.
    │               │
19  │               C         12.609 pFd.  <-- Added by matcher.
    │               │
20  └──── Source ───┘             50 Ohms
21  Fc = 99.499 MHz.
```

Networks containing notch sections can be done also, but flexibility is restricted compared to the forced shunt design method. This method is best used for high order all-pole designs.