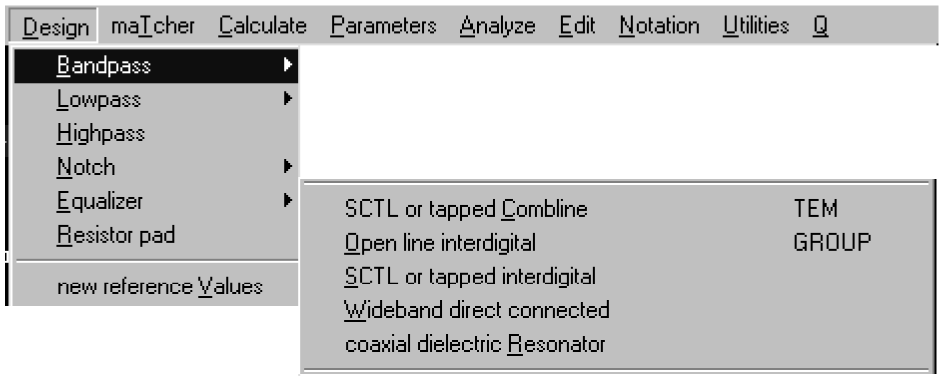
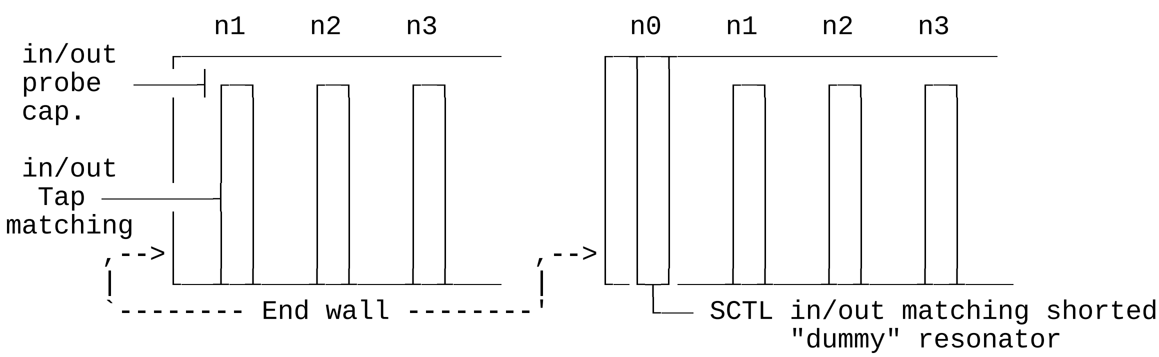
Transmission line bandpass filters



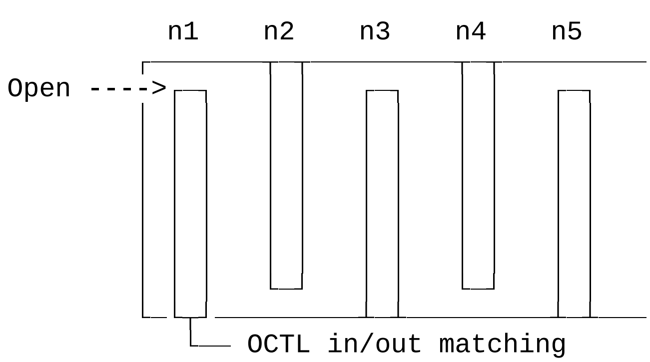
SCTL or tapped Combline
SCTL or tapped Interdigital

The two basic types of coupled resonator bandpass filters that can be designed are the comb line and the interdigital. Either of these types may be matched to the system impedance into which it is to operate by an additional "dummy" resonator at each end of the filter which forms a shorted transmission line (SCTL), by a physical "tap" somewhere along the length of each end resonator, or by a series "probe" capacitor. The choice of matching type is made on the parameters menu (confIg: S=SCTL T=Tap C=Cap.). In the case of a comb filter, the configuration would look like the following:



Open Line Interdigital

An interdigital filter may also be matched to the system impedance by means of an open circuit transmission line (OCTL) formed by the end resonators themselves.



Resonator electrical length

In both comb and interdigital filters, the resonator length may be specified to be any length desired within the limits appropriate for the type of filter. The resonator length design parameter may be specified directly on the Parameters menu: electrical Length (Deg.) 45.

Comb filters are usually built with resonators of about 45 degrees in length. The practical upper limit is about 80 degrees. Beyond this length, the electromagnetic and electrostatic fields tend to cancel each other out. Electrical length below 15 degrees is useful as the "image passband" that will always appear high in frequency is pushed up higher as the electrical length is shortened. Varying the resonator length also tends to allow some control over the stopband skirts.

The interdigital filter theoretically works best with a resonator length of exactly 90 degrees. In practice however, the capacity that exists between the end of each resonator and the sidewalls will load the resonators down in frequency. Setting the electrical length of the resonators below 89.5 degrees will cause tuning capacitors to be calculated for each resonator. With an electrical length of exactly 90 degrees the tuning capacitors are not included in the design.

The equations used in the calculation of interdigital filters with capacitively loaded resonators are approximate causing the passband return loss to degrade as the resonator length is made shorter. For this reason, a fudge factor is included which scales the internal admittance of the filter to compensate. This admittance scale factor as preset to .5 when an interdigital filter is selected from the New design menu. The .5 number is the default because this value is neutral and has no effect on the design. The actual value may be adjusted up or down on the parameters menu. Use it only as necessary to modify the passband response as the resonator length is reduced. It is best to set the resonator length to about 80 degrees and leave the admittance scale factor at .5. This way you are simply compensating for the inevitable capacity at the end of the resonators.

The comb filter is the usual choice for narrow bandwidth filters in the 10% and below range. Duplicated below is the example SCTL comb filter described on pages 501 to 505 of Microwave Filters, Impedance-Matching Networks and Coupling Structures By Matthaei, Young and Jones.

```
File name = MYJCOMB
Design = Combline bandpass
Equal resonator zo. (Y or N) N
order N                      4
passband Ripple (0=Butt. dB) 0.1
Define pass / stop      (dB) 0.1
arithmetic Fo.          MHz. 1500
Bandwidth               MHz. 150
design Zo.                   74
 Source zo.                  50
confIg: S=SCTL  T=Tapped     S <-- in/out impedance matching selection.
tYpe: 1=sing 2=doub 3=ratio  2
electrical Length     (Deg.) 45
```

The circuit editor open wire line equivalent of the filter gives the values of the tuning capacitors needed at the top of each resonator (branches 7, 12, 17, and 22).

```
 0 ┌─ Termination ─┐             50 Ohms
 1 │               │      Ref. freq. = 1505.2 MHz. <-- 45 Deg. frequency
 2 ╞════[ N:1 ]════╡          3.514 :1 turns                 <-,
                                                                | SCTL
 3.║ + + + + + + + ║        617.25 Ohms           45 Deg.     | network
                                                             <-'
 5.╞═════:───:═════╡        79.804 Ohms           45 Deg.  <-- Resonator
 7 ├────── C ──────┤        1.4828 pFd.  <-- Tuning cap
 │        [:═════╛
 8.│        └:═════╕        669.94 Ohms           45 Deg.  <-- Inverter
                                                             
10.╞═════:───:═════╡         88.11 Ohms           45 Deg.
12 ├────── C ──────┤        1.4828 pFd.
           [:═════╛
13.       └:═════╕        846.53 Ohms           45 Deg.

15.╞═════:───:═════╡         88.11 Ohms           45 Deg.
17 ├────── C ──────┤        1.4828 pFd.
           [:═════╛
18.       └:═════╕        669.94 Ohms           45 Deg.

20.╞═════:───:═════╡        79.804 Ohms           45 Deg.
22 ├────── C ──────┤        1.4828 pFd.

23.║ + + + + + + + ║        617.25 Ohms           45 Deg.

25 ╞════[ N:1 ]════╡        0.2846 :1 turns
26 └──── Source ───┘            50 Ohms
27  Fc = 1505.2 MHz.
```

The internal data on the design is shown below. Note that the example in the book was calculated using a G1 value of 1.0880 by mistake. The correct value of 1.1088 noted below table 8.13-1 in the book is marked below.

	Normalized caps.		Internal impedances			Gi	Ki,i+1	Kbw
i	Self	Mutual	Zoe	Zoo	Zo			MHz.
0	5.390	2.144	69.892	38.922	54.407	1.000	1.109	135.283
1	3.186	0.562	118.224	43.805	81.014	-->1.109	0.831	124.642
2	4.275	0.445	88.110	59.890	74.000	1.306	0.658	98.641
3	4.275	0.562	88.110	59.890	74.000	1.770	0.831	124.642
4	3.186	2.144	118.224	43.805	81.014	0.818	1.109	135.283
5	5.390	0.000	69.892	38.922	54.407	1.355		

Network analysis of the line equivalent shown above for the design shows close agreement with the curve in Fig 8.13-6 of the book.

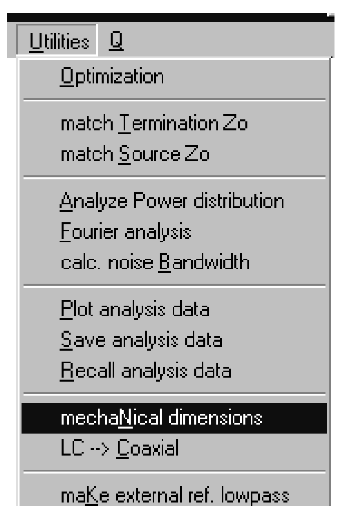
Inductor Q=150 Cap. Q=1500 Trans. Q=1000

Frequency (MHz.)	Rtn. loss (dB)	Atten. (dB)	Delay (nSec)	Phase (Deg.)	Impedance R	+-jX
1200.000	0.010	44.946	0.438	6.088	0.06	55.15
1250.000	0.016	39.032	0.572	15.049	0.12	64.50
1300.000	0.030	31.505	0.855	27.537	0.31	81.11
1350.000	0.095	21.166	1.677	48.761	2.08	128.48
1400.000	1.887	5.418	6.916	110.050	158.63	-215.68
1450.000	15.784	0.385	5.877	249.691	67.34	8.03
1500.000	16.679	0.345	5.336	350.005	45.71	13.50
1550.000	17.818	0.383	6.436	454.186	38.64	0.95
1600.000	1.185	7.732	6.630	608.845	3.49	-7.86
1650.000	0.083	25.700	1.604	666.258	0.27	17.22
1700.000	0.035	37.735	0.837	686.814	0.13	27.78
1750.000	0.021	46.942	0.565	699.099	0.09	35.12
1800.000	0.015	54.540	0.433	707.962	0.07	41.14

Mechanical dimensions and spacings

Any coupled resonator bandpass filter depends on precise mechanical dimensions between adjacent resonators to realize the needed bandwidth. These dimensions are determined from the normalized mutual capacity by means of published curves. These curves have been entered into the program in the form of numerical data for about 18 single points along each curve with a logarithmic interpolation scheme to find points between those entered and between curves.

The mechanical dimensions module is available from the Utilities menu to determine the resonator spacings:



Mechanical dimensions for the example comb filter are shown below. (You might want to compare them with the dimensions given in table 8.13-1 in the book in spite of the G1 mistake noted earlier):

```
 >  MECHANICAL DIMENSIONS and SPACING  <
 ** General bandpass - rectangular resonators **   ══════════> Control <══════════
 Transmission line bar size = 0.1880 Inches             Resonator type:
  Resonator          Spacing   (Inches)               (C) * reCtangular
 #   Width        Gap     Center - Center             (O)   rOund
 0   0.3571     0.1226        0.3854                        Q = 1071.7
 1   0.1686     0.3385        0.5285                       Zo = 74.000
 2   0.2114     0.3830        0.5945                  (G) Ground plane = 0.625
 3   0.2114     0.3385        0.5285                  (R) Resonator size
 4   0.1686     0.1226        0.3854                  (W) Wall spacing = 999.000
 5   0.3571                                           (D) Dielectric k = 1.000
                                                      (P) Parameters
                                                      (X) eXit to main menu

Quarter wave = 1.96715   Resonator length = 0.983573 Inches (45 Deg.)
 Ground plane spacing = 0.625 Inches   -- No walls --
 Length from rod 0 to rod 5 = 2.4223 Inches    Dielectric k = 1
```

The length between the first and last resonators (center to center) is given if the filter has no end walls. If you have specified a wall space, the total length between the end walls is given instead.

Spacing dimensions for two types of resonator configurations are provided, round rods and rectangular rods. The choice made is indicated by the "*" asterisk:

```
       Resonator type:
   (-) * reCtangular
   ( )   rOund
```

The unloaded "Q" of a TEM resonator is a function of the physical sizes of the resonators and the ground plane spacing. It is displayed along with the internal impedance of the filter just below the resonator type selection.

```
 ══════════> Control <══════════
      Resonator type:
  (C) * reCtangular
  (O)   rOund
----->    Q = 1071.7
         Zo = 74.000
  (G) Ground plane = 0.625
  (R) Resonator size
  (W) Wall spacing = 999.000
  (D) Dielectric k = 1.000
  (P) Parameters
  (X) eXit to main menu

    * Q is less than assumed *
```

Notice that the Q determined for the example comb filter is greater than the assumed Q used in the analysis done earlier. In the event the filter has lower Q than was assumed (and therefore might -not perform as predicted by the analysis) a warning is displayed below the control menu window. An arrow also points to the Q value displayed.

(g) Ground plane = 0.625

The internal distance between the sidewalls of the filter is referred to as the "ground plane spacing". This is equivalent to the inside diameter of the outer conductor of a coaxial transmission line where the resonator itself is the inner conductor. The dimension can be set to anything desired below the point where the area itself begins to "mode".

(R) Resonator size

The size of the resonator may be set here. This will determine the internal design impedance of the filter when working with round resonators and will cause an immediate recalculation when set. The new internal impedance will be displayed immediately. If the "equal resonator Zo" parameter is set to "N" on the parameters menu, the innermost resonator will be the one that is set.

When working with rectangular resonators, the resonator size is the thickness of all the resonators. The width of each resonator and the spaces between each one and the next will be adjusted to set the impedance and bandwidth. Setting the equal resonator Zo parameter to "Y" will not make equal sized resonators as it will with round resonators. It will help though.

(W) Wall spacing = 999.000

The gap between the end resonator and end wall (on which the in/out connector is usually mounted) is referred to as the "wall spacing". Placing a wall next to a resonator lowers its impedance. In order to compensate for this, the impedance represented by the distance from the wall to the resonator, the ground plane spacing and the resonator diameter is calculated. The impedance of the end resonators is then scaled to match that impedance. This distance may be specified to any value down to .05 times the ground plane spacing. Any dimension specified that is greater then .75 times the ground plane spacing is assumed to have no wall at all (as with the example comb filter).

(D) Dielectric k = 1.000

Sets the dielectric constant of the material surrounding all resonators.

(P) Parameters

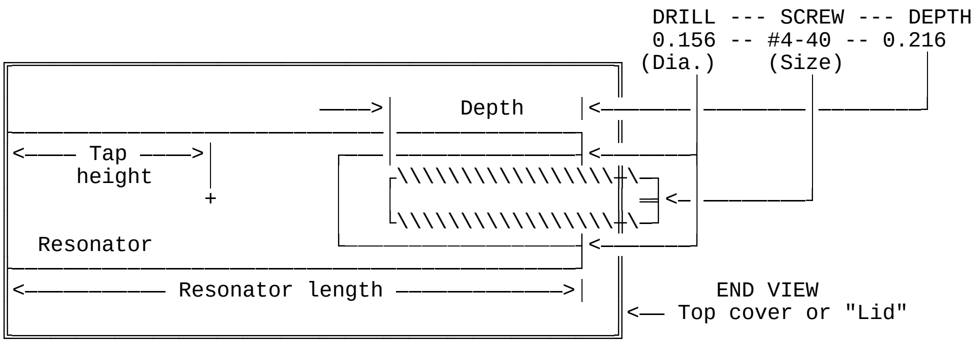
This option provides access to the main parameters menu allowing parameter changes to be made without leaving the spacings module.

(X) eXit to main menu

This allows a return to the main control menu. The <Esc> key can be used to drop back to the Utilities menu instead.

```
                Tuning screws
          ________________________
      DRILL --- SCREW --- DEPTH In.
         0.156 -- #4-40 -- 0.216
            (Cp = 1.480 pFd.)
```

The suggested tuning screws for the resonators are displayed below the menu. This represents the average capacity between the resonators and ground. A side view of one resonator is shown below.



NOTE: Fringe capacity from the end of the tuning screw to the sides of the drill hole is taken into account. Capacity from the end of the screw to the bottom of the drill hole and capacity from the top of the resonator to the top cover is NOT. Note also that no actual dimension is specified for the distance from the end of the resonators to the top cover or "lid". This distance simply represents part of the tuning capacity from the resonators to ground which must be minimized and subtracted from the capacity of the tuning screw within the resonator.

<– Error level

Because the spacing dimensions are determined by interpolation between 4 data points taken from look-up tables (a point above and below each needed point on 2 different curves) it is possible that one or more of the 4 needed data points may be "off the curve". A warning is displayed to the right of each spacing dimension indicating now many data points were off the curve (if any). The interpolation scheme will compensate to some degree, but an error level higher than 1 should not be accepted. This will usually happen at extreme bandwidths or some other extreme condition. Shown below is the results of an attempt to realize the example comb filter using 1/16 inch round resonators in the middle. Resonators 1 and 4 are clearly too small.

```
>  MECHANICAL DIMENSIONS and SPACING  <
** General bandpass - round resonators **       ╒═════════> Control <═══════╕
 Resonator          Spacing   (Inches)          │     Resonator type:        │
#  Diameter      Gap     Center - Center        │ (C)   reCtangular          │
0   0.3340     0.0893       0.2675 <— Error 1   │ (O) * rOund                │
1   0.0224     0.2850       0.3272 <— Error 1   │        Q = 1071.7          │
2   0.0620     0.3755       0.4375              │       Zo = 152.959         │
3   0.0620 <-, 0.2850       0.3272 <— Error 1   │ (G) Ground plane = 0.625   │
4   0.0224   | 0.0893       0.2675 <— Error 1   │ (R) Resonator size         │
5   0.3340   |                                  │ (W) Wall spacing = 999.000 │
             |                                  │ (D) Dielectric k = 1.000   │
        Spacings "off the curves" because       │ (P) Parameters             │
   of a poor choice of resonator size.          │ (X) eXit to main menu      │
                                                └────────────────────────────┘
Quarter wave = 1.96715   Resonator length = 0.983573 Inches (45 Deg.)
Ground plane spacing = 0.625 Inches   -- No walls --
Length from rod 0 to rod 5 = 1.62691 Inches   Dielectric k = 1

        ==============================================================
```

Wideband direct connected

This bandpass filter is suited for requirements with bandwidths from about 50% to 140%. The minimum order is 6 elements. This filter was described in the following publication:

```
Stanford Research Institute
Novel Microwave Filter Design Techniques
Wide Band Diplexers, Page 39
Report No: 5, April 1964
By: G.L. Matthaei, E.G. Cristal, D.B. Weller
```

The authors proposed that the first element be deleted to allow the second (series stub) element to be connect to a lowpass filter forming a contiguous multiplexer. The lowpass was also modified by removing its first parallel element. This technique allows doubly terminated filters having contiguous passbands to be combined.

---

dielectric Resonator

This design module utilizes the miniature dielectric filled resonators commonly available from several manufactures in narrow bandwidth filters coupled and impedance matched by lumped components. These resonators will be specified to the program in terms of their internal impedance and electrical length at the arithmetic center frequency of the passband. In order to achieve the best possible Q, the resonators should be operated as close to 90 degrees as the needed bandwidth will allow. Normally this will be in the neighborhood of 80 to 85 degrees. The length you set will be automatically reduced if it is too long. The final length used will be displayed on the parameters menu after the design is done. If the "(*) Equal resonators (Yes or No)" parameter is set to "Y", the program will force all of the resonators in the filter to be equal in length and impedance. If the parameters chosen would normally result in a non-symmetrical filter, the forcing technique will cause the termination impedance to be something other than that expected.

A typical dielectric resonator design might look like this:

```
File name = default
Design = Dielectric resonator
Equal resonator zo. (Y or N) Y    <--- This should normally be "Y"
order N                      3
passband Ripple (0=Butt. dB) 0.05
Define pass / stop      (dB) 3
arithmetic Fo.          MHz. 1000
Bandwidth               MHz. 30
design Zo.                   12   <--- The resonator Zo  -----------,
 Source zo.                  50                                     |
 Termination zo.             50                                     |
Couplings                     C C <--- L or C couplings             |
tYpe: 1=sing 2=doub 3=ratio  2                                      |
electrical Length     (Deg.) 85   <--- The resonator length --------|
Wire inductance         nHy  0                                      |
                                                                    |
                                                                    |
 0 ┌── Termination ─┐             50 Ohms                           |
 1 │                │      Ref. freq. = 1000 MHz.                   |
   │                │                                               |
 2 │                C        0.90257 pFd.                           |
   │                │                                               |
 3 ├────── C ───────┤         0.1144 pFd.                           |
 4.╞══════:───:═════╡             12 Ohms          85 Deg. <----------'
   │                │
 6 │                C        0.21055 pFd.
   │                │
 7 ├────── C ───────┤        0.73926 pFd.
 8.╞══════:───:═════╡             12 Ohms          85 Deg.
   │                │
10 │                C        0.21055 pFd.
   │                │
11 ├────── C ───────┤         0.1144 pFd.
12.╞══════:───:═════╡             12 Ohms          85 Deg.
   │                │
14 │                C        0.90257 pFd.
   │                │
15 └───── Source ───┘             50 Ohms
16  Fc = 1000 MHz.
```

NOTICE: This type of filter is extremely sensitive to the inductance of the lead wires connecting the resonators to the other components. The inductance of these leads will invariably pull the final realization down in frequency. A method has been implemented that will compensate for this frequency shift. This compensation causes the bandwidth to become wider. It is up to the designed to analyze the filter and reduce the bandwidth parameter manually to compensate for this effect. To use this compensation, simply set the inductance of the wires connecting the resonators to their associated section capacitors on the parameters menu.

(*) Wire inductance   nHy. 2

The same design shown above is repeated below assuming 2 nHy. lead wires on all resonators. Note that the lead wires are shown as inductors in series with each resonator. A comparison of the part values with and without the compensation illustrates the effect even a lead wire of only 2 nHy. will have on the filter. The capacitors associated with the end section resonators have virtually disappeared! 2 nHy. represents a 30 gauge wire only about .13 inch long! It is up to you to determine the actual value of the lead wires. Make every effort to keep the lead wires very short.

```
File name = default
Design = Dielectric resonator
Equal resonator zo. (Y or N) Y
order N                      3
passband Ripple (0=Butt. dB) 0.05
Define pass / stop      (dB) 3
arithmetic Fo.          MHz. 1000
Bandwidth               MHz. 30
design Zo.                   12
 Source zo.                  50
 Termination zo.             50
Couplings                     C C
tYpe: 1=sing 2=doub 3=ratio  2
electrical Length     (Deg.) 85
Wire inductance         nHy. 2    <--- Resonator lead inductance

 0 ┌─ Termination ─┐            50 Ohms
 1 │               │      Ref. freq. = 1000 MHz.
   │               │
 2 │               C        0.86097 pFd.
   │               │
 3 ├────── C ──────┤       0.067819 pFd.  <-- NOTE!
 4.╞══:──:══*─L─┤ <--,          12 Ohms           85 Deg.        ,--> 2 nHy.
   │               │   '--- Resonator lead wire inductance. ---'
 7 │               C        0.19287 pFd.
   │               │
 8 ├────── C ──────┤        0.67722 pFd.
 9.╞══:──:══*─L─┤             12 Ohms           85 Deg.             2 nHy.
   │               │
12 │               C        0.19287 pFd.
   │               │
13 ├────── C ──────┤       0.067819 pFd.  <-- NOTE!
14.╞══:──:══*─L─┤             12 Ohms           85 Deg.             2 nHy.
   │               │
17 │               C        0.86097 pFd.
   │               │
18 └──── Source ───┘            50 Ohms
19  Fc = 1000 MHz.
```

Eliminating the shunt section capacitors

If the "(*) Equal resonators (Y or N)" parameter is set to "N". The resonators will be equal Zo, just as with the previous example, but the length of each resonator will be adjusted to compensate for the shunt capacitors which are removed.

```
File name = default
Design = Dielectric resonator
Equal resonators    (Y or N) N <--- N removes the shunt capacitors
order N                      3
passband Ripple (0=Butt. dB) 0.05
Define pass / stop      (dB) 3
arithmetic Fo.          MHz. 1000
Bandwidth               MHz. 30
design Zo.                   12
 Source zo.                  50
 Termination zo.             50
Couplings                     C C
tYpe: 1=sing 2=doub 3=ratio  2
electrical Length     (Deg.) 85
Wire inductance         nHy. 2
```

```
 0 ┌─ Termination ─┐              50 Ohms
 1 │               │       Ref. freq. = 1000 MHz.
   │               │
 2 │               C         0.90257 pFd.
   │               │
 3.╞══:──:══*─L───┤              12 Ohms       85.087 Deg.            2 nHy.
   │               │
 6 │               C         0.21055 pFd.
   │               │
 7.╞══:──:══*─L───┤              12 Ohms       88.119 Deg.            2 nHy.
   │               │
10 │               C         0.21055 pFd.
   │               │
11.╞══:──:══*─L───┤              12 Ohms       85.087 Deg.            2 nHy.
   │               │
14 │               C         0.90257 pFd.
   │               │
15 └──── Source ───┘              50 Ohms
16  Fc = 1000 MHz.
```

The section tuning capacitors are removed by converting each one to a negative value inductor and combining it (in parallel) with the section inductance before the length is calculated for the equivalent shorted shunt stub that is to become the resonator. This makes the "electrical length" parameter simply an intermediate step in the design. It may be used to adjust the coupling capacitor values in much the same way as the design impedance can be adjusted in an L-C filter to set the ratio of L to C of each section. The bandwidth is also effected and must be check by analysis whenever the electrical length parameter is changed.

Both the equal and unequal resonator Zo design methods perform a safety check to see that the electrical length is not set too long. As electrical length increases, the section capacitors become smaller and will become negative. If this happens, the electrical length will automatically be adjusted down to nearly the maximum value possible before negative values occur. This will represent the highest internal impedance possible.

> NOTE: The coaxial resonators used in these designs must be specified in terms of their ¼ wavelength or 90 degree length! The resonators in the previous examples are 85 degrees long at 1000 MHz. Their ¼ wavelength frequency will be 90/85 times 1000 Mhz, or 1058.82 MHz.

In the previous example, all of the resonators are connected to form shorted shunt stubs. This configuration has a monotonic attenuation response in both stopbands. If the same type of resonator is series connected however, the frequency at which the resonator becomes 90 degrees will generate a notch in the upper stopband. This effect may be utilized to sharpen the upper skirt by using the matcher "tubular end section" or "K inverter" matching option (E) rather then the series "C" option (A) used in the previous example. Continuing with the previous example, reset the matcher and recalculate. When the matcher options appear, select the (E) option:

```
(E)     0.28    21.83  nHy.
──┬───┬───C─────┬──L────┬────>
  │   │         │       │
  L2  C         Cs      C  2.16   pFd.
──┴───┴─────────┴───────┴────
    0.73      1.12   pFd.
 (Sec. 2 was: 21.83  nHy. 0.74   pFd.)
```

The matcher will transform the end resonator into a series inductor which can be replaced by a series connected shorted stub by using the L-C to Stub Generator feature available from the Utilities menu. Once the matcher and stub generator have been programmed, they will perform this transformation automatically each time a recalculation is done.

In order to control the frequency of the notch, simply adjust the value of the series inductor while in the matcher. This will require resetting the matcher each time a change is made. In this example, the matcher default value for the series inductor was used. This is equal to the equivalent value of inductance associated with the resonator of the adjacent section. In this situation, assuming equal resonator impedances, all of the electrical lengths will also be equal. The end resonators of 85 degrees length at 1000 MHz, will become 90 degrees long at 1058.8 Mhz. and will generate the stopband notch at that frequency. To determine the inductance to specify to the matcher for a given notch frequency, the following equation can be used:

$$L = \frac{Zo \tan(\varphi)}{2\ Pi\ Fo} \qquad \text{Where: } \varphi = 90 \frac{Fo}{Fx}$$

L = Series L in Henrys.
Fo = Ref. freq. of filter.
Zo = Impedance of resonator.
Fx = Desired notch freq.

To program the stub generator, select the (J) option from the menu and specify the "Constant" to be the impedance of the resonator you plan to use (for the 12 Ohms in this example, specify "Z12"). You can exit from the stub generator with the (X)-eXit command to see the results immediately.

```
╒══════════════════════════> L-C ──> Stub Generator <══════════════════════════╕
=============================================================================
│--│(E)------│---------│(F)----------│---│(G)---------│----│(H)----------│--│
│  │         │         │        ┌:═════╡   │    High    │                    │
│  │         L  ────>  │        └:═════╡   ║ + + Zo + + ║                    │
│--│(I)------│---------│(J)----------│---│(K)---------│--                    │
│  │         │         │             │   │    Low     │ ╒══> Constants <══╕ │
│  ├─── C ───┤  ────>  ╞═══:   :═════╡   ║ + + Zo + + ║ │ (A) L/C  0.00    │ │
=============================================================================
│  │         │         │             │                  │ (U) L/C  0.00    │ │
│  ├─── L ───┤  ────>  ╞═══:───:═════╡                  └──────────────────┘ │
│--│(U)------│---------│(V)----------│--                                     │
└─── (Cr)-exit * (X)-eXecute * (Y)-clear * (Z)-disable ─── (P)-swap menu ───┘
Constant: (Z)-Zo.  (L)-Length Θ  (F)-relative Freq. of 1st anomaly > Z12
```

```
 0  ┌─ Termination ─┐            50 Ohms
 1  │               │      Ref. freq. = 1000 MHz.
                    │
 2  │               C        0.90257 pFd.
                    │
 3  ├────── C ──────┤         0.1144 pFd.
 4. ╞═════:───:═════╡            12 Ohms            85 Deg.
                    │
 6  │               C        0.21055 pFd.
                    │
 7  ├────── C ──────┤        0.72581 pFd.
 8. ╞═════:───:═════╡            12 Ohms            85 Deg.
                    │
10  │               C        0.28019 pFd.
                    │
11  ├────── C ──────┤         1.1169 pFd.
               ┌:═════╛
12. │          └:═════╕          12 Ohms            85 Deg.
14  ├────── C ──────┤         2.1628 pFd.
15  └──── Source ───┘            50 Ohms
16   Fc = 1000 MHz.
```

The physical layout will require that the resonator outer conductor be connected directly to either the capacitor at branch 11 or 14, not to ground. The center conductor will be connected to the other capacitor. By making a capacitor from a substrate material having a low dielectric constant, it may be made larger than the resonator allowing the resonator to be soldered directly on top of the capacitor without it hanging over the edge. The resonator inner conductor can be connected to the other shunt capacitor. The illustration below shows the resonator setting on the capacitor at branch 11.

```
            ┌───────────────────┐
C10 --->┌──┐ ┌────────────┐ │ ┌───┐
    ────┼  │ │ Resonator  ├─┼─┼─  │
        │└──┘ └────────────┘ │ └───┘<--- C14
        └───────────────────┘<--- C11
```

Note that this same scheme can be employed on both ends of the filter allowing two notches in the upper stopband, each at a different frequency.